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Memorandum

Memorandum
: Chief, Hydraulics Branch WHW 12/28/73

Denver, Colorado
DATE: November 27, 1973

: R. B. Dexter, Hydraulic Engineer

: Results of air demand and gate operation measurements during simulated emergency closure of a penstock intake gate at Morrow Point Dam, Colorado River Storage Project

PURPOSE

The purpose of this field test was twofold. One purpose was to measure air demand and related phenomena during simulated emergency closure of a penstock intake gate at Morrow Point Dam for comparison with predictions from a mathematical model used to size the gate chamber air duct. The second purpose was to obtain gate hoist load and gate operation data during closure of the gate at near maximum reservoir elevation as required by the Designers' Operating Criteria.

CONCLUSIONS

1. The individual 2.75-foot by 3-foot air duct for each gate chamber is sufficient to prevent formation of subatmospheric pressure that would create structural or water column separation problems in the gate chamber or in the steel-lined penstock.

2. The maximum air velocity measured at the air duct intake was 264 feet per second and this velocity persisted for about 2 seconds, Figure 5.

3. The maximum air velocity was less than that which will create an objectionable whistling sound. The maximum sound pressure level indicated by a decibel meter was 105 db (C_S scale) at a location 16 feet from and directly in line with the air duct intake opening.

4. The mathematical model predictions of air demand created by emergency closure of the gate were precisely confirmed by the field test with respect to type of occurrence as shown by the nearly identical shapes of the model and prototype gate chamber pressure and air velocity curves of Figures 4 and 5.

5. The model predictions of magnitudes of negative pressures developed in the gate chamber and air velocities at the air duct intake were in good agreement with measured prototype values, Figures 4 and 5.

6. Rate of gate closure, controlled by the gate hoist, was the same for both balanced closure and simulated emergency closure. The gate traveled from the 17-foot full open position to closed in 102 seconds or at a rate of 10.0 feet per minute, Figure 3.

7. Gate travel was trouble-free under both balanced closure and emergency closure conditions.

8. The gate hydraulic hoist load during emergency closure did not exceed 68,000 pounds.

9. No significant hydraulic uplift or downpull forces acted on the gate during emergency closure.

10. The emergency closure did not cause gate seal damage that would be apparent from leakage past the seals.

APPLICATIONS

Results of the prototype test confirmed that the mathematical model produced dependable predictions of penstock-intake structure air demand resulting from emergency gate closure. The mathematical model provided an excellent basis for sizing the air duct. The model has been used to size air ducts for the Grand Coulee Third Powerplant penstock-intake structures and can be used for other appropriate future structures during the design stage.

INTRODUCTION

The power generation facilities at Morrow Point Dam include two turbine-generator units each with rated capacity of 66.67 megawatts. The design head of the Francis-type turbines is 396 feet. The hydraulic structures associated with the hydroelectric units are an intake structure at the reservoir with two penstock inlets and a fixed-wheel gate in each inlet, Figure 1.

During normal flow through the turbines the intake gates are fully open and water stands in the intake gate chamber, Figure 2. Normal flow shutoff is accomplished with the turbine wicket gates. This operation keeps the penstock and gate chamber filled and eliminates the problem of draining and refilling. However, in the event of emergency conditions such as loss of wicket gate control or penstock rupture, the intake gate can be closed and the intake gate chamber and penstock will drain. In this case the water level in the gate chamber would fall rapidly and the penstock would drain immediately after the gate chamber drained.

The fixed-wheel shutoff gate design includes upstream seals and a passage on the downstream side of the gate for gate chamber water to drain directly into the penstock. Rapid emptying of the gate chamber and penstock without admittance of air would decrease the pressure inside of these structures to dangerous levels. The formation of excessive subatmospheric (negative) pressures in these structures is prevented by admission of air to the system through an air duct for each gate chamber, Figure 2, Section B-B. Details of the air ducts and air intake structure can be found on Design Drawing No. 622-D-941.

Experience with earlier structures has shown that air demand of a rapidly draining gate chamber should not be satisfied by admitting air through openings in the gate hoist enclosure and openings in the chamber cover plates. The sudden large air demand can be dangerous to personnel and can cause damage to the enclosure building. During design of the intake structure the problem of adequate air duct size consistent with permissible negative pressure and economic considerations required solution. The need resulted in a fluid dynamic analysis (mathematical model) investigation of the effect of air vent dimensions on negative pressures in the gate chamber and penstock that could collapse the penstock steel liner. The study results are published in a Bureau of Reclamation Technical Report.1/ Results of the prototype field test to determine air demand and related phenomena are herein compared to corresponding mathematical model results. The scope of this report is limited to comparison of measured prototype air demand parameters with those determined by the mathematical model and to the relationship between gate travel and hydraulic hoist loads.

