PAP-447

ST~~E~~AMPEDE DAM OUTLET WORKS
AIR SLOT HYDRAULIC MODEL TESTS

BY

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To: Regional Director, Sacramento, California
Attention: Regional Engineer

From: ACTING Chief, Division of Research

Subject: Stampede Dam Outlet Works Stilling Basin Air Slot Model Study

The results of hydraulic model studies conducted on the Stampede Dam outlet works air slot are presented in the enclosed report. In conjunction with the report, a short video tape covering the main aspects of the model study is being prepared. We feel the video tape will be of value in illustrating the findings of the model study. The video tape will be sent separately upon completion.

Danny L. King

Enclosure

Blind to: D-1500
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D-220 (Muller)

BWMefford:bep

STAMPEDE DAM OUTLET WORKS
AIR SLOT HYDRAULIC MODEL TESTS

INTRODUCTION

Stampede Dam is an earth-filled structure located on the Little Truckee River in California. The reservoir is part of the Washoe Project. The Stampede Dam outlet works consists of a 12-ft-diameter concrete-lined tunnel controlled by two 4- by 5-ft tandem gates. The outlet works gates discharge into a type 2 hydraulic jump stilling basin.

During an underwater examination on July 29, 1982, cavitation damage was discovered on the outlet works chute floor. To reduce the potential for further cavitation damage during operation, an air slot was designed and installed in the fall of 1982. Operation of the basin in the spring of 1983 indicated the air slot was not performing as expected. The air slot displayed a weak air demand and experienced icing of the air vents during night operation. The left bay air slot failed in March 1983 and the right bay exhibited cavitation damage downstream of the slot. Three areas felt to be involved in the poor performance of the air slot were: (1) misalinement of the air slot during installation, (2) icing of the air intakes during cold weather operation, and (3) the large submergence of the air slot under some operating conditions.

A model study of the air slot was requested to determine the ability of the air slot to provide air to the floor of the chute under the operating conditions at Stampede Dam.

THE MODEL

An existing 1:8.25 scale model of Mason Dam outlet works and stilling basin was used to conduct the air slot studies for Stampede Dam. Both Mason and Stampede outlet works stilling basins are of a general type 2 hydraulic jump configuration. Although the Mason Dam model did not provide a perfect Froude scale model of Stampede Dam, the major characteristic lengths defining the flow boundaries were close to a 1:12 scale of the Stampede outlet works basin. Geometric differences affecting flow similitude were accounted for by adjusting discharge and gate opening to attain the desired velocity and depth of flow at Sta. 15+85.2, figure 1.

Both flow depth and velocity for prototype and model were determined numerically by computing the flow surface from the gate downstream using a finite difference computer model, assuming a gate contraction coefficient of 0.74 and a reservoir elevation of 5945 ft. The Mason Dam model gate size limited the largest Stampede model gate opening to 80 percent.

MODEL STUDIES - PART I

Cavitation Potential

To determine the cavitation potential of the flow in the original basin, pressures were measured from three piezometers located on 1.71-ft centers at Sta. 15+84.86. The pressures listed in table 1 are an average of the pressures measured by the water manometer across the chute floor. Under normal tailwater conditions, the turbulence within the toe of the hydraulic jump created significant pressure fluctuations. Falvey [1] suggests air slots are generally needed on chutes if the cavitation index is less than 0.20. The cavitation index was defined as $\sigma = (P_R - P_V)/H_V$ where:

P_R = reference pressure of ambient flow
P_V = vapor pressure of the fluid
H_V = free stream stagnation pressure

The values of sigma calculated using average pressure indicate the greatest potential for cavitation exists at between 50 and 60 percent gate openings.

To determine the minimum expected cavitation index at each gate opening, floor pressures were calculated for the free jet without the formation of a hydraulic jump. Assuming a free jet as the limiting case, cavitation could be expected to occur due to minor local imperfections in the flow boundary.

Table 1. - Cavitation index

% gate	P_R (ft) (submerged)	P_R (ft) (free jet)	P_V (ft of H_2O)	H_V (ft of H_2O)	σ (submerged)	σ (free jet)
20	36.7	27.9	0.28	182.8	0.193	0.150
30	34.4	28.1	0.28	189.2	0.180	0.148
40	34.6	28.3	0.38	187.2	0.189	0.151
50	33.9	28.6	0.28	187.2	0.179	0.153
60	32.5	28.8	0.28	180.1	0.179	0.160
70	32.5	29.0	0.28	168.6	0.191	0.172
80	34.5	29.3	0.28	144.6	0.238	0.202

MODEL STUDY - PART II

Air Slot Tests

Four air slots were milled from brass plate and tested in the model. The air slots tested are given in table 2.

Table 2. - Air slots tested

Air slot	Ramp slope (degrees)	R_L Ramp length (ft)	R_H Ramp height (ft vertical)	S_D Slot depth (ft vertical)
1	2° 17'	1.58	0.063	0.50
2	4° 34'	1.58	0.126	0.53
3A	4° 34'	2.69	0.215	0.53
3B	4° 34'	2.69	0.215	0.10

Air slots 1, 2, and 3A were tested with air grooves downstream of the ramp as shown on figure 2a. Air was vented to the slots through the triangular section formed by the air slot and old floor line. Air slot 3B was tested using a ported air vent below the ramp, figure 2b. Air was vented to the ports through the circular tube upstream of the air slot. All air slots were tested using a single-ended air vent - per bay - passing through the outside walls of the stilling basin. Each air slot was placed in the model with the upstream end of the ramp adjacent to the stainless clad steel liner, Sta. 15+84.12.

