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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF GATE-SEAL DESIGNS AND TESTS FOR GRAND COULEE DAM

HYDRAULIC LABORATORY REPORT 96
HYDRAULIC MACHINERY LABORATORY
REPORT NO. HM-7

Denver, Colorado,
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Bureau of Reclamation

Hydraulic Machinery Laboratory

Denver, Colorado
June 1941

Laboratory Report No. HM-7
Grand Coulee Dam
Columbia Basin Project
Compiled by: Edward S. Gray
Checked by: D.J. Hebert & H. Martin
Submitted by: G. J. Hornsby

Subject: Model tests for the design of hydraulic seals for gates at Grand Coulee Dam.

SYNOPSIS

When the preliminary inspection tests indicated unsatisfactory operation of the hydraulic seals for the Grand Coulee gates, it was decided that hydraulic model tests should be made to supply design information. Studies were made in two models with full-sized cross sections of the seal. One was a circular model of the seal on a 10-inch diameter and the other was a $2\frac{1}{8}$-inch straight segment of the seal installed between transparent plates. The seven types tested included diaphragm seals, roller seals, compression seals, shear seals, constant contact seals, double-acting seals, and stabilized flexible diaphragm seals. Operating characteristics and design criteria were established for each type by means of both quantitative and qualitative tests.

INTRODUCTION

Ordinary slide gates have been used as a means of controlling water for centuries and are still extensively used in relatively small sizes under heads up to approximately 200 feet. As gate sizes increased and greater heads came into common use, the hoist loads on sliding-type gates became prohibitive. In 1883, F. M. Stoney introduced the use of rollers to reduce friction in raising and lowering the gate. This solved the hoist-operation problem but, since the rollers held the gate off the seat, a new problem; namely, "sealing" was introduced. The use of fixed wheels for reducing friction had the same result.

A number of methods have been used to accomplish sealing. For low heads, as in the Bureau of Reclamation spillway gates, rubber belting or the rubber "music-note" type of seal is used for sealing purposes. These seals have proven quite satisfactory at all gate openings. Gates of this type are seldom used as regulating gates under the higher heads. They usually serve as emergency gates and are, therefore, used only in the fully opened or fully closed position. A number of other methods have been used to seal this type of gate. Depressions were made in the track for the wheels so that the gate might come in contact with the seat at the closed position. In another case the frame seat was raised and given a slight angle, the same angle being placed on the gate seat, allowing the seats to come in contact at the closed position. The disadvantage of such seals is that the initial load on the hoist is very high, due to drag on the seat at the instant the gate begins to open. This disadvantage was eliminated by the use of cams or wedges to lift the entire gate from the seat before raising the leaf and to keep it clear of the frame seat until it is again in the closed position. The Bureau of Reclamation uses the movable-wedge system in the "paradox" type of gate. These gates have been used both in pipe lines and on the face of dams. This type of gate eliminates excessive hoist loads and has proven to be very satisfactory in sealing but rather expensive to build due to a necessarily complicated mechanism.

In an attempt to eliminate the disadvantages of the seals previously used, the hydraulic-type of seal was introduced as a means of sealing gates of the roller or fixed-wheel type when used either in a pipe line or on the face of a dam. In the Grand Coulee Dam, a number of 102-inch ring-follower gates are used in the sluices. These gates have circular seals while the penstock head gates have rectangular ones. The method of adapting a hydraulic seal to one of the penstock gates is shown in figure 20.

These model tests were undertaken in an effort to determine the most effective type of hydraulic seal for the large gates at Grand Coulee Dam. Positive retraction against a static head of about seven pounds per square inch at the center of the gate was a paramount requirement. Incidental to this investigation, seals appropriate for low heads were also developed.

APPARATUS AND METHOD OF TESTING

The hydraulic tests of the various designs of seals were made in two different types of housings. These housings were designed for seal assemblies with full-size cross sections.

The first housing, used in the early tests, was made to simulate a circular gate in which a 10-inch diameter ring seal could be installed. This assembly is referred to as the "10-inch ring-seal model." In this model, the supply simulating the penstock was admitted in the center of the model chamber and then diffused radially by a cap plate which is also the seating plate for the seal ring. The seal assembly is supported below this cap in a suitable housing. A one-half-inch pipe line is connected to this housing to supply pressure for operating the seal ring. The seal ring actuated by this pressure moves against the seat to seal the radial flow from the penstock. The gap between the seal ring and seat could be varied by raising or lowering the cap plate. Bourdon gages and relief valves were installed at suitable points. A drawing of this model with the diaphragm seal is shown in figure 21.

The second housing was made in an effort to make the action of the seal more evident. This housing, which was a rectangular box with transparent plates for the front and back, held a straight section of the seal $2\frac{1}{2}$ inches in length. This assembly is referred to as the "visual sectional seal model." Supply lines were connected to provide penstock pressure upstream from the seal bar and to provide pressure for operating it. An additional connection was made but it was used only in testing the double-acting seals to supply pressure for the middle chambers. Gages and relief valves were connected at suitable points. The gap between seal bar and seat could be varied by raising or lowering the seal assembly. A drawing of this model with the double-acting packing-gland seal is shown in figure 22.

In the testing arrangement which is shown in plates 1 and 2, both models were connected so that flow of water to either model was available from three sources: Water-supply lines of the building (75 pounds per square inch), 12-inch, 100-foot head, centrifugal pump, and a high-pressure hand pump connected to an air tank. During the course of the investigation, several changes were made to increase the amount of water flowing through the model. When the supply was increased, the penstock pressure could be maintained for a greater range of seal bar movement and field conditions were more closely duplicated. With the higher penstock pressures, velocities through the gap were higher and the effects more noticeable. It is, therefore, important to make tests at the highest penstock pressures and velocities that would be encountered in the field.

The tests consisted principally of measurements, by means of gages, of the pressures necessary to accomplish a seal against various measured penstock pressures. With a given penstock pressure, the pressure under the seal bar was increased slowly until flow from the penstock stopped. Then, the pressure under the bar was lowered until the seal broke. There was a difference between the pressure readings for these two conditions which sometimes amounted to as much as 10 pounds per square inch. Sealing pressure was taken as the mean of these two readings. The penstock pressure was varied from the available maximum by means of a relief valve or by change of speed of the pump. Since maximum pressure was available at all times for moving the seal bar, the sealing pressure at times exceeded the applied penstock pressure. This represents a distortion of field conditions where the seal pressure equals but never exceeds the penstock pressure. Despite this distortion, the data obtained are useful. A few tests were made in which pressures were observed for various partial extensions of the seal bar. These positions were set by various increments which varied from one thirty-second to five-sixteenths of an inch. In addition to these tests, visual observations were made as to retraction, cocking, and the general action of the seal. These observations were augmented by taking photographs.

The type and quality of the rubber used in the tests is essentially a part of the test apparatus. Many different kinds of rubber were used because they were on hand or readily available. In a few cases the rubber was manufactured to specifications. Due to this variation, some of the seal designs are not directly comparable. All shapes other than solid round, flat, or in some cases tubular, were made up in the laboratory.

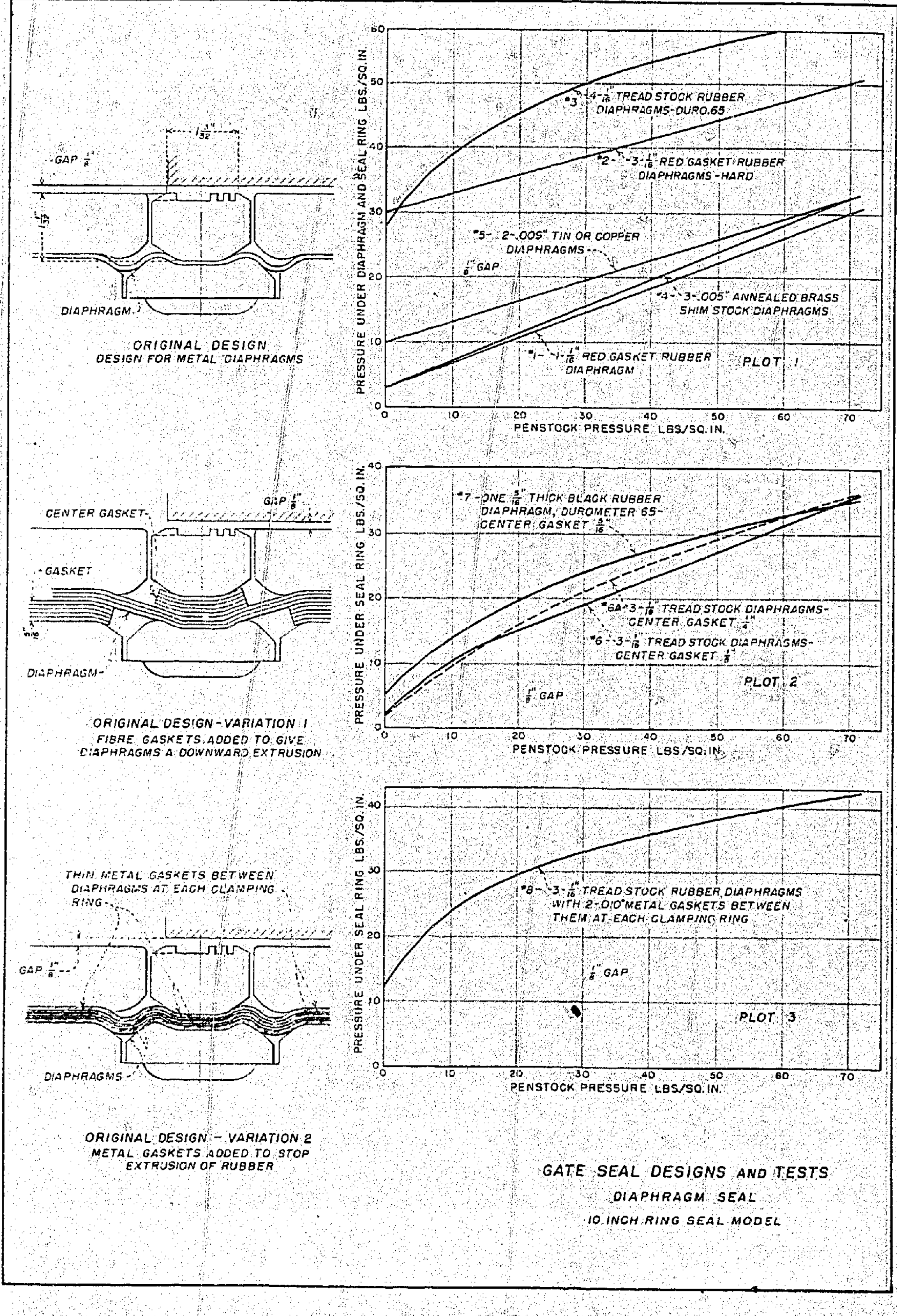
In making up the rubber rings for the ring-seal model, several attempts were made before a satisfactory joint was obtained. At first, uncemented butt joints were made with a short rubber plug to hold the ends together. This type of joint leaked and was unsatisfactory. Cementing of the butt joints proved to be more successful. A further improvement was obtained by cementing 45-degree joints. This type of joint was satisfactory for either tubing or solid rubber. In making up this joint, the roller was first cut to 45 degrees in a mold using a knife-edged hacksaw blade with water as a lubricant. The two ends were then fitted by means of a power-disk sanding machine. Two coats of rubber cement were then applied and each coat was scraped in with the teeth of a fine hacksaw blade. The ends were then squeezed and pounded together to give a smooth, strong joint that could not be pulled or twisted apart. It was found that a good rubber cement must be used to insure good results. At least one cement was found to give inferior joints.

In the operation of the visual model, the ends of the rubber seals rubbed against the transparent sides. Several lubricants, including glycerine, graphite, graphite in glycerine, fatty greases, and paraffin grease were tried in an effort to minimize the friction resulting from this rubbing. Only the paraffin grease proved to be satisfactory and then only when it was fresh. It not only prevented sticking of the rubber to the plates but it did not wash out and it was not injurious to the rubber. After standing for several hours, it adhered to the transparent plates with great tenacity.

DISCUSSION OF RESULTS

The results of the many tests are presented by means of figures which contain sketches of the designs and plots of test measurements. The discussion of the results, when there are so many different designs, is simplified by incorporating the figures in the body of the report. The discussion of each type of design is faced by the corresponding figure so that reference to it is readily made by the reader. Because the text cannot be printed on the back of the figures, this type of presentation entails many blank pages. Figures 1 to 19 are incorporated in the body of the report while figures 20 to 22, which are more general in nature, are found at the end of the text. The plates of photographs are also found at the end of the text.

FIGURE 1


GAP 1/8"
DIAPHRAGM
ORIGINAL DESIGN
DESIGN FOR METAL DIAPHRAGMS
CENTER GASKET
GAP 1/8"
GASKET
DIAPHRAGM
ORIGINAL DESIGN - VARIATION 1
FIBRE GASKETS ADDED TO GIVE DIAPHRAGMS A DOWNWARD EXTRUSION
THIN METAL GASKETS BETWEEN DIAPHRAGMS AT EACH CLAMPING RING
GAP 1/8"
DIAPHRAGMS
ORIGINAL DESIGN - VARIATION 2
METAL GASKETS ADDED TO STOP EXTRUSION OF RUBBER
PRESSURE UNDER DIAPHRAGM AND SEAL RING LBS./SQ.IN.
#3 - 4 - 1/16" TREAD STOCK RUBBER DIAPHRAGMS - DURO.65
#2 - 3 - 1/16" RED GASKET RUBBER DIAPHRAGMS - HARD
#5 - 2 - .005" TIN OR COPPER DIAPHRAGMS
1/8" GAP
#4 - 3 - .005" ANNEALED BRASS SHIM STOCK DIAPHRAGMS
#1 - 1 - 1/16" RED GASKET RUBBER DIAPHRAGM
PLOT 1
PENSTOCK PRESSURE LBS/SQ.IN.
PRESSURE UNDER SEAL RING LBS./SQ.IN.
#7 - ONE 5/16" THICK BLACK RUBBER DIAPHRAGM, DUROMETER 65 - CENTER GASKET 5/16"
#6A - 3 - 1/16" TREAD STOCK DIAPHRAGMS - CENTER GASKET 1/4"
#6 - 3 - 1/16" TREAD STOCK DIAPHRAGMS - CENTER GASKET 1/8"
1/8" GAP
PLOT 2
PENSTOCK PRESSURE LBS/SQ.IN.
PRESSURE UNDER SEAL RING LBS./SQ.IN.
#8 - 3 - 1/16" TREAD STOCK RUBBER DIAPHRAGMS WITH 2 - .010" METAL GASKETS BETWEEN THEM AT EACH CLAMPING RING
1/8" GAP
PLOT 3
PENSTOCK PRESSURE LBS/SQ.IN.
GATE SEAL DESIGNS AND TESTS
DIAPHRAGM SEAL
10 INCH RING SEAL MODEL

Diaphragm seals (figure 1). Sections of the principal parts of three diaphragm ring seals and their sealing characteristics are shown in figure 1. The test apparatus is shown in figure 22 and in plates 1 and 2. In the original design, the shape of the parts was drawn only for a metal diaphragm. The curved surfaces of the clamps and sealing ring were shaped in such a manner that the diaphragm cross-sectional length was the same when the seal ring was extended as when it was retracted. The diaphragm would at the same time be supported over nearly its entire free area when pressure was applied. The section of the diaphragm under the seal ring was also formed lower than the sections under the clamping rings in order that the seal ring would retract easily.

The forming of the metal diaphragms presented several problems. When the diaphragm was formed between two metal molds the sheet wrinkled badly and could not be used. An improvement was obtained by forming between one of the metal molds and a slab of rubber 1 inch in thickness. Further improvement was accomplished by confining the rubber slab laterally. With this arrangement, satisfactory diaphragms were formed with a pressure of 500 to 600 pounds per square inch. The shim stock diaphragms were formed in sections because this stock could be purchased only in 6-inch widths. It was found that the sheet brass had to be annealed before being formed to prevent splitting of the metal. In placing these sections in the seal assembly, three layers were used and the joints were lapped. Grease was applied between layers to prevent leakage. Tinplated steel and copper diaphragms were made in a complete ring since large enough sheets were available.

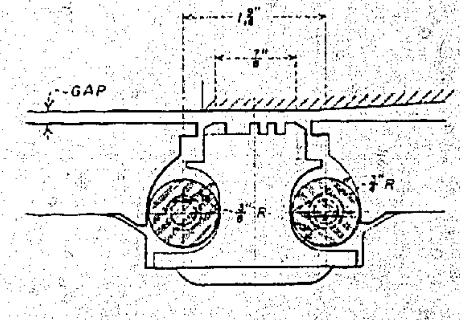
The action of the metal diaphragms under test was satisfactory from the standpoint of sealing but the retraction amounted to only 3/64 inch. This retraction diminished as the seal ring was operated because the diaphragms took a permanent set after they were deformed. Sheet-rubber diaphragms in various arrangements were tested. Retraction in each case was sluggish and incomplete except when the single diaphragm was used. In this case, the weight of the seal ring assisted in the retraction.

The operating-pressure curves in plot 1 indicate that the pressure required to move the seal bar increases with the thickness of the diaphragm. This is due to the fact that the rubber extruded by clamping filled the space intended for the movement of the diaphragm as the seal ring moved. In variation 2, fiber gaskets were added to the original design to give the diaphragms a downward extrusion and some improvement in retraction was obtained. In variation 3, metal gaskets were inserted between the rubber diaphragms at the clamping rings to prevent extrusion of the rubber. This device reduced the extrusion but retraction was still incomplete.

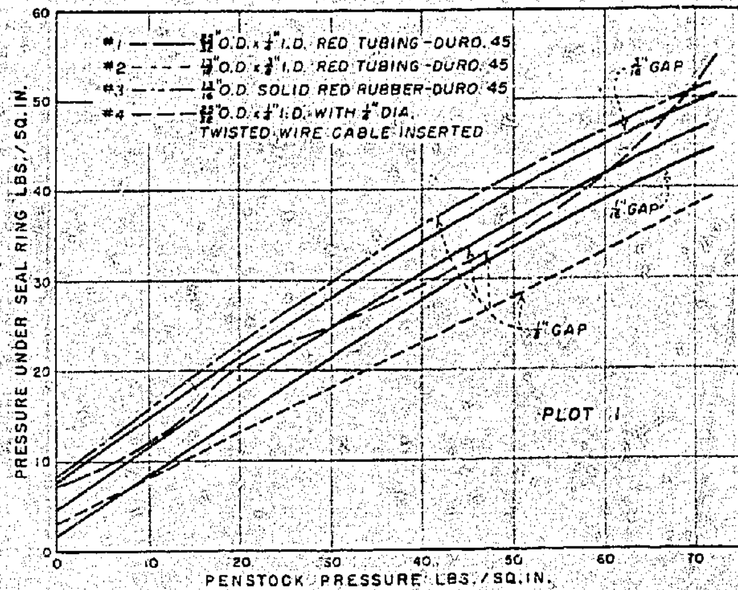
A high-pressure test was made with one of the diaphragms of red gasket rubber. By means of a hand pump, a pressure of 450 pounds per square inch was applied and released about a dozen times without injury to the seal.

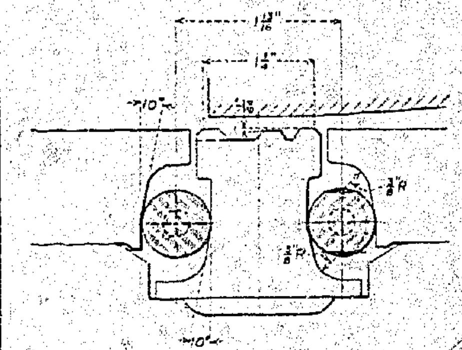
A fatigue test was made with the same set-up. A pressure of 70 pounds per square inch was applied and released by means of a 4-way valve operated by a motor and speed-reducing mechanism. After 3,300 cycles slight leakage occurred through the diaphragm. Considerable leakage occurred after 3,950 cycles indicating a rupture of the diaphragm.

FIGURE 2

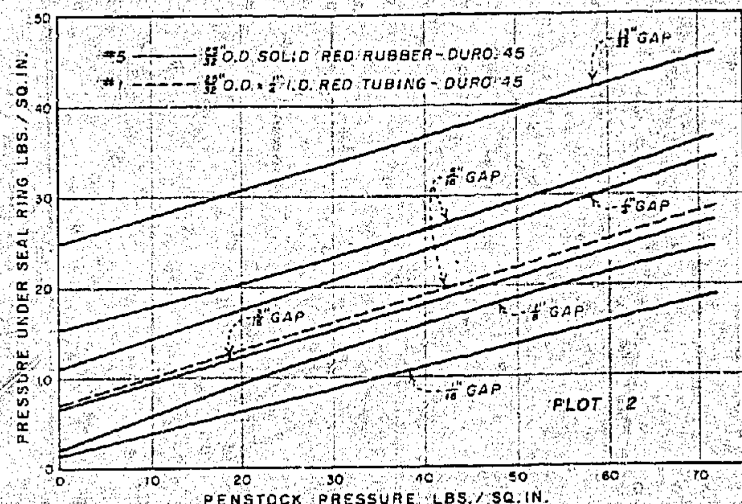


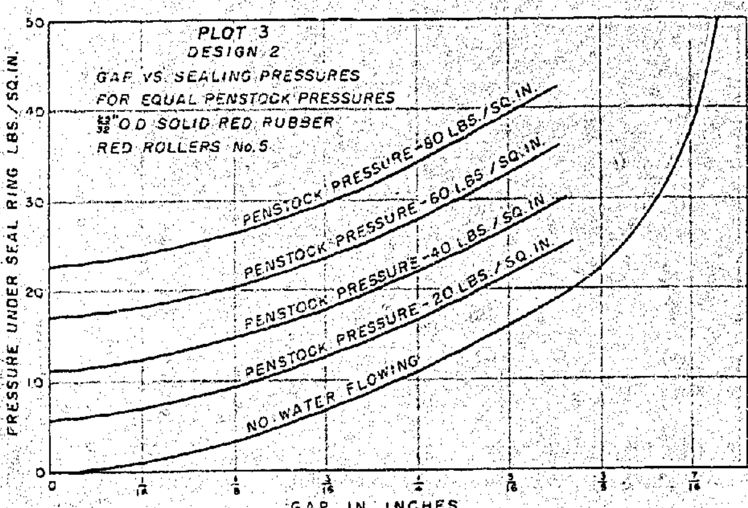
DESIGN 1
ORIGINAL DESIGN





DESIGN 2
SIDES WITH 10° SLOPE





GATE SEAL DESIGNS AND TESTS
7OLLER SEALS
ʜO INCH RING SEAL MODEL

Roller seals (figure 2). This type of sealing device was designed to produce a rolling action of the rubber rollers when the seal ring is moved. Compression of the rubber produces the force necessary for retraction. Before installing the three rings in the model housing, they were assembled with the rollers so that the rollers could be pushed well up into their respective slots.

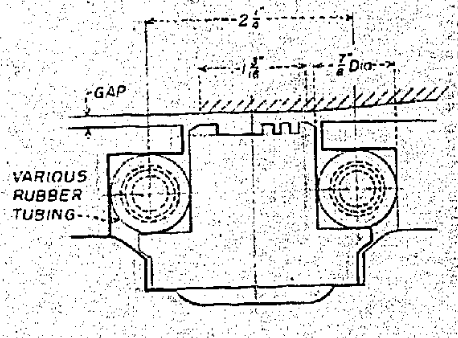
From a series of tests of design 1, it was found that slightly undersized rollers allowed leakage of water from the penstock into the chamber under the sealing ring with the result that the pressure under the sealing ring increased rapidly and the ring closed quickly. This action, hereafter called self-sealing, resulted in the unstable condition which is shown by the sealing-pressure curve in plot 1 of the 25/32-inch outside diameter by 1/4-inch inside diameter roller with a 1/4-inch twisted wire cable inserted. When leakage was excessive, the seal ring could not be unseated.

Oversized rollers produced violent chatter of the seal ring at the point of sealing for all penstock pressures. As the flow of water through the penstock was increased, the chatter decreased. Chatter was negligible when the seal ring was operated rapidly.

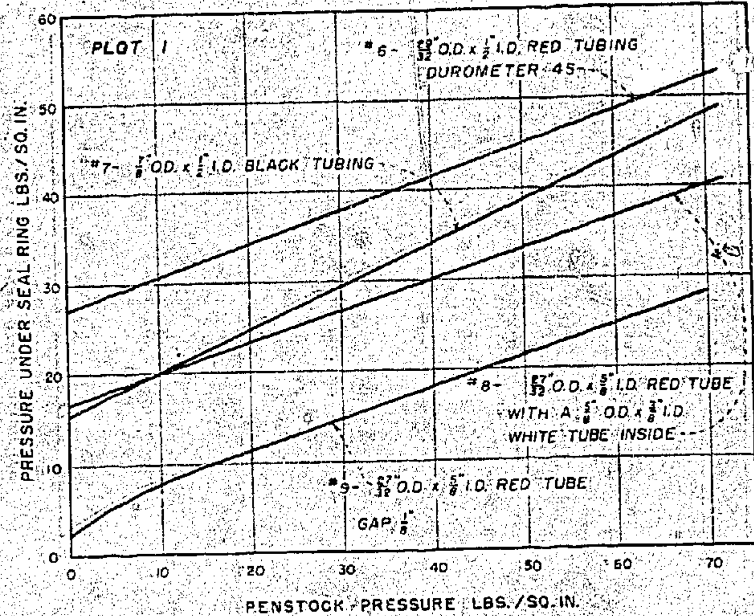
A high-pressure test of this seal was made by applying 500 pounds per square inch under the seal ring. The sealing mechanism was not injured and the seal ring retracted fully when the pressure was released.

