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UNITED STATES
DEPARTMENT OF THE INTERIOR
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HYDRAULIC LABORATORY REPORT NO. 105

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MODEL TESTS OF BULKHEAD GATE FOR UNWATERING ARIZONA SPILLWAY TUNNEL BOULDER DAM - BOULDER CANYON PROJECT

By

H. G. Dewey, Jr.

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Denver, Colorado

February 24, 1942

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado

Laboratory Report No. 105
Hydraulic Laboratory
Compiled by: H. G. Dewey, Jr.

February 24, 1946

Reviewed by:

Subject: Model test of bulkhead gate for unwatering Arizona spillway tunnel, Boulder Dam - Boulder Canyon Project.

I INTRODUCTION

As a result of spillway operation in 1941, the concrete tunnel lining at the lower bend of the Arizona spillway, Boulder Dam, has been severely eroded (see letter of December 17, 1941, from Director of Power to Chief Engineer, subject: Scour in Arizona spillway tunnel - Boulder Dam - Boulder Canyon Project). Since no provisions were made in the design of the spillway to unwater the horizontal portion of the spillway tunnel in case repairs were necessary, a bulkhead gate has been designed under the direction of Mr. D. C. McConaughy, Senior Engineer, to permit unwatering of the tunnel. This gate, which will weigh about 125,000 pounds, will be 53 feet wide by 31 feet high and will consist of 35 timber trusses assembled on 2-inch lagging and strengthened by horizontal and vertical cross bracing, as shown on figures 1 and 2. To place the gate in position for unwatering, the gate will be floated in the river to the tunnel portal where cables will raise the gate into a vertical position against the face of the portal, the bottom of the gate in this position resting on a sill at invert elevation 626. It is planned that the tailwater will be at elevation 649 for this operation.

Because of the difficulty in computing the force required to raise the gate, and because the design of the cross bracing was dependent on this force, a request was made to determine the following: (1) The lifting force required to raise the gate into several intermediate positions

between the horizontal and vertical, and the location of these positions; (2) the effect of tailwater elevation on the maximum lifting force; (3) the variation in the maximum lifting force with the initial angle of pull that the lifting cable makes with the water surface at the start of raising the gate; and (4) the action of the gate while raising it.

II RESULTS OF MODEL TESTS

A 1 to 18 scale model was constructed of the bulkhead gate in accordance with preliminary design sketches, so that the model as tested varied somewhat from the prototype details shown on figures 1 and 2. For example, the model contained 35 instead of 37 trusses at slightly different spacing than the prototype, and the position of the eyebolts for lifting the gate differed as may be seen by comparing section C-C on figure 1 with the side elevation shown on figure 4-A. Other differences between model and prototype relative to limitations in the model construction are explained in paragraph 4. Figure 3 shows the model gate, while figures 4 and 5 give the details of the model and testing arrangement. Results of the force measurements are tabulated on figure 6 and in table 1.

The quantitative data obtained were rather indefinite, but the qualitative study revealed several facts that should be helpful in placing the gate in position. The quantitative measurements of forces were inconsistent because of the uncertainty of the magnitude of the force to be used in the field for snubbing the bottom of the gate against the portal as the gate is slowly raised into a vertical position. The model gate was held against the portal by rubber bands stretched around pins placed on each side of the gate as shown on figure 6. In terms of the prototype, the snubbing force so produced varied from a maximum of 3,960 pounds to a minimum of 566 pounds. These limits depended on the tension of the rubber bands, which was governed by the distance of the pins from the bottom of the gate and from the face of the portal as the gate rotated, and whether one or two rubber bands were placed around each pin.

Accordingly, for a given set of conditions the maximum lifting force would vary, depending on the magnitude of the snubbing force, which changed with tension of the rubber bands, and for any test it was difficult to obtain uniform results because the snubbing forces were great in relation to the lifting forces being measured. The weight of the model gate also affected the measurements, since its weight gradually increased due to absorption of water, thereby causing the gate to submerge more rapidly and reach the vertical position with less lifting force.

Keeping in mind the influence of these factors on the model measurements, the following conclusions have been drawn:

(a) For tailwater elevation 640, the maximum lifting force is about 16,563 pounds. For this load the snubbing force at the start was 2,030 pounds and 747 pounds at the vertical position (test 1, figure 6). The intermediate positions of the gate and corresponding loads are tabulated on figure 6 for use in a stress analysis for designing the cross bracing. The bracing used in the model was tentatively assumed but found to be correct after checking the prototype design.

(b) For tailwater elevation 645, the maximum lifting force is about 8,334 pounds with the snubbing forces as in (a) (test 2, figure 6). A check on this test is given in table 1, run 5-A.

(c) For tailwater elevation 649, the maximum lifting force averages about 3,500 pounds for snubbing forces as in (a), but with the model portal face slick due to a collection of algae (runs 1, 2-A, 3, 3-A, and 4 of test 4, table 1). With the portal face clean and for an initial snubbing force of 566 pounds and a final snubbing force of 1,855 pounds, the maximum lifting force is about 3,000 pounds (test 5, table 1). The limits of the snubbing force were changed for test 5 by placing the pins nearer the bottom of the gate.

(d) From (a), (b), and (c) it is seen that for the same snubbing forces the maximum lifting force decreases as the tailwater elevation increases, and that a decrease in the sliding friction is tantamount to a reduction in the snubbing force.

(e) That the maximum lifting force increases with the snubbing force may be seen by comparing in table 1, runs 1 and 2, 2-A and 2-B, and 5 and 5-A under test 4. On the other hand, there seems to be little variation in the maximum lifting force as the initial angle $\emptyset$, the angle the lifting cable makes with the water surface, decreases from 79 to 63 degrees. See figure 6 and table 1, tests 4 and 5.

(f) Since the snubbing forces to be used in the field are not known, while those used in the model were probably conservative, it is believed that a maximum lifting force of 9,000 pounds will be reasonable for use in designing the cross bracing. This provides a factor of safety in case the tailwater is below elevation 649 but above elevation 645. The lifting capacity available at the prototype is not exceeded by this force.

