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OPERATION MANUAL

SHORE WAVE RECORDER, MARK IX, MODEL 5

BY

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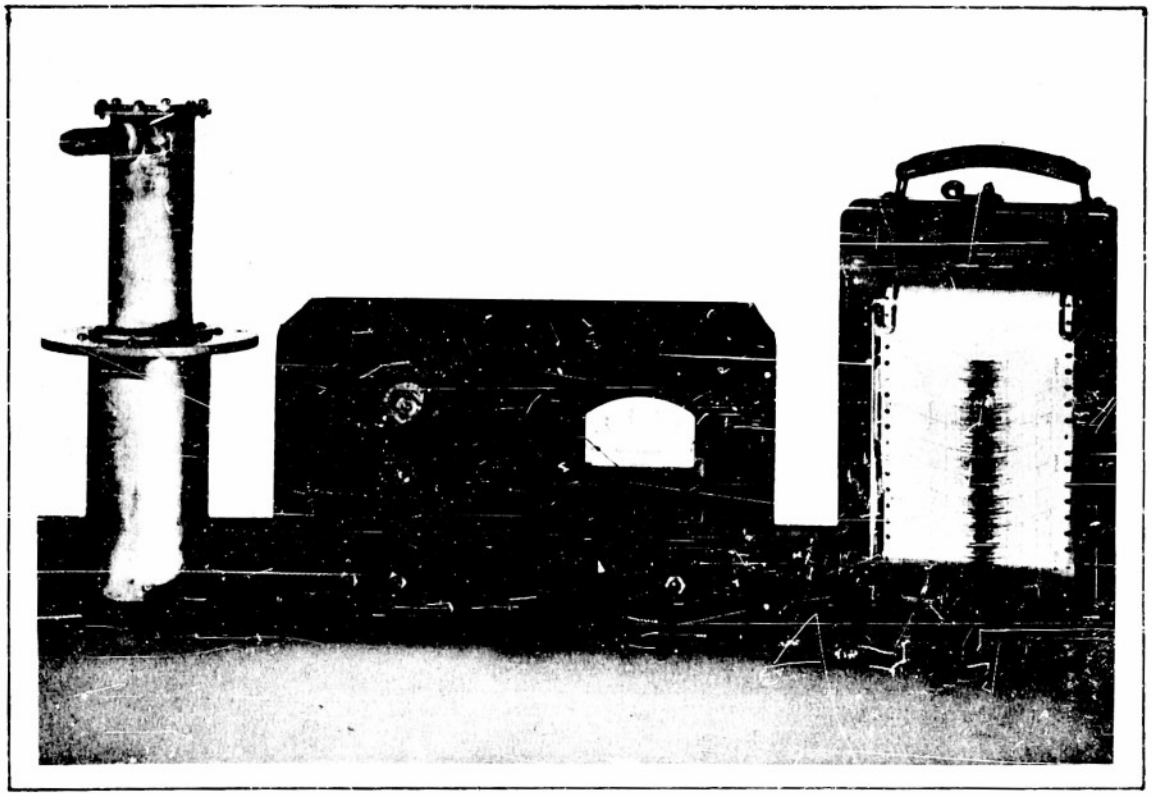
JUNE 1954

UNIVERSITY OF CALIFORNIA



MARK IX SHORE WAVE RECORDER

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ABSTRACT

The Mark IX, Model 5 shore wave recorder is the last of a series of wave recorders developed by the Wave Research Laboratory, University of California, Berkeley. It is the one in most general use at the present time. Units have been installed at several locations along the Pacific Coast of the U.S., at Guam, M.I., at Florida, in the Great Lakes, at the Barbados, B. W.I., and at Denmark. Details are presented on the design and manufacture of the underwater pressure head, the power supply and the bridge unit. Details of actual installation and maintenance of the complete units are also given, as is information on the analysis of the wave records.

INTRODUCTION

The Mark IX shore wave recorder system is designed as a general purpose instrument for permanent installations. Its principal component is the Bourns differential pressure potentiometer, which is used as the unit transducer. The movement of the pressure-sensitive brass bellows is magnified by a potentiometer-contact lever which (in normal position of zero differential pressure) divides the resistance of the potentiometer windings equally. Variations of differential pressure cause the potentiometer contact arm to move across the potentiometer windings. The position variation of the potentiometer arm is converted to a proportional current by the bridge circuit and is recorded by the recording milliammeter.

The low impedance (750 ohms) and high power dissipation (1 watt) of the transducer potentiometer enables the pressure head to be used with practically any type recorder available. An Esterline-Angus recording milliammeter connected in a 24-volt Wheatstone bridge circuit, of which the pressure head forms two legs, is used by the University of California as a standard recording system. Other equipment has been designed for use with this system, including: (1) a telephone telemetering system which provides telemetering over standard telephone circuits, (2) an ordinate distribution analyzer to provide automatic analyses of wave height and (3) an amplifier (now being developed) with a hyperbolic frequency characteristic to convert the pressure record to a surface wave record.

GENERAL DESCRIPTION OF THE COMPLETE SYSTEM

A differential-pressure transducer was selected as the basic component around which the system was designed. This transducer (see Figure 1) is built by the Bourns Laboratories located in Riverside, California, and can be purchased complete, with calibration, ready to be installed in the pressure head. The transducer can be obtained with any sensitivity normally required in oceanographic studies (full scale deflections of 1 to 20 feet of water) with linearity and resolution of one percent of full scale. Life tests in the Bourns

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* This report supercedes a previous report on an earlier model Mark IX (Reference 8)

Laboratory indicated no fatigue or wear failure after 5 million cycles. Field tests of an instrument operated at Elwood, California, for a period of slightly greater than one year also indicated the transducers have long life.

The Bourns transducer, called a Model 503 Differential Pressure Gage, is 2¼ inches in diameter and 2⅜ inches in length with two pressure inlets at one end and three electrical terminals at the other. One pressure port connects to the inside of a bellows while the second port connects to the inside of the pressure-tight case, and therefore, to the outside of the bellows. The bellows is connected through a simple lever system to the arm of a potentiometer. As the differential pressure varies, the arm is moved along a resistance winding approximately 1/2 inch in length. One electrical terminal is connected to each end of the potentiometer winding and one to the potentiometer arm. The potentiometer is rated at 750 ohms with 1 watt power dissipation.

A brass casing houses the transducer, provides a water-tight cable connection, and by means of a slow leak and complacent chamber, provides an average or static pressure which is applied to one pressure port of the transducer. The second pressure port of the transducer is connected directly to the dynamic underwater pressure through a rubber bellows. Details of the complacent chamber cable connection and bellows are discussed under "Pressure Head Design."

Armored submarine cable is used to connect the pressure head to the shore recorder which consists of a power supply, a Wheatstone bridge, and a pen recorder. The power supply can be dry or wet cell batteries connected for a total output of 24 volts, or an electronic power supply operated from a standard 110 volts a-c or d-c power source. The Wheatstone bridge is mounted in the power supply unit and is a conventional circuit except for special calibration potentiometers.

BRIDGE CIRCUIT DESIGN

The problem of designing a Wheatstone bridge using a 0.5-0-0.5 milliampere recording milliammeter in the galvanometer circuit was primarily the problem of selecting circuit constants that provided a reasonable compromise between the conflicting requirements of the circuit. The requirements of the circuit were as follows:

a. The damping resistance of the circuit should not overdamp the recording milliammeter.

b. Sufficient current should flow in the legs of the bridge to prevent errors greater than 1 percent in the recording current.

c. A minimum of power should be supplied to the circuit in order that dry cell operation of the bridge unit is practical.

Frequency response tests indicated that a damping resistance of not less than 10,000 ohms should be connected across the Esterline-Angus recording milliammeter. Considering this resistance to be entirely contained in the meters series resistance, g, (see Figure 2) the voltage across the bridge had to be 20 volts or more. 24 volts was selected for the bridge voltage so that four batteries of 6 volts each could be used as a power source.

A value of 750 ohms was selected for the resistance of the pressure head potentiometer since the Mark III pressure head, which this unit replaces, contained a 750 ohm potentiometer. Equipment designed to operate with the Mark III pressure head therefore could be used with the improved pressure head without modification. The Bourns Laboratories designed a transducer with a special potentiometer that met these specifications (i.e., 750 ohms, 24-volt, 1-watt). Precision resistors of 500 ohms each were selected for the remaining two legs of the bridge circuit.

The equivalent damping resistance and the accuracy with which the position of the potentiometer arm is recorded by the recording milliameter are discussed in the following two sections of this report.

Sensitivity Adjustment:

Under actual operating conditions of the circuit, the exact resistance of the pressure head potentiometer will not be 750 ohms; the calibration of the pressure head transducer (ohms per foot of sea water) will not be exactly the desired values, and the resistance of the submarine cable will vary from nearly zero to several hundred ohms resistance, depending upon the length of cable required. By adjusting the current in the pressure head to a value of 32 milliamperes, the effect of the cable resistance was minimized. If a cable of high resistance is used, the voltage across the bridge is increased, maintaining the 32-milliampere current so that 24 volts always appears across the 750-ohm pressure head potentiometer. By adjusting the resistance in series with the recording milliameter so that full scale current will flow at the desired full scale differential water pressure, the variations in potentiometer resistance and transducer calibration can be compensated. The method of making these adjustments and the error of the adjusted circuit is as follows:

The current that flows in the Esterline-Angus recorder is given by the general bridge equation

$$I_{EA} = \frac{E(bc-ad)}{ab(c+d)+bc\ (a+b)+g(a+b)(c+d)} \qquad (1)$$

where a, b, c, and d, g are the circuit resistance defined in the simplified diagram (see Figure 2) and E is the applied voltage.

Reducing the equation to eliminate b,d, and E by substituting the conditions of the circuit (see Figure 3) $a = b$, $E = I_p(c+d)$ and $d = (c+d)-c$, an equation involving the known constants of the circuit I_p, a, g, and $(c+d)$ and the independent variable, c can be formed.

$$I_{E.A.} = \frac{I_p \left[c - \frac{c+d}{2}\right]}{c - \frac{c^2}{c+d} + \frac{a}{2} + g} \qquad (2)$$

Since the potentiometer arm is at the mid-position of the potentiometer when zero pressure is applied to the pressure head, the independent variable is usually thought of as the displacement of the potentiometer arm from this position. Let y be the resistance between the zero pressure position of the arm and the position of the arm when a pressure, p, is applied to the pressure head. Then

$$y = \frac{c+d}{2} - c \qquad (3)$$

and

$$\alpha = \frac{y}{\frac{c+d}{2}} = 1 - \frac{c}{\frac{c+d}{2}} \qquad (4)$$

where α is the per unit displacement (with respect to the circuit constant $\frac{(c+d)}{2}$ of the potentiometer arm. The independent variable now can be expressed in terms of the per unit deflection of the arm and the resistance $(c+d)$

$$c = \frac{c+d}{2}(1 - \alpha) \qquad (5)$$

and

$$I_{EA.} = \frac{I_p \quad \alpha \quad \frac{c+d}{2}}{\frac{c+d}{4} - \alpha^2 \frac{c+d}{4} + \frac{a}{2} + g} \; . \qquad (6)$$

A further condition of the circuit is that full scale current will flow in the recording milliammeter when the deflection of the potentiometer arm is equal to some value, $\alpha = K$; the circuit will be adjusted so that a given pressure will cause the recorder to register full scale. The system will then be calibrated and the chart width will represent a known total pressure variation.

The necessary resistance of the recording circuit, g, to satisfy the condition that full scale current, $I_{E.A.} = 0.5 \times 10^{-3}$ amperes, will flow when the potentiometer arm is in the position $\alpha = K$ and the impressed voltage is such that $I_p = 32$ milliamperes, can be found from Equation (6):

$$0.5 \cdot 10^{-3} = \frac{32 \cdot 10^{-3} K \frac{c+d}{2}}{\frac{c+d}{4} - K^2 \frac{c+d}{4} + \frac{a}{2} + g} \qquad (7)$$

$$g = 64 K \frac{c+d}{2} + K^2 \frac{c+d}{4} - \frac{c+d}{4} - \frac{a}{2} \; . \qquad (8)$$

The values of the constants in Equation (8) can be defined in terms of the known circuit values as follows:

(1) $c + d = R_p + 2 R_c$ (9)

R_p = resistance of the Bourns potentiometer ohms

R_c = resistance of cable between the bridge and the pressure head; ohms/conductor.

(2) a = resistance of the fixed leg of the bridge = 500 ohms

(3) $$K = \frac{y_{f.s.}}{\frac{c+d}{2}} \qquad (10)$$

where $y_{f.s.}$ = resistance between the zero setting position of the potentiometer arm and the full scale position

$$y_{f.s.} = \frac{R_p}{2C_p} \; Cd \qquad (11)$$

where R_p = total resistance of the Bourns potentiometer

C_p = sensitivity of the Bourns potentiometer in feet of water

C_d = desired full scale calibration of the chart in feet of water.

K can also be computed directly by substituting the formula for $y_{f.s.}$ Equation (4) in the equation for K, Equation (3).

$$K = \frac{R_p}{c + d} \quad \frac{C_d}{C_p} . \tag{12}$$

Knowing the correct resistance of the recording circuit, g, as computed by Equation 8, the resistance of the "sensitivity potentiometers" can be computed as follows

$$R_{LOW} = g_{low} - 15{,}000 - R_c - R_{EA}. \tag{13}$$

where R_{LOW} = resistance of the low sensitivity potentiometer in ohms
R_c = resistance of the cable between the bridge and the pressure head in ohms/conductor
$R_{EA.}$ = resistance of the Esterline Angus recorder in ohms
g = total required resistance as in Equation (8)
15,000 = fixed resistance in the circuit.

Since the dial is calibrated in 100 divisions and the total resistance of the potentiometer is 10,000 ohms, the dial setting on the low sensitivity range is

$$\text{D.S. (low)} = \frac{R_{LOW}}{10{,}000} \; 100 . \tag{14}$$

The high sensitivity dial is set by computing g, Equation (8), using the correct "desired full scale calibration" C_d in Equation (12) to compute K, and using the following equations:

$$R_{HI} = g_{hi} - 6{,}000 - R_c - R_{EA}. \tag{15}$$

$$\text{D.S. (hi)} = \frac{R_{hi}}{5{,}000} \; 100 .$$

Sample Calculations for Sensitivity Potentiometer Settings

Given values

Site: Golden Gate, San Francisco
Bourns potentiometer No. 687
C_p = 10.2 feet sea water full scale
R_p = 746 ohms
Cable resistance: R_c = 10 ohms/conductor
Esterline Angus resistnace = 1325 ohms
Desired Calibration: C_d (low) = 10 ft. (± 5 ft.)
C_d (high) = 5 ft. (± 2.5 ft.)

Low sensitivity dial setting

(1) $c + d = R_p + 2\,R_c = 746 + 2(10) = 766$ ohms
(2) $a = 500$ ohms
(3) $K_{LOW} = \dfrac{R_p}{(c+d)} \; \dfrac{C_d}{C_p} = \dfrac{746}{766} \; \dfrac{10}{10.2} = .955$
(4) $g_{low} = 64K \dfrac{c+d}{2} + K^2 \; \dfrac{c+d}{4} - \dfrac{c+d}{4} - \dfrac{a}{2}$

$= 64(0.955) \dfrac{766}{2} + (0.955)^2 \dfrac{766}{4} - \dfrac{766}{4} - \dfrac{500}{2} = 23142$

(5) $R_{LOW} = g_{low} - 15,000 - R_o - R_{EA}.$

$= 23142 - 15,000 - 10 - 1325 = 6807$ ohms

(6) $D.S. (low) = \frac{R_{LOW}}{10,000} \quad 100 = \underline{\underline{68.0 \text{ divisions}}}$

High sensitivity dial setting:

(1) $c+d = R_p \quad 2R_o = 746+2(10) = 766$ ohms

(2) $a = 500$ ohms

(3) $K_{HI} = \frac{R_p}{(c+d)} \quad \frac{C_d}{C_p} \qquad \frac{746}{766} \quad \frac{5}{10.2} = 0.478$

(4) $g_{hi} = 64K \frac{c+d}{2} \quad K^2 \frac{c+d}{4} - \frac{c+d}{4} - \frac{a}{2}$

$= 64 (0.478) \frac{766}{2} + (0.478)^2 \quad \frac{766}{4} - \frac{766}{4} - \frac{500}{2} = 11306$ ohms

(5) $R_{HI} = g_{hi} - 6,000 - R_o - R_{E.A.}$

$= 11,306 - 6,000 - 10 - 1325 = 3971$ ohms

(6) $D.S. (hi) = \frac{R_{HI}}{5,000} \; 100 = \frac{3971}{5,000} \; 100 = \underline{\underline{79.4 \text{ divisions}}}$

Bridge Circuit Error

Substituting the value of g obtained from Equation (15) in Equation (13) the recording current for any position of the potentiometer arm can be expressed as a function of the desired full scale position of the potentiometer arm and the independent variable, , which represents the potentiometer arm position

$$I_{E.A.} = 0.5 \cdot 10^{-3} \frac{\alpha}{K + \frac{K^2 - \alpha^2}{2 \times 64}} \quad . \tag{16}$$

Assuming that the position of the potentiometer arm varies linearly with differential pressures, the recording current should vary linearly with the position of the potentiometer arm, α, being equal to 0.5×10^{-3} amperes when $\alpha = K$. Letting $I'_{EA.}$ be the correct recording current, we can express the above as

$$I'_{E.A.} = 0.5 \cdot 10^{-3} \; \frac{\alpha}{K} \; . \tag{17}$$

The error in the recording current, expressed as a percent of the full scale current, therefore, is

$$\frac{I'_{E.A.} - I_{E.A.}}{5 \cdot 10^{-3}} \, 100 = \frac{0.5 \cdot 10^{-3} \frac{\alpha}{K} - 0.5 \cdot 10^{-3} \quad \frac{\alpha}{K + \frac{K^2 - \alpha^2}{128}}}{0.5 \cdot 10^{-3}} \tag{18}$$

$$\% \text{ Error} = \frac{\alpha}{K} \quad 1 - \frac{1}{1+K \quad \frac{1-(\alpha/K)^2}{128}} \quad . \tag{19}$$

The maximum error for this circuit is less than 0.5 percent, as shown in the following table, and therefore is unimportant in comparison to the uncertainties of the interpretation of wave records.

PERCENT ERROR AS A FUNCTION OF THE FULL SCALE
CALIBRATION K AND THE POSITION OF THE POTENTIOMETER ARM

$\frac{a}{K}$	K = 0.25	K = 0.50	K = 0.75	K = 1.00
0	0	0	0	0
0.2	0.038	0.077	0.115	0.157
0.4	0.068	0.134	0.202	0.269
0.6	0.078	0.155	0.231	0.308
0.8	0.056	0.116	0.174	0.232
1.0	0	0	0	0

POWER SUPPLY DESIGN

Regulated d-c voltage for operation of the bridge unit is derived from 60-cycle a-c input voltage by passing it through a full wave rectifier, a choke input filter and a voltage regulator (see Figure 4).

The voltage regulator is a series-shunt type having as a reference a 22½-volt battery. A regulator circuit functions in such a way as to maintain a given ratio between the output voltage and the reference voltage.

The reference battery operates without load current and consequently has a life equal to the shelf life of the battery. A second battery, used as a bias in the grid circuit of the series tube, also operates at zero load. These batteries should be replaced approximately once each six months or whenever the current adjustment control on the front panel can no longer be set to provide the correct bridge current.

The circuits of the power supply and regulator are of conventional design and therefore will not be discussed in regard to the theory of operation. Several special features have been included in the design, however, and these details will be discussed, as will the various controls and methods of operation

Regulation

Tests were conducted to determine the effectiveness of the regulator circuit. The results of these tests are shown in Figures 5 and 6 . The operating range of the regulator is shown in Figure 5 and is indicated by the area below the 6Y6 G = 0 bias (90 v. a-c input) line and the 6SH7 zero bias (130 v. a-c input) line. Within this area the regulator is operating; with the output of the regulator adjusted to 24 v. d-c,regulation is obtained with load currents as high as 100 milliamperes. Regulation within this area was found to be of such a degree that variation in output voltage could not be detected without a differential voltmeter. As this regulation exceeded the required regulation, no attempt was made to determine the output error voltages.

Figure 6 indicates the regulation with constant current loads against power line voltage variations. The output of the regulator first was set at 38 volts (with loads of 60 to 180 ma.) and the input voltage decreased until the regulator became inoperative. As the output voltage decreased, the load was adjusted to maintain the given load current. These tests were then repeated with the regulator output adjusted to 24 v. d-c. The output voltage is shown as a straight line when the regulator is within the operating range since no differential voltmeters were used.

These tests indicate that a wide range of load currents can be supplied with large variations in input power. At the normal operating load condition of 24 v. d-c and 56 milliamperes, an extremely wide range of power line voltage (75 v. a-c to 130 v. a-c) can be regulated. This is desirable since many shore sites, such as lighthouses, fishing piers, sand plants and oil piers, have very poor voltage regulation.

The power supply is intended to be operated from 110 v. a-c, 60-cycle power, but also can be operated from 110 v. d-c power. The power supply transformer has been built specially so that the input voltage to the regulator is approximately 110 v. d-c with 110 v. a-c applied at the power transformer primary. Thus, if only 110 v. d-c power is available (as is often the case at lighthouses, where the gages are sometimes installed) the power line can be connected to the input of the regulator with minor changes in circuit wiring, and the circuit functions normally except for the program timer.

The filaments of the regulator circuit tubes have been connected in series so that a minimum of power will be dissipated in the necessary series resistor when the circuit is operated from a 110 v. d-c power source. A 25-volt winding is supplied on the power transformer so that the series connection is also used when operating the circuit from 110 v. a-c power.

Series connection of the filament also has the advantage of protecting the pressure head in the case of tube failure. For example, if the shunt tube (6SH7) should fail, the bias on the series tubes would be lost and the output voltage would increase. With the series filament connection, the shunt tubes also will be made inoperative by failure of the 6SH7 filament, preventing any damage to the bridge connected to the regulator output.

OPERATION OF THE POWER SUPPLY AND BRIDGE

Front Panel Controls (Figure 7)

Sangamo Timer: The timer, driven by a self-starting, synchronous motor, is connected directly across the a-c input line, hence it is in continuous operation regardless of the power switch position. The programming dial can be seen through the window provided in the case. The protective case cover may be removed for adjustment of the programming cams. Two cams are used in fixing the duration of the fast and slow speed runs. Each of these cams has four arms spaced 90° apart to provide 6-hour intervals; (other intervals may be obtained by cutting cams with more or less than the four arms)(see Figure 8). The duration of the fast run may be fixed to a minimum of 15 minutes by careful angular positioning of the "on" and "off" cams with respect to each other. They are securely clamped in place on the shank of the hub by a knurled nut.

In addition to automatic programming of the chart speed, a manual speed shift lever is provided which extends through a slot in the cover of the timer. This lever will shift the chart to the fast speed during any portion of the slow speed interval for additional fast sampling during storm periods. This lever should not be operated if the next fast-speed run is scheduled in less than two hours (minimum off time, 2 hours).

The dial of the timer may be set for the time of day by rotating it clockwise until the correct time is aligned with the red pointer located just below the dial.

Power Switch: With the power switch open, the only element in operation is the Sangamo timer. The rest of the circuit is inoperative including the chart movement, the power to the measuring circuit, the shift mechanism and the warning circuit. When the power switch is closed, the unit will operate according to the programming selected (see "Programming Switches").

Selector Switch: The Model III bridge and power supply unit provides for two pressure heads installed at different locations, or at the same location with one unit as a stand-by. Either pressure head may be operated individually. The selector switch is provided to bring one unit or the other into the bridge circuit. The two pressure heads (if two are used) are wired to the bridge circuit with one conductor common.

Bridge Current Control: To adjust the bridge current, the potentiometer control knob is turned ("cw"for increasing, "ccw" for decreasing) until the bridge current is 32 ma. The bridge milliammeter is located just above this potentiometer control knob on the front panel. The purpose of this adjustment is to provide the correct current in the Bourns differential pressure potentiometer. The output voltage to the bridge circuit is made sufficient by the above adjustment to compensate for the line drop in the cable from the bridge to the pressure head. The "current adjustment" is actually an adjustment of the regulated d-c output voltage of the regulator.

Sensitivity Switch: Two measuring sensitivities are built into the bridge circuit. The range switch may be placed in either of two positions corresponding to high or low sensitivity.

Chassis Controls (Figure 9)

Sensitivity Adjustment: As seen in the circuit diagram, Figure 4, potentiometers are connected in series with the range switch. The purpose, location and application of these potentiometers are given below. Hereafter, their operation will be referred to as sensitivity adjustments.

The dial-skirt knobs connected to the sensitivity adjustment potentiometers are located within the Bridge and Power supply cabinet. By varying the resistance in series with the range resistors, fine adjustments are made to correct for: (a) the change in sensitivity of the bellows-potentiometer transducer due to the air dome error, and (b) variations in the manufacturer's specification of the potentiometer. The setting of the sensitivity adjustments has been discussed under that section "Bridge Circuit Design". A method of calculating the dial setting for the conditions of the installation was presented in this section.

The advantage of this adjustment is that regardless of depth of installation, potentiometer resistance, transducer calibration, and cable resistance, full scale calibration of ± 5-foot and ±10-foot pressure variation can be obtained. There will be slight variations in the correct sensitivity setting caused by variable tides, but this error is well below the expected experimental error in analysis of the subsurface pressure records.

Programming Switches: These switches are located within the cabinet. Switch S_1 is the power programming switch, and Switch S_2 is the chart drive programming switch.

a. Normal programming: In "normal" programming, the Sangamo timer actuates only the magnetic speed shift of the recorder chart drive. With the S_2 switch in position "N", power is being supplied to the bridge circuit continuously as shown in Figure 4. The resulting record consists of a series of fast speed and slow speed intervals showing the time history of the wave action during both speeds. As mentioned before, the time durations of these fast chart speed runs and slow chart speed runs depend upon the positioning of the timer cams in the Sangamo timer.

b. Power programming with continuous chart movement: The power is programmed in that it is being supplied to the measuring circuits during the fast speed portion of the record only. The record obtained using the power programming with continuous chart movement is satisfactory for determining wave height and period, but does not enable a determination of storm arrivals.

Normally, a complete and continuous record is desired for analysis purposes. Formerly, the reason for this type of programming was to extend the life of the potentiometers used in the Mark III type pressure gages. This was accomplished by shutting off the power to the potentiometer and allowing the contact arm to wipe the windings "clean". The potentiometer used in the Mark IX is a more rugged model than the one used in the Mark III, and this procedure should not be necessary solely for attempting to extend the life of the potentiometer.