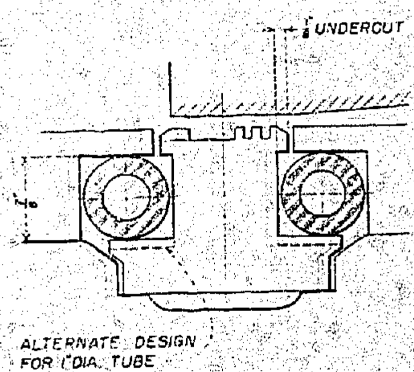
Design 2 differs from design 1 in the center distance of the rollers and in the shape of the slots. Sealing pressures are lower than those for design 1 and the retractive effort is also less. At closure, the seal bar had a very slow chatter or pulsation. The sealing-pressure curves in plots 2 and 3 show the effect of changing the gap between the seal ring and the seat. The extra-long slots in the design were made for the particular purpose of determining the relative position of the seal ring, retainer bars, and rollers, for any particular sealing effort desired. This effort for zero penstock flow, also represents the residual force in the rubber available to retract the seal ring. Plot 3 gives curves showing the effect of change of extension position of the seal ring and rollers. The curve for no penstock flow gives pressures necessary for seal-ring extension and was actually obtained with the cap plate of the model removed.

FIGURE 3

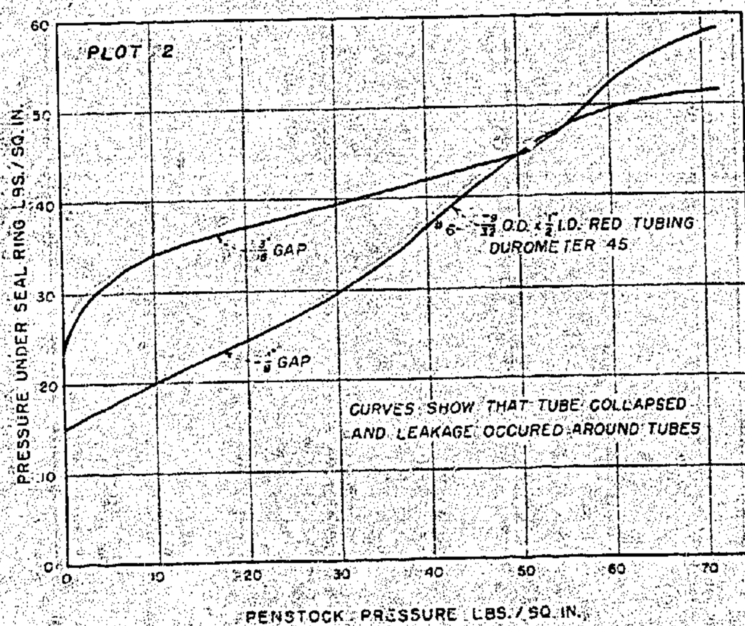


DESIGN 1
ORIGINAL DESIGN





DESIGN 2
REVISION OF DESIGN 1
SIDES OF SEAL RING UNDERCUT

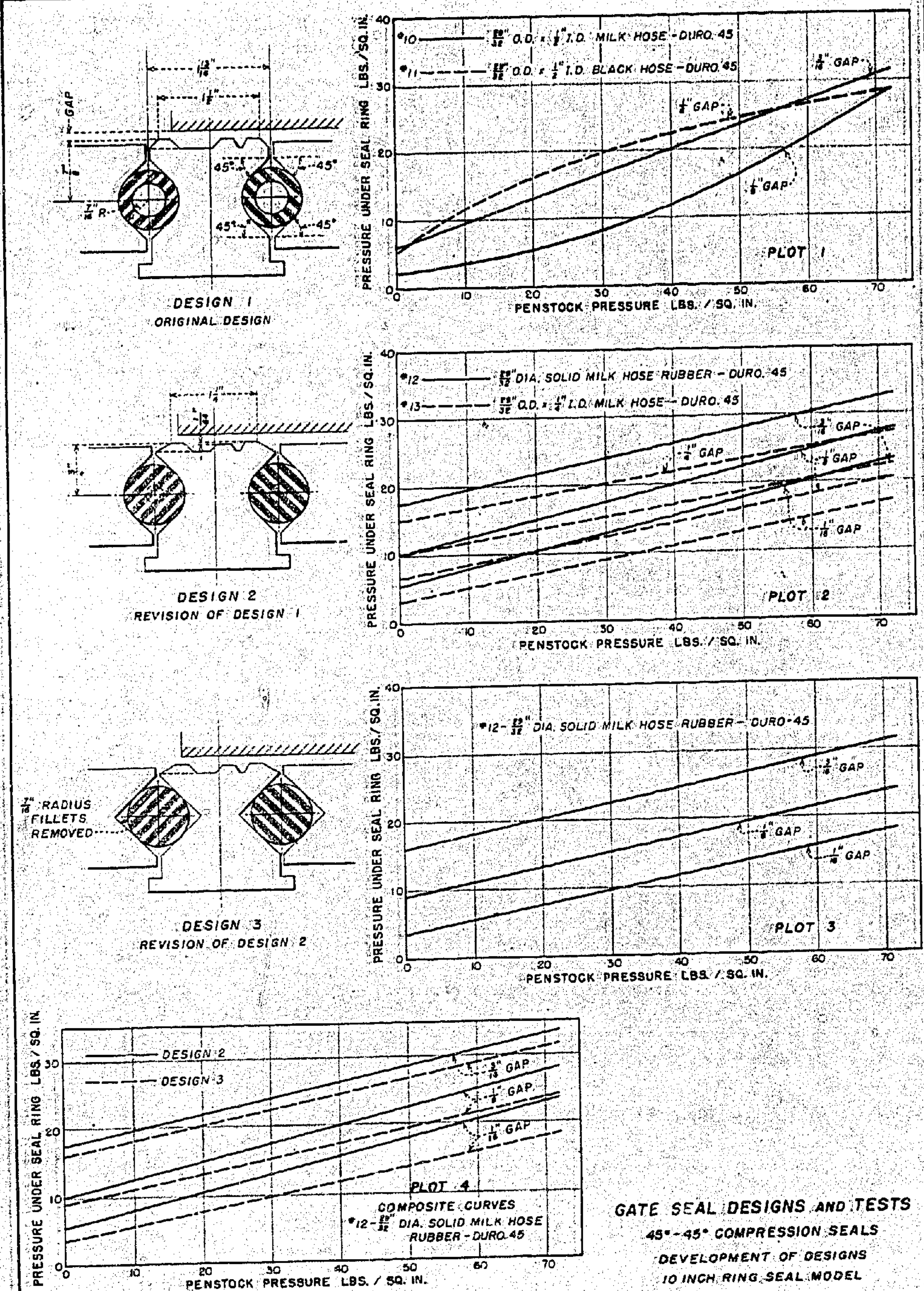


GATE SEAL DESIGNS AND TESTS
SQUARE COMPRESSION SEALS
10 INCH RING SEAL MODEL

Square compression seals (figure 3). This seal was designed to produce direct compression in the rubber. In design 1, the tubing sealed on all four sides when the proper size was used but with undersized tubing, self-sealing occurred. The curves in plot 1 for this design show the manner in which the sealing pressures increase when the rubber is either oversize or too hard. The seal ring chattered upon sealing, particularly at the higher pressures. The tubes with large inside diameters caused irregular action of the seal ring and showed a collapsed condition after being tested.

In design 2, the space for compression of the rubber was increased in order that solid rubber or tubing with a small inside diameter could be used. It was found that this design was not as satisfactory as design 1. Self-sealing took place more readily and the tubing collapsed. The sealing-pressure curves in plot 2 show the unstable operation of the sealing device. Retraction was hindered by self-sealing action or by the collapsing of the rubber tubes.

FIGURE 4



GATE SEAL DESIGNS AND TESTS

45°-45° COMPRESSION SEALS

DEVELOPMENT OF DESIGNS

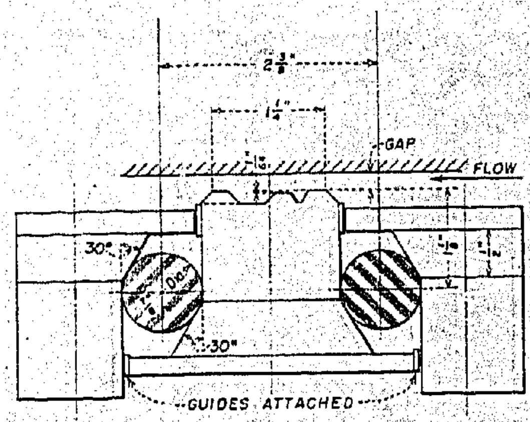
10 INCH RING SEAL MODEL

45 - 45-degree compression seal (figure 4). This seal employs the compression of the rubber, mainly, to give the retractive force although there is considerable shearing of the rubber. Design 1 was tested only a few times with tubing of large inside diameter. In the tests of the black hose, self-sealing occurred. At high penstock pressures, it was impossible to unseal the mechanism due to the leakage past the rubber into the chamber under the seal ring. In the case of the milk hose, self-sealing occurred only at penstock pressures less than 26 pounds per square inch and retraction was possible in all operating conditions. There was no chatter upon sealing, but the seal ring snapped closed. Curves for these tests are shown in plot 1.

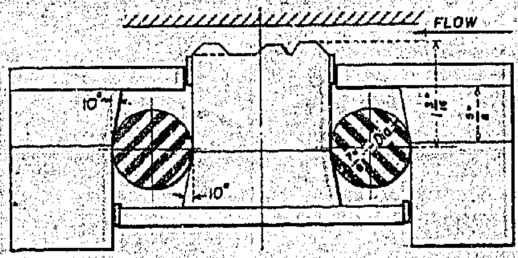
In design 2, the face of the seal ring was made narrower. The seal ring chattered violently upon sealing due to the more solid rubber used. This condition was considerably more violent and rapid with the solid rubber seals and at the higher heads. There was no leakage past the rubber rings and the retraction was good. Sealing-pressure curves are shown in plot 2.

In design 3, the 7/16-inch radius fillets were removed. This effected easier sealing as shown in the composite operating curves in plot 4. There was slight leakage past the inner rubber ring at all penstock pressures with gaps up to 1/8 inch in width. With wider gaps, no leakage occurred. There were pulsations and chatter of the seal ring upon sealing at all heads.

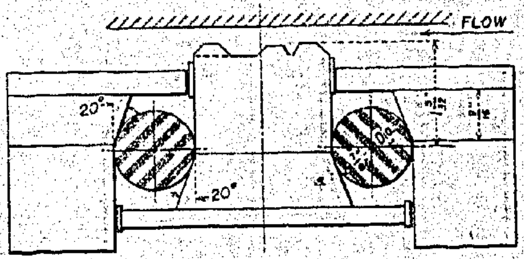
FIGURE 5



DESIGN 1
ROLLING SURFACES 30° SLOPES



DESIGN 4
ROLLING SURFACES 10° SLOPES
10° BLOCKS INTERCHANGED



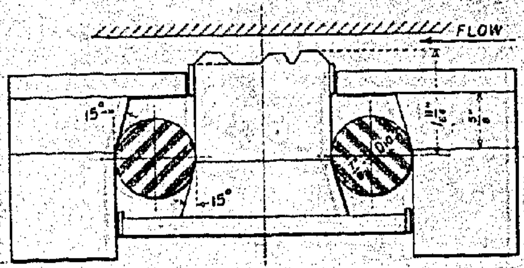
DESIGN 2
ROLLING SURFACES 20° SLOPES
20° BLOCKS INTERCHANGED

TEST OF DESIGN 1

Solid Red Rubber $\frac{29}{32}$" O.D., durometer 45, was used in this test.
With 70 #/□" under seal bar, both rollers slide up to stops.
With penstock pressure on, the upstream roller slides down to a balanced position.
Retraction is nearly $\frac{3}{8}$" but downstream roller does not recede to normal position.
Rolling action of rollers takes place only at lower pressures and until seal bar seals.

TESTS OF DESIGNS 2, 3 AND 4

Tests on these designs were not made after observing the action of rubber rollers in design 1. It would be expected that the rollers would slide to their stops more readily, depending on the angle of slopes.
Rolling action of the rubber rollers would take place only at low pressures, after which they would slide to their stops.



DESIGN 3
ROLLING SURFACES 15° SLOPES
15° BLOCKS INTERCHANGED

GATE SEAL DESIGNS AND TESTS
ROLLER SEALS
VARIOUS SLOPES
VISUAL SECTIONAL SEAL MODEL

VISUAL SECTIONAL SEAL-MODEL TESTS

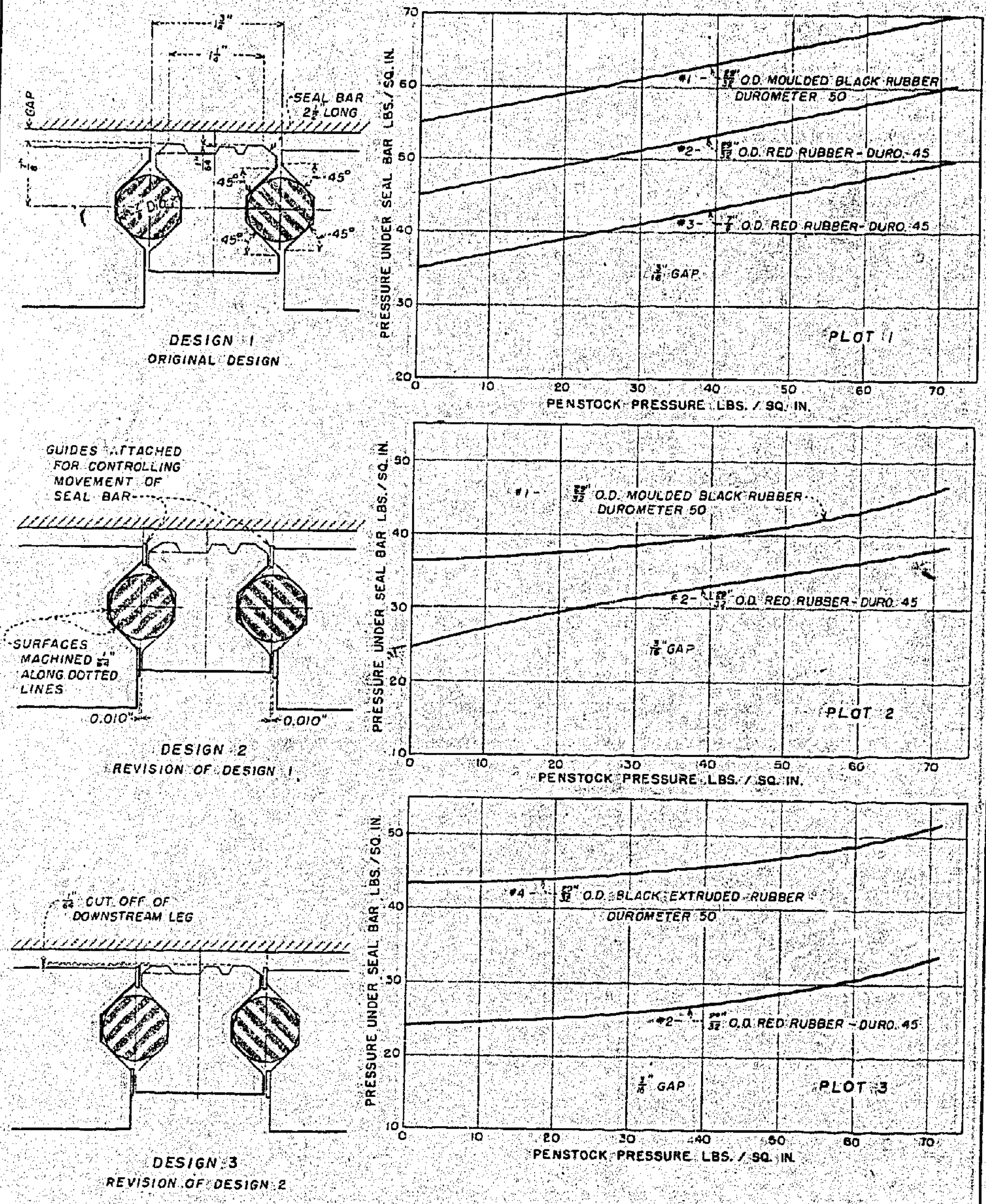
The roller seal (figure 5). The four designs shown were made for the purpose of determining the effect of various slopes of the rolling surfaces on the operation of the seal and the proper center location of the rollers in the slots. The test apparatus is shown in figure 22 and in plates 1 and 2.

In tests on design 1, it was found that when the seal bar was forced into the sealing position, the rollers rolled normally. As the pressure under the rollers was increased, the rollers merely slid to their stops. Upon application of the penstock pressure, the upstream roller assumed a balanced position and could be made to rise or lower by the adjustment of the pressures above and below it. As this test did not give promising results, further tests on designs 2, 3, and 4 were not conducted.

In the tests on design 1, it was found that it was necessary that the seal bar be carefully guided to prevent cocking when the penstock pressure exceeded about 20 pounds per square inch.

No photographs of this assembly were taken.

FIGURE 6



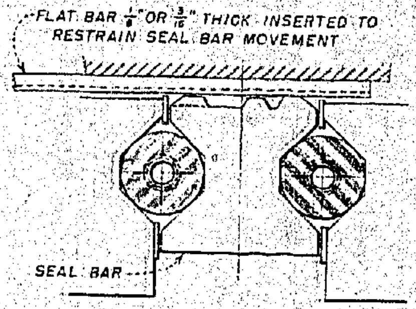
GATE SEAL DESIGNS AND TESTS
COMPRESSION SEALS
DEVELOPMENT OF 45-45 DEGREE DESIGNS
VISUAL SECTIONAL SEAL MODEL

Compression seals - 45 - 45-degree design (figure 6). Design 1 is the original design of the 45 - 45-degree seal which later was altered slightly for the Grand Coulee design No. 4 which is shown in figure 8. The sealing-pressure curves for this design shown in plot 1 are only approximate because of the small number of tests made and the difficulties in lubrication.

Design 2 differs from design 1 in that the slots are increased in size. The curves in plots 2 and 3 show that this change reduces the sealing pressure for all penstock pressures. The seal bar cocked seriously without the guides. The guides which were brass blocks about 1/4-inch square and 0.05 inch thick were soldered or screwed in place at four points along the 1/16-inch clearance. Without the guides, the sealing pressures are lower in general for the higher penstock pressures because of the cocking action which assists sealing.

Design 3 is the same as design 2 with the exception that the downstream leg of the seal bar is undercut 1/64 inch in order to insure that the upstream sealing edge leads in striking the seat. Plate 3 shows photographs of this design with the three kinds of rubber and the two sizes of rollers. In views B and D it is seen that the rubber was lifted from the lower seat whereas in views E, F, G, and H, the 0.017-inch oversize rollers fill the slots more fully. The 29/32-inch outside diameter rollers of black extruded rubber were made by the lead sheath process. This type of rubber was used in most of the ring-seal gates for Grand Coulee Dam.

FIGURE 7



DESIGN 3
REVISION OF DESIGN 2

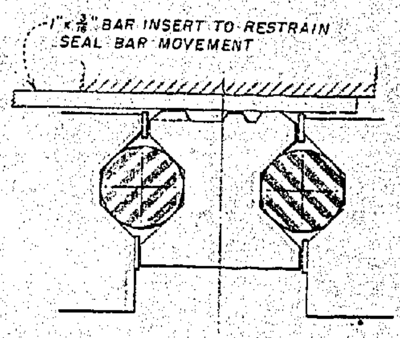
LIST OF RUBBER ROLLERS TESTED

Black Extruded 29/32" +.010" O.D. x 5/16" I.D. – Durometer 50
Black Extruded 29/32" +.005" O.D. x 3/8" I.D. – Durometer 50
Red Milk Hose 7/8" O.D. x 1/4" I.D. – Durometer 45
Red Milk Hose 27/32" O.D. x 3/8" I.D. – Durometer 45

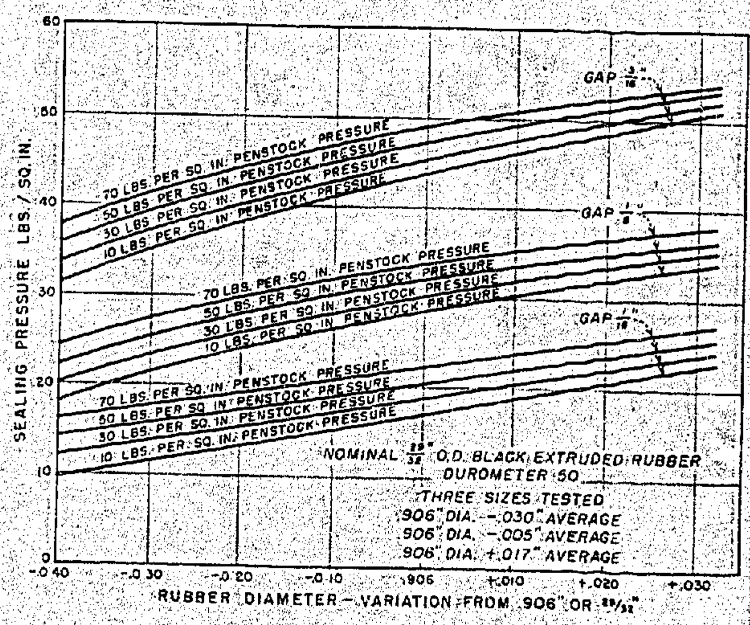
Gap was practically 3/16" for all tests.
Ends of Rubber rollers were sealed with Plasticine to prevent water from entering the hole.

TESTS TO DETERMINE EFFECT OF HOLE IN RUBBER – COLLAPSING TESTS

The tubes all partially collapsed when subjected to 70 lbs. per sq. in. pressure under the seal bar and penstock. The holes became narrow slits as the seal bar moved to the closed position. With seal bar restrained from moving by inserting a bar 1" x 1/8" or 3/16" thick above it, the hole grew smaller symmetrically as pressure was applied under the seal bar.
The larger the hole or the softer the rubber the greater was the collapsing.
The tubes of 3/16" I.D. were subjected to pressure of 130 lbs. per sq. in. with only partially collapsing them.



DESIGN 3
REVISION OF DESIGN 2



TESTS TO DETERMINE EFFECT OF DIAMETER OF RUBBER GASKETS

The rubber gaskets moved into the 45° slots as pressure was applied and the seal bar moved to the closed position.
Free space occurred between the gaskets and the retainers the amount depending on the size of the gaskets.
The largest size tested filled the cavity well at all times.
Restraining the movement of the seal bar caused leakage past the smaller sizes of gaskets when pressure under the seal bar was less than 5 lbs. per sq. in.
The gasket on the upstream side of the seal bar floated in the cavity when both penstock and sealing pressure were applied simultaneously.

GATE SEAL DESIGNS AND TESTS
45°– 45° COMPRESSION SEAL
COLLAPSING AND TOLERANCE TESTS OF RUBBER GASKETS
VISUAL SECTIONAL SEAL MODEL

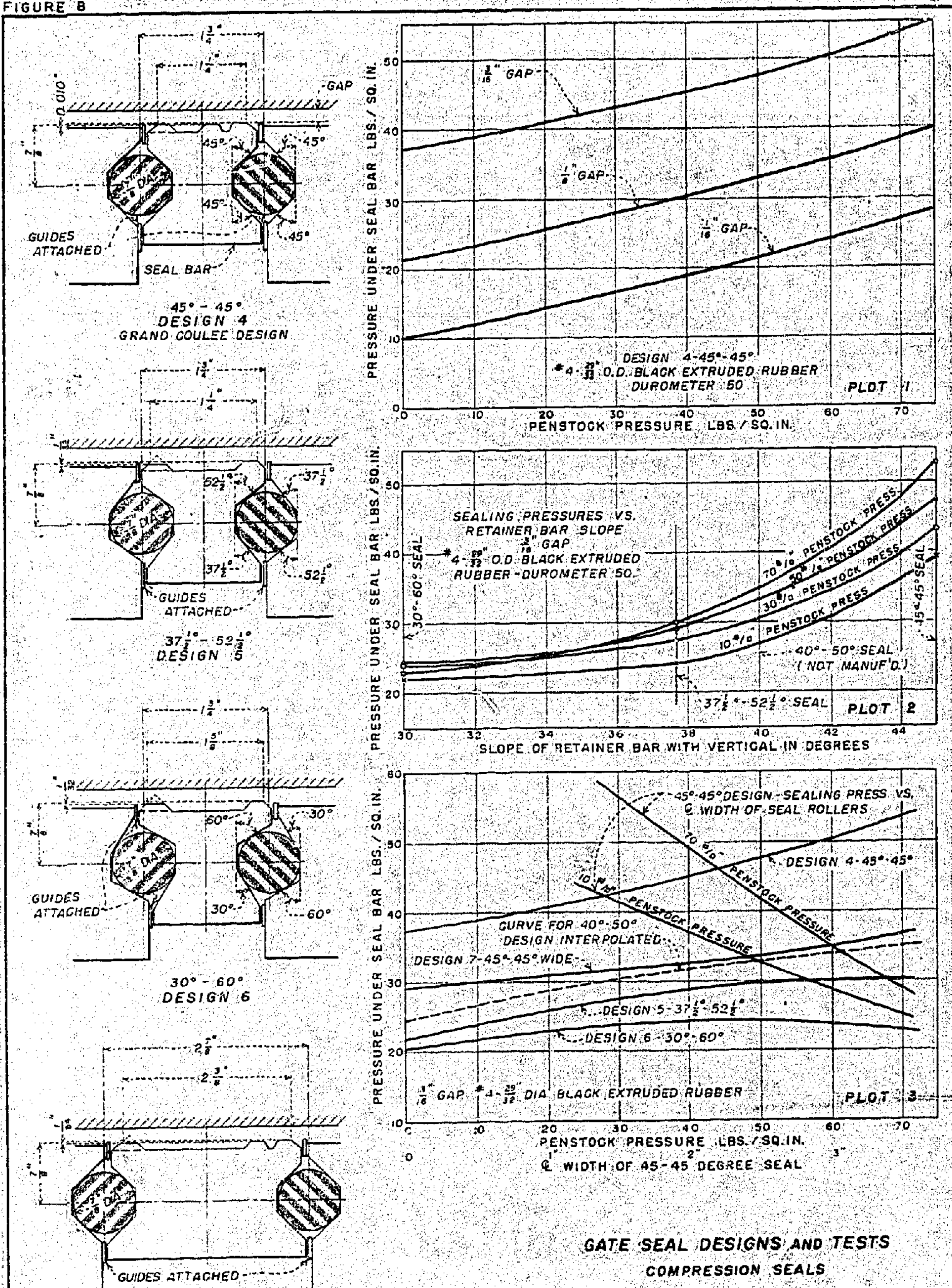
Compression seals - 45 - 45-degree design - Collapsing and tolerance tests (figure 7). A series of tests was conducted to determine the allowable size of hole in the rubber rollers. This determination was made by subjecting rollers of various inside diameters to collapsing pressures. In order to keep the bore of the roller free of water and to entrap free air in it, the ends of the rollers were sealed with a water-resistant clay which made a tight slip fit against the sides of the visual sectional model. It was found that a small axial hole approximately 5/16 inch in diameter could not be completely closed when the seal bar was extended 3/16 inch and subjected to a sealing pressure of 130 pounds per square inch. The test also showed that collapsing was due primarily to seal-bar movement, which compressed the roller, and not to the hydraulic pressure. This action is shown in plate 5.