It is important to emphasize here that the air demand results published in Report No. HYD-584 are not the final results obtained with the mathematical model. Subsequent to publication of Report No. HYD-584 the model was used by its originator, Dr. H. T. Falvey, to investigate air inlet duct sizes for the Grand Coulee Third Powerplant penstock-intake gate structures. During this use of the model, refinements were made to the relationship of waterflow from the reservoir through the closing gate and simultaneous waterflow from the gate chamber into the penstock. This refinement was applied to the Morrow Point gate structure and resulted in changes of the calculated air demand during drainage of the gate chamber and penstock. Dr. Falvey predicted that the unpublished revised mathematical model results for the Morrow Point structure would be in better agreement with prototype air demand than would the published results. Therefore, the Morrow Point prototype gate structure air demand results are compared to the revised mathematical model results in this writing.

1/ Falvey, H. T., Report No. HYD-584, "Air Vent Computation, Morrow Point Dam, Colorado River Storage Project," July 1968.

The simulated emergency closure test of one of the two 13.5-foot by 16.1-foot fixed-wheel gates in the Morrow Point Dam penstock-intake structure with near maximum reservoir elevation was performed in accordance with requirements of the Designers' Operating Criteria. Emphasis was placed upon acquisition of data necessary for evaluation of the gate chamber air duct. However, data were also obtained to define gate hydraulic hoist load with respect to gate travel.

FIELD TEST INSTALLATION

Locations of sensors used to obtain analog recordings of prototype test transient values at the intake structure are shown on Figure 2. The sensors are identified on Figure 2 by the arabic numerals used in the tabulation below and the corresponding numerals on Figure 2 are enclosed in a circle.

1. Gate travel potentiometer attached to the shaft of the gate position cable drum. The shaft completes five revolutions for full stroke gate travel of 17 feet.

2. Accelerometer fastened to a beam of the hydraulic hoist bridge to indicate movement caused by unsteady gate operation.

3. Pressure transducer to measure hoist cylinder pressure under the piston for calculation of hoist loads.

4. Electric contact probe to signal initial water surface drop in the gate chamber.

5. Pressure transducer to indicate air pressure in the gate chamber.

6. Submerged pressure transducer at the top of the gate track base to indicate rate of water surface drop in the gate chamber.

7. A pitot tube downstream of the intake grill of the gate chamber air supply duct.

8. A differential pressure transducer connected to the total-head and the static-head legs of the pitot tube to indicate air velocity at the air duct intake.

A sound intensity indicating meter was used for manual observation of maximum sound energy of the air flow at the gate chamber air duct intake.

FIELD TEST PROCEDURE

Two electronic analog-type recorders were used to simultaneously record test data. The output of all electronic sensors identified on Figure 2, except the gate travel potentiometer, were recorded on an eight-channel recorder at a chart speed of 5 millimeters per second. A separate recorder was used to provide suitable resolution of gate travel with respect to time. This recorder was used to provide a trace amplitude of 85 chart divisions (4.90 inches) for the gate travel of 17 feet, or 5 chart divisions per foot of gate travel. This provided gate position determinations at each one-tenth of a foot of gate travel. Figure 3 is a one-half size reproduction of the gate travel versus time recordings made during balanced and emergency closure of the gate.

Both electronic recorders were equipped with a chart time marker controlled by a 1-second interval timer. It was not practical to operate the time marker of both recorders from a common 1-second signal source. Immediately prior to the simulated emergency gate closure the recorders were put into operation with a 1-second interval mark being made on the traveling chart of each recorder. A voice signal was given to each recorder operator to identify the nearest 1-second mark as zero recorder time. These zero marks were used as a common time base for all test data obtained with the recorders. This procedure possibly introduced a timing error of plus or minus one-half second and a maximum difference of 1 second between the recorders time base. A 1-second timing error was not significant in the analysis of test results.

In addition to test data obtained with the electronic recorders, several factors were manually observed and recorded. At the gate structure these factors included maximum sound intensity near the air duct intake, observations to determine specific weight of air at the intake, and water surface elevation in the gate chamber during steady turbine flow immediately prior to simulated emergency gate closure.

Manual observations and recordings of critical values were made in the powerplant control room. Immediately prior to gate closure these included reservoir water surface elevation, generator megawatt output, and turbine wicket gate opening. During intake gate closure the generator output was recorded at 10-second intervals until the output decreased to zero.

To simulate an emergency intake gate closure and uncontrolled penstock drainage, the turbine governor gate limit control was set to limit the wicket gates opening at 79.5 percent (66Mw generator output). Manual servomotor control was then used to hold the gates at the opening limit to allow penstock drainage through the turbine. Morrow Point Powerplant can be operated from the Power Operations Center at Montrose, Colorado. In the event emergency closure of the penstock intake gate is required the closure can be initiated at the Operations Center. Therefore, the gate closure for test purposes was planned to include gate closure by an operator at the Operations Center. This plan was followed for both the balanced closure and simulated emergency closure of the penstock gate. Three-way telephone communication was used between the intake structure, powerplant control room, and Operations Center to coordinate test activities and to initiate remote gate closure.

