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E. LESTER JONES, Director

INSTRUCTIONS FOR TIDE OBSERVATIONS

By

G. T. RUDE

Hydrographic and Geodetic Engineer

Special Publication No. 139

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FOREWORD

The purpose of this publication is to summarize for field use the methods used by the Coast and Geodetic Survey in obtaining tide observations and in making the reductions of the tide records necessary for the establishment of planes of reference for reducing the soundings of a hydrographic survey. Since it is intended as a working manual, no theoretical discussions have been included, and the methods of computations and reductions have been limited to those necessary for field use.

A considerable part of the material contained herein is from other Coast and Geodetic Survey publications adapted to the purpose in view, especially Special Publication No. 26, General Instructions for the Field Work of the United States Coast and Geodetic Survey.

Several of the members of the division of tides and currents have assisted materially in preparing tables and specimen forms, and some of the sections dealing with tabulations and reductions have been prepared by those members of the division engaged on that phase of the work in the office.

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INSTRUCTIONS FOR TIDE OBSERVATIONS

By G. T. Rude, *Hydrographic and Geodetic Engineer, United States Coast and Geodetic Survey*

I. INTRODUCTORY

PURPOSE OF TIDE OBSERVATIONS

The tidal work of the Coast and Geodetic Survey is carried on for the purposes of serving the needs of the mariner, the engineer, the scientist, and the public generally. Among the more immediate purposes are (*a*) the reduction of soundings on hydrographic surveys to a uniform plane, (*b*) the determination of a datum plane to serve as a plane of reference for elevations on land, (*c*) the derivation of data for the prediction of tides which are published in the tide tables, (*d*) the accumulation of observations for the study of tidal phenomena and for advancing the underlying theory. While not a primary purpose under (*b*), the determination of mean sea level with respect to permanent bench marks furnishes quantitative data for determining whether any changes are taking place in the relative elevations of land to sea.

The particular purpose in view determines to a large extent the methods and procedure used in making the tide observations. The hydrographic parties of the Coast and Geodetic Survey make tide observations primarily for the purpose of determining the plane of reference and the corrections necessary to reduce soundings to the datum plane of the chart. In this publication, therefore, the instructions and methods outlined will be primarily with that purpose in mind.

Data from a series of tide observations made by a field party are also used by the office for increasing the scope of the table of tidal difference in the Tide Tables issued annually by the bureau, for tidal information in Coast Pilots, and for tide notes on charts. Series of tide observations several months in length made by field parties furnish a fair approximation to a determination of mean tide level by comparison with simultaneous observations at a nearby primary tide station. Such determinations, while approximate,

are of value to engineers locally. One or more tide gauges must be maintained in connection with all hydrographic work and the tide observations made as complete as circumstances permit.

DEFINITIONS

As is well known, the tides are caused by the attraction of sun and moon on the rotating earth, the moon being the principal agent since it is the closer to the earth. High and low water follow the moon's meridian passage at a given place by a very nearly constant interval. The moon crosses a given meridian on the average 50 minutes later each day, and the tide at most places also usually comes later each day by 50 minutes. The tidal day, therefore, is 24 hours and 50 minutes in length, on the average.

The "moon's meridian passage" refers to the instant the moon is directly above the meridian and also when directly below the meridian. There are, therefore, two meridian passages in a tidal day, called upper and lower transits.

The "high-water lunitidal interval" (HWI) is the interval between the moon's meridian passage (upper or lower) and the following high water. The "low-water lunitidal interval" (LWI) is similarly the interval between the moon's meridian passage and the following low water.

The terms high water (HW) and low water (LW) refer not so much to the actual height of the water as to the phase of the tide. High water is the maximum height reached by each rising tide and low water the minimum height reached by each falling tide. It may happen at some places that the actual height of a low water of one day is higher than the high water of another day.

The "range of tide" is the difference in height between a high water and a preceding or following low water.

The "mean range" is the average difference in the heights of high and low water at a given place.

The range of the tide at any given place varies from day to day. Variations in the range may at times be caused by varying meteorological conditions, but the principal variations are brought about by astronomic causes—variations in the relative positions of moon, sun, and earth. At the times of new and full moon the sun and moon are in line relative to the earth, and their tidal forces are then in concert, causing the tides to rise higher and fall lower than usual, so that the range at this time is greater than the average. These tides are known as "spring tides" and the range the "spring range."

When the moon is in quadrature the tidal forces exerted on the earth by the sun and moon are opposed, each force tending to minimize the effect of the other. At such times the tides do not rise as high nor fall as low as the average and are called "neap tides" and the range "the neap range." There is a lag of a day or two, known as "age of phase inequality" or "phase age," between the occurrence of spring and neap tides and the corresponding phases of the moon.

Due to the elliptical movement of the moon around the earth, its varying distance from the earth likewise affects the range of the tide. When the moon is in perigee, or nearest the earth, the rise and fall of the tide is increased. These tides are called "perigean tides," and the range at such times is known as the "perigean range." When the moon is in apogee, or farthest from the earth, the rise and fall of the tide is decreased. These tides are called "apogean tides," and the range is known as the "apogean range."

Similar to the response of the tides to the corresponding phases of the moon in the case of spring and neap tides there is also a lag of a day or two in the response of the tides to the moon's change from perigee to apogee.

Due to the moon's constantly changing declination, variations in the consecutive ranges of the tide occur. When the moon is on the Equator there is little difference in consecutive ranges. As the declination increases the difference in consecutive ranges increase, and at the times of the moon's maximum semimonthly declination the differences in consecutive ranges are very near a maximum. Similar to the phase age and parallax age there is also a lag in the response to the change in declination generally of about a day, known as the "age of diurnal inequality" or "diurnal age."

When the moon is on or near the Equator and the consecutive ranges very nearly equal the tides are known as "equatorial tides." When the moon is at or near its maximum declination and the difference of consecutive tides, therefore, at a maximum, the tides are called "tropic tides," since the moon at this time is near one of the tropics.

The difference between morning and afternoon tides due to the declination of the moon is known as "diurnal inequality." The difference between the average of the high waters and of the higher high waters is known as the "high-water diurnal inequality" (DHQ), and the difference between the average of the low waters and of the lower low waters is known as the "low-water diurnal inequality" (DLQ).

In different places the characteristics of the tide generally differ as to type and are classed under three types, according to the predominating features—semidiurnal, diurnal, and mixed. The terms semidaily and daily are frequently used instead of semidiurnal and diurnal.

The semidiurnal type of tide is one in which two high and two low waters occur each day with but little diurnal inequality, the morning and afternoon tides resembling each other closely. The diurnal type tide is one in which but one high and one low water occur in a day.

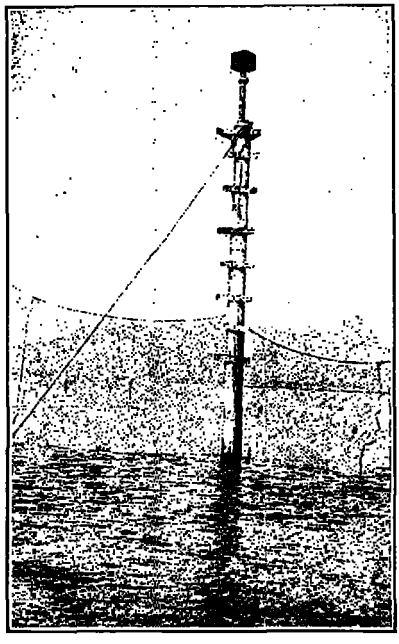

FIG. 1.—A portable automatic tide gauge installed on a fish trap stake in Alaska

The mixed type of tide is one in which two high and two low waters occur each day but with marked diurnal inequality. This inequality may be exhibited in the high waters only, in the low waters only, or in both high and low waters.

LOCATION OF GAUGE

Principal and subsidiary stations.—It will in general be desirable that an automatic gauge, either a standard Coast and Geodetic Survey model or a portable type, be established at some central location in the area to be surveyed and be maintained throughout the time the survey is in progress. Subsidiary portable type tide gauges or tide staffs are also to be maintained in the immediate vicinity of soundings as the work progresses. Generally, the detailed instructions issued by the office for a specific hydrographic survey contain suggestions to the chief of party as to the proper locations of tide gauges for the accurate reduction of his soundings, the exact locations, however, to be governed by local conditions with which he is familiar.

Gauges shall be located so as to approximate the conditions on the working ground. Should doubt attach to the use of the results of a tide gauge at some distance from the sounding work, a subsidiary staff or portable gauge should be established near the vicinity of the work and connected by simultaneous observations with the central gauge, the reducers from the subsidiary gauge being used for the reduction of soundings in its immediate vicinity.

FIG. 2.—A portable automatic tide gauge installed against a rocky cliff in Alaska

Selection of site.—In selecting a site for a tide gauge existing facilities and accessibility of the location to an observer must generally be taken into account. If a substantial wharf exists, a standard Coast and Geodetic Survey model gauge can be conveniently established as the central or principal tide station, plain staffs or portable type gauges being established over the area as subsidiary stations. A portable gauge can be secured to a single pile, to a net stake, or against a cliff (figs. 1 and 2). It is important, however, that the location be such in any case that there is free communication with the body of water being surveyed, shelter from heavy sea, and with sufficient depth of water at low tides.

For sounding on outer coast.—For use in reduction of soundings on offshore sounding work the tide record from a gauge located in a harbor, such as at a primary tide station, can be used with corrections applied for difference in time and height. It is advisable, however, to avoid a location well inside a river mouth or shallow estuary or in a body of water having a narrow connection with the sea. For use in connection with inshore hydrography along the

outer coast subsidiary staffs or portable gauges should be established where possible in the immediate vicinity of the work and connected by means of comparison of simultaneous observations with near-by stations where long series have been obtained, if available.

Upper reaches of tidal rivers.—In the narrow upper reaches of tidal rivers a tide station is not representative of any considerable area, and stations should be spaced sufficiently close together that sounding will not be done at a considerable distance from a tide station.

Exposed channel approaches.—For surveys of exposed channel approaches, where the depths are near the draft of vessels and where especially accurate soundings will therefore be required, for the reduction of which the record from an inshore tide staff is not sufficiently accurate, a temporary station should be established by pumping down a pile or stake and several hours' tide observations obtained on a portable gauge or fixed staff simultaneous with the inshore station. The observations at the temporary station should cover at least a high and a low water.

Abnormal tides due to configuration of shore.—In straits connecting two bodies of water having tides of different ranges and epochs of occurrence it usually happens that in portions of the straits the tide varies rapidly from place to place. Hell Gate, East, River, N. Y., and the channel north of Vancouver Island, British Columbia, are examples. When sounding in such straits, tide stations should be established at frequent intervals. At times also appreciable differences both in time and height of tide occur on the different sides of the same island in an archipelago.

Effect of wind.—In large bays of comparatively shallow depth and with small range of tide, and in broad stretches of rivers or along shores where the water is shoal, the wind has considerable effect on the time and height of the tide. In such places under unfavorable weather conditions the state of the tide at moderate distances from a tide gauge may be quite different from that at the gauge, particularly if differently exposed to the wind direction. Sounding at some distance from a tide gauge under such conditions will result in failure of sounding lines to cross, at times by several feet.

Where such conditions prevail, a tide staff or portable gauge should be established in the immediate vicinity of the work for the reduction of soundings and connected with the central or control gauge by simultaneous observations made during normal weather conditions. If a portable gauge is established at the auxiliary

station, two or three days of simultaneous observations should be obtained. If a plain staff is established as the auxiliary station, the observations for connecting with the central gauge need cover only those hours during which sounding dependent upon the auxiliary gauge is being done, except that several high and several low waters should be included, preferably a complete range of tide on each day that the staff is used.

When surveying shallow bodies of water, such as the sounds of North Carolina, where the range of tide is small and fluctuations due to meteorological conditions considerable, it will be necessary to confine the sounding work of any day during periods of heavy winds to an area in the vicinity of a tide gauge or, if sounding on long lines, to have sufficient auxiliary tide stations in actual operation scattered over the area to furnish correct reducers for the soundings at different positions along the sounding lines.

REPORT ON ESTABLISHMENT OF TIDE STATION

When an automatic tide station is established, a report, including the following information, should be forwarded to the office:

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

(*b*) Name and location of wharf, if established on one (with sketch).

(*c*) Name of owner of wharf and a statement of arrangements made for maintaining the station.

(*d*) Describe the tide staff, giving dimensions, limits of graduations, whether portable or fixed.

(*e*) Give position of tide staff and automatic gauge on wharf (with sketch).

(*f*) If portable staff is used, give reading on the tide staff that corresponds to the fixed point of support.

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

(*h*) Describe the float well, giving dimensions, method of securing it in position, exact position and size of opening in the bottom, and the depth of water below this opening.

(*i*) Give depth of water below zero of tide staff.

(*j*) State whether kerosene is used to prevent formation of ice in the float well, and if so the quantity used.

(*k*) Give brief statement regarding the recovery of old bench marks and the establishment of new ones, complete descriptions of the bench marks to be given separately in the leveling record.

(*l*) The leveling record should include a rough sketch showing the approximate location of the tide staff and bench marks and

the approximate distance between them, determined by pacing or otherwise.

(*m*) Give date of completion of installation and starting of the record.

(*n*) Give name of tide observer and occupation of observer if one is hired outside the party.

(*o*) Give any additional information about the station which appears of importance.

II. TIDE STAFFS

Though automatic gauges are generally used by the Survey for obtaining series of tide observations, staffs are necessary in connection with the gauges to refer the curve traced on these instruments to the actual height of the tide and to permanent bench marks. A fixed tide staff is the more usual type, though special circumstances at times make it desirable to use portable staffs or multiple staffs.

FIXED TIDE STAFF

The fixed tide staff is most conveniently made of a plain board, 1 or 2 inches thick and 5 or 6 inches wide, the length of which depends upon the extreme rise and fall of tide in the locality in which it is to be used. It is graduated to feet and tenths, with the numbers increasing upward from zero. The staff should be painted white, the graduations and figures painted in black.

If the staff is to be used for a considerable single period of time or for several field seasons, the graduations of feet and tenths should be cut into the wood on the edge of the staff. When installed, it is securely fastened in a vertical position to a pile or other suitable support. The zero should be placed lower than the lowest expected tide, and a temporary bench mark established directly alongside the staff in order that it may be readily replaced to its original position if displaced by any cause. At least three permanent standard disk bench marks should be established in the vicinity and connected with the staff by spirit levels (see p. 38).

If the record from the fixed staff is to be used for the reduction of soundings, readings of the staff should be recorded every half hour, except near the times of high and low water, when the readings should be made every 10 or 15 minutes.

Glass tube.—For accurate readings of the water level on the tide staff when the water is rough a glass tube about one-half inch in diameter, partially closed at the lower end by a notched cork, is secured to the face of the staff by means of spring clips or of cup hooks. Several short sections cut from a rubber hose of suitable size (fig. 3) and fastened to the staff have also been found quite sat-

isfactory for holding the glass tube in place on the staff. In order to give definition of the water line within the tube, a floating object,

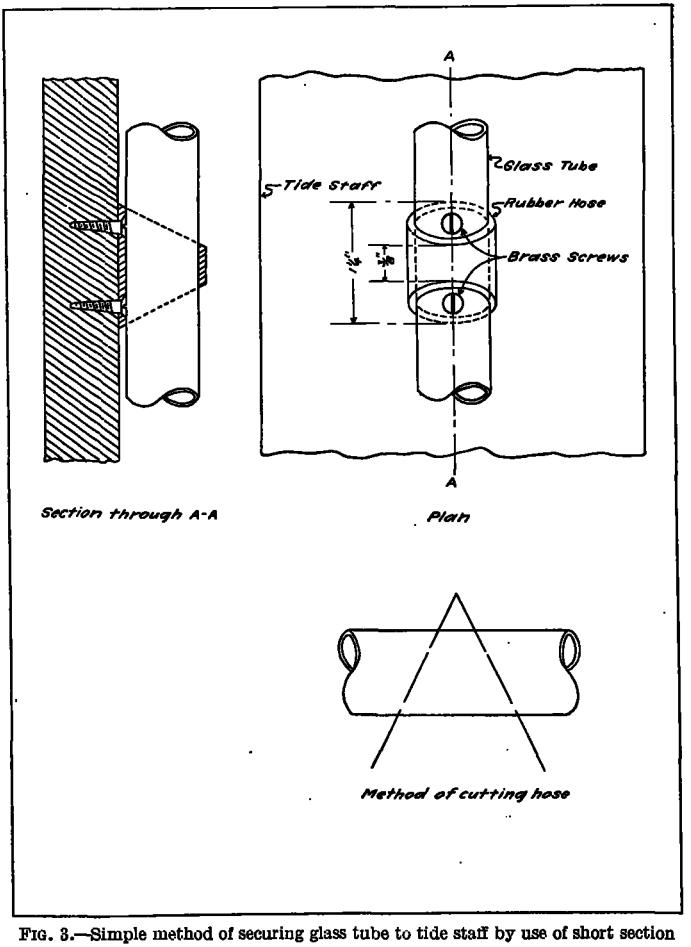

FIG. 3.—Simple method of securing glass tube to tide staff by use of short section of rubber hose

such as a thin slice of cork, should be placed in the tube. This slice of cork should be somewhat smaller than the bore of the tube in order not to increase the capillarity.

PORTABLE STAFF

If the tide staff is to be used for a considerable period of time, particularly in harbors where there is considerable refuse and fuel oil in the water, it is preferable to use a portable staff, which may be taken out and cleaned at intervals. In connection with a portable staff, a staff support must be used. The staff support is secured in a vertical position to a pile or to other suitable support and wooden guides nailed to it, so as to form grooves in which to accommodate the edges of the tide staff. These guides need not be the full length of the staff support but may be made in three sets, each set about a foot long. This staff support need not extend much below mean tide level. A metal plate is securely fastened on top of the staff support and another to the back of the portable staff at some even footmark. When placed in position for observations, the portable staff is lowered until the metal plate on the back of the staff is in contact with the metal plate on top of the staff support. The metal plate on the staff support also serves as a temporary bench mark, the relation of which to the zero of the graduation of the tide staff should be stated in a report or in the tide record. To counteract the buoyancy of the portable staff on a high tide, it should be screwed in place when installed.

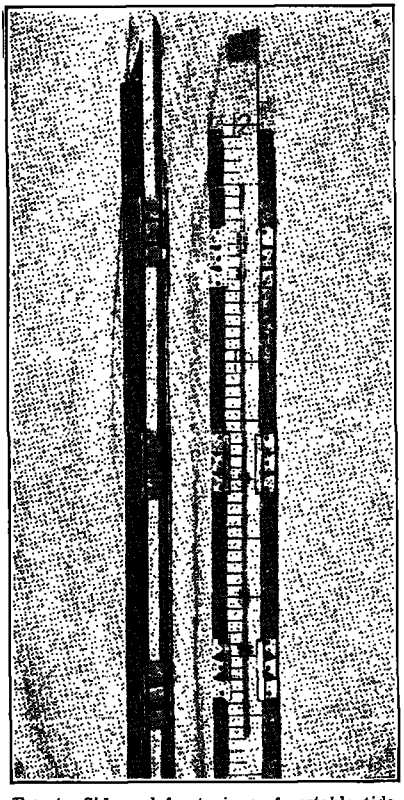

FIG. 4.—Side and front views of portable tide staff and support (upper half)

A standard portable staff has been devised for use at primary tide stations of the bureau. The staff proper consists of a board graduated in feet and tenths, three-fourths of an inch thick, 4 inches wide, and from 12 to 16 feet long, hinged in the middle for ease in handling. The staff support, which is secured permanently to a wharf or pile, carries on its surface metal guides into which the staff is inserted for the readings. This staff was designed for use at primary tide stations for taking a single reading daily and removing from the staff support after this reading.

