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HIGH HEAD GATE SEAL STUDIES

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Division of Design
Office of Chief Engineer
Bureau of Reclamation

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16. ABSTRACT

Studies were continued on rubber seals to determine the most suitable seal for use on wheel and roller-mounted gates operating under very high heads. The major problem encountered during the closing cycle under unbalanced pressure conditions is the pinching of the seal bulb between the seal clamp and seal seat. Seven factors affecting this pinching were varied in attempts to find the optimum seal assembly capable of withstanding high pressure heads. Ten double-stem seal variations using combinations of stem thickness, fluorocarbon cladding, and rubber compositions were tested at heads up to 600 ft (182.88 m). Tests were conducted in a special test rig accommodating 12-1/8-in.-long (30.798-cm) seal specimens. Tests consisted of measuring the seal bulb extension and photographing and observing general behavior of the seal under load during simulated opening and closing cycles of the gate.

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a. DESCRIPTORS--/ *gate seals/ *high pressure gates/ high pressure/ seals (stoppers)/ test procedures/ *laboratory tests/ physical properties/ hydraulic gates and valves/ friction/ test facilities

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by

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Walter J. Hickel, Secretary
Ellis L. Armstrong, Commissioner

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This study, successor to Report No. Hyd-582 (1968) by R. D. Mohrbacher, was initiated by D. B. Mountjoy of the Mechanical Branch and was conducted in the Hydraulics Branch under the supervision of W. E. Wagner, Head, Structures and Equipment Section. Photography was by W. M. Batts, Office Services Branch.

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PURPOSE

Several types of clamp-on seals for high-head gates were tested to obtain comparative operational data. Earlier tests[1] had indicated that the clamp-on type were the best supported seals and that the extent of fluorocarbon cladding had an effect on performance. For this study additional samples with various combinations of fluorocarbon and rubber composition with variations of seal assemblies were tested to compare relative performances. The seal best suited for 600-foot (182.88-meter) head was sought.

CONCLUSIONS

1. Using thicker stems on the seals decreased the bulb extension at high heads.

2. Reducing the pressure-slot area behind the seal appeared to reduce the amount of seal-bulb extension. (See Figure 1B.)

3. Using a new clamp, modified to increase the clamping action on the seal stem, appeared to decrease the bulb extension at all heads. (See Figure 1C.) This seal assembly would have to be installed with a "built-in" seal interference to insure proper sealing at low heads.

4. The fluorocarbon cap bonded to the bulb and stems decreased the bulb extension. However, a small "permanent set" was present in the seals after being subjected to very high pressures. This "permanent set" was more pronounced when the fluorocarbon cap covered both the stems. A fluorocarbon cap on the bulb and the pressure side of the stem would avoid this "permanent set," with little loss of the seal assembly effectiveness at very-high heads.

5. An appropriate seal would have to be chosen for each installation according to the design head as none of the seals are ideal for all heads.

Recommended Uses

All clamp-on type seals.

For heads up to 150 feet (45.72 m) use a seal with a 1/2-inch (1.27-cm) stem and a fluorocarbon cap bonded to the bulb only.

For heads of 150 feet (45.72 m) to 300 feet (91.44 m), use a seal with a 1/2-inch (1.27-cm) stem and a fluorocarbon cap bonded to the bulb and both stems.

For heads of 300 feet (91.44 m) to 450 feet (137.16 m), use a seal with an 11/16-inch (1.74-cm) stem and a fluorocarbon cap bonded to the bulb and both stems.

For heads of 450 feet (137.16 m) and above, use a seal with an 11/16-inch (1.74-cm) stem and a fluorocarbon cap bonded to the bulb and both stems installed with a clamp which limits movement of the seal stem over a small pressure slot.

The following conclusions were established earlier[1] and were used as a basis for these tests:

The clamp-on-type seals tested were superior to bolt-through design seals in two respects: (a) The bulb extension and resulting pinching tendency during the closing cycle of the gate was reduced, and (b) the clamp-on-type seals showed less tendency to vibrate when the bulb was in the proximity of the seal seat.

A brass or fluorocarbon cap bonded to the bulb significantly reduced the tendency for the bulb to be pinched between the clamp and the seal seat.

The fluorocarbon cap was superior to the brass cap because of its lower coefficient of friction and greater flexibility.

Extending the fluorocarbon cap to cover the lower (high-pressure side) stem of the seal reduced the tendency to disbond between the cap from the rubber, reduced the bulb extension, and reduced the tendency for vibration during the gate-operating cycle.

Extending the fluorocarbon cap to cover both stems further reduced the bulb extension and the tendency of the cap to disbond from the rubber during the gate-operating cycle.

Seal failure by pinching occurred more readily as the speed of the gate closure was increased.

Seal specimens appeared to pinch more as the clamp-to-seat clearance was reduced, when closed with the same bulb extension.

APPLICATIONS

These studies produced data and general information to aid the designer in choosing a suitable seal for a particular application. The choice will depend almost entirely upon the hydraulic head acting on the gate.

[1] Mohrbacher, R. D., "High-head Gate Seal Studies," Bureau of Reclamation Report No. Hyd-582, 1968.

Table 1 gives bulb-extension data and the heads at which seal failure, if any, occurred.

With this information an adequate and economical seal design may be chosen for a specific application.

SPECIFIC INFORMATION

All the seals tested were of the double-stem designs as shown in Figure 2. These seals are used on wheel- and roller-mounted gates which are used primarily as guard gates in penstocks, outlet works, and spillways in installations similar to that shown in Figure 3.

It is possible to use metal-to-metal sealing on relatively small gate installations. However, as the gate size increases it becomes impossible to maintain proper alinement of the metal-sealing surfaces. For this reason rubber seals are clamped to the gate in a manner that allows flexing of the seal to compensate for inaccuracies in gate fabrication and seal-seat alinement when large gates are used.

On earlier low-head gate installations, rubber seals with a cross-sectional shape similar to that of a music note were commonly used. When gates with higher heads came into use, the music-note seals no longer gave satisfactory service and a double-stem, bolt-through-type seal was developed and installed. As heads on gates continued to increase it was necessary to develop a seal which would perform satisfactorily under these higher heads. The double-stem, clamp-on seal shown in Figure 2 was developed and proved to have definite advantages over the bolt-through-type seal for high-head sealing applications. Different variations of the double-stem, clamp-on seal were developed and tested to determine the seal most suitable for very-high heads. This report gives the results of these tests.

Gates with rubber seals are generally operated under balanced water-pressure conditions, but they must also be suitable for emergency closure at unbalanced pressure conditions: full reservoir head on the upstream side of the gate leaf and approximately atmospheric pressure on the downstream side of the gate. During emergency closure the seals are subjected to the greatest stresses.

A typical seal assembly has a pressure groove behind the seal which provides a hydrostatic pressure that forces the seal bulb against the seat when the gate is under pressure. During the emergency closing cycle the unbalanced pressure acting on the top and bottom seals produces a bulb extension of the seal before the seal contacts the seal seat. As the bulb moves onto the seat, the extension of the bulb causes it to be pinched between the clamp and the seal seat. No pinching problem exists on the side seals because of continuous contact with the seal seats.

Seal failure due to pinching was found to be a function of the following factors:

1. Amount of seal-bulb extension.

2. Deformability of the bulb.

3. Clamp-to-seat clearance.

4. Coefficient of friction between the bulb and the seal seat.

5. Strength of bond between the cladding and the rubber.

6. Rate of gate closure.

7. Slope of the surface which forces the extended bulb of the seal inward to the seal seat.

In this test program, Factors 1 and 2 above were varied in an attempt to find the most-suitable seal assembly. The next four factors had been varied in previous tests but not in these tests. The retraction slope on the seal seat could not be changed readily, so Factor 7 was not varied in any of the tests performed. The slope of the test-rig seal seat was purposely made greater than the seal seats normally used in a gate installation to provide a more-critical condition than actually encountered in a typical gate installation.

The seals used in these tests were supplied, at no cost to the Government, by a commercial firm. The seals had the same shape as those used in recent Bureau of Reclamation installations, but utilized different combinations of fluorocarbon coverings, stem thicknesses, and rubber composition. The fluorocarbon used on these seals is a green opaque material which has proven satisfactory in previous seal tests.

TEST FACILITY

The seal tests were conducted in a special Bureau-designed test rig, shown in Figures 4 and 5. The rig has a fixed seal assembly and a movable seal seat operated by a hydraulic cylinder mounted on top of the rig. Although the seat is fixed and the seal moves in the prototype, this arrangement provided the same relative seal-seat motion, and had the advantage of keeping the seal in view through plastic windows throughout the gate test cycle. The hydraulic cylinder was actuated by a variable displacement pump located adjacent to the test rig.

