U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

MANUAL OF TIDE OBSERVATIONS

PUBLICATION 30-1

A REVISION OF SPECIAL PUBLICATION NO. 196

U.S. DEPARTMENT OF COMMERCE
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COAST AND GEODETIC SURVEY
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MANUAL OF TIDE OBSERVATIONS

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PREFACE

The revised 1965 edition of the Manual of Tide Observations, Special Publication No. 196, contains instructions for observing and recording the rise and fall of the tide and for making the necessary reductions to determine the datum planes and the nonharmonic quantities published in the Tide Tables. This revised edition of the manual supersedes all previous editions and includes the following new material: descriptions of new gages and methods that have been successfully used to measure tides; examples of new, and presently used, forms for recording tide data; and, tables that cover the years 1961 through 2000 for reducing observed ranges and diurnal inequalities in tide heights to mean values. Modification of parts used in the standard automatic tide gage and a preliminary description of the analog-to-digital recorder tide gage and its operation appear in the last section of the manual.

For information relative to the observation of tidal currents, the prediction of tides and tidal currents, and the special terminology used to describe the tidal phenomena of the world ocean, the reader is referred to the following Coast and Geodetic Survey publications: Manual of Current Observations, Special Publication No. 215, Revised (1950) Edition; Manual of Harmonic Analysis and Prediction of Tides, Special Publication No. 98, Revised (1940) Edition; and Tide and Current Glossary, Revised (1949) Edition. These publications are for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.

Instructions for observing water temperature and salinity at tide stations can be obtained from the Director of the U.S. Coast and Geodetic Survey, Washington, D.C., 20230.

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MANUAL OF TIDE OBSERVATIONS

1. Purposes of tide observations.—Tide measurements are made by the Coast and Geodetic Survey to serve the needs of the mariner, the engineer, the scientist, and the general public. This work began with the charting of coastal waters and the need to establish a uniform level, or datum plane, to which observed water depths could be referred, the soundings being taken at different stages of the tide during hydrographic surveys. In addition to satisfying the charting requirements of the Bureau, tide measurements also are made for the following purposes: (*a*) to determine mean sea level and other tidal datum planes for surveying and engineering purposes and to establish a system of tidal bench marks to which these planes can be referred; (*b*) to provide data for tide and current predictions and publication of this data in annual tide and current tables; (*c*) to investigate fluctuations of sea level and crustal movements of the earth; (*d*) to supply information concerning tidal conditions for engineering projects; (*e*) to provide pertinent data for special estuarine studies; and (*f*) to furnish information for legal cases regarding tidal boundaries—both State and Federal—and various other maritime interests. Self-registering gages also provide records of nonperiodic changes in sea level, such as, storm surges and tsunamis or seismic sea waves. This information has contributed to the establishment of the Seismic Sea-Wave Warning System to prevent loss of life and property in exposed areas. Improevd systems of monitoring observations at distant gage stations are expected to increase the effectiveness of the warning system.

2. Tide stations are classified as control stations and secondary stations. Control stations are those at which tide observations are continued for a number of years to derive basic tidal data for the locality. Secondary stations are operated only for limited periods of time to obtain tidal information for a particular purpose.

TIDE GAGES

3. A tide gage is an instrument that is used to measure the height of the tide. Two general types of gages are used—nonregistering and self-registering. Nonregistering gages require the presence of an observer to measure and record the height of the tide. Self-registering or automatic gages automatically record the rise and fall of the tide while unattended.

4. Nonregistering gages include the tide staff, some types of float-operated gages, and the electric tape gage. Self-registering gages include a variety of types, some of which record the rise and fall of the tide in the form of a graph, others by punched tape or printed figures, and still others by photographic means. The two principal kinds of automatic gages used by the Coast and Geodetic Survey—the standard automatic tide gage and the portable automatic tide gage—record by means of graphs. The standard automatic tide gage is designed for use at tide stations where observations usually are continued for long periods of time. The portable automatic tide gage is used at stations where observations are made for short periods and where ease of installation is a desired factor.

TIDE STAFF

5. The simplest kind of tide gage is a plain staff or board, about 1 to 2 inches thick and 4 to 6 inches wide, graduated in feet and tenths of feet. The length of the staff should be sufficient to extend from the lowest to the highest tide in the locality where the staff is used. The staff is secured in a vertical position by fastening it to a pile or other suitable support.

6. Vitrified scale.—The markings and graduations on wooden tide staffs usually become illegible after a relatively short time. For this reason, the Coast and Geodetic Survey has adopted a more durable set of scales, made by baking a vitrified coating on wrought-iron strips. The strips are prepared in 3-foot sections about 2½ inches wide and are graduated so that when placed end-to-end they form a continuous scale. They can be secured to a wooden staff or suitable piece of timber. Brass screws and lead washers are provided for the purpose.

7. Glass tube.—When the tide staff is used in rough water, a glass tube about ½ inch in diameter is secured to the face of the tide staff by spring clips or other devices. This tube has the upper end open and the lower end partially closed by means of a notched cork to lessen or dampen the effect of rapid changes in water level. The height of the water level in the tube is read from the scale of the tide staff. The reading obtained is free from the effect of rapid changes in water level produced by wave motion.

8. Portable staff.—After a fixed tide staff has been in the water for a considerable period of time, particularly in harbors where much refuse and fuel oil are present, the graduations or scale markings tend to become illegible. To avoid this, a portable tide staff (fig. 1) is used at many tide stations. This staff is easily removed from the permanent support and stored under shelter when not in use. The staff also can be constructed in hinged sections for convenience in storage. The zero point of the scale must always be at the same elevation when placed in the water for use; therefore, the tide staff support must be permanently secured in place.

9. Staff support.—The tide staff support may be constructed of 2-inch plank that is somewhat wider than the tide staff. The length of the support should be nearly that of the tide staff. The wood should be protected from teredos and other marine boring organisms by a cover of copper sheathing. The tide staff is held to the support in a vertical position by metal guides placed at intervals along the support. The zero point of the staff must be kept at a fixed elevation for all tide observations. This can be accomplished by mounting a metal-plate shoulder at the top of the support and by attaching the staff so that the metal stop (which is secured to the back of the staff) rests firmly on the metal shoulder of the support.

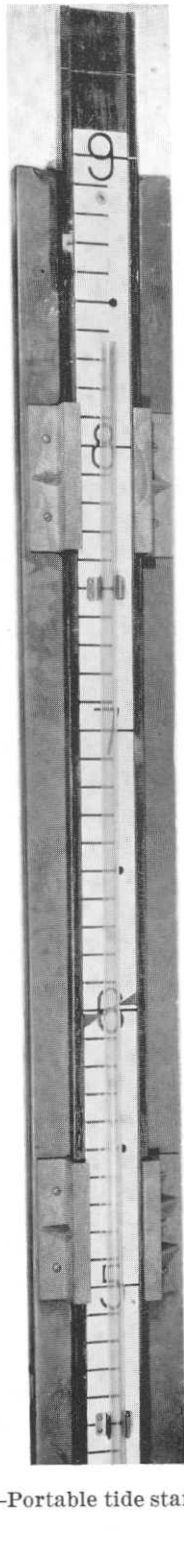


FIGURE 1.—Portable tide staff and support.

10. Multiple staff installations.—Where shoal water extends some distance offshore and the range of tide is too large to be measured by a single staff, a succession of tide staffs can be used. The staffs should be installed in consecutive sequence so that the graduations can be read as continuous from one staff to the next with all readings referred to the same zero.

TAPE GAGE

11. The tape gage (fig. 2) is used in place of the tide staff at exposed locations where the staff cannot be read conveniently or the water surface is too rough for staff readings. The gage is installed in a tide house and consists of a tape, an attached float, a pulley or system of pulleys, a weight or counterpoise to keep the tape taut, and a stilling well to lessen the effect of large wind waves. The stilling well extends from the floor of the tide house to a water depth below that of the lowest probable tide. (See pars. 66–74 for a discussion of stilling wells.) The tape passes over a pulley in the ceiling of the tide house and moves up and down with the movement of the float as the height of the tide changes. Although the counterpoise can be attached to the end of the tape, it generally is best to have the counterpoise supported by a movable pulley with the end of the tape attached to the ceiling of the tide house. This increases the limits of operation of the apparatus. However, where the range of the tide is very small or the ceiling of the tide house is very high, the counterpoise may be attached directly to the free end of the tape.

12. Tape gage readings.—There are two kinds of tape gages, the principal difference being in the method of reading the tide height. In one type of gage, a pointer or index is attached to the tape and moves over a fixed scale from which the tide height is read. In the other type of gage, the tape itself is graduated in feet and hundredths and the tide height is read from the scale on the tape as it passes a fixed reading mark in the tide house. In the latter case, the numerical values of the graduations on the tape should increase towards the float so that the height readings will increase with a rising tide. The tape should be of corrosion-resistant metal, preferably monel metal.

13. Tape gage float.—The float for the gage must be cylindrical in shape so that small changes in the plane of flotation will not affect the cross-section area in this plane. However, the top and bottom of the float can be tapered sufficiently to permit easy passage over any roughness on the inside wall of the stilling well. Either the 8½-inch float of the standard automatic tide gage or the 3½-inch float of the portable tide gage may be used. The larger float provides a more stable plane of flotation and is less sensitive to any frictional resistance in the operation of the gage.

14. Tape gage datum.—The tape gage datum may be defined as the level of the water surface at the time the gage reading is zero. However, the true datum of the gage will be lower than the observed scale reading. This is so because the graduations on the tape do not extend to the water surface and because the tape is attached to the float at a level which is slightly above the plane of flotation. Hence, the plane of flotation and the distance between the water surface and some graduation point on the tape must be determined and applied as a correction to all observed readings. Instructions for installing the tape gage and for determining the plane of flotation—a procedure which must be repeated from time to time—are given in paragraphs 31 through 88.

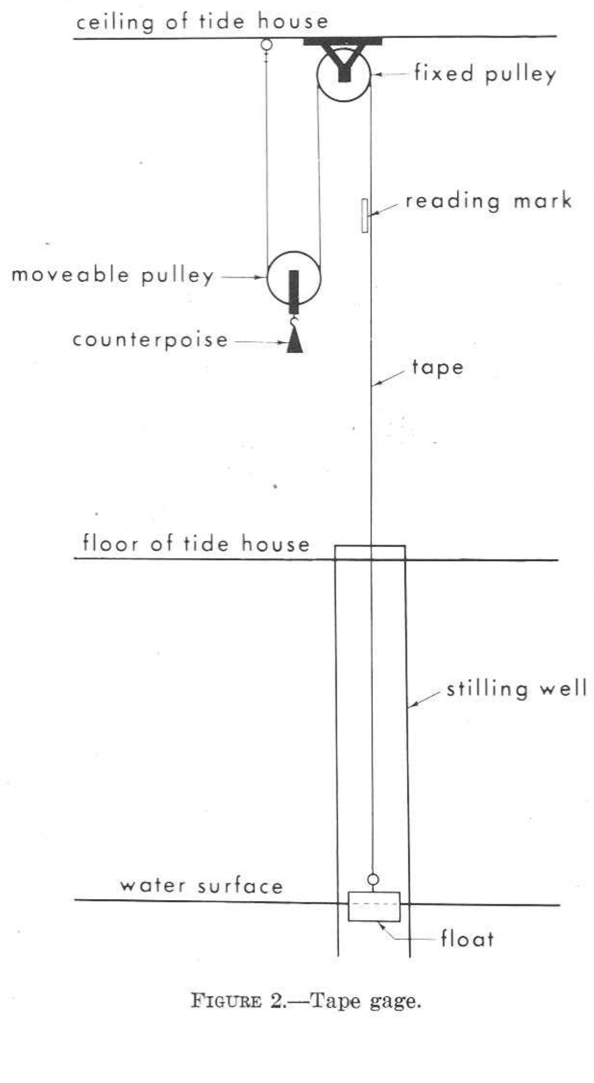


FIGURE 2.—Tape gage.

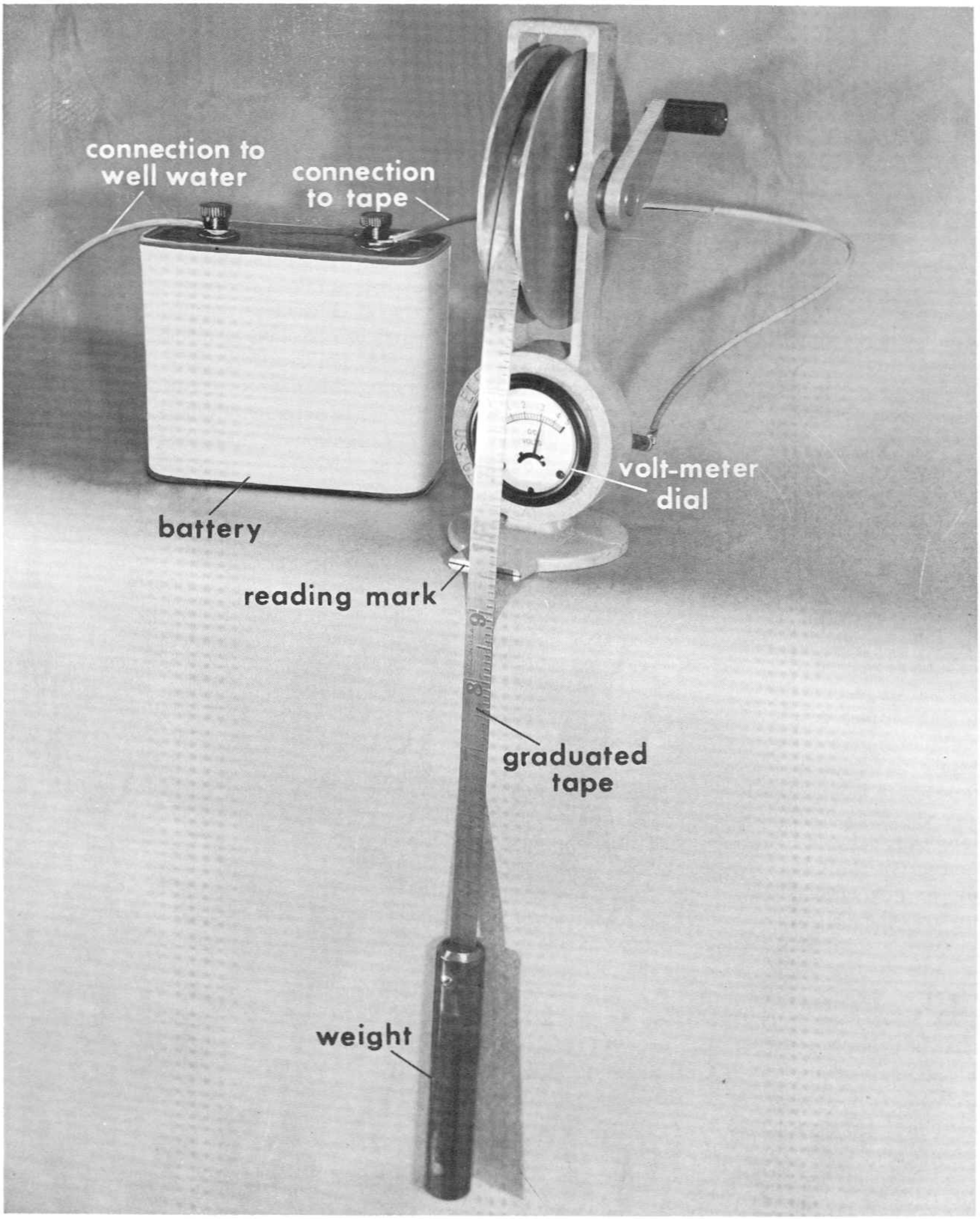


FIGURE 3.—Electric tape gage.

ELECTRIC TAPE GAGE

15. An electric tape gage can be used to measure the elevation of the water surface in a stilling well. The gage consists of a monel-metal tape conductor, attached to a metal drum and supporting frame, a volt meter, and a 4½- or 6-volt battery to supply the electric currents (fig. 3). The tape, which is graduated in feet with sub-units in hundredths, is connected through the frame to one of the terminals of the battery. The other terminal of the battery is grounded to the well water by a connecting wire that leads either to the metal wall of the well or to the water within the well when the well is constructed of fiberglass or other nonconducting material. The electric circuit is completed when the weight at the free end of the tape strikes the water surface. This is indicated to the observer by needle movement on the voltmeter dial. At the same instant, the graduated tape is read—at the reading mark of the gage—to give the distance of the water surface below the reading mark. The height datum for the tidal series is retained through the elevation of the reading mark, which is referred by levels to local bench marks. The electric tape gage can be used where it is impractical to install or use the tide staff.

GAS-PURGING PRESSURE TIDE GAGE

16. Satisfactory tide records have been obtained by using a gas-purging pressure tide gage, or bubbler gage (fig. 4). The underwater part of this gage consists of a small bubbler-orifice chamber attached to a gas-supply tube. The shore end of the tubing is attached to the gas system, which includes a pressure-regulating mechanism and the gas storage tank, and to the transducer (temperature-compensated pressure bellows) of a strip-chart recorder. Nitrogen gas is used because it is inert (safe to use), dry (does not form condensation or freeze in the tube), relatively inexpensive, and readily available. Names for the different parts of the gas-purging pressure tide gage are given in the list which follows. The numbers correspond to those in figure 4.

1. Nitrogen bottle
2. Pressure-reducing valve
3. Pressure differential regulator
4. Adjustible needle valve
5. Transparent bubbler chamber
6. Strip-chart recorder with transducer
7. Tubing
8. Bubbler orifice chamber

17. Operating principle.—When gas is bubbled freely into a liquid from the fixed end of a tube, the pressure in the entire length of the tube is approximately equal to the pressure head of the liquid over the bubble orifice. Any change in the hydrostatic pressure, such as that caused by the rise and fall of the tide, is transmitted by gas pressure through the tubing to the transducer bellows of the recorder where pressure variations are recorded as changes in depth of water. Use of a specially designed bubbler orifice chamber at the underwater end of the tube prevents rapid expulsion of gas and rise of water level in the tube, which would result from large waves if only a tube of fixed open end were used. Thus errors caused by wave action are reduced to within practical limits of accuracy. The required rate of gas supply is determined by the maximum rate of tide height increase and the volume of the system, including the orifice chamber, supply lines, and bellows. The rate of supply can be measured by counting the bubbles as the gas is released through oil in a transparent bubble chamber and regulated by an adjustable needle valve.

18. Use and installation.—The gas-purging pressure tide gage does not require a supporting structure. It can be used to advantage on open beaches, on shoals, at sites where it is impractical to install or use other types of tide gage, and where distances up to two thousand feet separate the orifice chamber and the recorder. The recorder can be placed in a buoy, on an offshore platform, or ashore. It also can be adapted to telemetering from remote and inaccessible areas. In installing the gage, the orifice chamber should be secured to a pipe that is driven into the ocean bottom or embedded in a block of concrete. The extent of tubing from the orifice chamber to the shore may be lashed to a weighted cable, but must be securely fastened at the shore end. Tidal datums for the observations are established by referring the elevation of the orifice chamber to the top of the pipe, which is, in turn, referenced to the elevation of bench marks on the shore. Special operating instructions for the gas-purging pressure tide gage are available from the Coast and Geodetic Survey.

PRECISION DEPTH RECORDER

19. The precision depth recorder, an instrument used primarily to measure depth of water, can be

FIGURE 4.—Gas-purging pressure tide gage.

used to measure the tide from (*a*) ships at anchor and (*b*) from submerged capsules or platforms.

(*a*) In tide measurements from ships at anchor, the difference in water depth caused by the rise and fall of the tide is recorded—the depth being determined by the time required for a sound wave to travel from the ship to the bottom and for the echo to return. The ship should be anchored over a nearly level bottom to keep the record free from changes in depth that can be recorded when a vessel swings back and forth over irregular bottom features. If repeat observations are needed—to detect differences in water levels produced by causes other than tides—the site should be marked by an anchored buoy.

(*b*) The depth recorder also can be used to measure tides from submerged capsules and platforms. The transceiver (transmitter-receiver unit) is mounted within a sealed capsule in an inverted position so that the sound impulse is diverted upward to the water surface. From the water surface the sound signal is reflected back to the transceiver where a continuous record is made of the changing heights of the surface above the instrument. Satisfactory tide records for short periods of time have been obtained from instrumented capsules moored in deep water. A level-sensing instrument also is mounted within the capsule to detect any tilt which might increase the recorded height of the water surface.

STANDARD AUTOMATIC TIDE GAGE

20. The standard automatic tide gage (fig. 5) that is presently used by the Coast and Geodetic Survey is a development of the Stierle gage adopted by the Bureau many years ago. The gage is operated by a float that moves up and down with the rise and fall of water level in a stilling well. The well eliminates the effect of horizontal water movement and, by the size of its intake opening, greatly reduces the effect of rapid changes in water level, such as those produced by wind waves (see discussion of stilling wells in pars. 66–74). The up and down movement of the float and attached line operates a worm screw on the gage and this in turn moves a pencil back and forth across a moving strip of paper. The paper is moved for-

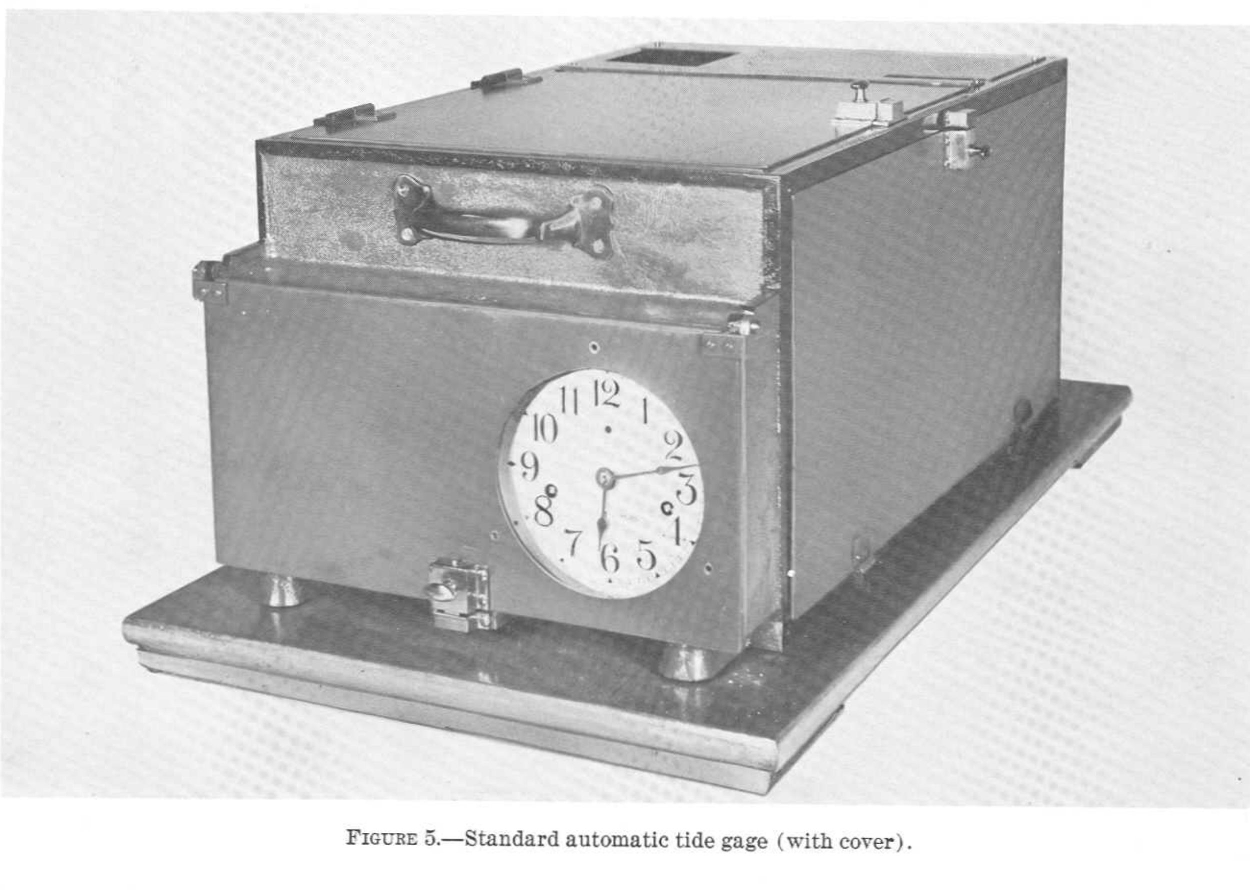


FIGURE 5.—Standard automatic tide gage (with cover).

ward at a uniform rate by a clock motor. The combined movement of pencil and paper provides a continuous graph of the rise and fall of the tide.

21. Names of parts.—The names applied to different parts of the standard automatic tide gage are given in the accompanying list. The numbers correspond to those given in figures 6 to 12.

1. Time clock.
2. Motor clock.
3. Clock case.
4. Supply roller.
5. Tension guide springs (2).
6. Pencil screw.
7. Pencil arm return spring (2).
8. Drum shaft ball bearings (2).
9. Drum shaft bearing caps (2).
10. Counterpoise drum or reel.
11. Float drum or reel.
12. Capstan lock nut, counterpoise drum.
13. Capstan lock nut float drum.
14. Main roller.
15. Bracing rod.
16. Tension weight drum or reel.
17. Receiving roller.
18. Receiving roller release buttons (2).
19. Winged nuts securing clock unit (4).
20. Datum pencil rod.
21. Datum pencil clamp.
22. Datum pencil holder clamping nut.
23. Datum pencil holder.
24. Datum pencil.
25. Datum pencil clamping screw.
26. Hour-tripping rod.
27. Clamping screws, tripping rod assembly (2).
28. Tripping hook stop.
29. Striker weight.
30. Striker weight clamping screw.
31. Striker weight spring.
32. Striker lifter binding screw.
33. Striker lifter.
34. Carrier arm.
35. Carrier wheel.
36. Hour tripping hook.
37. Recording pencil.
38. Recording pencil holder.
39. Recording pencil clamping screw.
40. Pencil holder adjusting screw.
41. Pencil arm.
42. Pencil weight.

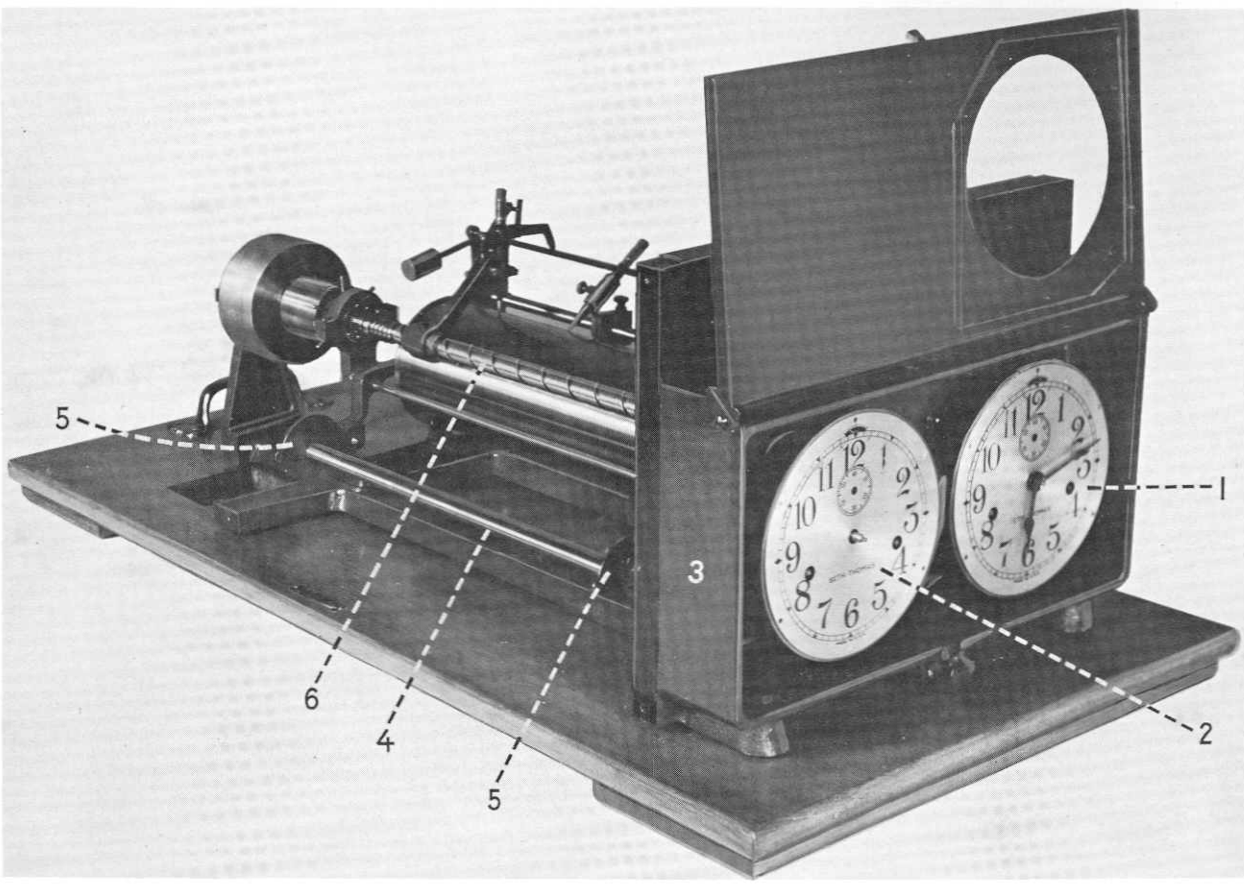


Figure 6.—Standard automatic tide gage (front view).

43. Pencil arm bearing screw.
44. Pivot screws for pencil holder (2).
45. Capstan bearing pin for pencil screw.
46. Lock screw.
47. Lock nut.

22. Clock unit.—The clock unit consists of two clocks mounted on a frame. The one on the right (1, fig. 6) is known as the *time clock* and the one on the left (2) without hands as the *motor clock*. For convenience, the corresponding sides of the tide gage may be called the *time side* and the *motor side*. The time clock operates the device which makes the hour marks on the record, while the motor clock serves to regulate the forward movement of the paper. By having a separate clock to move the paper, the time clock is relieved of unnecessary work and may therefore be more accurately regulated for recording the correct time. Moreover, the use of two clocks aids in securing a continuous record, because if either one of the clocks stops for a short period, it is sometimes possible to interpret the record during this period through the functioning of the remaining clock.

23. The clock unit is secured by four winged nuts (19, fig. 10) on the back of the clock case and is interchangeable with other units when replacements are necessary. In the older types of the instrument, the two clocks were mounted independently in the clock case, the time clock on the left and the motor clock on the right.

24. Each clock has an 8-day movement and may be regulated and corrected as similar clocks in ordinary use. To avoid injury to the hour-marking device of the time clock, however, the minute hand must not be turned backward when between 10 minutes before and 5 minutes after the hour "12." The hour hand may be turned in either direction, and if it is necessary to turn the clock backward within the limits noted above, it may be accomplished by turning the hour hand back a full hour and the minute hand forward to the correct time.

