UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

# MODEL STUDIES OF HYDRAULIC DOWNPULL FORCES THAT ACT ON THE PALISADES-TYPE REGULATING SLIDE GATE, AND ON THE GLENDO FIXED-WHEEL GATE

Hydraulic Laboratory Report No. Hyd-421

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

February 8, 1957

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Commissioner's Office, Denver
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Hydraulic Structures and Equipment Section
Denver, Colorado
February 8, 1957

Laboratory Report No. Hyd-421
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Subject: Model studies of hydraulic downpull forces that act on the Palisades-type regulating slide gate, and on the Glendo fixed-wheel gate

## PURPOSE

Studies were made to determine the magnitude of the downpull forces that act on the gate leaves so that hoists of adequate and yet not excessive capacity could be provided.

## PART ONE--PALISADES-TYPE REGULATING SLIDE GATE

### Conclusions

1. The maximum downpull during free-discharge operation is about 59 percent of the downpull computed by assuming full bonnet pressure on top of the leaf minus atmospheric pressure on the bottom of the leaf.

2. The maximum downpull force for free discharge occurs at a gate opening of about 40 percent (Figure 4D).

3. The downpull during submerged operation will be greater than during free-discharge operation at the same differential head because the pressure difference from the bonnet to the flat surface on the leaf bottom will be greater during the submerged operation. The pressure difference is greater because with free discharge the difference equals the bonnet pressure minus a bottom pressure that is essentially atmospheric and the same as the downstream pressure, whereas with submerged operation the difference equals the bonnet pressure minus a bottom pressure that is always appreciably less than the downstream pressure due to the pattern of flow beneath the leaf. Careful analysis and/or model studies will be required to accurately determine the downpull forces for submerged operation.

4. The downpull force on this type of gate will vary to a limited extent with small differences in leaf geometry.

## Introduction

The Palisades-type gate is a rectangular, downstream seal, high-capacity slide gate designed for use as a regulating device under high heads (Figure 1). The principal features of the gate are the small gate slots, the outwardly offset downstream slot corners followed by gradually inward sloping side walls, and a leaf with a flat upstream face and a 45° sloping bottom. This gate design was developed to meet the requirements of the outlet works at Palisades Dam where large flows of water at heads up to 240 feet were to be controlled.

The gate as originally designed had the gate slots at the downstream face of the leaf and was intended for free-discharge regulation (Figure 1). Recently the gate has been considered for use under water, and model studies have shown that this design is satisfactory for most submerged operating conditions. There is, however, a range of gate openings between 0 and 5 percent where, if the submergence is small, negative pressures will occur on the wall just downstream of the slot. To eliminate these negative pressures, a design revision was proposed which moved the slots 12 inches upstream from the downstream face of the leaf, and thus, upstream from the point of control in the gate (Figure 3).

Data on the hydraulic downpull characteristics of the Palisades-type slide gate were desired in order that adequate and yet not excessive hoists could be provided. To obtain this information, model studies were made using air as the testing fluid. The design with the gate slots moved 12 inches upstream was used in the tests, but the data are applicable to either the standard or to the proposed revised design.

## The Model

The studies were made with an air model and the air was drawn from the atmosphere by a centrifugal blower and forced through a stilling section and the test section, and then back into the atmosphere (Figure 2). The rate of flow was measured by a flat plate orifice at the entrance to the 12-inch-diameter inlet line of the blower. The test section consisted of a plywood conduit 8.23 inches wide by 16.67 inches high (Figure 3). The 2.48-inch-thick gate leaf was made of heavy-gage sheet metal, and was supported in the type of slots proposed for the revised gate design. Three rows of eight piezometers were placed on the leaf bottom so the pressure distribution could be determined at stations on the conduit centerline, and 0.18 and 1.10 inches from the side walls. An additional piezometer was placed in the bottom of one of the projections of the leaf that extended into the gate slots. The upstream pressure head was measured by a piezometer in the side wall 19 inches upstream from the leaf. A piezometer on the roof centerline 1 inch upstream from the leaf gave the approximate bonnet pressure. No bonnet was included in the model. All pressure measurements were made with water-filled U-tubes, and the readings were made in tenths of inches and estimated to the nearest hundreth of an inch. The test procedure consisted of setting the leaf at the desired position, allowing a few minutes of operation for conditions to stabilize, and taking the pressure readings. The leaf was then set at the next desired position and the process repeated. Readings were taken at a 5-percent gate opening, and at 10-percent increments from 10 to 80 percent.

## Investigation

A model that uses air as the flowing fluid and discharges into the atmosphere, operates under submerged conditions. In the case of the Palisades-type gate, the flow conditions along the upstream face and along the sloping bottom of the leaf are the same for free discharge and submerged operation. Pressures measured on this part of the air model are therefore applicable also to free-discharge conditions. A flow difference exists, however, along the horizontal portion of the leaf which lies downstream from the abrupt ending of the slope. During free discharge, the flow will spring clear of this surface and the pressure on it and on any seal extension will be atmospheric. During submerged operation, an eddy of the flowing fluid will be in contact with the surface and the pressures will be a function of the head, the gate opening, the conduit shape at the gate exit, and the back pressure on the gate. The lowest pressure that can occur on the surface when water is flowing is the vapor pressure of water, about -30 feet, gage. The pressure under a seal extension, if one is used, will be affected in about the same manner.

Practical considerations dictate the width of the flat on the leaf bottom and on any seal extensions required. Therefore, the geometry of the gate bottom may not be exactly similar for gates designed for different sized installations and heads. To make the data applicable to these variations in design, it was broken down into the data applicable to the sloping portion of the leaf, and the data applicable to the flat bottomed portion including slot projections and seal extensions (Figure 4A).