To counteract the effect of buoyancy and to hold the zero of the portable staff at the same fixed position when the staff is in place in the guides, a device has been developed for locking the staff in place. This device consists of a plate on the staff support and of a plate on the back of the tide staff, with a special mechanism for locking in place. This locking device is described in detail in Special Publication No. 113, page 14, and is carried in stock in the Washington office.

MULTIPLE STAFFS

Along shores with shoal water some distance offshore where the range of tide is too large to be measured by a single staff a succession of staffs may be used. These different staffs should be so graduated and installed that the graduations will be continuous from one staff to the next, so that the readings on all the staffs will be referred to the same zero.

III. NONREGISTERING GAUGES

TAPE GAUGE

A tape gauge is used in locations where the swell renders the use of a fixed staff inadvisable. It is used at primary tide stations on the open coast to furnish daily comparative readings for connecting the tide curve of an automatic tide gauge with bench marks. The type used by the survey consists of a float that rises and falls in a float well to which the tide has access. One end of a stock phosphor-bronze tape, one-fourth inch wide and graduated to feet and hundredths, is attached to the ring in the top of the float, the graduations decreasing upward from the float. The tape passes over one or more pulleys and terminates with a counterpoise weight. A board, on which a sharply defined horizontal line has been made as a reading mark, is securely fastened in the tide house close to the tape. The graduation of the tape opposite this reading mark is recorded as the height of tide.

A hole in the conical inlet coupling, varying from one-half inch in diameter for a 3½-inch pipe to 1¼ inches in diameter for a 12-inch pipe, permits the water to enter the float pipe freely enough to give a perceptible slow motion to the tape when the water outside is rough. Such a motion is desirable in order that it may be assured that the opening is not partially clogged with sediment. If the water outside is so rough that the tape has considerable motion, the mean or the highest and lowest reading on the tape is recorded as the height of the tide. If very little motion is apparent in rough weather, the opening in the float well should be cleaned.

The relation of the zero of a tape gauge to bench marks may be determined in two ways. Simultaneous readings are made on the tape and on a fixed tide staff, the readings are averaged, and the difference between the two values fixes the relation between tape and tide staff. The tide staff is then connected by spirit levels with the bench marks in the usual way.

At a station where it is impracticable to have a fixed tide staff the relation of the tape to bench marks may be obtained by determining by spirit levels the relation of the fixed reading mark of the tape gauge to bench marks and then adding the length of the tape from the zero graduation to the line of flotation. This is accomplished by placing the float in a pan or bucket of water of the same density as the water in the float well and measuring the distance from the water surface up to some graduation of the tape.

If the tape is short, the float may be raised sufficiently to permit placing it in the bucket of water by lowering the counterpoise weight which is attached to the other end of the tape. If the tape is long, such as used at primary tide stations on the open coast, it is impracticable to lower the counterpoise sufficiently to bring the float high enough to be placed in the bucket, and also on the side of accuracy it is undesirable to do so. In this case the tape is shortened by folding a section of it into several loops just above the float and securing the loops at one place by a screw clip or by binding securely with strong thread. The float is then placed in the bucket of water and the distance measured from the water to a graduation of the tape below the loops.

PIPE GAUGE

A type of pipe gauge especially adapted for use in the rough waters on offshore shoals has been used by this bureau, in a depth of 30 feet of water, for obtaining a short series of observations for getting the relation of the tide offshore with that along the coast.

This gauge consists of a white-pine rod staff, cross section 1 by 1 inch, with rounded edges, graduated on each of the four sides in feet and two-tenths with the zero (0) at the top, and set in a hollow cylindrical white pine float 1½ inches outside diameter and seven-eighths inch inside diameter. The float should be thoroughly covered with shellac and liquid paraffin. The length of the rod will depend upon the range of tide in the locality where it is to be used, and the length of the float should be about four-tenths that of the rod. The float well consists of a 2-inch iron pipe, the bottom of which is set in a 1,000-pound concrete block to serve as an anchor. The pipe should be long enough to reach above the ordinary waves at high tide, and a one-half inch hole should be drilled in the pipe several feet above the concrete anchor. A cap with a square hole through which the staff passes, is screwed on top of the pipe after the float staff has been placed inside. Just below the cap a 2-inch flange for the attachment of guy wires is screwed on the pipe and four small sheaves, one for each guy wire, secured to this flange by wire loops. The top of the float pipe is secured in a vertical position by four guy wires of No. 6 wire with leads making an angle of 60° or more with the vertical. The end of each guy wire is anchored to concrete blocks, giving a total weight of about 2,000 pounds to each anchor. For convenience in handling each concrete block may be cast with wire rope loops projecting. After the anchors have been set the guy wires are led through the sheaves at the top of the float pipe and drawn taut, a fence-wire stretcher being convenient for this purpose.

IV. STANDARD AUTOMATIC TIDE GAUGE

While there are various types of self-registering tide gauges, the Coast and Geodetic Survey makes use of two curve-tracing types—the standard Coast and Geodetic Survey automatic tide gauge and the portable automatic gauge. The former is a development of the Stierle gauge and the latter a recent development by the survey for the use of hydrographic and tidal parties in obtaining tide observations covering short periods of time for the reduction of soundings and for comparative purposes.

DESCRIPTION

The standard gauge traces a curve which graphically represents to appropriate scale the rise and fall of the tide, the abscissae indicating time and the ordinates the height of the tide. The essential parts of the instrument consist of a clock that moves a roll of paper

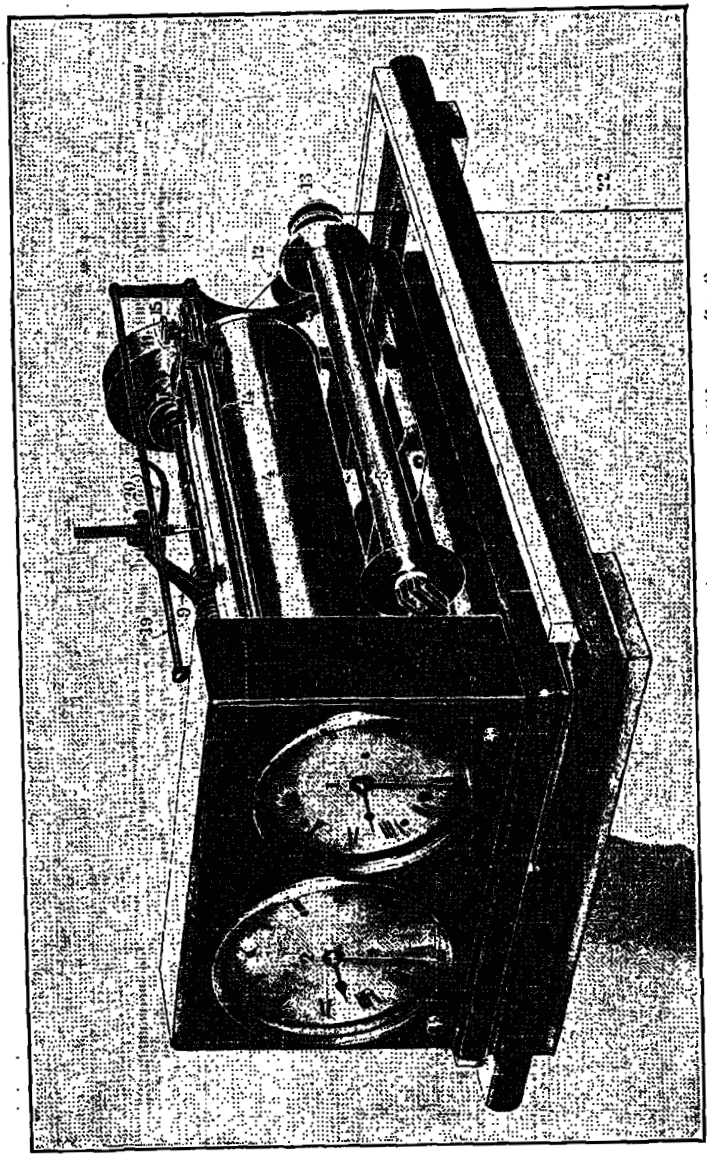

FIG. 5.—Coast and Geodetic Survey standard automatic tide gauge (front)

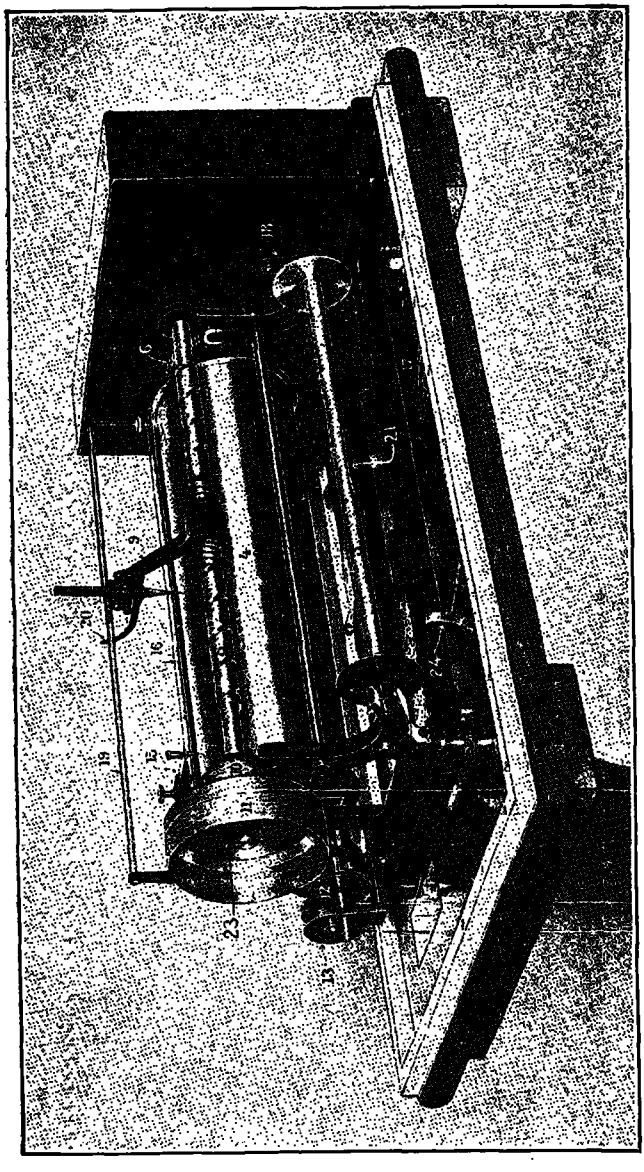

FIG. 6.—Coast and Geodetic Survey standard automatic tide gauge (back)

forward on a drum at a uniform rate and a float that is free to rise and fall in a float well with the rise and fall of the tide on the outside, the float well having an opening of sufficient size for the free access of the water but small enough to dampen somewhat wave action due to wind waves. The float is connected by means of a phosphor-bronze wire and a worm screw to a pencil that moves perpendicularly to the motion of the paper and proportional to the rise and fall of the tide. The combined motion of the paper and the pencil produces a curve or marigram from which the height of the tide for any desired time can be read by means of a scale. Two views of this gauge are shown in figures 5 and 6.

Clocks.—There are two clocks. The one on the right (fig. 5) is the motor clock, which actuates the main cylinder, regulating the motion of the paper. This cylinder, which is 12 inches in circumference, turns on its axis once in 12 hours, moving the paper forward at the rate of 1 inch per hour. The clock on the left (fig. 5) is the time clock, which marks the hours on the record. It is similar to an ordinary striking clock, the striking mechanism operating a device that trips the recording pencil, making a short horizontal mark on the record each hour.

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

Rollers.—There are three rollers.—the supply roller (*3*, fig. 6), with flanges at each end, one of which is removable for putting on the paper; the main roller (*4*, fig. 5), a hollow cylinder of brass tubing 1 foot in circumference, with 12 sharp steel pins set at equal intervals around the cylinder near each end to prevent the paper from slipping on the cylinder as it is revolved by the motor clock; and the receiving roller (*5*, fig. 5), a hollow brass tube, with a slit running its entire length for securing the end of the paper record. The receiving roller has two flanges, one of which is removable, so that the completed record may be removed.

Connection between clock and main cylinder.—The axle of the hour hand of the motor clock extends through the back of the clock case, with a toothed wheel at its extremity (*6*, figs. 6 and 7). The main cylinder has a hinged arm attached to its axis. This hinged arm can be made to engage or disengage the teeth of the wheel on the hour axle, thus making or breaking the connection between motor clock and cylinder when necessary.

Paper.—The paper for the record consists of a roll about 13 inches wide and 66 feet long, sufficient for one month of record. This roll is placed on the supply roller, led over the top of the main cylinder and thence to the receiving roller on which it is wound by action of a tension weight.

Tension weight.—The tension weight for winding the paper on the receiving roller is the smaller of the two weights furnished with the instrument. It is attached to a cord of silk fish line (*22*, fig. 5) which is wound on the tension weight pulley (*13*, figs. 5 and 6). This pulley is provided with pawl and ratchet for winding up the tension weight each time the gauge is visited. The action of the tension weight in addition to winding the tide roll on the receiving roller tends to keep the paper taut and also to assist the action of the motor clock in turning the main roller.

Tension spring.—The tension spring (*21*, fig. 6) presses against the roll of paper on the supply roller and tends to keep taut the paper on that side of the main roller. Care should be taken that there is not an excess of tension on either the tension spring or on the tension weight, since it is likely to cause the paper to tear on the sharp pins of the main roller, especially if the weather be damp.

Float.—The float is a copper cylinder, 8½ inches in diameter and 3 inches high, weighted so as to float with about one-third of its height above the water surface. The float is connected with the float pulley of the instrument by phosphor-bronze wire, No. 23 American wire gauge.

Float wire drum.—A set of four interchangeable threaded drums (*11*, figs. 5 and 6), with circumferences of 6, 9, 12, and 16 inches, respectively, is provided with each instrument in order to adapt it to different ranges of tide. Special drums of other sizes are sometimes necessary to adapt the instrument to tides of very large range. When needed, these are obtained by special requisition on the office at Washington.

These drums are about 1 inch wide and have 18 threads cut in their faces to accomodate the turns of the float wire, one end of which is attached near the edge of the drum. For the removal or adjustment of the drum two clamp nuts are provided. These nuts are set by means of a special wrench (*24*, fig. 6). The float wire drum is clamped by means of these two clamp nuts to the pencil screw, causing it to turn as the tide rises and falls.

Counterpoise drum.—The counterpoise drum, which is threaded similarly to the float-wire drum, to which it is clamped by means of the two clamp nuts, accomodates the turns of the phosphor-bronze wire, to which is attached a counterpoise weight.

Counterpoise weight.—The counterpoise is the larger of the two weights provided with the tide gauge, the smaller being the tension weight described heretofore. The counterpoise weight is attached to the phosphor-bronze wire mentioned above and serves to take up the slack in the float wire as the tide rises.

Sliding groove pulley.—The sliding groove pulley (*12*, fig. 6) is free to slide on an axle just below the counterpoise pulley. Its purpose is to keep the counterpoise wire away from that float wire and also to keep the counterpoise wire opposite its proper thread on the counterpoise drum. When the counterpoise wire is carried directly to a fixed pulley in the ceiling of the tide house, the use of this sliding pulley is unnecessary.

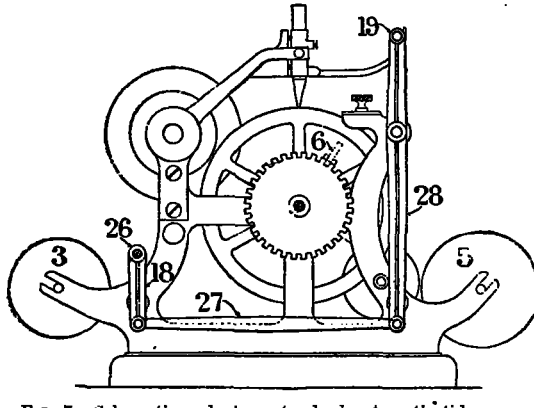

FIG. 7.—Schematic end view, standard automatic tide gauge

Pencil screw.—The purpose of the phosphor-bronze pencil screw (*8*, fig. 6) is to actuate the pencil arm as the tide rises and falls. It is about three-eighths inch in diameter, with a square thread of 1 inch pitch for ranges of tide up to 16 feet. For stations having a larger range of tide a pencil screw with a one-half inch pitch is used.

Pencil arm.—The pencil arm (*9*, figs. 5 and 6) carries the recording pencil. In its bearing is a nut which fits into the thread of the pencil screw, so that as the latter is turned the pencil arm moves backward and forward along the screw as the tide rises and falls.

Datum pencil holder.—The datum pencil holder (*15*, fig. 5) carries the pencil which traces the datum line. On some of the gauges still in use the datum pencil holder consists of a tube for

carrying pencil points; in later gauges the pencil holder is designed to carry an ordinary pencil.

Scale.—The height scale of the gauge depends upon the circumference of the float pulley and the pitch of the pencil screw. The probable extreme range of the tide at the station will decide the scale to be used. The following table will indicate the proper pulleys and pencil screws to be used for different ranges of tide. For an extreme range exceeding 24 feet a requisition should be forwarded to the office for a special pulley.

For an extreme range between following limits	Scale	Float pulley circumference	Pencil screw pitch
		Inches	*Inch*
Less than 6 feet	1:6	6	1
From 6 to 9 feet	1:9	9	1
From 9 to 12 feet	1:12	12	1
From 12 to 16 feet	1:16	16	1
From 16 to 18 feet	1:24	12	½
From 18 to 24 feet	1:32	16	½

Hour-marking device.—The time clock on the hour moves a lever (*18*, figs. 6 and 7) connected with a tripping rod (*19*, figs. 6 and 7) which is supported on rocker arms. The pencil arm is jointed and provided with a hook which passes over the tripping rod. On some of the older gauges still in service the hook passes under the tripping rod. On the hour the striking mechanism of the clock moves the lever, which in turn rocks the tripping rod. The latter engages the pencil hook and pulls the pencil arm, causing the pencil to make a short stroke parallel to the edge of the paper. The pencil, which also traces the tide curve, is returned to position by a spring. The pencil should be sufficiently soft to trace a distinct line which will remain legible for a long period. A No. 1 or No. 2 pencil is recommended. It should be kept carefully sharpened and adjusted in its holder. The efficiency of the hour-marking device depends upon this adjustment.

INSTALLATION AND OPERATION

When establishing an automatic tide-gauge station, the approximate range of the tide for the locality should be obtained from the tide tables, or a plain tide staff should first be established in order that a rough estimate of the range of the tide and also of mean tide level may be obtained from a few observations.