Plastic windows on each side of the test rig allowed photographing the seal behavior. Water was pumped through an 8-inch (20.32-cm) pipe into the bottom of the test rig at a maximum head of 612 feet (186.54 m). Flow past the seal was upward and was deflected to the bottom rear of the test rig where it was discharged. Pressure was applied to a pressure slot at the back side of the seal by a 1-inch (2.54-cm) pipe connection from the 8-inch (20.32-cm) supply line. Shims behind the seal base provided a means of varying the clamp-to-seat clearance. The seal assembly was removable from the upstream side of the test rig to facilitate changing of the seal specimens.

Description of Seal Specimens

The seal specimens were prototype-size sections, 12-1/8 inches (30.798 cm) long. (See Figure 2 for seal dimensions.) Twelve specimens of ten different designs of rubber seals were tested in the tests described above. A description of the cladding and the modules of the rubber used on each specimen is given in Table 2.

Physical properties for all specimens referred to as regular modulus rubber: (As tested and reported by the manufacturer).

Shore A Durometer Hardness = 71
Tensile strength = 4,191 psi (294.65 kg/cm^2)
Elongation at break = 600 percent
Modulus of elasticity at 300 percent elongation = 1,422 psi (99.97 kg/cm^2)

Physical properties for all specimens referred to as high-modulus rubber: (As tested and reported by the manufacturer).

Shore A Durometer hardness = 70
Tensile strength = 3,809 psi (267.79 kg/cm^2)
Elongation at break = 500 percent
Modulus of elasticity at 300 percent elongation = 1,808 psi (127.11 kg/cm^2)

Fluorocarbon specifications: 0.030 inch (0.762 mm) thick; tensile strength = 2,000 psi (140.61 kg/cm^2) minimum; elongation = 250 percent (minimum).

TEST PROCEDURE

Data taken in this study included:

1. Measurement of the seal-bulb extension in a horizontal direction from its initial position when subjected to a given head of water.

These measurements were taken at increments of 25 to 100 feet (7.62 to 30.48 meters) of head up to seal failure or to a maximum head set for the specific seal tested if failure was not desired. The maximum head used in any of the tests was 600 feet (182.88 m). These measurements were taken by alining a grid of lines, spaced at 0.10-inch (2.54-mm) intervals on both sides of a 2-inch-thick piece of transparent plastic, with a similar grid of lines on the test-rig window. As all of the specimens had a 0.030-inch (0.762-mm) thick fluorocarbon cap on the bulb, it was possible to estimate the seal extension to the nearest hundredth of an inch (0.254 mm).

2. General observations of seal performance during gate operations.

3. Motion pictures of seal performance during test-rig operation.

4. Still photographs of a few seals at selected heads with the seal under load or sometimes not loaded.

5. Visual examination and photographs of seals after removal from test rig.

The clamp-to-seat clearance was varied from 7/32 inch (0.56 cm) to 15/32 inch (1.19 cm) at different times during the testing of the different seal specimens. Some specimens were tested at more than one clearance. The size of the pressure slot was also reduced during the testing program and all seals subsequently tested reflected this change (Figure 1B). A modification was also made to the seal clamp (Figure 1C) during the testing program in an effort to determine the effect of seal clamping.

Comparisons of Seal Performance

All of the following specimens discussed in this comparison are tabulated in Table 1.

All seal specimens tested were of the clamp-on design having a green fluorocarbon cap bonded to the bulb and sometimes one or both of the stems.

Specimen No. 5B had a 1/2-inch (1.27-cm) stem with fluorocarbon bonded to the bulb and the lower stem (pressure side) and was made of regular-modulus rubber. This seal specimen was tested with a 3/8-inch (0.95-cm) clamp to seat clearance to show that a 1/2-inch (1.27-cm) stem seal was unable to sustain high heads (over 400 feet [121.92 m]) with an unmodified seal assembly. (Figure 1A.) When tested, the seal bulb was pinched enough to crease the fluorocarbon cap during the gate-closing cycle at 450 feet (137.16 m) of head. (Figure 8.) Testing was stopped at this point. (It should be noted that this crease in the fluorocarbon cap would not prevent the seal from sealing.) When the seal specimen was removed from the test rig, a slight permanent set was observed on the fluorocarbon stem side of the bulb. (Figure 8.)

Specimen No. 3B had an 11/16-inch (1.74-cm) stem with a fluorocarbon cap bonded to the bulb and the lower stem (pressure side) and was made of high-modulus rubber. This specimen was tested at 7/32-inch (0.56-cm), clamp-to-seat clearance to give a comparison with the 1/2-inch (1.27-cm) stem seals tested in the previous report (1). The seal performed well up to 500 feet (152.40 m) of head without any permanent damage. The test was stopped at 550 feet (167.64 m) of head as it appeared the seal would be damaged if allowed to close. Upon removal from the test rig no permanent damage was observed. No permanent set was observed.

Specimen No. 2B had an 11/16-inch (1.74-cm) stem with fluorocarbon bonded to the bulb and both stems and was made of regular-modulus rubber. This specimen was tested at 3/8-inch (0.95-cm) clamp-to-seat clearance. The seal performed very well under up to and including 600 feet (182.88 m) of head. Upon removal from the test rig no permanent damage to the specimen was observed, however there was a slight indentation on the upper side (nonpressure side) of the fluorocarbon cap where it contacted the clamp while under pressure. A slight permanent set was noticed directly under the bulb.

Specimen No. 4B had an 11/16-inch (1.74-cm) stem with fluorocarbon bonded to the bulb and both stems and was made of high-modulus rubber. This specimen was tested at 3/8-inch (0.95-cm) clamp-to-seat clearance. Specimen No. 4B performed almost exactly the same as 2B including the indentation in the fluorocarbon on the upper side (nonpressure side) of bulb. A slight permanent set was also observed at the bulb. (See Figure 11B.)

At this point in the testing program the width of the pressure slot behind the seal was reduced from 3 to 2 inches (7.62 to 5.08 cm) by filling it with 2-1/2-inch (1.27-cm) square bars.

Specimen No. 7B had a 1/2-inch (1.27-cm) stem with fluorocarbon bonded to the bulb and lower stem (pressure side) and was made of high-modulus rubber. This specimen, about the same as 5B, was tested at 3/8-inch (0.95-cm) clamp-to-seat clearance to check the effectiveness of the reduced pressure slot in reducing the amount of bulb extension. The seal specimen was tested to 400 feet (121.92 m) of head with no perceivable damage. It appeared that the smaller pressure slot helped to reduce the bulb extension on this specimen. A very-slight permanent set was noticed on the side with fluorocarbon on the stem.

Specimen No. 1B had an 11/16-inch (1.74-cm) stem with fluorocarbon bonded to the bulb and lower stem (pressure side) and was made of regular-modulus rubber. This specimen was tested at 15/32-inch (1.19-cm) clamp-to-seat clearance. It was tested to 400 feet (121.92 m) of head with no damage to the seal and a nominal amount of bulb extension. The tests were stopped at 400 feet (121.92 m) of head to prevent any damage to the seal so that it could be retested upon modification of the clamps. No permanent set was observed.

At this point in the testing program the seal assembly was further revised by soldering a 1/8-inch (0.32-cm) diameter brass rod to the underside of the seal clamp at the point where it contacts the seal stem at the base of the bulb. (See Figure 1C.) This created a clamping action at that point. The change was made in an attempt to reduce the amount of bulb extension, especially at high heads. (Fabrication of a seal clamp in this manner would not be recommended as this should be accomplished by gradually building it up to a point.)

Specimen No. 1B was retested at this point to give a direct check of the effectiveness of the modified clamp in reducing the amount of bulb extension at high heads. This specimen was retested at 15/32-inch (1.19-cm) clamp-to-seat clearance as it was in the previous test without the modified clamps. The seal specimen performed well up to and including 600 feet (182.88 m) of head with no apparent damage to the seal specimen. The modified clamps appeared to reduce the amount of bulb extension slightly at low heads and reduced the bulb extension significantly at higher heads. Upon removal from the test rig the seal specimen appeared to be in perfect condition except for a very slight permanent set on the side with fluorocarbon on the stem. (Figure 10B.)

Specimen No. 1A had an 11/16-inch (1.74-cm) stem with fluorocarbon bonded to the bulb only and was made of regular-modulus rubber. This specimen was tested at 3/8-inch (0.95-cm) clamp-to-seat clearance. It performed adequately up to 600 feet (182.88 m) of head, except for the fact that the fluorocarbon cap broke loose at lower edge of the bulb at 550 feet (167.64 m) of head. Upon removal of the specimen from the test rig it was found that the fluorocarbon cap had come loose only at the edge and could not be considered a real failure but rather a spot that was not bonded properly. No permanent set was observed.

Specimen No. 2A had an 11/16-inch (1.74-cm) stem with fluorocarbon bonded to the bulb and both stems and was made of regular-modulus rubber. This specimen was tested at 3/8-inch (0.95-cm) clamp-to-seat clearance and performed adequately up to 600 feet (182.88 m) of head with no extensive pinching of the bulb. When removed from the test rig the seal was in good condition, except that it had a slight permanent set directly under the bulb. (Figure 10A.)

