REC-OCE-69-3

HYDRAULIC MODEL STUDIES OF PUMP INTAKE MANIFOLD AND EVAPORATION TRAYS

SAN DIEGO SALINE WATER TEST FACILITY

OFFICE OF SALINE WATER

D. L. King
Division of Research
Office of Chief Engineer
Bureau of Reclamation

November 1969

Prepared for
Office of Saline Water
Washington, D.C. 20240

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HYDRAULICS BRANCH
DIVISION OF RESEARCH

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Office of Chief Engineer . Denver, Colorado

ACKNOWLEDGMENTS

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ABSTRACT

The San Diego Saline Water Test Facility includes a test module to aid designing a multistage flash distillation desalting plant. The module contains evaporation, collection, and recirculation components. Design of the intake for recirculation pumps required special attention to maintain sufficient net positive suction head on the pumps while operating with a fluid near the flashing point. With improper intake design, vortex formation or water surface drawdown could result in reduction of suction head, cavitation on pump impellers, and severe pump vibration from entrainment of vapor. Tests performed on a 1:8.93 hydraulic model of a pump intake manifold enabled recommendations for several modifications to the preliminary design, alleviating vortex formation and vapor entrainment. Brine mixing devices in the last 2 stages of the evaporation trays were tested for effects on velocity distribution.

DESCRIPTORS—/ *pump intakes/ centrifugal pumps/ open channels/ velocity distribution/ hydraulic models/ hydraulics/ *model tests/ vortices/ open channel flow/ distillation/ appurtenances/ flash distillation/ desalination
IDENTIFIERS—/ *intake systems & manifolds/ Office of Saline Water/ San Diego Saline Fac, Calif/ multistage flash distill

CONTENTS

PURPOSE

The tests were performed to determine tendencies for vortex formation and vapor entrainment in the pump intake manifold, and to develop modifications or appurtenances to alleviate these tendencies. The effect of mixing devices on velocity distribution in the evaporation trays was also determined.

CONCLUSIONS

1. The preliminary design exhibited tendencies toward vortex formation and vapor entrainment in the pump intake manifold.

2. Flow improving modifications were developed which consisted of changing the location and orientation of the pump suction line, widening and streamlining the transitions between the evaporation trays and the manifold, and installing a vertical solid baffle above the intake to the pump suction line.

3. The tendency toward vapor entrainment was reduced, but not eliminated.

4. The overflow weir portion of the mixing devices improved the distribution of flow in the evaporation trays, but some asymmetry remained.

APPLICATION

The study was performed specifically for the Office of Saline Water. However, the results should be of general interest to designers of pump intakes.

INTRODUCTION

The San Diego Saline Water Test Facility includes a test module to aid in the design of a multistage flash distillation desalination plant. The module is a full-scale facility and includes a portion of the complete plant, with representation of the evaporation, collection, and recirculation components.

The design of the intake for the recirculating pump would not normally be of major concern. However, two considerations occur in the design of multistage flash distillation plants which warrant special attention. First, for cost efficiency, minimum excavation is desired for installation of the recirculating pumps. Second, it is necessary to maintain sufficient net positive suction head (NPSH) on the pumps even though they are operating with a fluid which is at its flashing point. With improper intake design, vortex formation or water surface drawdown could result in reduction of suction head, and cavitation on the pump impellers. Also, entrainment of vapor could cause severe vibration of the pump.

INVESTIGATION

Model Configuration

The 1:8.93 model represented the final two test stages (Numbers 8 and 9) of the test module, the pump intake manifold, and a portion of the pump suction line. Water was recirculated as in the prototype, and provisions were included for simulating the brine blowdown (waste water), product water, and raw water makeup discharges. The recirculated flow was measured with a standard orifice meter and the makeup water was measured with an orifice plate in the discharge line of a centrifugal pump. A centrifugal pump was also used for the recirculated flow. The gate valves in the blowdown and product lines were calibrated for control of those discharges.

Fresh water from the laboratory supply reservoir was used for the tests. Since the prototype module operates with concentrated brine at elevated temperature and near-vacuum pressure conditions, the model test results were necessarily partly qualitative.

The Preliminary Design

The preliminary design is shown in Figure 1. The model was designed according to Fluor Corporation's Drawing No. 4L-5003. The model was tested for a maximum recirculated discharge of 171.5 cfs (4.85 cms) (prototype), a brine blowdown discharge of 8.5 cfs (0.24 cms), a makeup discharge of 14.5 cfs (0.41 cms), and a product discharge of 6.0 cfs (0.17 cms). The recirculated discharge minus the product discharge results in a rate of flow in the evaporation trays of 165.5 cfs (4.68 cms). The trays were installed horizontally for these tests, and each tray carried 25 percent of the total discharge. The recirculating pump and manifold were designed for this condition, which will ultimately occur in the full-scale plant. However, only three trays will act as evaporators in the test module.