Float well.—The float well should be located where the water is several feet deep at the time of the lowest tides. For a station that is to be occupied for only a short time the float well may be constructed of plain pine boards 12 inches wide and 2 inches thick, so assembled as to form a box 10 inches square on the inside and long enough to reach from the floor of the wharf to several feet below the lowest tides. It should be secured in a vertical position and well braced, so as to be held in that position to prevent the float from scraping on the sides as the tides rise and fall. A single opening from 1 to 1½ inches in diameter for the access of the tide is made in the bottom of the well near one corner, or, if the bottom of the well rests on the ground, the hole may be made in the side of the box. Unless the station is exposed to heavy seas the opening should be not less than 1½ inches in diameter.

For a station that is to be occupied for several years the float well should be constructed of 2-inch plain pine boards, 12 or 14 inches wide, preferable 14 inches, painted with copper paint and covered on the outside with 16-ounce sheet copper or yellow metal from the bottom to a height about mean high water. When using sheet copper, the float well should be assembled with copper nails 4 to 5 inches long. In this case where the station is to be maintained for a considerable period the well should be secured in place with the bottom several feet from the ground and the opening for access of the water made in the bottom near one corner in order to facilitate the cleaning of the opening of sediment.

Shelter.—Generally, a small house of rough boards is constructed to protect the gauge from the weather and from molestation. At times, when a station is located on a private pier, the owners may require an attractive shelter, built and painted to conform with other buildings on the pier. Such a structure, about 6 feet square, will furnish sufficient room for the installation of the gauge, the arrangements of which is shown in Figure 8.

At times it may be convenient to have the float well opening outside the house; in this case a sloping cover should be provided for the well. This cover may be hinged and padlocked to permit of easy access to the float while protecting it from molestation. If the float well opens inside the tide house, it should also be provided with a cover to prevent anything from being dropped down the well. Such a cover may be made of two pieces of board with a narrow slit between the boards in the center for the float wire. For the support of the instrument a table or shelf about 2½ feet high should be provided.

If reasonably protected from molestation, the gauge at a station which is to be operated for a short period only may be sheltered from the weather by a painted canvas-covered box placed over the gauge, hinged at one end so as to be raised clear of the gauge when visited for inspection and attention. A padlock should be installed at the other end of the box. The box in which the gauge is shipped from the office, covered with canvas and painted, will serve this purpose.

Setting up automatic gauge.—When the top of the float well opens inside the tide house, as is usually the case, the gauge should be placed on the table or shelf, so that the float wire drum is directly over the center of the float well. If for any reason this can not be done, a series of pulleys must be arranged to lead the float wire to the float well.

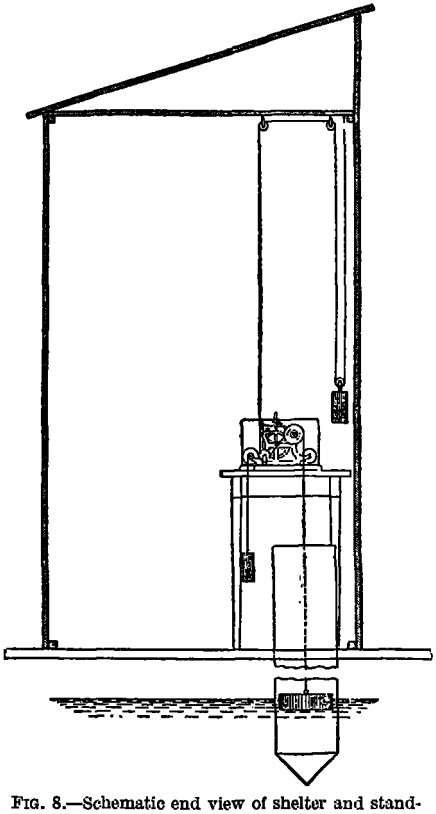

FIG. 8.—Schematic end view of shelter and standard automatic tide gauge, showing method of installation

The gauge is to be adjusted so that at approximately mean tide level the pencil arm will be near the middle of the main cylinder the float- wire drum and counterpoise drum each about half filled with wire, and the counterpoise weight arranged so that it can move freely between the limits of extreme high and low water. The datum-line pencil should generally be set near the middle of the paper, but if trouble is experienced by its fouling the curve-tracing

pencil it may be set near the low-water edge of the paper, although the middle is preferable.

Attaching counterpoise weight.—The first step when installing the gauge is the threading of the counterpoise. Before beginning the threading the pencil screw is thoroughly cleaned and the pencil arm is run clear of the threads of the pencil screw in a direction away from the wire drum and kept in that position till the float is lowered into the well.

One or more fixed pulleys are placed overhead in such positions as to carry the counterpoise weight over to one side of the house or otherwise out of the way (fig. 8). If the gauge is installed for only a short period and sheltered only by a box placed over it, the counterpoise wire is led, by means of fixed pulleys, beneath the gauge stand and suspended in a well made of 1 by 6 inch boards or otherwise protected as conditions require.

When a house is provided for shelter, the counterpoise, which is the larger of the two weights with the gauge, is attached to a movable pulley and placed on a block of wood to raise it about 2 inches above the floor. The end of the phosphor-bronze wire, furnished for the purpose, is passed through the small drill hole near the inner edge of the counterpoise drum and a knot tied in its end. The other end of the wire is then passed over the pulley fixed overhead, down through the movable pulley to which the weight is attached, and up again to the ceiling where this end is fastened. The block is removed from under the weight, which should now hang just clear of the floor. The counterpoise wire will later be wound on its drum after the float is attached and lowered to the water.

Attaching float.—The next step in the operation is the threading of the float wire on its drum and attaching the float. The length of wire, in feet, required for the various sized drums may be determined as follows:

Let A = distance in feet, float-wire drum to water surface.

Let B = height in feet of tide above or below approximate mean tide level.

(In the formula below use plus (+) B if tide level is above mean tide level and minus (−) B if below mean tide level.)

1. For float drum 6 inches in circumference: Length of wire required $= A + 4\frac{1}{2}$ feet $\pm B$.

2. For float drum 9 inches in circumference: Length of wire required $= A + 6\frac{3}{4}$ feet $\pm B$.

3. For float drum 12 inches in circumference: Length of wire required $= A + 9$ feet $\pm B$.

4. For float drum 16 inches in circumference: Length of wire required $= A + 12$ feet $\pm B$.

It is unnecessary to make an actual measurement of the distance A. Attach the float to one end of the spool of wire and lower it into the well until it rests upon the water, the wire previously being passed through any intermediate pulleys which may be required. The wire from the float to the float drum will respresent the distance A. Then, having estimated the value of B from the stage of the tide at the time, an additional length of wire may be measured off equal to the scale constant ($4\frac{1}{2}$, $6\frac{3}{4}$, etc.) $\pm B$, and the wire cut.

Remove the float-wire drum and pass the end of the wire through the small drill hole near the outer edge of the drum and wind the wire on the drum, filling all the 18 threads in its surface. In doing this it will be necessary to partly raise the float in the well, the weight of the float keeping the wire taut during the winding. Replace the drum on the gauge and secure it in place with the two clamp nuts, but holding it carefully to keep it from being turned by the weight of the float. Next, holding the pencil arm to one side to keep it from immediately engaging the threads of the pencil screw, allow the float-wire drum to make two and one-half turns; then releasing the hold on the pencil arm, let the float-wire drum turn slowly until the float again rests upon the water. This will automatically wind up the counterpoise wire and bring the pencil arm approximately to its correct position.

Adjustment of pencil arm.—It may happen after thus threading the gauge, that the pencil arm, having been set only approximately as it engaged the threads of the pencil screw, is not sufficiently close to the middle of the paper when the water surface is at mean tide level. It is not necessary to wait until the tide is actually at its mean level. Knowing the difference between that level and the actual stage of the tide, the pencil may be set accordingly by the scale of the gauge, as follows: Press on the counterpoise drum with one finger to prevent the counterweight from turning it, a finger of the same hand resting on the last thread of wire on the float-wire drum to prevent the wire from springing out of the thread; then with the other hand slightly unclamp the two set screws holding the float drum. Next revolve the counterpoise drum until the pencil arm is in the desired position, and then firmly clamp the two set screws.

Attaching tension weight.—The tension weight is attached by a cord of silk fishline to the pulley at one end of the receiving roller.

This pulley has a small hole in one flange, through which the end of the cord is passed and knotted. To provide sufficient drop for the unwinding of this weight, it is desirable that the cord be led upward and over a fixed pulley in the ceiling of the tide house. If found necessary, the tension weight may be suspended on a movable pulley, so as to diminish its motion one-half.

Placing paper on gauge.—Before placing the paper on the gauge a note should be made at the beginning of the roll giving the name of station, chief of party, date, scale of gauge, kind of time used, and name of observer. The supply roller is removed from the gauge and the roll of paper placed on it by removing one of the flanges and running the rod through the central hole in the roll. The roller is then placed in its supports, the loose end of the paper passing from below inward toward the main cylinder. The main cylinder is now disconnected from the motor clock by throwing out of gear the carrier lever from the toothed carrier wheel. The paper is led over the main cylinder and about three-fourths inch of the end inserted into the longitudinal slit of the receiving roller. Several turns of the paper are now wound on by turning the roller in a direction such that the paper passes from the main cylinder over the top of the receiving roller. The main cylinder is again connected with the motor clock by throwing the carrier lever into gear with the carrier wheel. One roll of paper is sufficient for a month of record.

Starting the gauge.—The paper having been placed on the gauge and properly adjusted and the gauge ready to function, the observer should make sure that the tension weight is wound up, both clocks wound and the time clock set to correct time, the datum-line pencil clamped in position, the recording pencil adjusted in its holder, and the hour-marking device tested by tripping the time clock.

Removing paper from gauge.—To remove the paper from the gauge, the tension weight of the receiving roller is placed on the gauge table and the main cylinder disconnected from the motor clock. The paper remaining on the supply roller is wound on the receiving roller and this roller removed from its supports. The record is removed from the receiving roller by unscrewing one of the flanged ends. A label (Form 489) filled out completely as possible should be pasted on the outside of the roll. The label should not be pasted so as to seal the roll.

Comparative note.—A rubber stamp for recording the daily note on the record is furnished. This note should contain the date,

tide-staff reading, correct time, time indicated by time clock, and a statement as to wind and weather conditions. If the time clock is not correct, it should be corrected and a note made to that effect. Care should be taken that the time recorded in the comparative note is the time indicated by the clock which makes the hour marks on the curve and not by the motor clock which actuates the main

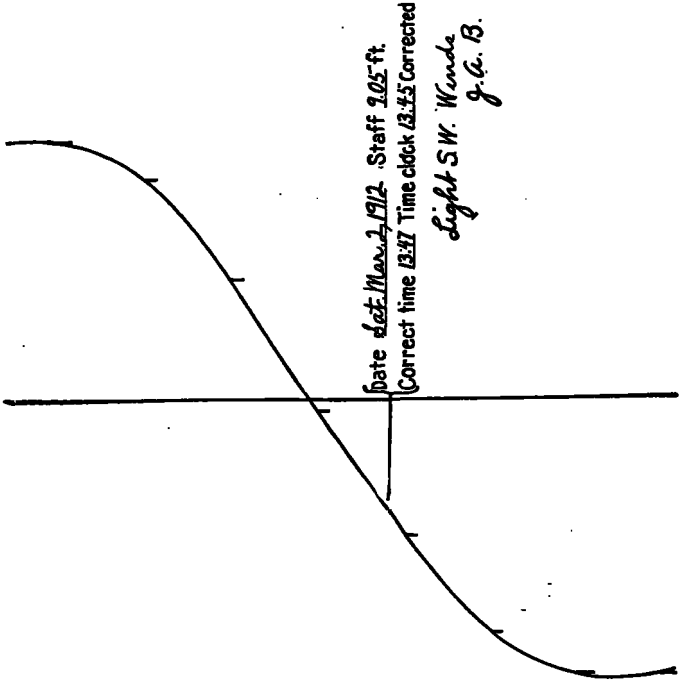

FIG. 9.—Portion of record of standard automatic tide gauge, showing method of entering comparative note

cylinder. The exact position of the recording pencil of the gauge at the time the tide-staff reading was made for this comparative note must be indicated by an arrow connecting the exact position of the recording pencil at the time with the comparative note. The manner of connecting the note to the point on the tide curve is shown in Figure 9. The note may be placed either above or below the curve, but it must be connected by a pencil line with

exact position of the recording pencil at the time the comparison between staff and curve is made. At the time the note in Figure 9 was made the recording pencil was at the point in the curve indicated by the arrowhead, and only that part of the curve to the left of this point was completed. The portion of the curve to the right of the arrowhead was made after the note had been entered.

Reading tide staff.—At the time the gauge is visited each day the height of the water level on the tide staff should be read to the nearest half-tenth of a foot and this reading recorded on the marigram. If the water is too rough to obtain directly a reliable mean reading of the water level on the staff, both highest and lowest oscillation of the waves should be recorded on the roll and a note made that water is rough. When tabulating the record, the tabulator will take in such cases the mean of these two readings for comparison of staff and scale on Form 455.

Attention is called particularly to the necessity of obtaining unbiased staff readings for the daily comparative notes. Unbiased staff readings are necessary for the accurate reference of the tide planes to bench marks. At times a tide observer misunderstands this purpose, and in entering the daily notes is influenced by the height as indicated by the automatic gauge itself. This is especially true of the portable gauge.

In the case of the standard gauge, an observer, having noted an approximately fixed relationship between the tide staff and the tide curve, may in good faith be tempted to check the daily staff reading by a scale reading of the tide curve before entering the staff reading on the roll. In this practice it is impossible to avoid being biased by the scale reading. In order that the tide records may be directly referred to bench marks, it is important that actual readings of the tide staff, unbiased by any other consideration, be entered on the tide roll. No scale of any kind, nor a substitute for the same, should be used in the tide house for checking the tide-staff readings.

Correct time.—The tide observer should be furnished a good watch which has been regulated so as to carry as near as possible correct standard time. This timepiece should be compared with correct standard time at frequent intervals and a note made on the tide roll when these comparisons are made and the error of the observer's watch.

Lost record.—If any portion of the record is lost from any cause it is desirable that the paper be moved forward a few inches and a new curve started. When disconnecting the main cylinder from the motor clock for this purpose the cylinder should be held firmly

by hand to prevent the paper being jerked suddenly forward by the tension weight.

Changes in adjustment.—After the automatic tide gauge has been properly set up and adjusted satisfactorily changes in the adjustment of the float drum or in the position of the datum-line pencil should be avoided except when actually necessary. When any change in the adjustment is made a note of the fact and the reason for the change should be entered on the marigram at the time.

Cleaning pencil screw.—For the efficient functioning of the gauge it is important that the pencil screw be cleaned at frequent intervals. It should be wiped with a clean piece of cloth moistened with gasoline. In addition, when changing the paper at the end of each month the pencil carriage should be run back and forth on the screw by hand and the screw wiped with a piece of cloth thoroughly soaked in gasoline. Oil should not be put on the screw, since it tends to catch dust and to gum the surface of the screw.

The following are indications of a dirty pencil screw: Distorted curve on a falling tide; steps in the curve on either a rising or falling tide; flattening of the curve at both high and low water; frequent breaking of float wire.

Clearing float-well opening.—At tide stations maintained for considerable periods the intake opening of the float well is liable to clogging due to accumulation of sediment in the bottom of the well. The observer should establish the practice of clearing the opening once a month. When the opening is in the bottom of the well this can be done by a rod made up of sections of gas pipe. For an iron float well with a conical inlet casting a special tool is provided.

The clogging of the intake opening is indicated by the smoothness of the tide curve when there is perceptible wave motion outside the float well. The intake opening should be of such size and kept clear so that except in very smooth weather the pencil will have a perceptible movement and make "saw teeth" in the tide curve. A smooth, regularly traced curve is to be regarded with suspicion, as it frequently indicates a lag in the tide movement in the well behind the actual tide conditions outside, and should be avoided.

To prevent freezing.—A column of kerosene is used to prevent the formation of ice in the float well of this type automatic gauge during cold weather. A column 2 to 3 feet in height suffices for ordinarily cold regions and from 4 to 5 feet for colder climates. The amount of kerosene is limited by the depth of the inlet opening of the float well below the lowest tides.

Since the specific gravity of kerosene is less than that of water, its introduction in the float well will change the line of flotation of the float and therefore change the relation of the tide curve to the datum line. A comparative tide-staff reading should be made immediately before and another after the kerosene is put in and a note entered on the record that kerosene is being used. No inaccuracy in the record of this type automatic gauge will be caused by this change in line of flotation, since the observer records daily readings of the fixed tide staff which determine the relation of fixed tide staff to the datum line of the tide record.

Kerosene can not be used in the float well of a tape gauge, since in this type gauge the line of flotation of the float must coincide with the level of the water surface outside the float well.

Operating difficulties.—Some of the difficulties likely in the operation of this automatic gauge are:

1. Partial clogging of float well, due to accumulation of sediment in the bottom of the well. This should be cleared frequently.

2. Failure to have float well in a vertical position, causing the float to scrape on the side of the well.

3. Formation of ice in float well in cold climate during cold weather. A column of kerosene should be introduced into the float well.

4. Breaking of the float and counterpoise wires, due to kinks in the wires. This should be guarded against when installing a gauge.

5. Fouling and breaking of float wire, due to slackening caused by sticking of pencil arm on the pencil screw. To avoid this, the pencil arm should be cleaned frequently.

6. Fouling and breaking of float wire, due to its not being cut to proper length when gauge is installed. If too short, it will become completely unwound before an extreme low water; if too long, it may run off the edge of drum on an extreme high water.

7. Tearing of edge of paper on flanges of cylinders, due to being out of alignment and not running true. At times a proper alignment can be made by slipping the roll by hand along the shaft of the supply roller or of the receiving roller. If proper alignment can not be made in this manner the paper on the receiving roller should be rewound. Sometimes the alignment can be improved by reversing the supply roller end for end.

8. Failure of hour-marking device, generally due to improper adjustment of recording pencil in its holder. The tripping hook should be adjusted by raising or lowering the recording pencil, so

that the hook just clears or rests very lightly on the tripping-rod. If jammed tightly against the rod it will prevent the device from working.

9. Failure of clocks. This may be due to clocks being wound too tight, interference of hands, jamming of hour-marking device, hardening of oil, or collection of dust on the works. This last condition may be temporarily remedied by use of kerosene on the works, while another clock is obtained on requisition from the Washington office. The screws which secure the clock to the case should not be drawn too tight when installing a new clock.

V. PORTABLE AUTOMATIC TIDE GAUGE

DESCRIPTION

The portable automatic tide gauge was devised by the Coast and Geodetic Survey primarily for use in obtaining short series of observations for the reduction of soundings in hydrographic surveys. The aim was to provide a gauge more portable and more easily installed than the large-type standard Coast and Geodetic Survey model for which a more or less elaborate platform and float well are necessary. Following is a description of this gauge. A more detailed description is given in United States Coast and Geodetic Survey Special Publication No. 113.

Record cylinder.—The record cylinder (*A*, fig. 10) on which the paper for the record is wound is 7 inches in length and about 6 inches in diameter. The cylinder is geared to a clock movement carried within the cylinder so as to rotate once in 48 hours.

Clock movement.—The clock is an ordinary eight-day movement mounted within the record cylinder. When properly adjusted, the gauge will operate for seven days without attention in the meantime.