In addition to visual observations, three piezometers were placed on equal centers across the air groove of each slot. Average pressures were measured on each tap to determine the air distribution across the slot. The air vent intake for each slot was connected to a vane anemometer. The anemometer was used to measure total air volume over a 10- to 15-minute test period. The air volume was converted to an average air discharge passing through the model vent. Prototype air vent head losses were not modeled.

Each air slot was tested in the model using outlet gate openings from 20 to 80 percent in 10 percent increments. Tailwater elevations used were based on prototype measurements conducted during the January 1983 field tests, figure 3.

AIR SLOT TEST RESULTS

Air slot 1, table 2, was initially placed in the model for testing. The air slot partially flooded with water at 20 and 30 percent gate openings. From 40 to 60 percent gate, a pulsating flow of air into and out of the slot occurred. Gate openings above 60 percent again showed significant flooding of the air groove, figure 4. The pressure at tap 3 was lower than tap 1 during all tests. The air volume being drawn in by the air slot was too small to be measured by the vane anemometer.

The slot appeared highly sensitive to tailwater conditions. The tailwater was lowered and the slot performance was again observed. The slot exhibited only minor intermittent flooding and blowback as long as the toe of the hydraulic jump was downstream of the air groove.

The ramp angle and offset height were doubled on the second air slot. Gate openings of 20 to 40 percent resulted in a strong pulsating airflow in the air vent. The air cavity downstream of the air slot appeared very unstable. At gate openings of 40 to 60 percent, the air vent pulled air with occasional blowback from the slot. At larger gate openings, the air in the vent returned to a weak pulsating flow condition. Pressures measured at tap 3 were lower than at tap 1 for gate openings of 20 to 70 percent. The average ratio of air to water downstream of the slot is shown on figure 5. The air volume induced by the slot was too small to be measured by the anemometer at 20 percent gate.

The ramp length and offset height were extended on the third air slot tested. The longer ramp placed the air groove 1.1 ft downstream from the prior location creating approximately 0.5 ft higher tailwater submergence. Steady pulsating airflow was again observed at 20 to 30 percent gate openings. Some intermittent blowback associated with partial air cavity collapse was observed at all gate openings above 30 percent. The average percent of air being pulled into the chute was about 40 percent higher than occurred using the second air slot.

The third air slot design was modified to eliminate choking of the entire air slot by the random feedback of small jets of water into the slot area. A ported air vent was installed to replace the open triangular air slot, figure 2b. The ported vent design was implemented to provide better air access to the total width of the chute. Air slot 3B provided a nearly uniform pressure distribution across the width of the slot during each test. At low discharges the amount of air introduced to the flow by the air slot showed a significant increase over the open slot designs tested, figure 5. The model gates were shut and reopened to determine if the ported vent would clear itself of water during initial outlet works operation. As the outlet gates were opened, the air vent quickly drained itself entirely of water through the ports.

AIR SLOT SUBMERGENCE

During spillway operation the outlet works tailwater elevation at Stampede may exceed the levels given on figure 3. Model tests were conducted using air slot 3B to determine the effect of 1.0 and 2.0 ft additional submergence on air demand, figure 6. For a reference, the air demand of a free jet passing over the slot is also shown. Increasing the slot submergence produces a sharp decrease in the air demand at gate openings less than 40 percent. At gate openings of 40 to 60 percent the air slot pulled a strong steady stream of air under the additional submergence. Above 60 percent gate opening, the air slot exhibited a steady but reduced inflow. The air cavity was suppressed to a length of about 2.0 ft at 80 percent gate under 2 ft of additional tailwater.

The air demand is largely dependent on tailwater at small gate openings where a thin jet exists. Depending on submergence, the air demand may increase or decrease over that of a free jet. For a thick jet, gate openings above 70 percent, the air demand consistently drops with increasing tailwater. A series of air demand readings were taken at 20 percent gate opening to define the full effect of tailwater from sweepout to high tailwater levels, figure 7. The air demand was found to decrease as the toe of the hydraulic jump submerged the lower half of the air cavity. As the jump submerged the air slot and ramp, the air demand increased sharply rising above the free jet level. Continued submergence of the air slot then produced a steady decrease in air demand to levels well below the free jet.

CONCLUSIONS

The turbulent intensity of the stilling basin, depth of air slot submergence, and air vent icing at Stampede Dam require special design considerations. The model study test results indicate at normal tailwater a minimum offset height of 0.2 ft is needed to develop stability in the air cavity downstream of the air slot. Open air slot designs have the potential for air cavity collapse and intermittent flooding of the air slot. Flooding of the triangular air slot near the single air vent opening can block air access and produce flooding of the entire slot width.

The ported air slot was effective in reducing air cavity collapse and flooding of the model air slot. The single air access vent can be used to supply air evenly across the width of the chute for the ported-type air slot.

Peterka [2] suggests - from laboratory tests on concrete samples - a minimum of 2.0 to 7.0 percent air concentration by volume is needed to significantly reduce the cavitation damage potential. Although the air concentrations given on figures 5, 6, and 7 cannot be directly scaled to prototype due to geometric model differences and scale effects, prototype air contents are expected to be greater than those measured in the model. Prototype air velocity measurements should be made to define the air demand over the operating range.

Tailwater has a major effect on the air slot's ability to induce sufficient air to the flow. The outlet works should be operated to maintain an air demand of at least 7 percent when operating at gate openings lower than 70 percent. At gate openings above 70 percent where the model air demand falls below 7 percent, the outlet works should be operated only at tailwater levels at or below those shown on figure 3.