FIELD TEST RESULTS

Intake Gate Balanced Closure

The significant factors of a no-flow balanced closure of the gate were rate of gate closure, hoist load, and performance of the gate and hoist. The gate closed from 17 feet open to fully closed in 102 seconds at an essentially constant rate of 10.0 feet per minute. The pressure under the hoist was constant at 345 pounds per square inch during closure. The effective piston area is 188.5 square inches so the load was 65,030 pounds. This load value neglects the oil pressure that varies from about 2 feet to 19 feet of oil, acting on top of the piston. Hoist operation and gate travel were regular and trouble-free as shown by the gate travel versus time diagram in the upper portion of Figure 3. The hoist loads during both balanced and emergency closure of the gate have been manually plotted on the gate closure charts of Figure 3.

Simulated Emergency Closure

Initial conditions for the field test emergency gate closure are listed below with corresponding mathematical model values in parenthesis.

Reservoir water surface elevation = 7157.60 (7165.00)

Gate chamber water surface elevation = 7155.77 (7162.65)

Turbine gate opening = 79.5 percent (---)

Turbine discharge = 2180.cfs (2544.)

The field test turbine discharge was determined from results published in Report No. HM-15, Hydraulic Turbine Acceptance Test, Morrow Point Power Plant, February 1972.

The rate of gate travel during the simulated emergency closure was the same as that during the balanced closure. The gate closed in 102 seconds as shown by the recorder chart copy in the lower portion of Figure 3. Refer to the emergency closure hoist load plot on Figure 3 for graphical representation of the hoist load changes listed below:

1. The hoist load was 64,000 to 66,000 pounds from 17 feet of gate opening until the gate was 6 feet open.

2. The load then decreased to 60,000 pounds at about 5 feet of gate opening and held constant to 3.1 feet of gate opening.

3. At 3.0 feet open the load started a momentary decrease to 53,000 pounds then rapidly increased to 68,000 pounds at 2.5 feet open.

4. This maximum load of 68,000 pounds existed until the gate was 0.8 of a foot open.

5. During the last 0.8 of a foot of gate closure the load decreased from 68,000 pounds down to about 20,000 pounds of residual hydraulic force under the piston.

Evidently the fixed-wheel and track system of the gate operated smoothly and without binding because the gate travel rate was constant and there was no extreme change of gate hoist load. The accelerometer on the hoist bridge did not indicate movement or vibration of the bridge even though the sensitivity of the accelerometer output circuit was 10 millimeters of chart amplitude per 1 g of acceleration.

The decrease of air pressure in the gate chamber during the emergency gate closure was less than predicted by the revised mathematical model as shown by Figure 4. The decrease of pressure referred to atmosphere was 0.78 pound per square inch in the prototype structure compared to a model predicted decrease of 0.96 pound per square inch. Therefore, decrease of air pressure in the prototype gate chamber was 81 percent of that predicted by the mathematical model study. The prototype gate closure time of 102 seconds compared to the model closure time of 60 seconds could be the reason for less than predicted pressure drop in the prototype gate chamber. The most important consideration is that the gate chamber air duct, 2.75 feet by 3 feet cross section, that was determined to be of sufficient size by the model study did limit the pressure drop in the gate chamber and penstock to a safe value.

The maximum air velocity measured at the intake of the prototype air duct was 264 feet per second. The model predicted maximum duct velocity was 187 feet per second, Figure 5. The prototype air velocity was measured with a Pitot tube behind the intake grill at one point in the 42-inch-high by 33-inch-wide intake of the air duct. The measuring location was on the vertical centerline of the opening one-third of the distance from the bottom to the top of the opening and about 5 inches behind the grill. This location was chosen because of convenience and the belief the shape of the air velocity profile would be reasonably flat except at the boundaries of the inlet. No definite information is available on velocity distribution at the Pitot tube location in relation to the duct velocity distribution, so a precise quantitative comparison between model and prototype air velocities in the duct could not be made.

The mathematical model predicted a larger pressure drop in the gate chamber than was measured in the prototype. The prototype air duct velocity apparently exceeded that predicted by the mathematical model. Although the model predictions produced a satisfactory air duct, an evaluation of the model to refine the computations may be necessary to accomplish better conformance.

One purpose of the model study was to limit the inlet air velocity to 300 feet per second at which an objectionable whistling sound occurs. This purpose was accomplished because there was a roaring sound of rushing air at the duct intake but no whistling sound at maximum air demand. The sound energy was measured 16 feet from and directly in line with the air duct intake. The maximum sound energy was 105 decibels measured on the C_s scale of a sound energy meter.