Float.—The float is a hollow brass cylinder 3¼ inches in diameter and 15 inches long, connected to the mechanism of the gauge by means of a phosphor-bronze wire. This float is weighted with shot to float with its upper end about 3½ inches above the surface of sea water and about one-half inch above the surface of kerosene oil.

Float pipe.—The float pipe (*D*, fig. 10) consists of sections of ordinary stock iron pipe of suitable length for the range of the tide and depth of water, joined by ordinary stock couplings. The instrument and the conical inlet coupling were designed for use with 3½-inch pipe, but larger pipe may be used with reducers. Where the weight of the pipe is not a factor in the installation it

is of advantage to use 4-inch pipe, which requires a less precise alignment for the proper functioning of the float.

Conical inlet coupling.—As an inlet for the tide to the float pipe a conical inlet coupling, threaded for 3½-inch pipe, is furnished with the gauge. This is installed with the apex downward.

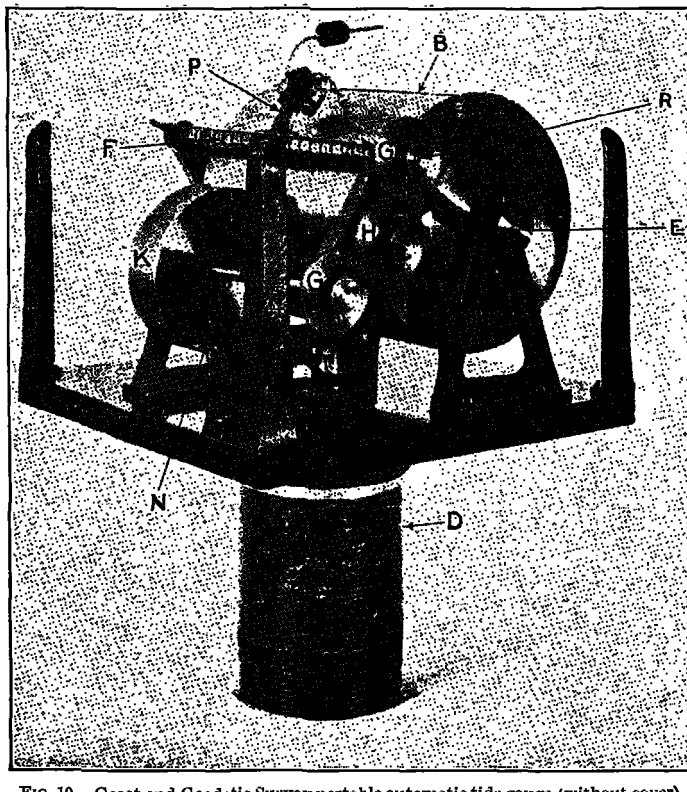

Fig. 10.—Coast and Geodetic Survey portable automatic tide gauge (without cover)

Cleaning tool.—For cleaning the opening to the float pipe of sediment a weighted cleaning tool with pointed shank is furnished with the gauge.

Float wire drum.—The phosphor-bronze wire which connects the float with the mechanism of the gauge is wound on a threaded drum (*K*, fig. 10) 12 inches in circumference. This drum is rigidly

fixed by means of a screw (*N*, fig. 10) to that part of its axle which extends toward the gear wheels.

Counterpoise spring.—To take up the slack in the float wire on a rising tide a flat spring is coiled within the case of the float-wire drum.

Stylus screw.—The stylus screw is made of phosphor-bronze with a square screw thread with pitch of four-tenths of an inch.

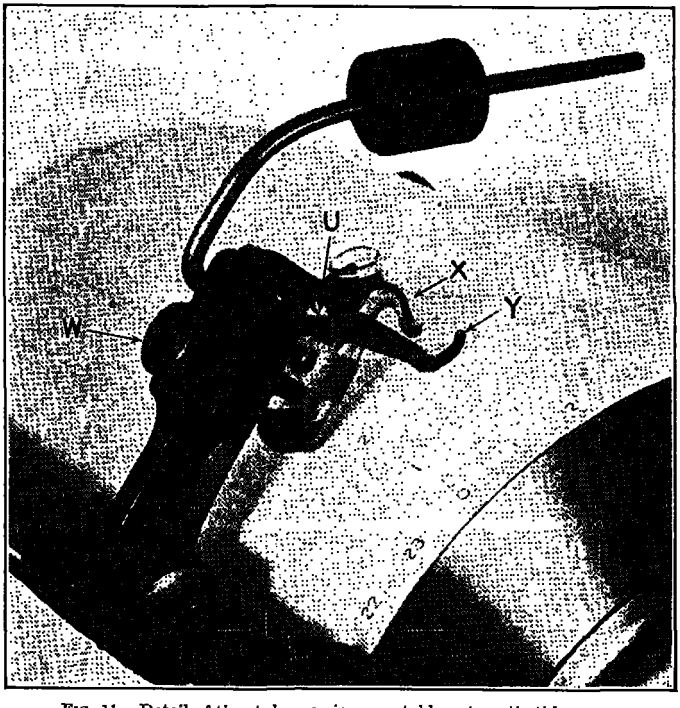

FIG. 11.—Detail of the stylus carriage, portable automatic tide gauge

Stylus arm.—The stylus arm, which carries the recording stylus, has in its bearing a nut that fits into the thread of the stylus screw, so that as the latter is turned the arm moves along the screw.

Recording stylus.—In the first development of this gauge a pencil was employed for recording the tide curve. A special chronograph pen (*X*, fig. 11) is now used on the later model.

Record paper.—The tide curve is traced by the recording stylus on sheets of special cross-section paper 7 by 19.7 inches, allowing in length for a half-inch overlap. This paper is furnished with the gauge.

Scale.—The relationship of the circumference of the float-wire drum and the relative sizes of the uppermost and lowest gear wheels (*G*, *G*, fig. 10) of a train of gears determine the scale of reproduction of the tidal curve. The two gears (*G*, *G*, fig. 10) are removable and, with the several separate gears furnished with gauge, provide for five different height scales, as follows:

Scale	Maximum range of tide	Number of teeth	
		Gear attached to float pulley axle	Gear attached to stylus screw
1:11¼	6	96	36
1:16⅞	9½	96	54
1:22½	12½	96	72
1:30	17	72	72
1:45	25	64	96

INSTALLATION AND OPERATION

Since the reading at any instant of the tide curve on the cross-section paper record of the portable gauge should agree with the reading of the actual height of the tide on a tide staff, it is important when installing this type gauge that a fixed staff be first installed, and that that footmark of the tide staff, agreeing with the middle graduation of the scale of the record paper to be employed on the gauge, be placed as near as possible to mean tide level; otherwise the tide curve traced on the record will not be centered.

Float well.—The base of the portable automatic tide gauge is provided with a sleeve to fit on the top of the float well of stock 3½-inch iron pipe, but larger pipe with reducers may be used when the weight of the pipe is not a factor in the installation. This pipe in addition to serving as a float well acts also as a support for the instrument. When the gauge is installed on a wharf a flange coupling with a short section of pipe above the deck affords a ready means of supporting the float pipe. The conical inlet coupling is screwed into the bottom of the longer section, reaching below extreme low water. To provide a support for the instrument in a location at which no wharf or platform is available, an additional section of pipe is screwed into this conical inlet coupling

on its bottom end and perforated with several large holes to allow free access of the water to the inlet in the coupling. (These holes should be as large as can be conveniently made, so as not to become clogged.) This lower section rests on the bottom, and the float pipe may be lashed to a single pile or net stake or lashed securely against an overhanging cliff where depth of water permits. (Figs. 1 and 2.) In localities where little penetration can be obtained for a single stake three sharpened poles of suitable length may be driven about 6 or 8 feet apart and the upper ends brought together and lashed in the form of a tripod, the float pipe being lashed in a vertical position to the apex of the tripod.

If 3½-inch pipe is used for the float well the diameter of the float of this gauge is only one-fourth inch less than the inside diameter of the float pipe. It is therefore important that the float pipe be installed and maintained in a truly vertical position to prevent the float scraping the side of the float well, tending to furnish a record of the tide of less range than the actual tide.

Attaching float.—When installing the instrument on the float pipe the first step is the attaching of the float. The length of phosphor-bronze wire required may be determined as follows:

Let A = distance in feet, float wire drum to water surface.

Let B = height in feet of tide above or below approximate mean tide level.

(In the formula below use plus (+) B if tide at the time is above mean tide level and minus (−) B if below mean tide level.)

Length of wire required $= A + 15$ feet $\pm B$.

Attach the float to one end of the spool of wire and lower it into the well. Allowing a few inches for the distance from the top of the well to the float-wire drum, measure off an additional length equal to 15 feet $\pm B$, the value of B being estimated from the stage of the tide, and then cut the wire. Pass the loose end of the wire over the fixed fair leader and through the opening in the base of the instrument, and then before attaching the wire to the drum wind up the spring either by turning the drum counterclockwise, as viewed from the side shown in Figure 12, or by use of the clock key on the drum axle at M (fig. 12). The spring should be wound up completely and then slackened off about four turns. Holding the drum in this position, the float wire is now passed through the small drill hole near the edge of the drum and knotted. The drum should now be permitted to turn slowly through the action of the spring, winding up the float wire, care being taken that the wire follows the threads in the face of the drum. To avoid the tangling

of the float wire by an excessive amount of slack, the gauge may be set some distance from the float pipe when attaching the wire to the drum and afterwards moved slowly toward the float pipe as the wire is being wound on the drum. When all the slack in the wire has been taken up the gauge is placed in position on top of the float pipe and locked by means of the two hook screws provided.

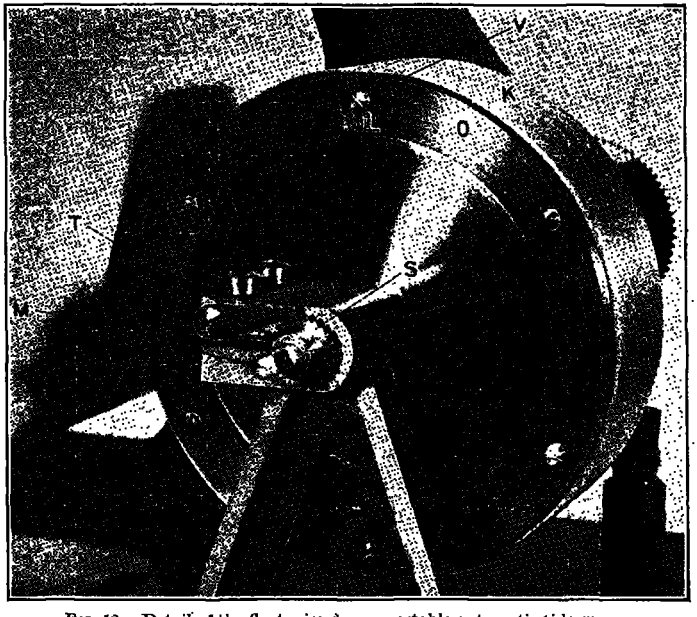

FIG. 12.—Detail of the float wire drum, portable automatic tide gauge

Counterpoise spring.—If the float wire has been cut off at the proper length and the instructions described in the preceding paragraph followed the counterpoise spring will be wound to the proper tension; but if further adjustment to the tension is necessary this may be made by using the clock key on the subsidiary axle of the float drum just outside the ratchet and pawl.

Should the counterpoise spring be broken, a spare one may be installed as follows: Loosen screw (*N*, fig. 10) which holds the shaft connecting the float-wire drum with its driving gear, then take out the six screws holding the cover plate (*O*, fig. 12) and remove

it from the face of the drum. Slide the drum away from the standard toward the gear train and remove the screw which fastens the inner end of the spring to the fixed shaft. (This screw is slotted in its shank instead of in its head.) Take out the screw holding the other end of the spring in the drum and remove broken spring. Now, put in the screw, which is slotted in its shank, through the round hole in the inner end of the new spring and fasten this end of the spring in place to the fixed shaft, wind the spring so that it will fit into its recess in the drum and attach its outer end in the drum case by means of the screw provided for that purpose, and reassemble. About a teaspoonful of fine watch oil should be put inside the case through the charging hole, which is closed by means of one of the six small screws holding the cover plate in place.

Record cylinder.—The record cylinder is now installed in its supports. The clockwork rotates the cylinder in such direction that its top moves toward the stylus screw (*F*, fig. 10), and when installing the gauge the cylinder should be so placed in its supports that the capstan nut (*E*, fig. 10) at the end of the axle comes on the same side of the instrument as the train of three gear wheels (*G*, *H*, *G*, fig. 10) which connect the axle of the float-wire drum with the stylus screw.

Upon unclamping the capstan nut (*E*, fig. 10) the cylinder may be turned freely and the stylus set on the cross-section marigraph paper to the nearest 10 minutes of the time scale, after which this screw is clamped. Then, in order to set the stylus accurately to the nearest minute, the stylus tangent screw is used. Care should be taken, however, that whatever slack there may be in the record cylinder due to lost motion in the gears should first be taken out by lightly placing the hand on top of the cylinder and drawing it in a direction away from the stylus.

Gear train.—A train of three gears (*G*, *H*, *G*, fig. 10) connects the axle, on which the float-wire drum is mounted, to the stylus screw. Six different gears, in addition to an idler gear, are furnished with the instrument; the interchanging of these gears determines the different height scales for the operation of the gauge. The middle gear (*H*, fig. 10) is the idler which connects the other two gears and is used for all scale ratios. The other two gears (*G*, *G*, fig. 10) are removable, and the several separate gears furnished with the gauge provide for five different height scales. (See table, p. 32.)

Having determined the scale of record to be employed from a knowledge of the range of the tide at the station, the two gears proper for that scale are selected from the six furnished with the instrument. (See table, p. 32.) The number of the gear to be used on the float-drum axle and the number of the one to be used on the screw-gear axle for the different scales are shown in the table on page 32 and also printed in the blank space at one end of the cross-section record paper. Care should be taken when installing these gears that they are properly chosen and placed for that scale; otherwise the height graduations of the cross section record will not indicate directly the true height of tide.

When installing these gears care should also be exercised in meshing the idler gear into the uppermost and lowest gear wheels. It should be meshed sufficiently to obviate unnecessary lost motion, but not so tightly as to lock the gear wheels or to cause undue friction in the turning of the float-wire axle. In the latest model of this instrument the positions of the idler gear for each scale have been definitely fixed in the design of the instrument, so that adjustment is unnecessary other than screwing the idler gear-bearing screw into the particular hole provided for the gears being used.

Recording stylus.—On the earlier gauges, on which the record is made by pencil, a No. 1 pencil will give best results. When using the later model on which the record is made by stylus care should be taken that it is tight in its holder and also that the shoe (*Y*, fig. 11) is properly adjusted, so that the point of the stylus will clear the spring clip which holds the paper in place. It is also important that the level of the ink in the reservoir be kept below the level of the stylus point in order that the ink will not flow too freely. If the ink fails to flow freely enough the stylus should be cleaned by insertion of the fine wire furnished for this purpose. Care should also be taken in using the tangent screw for setting the stylus to the exact time that the reservoir is not set so low that it drags on the clip which holds the paper on the record cylinder.

Setting recording stylus.—For adjusting the stylus to the height of the tide as read on the tide staff the milled-head nut (*R*, fig. 10) holding the upper gear wheel to the stylus screw is unclamped and the stylus screw turned freely, without connection with the float-wire drum, until the stylus point indicates on the cross-section paper the approximate mean height of the tide on the tide staff at that instant. This milled-head nut is then clamped, and the tangent screw (*U*, fig. 11) permits of a finer adjustment. The stylus should be reset to the actual mean staff reading each time the record paper is renewed.

Record paper or marigram.—Five different scales of record paper are furnished with the instrument, allowing for the accommodation to suitable scales of ranges of tide from 0 to 25 feet. When starting the gauge a sheet of this paper is wrapped around the record cylinder and held in place by the metal clip (*B*, fig. 10) running lengthwise of the cylinder. The paper is placed on the cylinder with the zero of the height scale at the same end af the cylinder as the capstan-headed nut.

Clock.—In the design of the instrument the clock is installed within the record cylinder, but suitable arrangements are provided for winding and adjusting. When properly adjusted the gauge will operate for seven days without attention in the meantime. The cylinder revolves once in two days, but when used in any locality where the range is 3 feet or more and not considerably affected by meteorological conditions the tide curve traced on the record advances sufficiently from one revolution of the cylinder to the next to obivate any interference of the curve for one day with that of any succeeding day. In general, it will be of advantage to have a single sheet of paper serve for about a week, with comparative time note and staff reading once each day. The daily comparison may be dispensed with in cases where the gauge can be visited by the hydrographic party at the end of the week only.

In localities where the range of tide is less than about 3 feet and the water level is considerably affected by meteorological conditions the marigraph sheet should be changed after one revolution of the drum—two days.

Clock regulation.—The clock can be regulated by means of the regulating attachment at one end of the record cylinder. When regulating the clock, however, the record cylinder should be allowed a full 48-hour revolution and the clock movement adjusted according to the amount that it fails or overruns a complete revolution of the cylinder and not for any particular hour on the cross-section paper.

Cleaning stylus screw.—For the efficient functioning of the gauge it is important that the stylus screw be cleaned at frequent intervals. This should be done in the same manner as with the pencil screw of the standard gauge. (See p. 27.)

Cleaning float pipe.—If the gauge is to be operated for a considerable period of time the float pipe should be cleaned occasionally to prevent the opening in the conical inlet coupling becoming clogged. It should be cleaned by removing the float from the pipe, inserting the cleaning rod to which a rope has been attached, and raising and lowering it several times in the pipe.

Comparative note.—A rubber stamp is furnished for the use of the observer in recording the actual staff reading on the marigram at each visit to the gauge (fig. 13). Unbiased staff readings are necessary for the proper reference of the various tide planes to bench marks. At times a tide observer misunderstands this purpose, and in entering the daily notes is influenced by the reading of the height of the tide on the cross-section paper. The staff reading should be the unbiased mean reading taken directly from the tide staff before having noted the height of tide as indicated by the record of the instrument. If the water is rough an estimate of the average height on the staff should be taken and a note made that the water was rough. The stylus should always be readjusted when necessary to agree with the correct time and the actual mean staff reading.

To indicate on the tide curve the exact point to which the comparative note refers, the hand should be placed lightly on top of the record cylinder and the cylinder moved slightly toward the stylus screw and back again to position. The hand should then be placed lightly on the float-wire drum and the float raised a little way out of the water and back again to position, causing the stylus to make a horizontal line on the marigram. Near the right angle (fig. 13) made by these two operations no writing should be done, except the date, in figures, agreeing with the date on the comparative note to which it refers. A light line connecting the comparative note to the point of the tide curve to which it refers, as indicated by the right angle, is helpful in interpreting the record, especially when the same sheet of record paper is left on the gauge for several days.

VI. BENCH MARKS

Value.—Tide observations obtained and bench marks established prove of value for various other purposes as well as for the hydrographic work performed at the time. Many cities and towns base their elevations on the survey's planes of reference and make frequent use of the bench marks. All tide observations for hydrographic purposes therefore, should be referred to bench marks, irrespective of the shortness of the series or of the temporary character of the station. This is of importance not only in making the established tide planes available for future surveying but in the correlation of hydrographic surveys made at different periods.