A few tests were run to determine the permissible tolerances for the 29/32-inch diameter (nominal) solid rubber rollers. These tests were run using design 3 because design 4, the Grand Coulee design shown in figure 8, was not available at the time of this test. The free area available for the rubber in this seal is greater than in design 4. Therefore, the rubber would be tighter in design 4. The effects of variations in diameter of the roller are shown by the sealing-pressure curves in figure 7. The effect of varying the gap width is also shown.

The normal area available in design 4 is 0.696 square inches (column 4, figure 9) whereas the cross-sectional area of the rubber for 29/32 plus 0.020 inch outside diameter is 0.673 square inches. With the seal bar extended, the area available drops to 0.678 square inches. Therefore, 0.020 inch is practically the limit of oversize in diameter of the rubber rollers. The smallest rollers tested had a diameter of 29/32 minus 0.030 inch. There was leakage past the rollers with a pressure of 5 pounds per square inch, which indicates that rollers 0.030 inch undersize are too small.

Photographs of design 3 with oversize rollers are shown in plate 3. Photographs showing 29/32-inch outside diameter exact-size rollers in a design which has the same slots as design 4 are shown in plate 4.

FIGURE 8



GATE SEAL DESIGNS AND TESTS

COMPRESSION SEALS

VARIOUS RETAINER BAR SLOPES AND CENTER-LINE WIDTHS

VISUAL SECTIONAL SEAL MODEL

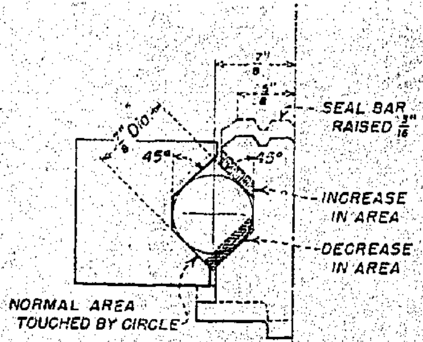
Compression seals - Effect of changes in angles and widths (figure 8). Four different designs of compression-type seals were tested and the results are shown. Tests were made on designs 4, 5, and 6 to show the effects of varying the slope of the retainer bar with the center-to-center distance of the slots held constant. Test on designs 4 and 7 show the effects of varying the center-to-center distance with the slope held constant. In all the designs, the height of the seal bar above the center of the rollers was held constant.

Design 4 was tested with three different gap widths and the sealing-pressure curves are shown in plot 1.

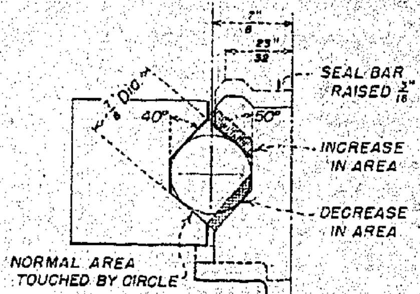
The sealing-pressure curves for all designs with a 3/16-inch gap are shown in plot 3. The effects of the various changes are apparent in this figure. Plot 2 was obtained from plot 3 to show more clearly the effect of change in the slope of the retainer bars. The location of a 40-50-degree design is noted in this plot. This design is the ideal one which was deduced from a study of the cross-sectional areas of the slots as shown in figure 9. The curves in plot 2 are somewhat irregular due to the fact that the face width of the seal bars was inadvertently allowed to vary. The effect of varying the center-to-center distance of the slots is emphasized in plot 3, which shows sealing pressure versus center-to-center width at constant penstock pressures of 10 and 70 pounds per square inch, respectively.

All these designs required accurate guiding to prevent excessive cocking. Slamming of the seal bar was prevalent in all the designs, especially at the higher penstock pressures and velocities.

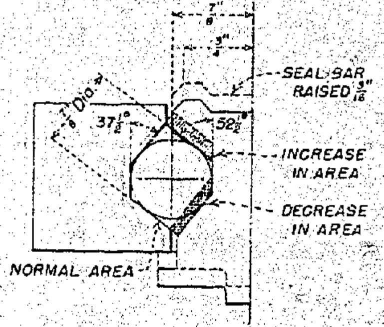
FIGURE 9



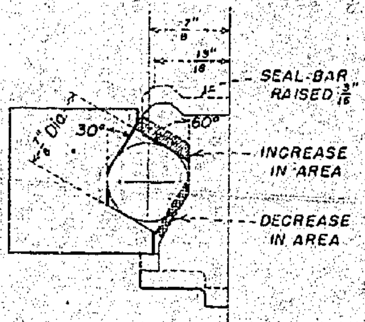
45° - 45° COMPRESSION SEAL



40° - 50° COMPRESSION SEAL



37 ½° - 52½° COMPRESSION SEAL



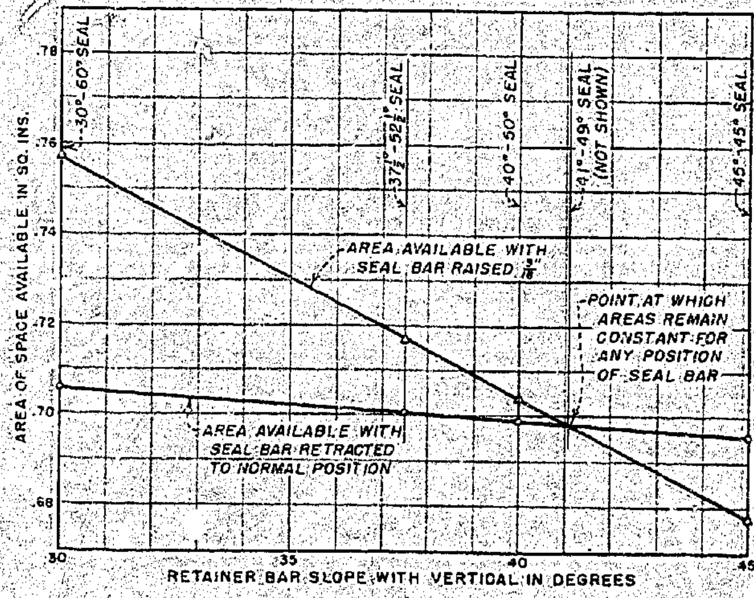
30° - 60° COMPRESSION SEAL

AREAS INVOLVED IN SPACE AVAILABLE FOR RUBBER GASKETS IN VARIOUS COMPRESSION SEALS

SEAL TYPE	(1) SEAL BAR RAISED 3/16" INCREASE IN AREA — SQ. INS.	(2) DECREASE IN AREA — SQ. INS.	(3) CHANGE IN AREA (1)-(2)	(4) NORMAL AREA AVAILABLE — SEAL BAR RETRACTED	(5) AREA AVAILABLE — SEAL BAR RAISED 3/16" (4)+(3)
45-45 DEGREE	.0749	.0931	-.0182	.696	.678
41-49 DEGREE	.0871	.0869	+.0002 (IDEAL DESIGN NOT SHOWN)	.6985	.6983
40-50 DEGREE	.0885	.0834	+.0051 (PRACTICAL DESIGN)	.699	.704
37½-52½ DEGREE	.0968	.0810	+.0158	.701	.717
30-60 DEGREE	.1073	.0563	+.0510	.706	.757

CROSS SECTIONAL AREAS OF RUBBER GASKETS COMPARED

DIA. EXPRESSED RELATIVE TO NOMINAL DIA. OF .906	CROSS-SECTIONAL AREA IN SQ. INS.
.906" - .020"	.616
.906" - .010"	.631
29/32" = .906"	.645
.906" + .010"	.659
.906" + .020"	.673
.906" + .030"	.686



NOTES

From the curves above, the point at which Areas Available remain constant with Seal Bar either raised or retracted is shown to require a seal design of 41⅓ - 48⅔ degree slopes.

A seal design having more practical angles would be one having 40-50 degree angles. The Area Available increases slightly in raising the Seal Bar. This will give a Seal Bar of better action than the 45-45 degree design, where the Area Available decreases as the Seal Bar rises.

GATE SEAL DESIGNS AND TESTS

VARIOUS ANGLE COMPRESSION SEALS

CROSS SECTIONAL AREAS COMPARED

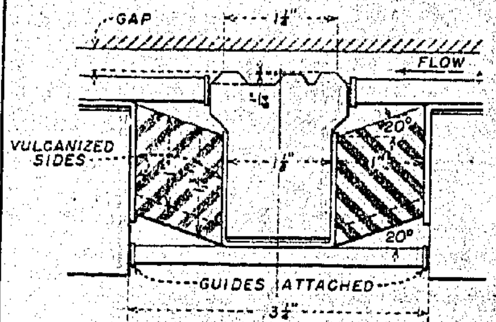
Compression seals - Study of cross-sectional areas (figure 9). A tabulation of the cross-sectional areas of several designs of compression seals is presented. From this figure it is apparent that the area available for the rubber changes as the seal bar is extended from its normal position. This change may be either positive or negative.

The computations for this change in area are shown in tabular form. The area changes which were used are indicated by cross-hatching in the drawings of the cross sections of the various seal designs. These computations were made for a seal-bar extension of 3/16 inch.

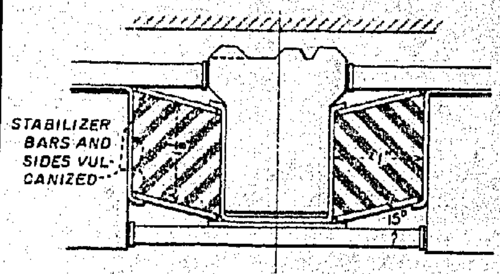
These results were plotted in curves as shown. These curves show that the areas are the same when the slope of the retainer bar is 41 degrees and the slope of the seal bar is 49 degrees. These slopes are approximated by the more practical design of 40-50-degrees.

In the 45-45-degree seal the area available for the rubber decreases as the seal bar is extended. Therefore, when oversize rollers are used, sealing pressures become excessive.

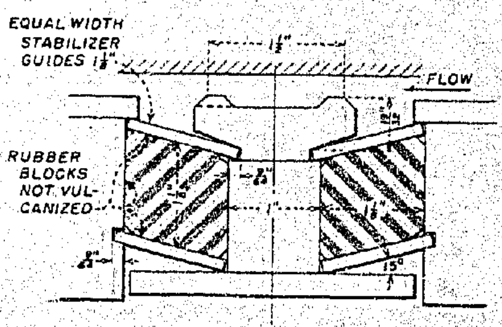
FIGURE 10



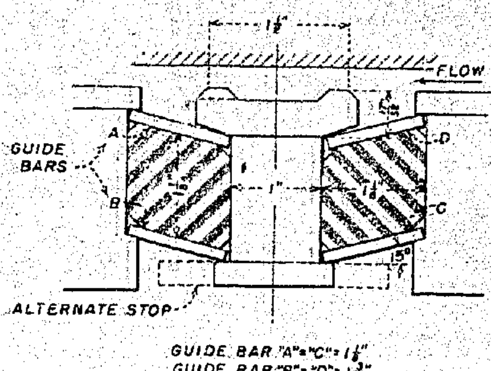
DESIGN 1
FLOATING SHEAR SEAL
ORIGINAL DESIGN



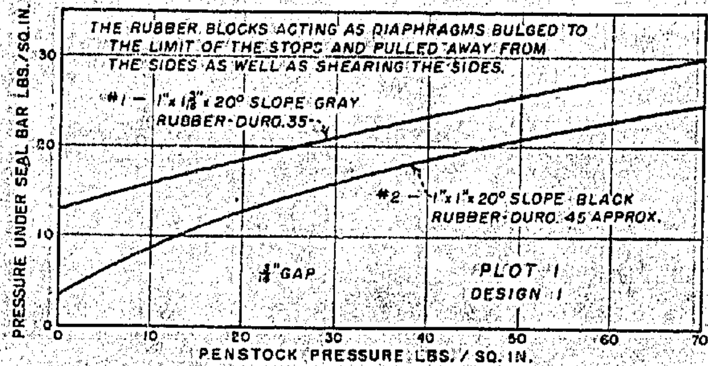
DESIGN 2
STABILIZED SHEAR SEAL
VARIATION OF DESIGN 1

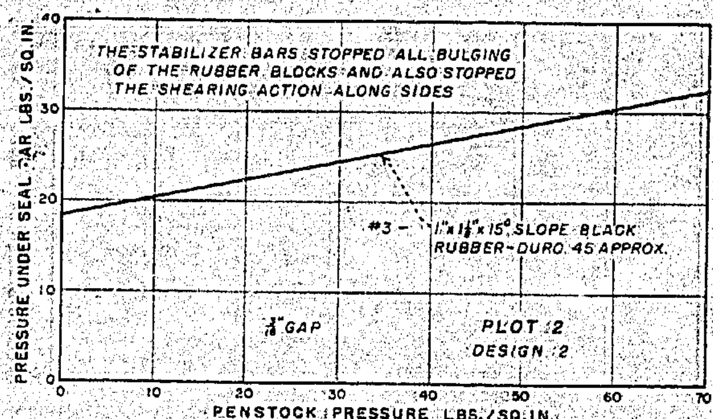


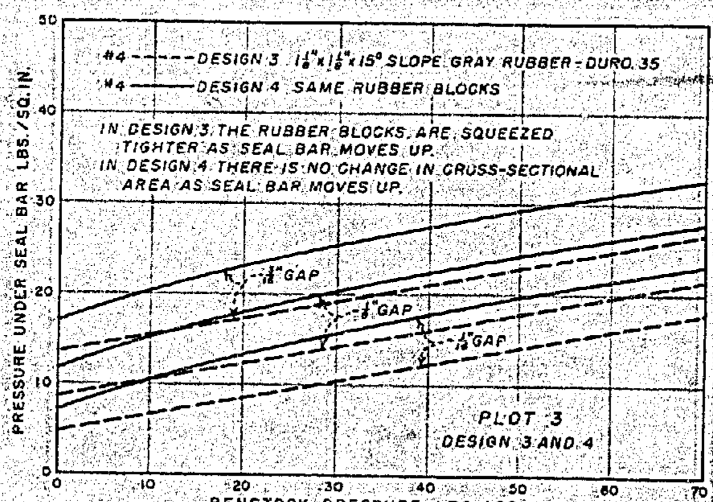
DESIGN 3
STABILIZER-GUIDED SHEAR SEAL
RECESSED GUIDE BARS
RUBBER NOT VULCANIZED



DESIGN 4
GUIDE BARS NOT RECESSED
VARIATION OF DESIGN 3







GATE SEAL DESIGNS AND TESTS
SHEAR SEALS
DEVELOPMENT OF DESIGNS
VISUAL SECTIONAL SEAL MODEL

Shear seals (figure 10). The shear seal was developed by applying the principle used in designing rubber springs wherein the rubber is subjected to shearing stresses only. This principle provides an effective method for storing energy in the rubber so that it is available for the retractive effort. The progressive stages of the design of the shear seal are shown in this figure.

In design 1, the metal parts were attached to the sides of the rubber blocks by means of a suitable cement. After several trials it was found that "running board matting cement" was the most satisfactory for this purpose. Although this design had a good retractive force, it was unsatisfactory because the rubber blocks distorted badly when hydraulic pressures were applied. This distortion of the blocks when the seal operates under a pressure of 68 pounds per square inch is shown in plate 6, A and B.

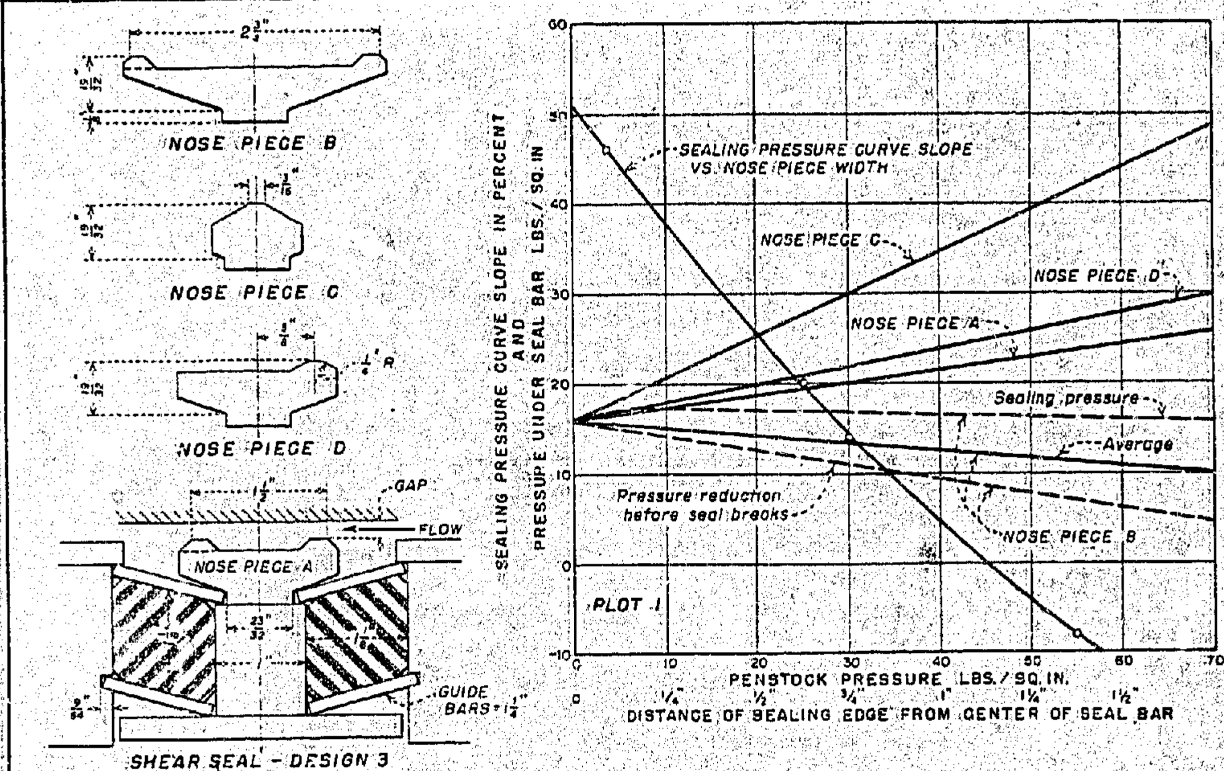
In order to prevent the distortion, design 2 was made with metal plates above and below the rubber blocks as shown in plate 6 C. These plates were also cemented to the blocks. The addition of these plates completely eliminated the distortion of the blocks. The action of this seal was very satisfactory as demonstrated in plate 6 D.

In design 3, the metal parts holding the rubber blocks were simplified and all cementing was eliminated. Watertightness was obtained by making the blocks slightly oversize so that they were under compression after installation. The corners of the blocks were chamfered to provide clearance for excess rubber. The action of this seal is shown in plate 6 E and F. It will be noted that in this design the blocks are compressed as the seal bar is extended. The voids shown in E are completely filled in F.

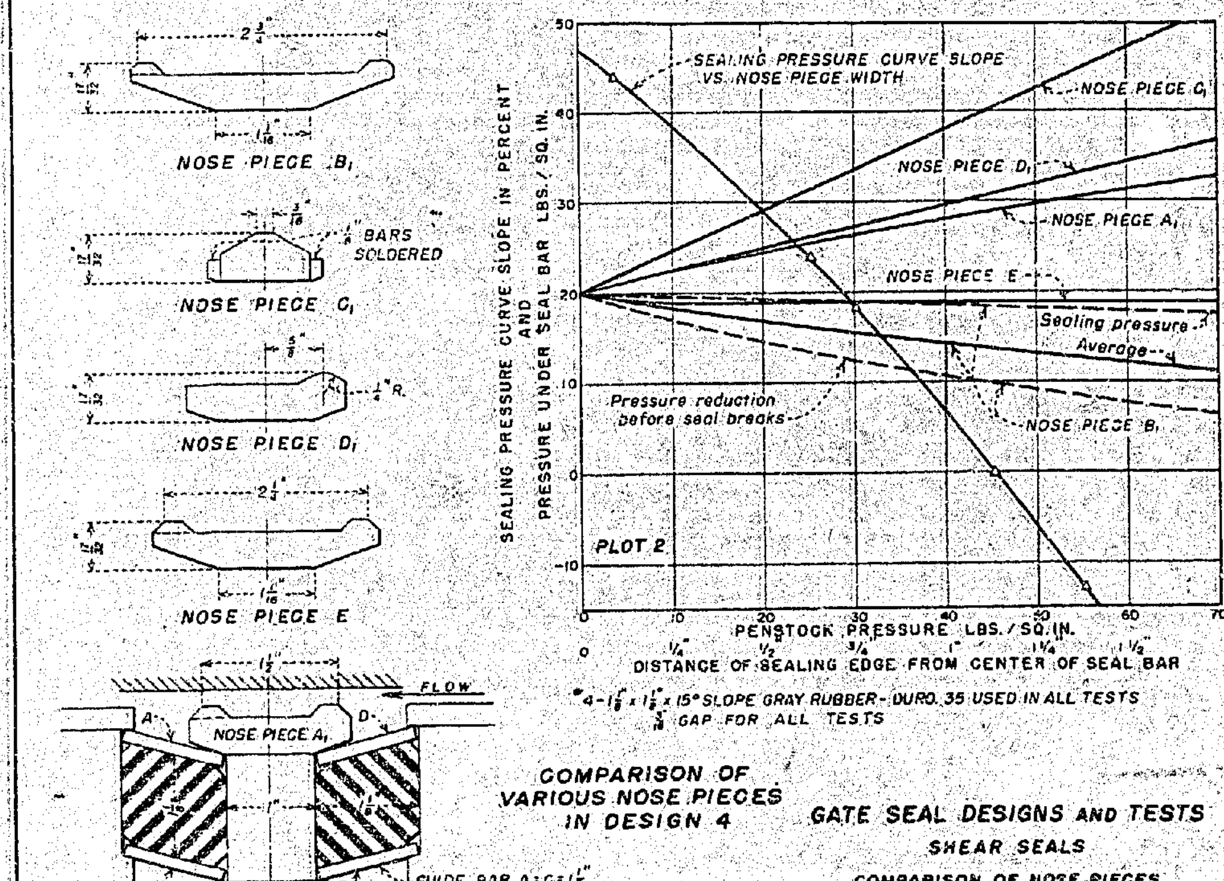
In design 4, additional simplification was obtained by eliminating the grooves for the guide plates, as shown in plate 6 G and H. In this design most of the additional compression of the blocks which occurs when the seal bar is extended has been eliminated. Design 4 retracted better than design 3 because friction at the hinges had been reduced. A special test was made to determine the watertightness of the blocks in design 4. Leakage past the ends of the blocks was prevented by smearing a sticky modeling clay on the ends of all parts before assembly. The seal bar was then closed under the maximum available pressure of 70 pounds per square inch and proved to be droptight. The seal was opened and closed several times and each time it sealed droptight.

The sealing-pressure curves for the designs illustrated are given in the plots together with the types of rubber blocks used in each case.

FIGURE II



COMPARISON OF VARIOUS NOSE PIECES IN DESIGN 3



*4 - 1 1/8" x 1 1/8" x 15° SLOPE GRAY RUBBER - DURO. 35 USED IN ALL TESTS
3/16" GAP FOR ALL TESTS

COMPARISON OF VARIOUS NOSE PIECES IN DESIGN 4

GATE SEAL DESIGNS AND TESTS

SHEAR SEALS

COMPARISON OF NOSE PIECES IN DESIGN 3 AND 4

VISUAL SECTIONAL SEAL MODEL

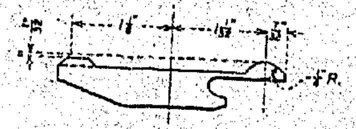
Shear seals - Comparison of nosepieces (figure 11). In testing the different types of seals, it was necessary to use different nosepieces. It was noticed that the width of the nosepiece had a marked effect on the amount of sealing effort required and also on the tendency of the seal bar to cock when it was extended. It was decided that a more thorough investigation of this effect should be made so that some criterion for selecting the proper nosepiece could be set up. A comparison of the different nosepieces is given in the accompanying figure. The two designs of seals used for the comparison have the same rubber blocks so that this feature is not a variable.