REFERENCES

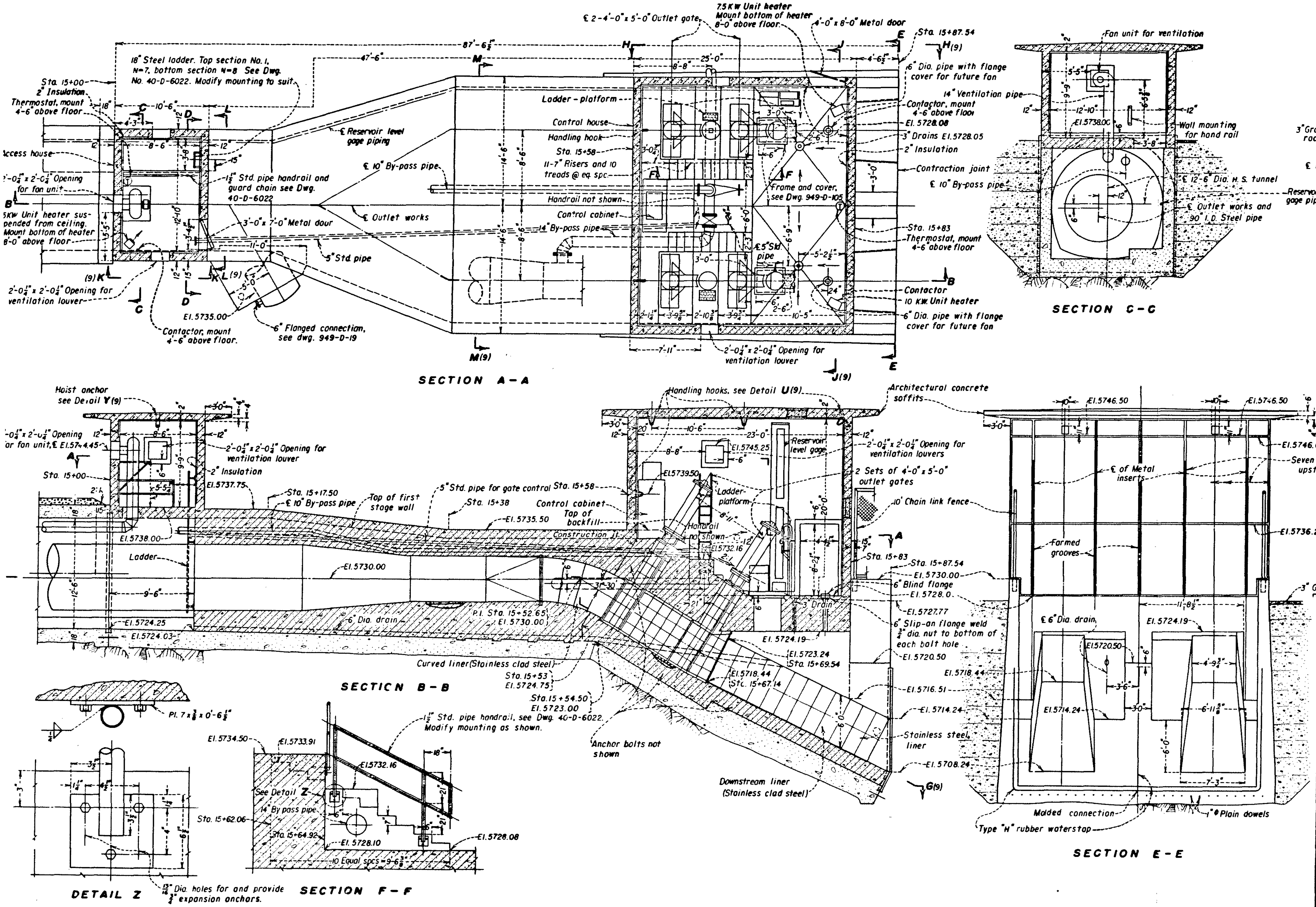
1. Falvey, Henry T., Aeration Groove Design for Cavitation Protection, Unpublished USBR Research Paper

2. Peterka, Alvin J., The Effect of Entrained Air on Cavitation Pitting, IAHR Hydraulics Conference, September 4, 1953

3. Pan, Shui-bo, Shao Ying-ying, Shi Qu-sui, Dong Xing-lin, Self Aeration Capacity of a Water Jet over an Aeration Ramp, Translation from Chinese Journal of Hydraulic Enginering, Beijing, No. 5, 1980

4. Siegenthuler, A., and L. Eccher, Spillway Aeration of the San Rogue Project, Water Power and Dam Construction, September 1982

5. Colgate, D. M., Hydraulic Model Studies of Aeration Devices for Yellowtail Dam Spillway Tunnel, Pick-Sloan Missouri Basin Program, Montana, USBR publication REC-ERC-71-47



NOTES

For general notes and reference drawings see Dwg. 949-D-1.

REFERENCE DRAWINGS

RESERVOIR LEVEL GAGE PIPING	949-D-16
STEEL OUTLET PIPE	949-D-17
LATERAL-WYE-TRANSITIONS-BENDS	949-D-19
BY-PASS PIPING-DRAINS	949-D-20
BY-PASS, AIR AND DRAIN PIPING	949-D-21
VENTILATION SYSTEM	949-D-36

8-12-70 D. C.C.R.	AS BUILT BY 235, LTR. 5-8-70.

