USGS
science for a changing world

Techniques of Water-Resources Investigations
of the United States Geological Survey

Chapter A7

STAGE MEASUREMENT AT GAGING STATIONS

By Thomas J. Buchanan and William P. Somers

Book 3

APPLICATIONS OF HYDRAULICS

Click here to return to USGS Publications

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

First printing 1968
Second printing 1974
Third printing 1978
Fourth printing 1982

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1982

For sale by the Distribution Branch, U.S. Geological Survey
604 South Pickett Street, Alexandria, VA 22304

PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called books and further subdivided into sections and chapters; Section A of book 3 is on surface-water techniques.

The unit of publication, the chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises.

Provisional drafts of chapters are distributed to field offices of the U.S. Geological Survey for their use. These drafts are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment. After the technique described in a chapter is sufficiently developed, the chapter is published and is sold by the U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202 (authorized agent of Superintendent of Documents, Government Printing Office).

CONTENTS

	Page
Preface	III
Abstract	1
Introduction	1
Datum of gage	1
Sensors of water level	1
Float sensor	2
Bubble-gage sensor	2
Water-stage recorders	2
Digital recorder	5
Graphic recorder	5
Stilling wells	7
Instrument shelters	15
Telemetering systems	17
Position-motor system	17
Impulse system	17
Telemetering systems—Con.	
Telemark system	17
Resistance system	18
Nonrecording gages	19
Staff gage	20
Wire-weight gage	21
Float-tape gage	21
Electric-tape gage	21
Chain gage	22
Remote indicating staff gage	23
Water-level finder	23
Operation of stage gages	24
Special purpose gages	24
Model T recorder	24
SR recorder	25
Crest-stage gage	27
References	28

FIGURES

	Page
1–3. Photographs of:	
1. Float-type gage	3
2. Major units of bubble gage	4
3. Digital recorder	6
4. Drawing of a digital recorder tape	7
5–14. Photographs of:	
5. Digital recorder timer	8
6. Continuous strip-chart recorder	9
7. Horizontal-drum recorder	10
8. Reinforced-concrete well and shelter	11
9. Concrete well and wooden shelter with asphalt shingle siding	11
10. Corrugated-galvanized-steel-pipe well and shelter	11
11. Concrete-pipe well and shelter	12
12. Concrete-block shelter	13
13. Steel-pipe well and look-in shelter attached to bridge abutment	13
14. Corrugated-steel-pipe well and wooden shelter attached to bridge pier	13
15. Diagram of flushing system for intakes	14
16. Photograph of static tube for intakes	15
17. Diagram of a typical bubble-gage installation	16
18–26. Photographs of:	
18. Telemark gage	18
19. Resistance system transmitter unit	19

Page

20. Resistance system indicator unit ---- 20
21. Vertical staff gage ---- 21
22. Type A wire-weight gage ---- 22
23. Electric-tape gage ---- 23
24. Remote indicating staff gage ---- 23
25. Model T recorder ---- 25
26. Model SR recorder ---- 26
27. Representation of a crest-stage gage ---- 28

STAGE MEASUREMENT AT GAGING STATIONS

By Thomas J. Buchanan and William P. Somers

Abstract

Continuous measurements of stream stage are used in determining records of stream discharge. In addition a record of stream stage is useful in itself, as in designing structures affected by stream elevation or in planning the use of flood plains.

This report describes instruments and structures commonly used in obtaining a record of stream stage.

Introduction

The stage of a stream or lake is the height of the water surface above an established datum plane. The water-surface elevation referred to some arbitrary or predetermined gage datum is called the gage height. Gage height is often used interchangeably with the more general term stage although gage height is more appropriate when used with a reading on a gage. Stage or gage height is usually expressed in feet and hundredths of a foot.

A record of stream stage is useful in itself, as in designing structures affected by stream elevations or in planning use of flood plains. In stream gaging, gage heights are used as the independent variable in a stage-discharge relation to derive discharges. Reliability of the discharge record is therefore dependent on the reliability of the gage-height record as well as the stage-discharge relation.

Gage-height records of lakes and reservoirs provide in addition to elevations, indexes of head, contents, storage capacity, and other properties.

Gage-height records may be obtained by a water-stage recorder, by systematic observation of a nonrecording gage, or by noting only peak stages with a crest-stage gage. Telemetering systems are used to transmit gage-height information to points distant from the gaging station.

Datum of gage

The datum of the gage may be a recognized datum, such as mean sea level, or an arbitrary datum plane chosen for convenience. An arbitrary datum plane is selected for the convenience of using gage heights of relatively low numbers. To eliminate the possibility of minus values of gage height, the datum selected for operating purposes is below the elevation of zero flow on the control for all conditions.

A permanent datum must be maintained so that only one datum for the gage-height record is used for the life of the station. To maintain a permanent datum each gaging station requires at least two or three reference marks that are independent of the gage structure. All gages are periodically checked by running levels using the reference marks to maintain a fixed datum.

If an arbitrary datum plane is used, it is desirable that it be referred to a bench mark of known elevation above mean sea level by levels so that the arbitrary datum may be recovered if the gage and reference marks are destroyed.

Sensors of water level

Water level is sensed by a float in a stilling well or by a gas-purge system which transmits the pressure head of water in the stream to a manometer. The later system is known as a bubble gage.

Float Sensor

The float sensor consists of a tape or cable passing over a pulley, with a float in a stilling well attached to one end of the tape or cable and a counter weight to the other. (See fig. 1.)[1] The float follows the rise and fall of the water level, and the water level can be read by using an index and graduated tape, or the pulley can be attached to a water-stage recorder to transmit the water level to the recorder.

Bubble-gage sensor

The bubble-gage sensor (Barron, 1963) consists of a gas-purge system, a servomanometer assembly, and a servocontrol unit. (See fig. 2.)

The gas-purge system transmits the pressure head of water in the stream to the manometer location. A gas is fed through a tube and bubbled freely into the stream through an orifice at a fixed elevation in the stream. The gas pressure in the tube is equal to the piezometric head on the bubble orifice at any gage height.

The servomanometer converts the pressure in the gas-purge system to a shaft rotation for driving a water-stage recorder. Mercury is used as the manometer liquid to keep the overall length to a minimum. The manometer has a sensitivity of 0.005 foot of water and can be built to record ranges in gage height in excess of 120 feet. The use of mercury in the manometer permits positioning of the pressure reservoir to maintain the float-switch contacts in null position. In this position, the vertical distance between mercury surfaces will be 1/13.6 times the head of water. A change in pressure at the reservoir displaces the mercury which in turn activates the float switch. This causes movement of the pressure reservoir until the distance of head of water divided by 13.6 is again maintained. This motion in turn is translated to the recorder.

The servocontrol unit provides the relay action necessary to permit the sensitive float switch to control the operation of the servomotor and also to provide an appropriate time delay between the closing of the float switch and the starting of the motor.

The proper placement of the orifice is essential for an accurate stage record. The orifice should be located where the height of water above it represents the stage in the river. If it is partly buried in sand or mud, the recorded stage will be greater than that in the river. An orifice preferably should not be installed in swift currents. If this is unavoidable, it must be kept at right angles to the direction of flow. A recommended mounting for swift-flow conditions is for the orifice to be mounted flush with the wall of the mounting structure. Care should also be taken to keep the orifice out of highly turbulent flow.

Water-stage recorders

A water-stage recorder is an instrument for producing a graphic or punched tape record of the rise and fall of a water surface with respect to time. It consists of a time element and a gage-height element which, when operating together, produce on a chart or a tape a record of the fluctuations of the water surface. The time element is controlled by a clock which is driven by a spring, by a weight, or by electricity. The gage-height element is actuated by a float or a bubble gage.

If a float sensor is used, the float pulley is attached to the recorder. The float and counterweight are suspended on a perforated steel tape or on a plain or beaded cable. Cone-shaped protrusions on the circumference of the float-tape pulley match perforations in the tape. As the float rises or falls the float pulley turns a proportional amount, thereby changing the gage-height reading on the recorder. A copper float 10 inches in diameter is normally used, but other sizes are used depending on the type of recorder, gage-height scale, and accuracy requirements.

[1] Figures 1, 6, 7, 18, and 22 are photographs used by permission of Leupold & Stevens Instruments, Inc.

Figure 1.—Float-type gage.

If a bubble-gage sensor is used the stage is translated to the recorder by a chain and sprocket arrangement. (See fig. 2.)

Stage recorders are either digital or graphic. Both types may be used with the float or bubble gage.

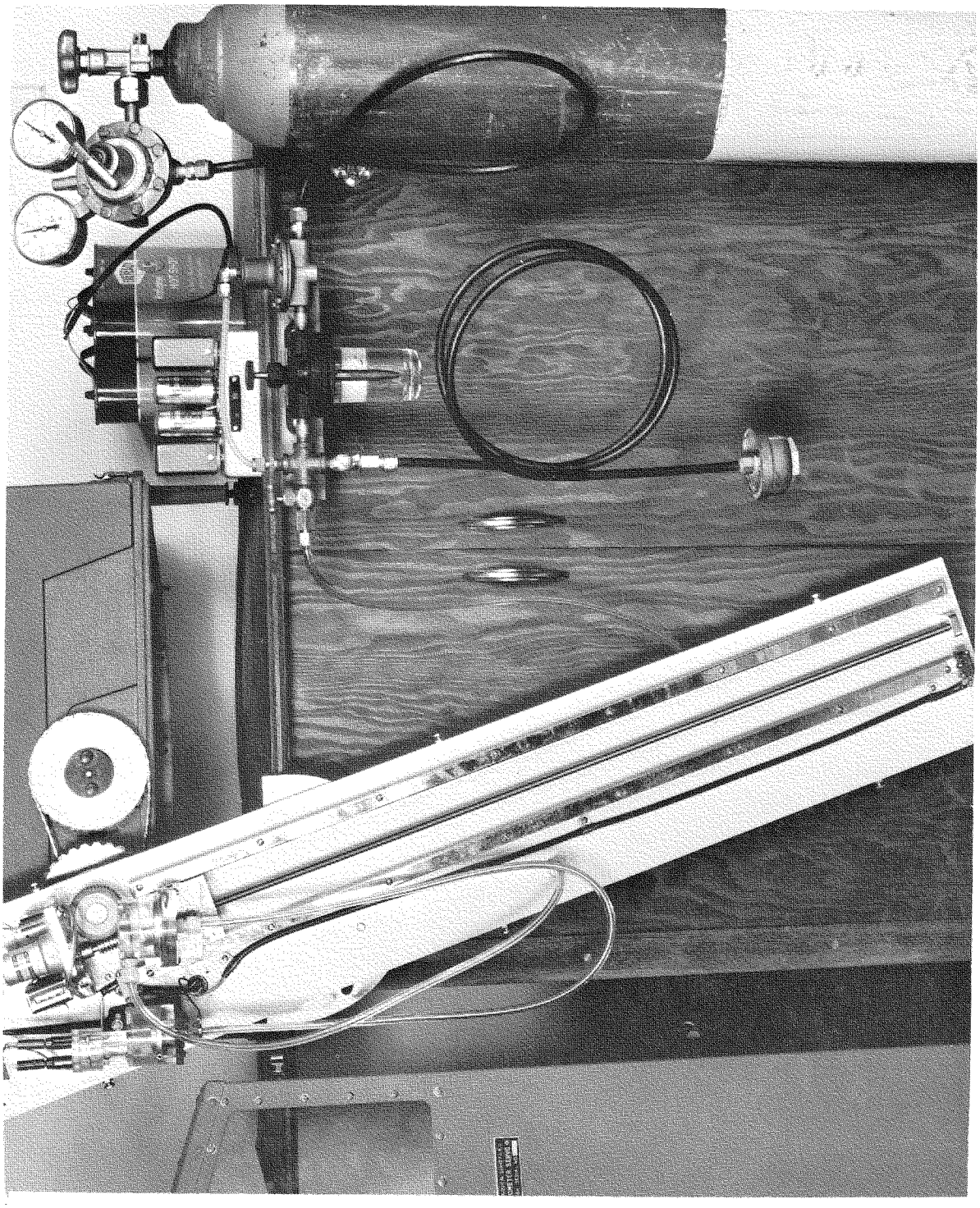

Figure 2.—Major units of the bubble gage.

Digital recorder

The digital recorder (Isherwood, 1963) is a battery-operated, slow-speed, paper-tape punch which records a 4–digit number on a 16–channel paper tape at preselected time intervals. (See fig. 3.)

Stage is recorded by the instrument in increments of a hundredth of a foot from zero to 99.99 feet and is transmitted to the instrument by rotation of the input shaft. Shaft rotation is converted by the instrument into a coded punch-tape record that is simple enough to be read directly from the tape. The code consists of four groups of four punches each. In each group, the first punch represents "1," the second "2,", the third "4," and the fourth "8." Thus a combination of up to three punches in a group represents digits from one to nine, with a blank space for zero, and the four groups of punches represent all numbers from 1 to 9,999. (See fig. 4.)

Coding is done by means of two discs containing raised ridges in accordance with the punch code outlined above. One disc is mounted directly on the input shaft. The second code disc is connected to the first by a 100:1 worm gear so that one hundred revolutions of the input shaft rotate the second, or high-order disc, one complete revolution. A paper tape is moved upward through a punch block which is mounted on a movable arm hinged at the base of the recorder. The punch block contains a single row of 18 pins, 16 pins for the information punches and 2 for punching feed holes.

The tape is punched when the punch block with its protruding pins is forced against the code discs by spring action. Those pins which strike the raised ridges of the discs punch through the paper tape and record the position of the discs at that instant. The readout cycle begins with an impulse from the timer which causes a 6–volt motor to turn a sequencing camshaft. The sequence of operations for one reading includes punching the paper, advancing the paper, and compressing the punch spring for the next readout cycle.