The switching necessary to effect this type of programming is as follows: $S_1$is placed in position "P" so that the power will be supplied to the bridge circuit according to the timer schedule; S_2 is placed in position "N" which gives continuous chart movement (when the main power switch is on). The resulting record consists of a series of fast chart speed intervals with the recorded time history of the wave action. During the slow chart speed portion, a straight line appears centered on the chart record.

c. Power programming with discontinuous chart movement: This alternative method of programming is essentially the same as the one mentioned above except that the clock chart drive is also programmed. The chart is driven only during the fast speed interval. The switching necessary to effect this type of programming is as follows: The Switch S_1 is placed in position "P", Switch S_2 in position "P". The record consists of a series of fast speed runs giving the time history of the wave action during this period only.

SWITCHING SUMMARY OF RECORD PROGRAMMING METHODS

	Item description	Power Switch	S_1		S_2	
			N	P	N	P
(1)	Normal programming	on	✓		✓	
(2)	Power programming with continuous chart movement	on		✓	✓	
(3)	Power programming with discontinuous chart movement	on		✓		✓

Fuses: As noted in the circuit diagram, one 2-amp. and three 1/16-amp. fuses provide overload protection. The 2-amp fuse provides protection to the input circuit, and the 1/16-amp fuses, located in each line of the bridge circuit, provide protection to the pressure head.

Terminal Board Wiring (Figure 7)

All external connections to the bridge and power supply are made on the main terminal board at the back of the cabinet. Five terminals are provided for the pressure head cables with the "-" lead common. The pressure head's fusite terminals are stamped with "+" and "-" and "CT" (Center Tap) so that with color coded submarine cable there should be little confusion in making the correct connections between the pressure heads and the bridge unit.

Two other sets of terminals include the plus and minus recorder terminals connected to corresponding binding posts on the Esterline-Angus recorder, and the auxiliary 24-volt d-c terminals. The latter may be used in either of two situations:

a. In case of unavailability or failure of a-c power source, the bridge power may be supplied by dry cell batteries. The only drain on the battery supply would be the total bridge current (56 ma.). When batteries are used, the regulator circuit is inoperative, since the filaments of the tubes are not being supplied with power.

b. It may be desirable to use additional capacity of the power supply to operate a complementary instrument (such as the direction indicator). Current may be drawn from the power supply through these connections (100 ma. maximum), in addition to that required by the pressure head.

The shift, clock and a-c common terminals are connected to corresponding terminals on the Esterline-Angus recorder with an a-c common connection to one post of each circuit.

ESTERLINE-ANGUS RECORDER

The instrument used to construct a graphic record is the Esterline-Angus recording milliammeter. The metering element of this instrument is a permanent magnet, moving-coil type. The instrument is housed in a portable case. The writing pen is supplied with ink fed to the point by capillary action. A center zero calibration is used, the range being plus and minus 0.5 milliamperes.

Standard chart drives are available as follows:

a. Slow and rapid speed 8-day spring clock giving all speeds: 3/4, 1½, 3, 6 and 12 inches per hour and inches per minute.

b. Slow and rapid speed synchronous motor clock giving all chart speeds 3/4, 1½, 3, 6 and 12 inches per hour and inches per minute.

For use in conjunction with an automatic programming timer, a magnetic gear shift can be obtained to change chart speed. With this device, the shift from hourly speeds to minute speeds and vice versa may be controlled automatically according to the programming schedule. In addition to the magnetic gear shift, a manual control is available for shifting the chart speed.

Frequency Response

In the standard Esterline-Angus recorder the metal bobbin on which the moving coil is wound is constructed to act as a shorted turn and cause the instrument to be critically damped. Connecting any external circuit to the recorder further increases the damping with the result that the high frequencies are attenuated. At a very nominal extra cost, Esterline-Angus recorders can be purchased with special high resistance bobbins made of nickel-silver which cause the recorders to be underdamped. These special recorders become critically damped when shunted with a resistance of 15,000 ohms.

The damping resistance of the bridge circuit is for all practical purposes the resistance of the galvanometer series resistance, g, as defined in Figure 2. Examination of the circuit diagram shown in Figure 3 indicates this resistance will vary between 12,000 ohms and 24,000 ohms for the various operating conditions of the circuit. The frequency response of both the standard and the special type recorders, therefore, was measured to determine the recorder error at various frequencies. The results of these tests are shown in Figure 10.

Since the shortest period normally encountered in ocean wave measurements is about 5 seconds and the average period is normally between 8 and 15 seconds, the frequency response of either the special or standard recorder with damping between 12,000 ohms and 24,000 ohms is satisfactory. However, if the recorder is used to record waves of shorter period, such as in lakes, special consideration must be given to the damping of the recorder. In this case only the special recorder can be used. If an optimum damping resistance is connected to the recorder, wave periods as short as 1.5 seconds per cycle can be recorded with little error.

BRIDGE UNIT FOR SPEEDOMAX RECORDER

One advantage of the Mark IX pressure head is that it can be adapted for use with any standard recorder. By connecting the potentiometer in a bridge circuit with low voltage applied (10 millivolts, approximately), standard thermocouple recorders, or millivoltmeters, such as the Speedomax or Brown recorder can be used.

One such modification was made for a Speedomax with a +5, 0, -5 millivolt range. The circuit diagram is shown in Figure 11, together with the necessary mounting bracket and other small modifying parts. A photograph of the unit also can be seen in Figure 11.

UNDERWATER PRESSURE HEAD

The Mark IX differential pressure gage is one of several underwater-type instruments that have been designed to measure wave heights by recording subsurface pressure fluctuations. The Mark IX. Model 5 is essentially a modification of the Mark III(5)* instrument which has been used by the University of California since 1947. The Mark IX employs a potentiometer coupled to a pressure-sensitive brass bellows as the electro-mechanical transducer that translates subsurface pressure fluctuations into a proportional current that can be recorded by conventional recording milliammeters. The manufacturing

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* Superscript numbers in parentheses refer to References at end of report.

and assembly drawings are appended (Appendix II).

Pressure Potentiometer

The principal component of the Mark IX is the Bourns differential pressure potentiometer, which is employed as the unit transducer. The movement of the pressure-sensitive brass bellows, contained within the potentiometer case, is magnified by a potentiometer-contact lever which, in the normal position of zero differential pressure, divides the resistance of the potentiometer windings equally. Variations of differential pressure cause the potentiometer contact arm to move across the potentiometer windings. The variation of position of the potentiometer arm is converted to a proportional current by the bridge circuit and recorded by the recording milliammeter.

Pressure Head Construction:

The potentiometer chamber acts as a water tight incasement surrounding the potentiometer unit. A silver soldered separation disc, provided with Fusite hermetically-sealed terminals, divides the connection chamber and the potentiometer chamber. The lower flange of the potentiometer chamber is sealed against surrounding water pressure by an O-ring gasket.

When the instrument is submerged in a given depth of water, the static pressure at this level will act on the rubber bellows clamped on the shoulder provided on the bottom of the mounting flange. The rubber bellows are filled with a silicone fluid (DC 200) and this fluid is forced to flow through two inlets to the potentiometer chamber.

The first of these inlets is fitted with a "slow leak" that restricts the flow of silicone fluid. Normally the screw is adjusted so that the time constant of flow into the transducer is about one minute (see air dome calculations). When the unit is installed in the sea, fluid will flow from between the rubber bellows and the transducer chamber until the pressure within the chamber is equal to the average pressure of the sea. The pressure of the air in the chamber acts on the inside of the bellows in the transducer.

The second inlet is connected directly to the outside of the transducer bellows with no impediment to the flow of fluid from the rubber bellows. The dynamic pressure caused by the action, in addition to the static pressure of the sea, therefore acts on the outside of the transducer bellows. The difference in the pressures on the two sides of the bellows (the dynamic pressure fluctuation caused by wave action) causes the bellows to be displaced.

Cable Connection: The electrical cable is connected to the instrument in a chamber located at the top of the pressure head. Since the inside of the electrical cable is at atmospheric pressure, the shore end being open to the atmosphere, the connection chamber will also be at atmospheric pressure. The chamber, therefore, must be sealed against the pressure of the sea. Standard packing glands were found to be unsatisfactory as pressure seals when an instrument was to be installed for long periods of time, due to the plastic flow of the usual synthetic rubbers in the cable. A cable connection, therefore, was developed which has a clamping ring inside the connection chamber for mechanical strength, and a rubber tape seal between a smooth cable nipple and the electrical cable external to the chamber. Tape seals of this type have been found to be satisfactory for periods of two years.

Transducer Mounting: The Bourns transducer has been mounted in the pressure head with the inlet ports at the top. With the transducer installed in this position, the unit can be filled with fluid to cool and lubricate the potentiometer. The transducer is filled with fluid by opening the transducer case before the transducer is installed in the pressure head. It is not necessary to completely fill the transducer or the pipe leading to the transducer, since it is necessary that the fluid cover only the potentiometer winding.

Fusite Insulators: The fusite insulators which provide a pressure tight electrical connection between the cable connection chamber and the transducer chamber were mounted in soft copper pedestals. This prevents the glass seals from breaking during the soldering operation when assembling the unit.

Rubber Bellows Chamber: An "O"ring seal has been provided in the flange of the rubber bellows chamber so that the rubber bellows chamber can be pressurized for calibration purposes. A simple plate with a gasket seal and appropriate fittings can be clamped against the bottom of the chamber by bolts through the mounting flange for this operation.

The inside of the rubber bellows chamber has been so shaped and dimensioned that the rubber bellows can be pressurized before installation.

Slow Leak: A loose fitting screw in a tapped pipe plug is used as a slow leak in preference to a capillary tube. The screw type leak cannot be plugged from dirt and foreign particles in the fluid as readily as the single hole of a capillary tube.

Tilt Indicator: A tilt indicator has been installed in the connection chamber as a safety feature. The pressure head will operate satisfactorily at moderately large angles of tilt, but will not operate properly if the fluid in the transducer chamber does not cover the slow leak. The primary purpose of the tilt indicator is to indicate whether the tripod is upset during installation, which would cause the instrument to lay on its side.

Air Dome Design: An air space is necessary in the transducer chamber to prevent hydraulic locking of the transducer bellows, and a sufficient air volume must be provided to prevent excessive pressure variation of the air volume due to variation in volume of the transducer bellows. As the bellows is deflected, its volume must necessarily vary in order that work be done on the system; this variation in bellows volume causes an equal variation in air dome volume. The variation in air dome volume in turn causes a pressure variation of the air volume that opposes the dynamic pressure variation causing the bellows to be displaced and thereby reduces the sensitivity of the instrument.

Assuming that a negligible flow of fluid through the slow leak occurs during the relatively short period of the wave generated pressure fluctuations, the differential pressure across the bellows is equal to the instantaneous sea pressure less the instantaneous air volume pressure.

$$(P+p_w) - (P+p_a) = p_w - p_a \qquad (20)$$

where P = average absolute water pressure at instrument

p_w = hydrodynamic pressure of waves

p_a = pressure in the air dome due to the transducer bellows expanding.

The displacement of the bellows and the reading of the instrument is proportional to the differential pressure across the bellows, while the correct reading is proportional to p_w . The per unit instrument error is, therefore,

$$E = \frac{p_w - (p_w - p_a)}{p_w} = \frac{p_a}{p_w} . \qquad (21)$$

The change in volume of the transducer bellows, which is equal to the volume change of the air volume , v_a, is a function of the differential pressure across the bellows and the bellows spring constant c_1

$$v_a = c_1 \; (p_w - p_a) = c_1 p_w (1-E) . \qquad (22)$$

Also the pressure change, p_a, and the bellows volume change, v_a, are related by the gas law and can be expressed to the first approximation as

$$\frac{P}{P+p_a} = \left(\frac{V - v_a}{V}\right)^n \cong 1 - \frac{n \, v_a}{V} \qquad (23)$$

where n, is the polytropic expansion component. Now

$$v_a = \frac{V}{n} \; \frac{p_a}{p_a + P} \qquad (24)$$

and equating Equation (22) and Equation (24), we have

$$c_1 \, p_w \;\; (1-E) = \frac{V}{n} \;\; \frac{p_a}{p_a + P} . \qquad (25)$$

Equation 25 can be solved for the instrument error as a function of the bellows spring constant and the pressure and volume of the air.

$$E = \frac{1}{1 + \frac{V}{c_1 \, n \, P}} \qquad (26)$$

assuming $P + p_a = P$.

For the Mark IX pressure head the volume of the air space cannot be less than 11 cubic inches nor greater than 22 cubic inches, with an optimum working volume of 17 cubic inches (see Pressurization of the Pressure Head). The ± 3.3 psi (± 7.5 feet of sea water) Bourns transducer bellows expands 0.1 cubic inches for full deflection and therefore has a spring constant of 0.1/7.5 cubic inches per foot of sea water pressure. Further, assuming n to be equal to unity for the long period pressure fluctuations of the waves, the instrument error can be calculated for the normal working depths.

$$E = \frac{1}{1 + \frac{V}{c_1 \, P}} .$$

For $c = 0.1/7.5' = 0.0133$ cu. in/ft of water $V = 11, 17, 22$ cu.in.

Depth of instrument in feet	Absolute Pressure. ft. of water	Percent decrease in sensitivity		
		E_{11}	E_{17}	E_{22}
0	33	3.8	2.5	1.9
25	58	6.5	4.4	3.4
50	88	10.6	6.4	5.1
75	108	11.6	7.8	6.1
100	133	13.8	9.4	7.5

The decrease in sensitivity of the pressure head can be compensated by adjusting the sensitivity controls (see Adjustment of Sensitivity Controls) for a correspondingly greater sensitivity. The correction can be made by assuming the Bourns pressure transducer to be correspondingly less sensitive when calculating the sensitivity control settings. Thus if a transducer with a sensitivity of 750 ohms/15 feet of water is to be installed in 50 feet of water, a sensitivity of 750 ohms/1.064 x 15 ft. would be used in the calculations. Regardless of the final volume of the air dome, within the working range of the bellows the recorder sensitivity will be correct within a few percent.

Slow Leak Design

The purpose of the slow leak is to seal the air chamber against the pressure fluctuations generated by the waves, but at the same time to allow a sufficiently rapid flow into and out of the air chamber to prevent the instrument from recording tides. Considering viscous friction as the only factor restricting flow, the flow of fluid through the slow leak is proportional to the pressure across it; that is,

$$\frac{dq}{dt} = c_2 (p_w - p_a) \qquad (27)$$

where q = quantity of fluid in the air dome (in.^{3})

c_2 = slow leak constant ($\frac{\text{in.}^3/\text{sec}}{\text{psi}}$)

p_w = pressure of the water (psi)

p_a = pressure in the air dome (psi)

t = time (sec.).

If the pressure head has been pressurized according to the procedure outlined in "Pressurization of the Pressure Head" of this report, the air volume in the transducer chambers, V, will be 17 cubic inches with the instrument installed in the sea. The absolute pressure in the chamber, P, will be equal to the absolute pressure of the water, and a quantity of fluid, q, will have been forced into the chamber. If an additional quantity of fluid, q, is forced into the chamber, the pressure in the chamber will be

$$p_a = \frac{P V}{V - q} \, . \qquad (28)$$

Therefore

$$q = V - \frac{PV}{p_a} \qquad (29)$$

$$\frac{dq}{dt} = \frac{PV}{{p_a}^2} \frac{dp_a}{dt} \qquad (30)$$

and Equation (27) can be written

$$\frac{PV}{{p_a}^2} \frac{dp_a}{dt} = c_2 (p_w - p_a). \qquad (31)$$

A general solution of Equation (31) cannot be found easily but the special case which covers the normal operating conditions of the instrument can be solved readily. In this special case the assumption is made that the pressure fluctuation in the transducer chamber is small relative to the pressure fluctuation in the sea due to wave action, and therefore the fluctuation in the chamber is very small relative to average pressure. The pressure, p_a, then can be assumed equal to P and Equation (31) can be written

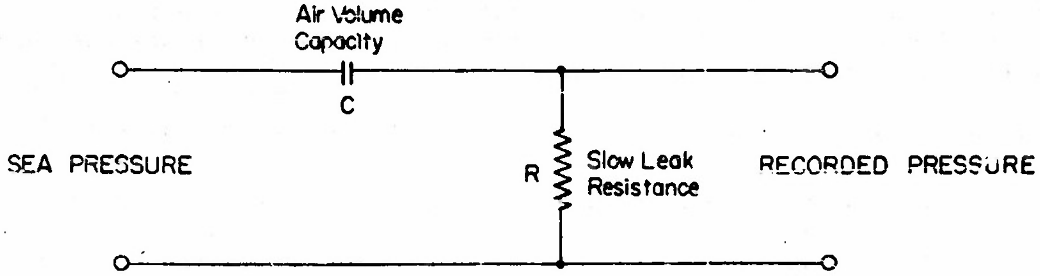
$$\frac{V}{c_2 P} \frac{d\,p_a}{d\,t} = p_w - p_a . \qquad (32)$$

If $p_w = P + p' \sin \frac{2\pi t}{T}$ where P is the average pressure and $p' \sin \frac{2\pi t}{T}$ is the pressure fluctuation due to ocean waves of period, T , Equation (32) can be solved for the response of the instrument which is equal to

$$R = \frac{\text{Pressure variation recorded by the instrument}}{\text{Actual pressure variation due to wave action}}$$

$$R = \frac{1}{\sqrt{1 + \left(\frac{T}{2\pi t_o}\right)^2}} \quad \text{where} \quad t_o = \frac{V}{c_2 P} \qquad (33)$$

The above results can be obtained by assuming that the pressure head can be replaced by the equivalent electrical circuit



Several interesting conclusions can be made from the above results, as follow;

(1) The slow leak can be adjusted for a greater rate of flow than would be intuitively thought possible. The time constant of the instrument can be adjusted to be equal to the longest wave period to be recorded without loss of sensitivity. This means that normally $t_o = V/c_2P$ can be adjusted as low as 15 seconds without jeopardizing the operation of the recorder, since a wave of fifteen second period will be recorded with only a one percent loss in sensitivity. A frequency test on a Mark IX Model 2 instrument showed close agreement between Equation (33) and the operation of the recorder.

Adjusting the slow leak to as rapid a flow as possible is desirable since it will permit the pressure head to be lowered during installation at a faster rate. Also, the slow leak is less subject to plugging with the more rapid flow rates.

(2) The equation for the instrument time constant suggests a simple way to adjust the slow leak. The flow rate c_2, of the slow leak can be measured directly and the time constant of the instrument computed for the condition of the installation. Any attempt to perform "step tests" or "frequency response tests" under conditions equivalent to the final installation would be difficult and the instrument would have to be disassembled to readjust the slow leak screw setting.

(3) After final adjustment of the pressure head, the dynamic operation of the head can be studied at atmospheric pressure and the actual characteristics computed for the final installation pressures.

PRESSURIZING THE PRESSURE HEAD UNIT BEFORE INSTALLATION

General Procedure

The total volume of the rubber bellows when expanded under pressure to the full extent of the lower dome has been measured and found to be equal to 24 cubic inches. If the pressure head contains 20 cubic inches of fluid, and the pressure head then is pressurized, this entire volume of fluid will be forced into the expanded rubber bellows. The volume of fluid is not sufficient to completely fill the bellows, however, and an air pocket will exist above the fluid.

The air pocket in the pressurized rubber bellows has been provided to simplify the pressurization procedure as follows: (1) the slow leak between the air dome and the rubber bellows will not restrict appreciably the flow of air between the two chambers, and therefore will permit rapid pressurization of both chambers without damage to the Bourns transducer; (2) the fluid in the rubber bellows will be in direct contact with the air and will reach an equilibrium between the air pressure and the amount of absorbed air in the fluid in a relatively short time.

The following procedure can be used to pressurize the pressure head unit:

a. Twenty-four hours before installation, pressurize the unit to a pressure equal to the depth of the proposed installation. The fluid will then absorb air from the air-pocket above the fluid until it is saturated for the condition of the final installation. The pressure in the pressure head should be checked every few hours, and repressurized if necessary, until equilibrium is reached. A slight seepage of fluid past the rubber bellows seals may occur at this time, but this seepage will not occur under the conditions of the installation.

b. At the time of the installation, the actual depth of the proposed installation should be checked and the absolute pressure in the pressure head unit reduced to 0.55 x (absolute pressure of the installation depth) or to the pressure calculated in the following sections. The air in solution in the silicone fluid will not be able to escape during this readjustment of the pressure. The readjustment of the pressure can be done any time after equilibrium, as described in part (a), has been reached. It is best, however, to wait until the pressure head has been spliced to the cable and is ready for installation.

Calculation of Initial Pressure

The initial pressure must be adjusted so that the rubber bellows will collapse to the correct working volume, and the air dome pressure will increase to the average or static pressure of the water when the pressure head unit is installed in the sea. The calculation of the initial pressure is based, therefore, on: (1) the final pressure, (2) the initial and final air volumes within the pressure head unit and (3) the initial and final temperature corresponding to the air temperature and the sea temperature. Note that the calculations do not allow for absorption of air by the fluid. It is assumed the fluid is pre-saturated as described in the previous section.

$$P_i = P_f \frac{V_f}{V_i} \quad \frac{T_a}{T_w}$$

where P_i = absolute initial pressure

P_f = absolute final pressure

V_f = final air volume within the pressure head unit

V_i = initial air volume within the pressure head unit

T_a = absolute temperature of the air

T_w = absolute temperature of the water.

The initial air volume within the pressure head is:

$$V_i = V_d + V_b' - 20 = 27 + 24 - 20 = 31 \text{ cu. in.}$$

where V_d = measured net volume of the air dome = 27 cu. in.

V_b' = total volume of the pressurized rubber bellows = 24 cu. in.

20 = total volume of fluid in the pressure head in cubic inches.

In order that the rubber bellows will not affect the instrument reading, the final air volume within the pressure head must remain within a given maximum and minimum volume. If the rubber bellows has collapsed too far, or remains pressed against the walls of the lower dome, the pressure within the bellows will not be the same as the sea pressure and an error will be introduced in the instrument reading. The maximum and minimum allowable final air volume as determined by the maximum and minimum rubber bellows volumes are as follow:

$$(V_f)_{max} = V_d + (V_b)_{max} - 20 = 27 + 15 - 20 = 22 \text{ cu. in.}$$

where V_d = net volume of air dome = 27 cu. in.

$(V_b)_{max}$ = measured maximum working volume of the rubber bellows = 15 cu.in.

$$(V_f)_{min} = V_d + (V_b)_{min} - 20 = 27 + 4 - 20 = 11 \text{ cu. in.}$$

where V_d = net volume of air dome = 27 cu. in.

$(V_b)_{min}$ = measured minimum working volume of the rubber bellows = 4 cu. in.

If the optimum working volume of the rubber bellows of 10 cubic inches is used, and the difference in absolute temperature of the air and water is small, the initial pressure can be computed as follows:

$$P_i = P_f \frac{V_d + (V_b)_{opt} - 20}{V_d + V_b - 20} = P_f \frac{17}{31} = 0.55\ P_f$$

or

$$(P_i)_{gage} = 0.55\ (z + 33) - 33 \quad .44 = \left(\frac{z}{4} - 6.5 \right) \text{psig}$$

where

$(P_i)_{gage}$ = optimum initial gage pressure in psig

z = depth of instrument below surface of water in feet

33 = atmospheric pressure in feet of sea water

.44 = psi/foot of sea water.

After computing the optimum initial pressure, the extremes in final pressure due to tide variations, and the extremes in water temperature variations should be used to calculate the final bellows volume to be sure the volume remains within the allowable range under all conditions.

Initial Pressure for Shallow Working Depths

Approximately 1.5 psig is needed to expand the rubber bellows to the full volume of the lower dome. With an initial pressure of 1.5 psig, the optimum working depth is about 34 feet and the minimum depth is 18 feet.

If the unit is pressurized to force all the fluid into the rubber bellows but without forcing any air into the rubber bellows, the following conditions will be found to exist:

1. Only about 17 cubic inches of fluid will be forced into the rubber bellows due to the height of the slow leak opening in the air dome.
2. The pressure required to expand the rubber bellows to a volume of 17 cubic inches will be approximately 0.25 psi, which can be neglected when considering the initial air dome pressure.
3. The initial volume of air will be $V_d - 3 = 24$ cu. in., and the initial pressure will be atmospheric; the instrument therefore will operate satisfactorily for depths between 3 and 30 feet with an optimum depth of 14 feet.

The procedure for pressurizing the head will be the same as before, except that the final pressure will be adjusted to atmospheric.

1. Twenty-four hours in advance, pressurize the unit to a pressure equal to the depth of the proposed installation.
2. At the time of installation, open the valve in the air dome and allow the pressure in the air dome to decrease to atmospheric.

Any air trapped in the lower bellows will escape quickly through the slow leak leaving the rubber bellows filled with silicone fluid without an air pocket. The valve should remain open approximately 10 seconds.

Equipment Necessary to Pressurize Unit

By adding a pressure gage to a standard bicycle pump, and attaching an ohm-meter to the fusite terminals of the pressure head, (see Figure 12) the following procedure will prevent damage to the transducer:

1. Increase the pressure in the air dome until the ohm-meter indicates zero or 750 ohms (the limit of the potentiometer) and disconnect the tire pump.

2. Allow several minutes for the pressure to equalize between the air dome and the rubber bellows as indicated by the ohm-meter reading returning to $R_p/2$ ohms (usually about 375 ohms).

3. Repeat (1) and (2) until all possible silicone fluid has been forced from the air dome into the rubber bellows.

4. Pressurize the unit to the desired pressure. The ohm-meter will indicate a value near $R_p/2$ at all times during this operation, since the slow leak will be ineffective. Also the check valve in the pump will be ineffective if the pump handle is moved slowly and the pressure in head can be increased or decreased as desired.

INSTALLATION OF THE PRESSURE HEAD

Introduction

Installation of wave recorders can be classified under two general headings, "temporary installations" and "permanent installations". Temporary installations of wave recorders would probably be made in order that wave height and period could be measured for a short period of time, seldom more than a few days. Permanent installations of wave recorders would probably be made to study waves acting at various sites, to determine "wave climate" in the regions of interest.

Selecting the Site:

The general location of a wave gage depends upon the purpose for which it is intended. If data are needed to compile statistical information describing the general wave action along a section of coastline, the gage should be located so that it is well exposed to the open sea. There should be no islands, bars or prominent points to interfere with the waves before they reach the instrument. In this case, the most suitable sites are along straight beaches and at exposed points. If data are needed for a beach of particular interest, the recorder should be located near that beach.

The wave data obtained from gages exposed to the open sea can be used to estimate the amplitude of waves acting at a particular site along the same section of the coast, if the wave direction is also known. Wave direction must be determined by visual observation, or by the study of weather maps, since no satisfactory instrument has been devised to measure and record this factor. Visual observation is often made difficult by local wind chop, which hides the more important swell coming from distant storms. Weather maps are employed to determine the location of the storms which generated the waves, thereby determining the direction from which the waves must have approached the shore. The calculation of wave height at a particular site can then be made providing the following information is known:

1. The wave height, period and direction in deep water.
2. The contours of the bottom over which the waves must pass to reach this site.