FUTURE EVALUATION

Use of the mathematical model to calculate air demand during emergency closure of a Grand Coulee Third Powerplant penstock intake gate resulted in design and construction of two 4-foot by 4.5-foot air ducts for each gate chamber. The Designers' Operating Criteria will require an emergency closure test of one of the penstock intake gates. When these gates are operational a plan should be formulated jointly with the Mechanical Branch to perform a gate operation and air demand test similar to the Morrow Point penstock intake gate test.

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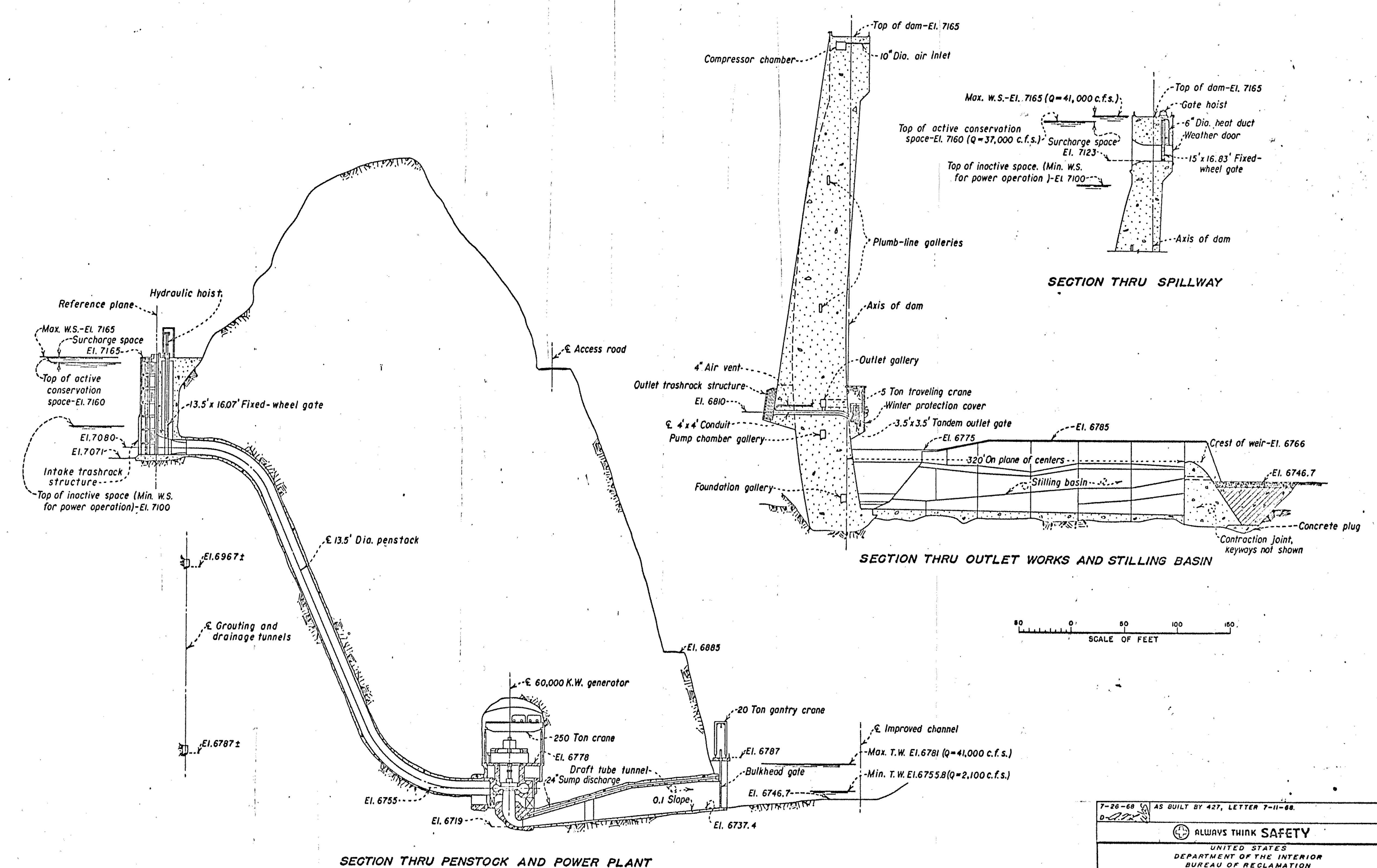
Figure 1



7-26-68 AS BUILT BY 427, LETTER 7-11-68.