(g) The best method for raising the gate to a vertical position is to float the gate with the trusses upward to the tunnel portal, place the bottom of the gate against the portal, and then pull the top of the gate upward toward the portal as shown on figure 5.

(h) Should the gate be launched with the trusses pointing downward in the water, it would require a force of about 27,100 pounds to raise the gate into a vertical position for turning it over prior to floating the gate trusses upward to the tunnel portal (test 3, figure 6).

(i) Based on model performance, as the gate became heavier due to absorption of water, the force required to raise it became

less. For excessive absorption of water, the gate would reach the vertical position apparently without any external force being applied.

(j) As the gate approaches a vertical position with a steady force being applied, a point is reached where no additional force is required to complete the movement against the portal, in fact the gate tends to accelerate into the final position, producing impact against the portal. Accordingly, it is recommended that snubbing lines be attached to the top of the gate to restrain its movement as the final position is approached. Relative to the snubbing forces at the bottom of the gate, it has been shown in (e) that excessive snubbing increases the lifting force; hence, it is believed that the bottom of the gate should be snubbed only enough to keep it against the portal but not enough to prevent the gate from sliding down the portal as it approaches its vertical and final position. In any event it is urgent that the gate be kept completely under control during the lifting operation.

(k) It is not anticipated that any weights will have to be added to the gate to force it down against the portal sill after the gate has been raised to the vertical, unless the tailwater is at elevation 654 or above.

III SIMILITUDE REQUIREMENTS

A model study to measure forces requires both geometric and dynamic similitude. Accordingly, each member of the bulkhead gate must be geometrically similar to the corresponding prototype member, and the specific weights of the material must be the same for the model and prototype. If W_p is the weight of the prototype gate and V_p is its volume, then $W_p = V_p \cdot w_p$, where w_p is the specific weight of the prototype material. Similarly, $W_m = V_m \cdot w_m$ for the model. The ratio of the two systems is then:

$$\frac{W_o}{W_m} = \frac{V_p \cdot w_p}{V_m \cdot w_m}$$

If the materials of the model and prototype are the same, then $w_p = w_m$, so that,

$$\frac{W_p}{W_m} = \frac{V_p}{V_m}$$

Since the ratio of the volumes is equal to L_r^3, where L_r is the scale ratio, prototype to model, then:

$$W_p = W_m \cdot L_r^3, \text{ in which}$$

$$L_r^3 = (18)^3 = 5832$$

It may be shown in a similar manner that where the accelerative forces and densities in the two systems are nearly the same and constant, the forces are related as:

$$F_p = F_m \cdot L_r^3$$

With correct geometric and dynamic similitude for this gate test, it is assumed that the center of gravity and the center of buoyancy is the same for model and prototype. Accordingly, the model gate will float at the correct elevation and inclination as the prototype. As explained above, however, the absorption of water by the model gate will have an effect on the forces measured.

IV THE MODEL

For convenience in handling, a 1 to 18 scale model was built of the gate as shown in figures 3 and 4. It was estimated that the specific weight of the prototype timbers, which were to be obtained from Friant Dam form lumber, would be 40 pounds per cubic foot. The material used for the model was birch, a hard wood weighing approximately 40 pounds per cubic foot. Each member of the trusses was cut proper size to provide geometric similitude. The gusset plates were made of 24-gage galvanneal, and small brads were used to assemble the

trusses, the assembly being hastened by using a full-size layout drawing as a template. Although some of the prototype trusses at the bottom of the gate required larger tie rods than those near the top, it was found necessary in the model to use wire of the same size (0.083-inch) for all trusses. By adding short pieces of heavier wire (0.110-inch) to some of the bottom trusses, however, this difference was corrected, and the proper ratio of metal to timber was obtained (figure 4-A). The completed gate as shown on figure 3 weighed 21.875 pounds equivalent to 127,575 pounds for the prototype ($21.875 \times (18)^3 = 127,575$). This weight was 2 percent greater than an estimated prototype weight of 125,000 pounds.

The spillway tunnel portal and lifting equipment are shown on figure 4-B. To keep the bottom of the gate against the portal face during testing, rubber bands were attached to each side of the portal and stretched around pins inserted on each side of the gate (figure 6), while vertical strips of wood were fastened to the portal face to keep the gate from moving laterally. This combination simulated to a certain extent the snubbing action to be used in the field, which will be accomplished by cables attached near the bottom of the gate and kept taut from inside the tunnel. Since the model was tested in one of the laboratory supply channels, the tailwater depth above the portal sill was varied by moving the portal vertically and clamping or bolting it at the desired position.

V TESTING PROCEDURE

To measure the lifting force necessary to raise the gate into a vertical position against the portal, a wire cable was placed over two pulleys supported on a wooden frame, as shown on figure 4-B. One end of the cable was attached to a wire sling at the top of the gate, while the other end was attached to a pan for holding gram weights. With the gate in position as shown on figure 5, the rubber bands for snubbing the bottom of the gate were placed around the pins and weights were then added to the pan until the gate reached a position

of equilibrium for the load being applied. Measurements of the gate position were then recorded as shown on figure 6 for use in a stress analysis for designing the cross bracing. This procedure was repeated for several positions until the maximum lifting force was found which would place the gate in the vertical position. The gate position for this load could not be measured since the gate accelerated into the vertical position from the previous equilibrium position measured. For the data given in table 1, only the maximum lifting force was required for various initial angles (angle Ø, figure 6), the initial angles being changed by lowering the downstream pulley. The total lifting force in the model was equal to the weight of the pan plus the gram weights; the pulley friction was less than 1 percent so was neglected.

VI WEIGHT OF MODEL GATE CHANGES

Before the record tests were made as recorded on figure 6 and in table 1, a demonstration of the model operation was given during which the gate absorbed over a pound of water even though it had been sprayed with lacquer. To prevent this increase in weight from recurring, linseed oil was applied to the gate after it had been dried, but this increased the weight considerably more than anticipated. By heating the gate in an oven and by replacing the original lagging with redwood, the weight was reduced to 22.625 pounds, an increase of 12 ounces over the original dry weight. Unfortunately, the absorption of water could not be prevented, so it was necessary to dry the gate between the tests to reduce the weight to a minimum.