The timers used on the digital recorders are electro-mechanical timing devices that are powered by the same 7½–volt battery that operates the 6–volt motor. The timers provide contact closure for actuating the digital recorder at preselected time intervals of 5, 15, 30, or 60 minutes by using a different cam for each different time interval.

The cam on the timer corresponds to the minute hand on a clock, that is, it makes one revolution per hour in a clockwise direction. If the cam has one dropoff point the recorder will punch hourly, if it has two dropoff points it will punch every 30 minutes, and if it has four dropoff points it will punch every 15 minutes. The timer in figure 5 has four dropoff points. The arm positioned by the cam operates a single-pole double-throw switch. When the cam dropoff point passes the arm, the switch initiates the major part of the readout cycle which includes punching of the tape. A preset action returns the switch to the initial position prior to the next readout cycle. Alternating-current timers can be used with the digital recorders at places where reliable alternating-current power is available.

Digital recorders may miss the absolute peak, especially on flashy streams. However, a measure of the maximum peak that occurs between inspections of the recorder can be obtained by attaching a paper clip or small magnet on the float tape just below the instrument shelf in such a manner that it will slide along the tape as the stage rises but remain in a fixed position as the stage declines.

Mechanically punched tape is the most practical for field use under widely varying conditions of temperature and moisture. Electronic translators are used to convert the 16–channel punch-tape records to a tape suitable for input into a digital computer for computation of daily mean gage height and daily mean discharge.

Graphic recorder

The graphic recorder supplies a continuous trace of water stage with respect to

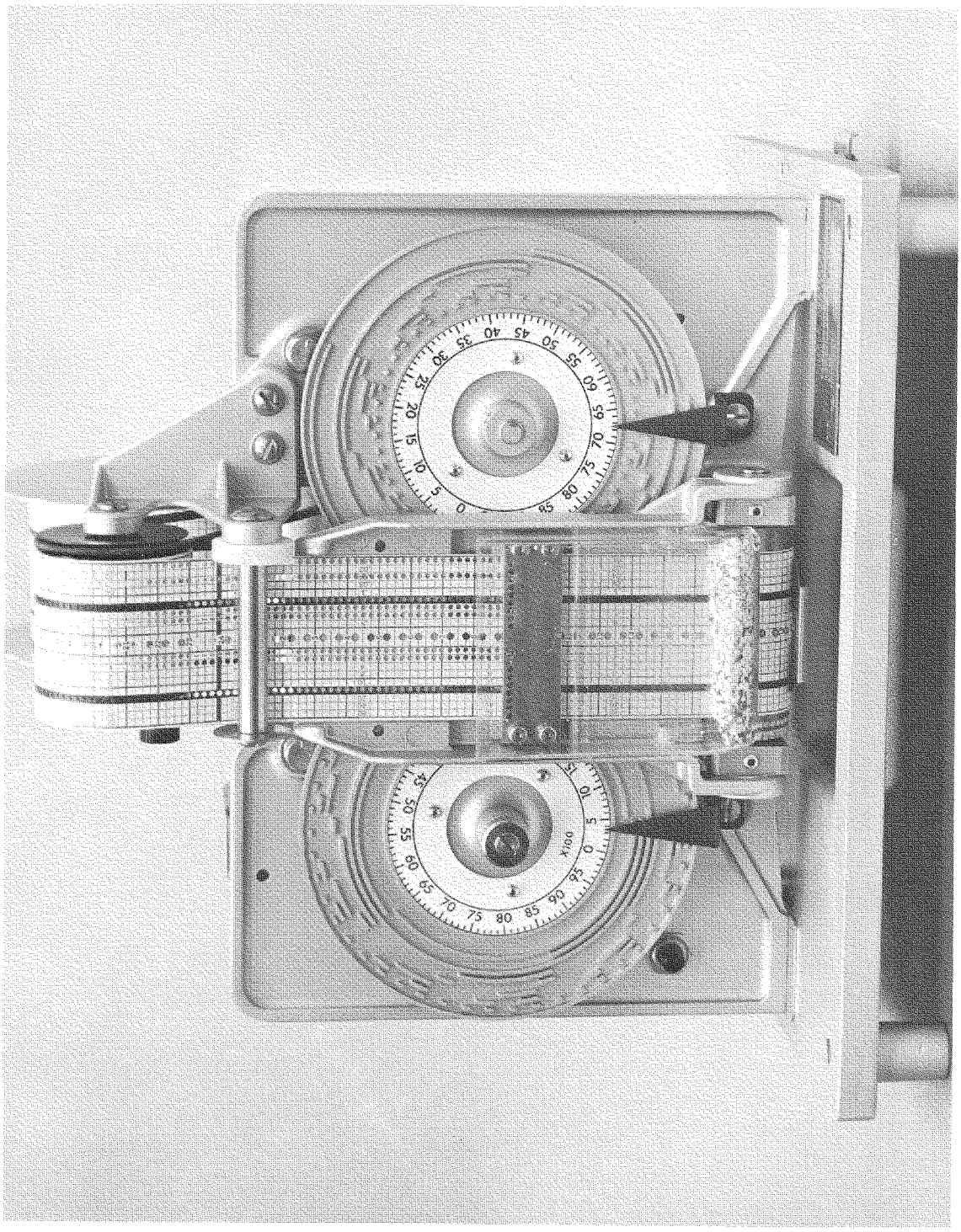

Figure 3.—Digital recorder.

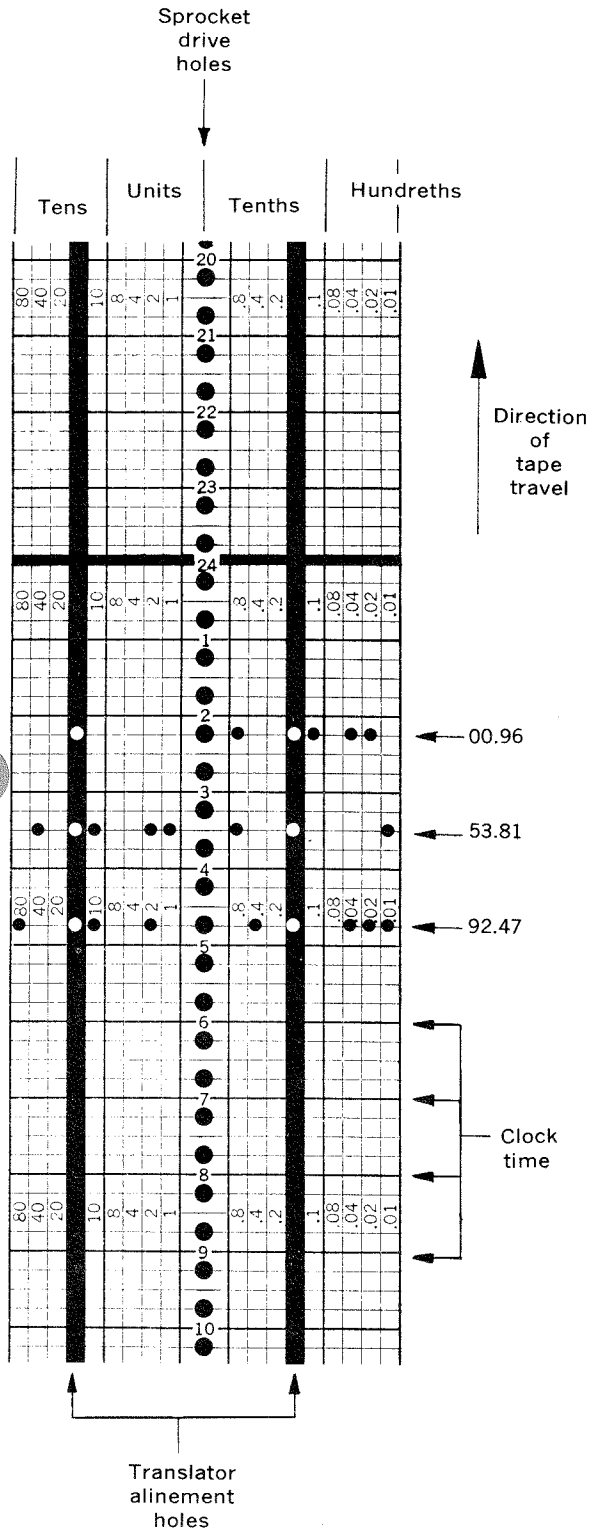

Figure 4.—Illustration of a digital recorder tape.

time on a chart. Usually the gage-height element moves the pen or pencil stylus and the time element moves the chart, but in some recorders this is reversed. The range of available gage-height scales is from 10 inches=1 foot (10:12) to 10 inches=20 feet (1:24). The width of strip charts is usually 10 inches. The range of available time scales is from 0.3 to 9.6 inches per day. Normally the 10 inches=5 feet (1:6) or the 10 inches=10 feet (1:12) gage-height scale is used along with 1.2, 2.4, or 4.8 inches per day time scale.

Most graphic recorders can record an unlimited range in stage by a stylus-reversing device or by unlimited rotation of the drum.

Most strip-chart records will operate for several months without servicing. Drum recorders require attention at weekly intervals. Figure 6 shows a commonly used continuous strip-chart graphic recorder, and figure 7 a horizontal-drum recorder that must be serviced at weekly intervals. Attachments are available for the recorder shown in figure 6 to record water temperature or rainfall on the same chart with stage.

Stilling wells

The stilling well protects the float and dampens the fluctuations in the stream caused by wind and turbulence. Stilling wells are made of concrete, reinforced concrete, concrete block, concrete pipe, steel pipe, and occasionally wood. They are usually placed in the bank of the stream (see figs. 8, 9, 10, 11, and 12), but often are placed directly in the stream and attached to bridge piers or abutments. (See figs. 13 and 14.) The stilling well should be long enough for its bottom to be at least a foot below the minimum stage anticipated and its top above the level of the 50-year flood. The inside of the well should be big enough to permit free operation of all the equipment to be installed. Normally a pipe 4 feet in diameter or a well with inside dimensions 4 by 4 feet is of satisfactory size, but pipes

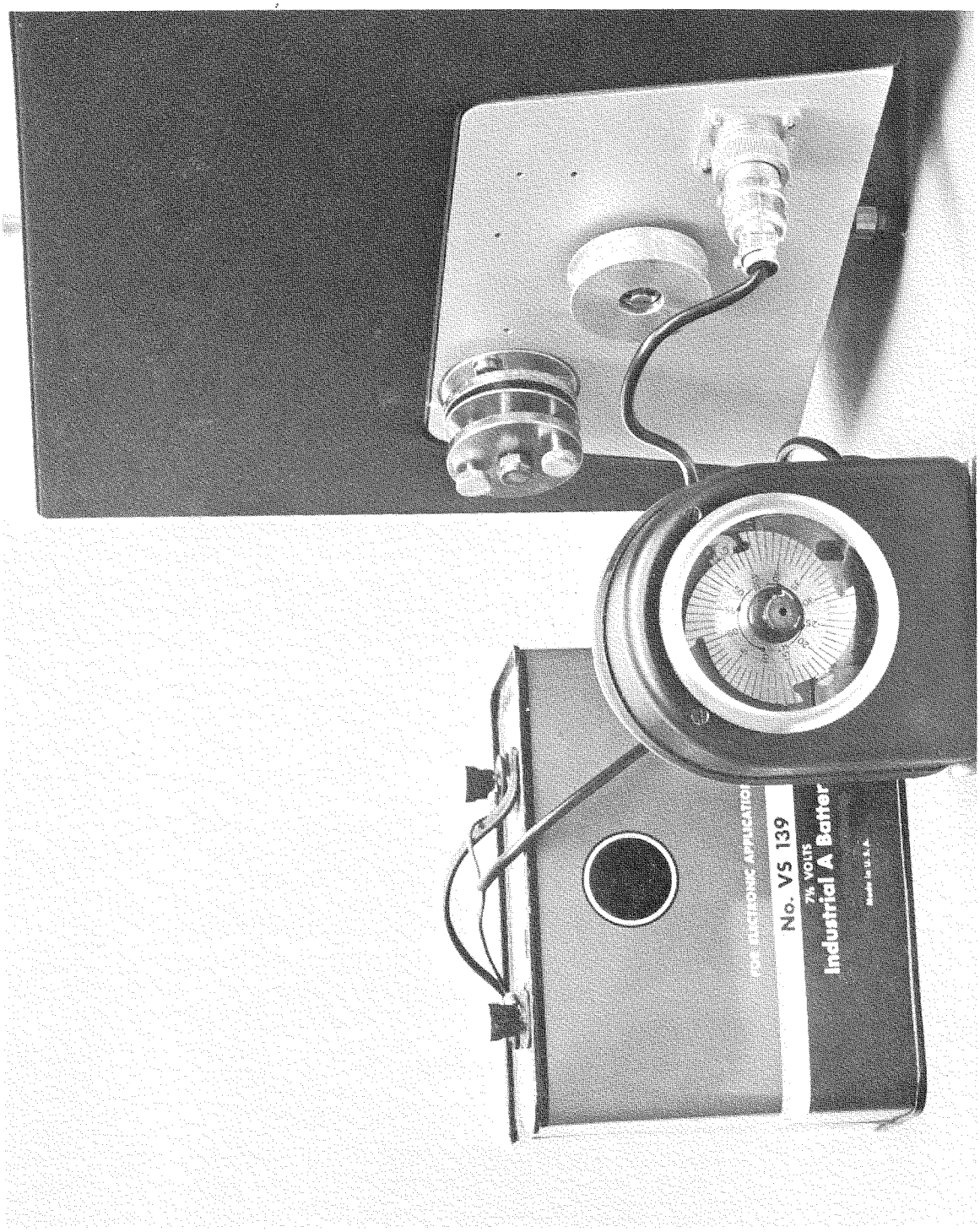

Figure 5.—Digital recorder timer.