These calculations are based on the principles of refraction and diffraction of ocean waves, and will not be discussed herein. The effects of offshore islands, irregular coastline contours and interfering points usually can be determined with reasonable accuracy. These calculations normally are not made to compile data describing the wave action at a particular site, but are made to determine possible critical wave conditions that cause convergence of the wave energy at a particular site.

Gages installed to study the waves acting at a harbor entrance, at a pier, or along a breakwater should be located near the site. Careful attention should be given to the local refraction to determine the relation between the waves at the gage and the site being studied. Often within a few hundred feet a noticeable difference in wave action can be observed. Gages not exposed to the open sea are seldom used in estimating the wave conditions offshore.

Pier Mounted Gages

Piers provide supporting structures from which gages can be installed easily. Unfortunately piers are seldom built in locations exposed to the sea, rather, they are located in protected regions such as coves, bays or where sheltered by offshore islands. At the same time, many piers can be found to provide suitable locations for gages to study local wave action. For example, wave recorders have been located off piers at El Segundo and at Huntington Beach, California, by the Beach Erosion Board, Corps of Engineers, U.S. Army, and the data obtained from them have been used to determine the wave action along the coast of Southern California. When piers are available, a surface type gage, such as the Beach Erosion Board Step Resistance Gage, can be installed, which records the actual variation of water surface elevation(4). Surface fluctuations caused by tides and local wind chop are recorded, and in many cases may be desirable in the record. Pressure type wave recorders, such as the Mark IX (Figure 13) also can be installed easily off piers. By suspending the pressure recorder close to the water surface, pressure records corresponding closely to the surface profile can be obtained. This has been done at Davenport, California, by the Wave Research Laboratory, University of California, Berkeley. Pressure type gages that either do or do not record tides can be used. The extent to which the pressure recorder will reproduce the locally generated short-period waves can be controlled by adjusting the depth at which the gage is installed below the surface.

In some locations offshore oil well structures have been built that provide mountings for wave gages(9). Also, an installation has been completed at Cape Henry, Virginia,(10) in which a step-resistance gage was attached to a pile specially driven for the purpose of installing the gage. The pile, 60 feet in length, was driven 25 feet into the sand bottom at a site 2500 feet from shore; the water depth was 20 feet. The gage was connected by armored cable to recorders located at the shore station. A similar installation has been made by the author, for the University of Texas, off Bakers Beach, San Francisco, California.

Surface type gages, although requiring cleaning at three to four month intervals, can be operated for several years without major repair. Several pressure type gages are also available that provide continuous service for at least one year without repair or maintenance. Either type gage should be installed at least three pile diameters from the nearest pile.

Tripods for Subsurface Pressure Heads:

Pressure type gages, supported by small tripods resting on the ocean bottom, provide a practical method of recording the wave action where there are no piers. The tripods vary in design depending upon the material available, the equipment available for handling the tripod during installation, the size and type of marker buoy to be used, and the size and shape of the pressure head. The two primary requirements of the tripod are as follows:

1. The tripod should have sufficient weight to keep it in place on the bottom, and should be stable so that wave motion or currents can not tip it over. Marker buoys, when acted upon by heavy seas, may exert a considerable upsetting force on the tripod if the marker buoy cable is attached to the top of the tripod. Also, the electrical cable usually attached to the base of the tripod may tend to drag the tripod when the cable is acted upon by longshore currents. Normally tripods weigh between 250 lbs. and 2000 lbs. depending primarily on the marker buoy size and the equipment available for handling the tripod.

2. The tripod should have sufficient height to prevent the "sanding down" of the pressure head; sediment movement is known to occur considerable distances offshore, often changing the bottom elevation by several feet. This is especially true of the seasonal movement of sand onshore during the summer months and offshore during the winter months.

The Woods Hole tripod(13) (Figure 14a) has a special design feature which allows the instrument to be detached from its concrete base in case the unit becomes covered with sand and cannot be lifted without possible breaking of the lifting line. This tripod is made in two parts; a concrete base weighing approximately 300 pounds and a pipe framework which supports the pressure head. A shear pin, whose strength is less than that of the lifting cable, but of sufficient strength to lift the concrete base, holds the two sections of the structure together. A lifting line of 3/8-inch wire rope is attached to the top of the pipe framework and to a marker buoy. If an attempt is made to lift the tripod while it is covered with sand, the shear pin will fail and only the pipe framework need be lifted to recover the instrument. The concrete base of the Woods Hole tripod is provided with a cavity directly below the tripod in which cable can be coiled. A sufficient amount of cable is stored in this cavity to reach the surface of the water, allowing the instrument to be removed and replacement connected without pulling off the bottom any cable which might also be covered with sand.

In Figure 14-b the standard University of California tripod is shown. Its main feature is the circular base, designed for maximum stability. The base is constructed of 3-inch O.D. black iron pipe, in which several holes have been drilled to avoid buoyancy.

In Figure 14c are shown two other tripods used by the Wave Research Group of the University of California. These tripods are usually five to seven feet in height with the instrument located four to five feet above the base. Scrap metal or cast concrete blocks are used to increase the tripod weight. The lifting cable is attached between the top of the tripod and the marker buoy.

Marker Buoys for Subsurface Pressure Heads

In the past the methods of attaching the lifting line and marker buoy had been unsatisfactory. Usually the tripod was lowered to the bottom by a 3/8-inch to 1/2-inch wire rope and a buoy attached to the lifting line after the tripod was in place on the bottom. To provide working cable to pass over the hoisting frame and attach to the winch, the lifting cable length was normally made twice the depth of the water. Several difficulties arose from this type of installation. The continual working of the cable due to the buoy following the surface waves weakened the cable and eventually caused failure. To reduce this action, a small buoy with buoyancy just sufficient to remain afloat under the weight of the cable was used. These small buoys would still break the cable under the action of large waves, especially after several months of exposure of the cable to the salt water.

Marker buoys installed according to Coast Guard Specifications, using chain between the anchor and the buoy, certainly would last a longer time, but would require larger boats to make the installation, and a larger tripod to serve as an anchor. Typical Coast Guard Specifications for a small open-sea type buoy would be as follows: 3rd class special nun buoy, 656 lbs; 3/4-inch chain; maximum water depth 14 fathoms; chain length 2½ times water depth; 2000-pound concrete block anchor. An installation of this type should be serviced once each six months (paint buoy and check chain). The chain should last between one and two years depending upon the amount of wave action.

Greatest wear of the chain occurs between the links that touch bottom during wave troughs at low tide and the links that are lifted off bottom during wave crests at high tide. This wear is due to the rotation of each link as it is lifted. Additional chain may be lifted off bottom during storms and high winds, but the percentage of time is small and the wear of these links is not as critical as that caused by normal wave action.

Using a chain whose entire length cannot be lifted by the buoy allows the use of a relatively small anchor. The anchor serves only to prevent the chain from being dragged along the bottom during large storms. A long chain also prevents any snapping action caused by the buoy lifting all the slack out of the line. This snapping action is probably the greatest cause of cable failure when small round buoys are used with wire cable lifting lines.

The inconveniences of handling larger anchors, buoys and cables, as normally used by the Coast Guard, have prevented their use. A small, light, marker-buoy system that is proving to be more satisfactory, is comprised of a short line and a spar type buoy. The basic idea behind this scheme is to provide a buoy that holds the short line taut at all times to prevent continual working of the line and to prevent failure by snapping action. One such scheme used by the Beach Erosion Board employs a wooden spar buoy approximately five feet in length which is connected to a 3/8-inch wire cable. The length of the cable is adjusted according to the water depth so that the buoy is exposed only at low tide . A positive net buoyance is assumed at all times except possibly during troughs of large waves at low tides.

A second example of the short-line spar-buoy scheme is provided by an installation made at Point Pinos, California, by the Wave Research Group of the University of California (Figure 15). This system employs a 30-foot metal spar-buoy, six inches in diameter, and a five-foot length of chain. The chain is connected between the top of a six-foot 1500-pound tripod and the buoy. The length of the chain is adjusted so that the top of the buoy is exposed at low tide. A net positive buoyance exists at all times and is equal to 150 pounds at the connection between the chain and the tripod when the buoy is completely submerged. This installation was checked after five months of service and was found to be in good condition; very little wear of the chain had taken place.

The disadvantages of the short-line spar-buoy system are twofold;

1) Special provisions must be made to lower and lift the instrument, and
2) The replacement or cleaning of the buoy requires lifting the instrument.

The first difficulty is easily overcome, the instrument can be lowered by a separate line attached to the tripod by a hook which will free itself when the instrument reaches bottom. The instrument can be lifted by lowering a chain noose around the buoy to contact the buoy chain near the top of the tripod. When the noose is pulled tight by the lifting line, the two chains inter-link so that the tripod can be raised.

The second disadvantage of the short-line spar-buoy system, the inconvenience of lifting the instrument for periodic cleaning of the buoy, cannot be overcome simply. Periodic cleaning must be done to prevent excessive sea growth on the buoy. If the growth is allowed to accumulate, the downward drag force exerted by the motion of the water may be sufficient to overcome the net buoyancy with the result that snapping action could take place.

A third scheme combining the features of the short-line spar-buoy type marker and the Coast Guard buoy type marker, has been developed by the University of California (see Figure 16). This system utilizes;
(1) a medium sized spar buoy (15 feet long, 7 inches in diameter, 149 pounds total weight); (2) a small chain (3/8") connecting the buoy to a section of large chain (1") which acts as a "variable anchor"; (3) a lifting chain (3/8") between the one-inch chain and the tripod; and (4) a 1200-pound tripod. The buoy size is determined by the amount of chain to be supported which includes a section of the large chain. The system is designed so that at a -1 foot tide the buoy is exposed two feet; at a 4-foot tide, the buoy is totally submerged. The large chain, therefore, acts as a "variable anchor" in that it reduces the motion of the spar buoy, maintains tension in the buoy chain, and prevents snapping action in the chain.

By adjusting the length of the buoy chain to a length equal to the water depth (at MLLW) less 18 feet, the amount of one-inch anchor chain lifted off the bottom will be sufficient to submerge the buoy at a +4-foot tide. This can be shown as follows (with reference to Figure 16):

Buoyant force of the spar buoy (B) = 17.2 l_1 pounds
Weight of the anchor chain = 9.3 l_2 pounds
Weight of the buoy = 150 pounds
Weight of buoy chain (in air) = 46 pounds.

Therefore

$$17.2\ l_1 = 9.3\ l_2 + 190 \tag{34}$$

and

$$l_1 + l_0 + l_2 = (\text{MLLW}) + T. \tag{35}$$

If the buoy submerges, l_1 will be equal to the length of the buoy (15 feet) and the amount of anchor chain lifted will be:

$$l_2 = \frac{17.2\ (15) - 190}{9.3} = 7.3 \text{ feet}. \tag{36}$$

By adjusting the length of the buoy chain the buoy will be submerged at the desired tide state of four feet. Equation 2 now becomes:

$$l_0 = \text{MLLW} + 4 - 15 - 7.3 = \text{MLLW} - 18.3$$

$$l_0 \cong \text{MLLW} - 18. \tag{37}$$

The length of anchor chain lifted off bottom for any water level can now be determined from Equations 2 and 4.

$$\begin{aligned} l_1 + l_2 &= \text{MLLW} + T - (\text{MLLW}-18) \\ &= T + 18 \end{aligned} \tag{38}$$

and

$$l_2 = 0.649T + 4.14. \tag{39}$$

Equation 6 indicates that the water level must be about 6½ feet below MLLW to cause all of the anchor chain to rest on bottom.

Specifications for Submarine Electrical Cable

A cable that has been used along the Pacific Coast for several years and has proven satisfactory except under very unfavorable conditions has specifications as follows:

Simplex Wire and Cable Company
Anhydrous S.A. Neoprene galvanized armor; jute covered submarine cable.
Conductors #14 - 7 strand #22 tinned
5/64" wall Anhydrex S A colored cotton braid cable, fill waterproof jute tape, 6/64" neoprene
Tape waterproof, jute serve
#10 BWG galvanized armor
Waterproof jute serve

These cables have shown only slight wear over a period of one to two years. One cable which was continually exposed at the uprush of a cobble beach failed in approximately four months. The combination of the alternate exposure of the cable to the water and air, and the abrasion by the cobbles caused a rapid removal of the armor and the subsequent cable failure.

The most suitable cable available on the commercial market for installations where the cable may be subjected to abnormal abrasion and large tension forces is built by the Simplex Wire and Cable Co. The specifications of this cable are as follows:

Anhydrex SA Neoprene galvanized armor
Neoprene jacketed submarine cable
Conductors #14- 7 strands #22 tinned
5/64" wall anhydrex SA colored cotton braid cable- fill waterproof jute tape
6/64" wall neoprene
Tape waterproof jute serve
#10 BWG galvanized armor
5/64" wall neoprene
Two serves seine twine
7/64" wall neoprene
Approximate OD 1.66 inches, 2320 lbs/1000 ft.

Installation of Submarine Electrical Cables:

The installation of the submarine electrical cable between the offshore tripod and the shore station is a relatively simple task under favorable conditions and with proper equipment. Favorable conditions include a straight sandy beach without reefs and a sand bottom from the beach to the instrument. Under these conditions an armored cable can be laid along the bottom without anchors or additional protection and little or no cable wear will take place. The cable will quickly "sand down" so that it is not exposed to the turbulent action of the surf zone or to currents that may exist at times parallel to the beach. After a few months the cables usually will be covered by sand to such depths that they cannot be recovered.

The "sanding down" takes place for two reasons; first, the fluidity of the sand (especially in the surf zone) will allow the cable to settle until it is covered to a depth of a few inches or more; and second, the movement of sand bars--the movement of sand onshore and offshore and the movement of sand along the shore will alternately undercut and bury the cable until it may be covered to a depth of several feet. During the summer when the sand moves toward the beach, the offshore cable may be very near the sand surface, or actually exposed. Directly under the summer berm on the beach the cable may be buried as much as ten feet. Conversely, during the winter the cable may be near the sand surface in the surf zone while offshore it may be buried several feet. The cable seldom, if ever, will be exposed along its entire length.

The greatest danger to the cable exists during storms when the waves approach the shore at a sharp angle. The waves may cut a scarp several feet high (see Figure 17) which will expose the cable to the turbulence and littoral currents of the surf zone during the storm.

Under favorable conditions the armored cable need be used only to cross the surf zone. Unarmored cable can then be spliced to the armored cable and laid along the bottom to the instrument site. The splice normally does not have the full strength of the cable and care must be taken to prevent tension at this point. Anchoring the cable near the splice will reduce the tension of the splice. An installation of this type was made by Wiegel at Oceanside, California(11), which was described as follows:

> "A two thousand foot section of four-conductor armored cable was used through the surf zone, with three thousand feet of two conductor demolition cable, spliced to the end of the armored cable, for the remainder of the distance. The armored cable was faked, in the shape of a figure 8 into the cargo compartment of the DUKW, with the bottom ten feet left sticking up alongside of the craft's gunwale. This was spliced to the top end of the demolition cable which had been faked into the cargo compartment of a second DUKW. The bottom end of the demolition cable then was spliced to the Mark V, No. 1, which, mounted in an iron stand, was placed in the second DUKW. All splices were completed while the craft were still on the beach. The remaining thousand feet of armored cable was laid out on the beach and a bight taken on it with a rope which was attached to the DUKW. This remaining cable was to be pulled out to sea by the DUKW as it went through the surf. In order that there would be no tension on the splice, the demolition cable had been doubled back for about three feet and securely bound to the armored cable."

When reefs exist along the beach (see Figure 17) or the bottom offshore is covered with rock, the cable cannot sand-down and special anchoring of the cable is necessary to hold the cable in place. Anchoring prevents wear of the cable on sharp edges of rocks and prevents excessive tension in the cable due to long lengths of cable being exposed to underwater currents. The problem of rocky bottoms offshore can be dealt with effectively by having a deep sea diver walk the cable, laying it around and between the rocks and perhaps anchoring the cable periodically with concrete blocks set on top of the cable.

At Guam, the problem of laying a cable over a reef was solved by the author in the following manner(7).

> "By installing the cables in the crevices, which extended across the reef face, the cable was not required to withstand the direct force of the breaking waves. However, they were required to withstand large forces due to the turbulence caused by the waves and due to the surge currents present in the crevices. The weight and strength of the armored electrical cable was not considered sufficient to withstand the forces. Both weight and strength were added by lashing the electrical cable to $1\frac{1}{2}$-inch chain (18 pounds per foot) as shown in Figure 18 a and b. The armored cable first was attached to the chain with rings made of 3/8-inch diameter iron rod and then tightly lashed with seizing wire. The iron rings were used to bind the chain and cable together and the seizing wire prevented the electrical cable from being snagged on the bottom during installation. Three hundred and sixty feet of chain was used to reinforce the cable along the section that extended 100 feet shoreward and 260 feet seaward of the reef face."

"The day of the installation of the cable, buoys were brought to the reef and attached to the chain and cable. Fifty-five-gallon buoys were attached at seventy-five-foot intervals to support the electrical cable and three-hundred-gallon buoys were attached at seventy-five-foot intervals to support the chain, as shown schematically in Figure 18c. The small buoys were tied to the electrical cable with manilla rope that was cut to free the buoys after the cable was pulled into position. The large buoys were attached to the chain by steel cable straps which first were passed through the bottom eye of the buoy and then attached to the top eye with a pelican hook. When the chain had been pulled into position, the pelican hook was tripped, allowing the strap to run through the bottom eye to free the chain from the buoy.

The chain was pulled off the reef by the diving tug as follows (Figures 18 d and e). A messenger line was shot to the reef and was used to pull a 1/2-inch diameter manila line off the tug to the reef. This line was tied to the end of the electrical cable and was used to pull the buoyed cable off the reef. A second line then was shot to the reef and was used to pull a four-inch (circumference) manila line to the reef. The four-inch line was used to pull a 3/4-inch steel cable off the reef to the tug. The steel cable, attached to the end of the chain, was used to pull the chain off the reef with the tug's capstan. While the chain was being pulled off the reef, the electric cable was kept taut at all times. This prevented the sections of cable between the buoys from touching the bottom and becoming snagged. When all the cable was pulled off the reef, the buoys were cut free, dropping the cable to the bottom."

Installation of Submarine Electrical Cables by DUKWs

The length of cable usually installed for a wave recorder varies between one thousand and five thousand feet depending upon how far offshore the desired depth of water can be found. Cable-laying ships cannot be used economically to install these short lengths of cable. It is, therefore, necessary to use small boats, landing craft and amphibian vehicles to perform this operation. The DUKW is used more often than the other craft, since it can be loaded with the cable, driven to the shore site and used to lay the cable in one operation. The remarks which follow apply directly to the use of a DUKW to install the cable, but should also apply in general to the use of any small craft.

Figure 19 shows cable spool holders designed to mount 2500-foot spools of armored cable in the cargo compartment of a DUKW. The design includes a foot brake which acts on the rims of the spool to hold tension in the cable as it is being laid. Without the foot brake, the spool will spin due to the weight of the cable hanging in the water and cable will be unreeled faster than the craft progresses.

The cable can also be faked in the DUKW as illustrated in Figure 20. By faking the cable (coiling the cable to form a "figure 8") as shown, the cable can be played out without twisting. A full spool of armored cable (2500 feet) can be stowed in a DUKW cargo compartment without difficulty.

The disadvantages of faking cable in the cargo compartment are as follow;

1. There is always a possibility of the cable becoming tangled and a danger to anyone attempting to free such tangles.

2. There is no simple way to hold tension on the cable being laid and the cable tends to uncoil too rapidly .

3. Considerable work is involved in unspooling and recoiling the heavy armored cable.

Attempts have been made to drag a portion of the cable offshore from a spool mounted on the beach. Not more than 1000 to 1500 feet of armored cable can be dragged by a floating DUKW unless floats are attached to the cable to reduce the bottom friction. The following quotations taken from the field notes of a DUKW party illustrate some of these techniques and the difficulties that can be encountered

Bascom(2)(Figure 21): Installation of a wave recorder at Point Arguello, California.

"In accordance with the plan, the DUKWs entered the water at the Arguello surf station, moved north the four miles of water to Point Arguello, tied up side-by-side and anchored in the lee of a large rock. Radio contact was established between the five men in the DUKWs and the three on the cliff. The DUKWs launched a skiff with one man aboard. The end of a pilot line (½ inch manila) was lowered into the skiff by means of a light linen line slung between the two rocky promontories. The skiff took the pilot line to the DUKWs. With considerable effort, and help in turning the cable spool from the cliff crew, the end of the submarine cable was hauled aboard the DUKW. About 1200 feet of the cable was then flemished down between the two DUKWs in the following manner: the cable was too heavy to pull off the cliff by manpower; therefore, the DUKWs would tow off about 300 to 400 feet of cable, the crew would pull it aboard and flemish it down. This would, of course, pull the DUKWs slowly backward toward the cliff. When they attained their original position they would take a new bend on the cable and tow out a few hundred feet more to repeat the process. When the required 1200 feet was aboard, the DUKWs took a firm grip on the cable; a 55-gallon drum was attached to the cable on the cliff. Thenceforth, the DUKWs pulled the cable straight south from the cliff, stopping at 250-foot intervals for the crew on the cliff to attach another drum. After the last of the 10 drums was attached, the DUKWs continued to pull off cable (unbuoyed), swinging about to the west at the same time. When another 800 feet of cable was off, the drum was braked and the unsupported cable allowed to settle to the bottom. The DUKWs then headed for the buoys which marked the cable course; the floating line of 2500 feet of cable gradually swung around to follow this course. While tension was kept on the cable, the float barrels were cut free. The grip on the cable was then released and the 1200 feet of cable on the DUKWs was allowed to play out over the stern as they moved seaward on the cable course. The end of the cable was sealed and buoyed with a large round marker buoy and cast off. The cable served as its own anchor and the buoy was picked up in the same position the next day."

Bascom(1)(Figure 22): Installation of wave recorder at Heceta Head, Oregon.

"Sea was calm (H_B = 5', T = 10") and the day was clear; there was a light westerly wind. The green DUKW with the spool of cable aboard was backed out to the waters edge. The pressure head was fixed in the triangle and the final connection made and tested. The #511 submarine cable was fastened to the triangle by means of special brackets; the cable was to be towed by the cable sock which was fastened to the cable about ten feet from the triangle. The sock was connected to the grey DUKW with ten feet of 1/4-inch steel cable. The grey DUKW hoisted the triangle in its "A" frame and put out through the surf. The first heave carried the cable about 1,000 feet offshore. At that point the sock slipped on the cable and put the strain on the triangle. To avoid any damage to the instrument, the submarine cable was cut and the DUKW returned to the beach. The cable was retracted and another splice made. The grey DUKW then carried a bight of cable to about 800 feet offshore, dropped it, and returned for the triangle. The procedure was the same as before, but the sock was securely fastened this time. This time the DUKW got to about 1500 feet offshore (30 feet of water). By this time a rather strong wind had come up and carried the DUKW south of its course, the triangle was lowered and buoyed and the party secured."

Bascom(3): Installation of wave recorder at Quillayute, Washington

"The cable was moved out onto the beach and set up in the spool frame so that it would rotate freely. About 1800 feet of the seaward end was flemished down in the hold of a DUKW, and secured there. The DUKW then put out to sea towing the cable behind it. It was hoped that enough cable would be unreeled and dragged off the beach to complete the cable laying in a single operation. Such was not the case. After about 1500 feet was off, the DUKW could move no more; the line securing the cable to the DUKW was cast off and the 1800 feet aboard the DUKW was laid out along the course. The empty DUKW came back ashore, seized a bight of the cable and towed about 100 feet more out to sea. This was a mistake. Apparently underwater obstructions or rapid sand changes held it fast, for although the outer end of the cable was picked up with a grappling hook, the DUKW was unable to tow any more cable out to sea. After landing it was found impossible to winch any part of the cable back ashore. This means that about 1000 feet of the cable is still in a large loop in the surf zone, probably lost forever. Enough cable was then unlaid from the reel to adequately complete the shore end. The remaining cable was flemished down on the DUKW, taken out to sea and the seaward end of the laid cable was recovered and a splice was made. The rest of the cable was then laid off the DUKW and buoyed."

Splicing Cable to Pressure Head:

The steps involved are illustrated in Figure 23.

1. Figure 23a shows the cable inserted in the tapered sleeve and clamped into position. The conductors have been stripped back approximately $\frac{1}{2}$ inch and flexible leads have been soldered to the fusite terminals.

2. Figure 23b shows the spliced connection that joins the cable conductors to the fusite terminal leads. This junction has been made by using Burndy #10 Hylug solderless connectors.

3. Figure 23c illustrates the next step in the procedure. (a) The junction has been insulated by a short piece of Wasco # 608, gauge #2 spaghetti bound in place by electrical splicing twine. (b) The excess length of fusite lead and cable conductors is stuffed into the connection chamber. (c) The cable and sleeve have been wrapped with alternate layers of rubber tape and rubber cement to form a homogeneous water-tight seal at the point of entry of the cable to the connector chamber.

4. Figure 23d illustrates the final step in the splicing and insulating procedure; the filling of the void remaining in the connection chamber with Dow Corning DC-4 Silicone Compound, and wrapping the cable with friction tape.

MAINTENANCE

The Mark IX, Model 5 is the most satisfactory instrument developed to date at the Wave Research Laboratory, University of California. However, in common with any instrument used in the field, it must be checked at short intervals, and in case of poor, or no operation, the trouble must be found and the system repaired. Following is the procedure.

Standard Test Procedure

For maintenance purposes, it is necessary to use a 750-ohm potentiometer as a "Dummy pressure head" in order to test the shore equipment. Unless there are two pressure heads at sea connected to the power supply and bridge unit, the dummy should be connected to the Pressure Head No. 2 lugs at the rear of the power supply and bridge unit.

When the pressure head is being installed, the power supply and bridge unit is adjusted as outlined previously. Then the dummy head is switched into the circuit and the settings on it to give full scale deflection of the Esterline-Angus recorder are noted. It can then be used in trouble shooting

1.0 Switch the "pressure head" from the pressure head at sea to the dummy pressure head. This disconnects the sea cable and pressure head and connects the 750-ohm potentiometer "dummy pressure head" (which can be controlled from the front panel). The bridge current, indicated by the front panel meter should remain at 32 ma. (normal bridge current). The following tests then should be made

1.1 Rotation of the bridge current control should cause the bridge current to vary between 28 and 45 milliamperes. If the bridge current cannot be varied over this range either the tubes or the batteries are weak and should be replaced.

1.2 Check zero axis setting as follows; set the pressure head switch to dummy pressure head, and set the dummy pressure head control to the position which gave a center of scale reading on the Esterline-Angus at installation.