The pressure measurements showed that without submergence the bonnet pressure at zero opening was the same as the total head, and that it decreased with respect to the total head as the gate opened (Figure 4B). At zero opening the average pressure acting upward on the plan area of the sloping bottom, without submergence, was the same as the total head. It decreased to a minimum at 70 percent open, and increased again at 80 percent open. The pressure distribution envelopes for the sloping gate bottom were applied to the appropriate areas and the totals of the pressure times the areas were added together. This sum was divided by the cross-sectional areas of the leaf to give the single equivalent pressure value that can be assumed to act over the full area. The difference between the bonnet pressure and the average pressure over the sloped bottom was a maximum at an opening of about 45 percent, and the difference did not exceed about 53 percent of the total head (Figures 4B and C). Submerging the gate had the effect of equally raising the pressures in the bonnet and on the sloping bottom of the leaf. Thus no net pressure difference occurs on this portion of the leaf for submerged or free-discharge conditions for a given head differential producing flow. The total head producing flow at free-discharge conditions was taken as the difference between the total head upstream from the gate and atmospheric pressure. Under submerged conditions the total head producing flow was taken as the difference between the total head upstream from the gate and the static head well downstream.

For free-discharge flow the net downpull on the flat bottom, the slot projections, and any seal extension can be determined from the difference between the bonnet pressure and atmospheric pressure. For submerged flow the greatest possible net downpull on the flat bottom and on any seal extension would be determined from the difference between the bonnet pressure and vapor pressure. It is unlikely that vapor pressure would ever occur over the whole area so this extreme condition should not exist. In the more likely cases where there might never be conduit failures or unexpectedly low tail water, and where the submergence will always be sufficient to hold the pressures on the flat of the leaf and on the seal above vapor pressure, the net downpull would be determined from the difference between the bonnet pressure and these surface pressures. Such pressures would probably have to be determined experimentally for the particular geometry and flow conditions involved.

The total downpull force acting on the leaf will be the sum of the downpull forces acting on the various portions of the leaf.

A sample calculation of the downpull forces follows:

Free-discharge conditions
Assume: Standard gate leaf 6.0 feet wide, 2.0 feet thick, 3-inch flat on bottom, 6- by 6-inch slot projections, no seal extension, (Figure 4D).
Head; 200 feet.

The net force acting downward on the plan area over the flat part of the leaf bottom is:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (1) | Gate Opening, % | 10 | 30 | 40 | 50 | 60 | 80 |
| (2) | Head diff % / $H_T$ | 21.3 | 47.1 | 52.5 | 52.9 | 51.4 | 25.1 |
| (3) | (2) x $H_T$ = head diff (feet, $H_2O$) | 42.6 | 94.2 | 105.0 | 105.8 | 102.8 | 50.2 |
| (4) | (3) x 62.4 = Pres diff psf | 2,658 | 5,878 | 6,522 | 6,602 | 6,414 | 3,132 |
| (5) | (4) x area = downpull, lb (Area = 6.0 x 1.75 = 10.50) | 27,909 | 61,719 | 68,796 | 69,321 | 67,347 | 32,886 |

The net force acting downward on the plan area of the flat bottom and the slot projections (no seal extension on standard gate) is:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (6) | Bonnet Pres % / $H_T$ | 99.5 | 96.0 | 92.2 | 86.3 | 78.0 | 50.1 |
| (7) | (6) x $H_T$ = Bonnet Pres = Head diff (ft, $H_2O$) | 199.0 | 192.0 | 184.4 | 172.6 | 156.0 | 100.2 |
| (8) | (7) x 62.4 = Pres diff (psf) | 12,417 | 11,981 | 11,507 | 10,770 | 9,734 | 6,252 |
| (9) | (8) x Area = Downpull; A = (0.25 x 6.0) + 2(0.5 x 0.5) = 2.00 | 24,834 | 23,962 | 23,014 | 21,540 | 19,468 | 12,504 |
| (10) | (5) + (9) = Total downpull lb | 52,743 | 85,681 | 91,810 | 90,861 | 86,815 | 45,390 |

$H_T$ = Total head upstream of gate.

If it were assumed that the full total head minus atmospheric pressure acted over the full area of the leaf, the calculated downpull would be 200 x 62.4 x (10.5 + 2.0) = 156,000 pounds. The maximum downpull of 91,810 pounds obtained with the above test information is 59 percent of this value. This percentage value will vary somewhat depending upon the width of the flat bottom of the leaf, the location of the leaf projections and whether or not seal extensions are used.

For submerged flow where conditions could arise to allow vapor pressure under the flat of the leaf, the method of calculation would be the same as that in the free discharge example, except that head differential in Item (7) becomes the total bonnet pressure minus vapor pressure. When back pressure conditions can be depended upon to maintain appreciable pressures under and just downstream from the leaf, the head differential becomes the total bonnet pressure minus the pressure on the leaf bottom for the particular operating condition.

## PART TWO--GLENDO FIXED-WHEEL GATE

### Conclusions

1. The maximum downpull force will be about 40, 000 pounds, and it will occur under submerged conditions at a gate opening of about 3. 3 inches prototype with the reservoir at the maximum elevation (Figure 7B). The downpull decreases rapidly as the gate opening is increased beyond 3. 3 inches. No downpull occurs during free-discharge operation.

2. Cavitation may occur under the bottom seal of the leaf when the gate opening is small and the head differential across the leaf is large.

3. The downpull data for the Glendo gate may be applied to other gates of similar geometry by simple steps outlined in this report.

### Introduction

The fixed-wheel bulkhead gate at Glendo Dam is 3. 3 feet thick, 16. 5 feet wide and 21. 0 feet high and is located near the entrance of the 21-foot-diameter outlet and power tunnel (Figure 5). In normal use the gate remains fully open. When a normal closure is required it is made with no flow taking place and with the pressures upstream and downstream of the leaf balanced. Emergency closures with unbalanced pressures, as would be the case following a penstock break, can be made when necessary. Operation with unbalanced pressure conditions will also occur during the tunnel filling period when the gate will be used as a flow regulator at openings of 3 to 6 inches.