The results of the tests are shown in graphical form where the required sealing pressure for each nosepiece is plotted against the penstock pressure. These plots resulted in practically straight lines of different slopes, depending on the nosepiece being considered. A curve was then constructed by plotting the width of each nosepiece against the slope, expressed in percent, of its corresponding line in the previous plot. From this curve it is possible to select a width of nosepiece to give any required sealing characteristic. Nosepiece E provides a good example of such a selection. It was decided that a nosepiece having a constant sealing effort should be tested. From the curve in plot 1, described above, which was based on tests of design 3, a width was selected to give zero slope of the sealing-pressure curve. This nosepiece, labeled E, was made up and tested in design 4. It is evident from the test results shown in plot 2, that this nosepiece has a practically constant sealing effort.

In general, the sealing effort is higher for design 4. The reason for this difference is the additional leverage resulting from the extra width of the guide plates in design 3. It is also apparent from the plots that the sealing pressure decreases with the increase in width of nosepiece. However, there are certain drawbacks to offset this advantage. It was found that the tendency of the seal bar to tip and snap shut increased with the width of the nosepiece. In addition it was found that an increase in width of nosepiece decreased the ability of the seal bar to retract when the pressure under it was relieved. The reason for this action is the fact that with a wider nosepiece there is a larger force, due to the increase in area, which acts to tip the seal bar and also to aid sealing. This force also acts against the retraction effort of the seal. An additional force which interferes with proper action of the seal results from the drawdown in pressure above the nosepiece when the seal is broken and water starts to fill. The wider nosepieces form a passage which has sufficient length to make the passage flow downstream from the sealing edge and since the passage is diverging, negative pressures are set up. These points must be considered in the design of a satisfactory seal.

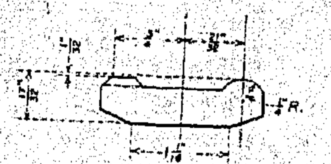
Photographs which illustrate the action of the various nosepieces in the two designs of seals, are shown in plate 7. Tilting of the seal bar is particularly noticeable in views A and C.

FIGURE 12

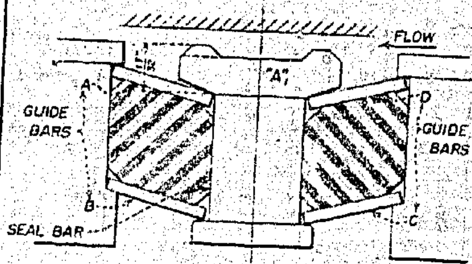


NOSE PIECE E_2
VARIATION OF NOSE PIECE E_1

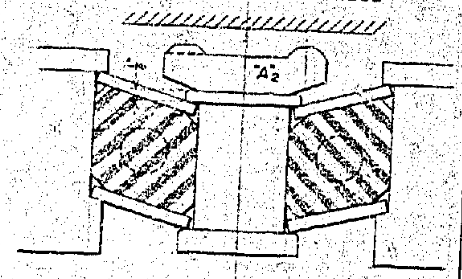
NOSE PIECE D_1



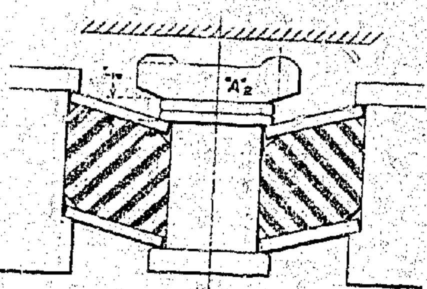
NOSE PIECE A_2
VARIATION OF NOSE PIECE A_1



SHEAR SEAL - DESIGN 4
NO SHIM UNDER NOSE PIECE



SHEAR SEAL - DESIGN 5
1/8" SHIM UNDER NOSE PIECE



SHEAR SEAL - DESIGN 6
2-1/8" SHIMS UNDER NOSE PIECE

NOSE PIECE	ACTION OF SEAL BAR ON RISING	ACTION ON SEALING ABOVE 40#/□" HEAD	ACTION OF SEAL BAR WITH PRESSURE UNDER IT EQUAL TO HEADS OVER 40 #/□"	CLASSIFICATION OF SEAL ACTION
NO SHIM UNDER NOSE PIECE				
OPPOSITE GUIDES "A" AND "C" EXACT WIDTH - "B" AND "D" UNDERSIZE				
A_1 and A_2	Cocks to right	Closes with a snap-cocks left	Cocks to right to close downstream gap	Excessive cocking
D_1	Without cocking	Closes with a snap	Cocks to right to limit of guide bars	Extreme cocking
E_2	Cocks to right	Closes with a snap	Cocks to right to close downstream gap.	Excessive cocking
DOWNSTREAM GUIDES "A" AND "B" EXACT WIDTH				
A_1 and A_2	Without cocking	Snaps shut within 1/32" of closed	Cocks to right to close downstream gap	Excessive cocking.
D_1	Cocks to left	Closes with a snap	Cocks to right	Excessive cocking
E_2	Cocks to left	Snaps shut when within 1/16" of closed	Straightens up and does not cock either way	Fair action but too wide
1/8" SHIM UNDER NOSE PIECE				
OPPOSITE GUIDES "A" AND "C" EXACT WIDTH - "B" AND "D" UNDERSIZE				
A_2	No cocking to within 1/16" of closed then cocks left	Snaps closed and cocks left	Cocks right to barely close downstream gap	Excessive cocking
E_2	Cocks right to 1/16" of closure, then cocks left	Seals with snap and cocks left	Cocks right to close downstream gap	Excessive cocking
DOWNSTREAM GUIDES "A" AND "B" EXACT WIDTH - "C" AND "D" UNDERSIZE				
A_2	Without cocking	Closes without snap - slight cocking to left	Seal bar straightens up and cannot be cocked to right	Best action - practically no cocking
A_2" with different rubber blocks*5	Without cocking	Without cocking	Without cocking up to 120 #/□"; with rubber blocks having a 2" hole axially and 15° slope	Same as above - no cocking
E_2	Cocks left slightly	Closes without snap-cocks left to limit of guides	Straightens up and does not cock to right	Action good - too wide a nose piece
1/4" SHIM UNDER NOSE PIECE				
OPPOSITE GUIDES "A" AND "C" EXACT WIDTH - "B" AND "D" UNDERSIZE				
A_2	Slight cocking left	Closes without snap-cocks left	Slight cocking to right	Action very good
DOWNSTREAM GUIDES "A" AND "B" EXACT WIDTH - "C" AND "D" UNDERSIZE				
A_2	Cocks to left	Closes with snap and cocks left	Straightens up and does not cock to right	Action poor

NOTES

*4-Rubber blocks used in these tests the same as in former tests.
*5-Rubber blocks as described on following plate in Shear Seal Design 5.

The above tests were made with the definite plan to balance hydraulic forces acting on the seal bar so that no cocking would result, and good action made possible.

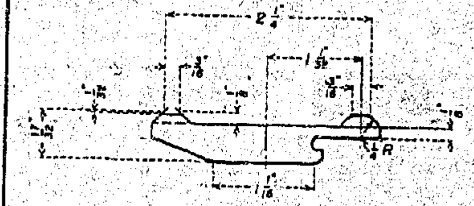
GATE SEAL DESIGNS AND TESTS
SHEAR SEALS
LOCATION OF GUIDE BARS AND SEALING EDGE
HEIGHT AND WIDTH FOR BEST OPERATION
VISUAL SECTIONAL SEAL MODEL

Shear seals - Determination of optimum dimensions (figure 12). In these tests certain modifications of design 4 were made and tested in an attempt to balance the hydraulic forces acting on the seal bar and nosepiece so that there would be no tipping or cocking of the seal.

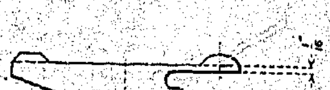
Nosepieces A_1, A_2, D_1, and E_2 were used and their heights measured from the top of the seal bar were varied by inserting 1/8-inch shims of proper width. In design 5, one shim has been added and in design 6, two have been added. Dimensions of the nosepieces are shown along with the test results in this figure. Another modification of the set-up was made by interchanging the guide plates. Two of these plates were 1-1/8 inch and two were 1-3/32 inches in width. The narrower width was used to give the necessary clearance.

The results of the tests of all these variations are shown in tabular form. These tables are self-explanatory. Design 5 with the longer guide plates downstream to guide the seal bar accurately and the shorter plates upstream to give the necessary clearance was found to be the most satisfactory design. Photographs of this design are shown in plate 8. It is evident from these views that no tipping occurs throughout the entire range of pressures from 0 to 120 pounds per square inch. These views also show the recommended design of the rubber blocks. Additional details of the design are shown in figure 13.

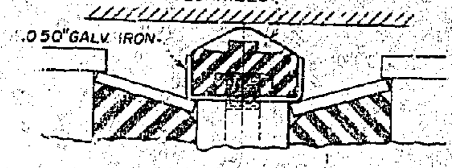
FIGURE 13



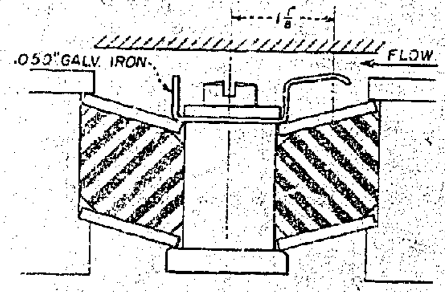
NOSE PIECE E_1
VARIATION OF NOSE PIECE "E"



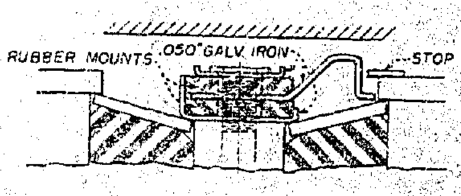
NOSE PIECE E_2
VARIATION OF NOSE PIECE "E_1"



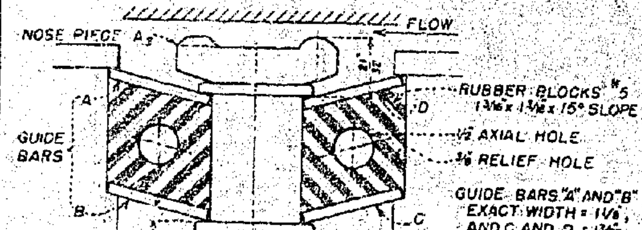
NOSE PIECE F
RUBBER MOUNTED FLEXIBLE CAP



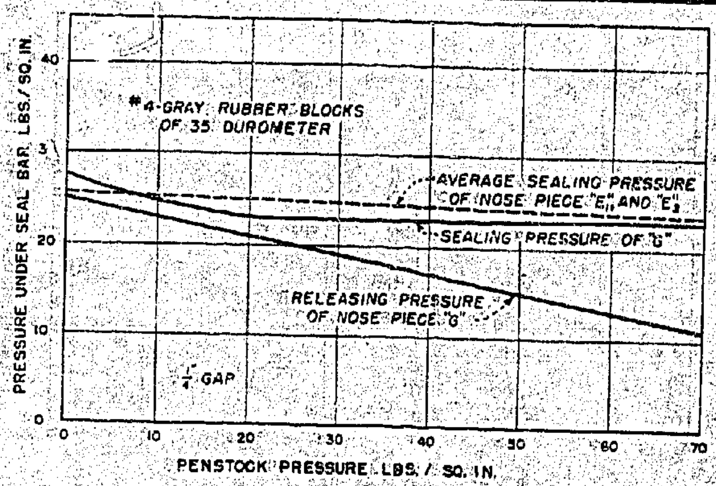
NOSE PIECE G
SHEAR SEAL DESIGN 4 USED IN TESTS

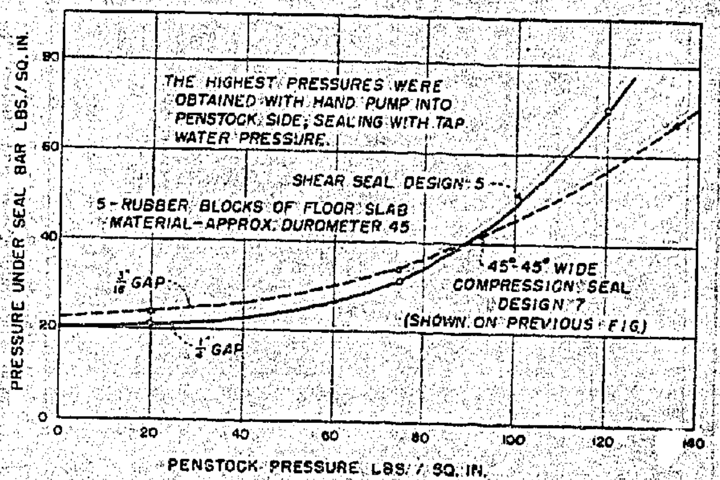


NOSE PIECE H
ORIGINAL DESIGN FOR TESTING FEASIBILITY OF THE CONSTANT CONTACT SEAL



SHEAR SEAL-DESIGN 5
NOSE PIECE CORRECT HEIGHT AND DOWNSTREAM GUIDE BARS EXACT WIDTH
BEST DESIGN FOR RUBBER BLOCKS





The Rubber Gaskets in Shear Seal Design 5 are designed for greater ease of manufacture because the axial hole admits the same process as for hose. The hole furthermore takes care of surplus rubber thus tolerance may be greater. The occasional relief holes allow water pressure to develop inside the gaskets thus providing a still better seal.
The edges of the gaskets need not be chamfered.

GATE SEAL DESIGNS AND TESTS

SHEAR SEALS

FLEXIBLE NOSE PIECES AND BEST SHEAR SEAL DESIGN

VISUAL SECTIONAL SEAL MODEL

Shear seals - Flexible nosepieces and best shear-seal design (figure 13). The flexible nosepieces shown are a few of the designs made and tested. In order that a seal be effective, it is necessary that the seal bar conform to the seating surface. Flexible nosepieces were investigated for this purpose.

The photographs on plate 9 show three of these nosepieces. The rubber-mounted nosepiece in views B and C and its behavior under pressure are particularly interesting.

Design 5, which is also shown in plate 9 was designed from the data compiled in figure 12. The nosepiece height and width and the length of the guides were selected for best performance. The rubber blocks are considered to be the best design from the standpoint of both operation and manufacture.

A condition experienced in practically all tests is shown in plate 9 F. The suction pressure developed above the seal bar assisted in the sealing operation when the penstock pressure and volume of water was great enough to give velocities of appreciable magnitude in the gap. As the sealing pressure was slowly released, the seal bar retracted about 1/32 inch and did not completely retract until the pressure under it dropped below 3 pounds per square inch. The suction pressure assists in slamming the seal bar into the sealed position. In some cases the slam was rapid enough to cause water hammer.

Nosepiece "E" of figure 11 was designed of such a width that the sealing pressure would remain constant regardless of the head. "E_1" was made from "E" and a further change to produce some measure of flexibility was made resulting in "E_2."

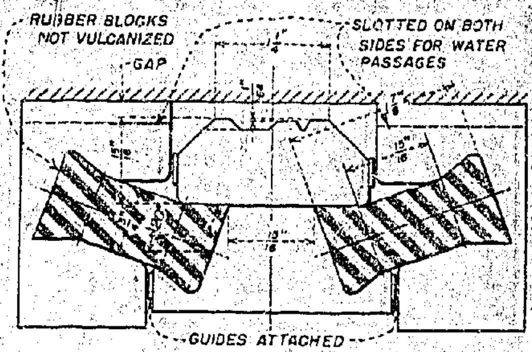
Nosepiece E_2 showed slight bending of the sealing edge at the higher heads. The rounded sealing edge offered a greater area in contact than the sharp corner of "E."

Nosepiece "F" was designed to make the sealing edge as flexible as possible to take care of any waviness in the contact surfaces of the nosepiece or the seat. The brass sealing cap strip floats on rubber and is vulcanized to it. It is realized that a rubber contact would make a perfect seal because of its inherent resilience, but the sticking of the rubber to the seat presents serious drawbacks to a solid rubber nosepiece.

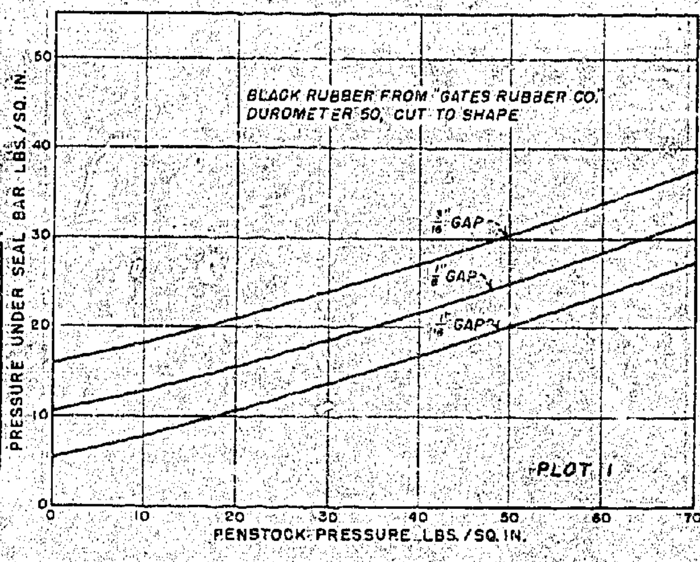
Nosepiece "G" is an overhanging sealing edge that has little stiffness. From the curve of "releasing pressure of nosepiece 'G'" it is seen that retraction is retarded as head is increased. The sealing edge also closed with a snapping action.

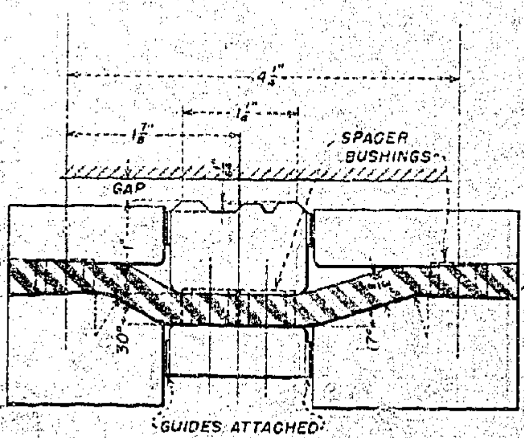
Nosepiece "H" is flexible and by means of the rubber mounting it performs as a constant contact seal and could be as such.

FIGURE 14

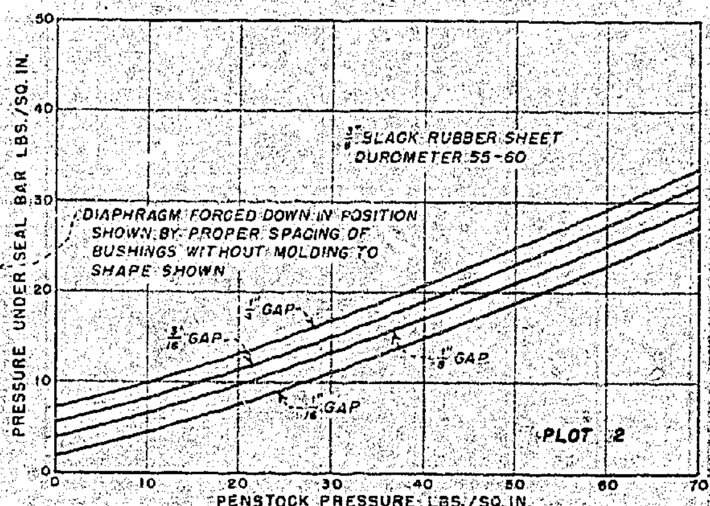


DESIGN 1
MOLDED RUBBER BLOCK DESIGN





DESIGN 2
MOLDED RUBBER DIAPHRAGM DESIGN

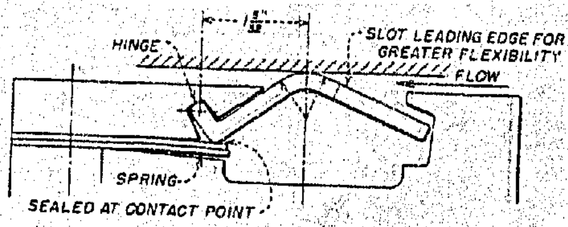


GATE SEAL DESIGNS AND TESTS
DIAPHRAGM TYPE SEALS
VISUAL SECTIONAL SEAL MODEL

Diaphragm-type seals (figure 14). Two designs of diaphragm seals were made and tested. In design 1, the rubber blocks act in bending and shear. The shear action is somewhat like that of the shear-type seal, particularly like design 1 in figure 10 and plate 6, in that the rubber is not restrained. Retraction was complete and quick under all operating conditions. Sealing-pressure curves are shown in plot 1. The model in operation under normal conditions is shown in plate 10, views A, B, and C. In this case the seal bar is equipped with guides as shown in figure 14. View D shows the serious cocking of the seal bar and the manner in which it is moved downstream when the guides are removed.

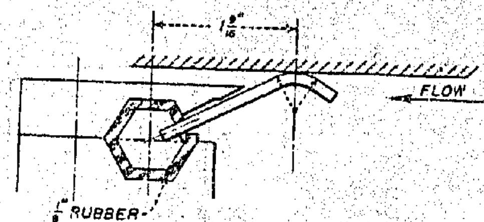
The rubber diaphragm of design 2 would be molded ordinarily but in making this small model it was impractical to obtain a molded diaphragm. Therefore, it was cut from flat rubber stock on hand and forced into shape in the assembly. It was necessary to provide guides for the seal bar to prevent cocking. Sealing pressures were lower than those of design 1, as shown in plot 2; retraction was sluggish and not positive. The action of the seal for various operating conditions is shown in plate 11. View A shows only a slight extrusion of the rubber at the clamped edges while B shows a thickening of the diaphragm when the seal bar is in the sealed position. With greater pressures above and below, the diaphragm bulges as shown in views C and D.

FIGURE 15



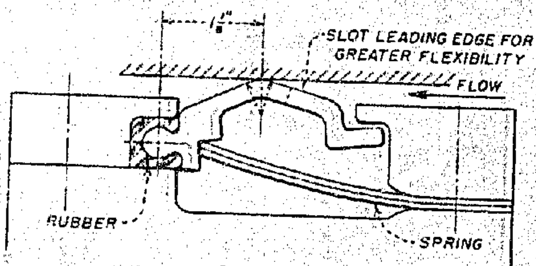
DESIGN 1
SPRING ON DOWNSTREAM SIDE
HINGE IN METAL GROOVE

Sealing is accomplished at any head.
The spring keeps the seal bar in contact for very low heads.
Hydraulic pressure under spring makes seal at contact edge.
Line pressure per inch on sealing edge is about 3/8 of the head.



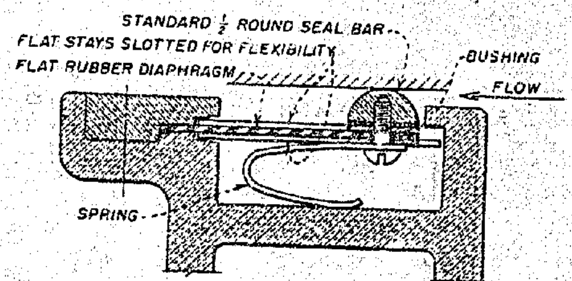
DESIGN 2
RUBBER MOUNTED HINGE

Sealing is accomplished at any head.
The rubber mounted hinge keeps the seal bar in contact at very low heads, provides a seal at the hinge and also some flexibility for the seal bar.
Line pressure per inch on sealing edge is about 9/10 of the head.



DESIGN 3
SPRING ON UPSTREAM SIDE
RUBBER MOUNTED HINGE

Sealing is accomplished at any head.
The rubber mounted hinge provides a seal at the hinge and some flexibility for the seal bar.
The spring keeps the seal bar in contact for very low heads and also holds the seal bar in place at the hinge.
Line pressure per inch on sealing edge is about one-half of the head.



DESIGN 4
FLEXIBLE SEALING EDGE
ENCLOSED RUBBER DIAPHRAGM

Sealing is accomplished at any head.
The brass stays give rigidity to the seal design and the slots provide flexibility to the seal bar. If sealing surfaces are not parallel, seal bar will conform to its seat.

GATE SEAL DESIGNS AND TESTS
CONSTANT CONTACT SEALS
VISUAL SECTIONAL SEAL MODEL

Constant-contact self-sealing seals (figure 15). The designs shown in this figure are developments which may be used to advantage with low heads. This type of seal seals against any pressure but does not retract. In all four designs, the seal bar remains against the seat at zero pressure. Penstock pressure exerted directly on the bar furnishes the sealing force. The line contact pressure along the sealing line was kept to a minimum in these designs.

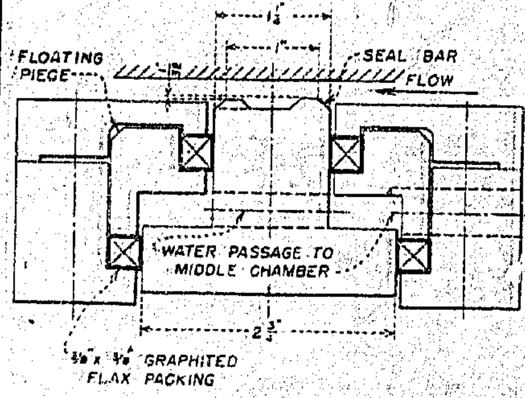
Tests showed that designs 1 and 2 were satisfactory from the standpoint of sealing but that in design 1, particularly, the sealing edge must be parallel to the seat. When the two were not parallel, a perfect contact was not obtained even at heads of 70 pounds per square inch.