25. If the time clock runs consistently fast day after day, the regulating lever should be moved slightly toward the letter "S"; and if consistently slow, the lever should be moved toward the letter

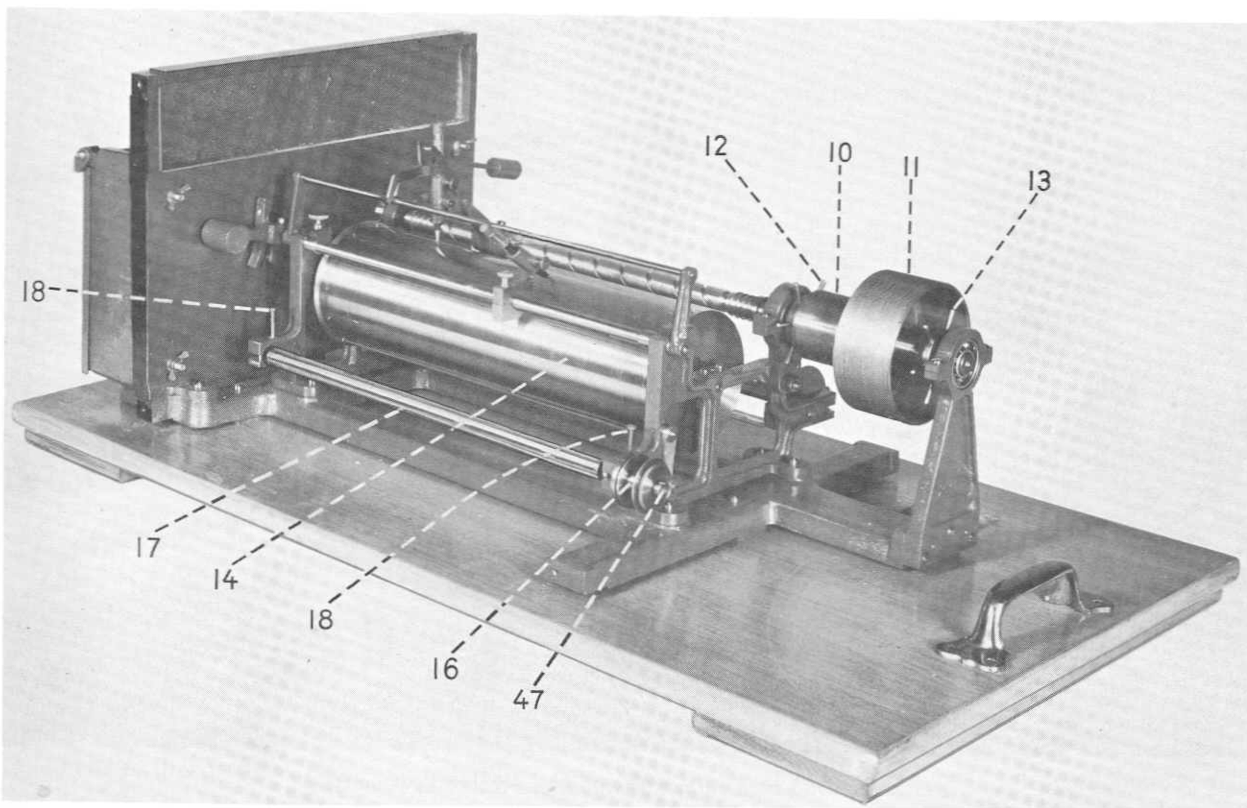


FIGURE 7.—Standard automatic tide gage (side and back).

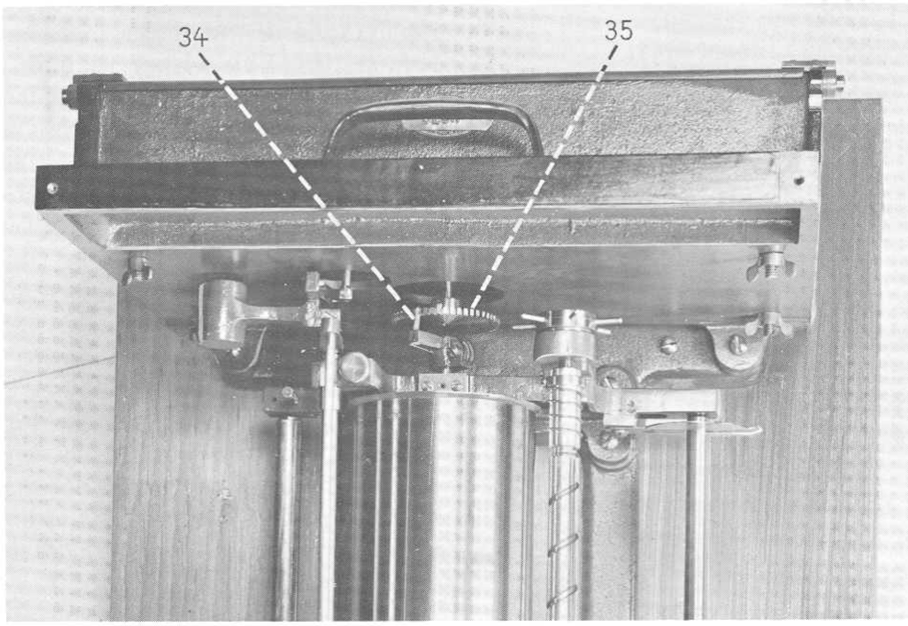


FIGURE 8.—Standard automatic tide gage (clock connection).

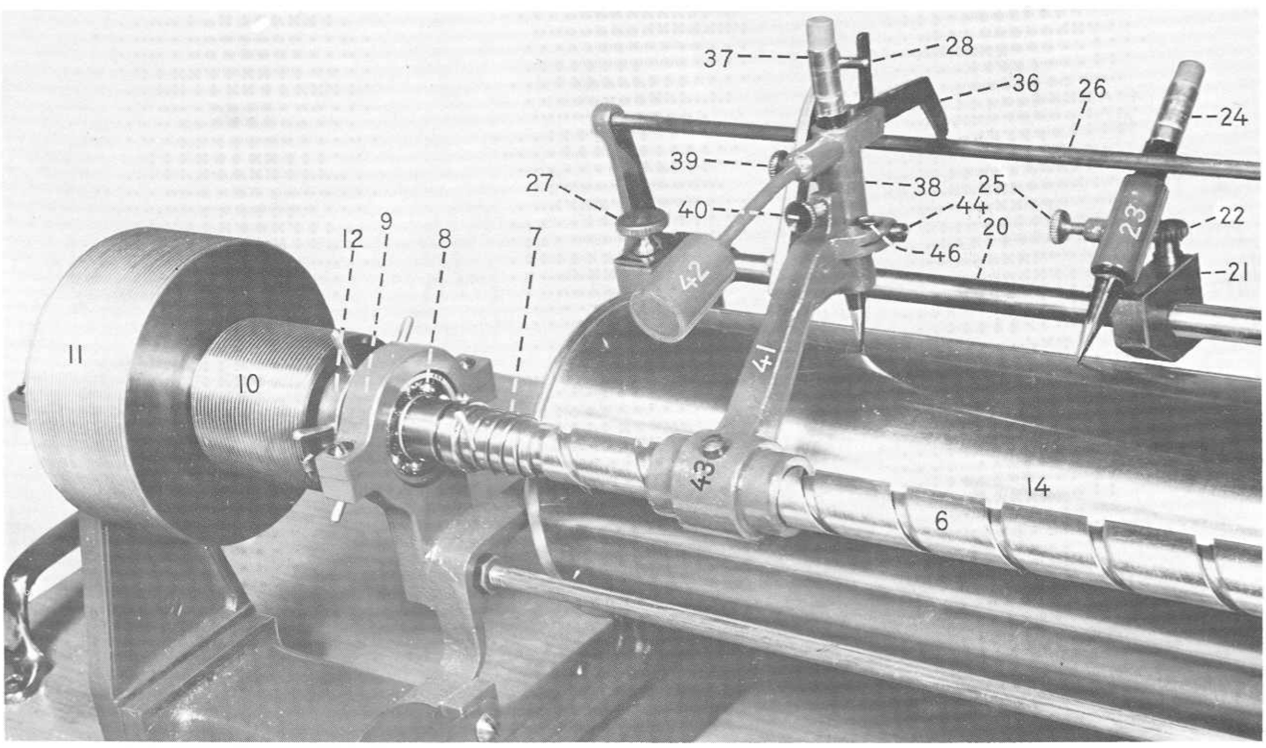


FIGURE 9.—Standard automatic tide gage (recording pencils).

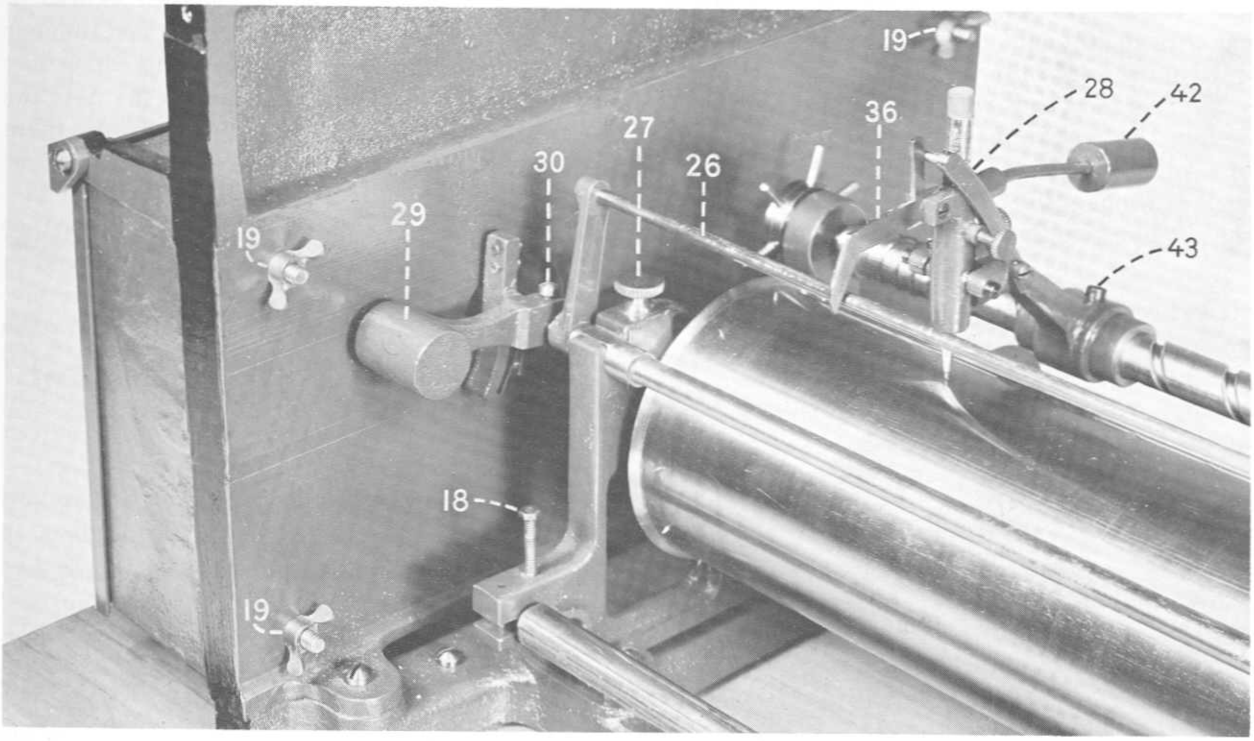


FIGURE 10.—Standard automatic tide gage (right forward end).

"F," care being taken not to move the lever so far as to introduce an error in the opposite direction. A movement of the regulating lever of 1 division usually changes the rate about 3 minutes per day. If the loss or gain in any 1 day is less than 3 minutes, it is, in general, inadvisable to move the regulator unless there has been a similar loss or gain on a number of consecutive days. No refined regulation is necessary for the motor clock. Normally this runs at a rate which moves the paper forward 1 inch an hour, but any small variation from this rate is unimportant.

26. A spindle operated by the motor clock extends through the back of the clock case and has secured to its extremity a toothed carried wheel (35, fig. 8), also known as the clutch wheel, which actuates the main roller of the gage when engagement is made through a hinged carrier or clutch arm (34) attached to the roller. Projecting from the time clock through the back of the clock case is a spindle carrying a short arm (33, fig. 11) called the striker lifter. This is actuated by a cam in the clock and operates the hour-making device. A clutch assembly is now used on most gages to connect the motor-clock drive shaft with the main roller (see par. 259).

27. Rollers.—There are three rollers on the gage, which are designated as the *supply roller*, the *main roller*, and the *receiving roller*. The *supply roller* (4, fig. 6) is a solid rod on which the blank roll of paper is placed. When installing a new roll of paper, this rod may be readily removed from the gage and passed through the hole in the center of the blank roll. When on the gage it is held in place by guide springs (5) at each end. These springs also press against the ends of the roll of paper to keep it from unwinding too fast and thus hold the paper taut as it is fed over the main roller. The pressure exerted by these springs may be regulated by slightly bending them.

28. The **main roller** (14, fig. 7) is a hollow cylinder 13¼ inches long and 12 inches in circumference. Near each end of the cylinder sharp steel pins are set at 1-inch intervals to keep the record paper from slipping. Attached to the axis of the cylinder at one end there is a hinged carrier arm (34, fig. 8) which engages the carrier wheel geared to the motor clock. Through this connection the main roller is rotated at the approximate rate of one turn in 12 hours, thus feeding the paper forward at the rate of 1 inch per hour.

29. The **receiving roller** (17, fig. 7), which is designed to receive the completed record, consists of a solid core with one side flattened and an outer shell in which a slit runs the entire length. With the slit opposite the flattened side of the core, the end of the paper is inserted and then secured in place by a slight turn of the shell. The roller is held in place in its bearings by two pins which may be released by pressure on buttons (18) near the ends of the roller. At one end of the roller there is a small drum (16) known as the *tension weight drum*, upon which is wound a cord attached to a weight which serves to wind up the record paper on the receiving roller. The drum is arranged so that it can be turned independently of the receiving roller when winding up the weight. In some of the instruments this is accomplished by a pawl and rachet, while in other instruments the loosening of a lock nut enables the drum to be moved aside, thus disengaging it from the roller itself.

30. Record paper.—The paper for the standard automatic tide gage is furnished in rolls about 13 inches wide and containing approximately 66 feet

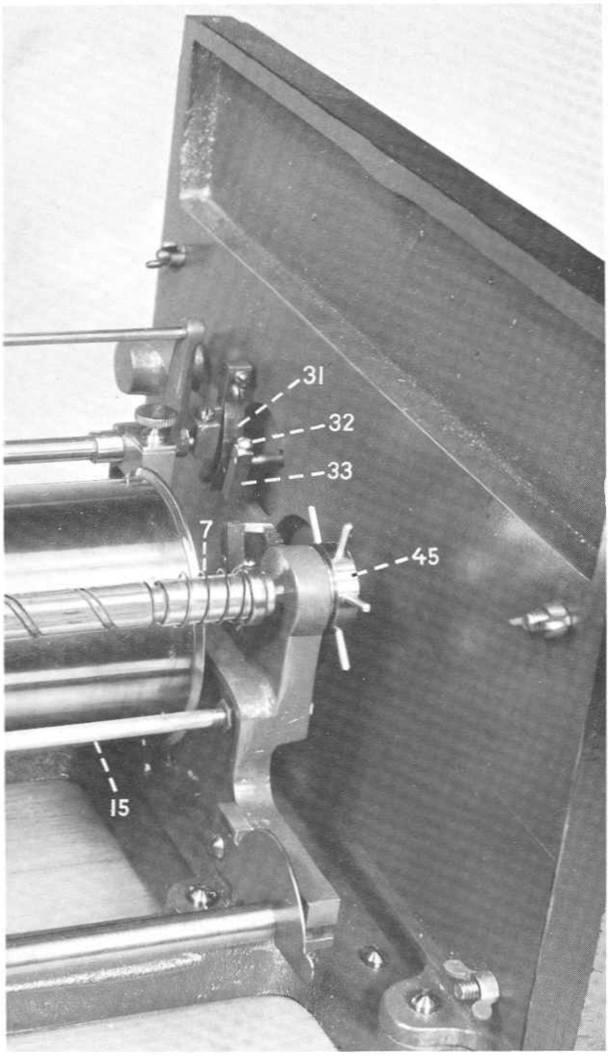


FIGURE 11.—Standard automatic tide gage (left forward end).

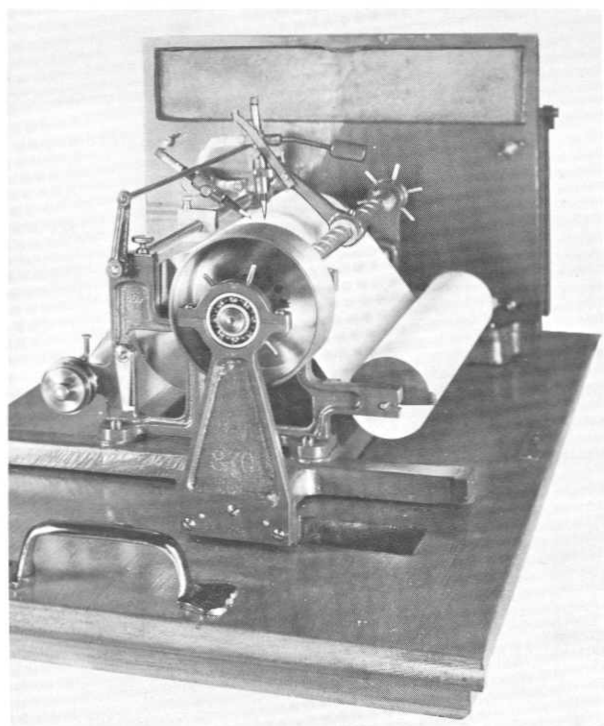


FIGURE 12.—Standard automatic tide gage (paper installation).

in length, which is sufficient for 1 month of record. The paper is plain without any ruling. After the tide curve has been traced upon the tide roll the record is called a *marigram*.

31. Pencil screw.—The pencil screw (6, fig. 6) is a rod about 5/8 inch in diameter with a square screw thread with a 1-inch pitch, except that for a very large range of tide a screw with a 1/2-inch pitch is used. The pencil screw is rotated through the action of the float as the tide rises and falls, and in turn actuates the pencil arm causing a pencil to trace the record. The threads at each end of the pencil screw are turned down to prevent the pencil arm from jamming on reaching the extreme limits of the rod, and springs (7, figs. 9 and 11) are provided at each end to return the arm to the threaded portion of the screw as soon as the tide reverses. In the latest type of instrument the pencil screw may be removed from the gage for cleaning without disturbing the wiring to float or counterpoise. At one end it is connected with the drum shaft by a slotted joint and at the other end is held in place by a capstan bearing pin (45, fig. 11). By backing off this bearing pin the pencil screw is easily released so that it may be lifted out.

32. Recording pencil.—The recording pencil (37, fig. 9) traces the tide curve. This pencil is secured in its holder (38) by a clamping screw (39). The gage is provided with a special automatic pencil but any ordinary pencil with a medium soft lead can be used for the purpose. The holder is secured to the pencil arm (41) by two pivot screws (44) which permit a small lateral movement for striking the hour marks. One pivot screw is clamped by a lock screw (46). In the bearing of the pencil arm there is a pin screw (43) which fits into the thread of the pencil screw, and as the latter is rotated through the action of the tide, the pencil arm is moved toward the clock unit or away from the same according to whether the tide is rising or falling.

33. Datum pencil.—The datum pencil (24, fig. 9), which draws the datum line from which the record is scaled, is similar to the recording pencil. Its holder is secured to the rod (20) by a clamp (21). This clamp consists of a split block held together by two screws. One of the screws is covered by the spring attached to the holder and must be tightened before the spring is placed in position. The other screw is secured by the clamping nut (22) after the holder has been adjusted to the position desired.

34. Hour-marking device.—The hour-marking device is actuated by the time clock. A cam attached to the main shaft of the clock turns with the minute hand and operates a lever which is connected with a small arm (33, fig. 11) projecting from the back of the clock case. This arm presses against a spring (31) attached to the striker weight (29, fig. 10). The latter is secured by a binding screw (30) to a rod that actuates the tripping rod (26). Beginning 30 minutes before the time for striking the hour, the cam in the clock gradually swings the small arm upward, raising the striker weight and moving the tripping rod in toward the recording pencil. On the exact hour the cam suddenly releases this arm, thus causing the weight to fall and the rod to move suddenly outward. The latter strikes the end of the hour-tripping hook (36) attached to the pencil holder, causing the pencil to make a short hour mark parallel to the edge of the paper. Through the action of the pencil weight (42) the pencil is then immediately returned to its original position.

35. Float and counterpoise drums.—The *float drum* (11, fig. 7), which operates the pencil screw, is threaded to accommodate the wire to which the float is attached. The *counterpoise drum* (10) is similarly threaded for the wire to the counterpoise. A small hole or a clamp near one edge of each drum affords a means for attaching the wire. The drums now in use are either 1 1/8 or 1 3/4 inches wide. As the threads are cut 16 turns to the inch, the narrower drums will accommodate 18 turns of wire and the larger ones 28 turns. To provide suitable recording scales for different tidal ranges, interchangeable float drums of different sizes may be used. Those now available have circumferences of 6, 9, 12, 16, and 24 inches. The counterpoise drum is 6 inches in circumference for all scales. The wiring on the two drums is so arranged that one winds as the other unwinds.

36. In the old type of gage, the counterpoise drum was mounted directly on one end of the pencil screw and the float drum was then clamped to the counterpoise drum. In the newer instruments with removable pencil screw, the two drums are mounted independently on a short rod, known as the *drum shaft*, which turns in ball bearings at each end and is connected with the pencil screw by a slotted joint. Around the middle of the drum shaft is a flange which separates the two drums and contains a pin projecting from both sides which is designed to engage one of a series of holes in the end of each drum. The drums are held against this flange by capstan lock nuts (12, 13, fig. 7), which may be loosened independently to release either drum so that it may be turned when installing a new wire. In the normal operation of the gage these lock nuts are not to be disturbed since any change in the position of the float drum on its shaft will affect the adjustment of the gage.

37. Wire.—The float and counterpoise drums are designed for use with No. 23 American gage wire which is 0.024 inch in diameter, and wire of this size must be used to preserve the correct scale in the operation of the gage. Formerly a single-strand phosphor-bronze or nickel-chromium wire was used for suspending the float and counterpoise weight, but there is now available a seven-strand stainless steel wire containing 18 percent chromium and 8 percent nickel, which is more satisfactory for the purpose.

38. Float.—The standard float now used for the automatic tide gage has a cylindrical section 8½ inches in diameter and 2 inches high with tapering top and bottom sections. Its weight is 4½ pounds. Assuming the weight of sea water, fresh water, and kerosene to be, respectively, 64 pounds, 62.4 pounds, and 55 pounds per cubic foot, the corresponding buoyancy per inch of immersion of the cylindrical section of the float is 2.10 pounds, 2.05 pounds, and 1.81 pounds, respectively. In the normal operation of the gage with a strain of from 12 to 16 ounces on the float wire, the float will be approximately one-half submerged. As a free float the immersion will be about one-half inch deeper.

39. Counterpoise.—The counterpoise acts upon the counterpoise drum to take up the slack in the float wire as the tide rises. Although it may be attached directly to the end of the counterpoise wire, it is preferable to have it act through a movable pulley with the end of the wire fastened to the ceiling of the tide house as this arrangement increases the operating limits of the gage when the height of the ceiling is otherwise insufficient to provide for the full range of tide. The weight of the counterpoise together with the operating scale of the gage determines the amount of tension on the float wire. As a tension of 12 to 16 ounces has been found to be generally the most satisfactory, the weight should be selected accordingly. The weights recommended for use with different size float drums are listed in paragraph 91.

40. Tension weight.—This weight, acting upon the drum at one end of the receiving roller, serves to wind up the paper on which the record is traced, and, by keeping a tension on the paper, also assists the motor clock in turning the main cylinder. A silk fish line is generally used to connect the weight with the drum. This is called the *tension cord*. The weight may be either attached directly to the end of the cord or supported from a movable pulley with the end of the cord attached to the ceiling of the tide house. The latter method is to be preferred as it increases the period during which the gage will operate with a single winding up of the weight. A weight of 1 pound is recommended regardless of whether it is used with or without a movable pulley. When suspended from a movable pulley, the extra weight of the latter offsets the reduced strain on the cord resulting from this arrangement.

41. Scale of gage.—The height scale of the gage depends upon the circumference of the float pulley and the pitch of the pencil screw. The different scale combinations are shown in table 1.

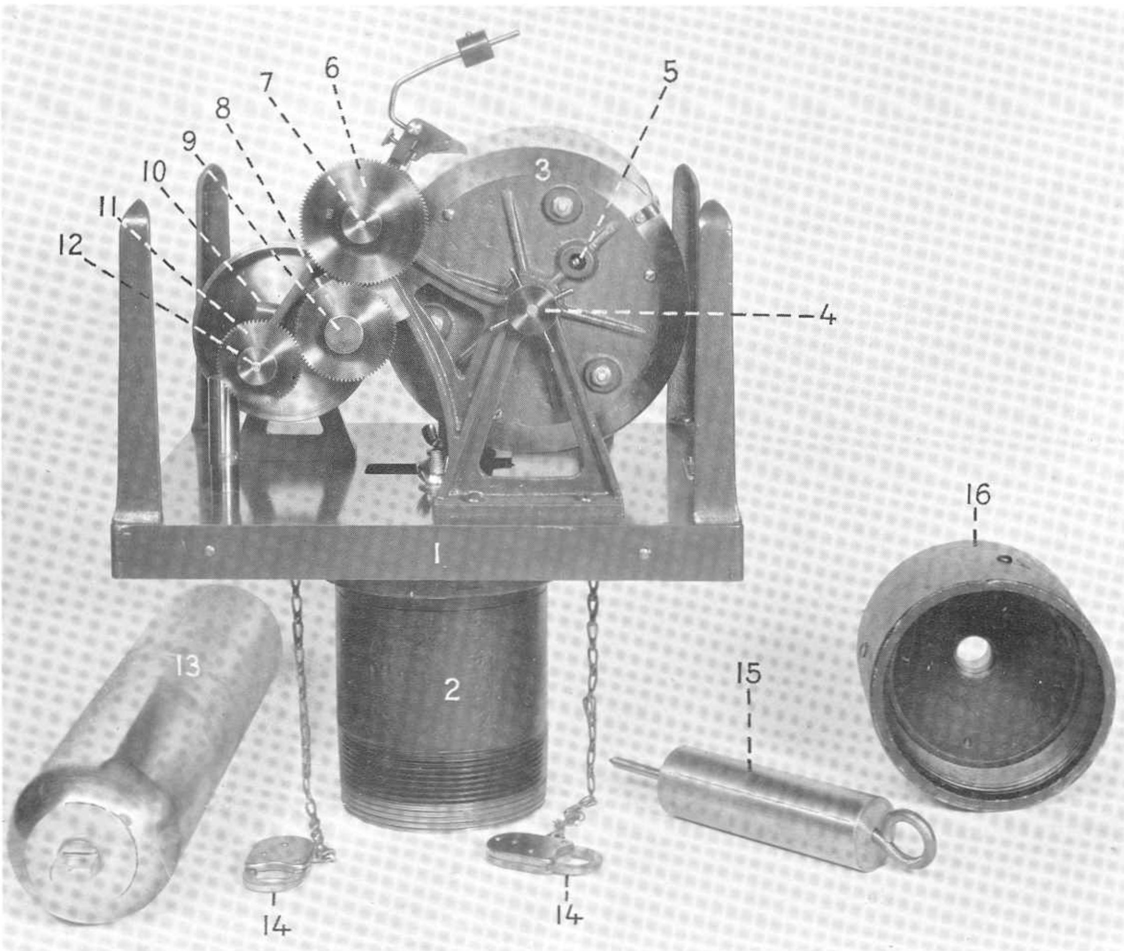
TABLE 1.—*Standard gage scale combinations*

Float drum circumference	Pencil screw pitch	Scale of gage	Range limit		
			Curve	Extreme	
Inches	*Inch*		*Feet*	*Feet*	*Feet*
6	1	1:6	6	9	14
9	1	1:9	9	13	21
12	1	1:12	12	18	28
16	1	1:16	16	24	37
24	1	1:24	24	36	56
16	½	1:32	32	24	37
24	½	1:48	48	36	56

In table 1 the tidal range limit of the curve shows the maximum range that can be recorded by a continuous curve with the scale indicated. Beyond this limit the pencil arm becomes disengaged from the threads of the pencil screw and further rise and fall is registered by a series of jogs near the margin of the paper. The extreme range which can be recorded by these jogs depends upon the size of the float drum. In the columns for the extreme range limit two values are given for each scale. The first value is the limit when float and counterpoise drums have a width of 1⅛ inches, and the second value when the width is 1¾ inches.

PORTABLE AUTOMATIC TIDE GAGE

42. The portable automatic tide gage was designed primarily to obtain short series of observations for the reduction of soundings in hydrographic surveys. The portable gage is smaller than the standard gage, is readily transported, and is more easily installed. It is equipped with a single roller, a single clock concealed inside the roller to control uniform movement of the record paper, a smaller float which operates in a pipe of less diameter, and a counterpoise spring ratchet instead of a counterpoise weight as used in the larger gage. The pipe also serves as a support for the smaller gage. An iron cover protects the gage from the weather or any damage and, together with the other features of the gage, eliminates the need for a special shelter. The scaled record paper on which the tide trace is drawn is easily removed from the roller and gage. Although some of the



1. Base.
2. Float pipe section.
3. Record cylinder.
4. Clamping nut for record cylinder.
5. Keyhole for winding clock.
6. Stylus screw gear.
7. Stylus screw gear nut.
8. Idle gear.
9. Idle gear screw.
10. Idle gear lever nut.
11. Float drum gear.
12. Float drum gear nut.
13. Float.
14. Cover locks.
15. Cleaning tool.
16. Intake coupling.

FIGURE 13.—Portable automatic tide gage (front).

precision of the standard gage has been sacrificed to obtain this more compact gage, its accuracy is sufficient for the purpose for which it was designed but its use for long series of observations is not recommended. Three views of the gage are shown in figures 13, 14, and 15. Names of the numbered parts are given beneath each figure.

43. Record cylinder.—The record cylinder (3, fig. 13) on which the paper for the record is wound is 7 inches in length and 19.2 inches in circumference. The cylinder is geared to a clock movement carried within itself which causes it to rotate on an axle through its center. The axle is clamped in its supports by a capstan nut (4, fig. 13) and the cylinder should be so placed that this nut is on the same side of the instrument as the train of gear wheels. In this position the cylinder rotates in such a direction that the top moves towards the stylus screw. The cylinder is provided with a clip (24, fig. 14) for holding the record paper in place.

44. Clock movement.—An 8-day clock movement is mounted inside the record cylinder, its function being to rotate the cylinder at a uniform rate, which is once in 48 hours. The circumference of the cylinder moves forward 0.4 inch per hour, the time scale of the record. Keyholes for winding and regulating are in the end of the cylinder containing the clamping nut.

45. Stylus screw.—The stylus screw (21, fig. 14) is actuated by a train of gears connecting with the float drum and operates the arm that carries the recording stylus, moving this arm backward and forward as the tide rises and falls. The screw is made of phosphor bronze and has a square screw thread with a pitch of 0.4 inch. The screw thread terminates in circular grooves at each end to prevent the stylus arm from jamming when the limit of its movement is reached, and springs (23, fig. 14) are provided to force the arm back again on the thread when the tide reverses. A gear wheel (6, fig. 13) is clamped to one end of the screw by a milled-head nut (7, fig. 13) and may be released when it is desired to reset the stylus.