The control point of this fixed-wheel gate is located at the upstream bottom edge of the leaf, and when the gate is controlling the flow, the pressure on the bottom of the leaf will be less than the pressure on top of the leaf and in the tunnel just downstream. This is due to the fact that as the flow passes beneath the leaf, the flow velocity is high while the piezometric pressure is correspondingly low. The leaf bottom pressures to be expected during the tunnel filling period were of primary interest because at very small gate openings the flow beneath the thick leaf, after passing through the vena contract, tends to expand and occupy the full section beneath the web at the downstream face of the leaf and therefore to appreciably lower the pressure on the entire gate bottom. At these conditions the downpull forces will be large. As the gate opening increases, the jet contraction and subsequent expansion is altered so that space is left between the downstream web and the jet, and fluid is able to travel upstream through this space to partially relieve the low pressures on the gate bottom. When the gate reaches the full open position, the pressures beneath the leaf are essentially the same as in the tunnel and on top of the leaf. At this point the downpull is quite small.

Model studies were made to determine the magnitude of the downpull forces that will act on the gate through a wide range of gate openings, and special emphasis was given to the small openings to be used while filling the tunnel. The data may be applied to other gate installations that are geometrically similar to the Glendo gate.

## The Model

The basic model components described in Part I of this report were used to determine the hydraulic downpull forces that will act on the Glendo gate. A new gate leaf was constructed and the slots were shaped to represent those for the Glendo structure (Figure 6). The leaf was 2.82 inches thick and contained 10 piezometers on the bottom along or near the gate centerline. A piezometer in the tunnel roof upstream from the gate and another downstream from the gate were used to obtain pressures for determining the head drop across the gate. The position of the gate could be observed and measured through the transparent plastic windows that formed the outer walls of the gate slots.

## Investigation

The head drop across the prototype gate was determined by computation. It was assumed that the 21-foot-diameter tunnel was ruptured at the power bifurcation, and that the reservoir was at the maximum water-surface elevation of 4669.0. The head loss through the intake structure and tunnel with the gate 100 percent open set the maximum flow at 21,500 cfs. As the gate closes to reduce the flow, the tunnel losses become smaller and the head drop across the gate becomes larger, until at very small openings, the total head of 178 feet is expended across the gate. The relation of the prototype head drop to the gate opening is shown in Figure 7A. Tests were made on the model at a number of gate openings, and the pressure drop across the gate at each setting was measured. The prototype head drop for a particular gate opening (Figure 7A) was divided by the model head drop for the equivalent opening to obtain the factor by which the remaining model values should be multiplied to obtain the prototype pressures.

A plot was made of the computed prototype downpull forces which in this case are caused by the reduction in pressure under the seal, under the lower web of the gate, and under the downstream lip (Figure 7B). The total downpull, which is the sum of the individual downpulls, for these portions of the gate is also shown. A sample calculation of the downpull forces, working directly from the model data, follows.

Assume a 3-inch gate opening (prototype)

Model pressures obtained are:

| Up-stream head | Down-stream head | Seal | Gate (av) | D.S. lip |
|---|---|---|---|---|
| +8.07 | -0.09 | -1.25 | -0.51 | -0.52 (inches of water) |

Prototype head drop (from Figure 7A) = 178 feet

$$\text{Factor for conversion} = \frac{178}{8.07 + 0.09} = 21.80$$

Downstream head = -(0.09) (21.80) = -1.96

Under the seal = -(1.25) (21.80) = -27.21

Under the gate = -(0.51) (21.80) = -11.12

Under the DS lip = -(0.52) (21.80) = -11.34

Assume that the pressures are the same over the full width of the gate. Then the downpull is found by multiplying the pressure difference between the gate top and bottom by the specific weight of water and by the area of the gate section on which the pressure difference acts:

Seal = (27.21 - 1.96) (62.4) (16.5) (0.3802) = 9,900 pounds

Gate = (11.12 - 1.96) (62.4) (16.5) (2.9282) = 27,610

DS lip = (11.34 - 1.96) (62.4) (16.5) (0.2240) = 2,160

Total 39,670 pounds

The Glendo downpull information may be converted to apply to any geometrically similar installation by the following method:

