# MODERN EQUIPMENT FOR APPLICATION OF SALT VELOCITY METHOD OF DISCHARGE MEASUREMENT FOR PERFORMANCE TESTS

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## SUMMARY

The salt-velocity method has for some time been recognized as a convenient means of measuring the rate of flow in closed conduits. Use of the method for measuring the discharge for pump and turbine acceptance tests has been questioned because considerable salt was necessary to produce a brine cloud of sufficient conductivity to obtain suitable records with conventional equipment. The specific gravity of the cloud was considerably greater than unity. A cloud having such a specific gravity could conceivably travel at a different velocity than an equal amount of water in inclined penstocks or pump discharge lines.

Refinements in the equipment and test techniques presently employed by the Bureau of Reclamation should alleviate this criticism. These developments have been accomplished over a period of years by analytical, laboratory, and field study. Recent advances in commercial instrument design have greatly assisted.

The presently used equipment consists essentially of: a brine injection cylinder which is positively activated by a compressed air cylinder controlled by solenoid valves; quick acting pop valves to introduce the brine into the flow; two electrode stations in the conduit; electrical circuits and recorder; and a turbulator, when low velocites or upset velocity distribution are anticipated. The electrical circuit for each electrode station consists of an alternating current Wheatstone bridge. The passage of the brine between the electrodes changes the balanced resistance and the resulting current flow is amplified and recorded as a rectilinear diagram which may be analyzed readily. Accurate time intervals are recorded simultaneously. The improved equipment is described in detail and sample results of actual tests are shown.

## INTRODUCTION

The salt-velocity method of measuring water in closed conduits has been used for a number of years in several countries throughout the world. This method has found more extensive use in the United States than elsewhere because of the great amount of development work done by the late Professor Charles M. Allen.

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Numerous technical articles have been written regarding the development and use of the method. Therefore, is is sufficient to say here that the technique employed is to introduce a brine solution into the flow in a short interval of time. Electrodes are installed at two stations downstream from the point of salt injection and are connected through associated circuits to a source of current and an electrical indicator, or recorder. Passage of the brine is accompanied by a change in electrical current passing between the electrodes. Careful determination of the time required for passage of the brine between the two test stations and the volume of the conduit in the same reach permit calculation of the rate of flow. Although some application has been made of the technique to measure flow in open channels, the primary use has been in closed conduits. This discussion will be limited to the latter case with particular attention to performance tests of hydraulic machines.

The precision with which the flow rate may be determined has rendered the method quite adaptable to acceptance tests of pumps and turbines. Recently developed pump-turbine units can be tested readily by following similar procedures for the unit operating either as a pump or a turbine.

Accuracy of the method for determining rate of flow in inclined conduits, normally found at pump and turbine installations, has at times been questioned because the specific gravity of the brine cloud, being greater than unity, could conceivably cause the cloud to travel faster or slower than an equal volume of water, depending upon the direction of slope in relation to flow. It was necessary to use a large amount of highly concentrated brine to obtain readable changes in current flow with the equipment available in past years. In addition to the objectionable characteristics of a cloud of high specific gravity, equipment to handle large amounts of concentrated brine was quite bulky.

The presently used procedure has been developed over a period of years by analytical, laboratory, and field study. During the same interim, greatly improved instruments for measuring time and changes in electrical current and recording the results have become available commercially. As a result of these advances and developments in the Engineering Laboratories of the Bureau of Reclamation, a small amount of low-concentration brine can now be employed. Consequently, equipment can be kept to reasonable dimensions. Excellent results are obtained when working in water having a wide range of basic salt content.

## GENERAL DISPOSITION OF EQUIPMENT

Equipment necessary for determination of rate of flow may be divided generally into that which is installed in the interior of the conduit and that which is employed on the exterior.

In selecting a reach of conduit in which to accomplish measurements, consideration must be given to uniformity of diameter, absence of bends or other disturbances, access to the interior for injection of brine and for making the necessary installations, and others. Equipment on the exterior of the conduit should be located as close to the interior installation as is possible for economy and convenience.

## Interior Installations

The necessary equipment within the conduit is, from upstream to downstream: a turbulator, if velocities are low or if upset velocity fronts are anticipated; a set of spring-loaded pop valves connected to suitable brine supply piping extending to the exterior of the pipe; and two identical electrode stations with associated insulated electrical conductors carried through packing glands and terminating on the outside of the conduits.

As shown on Figure 1, the pop valves are installed four pipe diameters downstream from the turbulator. The first electrode station is at least an equal distance downstream from the pop valves. The distance between electrode stations will vary with local conditions. To minimize the effect of velocity distribution changes and consequent alteration of shape of the brine cloud between electrodes, the distance separating the two electrode stations should be kept as short as possible consistent with the existing range of velocities, the type of timing device, and the recorder employed. However, the stations must be separated by a distance such that a single brine cloud will not be in contact with both stations at the same time. (The reason for this is not entirely clear, but studies have shown that erratic results are obtained when the head of the brine cloud reaches the second electrode station before the tail has cleared the first.)

## Exterior Installations

Necessary exterior equipment is: a brine injection apparatus connected to the piping from the pop valve assembly (and also to the flow in the conduit if under high pressure); a brine mixing tank, usually one or more 50-gallon oil drums; electrical leads; an electrical recorder or indicator together with associated electrical and electronic circuits. Arrangement of this equipment is shown on Figure 1.

As previously stated, these exterior installations should be close to the interior installation. Experience has shown that the brine injection cylinder should be located as close as practicable to the pop valves to minimize the possibility of air traps and excessive water hammer in the injection line. Electrical leads from the electrodes may be carried through the wall of the conduit at the electrode stations or, as is usually more convenient, at or near the entry of the brine piping.

## DESCRIPTION OF EQUIPMENT IN CONDUIT

### Turbulator

The turbulator serves the purpose of breaking up irregular velocity fronts and insuring a high degree of turbulence at the pop-valve station for mixing the brine throughout the flow. The turbulator should cover approximately 30 percent of the cross-sectional area of the conduit. In large diameter conduits, structural steel members, spaced at intervals and extending across the interior, are used to restrict the necessary area, Figure 2A. A circular plate pierced by a rectangular hole has been used in conduits up to 4-1/2 feet in diameter, Figure 2B.

