UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF GATE SEAL DESIGNS AND TESTS FOR GRAND COULEE AND SHASTA DAMS

By

E. S. GRAY, ASSISTANT ENGINEER

Denver, Colorado
June 8, 1943

HYD 128

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MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL STUDIES OF GATE SEAL DESIGNS
AND TESTS

FOR

GRAND COULEE AND SHASTA DAMS

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By E. S. GRAY, ASSISTANT ENGINEER

- - - - -

Under Direction of

J. E. WARNOCK, ENGINEER
and
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Denver, Colorado,
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MEMORANDUM TO CHIEF DESIGNING ENGINEER
(E. S. Gray through J. E. Warnock)

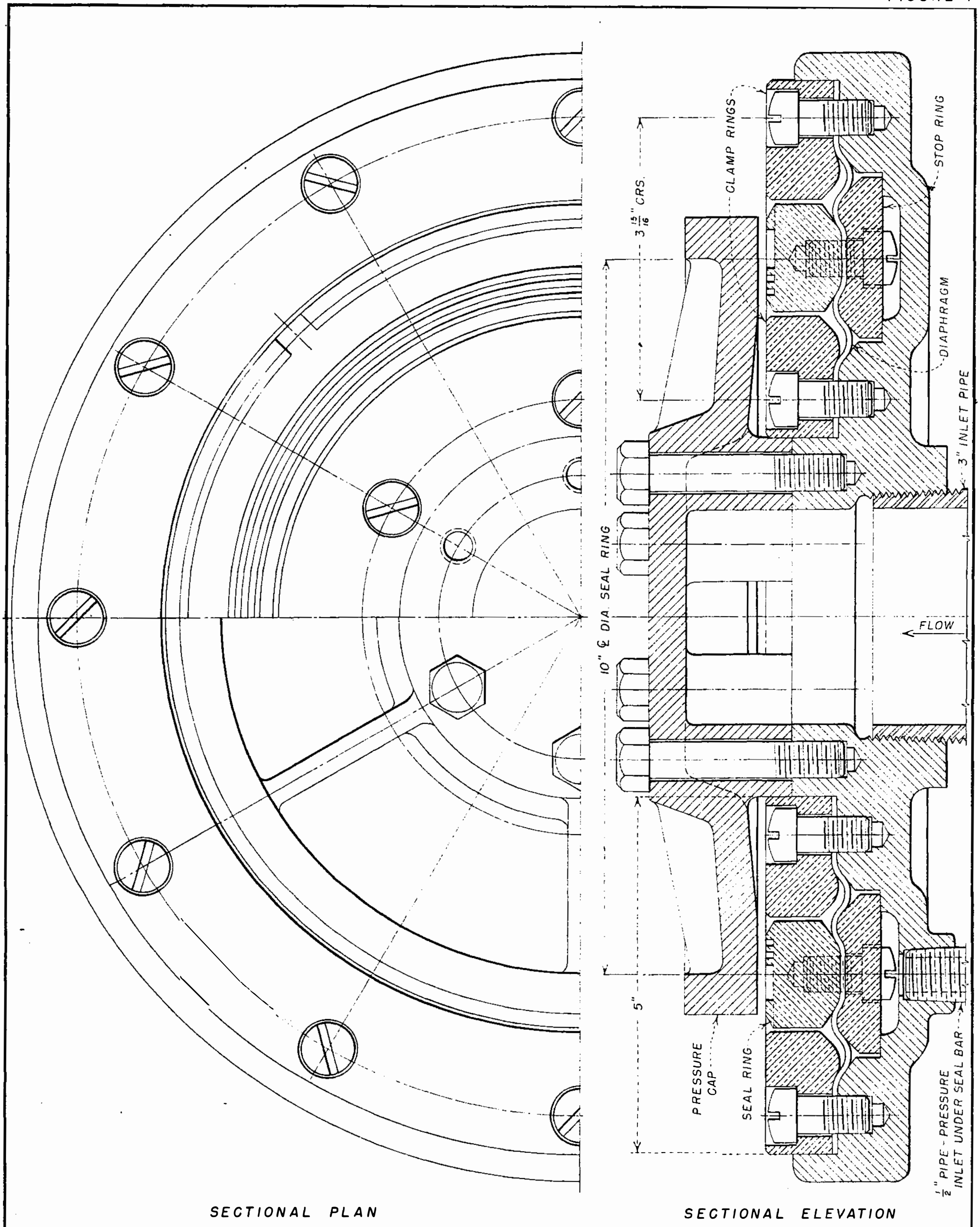
Subject: Hydraulic model studies of gate seal designs and tests for Grand Coulee and Shasta dams.

1. Introduction. When gate seals on the 15- by 29.65-foot penstock coaster gates for Grand Coulee Dam were tested at the manufacturer's plant, trouble was experienced due to leakage from the actuating chamber. The design used was the 45-45-degree compression seal studied in the original model tests, referred to as design 4 and described on pages 9, 11, 12, 13, and 14 of "Hydraulic model studies of gate-seal designs and tests for Grand Coulee Dam," June 1941 (HM-7 and HYD-96) by E. S. Gray. Results of field tests on the 102-inch ring-follower gates are described on page 26 of the same reference. An abstract of the results of the tests on the 45-45-degree compression seals is shown on figure 4B and in section 2(b) of this report.

In an effort to develop a more satisfactory seal for the Grand Coulee installation and to develop a seal for the 19.5- by 24.9-foot fixed-wheel gates for the Shasta Dam diversion tunnel, a series of tests was made as described in this report. Since both gates were to operate under high heads, 265 feet at Grand Coulee and 190 feet at Shasta Dam, the same design possibly could be used for both installations.

2. Review of previous studies. Two models were used in these tests as shown in figures 1, 2, and 3; a visual, sectional seal model and a 10-inch ring-seal model. The designs and results of the studies described in the first series of tests are summarized on figure 4 of this report, for the sake of completeness.

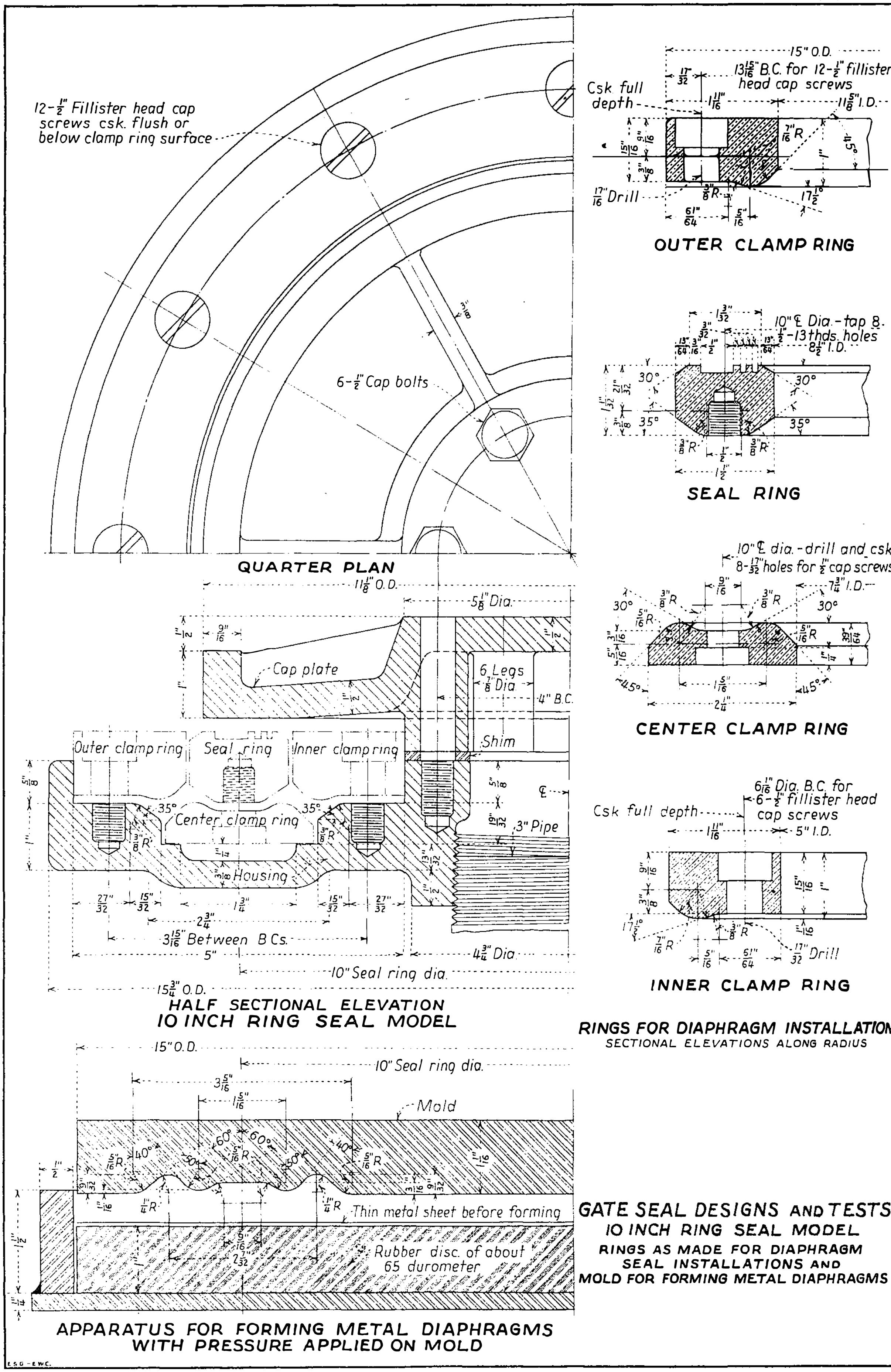
The visual, sectional seal model was a rectangular housing with transparent front and back plates and thickness sufficient to hold a 2-1/2-inch straight length of the seal assembly. Supply lines were con-



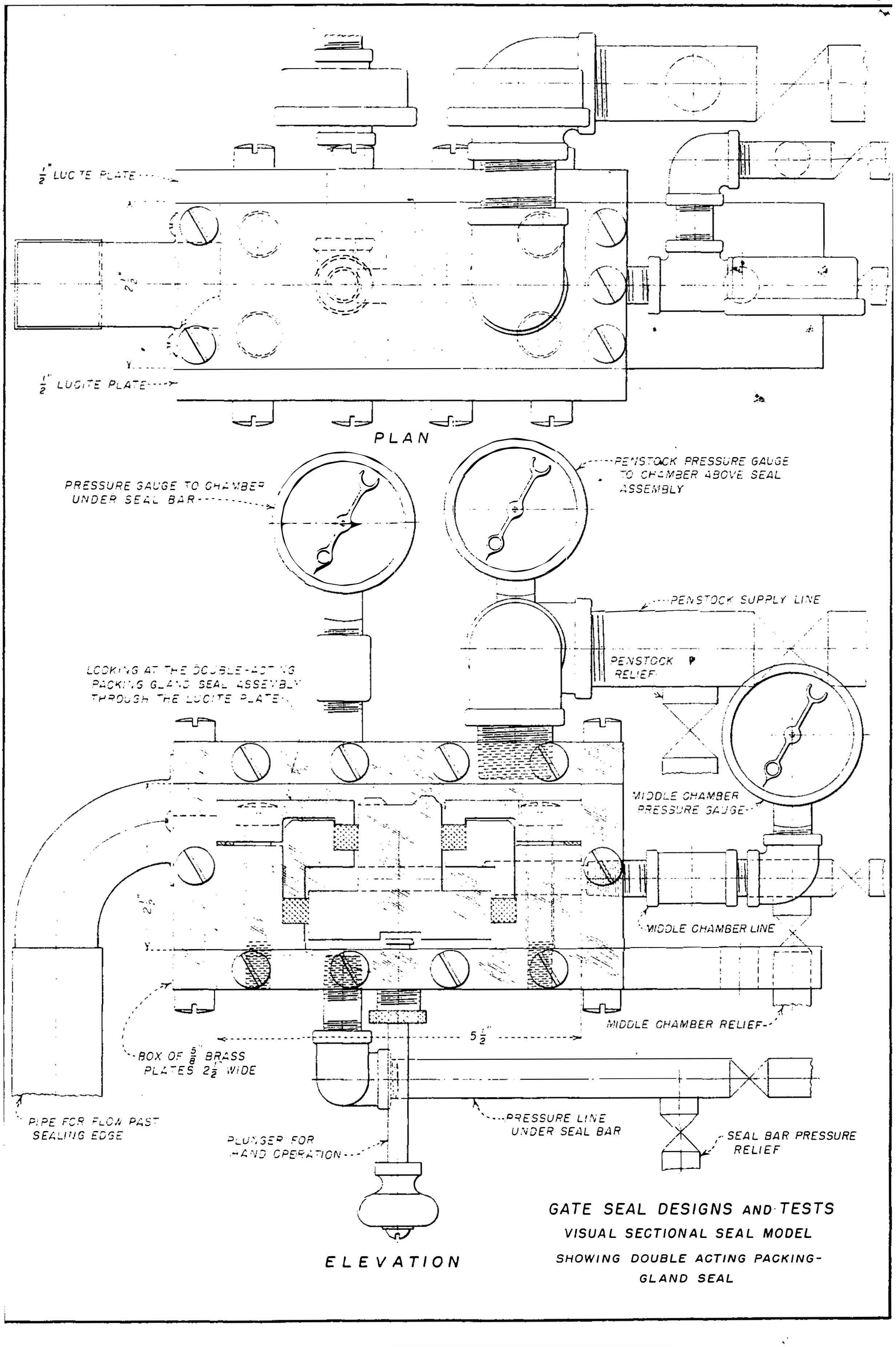
GATE SEAL DESIGNS AND TESTS

10" INCH RING SEAL MODEL

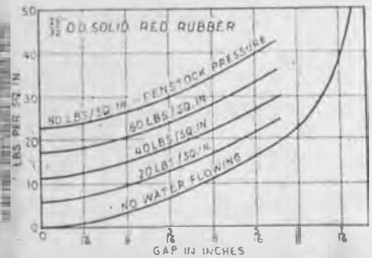
SHOWING DIAPHRAGM SEAL



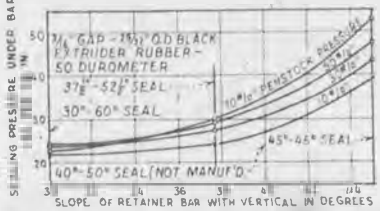
GATE SEAL DESIGNS AND TESTS
10 INCH RING SEAL MODEL
RINGS AS MADE FOR DIAPHRAGM SEAL INSTALLATIONS AND MOLD FOR FORMING METAL DIAPHRAGMS



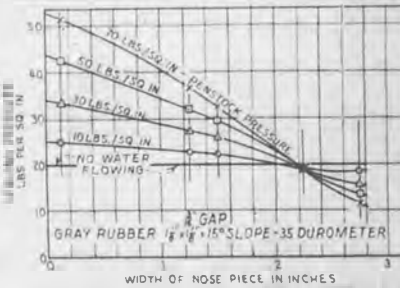
GATE SEAL DESIGNS AND TESTS
VISUAL SECTIONAL SEAL MODEL
SHOWING DOUBLE ACTING PACKING-GLAND SEAL



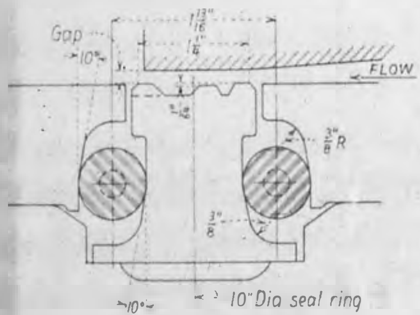
SEALING PRESSURE AT VARIOUS HEADS VS GAP OPENING



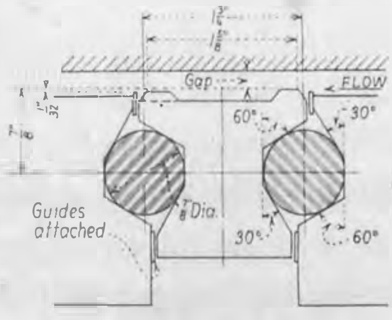
SEALING PRESSURE AT VARIOUS HEADS VS ROTATION OF SLOT



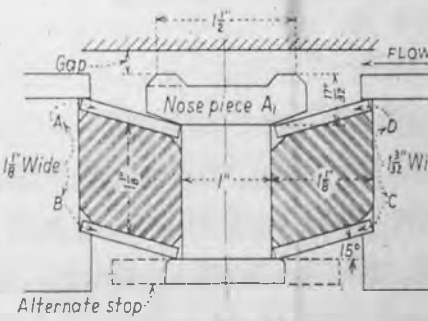
SEALING PRESSURE AT VARIOUS HEADS VS. WIDTH OF NOSE PIECE



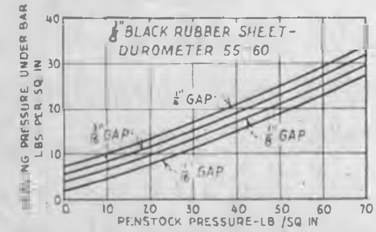
A - ROLLER SEAL



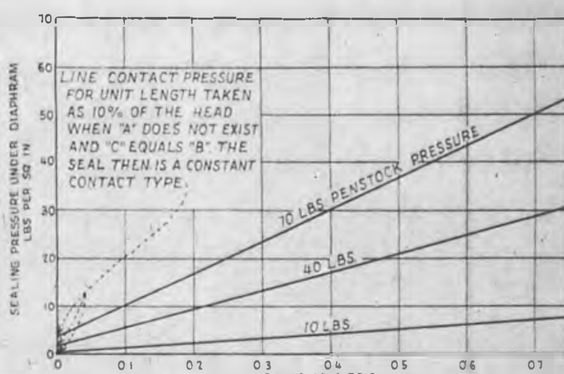
DESIGN 6 - 30°-60°
B - COMPRESSION HEAD



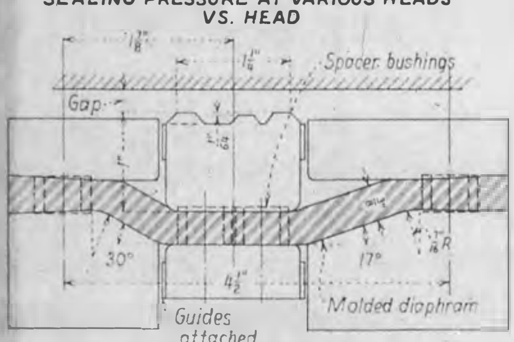
C - SHEAR SEAL



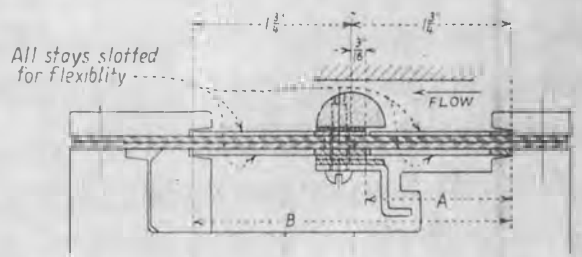
SEALING PRESSURE AT VARIOUS HEADS VS. HEAD



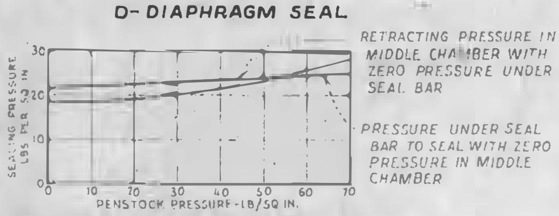
SEALING PRESSURE AT VARIOUS HEADS VS LOCATION OF SEALING EDGE WITH RESPECT TO HINGES



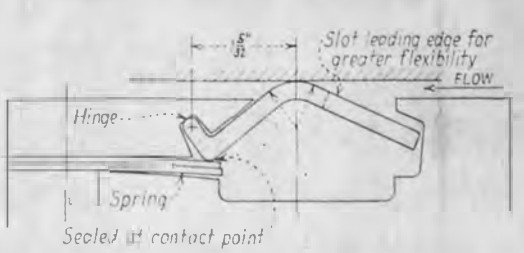
D - DIAPHRAGM SEAL



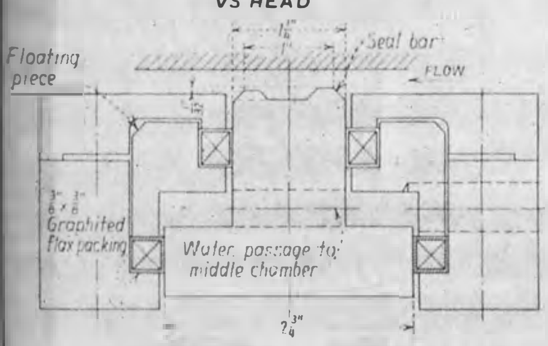
E - STABILIZED FLEXIBLE DIAPHRAGM SEAL



SEALING PRESSURE AT VARIOUS HEADS VS HEAD



G - CONSTANT CONTACT ALL METAL SEAL NON-RETRACTING



F - DOUBLE-ACTING PACKING GLAND SEAL

GATE SEAL DESIGNS AND TESTS
SUMMARY OF FIRST SERIES
TYPICAL DESIGNS

nected to provide penstock pressure upstream from the seal bar and pressure to actuate the seal bar itself. An additional connection provided pressure for actuating the middle chamber of the double-acting seals. Gages and relief valves were connected at suitable points. The gap between the seal bar and the seat could be varied by raising or lowering the seal assembly.

The 10-inch ring-seal model was a circular housing made to resemble a circular gate in which was installed a ring seal with a diameter of 10 inches. The penstock pressure was admitted in the center of the model chamber and dispersed radially by a cap plate which also served as the seating plate for the seal ring. The seal assembly was supported below this cap by a base through which a 1/2-inch pipe line supplied pressure for actuation of the seal ring. The seal ring moved against the seat to effect a closure against the radial flow from the penstock. The gap between the seal ring and seat could be varied by raising or lowering the cap plate. Pressure gages and relief valves were provided at suitable points.

By interconnections, water under pressure was supplied to both models from three sources; the city water mains with a pressure of 75 pounds per square inch, a 12-inch centrifugal pump with a pressure of 100 feet of water, and a high-pressure hand pump connected to an air tank. It was necessary to increase the amount of water through the model, since it was found that the penstock pressure could be maintained for a greater range of seal bar movement and the field conditions could be more closely duplicated. With higher penstock pressure, velocities through the gap were higher and the effects more noticeable. An endeavor was made to operate the models with the pressures and velocities which will occur in the field, but these conditions were not fully realized.

A summary of the tests on seal designs studied in the original program is given in the following paragraphs. For a more detailed description, reference is made to the original report, HYD-96.

(a) Roller seals (figure 4A).--The roller slot is designed to produce a rolling action of the rubber rollers when the seal ring or bar is moved. Compression and torsion of the rubber produces the force necessary for retraction.

The extension of the roller seal bar was easy until the rollers became restrained by the limits of their slots, after which the effort increased rapidly. The retraction of the seal bar was assisted in the ring model by the torsional effect, making it complete and rapid; but in the sectional model the retraction was sluggish and incomplete.

With oversize rollers violent chattering occurred, and with undersized rollers self-sealing occurred which made unsealing impossible. In the sectional model the rollers slid up and down without rolling as pressure was applied. In the ring model greater friction and torsional force prevented sliding to any great extent.

The principal advantages of this design are that the seal bar could be made to extend easily and, because it floats, the sealing action was aided. The disadvantages are that there was low retractive force unless rollers were operated on part of slots where compression was greater; the rollers are difficult to assemble, as they must be correctly placed to work properly; the rollers slide at higher pressures and in straighter sections; the type is not applicable to rectangular gates; and the seal bars are stiff, making conformity between seal bar and seat difficult.

(b) Compression seals (figure 4B).--In these designs the retractive force on the seal bar is provided by the energy stored in the rubber gaskets as the seal bar is extended. The rubber is forced either in compression only or in compression and shear, together with some rolling action, depending on the shape of the slot. The degree of difficulty in extension can be changed by rotating the square outline of the slot in the design so that a greater or lesser degree of compressive action can be attained. The rotation of this square slot may be 90 degrees, to cover all conditions of action from pure compression, as in the square compression design, to a design in which only sliding action would take place along the vertical retainer bar surface. The design shown illustrates the principle of changing the angles on the retainer bars and on the seal bar.

In extension, the pressure required depends on the resistance of the rubber gaskets to change in shape, on the change in the cross-sectional area of the slots as the seal bar is extended, and on the width of the seal bar. In the square slot design the area changes directly with the movement; in the 45-45-degree design the area becomes only slightly less, whereas in a 40-50-degree design the area remains constant and therefore is to be preferred. Furthermore, as the angle of the retainer bar slope becomes less than 40 degrees, the area increases with seal bar extension, and thus the rubber is released as in the 30-60-degree slot design instead of being further cramped. When the rubber becomes cramped in a reducing area, the force necessary to extend the seal bar rises rapidly.

There is, therefore, a practical limit placed on the extension to be allowed in these designs and generally it is not more than 3/16 inch. Retraction was nearly complete and usually rapid, and the residual effort was practically equal to the force required to extend the seal bar. The overhang of the sealing edge contributed to the rapidity or sluggishness of the release.

At the point of sealing there was chatter and pulsation of the seal ring in the 10-inch ring-seal model, especially with the solid rubber gaskets. With undersized gaskets self-sealing occurred, and in some cases it was impossible to unseal the ring. Slamming and rotation of the seal bar took place in the visual model at the higher penstock pressures and velocities, and full guiding of the seal bar was necessary to prevent these conditions as much as possible.