A. Find the downpull on the Glendo gate for the desired percent gate opening and the desired head drop:

$$DP_2 = DP_1 \times \frac{H_n}{H_g}$$

where

$DP_1$ = Glendo downpull, Figure 7B

$DP_2$ = Glendo downpull with $H_n$

$H_g$ = head drop across the Glendo gate, Figure 7A

$H_n$ = desired head drop

B. Find the desired hydraulic downpull by the ratios of the areas under the two gates:

$$DP_3 = DP_2 \times \frac{A_n}{A_g}$$

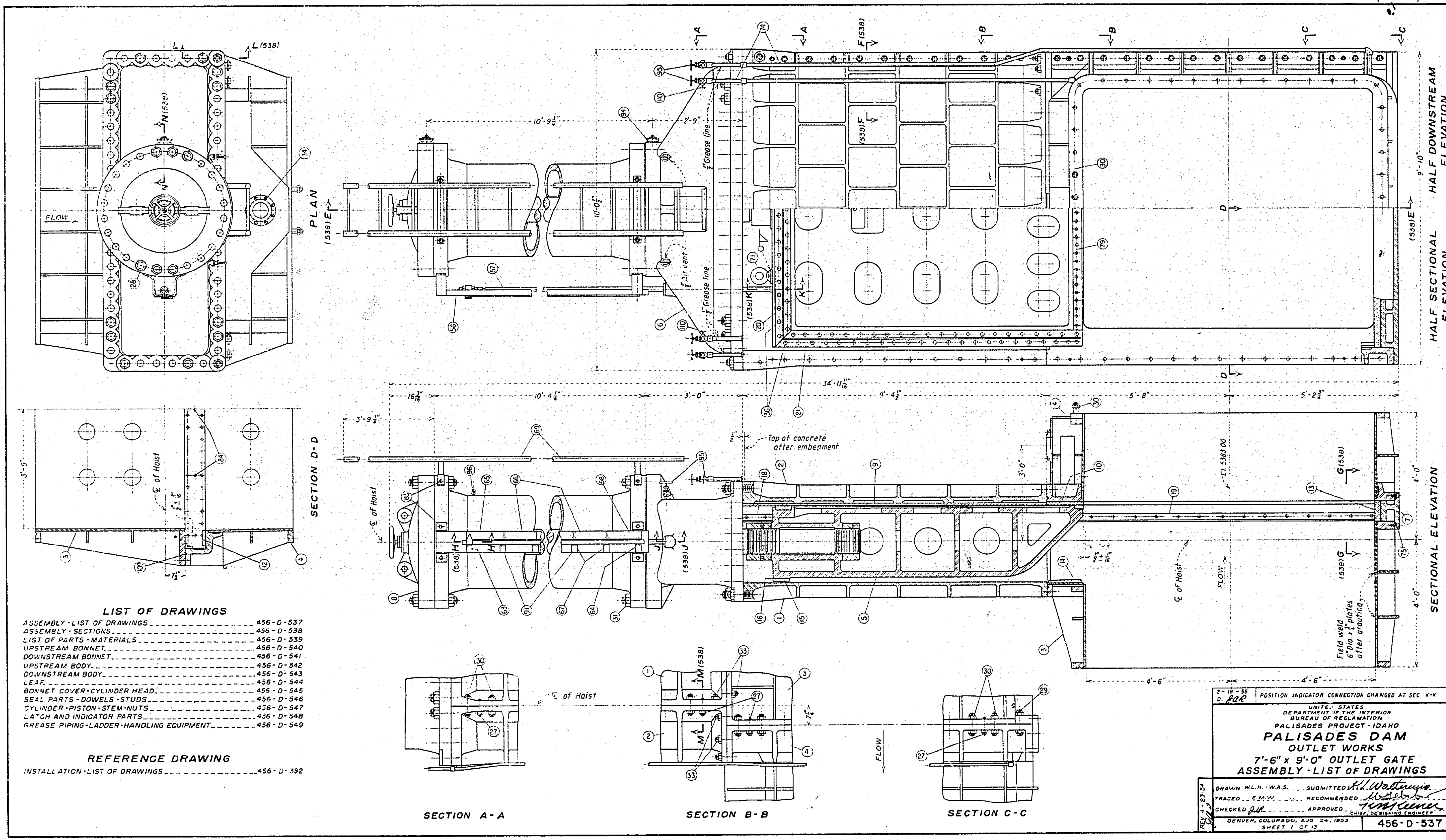
where

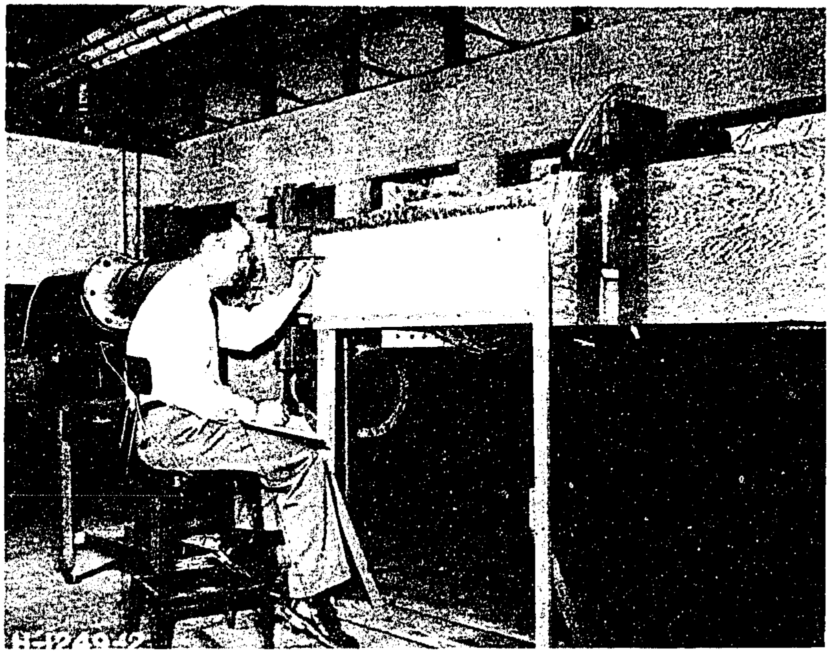
$DP_3$ = downpull under the new gate with $H_n$

$A_n$ = area under the new gate

$A_g$ = area under the Glendo gate

Cavitation pressures are apt to exist under the bottom seal when the gate opening is small and the differential head across the gate is large. If these conditions prevail, the downpull under the seal may be computed by applying cavitation pressures to the area under the seal of the gate being studied. The above method of conversion may also be used to compute the downpull under sections of the gate such as the web and the downstream lip.


PLAN
SECTION D-D
SECTIONAL ELEVATION
HALF SECTIONAL ELEVATION
HALF DOWNSTREAM ELEVATION
FLOW
Top of concrete after embedment
Grease line
Air vent
Field weld 6" Dia. x 1/4" plates after grouting
LIST OF DRAWINGS
ASSEMBLY - LIST OF DRAWINGS ........ 456-D-537
ASSEMBLY - SECTIONS ........ 456-D-538
LIST OF PARTS - MATERIALS ........ 456-D-539
UPSTREAM BONNET ........ 456-D-540
DOWNSTREAM BONNET ........ 456-D-541
UPSTREAM BODY ........ 456-D-542
DOWNSTREAM BODY ........ 456-D-543
LEAF ........ 456-D-544
BONNET COVER - CYLINDER HEAD ........ 456-D-545
SEAL PARTS - DOWELS - STUDS ........ 456-D-546
CYLINDER - PISTON - STEM - NUTS ........ 456-D-547
LATCH AND INDICATOR PARTS ........ 456-D-548
GREASE PIPING - LADDER - HANDLING EQUIPMENT ........ 456-D-549
REFERENCE DRAWING
INSTALLATION - LIST OF DRAWINGS ........ 456-D-392
SECTION A-A
SECTION B-B
SECTION C-C
2-18-55 D. JAR
POSITION INDICATOR CONNECTION CHANGED AT SEC K-K
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PALISADES PROJECT - IDAHO
PALISADES DAM
OUTLET WORKS
7'-6" x 9'-0" OUTLET GATE
ASSEMBLY - LIST OF DRAWINGS
DRAWN W.L.H. - W.A.S.
SUBMITTED
TRACED E.M.W.
RECOMMENDED
CHECKED
APPROVED
CHIEF, DESIGNING ENGINEER
REV 4-23-54
DENVER, COLORADO, AUG 24, 1953
SHEET 1 OF 13
456-D-537