A minimum manifold water depth of 5 feet (1.52 m) occurs temporarily during startup. Figure 2 shows an overall view and an end view of flow conditions in the manifold with the minimum depth. Air entrainment

(vapor entrainment in the prototype) was severe, and large quantities of air were pulled into the pump suction line. A closeup view of the suction line transition is shown in Figure 3. Some of the air entrainment originated on the downstream side of the manifold, where the flow tended to climb the conduit wall and air was "folded" into the water. However, most of the air entrainment occurred at the entrance to the manifold. Figure 4 shows the contracting flow due to the shape of the entrance. This contraction resulted in higher flow velocities which, with the drop in elevation, produced strong surface turbulence in the manifold.

A zero-pitch (plane) vane in the pump suction line showed no tendency toward consistent swirling action in the suction line. The vane wavered back and forth, but rotation in either direction did not develop. This observation held for other manifold water depths.

For a manifold water depth of 6 feet (1.83 m), air entrainment was much less severe, as shown in Figure 5. Surface turbulence was reduced because of the smaller elevation difference between the water surface in the evaporation trays and the manifold water surface.

With the maximum depth of 7 feet (2.13 m) in the manifold, air entrainment was negligible and operation was entirely satisfactory, Figure 6.

The discharge was increased above the maximum design value to determine tendencies toward vortex formation above the suction line. The manifold water depth was held constant at 7 feet (2.13 m). Small, unstable vortices formed on the water surface above the suction line for recirculating discharges less than about 370 cfs (10.47 cms) (216 percent of maximum). These vortices entrained small quantities of air but did not exhibit a constant direction of rotation. The intensity of the surface action increased with an increasing discharge. At Q = 370 cfs (10.47 cms) the direction of rotation was predominantly clockwise. Similar conditions were observed, with increased strength of rotation, up to Q = 460 cfs (13.02 cms) (268 percent of maximum).

Figure 7 shows the results of air entrainment and water surface drawdown tests for discharges up to the maximum of 171.5 cfs (4.85 cms). For a given discharge, the manifold water depth at which significant amounts of air began to be entrained was determined. The water surface drawdown above the suction line was measured at manifold water depths of 6 and 7 feet (1.83 and 2.13 m) for various discharges. At a water depth of 5 feet (1.52 m), the water surface was too rough to allow a reasonably accurate measurement of the drawdown. The curves indicate that a maximum drawdown on the order of approximately 1 foot (0.30 m) might be expected.

Tests on the preliminary design indicated that air entrainment in the manifold might be reduced by streamlining the sides and bottom of the transition between the evaporation trays and the manifold, and by widening the transition to reduce the flow velocity. Also, use of a perforated baffle, as shown in Figure 8, helped alleviate air entrainment during operation at the minimum manifold water depth. A four-vane flow straightener, placed in the suction line transition immediately below the manifold, did not inhibit vortex formation.

The Modified Design

The model was modified to include widened, streamlined transitions from the evaporation trays to the manifold. The location and orientation of the pump suction line were revised to correspond with Fluor's Drawings No. 4-5503 and 4-5504. The prototype slope of 0.4 foot (0.12 m) per stage was installed in the evaporation trays. The evaporation tray mixing baffles were temporarily simulated with metal blocks placed in the trays. The revised model is shown in Figure 9. Some of the features shown will be described later.

At the minimum manifold water depth of 5 feet (1.52 m), air entrainment was essentially the same as observed in the preliminary design. Although the streamlined transition section eliminated acceleration of the flow through the section, the higher tray velocity due to the slope allowed turbulent surface flow to continue into the manifold. Also, a well-established vortex tended to form above the suction line. Flow conditions are shown in Figure 10. With a manifold water depth of 6 feet (1.83 m), air entrainment was greatly reduced, but the tendency continued for vortex formation above the suction line, Figure 11. At a depth of 7 feet (2.13 m), Figure 12, performance was satisfactory. A thin horizontal vortex formed near the manifold centerline, but very little air was drawn into the suction line.

Similar conditions were observed with 75 percent of the flow through the three right trays. Flow conditions at the minimum manifold water depth are shown in Figure 13.