There was good retractive force developed in the rubber when it was subjected to both compression and shear, as in the diamond-shaped slot designs; and, since the 45-45-degree shape was the first shape so tested and offered a good solution to the problem at hand, it was accepted as the design for the Grand Coulee ring-follower penstock gates.

Since the seal ring floats on rubber, alinement to the seat is aided, but on the other hand, the varying diameter along the gaskets caused the seal ring to bend and conform to the pressure exerted on it by the rubber. This condition caused contact at the seat at one point, but at another point a gap still existed, so that more pressure was required to cause the seal ring to seat all along its length.

The rubber fabrication was difficult, but installation of the gaskets was performed readily. The seal bar is heavy and stiff and difficult to support in rectangular gates. At the manufacturer's plant an installation in a rectangular gate for Grand Coulee Dam gave trouble in excessive leakage from the chamber under the seal bar, probably through the joints of the clamping bars.

(c) Shear seals (figure 4C).--The shear seal was developed to apply the principle used in designing rubber springs, wherein the rubber is subjected to shearing stresses only and energy is stored in the rubber during the closing cycle to provide a retractive force.

The action of these seals was smooth and free, with any reasonable degree of extension. The force required to extend the seal bar depended on the quality of the rubber and the head. The pressure on the upstream guide bar assisted retraction. The retractive action was complete and rapid. There was no chatter during sealing, and self-sealing did not occur because the gaskets are installed tightly. The guide bars transmitted the forces to the seal bar. The guide bars, made to proper dimensions, nullified any tendency for the seal bar to rotate and prevented the rubber from bulging as a diaphragm.

The advantages of this type of seal are that the rubber is stressed principally in shear, and the seal bar is fully guided. The design is especially good for rectangular gates but may be adapted to circular ones by installing the guide bars in short segments. Considerable tolerance is permissible in the parts.

The disadvantages would be difficulty of adjustment of any misalinement between seal bar and seat, the cost, and the weight of the seal bar.

(d) Diaphragm seals (figure 4D).--The curved surfaces of the clamp and seal rings (figures 1 and 2) were shaped so that the diaphragm cross-sectional length was the same when the seal bar was extended as when retracted and would be supported over practically its entire free area when extended. The section of the diaphragm under the seal ring was formed lower than those under the clamp rings, to assist retraction.

The extension property of this type is hindered by the extrusion of rubber in clamping, which forces the rubber into compression and shear when the seal ring is moved. The metal diaphragms permanently deformed. In retraction, the action was slow and sluggish and the retractive force small.

In sealing, the diaphragm was pushed against the stops and imparted very little force to the seal bar. The effective hydraulic force was then applied to the seal bar only. Without close guides, the seal bar rotated when tested as a straight section in the visual model.

The chamber under the seal bar was easily made watertight. The seal bar practically floats, which assisted in the bar conforming to the seat. The extrusion of the rubber in clamping made the seal partly inoperative. The seal bar is heavy and stiff. The manufacture of the diaphragms to some predetermined shape required expensive molds in the field assembly.

(e) Stabilized flexible diaphragm seals (figure 4E).--Diaphragms, when free to move, respond readily to the slightest pressure, but due to lack of rigidity distort in the direction of the applied force until a definite stop is reached. Tests on shear and constant-contact seals showed that the seal-bar face must not only be parallel to the seating surface but must also be flexible to insure perfect sealing. In designs where energy is stored in rubber, chatter of varying intensity and frequency developed at the sealing position. Increasing the rate of application of sealing pressure generally eliminated the difficulty, but a tendency to slam at final closure persisted. In all the retractable seals, except the double-acting type, to obtain positive retractive force it was necessary to make the unit quite stiff. Accurate guides were necessary to prevent tipping or rotation of the seal bars. The stabilized flexible-diaphragm seal represents an attempt to compromise all of these factors.

The seal could be extended smoothly and easily to any reasonable amount with practically constant pressure. The extrusion of the rubber in clamping was not detrimental. The retraction was complete, rapid, and positive. Because of the flexibility of the seal bar, there was conformity between it and the seat in cases of misalinement. There was no chatter, and because of the confinement of the rubber, there was no self-sealing. Support of the diaphragm prevents bulging. The seal bar, being fully guided, did not rotate or slam.

The stability and flexibility of this design are inherent, and the seal will operate under any head. Standard parts may be used and no vulcanizing or molding is required for the double-stay construction shown. The diaphragm may be any suitable, inexpensive material. In a vulcanized construction the lower stays would be eliminated. The design is adaptable to either rectangular or circular gates. The light weight of the parts eliminates any problem of support. The principal disadvantage might be the difficulty of handling the parts when assembling on a large gate.

(f) Double-acting seals (figure 4F).--Designed to produce positive sealing as well as positive retraction of the seal bar, which is actuated by hydraulic pressures applied in three chambers. Pressure in the chamber under the bar tends to extend it, and pressures in the two middle chambers tend to retract it. In the packing-gland design shown, the extension effort was constant, while in the roller design tested, it increased with movement of the seal bar. The retractive action was smooth and positive in both cases.

In the former design, after the seal was effected, it was possible to reduce the sealing pressure to zero without unsealing. In the latter design, since the rubber rollers are in compression and shear, pressure must be maintained under the seal bar to hold it in place. No chattering was evident in either unit. No tendency for the seal bar to rotate or slam was evident in the former design, but in the latter design a guide was needed at the top to prevent both rotation and slamming. The seal bar movement was positive either in extension or retraction for both designs. The former design is well guided; the latter design needs downstream guides at the nose. This type can be used either in rectangular or circular gates.

The principal advantage of this seal is its positive action; the disadvantages are that the construction assembly and the operation would be complicated and expensive. In the packing-gland design the sliding surfaces may become inoperative due to scale deposition in certain installations. The seal bar is heavy and stiff for both designs.

(g) Constant-contact seals (figure 4G).--Developed for use in low head installations when the friction due to constant contact will not be excessive. The seal is actuated by any head but does not retract. Penstock or reservoir pressure exerted directly on the bar furnishes the sealing force. The line contact pressure was kept to a minimum by making the distance from the hinge to the contacting nose as short as possible.

The constant-contact seal bar should have sufficient flexibility to care for misalinement between the seal bar and the seat. The seal bar must be dragged from the seat; therefore, the line contact pressure on the seat should be low. The all-metal design was too stiff to twist even a few thousandths of an inch. A rubber-mounted design was slightly more flexible.

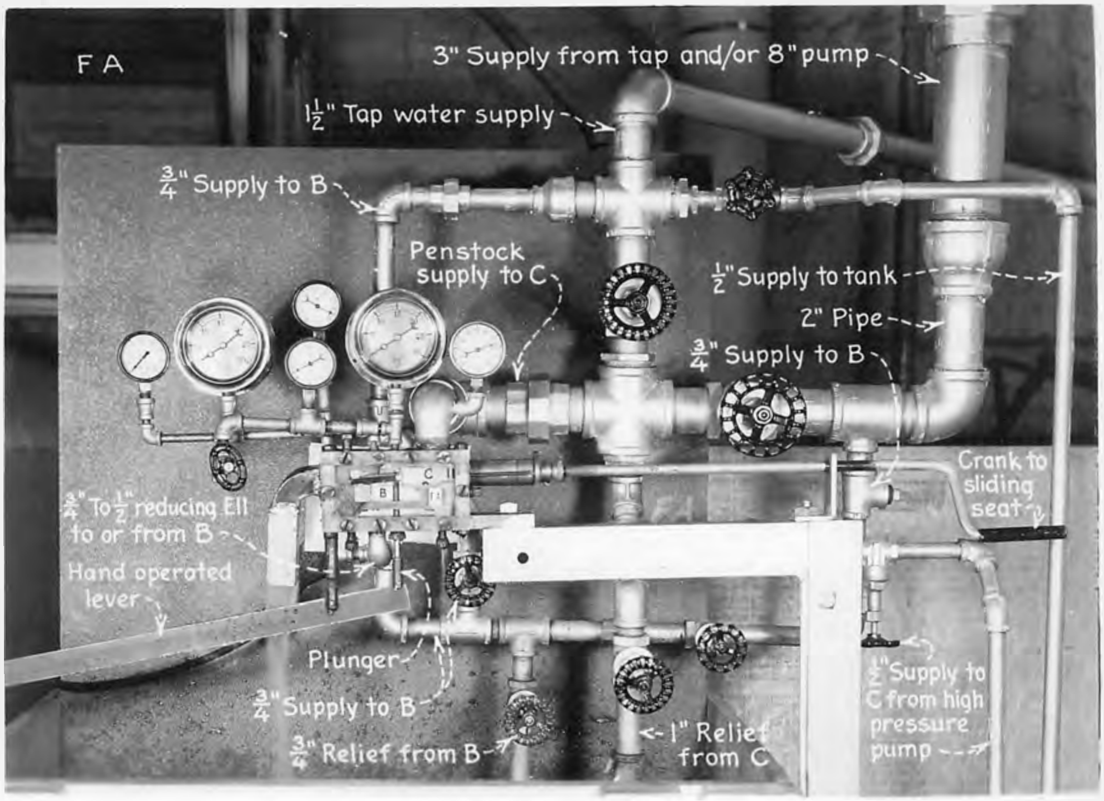
The advantages are the ability to seal at any pressure, the absence of retraction devices, and the low construction cost; the disadvantages are the additional power needed to move the gate due to the friction between the seal bar and seat, the necessity of flexibility for good sealing, and the limitation of the hinged design to rectangular gates.

The tests consisted of measurement of pressures necessary to accomplish a seal against various penstock or reservoir pressures. With a given penstock pressure, the pressure under the seal bar was increased slowly, which caused the bar to be extended until flow from the penstock was stopped. To unseat the bar the pressure under the bar was lowered until the seal broke. These two pressures varied at times as much as 10 pounds per square inch, but the sealing pressure was taken as the mean of these two readings. Positive retraction against a static head of about 7 pounds per square inch at the center of the gate was required.

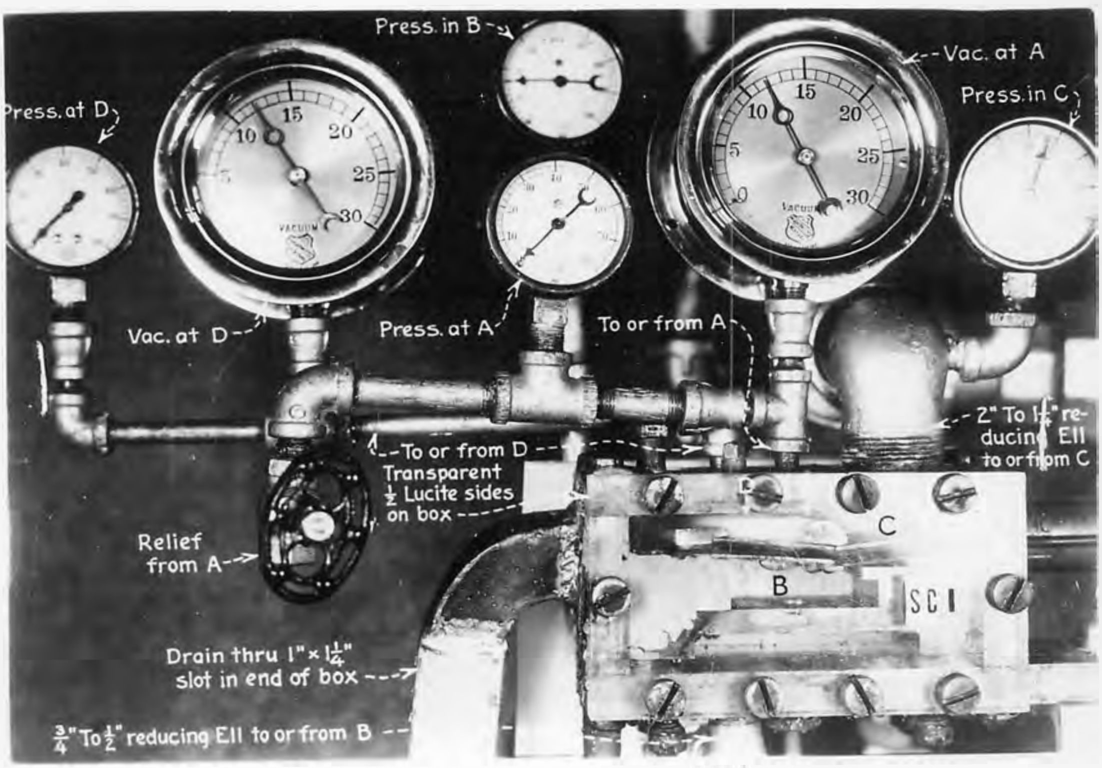
3. Scope of new test series. The designs tested in the new series of gate-seal designs and tests, as described in this report, are divided into two types - constant-contact seals and retractable seals. The tests on the constant-contact seals were an outgrowth of the four designs for rectangular gates studied in the original program. The main constant-contact seal designs tested in this series are as follows:

(a) Music-note constant-contact seal - Brass on curved section of rubber only - Design 1C (figure 6A).
(b) Music-note constant-contact seal - Formed brass strip vulcanized to bottom and curved portion of rubber - Design 2C (figure 6B).
(c) Hinged bar and rubber constant-contact seal - Design 3C (figure 6C).
(d) Hinged flexible constant-contact seal - Design 4C (figure 6H).
(e) Hinged, sustained, constant-contact seal - Design 5C (figure 6I).
(f) Floating, sustained-bar, constant-contact seal - Design 6C (figure 6J).
(g) Sliding-bar, constant-contact seal - Design 7C (figure 6L).

During the studies on the floating, sustained, constant-contact seal

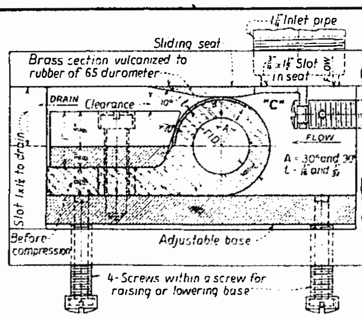


A-Visual sectional seal model test apparatus.

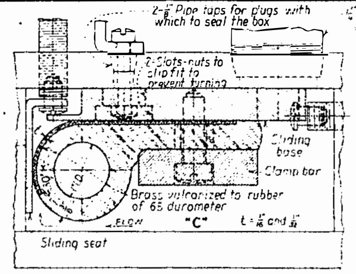


B-Visual sectional seal model with stabilized flexible diaphragm seal, design 6R, installed.

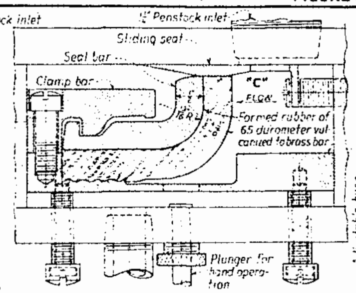
STABILIZED, FLEXIBLE DIAPHRAGM SEAL - DESIGN 6R



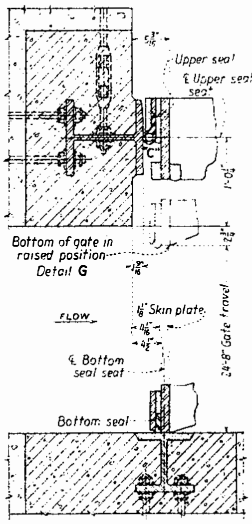
A-MUSIC NOTE CONSTANT CONTACT SEAL-BRASS ON CURVED SECTION OF RUBBER ONLY
DESIGN 1C



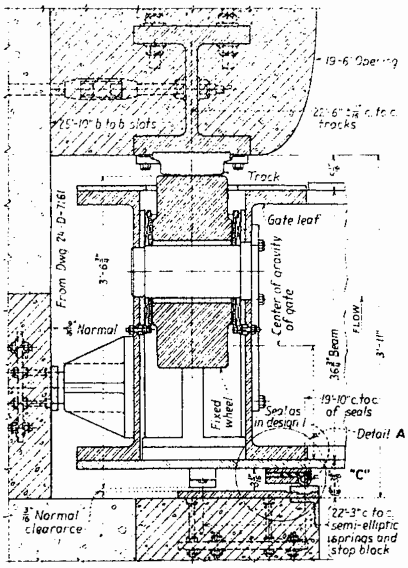
B-MUSIC NOTE CONSTANT CONTACT SEAL-FORMED BRASS STRIP VULCANIZED TO BOTTOM AND CURVED PORTION OF RUBBER
DESIGN 2C



C-HINGED BAR AND RUBBER CONSTANT CONTACT SEAL RUBBER FORMED AND VULCANIZED TO BAR
DESIGN 3C

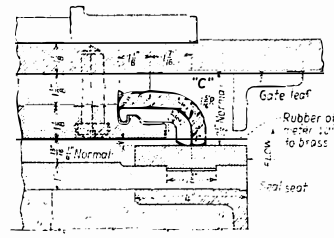


D-UPPER AND BOTTOM SEALS

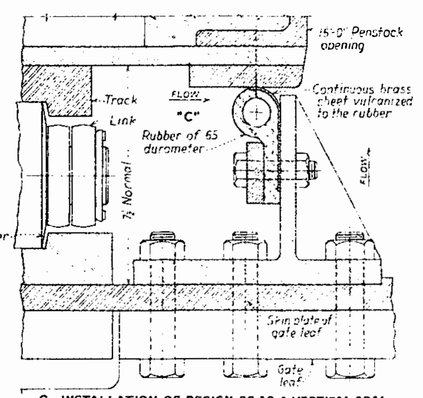


E-VERTICAL SEAL

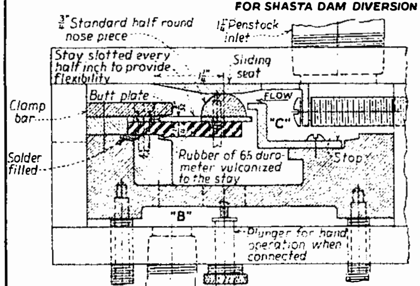
INSTALLATION OF DESIGN 1C AS PROPOSED FOR 19.5 FT. BY 24.9 FT. FIXED WHEEL GATE FOR SHASTA DAM DIVERSION TUNNEL



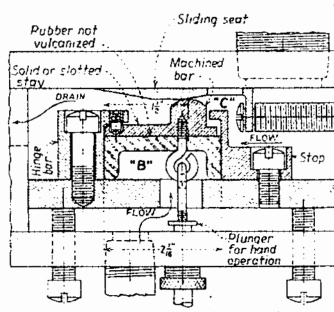
F-INSTALLATION OF DESIGN 3C AS A VERTICAL SEAL PROPOSED FOR 19.5 FT. BY 24.9 FT. FIXED WHEEL GATE FOR SHASTA DAM DIVERSION TUNNEL-SEE DETAIL A



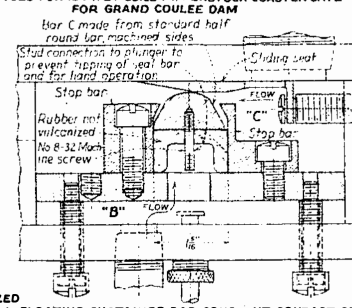
G-INSTALLATION OF DESIGN 2C AS A VERTICAL SEAL PROPOSED FOR 15 FT. BY 29.65 FT. PENSTOCK COASTER GATE FOR GRAND COULEE DAM



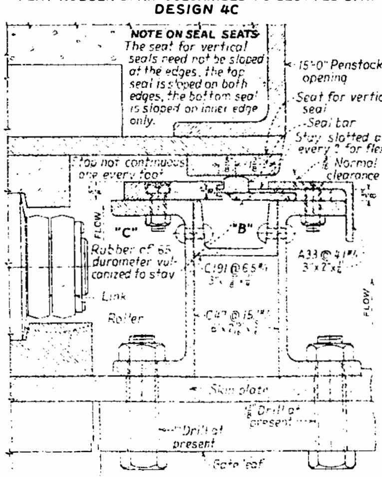
H-HINGED FLEXIBLE CONSTANT CONTACT SEAL FLAT RUBBER STRIP VULCANIZED TO SLOTTED STAY
DESIGN 4C



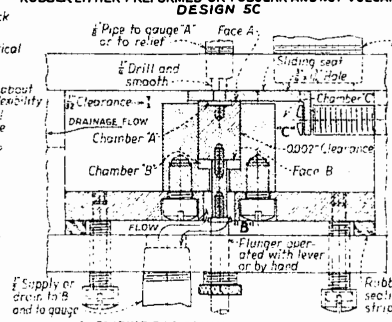
I-HINGED SUSTAINED CONSTANT CONTACT SEAL RUBBER EITHER PREFORMED OR TUBULAR AND NOT VULCANIZED
DESIGN 5C



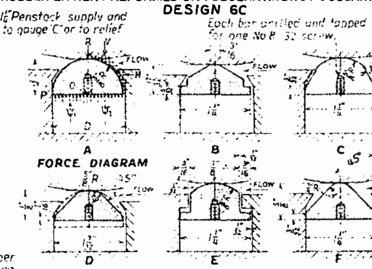
J-FLOATING SUSTAINED BAR CONSTANT CONTACT SEAL RUBBER EITHER PREFORMED OR TUBULAR AND NOT VULCANIZED
DESIGN 6C



K-INSTALLATION OF DESIGN 4C AS A VERTICAL SEAL PROPOSED FOR 15 FT. BY 29.65 FT. PENSTOCK COASTER GATE FOR GRAND COULEE DAM



L-SLIDING BAR CONSTANT CONTACT SEAL
DESIGN 7C
Tested (1) with face A to seat (Legs) and (2) with face B to seat (Flat)



M-VARIATIONS OF SEAL BAR FOR DESIGN 6C

GATE SEAL DESIGNS AND TESTS

SECOND SERIES

CONSTANT CONTACT SEALS

MODELS AND INSTALLATIONS

(design 6C), consideration was again given to designs for retractable seals. A roller was substituted for the floating, half-round bar as a constant-contact seal. During the studies it developed that by the addition of a retraction spring, the bar or roller would retract hydraulically. Thus, by the addition of the retraction spring to four of the constant-contact seal designs these were developed as retractable seals.

The main, retractable seal designs studied in this series are as follows:

(a) Roller retractable seal - Design 1R (figure 9A).
(b) Floating-bar retractable seal - Design 2R (figure 9C).
(c) Hinged, sustained retractable seal - Design 3R (figure 9G).
(d) Sliding-bar retractable seal - Design 4R (figure 9F).
(e) Hinged, flexible retractable seal - Design 5R (figure 9G).
(f) Stabilized, flexible diaphragm seal - Design 6R (figure 9H).
(g) Music-note retractable seal - Design 7R (figure 9I).

Both designs of the music-note constant-contact seals were proposed for installation on the Grand Coulee gates; but, since the addition of the retraction spring made design 1 a retractable design which gave acceptable results, the proposed field installation was so converted and adopted (figure 9L). The gates were already equipped with the necessary fittings and valves for retractable seal operation so no additions or changes on the gates were required.

The music-note constant-contact seal, design 1, proposed for installation on the Shasta gates, was finally accepted as a satisfactory design (figure 6A).

The stabilized, flexible diaphragm seal studied in the first series was further tested and suggested as a solution of a retractable seal.

4. The model. The visual, sectional seal model (figures 3, 5, and 9D), used in the first tests and designed to accommodate full-size seal sections 2-1/2 inches long, was modified by the addition of horizontal and vertical sliding seats and horizontal and vertical shifting bases. The piping and arrangement of the test apparatus was modified to give greater flexibility of operation. The changes in piping included a

larger penstock inlet into chamber C, figure 5, which could be supplied from different sources. Water from the building supply system could be supplied directly through a 1-1/2-inch line at 75 pounds-per-square-inch pressure. A 2-inch line from the building system into the suction side of an 8-inch centrifugal pump permitted boosting the supply pressure from 75 to 110 pounds per square inch and supplying a large volume of water to the model. A high-pressure piston hand pump with a storage tank supplied high pressures with very limited volume. A cross connection from the supply lines to chamber B supplied pressure for actuating the seal bar. Relief lines from penstock chamber C and the actuating chamber B provided fairly close regulation of the pressures and volumes.

As previously stated, the true action of the seal unit can be obtained only when the volume of water passing it is the maximum for any constant head. The difficulty of maintaining constant heads for changing conditions still persisted to a degree with the new arrangement. Since the available water supply under constant head was limited by the piping and the supply systems, it was practically impossible to manipulate the relief valves to maintain constant conditions as the seal bar was operated, due to the rapidity of the seal bar action at the sealing and breaking points.

Piezometers were installed to measure pressures downstream from the nose of the seal bar at points A and D. The piezometer at A was a 1/4-inch hole on the center line of the model, later reduced to a 1/16-inch hole so as to open immediately downstream from the center line of the model and also downstream from the sealing edge of the roller retractable seal (figure 9A). The piezometer at D was a 1/4-inch hole one inch downstream from the center line of the model. A relief valve was provided on the line to piezometer at A.

A lever with a 7 to 1 ratio was attached to the model and could be connected to the plunger to permit measurement of forces or hand manipulation of the seal bar during the tests. Measurements of the forces involved were made with a spring balance hooked to a pinned fulcrum on the lever.

It was found that when computations were made the forces did not balance because of discrepancies in areas over which hydraulic pressures existed. The areas were indeterminate due to the infiltration of water pressure between contacting surfaces. The results are therefore not given.

5. Operation of the model. In the tests on the constant-contact seals (figure 6), normally only penstock pressure was applied, as no hydraulic retraction was involved. But in those cases, such as in figures 6H to L, inclusive, where the seal bar had a more or less confined space in chamber B, under it, water was admitted to both chambers B and C, either at the same pressure or at different pressures, to study the action of the rubber or seal bar when a differential existed.