Specimen No. 3A had an 11/16-inch (1.74-cm) stem with fluorocarbon bonded to the bulb only and was made of high-modulus rubber. This specimen was tested at 15/32-inch (1.19-cm) clamp-to-seat clearance. The general performance appeared to be about the same as Specimen No. 1A with the exception that the bulb extended slightly more. The increased bulb extension appeared to be caused by the larger clamp-to-seat clearance. Upon removal from the test rig (see Figure 9) it was found to have a ridge in the fluorocarbon cap along the upper (nonpressure) side of the bulb and a slight disbonding of the fluorocarbon was noted on the upper (nonpressure) side of the fluorocarbon cap. (It should be pointed out that the crease in the fluorocarbon would not prevent the seal from sealing.) No permanent set was observed.

Specimen No. 4A had an 11/16-inch (1.74-cm) stem with fluorocarbon bonded to the bulb and both stems and was made of high-modulus rubber. This specimen was tested at 15/32-inch (1.19-cm) clamp-to-seat clearance and its performance was almost the same as that of Specimen No. 2A. A permanent set was observed at the bulb.

Specimen No. 6A had a 1/2-inch (1.27-cm) stem with fluorocarbon bonded to the bulb and both stems and was made of regular-modulus rubber. This specimen was tested at 3/8-inch (0.95-cm) clamp-to-seat clearance and it performed well up to 500 feet (152.40 m) of head. There was no visible damage to the seal specimen when it was removed from the test rig. The improved performance of a 1/2-inch (1.27-cm) stem seal appeared to be due to the modified clamp and reduced pressure slot. A very-pronounced permanent set was present directly at the bulb.

Specimen No. 8A had a 1/2-inch (1.27-cm) stem with fluorocarbon bonded to the bulb and both stems and was made of high-modulus rubber. This specimen was tested at 3/8-inch (0.95-cm) clamp-to-seat clearance and it performed without damage up to 600 feet (182.88 m) of head. This seal specimen also had no visible damage when removed from the test rig. The improved performance of the seal specimen, testing a 1/2-inch (1.27-cm) stem seal to 600 feet (182.88 m) of head with no damage, appeared to be due to the modified clamp and reduced pressure slot. A very-pronounced permanent set was present at the bulb. (Figure 11A.)

Table 1

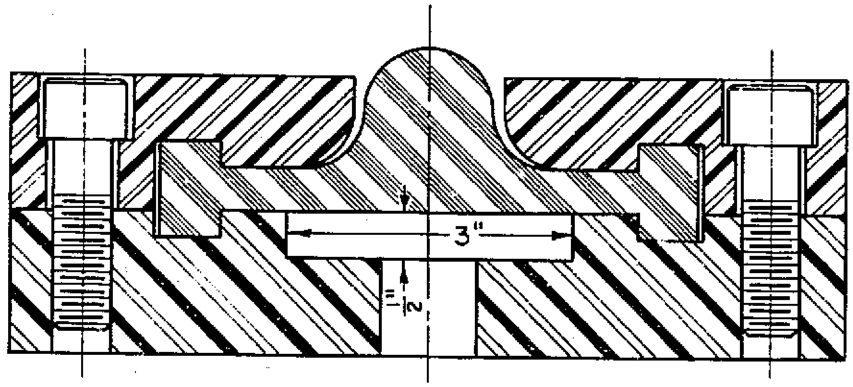
SUMMARY OF DATA OBTAINED ON GATE SEAL SPECIMENS

Specimen No.	Bulb extension (inches) Head (feet of water)													Remarks
	0	68	100	150	200	250	300	350	400	450	500	550	600	
Wide pressure slot (see Figure 1A)														
5B (1/2 inch—F.C. on bulb and lower stem, reg. mod.)	0	0.10	0.15	0.16	0.20	0.25	0.30	0.40	0.44	0.65				Seal pinched at 450 feet 3/8-inch clamp clearance
3B (11/16 inch—F.C. on bulb and lower stem, high mod.)	0	0.09	0.10	0.11	0.12	0.20	0.26	0.32	0.37	0.42	0.62			Too far extruded at 500 feet 7/32-inch clamp clearance
2B (11/16 inch—F.C. on bulb and both stems, reg. mod.)	0	0.02	0.03	0.04	0.05	0.07	0.12	0.13	0.14	0.23	0.26	0.34	0.39	3/8-inch clamp clearance
4B (11/16 inch—F.C. on bulb and both stems, high mod.)	0	0.01		0.05	0.06	0.06	0.10	0.14	0.20	0.23	0.29	0.32	0.40	3/8-inch clamp clearance
Pressure slot reduced (see Figure 1B)														
7B (1/2 inch—F.C. on bulb and lower stem, high mod.)	0	0.08	0.10	0.10	0.13	0.16	0.17	0.25	0.29					Trend established 3/8-inch clamp clearance
1B (11/16 inch—F.C. on bulb and lower stem, reg. mod.)	0	0.08	0.09	0.11	0.13	0.19	0.24	0.29	0.33					Trend established 15/32-inch clamp clearance
Modified clamp and pressure slot reduced (see Figure 1C)														
1B (retest)	0	0.05	0.08	0.12	0.15	0.18	0.23	0.26	0.31	0.31	0.33	0.36	0.39	15/32-inch clamp clearance
1A (11/16 inch—F.C. on bulb only, reg. mod.	0	0.05	0.07		0.13		0.24	0.29	0.34	0.41	0.50	0.56	0.57	3/8-inch clamp clearance
2A (11/16 inch—F.C. on bulb and both stems, reg. mod.	0	0.01	0.05		0.09		0.15	0.19	0.25	0.30	0.34	0.43	0.50	3/8-inch clamp clearance
3A (11/16 inch—F.C. on bulb only, high mod.)	0	0.05	0.10		0.17		0.26	0.35	0.37	0.44	0.55	0.63	0.69	Seal pinched at 600 feet 15/32-inch clamp clearance
4A (11/16 inch—F.C. on bulb and both stems, high mod.)	0	0.01	0.05		0.12		0.16	0.20	0.24	0.27	0.37		0.45	15/32-inch clamp clearance
6A (1/2 inch—F.C. on bulb and both stems reg. mod.)	0	0.03	0.04		0.11		0.14	0.27	0.33	0.34	0.36			Trend established 3/8-inch clamp clearance
8A (1/2 inch—F.C. on bulb and both stems, high mod.)	0	0.02	0.04		0.08		0.13	0.17	0.23	0.32	0.37	0.47	0.54	3/8-inch clamp clearance

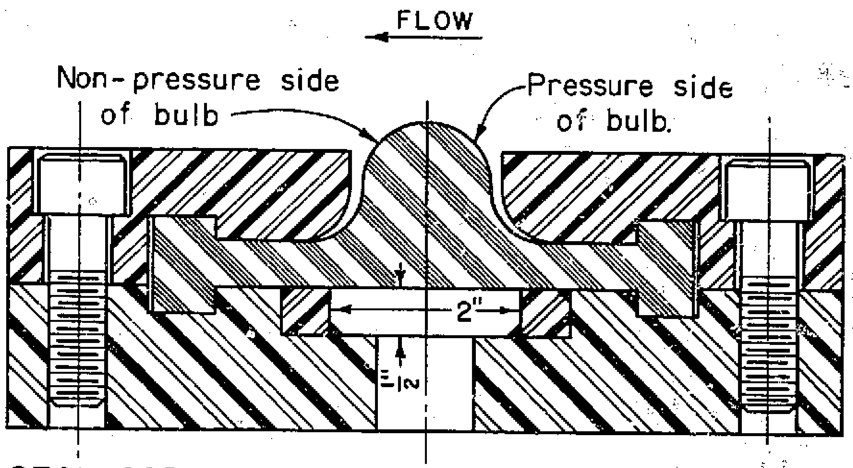
Table 2

DESCRIPTION OF SEAL SPECIMENS
(All seals clamp-on-type with green fluorocarbon cladding)