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
WASHOE PROJECT
STAMPEDE DIVISION-NEVADA-CALIFORNIA

STAMPEDE DAM

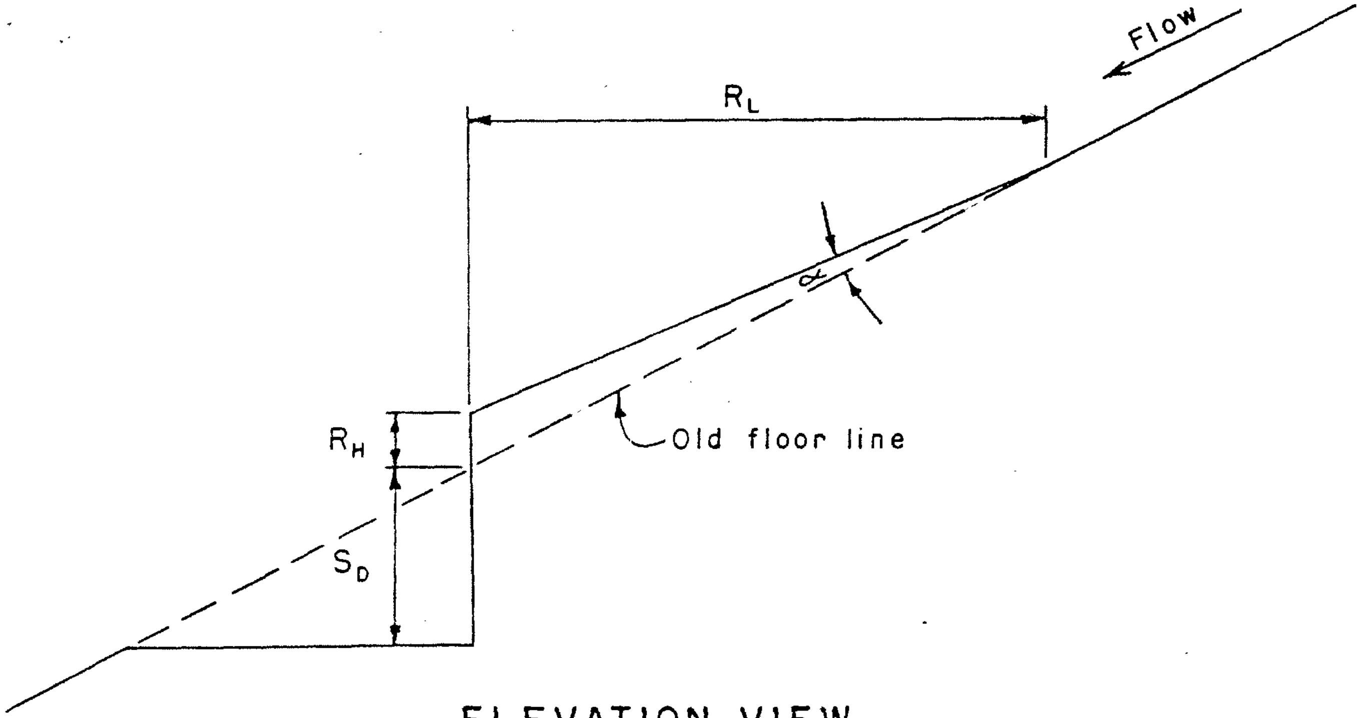
OUTLET WORKS
CONTROL STRUCTURE
SECOND STAGE

DRAWN J.I.B. SUBMITTED S.C. Dom
TRACED C.W.B. RECOMMENDED R.W. Whinnerah
CHECKED C.C.R. APPROVED R.J. Larsen
CHIEF, DAMS BRANCH