1.3 Check the calibration of the high sensitivity scale by setting the range switch to High Sensitivity Range and the dummy pressure head dial to the position which gave full scale readings on the Esterline-Angus at installation. Full scale reading should be obtained. If full scale readings are not obtained, a complete check of the shore equipment must be made

NOTE: The dummy pressure head dial settings will be different for each new pressure head. The dial settings for a new pressure head can be found by adjusting the dial for a full scale reading immediately after the bridge has been adjusted and is known to be correct.

1.4 Check the calibration of the Low sensitivity range by setting the range switch to Low Sensitivity Range and repeating Section 1.2. Half scale reading should be obtained.

2.0 Disconnect the sea cable from the recording unit and check the cable resistances as follows:

2.1 All cable leads should have a resistance of 0.5 megohms or greater to ground.

2.2 Resistance between the "+" and "-" leads should be the same as when installed.

2.3 Resistance between the "+" or "-" lead and the "C.T." lead should be the same as when installed and should fluctuate with the wave action.

3.0 Visually check the lines from the recorder to the junction box at the beach and the junction box.

4.0 Visually check the sea cable on the beach as far as possible.

Trouble Shooting Procedure

1.0 If the equipment does not function properly, switch the "pressure head" switch from dummy pressure head position to pressure head position and follow the test procedure to determine whether the trouble is: (1) in the onshore equipment, or (2) in the sea cable and pressure head.

2.0 Possible difficulties in the shore equipment. (Pressure head switch in "pressure head" position.)

2.1 Bridge current cannot be adjusted to correct value (1.0 and 1.1 of test procedure) - weak batteries and tubes.

2.2 Bridge current fluctuates with wave action - weak batteries and tubes.

2.3 No bridge current -

- a. Fuses in power supply and bridge circuit burned out
- b. Filament of a tube burned out (note that the filaments of the tubes are connected in series).
- c. Power transformer, choke or filter condenser burned out.

2.4 Esterline-Angus recorder pen writes at one side of the chart -

- a. A 500-ohm precision resistor in the bridge circuit burned out.
- b. Dummy pressure head potentiometer burned out.

2.5 Esterline-Angus recorder pen writes only at center of the chart -

- a. Lead between E.A. recorder and the bridge unit disconnected
- b. Precision resistor or calibration potentiometer in series with the recorder burned out
- c. E.A. recorder burned out.

3.0 Possible difficulties in the pressure head or the sea cable.

3.1 Resistance tests (resistances of test procedure 2.0 not correct) give incorrect values:

a. Lines between recorder and junction box are faulty. Repeat the resistance check of the sea cable from the junction box between the sea cable and the telephone line.

b. Low resistance readings indicate that the sea cable has broken or the instrument has flooded with sea water. High resistance readings indicate that the 750-ohm potentiometer has burned out. Retrieve the pressure head and test the sea cable and pressure head separately.

3.2 Recorder pen frequently jumps toward the center of the chart producing a jagged record:

The pressure head potentiometer is worn and the arm does not make contact. Replace the pressure head.

Resistance test of the sea cable between leads "+" and "C.T." should read the same resistance as at the time of installation, except for sudden jumps toward infinite resistance.

3.3 Recorder pen sticks at a given level on the chart –

Mechanically adjust the Esterline-Angus recorder to a new zero position. If the recorder continues to stick at the same point in the wave record, the potentiometer in the pressure head is worn and should be replaced. If the pen recorder sticks at the same position on the chart, the meter movement of the pen recorder should be cleaned

3.4 Sensitivity of the wave recorder decreases during periods of high tide:

This trouble is noticed as a decreased wave height being recorded each time the tide is maximum, or above a given level. The effect will increase with time until the recorder stops completely.

The instrument is losing air from the air chamber. Replace the pressure head.

Replacement and Servicing Parts List.

Replacement parts for electronic equipment:	Vendor
Standard Time Switch, type SR for 110-volt, 60-cycle operation	Sangamo Elect. Co. 1061 Howard St. San Francisco, Calif.
T.E.C. Cramer timer, 110 V. a-c 60 cycles 30-min. time range - to operate for remote sustained contact SPDT switch	R. W. Cramer Co 120 Main Stret San Francisco, Calif.

Power Transformer — Electric Engineering Co.
Berkeley, Calif.

(a) Input voltage: 110 V.a-c, 60 cycles
(b) Output voltages: 25 V. 1.5 amperes
5 V. 3 amperes
350 V. 150 milliamperes

Batteries 22½ Volt (2 required) - Replace at six-month intervals

JAN Battery BA-2
Navy 19033
SO Order No. 23596-PH-49-7

or

Burgess type 4156

Vacuum Tubes - Replace at six-month intervals

1 - type 6SH7
3 - type 6Y6G
1 - type 5U4G

Materials for underwater cable splices:

2 8-oz. tubes 3M weather stripping cement - Minnesota Mining and Mfg. Co.
3 rolls Okanite cable splicing compound 3/4-inch wide — Okanite Co.
3 rolls Okoprene rubber tape - 3/4 inch wide "
3 2-oz. tubes Okanite rubber cement "
1 Burndy No. 10 Hylug Kit. — Burndy Electric Co.
2 Walsco No. 608 black insulating tubing (spaghetti) Gauge No. 2.

Materials needed for repair of pressure head

2 quarts DC 200 Silicone fluid, viscosity 10 centistokes — Dow Corning Co.
6 "O" Ring - linear No. 1866.16 — Bearing Specialty Co, Oakland, Calif.
6 "O" Ring - linear No. AN6227-B-9 " "
2 dozen, 1/4 -20 x 3/4" filister head machine screws
2 dozen 1/4 - 20 hex nuts
2 Rubber bellows 3-inch O.D. — Goodyear Rubber Co.
2½-inch I.D.
5 convolutions

Moulded of butyl synthetic or other material, water resistant and with low permeability to air.

1. Differential Pressure Potentiometer, Model 503, with the following specifications: — Bourns Laboratories
6135 Magnolia Ave
Riverside, Calif.

   a. Potentiometer: 750-ohm, 1-watt when submerged in silicone fluid
   b. Range: plus and minus 3.3 psi
   c. Potentiometer is midpositioned with zero pressure applied
   d. 1 percent linearity
   e. Capable of withstanding 100 percent overload without more than ± 1 percent shift in calibration.

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6. FOLSOM, R.G., Measurement of ocean waves; Trans. Amer. Geophys Union, Vol. 30, No. 5, pp 691-699, Oct. 1949.

7. SNODGRASS. F.E., Guam wave recorder installation: I ; Technical Report Series 3, Issue 353, IER., University of California, Berkeley, June 1954.

8. SNODGRASS. F.E. and STILING D.E., Operation manual for Mark IX shore wave recording system; Technical Report Series 3, Issue 320, IER., University of Calif., Berkeley, 16 pp 6 plates March 1951.

9. TEXAS A & M COLLEGE, Wave force experiments at Achafalaya Bya, Louisiana; Technical Report No. 38-1, Contract NOy-27474, The A & M College of Texas College Station, Texas, 56 pp plus illustrations, Feb. 1954

10. U.S. NAVAL ORDNANCE LABORATORY: The wave gage installed at Cape Henry, Virginia; U.S. Nav. Ord. Lab. NAVORD Report 1727, January 1951

11. WIEGEL, R.L., Installation of the thermopile wave meter at Santa Margarita River Beach, Camp Del Mar, Oceanside, California; Tech. Report 155-2, IER, University of Calif., Berkeley, June 1949.

12. WIEGEL, R.L., Gravity Waves; Tables of functions; Council on Wave Research, The Engineering Foundation, 30 pp. Feb. 1954.

13. WOODS HOLE OCEANOGRAPHIC INST., A Bermuda recording installation; Woods Hole Ocean. Inst. Contract NObs-2038, August 1947.

APPENDIX I

ANALYSIS OF OCEAN WAVE RECORDS

The wave recorders are programmed to run at slow-speed (3 inches per hour) for 5 hours and 40 minutes, and at fast-speed (3 inches per minute) for 20 minutes. When definite and pronounced increases in wave amplitudes (indicating the arrival of wave trains) are evident on the slow-speed portion of the record, the time and date of these arrivals are noted by the analyzer. Only the fast-speed sections of the chart are analyzed for wave height and period. A twenty-minute interval is selected for determining characteristic wave period and maximum and characteristic wave heights. Except in cases of storm arrivals, as previously mentioned, the records are analyzed at twelve-hour intervals. Records are analyzed every six hours during storm periods or when the slow speed portion of the record indicates rapidly changing conditions.

To standardize practices used in the analysis of ocean waves from underwater pressure-head records, the following list of definitions has been accepted(3)*.

1. Wave height is the vertical distance between the crest of a wave and the preceding trough.
2. Characteristic wave height is the average height of 33-1/3 percent of the highest waves.
3. Wave period is the time interval between the appearance at a fixed point of successive wave crests.
4. Characteristic wave period is the average period for the well-defined series of highest waves recorded.
5. Wave direction is the orientation of the line of travel of the largest well-defined waves.

PROCEDURE FOR ANALYZING WAVE RECORDS

The following steps in the procedure for analyzing wave records have been developed over a period of several years at the University of California.

Receipt of the Record:

The graphic chart represents the time history of the surface wave action and should be the final authority in case of future conjecture as to the validity of statistical information compiled therefrom. Hence, a system of logging charts is used for facility of future reference. The log of records contains: (a) the time and date the run began and ended, (b) the number of the chart (i.e., its chronological sequence) and (c) the date the record was received. Following is a form which has been used for logging records.

LOCATION		START		END		REMARKS
RECEIVED	ROLL NO.	TIME	DATE	TIME	DATE	

Log for Mark IX Wave Recorder Charts

---

* Superscript numbers in parentheses refer to References at end of main body of report.

Reading the Chart:

A. Frequency of taking samples

1. The wave records are analyzed during the fast-speed portion of the chart at approximately twelve-hour intervals. Recorders are programmed to obtain fast-speed records at 6 A.M., noon, 6 P.M., and midnight.*

2. Manual operation of the chart speed is provided on all records. Additional samples may be obtained by the operator during storm periods. The frequency of these samples and the number of the records analyzed is left to the discretion of the operator and analyst.

B. Establishing the point in time of readings

1. The beginning time should always be marked on the chart when a new roll is placed in operation, and also when it is removed from the recorder.

2. If possible, time checks should be made on the chart during the recording period together with supplementary remarks concerning the character of the surface waves.**

3. A progressive time determination is made assuming six-hour intervals between the beginnings of the fast-speed runs. The time at any point on the chart can be determined by measuring the chart length (or counting divisions) from the known time.***

4. The time of the reading is defined as the mean time of the interval chosen for analysis (see C "Selection of Interval").

C. Selection of interval to be analyzed within the fast-speed portion of the chart

The programming of the fast-speed portion of the wave record would logically be a direct function of the average period of waves during that portion. That is, the analysis is normally based on a given number of waves, and for equal numbers of waves measured per interval, one would select short and long fast-speed intervals for waves of shorter and longer periods, respectively. While this would be statistically consistent, it would require the impracticability of period forecasting and the inconvenience of variable programming, or the use of an excessive amount of chart paper. Hence the following plan is used, based on the analysis of a fixed time interval.

1. If the unit is programmed to run at fast speed for a longer time than 20 minutes, select the interval to include 20 minutes of the fast-speed portion and, if possible, select this interval such that its mid-point will approximately coincide with the mid-point of the fast-speed run.

---

* The Sangamo timer used for programming the frequency of fast runs and their duration may be used in a number of combinations.

** These periodic remarks should include time of observation, direction of waves, the stage of the tide, and descriptive remarks about the character of the water surface - such as calm, rough, white caps, etc.

*** Fast chart speed corresponds to 3 inches per minute, slow chart speed corresponds to 3 inches per hour.

2. In the event that this interval cannot be taken (due to the end of the chart or variation in cam action of the programmer), select as great an interval as may be possible, centering the interval so that at least one minute is allowed at the beginning of the interval in order for the chart speed to reach its full speed (particularly if the spring wound recorder is used).

A typical wave record has been analyzed and reproduced here to illustrate the analysis procedure*. Notice that the time of the beginning of the sampling interval is 0829 whereas the beginning time of the fast-speed run is at 0827. An interval of 20 minutes has been selected in this fast-speed portion, hence the end of the sampling interval is 0847.

The time of the interval being centered within this 20-minute interval is, therefore, 0839.

D. Determination of the characteristic period

1. Having defined the sampling interval, the next step is to select several groups of waves, within the interval, that contain a series of well-defined waves.

2. Measure the length of time from the beginning to the end of each of the series of well-defined waves and count the number of waves included in this series.

3. Divide the sum of the time-intervals of the groups of waves by the total number of waves counted in all such groups.

Thus $T_c = \frac{t}{n}$

where t = total time interval between the beginning and end of all well-defined series of waves.

n = total number of waves included in all of the series.

T_c = the characteristic wave period.

From the example, we see that there have been six such groups of waves selected and that the characteristic period of this interval is found to be

$$T_c = \frac{t}{n} = \frac{44 + 87 + 193 + 75 + 103 + 114}{3 + 6 + 13 + 5 + 7 + 8} = \frac{616}{42} = \underline{14.7 \text{ sec}}$$

E. Determination of the number of significant waves to be measured

1. Divide the interval by the characteristic wave period to determine the number of waves within the interval.

For example;

$$\frac{\text{Interval (in seconds)}}{\text{Period (seconds per wave)}} = N \text{ number of waves}$$

---

* This was not from one of the Guam recorders.

$$\frac{20 \times 60}{14.7} = \frac{1200}{14.7} = 82 \text{ waves}$$

2. Measure the highest N/3 waves ($N/3 = 82/3 \approx 27$)*

   (a) Scan the record selecting the highest waves observed until N/3 waves are selected.

   (b) Measure the height of the waves in divisions and record.

As may be seen in the sample analysis Data Sheet, the values of the wave heights have been recorded, the remaining part of the analysis being to arrive at the significant wave heights from these data.

F. Determination of significant wave heights

1. Determine the average of the highest N/3 waves as recorded (in this case 27 waves). Since the waves are measured in terms of the recorder chart divisions, the designation of this average is $R_1/3$. From the example, $R_1/3 = 15.9$**.

2. Record the maximum wave height encountered R_{max}, in this case 19.5 divisions.

G. Evaluation of wave heights from chart-divisions to wave height in feet-of-water

1. The following equation is used to obtain the surface wave height:

$$H = \frac{C}{K} R \qquad (1)$$

where H = wave height at surface in feet.

C = calibration factor of the instrument in $\frac{\text{feet of water pressure}}{\text{chart divisions}}$

K = pressure response factor based upon depth of the instrument, depth of the water and length (or period) of wave being recorded

R = reading (in divisions) taken from chart as shown above.

2. Since the characteristic wave height and the maximum wave experience are the only two surface wave heights required in compiling the statistical information, only the values from the preceeding determination need be used as the value of "R" in the above equation (1).

---

* In the example given, the highest 30 waves have been selected for measurement, and after measurement, the three lowest of this group have been omitted from the average. Normally the analyst need select only 1/3 of the waves for measurement.

** Omitting 12, 12.5, 12.5 (three lowest values of the 30 selected for measurement)

Example:

$$H_{1/3} = \frac{R_{1/3}}{K} C$$

$$H_{1/3} = \frac{15.9}{0.822} \; 0.0755 = \underline{1.46 \text{ feet}}$$

$$H_{max} = \frac{19.5}{0.822} \; 0.0755 = \underline{1.79 \text{ feet}}$$

3. The value of C, 0.0755, was determined by laboratory test.

4. The values of K for various conditions of depth, period, etc. may be readily computed or obtained from prepared tables(6).

H. Recording the statistical information

The purpose of analyzing wave data is to finally compile statistics that give a time history of the characteristics of surface waves. This information may be tabulated on a form as shown below and eventually may be graphed to a time scale.

CHARACTER OF THE SEA TABLE

AT____________________ FROM__________ TO__________

DAY	HOUR	T	$H_{1/3}$	H_{max}	REMARKS

SAMPLE ANALYSIS--DATA SHEET

POINT SUR, CALIFORNIA

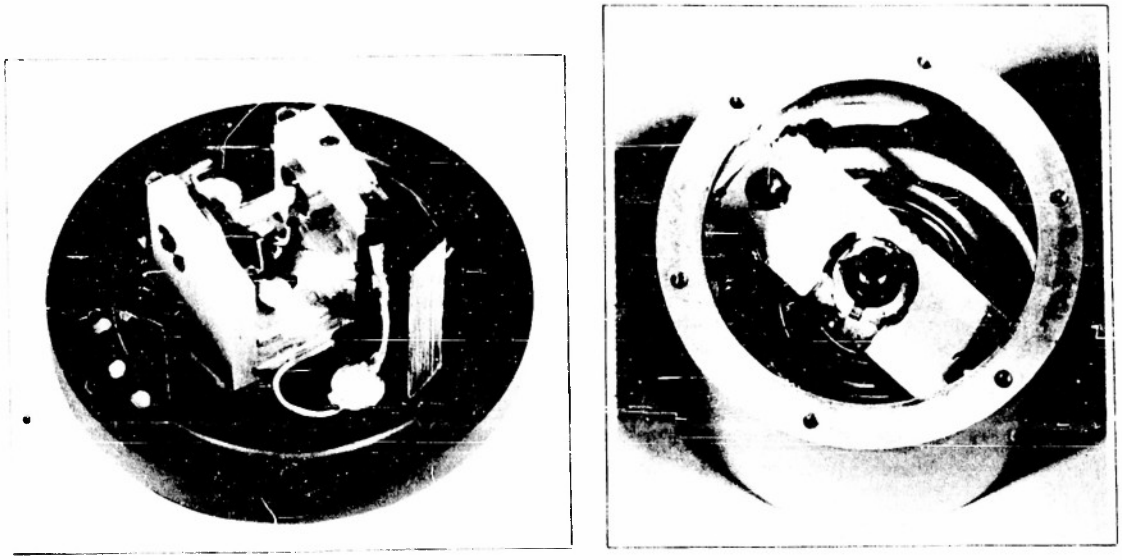
ROLL NUMBER	273
DATE	May 11, 1950
TIME OF READING	0839
PERIOD	13.6 sec.
N/3	27

WAVE NO.	WAVE HEIGHT - IN DIVISIONS
1	14
2	13.5
3	13
4	12.5*
5	15
6	17.5
7	16
8	17
9	18
10	19.5
11	18
12	14.5
13	18
14	15.5
15	12.5*
16	12*
17	17
18	16.5
19	18
20	18.5
21	13
22	13
23	17
24	17
25	16
26	18.5
27	14
28	12.5
29	15
30	16
R_{max}	19.5
$R_{1/3}$	15.9
K	0.822
$H_{1/3}$	1.46 Ft.
H_{max}	1.79 Ft.

K, the ratio of the subsurface pressure to the surface wave height, was determined for a depth of water of 65 feet and for an average period of 14.7 seconds.

* These values were not used (see footnote ** page AI-4)