In the tests on the retractable seals, the pressures in chambers B and C were controlled independently by manipulation of the inlet and relief valves to produce the desired results. With a more or less constant head in chamber C, the pressure required to produce a seal was obtained by admitting water under a controlled pressure into chamber B until the seal bar came into contact with the seat and stopped the penstock flow. The pressure in chamber B to produce the stoppage of flow is termed the sealing pressure. When the pressure in B was reduced, the contact between the seal bar and the seat would be broken and the penstock flow started. The pressure in chamber B to accomplish this separation is termed the breaking pressure. The sealing and the breaking pressures were in many cases nearly the same, but at times there was as much as 10 pounds per square inch difference due to inherent internal friction in bending or sliding and friction between the ends of the seal bar and the transparent sides of the model, or due to the shape of the seal bar nose. Sometimes all these factors were acting simultaneously.

If the valve supplying chamber B was opened quickly with the penstock supply flowing, the seal bar would slam into the closed position, causing severe water hammer.

The sliding bar seal in design 7C (figure 6) had an additional chamber designated as A between the face of the seal bar and the seat. Pressures above the atmospheric base in chamber A, as measured through piezometer A, were read in pounds per square inch. Subatmospheric pressures at piezometer A or at piezometer D were measured in feet of water. This terminology will be used throughout the subsequent discussion.

6. Constant-contact seals (figure 6). These seal designs do not embody retraction, but the seal bar is in constant contact with the seat while it is dragged off or on the seat as the gate is opened or closed. The designs are mainly applicable to rectangular gates, but design 6C (figure 6J) or design 7C (figure 6L) could be used on a circular gate by machining the bar as a ring which would float in the supporting groove. In rectangular gates the top and bottom seal must have a stop provided to prevent the seal bar from extending too far as it slides from the seat, because penstock pressure is maintained until the gate leaf moves far enough to relieve it. The seat should have a slope at the edge so that in closing or opening the gate the seal bar can climb or descend gradually into the final position. The vertical seal bars would ride guides extended from the seats in the same plane. The fact that the top and the bottom seal bars will be extended or retracted when the gate leaf is moved, whereas the vertical seal bars would be in constant contact with the side seats and guides, involves a problem in design of the corners which will give flexibility as well as stability.

The sliding friction between the nose piece and the seat must be allowed for in designing the hoist. The sliding friction on the flat portion of the seat was always small; it was greater along the slope.

(a) Music-note constant-contact seal, design 1C (figure 6A).--Sealing was imperfect, due to undulations and stiffness of the brass vulcanized strip. By moving the sliding seat back and forth, movement of the seal bar was produced as though the gate leaf moved, causing the seal bar to be extended or retracted while penstock pressure was maintained. Movement of the seal bar was restricted due to its inherent stiffness and the flat base. With a gap of 1/16 inch, 30-to 40-pounds-per-square-inch pressure in chamber C was required to close it. The seal is therefore not good for low heads. Friction on the sliding seat while penstock pressure was maintained was low, but considerably greater when the nose of the seal bar was climbing the slope. This condition was observed in all the constant-contact seals. The distortion of the rubber seal under pressure when the reinforcing strip is omitted is shown in figures 7A and 7B. In A, no pressure was applied and in B, the distortion under 110 pounds per square inch is shown. Design 1C is shown in figures 6D and E, applied to the 19.5- by 24.9-foot fixed-wheel gate for Shasta Dam diversion tunnel. This design was finally chosen for installation after the tests on the following designs were made.

(b) Music-note constant-contact seal, design 2C (figure 6B).--In this design the nose piece seals on its end instead of on its side, as in design 1C. Representation of the seal bar in sliding up or down the slope of the seat, or when the gap in the gate changed, was accomplished by mounting the seal bar unit on a sliding base. The seat was also made to slide by attaching to a vertical screw. As the base was moved while the penstock pressure in chamber C was maintained, there was undue bending in the vulcanized brass strip so that it crawled around the curve, eventually permanently deforming the brass strip. In one test arrangement the brass strip was slotted so as to make a hinge at the base. The strip still showed poor action. An installation of this design is shown in figure 6G for the 15- by 29.65-foot penstock coaster gate for Grand Coulee Dam.

(c) Hinged-bar and rubber constant-contact seal, design 3C (figure 6C).--A seal was accomplished in this design at the seat and at the hinge by the rubber acting under the hydraulic pressure. The bar had to be mounted only fingertight at the hinge to obtain any movement; otherwise no movement obtained. The seal between the rubber and the seat was excellent, but there was indication of sticking and tearing which would be a disadvantage. A brass, angle nose piece was tried, but the action was poor. The brass nose piece was torn from the rubber by the high-velocity flow through the gap as the seal bar left the seat and came into contact with the stop. This condition would exist at small openings of the gate at both the top and the bottom seals. The rupture was caused by the fluctuating subatmospheric pressures which existed at small gap openings. These pressures tended to pull the nose piece from the rubber by suction.

The bond between the rubber and the bar might be impossible to maintain in the case of the top and the bottom seals on a rectangular gate. During the opening of the gate in the case of the top seal, the friction between the rubber and the seat would tend to pull the rubber from the seal bar (figures 8C and G). The same condition would occur on the bottom seal during the closing of the gate, only to a lesser degree. During either the opening or closing of the gate, there is little contact at the bottom seal between the rubber and the seat, due to the metal seal bar being in contact with the slope of the seat, thus holding the rubber away from the seat until the seal bar is in contact with the flat portion of the seat (figures 8D and H). Figures 8A and B show the conditions with and without pressure before a brass angle was installed on the sealing edge of the rubber. Figures 8E and F show the same conditions after the brass angle was added. An installation of this type of seal is shown in figure 6F in a manner similar to the music-note seal installation in figure 6E.

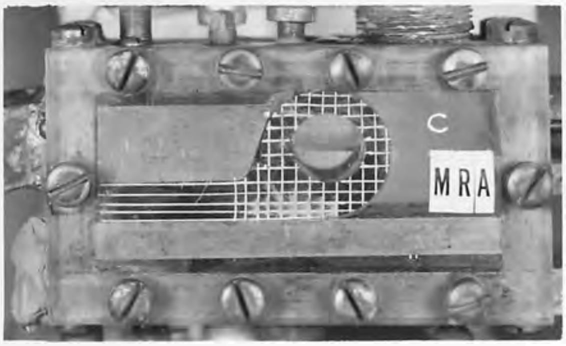
(d) Hinged, flexible, constant-contact seal, design 4C (figure 6H).--The seal bar was made from a test specimen of Gates rubber adhesion, stock No. 1080 (about 65 durometer and 1/4 inch thick), vulcanized to a flat steel plate 3/32 inch thick. The stay was slotted at 1/2-inch intervals for flexibility. The nose piece was a standard, half-round brass rod screwed to the stay. A machined or rolled stay and nose piece could have been used instead. The action of the seal was good and considerable movement of the seal bar was possible. The flexibility of the unit permitted 1/32-inch twist in the 2-1/2-inch length of seal bar, with a pressure of 20 pounds per square inch in chambers B and C. This flexibility allowed excellent contact between the nose piece and the seat, thus producing a tight seal. The force required to move the seal bar was very small as was evidenced by hand manipulation of seal bar with the plunger. The stay did not show any bending under 110-pounds-per-square-inch pressure. An application of this design is shown in figure 6K. If double stays were used, no vulcanizing would be necessary. A double stay construction is shown in HYD-96 (figure 15, design 4).

(e) Hinged, sustained, constant-contact seal, design 5C (figure 6I).--This design is another application of the hinged type of seal. Various shapes of sustaining rubber were studied. The force exerted by the cramped rubber holds the seal bar in place. The action was stiffer than design 4C, and the solid bar could not be twisted with 75-pounds-per-square-inch pressure. One slotted bar was made in which a twist of 1/64 inch could be produced with 70-pounds-per-square-inch pressure, in chamber C. In an application in a vertical position, the seal bar could be fully supported at the hinge because of the metal-to-metal contact. The rubber would be installed under slight compression.

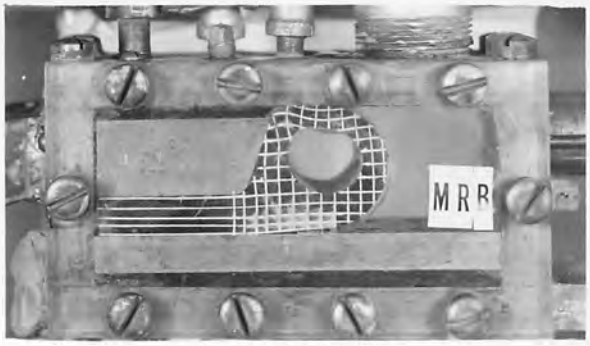
A 1/8-inch wall rubber tubing with sufficient cross section to comfortably fill the space under the seal bar would give good support and sealing action at the hinge. It would be necessary to expose the interior of the tube to penstock or reservoir pressure. The sealing action at the hinge can be seen by comparing figures 7D with 7C.

(f) Floating, sustained-bar, constant-contact seal, design 6C (figure 6J).--In this design all the unbalanced pressure exerted normal to the flat portion of the seat by the water in chamber B is used to effect a seal. In the hinged type of bar, approximately half of the unbalanced normal pressure is exerted on the hinge. Accordingly, in the floating type, the bar need be only half the width to produce the same pressure at the nose and the seat.

Of the various shapes of rubber tested, the channel shown in figure 6J and the 1/8-inch wall tubing in figures 7E and F showed the best results. The rigidity of the channel shape maintained good contact between the nose and the seat, but the large cross-sectional area of the channel tended to cramp the rubber seriously as the seal bar was depressed, thus limiting the bar movement. To obtain a more resilient unit, flexible 1/8-inch wall rubber tubing was substituted (figures 7E and F). The flexibility of the

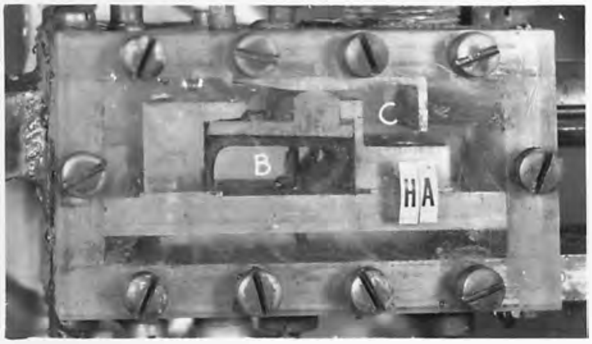


A-No pressure in chamber C.



B-Pressure of 110 lb. per sq.in. in chamber C.

DISTORTION IN MUSIC-NOTE SEAL WITHOUT REINFORCING STRIP
POSITION AS IN DESIGN 1C

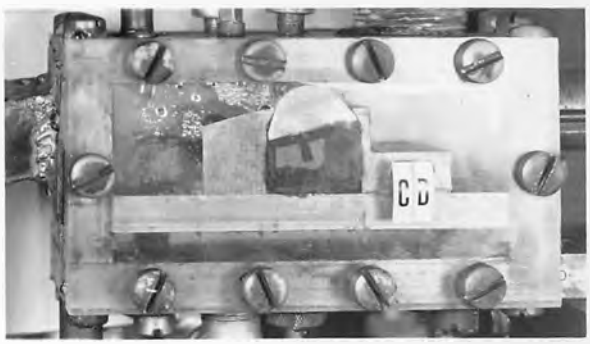


C-Seal bar mounted on 1/8-inch flat rubber strip showing looseness of rubber at hinge with no pressure.

D-Rubber pushed against hinge with 75-lb. per sq.in. pressure in chambers B and C.

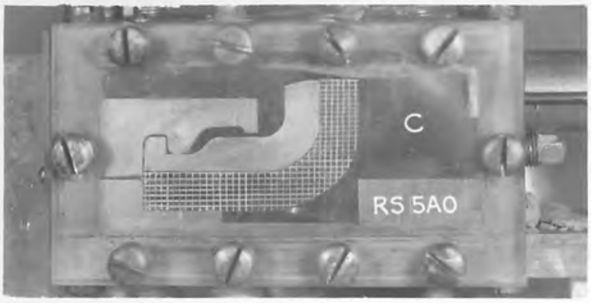
HINGED, SUSTAINED, CONSTANT-CONTACT SEAL - DESIGN 5C

E-Plunger connected and 75 lb. per sq.in. pressure in chambers B and C showing cramped position of rubber.



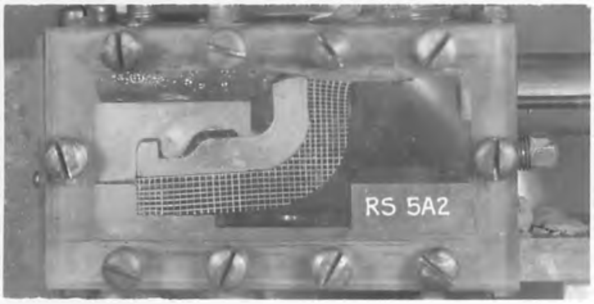
F-Plunger disconnected and seat retracted while penstock pressure was maintained showing rotation of seal bar in direction of flow.

FLOATING, SUSTAINED, CONSTANT-CONTACT SEAL - DESIGN 6C



A-No pressure in chamber C.

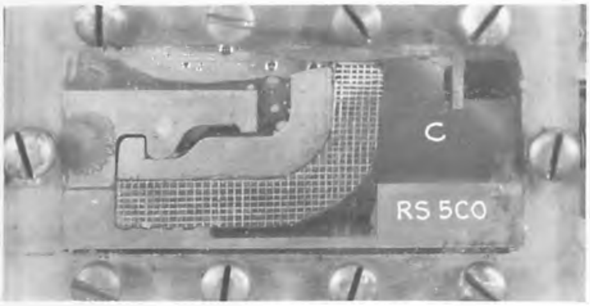
B-Seal on flat portion of seat with 70 lb. per sq. in. pressure.



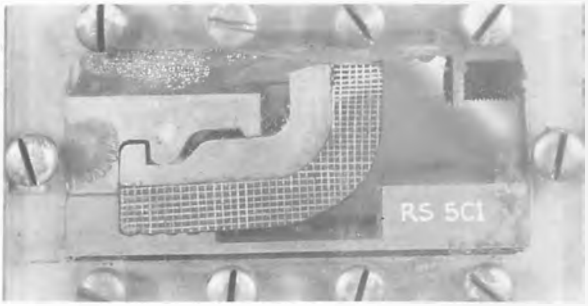
C-Seal bar under 70 lb. pressure leaving top seat of gate.

D-Seal bar under 70 lb. pressure leaving bottom seat of gate.

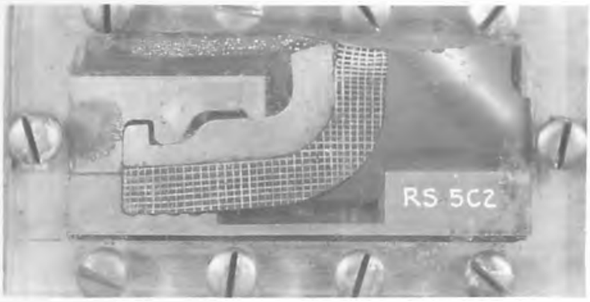
ORIGINAL DESIGN WITH SHIM UNDER CLAMP BAR



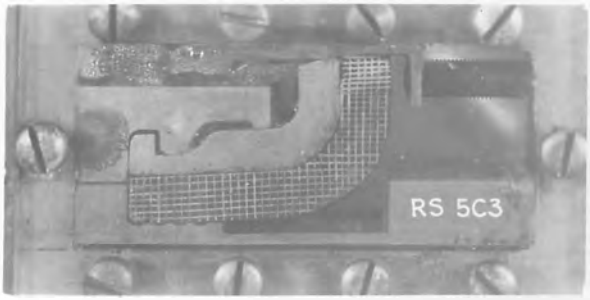
E-No pressure in chamber C.



F-Seal on flat portion of seat with 70 lb. per sq.in. pressure.



G-Seal bar under 70 lb. pressure leaving top seat of gate.



H-Seal bar under 70 lb. pressure leaving bottom seat of gate.

BASE ALTERED AND BRASS ANGLE ADDED
TO SEALING EDGE OF RUBBER

HINGED BAR AND RUBBER, CONSTANT-CONTACT SEAL - DESIGN 3C tube was greater, as anticipated, but rotation of the seal bar (figure 7F) by the unbalanced hydraulic pressures made it necessary to install a guide pin to maintain the seal bar in position. There was no objection to the guide pins, hydraulically, but their installation would increase the complexity and cost. The effectiveness of guide pins was shown by the use of one 8-32 machine screw attached to the plunger and seal bar. The sliding seat and seal bar were operated under a pressure of 110 pounds per square inch, but the machine screw was not bent by the unbalanced forces. This indicated their small magnitude.

The absence of a rigid hinge tends toward flexibility of the bar itself, which permits a tight fit between the seal bar and seat even where the seat may be misalined. This conformity increases the effectiveness of the sealing action. Of the nose shapes tested (figure 6M), shape A gave the best action because it is hydraulically balanced. Furthermore, the half-round section is more flexible than a rod or a tube because of its lesser resistance to bending. The strength of a half-round section in bending is approximately one-fourth that of a 1/8-inch wall tube with the same outside diameter. Shape C was developed to permit greater latitude of movement and hence greater clearance between the stop bars and the seat.

Shape B was objectionable because of the sharp contact between the seal bar nose and the slope of the seat and because of the greater tendency toward rotation due to the unbalanced hydraulic forces caused by the thickness being less than half the width. The rotation in this case was against the flow as compared to rotation with the flow, on shapes A and C. The lesser ratio of thickness to width on shape D increased the tendency to rotate, in this case against the flow. Shape E with new stop bars, as outlined, was developed to negate the rotation of the seal bar, but the permissible clearances were so small as to make the design undesirable. In shape F, the radius of the nose was reduced to 1/4 inch to reduce the subatmospheric pressures which occur downstream from the nose piece as the seal bar approaches the seat. The change was ineffective. Without the rubber under the seal bar the leakage between the seal bar and the stop bar was considerable, due to imperfect contact.

(g) Sliding, constant-contact, bar seal, design 7C, figure 6L).--The principal advantage of the sliding bar seal in a constant contact installation on a rectangular gate is the positive guides, but those positive guides have several disadvantages. To operate satisfactorily, the clearances must be small, which appreciably increases the cost of manufacture, installation, and maintenance. The action in the model was good, but in a field structure the formation of scale from the water, or deposition of foreign matter, would render the bar seal inoperative.

7. Retractable seals (figure 9). In retractable seals, forces are applied to the seal bar to cause it to unseal or to retract to produce a gap between the sealing edge of the nose piece and the seat. The distance

between the sealing edge and the seat is the measure of the retraction. It is generally considered preferable that the seal bar should remain in the retracted position while the gate leaf is in motion or until a seal is again required. However, a seal bar that lightly scrapes the seat when the leaf is moved has the advantage of a cleaning and seating action.

In this series of designs and tests one method of producing retraction predominated. It was the method developed for the retraction of the stabilized, flexible diaphragm seal in the first series of gate seal designs and tests (figure 4E). This method employed the penstock pressure acting on the upstream portion of the seal bar to produce retraction when the pressure in the sealing chamber under the seal bar was reduced below that required to effect a seal. Several other methods were employed in the first series of tests for producing retraction: Energy stored in rubber when the seal bar was extended, as in the compression type of seal designs (figure 4B); hydraulic forces applied in chambers, as in the double-acting packing-gland seal (figure 4F); hydraulic forces applied in addition to energy stored in rubber, as in the double-acting roller seal; hydraulic forces acting on the upstream portion of the seal bar in addition to energy stored in the rubber, as in the shear seal (figure 4C) and diaphragm seal (figure 4D).

In order to apply the hydraulic forces upstream from the sealing edge, a unique feature was incorporated in five of the seven designs shown on figure 9. This was the retraction spring (figures 9A, C, D, G, and I) added to similar or the same constant-contact designs. The retraction spring could also be added on the upstream side of the sliding bar seal, design 4R, thus eliminating the close clearance for the seal bar in the slot. However, the retraction spring is only applicable to rectangular gates in which the seal bar is straight. For curved or circular seal bars, the sliding bar seal (design 4R) or the stabilized, flexible diaphragm seal (design 6R) would operate. Of these two, the latter is to be preferred because it is not so subject to fouling due to scale encrustation or dirt deposition.

Tests were conducted for the express purpose of determining the pressure required at the seating surfaces to effect a perfect seal. In these tests the sliding bar seal, design 7C (figure 6L), was used in the same manner as a retractable seal. Since the seal bar is free to move in its slot and is thoroughly guided by the sliding fit of the sides of the slot, this seal unit was found ideal for these tests.

With the seal bar in position with face A to the seat and a flat, sliding seat installed (figures 6L and 10A), it was difficult to determine when both legs were seating because of some leakage between the contacting surfaces. Pressures in chamber A were controlled by a relief valve in the line to chamber A to determine the effect when pressure was allowed to build up in the chamber or when it was drained. With the relief valve open, the amount of water escaping by the upstream leg of the seal bar could be seen flowing out of the pipe; and when the relief valve was closed, the rise in pressure in chamber A, as read on gage A, indicated the relative amount of leakage between the upstream and the downstream leg. Restated: Leakage by the downstream leg could be seen squirting into chamber D. Pressure in chamber A varied from half to nearly equal that in chamber C. When the leakage over each leg of the seal bar was about equal, it was concluded that both legs were seating uniformly. No amount of additional pressure applied to the seal bar by the hand-operated lever and plunger (figure 5A) made a better seal. Sealing was accomplished by applying hydraulic pressure in chamber B or by pressing down on the lever. When chamber B was drained, all the leakage between the seating surfaces at the seat could be detected, and when pressure in B was applied with drain to chamber A open, all the leakage through the downstream sliding surfaces between the slot block and the seal bar was detected.

The pressures required to maintain the seal bar in the sealed position, or, in other words, the unit pressure required between the sealing surfaces, was found in two independent ways: the pressure in chamber B which would just cause the seal bar to seat, or the pounds of force required on the lever at a ratio of 7 to 1, was determined. These measurements were made with the drain to chamber A both open and closed.

Similar tests were conducted with face B of the seal bar to the seat. It was difficult to determine when the face was seating uniformly. Usually pressure at gage A registered almost that in chamber C, but when the relief valve to chamber A was opened, only a very thin stream of water flowed. This indicated that face B was seating uniformly. Sealing pressures were determined independently by finding the pressure required in chamber B or the load required on the lever, and also with the drain to chamber A either open or closed.

When the computations for both cases were made, which involved the forces acting on the seal bar either hydraulically or mechanically, the forces could not be reconciled to give consistent results. It was concluded that the methods failed because it was impossible to determine or estimate the areas subjected to hydraulic pressure at the seating surfaces due to the leakage creeping through and acting on these areas. The probable appearance of the actual surfaces in absolute contact in comparison with those that were not in perfect contact would be like that presented by a contour map where the landscape is a rolling or hilly countryside.

Another method of determining the pressure required to seal gave conclusive results. In the test with face A of the seal bar to the seat, if chamber A was relieved of pressure the seal bar remained in the sealed position even when the force upward on it was zero (figure 10A). The same fact was experienced when the sliding seat was retracted so that chamber A was completely exposed. With the seal bar inverted so that face B was to the seat, the sliding seat was retracted at a uniform rate, while pressure on the lever necessary to effect a seal, applied through a spring balance, was also uniformly released to correspond to the decrease in area covered by the sliding seat. When the seat was retracted until only about 1/16 inch remained in contact with face B of the seal bar (figure 10B), no force was required to maintain a seal. Contrariwise, only a very small force was required to break the seal. A force as low as one-pound pull on the plunger would cause this break, and, likewise, only one pound of force was needed to push the seal bar closed. These tests proved conclusively that the contact pressure necessary to effect a seal is zero. It was shown by an involved computation in the former report on gate seals (HYD. 96, figure 18, page 23) that the line contact pressure was about 10 percent of the head. The discrepancy can no doubt be waived when the accuracy and errors in the method are taken into account.

In many of the tests that follow, the condition of balanced pressures was seen to be such that the forces applied to cause the seal bar to make contact with the seat were equal to or only slightly greater than the forces tending to unseat the seal bar. This point will be brought out further in discussing the individual designs and tests. For design purposes, an arbitrary value of the unit pressure required for a seal to be effective has been taken as five times the head. It is seen that this figure is large. The tests described show further that only line contact is necessary to effect a perfect seal. This is concluded from the fact that the 1/16-inch wide surface produced as good a seal as the much wider surface of 3/4 inch. The wider surface at times showed less leakage, evidently because the longer path for the water provided a greater pressure drop across it.

The quality of the seal, or in other words the degree of the effectiveness in sealing, was also tested. The quality, as measured by the amount of leakage between the sealing surface of the nose piece and the seat, depended on the degree of contact between the two surfaces and not on the unit pressure at these surfaces. If line contact was possible by an increase in pressure on the seal bar, then the increased pressure was beneficial; otherwise it was not. In considering gates in the field installation, there is foreign matter that could prevent perfect contact in parts of the seating surfaces. Increased pressure might indent these particles into the metal itself or squeeze them thin. In the model, scale or other foreign matter prevented the seal bar from seating well, and, even with retraction on the bar, the dirt would not wash through. Therefore it might be advantageous to allow the seal bar to scrape or slide onto the seat to clean itself. In the tests with different materials at the sealing surface, it was seen that a soft or resilient nose piece prothat the contact pressure necessary to effect a seal is zero. It was shown by an involved computation in the former report on gate seals (HYD. 96, figure 18, page 23) that the line contact pressure was about 10 percent of the head. The discrepancy can no doubt be waived when the accuracy and errors in the method are taken into account.