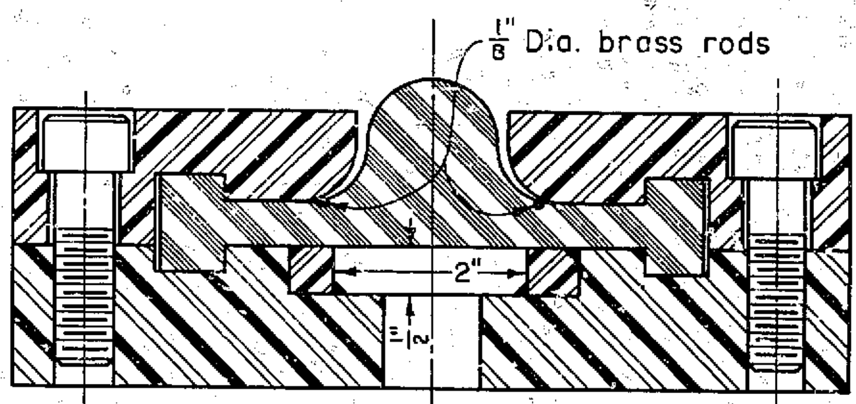
Specimen number	Stem thickness	Cladding on bulb	Cladding on lower stem	Cladding on upper stem	Modulus of rubber
1A	11/16 inch	Yes	No	No	Regular
1B	11/16 inch	Yes	Yes	No	Regular
2A, 2B	11/16 inch	Yes	Yes	Yes	Regular
3A	11/16 inch	Yes	No	No	High
3B	11/16 inch	Yes	Yes	No	High
4A, 4B	11/16 inch	Yes	Yes	Yes	High
5B	1/2 inch	Yes	Yes	No	Regular
6A	1/2 inch	Yes	Yes	Yes	Regular
7B	1/2 inch	Yes	Yes	No	High
8A	1/2 inch	Yes	Yes	Yes	High



a. UNMODIFIED SEAL ASSEMBLY



b. SEAL ASSEMBLY WITH REDUCED PRESSURE SLOT



c. SEAL ASSEMBLY WITH REDUCED PRESSURE SLOT AND MODIFIED CLAMPS

NOTE: All seal assemblies are shown with a $\frac{1}{2}$-inch stem.

Figure 1. Seal assemblies.

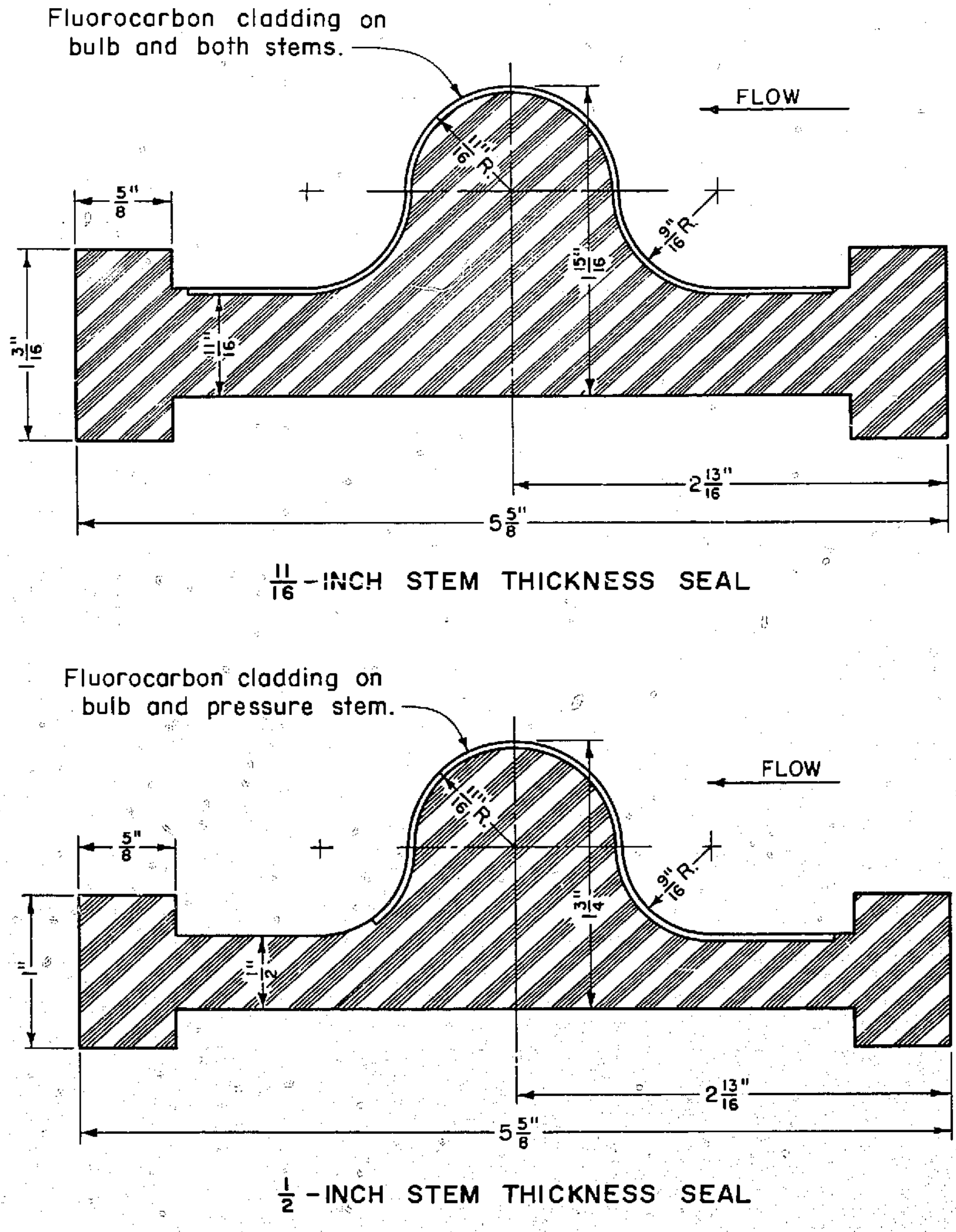


Figure 2. Seal designs (see Table 2 for extent of fluorocarbon cladding on specific seals).

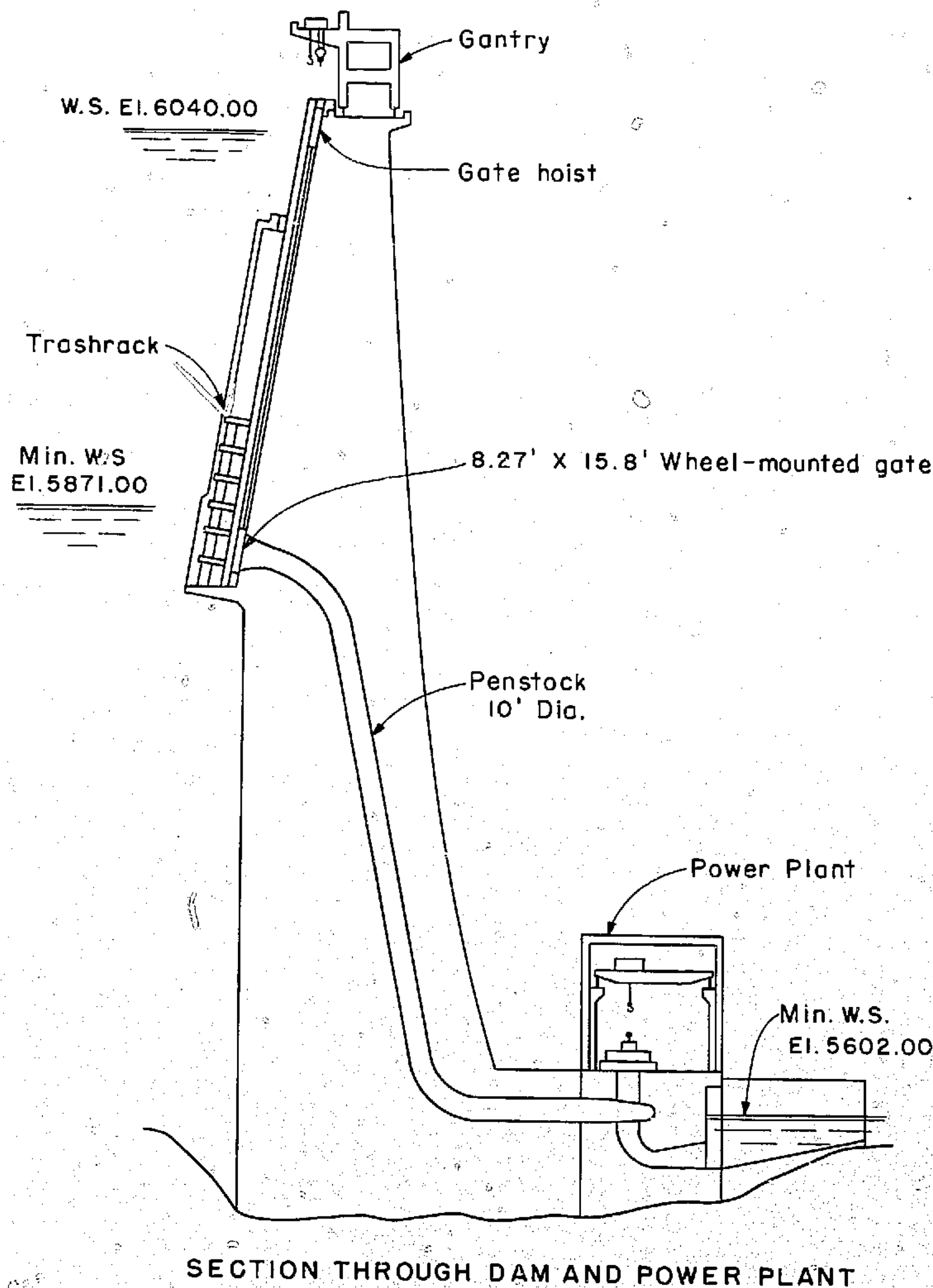
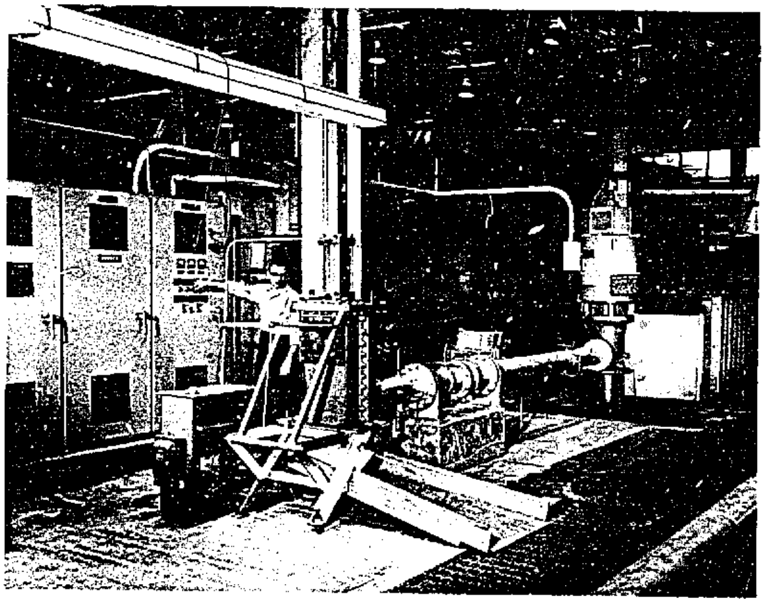
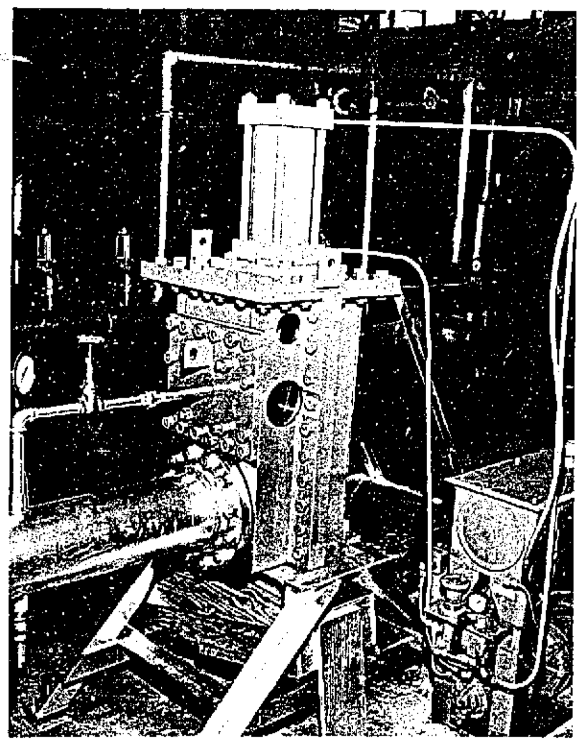