a. Top and bottom views

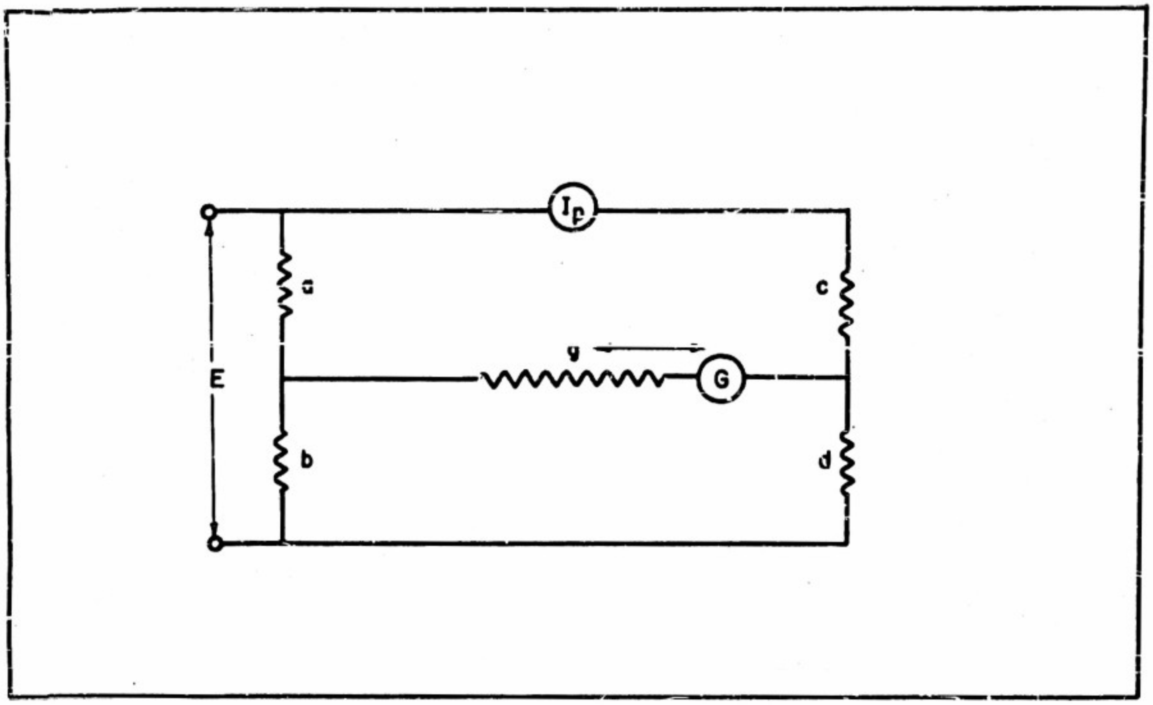


b. Potentiometer and top

c. Internal bellows and casing

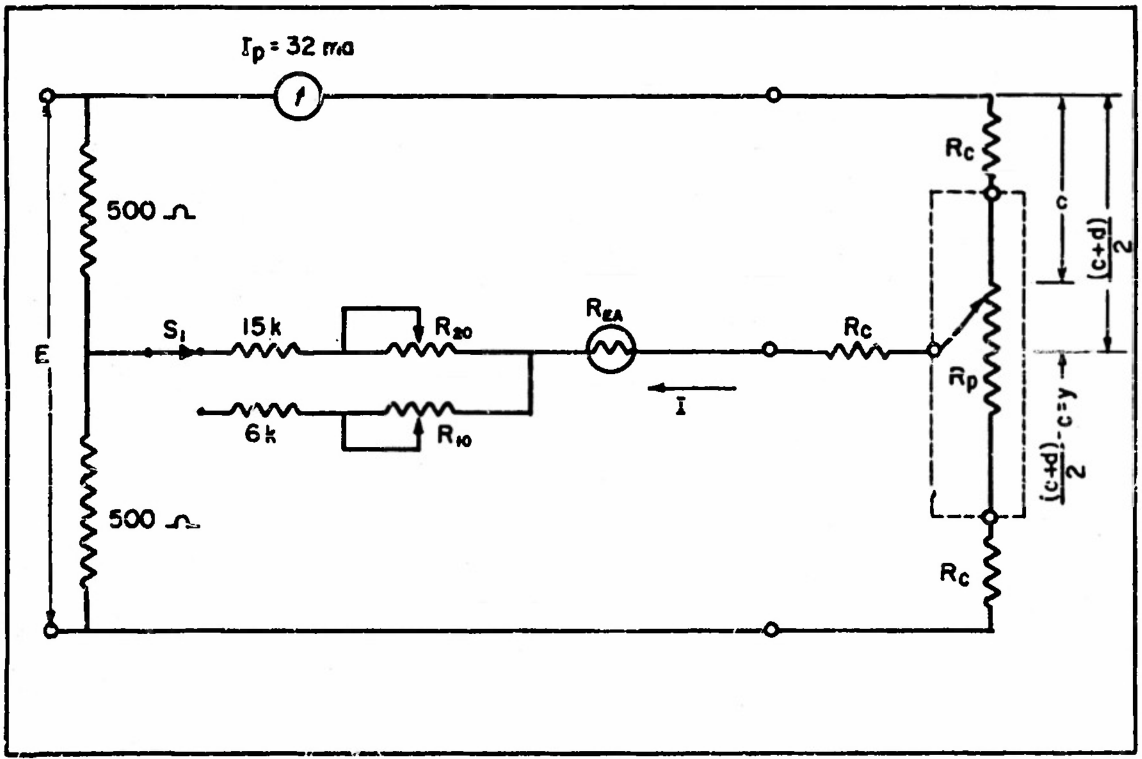
BOURNS TRANSDUCER

FIGURE 1



SIMPLIFIED BRIDGE CIRCUIT

FIGURE 2

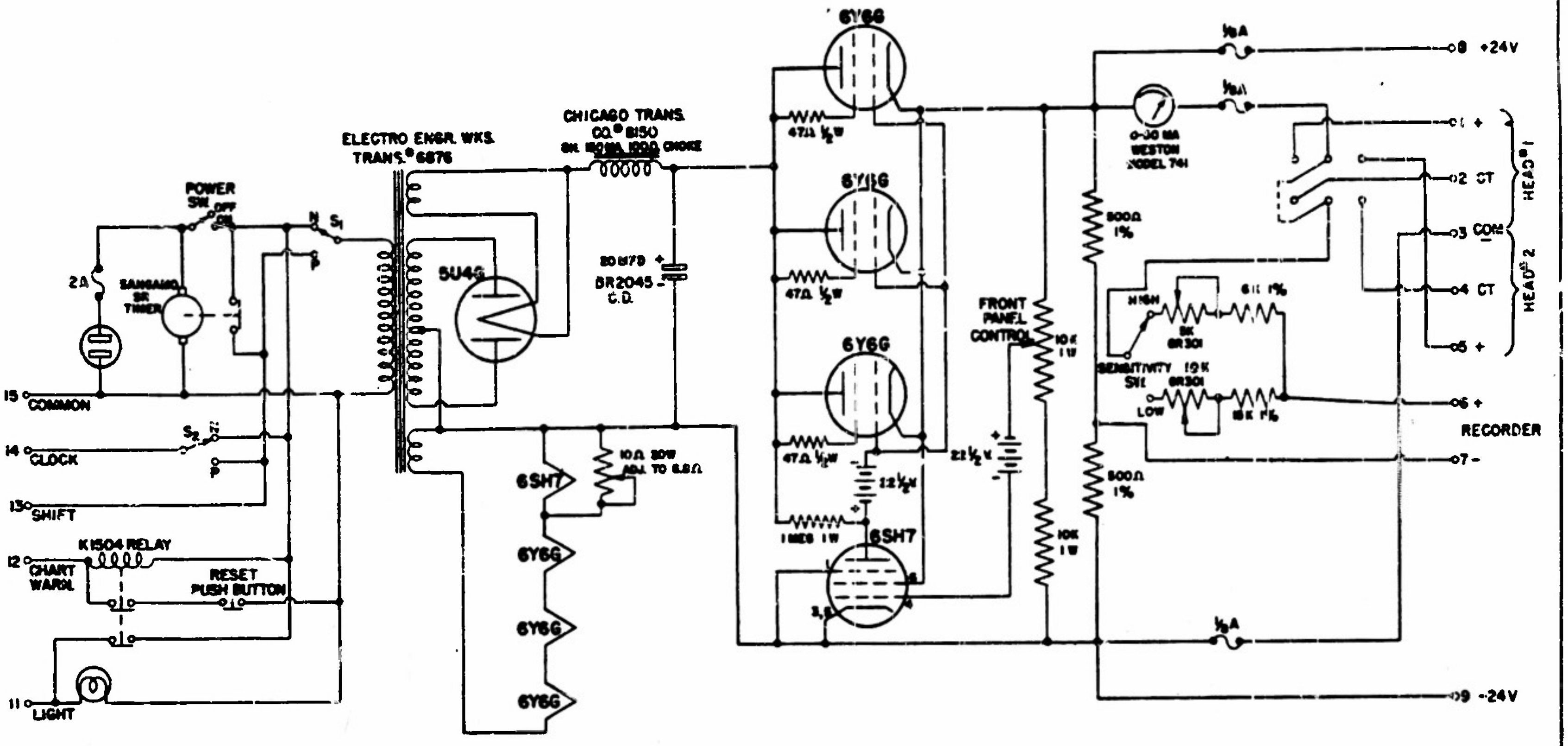


HYD-5803

COMPLETE BRIDGE CIRCUIT

FIGURE 3

FIGURES 2 & 3

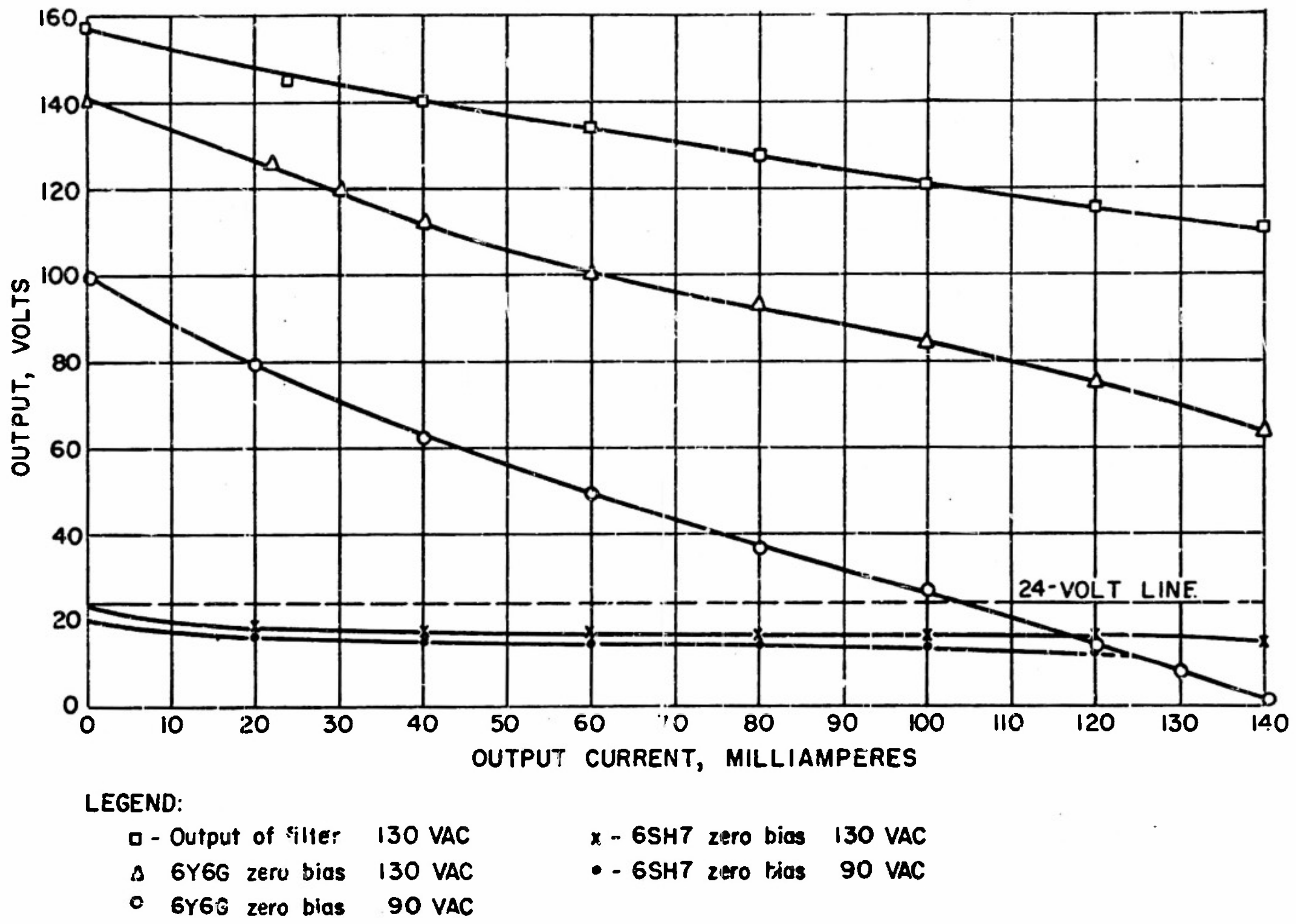


MARK IX BRIDGE UNIT - MODEL 3
CIRCUIT DIAGRAM

UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY

DATE 1-16-51 DRAWN BY W/H
H.T.D. 4989-1-16-00 TRACED BY

FIGURE 4

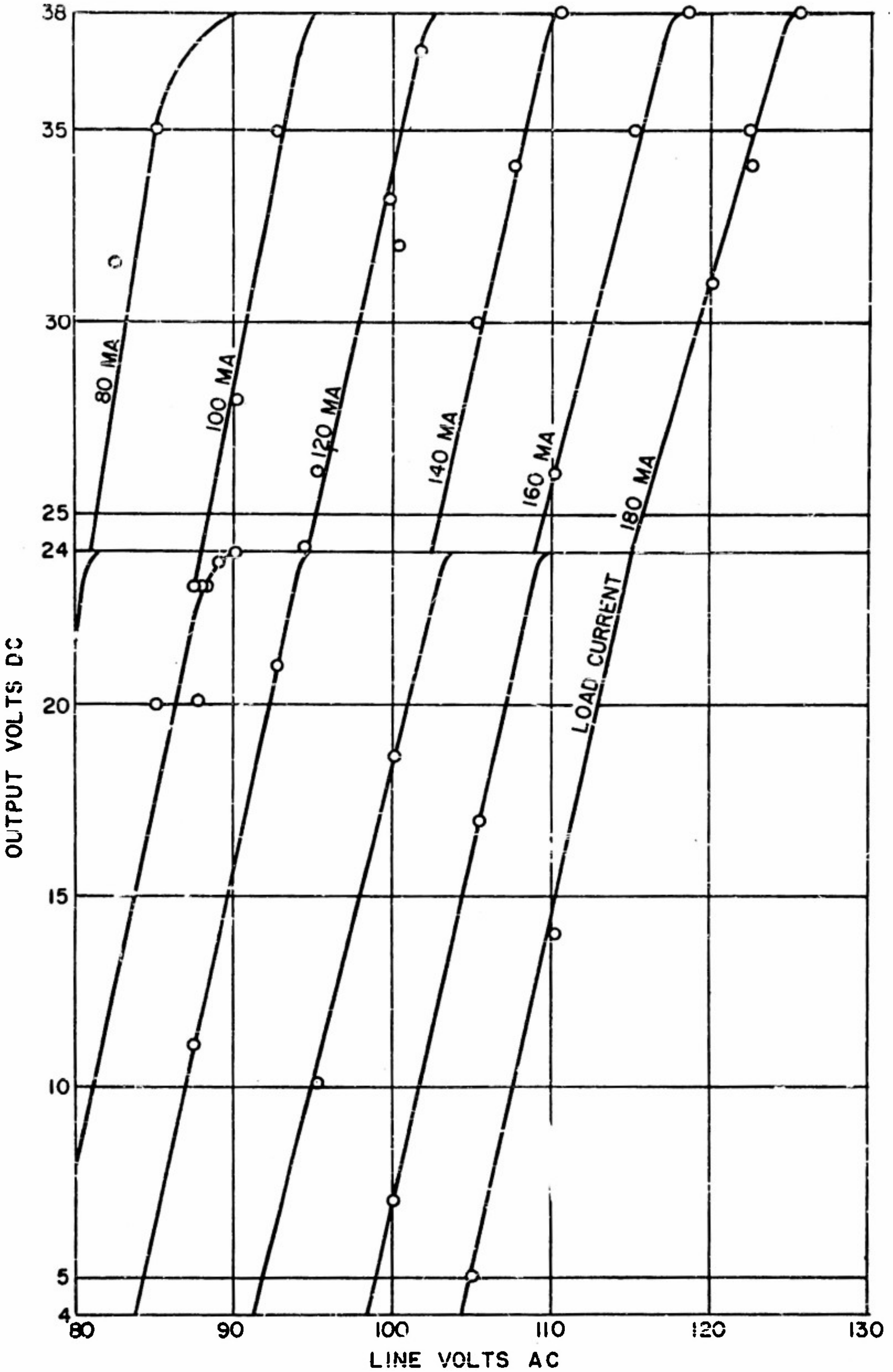


REGULATOR CHARACTERISTICS

OPERATING RANGE

HYD-5804

FIGURE 5

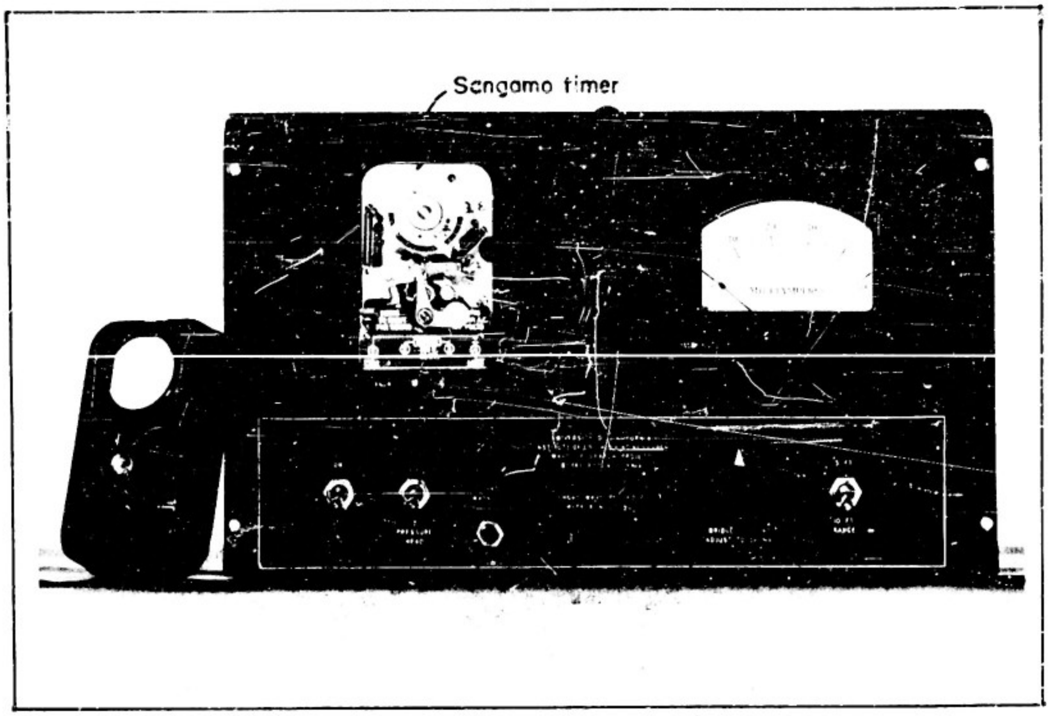


HYD-5605

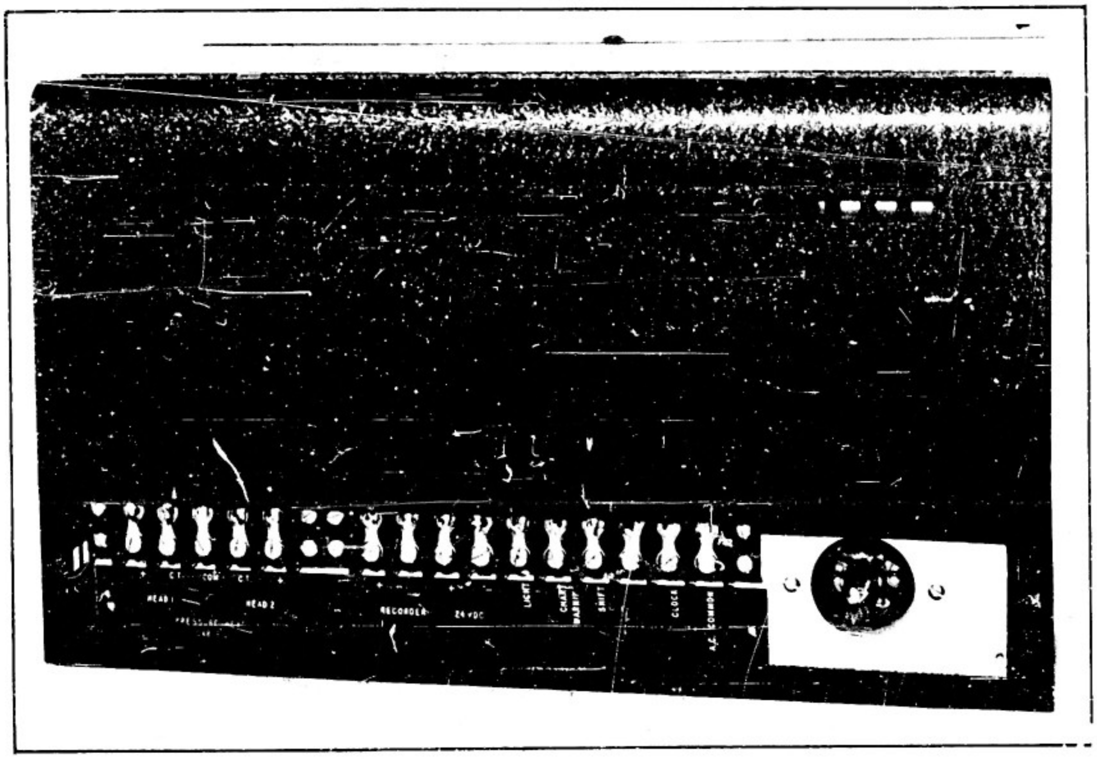
VOLTAGE REGULATOR CHARACTERISTICS

REGULATION OF LINE VOLTAGE VARIATIONS

FIGURE 6



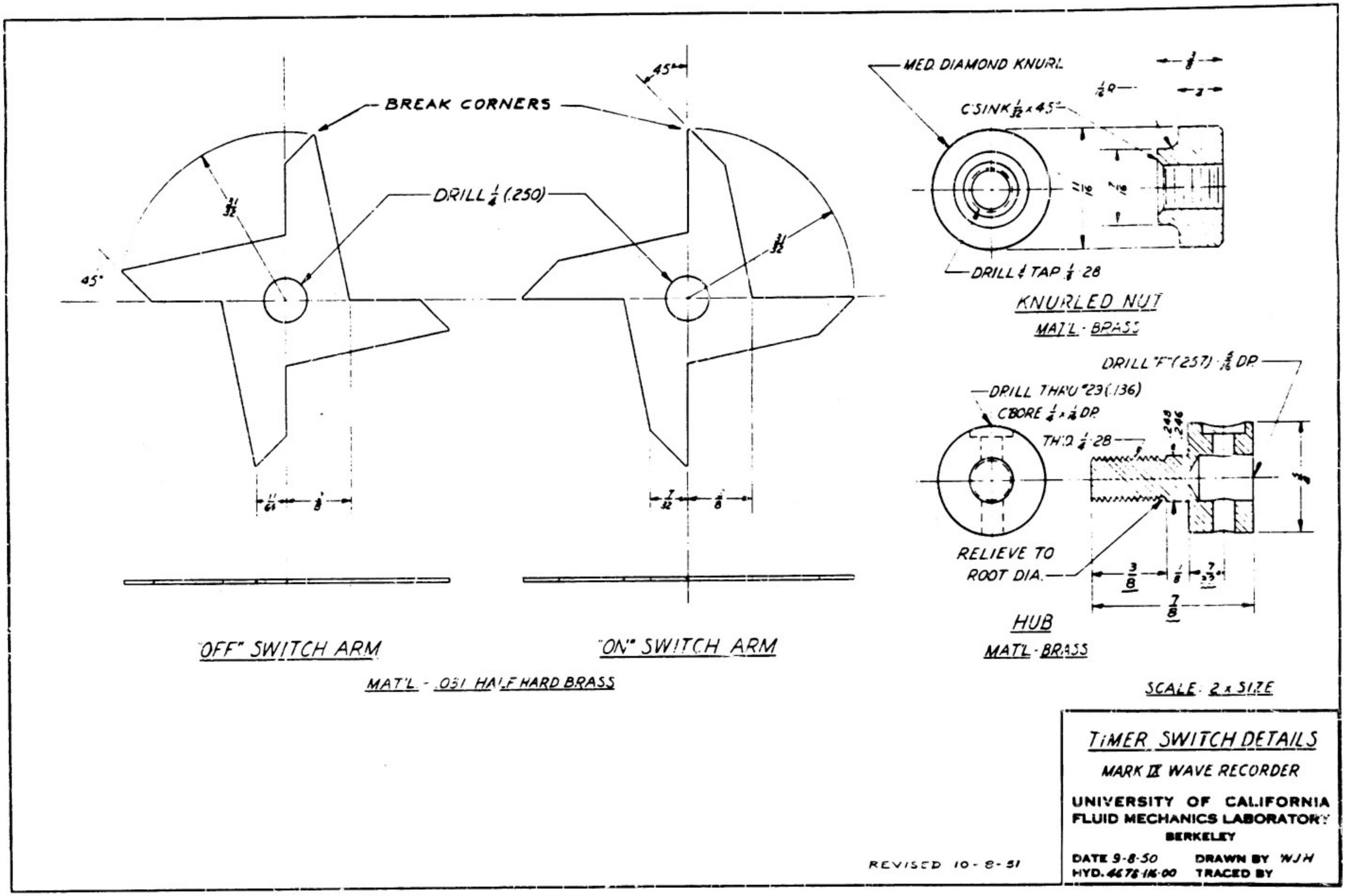
A. FRONT PANEL (Note program cams)



B. BACK PANEL (Terminal board)

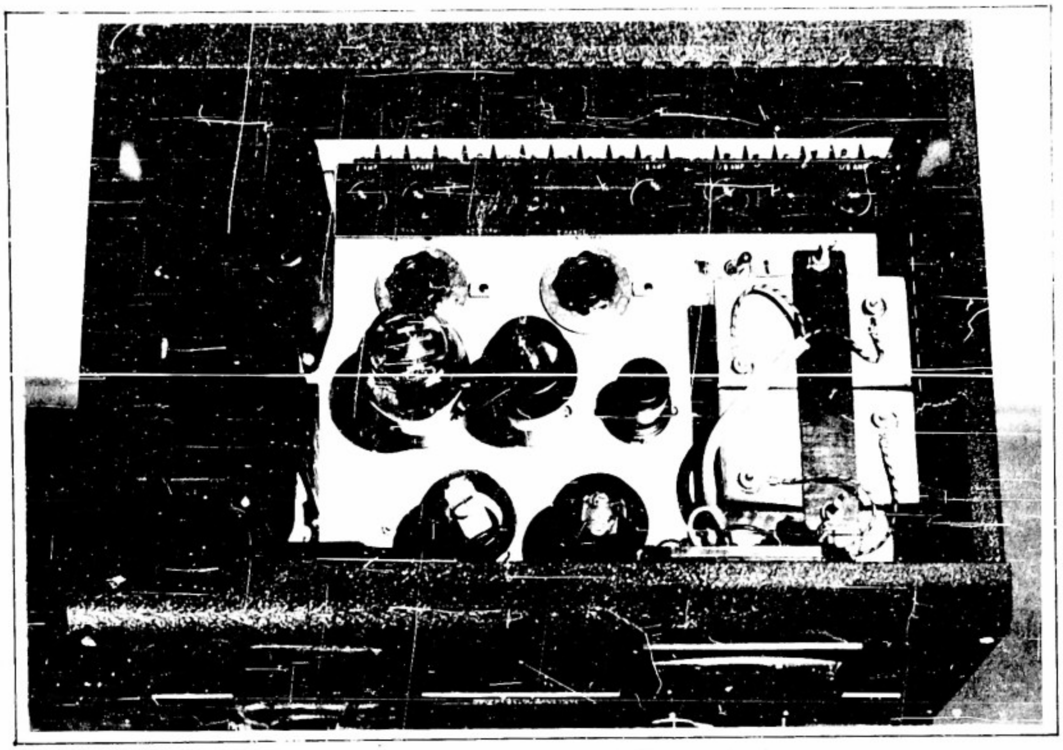
MARK IX, MODEL III BRIDGE AND POWER SUPPLY UNIT

FIGURE 7

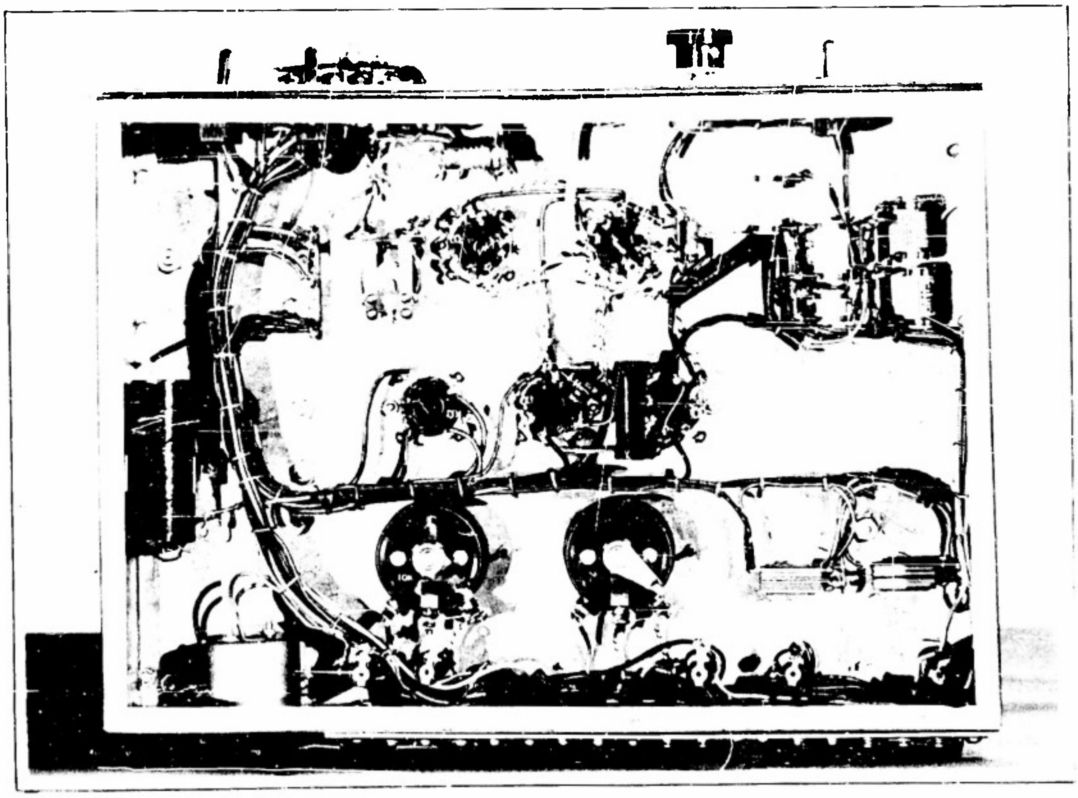


TIMER SWITCH DETAILS
MARK II WAVE RECORDER
UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY
DATE 9-8-50 DRAWN BY WJH
HYD. 4678-116-00 TRACED BY