VII CONCLUSIONS

The main results and conclusions have been enumerated in paragraph 2. Relative to the technique of model construction, it is quite evident that the attempts to prevent the model gate from increasing its weight due to absorption of water were entirely

inadequate. Although the original dry weight agreed closely with the prototype estimate, it is recommended that in similar problems a lighter wood such as redwood, pine, or fir be used. By experimenting beforehand, it should be possible to determine the unit weight of these materials after they have been oiled or painted and then allowed to soak in water. With this weight as a basis, the model material can be so chosen that the addition of moisture will be helpful instead of a hindrance. It is not recommended that a model be purposely made too light and then brought to the correct weight by adding more material, since the center of gravity and buoyancy may be affected adversely.

FIGURE 1

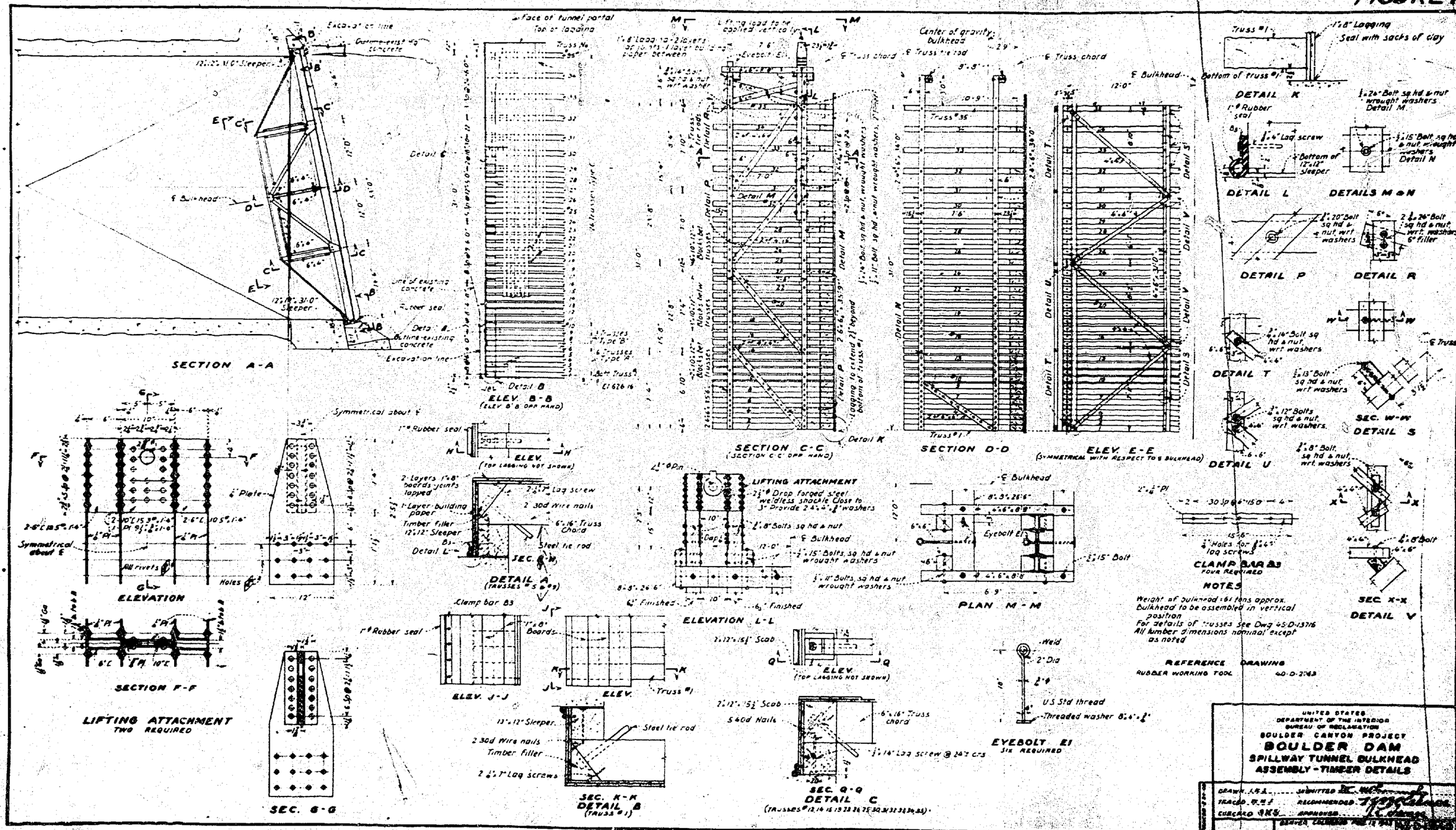
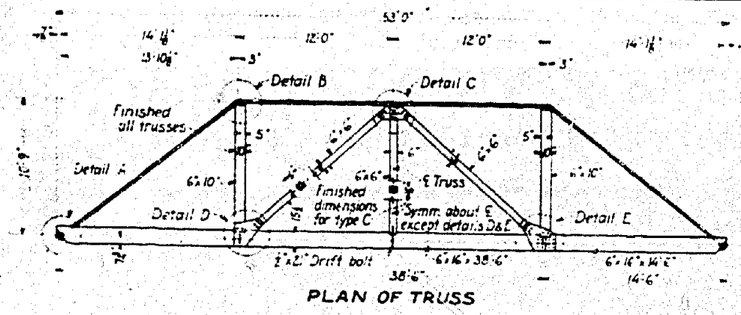
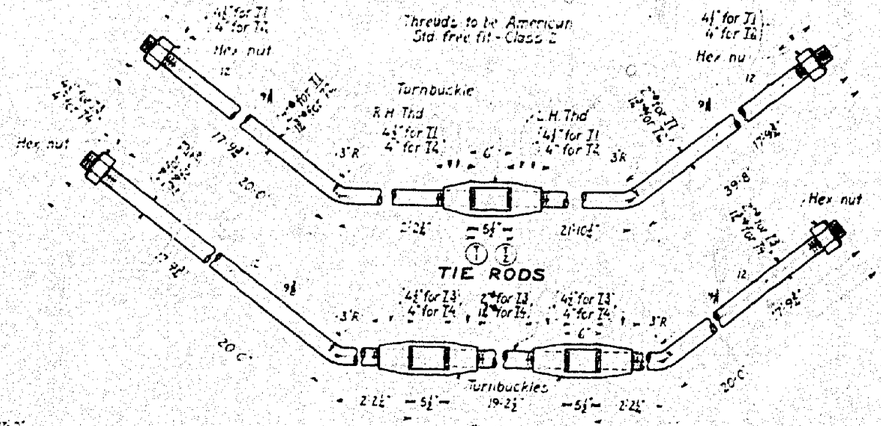