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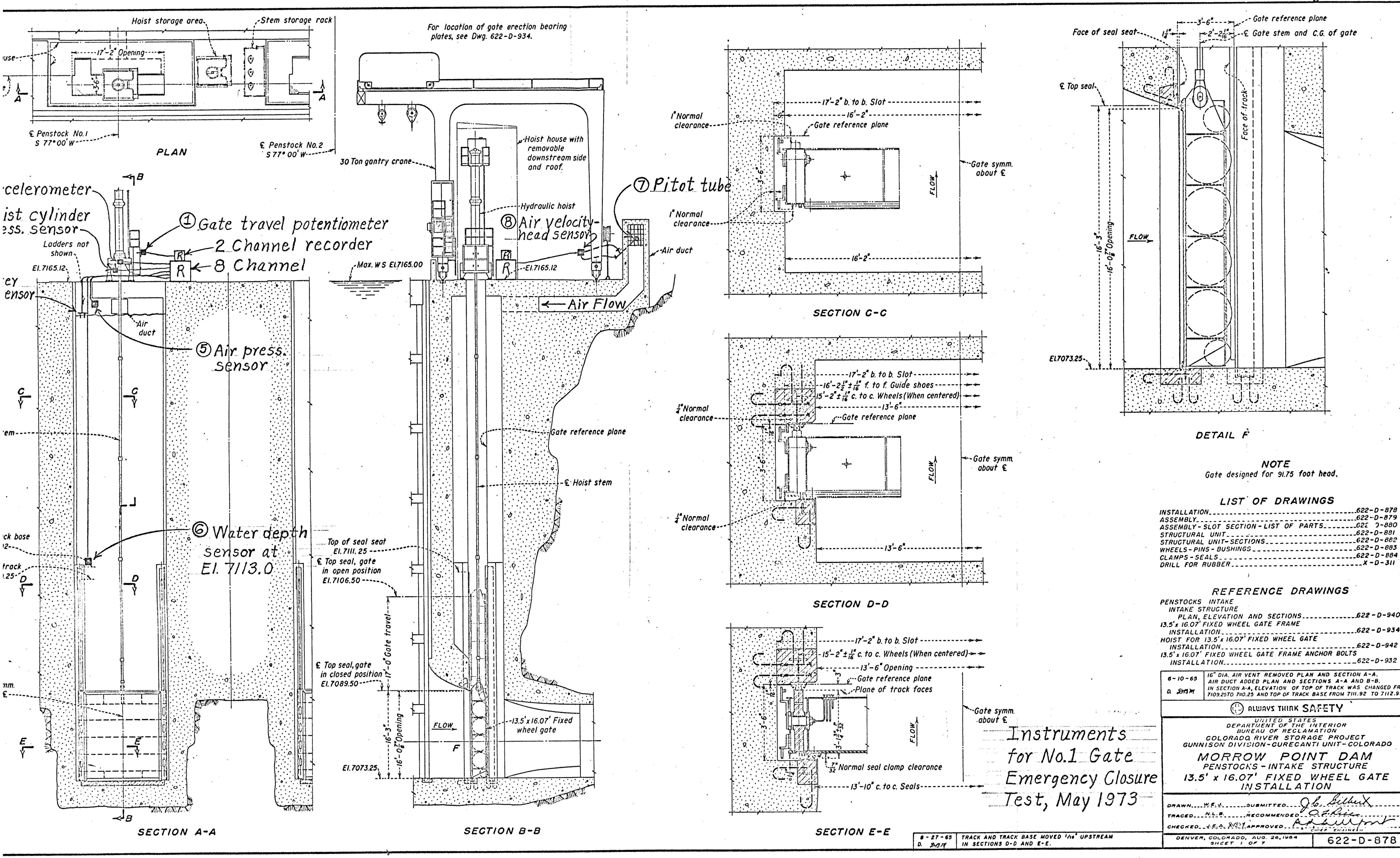
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
GUNNISON DIVISION- CURECANTI UNIT- COLORADO

MORROW POINT DAM AND POWER PLANT
SECTIONS

DRAWN W.A.T. SUBMITTED R. J. Larson
TRACED C.W.B.-J.L. RECOMMENDED John Parsakian
CHECKED J.E.Q. Jr. APPROVED Grant Bloodgood
ASST. COMM. AND CHIEF ENGINEER
DENVER, COLORADO, JAN. 16, 1963 622-D-434