FIGURE 8

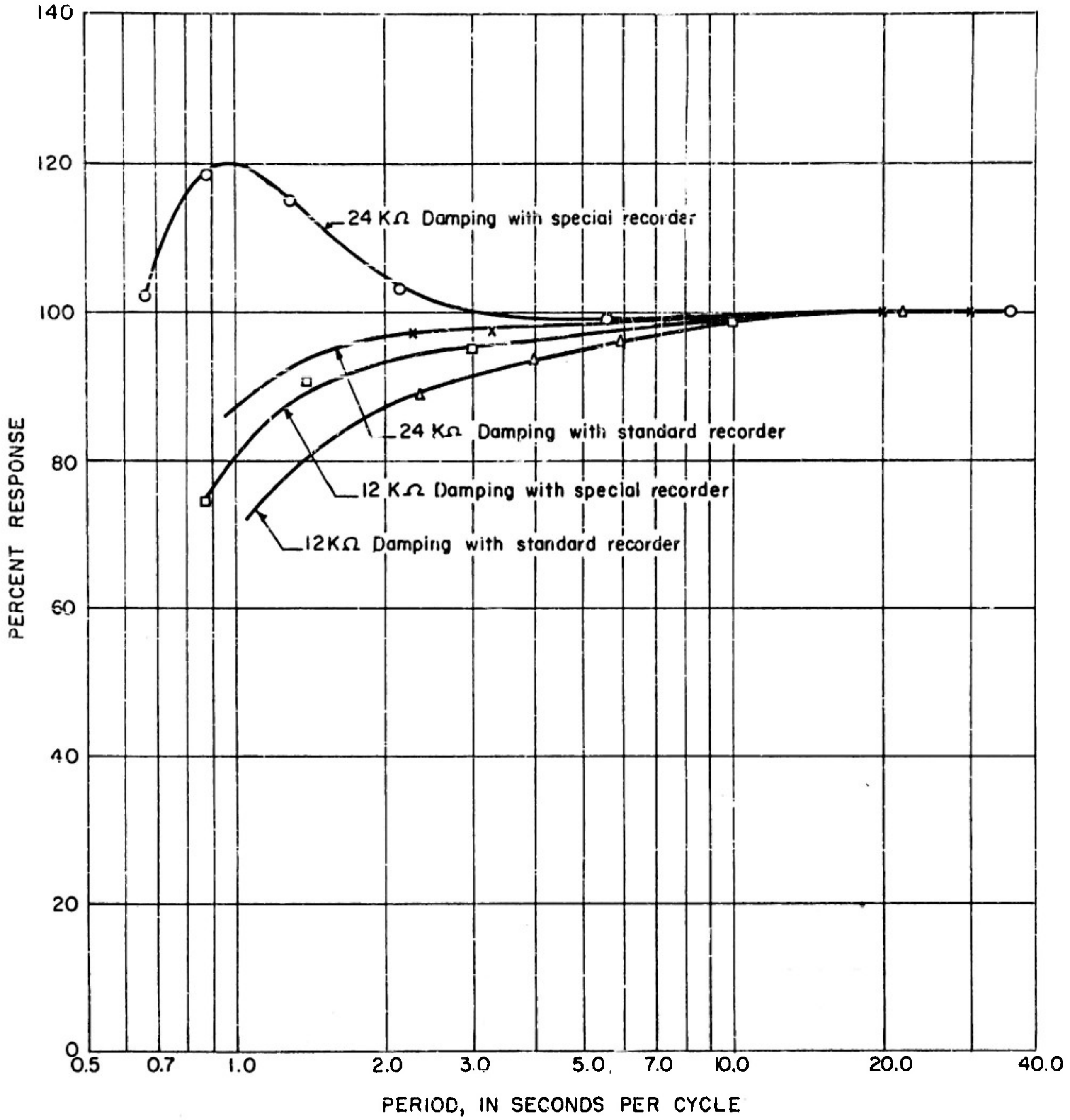


a. Top view; program switches and sensitivity adjustments



b. Bottom view; wiring layout

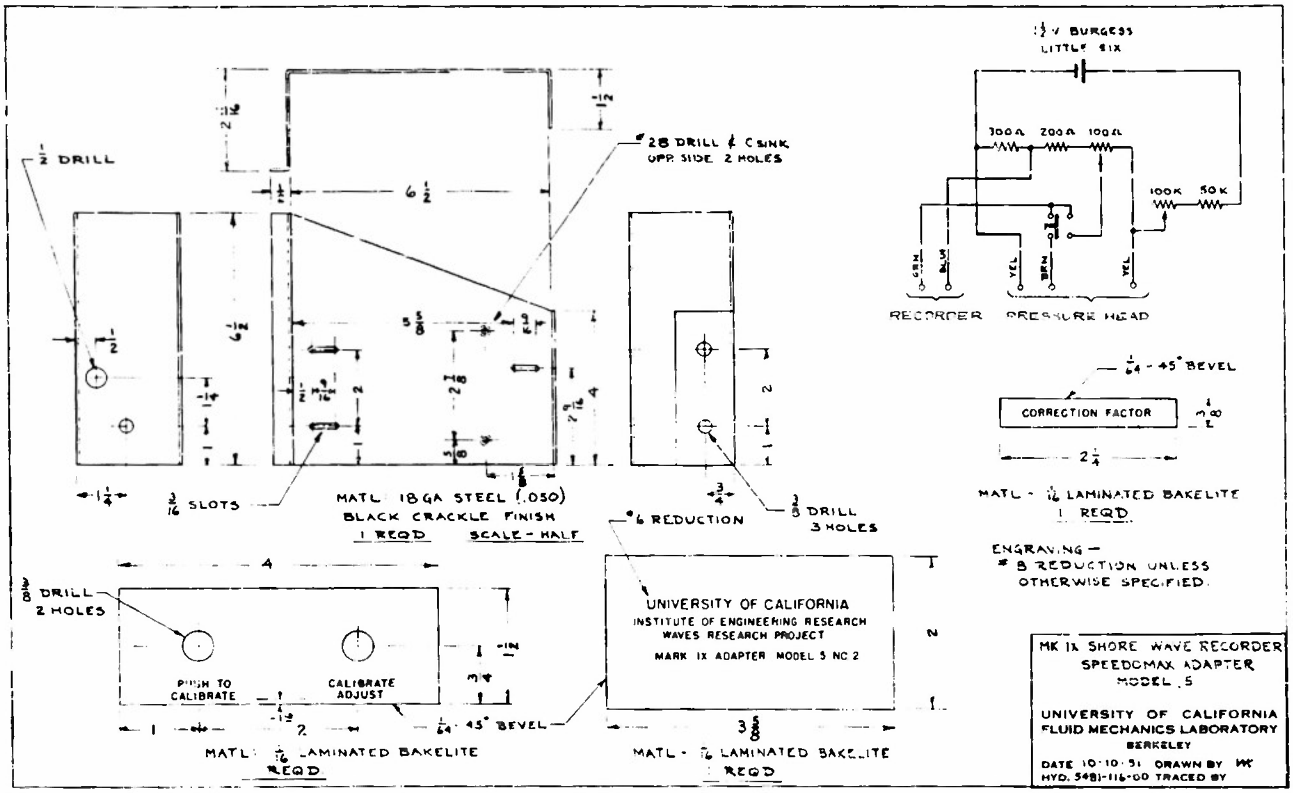
FIGURE 9

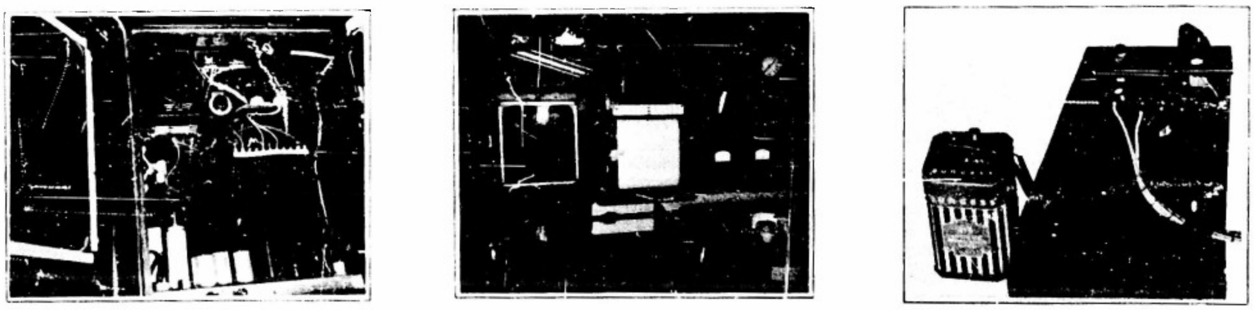


HYD-5806

ESTERLINE-ANGUS RECORDING MILLIAMETER
FREQUENCY RESPONSE

FIGURE 10

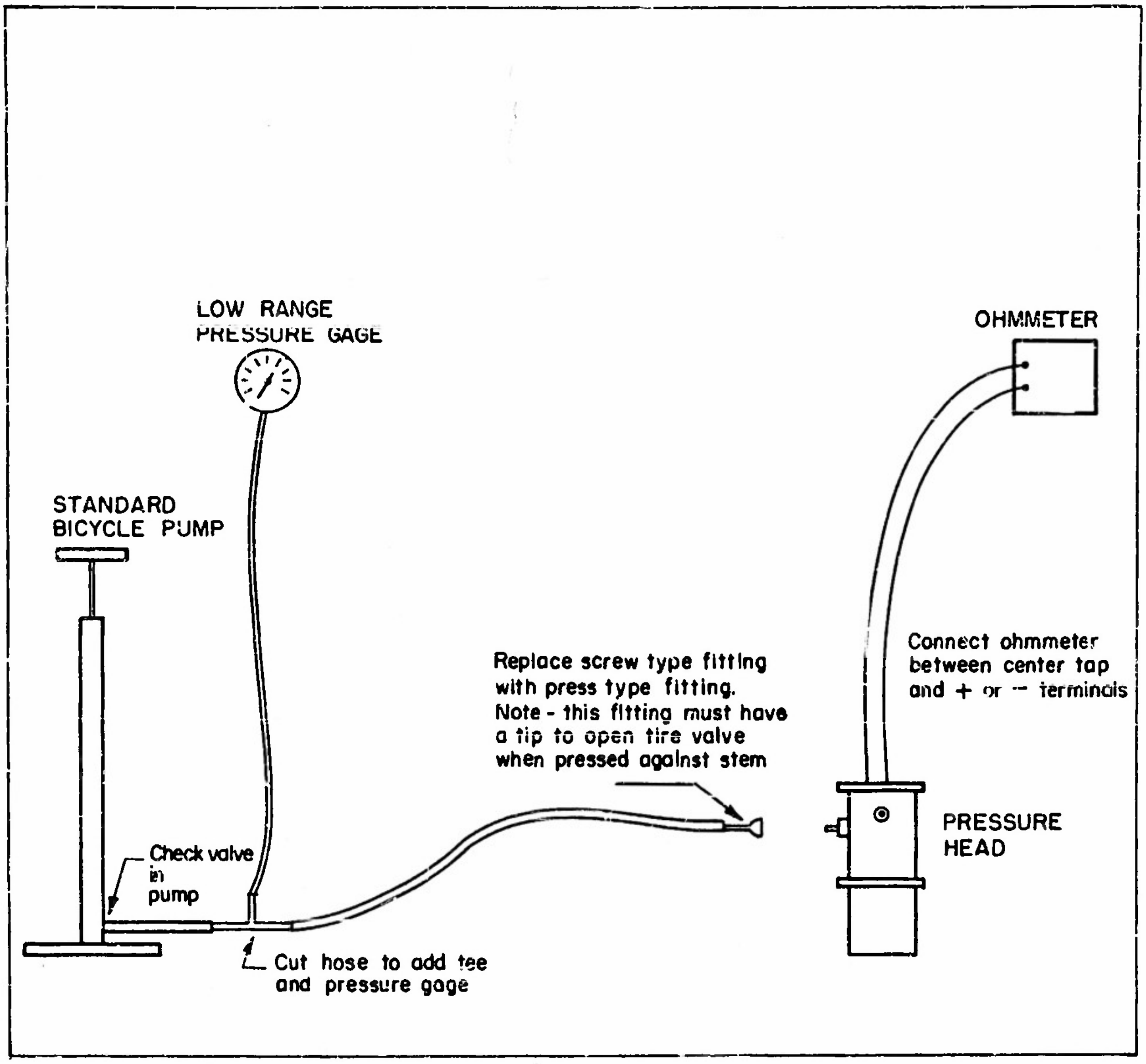




MARK IX SHORE WAVE RECORDER

SPEEDOMAX ADAPTER

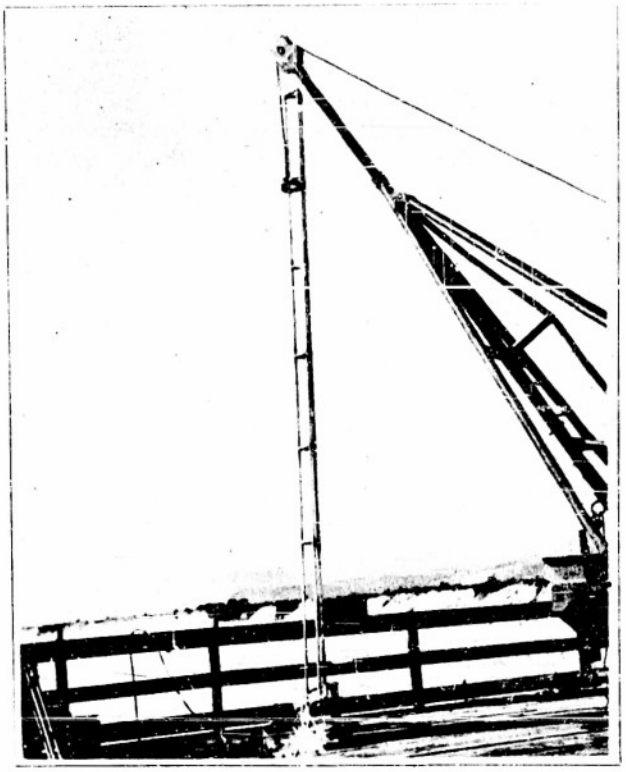
FIGURE 11



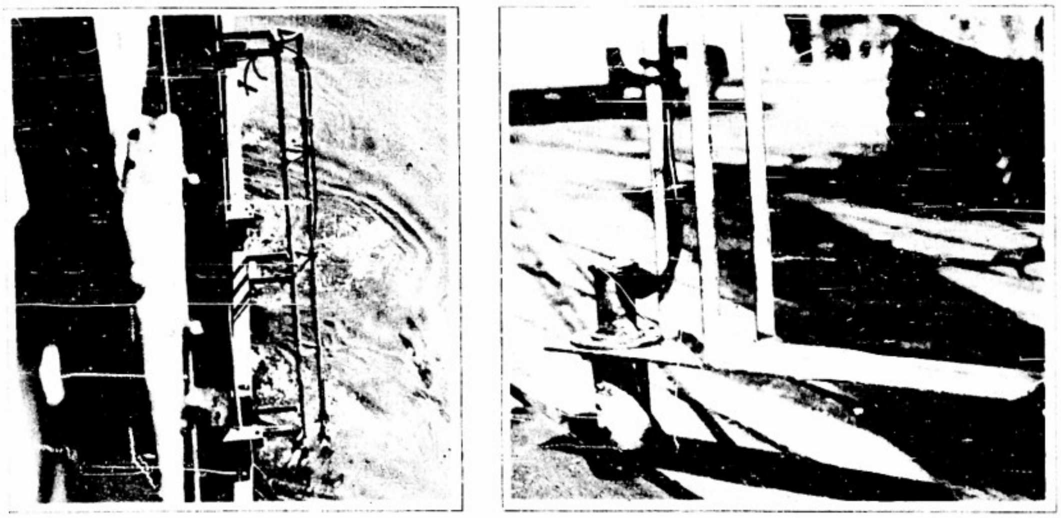
EQUIPMENT REQUIRED TO PRESSURIZE PRESSURE HEAD UNIT

HYD-6871

FIGURE 12



a. Pressure head ready to be installed.

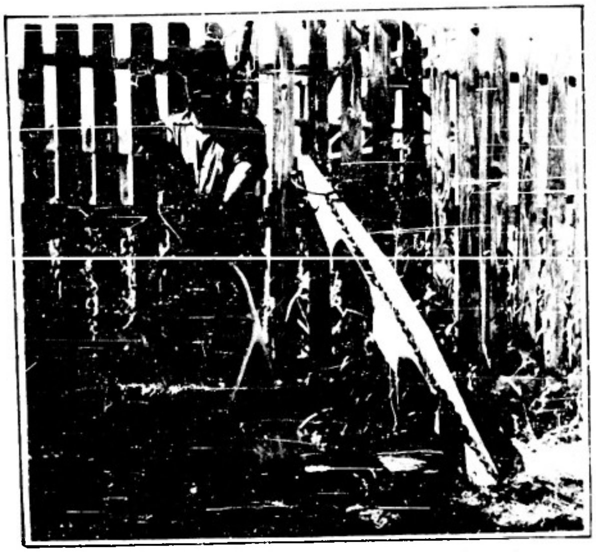


b. Pressure head installed, depth of pressure head is 7 feet below MLLW.

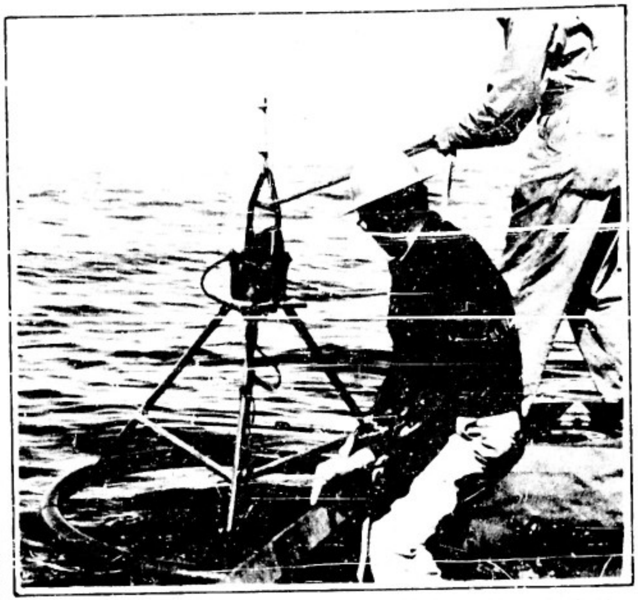
c. Close-up of pressure head.

Pier installation of a pressure type wave recorder.

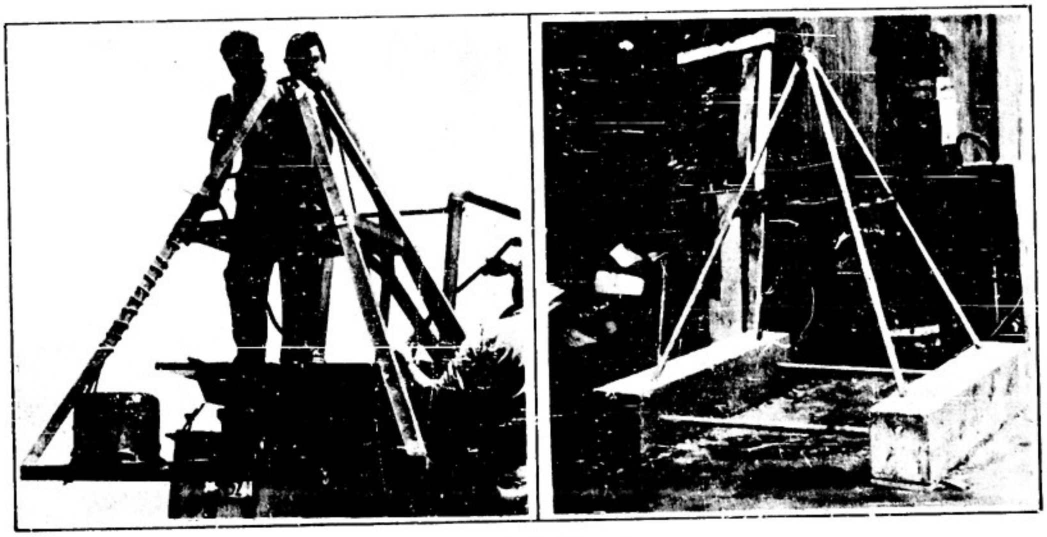
FIGURE 13



a. Woods Hole pressure gage, tripod and spar buoy.



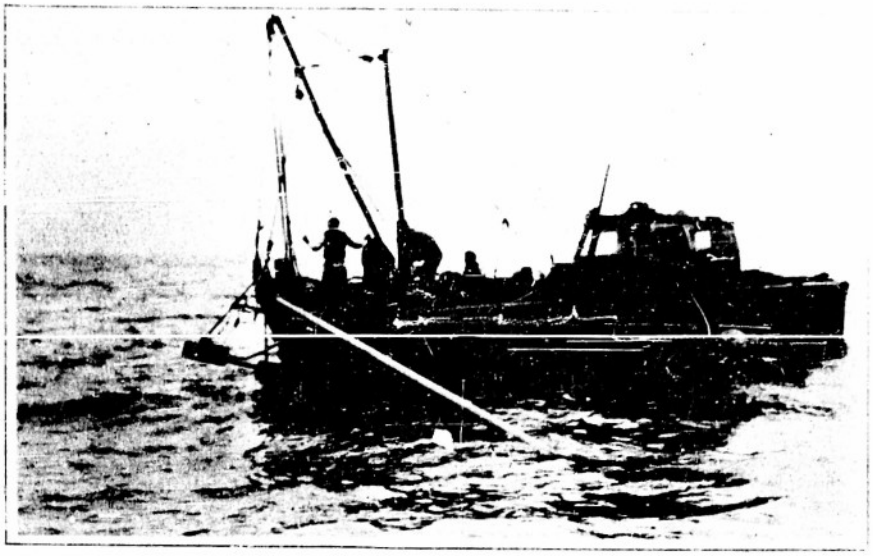
b. Standard tripod used by the University of California.



c. Two tripods built by the University of California.

Tripods for sub-surface pressure gages

FIGURE 14

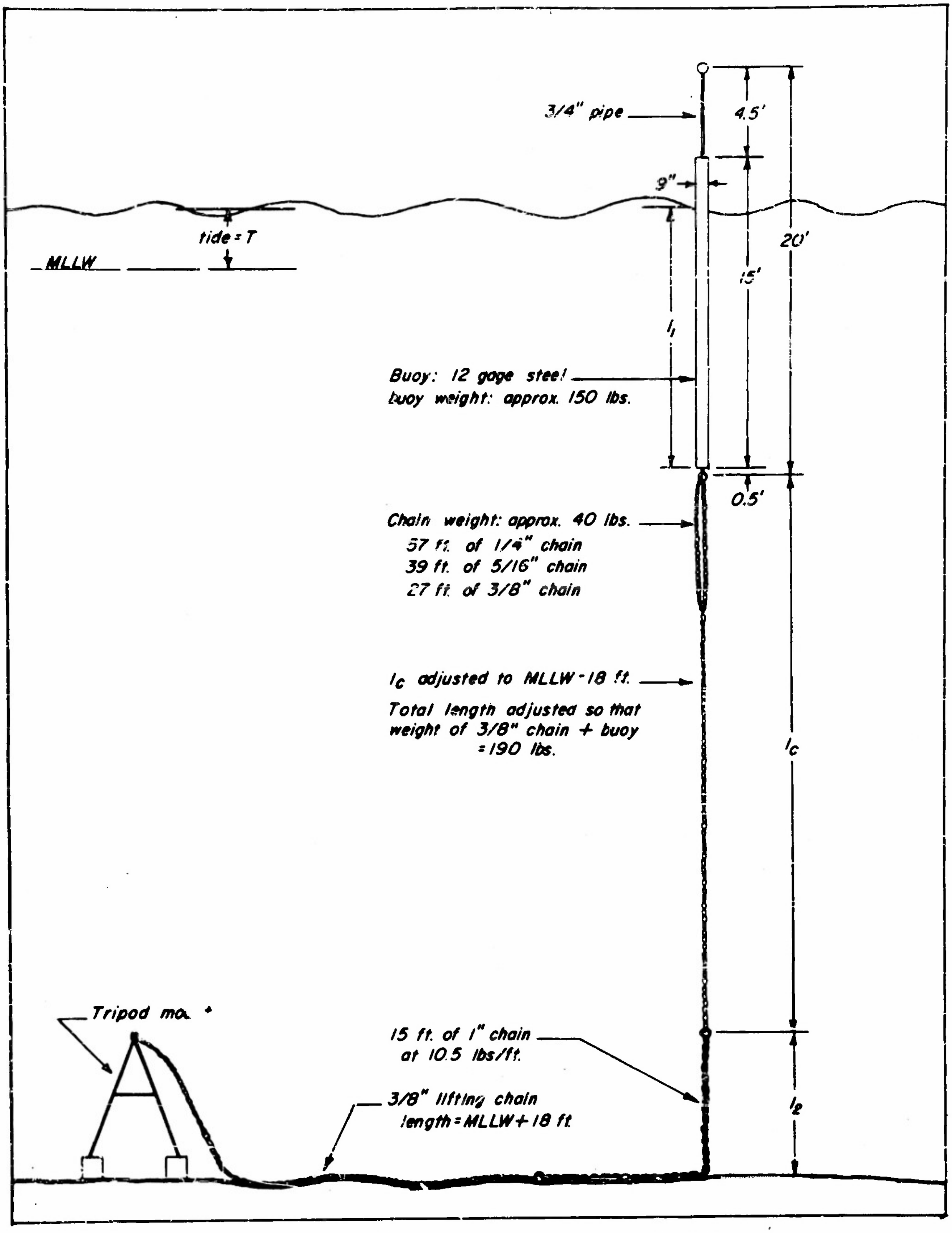


a. Preparing to lower the tripod; spar buoy length = 30 feet.

b. Tripod in place. Tide stage: 4 feet above MLLW.

Short-line spar buoy installation

FIGURE 15



Installation diagram for a spar buoy marker with chain anchor

FIGURE 16

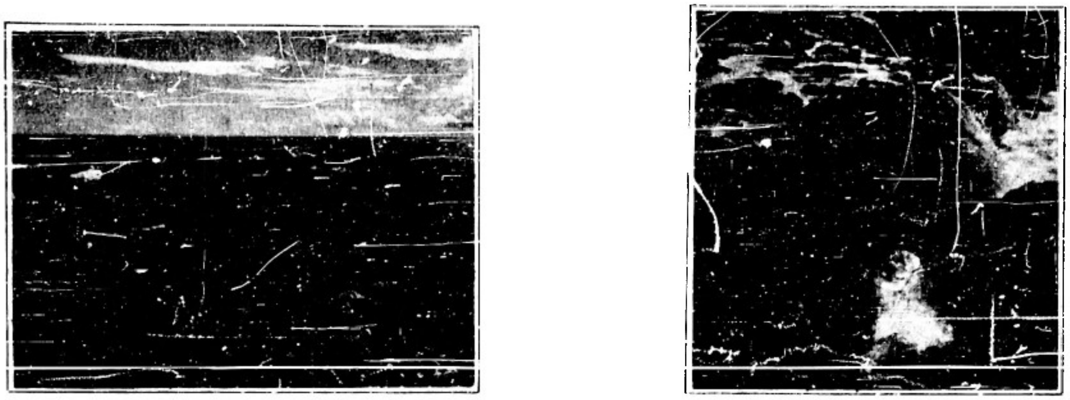
a. 4-foot scarp, Oceanside, California, October 1949.

b. Shallow water reefs exposed at low tide, Cocoa, Florida.

c. Cable exposed on reef.