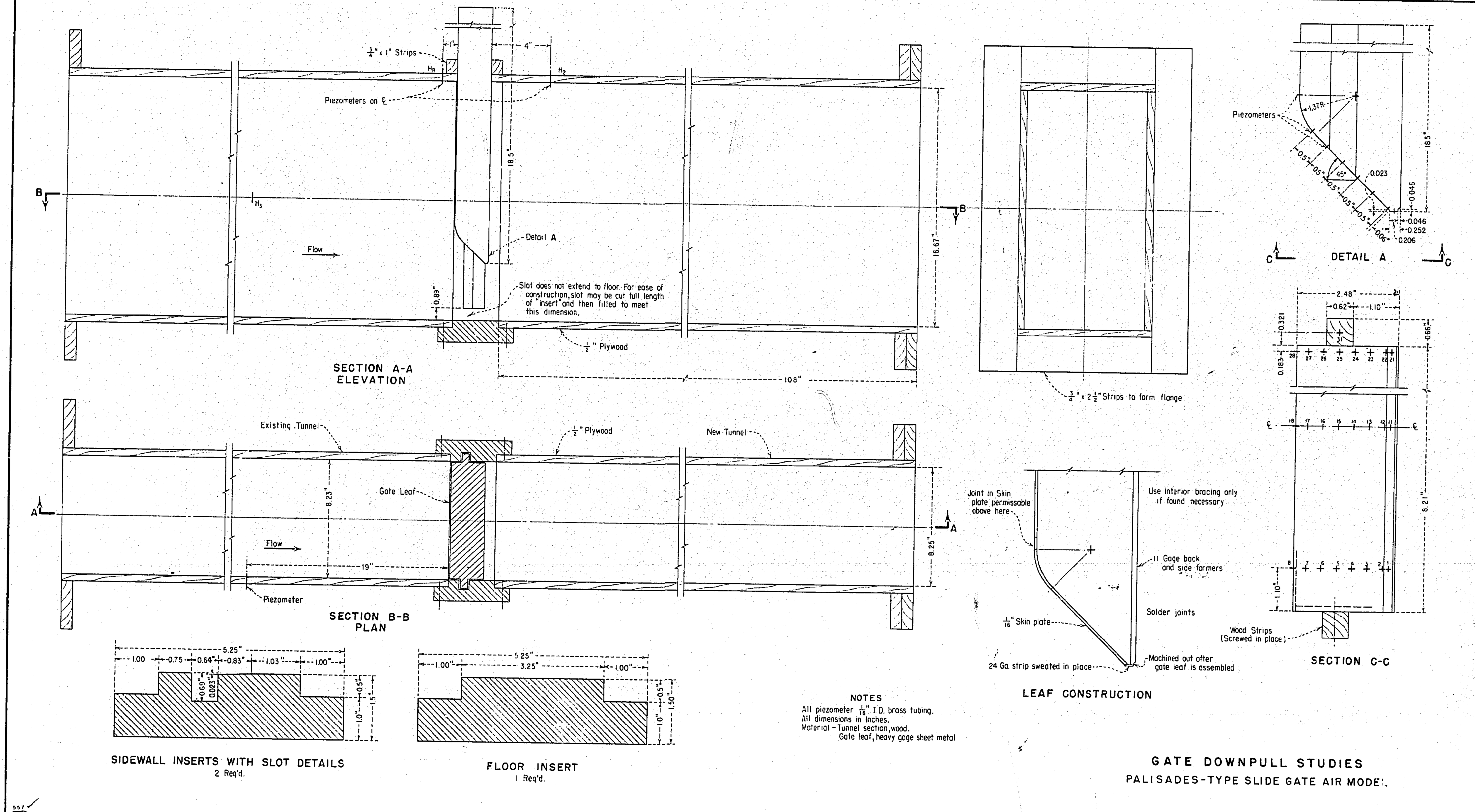


Air from atmosphere was drawn into inlet orifice (center) by centrifugal blower at left. Flow then passed through a stilling section, the test section (upper center and right), and back into atmosphere.