Qualities.—For the preservation of the tidal datums established by a series of tide observations the bench marks established should be of a permanent character, and it is desirable that standard

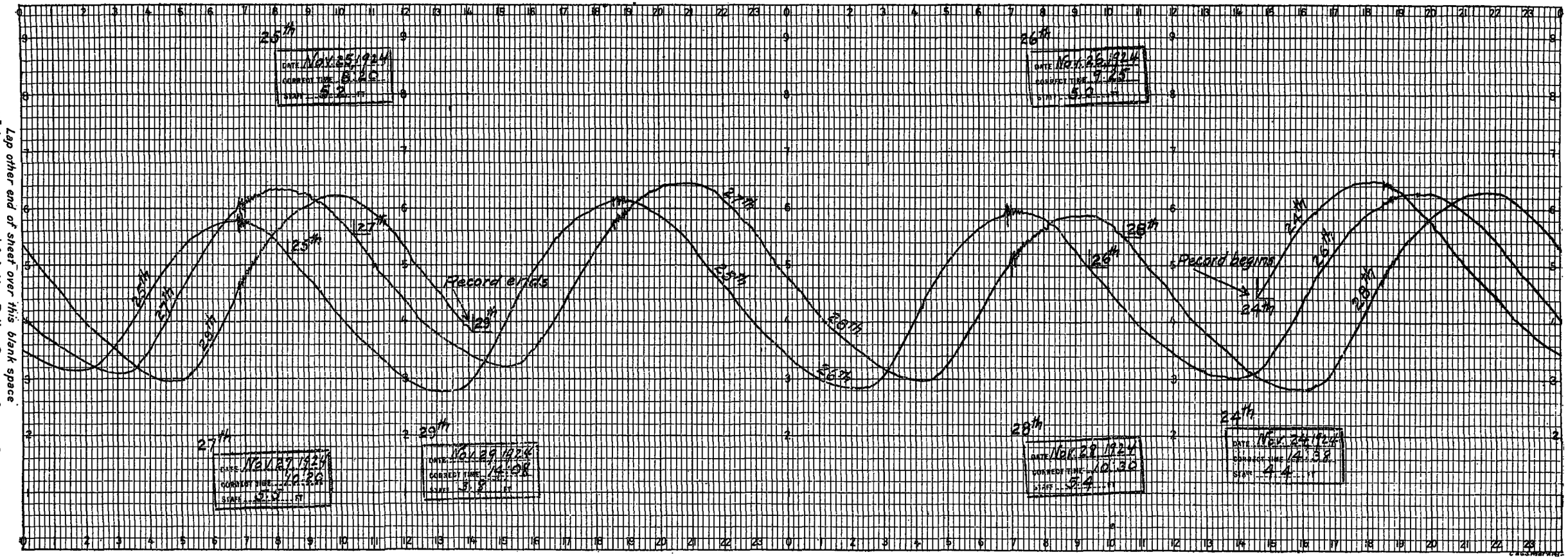

FIG. 13.—Marigram or tide record at Washington, D. C., for the period November 24 to November 29, 1924. (Portable automatic tide gauge)

marks be used, so they may be identified beyond doubt. Spikes in piles, water hydrants, curbstones, nails in trees, marks on wooden structures, or any structures liable to settlement should not be used. The principal qualities of a good bench mark are durability, freedom from likelihood of destruction or of change in elevation, and ease of recovery and identification. They should be so placed, if possible, that a leveling rod can be held vertically over them.

Standard disks.—While prominent and easily identified points on buildings or monuments may be connected into the level line as temporary bench marks, the required number of marks should

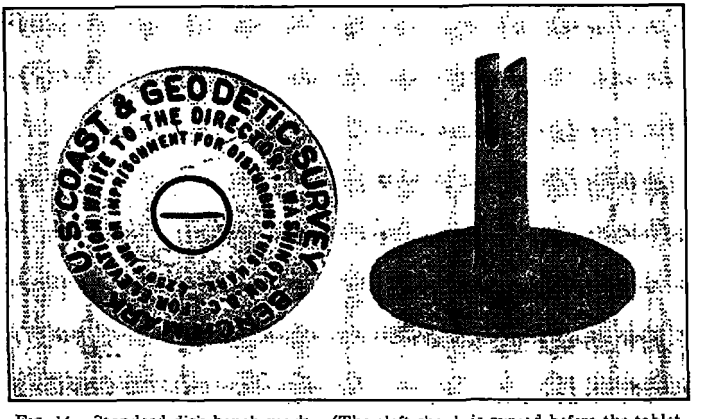

FIG. 14.—Standard disk bench mark. (The cleft shank is spread before the tablet is set in stone or concrete)

consist of the standard tablets of copper alloy furnished by the office, so fastened in rock, concrete, or foundation of building as to retain their elevation and not be easily removed.

Number.—At least three standard disk bench marks should be established at a tide station and connected by spirit levels with the zero of the tide staff and additional marks established if the station is reoccupied later. It is the practice of the survey to maintain at each tide station one standard disk bench mark for each year of observations up to 10 years with a minimum of five marks for a series one year in length and a minimum of three for a short series. They should be located so that they will not be liable to be destroyed or their elevations changed and should be sufficiently scattered that all will not be likely to be destroyed by a common cause or dis-

turbed by a local movement such as heavy fills, continuous traffic, or settlement of large buildings.

Primary bench marks.—At times a hydrographic party is instructed to establish a primary tide station to be maintained continuously by the survey over a considerable period of time. At a primary tide station there should be a near-by substantial bench mark, designated as the primary bench mark, located as near as practicable to the wharf or pier on which the tide gauge has been installed. This primary bench mark is to be used for checking the elevation of the tide staff from time to time with a single set up of the level if possible, and any changes in elevation of the tide staff are measured by reference to this bench mark. At least four other bench marks are established in the locality to check the stability of the primary bench mark and to provide for the establishment of a substitute primary bench mark if the original one should be destroyed. It is also desirable that a temporary bench mark be placed directly alongside the staff, so that the staff may be replaced without leveling should it be removed for any cause.

Descriptions.—Full descriptions of all bench marks should be carefully prepared and forwarded to the office, together with the leveling record. These descriptions should be written in the leveling record (Form 258) or in the tide record book (Form 277) when this form is used for recording staff readings at the station. The descriptions should be clear and distinct and sufficiently complete that the bench marks can be readily recovered and identified.

When a bench mark is located on a building the street and number should be given when possible. When not on a prominent structure all bench marks should be referenced, if feasible, by measurement and direction to several prominent objects, such as corners of substantial buildings, street curbs, prominent trees, large bowlders or sharply defined ledges, etc. A neat sketch, which will aid in locating or identifying the bench marks, should be made in ink in the leveling record or tide book. The year of establishment and the number of the mark should be stamped in the metal surface of the tablet.

When an old bench mark is recovered its description should be amended to agree with present conditions. When establishing additional bench marks at an old tide station duplication of numbers should be avoided and a number previously assigned to another bench mark in the same locality, whether destroyed or extant, should not be used for a new mark. Sets of dies for letters and figures can be obtained from the Washington office.

SETTING OF MARKS

The location of the mark, character of soil, or presence of ledges or bowlders will dictate the manner of setting the tablets. Permission from the Treasury Department has been obtained for placing standard disk bench marks on Federal buildings in the following authorization:

TREASURY DEPARTMENT,
Washington, November 11, 1914.

The honorable the SECRETARY OF COMMERCE,
Washington, D. C.

SIR: By direction of the Secretary, I have the honor to acknowledge the receipt of your communication of the 7th instant, requesting that permission be granted to the officers of the Coast and Geodetic Survey to place on the Federal buildings under the control of this department small inscribed metal tablets, which are to be used as bench marks in connection with the system of leveling, the custodians of the buildings to designate where the tablets are to be placed.

In reply you are advised that no objection will be interposed by this department to the placing of the tablets on the various public buildings, as desired, and this letter, or a copy thereof, upon its presentation to the custodian of a federal building, is to be considered by him as his authority for permitting the placing of one of the tablets on the building in his custody.

Respectfully,

(Signed) B. R. NEWTON,
Assistant Secretary,

On buildings.—When a tide station is established in a town or city, public parks, banks, city and Federal buildings, railroad stations and their grounds make good locations for bench marks. Permission will usually be granted for the establishment of a bench mark in such cases when its use is explained. Marks should not be placed on buildings known to be built on filled ground. Water hydrants, marks on curbstones, and on trees should not be used except as temporary marks and should be so described.

Permanent and substantial buldings afford the best locations for setting the disk bench marks. If a suitable location on a building is available for placing a standard disk bench mark with its face horizontal it is more convenient for placing a leveling rod than one set with its face vertical. A bench mark should be countersunk with its face flush with the surface of the part of the building into which it is set and securely cemented into place.

In ledges.—Where available, the marks may be cemented into rocky outcrops and in the surface of ledges. It is desirable that the tablet be counter sunk, but at times this is impracticable due to the hardness of the rock.

In bowlders.—Bowlders make satisfactory supports for bench marks. When a mark is set in a bowlder the latter should be of a

size as not to be readily disturbed and should extend below the surface sufficiently that it will not be affected by frost action.

In concrete.—When necessary to set the mark in a concrete mass the latter should be of such shape and set at a depth to withstand frost action. A concrete post about 3 feet long with enlarged base is easily constructed in place except in sandy soil and makes a satisfactory foundation, the bench mark being securely cemented into the top of the post. Unless in the path of traffic, the post should extend about 4 inches above the surface. It should be about 12 inches in diameter at the top and 16 inches at the base.

Sandy ground will not constitute a suitable mold for a concrete post. In such soil a sewer tile about 8 inches in diameter and 30 inches long will form a satisfactory mold. The tile is set with bell end down and in a mass of concrete. It is filled with concrete and the tablet set in the center of the top. If tile is not available, a pyramidal form made of boards may be used, the sides to have a batter of about 1 inch to the foot.

Material.—It is important in making the concrete that all materials be clean and thoroughly mixed before adding water. It should not be too wet and should be well tamped into the mold. When using rough aggregate the proportion should be about 1–3–5, the upper part of the mass to be of a richer mixture. When only sand and cement are obtainable the proportion of 1 part of cement to 3 parts of sand should be used for the lower part of the mass and 1 part of cement to 2 parts of sand for the upper part. To prevent rapid drying of the concrete, its surface should be covered with dampened paper or cloth or wet seaweed held in place with earth.

LEVELING

The tide staff and bench marks should be carefully connected by a double line of spirit levels, and it is desirable, when possible, for the leveling to be connected with at least one bench mark of other organizations, either Federal or municipal. If work has been previously done in the vicinity, all the old bench marks that can be recovered should be connected with the tide staff by levels.

The accepted closing error in the levels between the forward and backward measure shall not exceed $0.05\sqrt{K}$, in which K is the distance in statute miles leveled between adjacent bench marks. For convenience of use the following table is given:

Distance between bench marks (feet)	Maximum error allowed (feet)	Distance between bench marks (feet)	Maximum error allowed (feet)
500 or less	0.015	3,000	0.038
1,000	.022	4,000	.044
2,000	.031	5,000	.049

When the forward and backward measures differ in feet more than $0.05\sqrt{K}$ or for distance under 500 feet by more than 0.015 foot, both the forward and backward levels are to be repeated until the difference between two such levels falls within the limit. No one of the questioned values is to be used with the new levels to obtain this agreement.

VII. THE TIDE RECORD

STAFF READINGS

Generally the records from an automatic tide gauge are used by field parties for the reduction of soundings on a hydrographic survey. At times, however, when a station is to be maintained for only a short period and it is impractical to install an automatic gauge, the records from a plain staff are used. For the tabulation of the records from a tide staff and for getting the reducers for soundings at the required time intervals it will be found convenient to plot the staff readings on cross-section paper, plotting the time on the axis of X and the heights on the axis of Y. In addition such a graph permits of smoothing the tide curve of erroneous observations and also of obtaining the times and heights of high and low waters.

PORTABLE AUTOMATIC TIDE GAUGE RECORD

This type gauge is designed to furnish the tide record directly on cross-section paper, and in the operation of this gauge the recording stylus is set on the cross-section paper, when the gauge is started, to the reading at that instant on a fixed staff maintained in connection with the gauge for referring the observations to bench marks. The gauge thereafter traces on that record sheet a tide curve, the readings from which, as read from the cross-section paper, agree with the readings on the fixed staff. The record from this gauge is therefore ready for tabulation when removed from the gauge except for the application of any corrections in time and

height due to clock error or error in setting the stylus. The daily time and height notes made on the record by the tide observer indicate whether any such corrections are necessary. Since a tide record is tabulated to the nearest tenth of an hour in time and tenth of a foot in height, no such corrections will generally be necessary if the gauge has received proper attention.

STANDARD AUTOMATIC TIDE-GAUGE RECORD

The record from this type gauge consists of a continuous curve traced by a recording pencil on a roll of plain paper which is of sufficient length to contain a month of record, the time scale being 1 inch to the hour. A datum line to which the curve is referred is traced by a second pencil. The height of the tide is obtained by measuring with a glass scale the distance of the curve from the datum line, and the time of the tide is determined by an hour-marking device. At the beginning of each hour the hour-marking device of the gauge causes the recording pencil to make a short horizontal stroke, indicating on the curve the beginning of the hour. Before tabulation of this record it is necessary to establish the relation between the base line and the fixed tide staff and to mark the hours correctly. This is done by means of daily comparisons between the position of the recording pencil at a given instant and the reading on the staff. The gauge is visited each day by the observer and a note entered on the record at an indicated point on the curve of the correct time and the reading of the tide staff. These notes furnish the information necessary for marking the hours and for referring the heights measured on the curve to the tide staff.

The preliminary work necessary before tabulating the tide record from this gauge consists of marking the hours on the roll and preparation of a table of comparative staff and scale readings (Form 455) for obtaining the relation between the staff and datum line of the gauge and is explained in the following paragraphs:

Marking the hours.—The time notes entered on the record by the tide observer should be examined, and if it is found that the time clock does not vary appreciably from the correct time the hour marks automatically made by this clock may be accepted as correct and marked accordingly. The hour begins at the instant the mark leaves the curve, the length of the stroke having no significance. These marks should be numbered consecutively from 0^h (midnight) to 23^h (11 p. m.), and the numbering should be checked at each time note on the marigram.

In cases where the hour-marking device has failed to work or when the hour marks are unreliable on account of the time clock being appreciably in error the following method may be used: First, from the comparative time notes ascertain the position on the curve of the nearest exact hour. This is done by laying off 1 inch on a piece of paper and dividing it into 12 equal parts, the inch measured parallel to the datum line representing 1 hour on the tide curve and each of the divisions 5 minutes. The correct time of the point on the curve being known, as indicated by a time note, the nearest exact hour is layed off by means of this "time scale." Second, through the points thus found, indicating the exact hours, draw lines perpendicular to the datum line and extending across the paper. Third, prepare a "dividing scale" from a strip of paper somewhat longer than the greatest distance between the time notes on the marigram. On one edge lay off equal divisions about $1\frac{1}{32}$ inches long. These divisions should be numbered consecutively from 0^h to 23^h and repeated if necessary. This scale is then adjusted obliquely between two consecutive cross lines passing through the correct hour points, so that the numbers on the scale will agree with the hours represented by the cross lines. With the scale in this position, each division is marked on the marigram by a dot. Fourth, these hour dots are referred to tide curve by lines drawn through the dots and perpendicular to the datum line. These hour lines are numbered in the same manner as the hour marks automatically made by the time clock.

Comparative readings.—This form (fig. 15) is used to obtain the relation between the datum line of an automatic tide-gauge record and the zero of a fixed tide staff. The corrected setting as calculated in this form represents the scale reading of the datum line referred to staff.

In the first three columns the tabulator notes, respectively, the day, the time of staff reading, and the height of water level on staff, these items being taken directly from the observer's notes on the tide roll.

Next, the scale reading of the datum line, to be entered in the space provided in the heading of the form, should be arbitrarily chosen at any convenient value. This assumed or original setting should preferably be of such a value that the scale readings will be smaller than the staff readings by an amount from zero to 2 feet. The scale readings (B) in the fourth column are obtained by bringing the original setting on the scale into coincidence with the datum line on the marigram and reading from the scale the height of the

curve at the point referred to in the time note. The differences ($A-B$) in the fifth column are found by subtracting the scale reading from the corresponding staff readings. If the scale readings are larger, the differences will be negative.

If the gauge is run without any accident or adjustment, the differences ($A-B$) should be approximately equal, but if there has been any change in the adjustment, such as moving the datum pencil, breakage of float wire, or increase of kerosene in the float tube, etc., the differences will form distinct groups, one set of differences for each adjustment of the gauge. For example, in the specimen form (fig. 15) a new float wire was installed on November 13, and therefore the period November 1 to 12 forms a distinct grouping and November 13 to 30 another grouping.

In case there has been no change in adjustment the differences should agree fairly well with each other. However, any differences that vary strikingly from the apparent average should be rejected and excluded from the computation of the mean. Where there has been one or more changes in adjustment each set of differences must be considered separately.

Next, sum these differences which are approximately similar and obtain the mean by dividing the sum by the number of differences used, carrying the quotient to two decimal places. In case adjustments have been made to the gauge, more than one mean may be required. The algebraic sum of the assumed original setting and the mean difference gives the corrected scale setting. This setting should be ruled on the reading scale with ink and used as the scale setting of datum line for the tabulation of the high and low waters and hourly heights for the period covered by any set of uniform differences.

The column of differences affords an indication of the clogging of the float well. If the differences obtained with rising tides are consistently larger than those obtained with falling tides, a restricted movement of the float is indicated, and this condition should be remedied at once by cleaning the inlet opening. Since for each adjustment of the gauge a new setting must be computed, the original adjustment of the gauge should be maintained unless a change is necessary for its proper operation or from accident such as breaking the float wire, etc.

Form 455
Department of Commerce
Coast and Geodetic Survey

TIDES: COMPARATIVE READINGS.