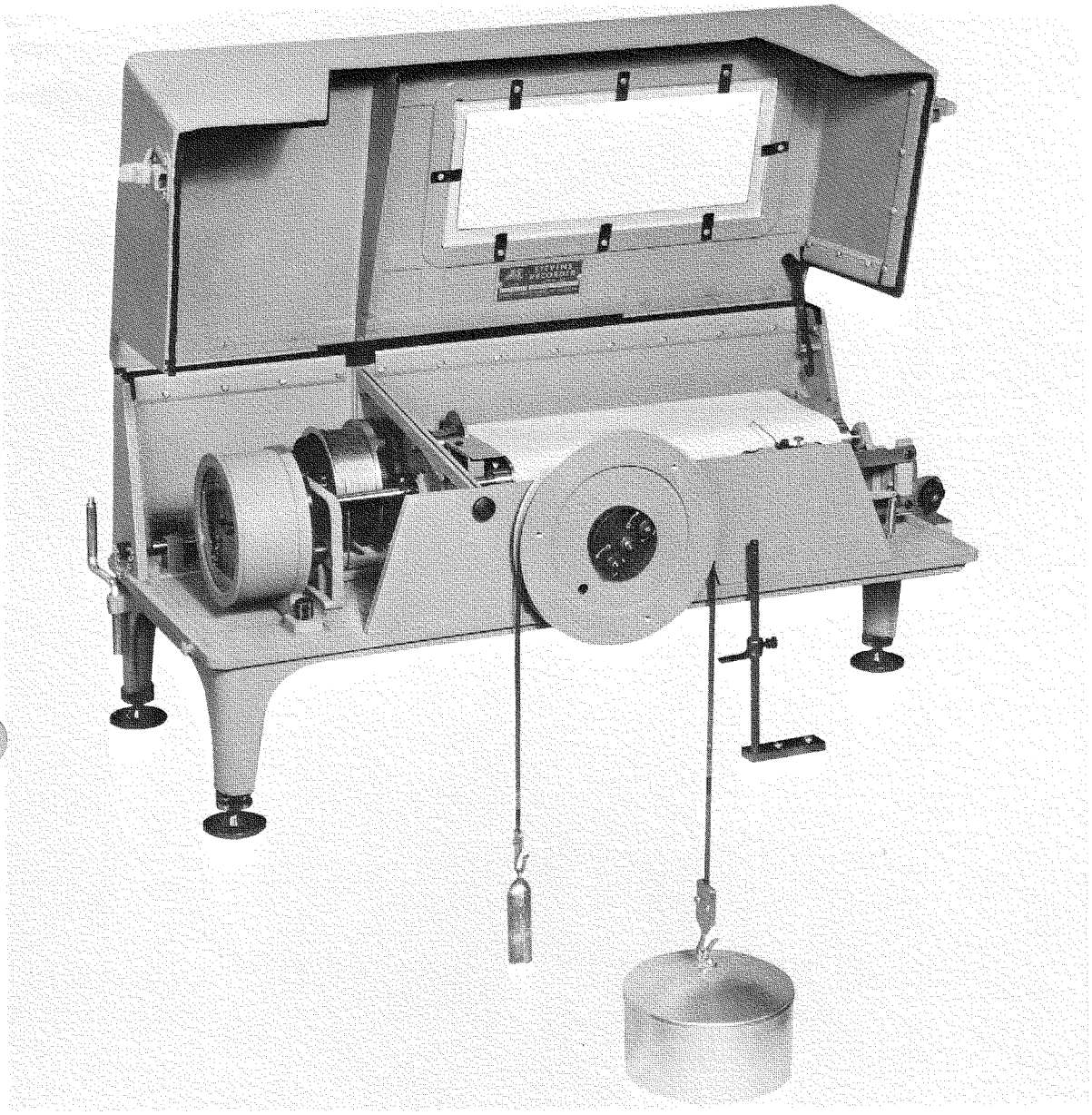

Figure 6.—Continuous strip-chart recorder.

18 inches in diameter have been used for temporary installations where a conventional water-stage recorder was the only equipment to be installed. The 4- by 4-foot well provides ample space for the hydrographer to enter the well to clean it or to repair equipment. The smaller metal wells and the deep wells should have doors at various elevations to facilitate cleaning and repairing. (See figs. 8 and 11.)

When placed in the bank of the stream the stilling well should have a sealed bottom so that ground water cannot seep into it nor stream water leak out.

Water from the stream enters and leaves the stilling well through the intake so that the water in the well is at the same elevation as the water in the stream. If the stilling well is in the bank of the stream, the intake consists of a length of pipe connecting the

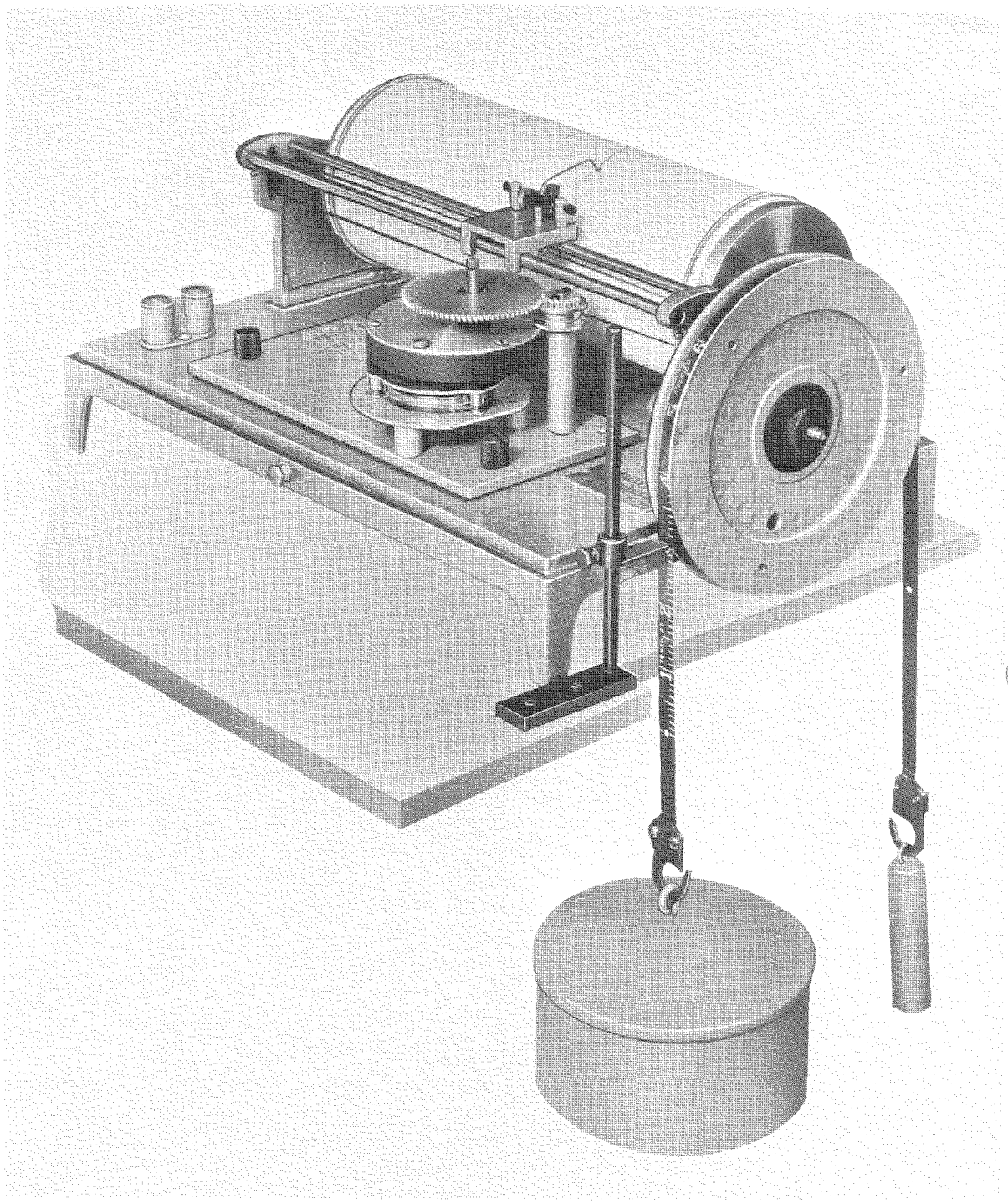

Figure 7.—Horizontal-drum recorder.

stilling well and the stream. The intake should be at an elevation at least 0.5 foot lower than the lowest expected stage in the stream, and at least 0.5 foot above the bottom of the stilling well to prevent silt buildup from plugging the intake. In cold

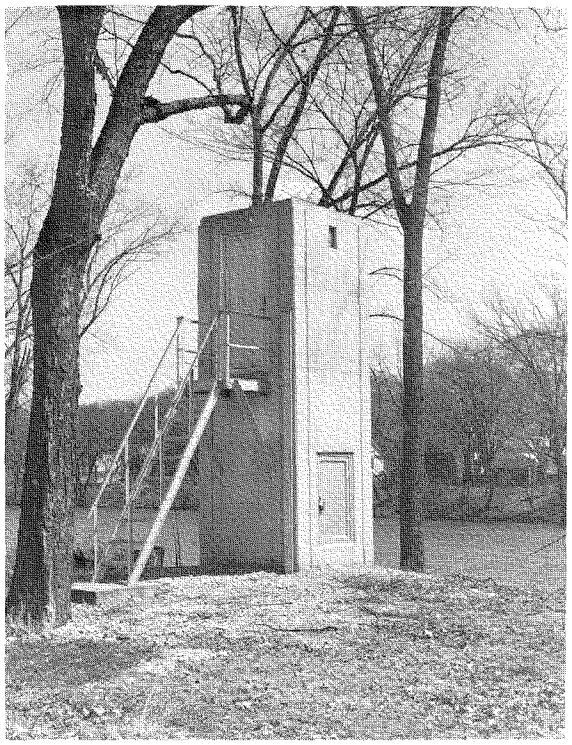

Figure 8.—Reinforced-concrete well and shelter. Note clean-out door.

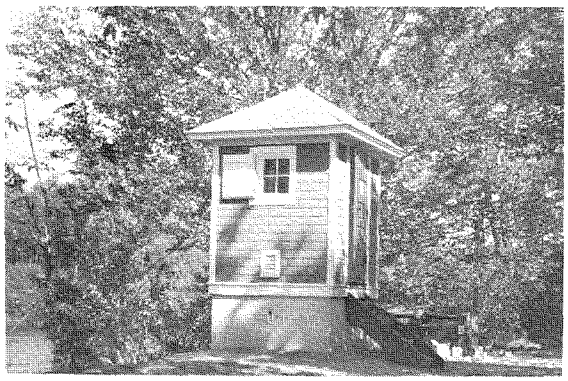

Figure 9.—Concrete well and wooden shelter with asphalt shingle siding.

climates the intake should be below the frostline. If the well is placed in the stream, holes drilled in the stilling well may act as an intake, taking the place of a length of pipe. Some wells placed in the stream have a hopper bottom which serves as an intake.

Two or more pipe intakes are commonly installed at vertical intervals of about one foot. During high water, silt may cover the stream end of the lower intakes while the higher ones will continue to operate.

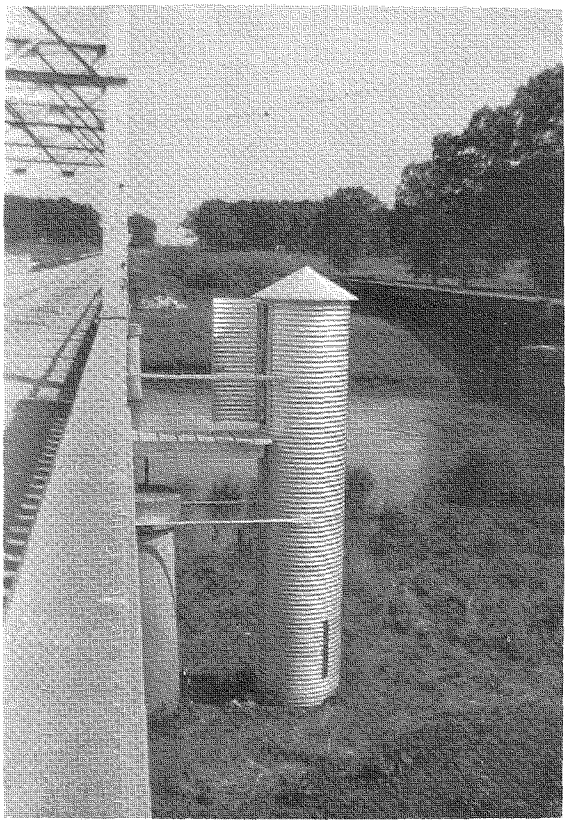

Figure 10.—Corrugated-galvanized-steel-pipe well and shelter.

Most stations that have intakes subject to clogging are provided with flushing systems (see fig. 15) whereby water under several feet of head can be applied to the gage-well end of an intake. Ordinarily a pump raises water from the well to an elevated tank. The water is then released through the intake by operation of a valve. Intakes without flushing systems may be cleaned with a plumber's snake or rod, or by building up a head of water in the well with a portable pump to force an obstruction out of the intakes.