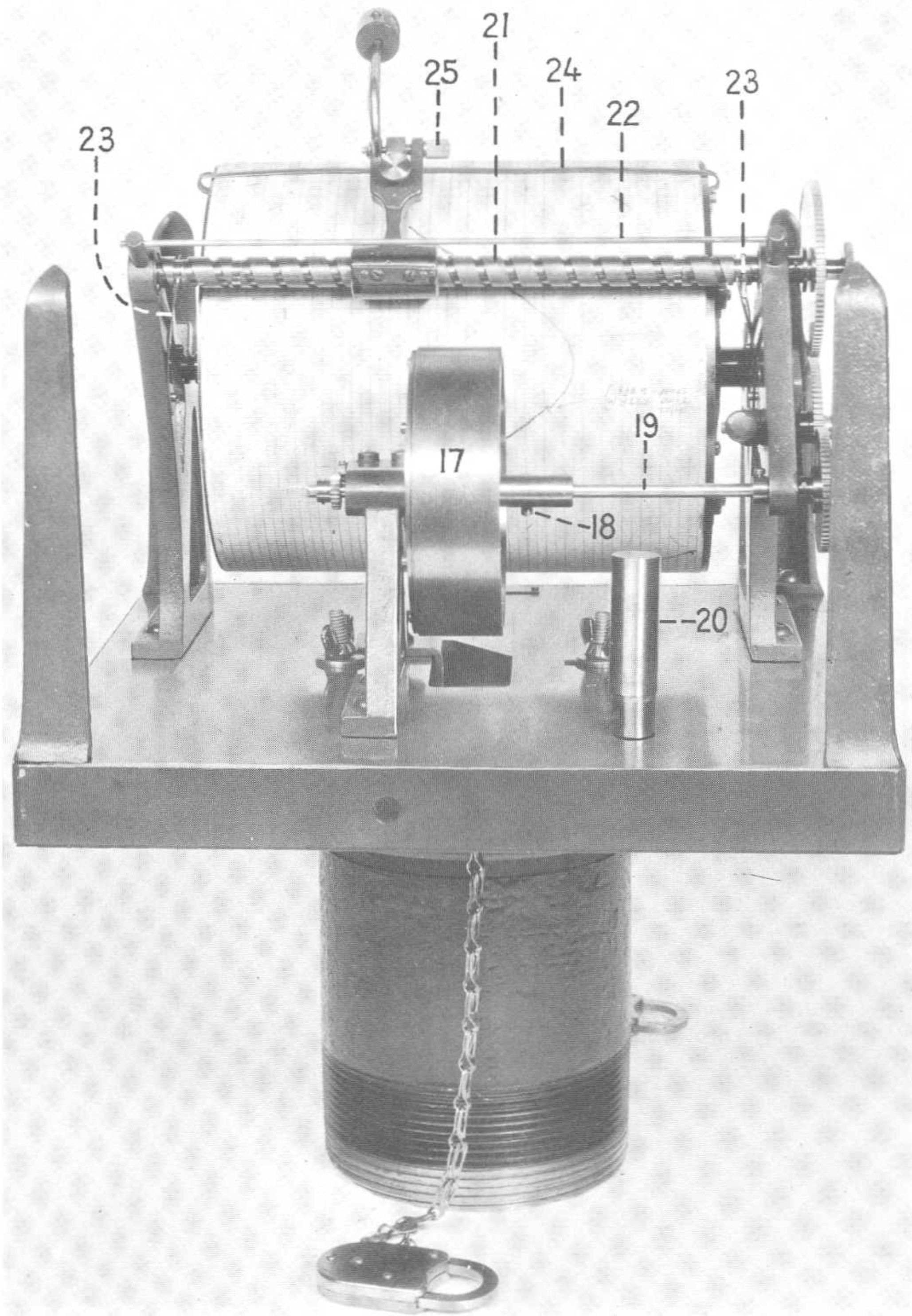
46. Stylus arm.—The stylus arm (33, fig. 15), which carries the recording stylus, has in its bearing a pin that fits into the thread of the stylus screw and when the latter is turned with the rising and falling of the tide the arm moves backward and forward along the screw. The stylus arm carries a small weight (37, fig. 15) to overcome the tendency to be thrown back on a rising tide. A stylus holder (35, fig. 15) is pivoted to the arm. Two slow-motion screws act upon this holder—one (34, fig. 15) is designed for a refined time setting of the stylus, and the other (25, fig. 14) is designed to set the stylus to an exact height reading.

47. Recording stylus.—The recording stylus (36, fig. 15) consists of a pointed blade, designed to trace the record on a specially prepared wax-coated paper. The stylus is so shaped that it will ride smoothly over the clip that holds the paper in place. In some of the older types of the gage, ordinary pencils and special chronograph pens have been used, neither of which proved entirely satisfactory. Special difficulties arose in the use of ink in the chronograph pen because of the excessive dampness to which the record paper is often exposed at the tide stations.

48. Float-wire drum.—The float-wire drum (17, fig. 14) is 12 inches in circumference and about 1 inch wide with the face threaded to accommodate 30 turns of the float wire. The drum, together with its oil-tight cover (31, fig. 15), forms a housing for the counterpoise spring. The drum is rigidly fastened by means of a screw (18, fig. 14) to that part of its axle (19, fig. 14) connected with the gear wheel. The subsidiary axle (30, fig. 15) on the opposite side of the drum is attached to one end of the counterpoise spring and does not turn with the drum.

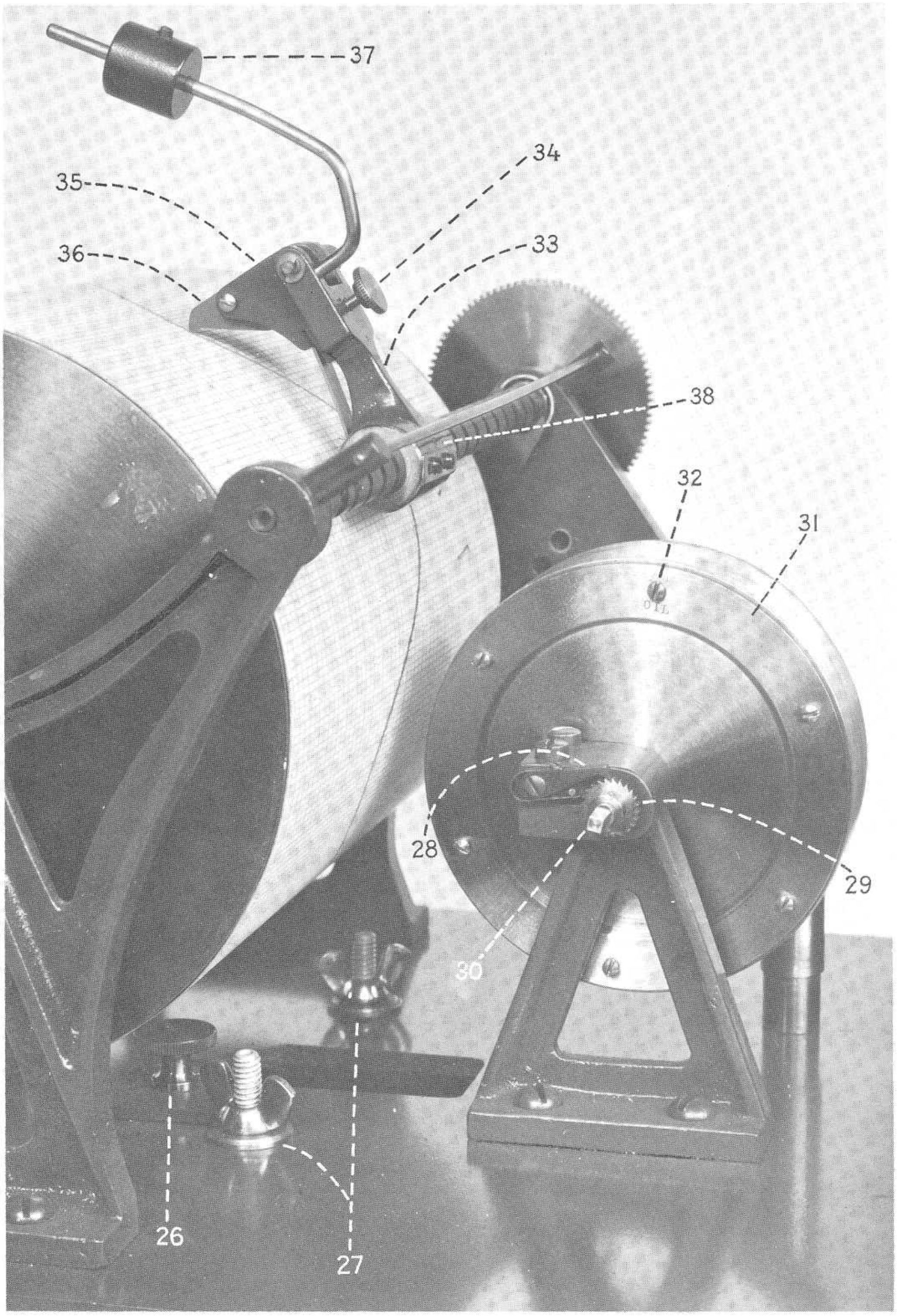
49. Counterpoise spring.—The counterpoise spring enclosed in the float wire drum operates against the weight of the float and takes up the slack in the float wire as the tide rises. One end of the spring is fastened to the inside of the drum and the other end is attached to the subsidiary axle (30, fig. 15). The latter is held fixed by a ratchet and pawl (29, 28, fig. 15) during the ordinary operation of the gage but may be turned by a clock key when it is desired to increase the tension of the spring. The spring is about 18 feet long and is completely wound by about 40 turns of the drum. The spring operates in a bath of watch oil which is introduced through one of the screw holes in the cover plate (32, fig. 15).

50. To replace a broken spring proceed as follows: Loosen screw (18, fig. 14) which holds the shaft connecting the float-wire drum with its driving gear, then take out the six screws holding the cover plate (31, fig. 15) and remove it from the face of the drum. Slide the drum away from the



17. Float-wire drum.
18. Float-wire drum axle screw.
19. Float-wire drum axle.
20. Oil container.
21. Stylus screw.
22. Stylus resting bar.
23. Stylus arm return springs.
24. Paper holding clip.
25. Height adjustment screw.

FIGURE 14.—Portable automatic tide gage (left side).



26. Fair leader clamping screw.
27. Float pipe anchor hooks.
28. Counterpoise spring pawl.
29. Counterpoise spring ratchet.
30. Counterpoise spring axle.
31. Float drum cover plate.
32. Screw covering oil hole.
33. Stylus arm.
34. Time adjustment screw.
35. Stylus holder.
36. Stylus.
37. Stylus weight.
38. Stylus arm bearing.

FIGURE 15.—Portable automatic tide gage (detail of stylus and float drum).

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 (32, fig. 15) holding the cover plate in place.

51. Fair leader.—This is a pulley mounted on a brass arm attached to the bottom of the base of the instrument and extending down inside the short section of float pipe. It is secured in place by a clamping screw (26, fig. 15). Its purpose is to guide the float wire from its drum to the center of the stilling well.

52. Gears.—The float-wire drum actuates the stylus screw through a train of three gears (11, 8, 6, fig. 13). The two gears (11, 6) are interchangeable with other gears furnished with the instrument to obtain different scale ratios. The middle gear (8) is an idler used for all scale ratios and provision is made for an adjustment of its position to properly mesh with the other gears in use. Each gear has the number of teeth stamped in the metal and the combinations to be used are shown in table 2.

53. Scale of gage.—By changing the combination of gears as indicated in table 2, five different height scales may be obtained ranging from 1:11¼ to 1:45. The maximum range of tide which can be recorded as a continuous curve with the different scales is also indicated in the table. However, if an unexpected extreme high or low water does carry the stylus to one end of the stylus screw beyond the limit, evidence is usually left which will enable an experienced tabulator to determine the approximate height reached by the tide. The absolute limit of range which can be recorded by the present gage, operating under usual conditions, is fixed by the length of wire which can be wound upon the float-wire drum, which is approximately 30 feet.

TABLE 2.—*Portable gage scale and gear ratio*

Scale	Maximum range of tide	Number of teeth	
		Gear attached to float-drum 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

54. Record paper.—The record paper for the portable automatic tide gage (fig. 24) consists of sheets with special cross-section ruling. These sheets are 7 inches wide and 19.7 inches long allowing for a ½-inch overlap, the ruled portion being 19.2 inches long to correspond to the circumference of the record cylinder. The coordinate lines ruled parallel to the short edge of the paper provide for the time scale, and those parallel to the long edge provide for the height scale.

55. The time scale is uniformly 0.4 inch to the hour and the hour lines are so spaced. The hour spaces are subdivided by lighter lines into six equal parts to represent 10-minute intervals. The length of each sheet is sufficient to include 48 hours which are numbered in two sets from 0 (midnight) to 23 (11 p.m.). The height scale ruling varies according to the scale with which the gage is to be operated as indicated by table 2, provisions being made for five different scales. For the smallest scale, 1:45, the sheets are ruled for feet and half-feet, but for all other scales the foot spaces are subdivided into five parts, each representing 0.2 foot. Printed on the margin of each sheet is a note indicating the height scale of the paper and the correct gears to be used with the same.

56. Originally the paper provided with the gage was finished with ordinary sizing for use with pencil or ink, neither of which was entirely satisfactory. The difficulty with the use of ink was due to the large changes in humidity to which a tide station is exposed. Because of the effect of excessive moisture on ordinary record paper it was found impossible to obtain an ink which would give satisfactory results under all conditions. To overcome this difficulty there is now used a wax-coated paper on which the record is traced by a stylus which removes the wax coating leaving exposed a colored paper beneath.

57. Float wire.—Size No. 28, American wire gage, is required to fit the grooved thread on the float drum. This is a little finer than that used for the standard tide gage.

58. Float.—The float (13, fig. 13) designed for use with the portable tide gage is a hollow brass cylinder 3¼ inches in diameter and 15 inches long. It is weighted with shot to float with the upper end about 3½ inches above the surface in sea water or about ½ inch above the surface in kerosene. The float was especially designed for use in a 3½- or 4-inch stilling well. The gage may also be operated with a larger diameter float in a larger well.

59. Float pipe.—There is furnished with the gage a short section of 4-inch pipe 7 inches long (2, fig. 13). The upper end is machined to fit into the socket in the base of gage and is secured to the latter by two screw hooks (27, fig. 15) which engage in small rectangular holes near the top end of the pipe. The lower end is threaded to form a union with additional lengths of pipe required for the stilling well. The gages were formerly designed for use with a 3½-inch pipe, and in order to adapt the earlier gages for use with a 4-inch stilling well reducing couplings are necessary.

60. Intake coupling.—A conical intake coupling (16, fig. 13) is furnished as one of the regular accessories to the portable tide gage. This is installed with the apex of the cone downward. The cylindrical part is threaded inside to serve as a coupling between the stilling well proper and a supporting section of pipe (fig. 16). In the apex of the cone there is a threaded 1-inch hole in which may be fitted a bushing with a smooth bore intake opening of the size desired. Bushings with openings ½ inch, ⅝ inch, and ¾ inch are provided with the gage.

61. Cleaning tool.—A special tool (15, fig. 13) is furnished with the portable gage for use in cleaning the intake to the stilling well. This consists of a cylindrical weight about 1½ inches in diameter and 5 inches long containing in the bottom a pointed shank about ¼ inch in diameter and 2 inches long. At the top is an eye for the attachment of a line.

CONTROL TIDE STATION

62. A control tide station is one that is maintained over a period of several years to obtain a continuous record of the tide in any locality. As the records from such a station constitute basic tidal data for present and future use, it is very important that the installation and maintenance of the station should be with the aim of obtaining the highest degree of reliability and precision that is practicable. The essential equipment of a control tide station includes an automatic tide gage, stilling well, shelter, tide staff or equivalent float gage, and a system of bench marks.

LOCATION

63. Special care should be taken in the selection of a site for a control tide station. If possible, there should be a depth of not less than 5 feet below the probable lowest tide. This is especially desirable in cold climates where kerosene is used in the stilling well to prevent freezing, and also in exposed locations where storm waves of large amplitude are common. When the determination of the height of mean sea level is an important aim, the station should be located on the open coast or in a bay with ample access of sea water. A river or bay connected with the sea by a relatively small-inlet is not a suitable location for this purpose because of the probable difference in the mean water level inside of the inlet and on the outer coast. A place separated by a bar from the main body of water should in general be avoided otherwise the records obtained will not be representative of the tidal conditions in the general area.

64. In selecting the site for a control tide station it is very desirable that attention be given to the cleanliness of the surroundings. Highly congested areas with a large amount of shipping should in general be avoided. Because of the commercial need for space in such areas, quarters obtainable for a tide station are usually cramped and poorly lighted and ventilated. These conditions, together with the presence of more or less refuse in the adjacent waters with accompanying offensive odors, tend to discourage the proper care of the gage by the observer. Moreover, in such areas both the automatic gage and tide staff are subject to damage or disturbance from the docking and loading of vessels. Especially, the tide staff may be accidentally knocked out of place and resecured at a different elevation without any report of the incident. Heavy vehicular traffic in such an area also renders the leveling between tide staff and bench marks especially difficult.

65. On the other hand, a tide station located some distance from a congested area, where the tide is equally representative of the general region, will be freer from these disadvantages and be no less accessible to the tide observer. In general, a Federal, State, or municipal wharf is preferable to a private one; but a pier maintained for public amusement and recreation often affords an ideal location for a control tide station.

STILLING WELL

66. The stilling well is a vertical tube or box that extends from the tide house or wharf to a water depth below that of the lowest possible tide. Water enters the well through an opening in the bottom and rises to the level of the water surface outside the well. The purpose of the well is to lessen or dampen the effect of water movement caused by large wind waves and to provide greater accuracy in measuring water-level fluctuations produced by the tide. The amount of damping effect is controlled by the size of the intake opening in the bottom of the well. The stilling well has been used with float-operated gages for many years and is often referred to as a float well. More recently, the stilling well has been used with the electric tape gage (par. 15). Wells of iron, wood, and fiberglass construction are used. For exposed locations on the outer coast, the iron well is used on account of its strength. For more quiet waters, the wooden well with a protective cover of sheet copper, is more economical to construct and install. Copper-sheathed wooden wells last for many years. In cold climates where kerosene is used to prevent freezing in the well, the iron well has the advantage over the the wooden well in retaining the kerosene over a longer period of time without leakage. Wells of fiberglass construction are now being used in place of iron and wooden wells at many tide stations.

67. Iron well.—The iron well (fig. 16) is made of sections of stock pipe. A pipe diameter of 12 inches is recommended for wells at control tide stations. The usual installation consists of the well proper, including a special intake coupling, and a supporting section of pipe below the intake coupling if the depth of water is not too great. The top of the well should extend several inches

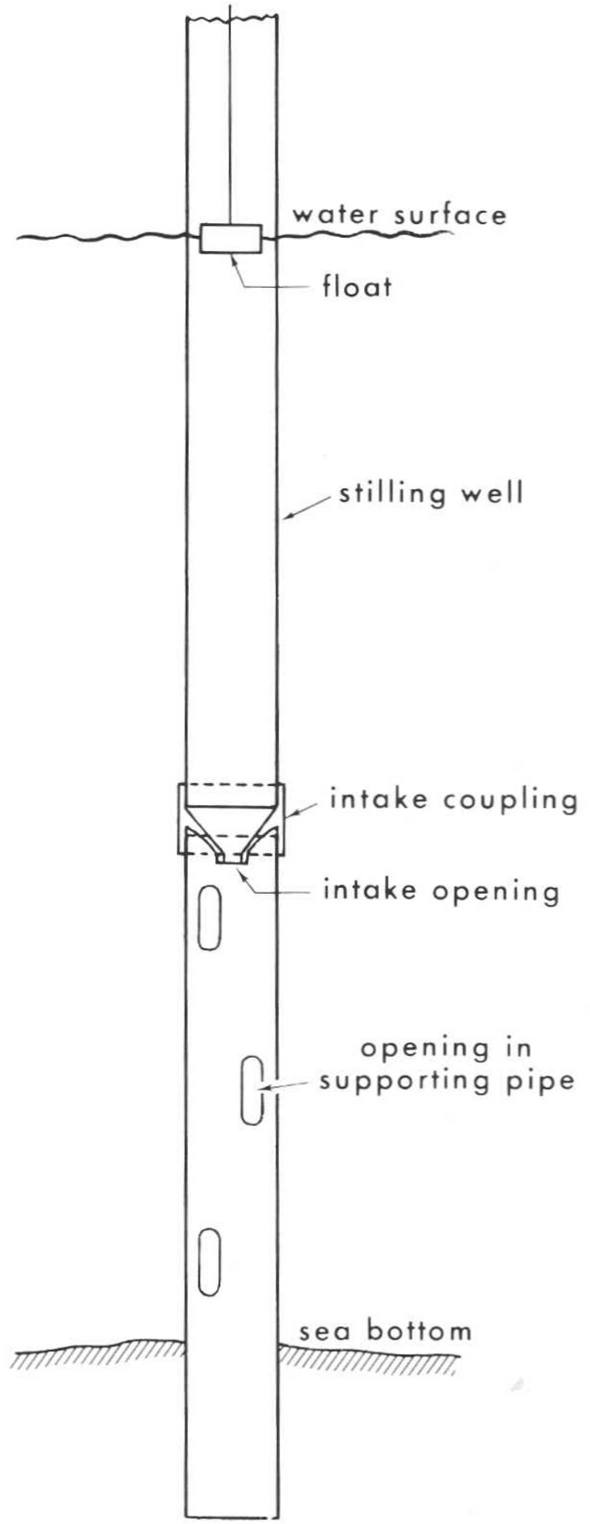


FIGURE 16.—Stilling well.

above the floor of the tide house. The intake coupling (fig. 17) joins the supporting section to the pipe above. One or more sections of pipe may be used above the intake coupling, but the section immediately above the intake should be long enough to extend above high water level. This eliminates the use of pipe joints in that part of the well where the float operates and provides an oil-tight section for kerosene when its use is necessary to prevent freezing in the well. Sleeve couplings are used to connect pipe sections below water level. Flange couplings, although less durable because of the tendency of bolts to corrode, may be used above high water level. Flange joints are easier to install and the bolts can be easily replaced from time to time.

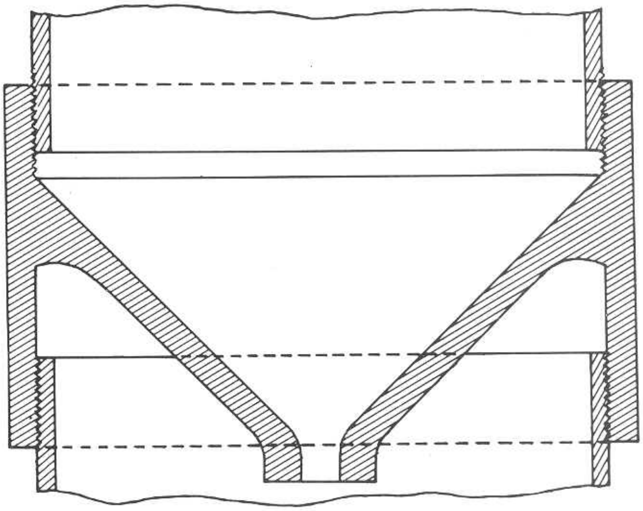


FIGURE 17.—Intake coupling for stilling well.

68. Supporting section.—The supporting section of pipe below the intake coupling should extend several feet into the sea bottom if possible. It also should contain six large openings, each about 3 inches wide by 9 inches long, for the water to enter. The openings should be arranged in pairs on opposite sides of the pipe and face in different directions. The center of the upper pair of openings should be about 1 foot below the top of the supporting section of pipe and the other pairs should be approximately 3 and 5 feet below the top of the section.

69. Wooden wells.—When used at control tide stations, wooden wells are usually constructed of 2- by 14-inch planks, assembled to form a box 12 inches square on the inside. The well should be long enough to reach from the floor of the wharf to several feet below the lowest tides. A sloping bottom with an intake opening in one of the lower corners should be provided and the corresponding corner at the top of the well should be marked for identification, preferably by beveling off the corner. If the depth of water is not too great, two opposite sides of the box can be extended below the intake to the sea bottom to support the well. The outside of the well should be covered with 16-ounce sheet copper from the well bottom to a height above mean high water to protect the wood against teredos and other marine animals. Brass screws or copper nails should be used in constructing the well as a precaution against electrolytic action between the nails and the copper sheathing.

70. Intake opening.—The intake to the stilling well should be of sufficient size to permit free access of water for tide measurements while damping the rapid changes in water level produced by heavy seas. However, it is imperative that major changes in the elevation of the water surface outside the well be recorded by a good trace of the tide curve. In protected areas, an intake opening of 1½-inch diameter is recommended for wells of 12-inch diameter, but in areas exposed to heavy seas an opening of ¾- to 1-inch diameter is sufficient. A single large intake is less likely to become clogged and is easier to clean than several small openings. To facilitate cleaning, openings should be in the bottom of the well and special cleaning equipment, such as that shown in figure 18, should be provided at all control tide stations. The intake coupling for iron wells is installed with the apex downward. The intake opening for wooden wells is made by sawing a square hole in the bottom panel of the well before the parts are assembled.

71. Fiberglass wells.—Stilling wells of fiberglass material can be manufactured in specific diameters and lengths and with specified intake openings. These wells are lightweight, can be handled without heavy equipment, are not affected

FIGURE 18.—Cleaning tool for stilling well.

by corrosion, and are easily installed and maintained. Wells of fiberglass material are now used at many tide stations.

72. Installation of well.—Special care must be taken to secure the stilling well in a vertical position so that the float can operate freely or, when the electric tape gage is used, so that the tape can be lowered without striking the side of the well. Where sufficient depth is available the well should be installed with the intake from 5 to 6 feet below the lowest probable tide. It also is essential that the intake be high enough above the sea bottom to prevent fouling by sediment and other marine growth. The top of the well, for convenience of access and to lessen the chance of objects falling into the well, should extend above the floor of the wharf. Where iron wells are used, the flanged collar at the top can be installed to rest upon iron plates that are secured to the floor of the wharf. The well should be strongly braced in position.

73. Precaution against freezing.—In cold climates kerosene generally is used to prevent freezing of the stilling well. The amount of kerosene that is required depends on the severity of the winter, but the kerosene should form a column in the well from 2 to 5 feet in height. For the 12-inch diameter well, about 6 gallons of kerosene is required for each foot of height; for the 12-inch square well about 7½ gallons is required for each foot of height. The amount of kerosene that can be retained in the well is limited by the depth of the intake below the lowest tide. In iron wells, which have intakes that are placed sufficiently low, the loss of kerosene after its introduction into the well is very small. Loss from evaporation also is small, hence the kerosene may remain for many years. In wooden wells, some leakage of kerosene occurs and the supply must be renewed at frequent intervals.

74. Height difference.—The specific gravity of kerosene is less than that of water, therefore the surface of the kerosene within the well will stand above the water level outside the well. The difference in level will be approximately equal to one-eighth the entire height of the column of kerosene. A note should be made in the tide record whenever kerosene is used in the well. Also, a comparative staff reading should be taken both before and after the kerosene is introduced. In tabulating the automatic tide gage record, allowance is made for the comparative staff readings and the effect of the height difference is thereby eliminated in the computations. However, it is very important that kerosene should not be used in wells where a tape gage or other nonregistering gage is used—where readings are taken directly—because the height difference will introduce errors of indeterminate amounts in the tide record.

TIDE HOUSE

75. When sufficient space is available, the tide house should be approximately 6 feet square and from 7 to 8 feet high. A house of this size provides room for the tide observer to move around the gage and give it such attention as may be required. The house should be well lighted by windows, neat in appearance, and painted to conform with other buildings in the immediate vicinity. A standard sign with the following inscription will be provided upon requisition:

U.S. DEPARTMENT OF COMMERCE COAST AND GEODETIC SURVEY TIDE STATION

76. The tide house will in general be placed over the top of the stilling well so that the wire from the gage may be led directly to the automatic recording unit. When this arrangement is impracticable, the float wire may be led from the stilling well over a system of pulleys and through a suitable conduit to the gage in the tide house. When this is necessary, facilities should be provided for the convenient replacement of a broken float wire by the tide observer. The top of the stilling well must be provided with a suitable cover as a precaution against the accidental dropping of anything into it.

77. A table or shelf must be provided for the support of the tide gage. A shelf can be conveniently constructed by setting the shipping box of the tide gage on one end and then laying boards from this to a cleat nailed to the wall of the tide house. The box and boards are secured by screws which may be easily removed when it is necessary to dismantle the gage. By hinging the cover of the shipping box a convenient cupboard is formed for the storage of extra tide rolls and other small articles.

INSTALLATION OF TIDE STAFF

78. Each control tide station must be equipped with a tide staff or equivalent tape gage to provide a temporary datum and reference scale for the automatic gage record. The tide staff, which is described in paragraph 5, is to be used in preference to a tape gage when practicable. In selecting the location for the tide staff consideration should be given to convenience in taking accurate readings and also in leveling between staff and bench marks. The staff must be reasonably near the automatic gage to avoid any long delay between the reading of the staff and the recording of the reading on the automatic gage record, and should be placed so that the graduations are clearly visible to the tide observer from an easily accessible position.

79. Special attention should be given to placing the tide staff so that its elevation may be conveniently checked by levels to bench marks. There should be sufficient clearance above the staff to hold the leveling rod in a vertical position. Sometimes a fixed tide staff can be so located that it can be sighted upon directly from a leveling instrument set up on the shore; but when this is possible only during low water, other arrangements should be made in order that a leveling party may not be unduly delayed by an unfavorable stage of the tide.

80. When installing a tide staff care must be taken to secure it in a vertical position. The piling of a wharf often offers a convenient support for a tide staff, but if an inclined pile is used for the purpose offsets must be provided to keep the staff vertical. At the time of the original installation, the exact elevation of the staff zero is usually unimportant and it is the general aim to place the zero sufficiently low to avoid frequent negative readings. However, if it is desired to set the zero at some previously determined datum, such as mean low water, the staff graduations must extend negatively below the zero. After installation it is very important that the zero be maintained at a fixed elevation, and any known or suspected change should be reported to the office.

INSTALLATION OF TAPE GAGE

81. In exposed localities where rough water renders the use of a tide staff impracticable, a nonregistering float gage may be substituted for the staff. The most satisfactory gage of this type now in use by this office is a tape gage (fig. 2) with a graduated steel tape attached to an 8½-inch float operating in a 12-inch stilling well. The reading mark should be a well-defined line on a board just back of the tape and from 4½ to 5 feet above the floor for convenient reading by the observer. This reading line may be engraved on a metal plate screwed fast to a board or it may be defined by the slot in the head of a brass screw placed in the board close to the tape. The counterpoise of the tape gage should be attached to a movable pulley to increase the range of operation otherwise limited by the height of the tide house ceiling.

82. To facilitate the determination of the plane of flotation, it is recommended that the bottom portion of the tape, which remains below the wharf floor during all stages of the tide, be detachable. It also is recommended that a secondary reading board be installed about 18 inches above the level of the floor with a horizontal line from the tape to a distance of a little greater than the radius of the float.

83. The stilling well for the tape gage may be similar to the one used for the automatic gage (par. 66). The size of the intake should not be less than that indicated for the automatic gage and must be large enough to provide perceptible motion of the tape when the outside water is moderately rough. When installing the float special care must be taken to arrange the supporting pulley so that the float will swing clear of the sides of the well at all stages of the tide.

84. Determination of plane of flotation.—To establish directly the relation of the datum of the tape gage to bench marks it is necessary to determine the plane of flotation of the tape gage float under normal operating conditions. This is accomplished by placing the float in a pan or bucket of water of the same density as that in the stilling well and measuring the distance from the water surface to some graduation of the tape. The pan is placed over the top of the stilling well and the float must be connected with its counterpoise. In order that the counterpoise may swing clear of the floor, surplus tape may be folded into several loops, avoiding sharp bends, and tied together with a cord. If the tape contains a detachable portion, this may be removed and placed in a coil on top of the float in order that its weight may be included in the determination of the plane of flotation. The length of the removed section must afterwards be taken into account in obtaining the relation of the plane to the scale graduations.

85. The float must be moved slowly up and down and allowed to come to rest from both the upward and downward movement to ascertain any difference in tape reading due to friction in the supporting pulleys. If any difference is noted the float should be placed with the mean of the two tape readings at the reading mark. Careful measurements should then be taken of the vertical distance from the water surface in the pan to some graduation on the tape, which requires that the line of the tape graduation be extended horizontally over the float to a point above the water surface. This may be conveniently done by having a horizontal line drawn on the reading board or on a similar board arranged closer to the floor of the tide house for the purpose. The measured distance added to the tape graduation to which the measurement was made, together with an allowance for any detached section of tape, will give the plane of flotation as referred to the tape graduations extended. It is also the distance which the tape gage datum is below the reading mark of the gage. The result, however, is subject to a small correction described in the following paragraph.

86. Correction to plane of flotation.—The necessity for this correction arises from the fact that the shifting of the tape from one side of the supporting pulley to the other may make a slight difference in the plane of flotation. Although the variation is too small to be of material importance in taking readings during the normal operation of the gage, it is desirable that in a careful determination of the plane of flotation under conditions differing from the normal, a correction shall be applied to reduce the measurement to a mean sea level reading. The correction will depend upon the weight of the tape, the diameter of the float, and whether the counterpoise is attached directly to the end of the tape or supported by a movable pulley.

87. In order to make this reduction, the tape reading taken at the reading mark at the time the measurements are made should be noted. In taking this reading it is assumed that the looped portion of the tape is below the reading mark.