In many of the tests that follow, the condition of balanced pressures was seen to be such that the forces applied to cause the seal bar to make contact with the seat were equal to or only slightly greater than the forces tending to unseat the seal bar. This point will be brought out further in discussing the individual designs and tests. For design purposes, an arbitrary value of the unit pressure required for a seal to be effective has been taken as five times the head. It is seen that this figure is large. The tests described show further that only line contact is necessary to effect a perfect seal. This is concluded from the fact that the 1/16-inch wide surface produced as good a seal as the much wider surface of 3/4 inch. The wider surface at times showed less leakage, evidently because the longer path for the water provided a greater pressure drop across it.

The quality of the seal, or in other words the degree of the effectiveness in sealing, was also tested. The quality, as measured by the amount of leakage between the sealing surface of the nose piece and the seat, depended on the degree of contact between the two surfaces and not on the unit pressure at these surfaces. If line contact was possible by an increase in pressure on the seal bar, then the increased pressure was beneficial; otherwise it was not. In considering gates in the field installation, there is foreign matter that could prevent perfect contact in parts of the seating surfaces. Increased pressure might indent these particles into the metal itself or squeeze them thin. In the model, scale or other foreign matter prevented the seal bar from seating well, and, even with retraction on the bar, the dirt would not wash through. Therefore it might be advantageous to allow the seal bar to scrape or slide onto the seat to clean itself. In the tests with different materials at the sealing surface, it was seen that a soft or resilient nose piece produced a perfect seal. For this reason a good grade of rubber was so very beneficial. It acted in the same manner in which a gasket or packing acts between two metal surfaces. The soft material flows into the depressions between the finely machined surfaces and makes a perfect seal.

In the tests on the sliding bar seal, several attempts were made to produce a droptight seal by remachining the seating surfaces. Great care was used in these operations and a very smooth surface was the result; yet the droptight seal could not be attained. Finally, flat grinding of the sliding seat on both sides was resorted to, as well as grinding the faces A and B of the seal bar, using FFF emery powder and water on a glass plate, then finishing with No. 304 pumice. Upon installation, a droptight seal was accomplished either with a wide or a narrow seating surface. To prevent end leakage in the model, the ends of the seal bar were greased and the sides of the box were clamped together with a large clamp. This stopped end leakage entirely when face B was to the seat but allowed a few drops when face A was to the seat. With face A, the leakage was by the ends of the two legs. Seals having rather hard material in contact ordinarily never sealed droptight because of slight undulations in the seating surfaces. In some cases water squirted through in thin sheets, and in other cases the leakage was seen to be in hairline streams and sometimes only in drops. Application of pressure aided the quality of the seal only when the seal bar could be twisted or made to aline itself better to the seat by the additional force. Generally one seal design could be made to give as good results as another as far as actual sealing quality was concerned, when the contacting surfaces were comparable, that is, of equal smoothness or of equal quality, provided only that contact was made as well for one as for the other along the length of the seal bar taken as a whole. This was a process of alinement and not of pressure application. To illustrate this point, a test with a Lucite plastic, standard, extruded round rod was used as a seal bar in the roller retractable-seal design 1R (figure 9A). The quality of the seal was poor. By inserting a sheet of typewriter carbon paper between the seating surfaces, an impression on the roller was taken. Contact was found to be along the two ends of the roller and not in the middle; the roller was rotated to several new positions and contact impressions made. The line of contact shifted in probably every case because of the change in the undulations along the roller. Micrometer measurements taken at several diameters of the roller gave readings varying by as little as 0.0015 inch. High pressure on the roller, applied by the hand-operated lever and plunger, did not increase the effectiveness of the seal because the Lucite could not be deformed so easily, and yet the material is much softer than brass or steel. This same condition occurred when the metal seal bars were tested. One bar would seal better than another, or even the same bar would seal better in one position than in another.

The general conclusions from the tests were that the quality of the seal (amount of leakage) is not a function of the unit pressure at the sealing surfaces but rather on the matching of the contact surfaces. Only enough force is needed to bring the parts together. However, if the surface or surfaces are soft and sufficiently resilient to deform easily, additional pressure is advantageous to make line contact continuous and unbroken. To produce this condition with machined metal-to-metal contact, the metal would have to be compressed beyond its elastic limit and deformed, a condition which is beyond the scope of possibility in a hydraulic gate seal. To illustrate, consider a hinged-type gate seal, as design 3R (figure 9D), having a bar four inches wide from hinge to nose. At a pressure of 200 pounds per square inch under the bar, the pressure at the nose would be about 400 pounds per linear inch. If the contact surface is 1/16 inch wide, the unit pressure would be 400 divided by 0.062 square inch, which equals 6,400 pounds per square inch. If the contact surface is 1/64 inch wide, the unit pressure is 25,600 pounds per square inch, whereas the ultimate compressive strength for brass is about 30,000 pounds per square inch, so that crushing pressure has not yet been reached. Furthermore, a seal bar four inches wide would hardly be designed, and pressures of 200 pounds per square inch on gates might only be attained in extreme cases. It is thus seen that the metal never is forced in compression so as to deform it in a manner similar to that of rubber.

The forces acting on the seal bar during the process of closure of the gap were investigated. In all the tests on gate seals when velocities of the water were high, it was seen how violently the seal bar was shifted, moved, and rotated in a tilting action. Negative pressures downstream from the nose piece were severe for the smaller gap openings. Piezometers A and D were installed (figure 9A) in the model to measure these pressures or observe the changes in conditions at these points or in these chambers as the seal bar was operated. Both a negative and a positive reading Bourdon pressure gage was installed in the same line to each piezometer.

The greatest negative pressures usually resulted with a gap of 1/32 to 1/16 inch and were as much as -25 feet of water. The maximum negative pressures were sometimes greater for a lower head than for a higher head at some particular gap and changed with the clearance allowed between the top of the downstream clamp bar and the seat. The shape of the nose piece also had various effects, but regardless of the shape, negative pressures always existed at gap openings smaller than the clearances.

Considering the action of the seal bar in any retractable seal, if the seal bar is in the fully retracted position and penstock flow is admitted, positive pressure is built up in chamber C upstream from the sealing edge, which is usually lower than the actual penstock head because of losses or restrictions in area up to the nose piece. The pressure downstream from the nose piece may be positive or negative, depending on whether the clearance area or the gap area controls the flow. In order for the gap area to control the flow so that negative pressures result, the nose piece must be extended so that it projects slightly above the downstream clamp bar, usually from 1/32 to 1/16 inch. If the projection is less, positive pressures will exist at A and D, or, in other words, over the whole seal bar, so that it will be forced down as far as restrictions will allow.

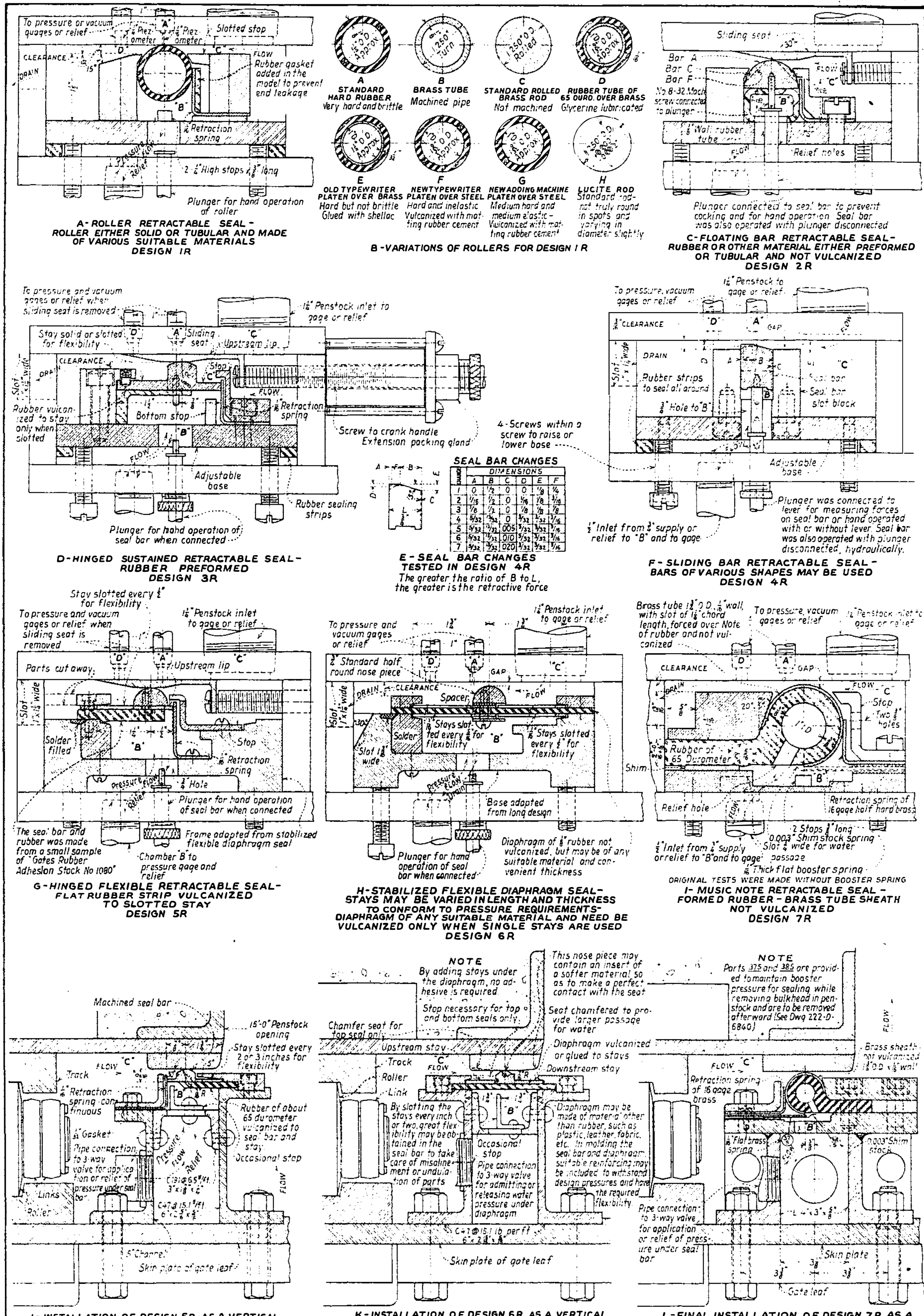
In the process of closing the gap, which is the sealing operation, the seal bar action will now be considered. If the nose piece is below the level of the stop bar and pressure is gradually admitted under the seal bar, in chamber B, the seal bar will not commence to rise until balanced forces are reached; that is, the force to extend it must equal the force to retract it. In this condition the seal bar is very susceptible to an overbalance of pressure in either direction. When pressure in chamber B is increased, the seal bar is extended very suddenly and quickly to a new position where negative pressures come into play. If the positive pressure in chamber B plus the negative pressure in chamber D was sufficient to close the gap at the existing penstock pressure, the seal bar slammed shut. This caused very severe water hammer at the higher heads. Several other conditions existed to increase the slamming action. The pressure in chamber C rose to full penstock pressure just as suddenly as the seal bar slammed shut, and in addition the rise in pressure in chamber C often increased the flow into chamber B because of the interconnection in piping or because of leakage between the two chambers. At the point of sealing, any chance for the seal bar to tilt or cock aided slamming. Most of the bad conditions described above could nearly always be overcome by not allowing the seal bar to be retracted to the point where the negative pressures ceased to exist on the downstream side of the nose piece. This was always a delicate point of balance because the seal bar floated. In the roller retractable seal, design 4R (figure 9A) this balance point was so delicate that the metal rollers bounced up and down unless the retraction spring was snug against them. To close the gap from this balanced position in any seal, the operation was to admit pressure into chamber B slowly until the seal bar moved in extension to close the gap. Sometimes the movement was very rapid until another new point of balance was reached to within about 1/32 inch of closure, after which the pressure required in chamber B with respect to the extension produced was much higher than formerly. The reason for this retarded action is due to the rapid decrease in negative pressure in chamber D as the remaining gap was closed, so that assistance from this source is lessened. The seal bar closed smoothly from this position except in cases where the bar could tilt or cock or move sideways, when it would do so with a slam. In the sealing cycle the valve controlling the pressure to chamber B should always be opened slowly. A seal bar that normally operated well could be made to slam by opening the valve to chamber B rapidly. It is assumed that in a field installation the flow to chamber B would be controlled and admitted slowly.

The action of the seal bar in retracting is the reverse of the sealing cycle except there is no particular violence to it. Usually, upon releasing pressure in chamber B below that required for sealing, the seal bar retracts rapidly and easily to a floating state, to a gap of about 1/8 of an inch. The clearance and inherent resistance of the seal bar control this retractive action to a large extent at any particular head. If the seal bar can tilt, the action is delayed and the gap may be smaller. When the pressure in chamber B is further released, the seal bar may collapse to the bottom of its slot or space. If it does, the action is as rapid as the resistance of the seal bar will allow and can can hardly be prevented once it starts, because the valve to chamber B cannot be manipulated delicately and fast enough. The rapidity of the retraction is due to the pressure changes which take place over the entire seal bar, which swing from negative to positive instantaneously, as explained before.

The discussion of the individual designs of retractable seals and their operational characteristics follow:

(a) Roller retractable seal, design 1R (figure 9A).--Of the various arrangements tested, the one shown gave best results as to the action of the seal bar which, in this case, is a round rod or roller. Various rollers were made and tested, some of which are shown (figure 9B). Roller G operated the best because of the resilient adding-machine platen-rubber covering which cushioned the action. Only a minor slam could be produced at the seat regardless of the rapidity with which pressure was admitted in chamber B. The retraction spring sealed very well and did not commence to vibrate or chatter easily, and when it did, the vibration was not so violent as for the metal seal bars. The downstream contacting surface flattened slightly, which retarded the folling action; the seal quality along this surface was perfect. This seal bar did not bounce when in the floating position. The quality of the seal was excellent, both at the seat and at the downstream contact surface, it being droptight. Sealing pressure required to close the gap was about five-eighths of the head. Retraction was smooth and nearly equal to the clearance.

The harder rollers did not seal as well, for the quality of the seal depended on the softness or smoothness of the material at the sealing surfaces. The downstream contacting surface at the stop bar also generally



A - ROLLER RETRACTABLE SEAL - ROLLER EITHER SOLID OR TUBULAR AND MADE OF VARIOUS SUITABLE MATERIALS DESIGN 1R

B - VARIATIONS OF ROLLERS FOR DESIGN 1R

C - FLOATING BAR RETRACTABLE SEAL - RUBBER OR OTHER MATERIAL EITHER PREFORMED OR TUBULAR AND NOT VULCANIZED DESIGN 2R

D - HINGED SUSTAINED RETRACTABLE SEAL - RUBBER PREFORMED DESIGN 3R

SEAL BAR CHANGES

CHANGE	A	B	C	D	E	F
1	0	1/2	0	0	1/8	1/4
2	1/16	1/2	0	1/16	1/8	3/16
3	1/8	1/2	0	1/8	1/8	1/8
4	5/32	11/32	0	3/32	3/32	3/16
5	5/32	11/32	.005	3/32	3/32	3/16
6	5/32	11/32	.010	5/32	3/32	3/16
7	5/32	9/32	.020	3/32	3/32	3/16

E - SEAL BAR CHANGES TESTED IN DESIGN 4R
The greater the ratio of B to L, the greater is the retractive force

F - SLIDING BAR RETRACTABLE SEAL - BARS OF VARIOUS SHAPES MAY BE USED DESIGN 4R

G - HINGED FLEXIBLE RETRACTABLE SEAL - FLAT RUBBER STRIP VULCANIZED TO SLOTTED STAY DESIGN 5R

H - STABILIZED FLEXIBLE DIAPHRAGM SEAL - STAYS MAY BE VARIED IN LENGTH AND THICKNESS TO CONFORM TO PRESSURE REQUIREMENTS - DIAPHRAGM OF ANY SUITABLE MATERIAL AND NEED BE VULCANIZED ONLY WHEN SINGLE STAYS ARE USED DESIGN 6R

I - MUSIC NOTE RETRACTABLE SEAL - FORMED RUBBER - BRASS TUBE SHEATH NOT VULCANIZED DESIGN 7R

J - INSTALLATION OF DESIGN 5R AS A VERTICAL SEAL PROPOSED FOR 15FT. x 29.65 FT. PENSTOCK COASTER GATE FOR GRAND COULEE DAM

K - INSTALLATION OF DESIGN 6R AS A VERTICAL SEAL PROPOSED FOR 15 FT. x 29.65 FT. PENSTOCK COASTER GATE FOR GRAND COULEE DAM

L - FINAL INSTALLATION OF DESIGN 7R AS A VERTICAL SEAL FOR 15 FT. x 29.65 FT. PENSTOCK COASTER GATE FOR GRAND COULEE DAM

GATE SEAL DESIGNS AND TESTS
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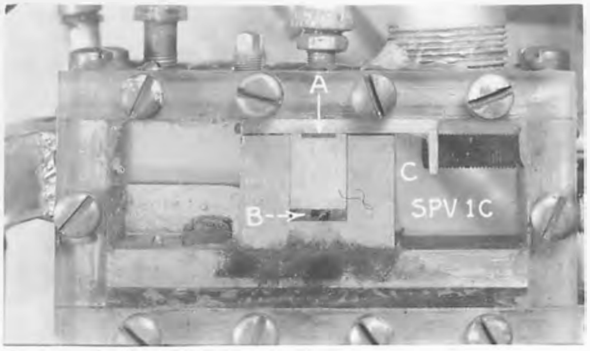
leaked a little and for the same reasons. The sealing pressure required was less. At the seal breaking point the retraction spring would vibrate or chatter unless it was snug against the roller seal bar. The vibration was caused by the velocity flow through the space between the spring and the roller when pressure in chamber B was reduced. The metal seal bars could be made to slam violently, especially when the retraction spring was loose.

The seal bar generally rolled when being extended or retracted. When chattering occurred it rolled downstream. It also rolled downstream when the sliding seat was moved in either direction while penstock pressure was maintained. The rolling action would be beneficial in a field installation because it would aid in loosening the bar in case of sticking; friction at the contacting surfaces would be less than sliding friction. By increasing the size of the seal bar, greater clearance may be allowed with consequent greater extension; the available pressure to seal would also be increased. Since the seal bar floats, alinement to the seat is easily accomplished.

The disadvantages are the chatter and vibration possibilities when metal rollers are used and the rolling action to be provided for along the length of the seal bar and at the joints. The support of the seal bar is also a problem. This design would not operate as a circular seal.

The design was tested with and without the sliding seat. During tests with the sliding seat, the amount of clearance for the downstream water passage had a marked effect on the action of the seal bar. When the passage was restricted by moving the sliding seat downstream, the roller seal bar was forced to retract to the bottom of its space (figure 10C), because of positive pressures produced over the whole width of the seal bar. A similar condition was prevalent without the sliding seat and a flat-topped stop bar when the clearance was 1/8 of an inch (figure 11C). When the clearance was greater and the path for the water divergent, the negative pressures were maintained, with the result that the seal bar remained only partly retracted even though pressure in chamber B was zero (figures 10D and 11A). As the sliding seat was retracted (figure 10D), the roller maintained the same constant gap opening.

These findings were used in the final design of the downstream stop bar (figure 9A) in that a 15-degree slope was cut on top and the edge next to the seal bar was 1/32 of an inch lower than the top of the upstream stop bar. The clearance of 3/16 inch was sufficient to permit 10-foot negative water pressure to exist at a maximum retraction of 5/32 of an inch with no reversal to positive pressures possible (figure 11A). The sealed position of the roller is shown in figure 11B. With the original flat-topped stop bars and the same clearance as above, the seal bar was forced down hard on the bottom stop when it was allowed to retract (figure 11C). The pressures at A and D were now 28 and 10 pounds per square inch, respectively, instead of being negative. Maximum negative pressures were obtained with the roller in the position shown in figure



A-Legs of seal bar to the seat. Seal bar remains sealed with 70 lb. per sq. in. in chamber C and with pressure in chambers A and B zero; to unseal required a downward force on the seal bar.

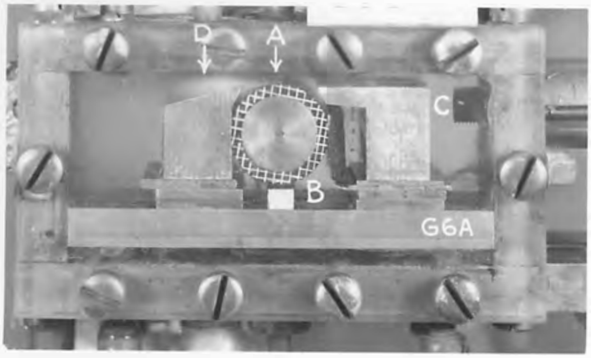
B-Flat of seal bar to the seat. Sliding seat retracted while penstock pressure was maintained at 75 lb. With 1/16 inch in contact, and sealing force reduced to zero the seal was unbroken; to unseal required a downward force on the bar.

SLIDING-BAR SEAL - DESIGN 4R OR 7C
SEALING PRESSURE REQUIREMENT TESTS

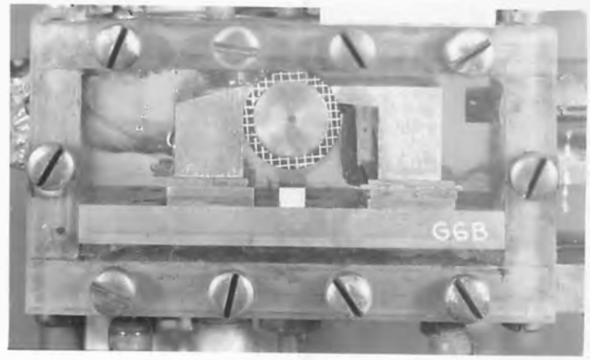
C-Roller is forced to collapse when sliding seat restricts clearance and pressure is reduced in chamber B.

D-With seat retracted and larger clearance, negative pressure along slope of seat prevents roller from retracting. Water passage is divergent.

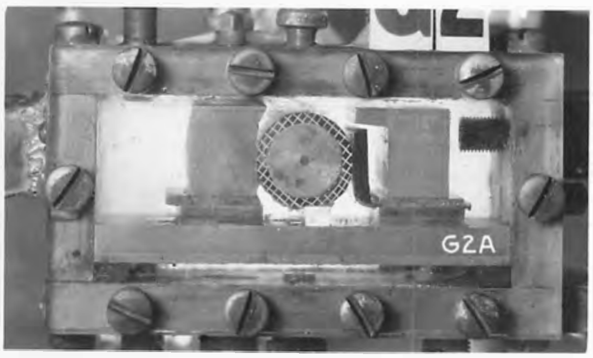
ROLLER RETRACTABLE SEAL - DESIGN 1R
ROLLER G IN INITIAL TESTS



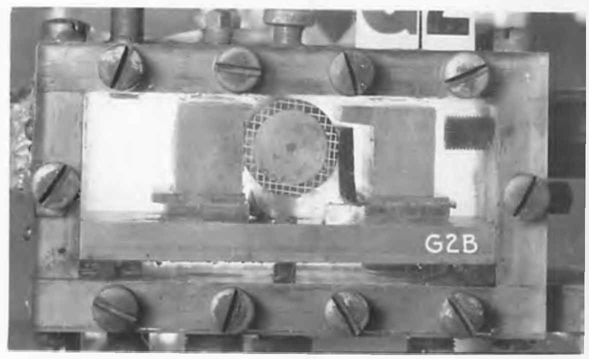
A-Maximum retraction of 5/32 inch with sloping downstream stop bar. Pressure in chamber C was 60 lb. per sq. in. and vacuum at A was 10 ft. of water. Clearance 3/16 of an inch.



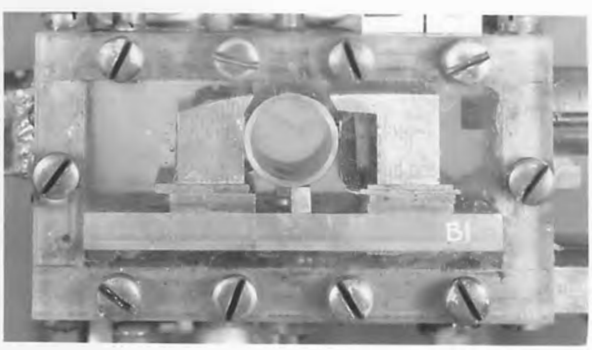
B-Sealed at 75 lb. penstock pressure with 46 lb. in chamber B. Rubber on roller only slightly deformed against downstream stop bar.



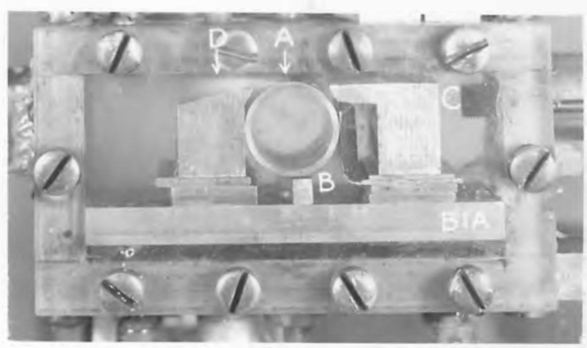
C-Seal bar is forced down hard with flat-topped stop bars. Pressure in chamber C was 60 lb. and at A 28 lb. Roller G is shown and no lip on upstream stop bar, with the clearance 1/8 of an inch.



D-Position of seal bar for conditions of maximum vacuum of 23 ft. of water. The gap of 1/32-inch for this case was the same when the sloping stop-bar arrangement was used.