A leakage test was made on design 1 with sticky modeling clay smeared on the ends of the seal bar and springs before installation. It was found that sealing was almost droptight at the spring and sealing edge. When a 3/16-inch gap was set up by pulling the seal bar down manually, a pressure of 10 pounds per square inch pulled the seal back strongly and accomplished a seal.

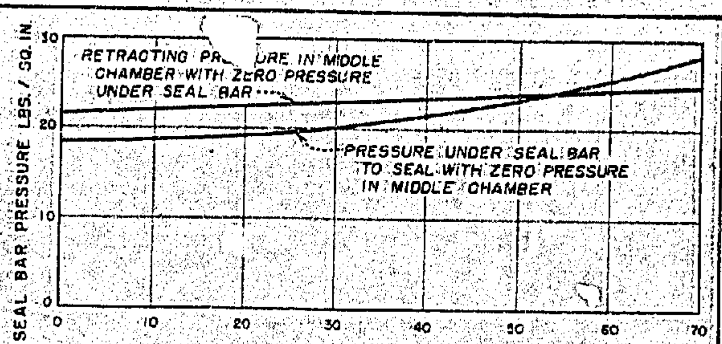
In design 2, the rubber mounting did not hold the seal bar in contact with the seat and compression was apparent with 70 pounds per square inch.

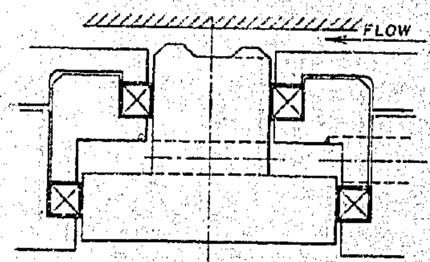
Designs 3 and 4 were not manufactured. The principal advantage of design 3 over design 1 is that the necessity for sealing at the spring contact points is eliminated. Design 4 has the advantages of flexibility at the sealing edge and greater possible movement over the other designs. This design is an adaptation of the stabilized-flexible diaphragm seal shown in figure 17.

FIGURE 16

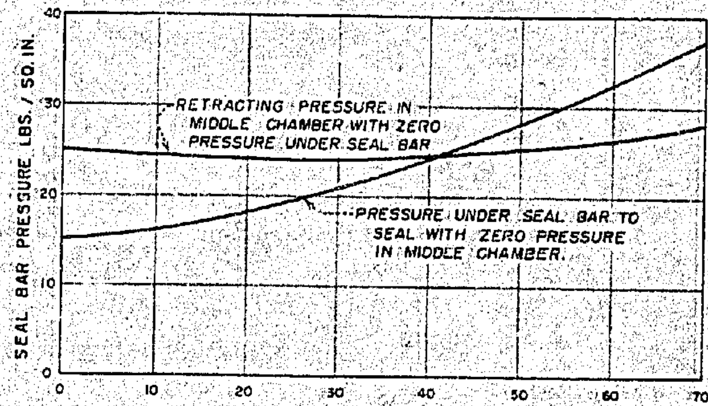


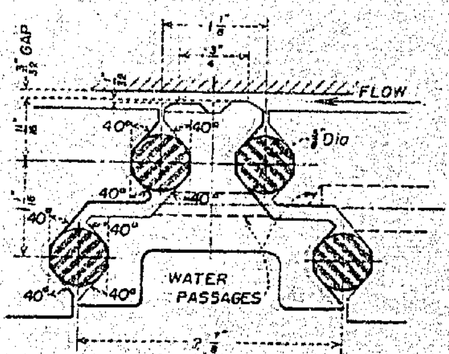
DESIGN 1
DOUBLE ACTING PACKING GLAND SEAL
SEALING EDGE UP STREAM
NORMAL SET-UP



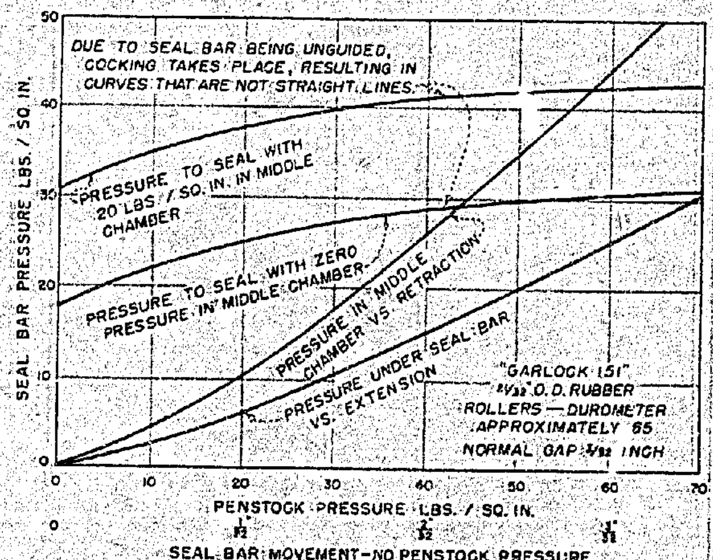


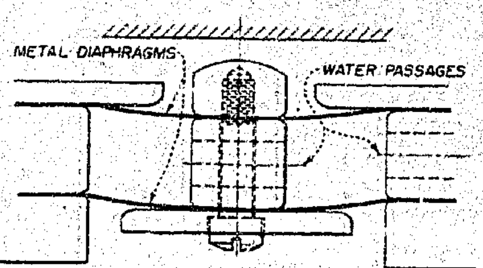
DESIGN 1 REVERSED
DOUBLE ACTING PACKING GLAND SEAL
SEALING EDGE DOWNSTREAM
ABNORMAL SET-UP





DESIGN 2
DOUBLE ACTING ROLLER SEAL
40° SLOPES - 21/32 ROLLERS





DESIGN 3
DOUBLE ACTING DIAPHRAGM SEAL
SHEET METAL DIAPHRAGMS

NOTES ON DESIGN 3

Sheet tin .010" thick withstood 70 lbs. per sq. in.
The diaphragms buckle between contact points when passing shortest distance between them.
There was slight cocking taking up slack in the diaphragms.
Seal Bar can be made to retract against pressure under it.

GATE SEAL DESIGNS AND TESTS
DOUBLE ACTING SEALS
VISUAL SECTIONAL SEAL MODEL

Double-acting seals (figure 16). The double-acting seals shown in figure 16 were designed to produce positive sealing as well as positive retraction of the seal bar. The seal bar is actuated by hydraulic pressures applied to it in three chambers. Pressure in the chamber under the bar tends to extend it and pressure in the two middle chambers tends to retract it.

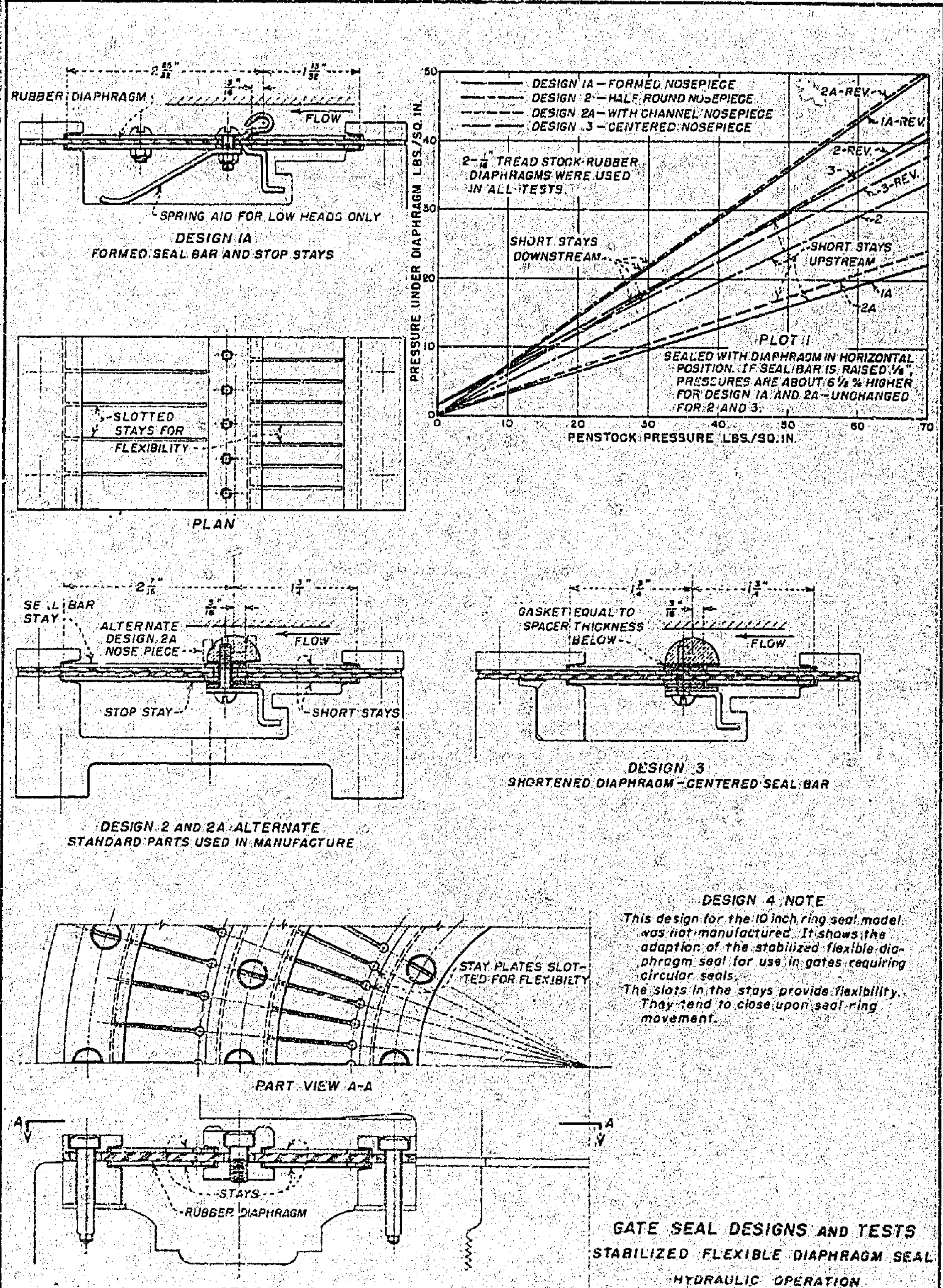
In the operation of the model made according to design 1, the seal-bar action was very good. There was no cocking or chatter and the movement was quite smooth. However, the graphited grease from the packing stuck to the brass seal bar and increased the friction somewhat. It was not necessary to tighten the packing very much to prevent leakage. Sealing and retracting pressures required for the operation of this seal are shown in plot 1.

A test was conducted on design 1 with the seal bar reversed in position. It was found that for penstock pressures above 20 pounds per square inch, extension of the seal bar was assisted by the formation of a reduced pressure above the seal bar. As the seal bar came within 1/32 inch of the sealed position, additional pressure was required to force it into the fully sealed position. Sealing and unsealing pressures are indicated by the operation curves in plot 2. Photographs of this seal in operation are shown in plate 12, A and B. It will be noted that there is no cocking of the seal bar.

Design 2 utilizes information obtained in previous tests. Slots for the rollers have angles of 40 degrees from vertical and are shaped around a 5/8-inch diameter circle for rubber rollers with a diameter of about 21/32 inch. The seal performed very well in sealing and retracting. Tests showed that the seal-bar guides are necessary at the sealing edge on the downstream side and are probably not needed elsewhere because the rubber rollers stabilize the seal bar to a large extent. Two of the curves in plot 3 show the pressures required to move the seal bar in extension and retraction with no penstock pressure. Two other curves show the pressures necessary to perform sealing against penstock pressure with two different pressures in the middle chambers. These pressure curves show a gradual reduction in slope, with the higher penstock pressures, due to the unguided action of the seal bar at the higher heads. The seal bar had a tendency to cock and snap shut into the sealed position but there was no chatter. This seal is shown in operation in plate 12, views C, D, E, F, G, and H.

A model of design 3 was made and tested. The sheet metal diaphragms were installed in the bowed position as shown to provide enough freedom for at least 1/4-inch movement of the seal bar. Consequently they buckled when the seal bar moved through the horizontal center position.

FIGURE 17



GATE SEAL DESIGNS AND TESTS
STABILIZED FLEXIBLE DIAPHRAGM SEAL
HYDRAULIC OPERATION
VISUAL SECTIONAL SEAL MODEL AND
10 INCH RING SEAL MODEL

Stabilized flexible diaphragm seals (figure 17). The stabilized flexible diaphragm seal, which is shown in figure 17, was developed from the investigations which have already been described. It was found that in diaphragm seals, the diaphragms when free to move, responded readily to the slightest pressure but due to lack of rigidity, distorted in the direction of the applied force until a definite stop was reached. From the tests of the shear seals and constant-contact seals, it was found that the seal-bar face must be parallel to the seating surface in order to insure perfect sealing. In all the seal designs wherein energy stored in the rubber was used in retracting the seal bar, chatter, which varied in intensity and frequency, developed at the sealing position. This difficulty was generally eliminated by increasing the rate of application of the sealing pressure but there still remained a tendency for the seal bar to accomplish its final closure by slamming. The tests also established the fact that, in all the retractable seals except the double-acting types, the retractive force increased with the pressure required to move the seal bar against zero penstock pressure. The tests also brought out the necessity for accurate guiding of the seal bars to prevent tipping or cocking. The design of the stabilized flexible diaphragm seal represents an attempt to compromise all of these factors.

Details of the design are shown in the figure together with curves showing the sealing pressure versus penstock pressure for the different designs and nosepieces. The operation of this type of seal was very satisfactory. The seal bar moved smoothly into its sealing position without any chatter or cocking. The bar retracted at once when the pressure under the diaphragm was lowered from that required for sealing. Complete retraction was accomplished with a penstock pressure of about 3 pounds per square inch and zero pressure under the diaphragm. Most of this force was necessary to overcome friction along the edges of the diaphragm and glass. Photographs of the operation are shown in plate 13.

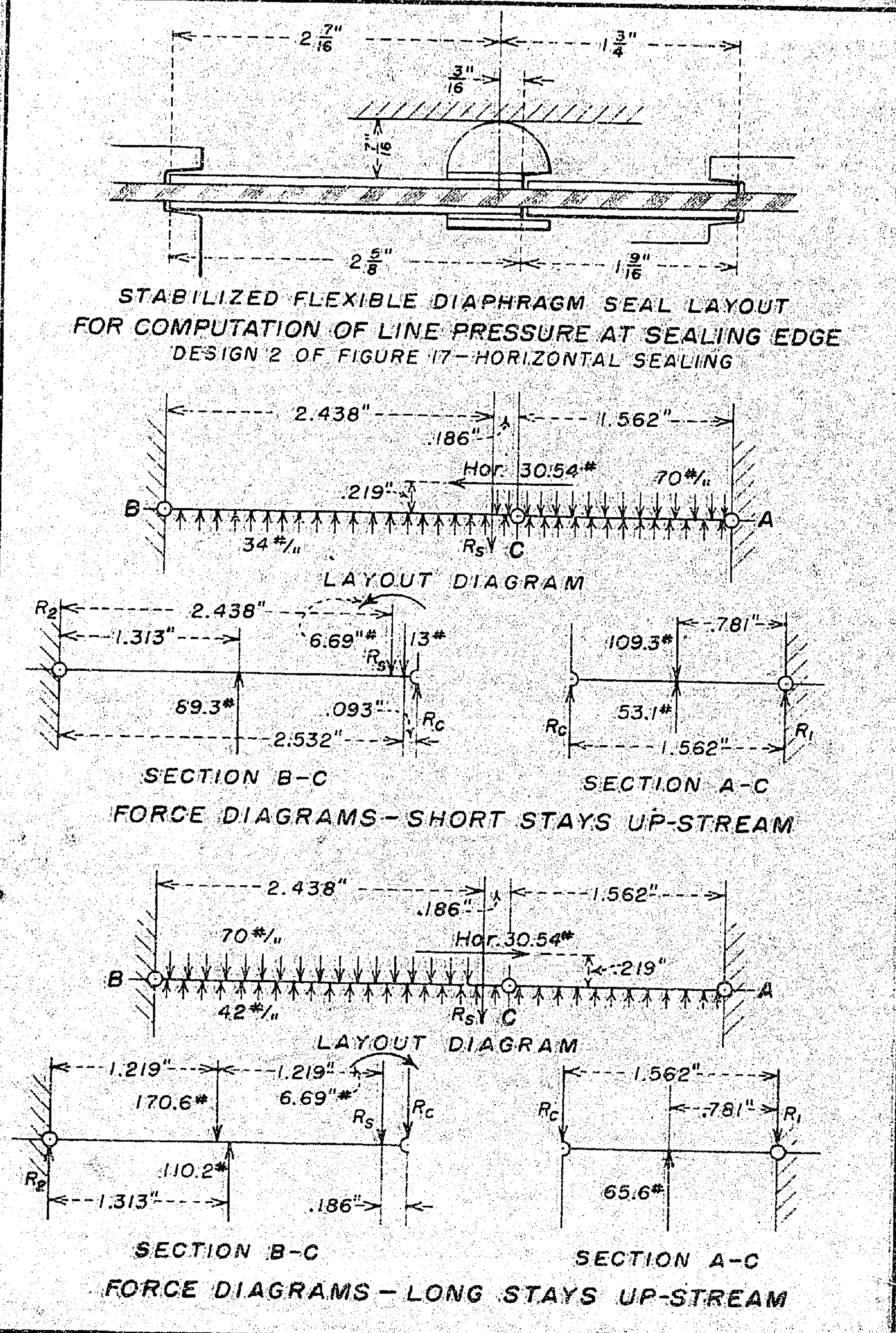
The flexibility of this type of seal was investigated by forcing the seal bar up to the seat with a bar 1/16 inch thick above one end. It required about 5 pounds per square inch to force the unrestrained end up to the seat. In this position, the seal has been twisted by 1/16 inch in a length of $2\frac{1}{2}$ inches.

Design 3 is essentially the same as design 2 with the span shortened. This change did not affect the sealing action but did eliminate the bending of the stay plates at the higher pressures.

Each design was tested in the reversed position and the results are shown in the plot. This reversing of the seal had the effect of changing the location of the sealing point for designs 1A, 2, and 2A. The curves of sealing pressure versus penstock pressure show the effect of this change. From the curves it is possible to estimate, by interpolation, the required sealing pressure for any location of the sealing point within the range shown.

Design 4 which was intended for the 10-inch ring-seal model and never tested is included because it shows the adaptation of this type of seal to circular gates. It shows the method of slotting the stays to obtain flexibility. Two joints are necessary at the seal ring to permit its movement without twisting.

FIGURE 18



STABILIZED FLEXIBLE DIAPHRAGM SEAL LAYOUT
FOR COMPUTATION OF LINE PRESSURE AT SEALING EDGE
DESIGN 2 OF FIGURE 17 — HORIZONTAL SEALING
LAYOUT DIAGRAM
SECTION B-C
SECTION A-C
FORCE DIAGRAMS — SHORT STAYS UP-STREAM
LAYOUT DIAGRAM
SECTION B-C
SECTION A-C
FORCE DIAGRAMS — LONG STAYS UP-STREAM

Line-contact pressure for sealing (figure 18). From time to time the question has arisen as to how much line contact is required between the seal bar and the seat in order to accomplish a seal. Although the proper evaluation of this line-pressure involves a consideration of the finishes of the two surfaces and the flexibility of the seal bar, it was felt that an analysis of the stabilized flexible diaphragm seal, neglecting the quality of the finish, would supply a reasonable value for thispressure. This analysis which is given in detail below indicated that the line pressure must be approximately 10 percent of the penstock pressure.

The values of sealing pressure used in the computations were obtained at 70 pounds per square inch penstock pressure with the stays and diaphragm in a horizontal position. Sealing was accomplished with 34 and 42 pounds per square inch under the diaphragm for short stays and long stays upstream, respectively. The sketches in figure 18 indicate the distributions of forces for both cases. The hinges are assumed to be frictionless.

Short stays upstream. Referring to the figure, the value of R_c in section A-C is obtained by taking moments about R_1. Clockwise rotation is considered positive.

$$(53.1 - 109.3)0.781 + R_c \times 1.562 = 0$$

$$R_c = \frac{-56.2 \times 0.781}{1.562} = -28.1 \text{ pounds}$$

Taking moments about R_2 in section B-C:

$$13 \times 2.532 - 89.3 \times 1.313 - (-28.1 \times 2.625) - 6.69 + R_s \times 2.438 = 0$$

$$R_s = \frac{32.93 - 117.2 + 73.75 - 6.69}{2.438} = \frac{-17.21}{2.438} = -7.06$$

or line-contact pressure equals 7.06 pounds per lineal inch.

Long stays upstream. Referring to the figure, the value of R_c is obtained by taking moments about R_1 in section A-C

$$65.6 \times 0.781 - R_c \times 1.562 = 0$$

$$R_c = \frac{-51.2}{1.562} = -32.8 \text{ pounds}$$

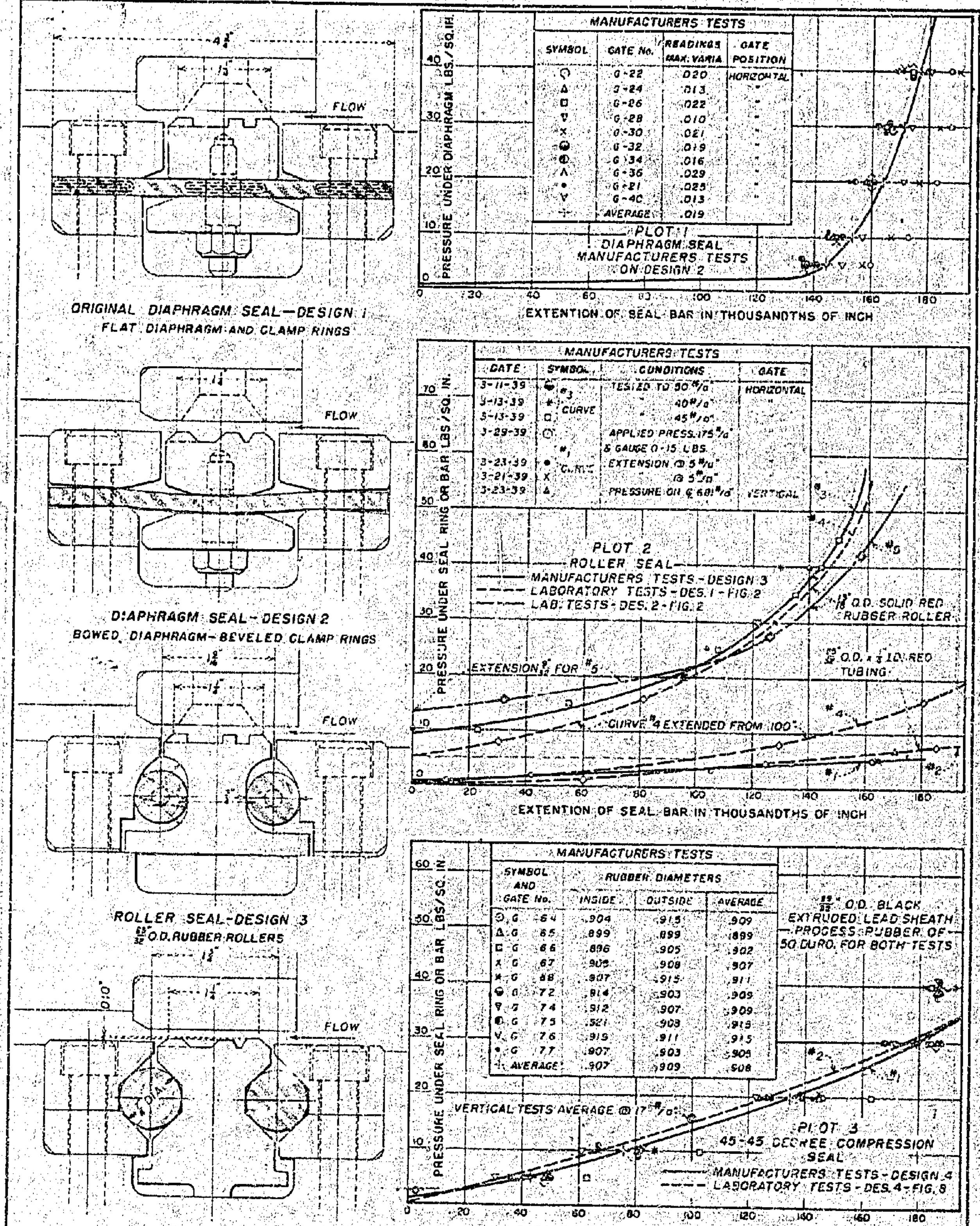
Taking moments about R_2 in section B-C:

$$170.6 \times 1.219 - 32.8 \times 2.625 - 110.2 \times 1.313 + 6.69 + R_s \times 2.438 = 0$$

$$R_s = \frac{208.1 - 86.1 - 144.8 + 6.69}{2.438} = \frac{-16.11}{2.438} = -6.62$$

or line-contact pressure equals 6.62 pounds per lineal inch.