### Pop Valves

To insure against leakage of brine into the flow and to provide quick cutoff of brine injection, spring-loaded pop valves are used at the terminus of the brine injection line. Usually four valves, properly spaced in a cross section of the conduit, are adequate to distribute brine throughout the flow. In large conduits more are used. Details of the valves, brine piping, and support are shown in Figure 3.

### Electrodes

Design of the electrodes should be such that all or nearby all of the flow passes between the component elements of opposite polarity. A close grid extending completely across the conduit and having alternate elements of opposite polarity would be an idealized case. Such an installation is not practical in the field. From an academic point of view, the size and shape of the electrodes is a moot question. Laboratory experiments indicate that considerable deviation from theoretically perfect electrodes is permissible without materially affecting accuracy of the results.

The electrodes shown in Figure 4 were developed from a series of tests in the laboratory and from experience gained in the field. The vertical electrode elements are made of cold-rolled steel bars of sufficient size to satisfy structural requirements of the electrode assembly; these bars are spaced to divide the cross-sectional area of the conduit into equal areas between bars. Adjacent electrode bars are of opposite electrical polarity, and all bars of like polarity are connected together. Although the illustration shows seven bars, in small diameter conduits this number must be decreased to retain practical distances between bars. An odd number of vertical bars is habitually used in order that the outside bars may be of like polarity, thus minimizing the possibility of leakage of electrical current through the wall of the conduit acting as a conductor. It may also be noted from the figure that there are two small areas of flow, one on each side of the conduit, that do not pass between the electrodes. These areas are kept as small as possible, but must be of sufficient width to provide working space at the anchor-ring spreading bolts.

The individual bars must be effectively insulated from each other and from the conduit to insure that the passage of current is through the water only. All nonconducting surfaces are coated with insulating varnish. Similarly, the electrical leads must be well insulated from each other and from the flow. If the leads must be carried along the interior of the conduit, they are normally enclosed in a small watertight tube of adequate wall thickness to withstand pressures existing in the conduit.

A series of laboratory tests were performed using two electrodes of the design shown in Figure 4 in an installation where the rate of flow was measured with a volumetrically calibrated orifice plate meter. These tests revealed that the accuracy of an average of five salt velocity tests at a given discharge was well within the range of plus or minus 1 percent compared to the discharge as determined by the calibrated meter.

## DESCRIPTION OF EQUIPMENT ON EXTERIOR OF CONDUIT

### Brine Injection Apparatus

The brine injection apparatus is shown in Figure 5. The basic elements consist of two cylinders each having inside dimensions of 12 inches diameter by 18 inches in length. They are alined on a base so the longitudinal center line is common to both.

Each cylinder is fitted with a double-acting piston. Both pistons are secured to a common piston rod. The forward part of the injection cylinder is connected to the brine supply tank and also to the pipe leading to the pop valves. The other end of the injection cylinder is connected by a pipe to the conduit in order that the line pressure may be admitted to the back side of the piston.

The forward part of the second cylinder is connected to a compressed air supply for use in forcing the pistons to the rear for loading the injection cylinder with brine. The rear of the second cylinder is also connected to a compressed air supply. This side of the piston provides the unbalanced force to drive the two pistons forward and inject brine into the conduit through the pop valves.

The air lines are controlled by solenoid valves which are actuated by interlocked electrical relays. This system provides almost complete push-button operation. Consequently, one operator at the injection equipment can control the sequence.

Briefly, the cycle of operation is as follows: With both pistons in the forward position, as at the end of a brine injection, the valve in the pressure line from the conduit is set manually so the pressure is shut off and the rear of the forward cylinder is open to atmosphere. This conduit pressure line is normally 4-inch pipe size fitted with a manually-operated plug valve. The Interlock switch on the control panel is placed in the Recharge position and the Recharge switch pressed. This action opens the solenoid valve on the compressed air line leading to the forward part of rear cylinder and the pistons move to the rear. Brine is drawn into the forward part of the forward cylinder through a swing-check valve located close to the cylinder. The amount of brine to be injected can be controlled in this operation by moving the piston assembly to the rear only a sufficient distance to charge the forward cylinder with the desired quantity of brine.

When the filling cycle is complete, the plug valve on the conduit pressure line is opened to admit pressure to the rear of the forward piston. The Interlock switch on the control panel is placed in the Inject position. This switching operation signals the operator at the recording equipment that the cylinder is loaded and injection can be made when the recording equipment is in readiness or on signal from the test supervisor. When the Inject switch located at the recorder is thrown, a solenoid valve opens the forward part of the rear cylinder to atmosphere and another solenoid valve opens and admits compressed air to the rear of the rear cylinder, driving the pistons forward and injecting brine through the pop valves. A limit swtich, properly positioned, causes the solenoid valve to arrest the admission of compressed air and at the same time, opens the cylinder to atmospheric pressure. The amount of brine injected may also be controlled to a desired quantity by properly positioning the limit switch. Should the electrical limit switch fail, additional valves are opened mechanically by a metal disc on the end of the piston rod to relieve the pressure and prevent the piston from striking the end of the cylinder while under pressure. A circuit diagram of the solenoid valve control system is shown in Figure 6.

This equipment has been used on a number of field tests and has functioned satisfactorily. The solenoid valves are of commercial manufacture. Approximately 50 amperes at 115 volts alternating current are required to operate the solenoids and electrical control system. An air supply at 90- to 120-pounds per square inch pressure is necessary to drive the piston when aided by conduit pressure on the back of the forward piston. Since the volume of the driving cylinder is relatively small and some time elapses between injections, a portable compressor of low delivery rate and with a medium capacity receiver is used at installations where a central air system is not available.

## Electrical Recorder and Associated Circuits

Two types of instruments are utilized to produce a permanent record of the results. Under normal conditions, a commercially manufactured instrument of the following specifications has proved very satisfactory: This recorder is a two-channel direct-writing instrument equipped with two extra event markers to record time, revolutions of a machine, or other phenomena along the edges of the record paper.

The direct-writing recording system transforms the input signals into a trace on continuous chart paper. The capacity of the recorder is 200 feet of chart. This paper is 5 inches wide and is cross-ruled at 1-mm intervals across a width of 4 inches. The trace is permanent in nature and is made by a heated stylus passing over treated chart paper. Recordings are in rectangular coordinates without curvature of time lines or negative time intervals.