SECTION A-A
ELEV. B-B
(ELEV. B' B' OPP. HAND)
SECTION C-C
(SECTION C'C' OPP. HAND)
SECTION D-D
ELEV. E-E
(SYMMETRICAL WITH RESPECT TO ℄ BULKHEAD)
DETAIL K
DETAIL L
DETAILS M & N
DETAIL P
DETAIL R
DETAIL T
DETAIL U
SEC. W-W
DETAIL S
SEC. X-X
DETAIL V
ELEVATION
SECTION F-F
LIFTING ATTACHMENT
TWO REQUIRED
SEC. G-G
DETAIL A
(TRUSSES #5 & #9)
ELEVATION L-L
PLAN M-M
CLAMP BAR B3
FOUR REQUIRED
NOTES
Weight of bulkhead = 61 tons approx.
Bulkhead to be assembled in vertical position
For details of trusses see Dwg 45-D-13716
All lumber dimensions nominal except as noted
REFERENCE DRAWING
RUBBER WORKING TOOL 40-D-2763
ELEV. J-J
ELEV.
(TOP LAGGING NOT SHOWN)
SEC. K-K
DETAIL B
(TRUSS #1)
SEC. Q-Q
DETAIL C
EYEBOLT E1
SIX REQUIRED
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
BOULDER DAM
SPILLWAY TUNNEL BULKHEAD
ASSEMBLY - TIMBER DETAILS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED

FIGURE 2

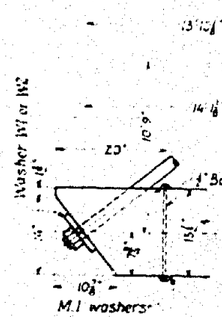


PLAN OF TRUSS



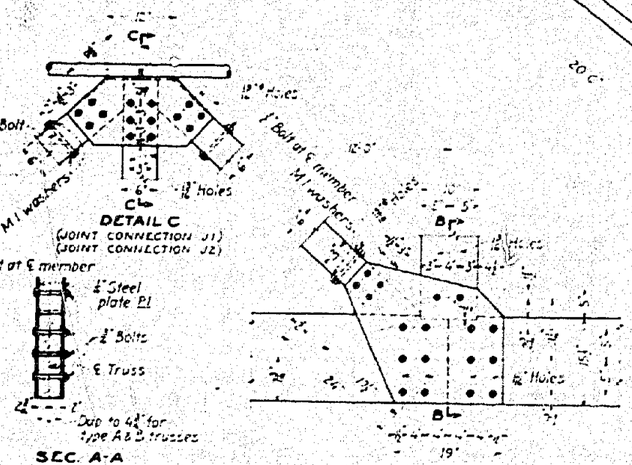
① ⑤ TIE RODS

② ④ TIE RODS



DETAIL B

DETAIL A

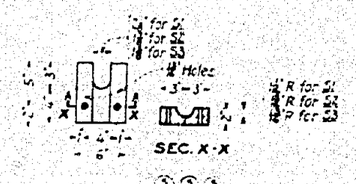


DETAIL D (PLATE P1)

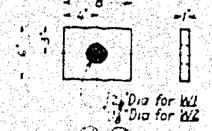
SEC. A-A

DETAIL E (PLATE P2)