FIGURE 19



MANUFACTURERS TESTS (Plot 1)

SYMBOL	GATE No.	READINGS MAX. VARIA	GATE POSITION
○	G-22	.020	HORIZONTAL
△	G-24	.013	"
□	G-26	.022	"
▽	G-28	.010	"
×	G-30	.021	"
◒	G-32	.019	"
◐	G-34	.016	"
∧	G-36	.029	"
•	G-21	.025	"
V	G-40	.013	"
+	AVERAGE	.019	

MANUFACTURERS TESTS (Plot 2)

DATE	SYMBOL		CONDITIONS	GATE
3-11-39	◒	#3	TESTED TO 50 #/□"	HORIZONTAL
3-13-39	*	CURVE	" 40 #/□"	"
3-13-39	□		" 45 #/□"	
3-29-39	○		APPLIED PRESS. 175 #/□"	
		#1	& GAUGE 0-15 LBS.	
3-23-39	●	CURVE	EXTENSION @ 5 #/□"	
3-21-39	X		" @ 5 #/□"	
3-23-39	△		PRESSURE ON ℄ 68 #/□"	VERTICAL

MANUFACTURERS TESTS (Plot 3)

SYMBOL AND GATE No.	RUBBER DIAMETERS INSIDE	OUTSIDE	AVERAGE
○ G 64	.904	.915	.909
△ G 65	.899	.899	.899
□ G 66	.896	.905	.902
x G 67	.905	.908	.907
* G 68	.907	.915	.911
◒ G 72	.914	.903	.909
▽ G 74	.912	.907	.909
◐ G 75	.521	.903	.913
V G 76	.919	.911	.915
• G 77	.907	.903	.905
+ AVERAGE	.907	.909	.908

45-45 DEGREE COMPRESSION SEAL
DESIGN 4
29/32" O.D. RUBBER GASKETS

GATE SEAL DESIGNS AND TESTS
102" RING SEAL GATE DESIGNS
COMPARISON OF MANUFACTURERS TESTS ON FULL SIZE GATES WITH LABORATORY TESTS

COMPARISON OF MODEL TESTS WITH MANUFACTURERS' TESTS

Although the emphasis in making the model tests was qualitative, many quantitative tests were made and, since the manufacturers' tests are available, a comparison between the two will be made. The comparison is necessarily a limited one because the two series of tests were made in different ways. The manufacturers' tests consisted of measuring the extension of the seal bar corresponding to various pressures under it. These tests were made on the 102-inch ring seals without taking into account the effect of penstock pressure. In the model, the tests, which take into account the penstock pressure, consisted mainly of measuring the pressure required to close any given gap against various penstock pressures. It is evident that most comparisons between the two tests must be general rather than specific. Sketches of four designs tested by the manufacturer are shown in figure 19. Many variations in the parts were made on design 1 and tested before arriving at design 2.

The diaphragm seal. In comparing tests on the diaphragm-type of seal, another factor, in addition to the lack of penstock pressure, must be considered. This factor is the extrusion of the diaphragms caused by clamping. Since the action of the seal ring is affected by the amount of extrusion, the tightness of the clamping bolts must be considered in making the comparison. Design 1 is the original design of the diaphragm seal. Design 2, which was developed from design 1, is the final design used in 10 gates at Grand Coulee Dam and in three gates at Seminoe Dam. The results of the acceptance tests on design 2 are shown in plot 1. Each point in the plot represents the average of 8 readings taken at 8 stations equally spaced around the seal ring. The variation in the readings attests the flexing of the seal ring. It is evident from this plot that the seal ring extends up to 9/64 inch with very little pressure but beyond this point, additional extension requires much higher pressures. This change is due to the fact that the diaphragm has reached its stops and diaphragm action ceases. The additional extension is accomplished by shearing action. The sealing-pressure curves in figures 1 and 14 indicate that for similar conditions in the model, that is, at zero penstock pressure, the seal ring extends to the seat with very little pressure. In this case the seal ring seats before the diaphragm reaches its stops and, therefore, diaphragm action maintains. When a laminated diaphragm with three or four layers was used in the model, extrusion of this greater thickness filled the grooves and shearing action occurred as indicated by the large increase in sealing pressure required.

Retraction of the seal ring in the manufacturers' tests was similar to that observed in the model, it being sluggish and generally incomplete.

The roller seal. A comparison of the manufacturers' tests with the model tests in the case of the roller-type seal is complicated by the facts that, because different methods of assembly were used, the initial position of the roller in its slot was not always the same for the two tests. The shapes of the slots also differ. Design 3 has slightly longer slots than those of design 1 in figure 2 but the curves compare very well. Since the operating characteristics of this type of seal depend to a considerable extent upon the initial position of the roller, a direct comparison between the two tests cannot be made unless this initial position is the same in both tests. In the model, the three brass rings were assembled together with the rollers, before placement in the housing so that the rollers could be pushed well up into the slots. In the acceptance tests, this method could not be used so there is no doubt that the rollers end up at the bottom of the slots after the clamping rings are bolted on.

The results of the acceptance tests of design 3 in figure 19 are shown in plot 2. Since the data for these tests are somewhat scattered, references to report dates are tabulated on the plot. Each point plotted represents the average of 9 readings taken at 9 stations equally spaced around the seal ring. The results of the model tests of designs 1 and 2 in figure 2 are also shown in the plot.

In the tests of the tubular rollers, a high-pressure test of 175 pounds per square inch was made. It is reasonable to assume that this pressure would accomplish the same adjustment of the roller position as that obtained manually in the model and that, therefore, the test should agree. The plot of curves Nos. 1 and 2 shows that the agreement is very good. Retraction was complete in both cases when the pressure under the seal ring was reduced to zero.

In the tests of the solid roller, the maximum pressure was only 50 pounds per square inch. This pressure is, no doubt, too small to adjust the solid rollers which would be harder to move than the tubular rollers. The discrepancy between the two tests as shown in the plot is not surprising. It will be noted that in the acceptance tests the pressure required to start movement was as much as 10 pounds per square inch. Obviously, there is some residual force stored in the rollers during assembly and this force prevents easy starting of seal-ring movement. If this same condition is used as a starting point in the model, the results of the two tests should have better agreement. This means that the starting position for the model must be taken at the point where the pressure under the seal ring equals about 10 pounds per square inch. Plot 2 shows the result when this change is obtained by shifting the curves of model performance. Curve No. 4 has been shifted in this manner, whereas only the upper part of curve No. 5 is shown. It is noted that the agreement is much better. Retraction was complete in the model tests but it was sluggish and incomplete in the acceptance tests.

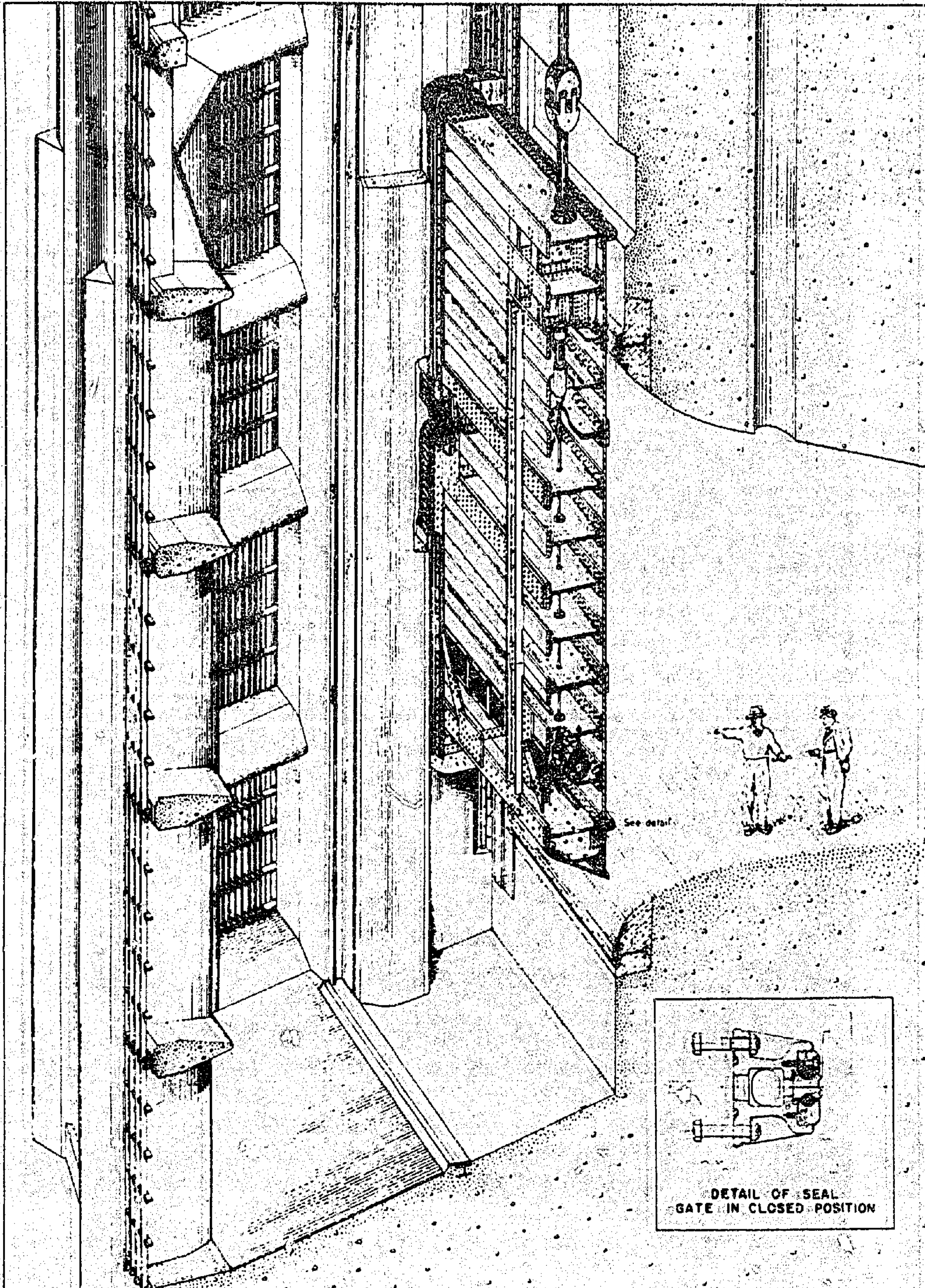
The 45-45-degree compression seal. Acceptance tests by the manufacturer and tests in the laboratory are directly comparable in the case of this type of seal because the designs, type, and size of rubber rollers used were identical and in addition, the methods of testing were as nearly alike as it was possible to make them.

A special test was made in the visual model using design 4 in figure 8 for obtaining the extension of the seal bar with no penstock flow. A dial gage was set up above the seal bar in such a way that extension could be measured to 0.001 inch for any pressure under the seal bar. Gage readings were taken at 5 pounds per square inch intervals of pressure rise, up to 70 pounds per square inch; then readings were again taken at the same intervals as pressure was released. By averaging these dial-gage readings, end friction was minimized. The dotted line in plot 3, figure 19, shows the results of this test.

The averaged results of acceptance tests by the manufacturer are also shown in this plot. Each plotted point represents the average of 8 readings at 8 stations equally spaced around the seal ring. The points obtained at 40 pounds per square inch are definitely off the curve and it is apparent that the seal ring has reached its stops. The average diameters of the rubber rings for each of the 10 gates are also tabulated in plot 3. Each value shown represents the average of 16 readings which were obtained by measuring the maximum and minimum diameters at each of the 8 stations around the seal ring.

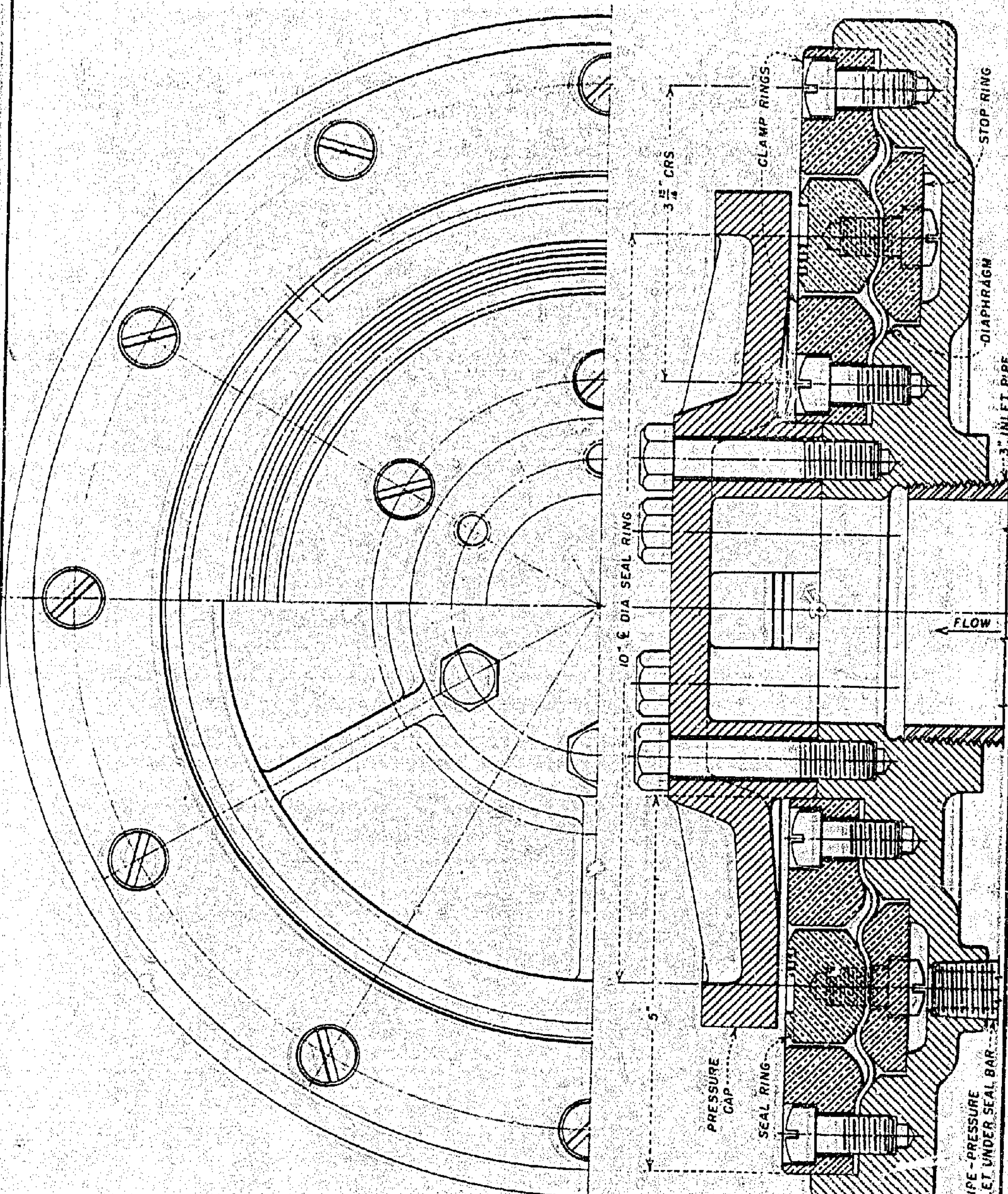
It is evident from the plot that the agreement between the two tests is very satisfactory.

FIGURE 20

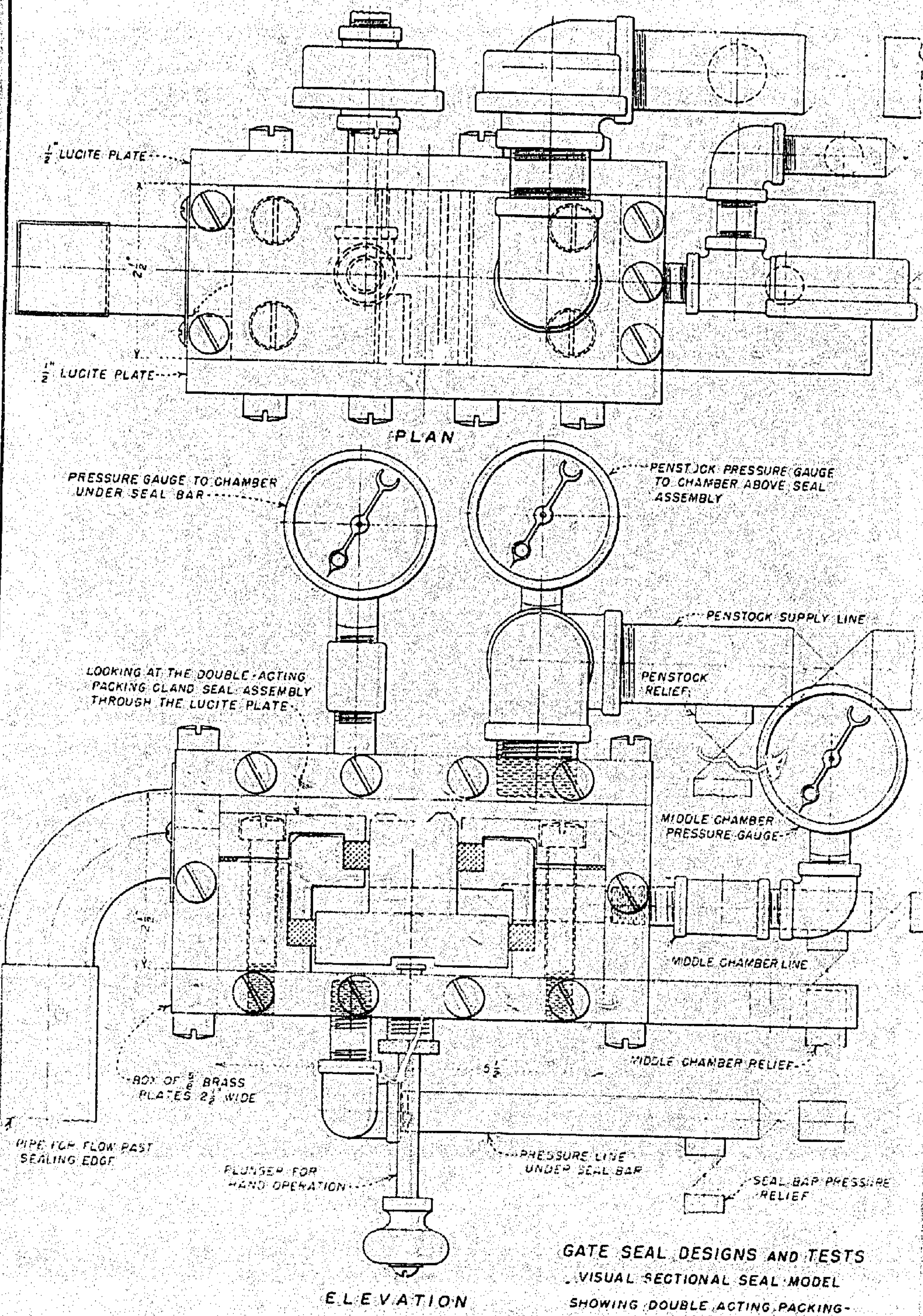


15' x 29.65' PENSTOCK COASTER GATE
GRAND COULEE DAM

FIGURE 21



GATE SEAL DESIGNS AND TESTS
10" INCH RING SEAL MODEL
SHOWING DIAPHRAGM SEAL



GATE SEAL DESIGNS AND TESTS

VISUAL SECTIONAL SEAL MODEL

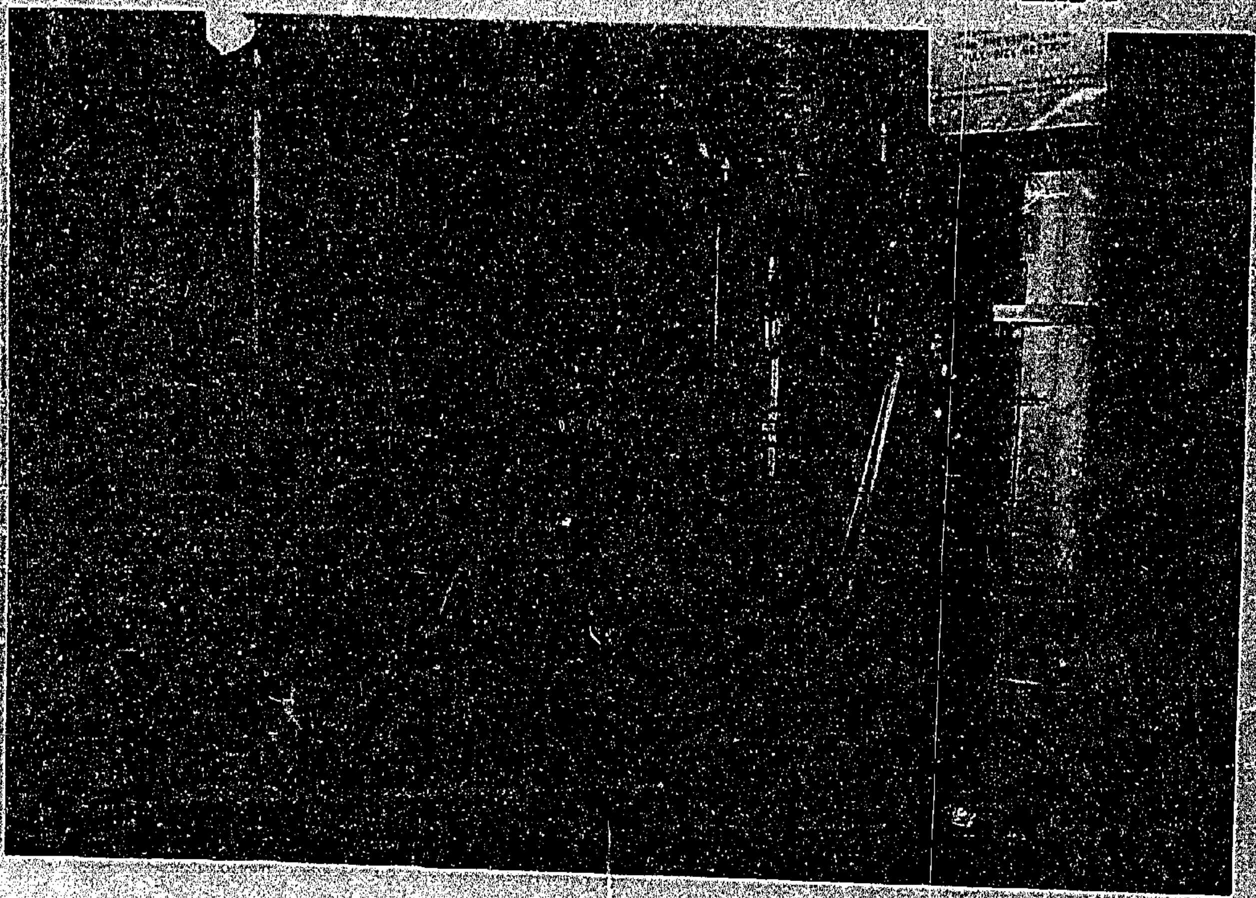
SHOWING DOUBLE ACTING PACKING-GLAND SEAL

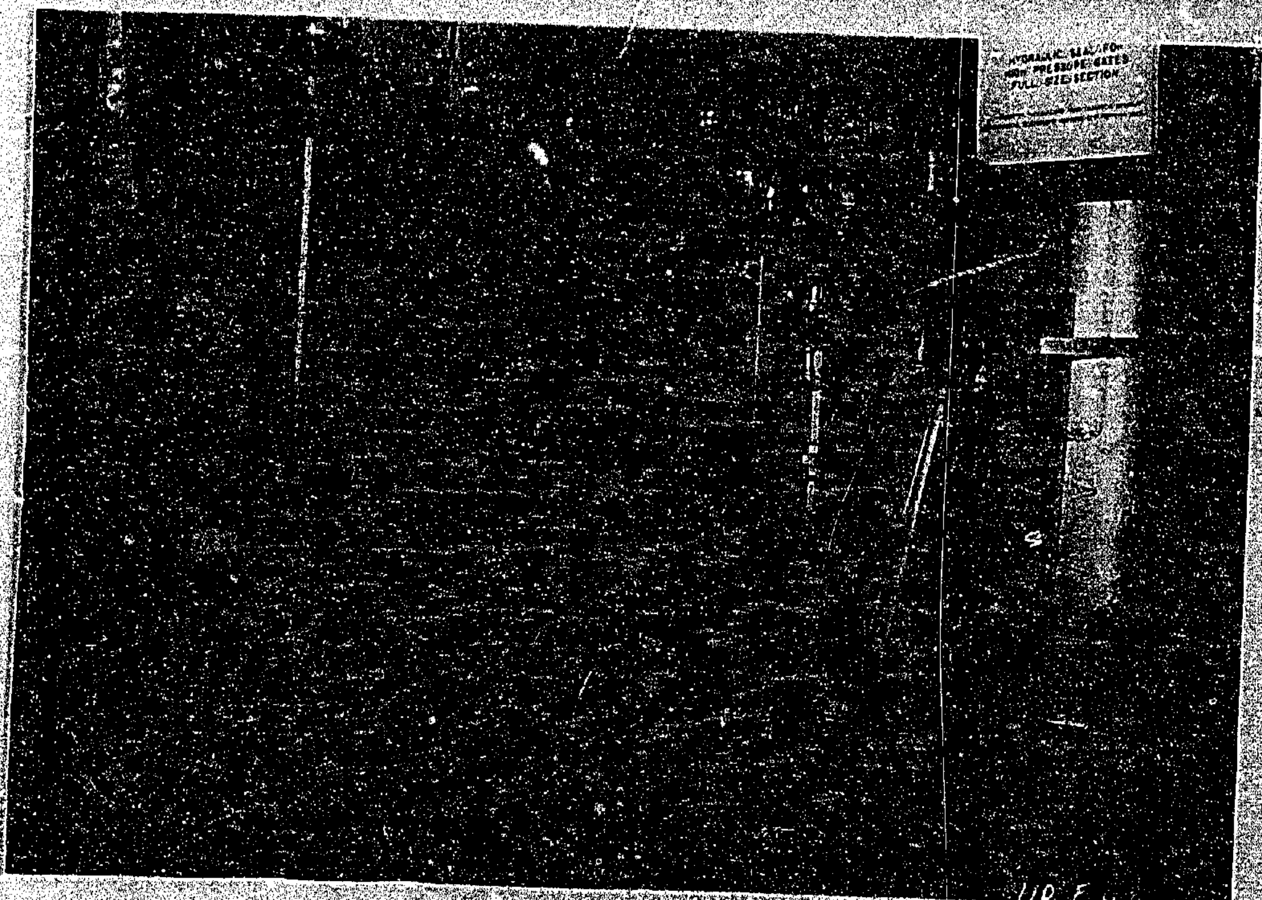
LIST OF FIGURES

Figure No.	Title
	10-inch Ring-Seal Model Designs
1	Diaphragm Seal.
2	Roller Seals.
3	Square Compression Seals.
4	45° - 45° Compression Seals - Development of Designs.
17	Stabilized Flexible Diaphragm Seal - Design 4.
21	Detail of 10-inch Ring-Seal Model.
	Visual Sectional Seal-Model Designs
5	Roller Seals.
6	45° - 45° Compression Seals.
7	Collapsing and Tolerance Tests of Rubber Gaskets - 45° - 45° Compression Seal.
8	Various Retainer Bar Slopes and Center-Line Widths - Compression Seals.
9	Cross-Sectional Areas Compared - Various Angle Compression Seals.
10	Shear Seals - Development of Designs
11	Comparison of Nosepieces in Design 3 and 4 of Shear Seals.
12	Location of Guide Bars and Sealing-Edge Height and Width for Best Operation - Shear Seals.
13	Flexible Nosepieces in Shear Seals and Best Shear-Seal Design.
14	Diaphragm-Type Seals.
15	Constant Contact Seals.
16	Double-Acting Seals.
17	Stabilized Flexible Diaphragm Seal - Hydraulic Operation.
22	Detail of Visual Sectional-Seal Model.
	Other Tests and Figures
18	Line Pressure at Sealing Edge - Layout and Force Diagrams.
19	Comparison of Manufacturers Tests on Full-Size 102-inch Ring-Seal Gates With Laboratory Tests.
20	15-foot by 29.65-foot Penstock Coaster Gate - General Installation Drawing.