Let R' = tape reading at time of measurement.
R = tape reading corresponding to mean sea level.
D = diameter of float in inches.
t = weight of tape per linear foot.
W = weight of cubic foot of water at tide station.

The cross section of the float is $\frac{\pi D^2}{576}$ square feet and the buoyancy due to an immersion of 1 foot of a cylinder of the same diameter is $\frac{\pi W D^2}{576}$ pounds. Therefore, when the float is operating under normal conditions, an application of a force of 1 pound would change the plane of flotation by $\frac{576}{\pi W D^2}$ feet. When the apparatus is arranged as in figure 2 with the counterpoise supported by a movable pulley, the shifting of 1 linear foot of tape from one side of the supporting pulley to the other side will cause a change of $1\frac{1}{2}t$ pounds in the pull on the float and the plane of flotation will be changed by $\frac{864t}{\pi W D^2}$ foot. The total correction to be applied to the plane of flotation as obtained by direct measurement, in order to reduce to the mean sea level value, is $\frac{864t}{\pi W D^2}(R-R')$ foot.

88. Taking the average weight of sea water as 64 pounds per cubic foot, the weight of a steel tape as 0.0071 pound per linear foot, and a float diameter of $8\frac{1}{2}$ or $3\frac{1}{4}$ inches, the following factors have been computed to give the necessary correction to the plane of flotation when applied to the difference $(R-R')$:

	8½-inch float	3¼-inch float
Steel tape with counterpoise on movable pulley.	0. 00042	0. 0029
Steel tape with counterpoise on end of tape.	. 00056	. 0039

As the correction varies directly as the weight of the tape and inversely as the square of the diameter of the float, corresponding corrections for floats of other sizes or for tapes of different weight may be readily derived from the above values. For example, the correcting factor for a $9\frac{1}{2}$-inch float with steel tape and movable pulley is

$$0.00042 \times (8\tfrac{1}{2})^2/(9\tfrac{1}{2})^2 = 0.00034.$$

INSTALLATION OF STANDARD AUTOMATIC TIDE GAGE

89. Preparatory to the installation of the tide gage, the instrument should be carefully checked to see that all parts are in satisfactory working order. The scale of the gage and the corresponding float drum will depend upon the extreme range of tide at the locality and will be selected in accordance with table 1 in paragraph 41. Special attention must be given to the pencil screw to see that the pencil arm moves freely along its entire length and that the arm is properly released on reaching each end of the screw thread and automatically returned to the thread through the action of the return springs when the direction of rotation is reversed. In the latest type of gage, the pencil screw may be removed from the gage and rotated by hand while the pencil arm is hanging freely by its own weight. Any tendency for the arm to swing upward with the rotation of the screw should be investigated and steps taken to remove the cause of any sticking until all perceptible resistance to a free movement of the arm along the screw has been eliminated. Special attention should also be given to the hour-marking device to see that it is functioning satisfactorily and that adjustments are made as may be necessary. (See pars. 126–127.)

90. Setting up automatic tide gage.—The standard installation, in which both counterpoise and tension weights are supported by movable pulleys, is illustrated in figure 19. When practicable, the gage is to be placed on a table or shelf over the stilling well so that the float may be suspended directly from its drum without any intervening pulleys. By means of a plumb line or the temporary installation of the float, the position of the gage should then be adjusted to center the float in the well. In doing this, consideration must be given to the possibility that the well may not be exactly plumb and the centering should be done at the water level rather than at the top of the well.

91. Installation of pulleys.—The standard pulleys used for the counterpoise and tension weights are 4 inches in diameter and weigh 1 pound each. Six pulleys are required for the arrangement shown in figure 19. Two movable pulleys support the weights and four fixed pulleys are attached to the ceiling of the tide house by screw eyes. Under operating conditions the fixed pulleys do not hang vertically but are deflected by an amount depending upon the weight of the pulley and the strain on the wire or cord. Allowance must be made for this deflection when the fixed pulleys are fastened in position so that the wires from the gage will pass vertically upward and the wire strands from the movable pulleys will remain parallel. Hence, the fixed pulleys A and B in figure 19 must be offset by the amounts shown in table 3 for the various combinations of counterpoise weights and float drums that can be used.

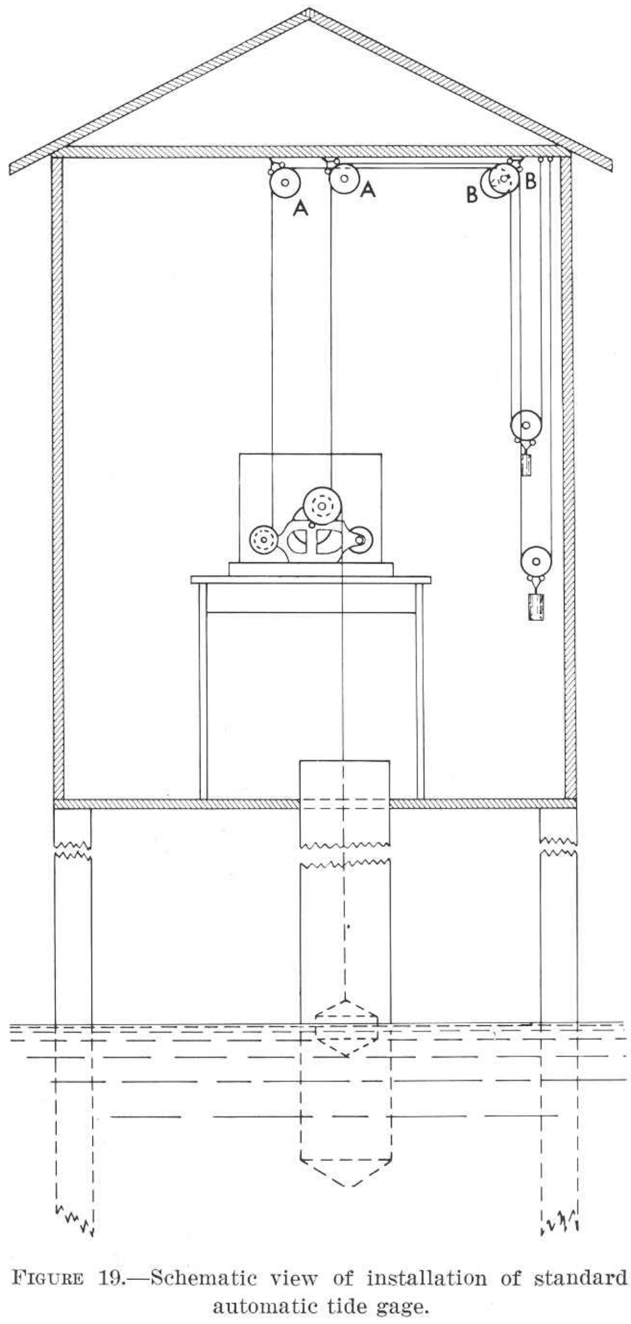


FIGURE 19.—Schematic view of installation of standard automatic tide gage.

TABLE 3.—*Standard gage counterpoise weights for different float drums*

Size of float drum	6-inch	9-inch	12-inch	16-inch	24-inch
Counterpoise weight	1 lb.	2 lb.	3 lb.	4 lb.	6 lb.
Counterpoise with pulley	2 lb.	3 lb.	4 lb.	5 lb.	7 lb.
Counterpoise wire tension	1 lb.	1½ lb.	2 lb.	2½ lb.	3½ lb.
Float wire tension	1 lb.	1 lb.	1 lb.	15 oz.	14 oz.
Offset, pulley-A	+⅛ inch	−⅛ inch	−¼ inch	−⅜ inch	−½ inch.
Offset, pulley-B	4 inches	3¾ inches	3½ inches	3⅜ inches	3¼ inches.

The offset of pulley-A for the counterpoise wire indicates the position of the screw eye for the support of the fixed pulley immediately above the gage as measured from a point in the ceiling in a vertical tangent to the counterpoise drum on the side from which the wire is led. The measurement is to be made in the direction toward which the wire leads if preceded by the plus sign and in the reverse direction if preceded by a minus sign. The offset of pulley-B indicates the position of the screw eye for the second pulley as measured from the point of attachment of the fixed end of the wire, the latter being in line with the two fixed pulleys. Measurements for the installation of the pulleys for the tension weight cord are made in a similar manner, the offsets being those corresponding to the 6-inch float drum, provided that a 1-pound tension weight is used. In this case the first offset is measured from a point vertically above the tension weight drum.

92. In order that the gage may be operated to its full capacity in recording extreme ranges of tide, it should be the aim to have the adjustment such that at approximate mid-extreme tide level the float drum and counterpoise drum will each be half filled with wire, the counterpoise half way between the limits of its motion, and the recording pencil near the middle of the main roller. As the larger of the counterpoise drums contains 14 feet of wire when filled, a fall of 7 feet for the counterpoise weight as supported by a movable pulley will be sufficient for the maximum limits of the gage operation. These limits would require a ceiling height of approximately 8 feet including an allowance of 1 foot for the combined length of the counterpoise weight and supporting pulley. The extreme limit, however, will seldom be required, and a ceiling height of 6½ to 7 feet will in general be ample for the operation of the gage. On the open coast the mid-extreme tide may be taken as approximately the same as mean sea level, but in rivers the height above mean river level reached by the extreme high waters is usually much greater than the depth to which the extreme low waters fall. However, in estimating the mid-extreme tide for the adjustment of the gage, no consideration need be given to a high-water height that is above the bottom of the tide gage or to a low water that is below the bottom of the stilling well, since beyond these limits the gage would cease to function regardless of adjustment. (See par. 118.)

93. Attaching counterpoise.—The weight of the counterpoise depends upon the size of the float drum and is to be selected in accordance with table 3 in paragraph 91. In the standard installation the counterpoise is used with a movable pulley, but if it is attached directly to the end of the counterpoise wire, its weight should be one-half the tabular value given for the combined counterpoise and pulley. Before installing the counterpoise, the pencil screw should be removed from the gage (par. 31) and the float drum released (par. 36) so that this drum and the counterpoise drum may be turned independently of each other. For the older type of instrument which does not permit the easy removal of the pencil screw, this screw should be rotated until the pencil arm has cleared the screw thread at the end nearest the clock case. Following the scheme of installation illustrated in figure 19, the necessary fixed pulleys being secured to the ceiling of the tide house and the counterpoise fastened to a movable pulley, the wire (par. 37) is passed through the fixed and movable pulleys and one end attached to a screw eye provided for the purpose in the ceiling of the tide house. The wire is then cut of such length that the counterpoise will hang just clear of the floor as the free end of the wire is attached to the counterpoise drum. A small hole or clamp near the edge of the drum is provided for this attachment.

94. Attaching float.—The proper float drum for the range of tide having been selected from table 1 in paragraph 41, the length of wire to be wound upon this drum at the time of installation will depend upon the stage of the tide. Let L equal length of wire to be wound upon the drum at time of installation, C the length of wire necessary to half fill the drum, and H the height of tide at time of installation referred to the mid-extreme tide level, H being negative if water surface is below this level, then $L=C+H$ for the required length. The value for C for drums $1\frac{1}{8}$ and $1\frac{3}{4}$ inches wide may be taken from table 4.

TABLE 4.—*Standard gage wire lengths for different float drums*

Circumference of float drum in inches	6	9	12	16	24
Width of drum:	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
$1\frac{1}{8}$	$4\frac{1}{2}$	$6\frac{3}{4}$	9	12	18
$1\frac{3}{4}$	7	$10\frac{1}{2}$	14	$18\frac{2}{3}$	28

Unless previous tide observations have been taken in the locality the value for H must be estimated. From best information available ascertain the approximate heights reached by the highest and lowest tides and then note the height of the water surface at the time of installation as compared with a plane midway between the estimated highest and lowest, taking H as positive if the surface is above mid-extreme level and negative if below this level.

95. Before installing the float it is a good plan to pass several loose loops of wire through the supporting ring to aid in its recovery from the stilling well if the float wire becomes accidentally broken. Next, taking a spool of wire, attach one end of wire to the float and lower it into the well until it comes to rest on the surface of water or kerosene. Lead the wire to the float drum of the gage and, after measuring off an additional distance equal to L as determined from the formula in the preceding paragraph, cut the wire from the spool and attach the end of the wire to the float drum by passing it through a small hole near the outer edge and knotting it.

96. If the gage is of the latest type, with removable pencil screw, wind up the float wire by turning the float drum on its shaft until all threads on the drum are filled or until the float has reached its upper limit of motion. When doing this the counterpoise drum is left undisturbed with the counterpoise hanging close to the floor. Both drums are then secured rigidly to the drum shaft by tightening the capstan lock nuts on the two sides. The float is then allowed to descend slowly until it rests upon the surface of the water in the well. As the float descends it automatically winds up the counterpoise wire on its drum. The pencil screw may now be replaced on the gage with the pencil arm set to bring the record curve near the middle of the paper, consideration being given to the present stage of the tide in its relation to the mid-extreme tide.

96a. The following instructions apply only to the old type gage without removable pencil screw. Having determined the proper length of wire in accordance with paragraphs 94–95, remove the float drum entirely from the gage and wind the float wire upon it, raising the float as necessary, until all the threads on the surface of the drum are filled or until the float has reached its upper limit of motion. Replace the drum on the gage and secure it with the two clamping nuts provided for the purpose, but holding it carefully against the sudden falling 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 to descend slowly. With a gage equipped with a pencil screw of 1-inch pitch, release the pencil arm after $2\frac{1}{2}$ turns if the drum is $1\frac{1}{8}$ inches wide, or after $7\frac{1}{2}$ turns if the drum is $1\frac{3}{4}$ inches wide. With the pencil screw of $\frac{1}{2}$-inch pitch, release the pencil arm immediately for the drum $1\frac{1}{8}$ inches wide or after $1\frac{1}{2}$ turns for the drum $1\frac{3}{4}$ inches wide. After the release of the pencil arm let the float continue to descend slowly until it rests upon the water or kerosene in the well. The lowering of the float automatically winds up the counterpoise wire and moves the pencil arm approximately to its correct position. If any further adjustment of the position of the pencil arm is necessary, it may be accomplished by loosening the clamping nuts holding the float drum and turning the pencil screw as desired. In doing this, care must be taken to hold the counterpoise drum against the pull of the counterpoise weight and also to press the float wire against its drum to keep it from springing off as the wire slackens.

97. Attaching tension weight.—In general it is best to have the tension weight operate from a movable pulley (fig. 19) to reduce the rate of fall. When thus suspended, the weight will descend on an average about 1 foot a day but the rate will vary with the amount of paper on the receiving roller. Place the weight with pulley attached on the floor at the lowest limit of its motion. After installing the necessary fixed pulleys in the ceiling of the tide house, take a spool of cord and pass one end of the cord through the fixed pulleys down through the movable pulley attached to the weight, and then secure the end to a screw eye in the ceiling. Next unwind enough additional cord to reach to the tension drum on the gage and cut from the spool. Pass the end of the cord through the small hole provided for the purpose and secure by knotting. The cord is now ready to wind upon the drum as soon as the record paper is installed.

98. Starting the gage.—The gage is now ready for the installation of the paper (pars. 114–115), adjustment of pencils (pars. 117–118) and entry of comparative note (pars. 119–125), these processes being described in detail under "Operation of tide station." Both springs on each clock should be wound. If the care of the gage is to be turned over to a new observer, he should be given such preliminary instructions as will aid him in interpreting the printed instructions in this volume.

TIDAL BENCH MARKS

99. An essential part of the establishment of a tide station is the installation of a system of bench marks to which the observed tides may be ultimately referred. A bench mark may be defined as a definite point on a more or less permanent object used as a reference for elevations. Bench marks established in the vicinity of a tide station for the purpose of preserving tidal planes determined from the observations are known as "tidal bench marks." These bench marks serve as the basis for elevations which are carried by levels to numerous other bench marks established in various parts of the country.

100. Qualities.—The two principal qualities desired in bench marks are permanency and certainty in identification. These qualities should be kept in mind when establishing new bench marks. In a settled community substantial buildings are excellent locations for the establishment of bench marks. In undeveloped areas a ledge of rocks or a mass of concrete partly buried will serve as a suitable foundation. Except for temporary use only, bench marks should not be located on hydrants, curbstones, trees, or any structure especially liable to destruction or change in elevation.

101. Standard disks.—Certainty in identification can be best obtained by the standard Coast and Geodetic Survey disk bench marks (fig. 20) and these should always be used when possible. The disk, which is made of bronze alloy, is 3⅝ inches in diameter and contains the inscription "U.S. Coast and Geodetic Survey Bench Mark" together with other information. It contains a

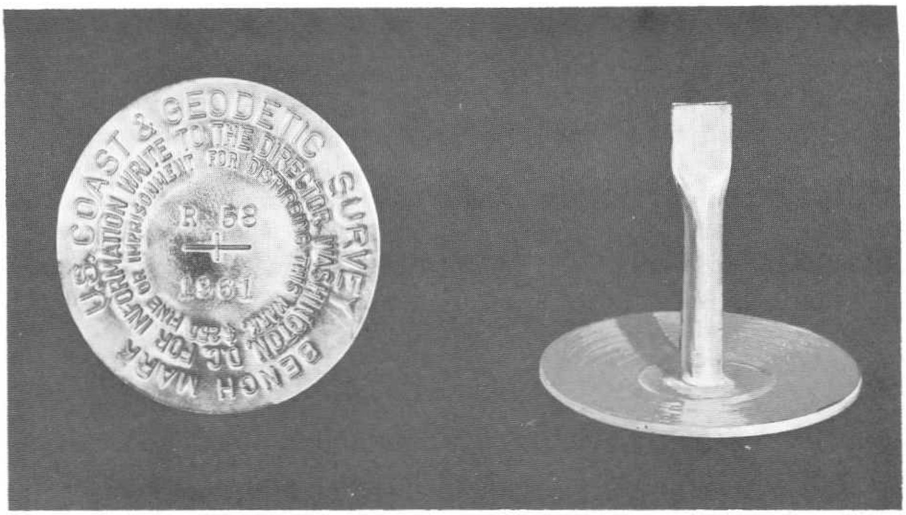


FIGURE 20.—Standard disk bench mark.

shank for cementing in place. The number of the mark and the year of establishment should be stamped on the disk. Duplications 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 stamping letters and figures can be obtained upon requisition.

102. Bench marks on buildings.—In a town or city, the post office, customhouse, city hall, schools, railroad stations, banks, and other substantial public and business buildings generally afford the best locations for bench marks. Buildings with foundations of questionable stability should be avoided. Permission will usually be granted for the installation of the standard disk bench mark on such buildings as may be selected when the use of the same is explained to the authorities in control.

103. Setting of bench mark.—When a suitable place can be found, it is in general desirable to set the face of the bench mark disk horizontal for convenience in holding the leveling rod, but there should be sufficient clearance above the bench mark for the rod used in the first-order leveling, which is approximately 11 feet long. Sometimes greater permanency can be secured by placing the bench mark in the vertical wall of a building. In this position the short horizontal line through the center of disk becomes the bench mark and a graduated tape may be substituted for the rod in making the leveling connections. A bench mark in a vertical wall should be several feet above the ground for convenience in holding the tape used by the leveling party. Care should be taken to set the disk with the reference line horizontal. The bench mark is to be countersunk with its face flush with the wall, and when set in a conspicuous place special care must be taken to have the work neatly done so that the building will not be defaced.

104. Bench marks in rock.—Boulders and rock outcrops that are not likely to be disturbed for many years make satisfactory locations for bench marks. If a boulder is used the bottom should extend far enough below the surface of the ground so that it will not be affected by frost action. The standard disk should be cemented in place with its face horizontal and countersunk.

105. Bench marks in concrete.—Where a suitable building or natural rock is not available, the bench mark disk may be set in a concrete monument built in the place desired. The monument should extend not less than 3 feet below the surface of the ground, and in localities having severe winters the depth should be sufficient to withstand frost action. In general the top will extend several inches above the ground in order that it may be readily found when needed. 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.

106. Number of bench marks.—To insure against loss of datum, there should be a number of bench marks widely scattered but in general within a radius of 1 mile from the tide station. For all series of tide observations, no matter how short, there should be a reference to at least three substantial bench marks. The minimum requirement for a series of tide observations covering a year or more is five bench marks. For a control tide station which is to be maintained over a long period of years ten substantial bench marks may be considered as adequate.

107. Primary bench mark.—At each principal tide station there is usually one bench mark, known as the "primary bench mark," which is selected for its stability and convenience of location and is used in checking the elevation of the zero of the tide staff from time to time, so that if any change takes place the proper allowance may be made in the tabulations. The stability of the primary bench mark is in turn checked by levels to a number of other bench marks which are so located that their elevations will not be likely to be changed by a common cause.

108. Descriptions.—Complete descriptions of all bench marks must be prepared and forwarded to the office with form 258, leveling record—tide station. The descriptions should be clear and distinct and sufficiently complete to enable the bench marks to be readily recovered and identified. If a standard disk is used, the description must include a defininte statement concerning whether the number of the mark and the year of establishment have been stamped in the metal. When a bench mark is located on a building, the street and number should be given when possible, or the name of the owner. When not on a prominent structure a bench mark should be referenced by distance and direction to several prominent objects. A sketch which will aid in locating or identifying the bench mark is desirable.

109. Leveling.—At the establishment of the tide station and at intervals thereafter, the tide staff must be connected with the bench marks by leveling. If possible all bench marks within a radius of 1 mile of the tide station should be connected with the tide staff at 2-year intervals or less. However, it is desirable that the tide staff be connected with not less than three bench marks, including the primary bench mark, each year or at each inspection so that any change in the elevation of the tide staff can be detected without unnecessary delay. It also is desirable that bench marks established in the vicinity by other organizations be connected with those of the Coast and Geodetic Survey from time to time.

110. The graduating lines on the tide staff now in use have a width of about 0.01 foot. The middle of each line is to be taken as the reference for heights on the staff. If a portable tide staff is used at the station, the leveling rod should be held on the flat top of the brass plate on top of the tide staff support (lower staff stop), and the reading on the tide staff to which this plate corresponds must be entered in the record. This staff reading is determined by the position of the metal stop (upper) attached to the back of the staff. It is important, however, that the staff be placed in its support to see that this upper staff stop comes in actual contact with the lower staff stop on the support without interference from any obstruction. When a tape gage is used at the station, levels must be run from the reading mark of the gage to the bench marks, the relation of this reading mark to the tape gage datum being determined from the position of the plane of flotation (pars. 84–88).

111. Before beginning the leveling care must be taken to have the instrument in adjustment and also to see that the bottom of the leveling rod corresponds exactly with the zero of the graduations. The latter is important if some sights are to be taken directly on the tide staff or on a graduated tape. Foresights and backsights should be approximately equal. The leveling between the marks must be checked by a forward and a backward line and the closing error in feet must not exceed $0.035\overline{K}$, in which K is the distance in statute miles leveled between adjacent bench marks. Table 5 gives the maximum, permissible closing error in leveling for selected distances between bench marks.

TABLE 5.—*Maximum leveling error between bench marks*

Distance between bench marks (feet)	Maximum error allowed
	Foot
500 or less	0.011
1,000	.015
2,000	.021
3,000	.027
4,000	.030
5,000	.034

If the difference between the results from the forward and backward lines between any two bench marks exceeds the allowable error, both the forward and backward lines between the marks must be repeated until an acceptable agreement is obtained. The questioned values should not be used with the new levels to obtain the agreement. Form 258, leveling record—tide station, should be used for this leveling.

OPERATION OF TIDE STATION

112. Satisfactory tide records depend largely upon the proper functioning of the tide gage and the careful observations of the observer. Hence tide observers should have some knowledge of mechanics and possess certain technical training in observing tidal phenomena.

113. Observer's duties.—The duties of the tide observer are summarized in this section; details of specific tasks are described in the numbered paragraphs which follow.

Daily: Inspect tide station; enter the comparative time and staff note on the tide record or trace (pars. 119–125) and on Form 660 (par. 135); correct gage clocks if necessary (par. 122); readjust pencils for wearing away of the lead (par. 127); wind up the tension weight; and record all pertinent items relating to the tide station and observations on form 660.

Semiweekly: Wind both clocks. Although these are 8-day clocks, semiweekly winding insures against stoppage that might result from an unexpected interruption in the observer's daily visits.

Weekly: Complete the information required on the back of form 660, the weekly report, and send to the office.

Monthly: Change the paper on the gage (par. 116); clean pencil screw (par. 130); and forward records to office (pars. 136–138).

Occasional: As frequently as necessary, clean the intake of the stilling well (pars. 131–134).

114. Placing paper on gage.—Before the paper is placed on the gage, the following information should be noted at the beginning of the roll: name of tide station; the date; scale of the gage; and name of person in charge. To place the paper on the gage, the supply roller (4, fig. 6) of the gage is removed, inserted in the blank roll of paper, and replaced in its supports so that the paper feeds from the bottom of the roll inward and over the main roller of the gage (fig. 12). The tension guide springs at each end of the supply roller (5, fig. 6) are moved down against the ends of the roll of paper to hold it firmly in place and to provide the needed tension in the paper as it is drawn forward. The springs may be slightly bent if more tension is required.

115. The main roller of the gage is disengaged from the motor clock by adjusting the carrier arm (34, fig. 8). The paper is then passed over the main roller to the receiving roller (17, fig. 7) where the end of the paper is inserted in a slot and locked in place by turning the core in the sleeve of the receiving roller. The end of the paper should be cut square before attaching it to the receiving roller. Care must be taken to secure the paper evenly so that it will wind smoothly around the roller. The receiving roller is turned several times in a direction such that the paper feeds over the top and onto the roller. Once the paper is properly in place, the main roller is engaged again to the motor clock. The tension weight, which drives the receiving roller (par. 29), is then wound up. A comparative time and staff note (pars. 119–125) must be entered on the new roll immediately after it is installed.

116. Removing paper from gage.—The paper on the gage is changed on the first day of each calendar month, or on the first visit to the station after the first of month. Before the paper is removed from the gage, a comparative time and staff note (pars. 119–125) must be entered on the old roll. To remove the old roll, the tension weight is secured to remove the strain on the paper and the main roller is disengaged from the motor clock by releasing the carrier arm (34, fig. 8). A few feet of unused paper from the supply roller is wound on the receiving roller to protect the record and the paper is cut. The receiving roller is then removed from the gage by pressing the release buttons at each end of the roller (18, fig. 7). The paper roll is separated from the receiving roller by turning the core inside the shell of the roller.

117. Adjusting datum pencil.—The initial setting of the datum pencil generally should be near the middle of the paper. Once set, its position should not be changed without good cause. If it is necessary to change the position of the pencil, an explanation should be noted in the record. Special care must be taken when securing the datum pencil holder in place to provide sufficient clearance for the recording pencil to pass. If difficulty is experienced in securing the datum pencil holder in position by means of its clamping nut (22, fig. 9), remove the nut and the datum pencil holder, tighten the small screw which is then exposed to view (par. 33), and reassemble the removed parts.

118. Adjusting recording pencil.—The initial setting of the recording pencil must allow for recording any occurrence of extreme tides. For tide stations on the open coast, the pencil should be adjusted to record the curve of the normal tide in the middle portion of the paper. For tide stations on rivers, the pencil should be adjusted to record the normal tide curve nearer the low-water side of the graph to allow space for recording flood stages of the river. Once the recording pencil is set, further adjustment should be avoided as it will necessitate making certain allowances in tabulating the data to retain a uniform datum. If further adjustment is necessary, an explanatory note should be entered in the record.

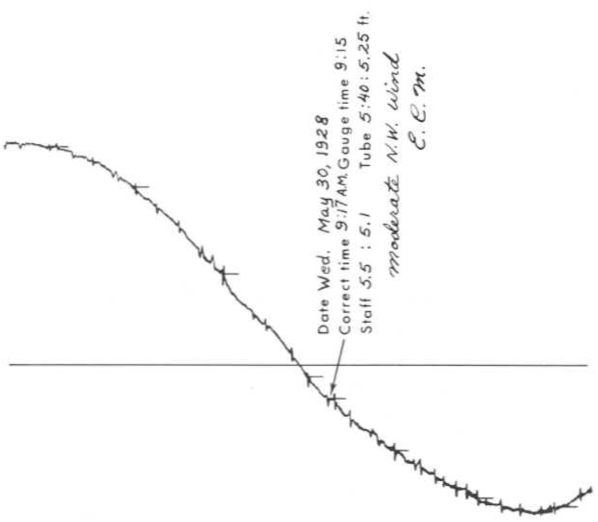


FIGURE 21.—Tide curve and comparative note (standard gage).

119. Comparative note.—When an automatic tide gage is originally installed, and daily during its operation, a comparative time and staff note must be entered on the tide roll and the corresponding point on the tide curve must be clearly indicated (fig. 21). This is absolutely essential in order to obtain the correct time relations and to establish tidal datum planes.

120. The comparative note must contain the date, the correct time as obtained from a reliable source, the corresponding time as indicated by the time clock of the tide gage, and the reading taken directly from an outside tide staff or from a nonregistering float gage which may have been installed as a substitute for the tide staff. A statement relative to the wind and weather and the name or initials of the observer making the note should be added. The exact point of the tide curve to which the note applies may be conveniently indicated by first tilting the recording pencil to make a short horizontal line similar to an hour mark and then drawing a tracer from the note to this line. The point also may be indicated by a short vertical line that can be made by rocking the float drum, but taking precaution to hold the float wire so that it will not spring off the drum.

121. A rubber stamp with suitable inscription is provided for convenience in making the note. In entering the date it is desirable to include the day of the week as a check on the day of the month. Standard time should be used for the record consistently throughout the year regardless of the fact that daylight saving time may have been adopted temporarily for other purposes during certain months. If desired the times may be expressed according to the 24-hour system in which the hours are numbered consecutively throughout the entire day thus avoiding the necessity of using the designations "a.m." and "p.m." If the usual 12-hour system is used care must be taken to indicate the forenoon and afternoon hours by their customary designations.

122. At the beginning of the record on a tide roll the correct time and the gage time should be in agreement. In subsequent notes the difference between the correct time and the gage time will indicate how much the time clock of the gage has gained or lost since the previous note was entered. *After* each entry has been made the time clock should be set to agree with the correct time. The minute hand of the clock, however, must not be turned backward when between 10 minutes before and 5 minutes after the hour. (See pars. 24–25 for setting and regulating clock.)

123. Reading tide staff.—In taking the tide staff reading, both the highest and lowest points reached by the waves are to be recorded, the two readings being separated by a dash or in some other distinctive manner. If a glass tube is used the height of the water in the tube should also be recorded.

124. The observer will note that the tide staff is graduated in tenths of feet and not inches. The heights in general are to be read to the nearest tenth or half-tenth of a foot, the half-tenth being recorded as 5 in the second decimal place. When the staff is equipped with a glass tube (par. 7) the staff reading corresponding to the water surface inside the tube should be read, but the observer must assure himself that the opening in the bottom of the tube is not clogged, and if there is any wave movement on the outside the water in the tube should show a perceptible oscillation.

125. While individual staff readings may at times seem rough and inaccurate, the final results, depending upon an average of a great number of such readings over a considerable period of time, reach a very satisfactory degree of precision provided they are taken in an unbiased manner. It is of great importance, therefore, that the tide observer when taking staff readings should be uninfluenced by any other consideration, and such readings should be entirely independent of any scale on the automatic tide gage.

126. Adjustment of hour-marking device.—Small variations in the hour-marking device on different instruments preclude detailed instructions applicable to all gages now in use. In all cases, however, care must be taken to avoid any binding between the tripping hook (36, fig. 9) and the tripping rod (26, fig. 9). In the latest type gage the tripping hook must just clear the rod during the first half of each hour. During the last half of the hour the tripping rod gradually recedes from the hook preparatory to striking the hour. When adjustments are necessary, they should, therefore, be made with the minute hand in the first half of the hour.