SEC. B-B

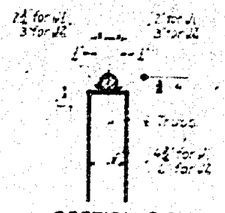


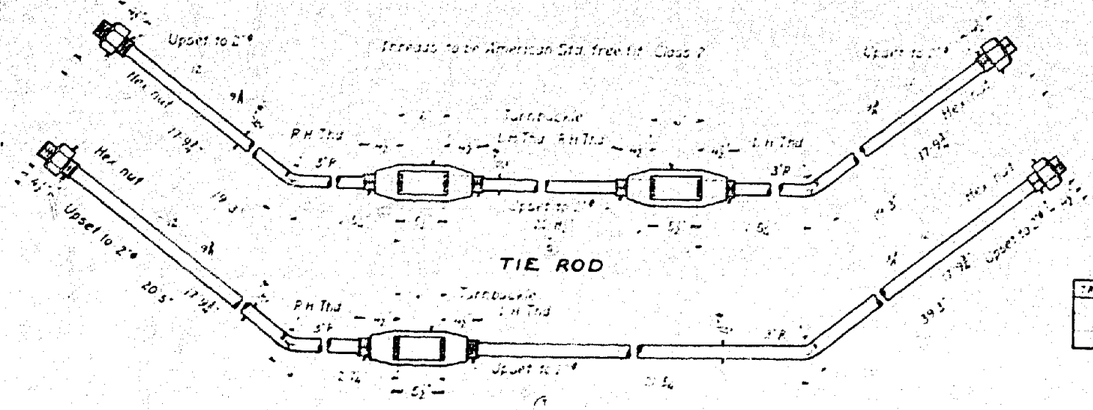
① ② ③ STEEL SHOES



① ② STEEL WASHERS

DETAIL F





LIST OF PARTS
SCHEDULE NO. 1

PART NO	DESCRIPTION	MATERIAL	NO REQ'D
J1	Joint connection	Structural steel	8
J2	Joint connection	Structural steel	13
P1	Gusset plate	Structural steel	35
P2	Gusset plate	Structural steel	35
S1	Shoe	Structural steel	6
S2	Shoe	Structural steel	3
S3	Shoe	Structural steel	26
W1	Washer	Structural steel	32
W2	Washer	Structural steel	3
T1	Tie rod	Structural steel	3
T2	Tie rod	Structural steel	2
T5	Tie rod	Structural steel	13
	1" Washer	Malleable iron	450
	¾"x21" Drift bolt	Bolt steel	42
	¾"x4½" Bolt-Sq head & nut	Bolt steel	80
	¾"x7" Bolt-Sq head & nut	Bolt steel	160
	¾"x5½" Bolt-Sq head & nut	Bolt steel	278
	¾"x7½" Bolt-Sq head & nut	Bolt steel	775
	1"x5½" Bolt-Sq head & nut	Bolt steel	115
	1"x7½" Bolt-Sq head & nut	Bolt steel	136
	¾"x7" Lag screw	Steel	136

SCHEDULE NO. 2

J1	Joint connection	Structural steel	4
J2	Joint connection	Structural steel	13
P1	Gusset plate	Structural steel	35
P2	Gusset plate	Structural steel	35
S1	Shoe	Structural steel	6
S2	Shoe	Structural steel	3
S3	Shoe	Structural steel	26
W1	Washer	Structural steel	32
W2	Washer	Structural steel	3
T1	Tie rod	Structural steel	3
T2	Tie rod	Structural steel	1
T5	Tie rod	Structural steel	13
	1" Square nut	Steel	195

NOTES

Tie rods T3 may be substituted for T1 in any quantity to make up number required.
Tie rods T4 may be substituted for T2 in any quantity to make up number required.
Tie rods T6 may be substituted for T5 in any quantity to make up number required.
Structural steel angles may be substituted for the tie rods under designs submitted by contractor. The features of detail A must be preserved. The net area of the angles must not be less than 2 sq in., 1.5 sq in., and 1.77 sq in. for the 2"ø, 1½"ø and 1¾"ø rods respectively. The resulting weight of such design must not exceed that given above by 13%, 16%, and 20% for the 2"ø, 1½"ø and 1¾"ø rods respectively.
All timber dimensions nominal except as noted.

TRUSS	TIE ROD	JT. CONN.	NO REQ'D
A	T1 or T3	J1	6
B	T2 or T4	J1	3
C	T5 or T6	J2	26

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT

BOULDER DAM
SPILLWAY TUNNEL BULKHEAD TRUSS DETAILS

DRAWN I.N.B. SUBMITTED
TRACED H.E.S. RECOMMENDED
CHECKED S.N.B. APPROVED

DENVER, COLORADO, JAN. 19, 1932

135-D-8 175

SUPERSEDING NOV. 7, 1930

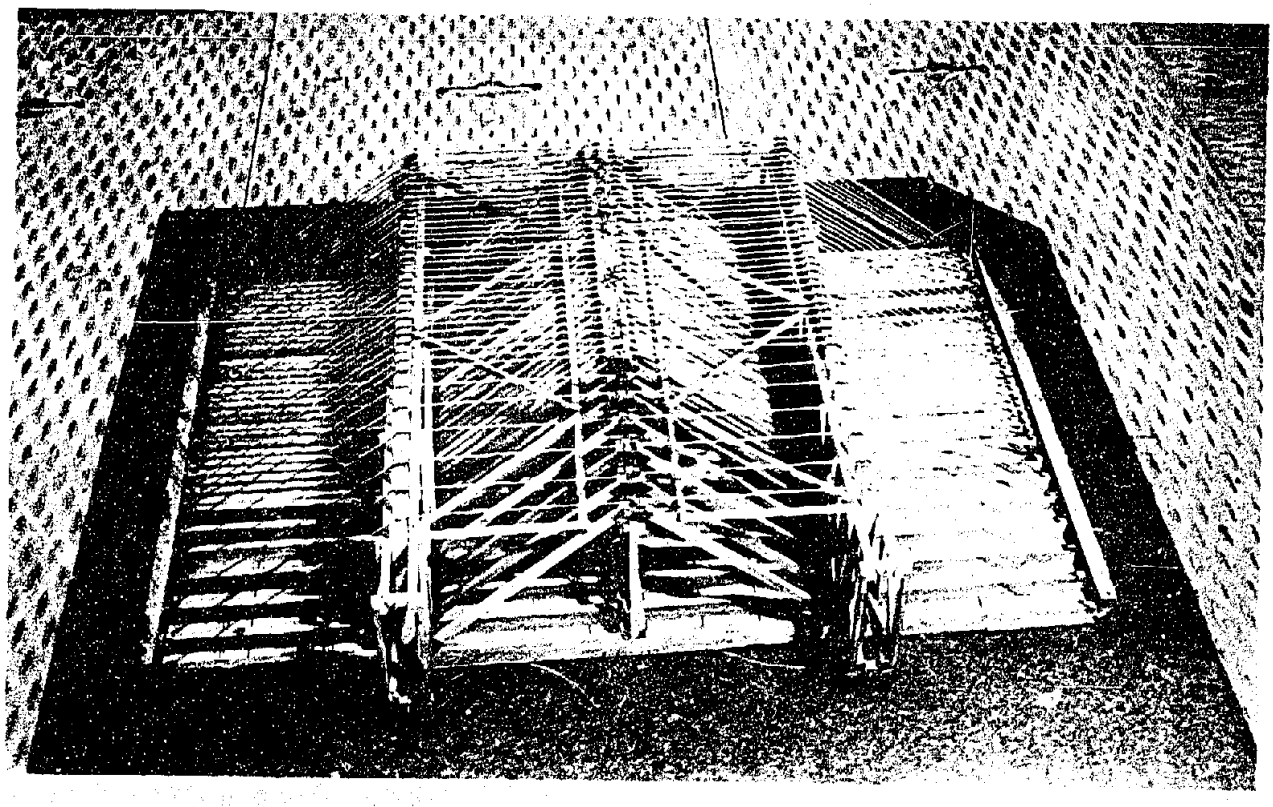
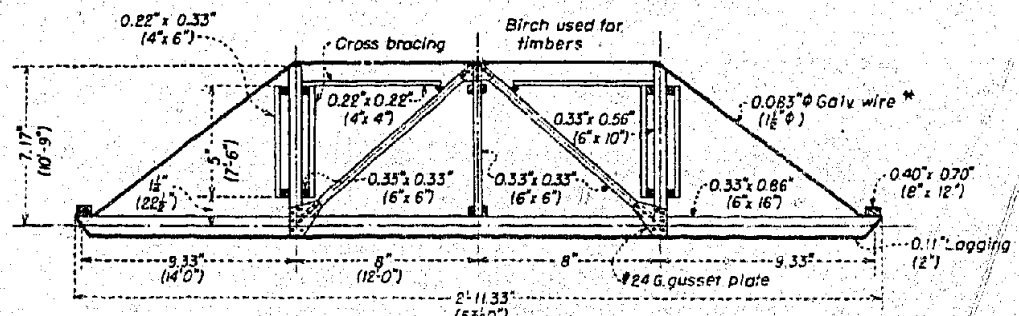
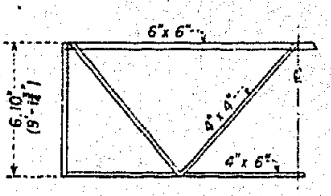