Figure 3. Typical gate installation.



A. Overall view of test facility—showing water pump, controls, and gate seal test rig. Photo PX-D-60628



B. Gate seal test rig. Photo PX-D-57233 NA

Figure 4. Test facility.

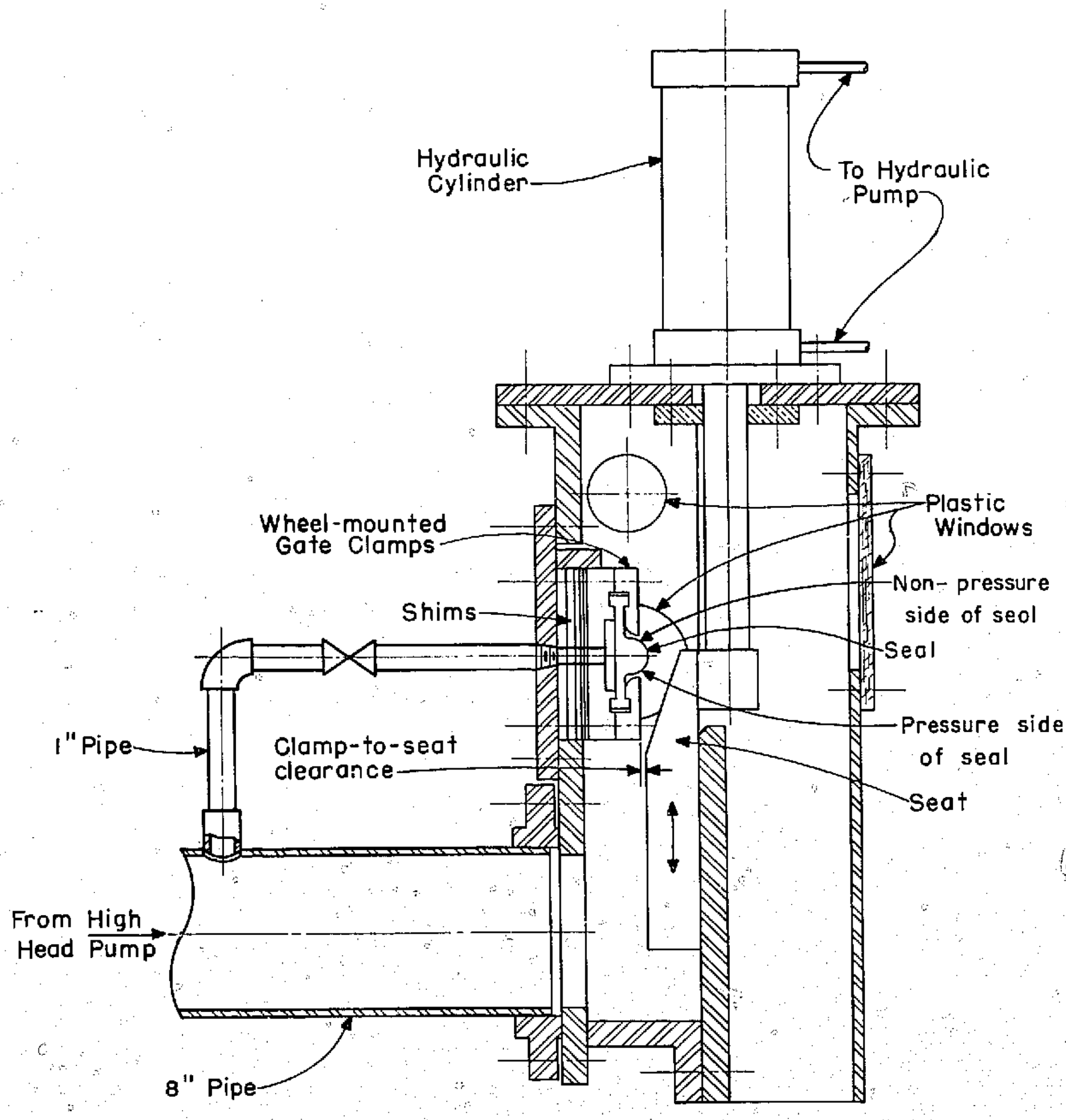
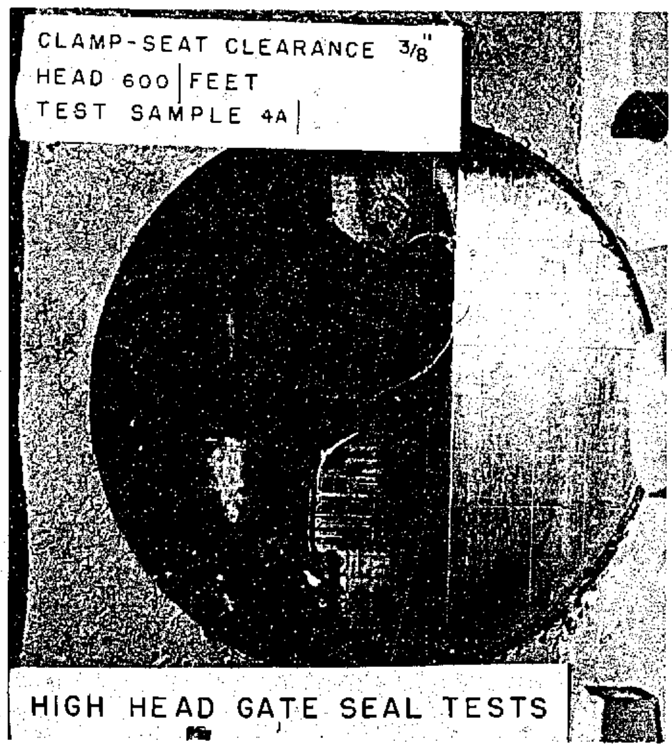