Station: Charleston, S. C. *Lat.* 32° 47' N.
Party of L. C. Lockwood *Time meridian* 75° W *Long.* 79° 55' W.
Obs. begin ..... *Obs. end* ..... *Tabulated by* L. C. L. *Date* November 1925
Tide Gauge No. 97 *Scale* 1:12 *The scale reading of Datum Line for this comparison is* 4.00 *feet.*

DATE. Year. 1925		TIME OF STAFF READING.		STAFF A.	SCALE B.	DIFFERENCE A—B.	PHASE OF TIDE.*	REMARKS.	
Mo.	d.	h.	m.	feet.	feet.	feet.			
Nov.	1	10	33	7.10	6.00	1.10	F	Nov. 1 — Nov. 12	
	2	13	09	4.30	3.15	1.15	F	Sum	12.20
	3	16	23	3.00	1.90	1.10	R	Divisor	11
	4	16	48	3.60	2.50	1.10	R	Mean	1.11
	5	16	26	4.00	2.90	1.10	F	Original Setting	4.00
	6	16	52	3.80	2.70	1.10	F	Corrected Setting	5.11
	7	16	28	4.85	3.75	1.10	F		
	9	16	02	6.95	5.85	1.10	F		
	10	16	31	7.10	6.00	1.10	F		
	11	15	48	7.55	6.45	1.10	R		
	12	16	37	7.95	6.80	1.15	R		
	13							New float wire put on	
	13	16	46	6.50	6.30	0.20	R		
	14	12	30	1.90	1.80	0.10	L		
	16	16	49	4.05	3.90	0.15	R	Nov. 13 — Nov. 30	
	17	15	49	1.60	1.50	0.10	R	Sum	2.20
	18	16	16	1.70	1.60	0.10	R	Divisor	14
	19	16	23	1.95	1.85	0.10	L	Mean	0.16
	20	16	48	2.50	2.35	0.15	F	Original Setting	4.00
	21	15	50	5.20	5.10	0.10	F	Corrected Setting	4.16
	23	16	30	6.50	6.30	0.20	F		
	24	16	13	7.50	7.30	0.20	F		
	25	16	30	7.30	7.10	0.20	H		
	27	16	18	6.90	6.70	0.20	R		
	28	12	46	2.60	2.40	0.20	L		
	30	16	30	4.90	4.70	0.20	R		

* In the column headed "Phase of Tide" write the appropriate use of the four following symbols: H, for high water; L, for low water; R, for rising tide; and F, for falling tide. Use Form 136 for tabulating high and low water. 11—4501

FIG. 15.—Specimen of Form 455, comparative readings

VIII. TABULATION OF TIDE RECORDS

HOURLY HEIGHTS AND HIGH AND LOW WATERS

A complete tabulation of the tide records is made only at the primary tide stations maintained at various places along the coasts by the survey for correcting to a mean value short series of observations made by hydrographic parties working in the general vicinity. A complete tabulation consists of two sets—the hourly heights of the tide and the times and heights of high and low waters. For the primary tide stations the tabulation of the hourly heights is used for the determination of mean sea level. For short series of tide observations such as are obtained by hydrographic parties mean tide level, which is the half sum of the average high and low waters, is sufficiently close to mean sea level for the purposes required, and the tabulation of the hourly heights may therefore be limited by the hydrographic party to the time that sounding work is actually in progress for use of the party in the reduction of soundings. For the determination of a tidal datum plane for sounding reduction by the hydrographic party it is sufficient to tabulate only the high and low waters.

In order to establish uniformity in the records for the files of the office, the tabulations should be made in black ink and on the forms provided for the purpose. Values interpolated to fill in lost record should be inclosed in brackets in the tabulations to distinguish them from observed values. In all forms the heading on the front side of each sheet should be filled out as completely as possible. On the back of the sheet the name of the station and the year and month of the observations should be repeated. In the tabulations the hours of the day are to be designated consecutively from 0^h (midnight) to 23^h (11 p. m.), avoiding the terms a. m. and p. m.

TABULATION OF HIGH AND LOW WATERS

The tabulation of the high and low waters is made on Form 13S (figs. 16 and 17), whether read from an automatic tide-gauge record or taken from a graph prepared from plain staff readings. For field use the second column, headed "Moon's transits," and the fifth and sixth columns, headed "Lunitidal interval," are not necessary, and it is not required that the field party fill out these columns.

When tabulating high and low waters, the tabulator goes through the record making a dot inclosed in a small penciled circle at the

highest and lowest points of the tide curve. In determining the highest and lowest points on the tide curve attention is given to the arc of the curve covering about an hour of time interval, and the highest and lowest parts of the smooth arc are taken as the points of high and low waters and not the actual highest or lowest points reached by the recording pencil if the curve is jagged due to "saw teeth" from wave action.

The height of these points are now read off by the tabulator to the nearest tenth of a foot and the times to the nearest tenth of an hour, the times of high and low waters being recorded in the third and fourth columns and the heights of high and low waters in the seventh and eighth columns, respectively. If the record is on cross-section paper, times and heights may be read off directly; if on the plain paper roll of the standard automatic tide gauge, the heights are scaled off with a glass reading scale furnished by the office, and the times are estimated from the hour marks made by the automatic hour-marking device. For convenience in tabulating, the following table gives the equivalent of minutes in tenths of an hour.

Minutes	Tenths of hour	Minutes	Tenths of hour	Minutes	Tenths of hour	Examples
						H.m. Hrs.
0 to 3	0.0	21 to 27	0.4	45 to 51	0.8	4 02=4.0
4 to 8	.1	28 to 32	.5	52 to 56	.9	4 31=4.5
9 to 15	.2	33 to 39	.6	57 to 59	1.0	4 50=4.8
16 to 20	.3	40 to 44	.7			4 58=5.0

The heights should be referred to the zero of the tide staff. If the position of the tide staff has been changed during the observations the heights should all be referred to the zero of one position of the staff and a full explanation given in the column of remarks on the form. On a cross-section paper record the heights are referred directly to the zero of the staff. On the plain-paper record of the standard gauge the heights are referred to the zero of the staff by using the corrected scale setting as calculated from the comparative readings on Form 455 (fig. 15).

When the series of observations is longer than one month the high and low waters for each calendar month should be tabulated on a separate sheet. As indicated by the numbers in the date column of Form 138, the first 17 days of the calendar month are to be tabulated on the front page and the remaining days of the calendar month are to be tabulated on the back of the form. If any part of the record is missing vacant spaces should be left for

the missing tides. If the series is less than one month in length and covers parts of two calendar months it may be tabulated on a single sheet of Form 138, the printed dates being changed accordingly.

Form 138
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

Specimen of front of Form 138.
TIDES: HIGH AND LOW WATERS

Station: San Diego (La Playa), California — Lat. 33°42' N.
Acc. No. — Party of John A. Watkins — Long. 117 14 W.
Observations begin Jan. 20, 1906 — Observations end — Time meridian 120° W.

DATE Year 1912	MOON'S TRANSIT (Greenwich mean civil)	TIME OF— High Water	TIME OF— Low Water	LUNITIDAL INTERVAL High Water	LUNITIDAL INTERVAL Low Water	HEIGHT OF— High Water	HEIGHT OF— Low Water	REMARKS
mo. d.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	feet	feet	
July 1		11.5	4.8	.	.	7.3	3.2	
	.	22.0	16.5	.	.	9.5	6.1	
2	.	12.0	5.2	.	.	7.3	3.4	
	.	22.5	16.5	.	.	9.0	6.1	
3	.	12.5	6.0	.	.	7.3	3.6	
	.	23.0	17.0	.	.	8.7	6.1	
4	.	13.5	6.5	.	.	7.4	3.7	
	.	23.5	18.0	.	.	8.2	6.3	
5	.	— —	7.0	.	.	— —	4.2	
	.	14.0	19.4	.	.	7.6	6.3	
6	.	0.5	7.5	.	.	7.6	4.6	
	.	14.5	21.0	.	.	7.9	6.0	
7	.	1.5	8.2	.	.	7.0	4.9	
	.	15.5	22.0	.	.	8.2	5.0	
8	.	3.0	9.0	.	.	6.7	5.4	
	.	16.0	23.5	.	.	8.7	5.0	
9	.	5.0	10.0	.	.	6.8	5.7	
	.	16.5	— —	.	.	9.2	— —	
10	.	6.5	0.5	.	.	6.8	4.1	
	.	17.5	10.8	.	.	9.6	5.8	
11	.	7.8	1.0	.	.	7.1	3.2	
	.	18.5	11.5	.	.	10.2	6.0	
12	.	8.5	2.0	.	.	7.5	2.8	
	.	19.2	13.0	.	.	10.7	6.1	
13	.	9.2	3.0	.	.	7.6	2.2	
	.	20.0	13.5	.	.	10.8	6.0	
14	.	10.0	3.5	.	.	7.7	*2.0	
	.	21.0	14.5	.	.	11.0	5.7	
15	.	10.8	4.2	.	.	8.0	2.0	
	.	21.8	15.5	.	.	11.0	5.7	
16	.	11.5	5.0	.	.	8.1	2.2	
	.	22.2	16.2	.	.	10.4	5.5	
17	.	12.0	5.5	.	.	8.4	2.7	
	.	23.4	17.4	.	.	9.6	5.5	
Sums: carried forward		.	.	.	.	278.9	153.1	

FIG. 16.—Specimen of Form 138, high and low waters (front)

The morning tides are entered on the first line and the afternoon tides on the second line for each day. A tide occurring at midnight (0^h) is taken as belonging to the morning of the day just beginning.

TABULATION OF HOURLY HEIGHTS

The tabulation of hourly heights is made on Form 362 (fig. 18). At primary tide stations the hourly heights are tabulated continuously throughout the year without regard to calendar months,

FORM 138
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

Specimen of back of Form 138.
TIDES: HIGH AND LOW WATERS

Station: San Diego (La Playa), California Lat.
Highest tide: Date July 14, 15 Height 11.0ft. Lowest tide: Date July 14, 15 Height 2.0 ft. Long.
$I = (K_1+C_1)+M_n$ or $2(DHQ+DLQ)+Mn = 1.2$ $F(Mn) = 1.016$ $F_1 \times 1.02 = 0.78$ Time meridian 120° W.

DATE Year 1912	MOON'S TRANSIT (Greenwich mean time)	TIME OF—		LUNITIDAL INTERVAL		HEIGHT OF—		REMARKS
		HIGH WATER	LOW WATER	HIGH WATER	LOW WATER	HIGH WATER	LOW WATER	
mo. d.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	feet 33	feet 33	
Brought forward						278.9	153.1	
July 18	.	13.0	6.4	.	.	8.7	3.2	HHW 29 / LLW 29
	.	—.—	18.5	.	.	—.—	5.5	Sums 275.3 / 100.9
19	.	0.5	7.0	.	.	8.7	4.0	Means 9.42 / 3.48
	.	13.8	20.0	.	.	8.8	5.6	
20	.	1.5	7.5	.	.	7.9	4.8	DHQ= 0.99 DLQ= 1.22
	.	14.5	21.2	.	.	8.9	5.3	feet
21	.	2.5	8.2	.	.	7.2	5.4	Corr. Mn= 3.73 × 1.016 = 3.79
	.	15.5	23.0	.	.	9.1	4.8	Corr. DHQ= 0.99 × 0.78 = 0.77
22	.	6.0	9.5	.	.	6.8	6.0	Corr. DLQ= 1.22 × 0.78 = 0.95
	.	16.0	—.—	.	.	9.1	—.—	
23	.	6.5	0.2	.	.	7.1	4.3	
	.	17.5	10.5	.	.	9.3	6.3	
24	.	7.8	1.0	.	.	7.4	3.9	
	.	18.2	12.2	.	.	9.5	6.5	
25	.	8.5	1.5	.	.	7.5	3.5	
	.	19.0	12.5	.	.	9.6	6.3	
26	.	8.5	2.2	.	.	7.4	3.2	
	.	19.5	13.0	.	.	9.7	6.1	
27	.	9.2	3.0	.	.	7.5	3.0	
	.	20.0	13.5	.	.	9.8	6.0	
28	.	10.0	3.5	.	.	7.6	3.0	
	.	20.5	14.5	.	.	9.2	5.9	
29	.	10.2	4.0	.	.	7.5	3.0	
	.	21.0	15.0	.	.	9.2	5.7	
30	.	10.8	4.2	.	.	7.5	3.1	
	.	21.5	15.5	.	.	9.4	5.6	
31	.	11.2	4.5	.	.	7.7	3.3	
	.	22.0	16.0	.	.	9.0	5.5	
Sums	.	.	.	.	.	50 / 506.0	50 / 281.9	
Means	.	.	.	.	.	8.43	4.70	
Correction to intervals		.	.	.	.	4.70		
		.	.	.	.	3.73	Mn	Tabulated by Jno. Smith
Duration of rise		.	.	.	.	6.56	MTL	Date Aug. 6, 1912
Mean rise interval		.	.	.	.	.	.	Reduced by Jno. Smith
		.	.	.	.	.	.	Date Aug. 6, 1912

FIG. 17.—Specimen of Form 138, high and low waters (back)

both sides of the form being used. For the short series of observations obtained by hydrographic parties for the reduction of soundings it will be sufficient to tabulate the hourly heights only

at such times as sounding work was actually in progress. The heading of the form should be filled out as completely as possible, and year, month, and day should be clearly indicated. Heights

Form 362
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY

TIDES: HOURLY HEIGHTS

Station: Lituya Bay, S. E. Alaska Year: 1926

Observer: A. N. Sobieralski Lat. 58° 37' Long. 137° 37'

Time Meridian: 135° W Tide Gauge No. 155 Scale 1:45 Reduced to Staff.

Month and Day / Day of Series	mo. d. Aug. 20	d. 21	d. 22	d. 23	d. 24	d. 25	d. 26	Horizontal Sum
Hour	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
0	.	.	.	.	.	.	.	.
1	.	.	.	.	.	.	.	.
2	.	.	.	.	.	.	.	.
3	.	.	.	.	.	.	.	.
4	.	.	.	.	.	.	.	.
5	.	.	.	.	.	.	.	.
6	.	.	.	.	.	.	.	.
7	3.2	5.9	4.0	4.5	6.2	6.9	8.0	.
8	6.4	4.8	3.5	3.0	4.8	5.6	6.5	.
9	7.8	6.3	4.5	4.0	3.9	4.5	5.2	.
10	9.5	8.2	6.2	5.5	4.4	4.3	4.5	.
11	10.8	10.2	8.2	7.5	5.8	5.6	5.0	.
Noon	11.3	11.6	10.3	10.0	8.0	7.5	6.5	.
13	10.8	11.5	12.0	12.3	10.4	10.2	8.6	.
14	10.0	10.6	12.2	13.0	12.8	12.7	11.1	.
15	9.1	9.4	11.0	12.0	13.5	14.1	13.5	.
16	8.1	8.3	9.6	10.6	12.3	13.2	14.2	.
17	7.7	7.3	8.1	9.1	10.4	11.6	12.8	.
18								
19								
20								
21								
22								
23								
Sum	.	.	.	.	.	.	.	.

Sum for month of Divisor=(28d) 672; (29d) 696; (30d) 720; (31d) 744. Mean for month=

Tabulated by _____ Date _____ Summed by _____ Date _____

FIG. 18.—Specimen of Form 362, hourly heights

are to be given to the nearest tenth of a foot. No summing is necessary for the hourly heights tabulated for use in hydrographic work. The left-hand column gives the height above the zero of

the staff. For the convenience of the field party the right-hand column may be used to give the hourly heights above the plane of reference.

IRREGULARITIES IN TIDE CURVES

In order that there be no retardation in the time of the tide as registered in the float well and no decrease in the range in the well as compared with the actual tide, the inlet opening of the float well should be made sufficiently large to allow free access of the water. The result will be that the large waves on the outside are reflected in numerous small irregularities or "saw teeth" in the tide-curve recorded on the gauge. At times the tide curve also contains irregularities of larger amplitude and longer period than the "saw teeth." These are caused by seiches.

When the irregularities in the curve are of appreciable magnitude it is preferable in the tabulations to read the hourly heights from a smooth curve, actual or imaginary, drawn through the irregularities. No part of the original curves, however, should be erased. The times and heights of high and low waters are also tabulated from the smooth curve.

The tide curve should not be smoothed beyond the elimination of short-period irregularities. When the curve is disturbed in time and height by unusual weather conditions the tabulations should be made from the actual tide curve and the disturbed values rejected, if necessary, from the computation for mean values.

INTERPOLATIONS

Before beginning the reductions, if any portion of the record is lost, it is desirable that the missing tides be supplied by interpolation. Interpolated tides should be inclosed in parentheses to distinguish them from observed tides.

If the heights of alternate high waters are plotted on cross-section paper it will be found that fairly smooth curves may be drawn through the plotted points. Such a graph affords a means of interpolating for missing tides where only a few tides have been lost. When only a few tides are missing the alternate heights for several days before and several days after the break may be plotted and spaces left for the missing values. The smooth curve connecting the observed values will generally determine the missing values with sufficient accuracy. Similar curves may be drawn for alternate low waters. The times as well as the heights will be

found to plot in fairly regular curves, and times of missing high and low waters may also be determined by this graphic method. Figure 19 illustrates the use of this method. It is assumed that the p. m. high waters at San Diego for July 10 and 11 (see fig. 16) are missing. The times and heights of the corresponding tides immediately preceding and following the break have been plotted on Figure 19 and smooth curves drawn through the plotted points. The interpolated values taken from the curve are 17.4 hours and 9.7 feet for the 10th and 18.4 hours and 10.3 feet for the 11th. These values are seen to agree quite closely with the observed values for these days (fig. 16).

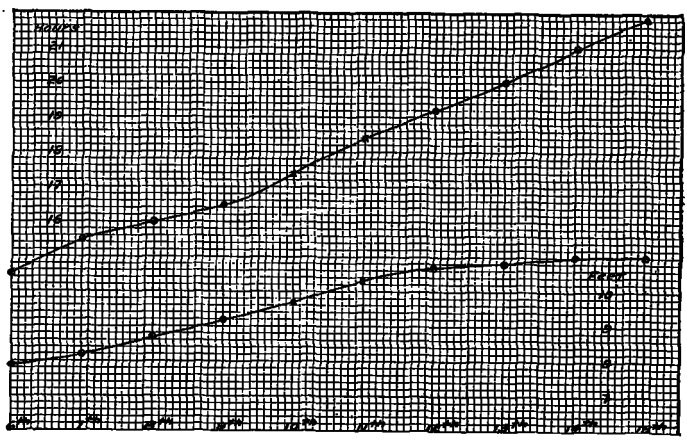

Fig. 19.—Graphic method of interpolating lost portions of tide records

Another method of supplying missing values is by direct comparison with simultaneous observations at some other station in the vicinity. This method is especially useful in extrapolating values at the beginning and end of a series of observations. Figure 20 will serve to illustrate this method of interpolation. Let it be assumed, for example, that the high waters for October 1, at Anacortes, are to be extrapolated by comparison with Seattle, where observations made on that day show the high water to have occurred at 1.2^h and 14.5^h, the height on staff being 15.8 feet and 18.4 feet, respectively. The comparison of observed values at the two stations shows average differences of 4.5 feet and 4.7 feet in the higher high waters and the lower high waters, respectively.

The high-water time differences are seen to form two distinct groups, the mean differences for alternate tides being 0.5 hours and −0.8 hours. Applying these differences to the corresponding observed tides at Seattle, the high waters at Anacortes for October 1 may be taken as occurring at 0.4^h (1.2−0.8) and 15.0^h (14.5+0.5), the corresponding heights being 20.5 feet (15.8+4.7) and 22.9 feet (18.4+4.5), respectively.

In the above case it was necessary to compute two average high-water time differences, owing to the different time relations of alternate tides. This condition is frequently met with where the diurnal inequality is large. Where the inequality is small, as along the Atlantic coast, the time differences will not exhibit this alternate irregularity, and a single mean time difference will be applicable to both high waters.

IX. PLANES OF REFERENCE

TIDAL DATUM PLANES

The simplicity of its definition as well as the certainty with which it may be reproduced at some future time gives value to the tidal datum as a plane of reference. In general, the most satisfactory plane is that of mean sea level, and this is the primary tidal datum plane to which all other tidal datum planes are referred. It is used by the Coast and Geodetic Survey as the basic plane for geodetic operations.

Mean sea level may be defined as that level about which the tides oscillate, and the method of determination is to obtain the average height of all the hourly readings of the tide curve for the series of observations. The observations obtained from the primary tide stations of the survey are used for the determination of mean sea level for geodetic control. The hydrographic party does not require the plane of mean sea level in its operations and therefore may limit the tabulation of hourly heights of the tide to such times as needed for the reduction of soundings.