E-Roller B installed without sliding seat and 3/16-inch clearance. The retraction spring was not touching the roller.



F-Maximum retraction only 5/32 inch with roller seal bar very free. Negative pressure at A was 10 ft. of water.

ROLLER RETRACTABLE SEAL - DESIGN 1R

11D when vacuums up to 23 feet of water were reached.

One of the test assemblies with metal or hard rollers is illustrated in figure 11E and the maximum retraction obtained and the region of high negative pressures is shown in figure 11F. With a gap of 3/16 inch the retraction was 5/32 of an inch and the negative pressure D was 10 feet of water. In all of the maximum retraction tests, pressure in chamber B was reduced to zero.

Considering the relationship between sealing pressure and head for the roller seal bar, the hydraulic pressure required in chamber B to effect a seal was one-half to five-eighths of the head in C. If all conditions are correct, such as no friction, no flattening of the roller, sufficient stop clearance, and correct shape of clamp bars, then the sealing pressure should be one-half of the head. The only pressures involved are those in chambers C and B, acting on their own respective areas to produce a balanced condition of the roller. To show this, reference is made to the force diagram for the half-round bar A (figure 4M), for which the following computations and considerations may be made.

If D is the diameter of the roller and C and B are the pressures in chambers C and B, respectively, the forces involved are:

$C \times \frac{D}{2}$ acting horizontally to the left,

$C \times \frac{D}{2}$ acting vertically downward,

and

$B \times D$ acting vertically upward.

Let the reaction at the seat be R. Then these forces should balance when taking moments about the downstream center point P of the roller where it touches the clamp bar.

Taking moments and assuming clockwise rotation as positive,

$$R \times \frac{D}{2} + \left(C \times \frac{D}{2}\right) \frac{3D}{4} - \left(C \times \frac{D}{2}\right) \frac{D}{4} - (B \times D) \frac{D}{2} = 0$$

or

$$\frac{1}{2} RD + \frac{1}{4} CD^2 - \frac{1}{2} BD^2 = 0$$

but if B is assumed one-half of C and the value $\frac{C}{2}$ is substituted for B in the above equation, then

$$\frac{1}{2} R D + \frac{1}{4} C D^2 - \frac{1}{4} C D^2 = 0$$

or

$$R \times \frac{D}{2} = 0$$

and

$$R = 0.$$

In a test using the metal tube roller B (figure 9B), C was 75 pounds and B at release was 38 pounds. For all practical purposes B was one-half C, allowing for accuracy and errors, which satisfies the equation when R equals zero.

Usually, exact dimensions and pressures are not so easily obtained in order to make this type of computation, but this case is ideal and should, therefore, serve as a sufficient proof that unit sealing contact pressure is zero.

In the case of roller G in figure 11B, the sealing pressure was 46 pounds to close and 42 pounds at break. The ratio of B to C is thus nearly five-eighths; so that we can say that sealing pressure will be about five-eighths of the penstock pressure at any head.

(b) Floating-bar retractable seal, design 2R (figure 9C).--In this design the seal bar of half-round dimensions is lightly supported by a 1/8-inch wall rubber tube which also is used to seal the downstream contacting surfaces. The tube had holes for passing the plunger connections through it and also holes in the upstream upper corner to admit pressure to chamber B from chamber C when the pressure in the former was lowered; otherwise a collapsing action of the tube resulted.

Various shapes of bars and of rubber were tried in order to find the shapes that would operate the best. The bars had a tipping action when loosely supported by tubes or a rubber strip, installed like an inverted "U." This action was prevalent in all the shapes tested (figure 6M), but the bars in which the depth was one-half the width or $d/D = 0.5$ as in bars A, C, E, and F, the tipping action was reduced to a minimum. Bars B and D have a ratio of d/D less than 0.5, and tipped to a greater degree. Tipping for all the bars was greater when operating against the slope of the sliding seat than when operating against the flat of the seat. Bar B tipped to the right when on the slope of the seat, and bar D tipped to the left. This shifting in direction was due to the change in the point of contact at the nose between the two bars. The round-nosed seal bars operated much better than the flat-nosed bars. Bar F was shaped with a short-radius nose in an attempt to reduce the high vacuum in chamber D, but this shape did not produce the desired result.

The seal bar was stabilized by connecting the plunger to it with a No.

8-32 machine-screw stud about one inch long. No amount of slamming or manipulation bent the small screw, which proved that only sparsely spaced and small guide studs would be necessary on the prototype bar. These guide studs would also sustain the weight of the bar in vertical seals.

The retraction was not as free or as great as for the roller seal because of the resistance of the rubber and the friction in sliding along the downstream surface, but from 1/32 to 5/32 inch was obtained, depending on the stiffness of the gasket and the head. Otherwise, the sealing and negative pressures and sealing qualities were practically the same as for the metal rollers in design 1R. Sealing occurred at pressures in B of from 9/16 to 5/8 of the head.

The advantages of this design are the flexibility of the seal bar, it being only one-fourth as stiff as a tube with 1/8-inch wall of the same diameter and material, and its ease of alinement to the seat because there is no hinge. This seal would not operate in a circular gate.

This design is illustrated in figures 12A to E, which show the action. The installation view is shown in A, and no pressure had as yet been applied. The looseness of the U-shaped rubber is also seen. In B, the bar is sealed against 75 pounds per square inch in chamber C with 46 pounds per square inch in chamber B. The seal broke with 41 pounds per square inch in chamber B. The rubber is not completely pushed in the downstream corner but has sealed droptight. Picture C shows the maximum retraction of 9/64 inch obtained when 70 pounds per square inch was maintained in chamber C. The vacuum at A was 10 feet of water and at D it was 13 feet of water; pressure in chamber B was zero. The rubber is seen to be tighter. In picture D the seal bar is sealed at 100-pounds-per-square-inch pressure in chambers C and B, and the rubber is pushed tight into the downstream corner; picture E shows the cramped position of the rubber with a maximum retraction of 5/32 inch when pressure in chamber B was zero.

The forces acting on the seal bar are depicted for bar A (figure 6M). The reason for the stability of this bar is that the ratio of d to D is exactly 0.5 when seating on the flat of the seat and the rotational forces about the center O balance, or

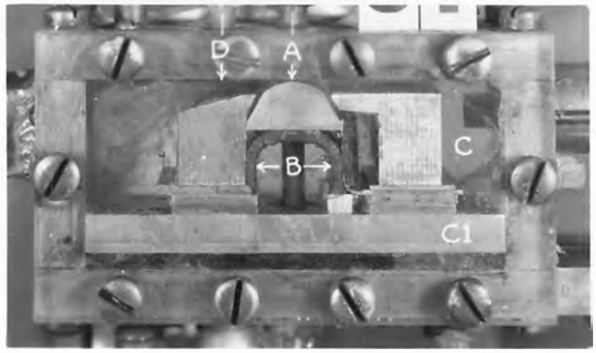
$$U_1 \times \frac{D}{4} + V \times \frac{D}{4} = H \times \frac{d}{2} + U_2 \times \frac{d}{2}$$

but since

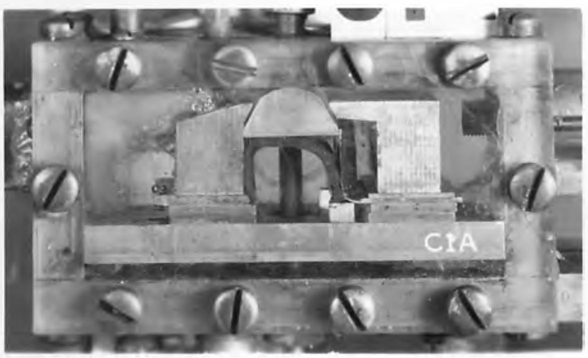
$$d = \frac{D}{2}$$

and

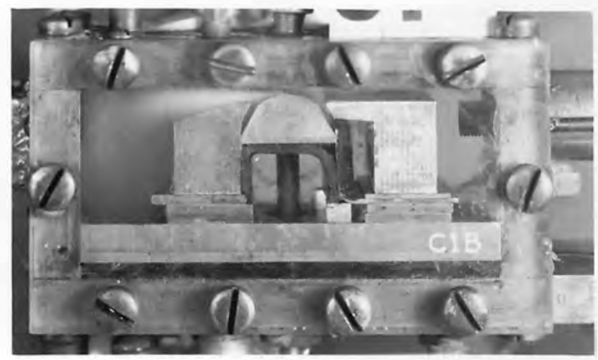
$$U_1 = U_2$$



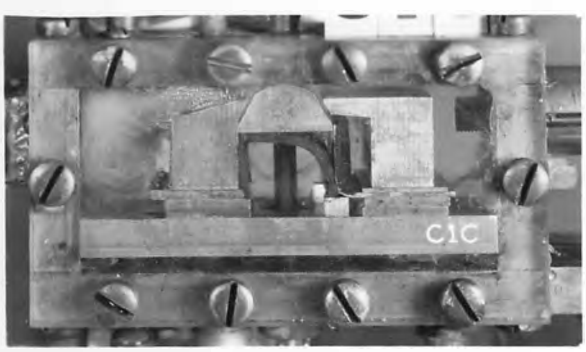
A-Half-round bar C, chamfered at 30° to give more extension. Rubber of 1/8-inch flat stock and about 60 durometer hardness. Plunger as guide connected with No. 8-32 machine screw. No pressures applied.



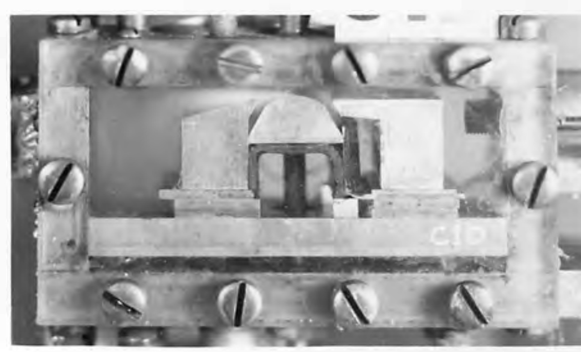
B.Sealed at 75 lb. per sq.in. penstock pressure with 46 lb. in chamber B, showing rubber sealing downstream corner at stop bar.



C-Maximum retraction 7/64 inch with 70 lb. pressure in chamber C and vacuum of 10 ft. at A and 13 ft. at D.



D-Sealod at 100 lb. penstock pressure with 66 lb. in chamber B, showing rubber pushed tight in downstream corner of seal and stop bars.



E-Maximum retraction 5/32 inch with 100 lb. pressure in chamber C and zero pressure in chamber B, showing cramped position of rubber.

FLOATING-BAR RETRACTABLE SEAL - DESIGN 2R then

$$V = H.$$

The bar is statically balanced.

If d is less than $\frac{D}{2}$, then $V \times \frac{D}{4}$ is greater than $H \times \frac{d}{2}$ and the rotation will be to the right, or clockwise.

If d is greater than $\frac{D}{2}$, then $V \times \frac{D}{4}$ is less than $H \times \frac{d}{2}$ and the rotation will be to the left, or counterclockwise.

When seating is on the slope of the seat, a point of eccentricity is developed due to the shifting of the point of contact, and the forces become unbalanced so that rotation in either direction may result. This was found to be the case in these tests.

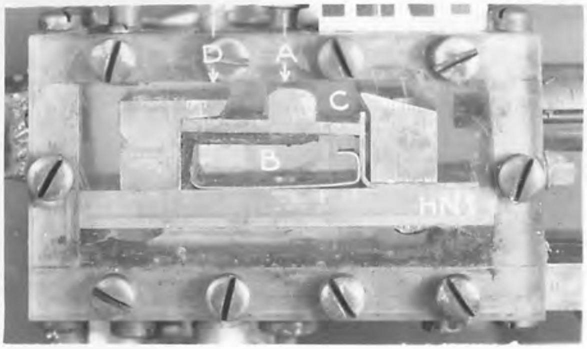
(c) Hinged, sustained retractable seal, design 3R (figure 9D).--This design is similar to design 5C (figure 6I). The seal bar is supported at the hinge by the formed rubber or other material and the hing stay pins. Firm clamping at the hinge is thus eliminated. The wide, flat, vulcanized rubber is only needed to seal the slots if a slotted seal bar is used. A solid seal bar would require only a block of compressible material for support and for effecting a droptight seal at the hinge.

This design depends on the length of the lip upstream from the nose piece for its retractive force. The longer the lip, the greater will be the retractive force. Retraction was generally to the stop, for this design. Sealing was accomplished with 52 pounds in chamber B when the pressure was 75 pounds in chamber C. Release occurred at 48 pounds in B. We may conclude that the sealing pressure will be about two-thirds of the penstock pressure at any head. The longer lip stiffens the seal bar; it may be slotted to permit greater flexibility in the prototype.

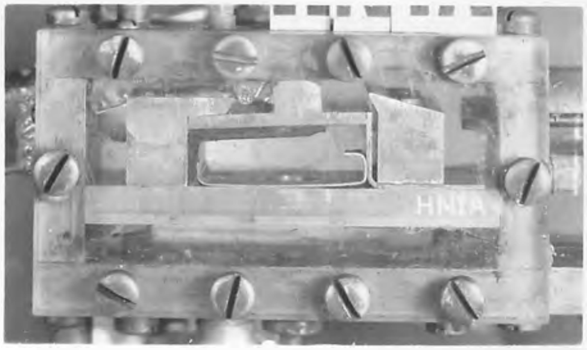
The hinge offers a means of supporting the weight for vertical seals, but stiffness is the result and therefore alinement to the seat is difficult. There was no twist possible in the solid bar at 75 pounds in chambers C and B. In the slotted bar with slots every 1/2 inch, some twisting was possible. It required 75 pounds in chambers B and C to produce 1/64-inch twist. It is concluded, therefore, that the seal bar may not seal well at low heads.

This design is illustrated by the pictures in figures 13A, B, and C. The installation in A shows the bar supported by the formed 1/8-inch thick rubber of about 60 durometer hardness, and the friction of the retraction spring. The thin, 1/2-inch wide stop bar was improvised to hold the lower part of the rubber in place, because the free lip had a tendency to curl away from the stop bar when hydraulic pressure was admitted in chamber B. However, the seal at the hinge was still perfectly maintained when the curling occurred. In picture B the seal bar is sealed against 75 pounds per

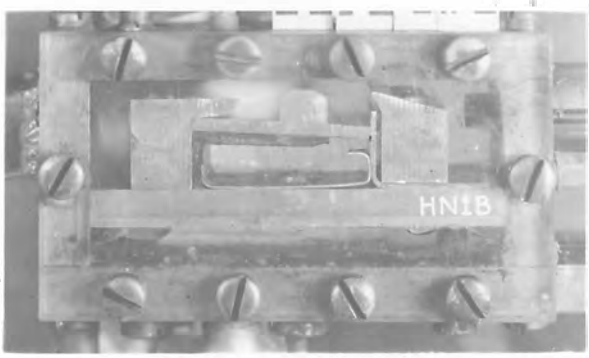
FIGURE 13



A-Assembled with 1/8-inch shaped rubber vulcanized to the stay but not to the downstream stop bar. Thin metal strip inserted holds rubber against stop bar.

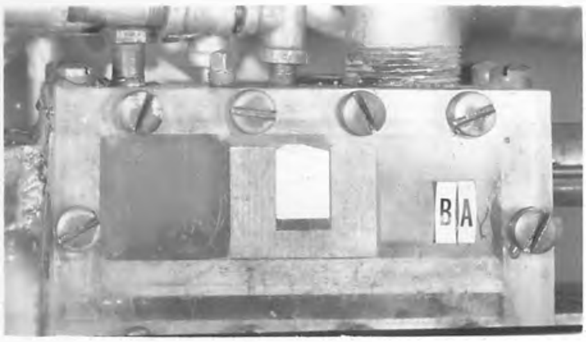


B-Sealed at 75 lb. per sq. in. penstock pressure with 62 lb. in chamber B. Upstream clearance 3/16 inch and downstream clearance 1/4 inch. Retraction spring against lip of seal bar.

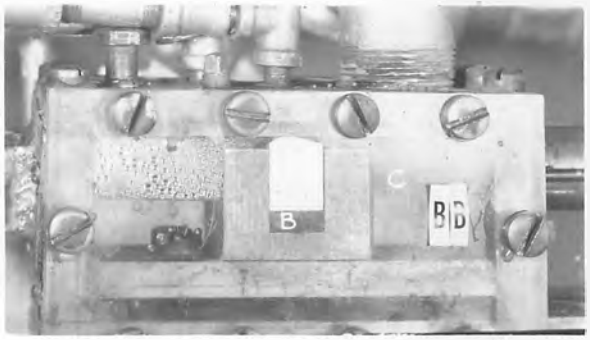


C-Maximum retraction of 1/8 inch with 70 lb. in chamber C and vacuum at D 12 feet of water. White part of picture shows region of high vacuum.

HINGED, SUSTAINED, RETRACTABLE SEAL - DESIGN 3R



D-Sealed at 75 lb. per sq.in. penstock pressure with 55 lb. in chamber B, showing upstream clearance space.



E-Maximum retraction 1/8-inch with pressure in chamber C 60 lb. and vacuum at A 4 ft. of water and at D 15 ft. of water.

SLIDING-BAR RETRACTABLE SEAL - DESIGN 4R
0.020-INCH CLEARANCE IN UPSTREAM CRACK;
3/16-INCH CLEARANCE BETWEEN SLIDE BLOCK
AND SEAT

square inch in chamber C with 52 pounds per square inch in chamber B. The seal broke at 48 pounds per square inch in chamber B. In picture C the conditions at the maximum retraction of 1/8 inch and at 70 pounds per square inch in chamber C are shown. The light portion of the picture shows the region of high vacuum which was 12 feet of water. With a penstock pressure of 110 pounds per square inch the upstream pressure overcame the negative pressure and the bar collapsed to the bottom, bending the stop with its force.

The sealing quality was good when the seal bar was perfectly alined to the seat; otherwise it was poor, because of incomplete seating. The seal bar slammed severely if closed from a position where negative pressures ceased to exist; otherwise the action was good. The retraction spring sealed well when alined closely to the lip. This seal bar was also tested before the longer lip was added, and the retraction obtained was not as great.

(d) Sliding bar retractable seal, design 4R (figure 9F).--The seal bar in this design was fitted into a machined slot block with 0.002-inch clearance. It was therefore well guided as it moved in extension or retraction. Any desired extension is allowable in the design by making the bar greater in depth. This would, of course, make the seal bar stiffer and difficult to bend to any undulations in seating. If the depth is made small, tipping action would result in its operation. The sliding friction along the downstream surfaces in the model was small because of their new, smooth, and water-lubricated condition. The leakage through these sliding surfaces was always considerable except in one case where paraffin grease was used, which stopped most of the leakage.

The quality of the seal depended on the match of the sealing surfaces when they were in contact. It was difficult to install the slot block in a position such that the flat seating surfaces were absolutely parallel. The seal bar was remachined several times to accomplish this end.

In making the retraction, sealing pressure, and action tests, the flat, 3/4-inch wide, original sealing surface of the seal bar was varied in a number of steps by chamfering the edges from 1/16 to 1/2 inch and by changing the sliding clearance of the seal bar in the slot block from 0.002 to 0.022 inch, according to the dimensions given in figure 9E. The seal bar was also tested in the reversed position from that shown for changes 1, 2, and 3. The edges of the seal bar were chamfered to ascertain the retractive forces developed and the sealing pressures required when surfaces of different widths were exposed to the hydraulic pressures acting on them. The changes in sliding clearances effected these conditions.

The tests showed that no retraction can be obtained unless the seal bar is shaped so that penstock pressure can act to tend to force it open. This was done by chamfering the upstream corner.

Good retraction was obtained when the upstream width of the surface exposed to penstock pressure was at least half the width of the seal bar. Then the retractive force is about half of the sealing force, and the unbalanced sealing force is used to effect a seal. The action in sealing was best when the seating surface was narrow and when negative pressures were allowed to act downstream from it. Thus a rounded nose would be better because the exposed surfaces can be made greatest while the sealing surface is narrowest.

Leakage tests to determine the behavior if large clearances occurred, showed that the seal bar might become inoperative due to deposited scale, dirt, etc. They also showed that if too much water leaked into chamber B from chamber C, it would be impossible for the drains to handle it when considering prototype sizes, and the bar would be self-sealing, with no unsealing or retraction possible.

The sealing pressure required was about equal to $\frac{B + F}{L} \times C$ where B, F, and L are the dimensions pertaining to the seal bar and C is the penstock pressure in chamber C (figure 9F). In one case the sealing pressure was 56 pounds per square inch, B was 13/32 inch, F was 3/16 inch, and L was 3/4 inch. By substitution,

$$\frac{B + F}{L} \times C = \frac{0.406 + 0.187}{0.750} \times 75 = 0.78 \times 75 = 58.5 \text{ pounds}$$

per square inch which is too high by about 6.5 percent and shows that full penstock pressure does not exist between the seating surfaces. The breaking pressure is approximately equal to $\frac{B}{L} \times C$, which, in this particular case was 42 pounds per square inch. By substitution, the breaking pressure is found to be

$$\frac{B}{L} \times C = \frac{0.406}{0.750} \times 75 = 0.541 \times 75 = 40.6 \text{ pounds per square}$$

inch, which is 3.3 percent too low. This percentage represents the resisting force of friction along the sliding surfaces and the force assisting retraction due to pressure areas between the seating surfaces, both of which are not readily determined.

The advantages of this design are the well-guided seal bar and the changed conditions that may be brought about between sealing pressure and retractive force by changing the shape of the nose.

The disadvantages are the stiffness of the bar, the leakage along the downstream sliding surfaces, the leakage into chamber B, the close clearances required which would tend to be fouled, and the large sliding surfaces involved. The bars in vertical seals would need to be supported.

As a matter of design in this type of seal, the seal bar could have a

plastic, leather, canvas, gasket material, reclaimed rubber, or even thin, metal sheets. It is believed that the diaphragm need never be thicker than 1/4 inch for rubber. In a vulcanized construction no bolts need pass through any part of the diaphragm, so that canvas enclosed by rubber would, for instance, not be subject to rotting. A molded construction of plastic with suitable characteristics might also be used.

The design in figure 9K is a single-stay, vulcanized construction with no bolts passing through the diaphragm. The design in figure 15 (section A-A) is a similar construction except with a wider seal bar and an off-center nose piece to lower the sealing pressure required. It is shown as a design for a radial-gate installation. The schematic plan of operation is also given there. The two designs further differ in that the base of the former is made of structural steel, whereas, in the latter, a machined

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inch, which is 3.3 percent too low. This percentage represents the resisting force of friction along the sliding surfaces and the force assisting retraction due to pressure areas between the seating surfaces, both of which are not readily determined.

The advantages of this design are the well-guided seal bar and the changed conditions that may be brought about between sealing pressure and retractive force by changing the shape of the nose.

The disadvantages are the stiffness of the bar, the leakage along the downstream sliding surfaces, the leakage into chamber B, the close clearances required which would tend to be fouled, and the large sliding surfaces involved. The bars in vertical seals would need to be supported.

As a matter of design in this type of seal, the seal bar could have a packing insert along the downstream sliding surface and at the nose; the upstream side could be sealed with the retraction spring.

Change 5 (figure 9E) is illustrated in figures 13D and E. In picture D the seal bar is shown pressed against the downstream sliding surface of the slot and the 0.020-inch clearance crack is clearly visible on the upstream side. In picture E the position of the bar is shown at maximum retraction of 1/8 inch with 60 pounds per square inch in chamber C, while the vacuum pressures at A and D were 4 and 15 feet of water, respectively. The pressure in chamber B was zero. The clearance was 3/16 inch.

The description and results of at least 10 of the tests performed will be stated. Tests with the seal bar in the reversed position from that shown in the drawing and in the plot of dimensions (figures 9E and F) will first be given.

For change 1 reversed, with no upstream chamfer, and for change 2 reversed, with the 1/16-inch upstream chamfer, there was no retraction obtained, even with heads up to 110 pounds per square inch in chamber C and with pressure in chamber B zero. While no sealing pressure was required to hold the bar in the sealed position, some pressure was required to close any initial gap opening because of positive pressures that develop between the flat seating surfaces.

In change 3 reversed, with the 1/8-inch chamfer upstream, the seal was barely cracked open at 75 pounds per square inch in chamber C. It required a pull of 5 pounds on the lever or a force of 35 pounds on the seal bar to retract it as much as 1/8 inch. The sealing action was always with a slam. Negative pressures up to 22 feet of water were attained along the downstream slope of the seal bar nose.

For change 1 (normal position), with the 1/2-inch chamfer upstream and no downstream chamfer, retraction was to the bottom of the groove. Negative pressures at the nose of the bar were too small to sustain it. The clearance in this test arrangement was only 1/32 inch and therefore was a contributing factor in building up positive pressure at the nose of the seal bar to force it to retract. Sealing and breaking pressures in chamber B for 75 pounds per square inch in chamber C were 56 and 50 pounds per square inch, respectively. Sealing pressure required was a little greater than stated, just before a seal was effected, because of the positive pressures existing between the 1/4-inch wide seating surfaces.

For change 2, with a 1/16-inch chamfer downstream and the clearance increased to 3/16 inch, the results were practically the same as for change 1.