DENVER, COLORADO, MAY 16, 1966
SHEET 1 OF 2

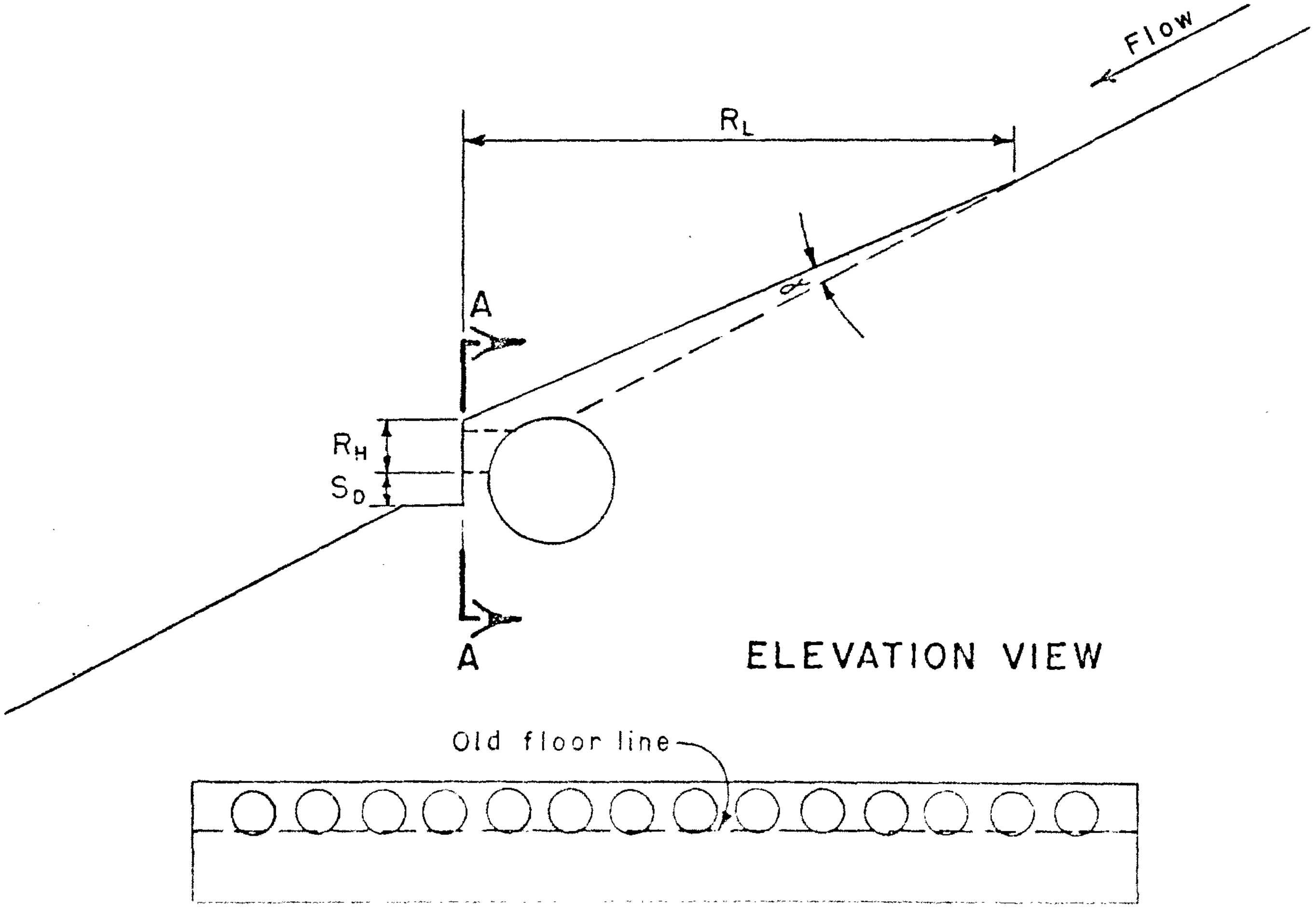
949-D-8

FIGURE 1



ELEVATION VIEW

FIGURE 2A-OPEN AIR SLOT



ELEVATION VIEW

SECTION A-A

FIGURE 2B-PORTED AIR SLOT

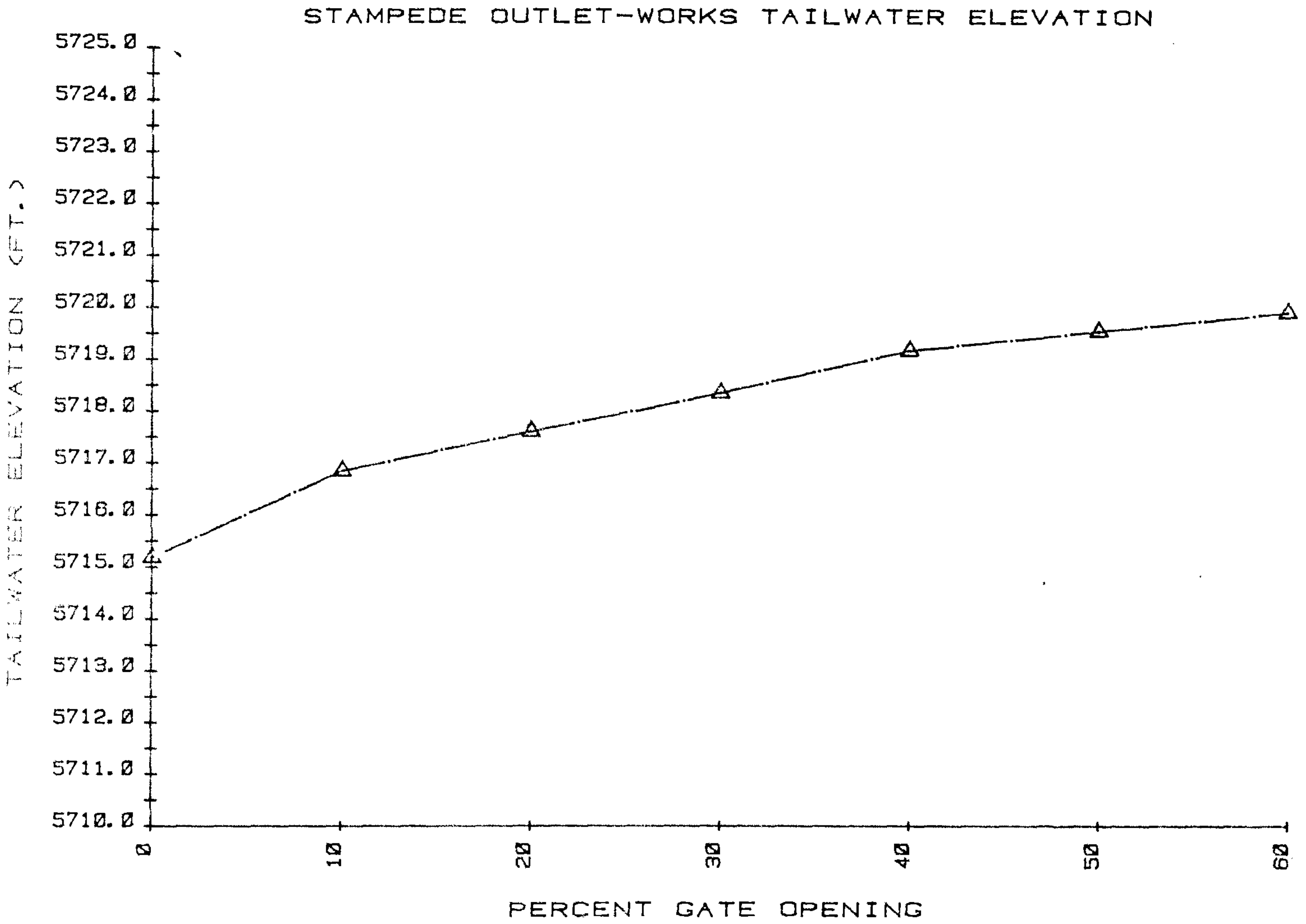

STAMPEDE OUTLET-WORKS TAILWATER ELEVATION
TAILWATER ELEVATION (FT.)
5725.0
5724.0
5723.0
5722.0
5721.0
5720.0
5719.0
5718.0
5717.0
5716.0
5715.0
5714.0
5713.0
5712.0
5711.0
5710.0
0
10
20
30
40
50
60
PERCENT GATE OPENING