Figure 3 - Model of bulkhead gate - 1 to 18 scale.

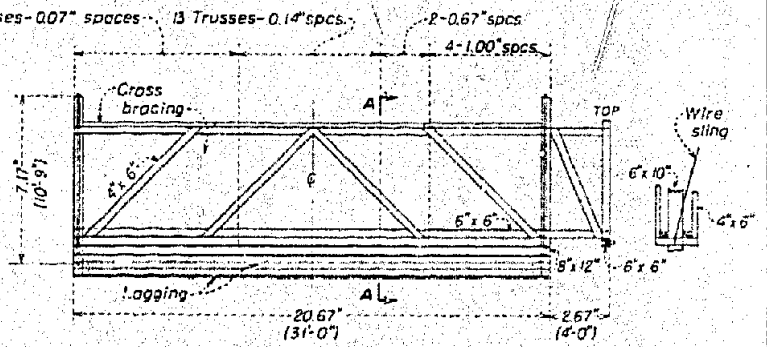


SECTION A-A (TYPICAL)

* First 6 bottom trusses have 2-pieces #10 galvanized wire 5" long added to tie rods; next 4 trusses have 2-pieces ½" long added.

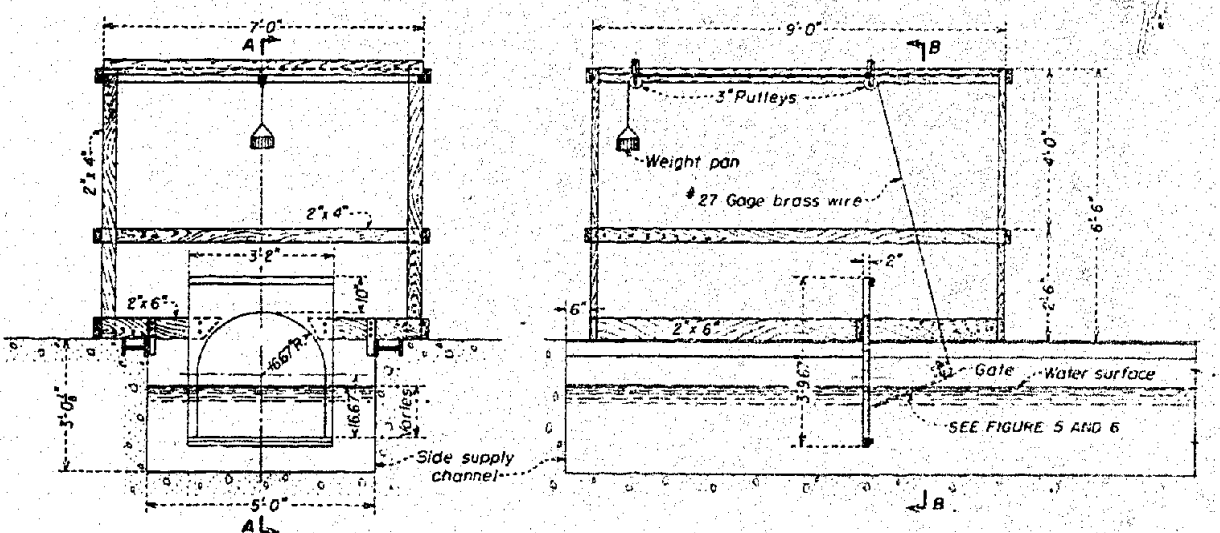


HORIZONTAL BRACING



SIDE ELEVATION