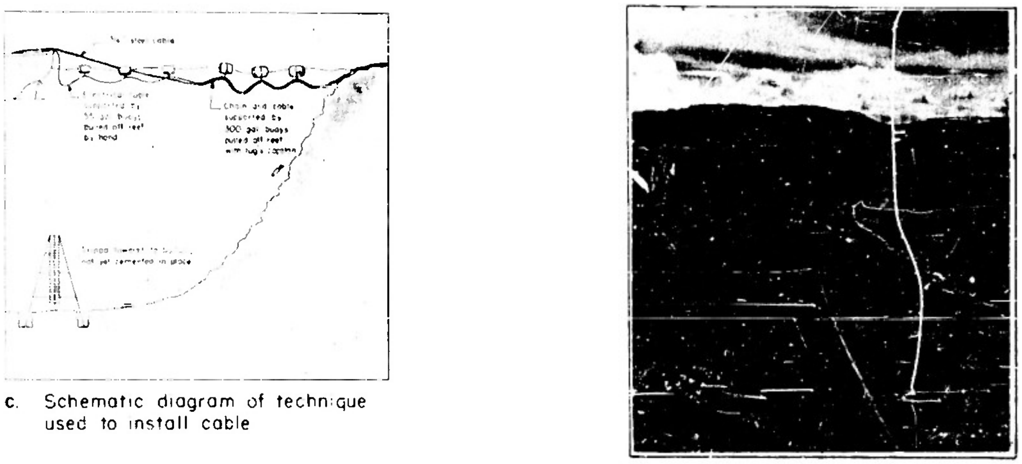
Scarps and reefs

FIGURE 17



a. Edge of reef

b. Cable at edge of reef



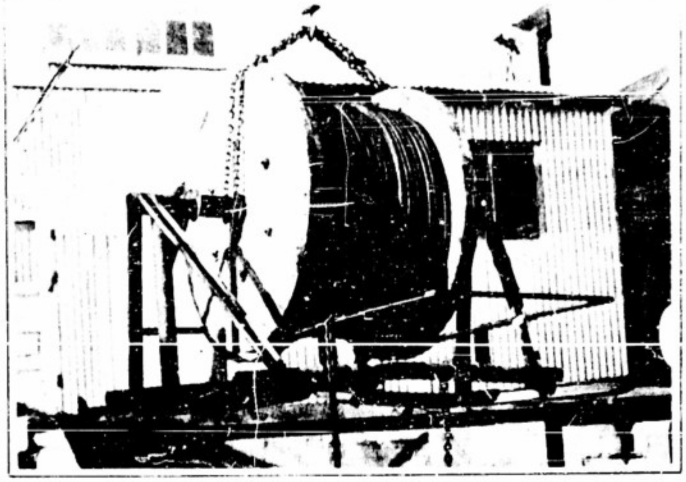
c. Schematic diagram of technique used to install cable

d. Pulling cable off reef

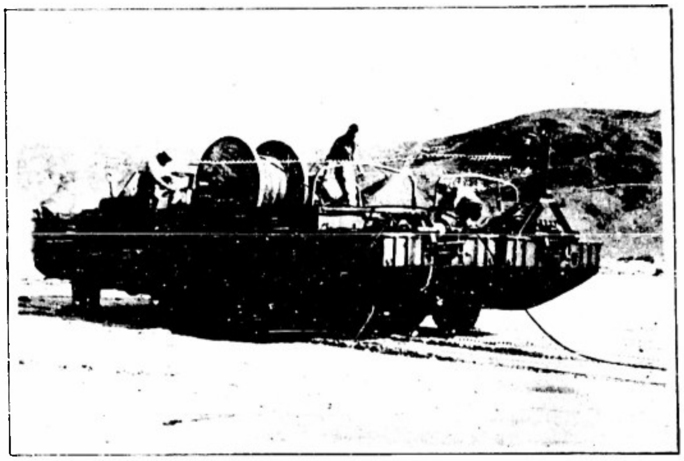
e. Electrical cable and chain being pulled off reef

INSTALLING CABLE OFF REEF

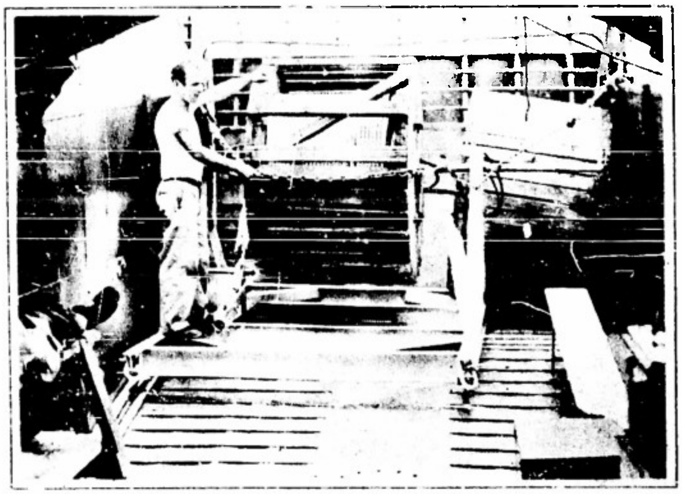
FIGURE 18



a. Spool holder mounting 2500 feet of armored cable.



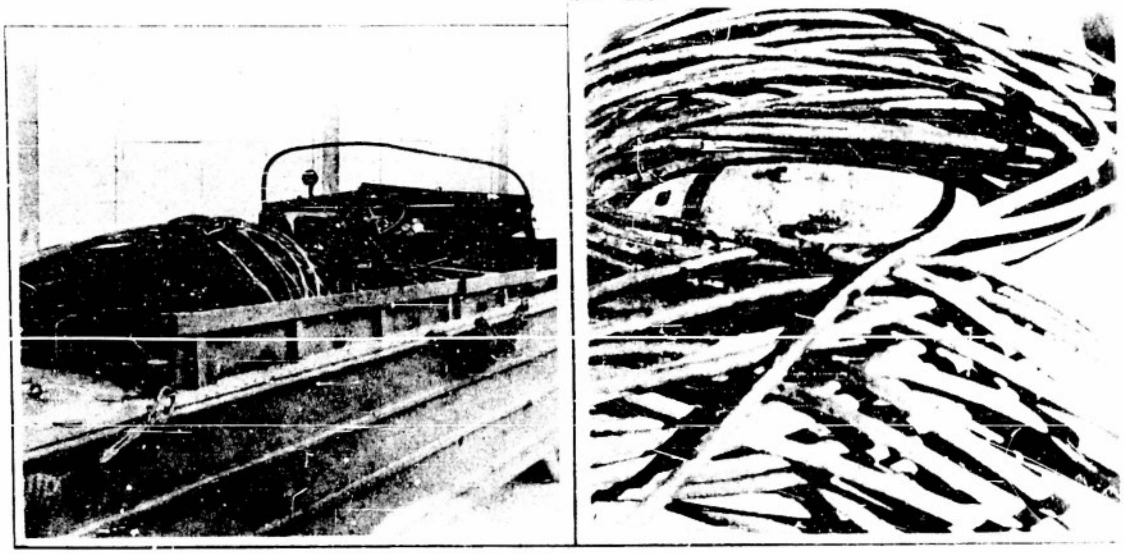
b. Spool holder mounted in a DUKW.



c. Spool holder mounted in an LCM.

Cable spool holders

FIGURE 19



a. 2500 feet of armored cable faked in a DUKW.

b. 4000 feet of unarmored cable faked in a DUKW. Pipe framework installed to prevent fouling of cable.

Cable faked in DUKW

FIGURE 20

Fig. 21 — Installing cable at Pt. Arguello, California.

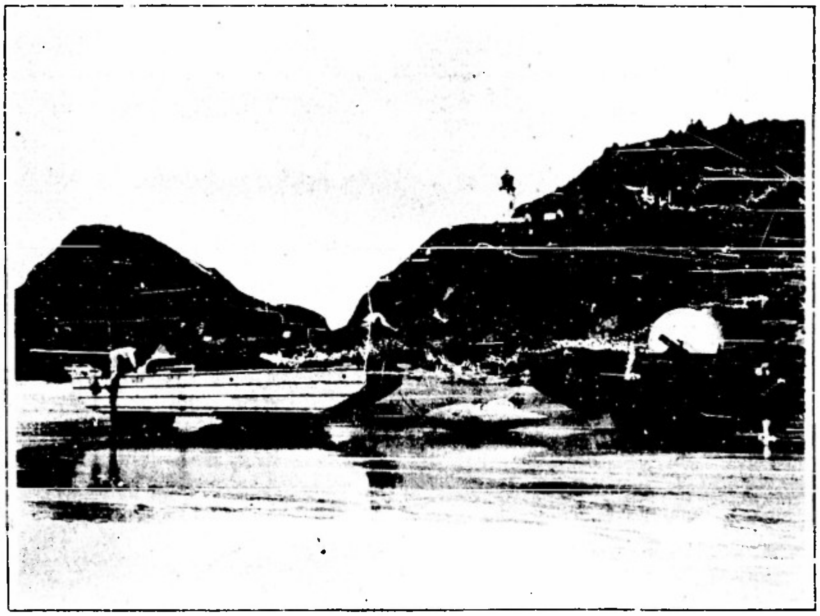


Fig. 22 — Preparing to lay cable at Heceta Head, Oregon. All connections have been made; aircraft wing tanks between DUKWs were used to buoy the cable and reduce drag.

A. Clamp cable in place; solder leads to fusite insulators

B. Splice fusite leads to cable

C. Wrap cable and sleeve with rubber tape; insulate cable splice

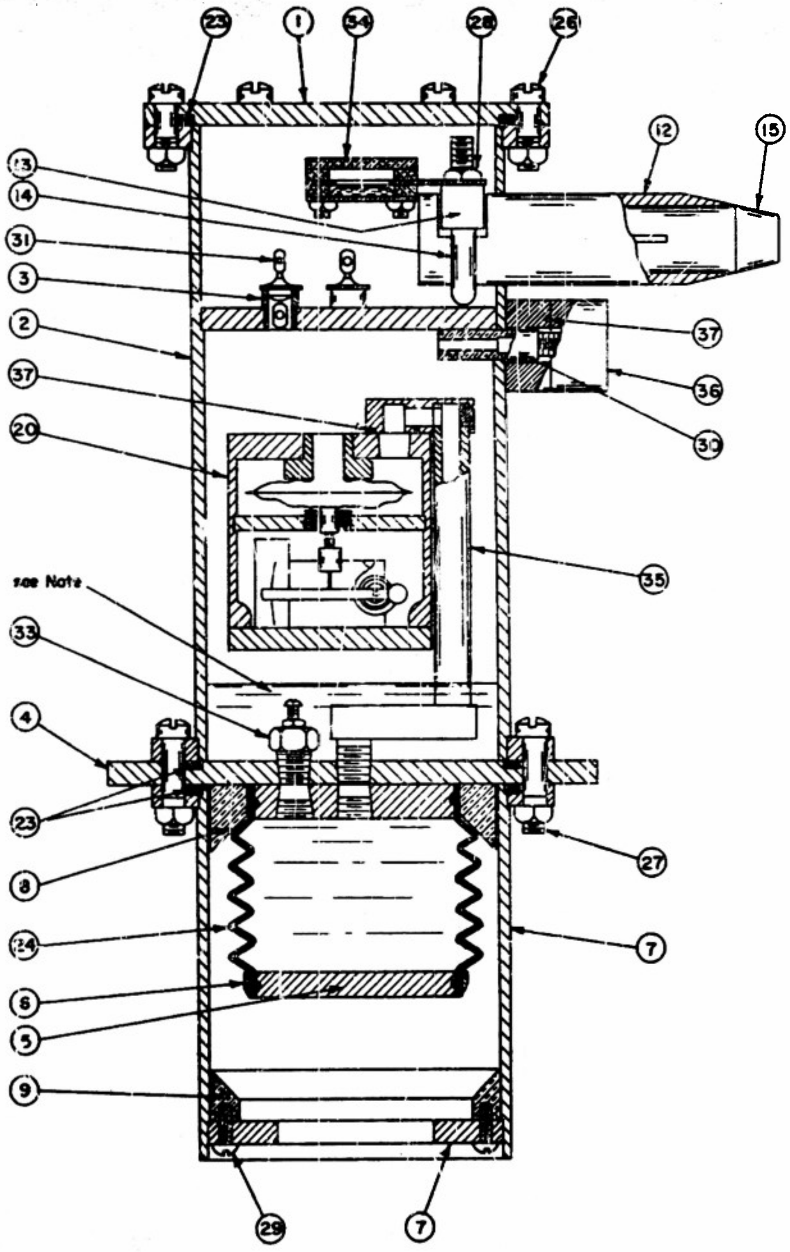
D. Fill connection chamber with silicone compound; wrap cable splice with friction tape

PRESSURE HEAD CABLE CONNECTION

FIGURE 23

APPENDIX II

MANUFACTURING AND ASSEMBLY DRAWINGS FOR PRESSURE HEAD, MARK IX, MODEL 5



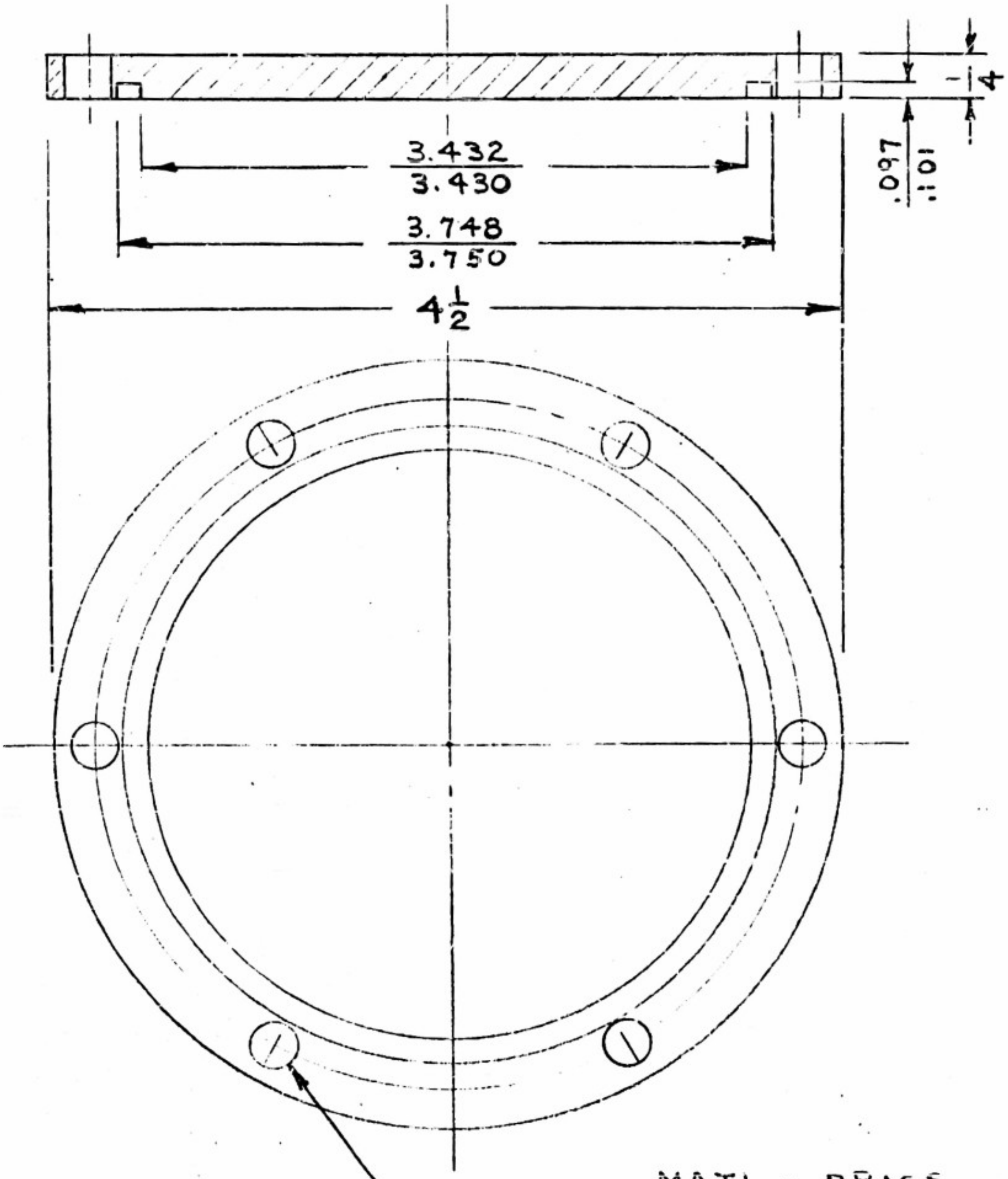
ITEM NO.	PARTS DESCRIPTION
1	Connection chamber cover
2	Transducer chamber
3	Fusite mounts
4	Mounting plate
5	Bellows end plate
6	Lower bellows clamp
7	Bellows chamber
8	Upper bellows clamp
9	Bellows support ring
12	Cable connector
13	Cable sleeve clamp
14	" " "
15	Cable sleeve
20	Bourns potentiometer #503
23	"O" ring-linear #1866-16
24	Rubber bellows
26	1/4 - 28 x 3/4 fillister head & nut
27	1/4 - 28 x 1 fillister head & nut
28	1/4 - 28 nut
29	8 - 32 x 7/16 RHMS
30	Schrader valve
31	Fusite connectors #112-FP
33	Slow leak
34	Mercury tilt indicator
35	Potentiometer mount
36	Valve stem cover
37	"O" ring #AN6227 B-9

Note: D-C 200 fluid silicone oil, fills Bourns potentiometer, potentiometer support, lower potentiometer chamber and bellows.

MARK IX, MODEL 5, PRESSURE HEAD

HYD-6144

FIGURE 24



"F"(.257) DRILL 6 HOLES
60° APART ON 4 1/16 DIA. B.C.

MATL - BRASS
1 REQD
①

BREAK SHARP EDGES
SCALE - FULL SIZE

COVER PLATE
MARK IX PRESSURE HEAD
MOD. 4, 5

UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY

DATE 11-8-51 DRAWN BY WK
HYD. 5544-116-00 TRACED BY

FIGURE 25

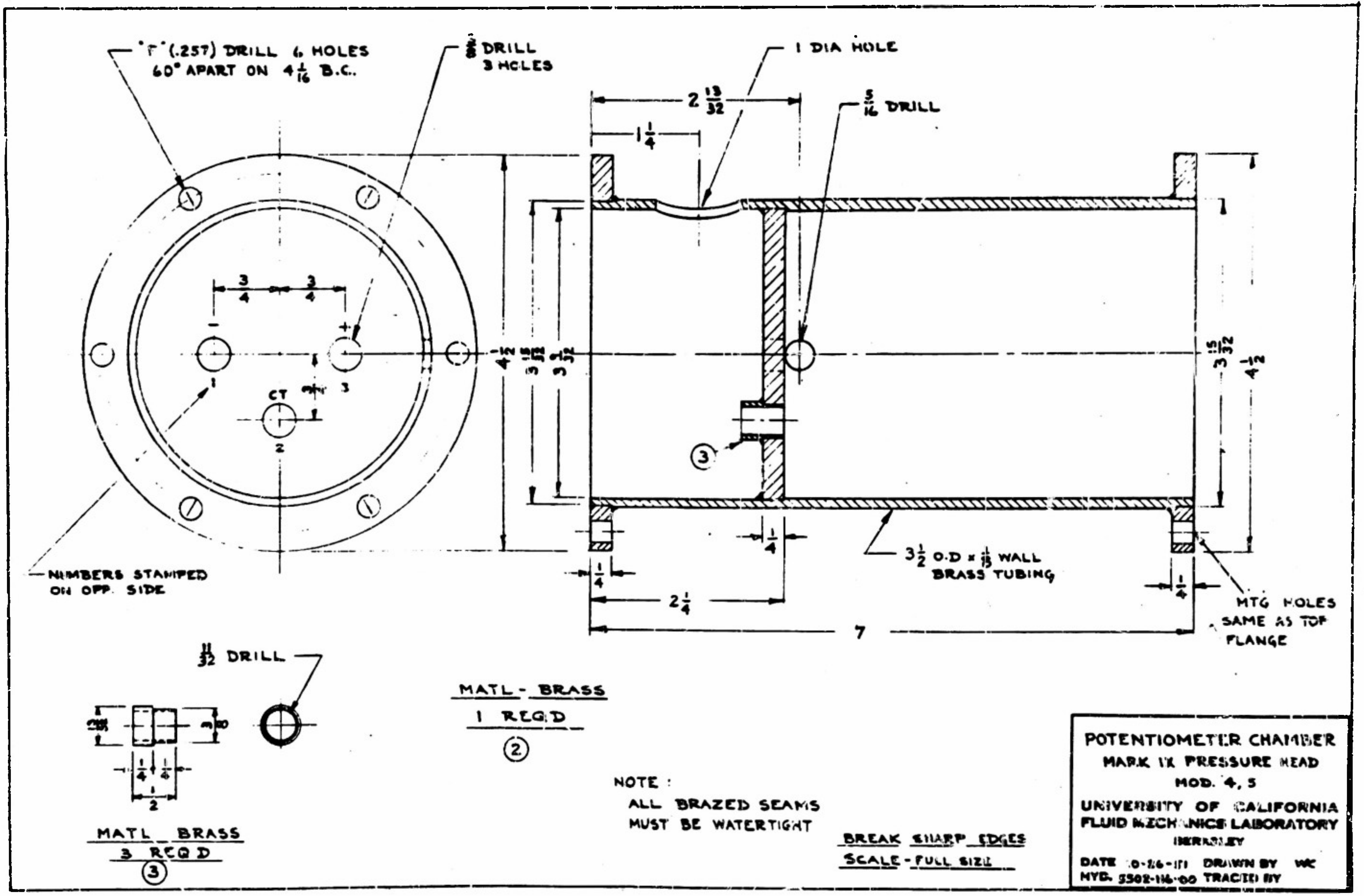

"F" (.257) DRILL 6 HOLES
60° APART ON 4 1/16 B.C.
3/8 DRILL
3 HOLES
3/4
3/4
+
−
1
2
3
CT
1/2
NUMBERS STAMPED
ON OPP. SIDE
4 1/2
3 15/32
3 9/32
1 DIA HOLE
2 13/32
1 1/4
5/16 DRILL
③
1/4
1/4
2 1/4
7
1/4
3 1/2 O.D × 1/16 WALL
BRASS TUBING
MTG HOLES
SAME AS TOP
FLANGE
3 15/32
4 1/2
11/32 DRILL
3/8
1/4
1/4
1/2
2
MATL BRASS
3 REQ D
③
MATL - BRASS
1 REQ D
②
NOTE :
ALL BRAZED SEAMS
MUST BE WATERTIGHT
BREAK SHARP EDGES
SCALE - FULL SIZE
POTENTIOMETER CHAMBER
MARK IX PRESSURE HEAD
MOD. 4, 5
UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY
DATE 10-26-51 DRAWN BY WC
HYD. 5502-116-00 TRACED BY

FIGURE 26

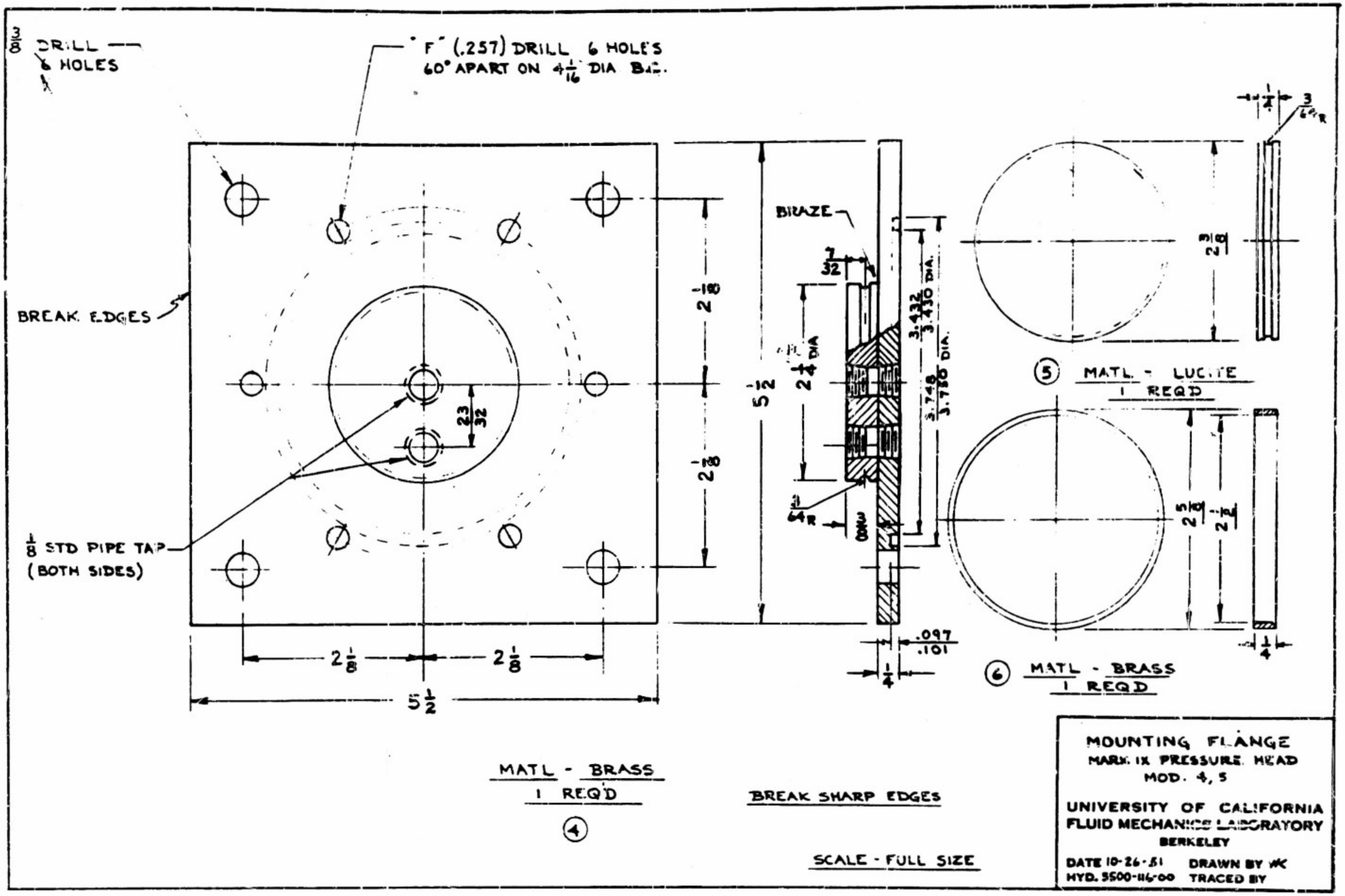
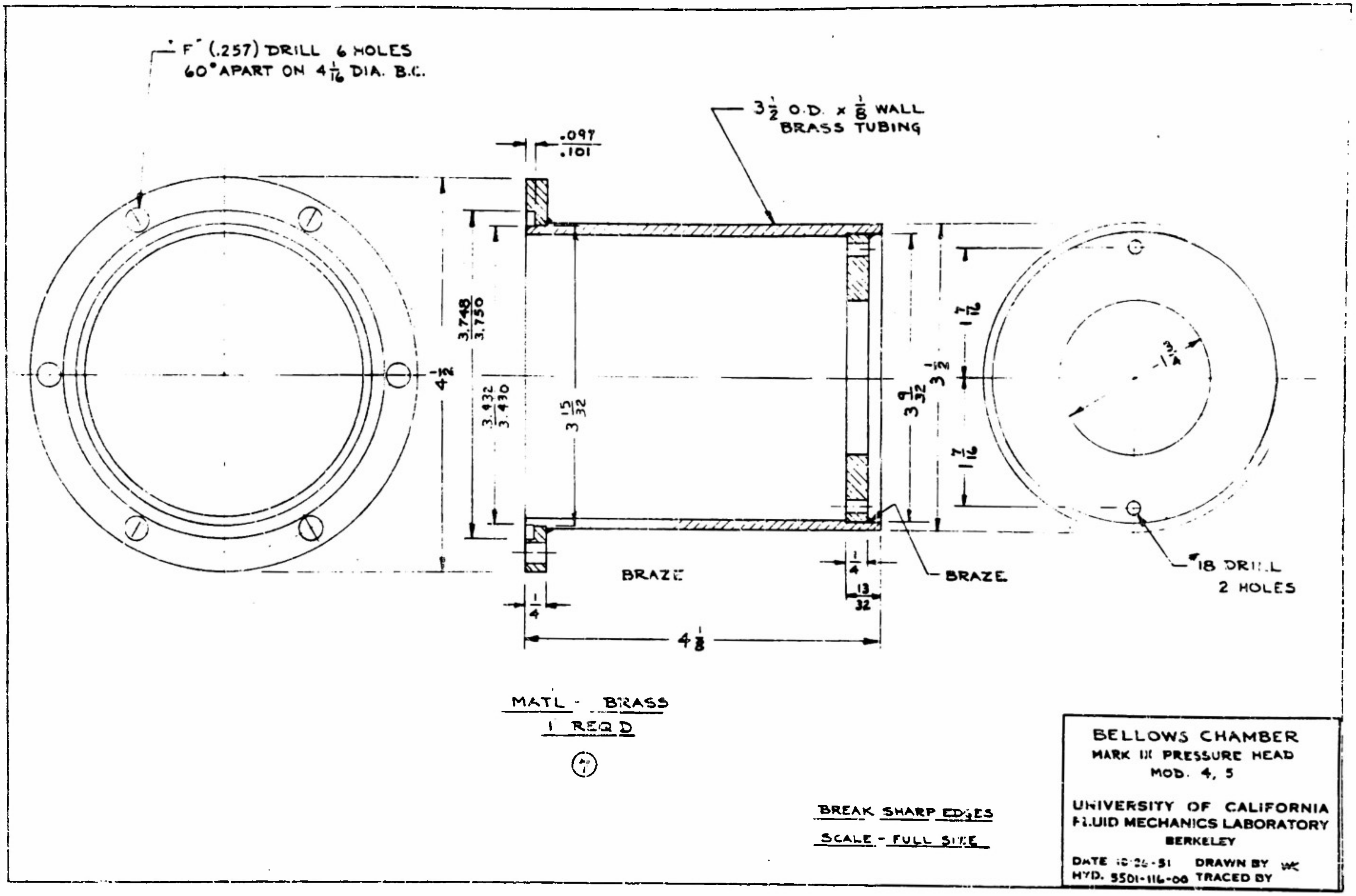