FIGURE 3

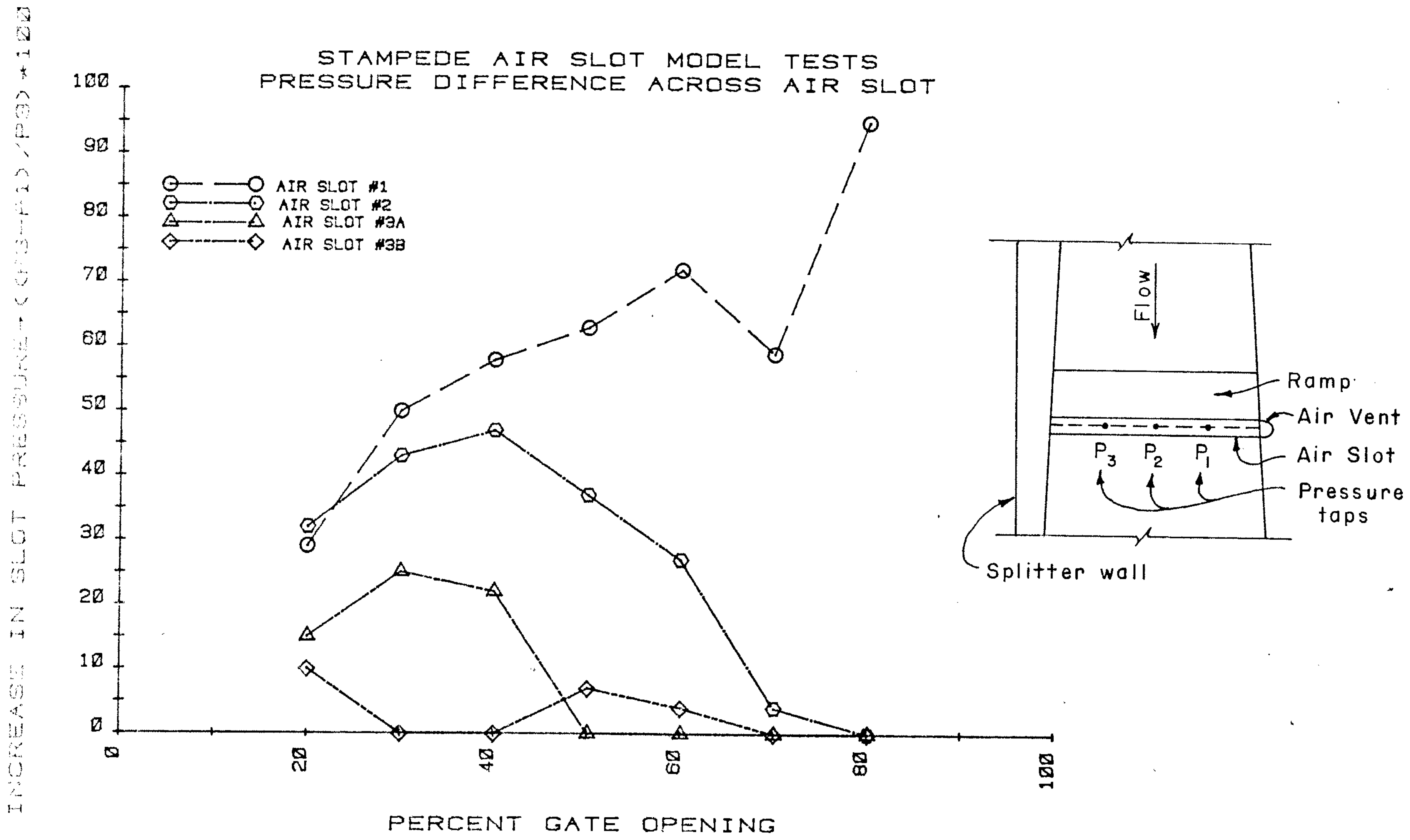

STAMPEDE AIR SLOT MODEL TESTS
PRESSURE DIFFERENCE ACROSS AIR SLOT
INCREASE IN SLOT PRESSURE ((P3-P1)/P3)*100
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
PERCENT GATE OPENING
AIR SLOT #1
AIR SLOT #2
AIR SLOT #3A
AIR SLOT #3B
Flow
Ramp
Air Vent
Air Slot
P_3
P_2
P_1
Pressure taps
Splitter wall