Figure 2


Hoist storage area
Stem storage rack
17'-2" Opening
℄ Penstock No. 1 S 77°00' W
℄ Penstock No. 2 S 77°00' W
PLAN
For location of gate erection bearing plates, see Dwg. 622-D-934.
30 Ton gantry crane
Hoist house with removable downstream side and roof.
Hydraulic hoist
Accelerometer
Hoist cylinder press. sensor
① Gate travel potentiometer
2 Channel recorder
8 Channel
⑦ Pitot tube
⑧ Air velocity-head sensor
Ladders not shown
El. 7165.12
Max. W.S. El. 7165.00
Air duct
Air Flow
⑤ Air press. sensor
⑥ Water depth sensor at El. 7113.0
Gate reference plane
℄ Hoist stem
Top of seal seat El. 7111.25
℄ Top seal, gate in open position El. 7106.50
℄ Top seal, gate in closed position El. 7089.50
17'-0" Gate travel
16'-3" Opening
16'-0 7/8" Opening
El. 7073.25
FLOW
13.5' x 16.07' Fixed wheel gate
SECTION A-A
SECTION B-B
1" Normal clearance
17'-2" b. to b. Slot
16'-2"
Gate reference plane
Gate symm. about ℄
SECTION C-C
16'-2 3/8" ± 1/16" f. to f. Guide shoes
15'-2" ± 1/16" c. to c. Wheels (When centered)
13'-6"
1/4" Normal clearance
SECTION D-D
13'-6" Opening
Plane of track faces
7/32" Normal seal clamp clearance
13'-10" c. to c. Seals
SECTION E-E
Face of seal seat
3'-6"
Gate reference plane
℄ Gate stem and C.G. of gate
℄ Top seal
Face of track
DETAIL F
NOTE
Gate designed for 91.75 foot head.
LIST OF DRAWINGS
INSTALLATION 622-D-878
ASSEMBLY 622-D-879
ASSEMBLY - SLOT SECTION - LIST OF PARTS 622-D-880
STRUCTURAL UNIT 622-D-881
STRUCTURAL UNIT - SECTIONS 622-D-882
WHEELS - PINS - BUSHINGS 622-D-883
CLAMPS - SEALS 622-D-884
DRILL FOR RUBBER X-D-311
REFERENCE DRAWINGS
PENSTOCKS INTAKE
INTAKE STRUCTURE
PLAN, ELEVATION AND SECTIONS 622-D-940
13.5' x 16.07' FIXED WHEEL GATE FRAME INSTALLATION 622-D-934
HOIST FOR 13.5' x 16.07' FIXED WHEEL GATE INSTALLATION 622-D-942
13.5' x 16.07' FIXED WHEEL GATE FRAME ANCHOR BOLTS INSTALLATION 622-D-932
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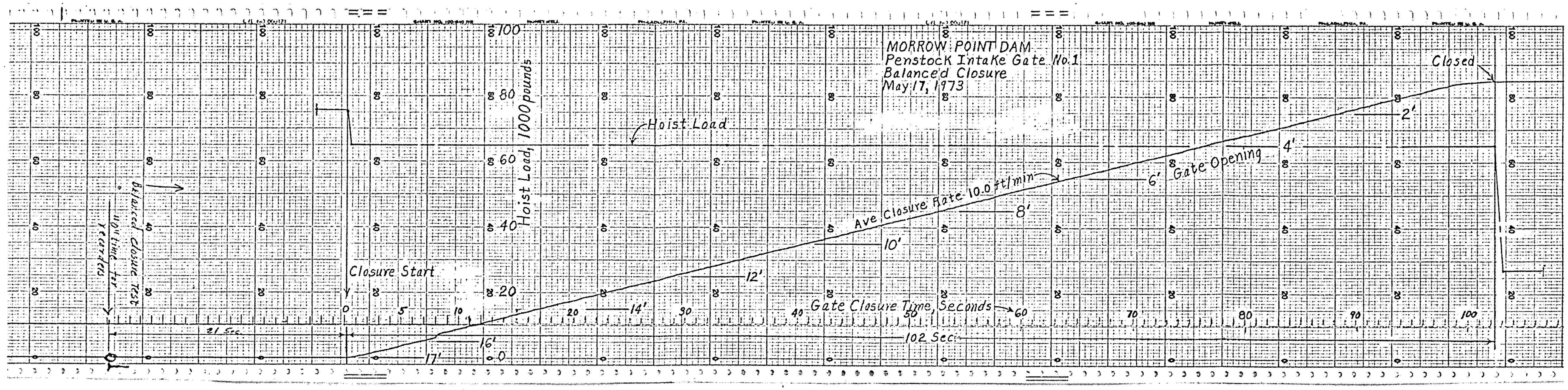
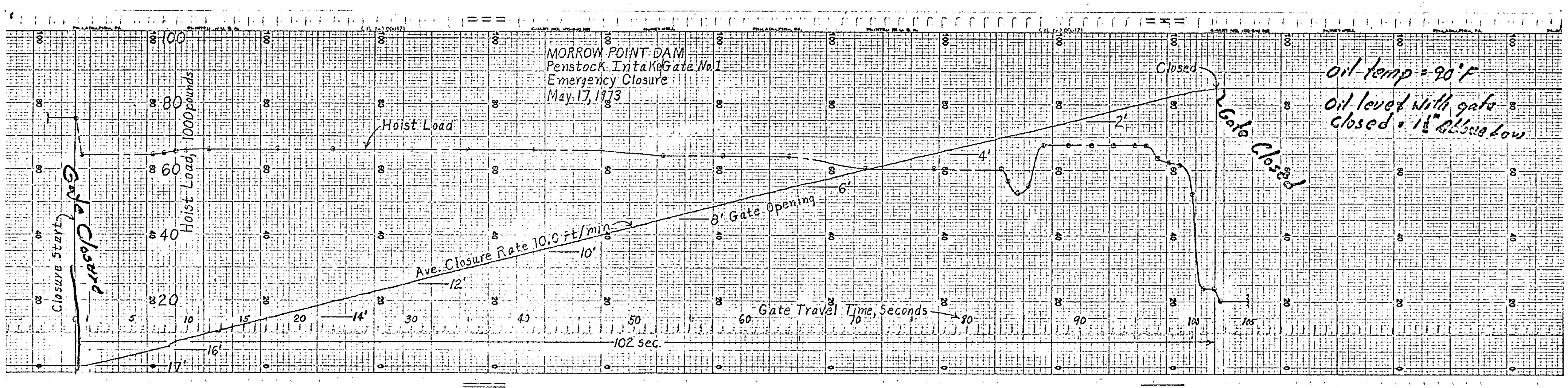
MORROW POINT DAM
PENSTOCKS - INTAKE STRUCTURE
13.5' x 16.07' FIXED WHEEL GATE INSTALLATION
DENVER, COLORADO, AUG. 26, 1964
622-D-878
TRACK AND TRACK BASE MOVED 1/16" UPSTREAM IN SECTIONS D-D AND E-E.
Instruments for No. 1 Gate Emergency Closure Test, May 1973