There are two basic recording galvanometers, each with a recording stylus. Each stylus has a recording deflection of approximately 2 inches. Each galvanometer has a sensitivity of 1 centimeter deflection per 10 milliamperes change in current.

Paper speed is governed by gear selection and manual control. The range of speeds includes 0.5, 1.0, 2.5, 5, 10, 25, 50, and 100 millimeters per second and has a speed accuracy adjustable to 0.5 percent. The paper speed and cross-ruled lines are not used as an exact measure of time since voltage or current fluctuations can cause speed variations in the driving motor. The output from an electrically-driven, chronograph-controlled, direct-current timer is supplied to the coil of one of the event markers that produces a record along the edge of the chart. This timer produces 1-second beats and is accurate to approximately 1 part in 3,600.

Each channel of the recorder is controlled by a strain-gage type amplifier unit. This unit is coupled with an external bridge network containing the electrode. The recorder-amplifier system operates from a 110-115-volt, 60-cycle power supply.

The strain gage amplifier unit used with the above components is of the modulated carrier type. It contains a bridge network, carrier amplifier, carrier frequency oscillator, mixer, demodulator, and output amplifier for the galvanometers.

Figure 7 shows one of the external or associated bridge networks used in connection with an electrode and an amplifier. The electrode forms one leg of the bridge circuit. This circuit has the additional function of matching the low impedance of the electrodes to the higher input impedance of the amplifier. There are identical circuits for each electrode station. The bridge is activated by a 2,500-cycle oscillator in the amplifier. This alternating current on the electrodes reduces their tendency to polarize.

The bridge is coarsely balanced with the external network and a fine balance is achieved by the bridge balance circuit in the amplifier.

When high velocities are to be measured, a recording oscillograph using sensitized photographic paper is substituted for the direct-writing recorder. This type of recorder is equipped with high-sensitivity galvanometers and amplifiers are not needed. A balancing bridge network and matching circuit for the galvanometers are essential, however. A mirror attached to the moving coil of the galvanometer deflects a light-beam which is recorded on photographic paper. An interval timer places time lines spaced at 1/100 at a second intervals on the record paper as it moves through the oscillograph. Time can be read to 1/1000 of a second. The length of the optical system and the direction of movement of the paper are such that the resulting record is rectilinear with regard to time and almost perfectly rectilinear in displacement.

Three different commercially produced oscillographs have been used to record the results of salt-velocity tests. All have operated quite satisfactorily.

The normal direct current resistance between immersed electrodes varies from approximately 5 to 250 ohms according to the conductivity charachteristic of the water and the design of the electrodes. With the above described circuits, this wide variance in the resultant bridge impedance can be compensated for, and the slightest change in water conductivity due to the passage of brine can be recorded. If the bridge is perfectly balanced, there is no current flow between electrodes until the brine makes its passage. At that time, the full characteristic of the brine cloud is recorded.

With previously used circuits, this was not possible and when working in waterof high conductivity an accurate recording was difficult to obtain.

## TECHNIQUE OF EMPLOYMENT

### Brine

A brine of specific gravity of 1.01 to 1.04 is normally used. The installation used in the conduit will vary from one job to the next and it is necessary to make a few trial runs to fix the specific gravity of the brine and the amount used to obtain optimum recordings. Length of time of injection of the brine will vary, but usually can be controlled to less than 1 second.

### Number of Records Made

In practice five brine clouds are injected and a record of each is made at the desired test discharge after flow conditions have become constant. The time interval between injections is sufficient to insure that the brine cloud has cleared the test section before another injection is made. When velocity surges are noticeable in the conduit, additional records may be necessary. The average of the discharges calculated from each record is used as the discharge for the test.

## Conduit Calibration

After the electrodes are anchored in position in the conduit, careful measurements are made of the distance between the center lines of the two electrode stations. Inside calipers, with a vernier reading to the thousandths of a foot, are used to obtain the average diameter of the conduit between the electrode stations. The number of observations made depend upon deviation of diameter from the nominal. The volume of the test reach of conduit, that is, the portion between the electrode stations, can be calculated from the above measurements.

# ANALYSIS OF RESULTS

## Records

The direct-writing recorder yields truly rectilinear plots of the deflection resulting from the passage of the brine cloud. A sample record of the curves produced is shown on Figure 8. All pertinent data derived from the curves and a sample calculation are included in the figure. The time distance between centers of gravity of the two deflection curves is obtained by tracing the curves on heavy bond paper. The curve, above the base line, thus traced is carefully cut out and balanced on a knife edge. The balance point, or center of gravity, for each curve is marked and transferred to the record. The time distance can then be determined from the time scale traced on the record by the event marker driven from the 1-second chronograph.

Records from the oscillograph used for high-velocity flows are treated in a similar manner. The extremely slight distortion in height of curves is not of sufficient magnitude to introduce errors in the results. The time lines on the photographic charts extend the full width of the record. Time can readily be determined to 1/1000 second. The photographic paper must first be developed, fixed, washed, and dried. Some delay is experienced in this process and the direct-writing recorder, therefore, is preferred.

# CONCLUSIONS

It has been demonstrated by usage in the field that the electric and electronic circuits described: are quite stable in operation; permit use of small amounts of low density brine thus allowing simplification of the brine mixing and injection facilities and allaying criticism of the method due to possible differential velocities of the brine and water; eliminate polarization of the electrodes; and encompass an adequate degree of flexibility for use under all local conditions thus far encountered in the field.

The injection appartus and the associated electric controls permit injection of the brine in a very short period of time thus producing brine clouds of minimum lengths. The time required to conduct a test program on a pump or turbine is also shortened.

Use of the direct-writing recorder allows immediate inspection of test results and renders a permanent record that is conveniently analyzed.

The equipment described has functioned very satisfactorily on numerous field tests. If has a certain degree of portability and is rugged enough to withstand field usage. Proper installation of the apparatus and exercise of careful technique in testing will render extremely consistent results.