127. Adjustments may be made at four different points and several trials may be necessary before securing a satisfactory operation of the device. One adjustment consists of changing the position of the recording pencil in its holder, the pencil being secured in place by a binding screw (39, fig. 9). A very slight change in the elevation of the pencil and even a change resulting from the wearing away of the lead in the pencil may have a sensible effect on the hour-marking device. A second adjustment consists of changing the angle which the recording pencil makes with the paper by means of an adjusting screw (40, fig. 9). A third adjustment changes the angle between the striker weight (29, fig. 10) and the upright supporting the tripping rod. In general this angle will not differ greatly from 90°. The weight is held in position by a binding screw (30, fig. 10), but because of the strain produced by the hourly dropping of the weight there may be a slipping at times. The fourth adjustment relates to the position of the striker lifter (33, fig. 11) attached to a spindle from the time clock. This is secured to the spindle by a binding screw (32, fig. 11) and during the first half of each hour its position should be vertical. During the last half of each hour its position changes through the action of a cam in the clock.

128. Cleaning pencil screw.—One of the most common sources of trouble, which cannot be overemphasized, in the operation of the automatic gage, is the sticking of the pencil arm on the pencil screw. Even when the pencil screw itself appears clean, there may be an accumulation of dirt in the bearing of the pencil arm. Also, while the arm may operate freely in covering the normal range of tide, there may be a sticking as it advances toward either end of the screw for an unusually high or low water. The following operating difficulties frequently have their origin in a sticking pencil screw: (*a*) recording pencil thrown back off the paper on a falling tide, (*b*) curve recorded on falling tide less legible than that of rising tide, (*c*) paper torn by pencil digging in on a rising tide, (*d*) distortion in tide curve, especially a flattening at time of high or low water and steps on a rising or falling tide, (*e*) float wire broken or off drum.

129. The pencil screw should be cleaned at least once each month and at other times when there is any evidence of sticking. The latest type gage is provided with a removable pencil screw which can be taken out of the gage without disturbing any of the wiring. It is released by backing off the capstan bearing pin (45, fig. 9) at the forward end of the screw. The other end of the screw is connected with the drum shaft by a slotted joint. When replacing the pencil screw in the gage, the pencil arm should be placed in the same position as before with allowances for any change in the height of the tide in the meantime. While out of the gage, the pencil screw and the inside of bearing of the pencil arm are to be thoroughly cleaned with kerosene or nonleaded gasoline and any roughness due to corrosion removed by a fine file. The use of emery or crocus cloth is to be avoided. Before replacing the pencil screw in the gage, the movement of the pencil arm along the entire length of the screw as well as the functioning of the return springs at the ends should be checked in the manner described in paragraph 89. Lubricating oil must not be used on the pencil screw or in the bearing of the pencil arm, as the oil tends to collect dust from the atmosphere and when dry forms a sticky film on the metal surfaces. The movement of these parts during the operation of the gage is so slow that the friction between the clean dry metal surfaces is practically negligible.

130. With the older type gage, a thorough cleaning of the pencil screw cannot be accomplished without disconnecting the wiring, and this is generally undesirable. However, at regular intervals the screw must be wiped clean with a rag moistened with kerosene or nonleaded gasoline and the best time to do this is when changing the paper after the close of each month. With care to avoid letting the float wire spring off of the drum, the screw may be turned a limited amount to move the pencil arm forward and backward during the cleaning process. A liberal application of kerosene or nonleaded gasoline with a squirt can will be helpful in removing dirt accumulated inside the pencil arm bearing.

131. Clearing stilling well intake.—Particular care must be taken to keep open the intake to the stilling well, as even a partial clogging may destroy the value of the record by creating a lag in both time and height of the tide. Clogging may be caused by an accumulation of sediment inside the well, by marine growth at the intake, or by the shoaling of the water in the vicinity. In an iron stilling well clogging may result from an accumulation of iron rust scales inside the pipe. A clogging of the intake is indicated by a smooth tide curve when the water outside the stilling well is somewhat rough. Although the stilling well is designed to dampen the outside waves, there should always be an unmistakable oscillation of the recording pencil whenever the water is somewhat rough in the vicinity. A smooth, regularly traced curve is to be regarded with suspicion and should occur only when the water outside the stilling well is smooth.

132. In localities where there is any tendency toward clogging, the observer should establish the practice of clearing the stilling well at regular intervals. When clearing an iron stilling well with intake in the center of the standard conical intake coupling, it will generally be necessary first to remove the float from the well and, to avoid any tangling of the float wire when raising the float, the wire should be secured by a clamp or loop around some convenient object to take up the slack. When the intake is not badly clogged it is most conveniently cleared by use of the cleaning tool shown in figure 18. This tool is lowered into the well by a line and is used to tap out any foreign matter which may have collected in the intake.

133. If there is a considerable accumulation of sand in the bottom of the well it may be necessary to use a jointed rod made up of sections of iron pipe which may be fastened together as it is lowered into the well. One-half-inch pipe with outside diameter a little less than ⅞ inch will generally be found satisfactory for the purpose when the diameter of the intake is an inch or more. If the obstruction in the intake is found to be especially difficult to remove, a drill of suitable size soldered in the end of the lowest section of pipe will usually be found effective when other means have failed.

134. For a wooden stilling well when the intake is in a lower corner of a sloping bottom, the use of the jointed rod without removing the float from the well will probably be found both convenient and effective in ordinary cases. When the intake is in the side of the well rather than the bottom, its clearing will generally be more difficult and necessitate the use of a boat at low tide. When the clogging occurs as a result of the shoaling of the water around the stilling well, the clearing of the intake becomes a problem which cannot be handled by the usual facilities of the observer and the circumstances must be reported to the office.

135. Weekly report (Form 660).—Tide observers are required to forward to the office at the end of each week a report on Form 660. The daily notes should correspond to those entered on the marigram itself, but the tube readings may be omitted in this form. If staff readings are taken more than once during the same calendar day, a single set will be sufficient for the weekly report, but all such readings are to be noted on the marigram. In the column of "Remarks" there should be noted such items as "Stilling well cleaned," ""Float wire broken," "Counterpoise wire off drum," "Timeclock stopped at 11:15," etc. The operating troubles are to be explained in detail on the back of the form, which must also include all other information requested.

136. Forwarding record to office.—Unless the tide observer tabulates the records, the tide roll is to be forwarded to the office immediately after removal from the gage after the close of each calendar month. If the observer does tabulate the records, the work must be expedited and the records forwarded promptly as possible, as the office has frequent calls for information based upon them. It is expected that the tabulations will be completed and the records forwarded within 1 week after the marigram has been removed from the gage.

137. Before forwarding the tide roll, it should be rewound to bring the record on the inside with the first of the month at the beginning. A label, Form 489, is to be filled out as completely as possible, except that at a control tide station it will be unnecessary to repeat the latitude and longitude each month. The marigrams are numbered consecutively from the beginning of the series regardless of calendar years. The label is to be pasted on the outside of the marigram in such a manner as not to seal the roll. As a protection against tearing, a few inches of the paper at the beginning of the roll should be folded inward, making a smooth edge of double thickness. The label is then pasted parallel to this edge and about 1 inch from it, with the bottom of the label towards the edge.

138. The roll should now be well wrapped for mailing and an addressed franking slip (Form 110) pasted on the outside. Two copies of Form 413 listing the record must be sent under separate cover. This form is used only for the formal transmission of records, and any matters requiring special attention should be sent as separate communications.

139. Shipment of Government property.—Shipments of instruments or other Government property when too bulky to be sent by mail are sent by express or freight on Government bill of lading. When it is necessary for the tide observer to make any such shipment to the office he will be provided with a bill of lading for the purpose, and no payment of charges, other than drayage which will usually be arranged for in advance, should be made by the tide observer for shipments sent or received by him. Form 412, in duplicate, is used as a transmitting letter when shipping instruments to the office.

140. Requisition for supplies.—A requisition for stationery for use at a tide station may be made by ordinary letter or by a short form requisition letter mimeograph copies of which may be obtained from the Chief of the Marine Data Division, upon request. Requisitions for instruments and general property must be made on Form 12. Requisitions for stationery and instruments should always be made on separate forms, as they are handled by different sections of the office.

141. Requisitions for supplies may be made from time to time as needed, but it is recommended that at a control tide station the quantity of any article requested in a single order be sufficient for a period of about 1 year. The following list is suggestive of the quantity of any article to be included in a single requisition:

Tide rolls for standard tide gage		12
Form 489 (label for tide gage record)		20
Form 660 (weekly report of tide station)		60
Form 413 (letter transmitting field records)		50
Form 110 (frank, mailing addressed to Director)		20
Form 12 (requisition for instruments and general property)		10
Requests for stationery (short form)		20
Letter paper for field use, medium	tablet	1
Envelopes addressed to Director, 3⅞ by 8⅞ inches	packages	2
Envelopes, manila, 9½ by 12 inches	package	1
Pencil leads, Scripto, black, BB	do	1
Cheesecloth for cleaning tide gage	yards	3
Tabulation forms (if observer tabulates marigrams):		
Form 2211 front (comparative readings) / Form 2211 back (high and low waters)		25
Form 362 (hourly heights)		50

142. Emergency expenses.—Tide observers are not expected to incur any expenses in the operation of the tide station unless especially authorized by the Director of the United States Coast and Geodetic Survey. Unless an emergency exists, the tide observer should inform the office of any needed repairs and then wait for instructions. Time will be saved if the tide observer obtains an estimate of the cost of making the needed repairs and submits this when informing the office of the need for the repairs. If the cost is more than nominal, at least three estimates are to be obtained when possible.

143. In case of an emergency in which there would be a considerable loss of record if the observer waited until receiving instructions from the office, he may make immediate arrangements for having the work done. In such cases arrangements will be made to have payment made directly by the office to the party doing the work, or the observer will be provided with suitable forms for obtaining necessary receipts.

144. When emergency work of considerable magnitude is necessary, the tide observer should inform the office by telegram, which is to be sent collect and not prepaid by the observer.

145. Furnishing information to public.—All employees of the United States Coast and Geodetic Survey are expected to be courteous to the public when inquiries are made concerning their work, but the regulations prohibit the furnishing of copies of the records without authority of the Director. When a tide station is so situated that there may be more or less frequent calls by local authorities for data from the tide-gage record, and this is brought to the attention of the office, permission will usually be granted to the tide observer to supply such information upon request, but when this is done, the party to whom the information is given should be informed that the results are preliminary and subject to revision by the office.

146. Operating difficulties.—It would be impossible to anticipate all difficulties which might arise in the operation of the automatic tide gage but the principal ones are listed below. The tide observer should become familiar with different parts of his gage by reading the description of the instrument contained in this manual. All the gages in use are not of the same identical pattern but the observer will note any differences which may exist in the gage at his station.

147. Broken or tangled float wire.—Observer visits station and finds float wire off drum, tangled, and perhaps broken. Although this may result from several causes, the most frequent one is a dirty pencil screw which has jammed the gage and prevented the counterpoise from taking up the slack in the float wire as the tide rose. The wiring should be entirely removed from the gage and the pencil screw examined and cleaned in accordance with paragraph 129. New wiring may then be installed as described in paragraphs 93–96. It will not be necessary to attempt to adjust the gage exactly as before, but a note should be entered on the roll itself and also in the weekly report stating that new wiring was installed, and a comparative staff reading must be taken and recorded.

148. Other causes which might lead to a broken or tangled float wire are improper installation of wiring, an obstruction in the path of the counterpoise weight, jamming of a pulley through which one of the wires passes, and an interference between the recording pencil and the datum pencil. If the instructions for attaching counterpoise and float are not strictly followed, it is possible that an excess of wire attached to the float may run off the edge of the float drum at the time of a specially high tide, thus causing a sudden jerk which could break or tangle the wire. An obstruction in the path of the counterpoise weight or the jamming of a pulley through which the wire passes might prevent the weight from functioning and thus permit the slackening of the float wire. A similar effect may be produced if the recording pencil fails to clear the datum pencil in passing because of an improper adjustment of the pencils. See paragraph 117.

149. Clock failure.—If either clock stops frequently or runs persistently fast or slow regardless of all efforts to regulate it by the customary method, a requisition should be made for a new clock unit, and an effort should be made to keep the old clocks functioning while waiting for the new unit. The stopping of either clock may be caused by winding too tight or by a collection of dirt in the works. The latter condition may be temporarily remedied by the use of kerosene. In some of the older types of gages, clock failure may result from a flexure of the frame caused by drawing too tight the screws securing the clock to its case. Any jamming of the supply roll of paper might affect the running of the motor clock, and any unusual resistance in the operation of the hour-marking device would have its effect on the time clock.

150. Failure of hour-marking devices.—Assuming that this is not the result of the stopping of the time clock, any failure will probably be found to be due to an improper adjustment of the device. Instructions given in paragraphs 126–127 should be carefully followed.

151. Torn paper.—If the paper is found torn along the record curve during a rising tide, it is probably the result of a dirty pencil screw which has forced the pencil arm downward and caused the pencil point to dig into the paper. The softening of the paper by damp weather may be a contributing factor. See paragraphs 128–130 for cleaning pencil screw. An improper adjustment of the hour-marking device whereby the tripping rod presses to tightly against the tripping hook may also result in a tear. A tear along the datum line suggests too great a pressure, too hard a pencil, or a broken pencil point. A tear along the line of prick points at the margin of the paper may result from too heavy a tension weight or too strong a resistance from the tension springs acting upon the supply roll of paper. A torn margin may result from an improper alignment when the tide roll is installed on the gage.

152. Failure to trace curve.—Sometimes sections of the tide curve will be missing without any apparent cause. Assuming the pencil point to be unbroken, if the missing section occurs on a falling tide, it is probably the result of a dirty pencil screw which has lifted the pencil off of the paper temporarily. In some cases the pencil arm may be thrown entirely back away from the paper and remain there until returned to its proper position by the observer. The obvious remedy is the cleaning of the pencil screw in accordance with paragraphs 128–130. If the entire tide curve is very faint, a pencil with softer lead should be used.

153. Distortion of tide curve.—A series of steps in the record or a flattening at the times of high or low water is most frequently caused by a dirty pencil screw and this should be given first attention when the trouble arises. An irregular distortion in the tide curve may also result from the same cause. In very cold weather, a distortion of the curve may be caused by the presence of ice in the stilling well. Ice collected on the inside wall of the well may impede the movement of the float without stopping it completely, thus causing an irregular movement. See paragraphs 73–74 for precautions against freezing. If ice has already formed in the well a liberal use of salt or hot water is helpful in freeing the float. If an insufficient quantity of kerosene has been placed in the well as a precaution against freezing it is possible for ice to form below the kerosene. See also the following paragraph.

154. Clogged stilling well.—A clogged stilling well is evidenced by a consistently smooth tide curve regardless of any roughness in the water outside. As a clogged well causes a lag in the record which greatly impairs its value, it is important that the observer be especially watchful for any indications of this trouble in order that it may be remedied without delay. Unless the surface of the outside water is quite smooth, there should always be a preceptible short-period wave oscillation in the record with an amplitude increasing in proportion to the roughness of the outside water. Whenever there is any evidence of the stilling well being clogged, the observer should follow the instructions in paragraphs 131–134 for clearing the intake. In localities where the clogging occurs frequently, the observer should adopt the practice of clearing the intake at regular intervals.

INSPECTION OF TIDE STATION

155. In making an inspection of a control tide station, note should be made of the following matters and a report of the conditions found forwarded to the office in Form 681, report—tide station. Information relating to the station supplied by the office should be verified by the inspector as far as practicable.

156. Location.—If changed conditions in the vicinity of a tide station make it desirable that the location be changed, the inspector should ascertain whether there is a more suitable site and report accordingly with his recommendations.

157. Tide staff.—A careful inspection should be made of the tide staff, the legibility of its scale, and to see whether it is firmly secured in a vertical position. If a portable tide staff is in use, the staff support should be examined to see that it is substantially secured and that the metal plate at the top is firmly fastened in place. The metal stop on the back of the portable staff must be checked in regard to its position relative to the tide staff scale (see par. 110) and to see that it is firmly secured. The staff should be lowered into its support to see whether any obstructions exist to prevent the stop on the staff from resting flatly upon the metal plate at the top of the support.

158. The tide observer should be questioned in regard to any changes in the position of the tide staff of which he may have knowledge, and should be advised to always report immediately to the office any occurrence that might affect the elevation of the tide staff. If a tide staff has been accidentally knocked out of place or loosened and afterward resecured by the observer, it is important that the office have a record of the date on which this occcurred.

159. Tape gage.—If there is a tape gage or other substitute for a tide staff at the station, this should be described and any known changes since the previous inspection reported. For a tape gage, the relation of the plane of flotation to the tape scale should be checked by the method described in paragraphs 84 to 88. If there is a tide staff in addition to some other form of nonregistering tide gage at the station, some simultaneous readings from both gages should be taken, preferably when the water is reasonably calm, but if the water is rough the amplitude should be noted as an indication of the reliability of the comparison.

160. Automatic tide gage.—The automatic tide gage is to be examined to ascertain if it is operating satisfactorily, special attention being given to the clocks, the hour-marking device, the pencil screw, and the wiring, which have been described in detail in the preceding pages. Note whether the gage is so placed over the float well that the float clears the sides of the well without scraping. Inquiry should be made as to whether the observer has experienced any of the operating difficulties listed in paragraphs 146 to 154, and such adjustments should be made and advice given as necessary.

161. Stilling well.—Note the general condition of the stilling well and whether it is securely fastened in place. Special attention must be given to the intake to the well and a rod or cleaning tool should be passed through the opening. (See pars. 131–134.) If there is a separate well for a tape gage, this must be given the same attention as the one for the automatic gage.

162. Observations.—The methods and procedure used by the observer in attending to his duties are to be noted and his attention called to any matter requiring change. Any unusual method or procedure should be noted in the report. The inspecting officer should make an independent reading of the tide staff and enter it on the tide record in accordance with instructions for comparative note in paragraphs 119–125.

163. Measurements.—The depth of the harbor bottom at the tide staff and at the stilling well as referred to the floor of the wharf or other specified fixed point should be taken and reported at each inspection in order that there may be a record of any change in the depth which may occur from time to time. These depths need be given only to the nearest foot or half-foot. Previous measurements of the relation of the tide staff and float well to the wharf floor should also be verified.

164. Bench marks.—At the time of station inspection search should be made for all bench marks within a radius of 1 mile from the tide station, their condition noted, and the old description revised if necessary. (See par. 108.) If an old bench mark cannot be found a statement to that effect should be included in the record, together with an explanation whether the failure to find the mark results from an inadequate description, inaccessibility of location, or positive information of its destruction. If the number of bench marks recovered is less than the minimum of five marks for a control tide station, the inspecting officer should arrange for the establishment of such additional marks as may be necessary. All tidal bench marks within a 1-mile radius of each control tide station should be connected by leveling at least every 2 years. Descriptions and reports concerning bench marks are to be included in the leveling record form 258.

165. Leveling.—On the occasion of each inspection the tide staff must be connected by a double line of levels with *not less than three substantial* bench marks including the primary bench mark, and the results must come within the limits of accuracy indicated in paragraph 111. For procedure in regard to leveling to a portable tide staff or to a tape gage, see paragraph 110. The height of a bench mark above the datum of a tape gage of the type illustrated by figure 2 is equal to the height of the bench mark above the reading mark of the gage plus the reading of the plane of flotation on the tape scale extended. If the bench mark is below the reading mark, the difference in elevation is subtracted from the reading of the plane of flotation. Form 258 is to be used for the leveling record.

166. Recommendations.—A report of inspection should include recommendations for such repairs or changes as may appear desirable, with an estimate of the cost when possible. When repairs are urgently required, the inspecting officer should give them immediate attention, requesting by telegraph approval for expenditure of such extra funds as may be needed.

SECONDARY TIDE STATION

167. Secondary tide stations include those which are operated over a very limited period of time, the observations in general extend over less than a year but in some cases covering more than a year Secondary tide stations are established for the purpose of obtaining general tidal information for a locality and also to obtain specific data for the reduction of soundings in connection with the hydrographic surveys. Observations at a secondary tide station are not usually sufficient for a precise independent determination of tidal planes, but when reduced by comparison with simultaneous observations at a suitable control tide station very satisfactory results may be obtained.

LOCATION

168. The selection of a location for a secondary tide station will depend upon the purpose for which it is to be established. For the hydrographic survey of any area there should be a principal station somewhat centrally located which will be maintained through the time the survey is in progress. If available, a standard automatic tide gage should be installed at the principal station. If there is already a control tide station located within the area to be surveyed this may serve as the principal station.

169. Gages are to be established at other points in the immediate vicinity of the soundings as the work progresses, the distribution depending upon the change in the tide from point to point. In some localities the tide may occur practically simultaneously with nearly equal range over a large area. In such a case a single tide station will serve for the entire area. In other localities the tide may change rapidly in passing from one point to another and it may be necessary to establish gages at close intervals. For the subsidiary stations, the portable automatic tide gage will generally be found most convenient to install and the records sufficiently accurate for the purpose. For a very short series of observations, a plain tide staff to be read at certain fixed intervals may be found sufficient.

170. Soundings off outer coasts.—For the reduction of soundings in offshore areas, the tide record from a gage located in a harbor—such as at a control tide station— can be used. Corrections are applied for the difference in time of observation and for differences in the height of the tide. In the reduction of such soundings it is advisable to avoid tide records from gages located well inside a river mouth or shallow estuary, or in a body of water having a narrow connection with the sea. For the reduction of soundings in inshore areas along an outer coast, subsidiary staffs or portable gages should be establihsed in the immediate vicinity of the work if possible. The observations at these locations should be compared with simultaneous observations at nearby stations where long series of tide records have been obtained.

171. Exposed channel approaches.—In charting exposed channel approaches, where depths are not much greater than the draft of vessels, especially accurate soundings are required. In such surveys, the tide records provided by an inshore tide staff may not be sufficiently accurate for the reduction of the soundings. A temporary station can then be established by driving a pile or stake in the channel and obtaining several hours of tide observations with a portable gage or fixed staff. The observations should be made simultaneously with those at an inshore station for comparison and reduction of reference planes and should include at least one high and one low water.

172. 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.

173. 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 so that sounding will not be done at a considerable distance from a tide station.

174. 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 gage may be quite different from that at the gage, particularly if differently exposed to the wind direction. Sounding at some distance from a tide gage under such conditions will result in failure of sounding lines to cross, at times by several feet.

175. Where such conditions prevail, a tide staff or portable gage should be established in the immediate vicinity of the work for the reduction of soundings and connected with the central or control gage by simultaneous observations made during normal weather conditions. If a portable gage is established at the auxiliary station, 1 week of simultaneous observations should be obtained. If a plain staff is established at the auxiliary station, the observations for connecting with the central gage need cover only those hours during which sounding dependent upon the auxiliary gage 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.

176. When surveying shallow bodies of water, such as the sounds of North Carolina, where the range of tide is small and fluctuations due to meterological 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 gage 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.

ESTABLISHMENT OF SECONDARY TIDE STATION

177. Certain precautions which are required when establishing a control tide station because of its more or less permanent character are unnecessary when installing a secondary tide station. Without sacrificing anything which might impair the reliability of the record, the installation of a tide station to be occupied for only a short period of time may be somewhat simplified.

178. The tide staff may be a plain board with graduated scale nailed to a convenient support. The staff must, however, be connected with a system of bench marks as described in paragraphs 99–111. The smaller and more conveniently installed portable automatic tide gage may usually be substituted for the larger standard gage. The stilling well may be a simple construction of plain boards; or, if the portable automatic gage is used, made up of convenient lengths of standard 4-inch iron pipe. If the observations are taken during the summer time only, no tide house is necessary, a waterproof box affording sufficient shelter for the standard gage, and the iron cover provided with the portable gage serving as ample protection for the latter. In the winter time a tide house is more or less necessary as a protection against the elements when changing the record on the gage.

179. In selecting the site for a secondary tide station existing facilities and the accessibility of the location to an observer must generally be taken into account. For the standard tide gage a convenient wharf is especially desired. Otherwise some special platform must be constructed. The portable gage, partially supported by its own 4-inch iron-pipe stilling well, may be secured to a single pile, to a fish-net stake, or against a cliff (figs. 22–23). Care should be taken to install the gage at a point where the depth is sufficient to operate the gage at low tide.

180. The installation of the standard automatic tide gage has already been described in paragraphs 89–98 and its operation discussed in paragraphs 112–154. However, all the instructions given for the guidance of the tide observer at a control tide station will not necessarily be applicable to a tide observer at a secondary tide station, who is working under the direction of the chief of party. The installation and operation of the portable automatic tide gage are described on the following pages.

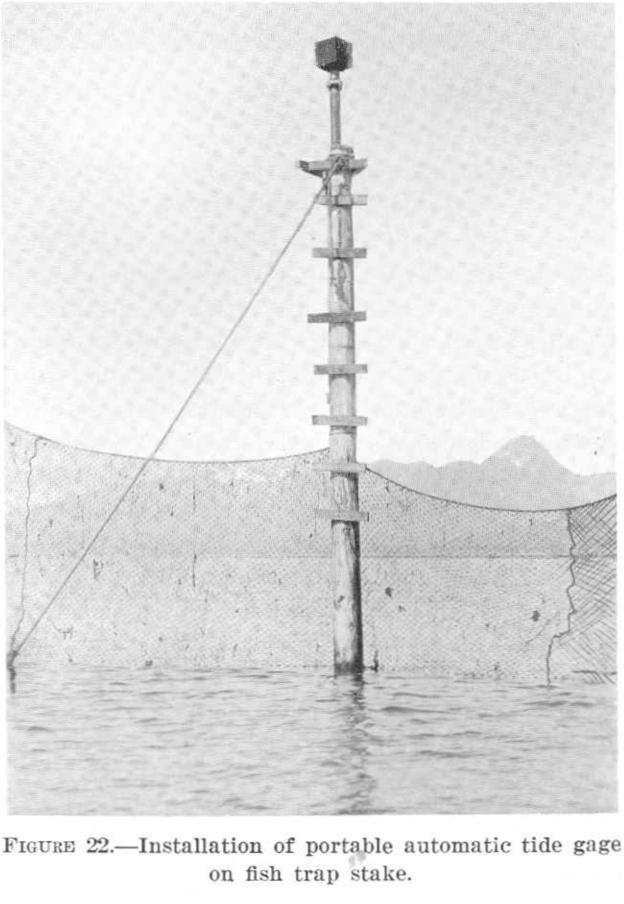


FIGURE 22.—Installation of portable automatic tide gage on fish trap stake.

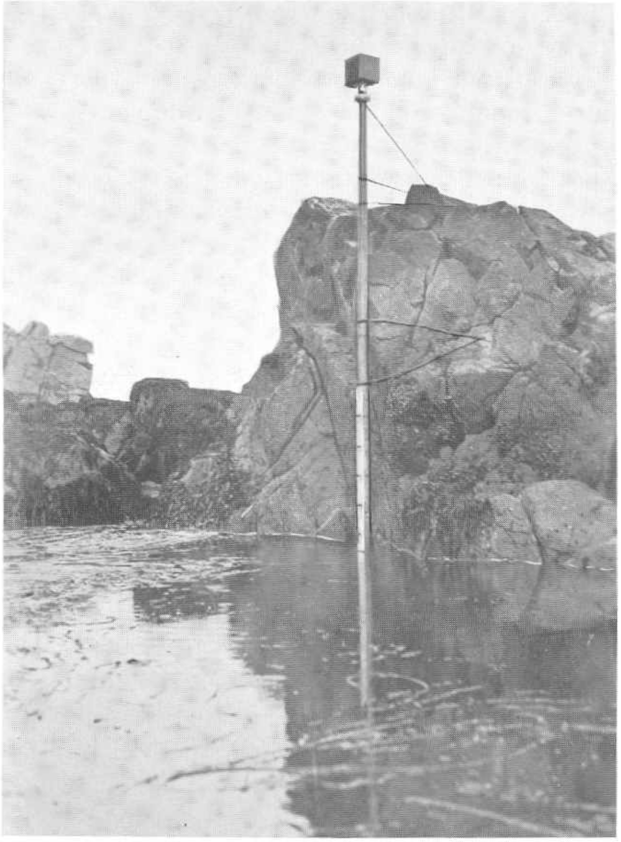


FIGURE 23.—Installation of portable automatic tide gage against rocky cliff.

INSTALLATION AND OPERATION OF PORTABLE AUTOMATIC TIDE GAGE

181. Since the portable tide gage is designed to be set with stylus reading in agreement with the reading on the tide staff, the latter when installed should be so placed that its graduation corresponding to the middle of the height scale of the record paper shall be at approximate half-tide level or midway between the extreme tides to be expected during the period of observations. With such a setting the curve traced by the portable gage will be approximately centered on the record paper.

182. Stilling well.—The base of the portable automatic tide gage is provided with a sleeve to fit on the top of a float pipe. In the later gages this provides directly for a 4-inch float pipe, but in the earlier gages it provided only for a 3½-inch pipe and a reducing coupling is necessary to adapt it to the larger pipe. The pipe in addition to serving as a stilling well acts also as a support for the instrument. When the gage 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 on 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. 22 and 23). 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.

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

Let A=distance in feet of float drum to water surface. (Actual measurement not necessary.)

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 $\pm B$.

Take a spool of wire and attach one end of the wire to the float 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 15, or by use of the clock key on the drum axle (30, fig. 15). 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. When all the slack in the wire has been taken up the gage is placed in position on top of the float pipe and locked by means of the two anchor hooks (27, fig. 15).

184. 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 (30, fig. 15) of the float drum.

185. Gear train.—Having determined the scale of the record to be employed from a knowledge of the approximate range of tide at the station, the proper gears for the float-drum axle and the stylus screw corresponding to that scale are given in table 2, paragraph 52. The gears to be used are also printed on the cross-section record paper for each scale. The number of teeth is stamped in each gear and care must be taken in selecting and installing the correct gears corresponding to the scale used.

186. Although the same idle gear (8, fig. 13) is used for all scales, its position varies with the different gear combinations. When changing the gears the idler must be removed, and after the other gears have been installed, it is replaced, being secured by the gear screw (9, fig. 13) in the particular hole provided for the combination. The lever nut (10, fig. 13) provides a convenient means for loosening or tightening the gear screw securing the idle gear. The gears attached to the stylus screw and the float-drum axle are easily removed after taking off the nuts (7, 12, fig. 13) holding them in place.

187. Record cylinder.—The record cylinder with the clock movement inside is now installed in its supports. The clockwork rotates the cylinder in such a direction that its top moves toward the stylus screw, and when installing the cylinder it should be placed in its supports with the capstan nut (4, fig. 13) on the same side of the instrument as the train of gear wheels, this being designated as the front of the gage.

188. Record paper.—The record paper is wax-coated and must be handled carefully. Rough usage or overexposure to direct sunlight can result in loss of tide records. Five different scales of record paper are provided. Care must be taken to select the scale desired and to see that the specifications for gears printed on the sheet are the same as the corresponding gears on the gage. With the capstan nut (4, fig. 13) loosened, the paper is placed on the cylinder with the zero of the height scale toward the front of the instrument; that is, at the same end of the cylinder as the capstan nut. The paper is held in place by a metal clip (24, fig. 14) which is released at one end when installing the paper. After the paper is in place, the cylinder is turned until the stylus reading on the paper scale corresponds approximately to the correct time. The nut at the end is then tightened to secure the cylinder in this position. The time should be correct with the backlash taken out by turning the drum away from the screw.

189. Ordinarily, 2 days (48 hours) of record are traced on the record paper for each revolution of the cylinder. Since the times of high and low water occur about 50 minutes later each day, the tide curve traced on the same sheet during several revolutions of the cylinder separates sufficiently to be distinctive unless the range of tide is very small. Although a single sheet of record paper might serve for an entire week, it is recommended that a new sheet be placed on the gage every 3 or 4 days. A special 4-day (96 hours) record paper is available for use where frequent visits are not feasible, or the 2-day marigram is not satisfactory for recording tides of small range.

190. Setting stylus.—To set the stylus to the approximate height of the tide as read on the tide staff, the nut (7, fig. 13) holding the upper gear to the stylus screw is unclamped, and the stylus screw may then be turned freely to bring the stylus to the reading desired. The gear is then again clamped in position. A finer adjustment for height may now be obtained by means of the slow-motion screw (25, fig. 14) provided for the purpose. The stylus should be reset to agree with the staff reading each time the record paper is renewed.