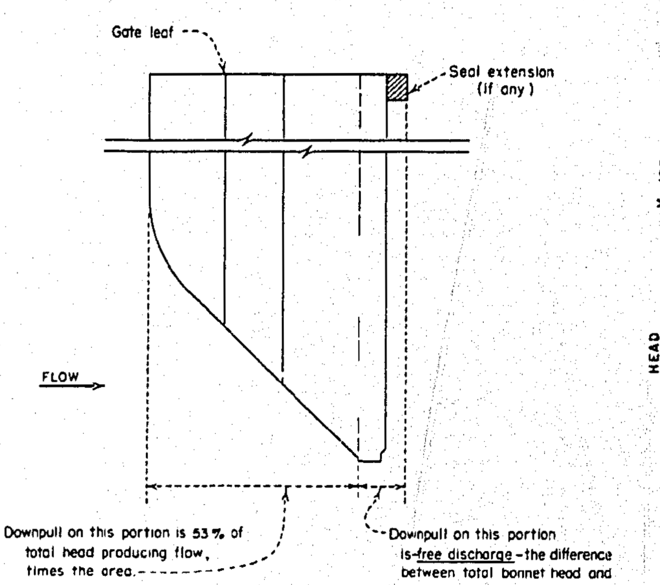
GATE DOWNPULL STUDIES

Air Model

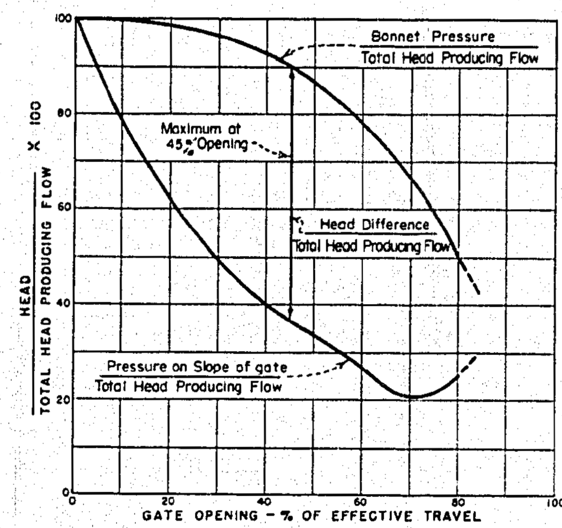
FIGURE 3
REPORT HYD 421



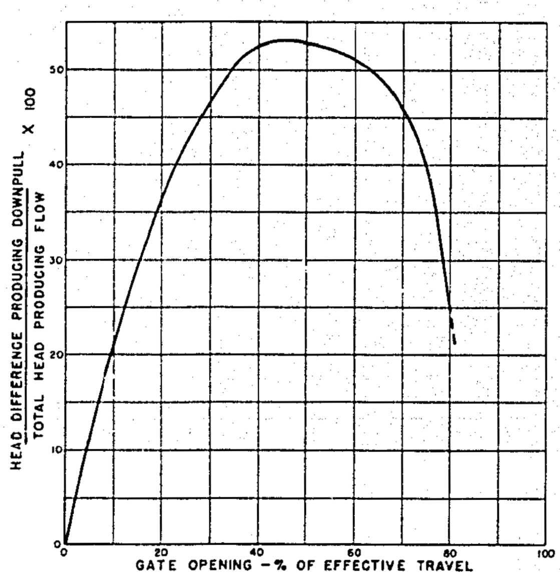

GATE DOWNPULL STUDIES
PALISADES-TYPE SLIDE GATE AIR MODEL



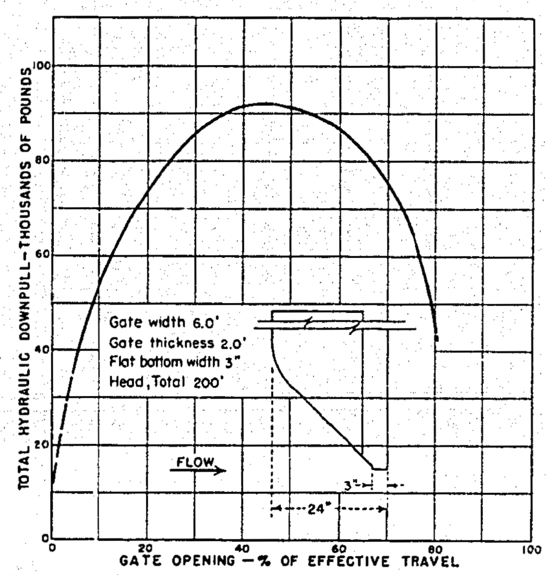

A. METHOD OF COMPUTING DOWNPULL ON GATE




B. PRESSURE IN BONNET AND ON SLOPE AREA OF LEAF BOTTOM, AND PRESSURE DIFFERENCE BETWEEN BONNET AND LEAF SLOPE




C. NET DOWNPULL PRESSURE FOR SLOPE AREA OF LEAF

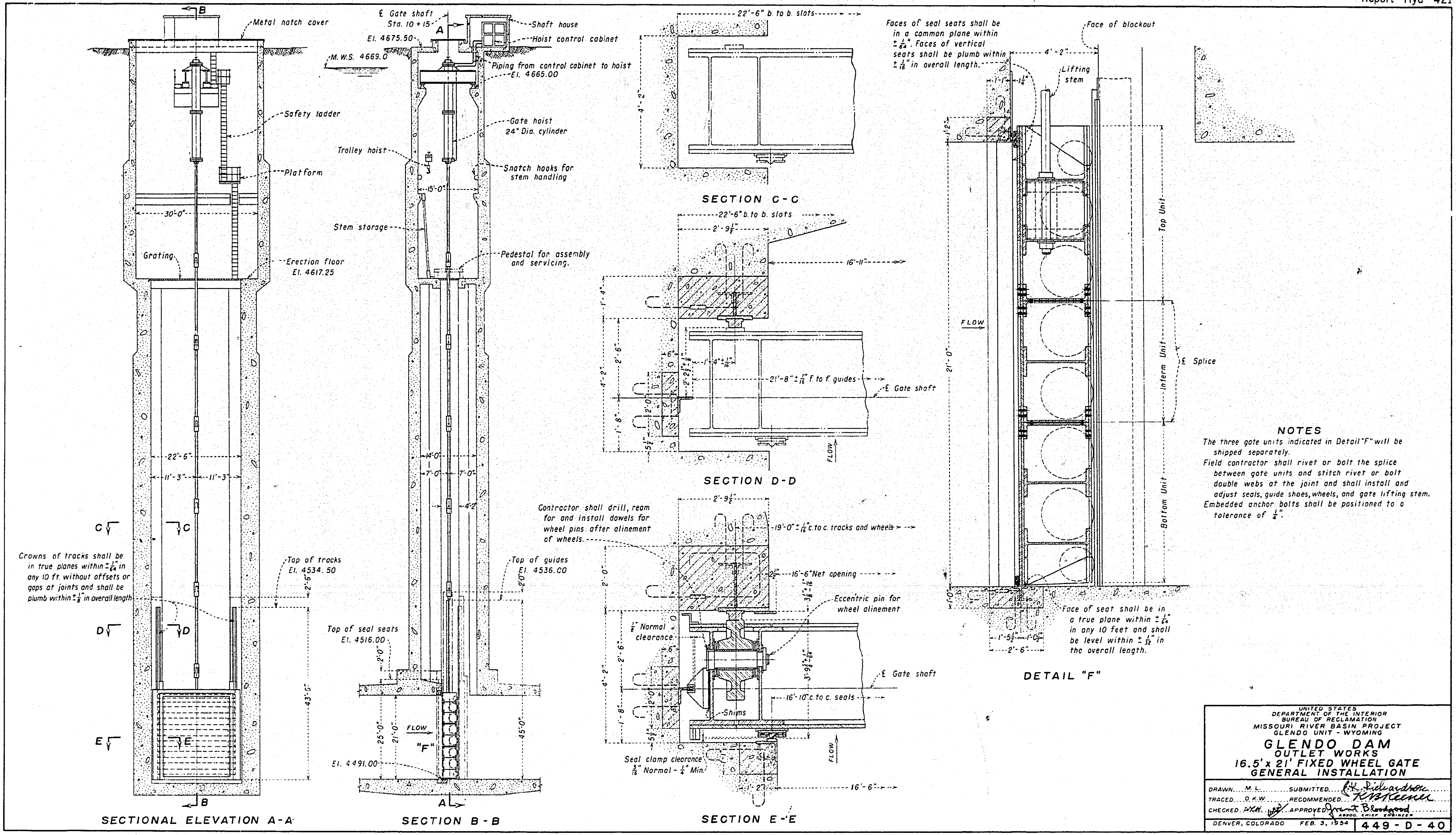


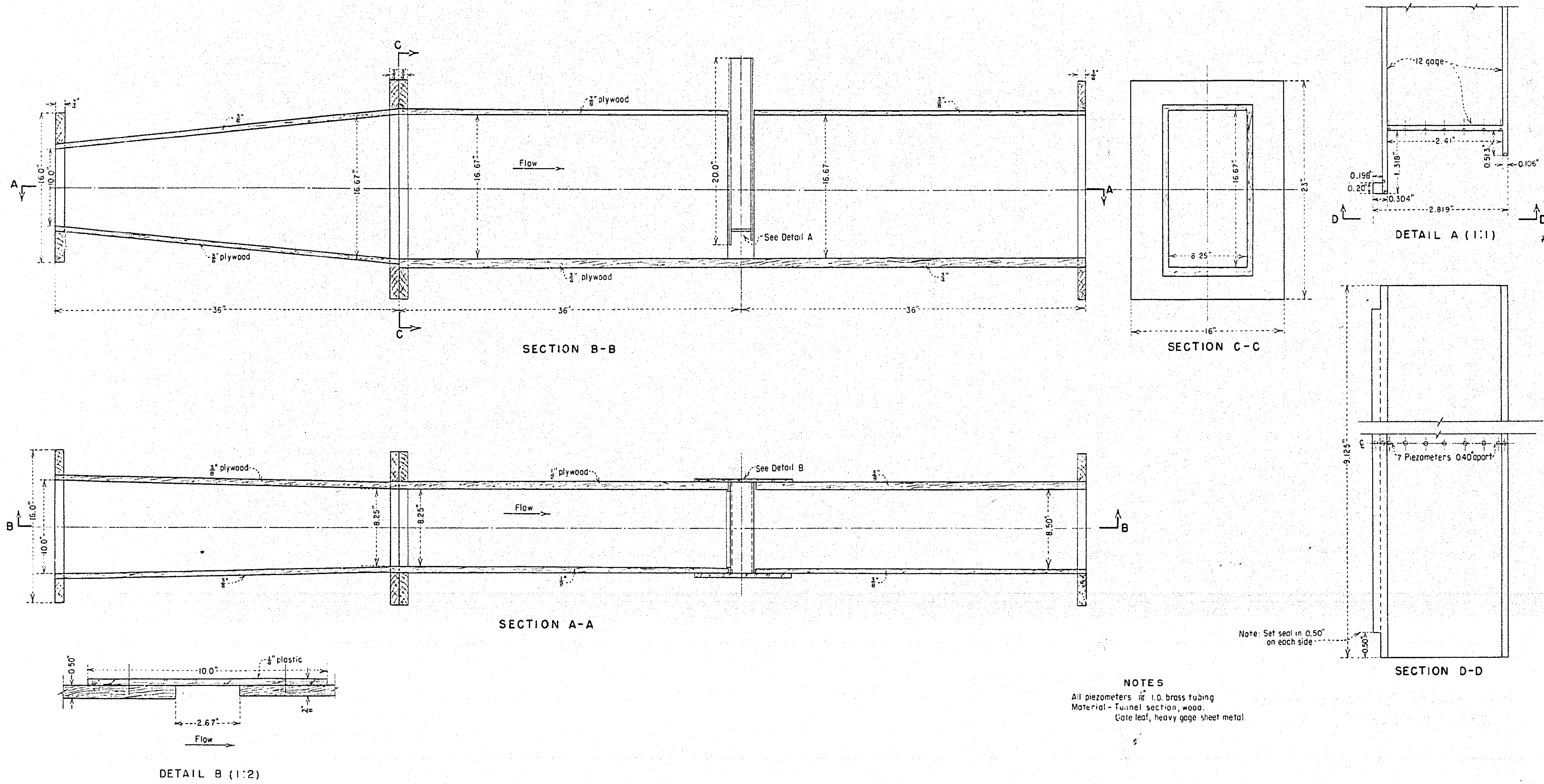

D. EXAMPLE OF DOWNPULL CURVE FOR STANDARD GATE DISCHARGING FREE UNDER 200 FOOT HEAD

# GATE DOWNPULL STUDIES

## PRESSURES ACTING IN BONNET AND ON LEAF, AND TYPICAL DOWNPULL CURVE FOR PALISADES-TYPE GATE

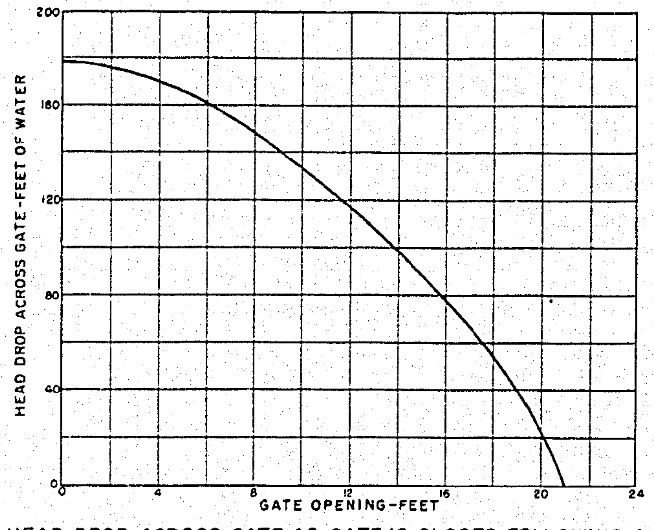
DATA FROM AIR MODEL


Metal hatch cover
Safety ladder
Platform
30'-0"
Grating
Erection floor
El. 4617.25
22'-6"
11'-3"
11'-3"
Crowns of tracks shall be in true planes within ± 1/64" in any 10 ft. without offsets or gaps at joints and shall be plumb within ± 1/8" in overall length
Top of tracks
El. 4534.50
2'-6"
43'-5"
SECTIONAL ELEVATION A-A
℄ Gate shaft
Sta. 10 + 15