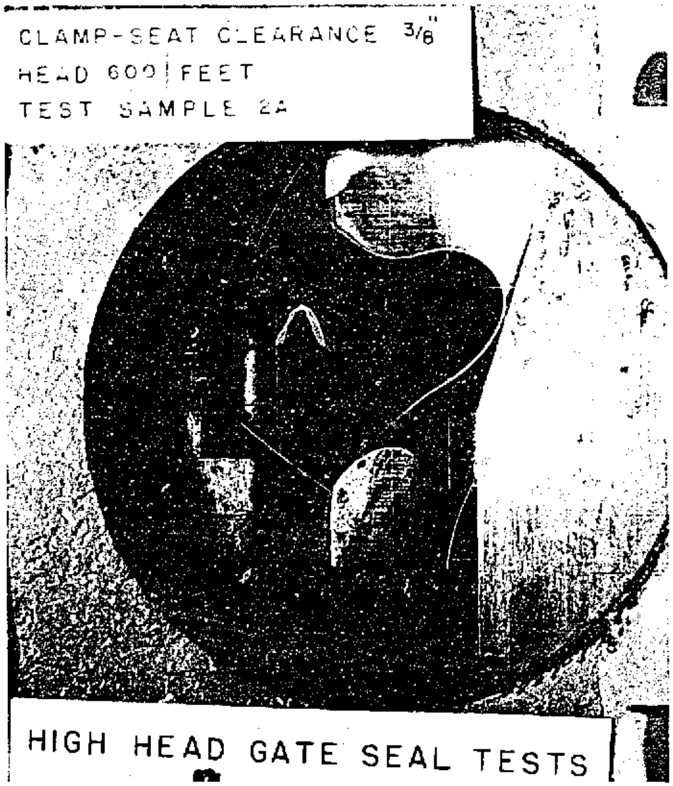
Figure 5. Section through high head gate seal test rig.

A. Seal bulb extended during closing cycle. Photo PX-D-67478

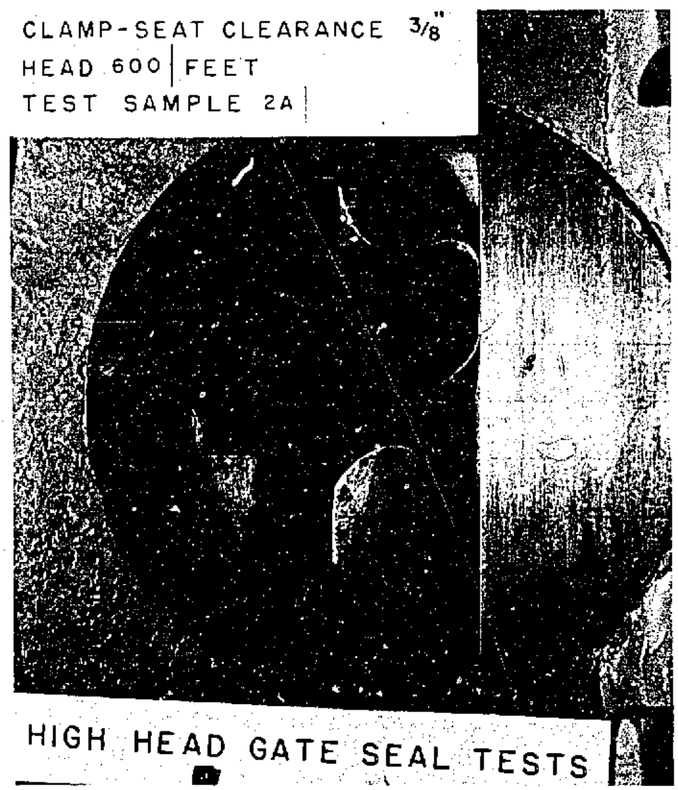


B. Gate in closed position. Photo PX-D-67477

Figure 6. High head gate seal studies.



A. Seal bulb extended during closing cycle. Photo PX-D-67476



B. Gate in closed position. Photo PX-D-67475

Figure 7. Specimen 2A being tested at 600 feet of head.

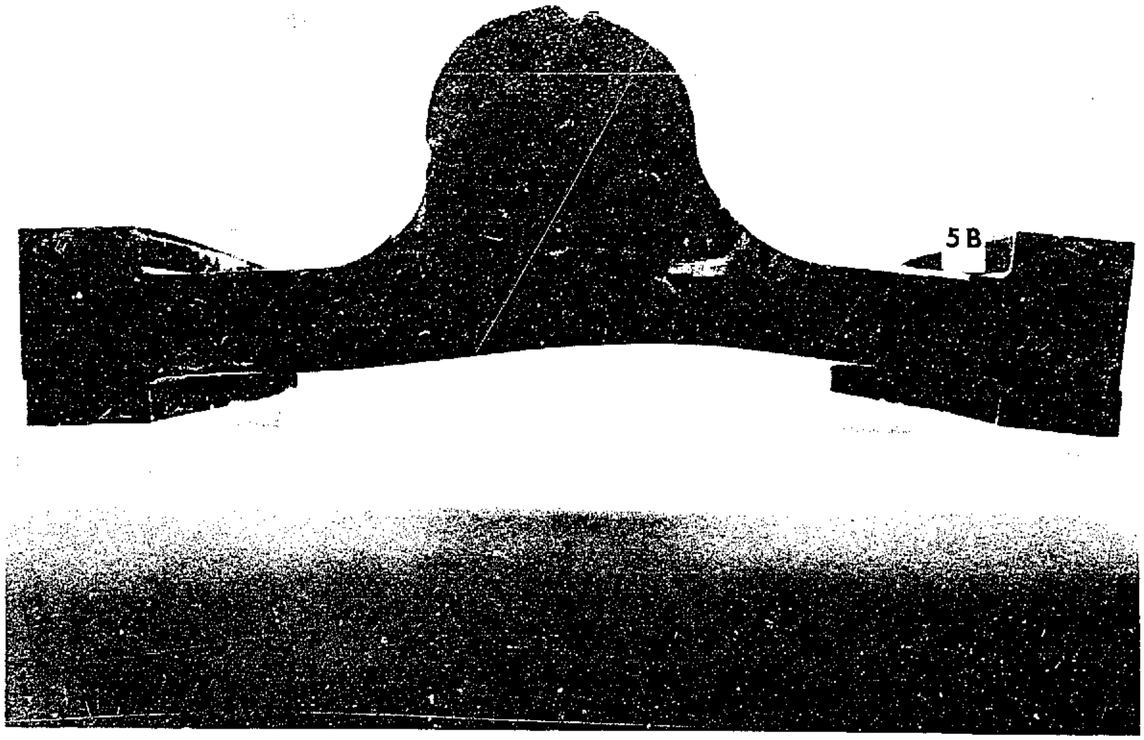


Photo PX-D-67484

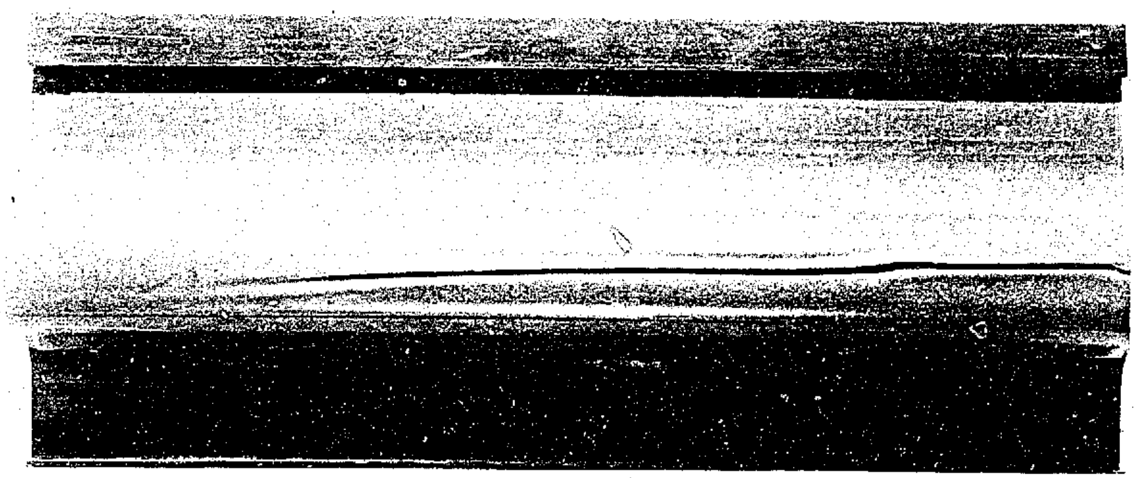


Photo PX-D-67486

Figure 8. Specimen 5B after testing to 450 feet (137.16 m).