Balanced Closure



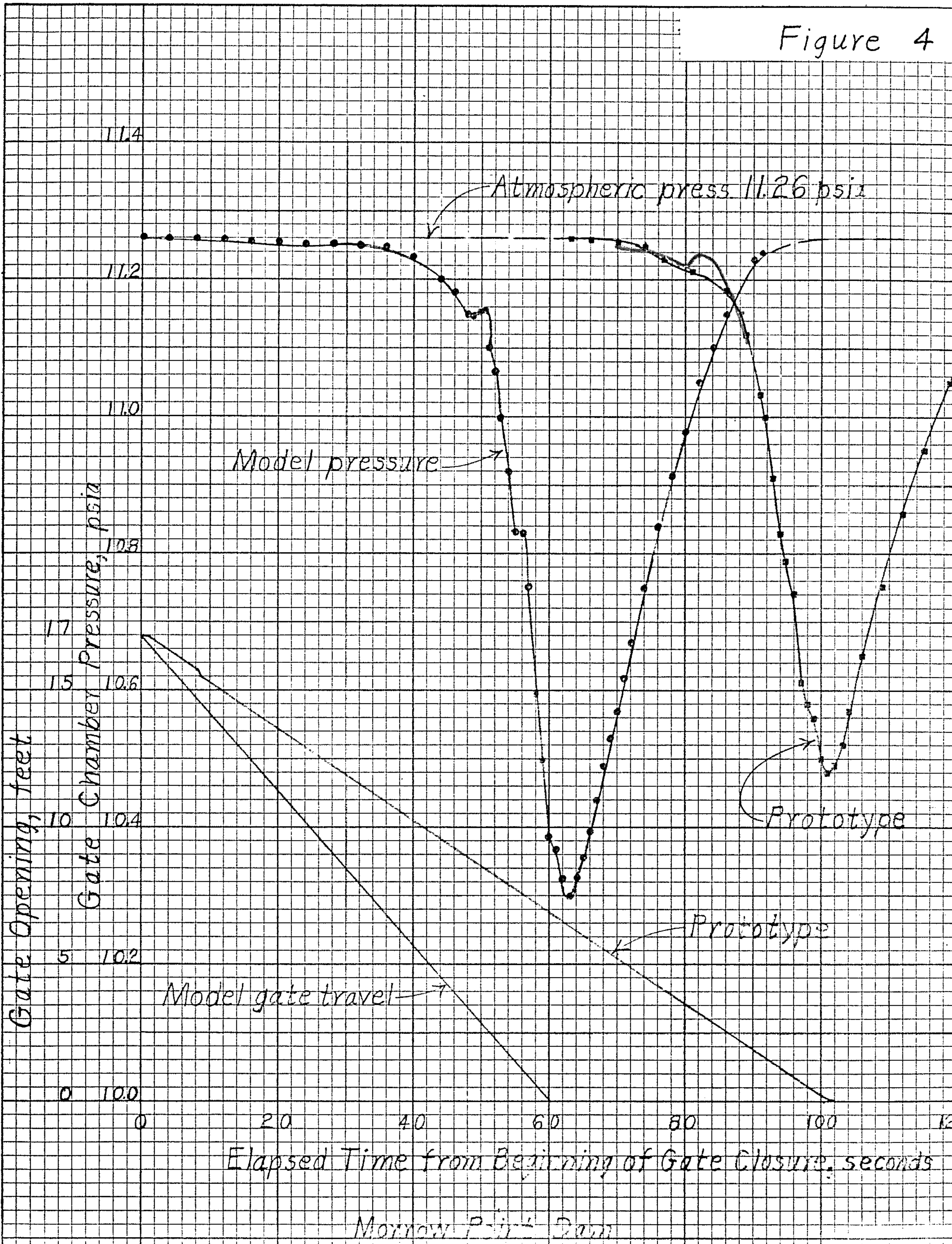
Emergency Closure

MORROW POINT DAM

Penstock Intake Gate No. 1

Prototype Test May 17, 1973

Hoist Load and Gate Closure Rate



Morrow Point Dam

Penstock Intake Gate Emergency Closure

Comparison of Mathematical Model with Prototype

Gate Travel and Gate Chamber Pressure

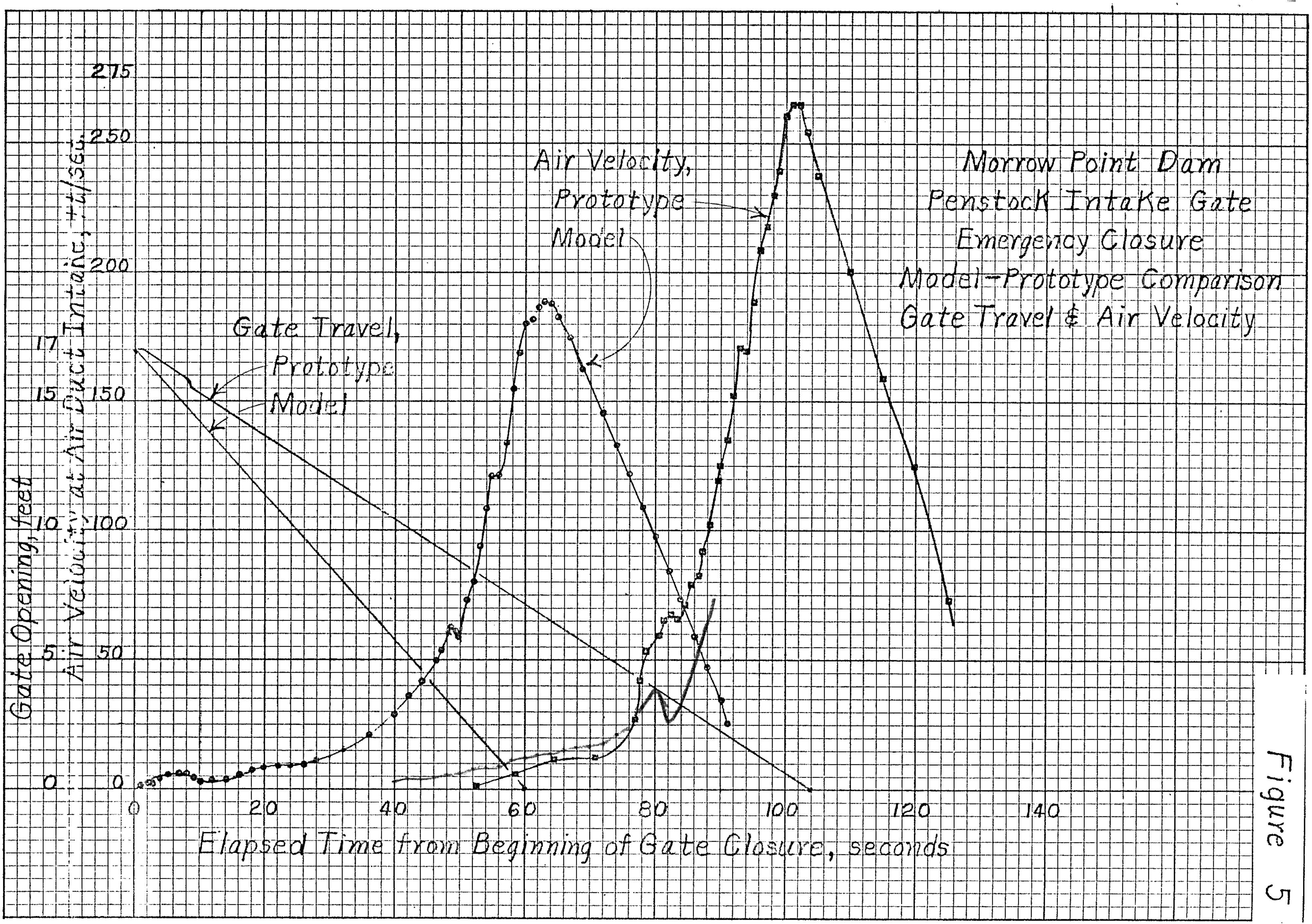

Morrow Point Dam
Penstock Intake Gate
Emergency Closure
Model-Prototype Comparison
Gate Travel & Air Velocity
Air Velocity,
Prototype
Model
Gate Travel,
Prototype
Model
Gate Opening, feet
Air Velocity at Air Duct Intake, ft/sec.
275
250
200
17
15
150
10
100
5
50
0
0
0
20
40
60
80
100
120
140
Elapsed Time from Beginning of Gate Closure, seconds

Figure 5