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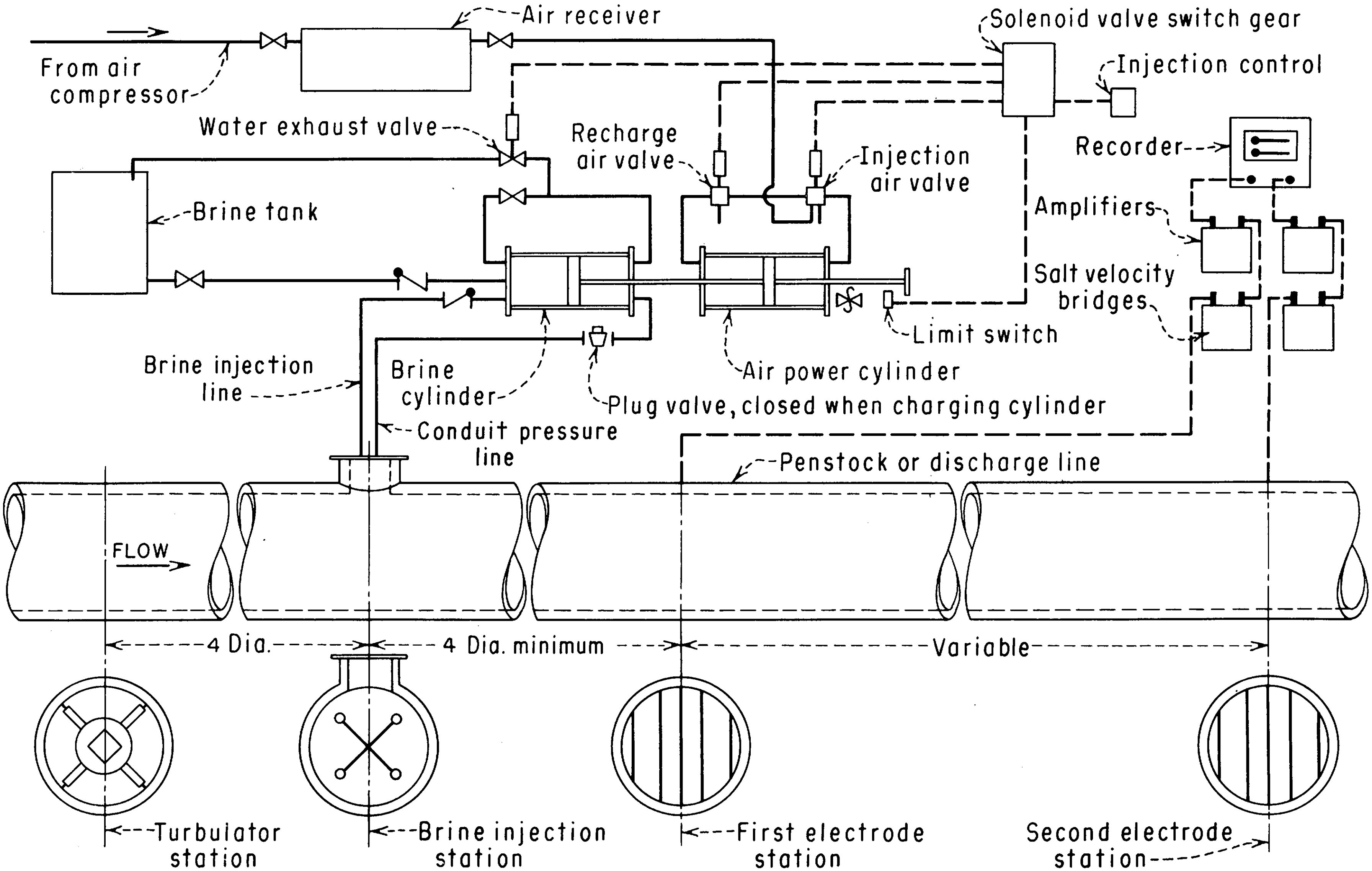