A - DETAILS OF 1:18 SCALE MODEL



SECTION B-B

SECTION A-A

B - TESTING ARRANGEMENT

ARIZONA SPILLWAY TUNNEL - BOULDER DAM

BULKHEAD GATE TEST

1:18 SCALE MODEL

H.G.D. JR. - 1-22-42

45-D-8985

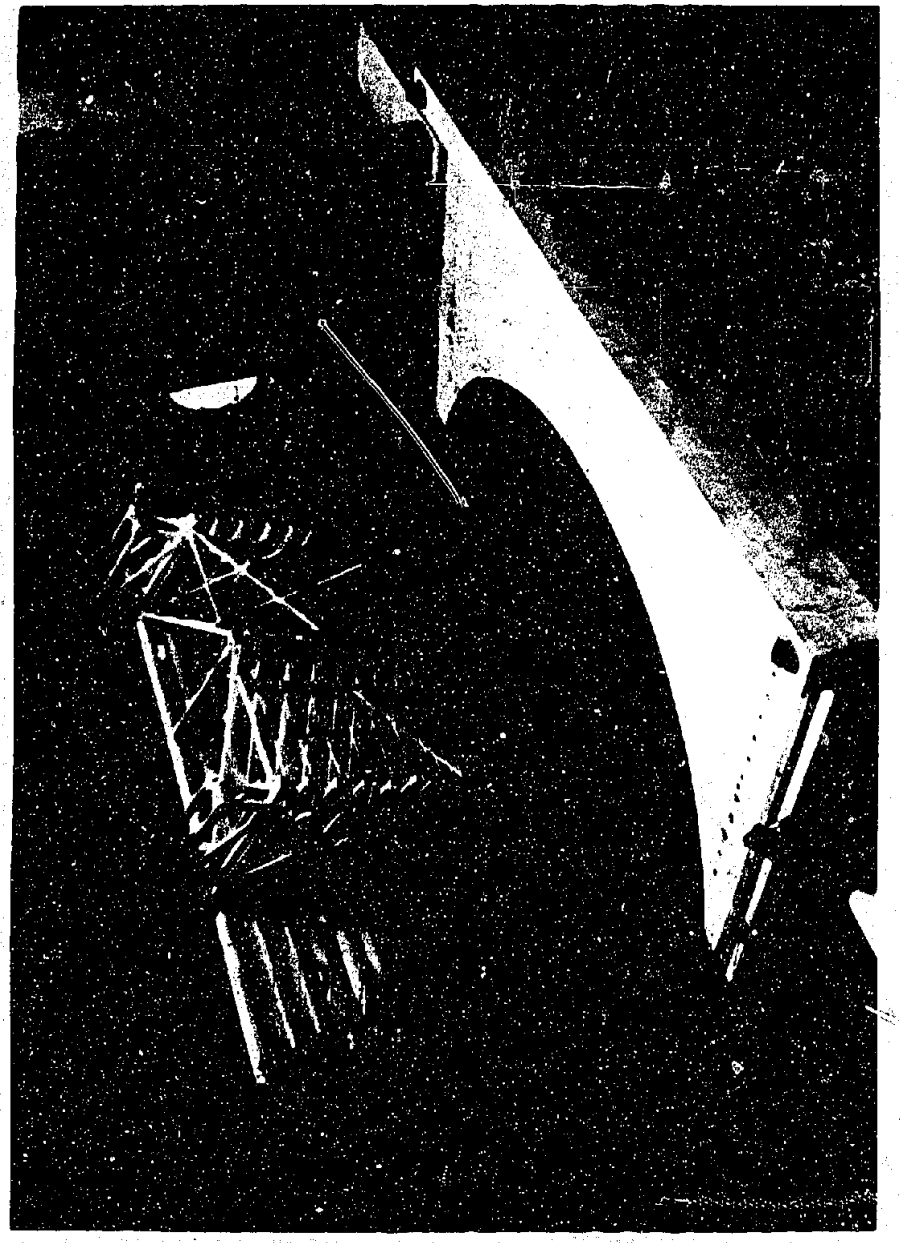
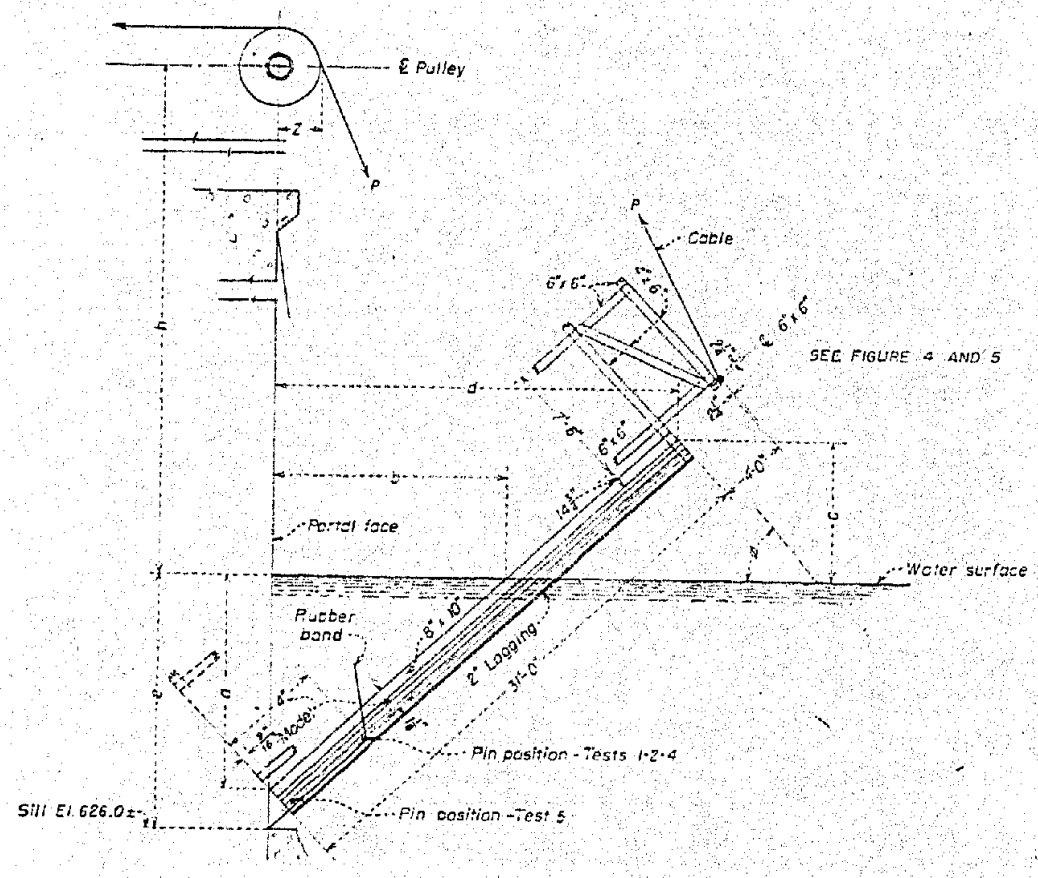


Figure 5 - Gate in position at tunnel portal.