The intakes for stations placed in the bank of the stream are usually galvanized-steel pipe. The most common size used is 2-inch-diameter pipe, but in some places up to 4-inch-diameter pipe is used. After the size and location of the well have been decided, the size and number of intakes should be determined.

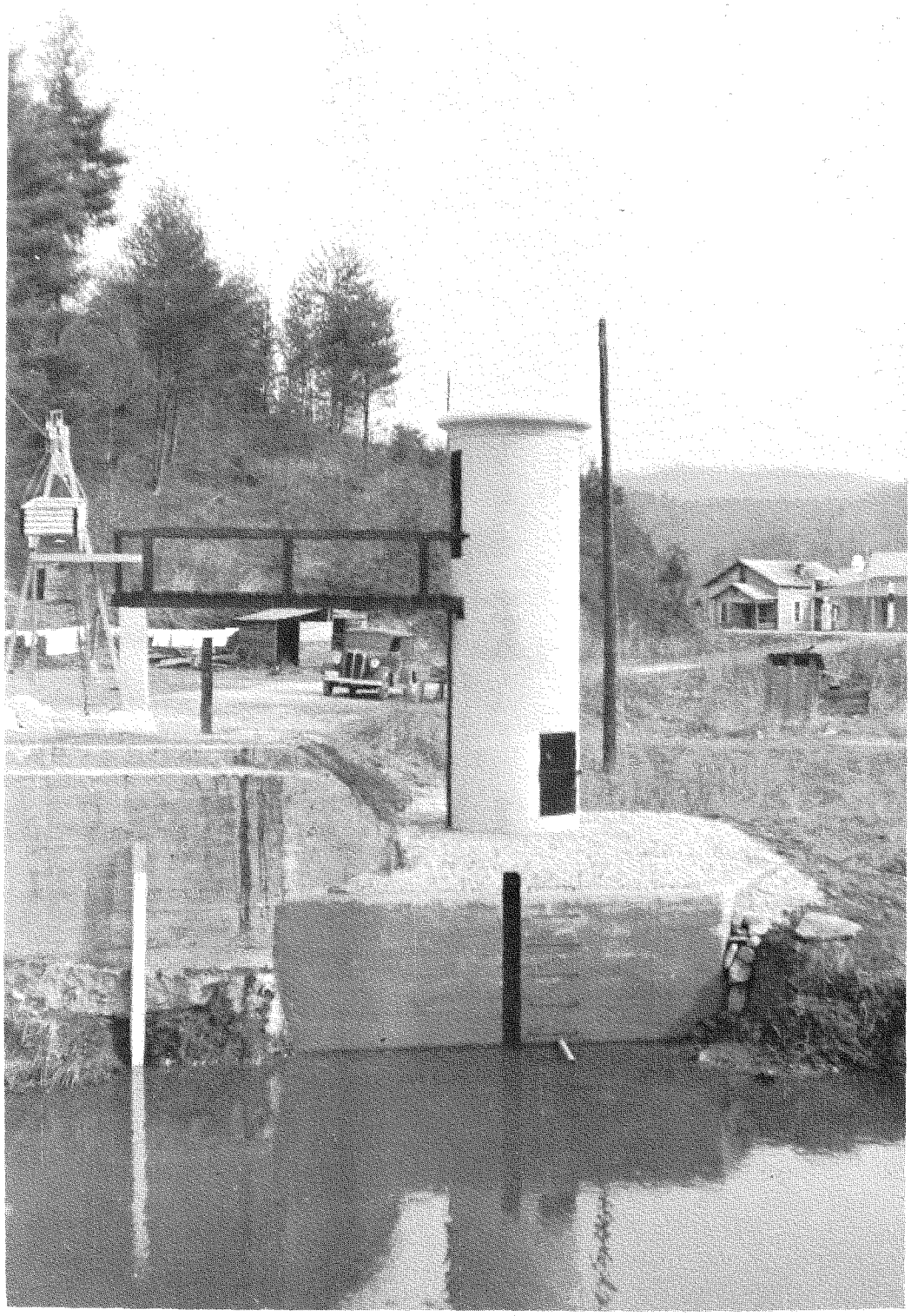

Figure 11.—Concrete-pipe well and shelter. Note clean-out door, staff gage, and upper intake pipe.

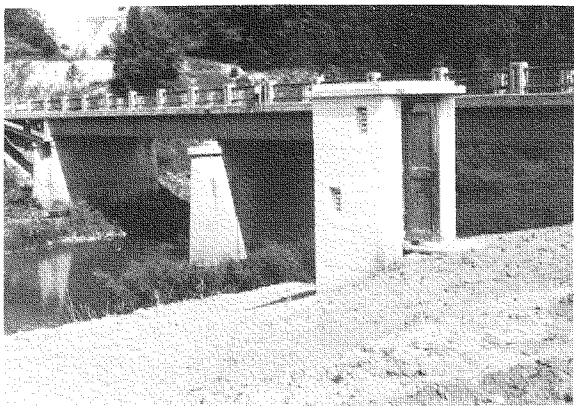

Figure 12.—Concrete-block shelter.

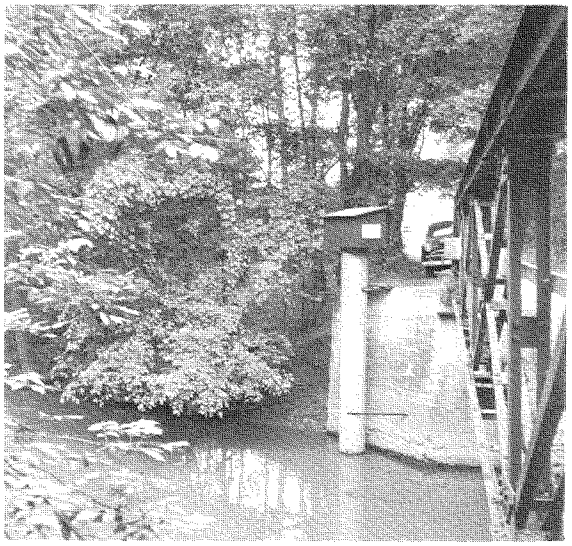

Figure 13.—Steel-pipe well and look-in shelter attached to bridge abutment.

The intake pipe should be large enough for the water in the well to follow the rise and fall of stage without significant delay. The following relationship may be used to determine the lag for an intake pipe for a given rate of change of stage:

$$\Delta h = \frac{0.01}{g} \frac{L}{D} \left(\frac{A_w}{A_p}\right)^2 \left(\frac{dh}{dt}\right)^2,$$

in which

Δh = lag, in feet,
g = acceleration of gravity, in feet per second per second,

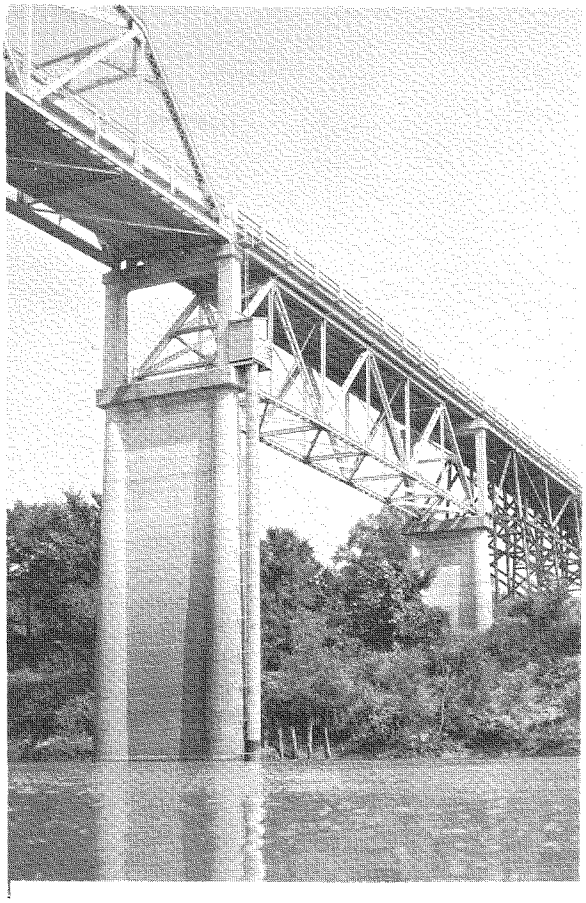

Figure 14.—Corrugated-steel-pipe well and wooden shelter attached to bridge pier.

L = intake length, in feet,
D = intake diameter, in feet,
A_w = area of stilling well, in square feet,
A_p = area of intake pipe, in square feet, and
$\frac{dh}{dt}$ = rate of change of stage, in feet per second.

Smith, Hanson, and Cruff (1965) have studied intake lag in stilling-well systems, relating it to the rate of change of stage of the stream and to the various types and sizes of components which are used in the stilling-well intake system.

The intake pipe should be placed at right angles to the direction of flow, and it should be level. If the velocity past the ends of the intake is high, drawdown or pileup of the water level in the stilling well may occur.

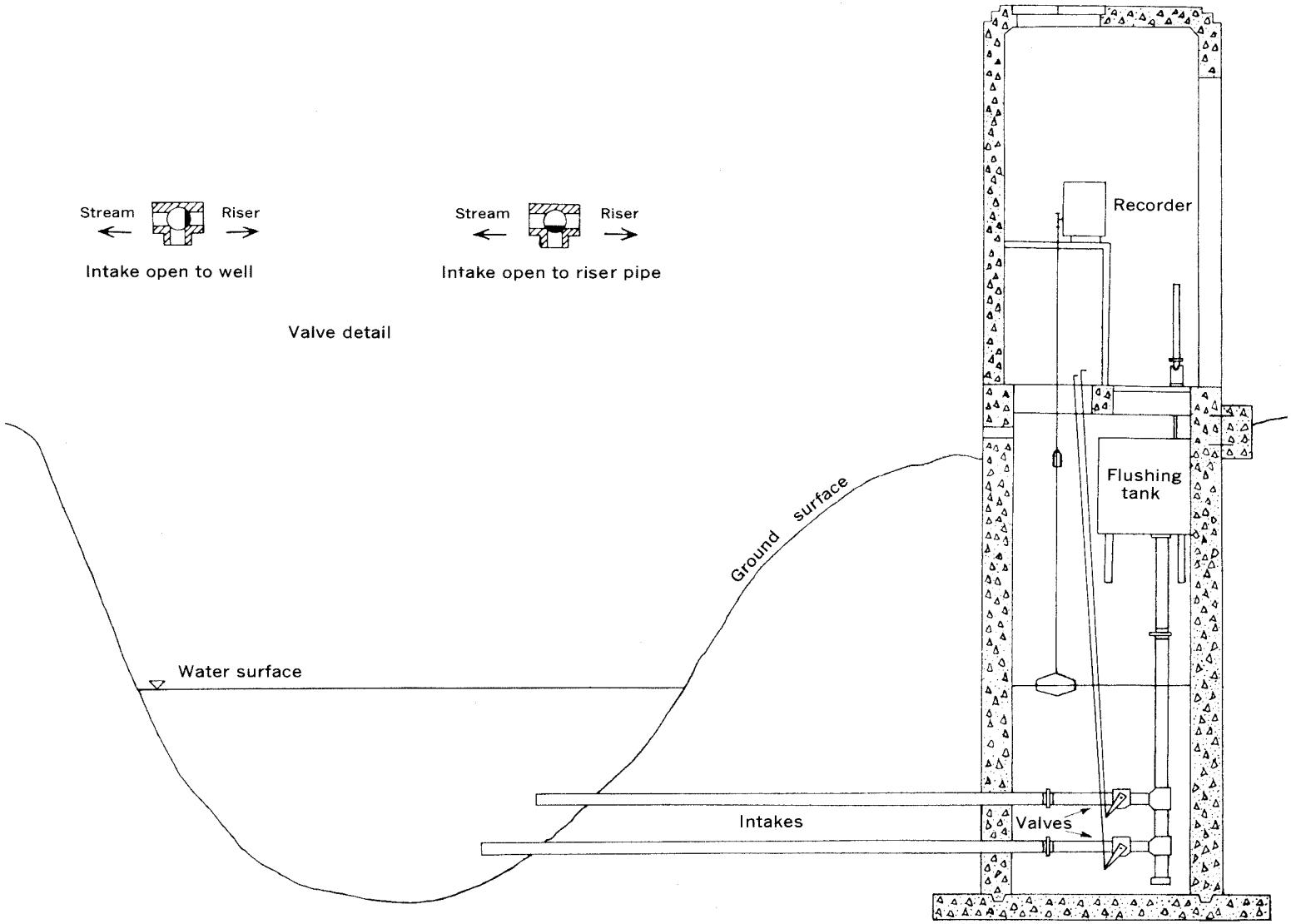

Figure 15.—Flushing system for intakes.

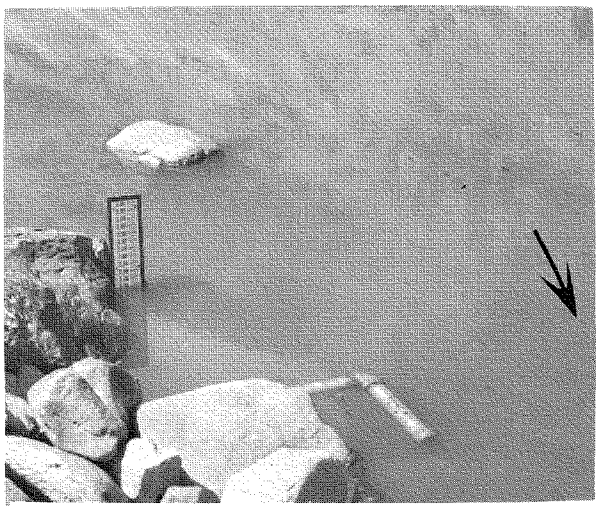

Figure 16.—Static tube for intakes. Note outside reference gage.