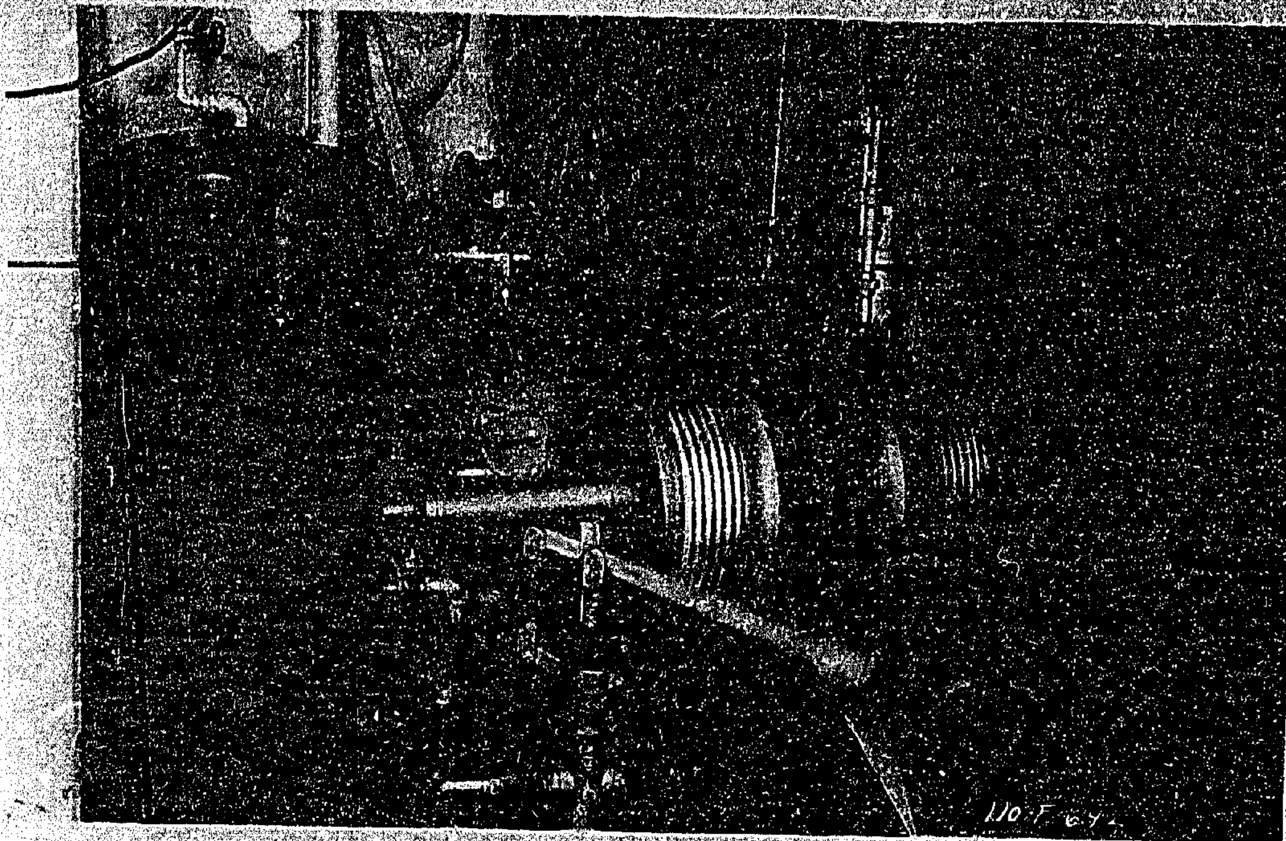
LIST OF PLATES

Plate No.	Title
1	Two Views of Test Set-Up.
2	Rear View of Test Set-Up and Disassembled Ring-Seal Parts.
3	45° - 45° Compression Seals.
4	45° - 45° Wide Compression Seal - Design 7.
5	Collapsing Test in Design 4 Compression Seal.
6	Development of the Shear Seal.
7	Comparison of Nosepieces in Shear Seals.
8	Shear Seal - Design 5 - Best Design.
9	Various Nosepieces - Shear Seals.
10	Diaphragm-Type Seal - Design 1.
11	Diaphragm Seal - Design 2.
12	Double-Acting Seals.
13	Stabilized Flexible Diaphragm Seals.

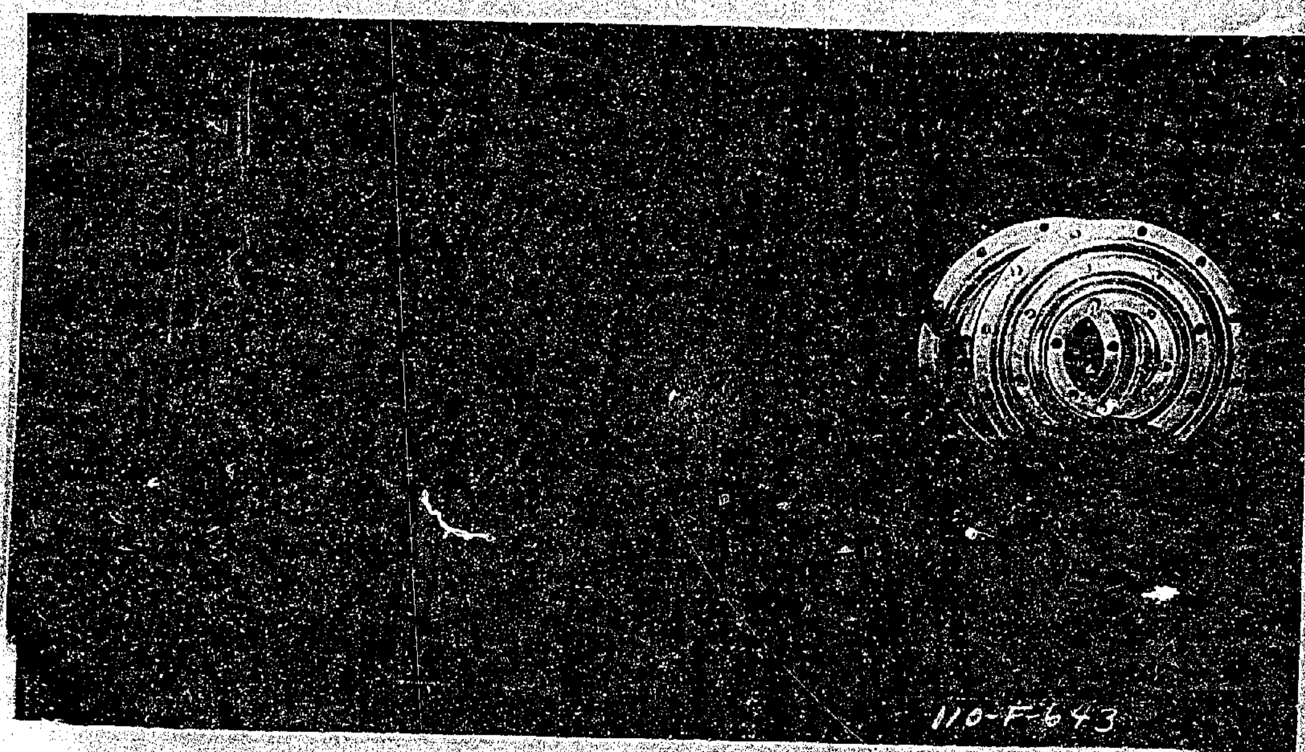




TWO VIEWS OF TEST SET-UP

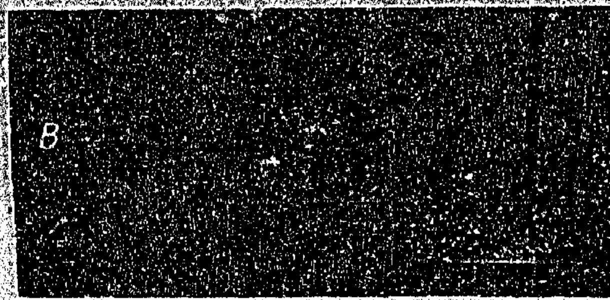


REAR VIEW OF ENTIRE SET-UP FOR TESTS



RINGS, TEST RUBBER AND DIAPHRAGMS FOR
10-INCH RING-SEAL MODEL

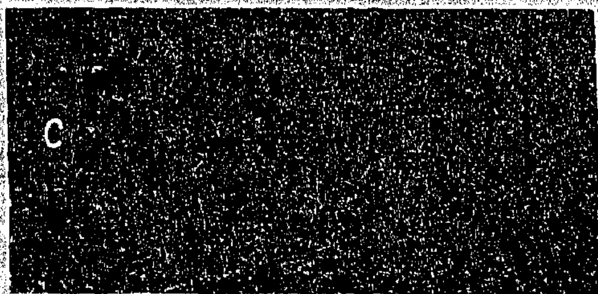
PLATE 3

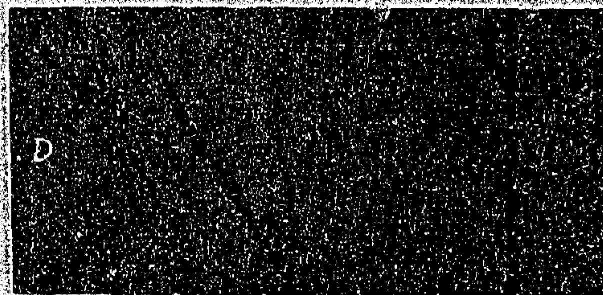


Seal Assembly as Set Up with 3/16" Gap - Fully Guided

70 lb./sq.in. Pressures in Penstock and Under Seal Bar

DESIGN 2 - 29/32" O.D. SOLID MILK HOSE RUBBER - DURO. 45

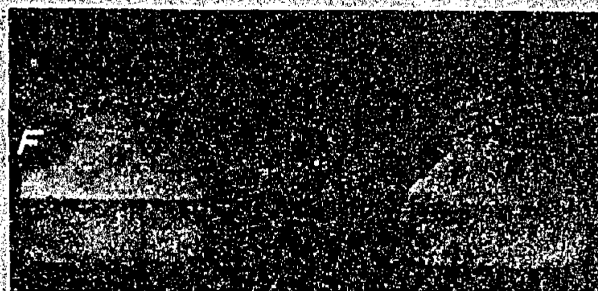




Seal Assembly as Set Up with 3/16" Gap - Fully Guided

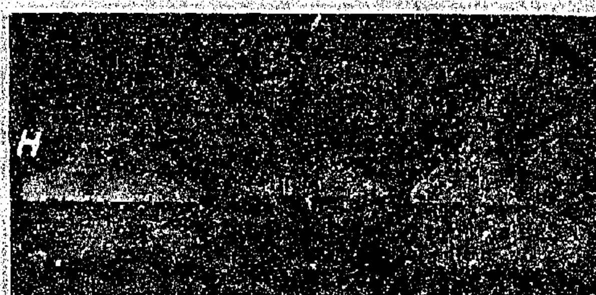
Sealed Against 70 lb./sq.in. Pens. Press. With 52 lb./sq.in. Under Seal Bar

DESIGN 2 - 29/32" O.D. BLACK MOLDED RUBBER - DURO. 50



Seal Assembly as Set up with 3/16" Gap - Fully Guided

Sealed Against 60 lb./sq.in. Penstock Press. With 54 lb./sq.in. Under Seal Bar

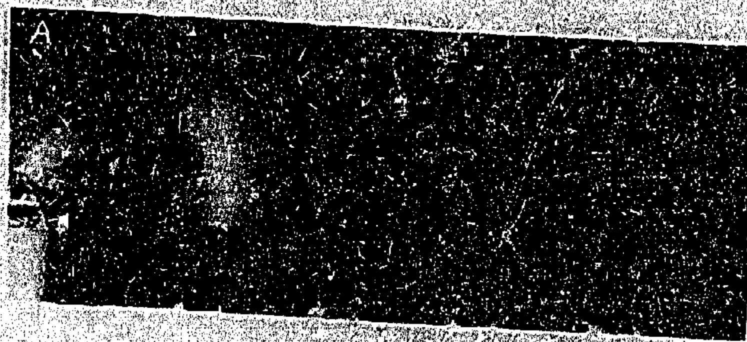


64 lb./sq.in. Under Seal Bar and No Penstock Pressure

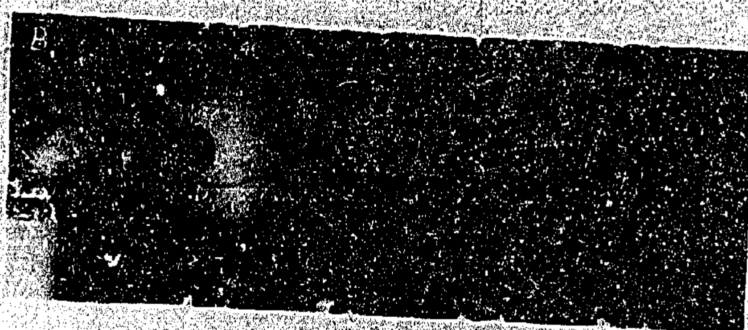
3/16" Bar Above Seal Bar to Stop Movement and 64 lb./sq.in. Under Seal Bar

DESIGN 3 - BLACK EXTRUDED RUBBER 29/32" +.017" O.D.
IN TOLERANCE TESTS

45 - 45 DEGREE COMPRESSION SEALS
DESIGN 2 AND 3 AND THREE TYPES OF RUBBER



Seal assembly as set up with 3/16" gap above seal bar. No pressures. Guided on both sides.

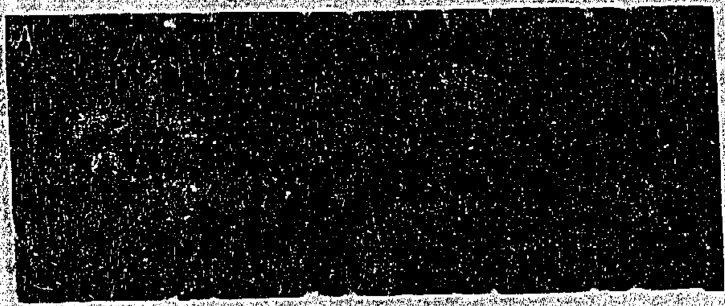


Sealed against 75 lb./sq.in. penstock pressure with 34 lb./sq.in. under seal bar.

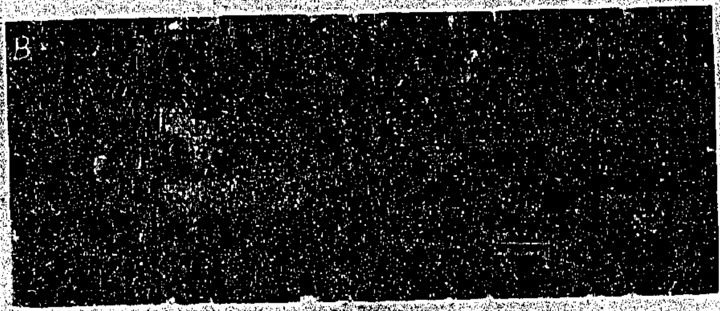
Sealed against 130 lb./sq.in. penstock pressure with 67 lb./sq.in. under seal bar.

130 lb./sq.in. pressures in penstock and under seal bar

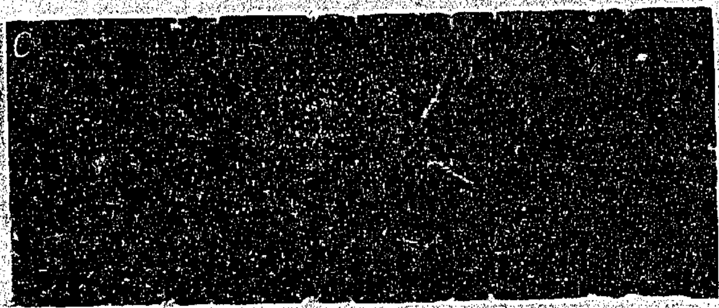
45° - 45° WIDE COMPRESSION SEAL DESIGN 7
GRAND COULEE DESIGN OF SLOTS AS DESIGN 4
29/32" O.D. BLACK LEAD SHEATH PROCESS RUBBER DURO. 50



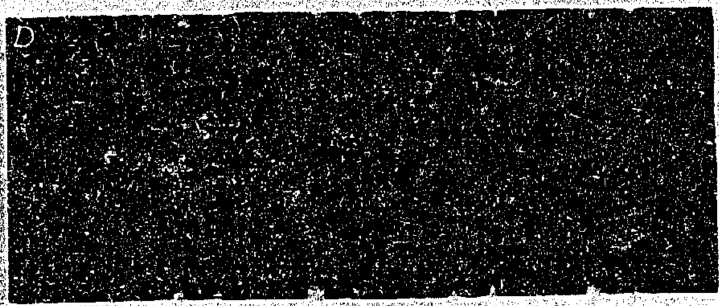
Seal assembly as set up with 5/32" gap above seal bar. No pressures. Guided on downstream side only. Rubber ends sealed with placticine to keep hole dry.



Sealed against 130 lb./sq.in. penstock pressure with 48 lb./sq.in. under seal bar.



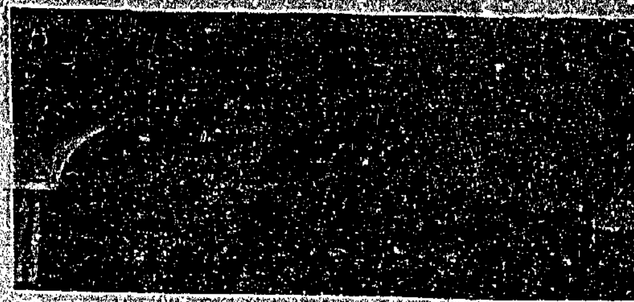
Penstock pressure 130 lb./sq.in. and pressure under seal bar also 130 lb./sq.in.



Seal bar held open 1/8" and 130 lb./sq.in. applied under it.

COLLAPSING TEST IN DESIGN 4 COMPRESSION SEAL
BLACK LEAD SHEATH PROCESS RUBBER - DURO. 50
29/32" +.005" O.D. x 5/16" HOLE - PLASTICINE SEALED ENDS

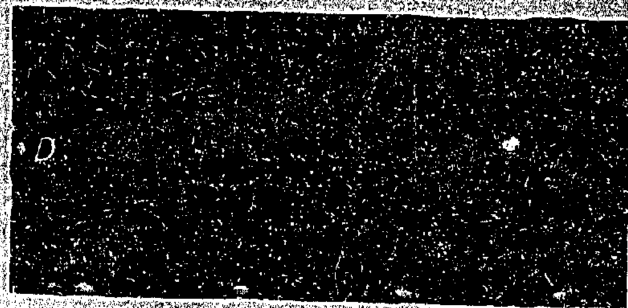
Seal assembly as set up
3/16" gap - No pressures



66 lb./sq.in. pressures in penstock
and under seal bar

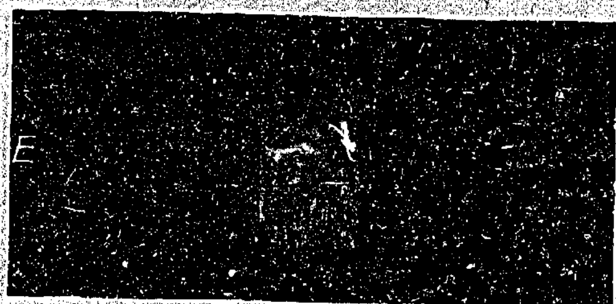
ORIGINAL DESIGN 1 - 1" x 1" x 20° SLOPE SLAB RUBBER DURO. 45

Seal assembly as set up
7/32" gap - No pressures

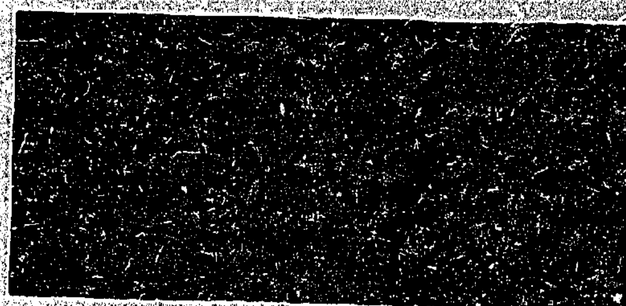


Sealed against 64 lb./sq.in. penstock
press. with 36 lb./sq.in. under seal bar

STABILIZED DESIGN 2 - 1" x 1-1/8" x 15° SLOPE SLAB RUBBER DURO. 45



Seal assembly as set up
7/32" gap - No pressures



Sealed against 68 lb./sq.in. penstock
press. with 34 lb./sq.in. under seal bar

STABILIZER-GUIDED DESIGN 3 - 1-1/8" x 1-1/8" x 15° SLOPE GRAY RUBBER DURO. 35

Seal assembly as set up
1/4" gap - No pressures

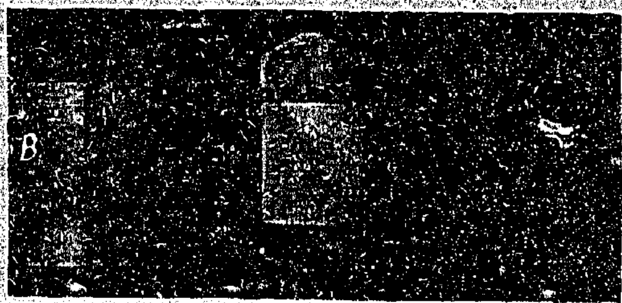
Sealed against 68 lb./sq.in. penstock
press. with 36 lb./sq.in. under seal bar

GUIDE BARS NOT RECESSED DESIGN 4 - RUBBER AS IN DESIGN 3

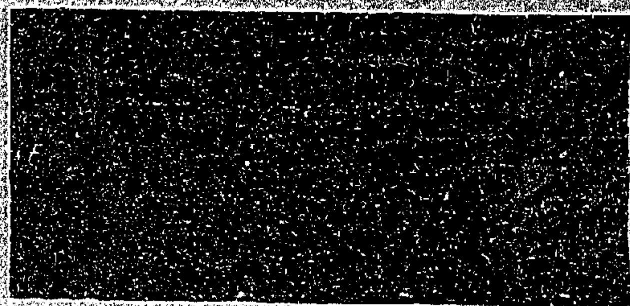
DEVELOPMENT OF THE SHEAR SEAL

Sealed against 68 lb./sq.in. penstock press. with 16 lb./sq.in. under seal bar
NOSE PIECE B 1/4" GAP

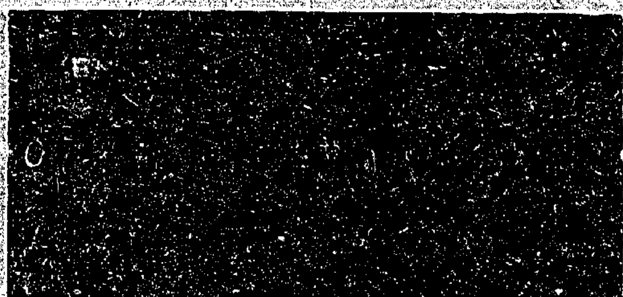
Sealed against 66 lb./sq.in. penstock press. with 24 lb./sq.in. under seal bar
NOSE PIECE B_1



Sealed against 60 lb./sq.in. penstock press. with 50 lb./sq.in. under seal bar
NOSE PIECE C 1/4" GAP