El. 4675.50
M.W.S. 4669.0
Shaft house
Hoist control cabinet
Piping from control cabinet to hoist
El. 4665.00
Gate hoist
24" Dia. cylinder
Trolley hoist
Snatch hooks for stem handling
15'-0"
Stem storage
Pedestal for assembly and servicing.
14'-0"
7'-0"
7'-0"
4'-2"
Top of guides
El. 4536.00
Top of seal seats
El. 4516.00
2'-0"
25'-0"
21'-0"
FLOW
"F"
45'-0"
El. 4491.00
SECTION B-B
22'-6" b. to b. slots
4'-2"
SECTION C-C
22'-6" b. to b. slots
2'-9 1/2"
16'-11"
1'-4"
2'-6"
4'-2"
1'-8"
21'-8" ± 1/16" f. to f. guides
℄ Gate shaft
SECTION D-D
Contractor shall drill, ream for and install dowels for wheel pins after alinement of wheels.
2'-9 1/2"
19'-0" ± 1/16" c. to c. tracks and wheels
16'-6" Net opening
Eccentric pin for wheel alinement
1/8" Normal clearance
℄ Gate shaft
16'-10" c. to c. seals
Shims
Seal clamp clearance 5/16" Normal - 1/4" Min.
16'-6"
SECTION E-E
Faces of seal seats shall be in a common plane within ± 1/64". Faces of vertical seats shall be plumb within ± 1/16" in overall length.
Face of blockout
4'-2"
Lifting stem
Top Unit
Interm Unit
Bottom Unit
℄ Splice
21'-0"
Face of seat shall be in a true plane within ± 1/64" in any 10 feet and shall be level within ± 1/32" in the overall length.