In change 3, with the same 1/2-inch chamfer upstream, a 1/8-inch chamfer downstream, and a 1/8-inch wide seating surface, retraction of 5/32 inch was obtained with a rapid action to a floating position of the seal bar. The pressure at A was 6 pounds per square inch and the vacuum at D was 17 feet of water. Sealing and breaking pressures in chamber B were 57 and 47 pounds per square inch, respectively, at a penstock pressure of 75 pounds per square inch. If the bar was hand-retracted so that a gap equal to the clearance existed, then the negative pressure at the balance point changed to positive pressure instantaneously, and the seal bar was forced to the bottom of the slot. Upon admitting water pressure in chamber B, the seal bar rose suddenly until a point of balance was reached at a gap of 5/32 inch, and then the continued closure was smooth if the valve to chamber B was opened slowly; otherwise a slam was produced.

In change 4 the upstream chamfer width B was decreased to 13/32 inch, the seat width increased to 3/16 inch, and the downstream chamfer width increased to 5/32 inch. For 75-pounds-per-square-inch penstock pressure the maximum retraction was 5/32 inch; then the pressure in chamber C dropped to 60 pounds per square inch from the penstock flow at about 75 pounds per square inch. The pressure at A was zero and the vacuum at D was 10 feet of water. Maximum vacuum occurred at a gap opening of 9/64 inch with a pressure of 60 pounds per square inch in chamber C, and was 15 feet of water at D while the pressure at A was 4 pounds per square inch. The pressure necessary in chamber B to sustain the bar at this point was 5 pounds per square inch. Sealing and breaking pressures were 56 and 42 pounds per square inch, respectively.

In change 5 the clearance space was increased from that in the previous tests by 0.005 inch. A new seal bar was machined. In the initial tests the bar tilted counterclockwise, but upon remachining and realining the seal bar it remained in a vertical position but pushed downstream when sealed against penstock pressure. There was increased leakage to chamber B. The sealing and breaking pressures were 47 and 40 pounds per square inch, respectively, which are lower than for change 4, probably because the drain size from chamber B was too small to relieve the increased leakage and the gage being in the pipe outside, it did not register true pressure. The controlling drain size up to this point was as shown in figure 6L and was an 11/32-inch hole made for a future packing gland through the slot block, and a 9/16-inch hole through the base plate. With the plunger connected in place, the opening was further restricted. The retraction action was sluggish and amounted only to 1/32 inch unless a slight downward pull was applied on the seal bar by the plunger and lever.

In change 6 the clearance was further increased to 0.010 inch by machining 0.005 inch from the upstream surface of the seal bar. The leakage now filled the 3/4-inch drain pipe when 75-pounds-per-square-inch penstock pressure was applied in chamber C. It was seen that the drain holes were too small; so both were redrilled to 3/4-inch diameter as shown in figure 9F.

The seal bar was remachined according to change 7 before further tests were made. This change involved an increased upstream clearance to 0.020 inch by further machining 0.010 inch from the upstream surface of the seal bar. The maximum retraction was 1/8 inch with 60 pounds per square inch in chamber C; the vacuum pressures at A and D were 4 and 15 feet of water, respectively. The sealing and breaking pressures in chamber B were 55 and 47 pounds per square inch, respectively. The leakage through the upstream slot produced a full 3/4-inch drain-pipe flow. The bar was pressed against the downstream surface of the slot. It could be slammed shut by opening the valve to chamber B rapidly.

(e) Hinged, flexible, retractable seal, design 5R (figure 9G).--The seal bar and frame in this test arrangement had been tested as the hinged, flexible, constant-contact seal, design 4C, figure 6H described in section 6(d), and were adapted to this retractable design by adding the retraction spring. The original stop bar was used as the spring in initial tests. The flexible slotted stay and the light, flexible nose piece are the outstanding features of this design. It has been shown in the description of tests on the hinged bar-seal designs how the hinge increases the stiffness of the bar so that the ability to aline itself to the seat was greatly frustrated. The slotted, flexible stay provides for ease of alinement and the light, flexible nose piece makes for ease in bending to conform to undulations either in the seal bar or the seat.

The slotted stay of 3/32-inch steel plate had a sheet of 1/4-inch rubber vulcanized to it. The rubber or other material is necessary to seal the slots. Furthermore, the clamped rubber at the hinge provided a sufficient support for the seal bar and yet permitted easy and great extension or retraction. The seal bar, as designed, closed a gap of 7/16-inch with two pounds per square inch in chamber B, which shows that the rubber extruded in clamping does not produce dilatory action.

The maximum retraction was 3/32 inch at 66 pounds per square inch in chamber C and the vacuum at D was 12 feet of water. Greater retraction could be obtained by extending the lip. The action in retraction was quick and was the same relative amount along the sloped portion of the sliding seat; hence a longer lip is not necessary.

Sealing action was greatly influenced by the downstream clearance and sizes of water passages to the drain, for with these too small, positive pressures developed over the stay. The original clamp bar was cut away to relieve the water pressure on the stay. When this was done, the clamp bar tipped downstream at the higher heads for want of support; so a narrow block was inserted behind it to prevent this tendency. The picture in figure 14E shows the restraining block in place, also the stop bar used as a retraction spring with the seal bar at maximum retraction. Negative pressures now existed over the stay. The upstream stop bar was notched to permit full and direct hydraulic pressure to act on the lip. This aided retraction. Sealing was accomplished with 43 pounds per square inch in chamber B against a head of 75 pounds per square inch in chamber C. Thus the sealing pressure is about 9/16 of the head over the whole range.

The advantages of the design are the vulcanized and slotted construction of the stay which impart the good features of support, simplicity, flexibility, and large movement to the seal bar. The material required is a minimum. By using double-stay construction, vulcanizing would be eliminated. The disadvantage in the single-stay construction is the vulcanization process itself. This design is not applicable to circular seals. A proposed installation is shown in figure 9J as a vertical seal for the 15- by 29.65-foot penstock coaster gate for Grand Coulee Dam, in which structural steel is used to advantage.

(f) Stabilized, flexible-diaphragm seal, design 6R (figure 9H).--This design was developed and tested in the first series of gate seal designs and tests, the results of which are given in figure 4E and in section (e) of the summary. The model assembly with the narrow diaphragm was retested under the new conditions of greater volume of water flow and higher maintained pressures with their resultant higher velocities. Under these conditions, more nearly like those in a field installation, the seal bar responded more rapidly and sometimes violently to pressure changes which made its control more delicate and difficult.

The underlying principles of the design are pure hydraulic operation of the seal bar in extension or retraction, together with the least possible inherent friction or restraint by the parts. The seal consists of a rather thin, flat diaphragm supported by hinged upstream and downstream slotted stays of minimum thickness enclosing a sealing chamber underneath. A nose piece, also of minimum dimensions and located at the central hinge, is either attached to or is a part of one of the stays. This diaphragm assembly is termed the seal bar. The outer hinges are located near the edges of the clamped diaphragm and are retained by the clamp bars. Retraction is produced by the positive head on the upstream stay and the upstream portion of the nose piece simultaneously with relief of pressure in the sealing chamber. Sealing is produced by admitting pressure in the sealing chamber, either from the penstock supply or reservoir heads, which acts on both stays to extend the seal bar and close the gap. The sealing pressure required at any head varies with the relative widths of the stays; so that within design limits the ratio of sealing pressure to the head may be varied. In the plot in figure 4E these relationships are given, where sealing pressure is plotted versus the ratio of the width of the upstream stay to the width of outer hinges. It is seen that if the upstream stay is relatively narrow, the ratio is small and the sealing pressure required will be comparatively low. A greater reserve of pressure will then be available to press every part of the nose piece against the seat and tend to accomplish a continuous line of contact. The more nearly a line contact is obtained, the better will be the quality of the seal with respect to leakage, as found from tests. For narrower upstream stays the retractive force is also lessened, but this force would be great enough to retract the seal bar for any operative design.

The design of the seal unit was made with a view toward eliminating the process of vulcanization and much fine machining in the field installation.

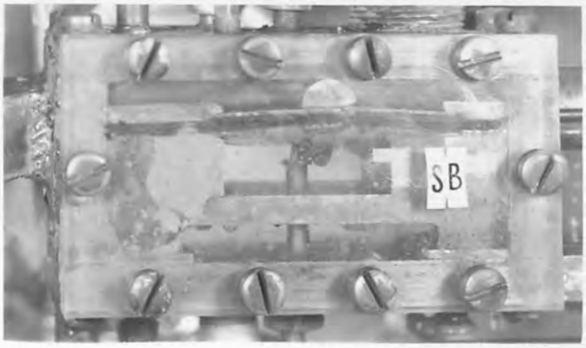
Since tolerances may be large, the flat stays may be sheared. The hinge construction may be made with standard steel shapes and a minimum of machining (figure 9K). In the original model design it was required that the sealing pressure should be low and that a large extension be attained; therefore the stays were wide. The stays were designed to support pressures which might be encountered in the operation of a radial gate. In the present model the original base was adapted for a narrower diaphragm and narrower stays, with a centrally located nose piece. In the tests, the thin stays easily withstood operating pressures of 70 pounds per square inch, and even pressures of 110 pounds per square inch did not greatly bend them.

The top and bottom stays were 1/16-inch, half-hard, slotted brass plates enclosing a 1/8-inch, 65 durometer rubber diaphragm. The nose piece, of standard 3/4-inch, half-round brass, formed the upper part of the central hinge with its overhanging edge and served as a clamp to which the several parts were bolted, thus making a watertight joint between the rubber, the stay, and the seal bar. Spacer bushings were used through the diaphragm. The end clearance at each hinge was 1/32 inch and an extension of 1/2 inch at the nose piece was easily obtained. The clamp bars at the outer edges of the diaphragm were tightened directly on the rubber so that diaphragms of varying thicknesses could be tested. In the present tests the 1/8-inch diaphragm shown was made of two 1/16-inch rubber sheets. No extrusion through the 1/32-inch slots in the stays was noticeable. The extruded rubber at the hinges did not hinder their flexible action as is proven by the fact that only one- or two-pounds-per-square-inch pressure extended or retracted the seal bar. Included in this measure of resistance was the end friction of the seal bar against the Lucite sides of the model box.

Other types of construction for this seal design may be employed, but the principles of operation and good characteristics of this design should be kept in mind. Several methods of construction may be mentioned. If the nose piece is made integral with its stay, the number of separate parts is decreased, thus aiding the work when making the assembly. In the double-stay design any suitable or available material could be used, such as plastic, leather, canvas, gasket material, reclaimed rubber, or even thin, metal sheets. It is believed that the diaphragm need never be thicker than 1/4 inch for rubber. In a vulcanized construction no bolts need pass through any part of the diaphragm, so that canvas enclosed by rubber would, for instance, not be subject to rotting. A molded construction of plastic with suitable characteristics might also be used.

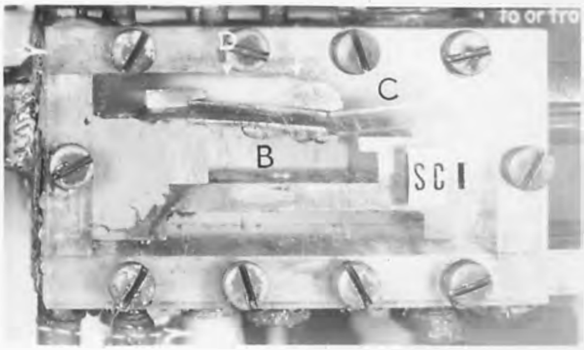
The design in figure 9K is a single-stay, vulcanized construction with no bolts passing through the diaphragm. The design in figure 15 (section A-A) is a similar construction except with a wider seal bar and an off-center nose piece to lower the sealing pressure required. It is shown as a design for a radial-gate installation. The schematic plan of operation is also given there. The two designs further differ in that the base of the former is made of structural steel, whereas, in the latter, a machined

A-Initial test arrangement with 5/16-inch clearance. Sealed at 75 lb. per sq.in. penstock pressure with 45 lb. in chamber B, showing bending of stays with 75 lb. in chamber B.



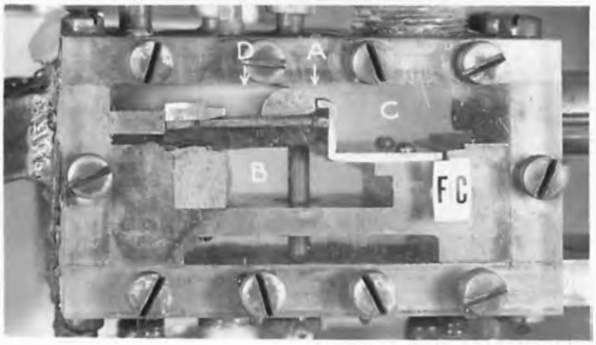
B-Sealed at 19 lb. per sq.in. in chamber C with 12 lb. in chamber B, showing stays nearly returned to flat condition and with 19 lb. in chamber B.

C-Maximum retraction 5/16 inch to the stop with pressure in chambers C 58 lb., in A 45 lb., and in D 42 lb. Maximum vacuum occurred at a gap of 5/32 inch and was 14 ft. and 12 ft. of water at A and at D, respectively.



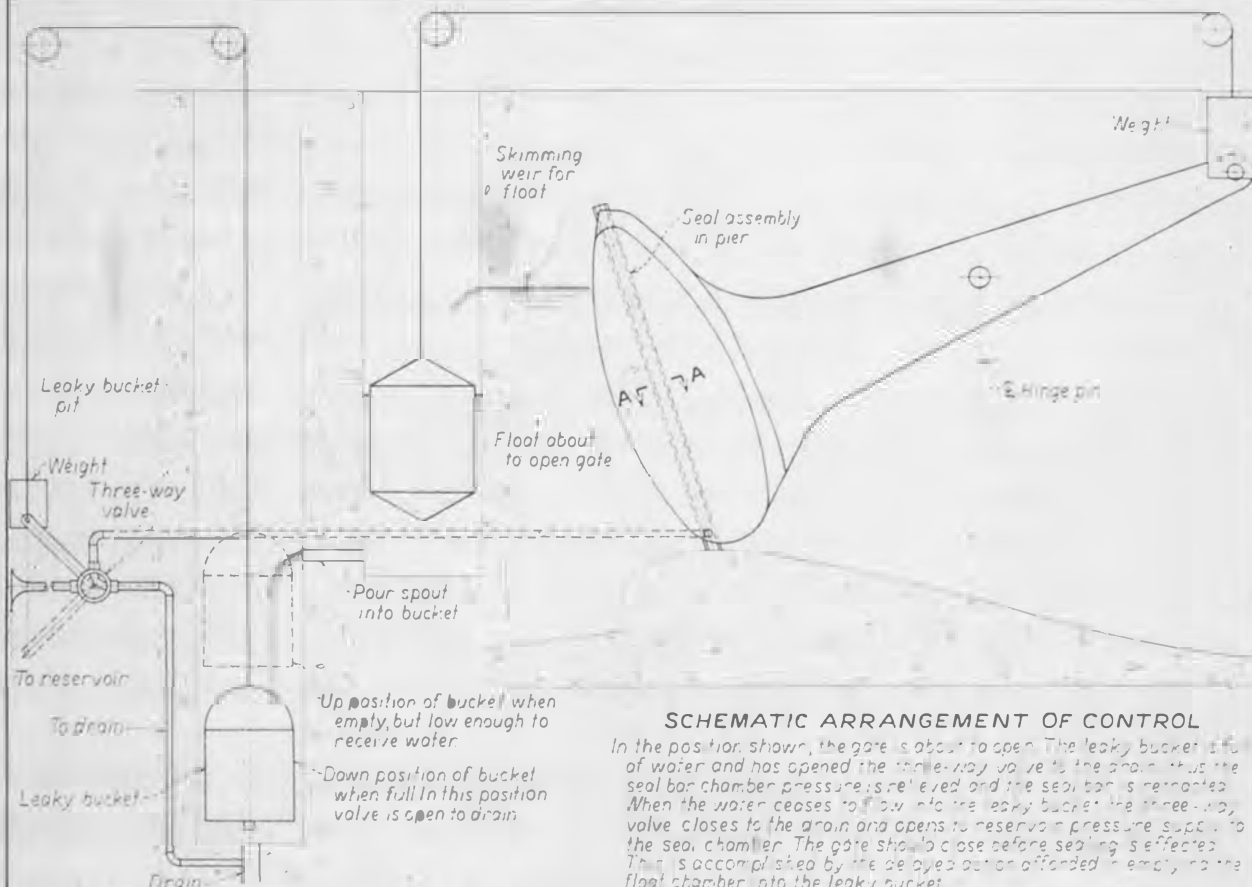
D-Final test arrangement with clamp bar cut away, and slot cut in the frame and in the rubber for greater water passage. For clearance and gap of 1/4 inch, pressure in chamber D was 17 lb., and with a clearance and gap of 7/16 inch, pressure in D was 30 lb. with C 60 lb.

STABLIZED, FLEXIBLE DIAPHRAGM SEAL - DESIGN 6R
1/8-INCH RUBBER NOT VULCANIZED, WITH DOUBLE-STAY CONSTRUCTION



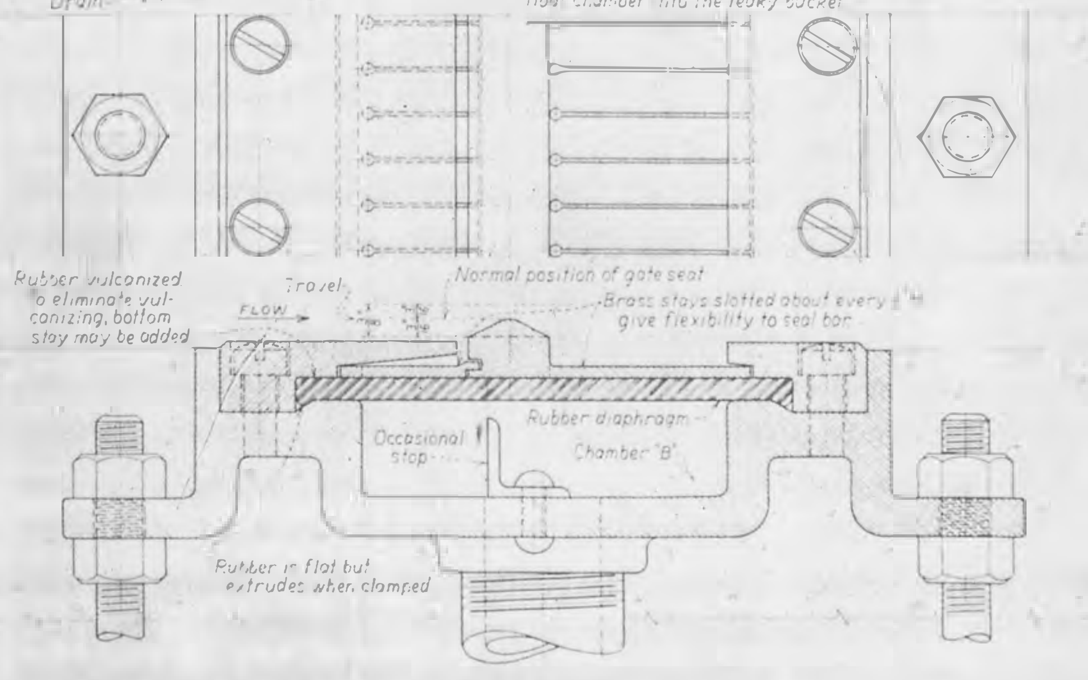
E-Maximum retraction 3/32 inch with 66 lb. per sq.in. in chamber C and 12 ft. of water vacuum in chamber D. Clamp bar is supported in rear by narrow blocks. Upstream stop bar is used as retraction spring in initial tests - plunger is used only as a lower stop. Seal bar collapsed at a penstock pressure of 110 lb.

HINGED, FLEXIBLE, RETRACTABLE SEAL - DESIGN 5R



SCHEMATIC ARRANGEMENT OF CONTROL

In the position shown, the gate is about to open. The leaky bucket [illegible] of water and has opened the three-way valve to the drain [illegible] the seal bar chamber pressure is relieved and the seal bar is retracted. When the water ceases to flow into the leaky bucket the three-way valve closes to the drain and opens to reservoir pressure supply to the seal chamber. The gate should close before sealing is effected. This is accomplished by the delayed action afforded in emptying the float chamber into the leaky bucket.



SEAL DETAIL

SECTION A-A FULL SIZE

Th[illegible] seal design at 10" of head should seal with about 6" [illegible] according to previous test data [illegible] in the same [illegible] at any head. Retraction is accomplished by the head pressure on the upstream stay when pressure in chamber "B" is released.

GATE SEAL DESIGNS AND TESTS

RADIAL GATE INSTALLATION AND DETAIL OF STABILIZED FLEXIBLE DIAPHRAGM SEAL

casting is used for the base. The principle of operation is the same for both.

In the model tests, with the new conditions of greater water volumes, velocities, and pressures, the former smooth operation of the seal bar ceased and a new problem for solution developed. This development was a serious slamming of the seal bar in the sealing operation. The problem was solved by increasing the downstream clearance area and drain size to accommodate the increased discharge through the gap and permit only negative pressures to exist over the downstream stay in chamber D. In the initial tests, at maximum retraction of 5/16 inch and maximum available penstock flow at 75 pounds per square inch, the pressures on the downstream stay attained a magnitude of 45 pounds per square inch while the pressure in chamber C dropped to only 58 pounds per square inch. This was a bad situation, for, as explained previously, when an attempt was made to close the gap by admitting pressure in chamber B, a point of balance was reached where the positive pressures in chamber D ceased and negative pressures commenced; then the seal bar slammed closed. These conditions were accentuated in this design above other designs because of the wider seal bar employed. The initial seal assembly for this test is shown in figure 14A when a clearance of 5/16 inch was set up. It is seen how the downstream clamp bar partially closed the slot to the drain. The bent position of the downstream upper stay is also shown when a pressure of 75 pounds per square inch in chambers C and B was applied. Sealing and breaking pressures were 44 and 43 pounds per square inch, respectively. The proximity of these pressures, which is a measure of the sensitivity of the action, shows that the response to pressure changes is almost immediate. In figure 14B the seal bar is sealed at a pressure of 19 pounds per square inch in chamber C, with a pressure of 12 pounds per square inch in chamber B. It is seen that the stays have almost returned to their original flat condition. Breaking pressure was also 12 pounds per square inch. The maximum vacuum occurred at a gap of 5/32 inch and was 14 feet of water at A and 12 feet of water at D, while the pressure in chamber C was 60 pounds per square inch. The pressure necessary to sustain the seal bar in this position was 17 pounds per square inch in chamber B, and this relatively high pressure is a measure of the retractive force. The sealing pressure as shown by the two cases cited is therefore about 0.6 of the head over the entire range.

In tests after the drain size was increased in area (figure 9H), the pressure in chamber D dropped from 45 to 23 pounds per square inch and the pressure in chamber C dropped from 58 to 50 pounds per square inch. The relative reduction of pressure in chamber D is thus estimated to be at least 14 pounds per square inch. The test assembly is illustrated in figure 14D, which shows the downstream clamp bar cut away. The rubber diaphragm was also partly cut away and the end of the base had a tapered slot machined in it. The slamming action of the seal in sealing was now greatly reduced. This shows that if the water passage were ample, the seal bar would operate smoothly under any head. For clearances of 1/4 and 7/16 inch, each at maximum retraction, the pressures in D were 17 and 30 pounds per square inch, respectively, while pressure in chamber C was 60 pounds per square inch for both cases. This shows that the drain size more nearly accommodated the smaller gap flow. The other conditions were practically unchanged. In figure 14D the conditions at maximum negative pressures are shown for a clearance of 1/4 inch. The white portion of the picture in chamber D clearly shows the region of high negative pressures when a gap of about 9/64 inch is allowed and the pressure in chamber C was 60 pounds per square inch.

In the installation drawing of this design, as a vertical seal for the 15- by 29.65-foot penstock coaster gate for Grand Coulee Dam (figure 9K), it is seen that the downstream water passage between the clamp bar and seat is ample so that no positive pressures would exist on the downstream stay. The action of the seal bar then would be smooth and without any slamming.

The advantages in this design are several. The seal will operate with great freedom under any head. It may be designed for circular as well as rectangular gates. The seal bar, of minimum required dimensions, is amply supported at the hinges, is flexible, light in weight, and the nose piece is stable in rotation or position. It encloses an ample, watertight sealing chamber, is easily and forcibly retracted under the smallest as well as the largest heads, and is extended just as easily through as great a movement as the design will allow. The ratio of sealing pressure to head may be varied within design limits, and, for a particular design, remains practically constant for any head or for any gap opening. The action may not be fouled or retarded easily. The selection of materials from which the diaphragm could be made is especially large, and even the selection of materials from which the seal unit could be made is large. The diaphragm need only be flat stock material and does not require an expensive mold. Ordinary rubber cementing would be sufficiently strong for joints. The corner construction and action would be good.

The disadvantage of the double-stay design is that some difficulty might be experienced in assembling the parts. In a vulcanized construction, the process itself is the disadvantage.

(g) Music-note retractable seal, design 7R (figure 9I).--When the music-note constant-contact seal was again proposed for the rectangular gates, it was first tried without any brass reinforcing. It has been used in this manner as end seals for radial gates at lower heads. The distortion produced in the rubber, when used in this manner, is shown by the pictures in figures 7A and B. The rubber was pushed into the clearance space and badly distorted at high heads. It was readily seen that this condition would be unsatisfactory. Next, an unvulcanized metal sheath around the rubber was proposed. The sheath was made by cutting a 1-1/4-inch slot out of 1-3/4-inch outside diameter by 1/16-inch wall brass tube and applied by forcing it over the note. The note was compressed and water lubricated in this operation. The assembly in the seal worked well, as is seen in the pictures in figure 16 which shows the sheath before too much manipulation in testing changed its shape or rotated it as is seen in the pictures in figure 17.