FIG. 1 - GENERAL ARRANGEMENT OF SALT VELOCITY EQUIPMENT

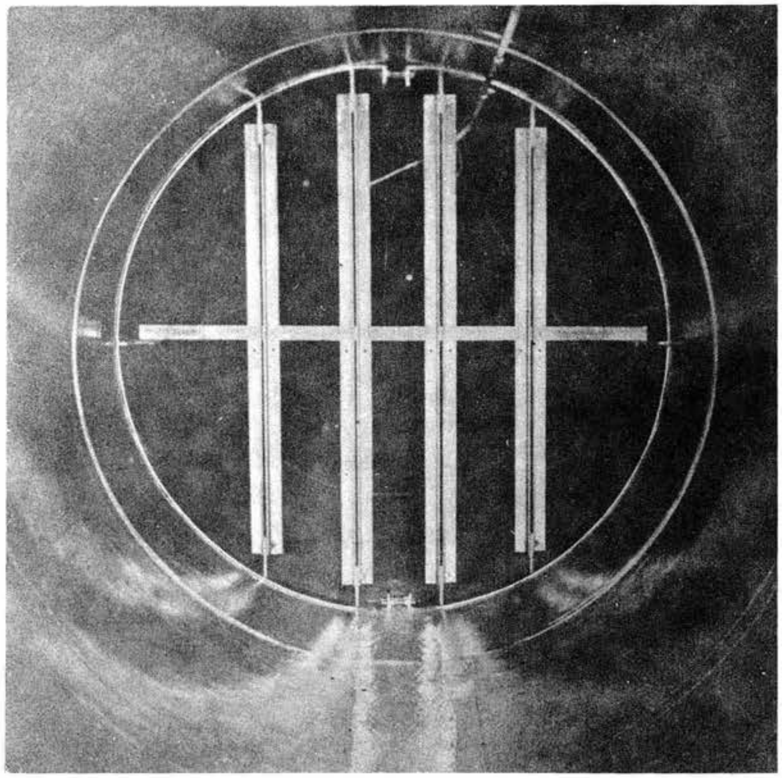


Figure 2A - Structural steel-type turbulator
in an 8-foot diameter conduit

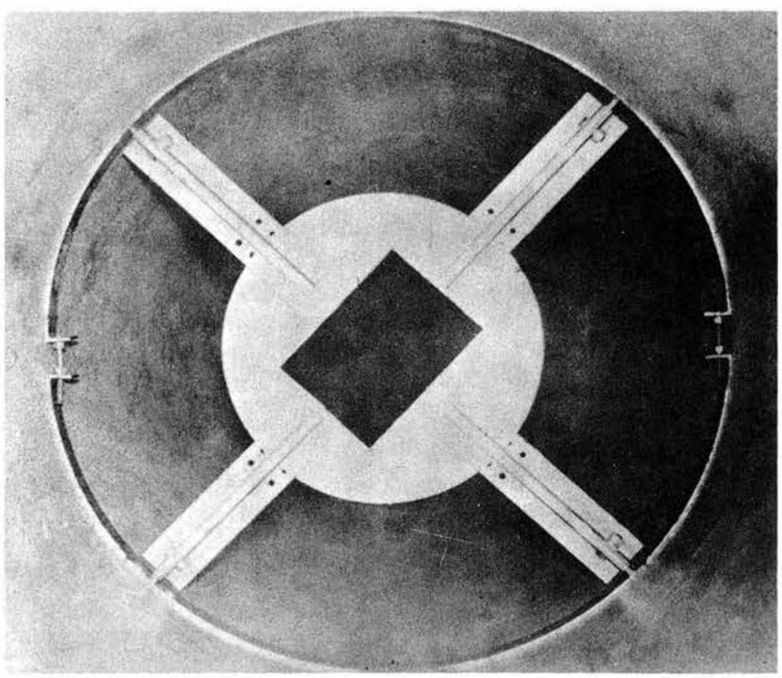
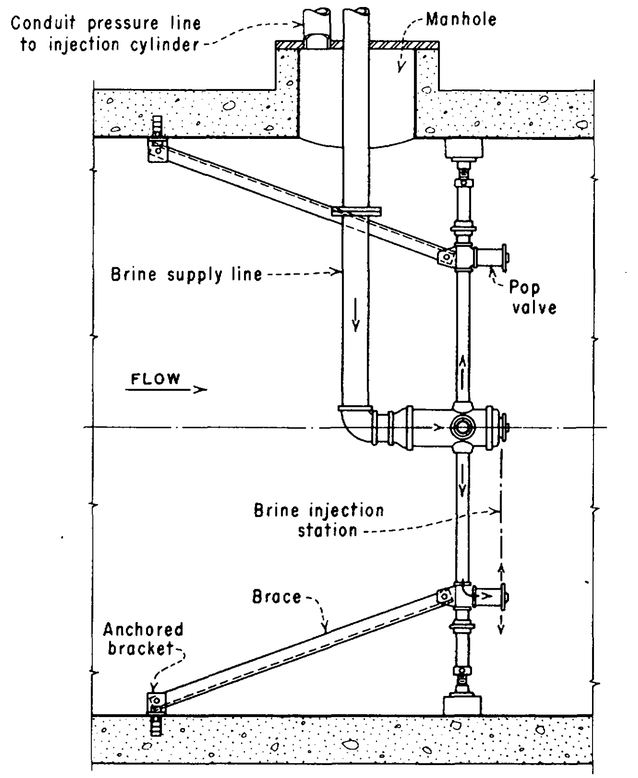
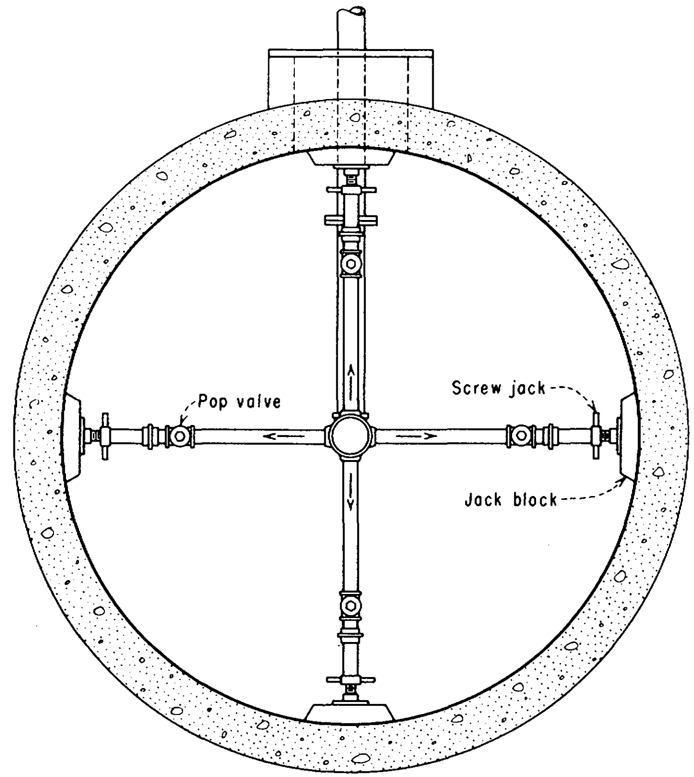