191. While the approximate time setting of the stylus is obtained by the turning of the record cylinder as described in paragraph 188, a finer adjustment is secured by means of the slow-motion screw (34, fig. 15). When setting the stylus for time, 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.

192. Care of clock.—Although the clock enclosed in the record cylinder has an 8-day movement, it is recommended that it be wound semiweekly. The clock is regulated by means of the small end of the clock key inserted in the small keyhole in the front end of the 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. Care should be taken to insure that an apparent error in time is not caused by distortion or slippage of the marigram.

193. Cleaning stylus screw.—For the efficient functioning of the gage 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 gage. (See pars. 128–130.)

194. Cleaning float pipe.—If the gage 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 tool to which a line has been attached, and raising and lowering it several times in the pipe. (See pars. 131–133.)

195. Comparative note.—Each day the tide gage is visited, a comparative note giving the date, the correct time, and staff reading should be entered on the marigram (fig. 24). The stylus is to be adjusted when necessary to agree with the correct time and staff reading. As unbiased staff readings are necessary for the proper reference of the various tide planes to bench marks, care must be taken by the observer to avoid being influenced by a previous setting of the stylus on the cross-section paper when taking a new staff reading. However, when an unusual rough state of the water renders a staff reading somewhat unreliable, a previous setting of the stylus under more favorable conditions should be retained without change.

196. To indicate on the tide curve the exact point to which the comparative note refers, first rock the stylus holder (35, fig. 15) slightly to make a short line parallel to the edge of the paper. Next place the hand lightly on the float drum (17, fig. 14) and raise the float a little way out of the water and then lower it, making a short vertical line on the marigram. The point indicated by the intersection of these lines is then connected with the comparative note by a light line.

FIELD REDUCTIONS

197. Preliminary computations of tidal data to obtain tide reducers for soundings are often carried on in the field. The processes are covered in the following chapter on Tabulation and Reduction, but for field purposes, parts of the instructions not directly applicable to the work in hand may be omitted. Unless there is special need to expedite the reductions in the field the planes of reference for the reduction of soundings will be furnished by the office upon the receipt of the original tide and leveling record.

TABULATION AND REDUCTION

PRELIMINARY WORK

198. The original tide records to be tabulated will vary in form according to the kind of tide gage used in taking the observations. The records generally consist of tide rolls from the standard automatic tide gage or tide sheets from the portable automatic tide gage. The following general instructions are applicable to the several forms used for the tabulations and reductions. The work is to be done neatly and in ink. Interpolated or inferred values are to be indicated by the use of brackets. The heading on each sheet will in general be filled out as completely as possible in order that it may be fully identified, but when a tabulation covers several sheets a repetition of the latitude and longitude of the place is unnecessary, and for a continuing series the spaces for the beginning and ending of the observations may be left blank. The height datum in the heading refers to the datum actually used for the tabulation, which is generally the tide staff zero. Standard time is to be used consistently throughout the year regardless of the fact that daylight-

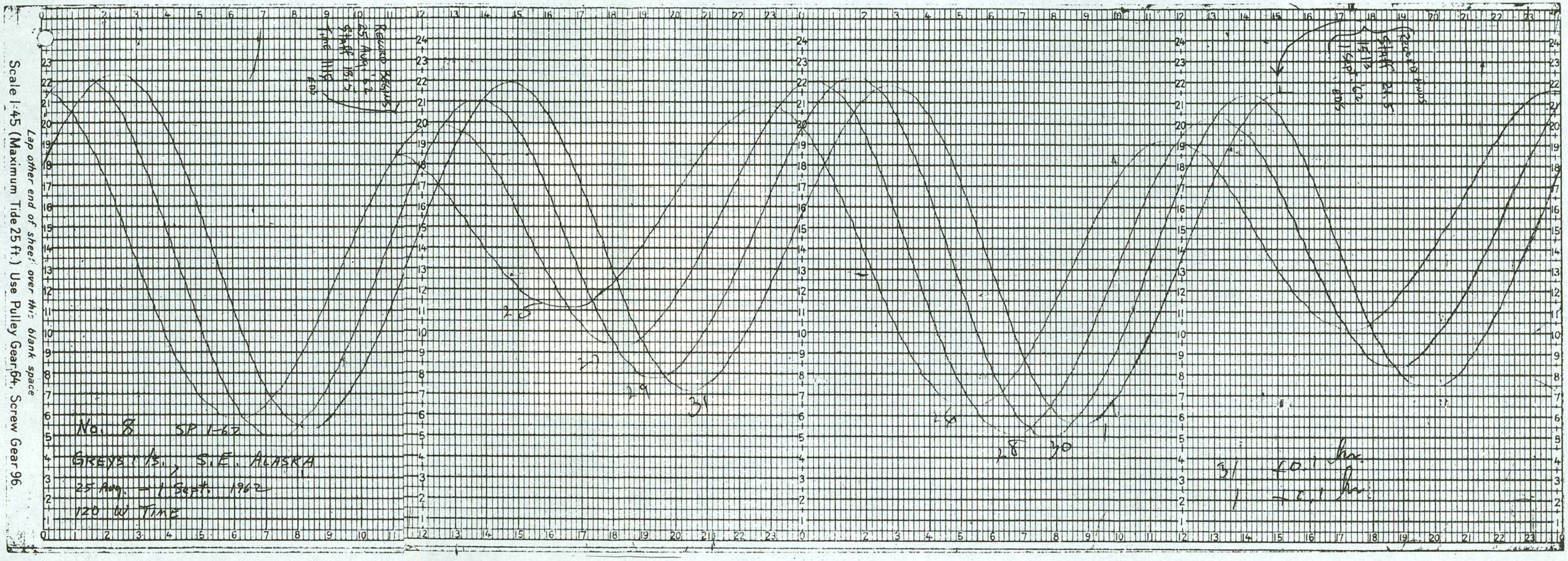


FIGURE 24.—Tide curve and comparative notes (portable gage).

saving time may have been temporarily adopted in some localities. The hours of the day are to be numbered consecutively from 0^h (midnight) to 23^h (11 p.m.) to avoid the necessity of using the terms "a.m." and "p.m."

199. Checking time.—In the portable gage record, the hours are indicated by the numbered vertical lines of the cross-section paper, the hours being subdivided into 10-minute spaces by finer vertical lines. The time as indicated by these vertical lines is to be compared with the correct time as given in the comparative notes entered by the observer. Assuming that the observer has corrected any clock error at each visit to the tide station, any loss or gain may be prorated over the period intervening between the visits unless there is evidence to indicate that the loss or gain was not uniform.

200. In the standard gage record the hours are indicated by short horizontal lines made automatically by the time clock of the gage. The hour begins at the instant the mark leaves the curve, the length of the stroke having no significance. The time notes entered on the record by the observer should be examined, and if it is found that the difference between the correct time and the gage time does not exceed 3 minutes at any time, the hour marks as automatically made by the gage may be accepted as correct and marked accordingly. In cases where the hour marks are appreciably in error due to failure of the time clock to keep correct time, the total error indicated by the time clock may be prorated among the hour marks effected on the assumption that the time clock has lost or gained uniformly between consecutive comparative notes. The marks are to be numbered consecutively from 0 (midnight) to 23 (11 p.m.), and the numbering checked at each time note on the marigram. In order to expedite the work, the numbering of the odd hours may be omitted if desired. The beginning of each day at the 0 hour should be marked with the appropriate date.

201. In cases where the hour-marking device has failed to work the following method may be used: First, from the comparative time notes ascertain the position on the curve of the nearest exact hour for each note made during the period when the hour-making device was not functioning. 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 laid 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 the 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 the 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.

202. Checking height datum.—In the portable gage record, the heights are indicated by the horizontal ruling of the profile paper, the zero of which is assumed to correspond to the tide staff zero unless otherwise stated. The height as indicated by the horizontal ruling is to be compared with the actual staff reading as recorded in the comparative notes and allowance made for any difference when tabulating the record. The portable gage is designed to be reset whenever necessary to keep the scale and staff readings in agreement.

203. The determination of the height datum for the standard gage record is radically different from the method used for the portable gage. In the standard gage, no attempt is made to establish in advance any particular relation between gage and staff datum. The aim is to keep the gage datum uniform throughout the entire month, and then, after the record has been removed from the gage, to determine the relation of its datum to the staff zero by the average of the daily comparisons covering the entire month. A special form is provided for the computation and its use is described in the following paragraphs.

204. Comparative readings (Form 2211).—This form (fig. 25) is used to obtain the relation between the datum line of a standard automatic tide-gage record and the datum adopted for the tabulations. The latter datum is either the zero of the tide staff or tape gage in actual use, or has a definite relation to the same. At primary tide stations it is the aim to maintain a fixed datum for the tabulations throughout the entire series of observations, and constants are introduced to take account of any changes in the elevation of the tide staff. The corrected setting as calculated represents the scale reading of the datum line as referred to the datum adopted for the tabulations. A movable scale is used in making these tabulations.

205. In the first three columns of Form 2211, the tabulator notes, respectively, the date, the time of staff reading, and the water level as read on the staff or tape, these items being taken directly from the observers notes on the tide roll. The staff reading entered in the form is the mean between the highest and lowest readings recorded, but if a glass tube is used on the staff, the reading entered in the form should be the mean of the tube readings. If a tape gage is used, the word "staff" at the head of the third column should be changed to "tape" and the reading entered should be the mean of the highest and lowest tape readings.

206. The preliminary scale setting of datum line, to be entered in the heading of the form, may be arbitrarily chosen at any convenient value. This preliminary setting should preferably be of such a value that the scale readings from the tide curve will be from ½ to 1½ feet less than the corresponding staff readings. The scale reading selected for the comparison should be ruled on the scale.

207. The values in the fourth column of the form are obtained by placing the scale on the record with the preliminary setting in coincidence with the datum line and reading the height of the curve at the point to which the corresponding staff reading refers. These readings are to be taken to the nearest 0.05 foot. The difference between staff and scale reading is to be entered in the fifth column, and the phase of the tide at the time the staff reading was taken in the next column. Any change in the adjustment of the gage should be explained in the column of "remarks."

208. If there has been no change in the adjustment of the gage, the differences (A–B) should be approximately equal. If an individual value differs materially from the apparent average of all, it must be rejected and excluded from the computation of the mean. The rejection is indicated by encircling the value in question. The differences are now summed and a mean obtained, the result being carried to two decimal places. To this mean difference there is added the preliminary scale setting and also any constant that may be necessary to refer to any datum other than staff zero. When a constant is necessary it is furnished by the office. The algebraic sum of these quantities will give the corrected scale setting to be used in the tabulations of the hourly heights and the high and low waters.

209. If there has been any change in the adjustment of the gage, such as would be caused by replacing a broken float wire, the introduction of kerosene in the stilling well, a change in the position of the datum line, etc., the difference will form distinct groups. In such cases separate means and corrected scale settings must be computed for each adjustment of the gage.

210. Sometimes an extreme high or low tide may move the pencil arm to the extreme limit of its motion so that it becomes disengaged from the threaded portion of the pencil screw. If the change in the height of the tide beyond this limit is small, the pencil arm will automatically reengage the screw thread after the tide reverses without any change in the adjustment of the gage, but if the tide continues to rise or fall after the disengagement of the pencil arm by an amount equal to or greater than the circumference of the float-wire drum, the adjustment of the gage will be automatically changed. Each complete turn of the drum at such times will be found registered by a jog in the record near the edge of the paper, and each such turn will signify a change in the adjustment equal to the circumference of the float drum in use. If such change takes place at the time of high water, the curve will be lowered and the scale readings diminished, but if it takes place at the time of low water, the curve will be raised and the scale readings increased.

TIDES: COMPARATIVE READINGS

Station: Seattle, Wash. Lat.
Tabulated by J. C. Date 7-2-62 Long.
Time Meridian 120°W Scale 1:24 Preliminary scale setting 8.0 feet

YEAR 1962		TIME OF STAFF READING		STAFF A	SCALE B	DIFFERENCE A-B	PHASE OF TIDE	REMARKS
mo.	day	hr.	min.	feet	feet	feet	*	
Jan.	2	13	46	16.05	15.70	0.35	F	
	3	14	01	16.50	16.10	0.40	F	
	4	10	10	12.40	11.95	0.45	R	
	4	10	27	12.55	12.20	0.35	R	
	5	12	03	13.80	13.40	0.40	R	
	8	15	47	14.55	14.00	0.55	R	
	9	15	58	12.45	12.05	0.40	R	
	10	16	03	10.90	10.40	0.50	R	
	11	13	55	9.85	9.45	0.40	F	
	12	16	08	8.10	7.75	0.35	F	
	15	15	41	11.05	10.60	0.45	F	
	16	11	02	14.70	14.20	0.50	R	
	17	11	46	13.85	13.50	0.35	R	
	18	15	09	15.30	14.80	0.50	F	
	19	12	40	13.15	12.80	0.35	R	
	23	10	42	12.65	12.15	0.50	F	
	24	10	50	13.45	12.90	0.55	F	
	25	11	35	13.10	12.80	0.30	F	
	26	10	14	15.55	15.20	0.35	F	
	29	14	50	9.80	9.20	0.60	F	
	31	12	27	15.15	14.75	0.40	R	
Feb.	1	13	10	15.30	14.80	0.50	R	

Reduction of scale-setting

Period: from Jan. 2 to Feb. 1

Sum of differences		9.50
Mean difference	(22)	0.43
Preliminary setting		8.00
Scale setting on staff		8.43
Constant for fixed datum		2.70
Setting for fixed datum		11.13

*Symbols used: H, high water; L, low water; R, rising tide; F, falling tide

FORM C&GS-2211 (10-62)
USCOMM-DC 8197-P62

FIGURE 25.—Form 2211 (front), Comparative readings.

211. In using Form 2211 the tide roll should be taken as the unit, regardless of the beginning or end of the calendar month, and each comparative note made by the observer on the tide roll should be included in the form.

HIGH AND LOW WATER TABULATIONS

212. Form 2211 (fig. 26) is designed for the tabulation of high and low waters, but for a very short series the high and low waters may be tabulated directly in Form 248 for the comparison of simultaneous observations (fig. 28). When Form 2211 is used the tabulations will in general be arranged by calendar months, but if the entire series of observations does not exceed 31 days the tabulations may be included on a single sheet of the form.

213. Times.—The times of the high and low waters are to be expressed in hours and tenths, the hours being numbered consecutively from 0 (midnight) to 23 (11 p.m.). A high or low water occurring at midnight (0^h) is taken as belonging to the day just beginning. Standard time is to be used consistently throughout the tabulations regardless of any temporary local use of daylight-saving time. In Form 2211 two lines are provided for each calendar day, and in general the morning tides will be entered on the first line and the afternoon tides on the second line for the day. Blank spaces should be left for tides missing because of lost record in order that inferred values may later be interpolated if desired; but when only a single high or low water actually occurs on any calendar day, the unused space may be filled with a dashed line.

214. In selecting the time of high or low water from the tide curve attention should be given to the general trend of the curve rather than the individual peaks arising from various causes. The aim should be to take the middle of a smooth arc covering an hour or more during the high or low water period. It is not necessary to actually draw such an arc, but the point at which a smoothed curve would have reached its maximum or minimum should be estimated as closely as possible. In determining the times of the high and low waters to the nearest tenth of an hour it may be found convenient to construct a small scale 1 inch long and divided into 10 equal parts for use between the hour marks on the curve. An experienced tabulator, however, will usually be able to estimate the tenth accurately without the use of such a scale.

215. Heights.—The high and low water heights are to be tabulated in feet and tenths and should refer to a uniform datum throughout the entire series of observations. In general the datum adopted for the tabulation is the zero of the tide staff as originally installed at the station, allowances being made for any subsequent change in elevation. However, any other datum may be adopted for the tabulations, but it is desirable that the datum be sufficiently low to avoid many negative readings.

216. When tabulating from a portable gage record, the heights may be taken directly from the scale of the profile paper provided the gage has been consistently kept adjusted to agree with the tide staff readings, but allowances must be made for any material variations from such an adjustment.

217. When tabulating from the standard gage record, a scale, graduated to conform to the scale of the record, is used. A line is ruled on this scale to correspond to the corrected scale setting as computed on Form 2211 (pars. 204–211). The scale is then moved along the record with this line in coincidence with the datum line on the record, the heights as read on the scale being referred directly to the desired datum. At any change in the adjustment of the automatic gage, the scale setting must be changed to accord with the new setting as computed in Form 2211.

HOURLY HEIGHT TABULATION

218. The hourly heights are tabulated in Form 362 (fig. 27). Unless otherwise directed these heights will be tabulated in yearly series, beginning with January 1 as the first day of each series. The days are to be entered consecutively, 7 days to the page and using both sides of the form, without regard to change in calendar months or to the time of changing the tide roll. If any part of the record is lost, blank spaces should be left for later interpolation of the missing tides. As stencils may be used in connection with this form, it is important that the tabulated heights be written within the spaces provided, these spaces being indicated by the printed decimal points.

FORM C&GS-2211
(10-62)

U.S. DEPT. OF COMMERCE
Coast and Geodetic Survey

TIDES: HIGH AND LOW WATERS

Station: Seattle, Wash. Lat. 47°36′N

Time Meridian 120° W Height Datum Long. 122°20′W

Highest Tide: Date 12 Height 20.3 feet

Year 1962 Month Jan. Lowest Tide: Date 6, 7, 9 Height 4.6 feet

DAY	MOON'S TRANSIT GMT	TIME OF HW	TIME OF LW	LUNITIDAL INTERVAL HW	LUNITIDAL INTERVAL LW	HEIGHT OF HW	HEIGHT OF LW
	(hours) (19.2)	hours	hours	hours	hours	feet	feet
1	7.6	1.5	6.3	(6.3)	(11.1)	15.4	13.6
	(20.0)	12.3	19.2	4.7	11.6	18.4	8.8
2	8.4	2.5	7.1	(6.5)	(11.1)	16.7	14.4
	(20.8)	12.9	20.1	4.5	11.7	19.1	8.4
3	9.2	3.5	8.1	(6.7)	(11.3)	18.3	15.7
	(21.6)	13.6	20.8	4.4	11.6	19.4	6.7
4	10.1	4.3	9.3	(6.7)	(11.7)	18.1	14.8
	(22.6)	14.5	21.5	4.4	11.4	18.7	5.8
5	11.1	5.1	10.1	(6.5)	(11.5)	19.0	15.1
	(23.6)	15.2	22.3	4.1	11.2	19.3	4.9
6	—	5.8	10.9	(6.2)	(11.3)	19.1	14.4
	12.1	16.1	22.8	4.0	10.7	19.1	4.6
7	(0.6)	6.2	11.7	(5.6)	(11.1)	19.6	14.3
	13.1	16.7	23.6	3.6	10.5	19.1	4.6
8	(1.6)	6.9	—	(5.4)	—	19.9	—
	14.0	17.5	12.4	3.5	(10.8)	18.4	13.8
9	(2.5)	7.6	0.3	(5.1)	10.3	19.6	4.6
	15.0	18.4	13.4	3.4	(10.9)	17.5	12.8
10	(3.5)	8.3	1.1	(4.8)	10.1	19.7	5.2
	15.9	19.4	14.3	3.5	(10.8)	17.1	12.2
11	(4.4)	9.1	1.9	(4.7)	10.0	20.1	6.8
	16.8	20.8	15.3	4.0	(10.9)	16.4	11.7
12	(5.2)	9.8	2.8	(4.6)	10.0	20.3	8.9
	17.6	21.9	16.5	4.3	(11.3)	16.0	10.9
13	(6.1)	10.4	3.8	(4.3)	10.2	20.0	10.8
	18.5	23.7	17.5	5.2	(11.4)	15.7	9.7
14	(6.9)	11.5	4.9	(4.6)	10.4	20.0	12.4
	19.3	—	18.5	—	(11.6)	—	9.2
15	(7.7)	1.5	6.2	6.2	10.9	16.3	13.8
	20.1	12.3	19.3	(4.6)	(11.6)	18.8	7.4
16	(8.6)	2.9	7.7	6.8	11.6	17.2	14.6
	21.0	13.2	20.3	(4.6)	(11.7)	18.7	7.1
17	(9.4)	3.6	8.9	6.6	11.9	18.1	14.7
	21.8	14.1	21.1	(4.7)	(11.7)	18.2	6.3

DAY	MOON'S TRANSIT GMT	TIME OF HW	TIME OF LW	LUNITIDAL INTERVAL HW	LUNITIDAL INTERVAL LW	HEIGHT OF HW	HEIGHT OF LW
	hours	hours	hours	hours	hours	feet	feet
18	(10.3)	4.5	9.8	6.7	12.0	18.5	14.6
	22.7	14.7	21.8	(4.4)	(11.5)	18.0	5.8
19	(11.1)	5.3	10.6	6.6	11.9	18.8	14.5
	23.5	15.7	22.3	(4.6)	(11.2)	18.2	6.3
20	(12.0)	5.8	11.3	6.3	11.8	19.1	14.3
	—	16.3	22.9	(4.3)	(10.9)	17.9	5.6
21	0.4	6.5	11.9	6.1	11.5	18.7	13.7
	(12.8)	17.1	23.6	(4.3)	(10.8)	17.4	5.9
22	1.1	7.1	—	6.0	—	18.6	—
	(13.5)	17.6	12.5	(4.1)	11.4	17.0	13.3
23	1.9	7.5	0.2	5.6	(10.7)	18.7	6.1
	(14.3)	18.3	13.2	(4.0)	11.3	16.8	13.0
24	2.6	8.1	0.7	5.5	(10.4)	19.0	7.1
	(15.0)	19.1	13.8	(4.1)	11.2	16.5	12.9
25	3.3	8.4	1.2	5.1	(10.2)	19.5	8.2
	(15.7)	19.8	14.5	(4.1)	11.2	16.0	12.7
26	4.0	8.9	1.8	4.9	(10.1)	19.2	9.2
	(16.4)	20.7	15.2	(4.3)	11.2	15.6	11.9
27	4.7	9.3	2.5	4.6	(10.1)	18.8	10.3
	(17.1)	21.9	16.2	(4.8)	11.5	14.7	10.8
28	5.5	9.9	3.3	4.4	(10.2)	18.4	11.4
	(17.8)	23.4	16.9	(5.6)	11.4	14.8	9.9
29	6.2	10.6	4.3	4.4	(10.5)	18.0	12.7
	(18.6)	—	17.8	—	11.6	—	9.0
30	7.0	0.9	5.6	(6.3)	(11.0)	15.5	13.9
	(19.4)	11.5	18.6	4.5	11.6	17.9	8.3
31	7.8	2.4	.6.9	(7.0)	(11.5)	16.5	14.6
	(20.3)	12.4	19.6	4.6	11.8	18.0	7.6
	.	.	.	60	60	60	60
Sums		.	.	302.3	666.4	1083.1	622.6
Means				5.04	11.11	18.05	10.38
Greenwich Interval				0.62	6.69	.	
Lunar Interval				8.44	8.44	7.67	Mn
Local Interval				4.60	10.67	14.22	MTL

	Mn	DHQ	DLQ		HHW	LLW
Observed	7.67	0.99	3.20		31	29
Factor	0.989	0.97	0.97	Sums	590.1	208.3
Corrected	7.59	0.96	3.10	Means	19.04	7.18
Tabulated by Winn					.	
Reduced by Winn					11.86	Gt
					13.11	(Drl)TL

REMARKS

FIGURE 26.—Form 2211 (back), High and low waters.

Form 362
Ed. May, 1929
U. S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

TIDES: HOURLY HEIGHTS

Station: *Seattle, Wash.* Year: *1962*

Observer: ______ Lat. ______ Long. ______

Time Meridian: *120° W* Height datum is ______ which is ______ ft. below B. M. ______

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Month and Day	mo. d. *Jan. 1*	d. *2*	d. *3*	d. *4*	d. *5*	d. *6*	d. *7*	Horizontal Sum
Day of Series								
Hour	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
0	15.0	15.0	14.4	11.8	9.9	7.7	5.9	.
1	15.4	16.2	16.4	14.3	12.9	10.4	8.3	.
2	15.4	16.6	17.7	16.1	15.4	13.5	11.9	.
3	15.0	16.6	18.2	17.7	17.5	16.1	15.0	.
4	14.5	16.2	18.2	18.0	18.7	17.9	17.3	.
5	13.9	15.6	17.8	18.0	18.9	18.9	18.8	.
6	13.7	14.8	17.0	17.4	18.7	19.0	19.5	.
7	13.8	14.4	16.0	16.2	17.9	18.3	19.3	.
8	14.6	14.6	15.7	15.2	16.7	17.2	18.4	.
9	15.8	15.4	15.9	14.9	15.6	15.8	17.3	.
10	16.9	16.5	16.6	15.0	15.2	14.8	15.8	.
11	18.0	17.6	17.7	15.8	15.5	14.5	14.6	.
Noon	18.4	18.7	18.6	17.0	16.5	15.1	14.5	.
13	18.2	19.0	19.3	17.9	17.7	16.3	15.4	.
14	17.2	18.8	19.3	18.6	18.7	17.5	16.7	.
15	15.6	17.7	18.5	18.6	19.2	18.8	18.0	.
16	13.4	15.7	16.8	17.4	19.0	19.1	18.9	.
17	11.2	13.1	14.1	15.1	17.4	18.3	19.0	.
18	9.7	11.2	11.1	12.7	14.9	16.7	17.8	.
19	9.0	9.1	9.0	9.6	11.6	13.9	15.7	.
20	9.2	8.5	7.2	7.4	8.4	10.5	13.0	.
21	10.0	9.1	6.9	5.8	6.2	7.6	9.4	.
22	11.5	10.3	7.7	6.0	5.1	5.4	6.7	.
23	13.4	12.4	9.6	7.7	5.6	4.7	4.9	.
Sum	.	.	.	.	.	.	.	.

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

Tabulated by ______ Date ______ Summed by ______ Date ______

FIGURE 27.—Form 362, Hourly heights.

TABLE 6.—*Arrangement of days for tabulating series of hourly tide heights*

Common year				Leap year			
Month	Page	Column	Day of series	Month	Page	Column	Day of series
Jan. 1	1	1	1	Jan. 1	1	1	1
Feb. 1	5	4	32	Feb. 1	5	4	32
Mar. 1	9	4	60	Mar. 1	9	5	61
Apr. 1	13	7	91	Apr. 1	14	1	92
May 1	18	2	121	May 1	18	3	122
June 1	22	5	152	June 1	22	6	153
July 1	26	7	182	July 1	27	1	183
Aug. 1	31	3	213	Aug. 1	31	4	214
Sept. 1	35	6	244	Sept. 1	35	7	245
Oct. 1	40	1	274	Oct. 1	40	2	275
Nov. 1	44	4	305	Nov. 1	44	5	306
Dec. 1	48	6	335	Dec. 1	48	7	336
Dec. 31	53	1	365	Dec. 31	53	2	366

219. As a check on the arrangement of the days in the form, table 6 gives the page, column of page, and day of series, for the first of each calendar month, when the series commences with January 1.

220. The tabulated hourly heights are to be expressed in feet and tenths and will be referred to the same datum as adopted for the high and low waters, the heights being scaled from the record in the same manner as described for the high and low water tabulations. The hourly heights are to be taken on the exact hour and allowance must be made for any time error in the record. This is especially necessary if the heights are to be used in an harmonic analysis of the observations.

INTERPOLATIONS

221. 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 enclosed in brackets to distinguish them from observed tides.

222. 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 mean of interpolating for missing high waters 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.

223. 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.

LUNITIDAL INTERVALS

224. A Greenwich lunitidal interval is the absolute difference in time between the transit of the moon over the meridian of Greenwich and the time of the occurrence of the following high or low water at any place, separate intervals being obtained for the high and low waters. A local lunitidal interval is the difference in time between the transit of the moon over the local meridian and the time of the following high or low water at a place on the same meridian. The Greenwich intervals have the advantage that they afford a direct means for obtaining the difference in the time of tide at different places.

225. Form 2211 (fig. 26) on which the high and low waters are tabulated provides for the computation of both high and low water lunitidal intervals. The Greenwich transits in hours and tenths, which will be furnished upon request or which may be taken from the American Ephemeris and Nautical Almanac, are entered in the column of "Moon's transits;" the lower transits are enclosed in parentheses to distinguish them from the upper transits.

226. From the time of each high and low water subtract the time of the first preceding moon's transit and enter the difference in the appropriate column of the form and on the same line as the tide from which it was obtained. In case the time of high or low water is nearly the same as that of the moon's transit, take the transit which precedes the tide by about 12 hours, but in no case must the same transit be used for two consecutive high waters or for two consecutive low waters. The lower transit of the moon applies to both high and low water, just the same as the upper transit does. When the time of the moon's transit is on one day and the following high or low water is on the next day the time of this tide must be increased by adding 24 hours before attempting to subtract the time of the transit. The high-water intervals will usually be approximately 6 hours greater or less than the low-water intervals, but the intervals for each phase of tide will usually agree among themselves within an hour or two. Intervals from the lower transits of the moon are to be indicated by parentheses. The high and low water intervals for the calendar month are summed separately and the means obtained to two decimal places.

227. In these computations the moon's transits are given in Greenwich time while the high and low waters are given in the standard time of the place of observations. To obtain the Greenwich lunitidal intervals it is therefore necessary to apply a correction corresponding to the time meridian of the place of observation, the correction to be added for west longitude and subtracted for east longitude. In figure 26, the mean uncorrected high and low water intervals for Seattle for the month represented are 5.04 hours and 11.11 hours respectively. As the time meridian for Seattle is 120° or 8 hours west, a correction of +8 hours must be applied to each of these intervals giving 13.04 hours and 19.11 hours, respectively, from which the lunar semidiurnal period of 12.42 hours may be rejected, leaving 0.62 hours and 6.69 hours, respectively, as the Greenwich high and low water lunitidal intervals from this particular series of observations.

228. Local lunitidal intervals.—To change from Greenwich to local intervals, it is necessary to apply a correction equal to the time required for the moon to pass from the meridian of Greenwich to the meridian of the place of observations. Table 7 has been prepared giving the correction for each degree of longitude from 1° to 180°, and the value for each minute of arc from 1′ to 60′ for interpolating between the whole degrees. In changing from Greenwich to local intervals, the tabular value is to be subtracted if the place of observation is in west longitude and added if in east longitude. In order that the local intervals may be positive and less than the half lunar day, the lunar semidiurnal period of 12.42 hours may be added or subtracted as desired. The longitude of Seattle, which is used as an example in figure 25, is 122°20′. In table 7 we find the corrections corresponding to 122° and 20′ to be 8.418 hours and 0.023 hours, respectively. Combining these we have 8.44 hours as the difference between Greenwich and local intervals at Seattle, and as Seattle is in west longitude this difference is to be subtracted from the Greenwich intervals. To avoid negative results, the Greenwich intervals are first increased by adding the semidiurnal period of 12.42 hours, after which the difference 8.44 hours is subtracted leaving 4.60 hours and 10.67 hours, respectively, as the local high and low water lunitidal intervals for these observations.