To reduce the effect, static tubes can be attached on the stream end of the intake pipe. A static tube is a short length of pipe attached to an elbow or tee on the end of the intake pipe and extending horizontally downstream. (See fig. 16.) The end of the static tube is capped and water enters or leaves through holes drilled in the tube.

The usual means of preventing the formation of ice in the well during cold weather are: (1) subfloors, (2) heaters, and (3) oil.

Subfloors are effective if the station is placed in the bank and has plenty of fill around it. If the subfloor is built in the well below the frostline in the ground, ice will not normally form in the well as long as the stage remains below the subfloor. Holes are cut in the subfloor for the recorder float and weights to pass through, and removable covers are placed over the holes. Subfloors prevent air circulation in the well and the attendant heat transfer.

An electric heater or heat lamps with reflectors may be used to keep the well free of ice. The cost of operation and the availability of electric service at the gaging station are governing factors. Heating cables are often placed in intake pipes to prevent ice from forming.

Oil is used in two ways: (1) where the well is small and leakproof, the oil may be poured into the well, and (2) where the well is large or not leakproof, a tube of sufficient diameter to accommodate the recorder float is placed in the well standing just off the bottom, and oil, usually kerosene, fuel oil, or diesel oil, is put in the tube. The oil tube should be long enough to contain the oil throughout the range in stage expected during the winter. When oil is put in a well, the oil surface stands higher than the water surface in the stream. A correction must therefore be made to obtain the true river stage.

Stilling wells often fill with sediment, especially those located in arid or semiarid parts of the country. If a well is placed on a stream carrying heavy sediment loads it must be cleaned out often to maintain record. In such locations, traps can greatly reduce the work of removing the sediment. A sediment trap consists of a large boxlike structure located between the intake and the main well. Inside it are one or more baffles to facilitate settlement before sediment reaches the well. The trap is made to open for easy removal of the settled material.

The determination of gage height at an outside gage should be made each time the gaging station is serviced. Intakes can become plugged, floats can leak water, oil can leak out of wells or oil tubes, and several other things can happen which can cause the recorded gage height to differ from the stream gage height. Often a comparison of the outside and inside gage heights will reveal the problem, and proper maintenance can be done, corrections can be made, and loss of additional record can be prevented.

Instrument Shelters

Shelters are made of almost every building material available and in various sizes depending on local custom and conditions. (See figs. 8–14). The most convenient type of shelter is one that the hydrographer can enter standing. A shelter with inside dimensions 4 by 4 feet with ceiling height 7 feet above the floor is about the ideal size. Look-in shelters (see fig. 13) are also used at sites

where a limited amount of equipment is to be installed and a portable and inexpensive shelter is desired.

In humid climates, shelters are well ventilated and have a tight floor to prevent entry of water vapor from the well. Screening and other barriers are used over ventilators and other open places in the well or shelter to prevent the entry of insects, rodents, and reptiles.

The bubble gage does not require a stilling well. The instrument shelter for a bubble gage may be installed at any convenient location above the reach of floodwaters. This gage may be used to take advantage of existing natural or artificial features in a stream without costly excavation for well or intake and without need for any external structural support. The bubble gage is especially well suited for short-term installations because the entire station is readily dismantled and relocated with practically no loss of investment.

A shelter with inside dimensions 4 by 4 by 7 feet is needed to accommodate the equipment for a bubble gage. Shelters similar to those in figures 8, 9, and 12 would be adequate. The shelter can be placed on a concrete slab or other suitable foundation. The bubble orifice is placed at least 0.5 foot below the lowest expected stage in the stream. The plastic tube connecting the orifice and the instrument is encased in metal pipe or conduit, or buried to protect it from the elements, animals, and vandalism. A typical

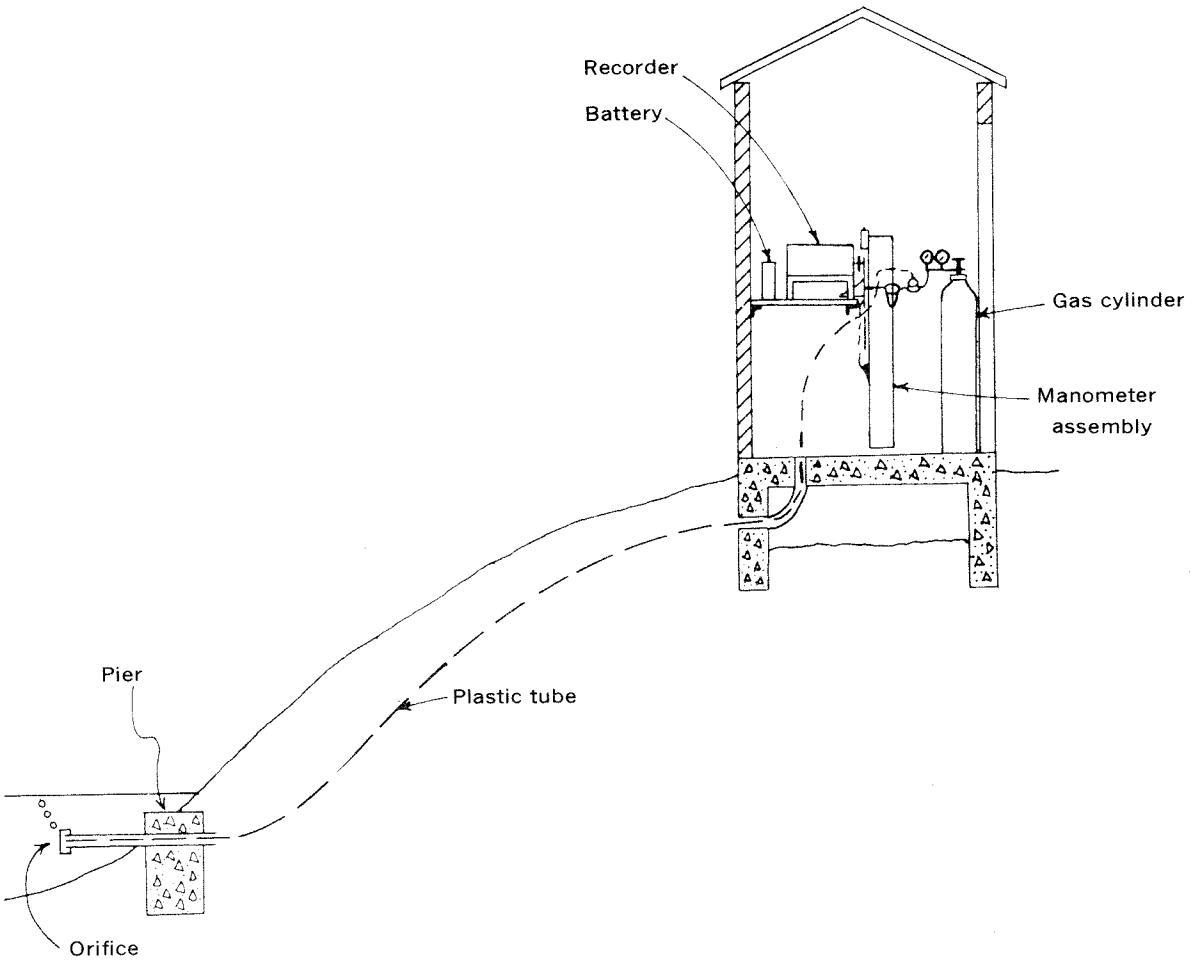

Figure 17.—Typical bubble-gage installation.

bubble-gage installation is shown in figure 17.

Telemetering systems

Telemetering systems are used when current information on stream stage is needed at frequent intervals, and it is impractical to visit the gaging station each time the current stage is needed. Current stage information is usually necessary for reservoir operation, flood forecasting, prediction of flows, and for current-data reporting. The types of telemetering systems are:

1. Those which continuously indicate or record stage at a distance from the gage site. Examples of this type are the position-motor and impulse telemetering systems.
2. Those which report instantaneous gage readings on call or at predetermined intervals. Examples of this type are the Telemark and resistance telemetering systems.

Position-motor system

The position-motor system provides remote registering of water levels on graphic recorders or on counter or dial indicators over distances up to 15 miles. This system employs a pair of self-synchronizing motors—one on the transmitter, whose rotor is actuated by a float-tape gage or a bubble gage, and the other on the receiving unit, whose rotor follows the rotary motion of the transmitting motor to which it is electrically connected. Alternating current is used to operate the system and a five-wire transmission line is required—two excitation wires and three line wires

Impulse system

The impulse system provides remote registering of water levels on graphic recorders or on counter and dial indicators over longer distances than does the position-motor system. This system will operate over leased telephone lines or other metallic circuits. The impulse sender at the gaging station is actuated by a float-tape gage or a bubble gage and sends electrical impulses over the line connecting it to the receiver. This system usually has a battery for the power source at the sender and alternating current at the receiver, though direct current or alternating current may be used at both ends. The advantage of this system over the position-motor system is that it will operate over long distances.

Telemark system

The Telemark system codes the instantaneous stage and signals this information either audibly over telephone circuits or by coded pulses for transmission by radio. The distance of transmission is unlimited since signals can be sent over long-distance telephone circuits or by radio. Telemark response to a telephone ring is automatic. When used in radio transmission, the signals are started by a timing device set for a predetermined broadcast schedule, or the Telemark may be interrogated by radio channel to start the signal.

The Telemark consists of (1) the positioning element which is actuated by a float-tape gage or a bubble gage (see fig. 18), and (2) the signaling element which, when signaled, drives a contact across the signaling drums that are postioned in correspondence with the stage. The Telemark may be operated by either alternating current or by batteries.

A Telemark that operates directly off a digital recorder is available and will probably be increasingly used. This Telemark does not need its own stage sensor; it uses that of the digital recorder. A memory system is used so that when the Telemark is signaled, the last gage height recorded on the digital recorder is transmitted.

Telemarks for radio reporting are equipped with an auxiliary switch and coding bar for transmitting identifying radio station call letters and numbers in international Morse code, in addition to transmitting the stage.

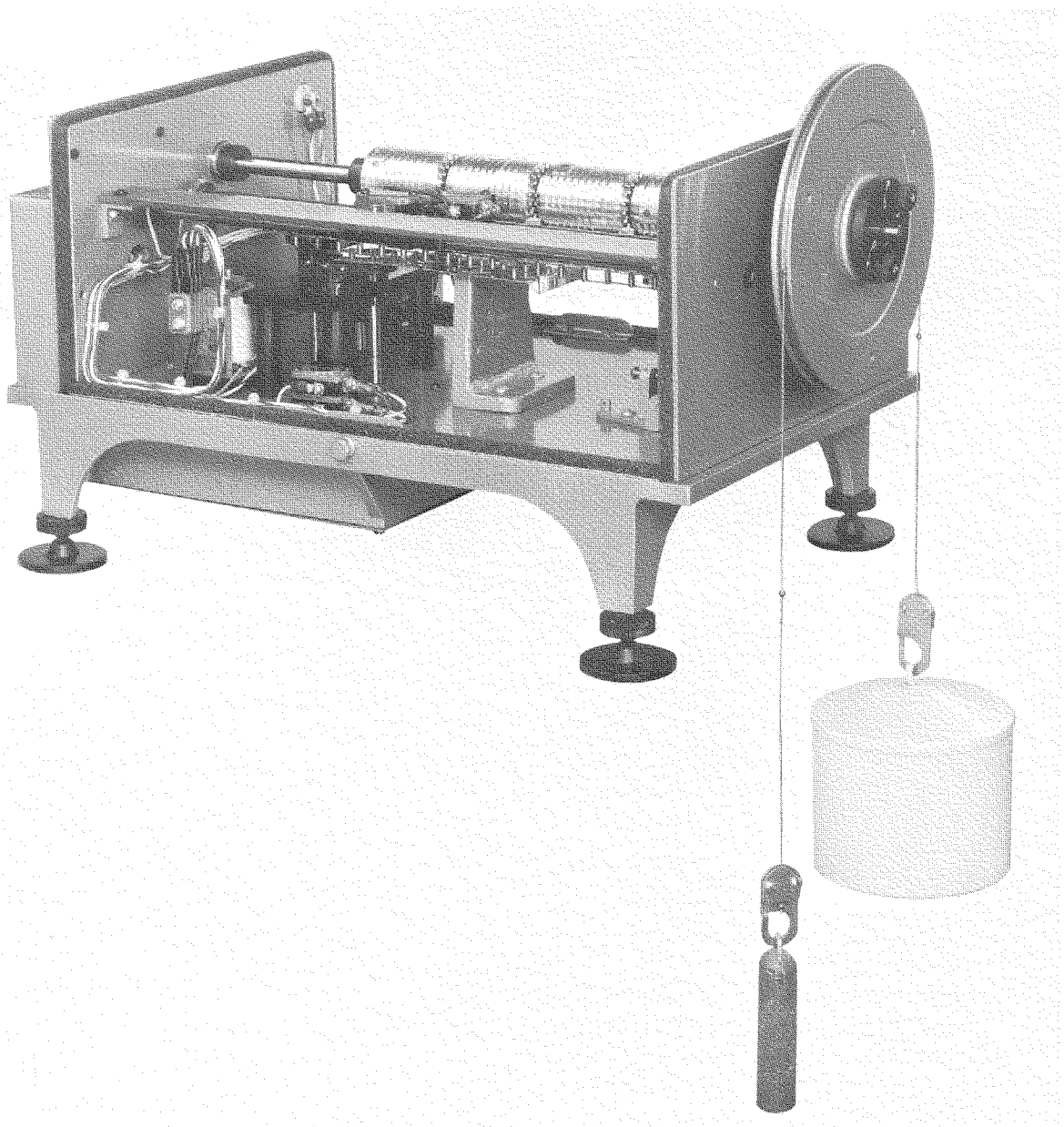

Figure 18.—Telemark gage.