FIGURE 4

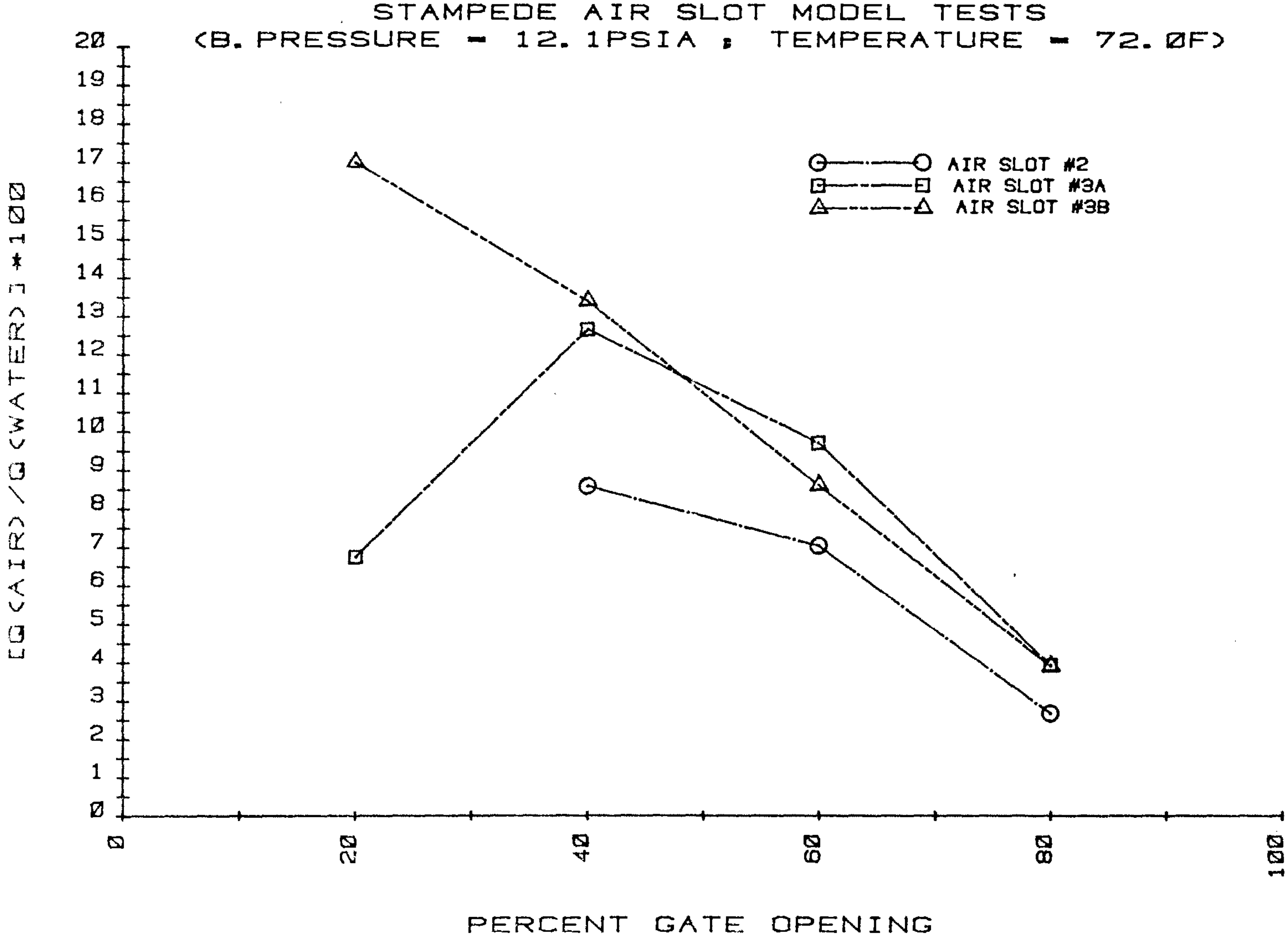

STAMPEDE AIR SLOT MODEL TESTS
(B. PRESSURE = 12.1PSIA ; TEMPERATURE = 72.0F)
AIR SLOT #2
AIR SLOT #3A
AIR SLOT #3B
[Q (AIR) /Q (WATER)] *100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
20
40
60
80
100
PERCENT GATE OPENING