A vertical baffle wall suspended from the crown of the

manifold above the suction line was successful in alleviating the vortex. The minimum wall dimensions necessary to maintain control of the vortex are: 20 feet (6.10 m) wide and 5 feet (1.52 m) high. Thickness of the baffle is not important. Figure 14 shows the proposed baffle arrangement and pier shape. Flow conditions with the baffle are shown in Figure 15. This photograph also shows the vaned flow straightener in the suction line transition. The straightener was reinstalled as an additional safeguard against vortex formation.

The baffle, even if extended the full length of the manifold, did not control air entrainment. A horizontal perforated plate, used successfully in the preliminary design, was also ineffective.

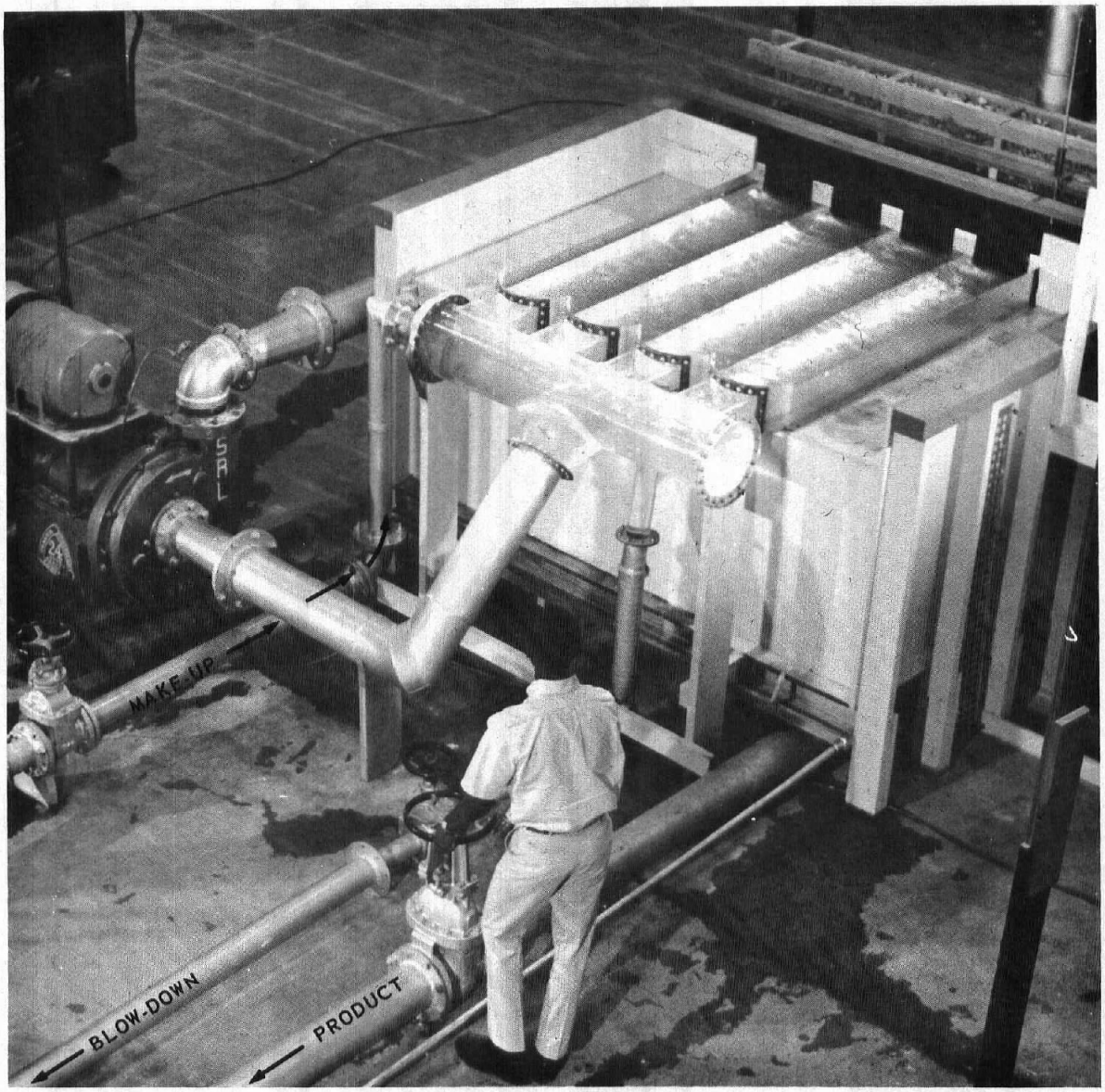
Evaporation Tray Mixing Devices

The model was modified to include the longitudinal structural members between the trays and the interstage dividers between Stages 7 and 8, and Stages 8 and 9. Each divider consisted of a wall across the three evaporation trays, Figure 16. The bottom of the wall was approximately 2 feet (0.61 m) above the invert. At the bottom of the wall was fastened an adjustable plate (hereafter referred to as the underflow weir) which could be lowered to within 10 inches (0.25 m) of the tray