Resistance system

The resistance system was developed by the U.S. Weather Bureau. It provides remote indications of water level for distances up to about 40 miles. Two models are available, one for distances of about a mile and the other for longer distances. The system consists of two potentiometers in a wheatstone-bridge circuit with a microammeter null indicator. One of the potentiometers is located in the gage house and is actuated by a float and pulley assembly. (See fig. 19.) The other potentiometer and the null indicator are housed at the observation site.

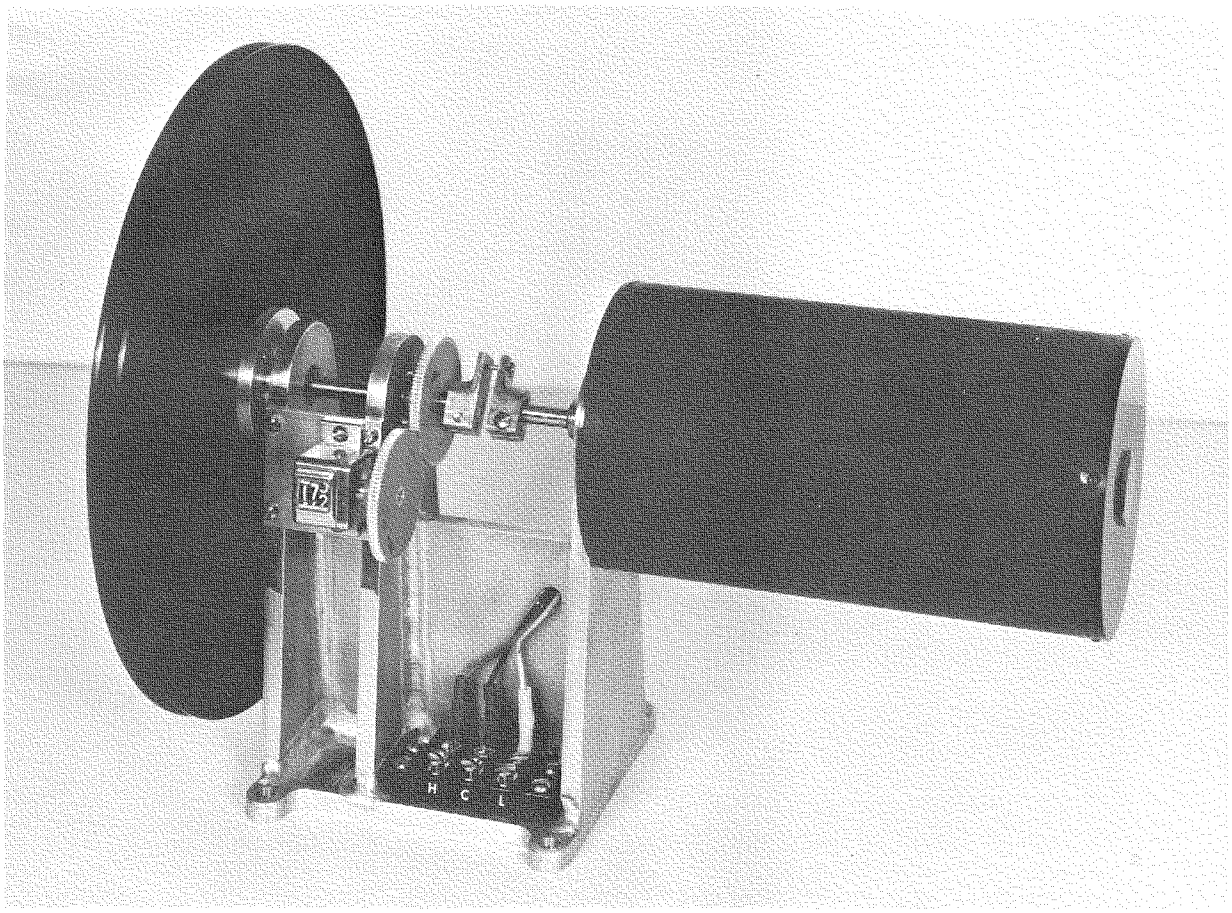

Figure 19.—Resistance system transmitter unit.

(See fig. 20.) By adjusting this potentiometer for a null balance on the meter, the gage height can be read directly to tenths of a foot from a dial coupled to the potentiometer shaft. This system operates on batteries, and three wires connect the unit.

Nonrecording gages

One method of obtaining a record of stage is by the systematic observations of a nonrecording gage. In the early days of the Geological Survey this was the means generally used to obtain records of stage, but now the water-stage recorder is used at practically all gaging stations.

The advantages of nonrecording gages are low initial cost and ease of installation. The disadvantages are the need for an observer and the lack of accuracy of the estimated continuous gage-height graph sketched through points of observation.

Nonrecording gages are still in general use as auxiliary gages at water-stage recorder installations to serve the following purposes:

1. As a reference gage to indicate the water-surface elevation in the stream.
2. As a reference gage to indicate the water-surface elevation in the stilling well. Gage readings on the stream are compared with the reference readings in the well to determine whether stream stage is being obtained in the well.
3. As a temporary substitute for the recorder when the intakes are plugged or there is equipment failure. The outside reference gage can be read as needed by a local ob-

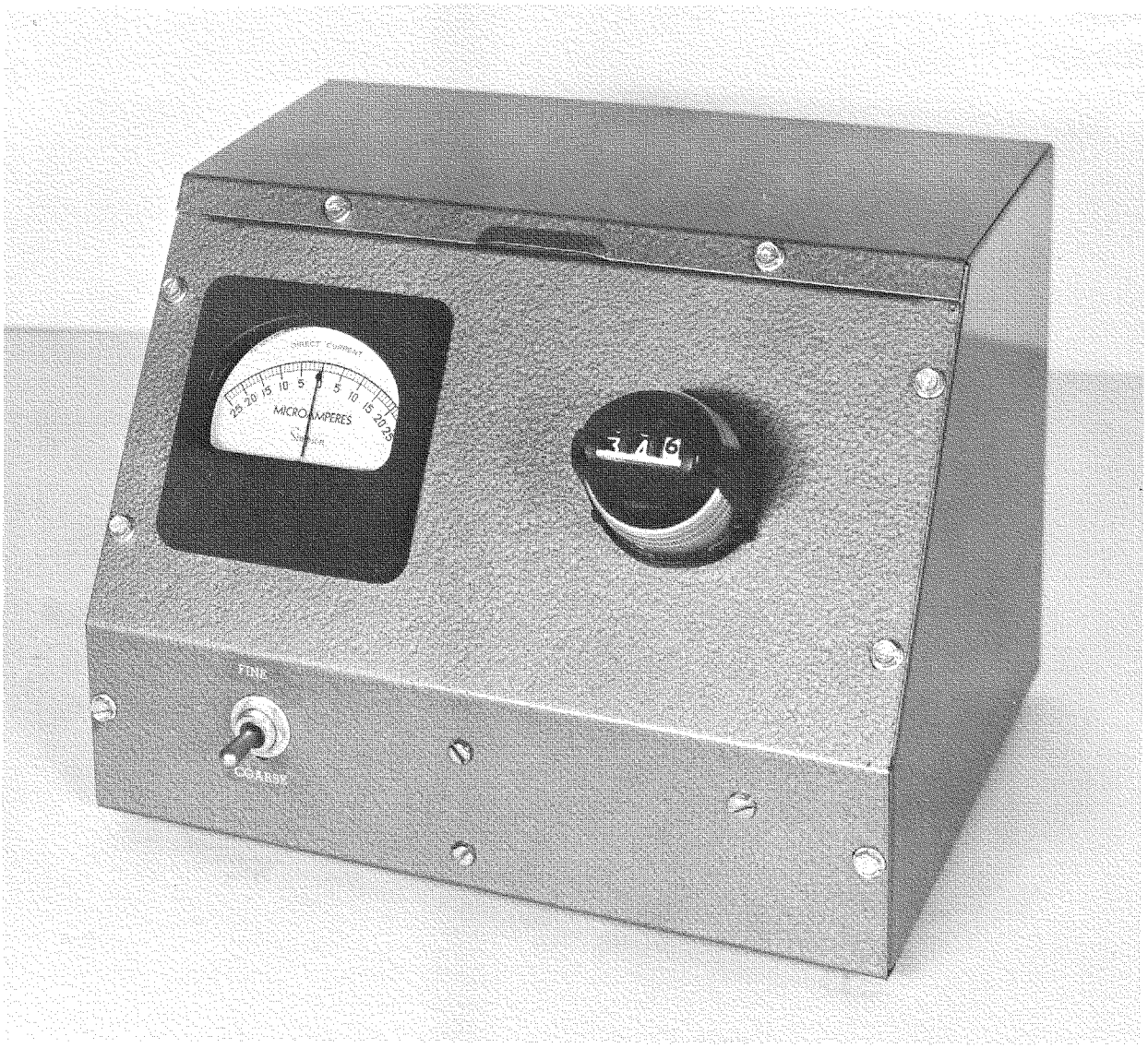

Figure 20.—Resistance system indicator unit.

server to continue the record of stage during the malfunction.

The types of nonrecording gages generally used are staff, wire-weight, float-tape, and electric-tape.

Staff and wire-weight gages are normally used at nonrecording gaging stations. They are also used as the outside reference gage at recording gaging stations. Float- and electric-tape gages and the vertical staff gage are used in stilling wells. Staff gages are read directly whereas the other three types are read by measurement to the water surface from a fixed point.

Staff gage

The staff gage is either vertical or inclined. The standard U.S. Geological Survey vertical staff gage consists of porcelain enameled iron sections 4 inches wide and 3.4 feet long and graduated every 0.02 foot. (See fig. 21.) The vertical staff gage is used in the stilling well as a reference gage or in the stream as an outside gage.

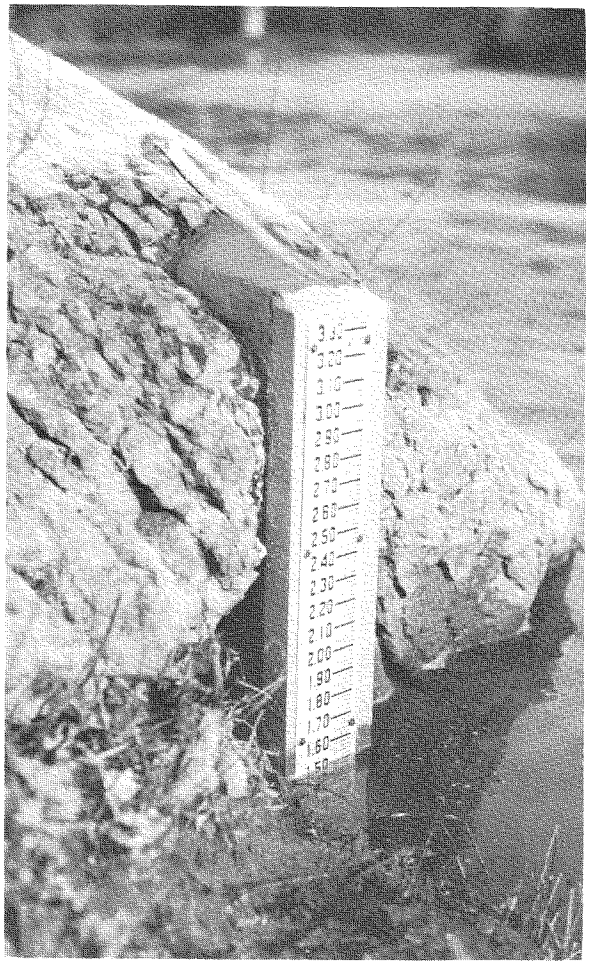

Figure 21.—Vertical staff gage.

An inclined staff gage usually consists of a graduated heavy timber securely attached to a permanent foundation. Inclined gages built flush with the streambank are less likely to be damaged by floods, floating ice, or drift than are projecting vertical staffs. Copper barrelhoop staples and bronze numerals are ordinarily used for the graduations. Inclined gages are used as outside reference gages.

Wire-weight gage

The type A wire-weight gage has replaced the Canfield wire-weight gage at most stations. The type A gage consists of a drum wound with a single layer of cable, a bronze weight attached to the end of the cable, a graduated disc, and a Veeder counter, all within a cast-aluminum box. (See fig. 22.) The disc is graduated in tenths and hundredths of a foot and is permanently connected to the counter and to the shaft of the drum. The cable is made of 0.045-inch diameter stainless-steel wire, and is guided to its position on the drum by a threading sheave. The reel is equipped with a pawl and ratchet for holding the weight at any desired elevation. The diameter of the drum of the reel is such that each complete turn represents a 1-foot movement of the weight. A horizontal checking bar is mounted at the lower edge of the instrument so that when it is moved to the forward position the bottom of the weight will rest on it. The gage is set so that when the bottom of the weight is at the water surface, the gage height is indicated by the combined readings of the counter and the graduated disc. The type A wire-weight gage is used as an outside reference gage.

Float-tape gage

The float-tape gage consists of float, graduated steel tape, counterweight, and pulley. (See fig. 1.) The float pulley is usually 6 inches in diameter, grooved on the circumference to accommodate the tape, and mounted in a standard. An arm extends from the standard to a point slightly beyond the tape to carry an adjustable index. The tape is connected to the float by a clamp which also may be used for making adjustments to the tape reading if the adjustments necessary are too large to be accommodated by the adjustable index. A 10-inch-diameter copper float and a 2-pound lead counterweight are normally used. The float-tape gage is used chiefly as an inside reference gage.