FIGURE 6



LABORATORY MEASUREMENTS

TEST 1											TEST 2										
MODEL						PROTOTYPE					MODEL						PROTOTYPE				
a	b	c	d	P GRAMS	P POUNDS	a	b	c	d	P POUNDS	a	b	c	d	P GRAMS	P POUNDS	a	b	c	d	P POUNDS
8 1/16"	16 7/8"	1/8"	18 7/8"	173	0.381	12'-1 1/2"	25'-3 3/4"	0'-9"	28'-3 3/4"	2,222	10 3/4"	14 1/16"	1 1/8"	16 9/16"	153	0.337	16'-1 1/2"	22'-0 5/16"	20 1/4"	25'-4 7/8"	1,965
8"	12 3/8"	2 7/8"	17 5/8"	803	1.771	12'-0"	18'-6 3/4"	4'-3 3/8"	26'-5 1/4"	10,328											
8 1/16"	8 1/8"	5 1/2"	15 5/8"	1103	2.432	12'-7/8"	13'-3 3/4"	8'-3"	25'-8 1/4"	14,183	11 1/8"	8 1/4"	4 3/8"	13 1/16"	603	1.330	16'-8 1/4"	13'-11 1/2"	7'-3 1/4"	19'-7 1/8"	7,757
7 3/4"	8"	6 3/8"	15 1/8"	1203	2.653	11'-7 1/2"	12'-0"	9'-6 3/4"	22'-8 1/4"	15,472											
Minimum load to complete raising of gate. Gate accelerates into position				1288	2.840	Maximum load Tailwater El. 640.04				16,563	Maximum load				643	1.429	Maximum load Tailwater El. 644.72				8,334
e = 0.78' h+e = 7.70' Z = 1 1/8" Weight of gate 22 lb. 10 oz.				SNUBBING FORCE Start = 0.348 lb. Finish = 0.128 lb		e = 1.404' h+e = 138.60 Z = 2.25' Weight of gate = 131,949 lb.				SNUBBING FORCE Start = 2,030 lb. Finish = 747 lb.	e = 1.04' h+e = 7.98' Z = 1 1/2" Weight of gate 23 lb. 13 oz.				SNUBBING FORCE Start = 0.348 lb. Finish = 0.128 lb.		e = 18.72' h+e = 143.64' Z = 2.25' Weight of gate = 138,875 lb.				SNUBBING FORCE Start = 2,030 lb. Finish = 747 lb.

TEST 3

Force required to raise gate into vertical position after launching - trusses downward, P_V = 27,100 lb
Weight of gate = 140,700 lb. (based on water-soaked model) for test.

ARIZONA SPILLWAY TUNNEL - BOULDER DAM
RESULTS OF BULKHEAD GATE TESTS

(FOR SUMMARY, SEE TABLE I)

H. G. D. JR. - 1-26-42

45-D-8984

TABLE I

TEST NO. 4

MODEL									PROTOTYPE							
RUN No.	INITIAL ANGLE ϕ	e feet	h+e feet	weight of gate before run-pounds	P grams	P pounds	Snubbing force (lbs.) start	Snubbing force (lbs.) finish	INITIAL ANGLE ϕ	e feet	h+e feet	P pounds	Snubbing force (lbs.) start	Snubbing force (lbs.) finish	Weight of gate before run-pounds	REMARKS
							Pins 4" from bottom of gate			Tailwater Elev. 649.00						
1	79°	1.284	8.513	22.813	238	0.525	0.348	0.128	79°	23.11	153.23	3,062	2,030	747	133,045	one rubber band each side - portal face slick
2	75°	1.280	7.510	23.188	363	0.800	0.679	0.216	75°	23.04	135.18	4,666	3,960	1260	135,232	two rubber bands each side - portal face slick
2A	75°	1.282	7.515	23.438	278	0.613	0.348	0.128	75°	23.08	135.27	3,575	2,030	747	136,690	one rubber band each side - portal face slick
2B	75°	1.285	7.515	23.813	703	1.550	0.679	0.216	75°	23.13	135.27	9,040	3,960	1260	138,877	two rubber bands each side - portal face clean
3	72°	1.280	6.510	23.250	268	0.591	0.348	0.128	72°	23.04	117.18	3,447	2,030	747	135,594	one rubber band each side - portal face slick
3A	72°	1.280	6.510	23.188	293	0.646	0.348	0.128	72°	23.04	117.18	3,767	2,030	747	135,232	do.
4	68.5°	1.280	5.510	23.250	283	0.624	0.348	0.128	68.5°	23.04	99.18	3,639	2,030	747	135,594	do.
										Tailwater Elev. 644.81						
5	77°	1.045	8.192	23.688	793	1.749	0.679	0.216	77°	18.81	149.08	10,200	3,960	1260	138,148	two rubber bands each side - portal face clean
5A	77°	1.045	8.288	23.938	683	1.506	0.348	0.128	77°	18.81	149.08	8783	2,030	747	139,606	one rubber band each side - portal face clean

TEST NO. 5

							Pins 7/16" from bottom of Gate			Tailwater El. 649.00±						
1	77°	1.290	8.518	23.313	253	0.558	0.097	0.318	77°	23.04	153.32	3,254	566	1855	135,961	one rubber band each side - portal face clean
2	75°	1.280	7.520	23.963	268	0.591	0.097	0.318	75°	23.04	135.36	3,447	566	1855	134,503	do.
3	71.5°	1.280	6.525	23.250	223	0.492	0.097	0.318	71.5°	23.04	117.45	2,869	566	1855	135,594	do.
3A	71.5°	1.280	6.525	23.313	213	0.470	0.097	0.318	71.5°	23.04	117.45	2,741	566	1855	135,961	do.
4	63°	1.280	4.320	23.250	198	0.437	0.097	0.318	63°	23.04	77.76	2,549	566	1855	135,594	do.

H.G.D.JR.