In making the first assembly with the sheathed rubber note, the retraction spring was added to make the seal bar retractable. This arrangement is shown by the pictures in figures 16A and B where the base has no space for retraction of the seal bar and there is no upstream stop bar. The initial tests showed the possibilities of the design and the development of this seal as the acceptable design followed.

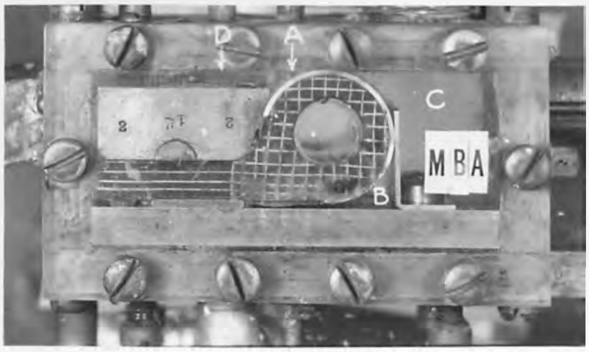
In the assembled seal unit, spacer bushings were used around the bolts passing through the rubber so that the clamp bar could be pulled tight. Without them too much extrusion of the rubber resulted. The 9/16-inch-thick rubber hinge was stiff and caused sluggish or dilatory action of the seal bar. If the nose piece was assembled so that it was snug against the clamp-bar stop and not against the seat, it was difficult to extend the seal bar because then the rubber hinge was forced to stretch. If the assembly was made so that the nose piece was in firm contact with the seat, then retraction was made more difficult because the hinge resisted further retraction. Therefore, if an initial gap is allowed in the installation, this seal design would not operate at low heads and if there is compression against the seat, retraction is hindered. The metal sheath made the seal bar stiff, and the sealing quality was fair. In a field installation the quality of the seal would depend on the straightness and smoothness of the sheath after it is applied. With the vulcanized, brass, reinforced construction for the music-note constant-contact seal bars, the bars were crooked and had undulations which would make alinement to the seat difficult. A similar condition might prevail in the sheathed bar because of the varying diameter of the rubber or because of undulations produced in the sheath upon its application.

After making the initial assembly with the retraction spring and limited retraction space, more clearance for retraction of the seal bar was provided in a second assembly, as is seen in the pictures in figures 16C, D, E, and F. In this assembly the clamping at the hinge should be noted as extending the full length of the flat part of the rubber. In a third assembly (figures 9I and 17), a 1/8-inch shim was used under the flat portion of the rubber to set the hinge back farther and allow for the possibility of easier and greater retraction of the seal bar. The action of the seal bar was sluggish but without slam, except when the bar was allowed to drop to the bottom of its space, as is shown in the picture in figure 17F. When pressure in chamber B was then applied and the seal bar started to be extended, the nose piece would slam closed.

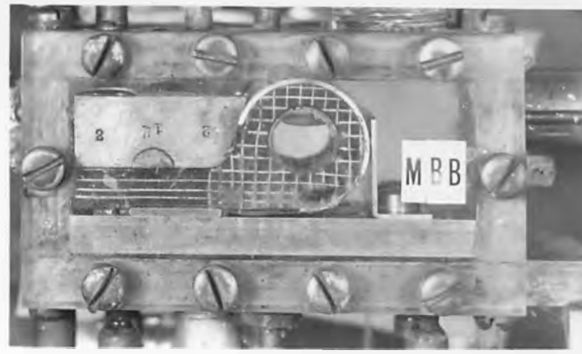
Several conditions in the operation of this design will be stated:

(1) In the first assembly (figures 16A and B) the gap was zero as installed. At 74 pounds per square inch in chamber C, the sealing and breaking pressures in chamber B were 45 and 39 pounds per square inch, respectively.

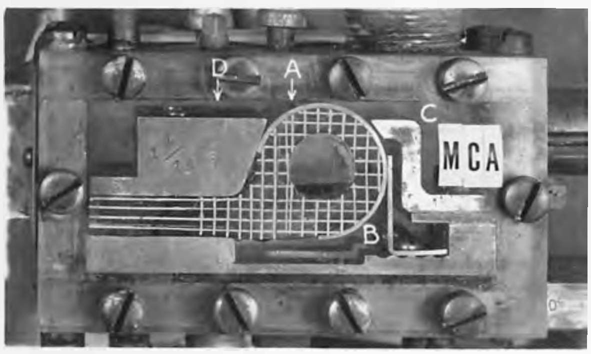
FIGURE 16



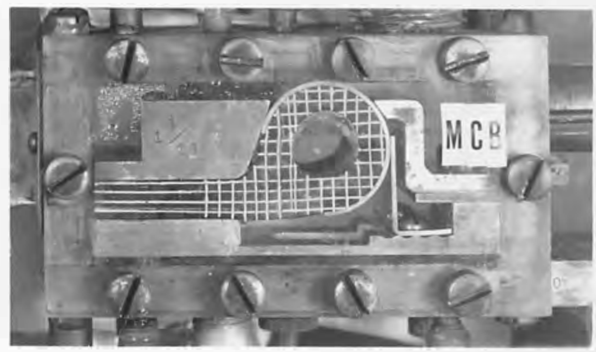
A-Initial assembly with nose of seal bar just touching seat and retraction spring. Brass sheath around rubber not vulcanized.



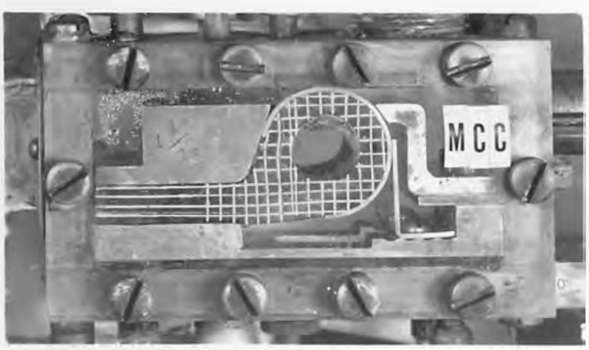
B-Sealed at 75 lb. per sq.in. in chambers C and B, showing the note of the rubber pushed away from the retraction spring. Sealing and breaking pressures were 45 and 39 lb., respectively.



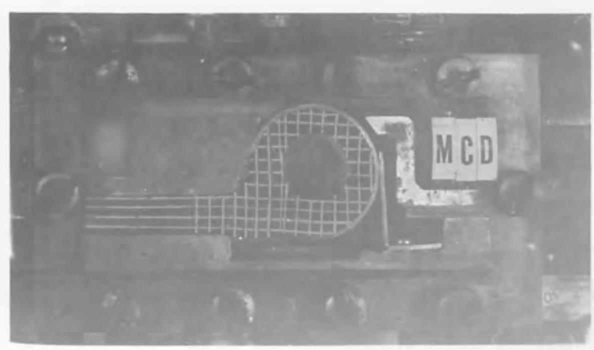
C-Remachined clamp bar and 1/4-inch clearance, base with 3/8-inch space under seal bar, 1/16-inch gap, and retraction spring just touching the note. Upstream stop bar was installed.



D-The 1/16-inch gap closed with 30 lb. per sq.in. in chambers C and B. The retraction spring is still in contact with the note.



E-Deformation of seal bar with 75 lb. in chambers C and B. The sealing and breaking pressures were 57 and 52 lb., respectively.



F-Maximum retraction 9/64 inch with 60-lb. pressure in chamber C and 19-ft. vacuum at A and 12 ft. of water at D. Maximum vacuum occurred at a gap of 1/16 inch and was 25 feet of water.

MUSIC-NOTE RETRACTABLE SEAL DEVELOPMENT DESIGN 7R

(2) In the second assembly (figures 16C, D, E, and F) the gap was 1/16 inch and a 3/8-inch space was provided under the seal bar. It now required 30 pounds per square inch in chambers B and C to close the gap of 1/16 inch. At a penstock pressure of 75 pounds per square inch in chamber C, the sealing and breaking pressures in chamber B were 57 and 52 pounds per square inch, respectively. From the corrected differences in sealing pressures between (1) and (2) the pressure necessary to close the gap is nearly 12 pounds per square inch. The sealing pressure in (1) is 0.608 of the head; hence for (2) it should only be 45.5 instead of 57 pounds per square inch. The difference is 11.5 pounds per square inch. For the head of 30 pounds per square inch, the sealing pressure should have been 18.2 pounds per square inch. The difference of 30 and 18.2 is 11.8, which represents the unit pressure necessary to close the gap. Thus the two cases are in agreement. Retraction was 9/64 inch with pressure in chamber C 60 pounds per square inch and pressure in chamber B zero. The vacuum at A was 19 feet of water and at D, 12 feet of water. Maximum vacuum attained was 25 feet of water when a gap of 1/16 inch was allowed.

(3) In the third assembly (figures 17A to F), the 1/8-inch shim was added at the hinge, but the sealing and breaking pressures were the same as before. Retraction was not particularly improved. At the balance point of the nose piece and with pressure in chamber B zero, the bar would drop slowly and finally, in about one minute, would collapse to the bottom of the space or to the stop, as is shown in figure 17F. Hence, so far as greater retraction is concerned, placing the hinge farther back does not aid it. The negative pressures in chambers A and D still hold the bar in the same position as for (2) above, where the 1/8-inch shim was not used.

The final design, as shown in the installation drawing (figure 9L), has booster pump springs added which consist of a horizontal 1/16-inch spring and a thin 0.003-inch shim stock closure spring. In the model, design 7R (figure 9I), these parts are shown dotted and were tested accordingly. The reason for these additions is that in the field installation, balanced pressures may be experienced when operation is initially desired, due to a bulkhead closure in the penstock below the gate. It was anticipated that the pressure downstream from the gate could not be relieved sufficiently through the 6-inch valve in the bulkhead to permit a differential of 12 pounds per square inch between chambers C and D to exist. In that case the initial sealing of the seal bar could not be performed with available penstock pressure in chamber B. Thus the booster pump springs will be installed, and at some later convenient time will be removed.

Tests to simulate the bulkhead closure conditions were made when the drain to the model was closed with a plate, 3/4-inch piping, and valve. The tests are demonstrated by the pictures in figures 17A to F. The tests showed that a pressure differential of at least 11 pounds per square inch between chambers C and D on the one hand, and chamber B on the other, was

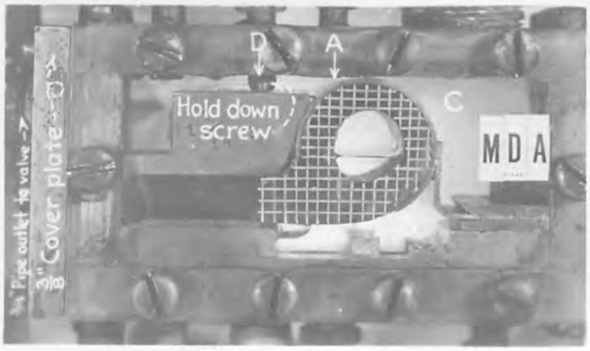
Neither will the retraction spring operate on a circular gate. The floating types would not need to twist and would operate similarly to a piston ring.

The diaphragm type of seal has already been tried in various fashions (figure 4A), but without the stays it is more or less inoperative. With the stays it becomes stable, operative, and extensible or retractable at any head. When the diaphragm is made very thick with respect to its width and stays are added, the design becomes the shear seal (figure 4D). Here again, while the rubber is stabilized, the stays are short and consequently stiff, alinement is difficult, and the seal is inoperative at low heads.

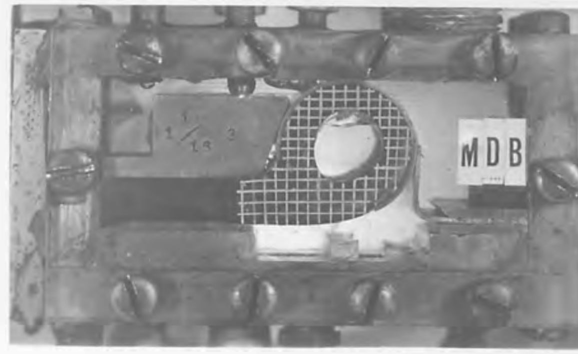
9. Recommendations. A design of seal should be developed that may, with slight changes, be used on any type of gate - rectangular, circular, low-head, or high-head. It is felt that variations of the stabilized, flexible, diaphragm seal (figure 9, design 6R), with the retractable feature, could be developed for such universal use. One low-head and one high-head design for rectangular gates and one low-head and one high-head design for circular gates might serve these purposes. A design for circular gates is shown in laboratory report HYD-96 in figure 17, design 4, where the double stays and unvulcanized diaphragm construction are used. Single stays and a vulcanized diaphragm construction may also be employed. For circular gates the seal ring must not be attached rigidly to any stay; otherwise twisting must take place when it extends or retracts.

In a constant-contact seal, either the hinged, flexible seal, design 4C, or the floating bar sustained seal, design 6C, would operate on rectangular gates to good advantage. Design 6C may be used on circular gates also. All constant-contact seals for rectangular gates present a problem in a good corner design, because the top and bottom seal bars move in extension and retraction but the vertical seals do not.

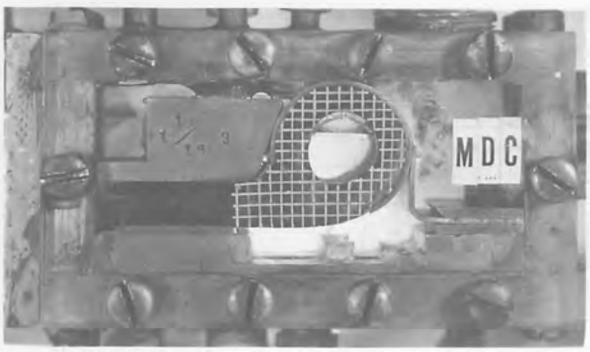
In considering other retractable seals the roller retractable seal, design 1R, with the rubber-covered roller, is highly favorable. The hinged, flexible, retractable seal, design 5R, worked very well also.



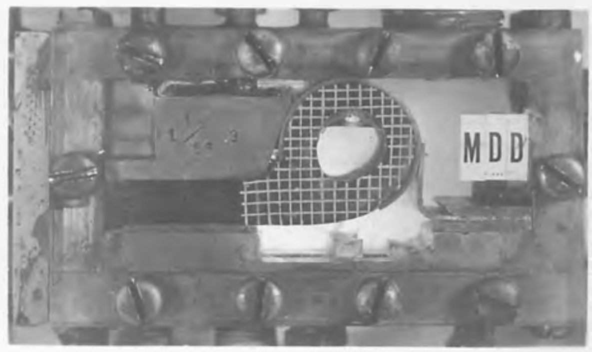
A-Assembled with cover plate and pipe over the drain slot in the end plate of the model box. Clearance was 7/32 inch, gap 1/16 inch, 1/32-inch tension in retraction spring and a 1/8-inch shim under flat of rubber hinge.



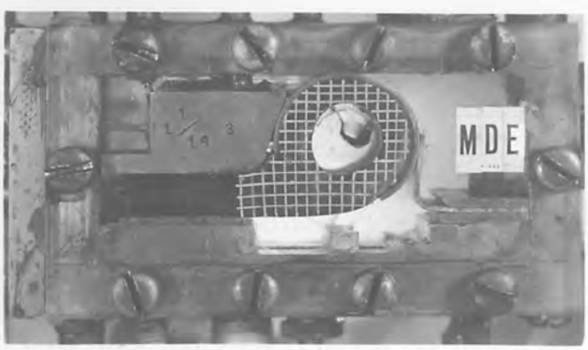
B-Drain valve closed--pressures balanced to close gap--55 lb. per sq.in. in chambers C and D, and 66 lb. in chamber B.



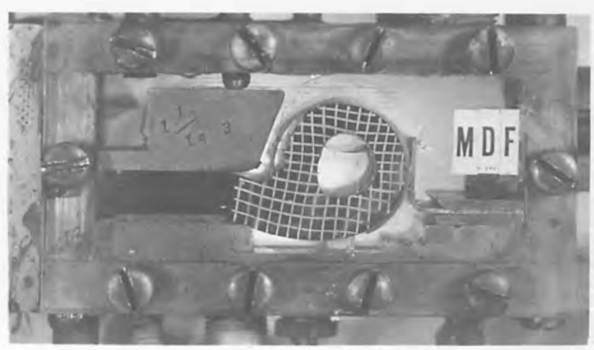
C-Drain valves to chambers C and D open--pressures balanced to close gap--zero in C and D, and 12 lb. in chamber B.



D-Brass shell pulled away from rubber with 26 lb. in chamber B and zero pressure in chambers C and D, and sealed against retraction spring.



E-Brass shell lifted from rubber half-way around note and rotated downstream with 67 lb. in chamber B and zero pressure in chambers C and D. Note is also deformed



F-Seal bar collapsed to the bottom stop when penstock pressure of 75 lb. flowed wide open; pressure in chamber C was reduced to 44 lb., and pressures in chambers A and D were 42 and 38 lb., respectively.

MUSIC-NOTE RETRACTABLE SEAL - DESIGN 7R
SIMULATION TESTS OF SEAL ACTION BEFORE BULKHEAD
IN PENSTOCK, DOWNSTREAM FROM GATE, IS REMOVED.
DRAIN CONTROLLED WITH PLATE, PIPE, AND VALVE

required to close the gap of 1/16 inch. This differential was practically the same whether hydraulic pressure was maintained in chambers C and D or not. Proof of this is seen by the pictures in figures 17B and C, where in B the pressure in chamber B was 66 and in chambers C and D, 55 pounds per square inch, respectively; whereas in C the pressure in chamber B was 12 pounds per square inch with no pressure in chambers C and D. This agrees with (1) and (2) above.

A bad condition resulted when the differential pressure between chambers C and B was greater than 26 pounds per square inch. Then the brass sheath pulled away from the rubber and sealed against the retraction spring. At the same time, the sheath rotated counterclockwise (downstream) on the note. This condition is shown by the pictures in figures 17D and E. In D the sheath started to leave the rubber when a pressure differential of 26 pounds per square inch existed, and in E the sheath has pulled away and rotated counterclockwise when a pressure differential of 67 pounds per square inch was applied.

The final accepted design is shown in the installation drawing for the 15- by 29.65-foot penstock coaster gate for Grand Coulee Dam in figure 9L.

The advantages in this design are the inherent stability of the seal bar and good support provided by the stiff hinge. An upstream stop bar may not be needed because it was so difficult to extend the seal bar when it was against the clamp bar. The dilatory action of the stiff hinge produced a cushioning effect when closing a gap at high heads; thus slamming was minimized. The seal unit appeared sturdy.

The particular advantage in this design is that a limited quantity of the music note molded rubber was already on hand at the dam site. Because rubber is a critical war material, any construction involving its use was not recommended. The metal sheath was to be applied in the field.

The disadvantages of the design are the inherent stiffness of the hinge and the seal bar and the possibility of undulations in the nose piece, all of which tend to make alinement to the seat difficult and sealing quality poor. The seal is not good for low heads and may be inoperative. There is too much excess material used in its manufacture, which adds little to its strength because all the water load, when sealed, is taken by the brass sheath. The seal would not operate on circular gates.

8. Conclusions. There are many mechanical ideas that could be developed into operative seals for gates. Several factors enter into their design, such as whether it is to be a constant-contact or a retractable seal; whether it is for a rectangular or a circular gate; the amount of extension or retraction desired; the operating heads; the available materials; the quality of the seal to be expected; the amount of allowable

misalinement; the structural ease; and the cost. All the seals shown in figures 6 and 9 required a great deal of development and many changes before the particular design operated to best advantage. A design chosen for one set of conditions may not fulfill another set.

The music note constant-contact seal, design 1C, and the music note retractable seal, design 7R, were chosen as the acceptable design because molded rubber was already on hand, operation was satisfactory, and they appeared rugged.

The quality of the seal against water flow between the nose piece and the seat, or between any contacting surfaces, is only dependent on how well the surfaces match and not on the unit contact pressure. Zero-unit contact pressure is all that is required for a ground or a perfect surface to make a droptight seal. Positive pressure is needed only to bring the parts together and to force them in alinement. Line contact only is necessary. Furthermore, if the materials, such as rubber, will compress, pressure will force the material into depressions or undulations which produce perfect line contact and thus effect a perfect seal. For this reason a soft or resilient nose piece is beneficial. A rounded nose piece is preferred. A wider, flat surface may decrease the leakage because of the longer path for water flow and consequent drop in pressure gradient, but, on the other hand, sealing pressures required are increased and line contact is more difficult to attain.

In retractable seals, the seal bar operates best in closing when the nose (sealing edge) does not drop below the level of the top of the clamp bars, and preferably, the nose should be higher by at least 1/32 inch. In this position the seal bar is usually balanced with negative pressures existing just downstream from the nose, while penstock flow and pressure are maintained. The action also depends on the clearance for water passage downstream from the nose piece. Usually the clearance should be as large as practicable so that negative pressures can be maintained at all times.

The pressure required to effect a seal was usually from 5/8 to 2/3 of of the penstock head for all designs tested, in addition to the pressure required to close the gap at zero penstock flow. In the stabilized, flexible, diaphragm seal, design 6R, this ratio may be decreased, but in all other designs it may be impractical, if not impossible.

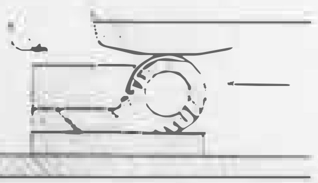
There is always great negative pressure just downstream from the nose piece for the small gap openings, tending to resist retraction of the seal bar. The maximum, negative pressures usually occurred at a gap opening of about 1/16 inch, but these also depended on the clearance, gap opening, drain capacity, and head. With optimum conditions the seal bar always floated at some particular gap opening. The shape of the nose piece affected the negative pressures to some extent, but negative pressures persisted in all shapes tested. Therefore, if the nose piece is in a balanced position, further retraction requires additional retractive force to be applied.

The seal bar should be flexible in order to bend to undulations or misalinement, be these conditions ever so small. A stiff seal bar must fit precisely. A flexible seal bar can be forced to contact the seat with the minimum pressure requirements. The surplus pressure available above sealing pressure required is at best not great; so flexibility is highly advantageous, and the seal bar may be forced to the seat at all points and tend to establish line contact.

The nose piece, or an insert in the nose piece or the seat of a soft material, seats perfectly even with the imperfections in the contact surfaces which slight pressure can overcome. Therefore, the rubber type of nose piece always worked well, provided the rubber was resilient.

The hinged types of seal designs, with one exception, will not operate on a circular gate, but the floating types will. The only exception is the stabilized, flexible, diaphragm seal which is a hinged type that will operate on a circular gate by incorporating a floating seal ring in the design. In the other hinged designs, the seal ring would have to twist when being extended or retracted, which would make the unit inoperative.

FIGURE 18



CHARACTERISTICS-DESIGN 1C-MUSIC NOTE CONSTANT CONTACT (TOP SEALING) SEAL.

EXTENSION-LIMITED BECAUSE OF RESTRICTED SEAL BAR ACTION.

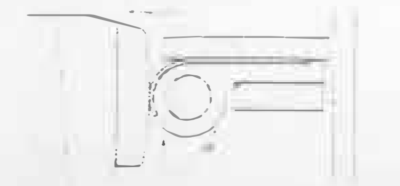
RETRACTION-NONE, UNLESS AN INITIAL GAP IS ALLOWED UPON INSTALLATION, OR AS NOSE PIECE SLIDES UP ON THE SEAT.

SEALING-QUALITY OF SEAL IS FAIR. SEAL BAR IS STIFF AND UNDULATIONS EXISTED IN BRASS STRIP. PRESSURE TO SEAL DEPENDS ON INITIAL GAP ALLOWED UPON INSTALLATION.

OTHER ACTION-THE BRASS NOSE PIECE BENT UNDER HIGHER HEADS.
THE RUBBER ADDED VERY LITTLE STRENGTH. THE HINGE WAS STIFF.

ADVANTAGES-IT APPEARS STURDY. THE RUBBER ACTS AS A HINGE AND SUPPORTS THE SEAL BAR.

DISADVANTAGES-THE ACTION IS STIFF. IT IS BULKY. TOO MUCH UNNECESSARY RUBBER REQUIRED WHICH ADDS NOTHING TO STRENGTH. THE BRASS NOSE PIECE TAKES ALL THE LOAD IN BENDING.
IN ORDER TO INCREASE CONTACT PRESSURE AT THE SEAT, THE SEAL BAR MUST BE LARGER AND MORE BULKY.
THE DESIGN IS INOPERATIVE AS A CIRCULAR SEAL.



CHARACTERISTICS-DESIGN 2C-MUSIC NOTE CONSTANT CONTACT (END SEALING) SEAL.

EXTENSION-PRACTICALLY NO EXTENSION POSSIBLE BECAUSE BRASS STRIP IS STIFF. IF BRASS STRIP IS THIN IT WILL NOT TAKE THE LOAD.

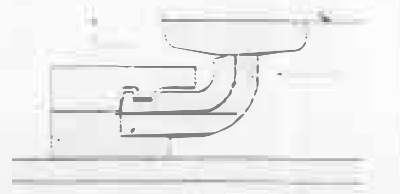
RETRACTION-NONE, UNLESS AN INITIAL GAP IS ALLOWED UPON INSTALLATION, OR AS NOSE PIECE SLIDES UP ON THE SEAT.

SEALING-QUALITY OF SEAL IS POOR. UNDULATIONS EXISTED IN THE BRASS STRIP DUE TO MANUFACTURING DIFFICULTIES.

OTHER ACTION-THE BRASS STRIP BENT WHEN PUSHED AGAINST [illegible] AND PERMANENTLY DEFORMED.

ADVANTAGES-NONE.

DISADVANTAGES-IMPROPER ACTION.