Figure 2B - Plate-type turbulator in a 4 1/2-
foot conduit

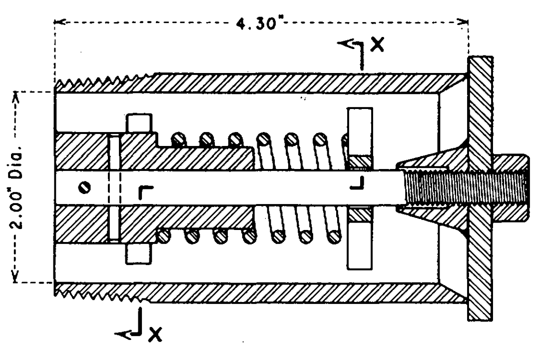
Figure 2



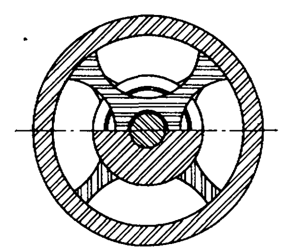

CONDUIT SECTION AT BRINE INJECTION STATION




DOWNSTREAM ELEVATION
OF BRINE INJECTION ASSEMBLY




LONGITUDINAL SECTION OF POP VALVE



SECTION X-X

FIG. 3 - BRINE INJECTION
EQUIPMENT IN CONDUIT

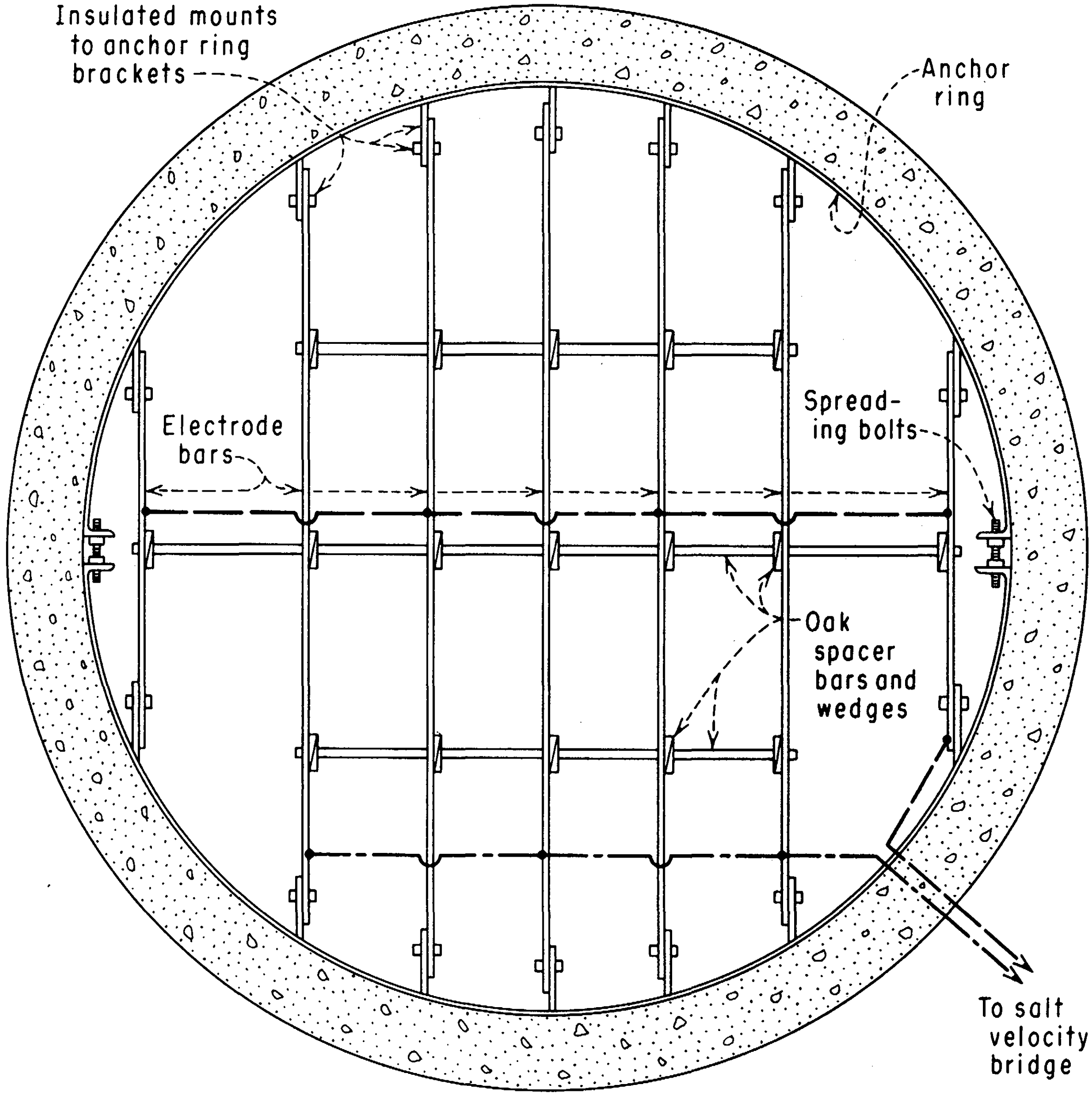



FIG.4 - ELECTRODE ASSEMBLY IN CONDUIT

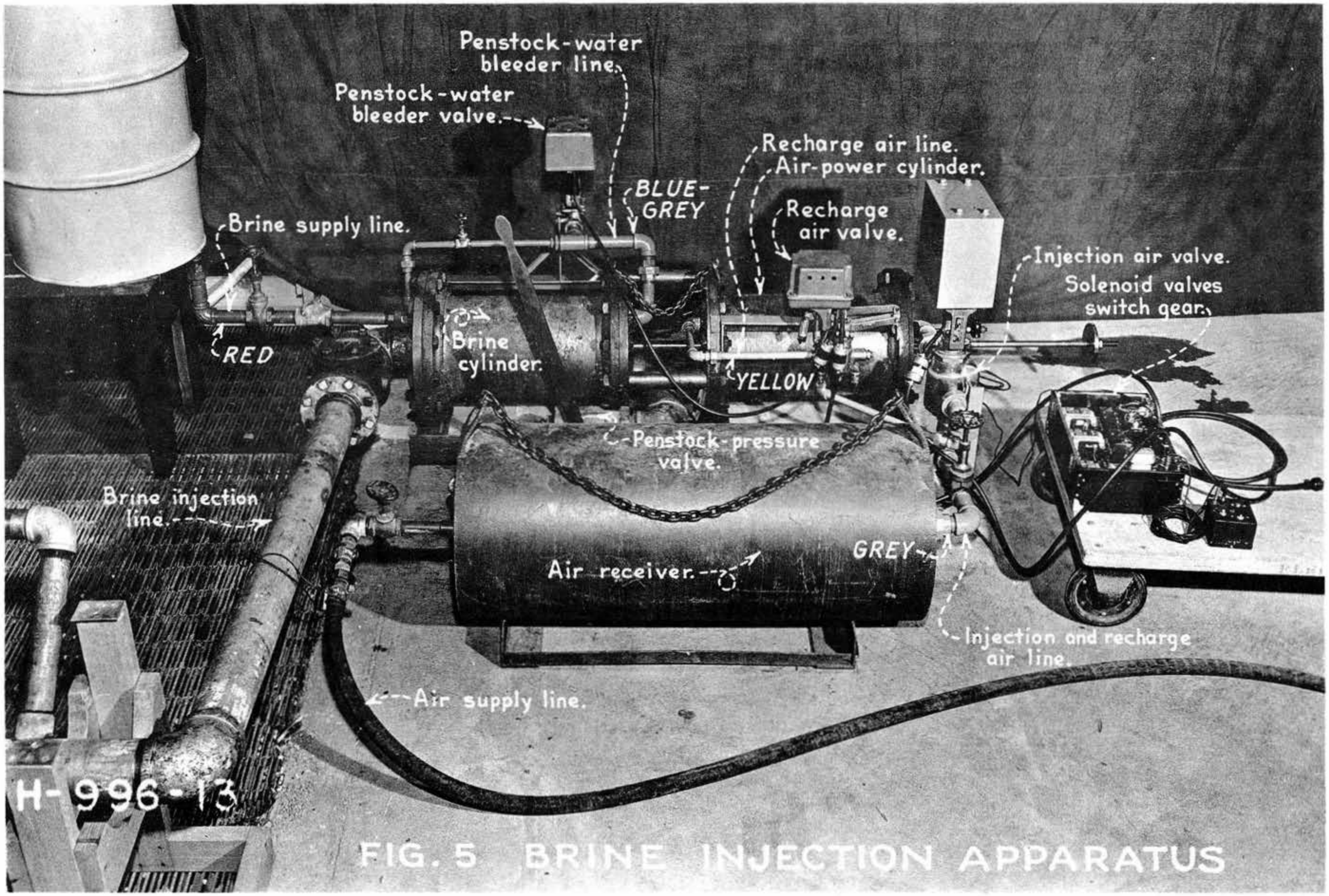



FIG. 5 BRINE INJECTION APPARATUS

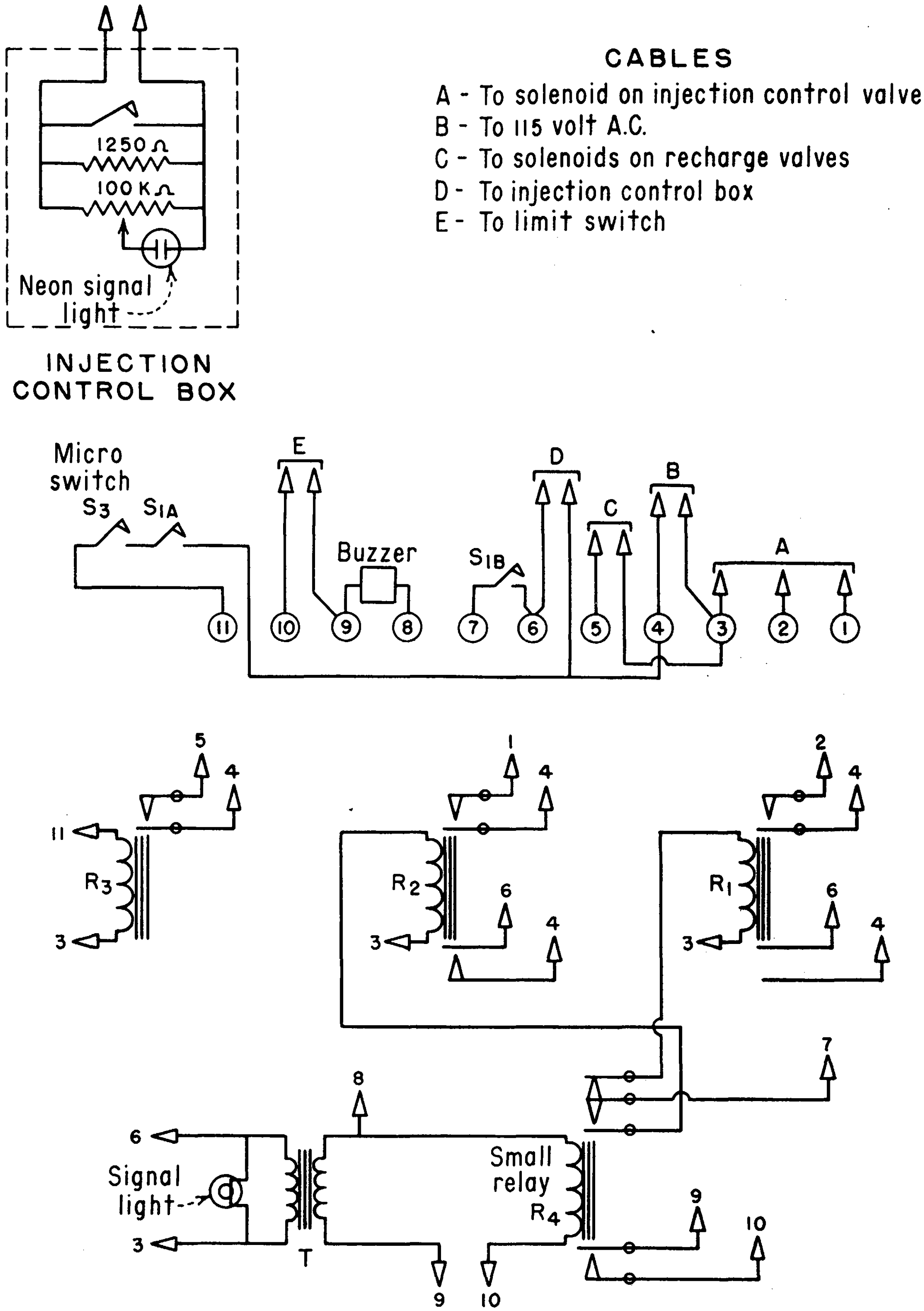



FIG. 6 - WIRING DIAGRAM FOR CONTROL OF SALT VELOCITY INJECTION EQUIPMENT