3/8 DRILL
6 HOLES
"F" (.257) DRILL 6 HOLES
60° APART ON 4 1/16 DIA B.C.
BREAK EDGES
1/8 STD PIPE TAP
(BOTH SIDES)
23/32
2 1/8
2 1/8
5 1/2
MATL - BRASS
1 REQ'D
④
BRAZE
7/32
2 1/4 DIA
3/64 R
3/8
3.432
3.430 DIA.
3.748
3.780 DIA.
.097
.101
1/4
BREAK SHARP EDGES
SCALE - FULL SIZE
1/4
3/64 R
2 3/8
⑤ MATL - LUCITE
1 REQ'D
2 3/8
2 1/4
1/4
⑥ MATL - BRASS
1 REQ'D
MOUNTING FLANGE
MARK IX PRESSURE HEAD
MOD. 4, 5
UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY
DATE 10-26-51
DRAWN BY WK
HYD. 5500-116-00
TRACED BY

FIGURE 27



BREAK SHARP EDGES

SCALE - FULL SIZE

BELLOWS CHAMBER
MARK III PRESSURE HEAD
MOD. 4, 5

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BERKELEY

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HYD. 5501-116-06 TRACED BY

FIGURE 28

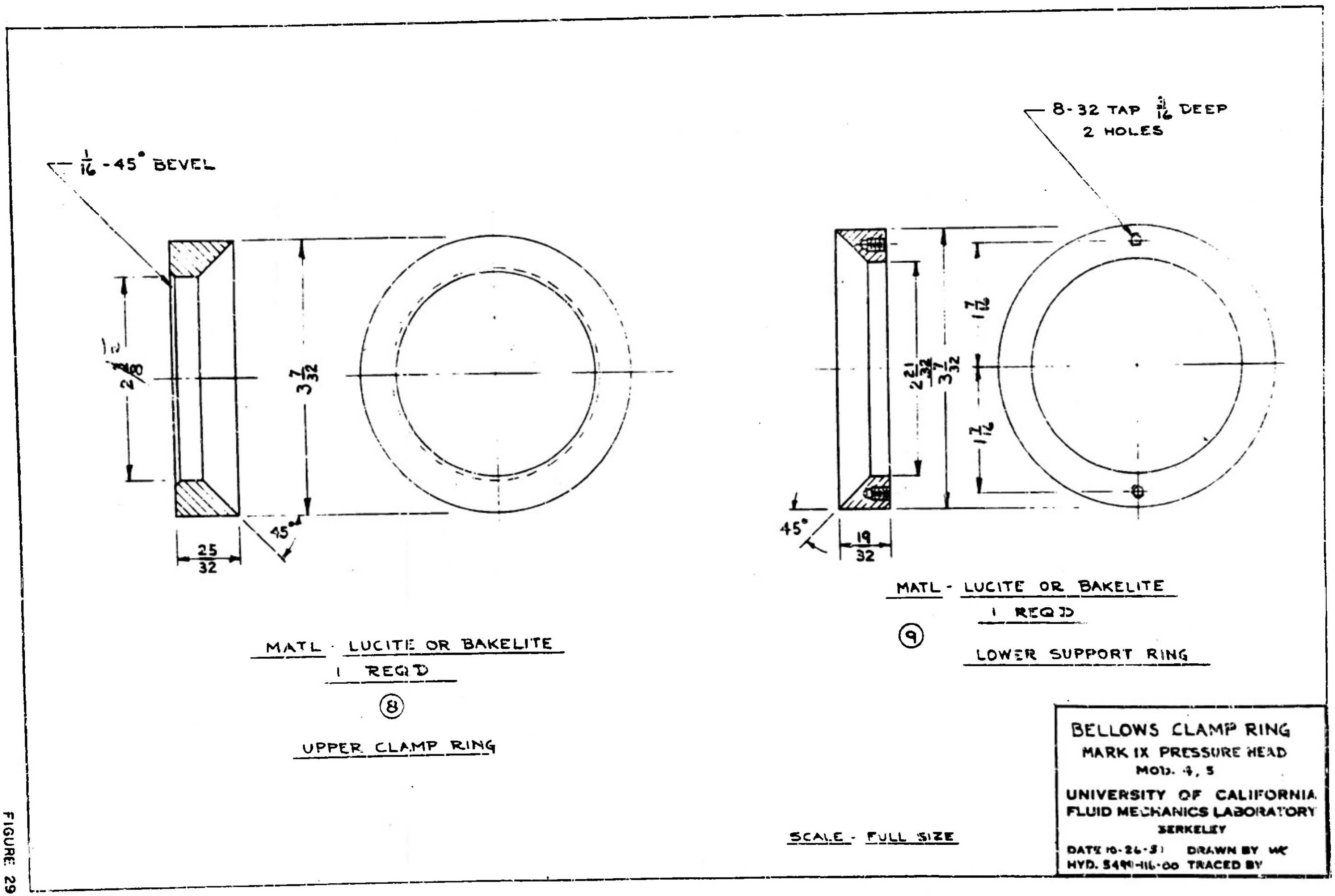
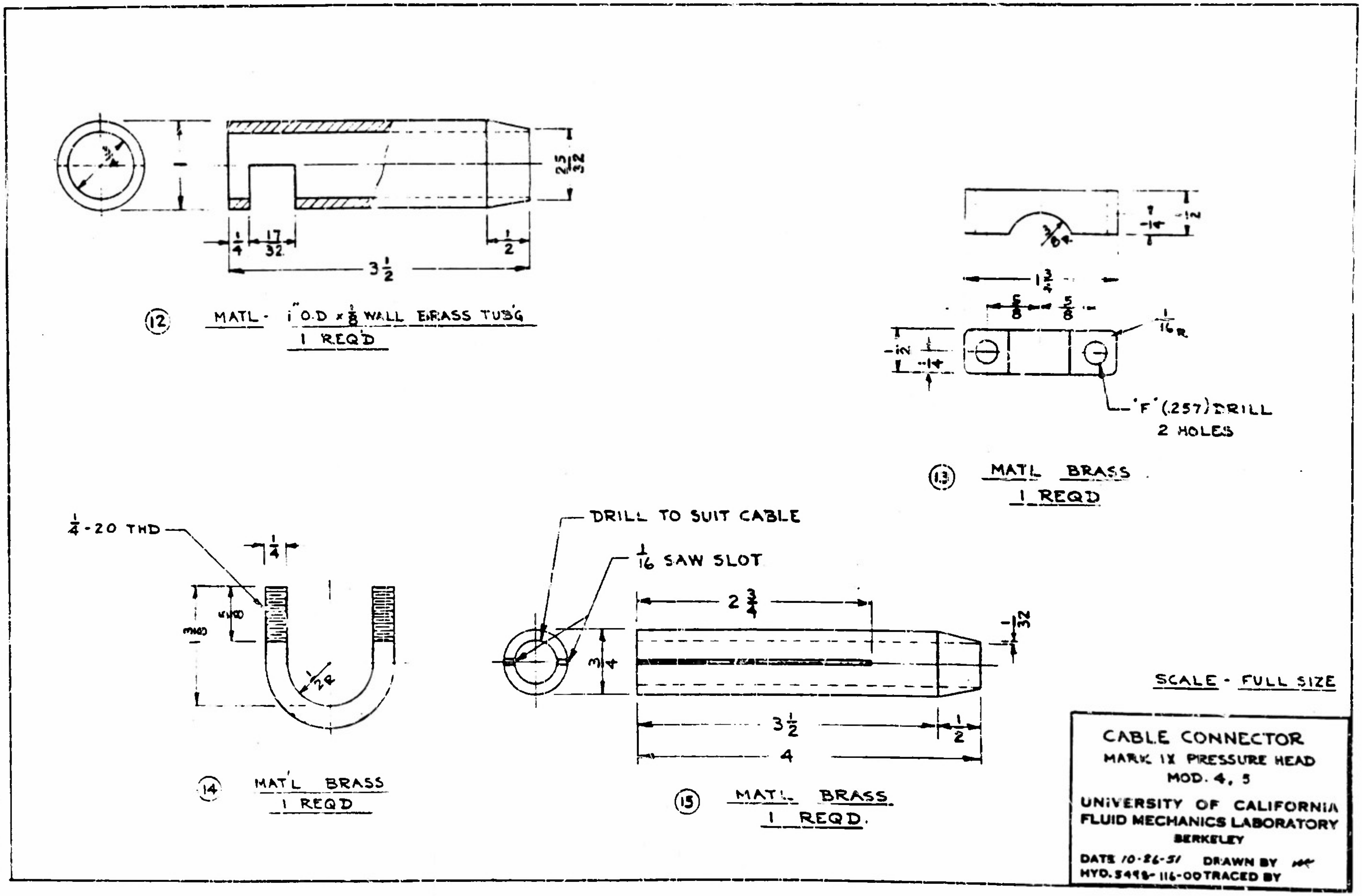
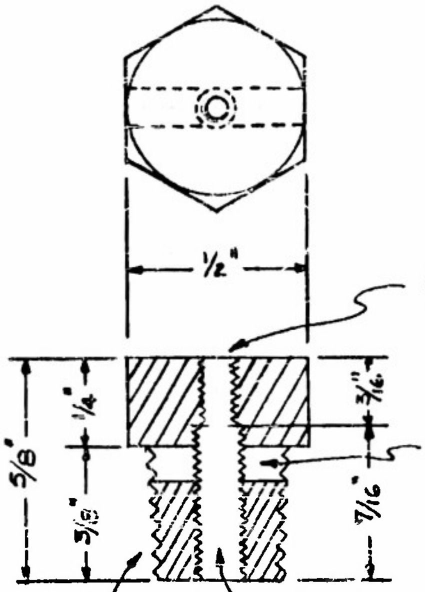

1/16 - 45° BEVEL
2 3/8
3 7/32
45°
25/32
MATL · LUCITE OR BAKELITE
1 REQ'D
⑧
UPPER CLAMP RING
8-32 TAP 3/16 DEEP
2 HOLES
2 21/32
3 7/32
1 7/16
1 7/16
45°
19/32
MATL - LUCITE OR BAKELITE
1 REQ'D
⑨
LOWER SUPPORT RING
SCALE - FULL SIZE
BELLOWS CLAMP RING
MARK IX PRESSURE HEAD
MOD. 4, 5
UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY
DATE 10-26-51 DRAWN BY WC
HYD. 5491-116-00 TRACED BY

FIGURE 29



⑫
MATL - 1" O.D × 1/8 WALL BRASS TUB'G
1 REQ'D
1/4
17/32
1/2
3 1/2
25/32
3/4
⑬
MATL BRASS
1 REQD
1 3/4
5/8
5/8
1/16 R
'F' (.257) DRILL
2 HOLES
3/64
1/4
1/2
⑭
MAT'L BRASS
1 REQD
1/4-20 THD
1/4
1/2 R
⑮
MAT'L BRASS
1 REQD.
DRILL TO SUIT CABLE
1/16 SAW SLOT
2 3/4
3/4
1/32
3 1/2
1/2
4
SCALE - FULL SIZE
CABLE CONNECTOR
MARK IX PRESSURE HEAD
MOD. 4, 5
UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY
DATE 10-26-51 DRAWN BY
HYD. 5498-116-00 TRACED BY

FIGURE 30



Solder lock nut & screw
after calibration

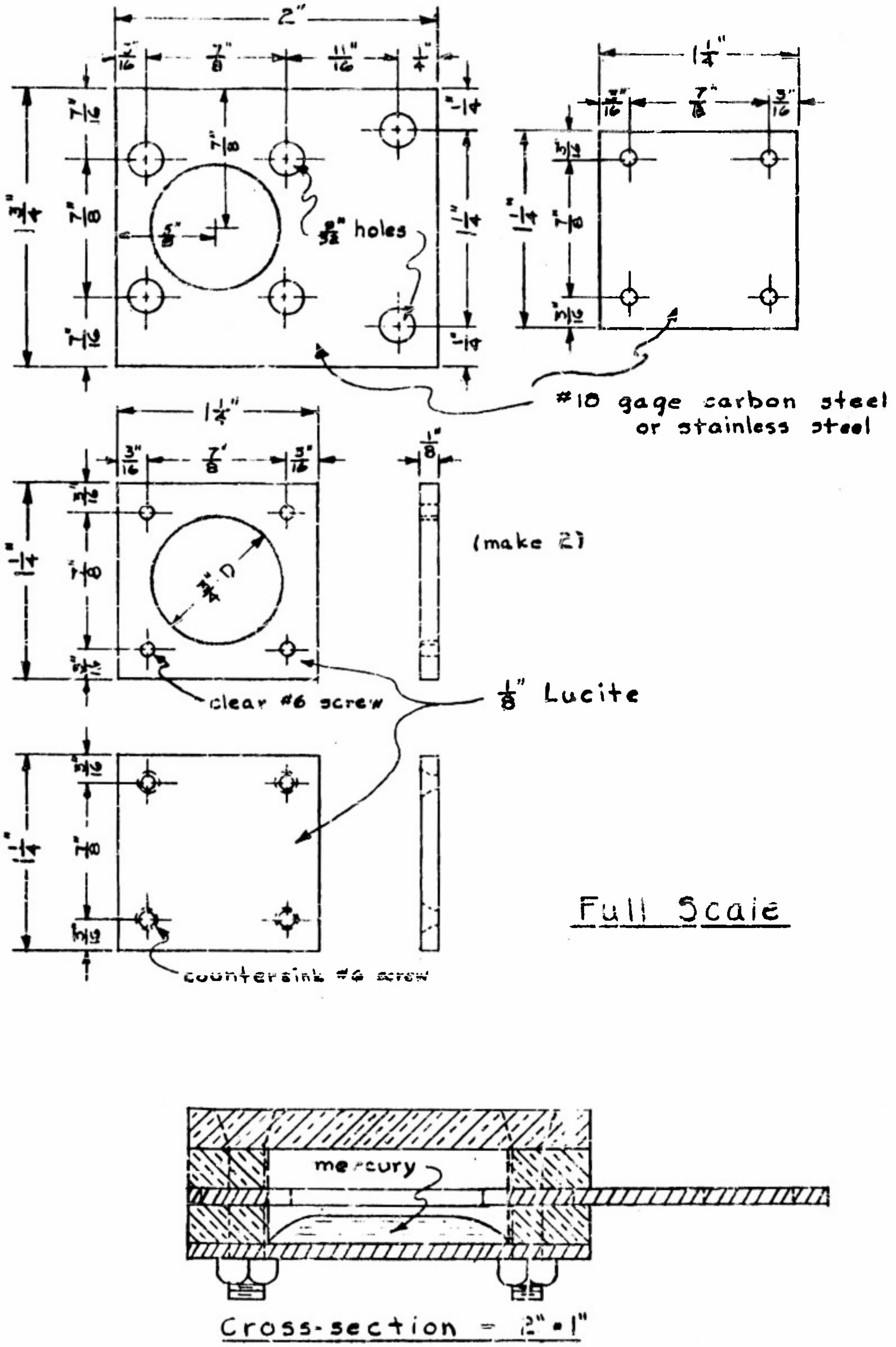
Material: Brass hex

Scale 2:1

SLOW LEAK
WITH SILICONE
for MARK IX, 4, 5
UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY

DATE 10-30-52 **DRAWN BY** MML
HYD. 6107 **TRACED BY**

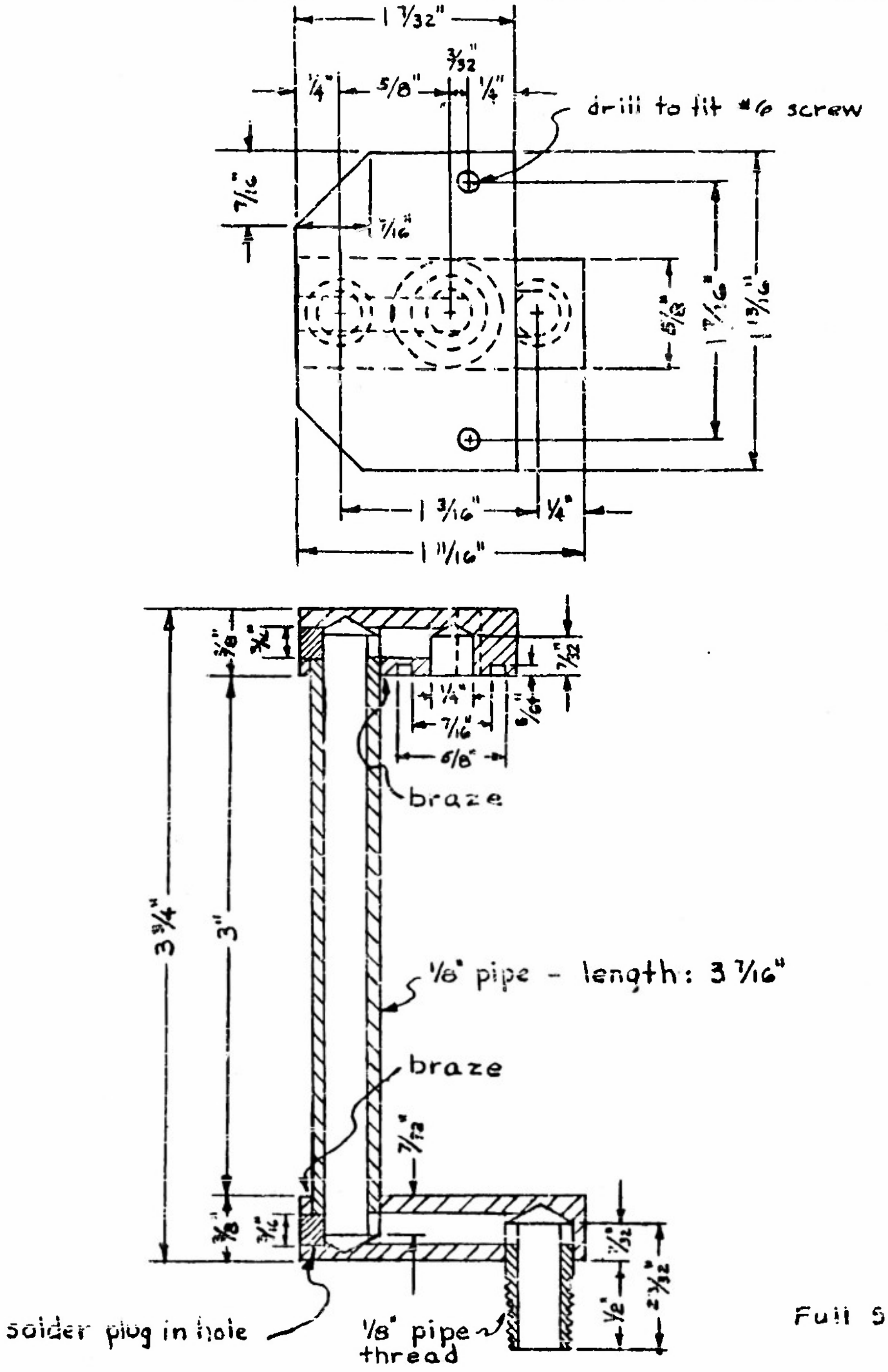
FIGURE 31



TILT INDICATOR FOR MARK IX MODEL 4, 5

HYD-5843

FIGURE 32



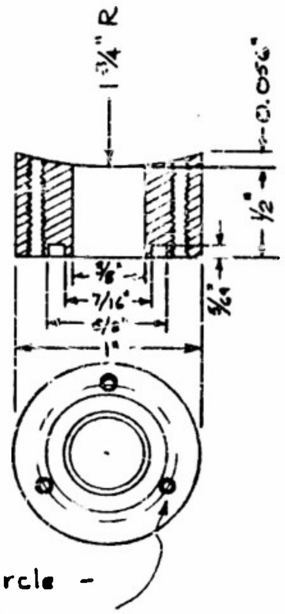
Full Scale

TRANSDUCER SUPPORT
ASSEMBLY
MARK IX, MODEL 5

UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY

DATE 11-12-52	DRAWN BY MML
HYD. 6125	TRACED BY

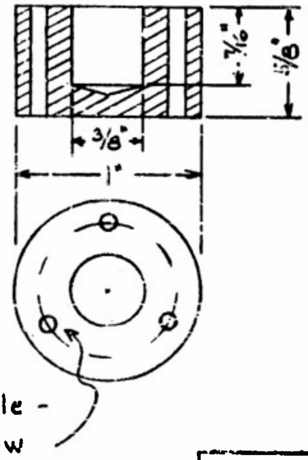
FIGURE 33



3 holes on 3/4" D circle -
drill & tap #4-40 NC

Make 3 sets - soft
solder to Mark IX M4-11
pressure head

Use O-ring AN6227 B-9
Parker 5427-9



3 holes on 3/4" D circle -
drill to clear #4 screw

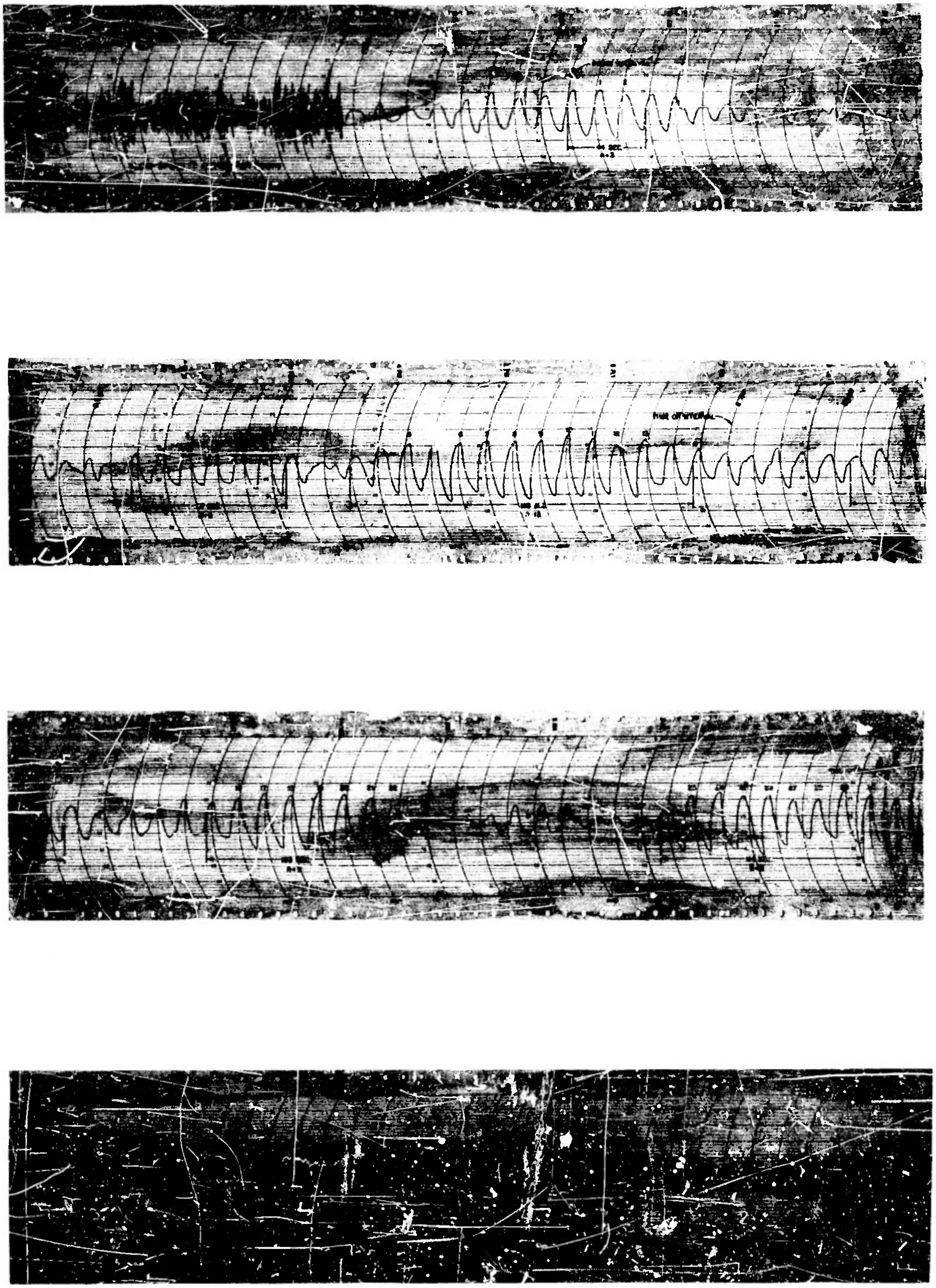
NIPPLE COVER

for MARK IX, M4, 5

UNIVERSITY OF CALIFORNIA
FLUID MECHANICS LABORATORY
BERKELEY

DATE 10·30·52 DRAWN BY MML
HYD. 6108 TRACED BY

FIGURE 34



SAMPLE WAVE RECORD ANALYSIS

FIGURE 35

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