Electric-tape gage

The electric-tape gage consists of a steel tape graduated in feet and hundredths, to which is fastened a cylindrical weight, a reel in a frame for the tape, a 4½–volt battery, and a voltmeter. (See fig. 23.) One ter-

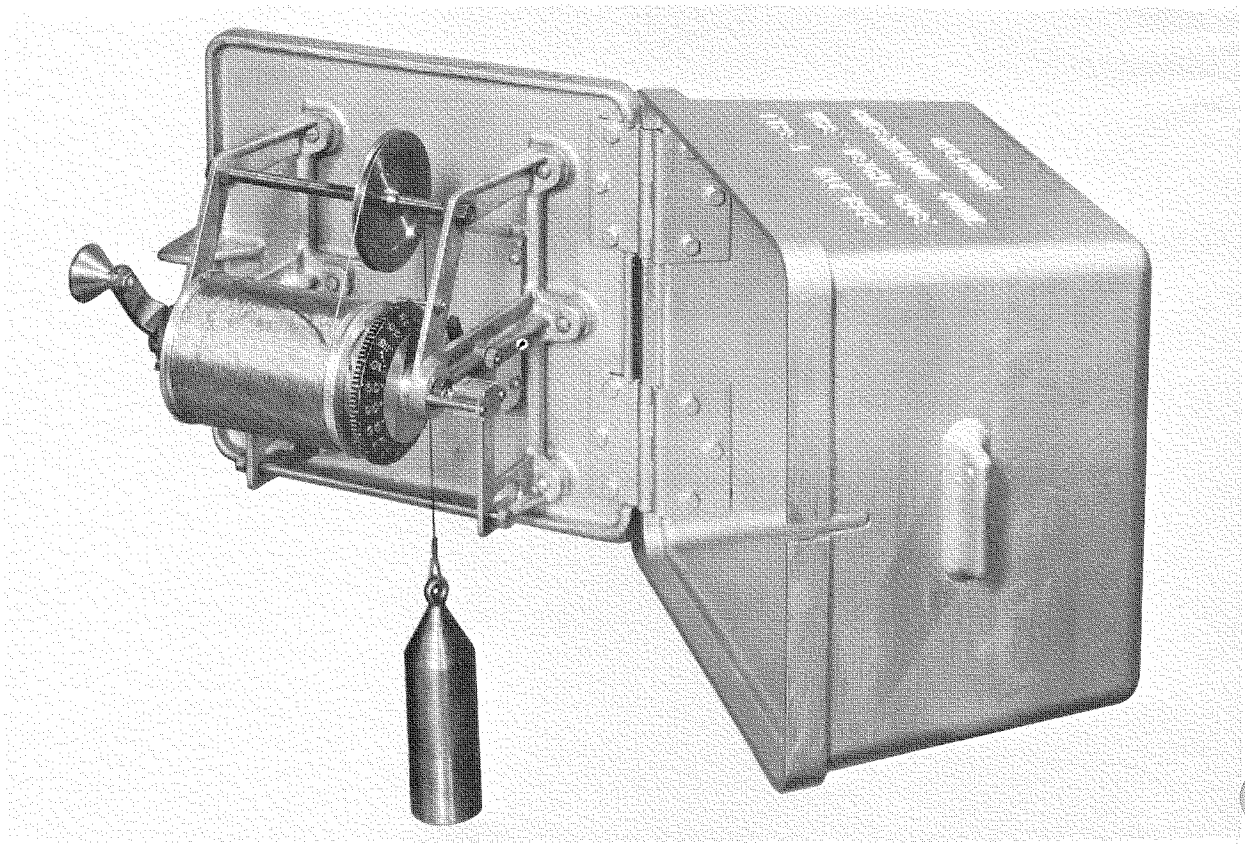

Figure 22.—Type A wire-weight gage.

minal of the battery is attached to a ground connection, and the other to one terminal of the voltmeter. The other terminal of the voltmeter is connected through the frame, reel, and tape, to the weight. The weight is lowered until it contacts the water surface; this contact completes the electric circuit and produces a signal on the voltmeter. With the weight held in the position of first contact, the tape reading is observed at the index provided on the reel mounting. The electric tape gage is used as an inside reference gage and occasionally as an outside reference gage. If oil is floating on the water surface, the gage will give the gage height of the interface, because oil is a dielectric.

Chain gage

A chain gage is used where outside staff gages are hard to maintain and where a bridge, dock or other structure over the water is not available for the location of a wire-weight gage. The chain gage can be mounted on a cantilevered arm which extends out over the stream, or which is made in such a way that it can be tilted to extend over the stream.

The chain gage consists of the cantilevered arm which is firmly held in place, one or more enamel gage sections mounted horizontally on the cantilever, and a heavy sash chain which runs over a pulley on the streamward end of the cantilever. A weight is attached to the streamward end of the chain, and a marker is attached to the chain near the other end. Additional markers can be attached to the chain at appropriate intervals to obtain gage heights greater than that directly obtainable from the mounted gage sections. The chain is mounted so that it moves along the gage sections.

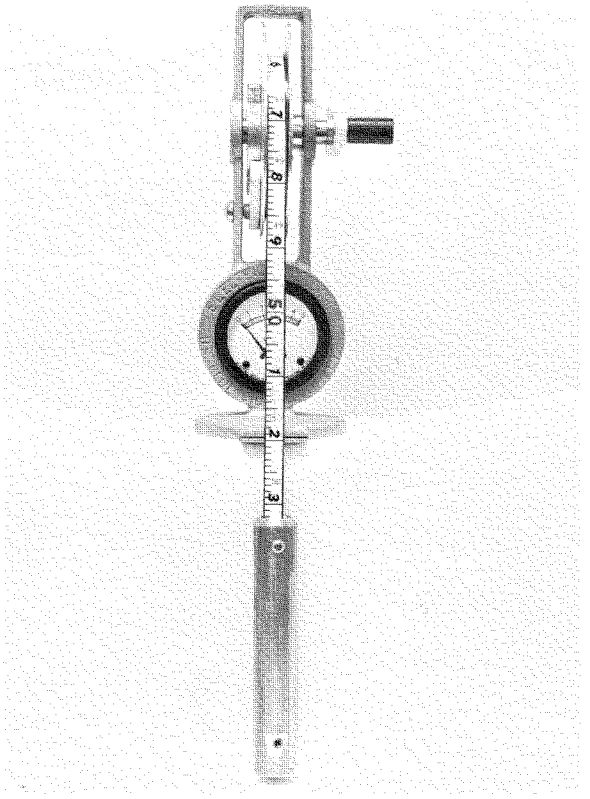

Figure 23.—Electric-tape gage.

Stage is determined by lowering the weight until the bottom of the weight just touches the water surface. The gage height then is read from the mounted gage at the location of the appropriate chain marker.

Remote indicating staff gage

The remote indicating staff gage, (developed by George Smoot, Hydraulic Engineer, U.S. Geological Survey) was designed as an aid for obtaining a record of stage where outside gages are difficult to maintain owing to ice conditions. The gage is a mercury manometer having a stainless-steel reservoir and a vertical glass tubing with a graduated scale. Pressure exerted by the height of water above the orifice is transmitted to the reservoir through a plastic tube by a gas bubbling technique similar to that used with the bubble-gage sensor described earlier. Figure 24 shows the main components of the gage.

Gas is supplied by gently pumping a bicycle pump, attached to the unit, just prior to taking a reading. A check valve is provided in the line to maintain pressure and to prevent water from backing up and freezing in the tube. The length of tubing which can be used is, from an operational viewpoint, unlimited as the system is static at the time of reading and no error due to friction losses is involved.

Limited vertical adjustment to the scale for datum correction can be made by movement of the scale relative to the manometer tubing. Since no temperature correction is provided, the gage should be located in a heated shelter, such as the observer's house if nearby.

Water-level finder

The water-level finder is useful for determining the outside stage at locations where

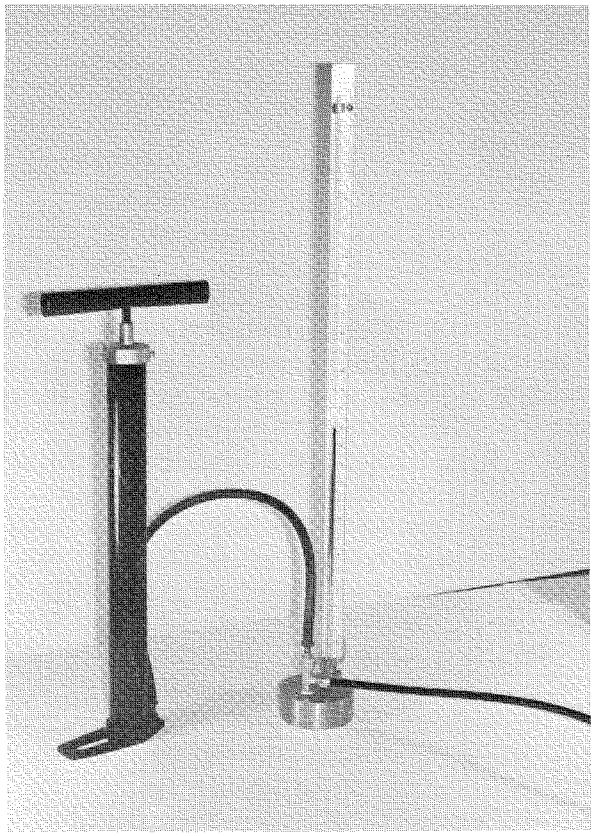

Figure 24.—Remote indicating staff gage.

waves or excess fluctuations of the water surface are present. A sensor is suspended from a graduated tape which is mounted on a reel whose elevation, relative to the gage datum, is known. Mounted with the reel is a milliammeter, battery, and index. The sensor consists of a 10-inch length of 1-inch-diameter pipe with a cap on one end and a brass rod inserted through a hole in the cap. The piece of 10-inch pipe has a small vent near its upper end. The graduated tape is attached to the brass rod which is insulated from the pipe and extends to about the midpoint of the pipe.

The gage height is determined by lowering the sensor to the water surface. When the lower end of the pipe touches the water, the milliammeter will show a small deflection. The sensor is then further lowered until the brass rod touches the water, at which time the milliammeter will show a large deflection. When the large deflection occurs, a reading is made from the tape at the index. Since the pipe acts as a miniature stilling well, an accurate reading can be obtained even in rather rough water.

Operation of stage gages

Continuous records of discharge at a gaging station are computed from the record of stage and the stage-discharge relation. For this purpose stage records to an accuracy of 0.01 foot are generally needed. This accuracy can be obtained by use of the stage-recording systems previously described. Strip-chart or digital recorders are designed to give a continuous record of stage, but careful attention is necessary to prevent malfunctions during unattended periods of 4-6 weeks. Attention to the following items will increase the accuracy and continuity of the stage record:

1. The datum of the gage should be maintained to 0.01 foot by running levels to reference marks at least once every 2–3 years. If conditions are known to be unstable, then levels should be run more often.
2. The recorded gage height should be checked against the water level in the stream during each visit of engineering personnel to insure that intakes are open or that there is no malfunction in the gas-purge system of the bubble gage.
3. Intakes to stilling wells should be properly located and sized to prevent surge. Static tubes or other devices should be installed to insure that the water level in the well is virtually the same as in the stream at all times. Comparison of inside and outside gage readings or comparison of floodmarks with recorded peak gage heights should be made at every opportunity.
4. Malfunctions of the recorder can be reduced by the periodic cleaning and oiling of the recorder and the clock.
5. Excessive humidity and temperatures in the gage house should be reduced to a minimum by proper ventilation.
6. Extremely cold temperatures in the gage house should be modified by providing heat, if this is feasible.

Experience has shown that a program of careful inspection and maintenance will result in a complete gage-height record about 98 percent of the time.