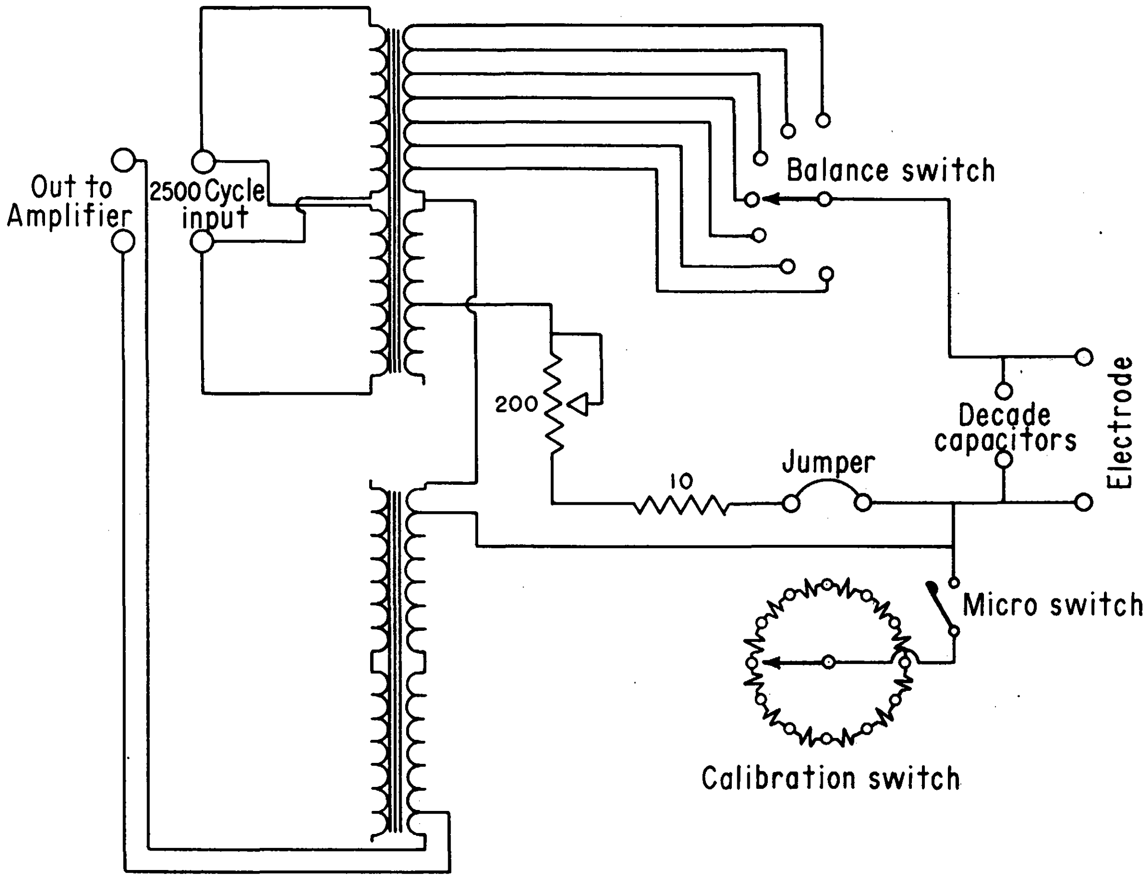
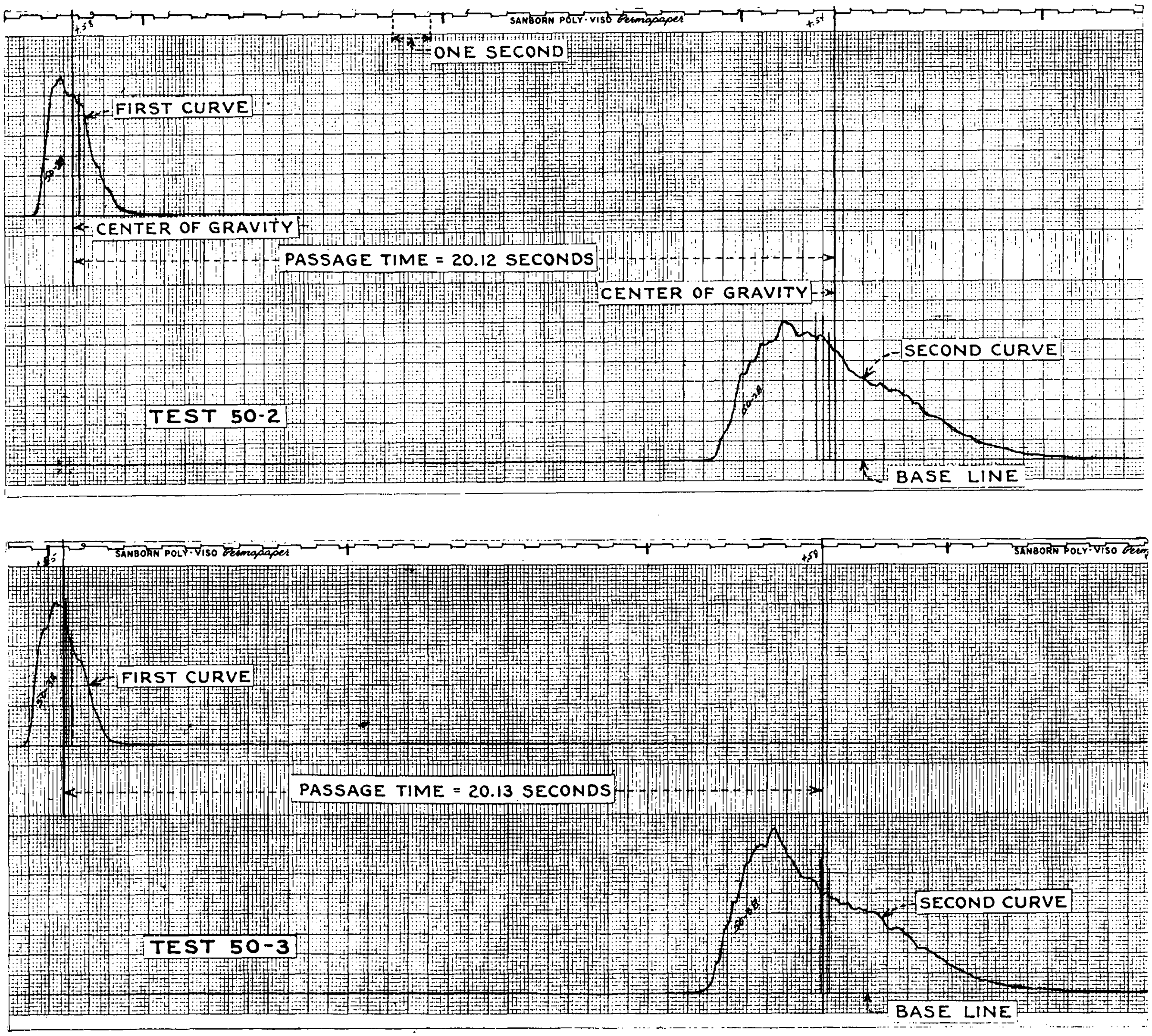



FIG. 7 - EXTERNAL BRIDGE NETWORK




NOTES

Volume of test section = 1258.49 cu.ft.
Average time of passage = 20.13 seconds.
Discharge = Volume / Time.
Discharge = 1258.49 / 20.13
= 62.52 cu.ft. per second.

FIG. 8 -SAMPLE SALT VELOCITY CURVES AND CALCULATIONS