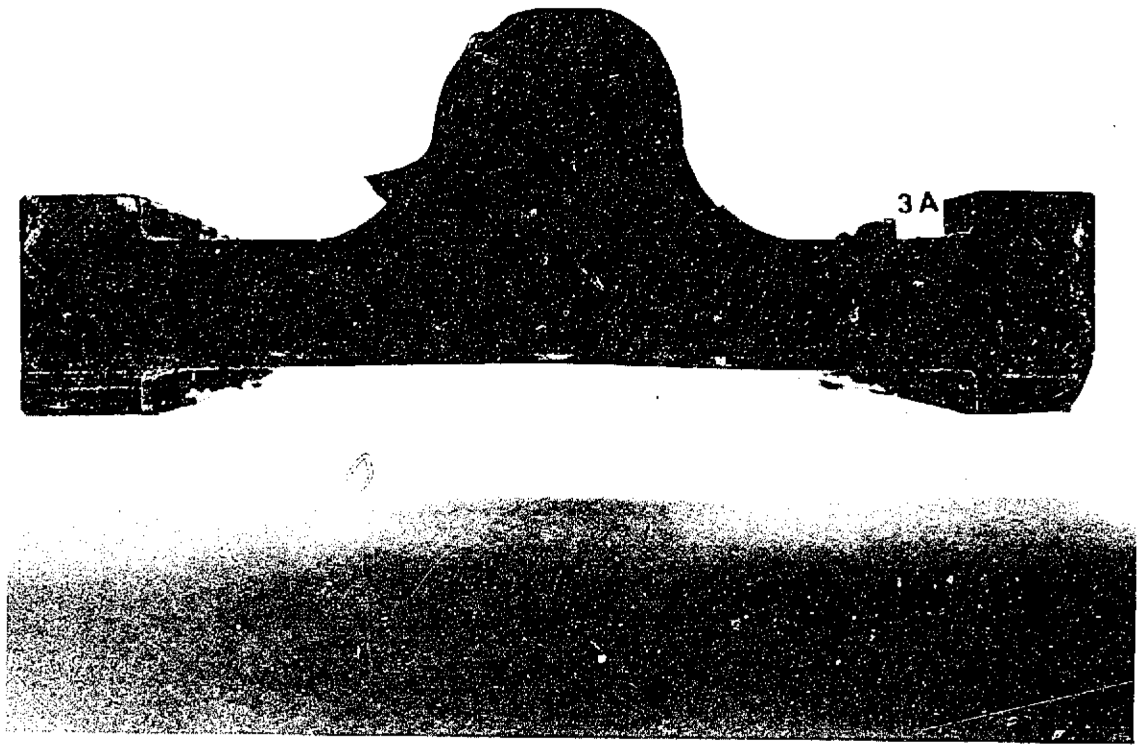


Photo PX-D-67480

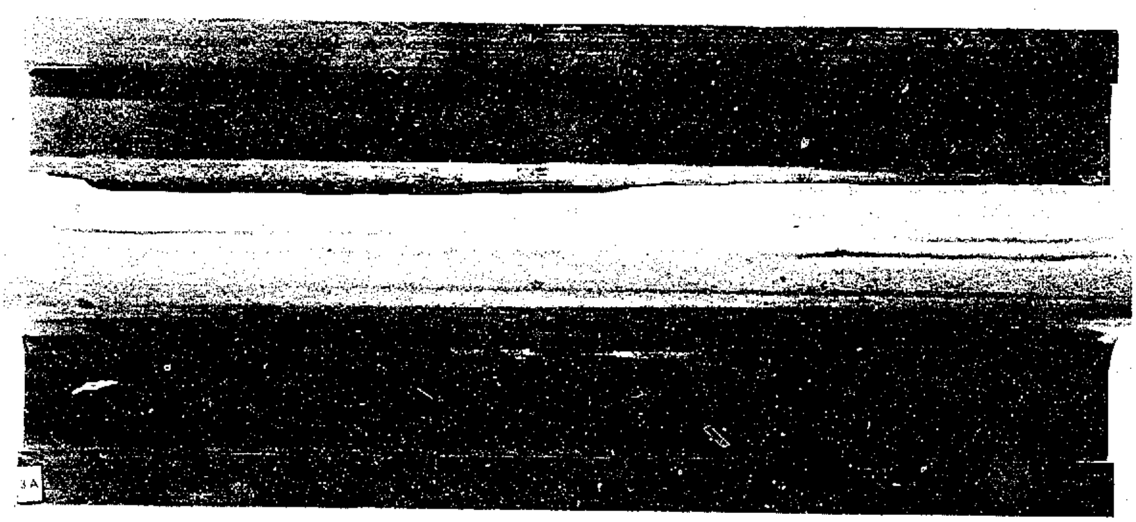
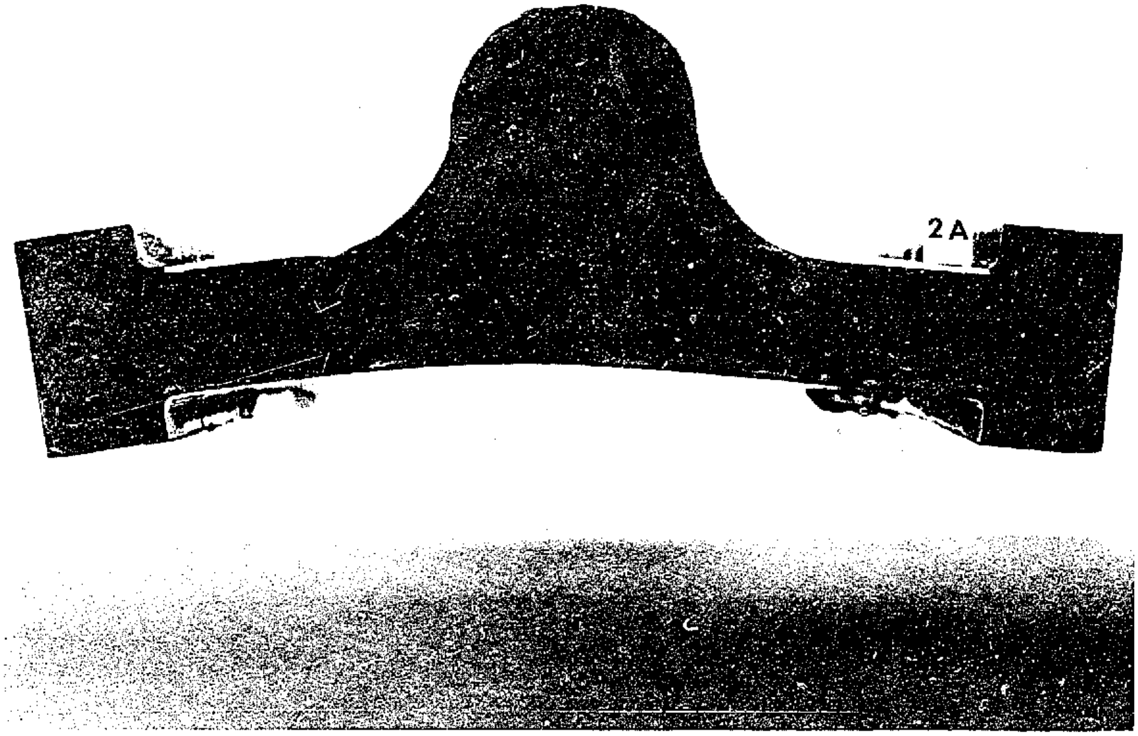
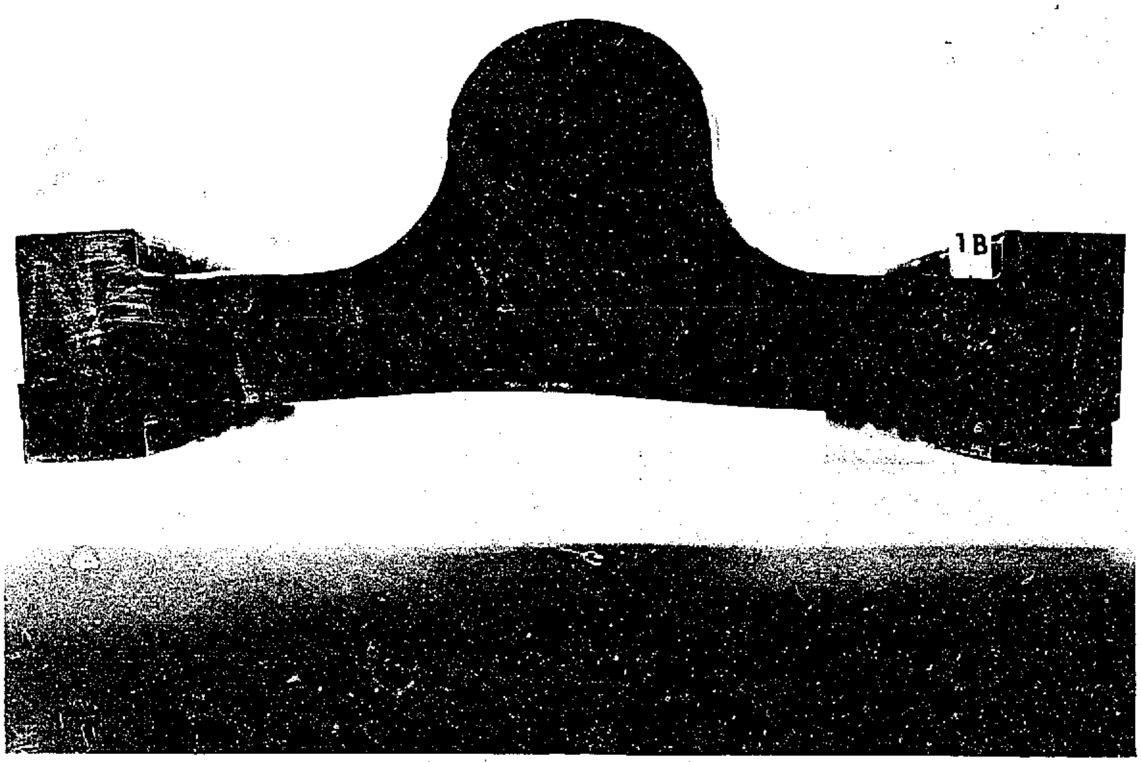