For the purpose of the mariner a low-water plane is the most satisfactory, and the plane of mean low water has been adopted as a reference plane for the Atlantic and Gulf coasts of the United States, including Porto Rico and the Atlantic coast of the Panama Canal Zone.

Due to the daily inequalities in the tides, a plane of mean lower low water has been adopted as a reference plane for the Pacific coast

of the United States, Alaska, Hawaii, and the Philippines, with the exception of Wrangell Narrows, Alaska, where the adopted plane is 3 feet below mean lower low water.

A plane of mean low water springs has been adopted as a reference plane for the Pacific coast of the Panama Canal Zone.

MEAN LOW WATER

The plane of mean low water is obtained by subtracting one-half the mean range (corrected for the longitude of the moon's node) from mean tide level as obtained from Form 138 (fig. 17). Since at most stations there is an annual variation in mean tide level, its value as computed from Form 138 should, when conditions permit, also be corrected to a mean value by comparing the monthly means with simultaneous monthly means computed for some near-by primary tide station where an accurate determination of mean tide level has been obtained from a long series of observations. The monthly means for the primary station can be furnished the field party by the office. Form 248, Comparison of simultaneous observations, can be adapted to this comparison of monthly means by entering the values obtained from Form 138 in the appropriate places at the bottom of the columns of "Time difference" and "Height difference" and the computation carried through as indicated.

If the series of observations is a short one, such as obtained for a few days at auxiliary tide stations established by the hydrographic party for local tidal control, mean low water is determined by subtracting one-half the mean range from the value of mean tide level obtained from Form 248 by comparison of simultaneous daily observations with the principal tide station maintained by the hydrographic party where more accurate planes have been determined.

In deriving the plane of mean low water independently it is necessary first to determine the following:

Mean high water (HW), mean low water (LW), mean range (Mn), and mean tide level (MTL). These are derived from Form 138 in the following manner: First, add the high-water heights and also the low-water heights for each calendar month; second, obtain the means by dividing the sum of the high-water heights by the number of high waters included and the sum of the low-water heights by the number of low waters; third, obtain the range (Mn) by subtracting the mean of the low waters from the mean of the high waters and enter the result in the space before the symbol

"Mn" on the back of the form; fourth, obtain the mean tide level (MTL) by taking one-half of the sum of the mean high water and the mean low water and enter the value in the space before the symbol "MTL."

The range must be corrected for the longitude of the moon's node before subtracting from mean tide level for obtaining a mean low water plane. To correct the range for the longitude of the moon's node, apply the factor "F (Mn)" or "Factor of mean range" from the following table prepared for the years 1925 to 1934:

Factor F (Mn)—For reducing the observed range of tide to its mean value

$\frac{2\,(DHQ+DLQ)}{Mn}$	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
0.0 to 0.2	0.981	0.991	1.001	1.011	1.020	1.026	1.029	1.029	1.026	1.020
0.3 to 0.4	.982	.991	1.001	1.011	1.019	1.026	1.028	1.028	1.026	1.019
0.5 to 0.6	.983	.991	1.001	1.010	1.018	1.024	1.026	1.026	1.024	1.018
0.7 to 0.8	.985	.992	1.001	1.009	1.016	1.021	1.023	1.023	1.021	1.016
0.9 to 1.0	.988	.994	1.001	1.008	1.014	1.018	1.020	1.020	1.018	1.014
1.1 to 1.2	.990	.995	1.001	1.006	1.011	1.015	1.017	1.017	1.015	1.011
1.3 to 1.4	.993	.997	1.000	1.005	1.008	1.011	1.013	1.013	1.011	1.008
1.5 to 1.6	.996	.998	1.000	1.003	1.005	1.006	1.008	1.008	1.006	1.005
1.7 to 1.8	.999	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001
1.9 to 2.0	1.003	1.002	1.000	.998	.996	.995	.994	.994	.995	.996

The factors in this table have been computed for the middle of each year, but since they change slowly the same value may be taken for any month of the year. The line in the table from which the value is to be taken is determined by the argument $\frac{2\,(DHQ+DLQ)}{Mn}$ which may be computed to one decimal place from the uncorrected values of DHQ, DLQ, and Mn as obtained from Form 138.

For stations on the Atlantic coast of the United States from Maine to Florida the value $\frac{2\,(DHQ+DLQ)}{Mn}$ is usually small, and if the values of DHQ and DLQ have not been obtained, the top line of the table may generally be taken without material error. For stations on the coast of the Gulf of Mexico from Key West to the Rio Grande the mean range of the tide is very small and $\frac{2\,(DHQ+DLQ)}{Mn}$ large, so that the factor "F (Mn)" need not be applied. For other localities where DHQ and DLQ are usually computed, as on the Pacific coast, Alaska, etc., the value of

$\frac{2\,(DHQ+DLQ)}{Mn}$ should be obtained and entered in the space provided in the heading on the back of Form 13S. If it is larger than 1.8, no correction need be applied to the mean range.

MEAN LOWER LOW WATER

The plane of mean lower low water is obtained by subtracting the corrected diurnal low water inequality (DLQ) from mean low water.

In deriving the plane of mean lower low water it is necessary to determine first the plane of mean low water as explained in the preceding section and in addition the following: Mean lower low water (LLW) and the low water diurnal inequality (DLQ).

While only the values of mean lower low water and the low water diurnal inequality are needed in the determination of the mean lower low water plane, little additional work is involved in getting at the same time mean higher high water (HHW) and the high water diurnal inequality (DHQ), and their determination furnishes the data for a higher high water plane if needed for any purpose.

The values of HHW, LLW, DHQ, and DLQ are derived on Form 138 as follows: First, check the higher of the two high waters and the lower of the two low waters of each day. When only one high or one low water occurs on a calendar day, by reason of the other tide having occurred after midnight and therefore on the next calendar day, the single tide should be checked if the tide just before it is unchecked, otherwise it should not be checked.

When the two high waters or the two low waters for any day are of the same height, either can be checked. If, however, the tide has become diurnal and only one high and one low water occur during the tidal day, both should be checked. Second, the higher high waters and the lower low waters thus checked are summed and the results entered in the spaces provided in the "Remarks" column on the back of Form 13S. Third, obtain the means and enter the results in the line below the sums. Fourth, subtract the mean of all the high waters from the mean of the higher high waters and enter the difference as the high-water diurnal inequality (symbol DHQ) on the back of the form. Fifth, subtract the mean of the lower low waters from the mean of the low waters and enter the difference as the low water diurnal inequality (symbol DLQ).

The diurnal inequalities DHQ and DLQ should be corrected by the factor F_1, which may be obtained from the following table for the years 1925 to 1934. This corrected DLQ, subtracted from the

mean low water reference plane, the determination of which is explained in the previous section, determines the plane of mean lower low water. Likewise the corrected DHQ added to the mean high water reference plane determines the plane of mean higher high water.

Factor F_1.—For correcting DHQ and DLQ

Month	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
January	0.97	0.92	0.88	0.85	0.82	0.80	0.79	0.79	0.79	0.80
February	1.14	1.08	1.03	.99	.95	.92	.91	.91	.91	.92
March	1.35	1.26	1.19	1.12	1.08	1.05	1.03	1.03	1.04	1.06
April	1.24	1.17	1.10	1.05	1.01	.99	.97	.97	.98	1.00
May	1.00	.96	.91	.88	.85	.83	.82	.82	.83	.84
June	.90	.87	.83	.80	.78	.76	.76	.76	.76	.78
July	.94	.89	.86	.83	.80	.79	.78	.78	.79	.80
August	1.11	1.06	1.00	.96	.93	.91	.91	.91	.92	.94
September	1.31	1.23	1.16	1.11	1.07	1.04	1.04	1.04	1.05	1.08
October	1 19	1.13	1.07	1.02	.99	.97	.96	.96	.98	1.01
November	.98	.93	.89	.86	.84	.82	.82	.82	.83	.85
December	.88	.85	.81	.79	.77	.76	.76	.76	.77	.78
Mean	1.084	1.029	.978	.938	.908	.887	.879	.879	.888	.905

When Form 248 for the comparison of *simultaneous* observations is used, the factor F_1 need not be applied

MEAN LOW WATER SPRINGS

The plane of mean low water springs has been adopted as a reference plane for the Pacific coast of the Panama Canal Zone. This plane is derived from the spring tides, which are those tides occurring at the times of new and full moon. The datum of mean low water springs is therefore lower than mean low water and is determined by subtracting one half of the spring range from mean tide level.

Since this datum is used by this survey only in the vicinity of the Pacific end of the Panama Canal, it may be determined by comparison with observed or predicted tides at Balboa. The ratio of ranges between the subordinate station in question and the standard station of Balboa is first determined from Form 248. This ratio multiplied by 16.2, the spring range in feet of the tide at Balboa, will give the spring range at the subordinate station. One-half of the spring range thus determined subtracted from mean tide level at the subordinate station gives the plane of mean low water springs.

COMPARISON OF SIMULTANEOUS OBSERVATIONS (FORM 248)

If tidal data have been well determined for one station, satisfactory data for another station near by may generally be obtained by observing the tides simultaneously for several days at the two stations and comparing the results. For this purpose there should be at least two days of both day and night tides observed, and if the stations are very far apart a longer series should be observed. It is generally most satifactory, especially when there is a large diurnal inequality, to have the tides compared consist of a whole number of tidal days, so that the number of higher high waters, lower high waters, higher low waters, and lower low waters will be the same.

Explanation of Form 248.—An explanation of the use of Form 248 (fig. 20) is given on the back of the forms, as follows: This form is designed for the comparison of tides at a subordinate station for which tidal results are sought, with the tides observed simultaneously at a standard station for which tidal constants are known. For short series of observations the high and low waters observed at the subordinate station may be tabulated immediately in this form, in which case it will be unnecessary to tabulate them also in Form 138. The time and height differences are to be obtained by subtracting the values at the standard station from the values at the subordinate station and the results entered with proper signs in the columns indicated.

Find the sums and means of columns of time difference, height of tide at both stations, and height difference. For stations on the Pacific coast, where the plane of reference is mean lower low water, the heights of the higher high, lower high, higher low, and lower low waters are to be summed separately, the higher highs and lower lows being indicated by pencil check marks. For stations on the Atlantic coast, where the plane of reference is mean low water, the heights of the high waters may be all combined into a single sum, and similarly the low water heights, the headings of their sums being made to read HW and LW, respectively, by striking out the extra letters. All mean results should be given to two decimals of its unit, whether hour or foot. If any individual difference varies greatly from the apparent average and an examination of the original record fails to show an error, that difference should not be included in the sum, and such a value should be encircled to show that it has been rejected.

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
FORM 248

TIDES : Comparison of Simultaneous Observations

(A) Subordinate station Anacortes, Wash. Lat. 48° 31' N Long. 122° 36' W
(B) Standard station Seattle, Wash. Lat. 47° 37' N Long. 122° 20' W
Chief of party Time Meridian: (A) 120° W (B)

DATE. Year. 1922	(A) STATION. Time of— HW	(A) STATION. Time of— LW	(B) STATION. Time of— HW	(B) STATION. Time of— LW	(A)—(B) Time difference. HW.	(A)—(B) Time difference. LW.	(A) STATION. Height of— HW.	(A) STATION. Height of— LW.	(B) STATION. Height of— HW.	(B) STATION. Height of— LW.	(A)—(B) Height difference. HW.	(A)—(B) Height difference. LW.
Mo. D	Hours.	Hours.	Hours.	Hours.	Hours.	Hours.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Sept. 24	7.4	0.1	7.2	0.6	0.2	-0.5	22.7	15.4	18.3	7.3	4.4	8.1
	18.5	12.3	18.8	13.0	-0.3	-0.7	23.2	18.7	19.2	11.0	4.0	7.7
25	8.6	1.0	8.0	1.5	0.6	-0.5	22.6	15.0	18.2	7.0	4.4	8.0
	18.9	13.0	19.4	13.8	-0.5	-0.8	22.9	19.8	18.7	12.3	4.2	7.5
26	9.9	1.9	9.4	2.3	0.5	-0.4	22.9	15.2	18.1	7.3	4.8	7.9
	20.0	14.4	20.5	15.0	-0.5	-0.6	22.9	20.7	18.4	13.5	4.5	7.2
27	11.0	2.9	10.4	3.2	0.6	-0.3	23.0	15.7	18.1	8.0	4.9	7.7
	20.5	16.0	21.5	16.4	-1.0	-0.4	22.1	20.9	17.1	13.8	5.0	7.1
28	12.5	4.0	12.0	4.3	0.5	-0.3	22.7	15.6	18.0	8.2	4.7	7.4
	21.6	18.0	22.3	17.8	-1.3	-0.2	21.0	20.4	16.1	13.6	4.9	6.8
29	13.5	6.0	----	5.5	0.6	-0.6	22.7	15.8	----	8.3	4.7	7.5
	23.2	19.0	12.9	19.0	-0.9	0.0	20.7	20.0	18.0	13.0	4.9	7.0
30	----	6.0	0.1	6.6	----	-0.6	----	16.3	15.8	8.9	----	7.4
	14.5	20.4	14.0	20.0	0.5	0.4	23.2	19.8	18.4	12.7	4.8	7.1
Sums							HW. 7 160.6	HW. 7 140.3	HW. 7 128.8	HW. 7 89.9	HW. 7 31.8	HW. 7 50.4
Means							22.94	20.04	18.40	12.84	4.54	7.20
Sums					13 -1.2	14 -5.0	LW. 6 132.0	LW. 7 109.0	LW. 6 103.5	LW. 7 55.0	LW. 6 28.4	LW. 7 54.0
Means					-0.09	-0.36	22.00	15.57	17.27	7.86	4.73	7.71

	HW.	LW.	
(1)=	-0.09	-0.36	=Mean difference in time of high and low water respectively.
(2)=	-0.02	-0.02	=Correction for difference in longitude. (Table on back of form.)
(3)=	-0.11	-0.38	=(1)+(2)=Mean difference in high and low water intervals, respectively.

(4)= 22.94 (Feet.) =Mean HHW height at (A).
(5)= 20.04 =Mean HLW height at (A).
(6)= 22.00 =Mean LHW height at (A).
(7)= 15.57 =Mean LLW height at (A).
(8)= 0.94 =(4)−(6)=2DHQ at (A).
(9)= 4.47 =(5)−(7)=2DLQ at (A).
(10)= 22.47 =½[(4)+(6)]=Mean HW height at (A).
(11)= 17.80 =½[(5)+(7)]=Mean LW height at (A).
(12)= 4.67 =(10)−(11)=Mn at (A).
(13)= 20.14 =½[(10)+(11)]=MTL at (A).

(14)= 4.54 =Mean HHW difference.
(15)= 7.20 =Mean HLW difference.
(16)= 4.73 =Mean LHW difference.
(17)= 7.71 =Mean LLW difference.
(18)= -0.19 =(14)−(16)=2DHQ difference.
(19)= -0.51 =(15)−(17)=2DLQ difference.
(20)= 4.64 =½[(14)+(16)]=Mean HW difference.
(21)= 7.46 =½[(15)+(17)]=Mean LW differences.
(22)= -2.82 =(20)−(21)=Mn difference.
(23)= 6.05 =½[(20)+(21)]=MTL difference.

(24)= 0.623 =(12)÷[(12)−(22)]=Mn ratio.
(25)= 0.832 =(8)÷[(8)−(18)]=DHQ ratio.
(26)= 0.898 =(9)÷[(9)−(19)]=DLQ ratio.

Results from comparison of Stations A and B.	HWI.	LWI.	MTL.	Mn.	DHQ.	DLQ.
Length of Series.	Hours.	Hours.	Feet.	Feet.	Feet.	Feet.
Accepted values for standard station, from obs. for 19 years	4.48	10.70	14.09	7.64	0.86	2.83
Differences and ratios: (3), (13), (24), (25), (26)	-0.11	-0.38	6.05	×0.623	×0.832	×0.898
Corrected values for subordinate station	4.37	10.32	20.11	4.76	0.72	2.54

Mean LW on staff at subordinate station=MTL−½Mn =_____ feet.
Mean LLW on staff at subordinate station=MTL−½Mn−DLQ= 15.19 feet.

Computed by C. D. A. (Date.) 5 − 12 − 27 Verified by F. J. H. (Date.) 5 − 12 − 27

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FIG. 20.—Specimen of Form 248, comparison of simultaneous observations

For stations on the Atlantic coast omit (4) to (9), (14) to (19), (25), (26), and the computation of DHQ and DIQ at the bottom of the form. Take (10)=mean high water height at the subordinate station, (11)=mean low water height at subordinate station, (20)=mean high water difference, and (21)=mean low water difference. For stations on the Pacific coast the lower part of the form should be filled out completely, as indicated.

The correction for difference in longitude (2) may be obtained from the following table (fig. 21). Find the difference in longitude by subtracting the longitude of the subordinate station from the longitude of the standard station, considering west as positive and east as negative. The correction has the same sign as the resulting difference of longitudes. If the kind of time used at the two stations is different, apply this difference, expressed in hours, to the difference in the time of tide as directly obtained, adding if the time meridain of the subordinate station is west of the time meridian of the standard station and subtracting if the time meridian of the subordinate station is east of that of the standard station.

X. TIDE REDUCERS FOR SOUNDINGS

GENERAL METHOD

After the plane of reference has been derived the tide reducers are obtained by subtracting the value which corresponds to the height of the plane of reference on staff from the recorded or tabulated heights of the tide for the time the soundings were made. Negative differences give positive reducers or reducers which are to be added to the soundings. Since the reducers are generally to be subtracted from the soundings, the minus sign may be omitted from the sounding book; but when the reducers are to be added to the soundings the plus sign should always be entered with the reducers.