229. Method of checking intervals.—The mean unreduced intervals as obtained above may be conveniently checked by the following method:

(*a*) Sum times of moon's transits occurring during month. The number of transits will usually be two less than twice the number of days in the month; that is, 54 for a 28-day month, 56 for a 29-day month, 58 for a 30-day month, and 60 for a 31-day month. For the sake of uniformity, if the number of transits should be one greater than this, the last transit must be omitted from the sum and the last day be considered as having only the single value. On the other hand, if the number of transits should be one less than the usual number, the deficiency must be supplied by including the last transit of the preceding month. From the sum of the transits subtract the product of 24 hours by the sum of the numerals indicating the days of the month on which only a single transit occurs. For example, if single transits occur on the 3d and 17th of a month, the sum 20 is multi-

TABLE 7.—*Reduction of Greenwich intervals to local intervals*

Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction	Longitude	Correction
′	*Hour*	′	*Hour*	°	*Hour*	°	*Hour*	°	*Hour*	°	*Hour*	°	*Hour*	°	*Hour*
1	0. 001	31	0. 036	1	. 069	31	2. 139	61	4. 209	91	6. 279	121	8. 349	151	10. 420
2	. 002	32	. 037	2	. 138	32	2. 208	62	4. 278	92	6. 348	122	8. 418	152	10. 489
3	. 003	33	. 038	3	. 207	33	2. 277	63	4. 347	93	6. 417	123	8. 487	153	10. 558
4	. 005	34	. 039	4	. 276	34	2. 346	64	4. 416	94	6. 486	124	8. 556	154	10. 627
5	. 006	35	. 040	5	. 345	35	2. 415	65	4. 485	95	6. 555	125	8. 625	155	10. 696
6	. 007	36	. 041	6	. 414	36	2. 484	66	4. 554	96	6. 624	126	8. 694	156	10. 765
7	. 008	37	. 043	7	. 483	37	2. 553	67	4. 623	97	6. 693	127	8. 763	157	10. 834
8	. 009	38	. 044	8	. 552	38	2. 622	68	4. 692	98	6. 762	128	8. 832	158	10. 903
9	. 010	39	. 045	9	. 621	39	2. 691	69	4. 761	99	6. 831	129	8. 901	159	10. 972
10	. 012	40	. 046	10	. 690	40	2. 760	70	4. 830	100	6. 900	130	8. 970	160	11. 041
11	. 013	41	. 047	11	. 759	41	2. 829	71	4. 899	101	6. 969	131	9. 039	161	11. 110
12	. 014	42	. 048	12	. 828	42	2. 898	72	4. 968	102	7. 038	132	9. 108	162	11. 179
13	. 015	43	. 049	13	. 897	43	2. 967	73	5. 037	103	7. 107	133	9. 177	163	11. 248
14	. 016	44	. 051	14	. 966	44	3. 036	74	5. 106	104	7. 176	134	9. 246	164	11. 317
15	. 017	45	. 052	15	1. 035	45	3. 105	75	5. 175	105	7. 245	135	9. 315	165	11. 386
16	. 018	46	. 053	16	1. 104	46	3. 174	76	5. 244	106	7. 314	136	9. 384	166	11. 455
17	. 020	47	. 054	17	1. 173	47	3. 243	77	5. 313	107	7. 383	137	9. 453	167	11. 524
18	. 021	48	. 055	18	1. 242	48	3. 312	78	5. 382	108	7. 452	138	9. 522	168	11. 593
19	. 022	49	. 056	19	1. 311	49	3. 381	79	5. 451	109	7. 521	139	9. 591	169	11. 662
20	. 023	50	. 058	20	1. 380	50	3. 450	80	5. 520	110	7. 590	140	9. 660	170	11. 731
21	. 024	51	. 059	21	1. 449	51	3. 519	81	5. 589	111	7. 659	141	9. 729	171	11. 800
22	. 025	52	. 060	22	1. 518	52	3. 588	82	5. 658	112	7. 728	142	9. 798	172	11. 869
23	. 026	53	. 061	23	1. 587	53	3. 657	83	5. 727	113	7. 797	143	9. 867	173	11. 938
24	. 028	54	. 062	24	1. 656	54	3. 726	84	5. 796	114	7. 866	144	9. 936	174	12. 007
25	. 029	55	. 063	25	1. 725	55	3. 795	85	5. 865	115	7. 935	145	10. 005	175	12. 076
26	. 030	56	. 064	26	1. 794	56	3. 864	86	5. 934	116	8. 004	146	10. 074	176	12. 145
27	. 031	57	. 066	27	1. 863	57	3. 933	87	6. 003	117	8. 073	147	10. 143	177	12. 214
28	. 032	58	. 067	28	1. 932	58	4. 002	88	6. 072	118	8. 142	148	10. 212	178	12. 283
29	. 033	59	. 068	29	2. 001	59	4. 071	89	6. 141	119	8. 211	149	10. 281	179	12. 352
30	. 035	60	. 069	30	2. 070	60	4. 140	90	6. 210	120	8. 280	150	10. 351	180	12. 421

plied by 24, and the product 480 hours is then subtracted from the sum of the transits. Designate the remainder by T, which may be either positive or negative.

(*b*) Sum separately the times of high and low waters, limiting the number of items in each case to two less than twice the number of days in the month, following the method described for the summation of the moon's transits. From the sum of the time of the high waters subtract the product of 24 hours by the sum of the numerals indicating the days of the month on which only a single high water occurred, and from the sum of the times of the low water subtract the product of 24 hours by the sum of the numerals indicating the days of the month on which only a single low water occurred. Designate these results by H and L, respectively.

(*c*) Find the differences (H−T) and (L−T) and divide by the number of items included in each summation, which should be twice the number of days in the month less two. Such multiples of 12.42 hours may be applied or rejected from the means as may be necessary to reduce them to positive values of less than 12.42 hours. The results obtained should check very closely with unreduced means as obtained directly from the individual intervals, although at times there may be a small difference in the second decimal place.

230. Example.—This method for checking the mean intervals is illustrated in the accompanying example for Seattle, Wash., month of January 1962—the intervals having been computed in the regular manner in figure 26. Since a 31-day month is used, the number of items included in each summation must be 60.

Example of method for checking mean intervals

Sum of times of 60 transits, January 1962	721.7
24×(6+22), single transits occurring Jan. 6 and 20	624.0
Difference (T)	97.7
Sum of times of 60 high waters, January 1962	686.8
24×(14+29), single high waters occurring Jan. 14 and 29	1,032.0
Difference (H)	−345.2
Sum of times of 60 low waters, January 1962	739.0
24×(8+22), single low waters occurring Jan. 8 and 22	720.0
Difference (L)	19.0

(H–T)÷60=−442.9÷60=−7.38 hours, high-water interval.
(L–T)÷60=−78.7÷60=−1.31 hours, low-water interval.

Applying the tidal period 12.42 hours to each of the negative intervals in the example, we have 5.04 and 11.11 hours, respectively, for the uncorrected (local) high and low water intervals. It will be noted that these results agree exactly with those obtained in figure 26 by the regular computation. An exact agreement is not always possible, but the results usually will agree within 1 or 2 hundredths of an hour.

231. Lunitidal intervals from Form 248.—For a short series of observations the lunitidal intervals can be computed in Form 248 (fig. 28) from a comparison with simultaneous observations at a standard station suitably situated. The form provides for the computation of the local intervals and contains an explanation of its use on the back. Table 7 may be used to obtain the correction for difference in longitude. The Greenwich lunitidal intervals at the subordinate station may be obtained by the simple application of the mean differences in the time of high and low water to the corresponding Greenwich intervals at the standard station.

HEIGHT REDUCTIONS

232. Form 2211 on which are tabulated the high and low waters, provides for the regular computation each month of certain tidal planes and ranges. Mean high water (*HW*) and mean low water (*LW*) for each month are obtained by summing all the high waters and all the low waters and dividing by the number of observations, the latter being indicated by small figures just above the sum. The means, written below the sums, should be carried to two decimal places. The mean range (*Mn*) is obtained by subtracting the mean of the low waters from the mean of the high waters. The mean tide level (*MTL*), which is also known as half-tide level, is obtained by taking the half sum of the mean of the high waters and the mean of the low waters.

233. For stations on the Pacific coast, the means of the higher high waters and of the lower low waters and the diurnal inequalities should also be obtained. The higher of the two high waters and the lower of the two low waters of each day of the month are first indicated by a check mark. If the two high or two low waters on the same day are equal, either may be selected as the higher high or lower low water. When only one high or one low water occurs on a calendar day, by reason of one of the tides having occurred after midnight and therefore on the next calendar day, the single tide is to be checked if the tide just above it is unchecked; otherwise it should not be checked. If, however, the tide has become diurnal and only one high and one low water occur during the tidal day, these should both be checked. The checked heights are to be summed separately for the high and low waters, the sums being entered in the spaces provided, with the number of observations written above in small figures. The mean of the higher high waters (*HHW*) and the mean of the lower low waters (*LLW*) are then obtained, each result being carried to two decimal places.

234. The diurnal high water inequality (*DHQ*) is obtained by subtracting the mean of all high waters from the mean of the higher high waters, and the diurnal low water inequality (*DLQ*) is

FORM 248
(1-28-59)
USCOMM-DC 27247

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

TIDES : Comparison of Simultaneous Observations

(A) Subordinate station *Port Susan, Wash.* Lat. *48° 8' N* Long. *122° 22' W*
(B) Standard station *Seattle, Wash.* Lat. *47° 36' N* Long. *122° 20' W*
Chief of party .... Time Meridian: (A) *120° W* (B) *120° W*

DATE. Year. *1962*	(A) STATION. Time of—		(B) STATION. Time of—		(A)−(B) Time difference.		(A) STATION. Height of—		(B) STATION. Height of—		(A)−(B) Height difference.	
	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.
Mo. D.	Hours.	Hours.	Hours.	Hours.	Hours.	Hours.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Oct. 1	6.5	0.1	6.4	0.1	0.1	0.0	11.0	2.6	18.1	9.4	−7.1	−6.8
	18.2	12.2	18.4	12.3	−0.2	−0.1	11.3	4.5	18.5	11.5	−7.2	−7.0
2	7.2	0.3	7.1	0.5	0.1	−0.2	11.2	2.3	18.4	9.2	−7.2	−6.9
	18.6	12.9	18.6	12.9	0.0	0.0	11.5	5.7	18.7	12.8	−7.2	−7.1
3	7.9	1.0	8.0	1.0	−0.1	0.0	11.0	2.3	18.1	9.1	−7.1	−6.8
	19.2	13.6	19.3	13.6	−0.1	0.0	10.7	6.0	17.8	13.0	−7.1	−7.0
4	9.3	1.6	8.8	1.8	0.5	−0.2	10.7	2.1	17.8	8.7	−7.1	−6.6
	20.0	14.5	19.9	14.3	0.1	0.2	10.1	6.8	17.3	13.8	−7.2	−7.0
5	10.2	2.7	10.2	2.5	0.0	0.2	10.6	2.3	17.6	8.4	−7.0	−6.1
	20.5	15.6	20.5	15.4	0.0	0.2	9.9	7.6	17.0	14.5	−7.1	−6.9
6	11.2	3.2	11.4	3.4	−0.2	−0.2	10.8	1.7	17.9	8.6	−7.1	−6.9
	21.5	17.0	21.6	16.7	−0.1	0.3	9.3	7.8	16.3	14.7	−7.0	−6.9
7	12.8	4.4	12.8	4.5	0.0	−0.1	11.9	1.7	18.9	8.5	−7.0	−6.8
	22.5	18.7	22.8	19.0	−0.3	−0.3	9.4	8.7	16.3	15.5	−6.9	−6.8
Sums							7 HHW. 77.8	7 HLW. 47.1	7 HHW. 127.5	7 HLW. 95.8	7 HHW. −49.7	7 HLW. −48.7
Means							11.11	6.73	18.21	13.69	−7.10	−6.96
Sums					14 −0.2	14 −0.2	7 LHW. 71.6	7 LLW. 15.0	7 LHW. 121.2	7 LLW. 61.9	7 LHW. −49.6	7 LLW. −46.9
Means					−0.01	−0.01	10.23	2.14	17.31	8.84	−7.08	−6.70

	HW.	LW.	
(1) =	−0.01	−0.01	= Mean difference in time of high and low water respectively.
(2) =	0.00	0.00	= Correction for difference in longitude. (Table on back of form.)
(3) =	−0.01	−0.01	= (1)+(2) = Mean difference in high and low water intervals, respectively.

Feet.

(4) = *11.11* = Mean HHW height at (A).
(5) = *6.73* = Mean HLW height at (A).
(6) = *10.23* = Mean LHW height at (A).
(7) = *2.14* = Mean LLW height at (A).
(8) = *0.88* = (4) − (6) = 2DHQ at (A).
(9) = *4.59* = (5) − (7) = 2DLQ at (A).
(10) = *10.67* = ½[(4)+(6)] = Mean HW height at (A).
(11) = *4.44* = ½[(5)+(7)] = Mean LW height at (A).
(12) = *6.23* = (10) − (11) = Mn at (A).
(13) = *7.56* = ½[(10)+(11)] = MTL at (A).

(14) = *−7.10* = Mean HHW difference.
(15) = *−6.96* = Mean HLW difference.
(16) = *−7.08* = Mean LHW difference.
(17) = *−6.70* = Mean LLW difference.
(18) = *−0.02* = (14) − (16) = 2DHQ difference.
(19) = *−0.26* = (15) − (17) = 2DLQ difference.
(20) = *−7.09* = ½[(14)+(16)] = Mean HW difference.
(21) = *−6.83* = ½[(15)+(17)] = Mean LW difference.
(22) = *−0.26* = (20) − (21) = Mn difference.
(23) = *−6.96* = ½[(20)+(21)] = MTL difference.

(24) = *0.960* = (12) ÷ [(12) − (22)] = Mn ratio.
(25) = *0.978* = (8) ÷ [(8) − (18)] = DHQ ratio.
(26) = *0.946* = (9) ÷ [(9) − (19)] = DLQ ratio.

Results from comparison of Stations A and B.	Length of Series.	HWI.	LWI.	MTL.	Mn.	DHQ.	DLQ.
		Hours.	Hours.	Feet.	Feet.	Feet.	Feet.
Accepted values for standard station, from	*1941-1959*	4.52	10.69	14.29	7.6	0.9	2.8
Differences and ratios: (3), (23), (24), (25), (26)		−0.01	−0.01	−6.96	×0.96	×0.978	×0.946
Corrected values for subordinate station		4.51	10.68	7.33	7.30	0.88	2.65

Mean LW on staff at subordinate station = MTL − ½Mn = *3.68* feet.
Mean LLW on staff at subordinate station = MTL − ½Mn − DLQ = *1.03* feet.

Computed by *Winn*, *9-6-63* (Date.) Verified by ...., ... (Date.)

FIGURE 28.—Form 248, Comparison of simultaneous observations.

obtained by subtracting the mean of the lower low waters from the mean of all low waters.

235. Correction for longitude of moon's node.—There is a long-period variation in the range of tide due to changes in the inclination of the moon's orbit to the Equator. When the longitude of the moon's node is 0° the inclination of the orbit to the Equator is at a maximum and the average range of the four tides of the day is less than usual; and when the longitude of the moon's node is 180° the inclination is at a minimum and this range of tide is greater than usual. The time required for the longitude of the moon's node to pass through the cycle of 360° is approximately 19 years. In addition to the variations caused by changes in the longitude of the moon's node, the diurnal inequalities are subject to variations from month to month caused by changes in the declination of the sun. Because of these variations certain factors are necessary in order to reduce to mean values the ranges and inequalities obtained from short series of observations. At the primary tide stations, the correction need not be applied to the results for each individual month, it being sufficient to correct the annual means as needed If the series of observations extends over a period of 19 years, the factors are unnecessary.

236.—Table 8 contains the factor $F(Mn)$ for reducing the observed range of tide to its mean value and table 9 the factor F_1 for reducing the

TABLE 8.—*Factor F (Mn) for reducing observed range of tide to its mean value*

$2(DHQ+DLQ)$ / Mn / Year	0.0 to 0.2	0.3 to 0.4	0.5 to 0.6	0.7 to 0.8	0.9 to 1.0	1.1 to 1.2	1.3 to 1.4	1.5 to 1.6	1.7 to 1.8	1.9 to 2.0
1961	0. 974	0. 975	0. 977	0. 979	0. 982	0. 985	0. 988	0. 993	0. 998	1. 005
1962	. 979	. 981	. 982	. 984	. 986	. 989	. 992	. 995	. 999	1. 004
1963	. 989	. 989	. 989	. 990	. 992	. 994	. 996	. 998	1. 000	1. 002
1964	. 999	. 999	. 999	. 999	. 999	. 999	1. 000	1. 000	1. 000	1. 000
1965	1. 009	1. 009	1. 008	1. 007	1. 006	1. 005	1. 004	1. 002	1. 000	. 998
1966	1. 018	1. 017	1. 016	1. 014	1. 012	1. 010	1. 007	1. 005	1. 001	. 996
1967	1. 025	1. 024	1. 022	1. 020	1. 017	1. 015	1. 011	1. 006	1. 001	. 996
1968	1. 029	1. 028	1. 026	1. 023	1. 020	1. 017	1. 013	1. 008	1. 001	. 995
1969	1. 030	1. 029	1. 027	1. 023	1. 020	1. 017	1. 013	1. 008	1. 001	. 995
1970	1. 027	1. 026	1. 024	1. 022	1. 019	1. 016	1. 012	1. 007	1. 001	. 996
1971	1. 022	1. 021	1. 019	1. 017	1. 015	1. 013	1. 009	1. 005	1. 001	. 996
1972	1. 013	1. 013	1. 012	1. 011	1. 009	1. 008	1. 006	1. 003	1. 001	. 998
1973	1. 004	1. 004	1. 004	1. 003	1. 002	1. 002	1. 001	1. 001	1. 000	. 999
1974	. 994	. 993	. 993	. 994	. 996	. 997	. 998	. 999	1. 000	1. 001
1975	. 983	. 984	. 985	. 987	. 989	. 992	. 994	. 996	. 999	1. 003
1976	. 976	. 978	. 979	. 981	. 983	. 986	. 989	. 994	. 999	1. 004
1977	. 972	. 973	. 975	. 977	. 980	. 984	. 988	. 993	. 998	1. 005
1978	. 970	. 971	. 973	. 975	. 978	. 983	. 987	. 992	. 999	1. 006
1979	. 970	. 972	. 974	. 976	. 979	. 983	. 987	. 992	. 999	1. 006
1980	. 976	. 977	. 978	. 980	. 983	. 986	. 989	. 994	. 999	1. 004
1981	. 983	. 984	. 984	. 986	. 988	. 990	. 993	. 996	. 999	1. 003
1982	. 993	. 993	. 993	. 994	. 995	. 996	. 998	. 999	1. 000	1. 002
1983	1. 003	1. 003	1. 003	1. 002	1. 002	1. 002	1. 001	1. 000	1. 000	. 999
1984	1. 012	1. 012	1. 011	1. 010	1. 008	1. 007	1. 005	1. 003	1. 001	. 998
1985	1. 021	1. 020	1. 019	1. 017	1. 015	1. 012	1. 009	1. 005	1. 001	996
1986	1. 027	1. 026	1. 024	1. 022	1. 019	1. 016	1. 012	1. 007	1. 001	. 996
1987	1. 030	1. 029	1. 027	1. 023	1. 020	1. 017	1. 013	1. 008	1. 001	. 995
1988	1. 029	1. 028	1. 026	1. 023	1. 020	1. 017	1. 013	1. 008	1. 001	. 995
1989	1. 025	1. 024	1. 022	1. 020	1. 017	1. 015	1. 011	1. 006	1. 001	. 996
1990	1. 019	1. 018	1. 017	1. 015	1. 013	1. 012	1. 008	1. 005	1. 001	. 996
1991	1. 010	1. 010	1. 009	1. 008	1. 006	1. 005	1. 004	1. 002	1. 000	. 998
1992	1. 000	1. 000	1. 000	1. 000	1. 000	1. 000	1. 000	1. 000	1. 000	1. 000
1993	. 990	. 990	. 996	. 992	. 993	. 995	. 997	. 998	1. 000	1. 001
1994	. 980	. 981	. 982	. 984	. 986	. 989	. 992	. 995	. 999	1. 004
1995	. 974	. 976	. 977	. 979	. 982	. 985	. 989	. 993	. 998	1. 005
1996	. 970	. 972	. 974	. 976	. 979	. 983	. 987	. 992	. 999	1. 006
1997	. 971	. 972	. 974	. 976	. 979	. 983	. 987	. 992	. 999	1. 006
1998	. 972	. 974	. 976	. 978	. 981	. 984	. 988	. 993	. 998	1. 005
1999	. 977	. 979	. 980	. 982	. 984	. 987	. 990	. 994	. 999	1. 004
2000	. 986	. 987	. 988	. 989	. 991	. 993	. 997	. 997	1. 000	1. 002

diurnal inequalities DHQ and DLQ to their mean values. These tables cover the years 1961 to 2000, inclusive, and are based upon tables 6, 14, and 32 of Harris' Manual of Tides. Similar tables covering the years 1891 to 1950, inclusive, will be found in Special Publication No. 135, Tidal Datum Planes. The factor $F(Mn)$ was computed for the middle of each calendar year, but as the factor changes very slowly, the tabular value may be used for any month in the year without material error. The factor F_1 was computed for the middle of each calendar month. The table includes also the mean of the monthly factors for each year which may be taken as the factor for correcting the yearly inequalities to their mean values.

237. The factor $F(Mn)$ depends not only upon the year of observaton but also upon the relation of the diurnal to the semidiurnal wave in the locality, this relation being expressed approximately by the formula $\frac{2(DHQ+DLQ)}{Mn}$, or if harmonic constants are available by the ratio $\frac{K_1+O_1}{M_2}$. For stations along the Atlantic coast of the United States from Maine to Florida this relation is generally small, and, if not already computed, may be assumed to be less than 0.2 without material error. For stations along the Gulf of Mexico from Key West to the Rio Grande the mean range of tide is very small and the correcting factor may be omitted. For stations on the Pacific coast the value of the ratio may be computed either from the inequalities or from the harmonic constants but need be carried to only one decimal place. If this ratio is larger than 2.0, no correction need be applied to the mean range.

TABLE 9.—*Factor F_1 for correcting diurnal inequalities, DHQ and DLQ*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1961	1.00	1.21	1.45	1.31	1.05	0.94	0.98	1.18	1.43	1.28	1.02	0.92	1.148
1962	.97	1.16	1.38	1.25	1.01	.91	.94	1.12	1.35	1.21	.98	.89	1.098
1963	.93	1.10	1.30	1.18	.96	.87	.90	1.07	1.27	1.14	.93	.85	1.042
1964	.89	1.04	1.22	1.11	.92	.83	.86	1.01	1.19	1.08	.89	.82	.988
1965	.85	.99	1.15	1.06	.88	.80	.83	.97	1.13	1.03	.86	.79	.945
1966	.82	.95	1.10	1.02	.85	.78	.81	.94	1.09	1.00	.84	.77	.914
1967	.80	.93	1.07	.99	.83	.76	.79	.91	1.06	.98	.82	.76	.892
1968	.79	.91	1.05	.97	.82	.76	.78	.90	1.05	.96	.81	.75	.879
1969	.78	.90	1.04	.96	.82	.75	.78	.90	1.04	.97	.81	.75	.875
1970	.78	.91	1.05	.97	.82	.76	.79	.91	1.06	.98	.82	.76	.884
1971	.79	.92	1.06	.99	.84	.77	.80	.93	1.09	1.00	.84	.78	.901
1972	.81	.95	1.10	1.02	.86	.79	.82	.96	1.13	1.04	.87	.80	.929
1973	.84	.98	1.15	1.06	.89	.82	.85	1.00	1.19	1.09	.90	.83	.967
1974	.87	1.03	1.21	1.12	.93	.85	.89	1.05	1.26	1.15	.94	.87	1.014
1975	.91	1.09	1.29	1.19	.98	.89	.93	1.11	1.34	1.22	.99	.90	1.070
1976	.95	1.14	1.38	1.26	1.02	.92	.97	1.17	1.42	1.28	1.03	.94	1.123
1977	99	1.20	1.45	1.31	1.06	.95	1.00	1.21	1.48	1.33	1.06	.96	1.167
1978	1.01	1.23	1.49	1.34	1.08	.96	1.01	1.22	1.50	1.34	1.06	.96	1.183
1979	1.01	1.22	1.48	1.33	1.07	.96	1.00	1.20	1.47	1.31	1.04	.94	1.169
1980	.99	1.19	1.43	1.29	1.03	.93	.97	1.16	1.40	1.25	1.00	.91	1.129
1981	.95	1.14	1.35	1.22	.99	.89	.93	1.10	1.32	1.18	.96	.87	1.075
1982	.91	1.08	1.27	1.15	.95	.86	.89	1.04	1.24	1.12	.92	.84	1.022
1983	.87	1.02	1.19	1.09	.90	.82	.85	.99	1.17	1.06	.88	.80	.970
1984	.84	.98	1.13	1.04	.87	.79	.82	.95	1.11	1.02	.85	.78	.932
1985	.81	.94	1.09	1.00	.84	.77	.80	.93	1.08	.99	.83	.76	.903
1986	.80	.92	1.06	.98	.83	.76	.78	.91	1.05	.97	.82	.75	.886
1987	.78	.91	1.04	.97	.82	.75	.78	.90	1.04	.96	.81	.75	.876
1988	.78	.90	1.04	.96	.82	.75	.78	.90	1.05	.97	.82	.76	.878
1989	.79	.91	1.05	.98	.83	.76	.79	.92	1.07	.98	.83	.77	.890
1990	.80	.93	1.08	1.00	.84	.78	.81	.94	1.10	1.01	.85	.78	.910
1991	.82	.96	1.12	1.03	.87	.80	.83	.98	1.15	1.06	.88	.81	.942
1992	.85	1.00	1.17	1.08	.90	.83	.86	1.02	1.21	1.11	.92	.84	.982
1993	.89	1.05	1.24	1.14	.95	.86	.90	1.07	1.29	1.18	.96	.88	1.034
1994	.93	1.11	1.32	1.21	.99	.90	.94	1.13	1.38	1.24	1.01	.92	1.090
1995	.97	1.17	1.41	1.28	1.04	.94	.98	1.18	1.45	1.30	1.04	.95	1.142
1996	1.00	1.21	1.47	1.33	1.07	.96	1.00	1.22	1.50	1.34	1.06	.96	1.177
1997	1.01	1.23	1.49	1.34	1.08	.96	1.01	1.22	1.49	1.33	1.06	.96	1.182
1998	1.01	1.21	1.46	1.32	1.06	.95	.99	1.19	1.44	1.29	1.03	.93	1.157
1999	.98	1.17	1.40	1.26	1.02	.92	.95	1.14	1.37	1.23	.99	.90	1.111
2000	.94	1.11	1.32	1.20	.97	.88	.91	1.08	1.28	1.16	.94	.86	1.054

238. Comparison of simultaneous observations.—For a short series of observations, reduction by comparison of simultaneous observations is generally the best method provided there is a suitable standard tide station from which the necessary simultaneous data may be obtained. For this purpose the standard station should be so situated that the effects of meteorological conditions may be expected to be similar to those at the station for which the results are sought. A reference to the use of this method in computing lunitidal intervals has already been made in paragraph 231. The process is especially valuable in the reduction of the heights of the tide. For observations covering a period of less than 1 month, Form 248 is generally used, but for series extending over longer periods, Form 657 for the comparison of monthly means will be found more convenient. The latter form is self-explanatory.

239. Form 248 (fig. 28) is designed to bring out the individual differences between the tides at the two stations compared, the accuracy of the resulting means depending somewhat upon the uniformity of these differences. If any single difference varies greatly from the apparent average of its group, and an examination of the original data fails to show an error, the difference should be rejected from the sum and the fact indicated by encircling the rejected value. For stations where the diurnal inequalities are desired, the higher high waters, lower high waters, higher low waters, lower low waters, and their differences are summed and averaged separately; and all the spaces in the bottom portion of Form 248 are filled in. If the diurnal inequalities are not needed, as is generally the case for stations on the Atlantic coast, all high waters and corresponding differences may be summed and averaged without distinction and likewise all low waters and differences, the notations at the bottom of the columns being corrected to read *HW* and *LW*. The mean high and low water heights for (A) station will then be entered directly as items (10) and (11) in the form, and the mean differences from the last two columns as items (20) and (21). The form will then be completed as far as necessary to obtain the results desired.

TIDAL DATUMS

240. A tidal datum is a plane or surface which may be defined by the tides and which is used as a reference for heights or depths. The principal tidal datums now in use by this Survey are (1) *mean sea level*, the datum of the first-order level net and in general use as a reference for heights; (2) *mean low water*, the datum of soundings on charts of the Atlantic coast of the United States; (3) *mean lower low water*, the datum of soundings on charts of the Pacific coast of the United States, Alaska, Hawaii, and the Philippine Islands; and (4) *mean low water springs*, the datum for the Pacific coast of the Canal Zone and in more or less general use as the datum of charts published by foreign countries.

241. Mean sea level.—Mean sea level may be defined as the average height of the sea for all stages of the tide. It is obtained by averaging the hourly heights as tabulated in Form 362. The heights in this form are summed both vertically and horizontally, and the total page sum covering 7 days of record is entered in the lower right corner of the page. For a continuing series of observations, the mean for each calendar month is obtained by combining all the daily sums for the month and dividing by the total number of hours as indicated at the bottom of the form for months of different lengths. The monthly mean carried to two decimal places is entered at the bottom of the sheet containing the record for the last day of the month.

242. Form 472a provides for the compilation of the monthly means and the computation of the yearly means from the same. It also provides for an accumulative mean combining all yearly means up to date. The precision of an independent determination of mean sea level depends largely upon the number of years of observations. In general a series covering not less than 3 years should be obtained for an independent determination of the datum. For a shorter series of observations, the sea level as directly obtained should be reduced by comparison with simultaneous observations provided there is a control tide station suitably located from which the necessary data for the comparison may be obtained. Form 657 for the comparison of monthly means may be used for this reduction.

243. The name "mean sea level" should be applied only to the datum derived from observations taken on the open coast or in adjacent waters having free access to the sea. The average of the hourly heights taken in a river is called "mean river level" and is higher than the mean sea level because of the river slope. The plane of half-tide level derived from the high and low waters approximates very closely to the mean sea level or mean river level determined from the hourly heights. For any one station the difference remains nearly constant from month to month and affords a convenient check on the work when both planes are computed.

244. Mean low water.—Mean low water is generally adopted as a datum for hydrographic operations along the Atlantic coast of the United States. It may be defined as the mean of all low waters over a considerable period of time. The datum may be derived independently from a long series of observations, but from a short series can best be obtained from a comparison of simultaneous observations at a nearby standard station (pars. 238–239). For the longer series, the range of tide is corrected for the longitude of the moon's node (pars. 235–237), and one-half of the corrected range is then subtracted from the half-tide level to obtain the corrected mean low water. When reduction is made by a comparison of simultaneous observations both range and half-tide level are subject to correction, and the corrected mean low water is obtained by subtracting one-half the corrected range from the corrected half-tide level.

245. Mean lower low water.—This datum is generally adopted for hydrographic operations along the Pacific coast of the United States and may be defined as the mean of the lower of the two low waters of each day over a considerable period of time. When determined independently from a long series of observations, the mean range and diurnal low water inequality must be corrected for the longitude of the moon's node as explained in paragraphs 235–237. The corrected mean lower low water is then obtained by subtracting from the half-tide level height the sum of the corrected half range and the corrected diurnal low water inequality. For a short series of observations, the mean lower low water datum may be computed by means of Form 248 for the comparison of simultaneous observations (pars. 240–241).

246. Mean low water springs.—While datums approximating this plane have been rather generally used by foreign countries, its use by this Bureau is limited to the Pacific coast of the Panama Canal Zone. The datum may be defined as the mean of the low waters of the spring tides which occur within a day or two after the moon is new or full, and may be obtained by subtracting one-half the spring range of tide from the half-tide level. Because of the limited use of this datum it is not regularly obtained at all tide stations. The most satisfactory method of obtaining the spring range of tide is from an harmonic analysis, an involved process not adapted to field use. From such analyses it has been found that the ratio of spring range to mean range is fairly constant over wide areas. For Balboa, Canal Zone, the ratio is 1.26, and this factor may be applied without material error to the corrected mean range at any station on the Pacific coast of the Canal Zone to obtain the spring range of tide. Therefore to obtain the datum of mean low water springs at any station in this vicinity, first compute the corrected mean range and half-tide level by methods already described. The datum may then be expressed by the formula "Mean low water springs = half-tide level $-$ 0.63 $\times$ mean range of tide." The factor may vary in other locations.

TIDE REDUCERS FOR SOUNDINGS

247. After the datum or plane of reference has been derived, the tide reducers for soundings are obtained by subtracting the reading corresponding to the datum from the recorded heights of the tide taken at intervals during the time of the soundings. The differences will in general be positive except when the tide falls below the datum. The positive differences are to be subtracted from the soundings, but when entered in the sounding books, the minus sign is usually omitted for convenience. When the tide falls below the datum, the difference is to be added to the soundings and this difference must always be prefixed by a plus sign when entered in the sounding record. Detailed instructions pertaining to the application of the tide reducers to the soundings will be found in the Hydrographic Manual (Publication 20–2).