Photo PX-D-67485

Figure 9. Specimen 3A after testing to 600 feet (182.88 m).

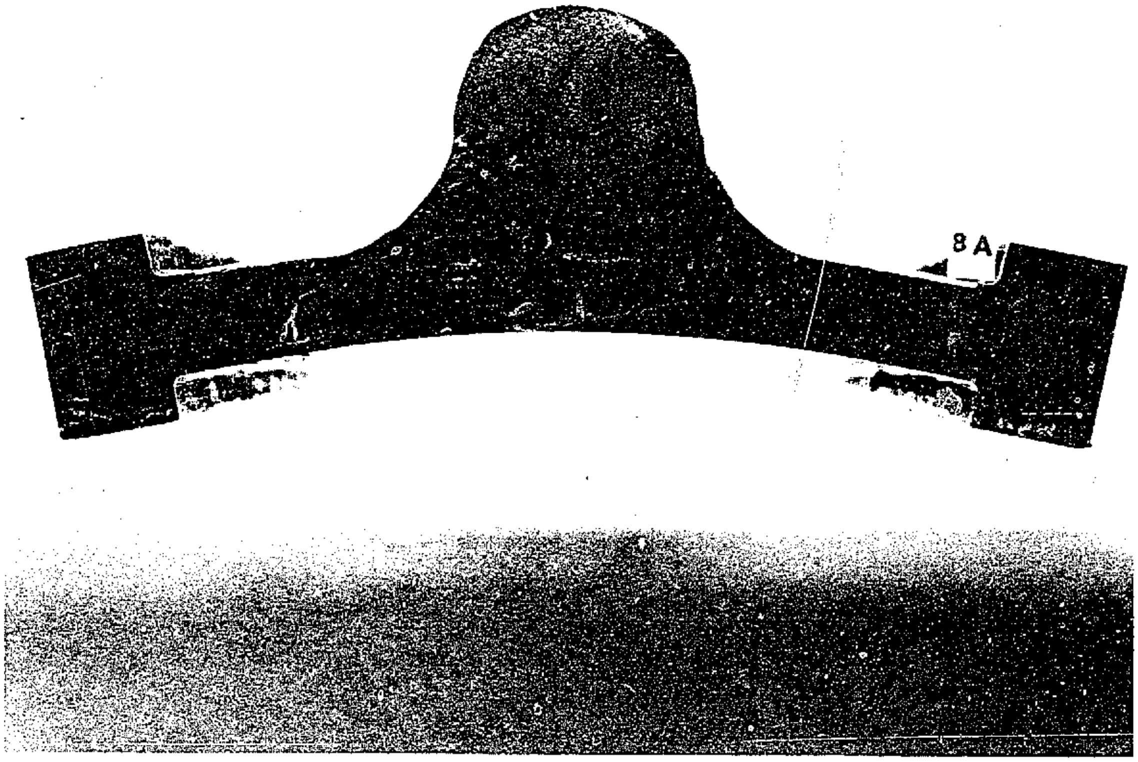


A. Fluorocarbon cap on both stems. Photo PX-D-67479

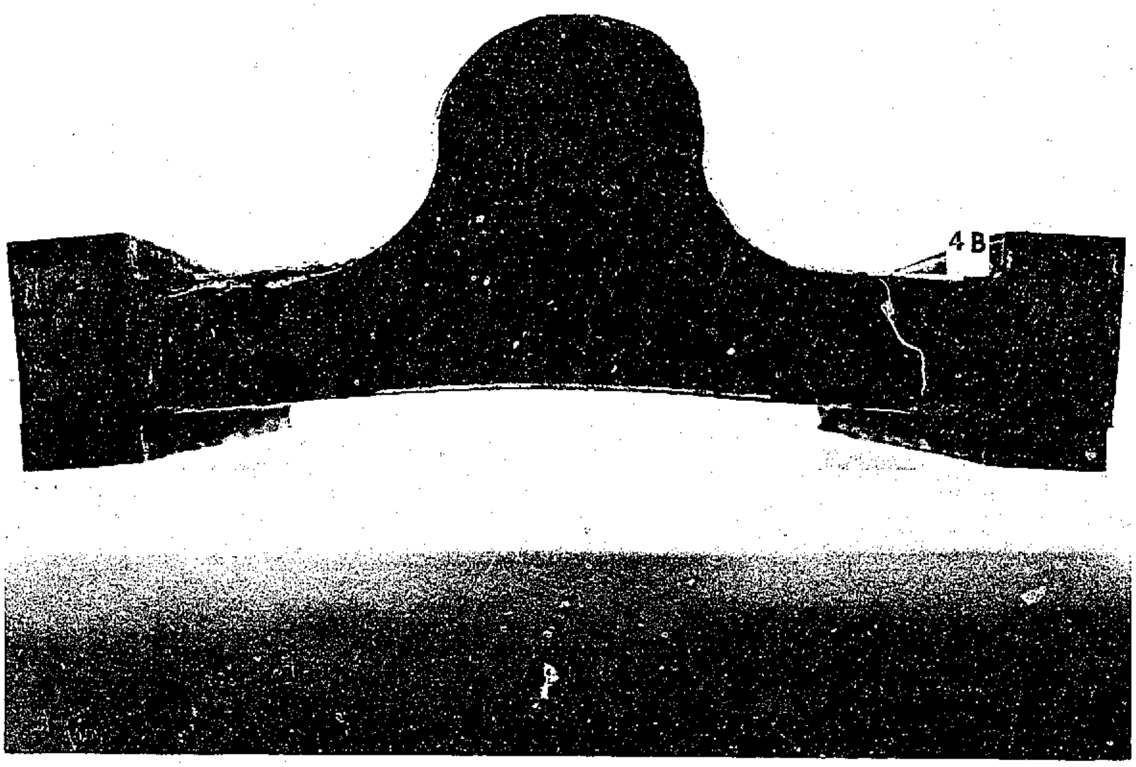


B. Fluorocarbon cap on pressure side stem only. Photo PX-D-67482

Figure 10. Comparison of permanent set of 11/16-inch stem seals.



A. 1/2-inch stem seal. Photo PX-D-67481



B. 11/16-inch stem seal. Photo PX-D-67483

Figure 11. Comparison of permanent set on 1/2- and 11/16-inch stem seals.

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 831-741

ABSTRACT

Studies were continued on rubber seals to determine the most suitable seal for use on wheel and roller-mounted gates operating under very high heads. The major problem encountered during the closing cycle under unbalanced pressure conditions is the pinching of the seal bulb between the seal clamp and seal seat. Seven factors affecting this pinching were varied in attempts to find the optimum seal assembly capable of withstanding high pressure heads. Ten double-stem seal variations using combinations of stem thickness, fluorocarbon cladding, and rubber compositions were tested at heads up to 600 ft (182.88 m). Tests were conducted in a special test rig accommodating 12-1/8-in.-long (30.798-cm) seal specimens. Tests consisted of measuring the seal bulb extension and photographing and observing general behavior of the seal under load during simulated opening and closing cycles of the gate.

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REC-OCE-70-37
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DESCRIPTORS—/ *gate seals/ *high pressure gates/ high pressure/ seals (stoppers)/ test procedures/ *laboratory tests/ physical properties/ hydraulic gates and valves/ friction/ test facilities
IDENTIFIERS—/ *high head/ fluorocarbons/ friction coefficient (mech)/ test results

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