It will be found convenient to derive the tide reducers from a plotting on cross-section paper. This plotting is most advantageously made from hourly heights of the tide, but instead of these hourly heights being plotted as recorded on the staff they are plotted to datum. It is therefore necessary as a preliminary to reduce the hourly heights to datum. This is done by subtracting from each hourly height, as given on Form 362, the height of the datum plane. The result may then be noted on another sheet of Form 362, but care must be taken to delete the word "Staff" and insert "Datum"

Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.
′	Hour.	′	Hour.	°	Hour.	°	Hour.	°	Hour.	°	Hour.	°	Hour.	°	Hour.	°	Hour.
1	0.001	31	0.036	1	0.069	31	2.139	61	4.209	91	6.279	121	8.349	151	10.420
2	0.002	32	0.037	2	0.138	32	2.208	62	4.278	92	6.348	122	8.418	152	10.489
3	0.003	33	0.038	3	0.207	33	2.277	63	4.347	93	6.417	123	8.487	153	10.558
4	0.005	34	0.039	4	0.276	34	2.346	64	4.416	94	6.486	124	8.556	154	10.627
5	0.006	35	0.040	5	0.345	35	2.415	65	4.485	95	6.555	125	8.625	155	10.696
6	0.007	36	0.041	6	0.414	36	2.484	66	4.554	96	6.624	126	8.694	156	10.765
7	0.008	37	0.043	7	0.483	37	2.553	67	4.623	97	6.693	127	8.763	157	10.834
8	0.009	38	0.044	8	0.552	38	2.622	68	4.692	98	6.762	128	8.832	158	10.903
9	0.010	39	0.045	9	0.621	39	2.691	69	4.761	99	6.831	129	8.901	159	10.972
10	0.012	40	0.046	10	0.690	40	2.760	70	4.830	100	6.900	130	8.970	160	11.041
11	0.013	41	0.047	11	0.759	41	2.829	71	4.899	101	6.969	131	9.039	161	11.110
12	0.014	42	0.048	12	0.828	42	2.898	72	4.968	102	7.038	132	9.108	162	11.179
13	0.015	43	0.049	13	0.897	43	2.967	73	5.037	103	7.107	133	9.177	163	11.248
14	0.016	44	0.051	14	0.966	44	3.036	74	5.106	104	7.176	134	9.246	164	11.317
15	0.017	45	0.052	15	1.035	45	3.105	75	5.175	105	7.245	135	9.315	165	11.386
16	0.018	46	0.053	16	1.104	46	3.174	76	5.244	106	7.314	136	9.384	166	11.455
17	0.020	47	0.054	17	1.173	47	3.243	77	5.313	107	7.383	137	9.453	167	11.524
18	0.021	48	0.055	18	1.242	48	3.312	78	5.382	108	7.452	138	9.522	168	11.593
19	0.022	49	0.056	19	1.311	49	3.381	79	5.451	109	7.521	139	9.591	169	11.662
20	0.023	50	0.058	20	1.380	50	3.450	80	5.520	110	7.590	140	9.660	170	11.731
21	0.024	51	0.059	21	1.449	51	3.519	81	5.589	111	7.659	141	9.729	171	11.800
22	0.025	52	0.060	22	1.518	52	3.588	82	5.658	112	7.728	142	9.798	172	11.869
23	0.026	53	0.061	23	1.587	53	3.657	83	5.727	113	7.797	143	9.867	173	11.938
24	0.028	54	0.062	24	1.656	54	3.726	84	5.796	114	7.866	144	9.936	174	12.007
25	0.029	55	0.063	25	1.725	55	3.795	85	5.865	115	7.935	145	10.005	175	12.076
26	0.030	56	0.064	26	1.794	56	3.864	86	5.934	116	8.004	146	10.074	176	12.145
27	0.031	57	0.066	27	1.863	57	3.933	87	6.003	117	8.073	147	10.143	177	12.214
28	0.032	58	0.067	28	1.932	58	4.002	88	6.072	118	8.142	148	10.212	178	12.283
29	0.033	59	0.068	29	2.001	59	4.071	89	6.141	119	8.211	149	10.281	179	12.352
30	0.035	60	0.069	30	2.070	60	4.140	90	6.210	120	8.280	150	10.351	180	12.421

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FIG. 21.—Table of corrections for difference in longitude for use on Form 248

in the upper right-hand legend, and the heights should be given in the right-hand column for each day, as shown in Figure 22. Frequently it is found convenient to insert the height reduced to datum

Form 362
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY

TIDES: HOURLY HEIGHTS

Station: Lituya Bay, S. E. Alaska Year: 1926
Observer: A. M. Sobieralski Lat. 58° 37' Long. 137° 37'
Time Meridian: 135° W Tide Gauge No. ____ Scale 1: 45 Reduced to Staff. Datum

Month and Day	mo.	d.		d.		d.		d.		d.		d.		d.		Horizontal Sum
Day of Series	Aug.	20		21		22		23		24		25		26		
Hour	Feet			Feet		Feet		Feet		Feet		Feet		Feet		Feet
0																
1																
2																
3																
4																
5																
6																
7		0.4		-0.9		-0.8		-0.3		1.4		2.1		3.2		
8		1.6		0.0		-1.3		-1.2		0.0		0.6		1.7		
9		3.0		1.5		-0.3		-0.8		-0.9		-0.3		0.4		
10		4.7		3.4		1.4		0.7		-0.4		-0.5		-0.3		
11		6.0		5.4		3.4		2.7		1.0		0.7		0.2		
Noon		6.5		6.8		5.5		5.2		3.2		2.7		1.7		
13		6.0		6.7		7.2		7.5		5.6		5.4		3.8		
14		5.2		5.8		7.4		8.2		8.0		7.9		6.3		
15		4.3		4.6		6.2		7.2		8.7		9.3		8.7		
16		3.3		3.5		4.8		5.8		7.5		8.4		9.4		
17		2.9		2.5		3.3		4.3		5.6		6.8		8.0		
18																
19																
20																
21																
22																
23																
Sum																

Sum for month of Divisor=(28d) 672; (29d) 696; (30d) 720; (31d) 744. Mean for month=

Tabulated by ____ Date ____ Summed by ____ Date ____

FIG. 22.—Specimen of Form 362, hourly heights, illustrating its use for tabulation of tide reducers

on the same sheet, with the heights reduced to staff, the right-hand column for each day being used for the former and the left-hand for the latter.

With the reducers plotted to zero plane of reference and the curve drawn in, the reducer for any given time may be read directly from the curve and entered in the sounding book. The curves should be marked with name of station, date and line of soundings to which applied, and forwarded to the office with the sounding records.

GRAPHIC METHOD

When the reduced soundings are to be given in integral feet, reductions for tide may be made easily and rapidly from either the standard automatic tide gauge or the portable automatic tide-gauge marigrams by a graphic method described in the following paragraphs. In using this method care should be taken, however, to avoid confusion as to the times or the heights of tides, especially when reading from a portable automatic tide-gauge record on which the curves representing the tide for different days are often close together. At times it may be necessary to strengthen a faintly traced curve of the record so that it may be sufficiently bold to be readily seen through the transparent graphic scale.

This scale is constructed on transparent tracing cloth or tracing paper by ruling a series of horizontal lines spaced at intervals representing feet in the same height scale as used on the marigram and a series of vertical lines spaced at intervals representing hours in the same time scale as used on the marigram. For the portable tide-gauge records the vertical lines may usually be omitted. The horizontal lines are numbered upward from the bottom of the scale +3, +2, +1, 0, −1, −2, −3, −4, etc., according to the range of tide, small figures being used for this numbering. A horizontal line in red ink is now drawn on the tracing at the scale reading corresponding to the value of the formula

$$x-y-0.7 \text{ ft.},$$

where x=height of plane of reference (LW or LLW) above zero of the tide staff, y=height of datum line of marigram as referred to zero of tide staff, and the value "0.7 ft." represents the fraction at which the reduced sounding changes by an integral foot.

For the standard tide-gauge record the value of "y" is the corrected scale setting as computed on Form 455 (fig.15). For the portable tide-gauge record the "0" of the marigram record may be taken as the datum line and "y" becomes equal to zero. The red line will be above or below the zero of the scale, according to whether the value from the formula is negative or positive.

The graph is laid over the marigram with the red horizontal line in coincidence with the datum line if a standard gauge record, or with the scale zero of the portable gauge record (assuming that this corresponds to the tide staff zero), and the hour marks of the graphic scale and of the marigram in coincidence. In case a time allowance is to be made, the graph is shifted to the right or to the left, according to the amount of time allowance.

The spaces between the horizontal lines are numbered with figures somewhat larger than those used for the scale lines, beginning

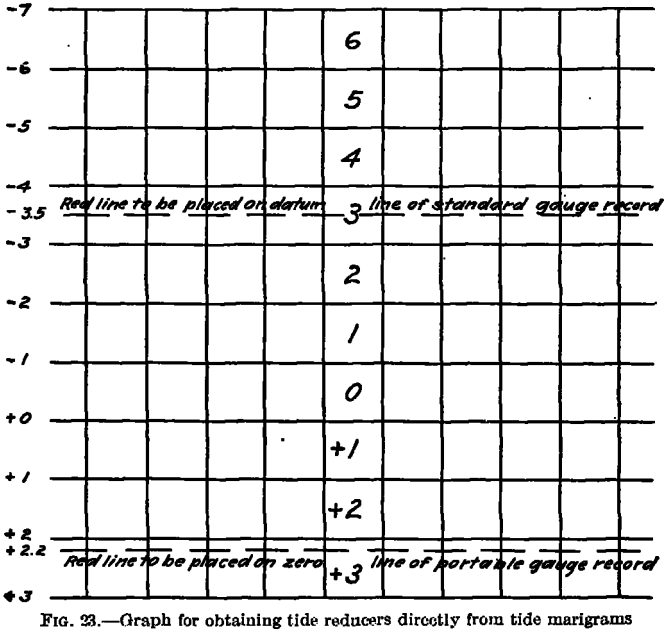

FIG. 23.—Graph for obtaining tide reducers directly from tide marigrams

with "0" for the space just above the zero (0) line and numbering consecutively above and below this space, using the plus (+) sign before the numerals for the lower spaces. These numbers will be the tide reducers to integral feet for all portions of the tide curve falling within the space so marked.

An example of a graphic scale is given in Figure 23. For the standard-gauge record, assuming that "x," the height of the plane of reference above the zero of the tide staff, is 2.3 feet, and that "y," the height of the datum line above the zero of tide staff, is

5.1 feet, the formula $x-y-0.7$ gives -3.5 feet as the scale reading at which the red line is drawn, this line to be placed in coincidence with the datum line of the marigram when the scale is in use.

For the portable gauge, assuming that "x," the height of plane of reference on tide staff, is 2.9 feet, and taking "y" as zero, the formula gives $+2.2$ feet as the scale reading for the red line, which is to be placed in coincidence with the zero of the marigram scale when in use.

TIME ALLOWANCE

When there is much difference in the time or height of the tide at the place of sounding and at the tide gauge, allowance should be made in the reduction of the soundings. The difference may generally be estimated from observations made at several stations in the vicinity of the work, but when it has been impossible to establish more than one tide station in the locality, the following formula may be useful in estimating the velocity of a progressive tidal wave and enable one to obtain the approximate difference in the time of the tide: $v=\sqrt{gd}=5.67\sqrt{d}$ feet per second, when $g=32.17$ feet per second and d=depth of water for the average cross section between stations, in feet.

In order to convert feet per second into nautical miles per hour, multiply by $\frac{3600}{6080}=0.592$, and we have

$$v=3.36\sqrt{d} \text{ nautical miles per hour.}$$

The time required for the tide wave is

$$t=\frac{6080}{60\times5.672\sqrt{d}}=\frac{17.87}{\sqrt{d}} \text{ minutes per nautical mile.}$$

$$t=\frac{5280}{60\times5.672\sqrt{d}}=\frac{15.51}{\sqrt{d}} \text{ minutes per statute mile.}$$

For convenience the following brief table is given:

Time required for the tide wave to travel

Depth	1 nautical mile	1 statute mile	Depth	1 nautical mile	1 statute mile
Fathoms	*Minutes*	*Minutes*	*Fathoms*	*Minutes*	*Minutes*
1	7.3	6.3	9	2.4	2.1
2	5.2	4.5	10	2.3	2.0
3	4.2	3.7	15	1.9	1.6
4	3.6	3.2	20	1.6	1.4
5	3.3	2.8	30	1.3	1.2
6	3.0	2.6	40	1.2	1.0
7	2.8	2.4	50	1.0	.9
8	2.6	2.2	60	.9	.8

For offshore areas where the continental shelf is broad and the tidal wave approaches parallel to the coast the tide will arrive offshore much earlier than inshore, and for an accurate reduction of soundings a time correction will be necessary. This time correction can be applied from the shore outward by taking sections where the time of the tide averages 15 minutes, 30 minutes, 45 minutes, 1 hour, etc., earlier than at the tide station. These sections can be determined by means of the above table, giving the time required for the tide wave to travel at different depths.

HEIGHT ALLOWANCE

When the tide station used for deriving the tide reducers is made to cover an area over which the range of tide varies height corrections will be necessary. For the adjustment of tide reducers between stations along the coast and inside waters it will be found convenient to divide the area covered into sections. Each section may cover an area in which the variation in range of tide does not exceed three-tenths of the unit used for the tide reducers; that is, 0.3 foot, 0.9 foot, and 1.8 feet when the reducers are entered in units of a foot, half fathom, and whole fathom, respectively. Take, for example, an area 15 miles long with no narrow restrictions and with depths of 3 fathoms or less. At one end is Station A, from which the tide reducers are to be derived; at the other end is Station B, where the time and height of the tide are known. The mean range of tide at Station A is 2.6 feet, at Station B 3.5 feet, the difference in range being 0.9 foot. The difference in the time of tide between the two stations will be assumed to be 45 minutes. The area should, therefore, be divided into four sections. Assuming the tide to increase uniformly with the distance, the first section will be 2½ miles long and the height and time of the tide the same as at Station A. The second section will be 5 miles long and the height of high water 0.3 foot greater and time 15 minutes later than at Station A. The third section will also be 5 miles long and the height of high water will be 0.6 foot greater and the time 30 minutes later than at Station A. The fourth section will be 2½ miles long and the height of high water 0.9 foot greater and the time 45 minutes later than at Station A.

The tide reducers for soundings in each of sections 2, 3, and 4 may be derived directly from the curves for Station A by reading the curves at points which are as many minutes earlier than the times of the soundings as there are minutes in the time allowance

for each section and multiplying the readings by the ratio of ranges. For offshore areas the range of tide may generally be taken the same as at the nearest point along the coast.

XI. PRIMARY TIDE STATIONS

PURPOSES

Datum planes for hydrographic purposes can be determined with sufficient accuracy from short series of observations when corrected to mean values by comparison with simultaneous observations at stations for which the results of long series of observations are available. The stations at which long series of observations are being made are known as primary tide stations and are located at a number of carefully selected points along the coast. The operation of these stations is under the direct supervision of the office, but advantage is taken of the presence of a survey party in the near vicinity of a primary tide station to have an inspection made.

The primary tide stations serve a number of purposes. They furnish primary determinations of mean sea level for use as starting and "tie-in" points of the precise-level net. The data from these stations make possible the correction to mean values of the results of short series of tide observations made for hydrographic purposes. They also furnish the data for computing the stage of the tide at any desired time at places in the general vicinity, and in addition they furnish the basic data for the study and advancement of the subject of tides. It is therefore important that these stations function as efficiently as possible, and it is for this purpose that periodic inspections are necessary.

INSPECTION

In making an inspection of a primary tide station note is to be made of the following matters and reported on in the report of the inspection:

(*a*) **Location.**—Changes frequently take place in connection with wharf structures which affect the suitability of a particular location as the site for a primary tide station. The inspection should cover the present suitability of the location. Several soundings should be made as close to the float well as possible, the depth of the water and the time of the soundings being given in the report.

(*b*) **Tide staff and staff support.**—A careful inspection should be made of the tide staff and staff support, with special regard to possible looseness of the stop plates. The setting of the stop plate on the tide staff should be verified to make sure that no change has occurred. If any such change is found, it should be measured and noted in the report with any explanation that may be gotten from the observer. If the staff used is a portable staff, it should be lowered into the staff support and noted whether any obstructions exist to prevent the two stop plates from coming together.

There have been cases where the tide observer has replaced a damaged tide staff without bringing the matter to the attention of the office. It is desirable, therefore, to obtain from the tide observer statements relative to any change in the staff of which he may have knowledge and to note the same in the leveling record, since it is important that the office have a complete record of all changes in the tide staff at primary stations, even though the changes may affect the elevation of the staff by only a very small amount.

(*c*) **Observations.**—The methods and procedure used by the observer in making the observations should be noted and his attention called to any matter that requires change. Any unusual methods or procedure should be noted in the report. The inspector should make an independent reading of the tide staff and note it on the tide record in accordance with the instructions under "Comparative note" in the section on the installation and operation of the standard automatic tide gauge.

Special attention is to be given to the observer's method of making the staff comparison and entry of the daily comparative reading; for, having noted an approximately fixed relationship between the tide staff and scale readings, an observer may in good faith be tempted to check the actual staff readings by a scale reading of the tide curve before entering the staff readings on the roll. In this practice it is impossible to avoid a biased staff reading. In order that the tide curve may be directly referred to bench marks, it is very important that actual readings of the tide staff, unbiased by any other consideration, be entered on the tide roll. No scale of any kind, or a substitute for the same, should be allowed in the tide house for checking the staff readings.

(*d*) **Adjustment of gauge.**—It should be noted whether, at approximately mean tide level, the recording pencil will be near the center of the paper and the float wire drum and counterpoise drum about half filled with wire. It should also be noted whether

the counterpoise weight is so arranged that it has free movement between the limits of extreme high and low water. If necessary, a movable pulley should be installed. If these adjustments are satisfactorily made, the observer should be instructed not to change them unless the float wire breaks or other accidents occur. When it becomes necessary to readjust the gauge, however, for any cause, the observer should enter a note on the roll explaining the fact.

(*e*) **Float well.**—The inspecting officer should make careful examination of the condition of the float well and note whether the float is free to move within the limits of the tide without scraping the side of the float well. If necessary, the gauge should be moved to bring the float into a central position over the well.

It is important that the inlet opening be clear at all times from accumulation of sediment for the free access of water to the well. The recording pencil should have perceptible motion when the water is moderately rough. The observer's attention should be called to the fact that a smooth curve under the conditions is indicative of a partially clogged opening and that "saw teeth" in the curve is desirable. He should be instructed to clear the opening immediately upon noting these indications of clogging.

(*f*) **Leveling.**—At primary tide stations special care should be taken in connecting the tide staff with the primary bench mark, and the following additional work, not required at ordinary tide stations, should be done. In leveling between the tide staff and primary bench mark there should be not less than four independent determinations of the relation of the zero of the staff to the primary bench mark. If any two of these determinations shall differ from each other by more than the maximum error allowed the line between the staff and the primary bench mark shall be again run and repeated if necessary until the elevation of the zero of the staff has been determined within the allowable error beyond reasonable doubt.

At least two other substantial bench marks, and if practicable all other bench marks in the locality, should be connected with the primary bench mark by forward and backward lines of levels to check the stability of the primary bench mark. If the forward and backward measurements between any two bench marks do not agree within the allowable error the work must be repeated.

If when connecting the tide staff and primary bench mark a direct reading is made on the tide-staff graduation and the leveling rod is used on the bench mark only, care should be taken to see that

the bottom of rod corresponds with its zero graduation. If a portable tide staff is used at the station, the leveling rod may be held on top of the brass plate (not on top of the stud) of the staff support, but the graduation of the tide staff to which the top of this plate corresponds must be carefully ascertained by placing the tide staff in position for actual use. It is not sufficient to accept the elevation of this plate as corresponding to the reading on the tide staff for which it was designed, since some unexpected obstruction in the guides may prevent the staff from being lowered to the proper position, but by actually placing the staff in position for use the true reading corresponding to the point on which the leveling rod is held may be determined, and this should be noted in the leveling record. In running the levels care should be taken to have the foresights and backsights approximately equal.

(*g*) **Recommendations.**—A report of inspection should include recommendation for such repairs or changes as may appear desirable, with an estimate of the cost whenever it is possible to do so. At remote stations, when it is found that repairs are urgently required and should be made while the inspecting officer is at the station, approval of the estimates to cover the cost of such repairs should be requested by telegraph.

At most of the primary tide stations the observer also tabulates the tide roll. These tabulations are checked at the office, so that, in general, the inspecting officer need not concern himself with this phase of the work unless specially instructed to do so in the orders.

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