248. 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-gage or the portable automatic tide-gage 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-gage 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.

249. 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-gage records the vertical lines may usually be omitted. The horizontal lines are numbered upward from the bottom of the scale +3, +2, +1, −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 $x-y-0.7$ 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-gage record the value of "y" is the corrected scale setting as computed on Form 2211 (fig. 25). For the portable tide-gage 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.

250. The graph is laid over the marigram with the red horizontal line in coincidence with the datum line if a standard gage record, or with the scale zero of the portable gage 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.

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

252. An example of a graphic scale is given in figure 29. For the standard-gage 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 datum line of the marigram when the scale is in use. For the portable gage 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.

253. Time allowance.—When there is much difference in the time or height of the tide at the place of sounding and at the tide gage, 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 time of the tide:

$$v=\sqrt{gd}=5.67\sqrt{d} \text{ feet per second,}$$

when $g=32.17$ feet per second and d=depth of water for the average cross section between stations, in feet.

In order to convert feet per second into nautical miles per hour, multiply by $\frac{3600}{6080}=0.592$, and we have $v=3.36\sqrt{d}$ nautical miles per hour.

The time required for the tide wave in minutes per nautical mile is

$$t=\frac{6080}{60\times 5.672\sqrt{d}}=\frac{17.87}{\sqrt{d}},$$

or in minutes per statute mile

$$t=\frac{5280}{60\times 5.672\sqrt{d}}=\frac{15.51}{\sqrt{d}}.$$

Table 10 is provided for convenience in estimating the travel times of tide waves between stations.

TABLE 10.—*Travel time for tide wave* [1]

Depth	1 nautical mile	1 statute mile
Fathoms	*Minutes*	*Minutes*
1	7. 3	6. 3
2	5. 2	4. 5
3	4. 2	3. 7
4	3. 6	3. 2
5	3. 3	2. 8
6	3. 0	2. 6
7	2. 8	2. 4
8	2. 6	2. 2
9	2. 4	2. 1
10	2. 3	2. 0
15	1. 9	1. 6
20	1. 6	1. 4
30	1. 3	1. 2
40	1. 2	1. 0
50	1. 0	0. 9
60	0. 9	0. 8

[1] Based on average cross-section depth between stations.

254. For offshore areas where the continental shelf is broad and the tidal wave approaches parallel to the coast the tide will arrive offshore 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 using table 10 which gives the time required for the tide wave to travel at different depths.

255. 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

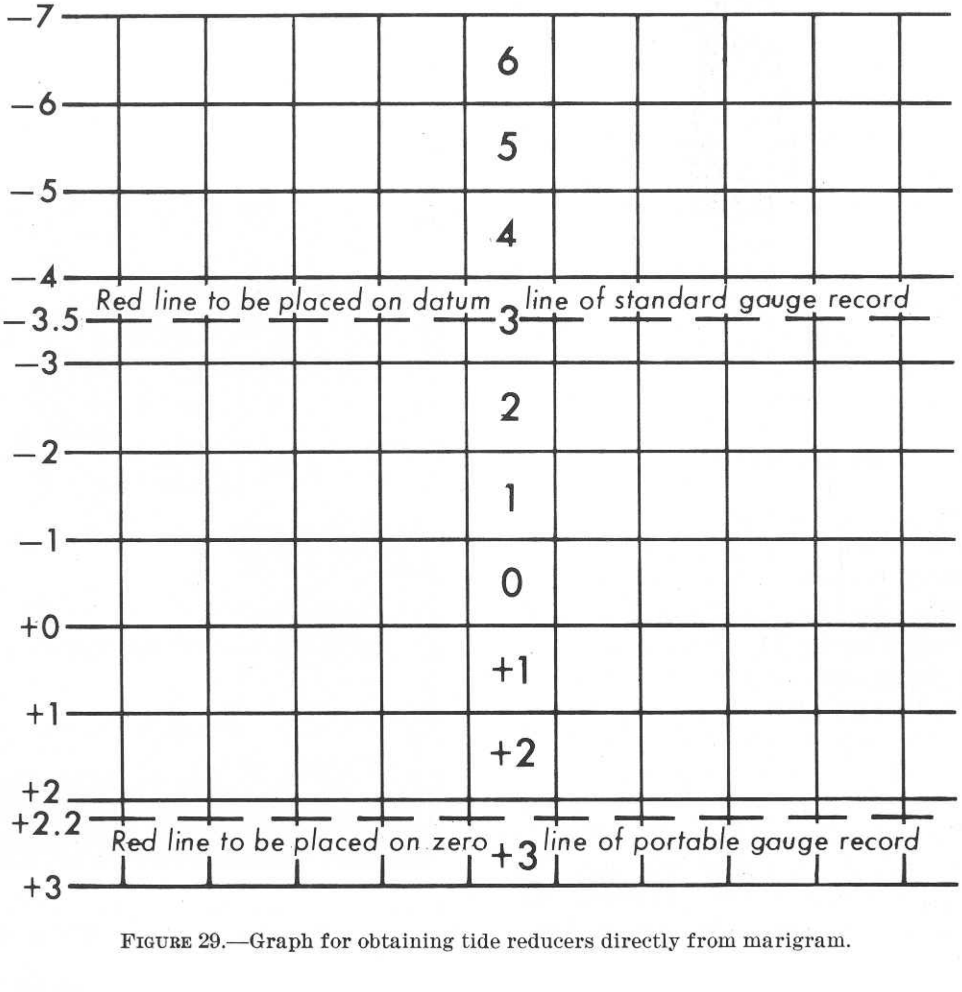

FIGURE 29.—Graph for obtaining tide reducers directly from marigram.

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, where tide observations have been taken during the time of the soundings; at the other end is station B, where the time differences and ratio of ranges have been determined. 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.

256. 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.

ADDENDA

257. The operating principal of the standard automatic tide gage, as used by the Coast and Geodetic Survey, has remained much the same for over a century. However, during this period, a number of modifications have been made to improve the operation and maintenance of the gage. Among these, are two modifications not described in the preceding section—the removable pencil-arm assembly of the recording pencil and the clutch connection between the motor clock drive shaft and the main roller of the gage. More recently a new type of recording instrument, the analog-to-digital recorder tide gage, has been tested and used in place of both the standard automatic tide gage and the portable automatic tide gage at selected stations.

MODIFICATIONS TO STANDARD AUTOMATIC TIDE GAGE

258. Recording pencil arm assembly.—One modification in standard automatic tide gages is the removable pencil arm assembly which holds the recording pencil (fig. 30). This assembly differs from that described in paragraph 32 by not completely enclosing the pencil screw and by possessing a keeper slide which permits the pencil arm assembly to be removed from the pencil screw while in place. A safety stop, mounted on the new assembly, limits any tendency of the recording pencil to lift off the record paper. Any such tendency of the arm to swing backward causes the safety stop to contact a special safety-stop bar. Numbered parts in figure 30 are identified as follows: 1, pencil arm; 2, pencil-arm bearing screw; 3, pencil screw; 4, keeper slide; 5, safety stop; and 6, safety-stop bar.

259. Clutch assembly.—A spring-loaded, horizontal-sliding type of clutch is now used to connect the shaft of the motor clock with the main roller of the gage (fig. 31). This new clutch assembly is less affected by eccentricity in opera-

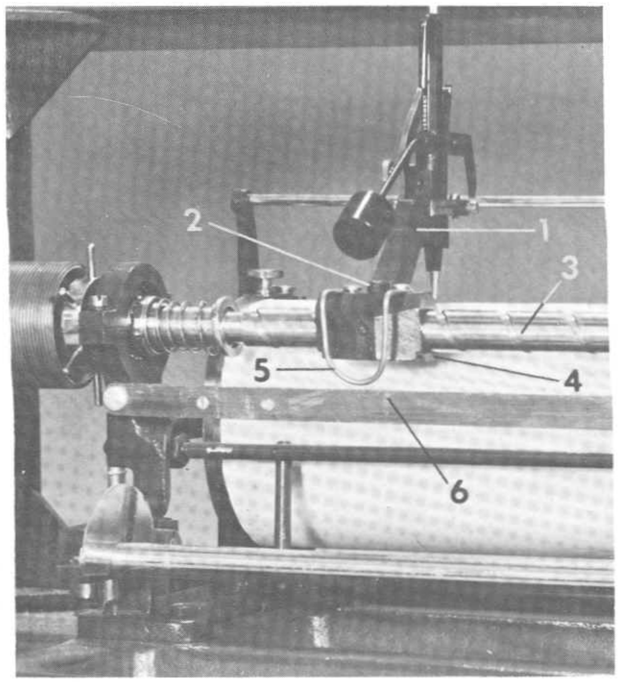

FIGURE 30.—Removable, recording pencil arm assembly for standard automatic tide gage.

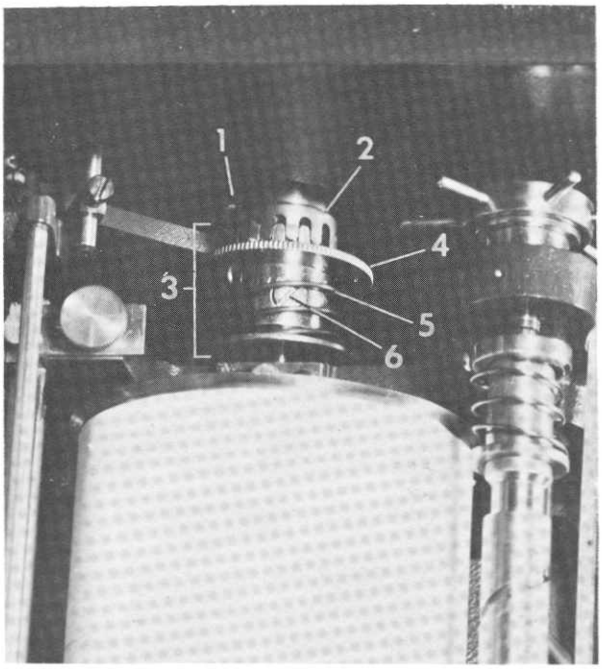

FIGURE 31.—Clutch assembly for standard automatic tide gage.

tion than the carrier-wheel and carrier-arm connection previously used and described in paragraph 26. The parts of the new assembly include: the clutch, the clutch-binding screw which secures the clutch to the shaft of the motor clock, clutch connector, clutch-connector spring, and clutch-connector positioning screw. The clutch can be disengaged by pressing the clutch-connector collar against the clutch-connector spring and turning the collar so that the positioning screw slides into the disengaged position slot (not shown in figure 31). Numbered parts in figure 31 are as follows: 1, clutch-binding screw; 2, clutch; 3, clutch connector; 4, clutch-connector collar; 5, clutch-connector spring; and 6, clutch-connector positioning screw.

ANALOG-TO-DIGITAL RECORDER

260. The analog-to-digital recorder tide gage is a float-operated, negator-spring counterpoised instrument, using a dry cell battery to mechanically convert the motion of a rotating float-wheel shaft into a coded punched-tape record. The water level, to the nearest 0.01 foot, is punched at selected intervals regulated by a small timer clock. The punched-tape record (fig. 32) is in a standard binary-decimal code that can be interpreted visually or machine processed by a special translating device. The compact recorder (fig. 33) can be used in place of the standard automatic tide gage. A negator-spring counter-balance assembly incorporated in the instrument eliminates the use of counterweights. This feature of the gage makes it easy to install and reduces the space required in the gage shelter. The recorder also can be used in place of the portable automatic tide gage, by using a special mounting platform or base (fig. 34) and a weather-resistant cover (fig. 35).

261. Measuring system.—The measuring system consists of a float that operates in a stilling well (pars. 66–74), a float cable or wire, one end of which is attached to the float, and a float wheel attached on the drive shaft of the recorder, and around which the other end of the float cable is securely wound. As the float rises and falls with changing water level, the float wheel rotates the drive shaft and code disks of the instrument. The movement of the drive shaft is controlled by (1) a safety brake to prevent unwanted movement that might result from parting of the cable, (2) a negator-spring counterbalance to provide constant tension and input energy, and (3) a dual torsion-spring assembly, or lost-motion coupler, to accumulate or store motion of the drive shaft during the brief lockout interval required for the punched-tape readout.

262. The safety-brake mechanism is needed in the event the float cable parts. Separation of the cable would result in a "flywheel action" in the float drum and allow the counterpoise system to accelerate at an excessive rate. If unchecked, spinning during the punch-out cycle could severely damage the lockout device on the low-order code disk. The safety brake is designed to immobilize the float wheel and prevent such spinning. It consists of a brake arm with a guide or safety-brake wheel attached to its upper end and a spring that tends to keep the arm in the braking position. Two small wheels guide the cable onto the float wheel (fig. 36). The cable passes over the uppermost guide wheel, which also is the safety-brake wheel mounted on the brake arm. Cable tension on this wheel keeps the brake arm disengaged. Any separation of the cable will immediately release the tension on the brake wheel and permit the spring to pull the brake arm into its braking position (fig. 37). In this position, protruding

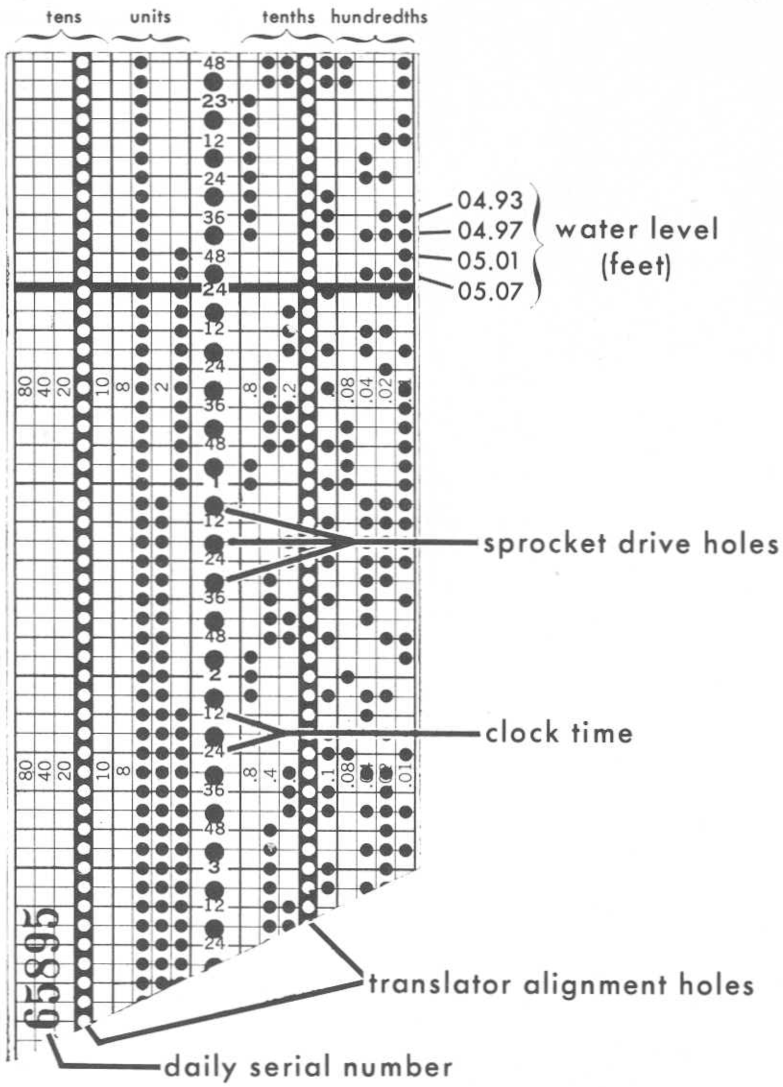

FIGURE 32.—Recording tape showing time divisions and binary-coded digital punch out.

pins on the back edge of the float wheel catch on the arm and immobilize the float wheel.

263. A negator-spring counterbalance on the drive shaft provides constant torque and energy input when the cable tension is reduced by rising water level. The mechanism consists of a spring band, a take-up drum, and an output drum connected to the drive shaft (fig. 38). This device eliminates the use of counterweights and the need for a counterpoise system of weights and pulleys.

264. A dual torsion-spring assembly on the drive shaft (fig. 38) accumulates or stores motion that would be lost during the brief, approximately 8-second, interval that the recording mechanism is locked for readout. Either spring of this lost-motion coupler, depending on the direction of rotation, can accumulate motion. Upon completion of the readout, the wound spring unwinds and turns the motion-transmitting shafts and code disks to positions which accurately indicate the water level at the end of the readout interval.

265. Drive and input coupling.—In addition to the float wheel and negator- and dual-torsion spring assemblies, the drive shaft has a 96-tooth spur gear at the forward end of the shaft. This gear connects with a 48-tooth spur gear on the input shaft as shown in figure 38. A spring coupling on the input shaft makes its possible to

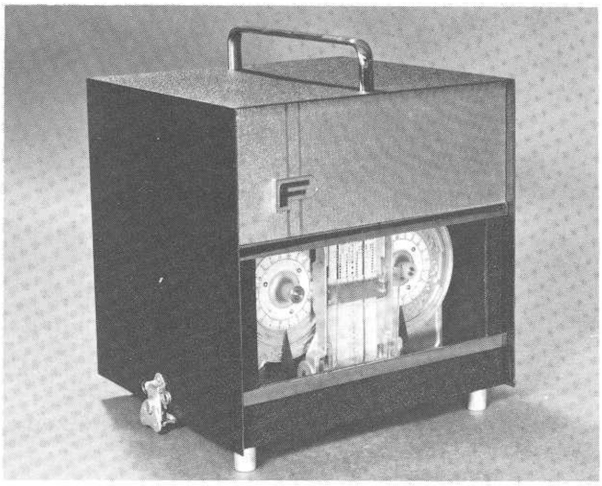

FIGURE 33.—Analog-to-digital recorder in instrument case.

disengage the input spur gear from the gear on the drive shaft. This is accomplished by pushing the input spur gear rearward against the spring and making one-quarter turn. The drive and input shafts must be disengaged when adjusting the recorder to the indicated water level on the tide staff.

266. Code-disk positioning mechanism.—The motion of the input shaft is transmitted through a system of gears to successive positions of two analog code disks, each having 100 discrete radial positions (fig. 39). The low-order code disk represents hundredths and tenths digits and is connected to the input shaft by a detent wheel. The high-order code disk represents units and tens

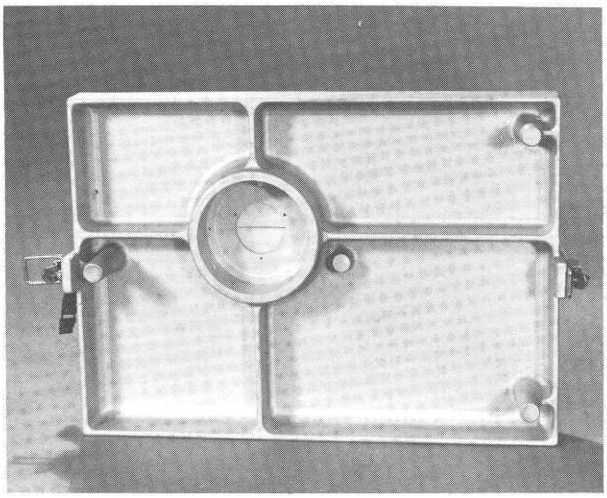

FIGURE 34.—Special base for mounting analog-to-digital recorder on 4-inch stilling-well pipe.

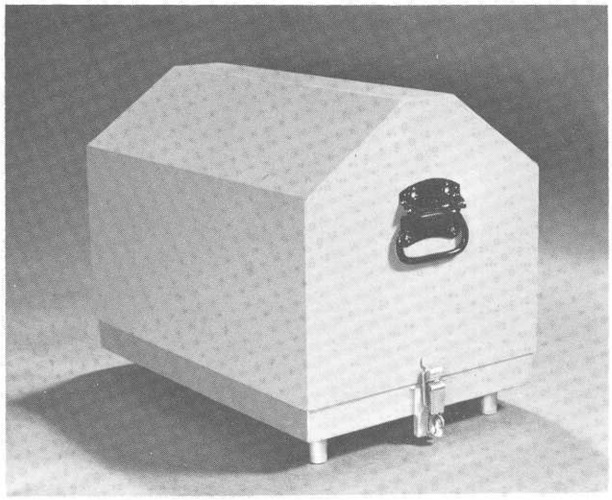

FIGURE 35.—Weather-resistant cover for analog-to-digital recorder. Cover attaches to base shown in figure 34.

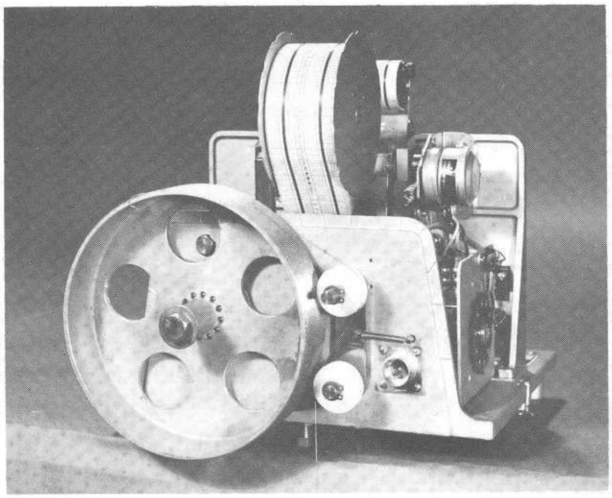

FIGURE 36.—View of analog-to-digital recorder tide gage showing float wheel, lower guide wheel, and upper safety-brake wheel. Cable tension on upper wheel keeps brake arm in disengaged position.

digits and is connected to the input shaft by integrally machined gears and beveled teeth. By this means, the rotary motion of the input shaft drives the low-order code disk at a ratio of 1 : 1 and the high-order code disk at a ratio of 100 : 1. The front of each disk has a circular dial affixed. Each dial is scaled in 100 graduations. A pair of pointers indicate the accumulated count at any disk position. This makes visual reading of the water level possible. Since the low-order disk moves through 100 positions, or one revolution, while the high-order disk moves but one position,

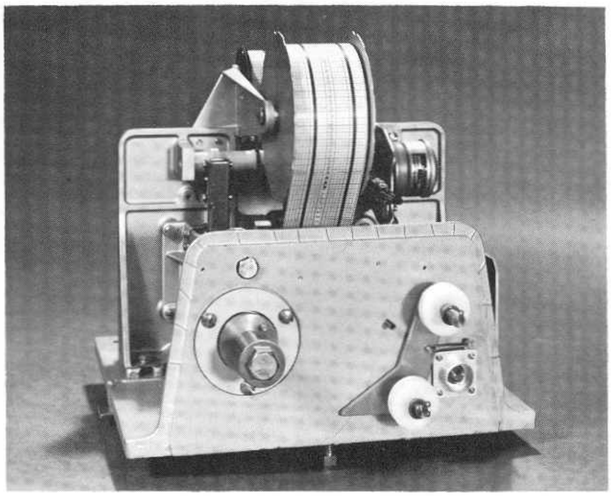

FIGURE 37.—View of analog-to-digital recorder tide gage with float wheel removed from drive shaft to show brake arm in engaged position.

a mechanical cam and gearing arrangement is used to keep the positions of the two wheels synchronized and the count correct.

267. Recording mechanism.—The water level is indicated on the recorder by the position of the analog code disks. It can be read directly from the circular dials at the two pointers. A continuous record of water level also is mechanically converted into a coded digital output and punched on tape at selected time intervals. This is accomplished by a punching mechanism and by the arrangement of hills and valleys on the outer area of the front surface of the analog code disks. Individual punches or pins slide freely in separate channels of the punching mechanism in such a manner that they align with the raised or unraised outer surface of the code disks. In the punching operation, the punches that fall into a valley on the face of the code disk do not punch the recording tape. The punches which strike hills punch holes in the recording tape. During the readout both disks are locked in position for approximately 8 seconds. The timer unit controls the time of punch out and the movement of the recording tape. The tape has printed time divisions which make it possible to synchronize the operation of the unit with the actual time. A manually initiated punch out can be obtained at any time for testing purposes by pressing the pushbutton on the front of the instrument.

268. Timing mechanism.—A clock mechanism is used to initiate the punch demand and to establish the various punching and reset operations required in recording the measured water-level values. Power to move the recording tape and operate the punch motor is provided from an external 7½-volt dc battery (fig. 40). The clock continuously rotates a timing cam, so arranged with a *cam follower-switch actuator* that the punch-out motor is actuated every 6 minutes. Time graduations on the cam are used when synchronizing the timer with the correct time.

269. Code-disk lock out.—During the punch out the code disks and input shaft are locked in the recording position by means of a code-disk locking cam, rocker arm assembly, and locking lever which engages the detent wheel. Upon completion of the punch out cycle, the locking lever is lifted clear of the detent wheel to again permit free movement of the input shaft and code disks.

270. Recording tape.—The recording tape is placed on the supply spool by removing the side of the spool and placing the roll of tape so that the printed time digits are right side up facing the front of the instrument. The tape is led off the back of the supply spool, under the bottom of the tape-drive sprocket at the base of the punching mechanism, up the front of the instrument between the punch holder and punch die, beneath the upper paper guide, and onto the take-up spool. Any slack in the tape is taken up by a spring drive belt which connects with the take-up spool. The tape can be positioned squarely by aligning any of the horizontal lines on the tape just even with the upper edge of the punch die. The center column of the tape designates the time of day on a 24-hour basis. The horizontal graduations between the hour marks represent the 6-minute time increments selected for recording the water level. The center column also contains the sprocket drive holes. Each horizontal row of punched holes represents the total amount of shaft rotation, or analog code disk position, in coded digital form at the time of punching. The punched-tape record can be read visually or processed rapidly by using an automatic translating machine. The tape is designed with four vertical columns representing from right to left, hundredths (00.01),

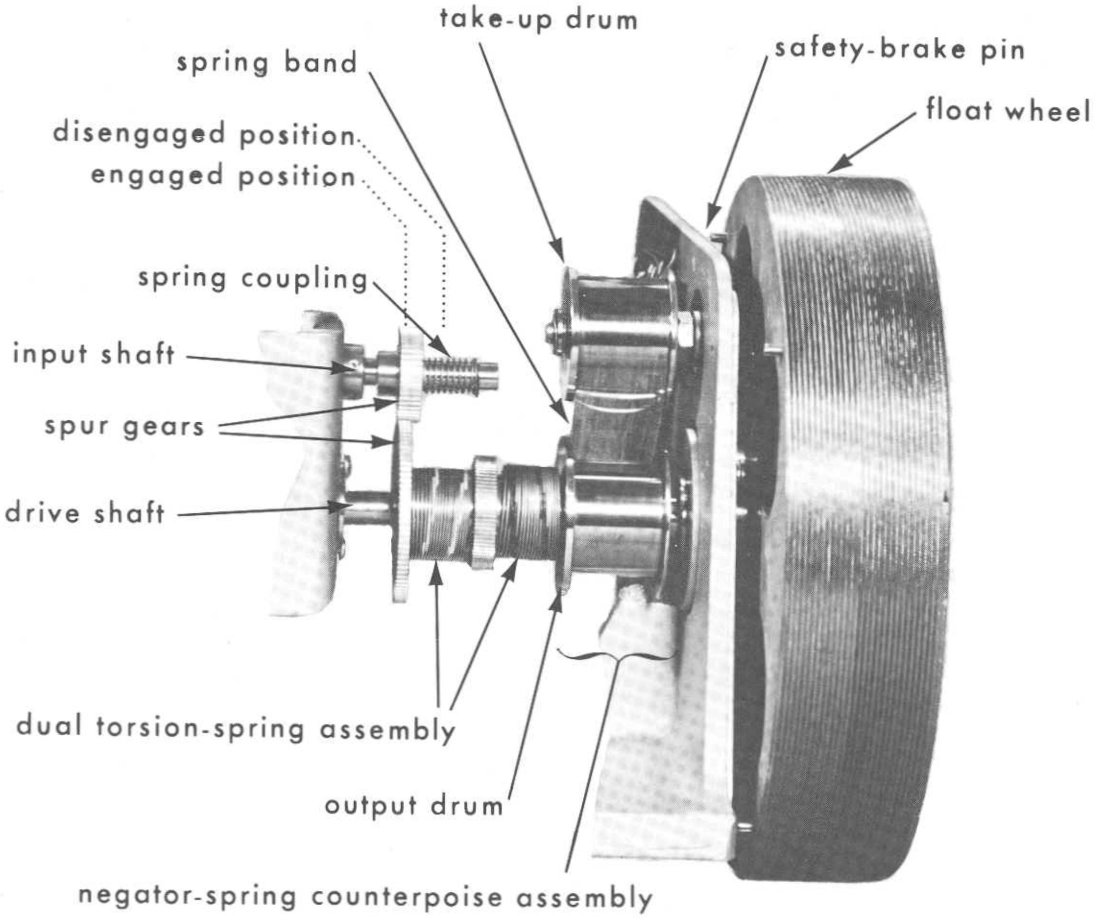

FIGURE 38.—Analog-to-digital recorder drive-shaft unit and input-shaft coupling (in engaged position).

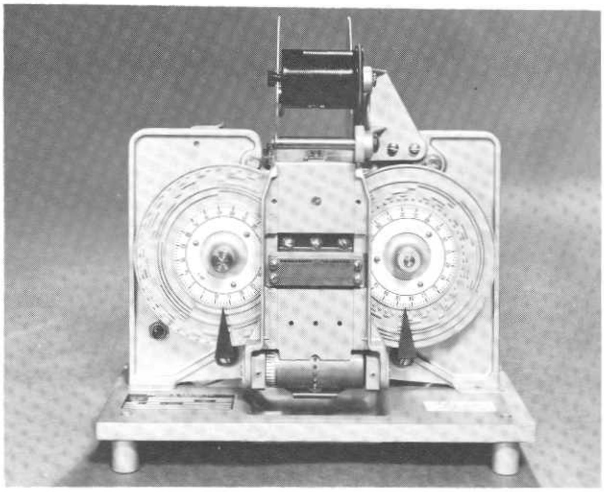

FIGURE 39.—Front view of analog-to-digital recorder with recording tape removed. Tape is fed upward from tape drive sprocket and under punch die (row of openings shown in center) onto take-up spool above. Pushbutton for manual punch out is shown at lower left.

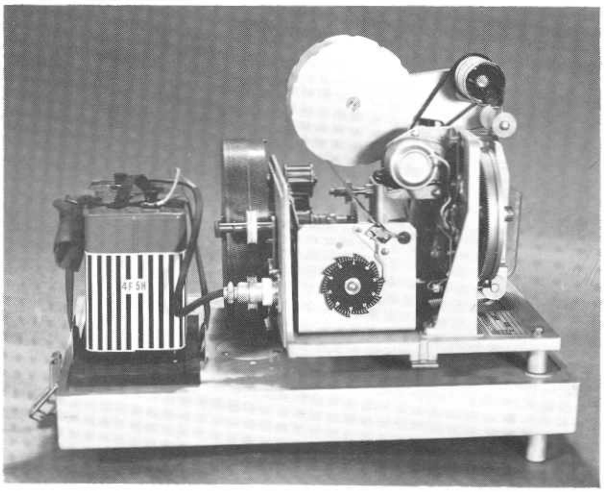

FIGURE 40.—Timing unit of analog-to-digital recorder. This unit controls the time of punch out. It consists of a battery-operated clock, a time cam and cam-follower lever (shown in illustration), and a switch assembly to supply power to the punch motor.

tenths (00.10), units (01.00), and tens (10.00) digits. Each of these columns is binary coded 8–4–2–1. Mental summation of the punched holes (bits) in each vertical column will give the digital reading (see figure 32). Two other holes in addition to the data readout are always punched so that the tape can be aligned in the special translator. These translator alignment holes are punched on the shaded vertical bands on the left and right sides of the recording tape.

271. Only a few of the salient features of the analog-to-digital recorder tide gage are described above. Instructions covering the installation, operation, and maintenance of the gage are available from the Director of the U.S. Coast and Geodetic Survey, Washington, D.C., 20230.

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