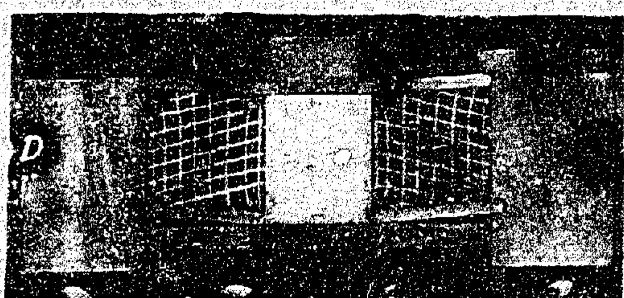


Sealed against 66 lb./sq.in. penstock press. with 57 lb./sq.in. under seal bar
NOSE PIECE C_1 3/16" GAP

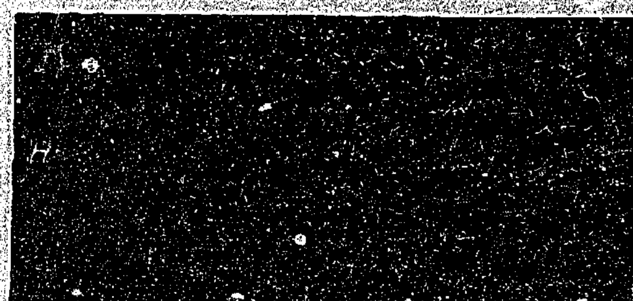


Sealed against 66 lb./sq.in. penstock press. with 31 lb./sq.in. under seal bar
NOSE PIECE D 1/4" GAP

Sealed against 66 lb./sq.in. penstock press. with 36 lb./sq.in. under seal bar
NOSE PIECE D_1



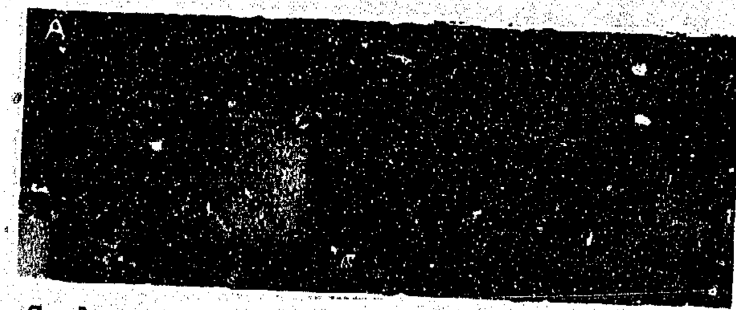
68 lb./sq.in. pressures in penstock and under seal bar
NOSE PIECE A (A_1 NOT SHOWN) 1/4" GAP
DESIGN 3



Sealed against 64 lb./sq.in. penstock press. with 28 lb./sq.in. under seal bar
NOSE PIECE E
DESIGN 4

COMPARISON OF NOSE PIECES IN SHEAR SEALS
1-1/8" x 1-1/8" x 15° SLOPE GRAY RUBBER DUR. 35

PLATE 8

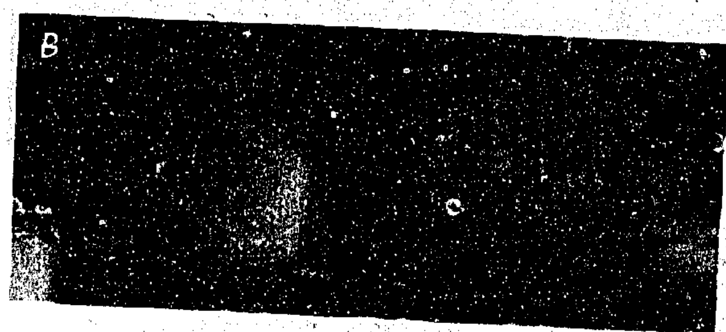


Seal assembly as set up
3/16" gap - No pressures -
No cocking of seal bar

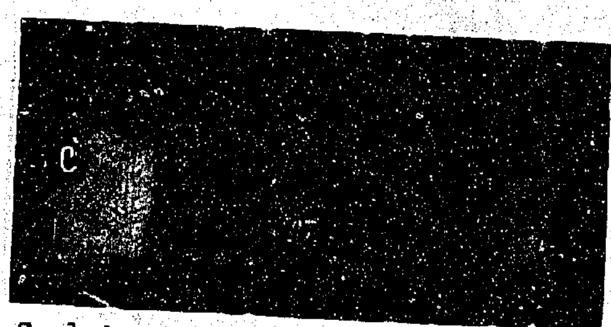
Nose piece A2 and height of 21/32" to sealing edge from upper side of seal bar. Exact width guides on downstream side of seal bar. The upstream guides have necessary clearance.

Rubber approximately 50 Durometer and was of poor quality - 1/32" oversize.

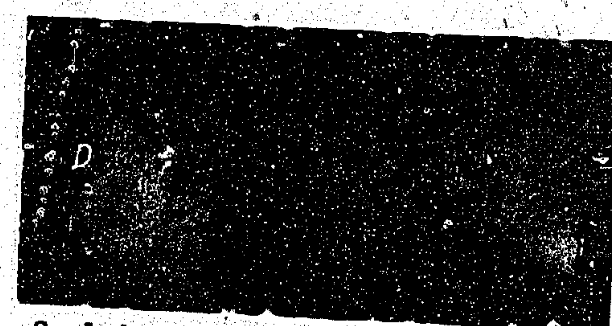
Axial hole had water pressure in it admitted through relief holes along lower outside corners.



Sealed against 20 lb./sq.in. penstock
pressure with 21 lb./sq.in. under seal bar
No cocking of seal bar

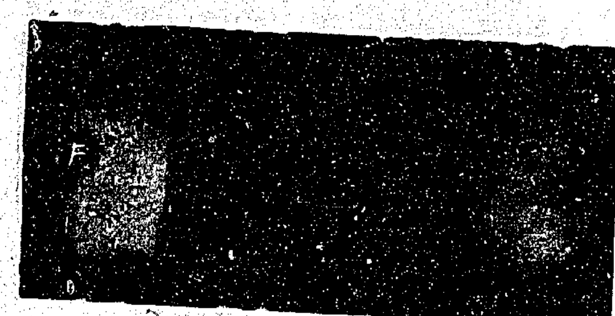


Sealed against 75 lb./sq.in. penstock
press. with 31 lb./sq.in. under seal bar
No cocking of seal bar



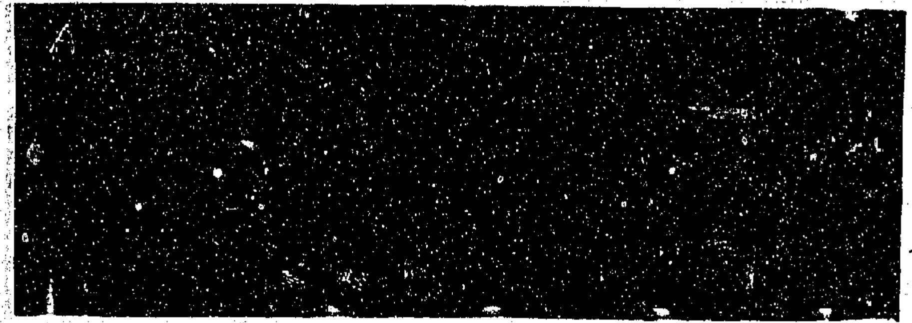
Sealed against 120 lb./sq.in. penstock
with 70 lb./sq.in. under seal bar
No cocking of seal bar

75 lb./sq.in. pressures in penstock
and under seal bar
No cocking of seal bar



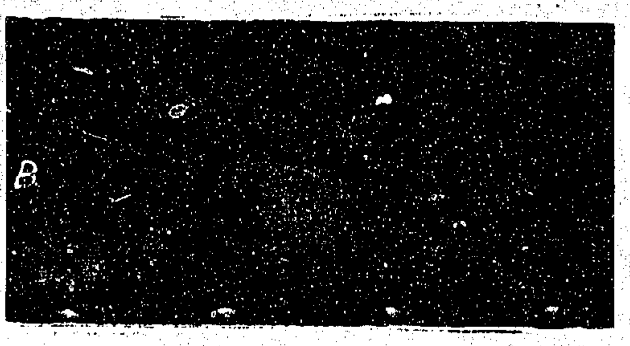
100 lb./sq.in. pressures in penstock
and under seal bar
Practically no cocking of seal bar

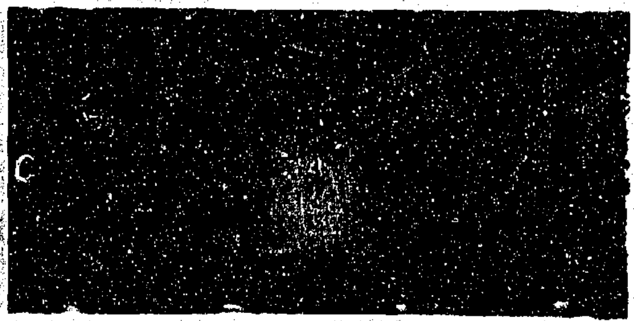
SHEAR SEAL - DESIGN 5
BEST DESIGN OF SEAL AND RUBBER BLOCKS
1-3/16" x 1-3/16" x 15° SLOPE RUBBER, 1/2" AXIAL AND RELIEF HOLES



Sealed against 10 lb./sq.in. penstock press.
with 26 lb./sq.in. under seal bar
NOSE PIECE A_1 - 1/4" GAP

This nose piece was not shown on plate 7 of shear seals in comparison of nose pieces in design 4.

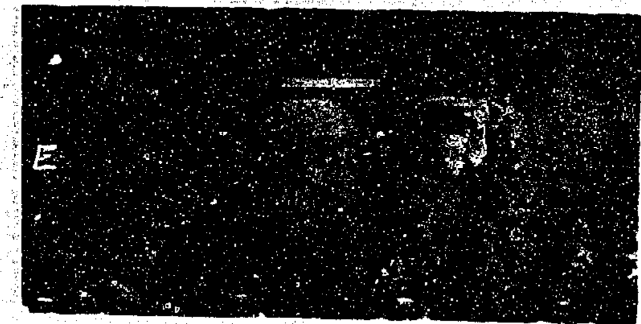




Seal assembly as set up
1/16" gap - No pressures

Sealed against 66 lb./sq.in. penstock press. with 40 lb./sq.in. under seal bar

NOSE PIECE F MOUNTED IN 50 DURO. RUBBER ON DESIGN 4



70 lb./sq.in. pressures in penstock and under seal bar
NOSE PIECE E_1

Sealed against 60 lb./sq.in. penstock press. with 23 lb./sq.in. under seal bar
NOSE PIECE G

1/4" GAP - DESIGN 4

70 lb./sq.in. penstock pressure released through 3/4" inlet from sealed condition
NOSE PIECE A_2 - DESIGN 5

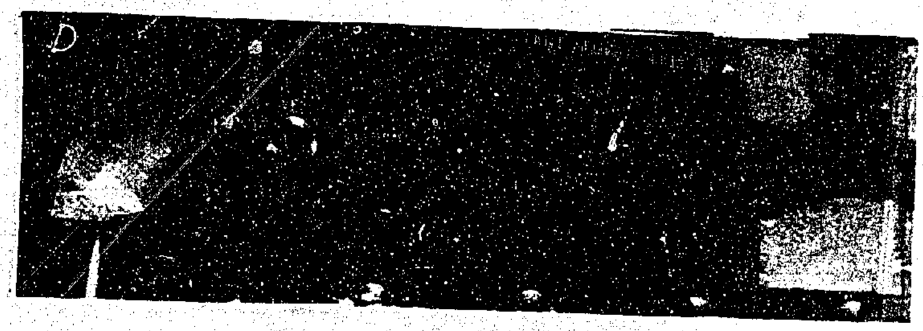
Pressure under seal bar was slowly released to 3 lb./sq.in. at which point retraction ceased at 1/32" due to negative pressure above seal bar, developing 55 lb./sq.in. penstock pressure from original 70 lb./sq.in.

VARIOUS NOSE PIECES - SHEAR SEALS
NOSE PIECE A_1 AND FLEXIBLE NOSE PIECES F, E_1, AND G -
NOSE PIECE A_2 IN RETRACTION TEST IN DESIGN 5

Seal assembly as set up with 7/32" gap above seal bar. No pressures. Guided on both sides.

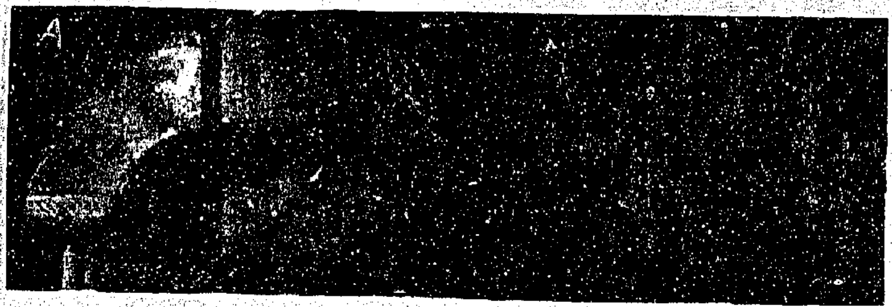
Sealed against 70 lb./sq.in. penstock pressure with 43 lb./sq.in. under seal bar.

70 lb./sq.in. pressures in penstock and under seal bar.



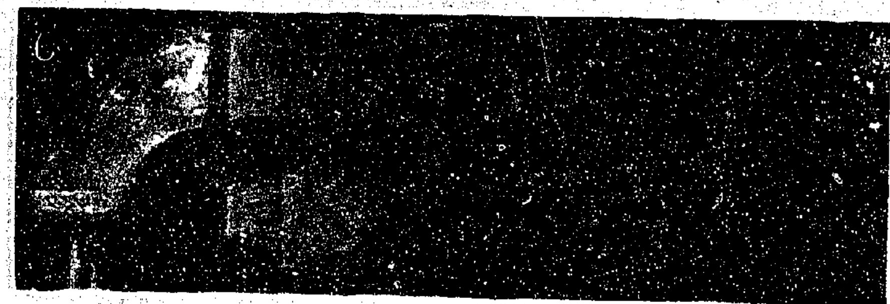
Not guided to see cocking of seal bar. Sealed against 62 lb./sq.in. penstock pressure with 39 lb./sq.in. under seal bar.

DIAPHRAGM TYPE SEAL - DESIGN 1
BLACK RUBBER DURO. 80 SHAPED AS IN "A"
CLAMPED BUT NOT VULCANIZED



Seal assembly as set up with 1/4" gap above seal bar. No pressures. Guided on both sides.

Sealed against 10 lb./sq.in. penstock pressure with 12 lb./sq.in. under seal bar.

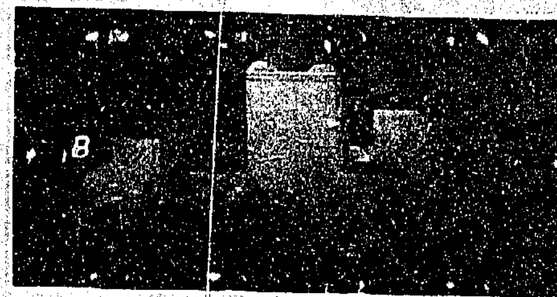


Sealed against 63 lb./sq.in. penstock pressure with 27 lb./sq.in. under seal bar

67 lb./sq.in. pressures on penstock and under seal bar.

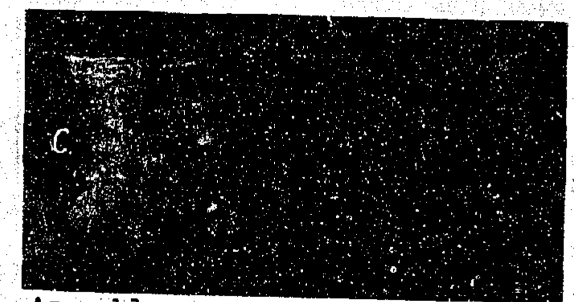
DIAPHRAGM SEAL - DESIGN 2
3/8" THICK BLACK RUBBER FLAT SHEET
DURO. APPROX. 60. FORCED INTO SHAPE AS IN "A"

Assembly with 3/8" x 3/8" graphited flax packing - 1/4" seal bar movement

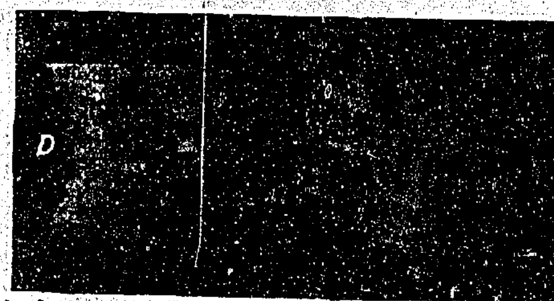


Sealed - 70 lb./sq.in. pens. press. & 10 lb./sq.in. in middle chambers - 52 lb./sq in. under bar

DESIGN 1 REVERSED - ABNORMAL SET-UP

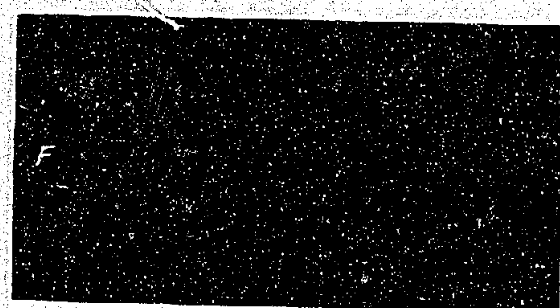


Assembly as set up unguided normal 3/32" gap

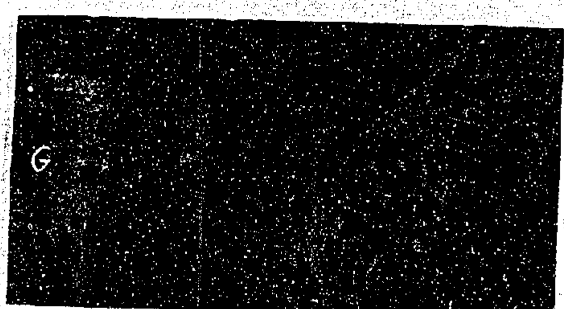


Extended to closed position with 30 lb./sq.in. under seal bar

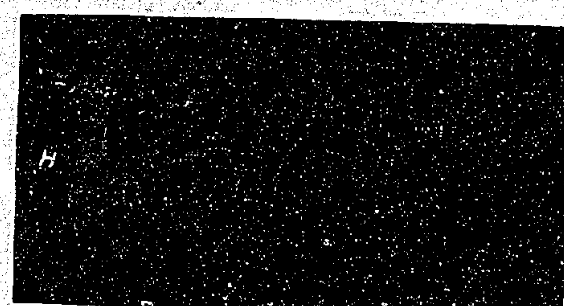
Retracted to 3/16" gap with 38 lb./sq.in. in middle chamber and no press. under seal bar



Sealed against 70 lb./sq.in. pens. press. and no press. in middle chambers with 32 lb./sq.in. under seal bar



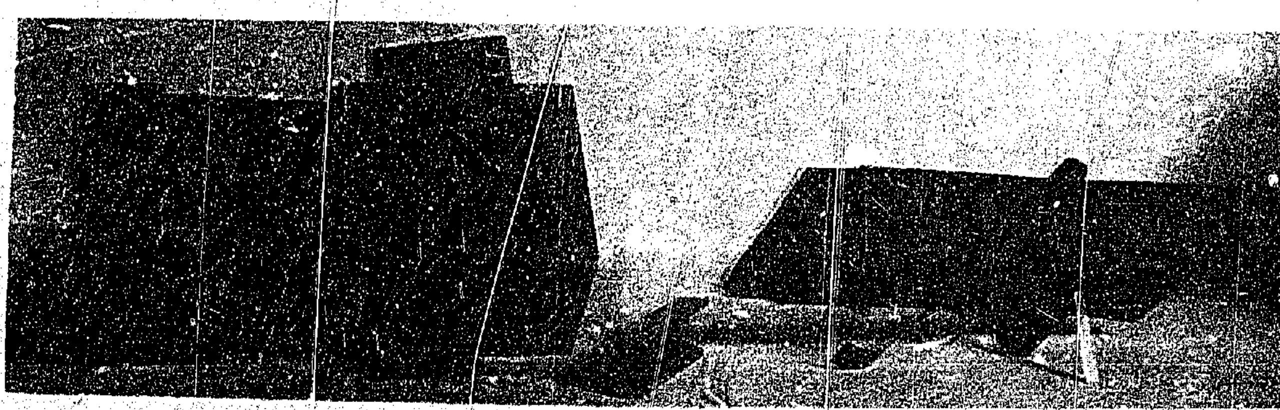
Sealed against 70 lb./sq.in. pens. press. and 20 lb./sq.in. in middle chambers with 43 lb./sq.in. under seal bar



Sealed against 70 lb./sq.in. pens. press. and 40 lb./sq.in. in middle chambers with 54 lb./sq.in. under seal bar

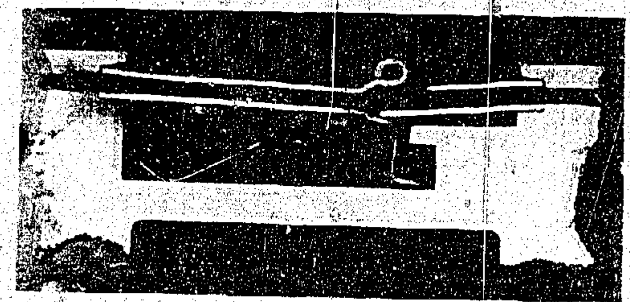
DESIGN 2 - 21/32" O.D. RUBBER - DURO. APPROX. 65 "GARLOCK #161"

DOUBLE ACTING SEALS
HYDRAULIC PRESSURE CHAMBER ACTUATED - DESIGNS 1 AND 2

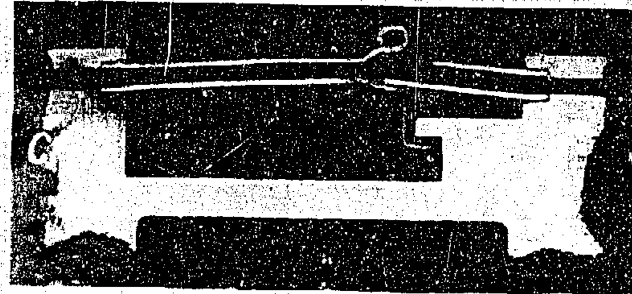


Top view of design 2 Channel nose piece Bottom view design 1A

DISASSEMBLED VIEWS OF DESIGNS 2 AND 1A

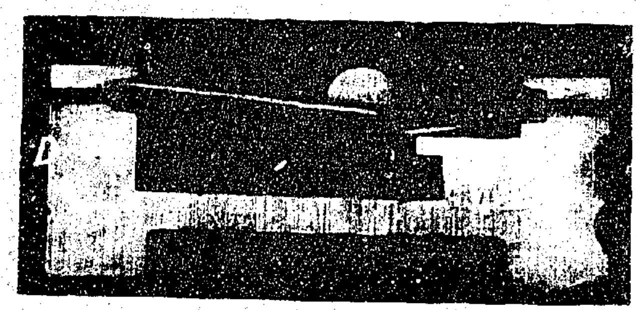


Retracted with 5 lb./sq.in. pens. press.
long stays bolted at midpoint

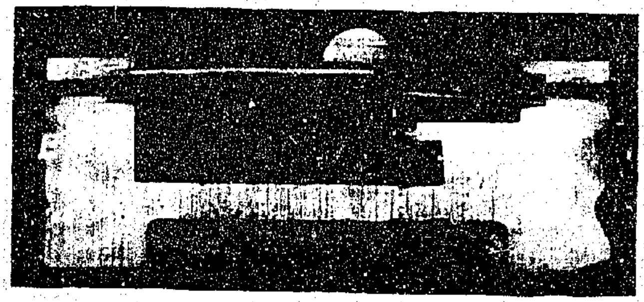


Sealed against 70 lb./sq.in. pens. press.
with 26 lb./sq.in. under diaphragm

DESIGN 1A - SHORT STAYS UPSTREAM

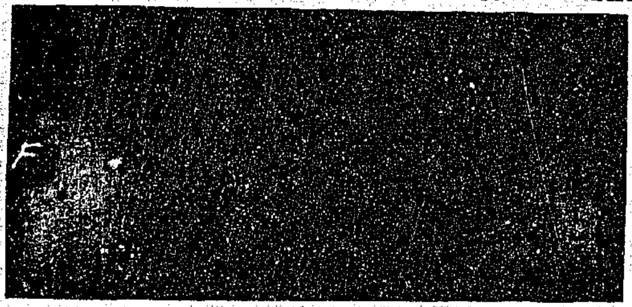


Retracted with 3 lb./sq.in. pens. press.

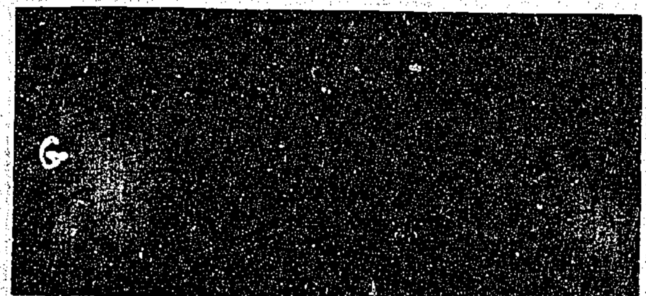


Sealed against 40 lb./sq.in. pens. press.
with 20 lb./sq.in. under diaphragm

DESIGN 2 - SHORT STAYS UPSTREAM



Retracted with 3 lb./sq.in. pens. press.



70 lb./sq.in. pressures in penstock
and under seal bar

DESIGN 2 REVERSED - SHORT STAYS DOWNSTREAM

STABILIZED FLEXIBLE DIAPHRAGM SEALS
2-1/16" RUBBER DIAPHRAGMS - TREAD STOCK - DURO. APPROX. 65