Special purpose gages

Model T recorder

The model T recorder (see fig. 25) is a graphic recorder which has a 1:6 gage-height scale and a time scale of 2.4 inches a day. It is limited in its use to a 3-foot range in stage and should be serviced weekly, although it will record more than one trace on the 7-day chart. The model T recorder is operated by a motor-wound spring-driven timer, and power is supplied to the timer by a 4½-volt battery. A timer is also available which operates on a 1½-volt battery. The housing of the recorder is designed to fit on the top of a vertical 3-inch-diameter pipe which can be used as the stilling well. This recorder is much cheaper and more compact than the conventional graphic re-

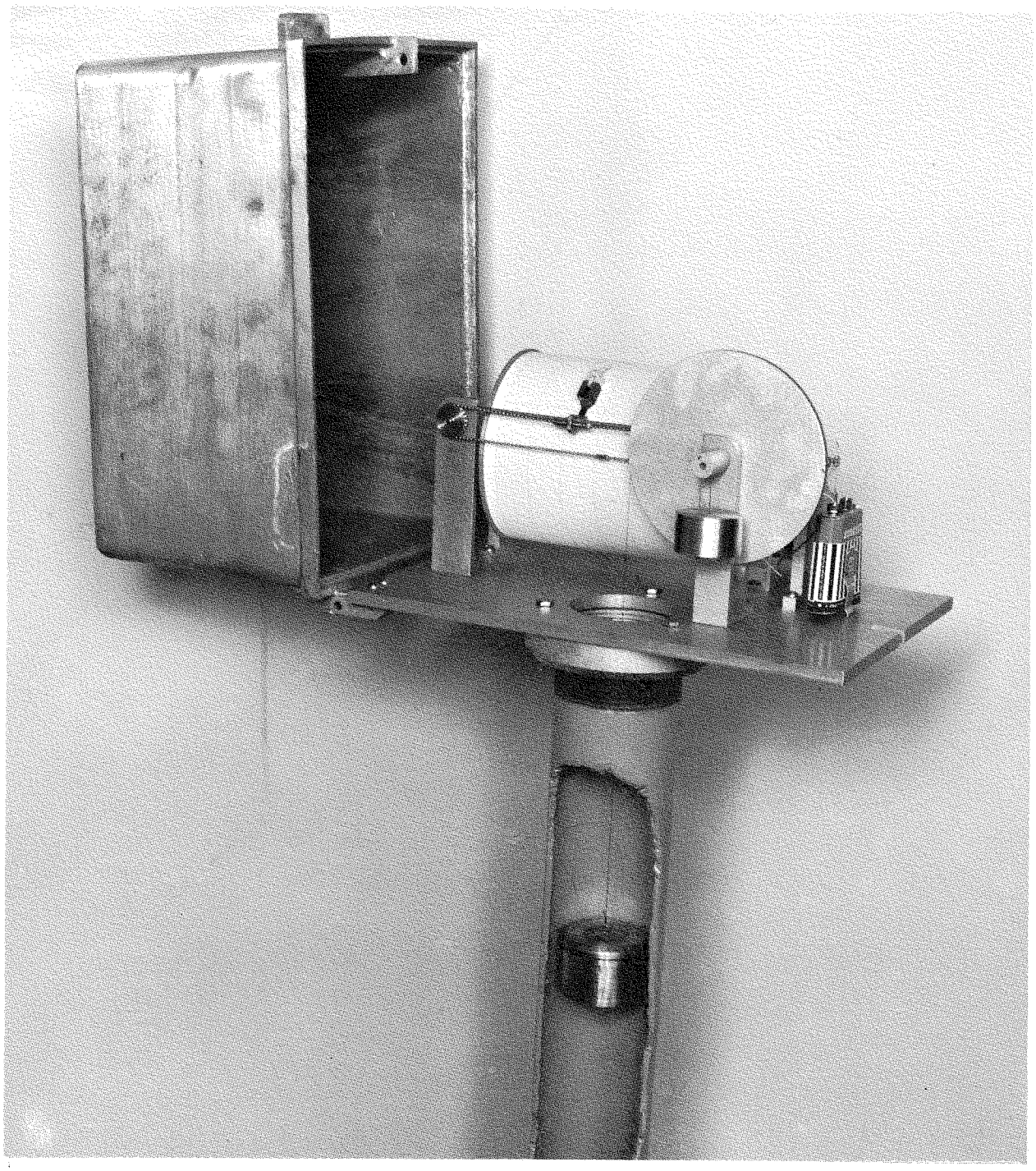

Figure 25.—Model T recorder.

corders and is well suited for temporary installations for low-flow studies. The recorder is not used at continuous-record gaging stations.

SR recorder

The model SR (see fig. 26) is a graphic recorder which records flood stages and rain-

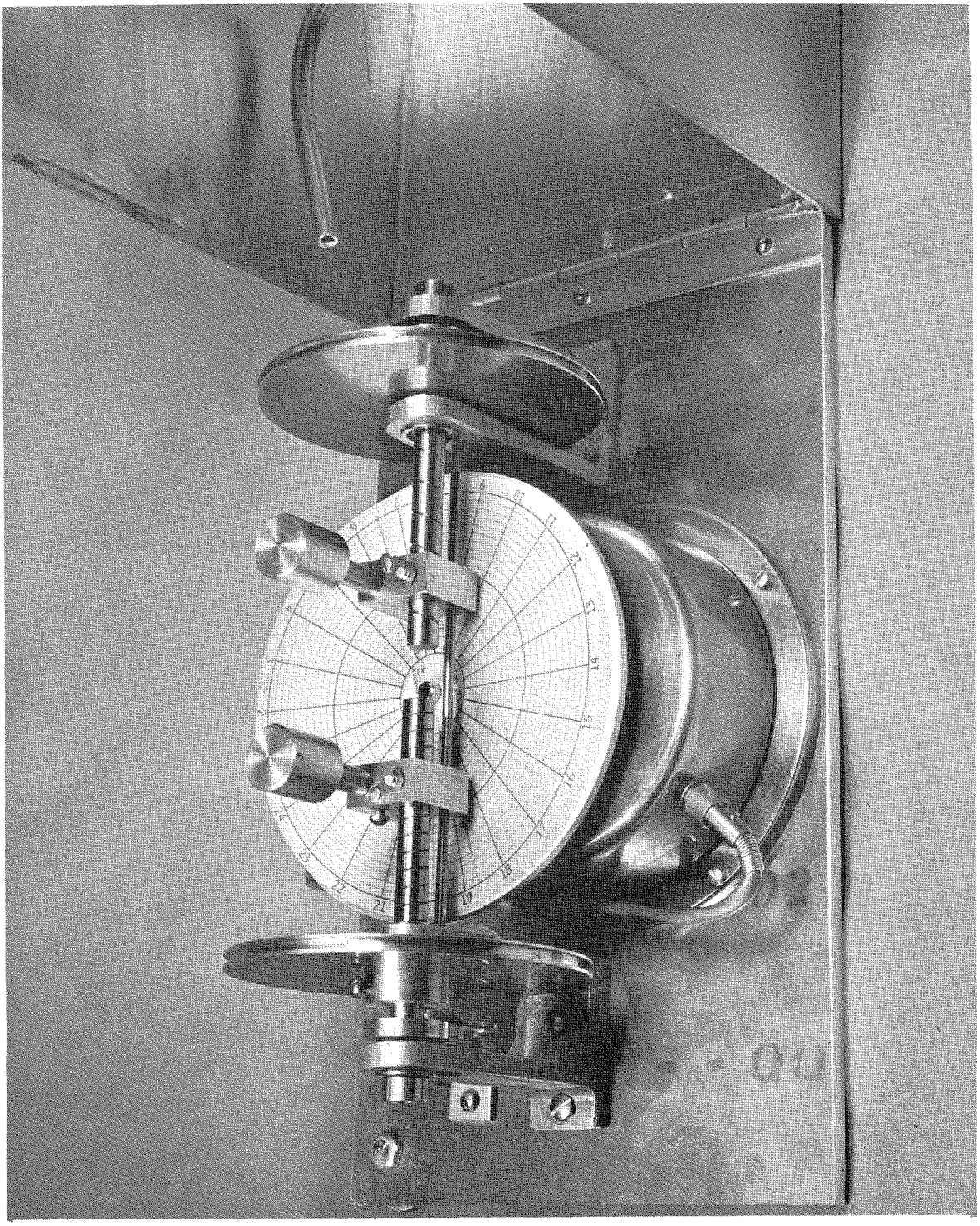

Figure 26.—Model SR recorder.

fall. A 5-inch-diameter flat circular disc is rotated by a battery-wound clock. The power source is a 1½-volt battery. The chart is circular and turns one revolution in 24 hours. Three ranges in stage are available for the effective chart width of 2 inches: 5, 10, or 20 feet. The recorder sits on a 2-inch-diameter pipe which serves as the stilling well (similar to the model T). Five inches of rainfall can also be recorded on the effective width of the chart, but the rainfall reservoir can be equipped with a siphon which will allow an unlimited amount of rainfall to be recorded. The rainfall reservoir is a separate 2-inch-diameter pipe that fills at the rate of 1 foot for each inch of rainfall. After the pipe has filled five feet, the siphon is tripped to empty the pipe.

Crest-stage gage

The crest-stage gage is a device for obtaining the elevation of the flood crest of streams. The gage is receiving widespread use because it is simple, economical, reliable, and easily installed.

Many different types of crest-stage gages have been tested by the Geological Survey. See, for example, Friday (1965) and Carter and Gamble (1963). The one found most satisfactory is a vertical piece of 2-inch galvanized pipe containing a wood or aluminum staff held in a fixed position with relation to a datum reference. (See fig. 27.) The bottom cap has six intake holes located so as to keep the nonhydrostatic drawdown or superelevation inside the pipe to a minimum. Tests have shown this arrangement of intake holes to be effective with velocities up to 10 feet per second, and at angles up to 30 degrees with the direction of flow. The top cap contains one small vent hole.

The bottom cap or a perforated tin cup or copper screening in cup shape attached to the lower end of the staff contains regranulated cork. As the water rises inside the pipe the cork floats on its surface. When the water reaches its peak and starts to recede the cork adheres to the staff inside the pipe, thereby retaining the crest stage of the flood. The gage height of a peak is obtained by measuring the interval on the staff between the reference point and the floodmark. Scaling can be simplified by graduating the staff.

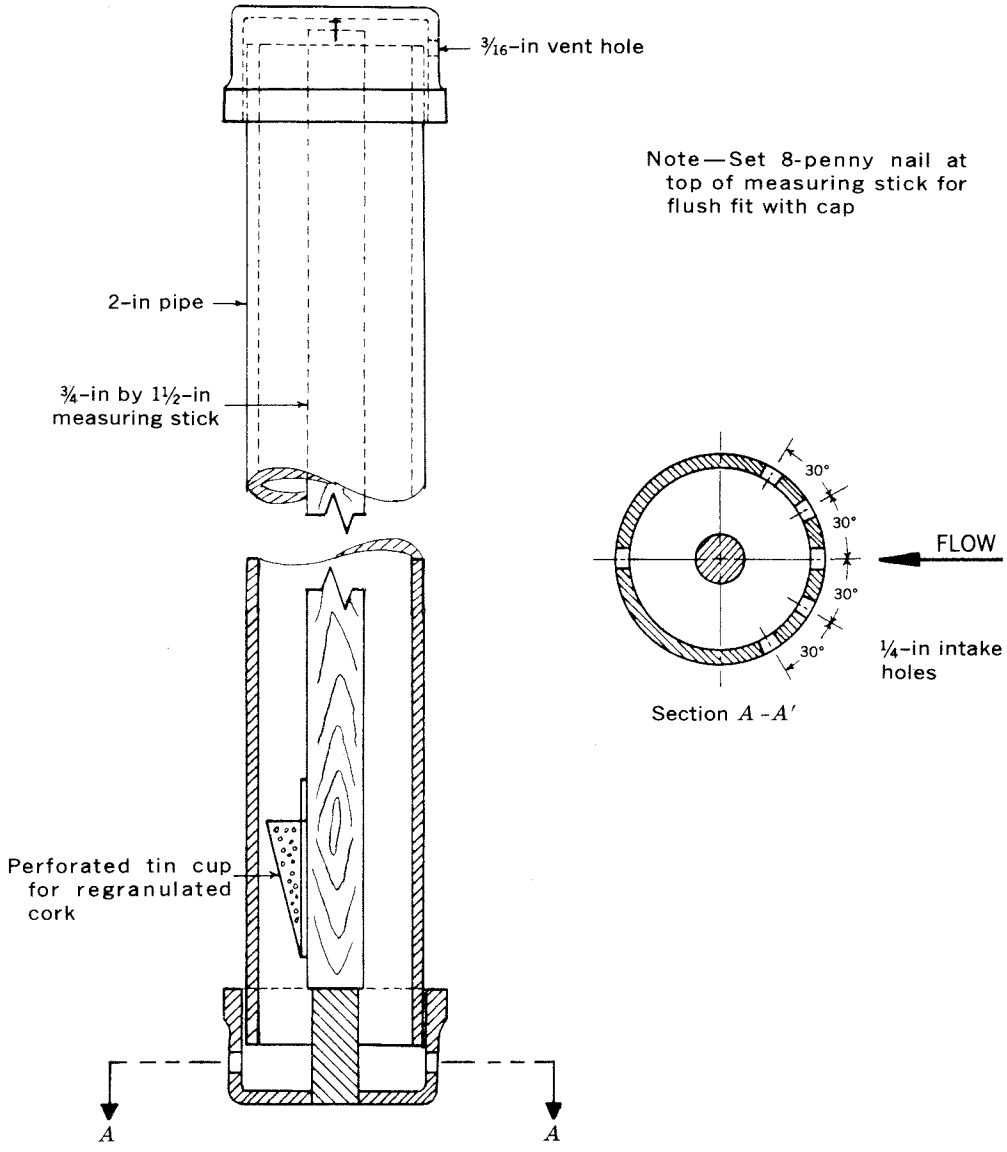

Figure 27.—Crest-stage gage.

References

Barron, E. G., 1963, New instruments for surface-water investigations, *in* Mesnier, G. N., and Iseri, K. T., Selected techniques in water-resources investigations: U.S. Geol. Survey Water-Supply Paper 1669–Z, 64p.

Carter, J. R., and Gamble, C. R., 1963, Tests of crest-stage gage intakes: U.S. Geol. Survey open-file report, Water Resources Division, Washington, D.C.

Friday, John, 1965, Tests of crest-stage intake systems: U.S. Geol. Survey open-file report.

Isherwood, W. L., 1963, Digital water-stage recorder, *in* Mesnier, G. N., and Iseri, K. T., Selected techniques in water-resources investigations: U.S. Geol. Survey Water-Supply Paper 1669–Z, 64p.

Mesnier, G. N., and Iseri, K. T., 1963, Selected techniques in water-resources investigations: U.S. Geol. Survey Water-Supply Paper 1669–Z, 64p.

Smith, Winchell, Hanson, R. L., and Cruff, R. W., 1965, Study of intake lag in conventional stream-gaging stilling wells: U.S. Geol. Survey open-file report, Water Resources Division, Menlo Park, Calif.

☆U.S. Government Printing Office: 1968 0—314-202