2'-6"
DETAIL "F"
NOTES
The three gate units indicated in Detail "F" will be shipped separately.
Field contractor shall rivet or bolt the splice between gate units and stitch rivet or bolt double webs at the joint and shall install and adjust seals, guide shoes, wheels, and gate lifting stem.
Embedded anchor bolts shall be positioned to a tolerance of 1/4".
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
GLENDO UNIT - WYOMING
GLENDO DAM
OUTLET WORKS
16.5' x 21' FIXED WHEEL GATE
GENERAL INSTALLATION
DRAWN M.L.
TRACED O.K.W.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO FEB. 3, 1954
449-D-40

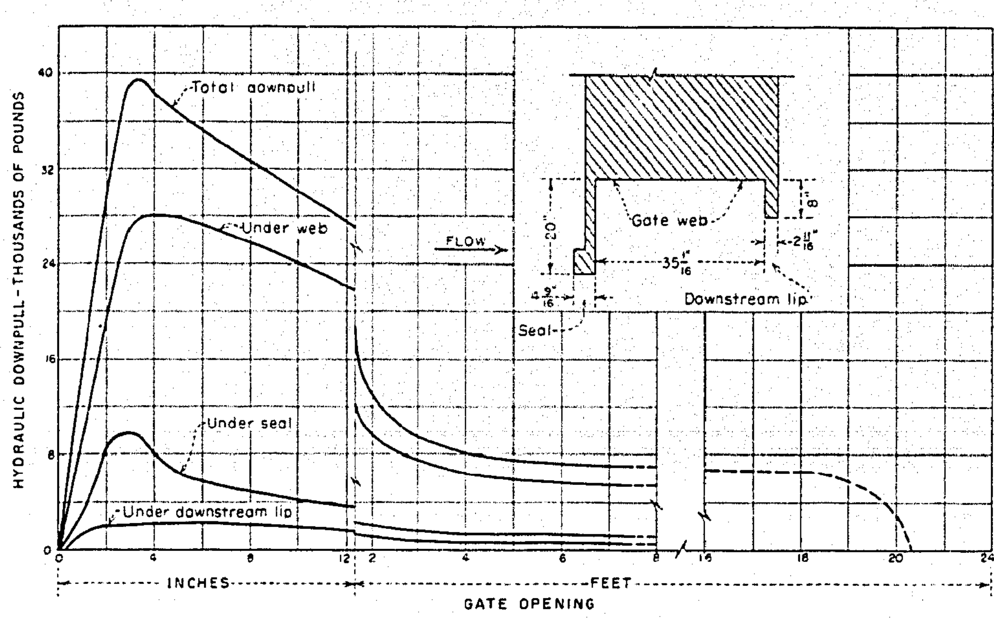



NOTES
All piezometers 1/16" I.D. brass tubing
Material - Tunnel section, wood.
Gate leaf, heavy gage sheet metal

GATE DOWNPULL STUDIES
GLENDO FIXED-WHEEL GATE AIR MODEL




A - HEAD DROP ACROSS GATE AS GATE IS CLOSED FOLLOWING A BREAK IN THE PENSTOCK 1865 FEET DOWNSTREAM. RESERVOIR ELEVATION 4669.0




B - DOWNPULL WHEN GATE CONTROLS FLOW AT RESERVOIR ELEVATION 4669.0

## GATE DOWNPULL STUDIES

### HEAD DROP ACROSS, AND DOWNPULL FORCES ON GLENDO 16.5' x 21.0' FIXED-WHEEL GATE

DATA FROM AIR MODEL

544