CHARACTERISTICS-DESIGN 3C-HINGED BAR AND RUBBER CONSTANT CONTACT SEAL.

EXTENSION-LIMITED BY LOOSENESS OF CLAMP AT THE HINGE. IF THE HINGE IS TIGHT THERE IS NO EXTENSION POSSIBLE.

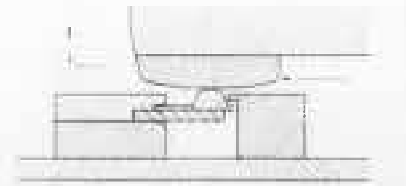
RETRACTION-NONE, EXCEPT AS NOSE PIECE SLIDES UP ON THE SEAT.

SEALING-QUALITY OF SEAL IS EXCELLENT. RUBBER FLOWS INTO UNDULATIONS OF SEAT DUE TO INITIAL AND HYDRAULIC PRESSURE.

OTHER ACTION-WHEN HINGE IS LOOSE, HYDRAULIC PRESSURE PUSHES RUBBER AGAINST DOWNSTREAM CORNER AND SEALS WELL.

ADVANTAGES-RUBBER CONTACT AT SEAT SEALS PERFECTLY. IT IS VERY STURDY AND HEAVY.

DISADVANTAGES-BAR HEAVY AND STIFF AND WILL NOT ALIGN ITSELF TO SEAT. MUCH ACCURATE MACHINING IS REQUIRED.
TOO MUCH UNNECESSARY RUBBER REQUIRED AND VULCANIZED CONSTRUCTION IS DIFFICULT.
LARGE CONTACT SURFACE OF RUBBER MAY CAUSE EXCESSIVE STICKING.
WEIGHT OF BAR FOR VERTICAL SEALS MUST BE SPECIALLY SUPPORTED.



CHARACTERISTICS-DESIGN 4C-HINGED FLEXIBLE CONSTANT CONTACT SEAL.

EXTENSION-SEAL BAR MOVES VERY EASY AND IS ONLY LIMITED BY THE STOPS.

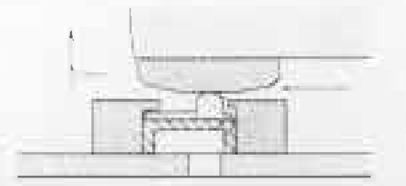
RETRACTION-NONE, EXCEPT AS NOSE PIECE SLIDES UP ON THE SEAT.

SEALING-QUALITY OF SEAL IS GOOD. THE FLEXIBLE SEAL BAR AND NOSE PIECE ENHANCE CONTACT WITH THE SEAT.

OTHER ACTION-EXTRUSION OF RUBBER (OR OTHER MATERIAL) BY CLAMPING AT THE HINGE, IS NOT DETRIMENTAL TO THE EASY ACTION OF THE SEAL BAR.
RUBBER DOES NOT EXTRUDE INTO THE SLOTS.

ADVANTAGES-FLEXIBILITY IS THE OUTSTANDING FEATURE OF THIS DESIGN. IT ALLOWS FOR THE NOSE PIECE TO SEAT UNDER ADVERSE CONDITIONS. CONTACT PRESSURE CAN BE INCREASED BY A LONGER STAY.
MINIMUM AMOUNT OF MATERIAL REQUIRED AND TOLERANCES MAY BE LARGE IN ITS MANUFACTURE.
BAR SUPPORTED BY CLAMPED RUBBER AT HINGE.

DISADVANTAGES-THE SEAL BAR APPEARS LIGHT. THE SLOTS REQUIRE EXTRA LABOR (THESE MAY BE MADE WITH HACK SAW).
VULCANIZED CONSTRUCTION NEEDED FOR SINGLE STAY AND MORE PARTS NECESSARY FOR DOUBLE STAY IF VULCANIZING IS NOT RESORTED TO.



CHARACTERISTICS-DESIGN 5C-HINGED SUSTAINED CONSTANT CONTACT SEAL.

EXTENSION-TO DESIGN LIMITS. AIDED BY SUPPORTING RUBBER OR OTHER SUITABLE MATERIAL.

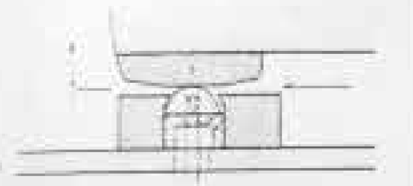
RETRACTION-NONE, EXCEPT AS NOSE PIECE SLIDES UP ON THE SEAT.

SEALING-QUALITY ONLY GOOD IF PERFECTLY ALIGNED. AIDED BY SLOTTED STAY WHICH GIVES FLEXIBILITY TO SEAL BAR.

OTHER ACTION-RUBBER (OR OTHER MATERIAL), UNDER SEAL BAR BENDS OR IS COMPRESSED INITIALLY AS WELL AS WHEN SEAL BAR IS FORCED TO RETRACT. THUS THE ACTION IS MADE MORE OR LESS DIFFICULT.

ADVANTAGES-SEAL BAR IS SUSTAINED BY RUBBER (OR OTHER MATERIAL), WITHOUT CLAMPING AT THE HINGE. VULCANIZED CONSTRUCTION NOT NECESSARY FOR SOLID STAY.

DISADVANTAGES-SEAL BAR TOO STIFF WHEN MADE 3/16" THICK AND NOT VERY FLEXIBLE EVEN WHEN IT IS SLOTTED. FOR THE LATTER CASE VULCANIZING IS NECESSARY.
SPECIAL CONSTRUCTION REQUIRED AT HINGE TO SUPPORT SEAL BAR.



CHARACTERISTICS-DESIGN 6C-FLOATING SUSTAINED CONSTANT CONTACT SEAL.

EXTENSION-TO DESIGN LIMITS. AIDED BY SUPPORTING RUBBER OR OTHER SUITABLE MATERIAL.

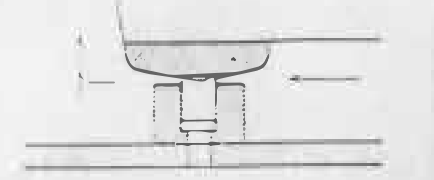
RETRACTION-NONE, EXCEPT AS NOSE PIECE SLIDES UP ON THE SEAT.

SEALING-QUALITY GOOD BECAUSE OF EASY ALIGNMENT OF THE SEAL BAR TO THE SEAT, AND AIDED BY INITIAL COMPRESSION OF THE SUPPORTING RUBBER. THERE WAS NO LEAKAGE AT DOWNSTREAM CONTACTING CORNER.

OTHER ACTION-RETRACTION THEN SLIDING UP ON SEAT, IS MADE MORE DIFFICULT BECAUSE THE RUBBER IS CLAMPED.
IF THE RUBBER IS TOO LIGHT, COCKING ACTION RESULTS UNLESS THE SEAL BAR IS GUIDED. GUIDE STUDS ALSO PROVIDE SUPPORT.

ADVANTAGES-SINCE THERE IS NO HINGE, ALIGNMENT OF NOSE PIECE WITH THE SEAT IS ESPECIALLY EASY. ENLARGING THE BAR INCREASES CONTACT PRESSURE.
FLEXIBILITY OF THE BAR IS ONE FOURTH THAT FOR A TUBE OF THE SAME DIAMETER AND 1/8" WALL.
NO VULCANIZING NECESSARY. TOLERANCES MAY BE LARGE.
THE DESIGN MAY USED ON CIRCULAR GATES.

DISADVANTAGES-SUPPORTING STUDS MAY STICK IN THEIR SLIDES [illegible] COST OF MANUFACTURING.



CHARACTERISTICS-DESIGN 7C-SLIDING BAR CONSTANT CONTACT SEAL.

EXTENSION-STOPS WOULD HAVE TO BE PROVIDED AS THERE IS NO LIMIT TO EXTENSION POSSIBLE.

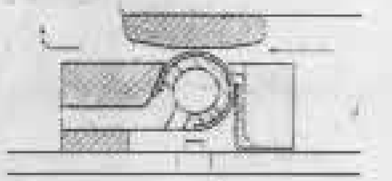
RETRACTION-NONE, EXCEPT AS SEAL BAR SLIDES UP ON SEAT.

SEALING-GOOD IF CONTACT IS GOOD. IT WAS DIFFICULT TO GET SEAL BAR SQUARELY ON SEAT, AND TO SEAL ON BOTH LEGS SIMULTANEOUSLY.
PRESSURE REQUIRED TO SEAL IS NOTHING, ONCE CONTACT IS MADE.

OTHER ACTION-THERE WAS LEAKAGE THROUGH DOWNSTREAM PLAY OF GROOVE; THE JOINT IS DEPENDENT ON SMOOTHNESS AND FIT OF SURFACES.
SEAL BAR SLIDES EASY WHEN NEW.

ADVANTAGES-NO PRESSURE REQUIRED TO SEAL ONCE CONTACT IS MADE SINCE THERE IS NO DOWNWARD FORCE IF SEALING IS ON UPSTREAM CONTACT SURFACE.

DISADVANTAGES-CLOSE CLEARANCES AND MUCH FINE MACHINING NECESSARY. DUE TO DEPTH OF BAR, IT IS STIFF NOT FITTING ITSELF TO THE SEAT EASILY.
SEAL BAR WOULD BE SUBJECT TO FOULING, AND PROBABLY BECOME INOPERATIVE.



CHARACTERISTICS-DESIGN 7R-MUSIC NOTE RETRACTABLE SEAL.

EXTENSION-MOVES WITH DIFFICULTY BECAUSE OF INHERENT STIFFNESS OF THE HINGE AND NOTE.

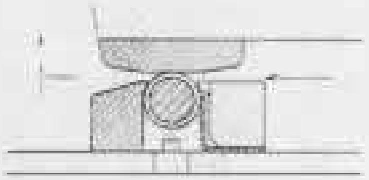
RETRACTION-RETARDED IF THE SEAL BAR IS INSTALLED IN A [illegible] POSITION.
[illegible], RETRACTION WILL BE ABOUT [illegible] SEAL BAR FLOATS.

SEALING-QUALITY DEPENDS ON CONDITION OF SEATING SURFACE AFTER MANUFACTURING THE SHEATH.
PRESSURE TO SEAL DEPENDS ON GAP ALLOWED AT INSTALLATION.
SEALING PRESSURE WAS 5/8 TO 3/4 OF THE HEAD.

OTHER ACTION-IF SEAL BAR IS ALLOWED TO FULLY RETRACT, IT COLLAPSES TO THE BOTTOM OF THE CHAMBER OR TO THE STOP. THIS DISTORTS THE NOTE AND SHEATH, AND CAUSES SLAMMING WHEN SEALING FROM THIS POSITION.
THE TUBULAR SHEATH MAY HAVE SURFACES MORE OR LESS UNDULATING DUE TO MANIPULATION DURING MANUFACTURE.

ADVANTAGES-MUSIC NOTE RUBBER HAS ALREADY MANUFACTURED IN SUFFICIENT QUANTITY TO HANDLE CURRENT NEEDS.
BRASS SHEATH COULD BE MADE AND APPLIED IN THE FIELD.
BRASS SHEATH NOT VULCANIZED, BUT SUSTAINS THE RUBBER NOTE.
IT APPEARS RUGGED AND WORKS WELL.

DISADVANTAGES-SEAL BAR ACTION IS TOO STIFF EXCEPT FOR HIGH HEADS.
TOO MUCH UNNECESSARY RUBBER AND MATERIAL USED IN CONSTRUCTION; SHEATH IS DIFFICULT TO APPLY.
SHEATH MAY ROTATE AS IT IS OPERATED.



CHARACTERISTICS-DESIGN 1R-ROLLER RETRACTABLE SEAL.

EXTENSION-EASILY EXTENDED TO STOPS AND ONLY RETARDED BY FRICTION OF SPRING, BECAUSE SEAL BAR ROLLS.

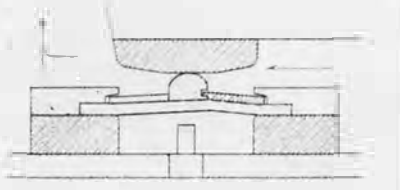
RETRACTION-RETRACTS TO FLOATING POSITION OR TO STOP DEPENDING ON SHAPE OF DOWN STREAM STOP BAR. IF STOP BAR IS SLOPED AT TOP, SEAL BAR USUALLY FLOATS, BUT IF STOP BAR IS FLAT, SEAL BAR IS FORCED TO THE STOP.

SEALING-FOR RUBBER COVERED METAL ROLLER IT WAS EXCELLENT. QUALITY IS GOOD FOR STANDARD ROLLED BRASS.
AIDED BY FREEDOM OF SEAL BAR MOVEMENT, AND EASE OF ALIGNMENT TO SEAT.
SEALING PRESSURE 1/2 TO 5/8 OF THE HEAD.

OTHER ACTION-METAL SEAL BARS COULD BE MADE TO SLAM SHUT BY RAPIDLY ADMITTING PRESSURE UNDER THEM; THE RUBBER COVERED ROLLER COULD NOT BE MADE TO SLAM.
SEAL BAR ROLLS COUNTER-CLOCKWISE (DOWNSTREAM) WHEN MOVING UP OR DOWN ON SEAT.
RETRACTION SPRING VIBRATES IF NOT SNUG AGAINST ROLLER. ROLLER MAY BOUNCE IN FLOATING POSITION WHEN SPRING IS LOOSE; METAL ROLLERS MORE SUBJECT TO THIS ACTION THAN RUBBER COVERED ROLLERS.

ADVANTAGES-ROLLING ACTION MAKES FOR EASE OF EXTENSION OR RETRACTION WHICH IS FAST AND NOT DELAYED.
SEAL BAR ALIGNS ITSELF TO SEAT EASILY.
A RESILIENT RUBBER COVERED ROLLER (SOLID RUBBER OR A SUITABLE PLASTIC MAY BE USED), MAKES A DROP-TIGHT SEAL AND THERE IS NO SLAM UPON SEATING.

DISADVANTAGES-VULCANIZED CONSTRUCTION OF RUBBER COVERED ROLLER IS ESSENTIAL, OTHERWISE RUBBER WOULD TEAR LOOSE.
SEAL BAR SUPPORT FOR VERTICAL SEALS COULD ONLY BE PROVIDED AT THE LOWER END CORNERS.
CORNERS MUST BE PROVIDED WITH ROLLING ACTION POSSIBLE.



CHARACTERISTICS-DESIGN 6R-STABILIZED FLEXIBLE DIAPHRAGM SEAL.

EXTENSION-VERY EASILY EXTENDED TO ANY DESIGN LIMIT, WITH ABOUT ONE POUND PER SQUARE INCH PRESSURE.

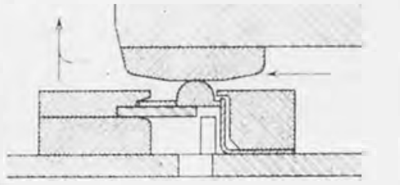
RETRACTION-VERY POSITIVE AND EASILY PERFORMED TO THE STOP WITH PRESSURE AS LOW AS TWO POUNDS PENSTOCK HEAD.
NEGATIVE PRESSURES DOWNSTREAM FROM SEAL BAR ARE LOW, AND DO NOT PERMANENTLY SUSTAIN THE SEAL BAR.

SEALING-QUALITY IS VERY GOOD. SEALING PRESSURES REQUIRED CAN BE CHANGED BY THE DESIGN.
SLOTTED STAYS MAKE ALIGNMENT OF NOSE PIECE TO SEAT EASY. RUBBER EXTRUDED BY CLAMPS HAS NO EFFECT.
SEALING PRESSURE 5/8 OF THE HEAD.

OTHER ACTION-THE CHAMBER UNDER THE SEAL BAR IS PERFECTLY SEALED AT ALL TIMES.
IF WATER PASSAGES ARE MORE OR LESS RESTRICTED DOWNSTREAM FROM NOSE PIECE, SEAL BAR MAY SLAM TO A GREATER OR LESSER DEGREE.
STAYS 1/16" THICK AS CONSTRUCTED WERE SUBJECTED TO 110 POUNDS PRESSURE WITHOUT TROUBLE.

ADVANTAGES-THE SLOTTED FLEXIBLE STAYS ARE FEATURES THAT MAKE SEALING AND RETRACTION POSITIVE FOR ANY HEAD.
IN ITS MANUFACTURE, TOLERANCES MAY BE COARSE; NO VULCANIZING NEEDED IF DOUBLE STAYS ARE USED.
SEAL BAR FULLY SUPPORTED AT [illegible]
CAN BE USED ON RECTANGULAR [illegible]

DISADVANTAGES-SLOTTED STAYS MAKE [illegible] HANDLING, AND IN INSTALLATION [illegible]
VULCANIZATION OR A MOULDED [illegible] PROBLEMS IN MANUFACTURING, BUT [illegible] SIMPLIFY THE NUMBER OF PARTS.



CHARACTERISTICS-DESIGN 5R-HINGED FLEXIBLE RETRACTABLE SEAL.

EXTENSION-MOVES IN CONTACT WITH THE SEAT OR TO THE STOP WITH ABOUT ONE POUND PER SQUARE INCH.
EXTENSION OF 1/2" EASILY OBTAINED AS DESIGNED.

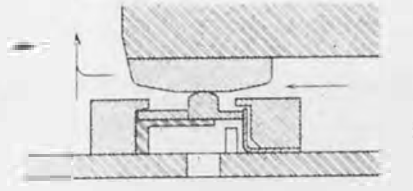
RETRACTION-DEPENDS ON LENGTH OF LIP UPSTREAM FROM NOSE OF SEAL BAR. WITH MINIMUM LIP, RETRACTION IS ABOUT 5/32". LONGER LIP GIVES GREATER RETRACTION.

SEALING-QUALITY VERY GOOD. FLEXIBILITY OF STAY MAKES ALIGNMENT OF NOSE PIECE TO SEAT EASY. LIGHT NOSE PIECE BENDS TO UNDULATIONS READILY.
SEALING PRESSURE 9/16 OF THE HEAD.

OTHER ACTION-SLAMMING DOES NOT TAKE PLACE READILY, AND IS LIGHT WITH THE SHORTER LIP.
RESISTANCE AT HINGE IS NEGLIGIBLE.
EXTRUSION OF CLAMPED RUBBER NOT DETRIMENTAL.

ADVANTAGES-THE SLOTTED FLEXIBLE STAY IS THE OUTSTANDING FEATURE OF THIS DESIGN. THE STAY AND NOSE PIECE ARE LIGHT SO THAT SEATING MAY BE ACCOMPLISHED WITH THE MINIMUM PRESSURE.
STAY AND NOSE PIECE MAY BE MADE IN ONE PIECE AND TOLERANCES NEED NOT BE CLOSE.
FLAT DIAPHRAGM OF RUBBER (OR OTHER MATERIAL), SHOULD NOT BE THICK.

DISADVANTAGES-THE SEAL BAR APPEARS LIGHT.
SOME METHOD MUST BE USED TO SEAL THE SLOTS; EITHER THE DIAPHRAGM IS MADE TO ADHERE TO THE STAY OR ELSE DOUBLE STAYS ARE USED, CLAMPING THE DIAPHRAGM BETWEEN THEM.



CHARACTERISTICS-DESIGN 3R-HINGED SUSTAINED RETRACTABLE SEAL.

EXTENSION-MOVES IN CONTACT WITH THE SEAT OR TO THE STOP EASILY, AND MAY BE ASSISTED BY SHAPE OF SUSTAINING RUBBER (OR OTHER MATERIAL).

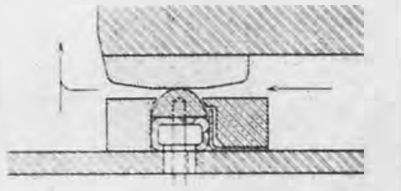
RETRACTION-DEPENDS ON LENGTH OF LIP UPSTREAM FROM NOSE OF SEAL BAR. WITH 7/8" LIP, RETRACTION WAS POSITIVE DOWN TO THE STOP.

SEALING-QUALITY POOR UNLESS NOSE PIECE WAS ACCURATELY ALIGNED WITH THE SEAT. WHEN THE SEAL BAR HAVING THE SLOTTED STAY WAS USED, SEALING WAS IMPROVED.
SEALING PRESSURE 5/8 OF THE HEAD.

OTHER ACTION-SLAMMING COULD BE PRODUCED READILY BECAUSE OF THE LONGER LIP.
EASE OF OPERATION DEPENDS ON THE DESIGN OF THE SUSTAINING MATERIAL.
SEALING AT THE HINGE WAS PERFECT.

ADVANTAGES-SUSTAINING RUBBER (OR OTHER MATERIAL) NEED NOT ADHERE TO THE STAY, BUT MAY BE FORMED SO AS TO STOP LEAKAGE.
SEAL BAR CAN BE SUPPORTED AT THE HINGE READILY.

DISADVANTAGES-STAY IS TOO HEAVY TO BEND SO AS TO CONFORM TO THE SEAT. IT WAS ONLY POSSIBLE TO TWIST THE SLOTTED STAY SLIGHTLY WITH PRESSURE ABOVE 75 POUNDS PER SQUARE INCH.
SUPPORTS AT THE HINGE ARE NOT EASILY MADE.



CHARACTERISTICS-DESIGN 2R-FLOATING BAR RETRACTABLE SEAL.

EXTENSION-TAKES PLACE TO THE SEAT OR TO THE STOPS WITH SOME PRESSURE REQUIRED UNDER THE SEAL BAR, BECAUSE OF SLIDING FRICTION.

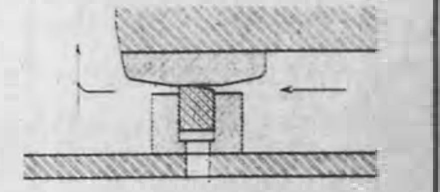
RETRACTION-HINDERED BY FRICTION OF SLIDING SURFACES, BUT ALWAYS ENOUGH TO OPEN A GAP OF 1/32" TO 1/16" FOR ANY POSITION OF THE NOSE ALONG THE SEAT.

SEALING-QUALITY IS GOOD. SINCE THERE IS NO HINGE, ALIGNMENT AND SEALING IS ENHANCED.
DOWNSTREAM CORNER SEALS DROP-TIGHT WITH HYDRAULIC PRESSURE OR SUPPORTING GASKET.
SEALING PRESSURE 5/8 OF THE HEAD.

OTHER ACTION-SEAL BAR COCKS COUNTER-CLOCKWISE (DOWN STREAM) UNLESS SUPPORTED WITH GUIDE STUDS. THIS ACTION IS NOT SERIOUS, FOR EVEN WITH SLAMMING UNDER HEADS UP TO 110 POUNDS, THE NO. 8-32 MACHINE SCREW STUD DID NOT DEFORM.

ADVANTAGES-THIS DESIGN EMBODIES EXTREME SIMPLICITY WITH NO VULCANIZING NECESSARY, OR NO HINGE TO MANUFACTURE. MACHINING AND TOLERANCES MAY BE COARSE.
EASE OF ALIGNMENT OF THE BAR TO THE SEAT AND EASE OF BENDING TO CONFORM TO UNDULATIONS ARE OPTIMUM IN THIS DESIGN.
ALSO SUITABLE FOR CIRCULAR GATES.

DISADVANTAGES-OCCASIONAL GUIDE STUDS NECESSARY.
FRICTION ALONG SLIDING SURFACES PREVENT FREE OR FULL RETRACTION OF SEAL BAR.



CHARACTERISTICS-DESIGN [illegible]-SLIDING BAR RETRACTABLE SEAL.

EXTENSION-SLIDES EASILY TO ANY POSITION WITH OR WITHOUT PENSTOCK PRESSURE MAINTAINED.

RETRACTION-DEPENDS ON RELATIVE POSITION OF NOSE OF SEAL BAR WITH RESPECT TO UPSTREAM EDGE. THE GREATER THIS DISTANCE, THE GREATER IS THE RETRACTIVE FORCE.
FOR 1/16" CHAMFER THERE WAS NO RETRACTION.

SEALING-QUALITY DEPENDS ON CONDITION OF CONTACT SURFACES. A DROP-TIGHT SEAL WAS PRODUCED BY GRINDING SURFACES PERFECTLY FLAT ON A GLASS PLATE.
SEALING PRESSURE WAS 5/8 OF THE HEAD.

OTHER ACTION-RETRACTION OCCURRED SUDDENLY. SEAL BAR DID NOT SEAL UNLESS IT WAS ALLOWED TO DROP BELOW LEVEL OF GROOVE BLOCK. SEAL BAR COCKED COUNTER-CLOCKWISE IN THE GROOVE.

ADVANTAGES-SEAL BAR IS GUIDED AND FLOATS IN THE GROOVE, [illegible] ALIGNMENT TO SEAT IS MADE EASY.

DISADVANTAGES-SLIDING SURFACES MUST BE ACCURATELY MACHINED TO CLOSE TOLERANCES. THIS MAY PRODUCE INOPERATIVE CONDITIONS BY SCALE, RUST AND DIRT DEPOSITS.
SEAL BAR IS STIFF. VERTICAL SUPPORT NEEDED FOR VERTICAL SEAL BARS.

GATE SEAL DESIGNS AND TESTS

SUMMARY OF SECOND SERIES

CONSTANT CONTACT AND RETRACTABLE TYPES

The floating bar retractable seal, design 2R, worked well, but retraction is not so great, although there would generally be enough to free the nose piece from the seat. None of these latter designs mentioned would operate on a circular gate.

11. Summary. For ease in comparing the various gate seal designs and hydraulic tests of this second series or constant-contact and retractable seals, a summary of each type considered is presented in figure 18. The drawing at the head of each individual section illustrates the type of seal involved.

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E. S. Gray.