FIGURE 5

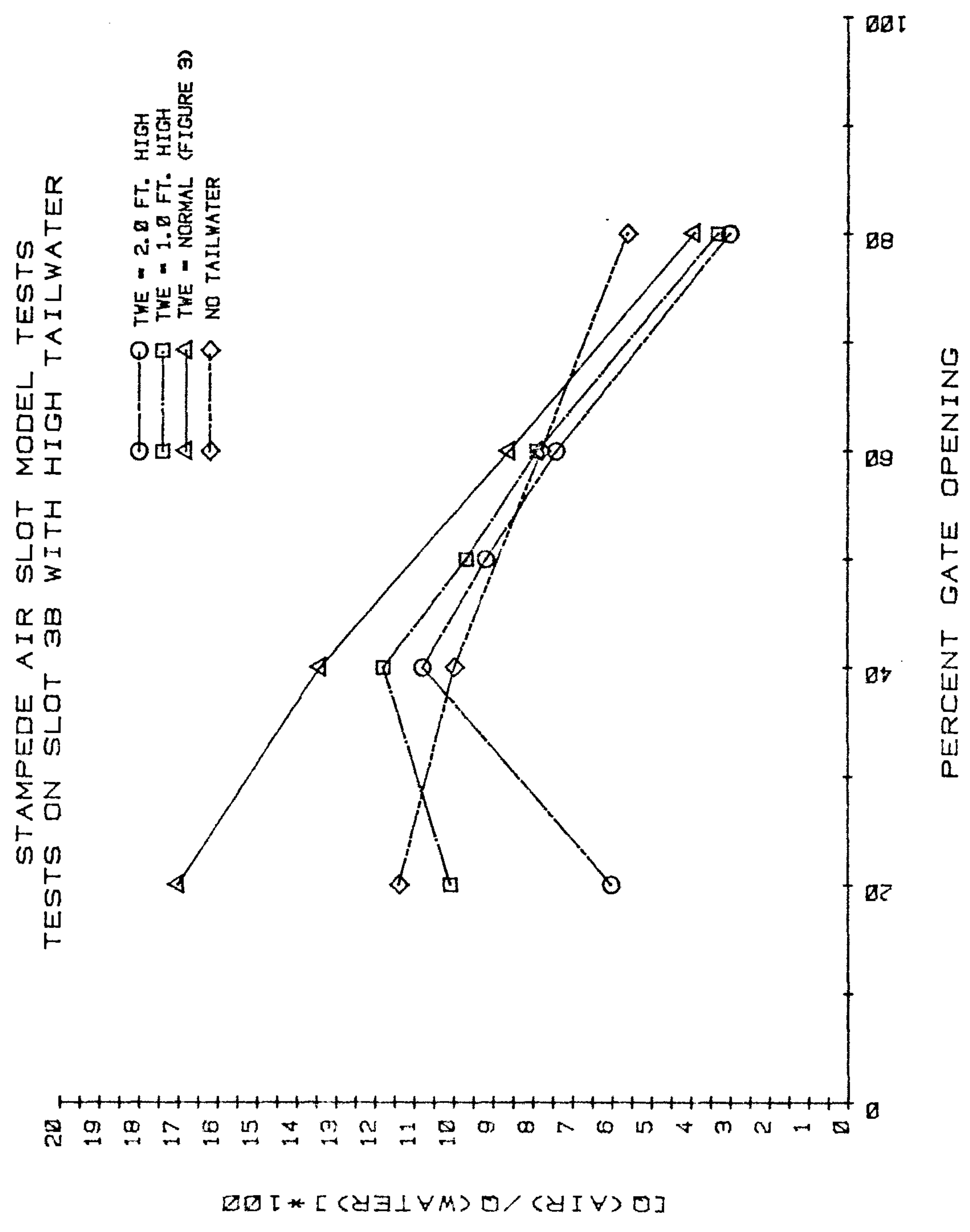

STAMPEDE AIR SLOT MODEL TESTS
TESTS ON SLOT 3B WITH HIGH TAILWATER

FIGURE 6

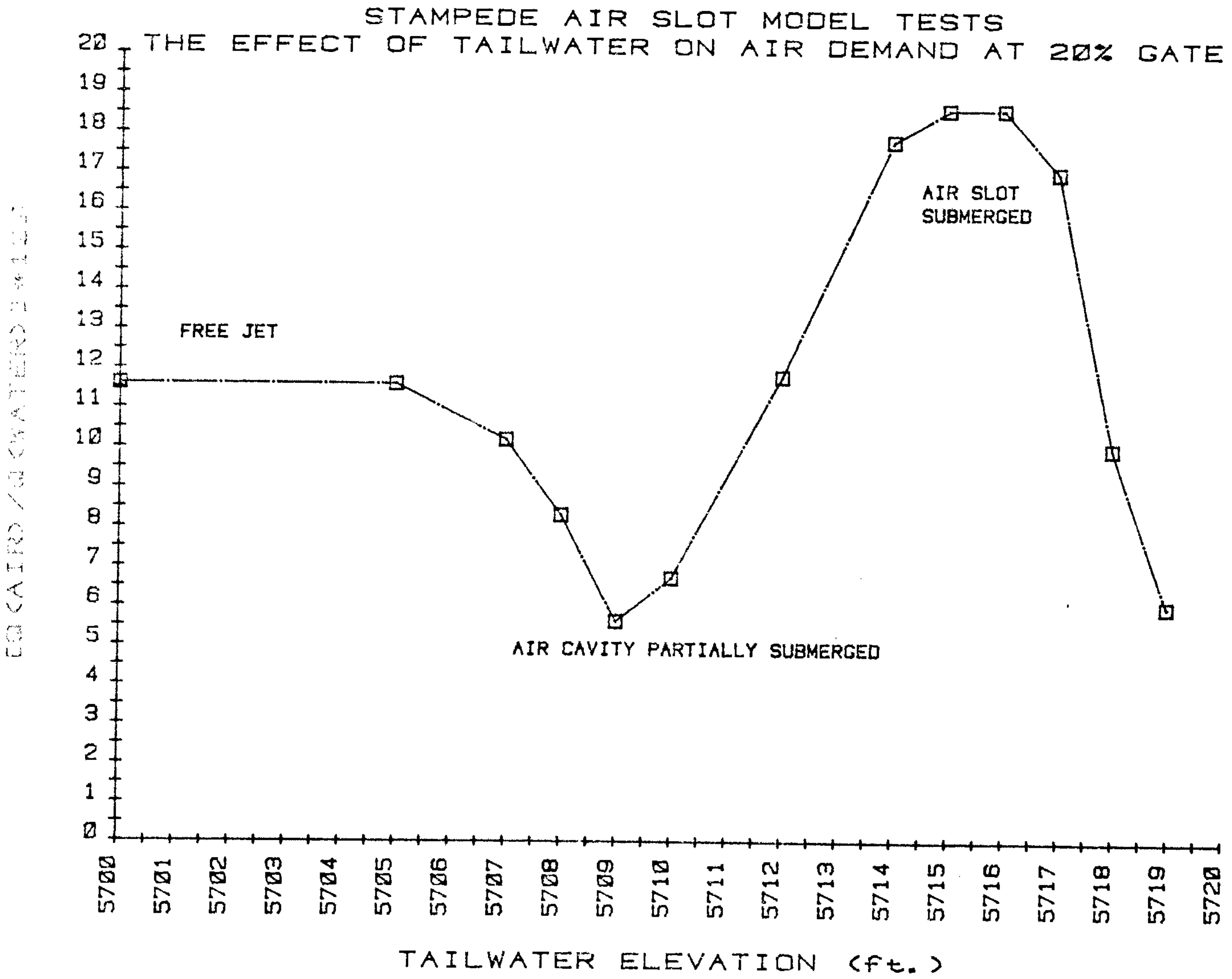

STAMPEDE AIR SLOT MODEL TESTS
THE EFFECT OF TAILWATER ON AIR DEMAND AT 20% GATE
Q(AIR)/Q(WATER)*100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
FREE JET
AIR SLOT
SUBMERGED
AIR CAVITY PARTIALLY SUBMERGED
5700
5701
5702
5703
5704
5705
5706
5707
5708
5709
5710
5711
5712
5713
5714
5715
5716
5717
5718
5719
5720
TAILWATER ELEVATION (ft.)

FIGURE 7