invert. An 8-inch-high (0.20-m) overflow weir was installed 2 feet 9 inches (.,84 m) (prototype) downstream from the underflow weir. This device was designed for the purpose of maintaining a well-mixed brine solution.

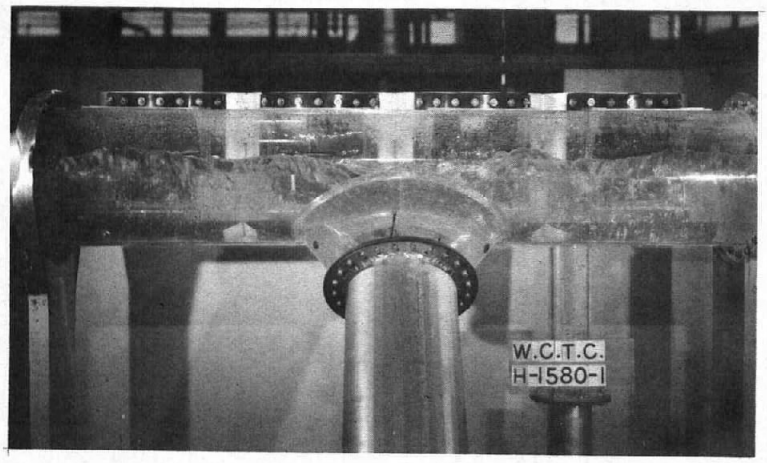
Velocity measurements were made with a miniature current meter about 14 feet (4.27 m) downstream from the start of Stage 9 (approximately 5 feet (1.52 m) upstream from the transition into the manifold). The test flow rate was 820,000 pounds per hour per foot of width through the three trays (about 165.5 cfs (4.68 cms) total flow). The underflow weirs were set at 16 inches (0.41 m) above the invert and the manifold depth was maintained at 7 feet (2.13 m). Velocities were measured with and without the overflow weirs. Flow depth at the measuring section was about 2 feet (0.61 m) for both conditions.

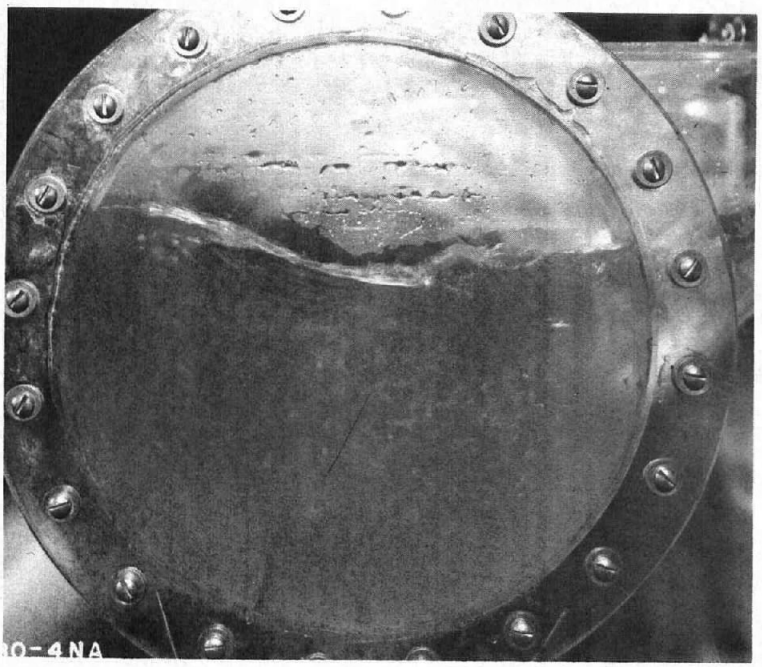
The test results, Figure 17, showed that the overflow weirs resulted in a more uniform distribution of velocity across the depth of flow, as compared to the distribution with the underflow weirs alone. The transverse asymmetry was also reduced by the overflow weirs. The apparent reduction in average velocity with the overflow weirs was probably due to the slightly increased depth at the measuring station.

FIGURE 1
REPORT HYD-597



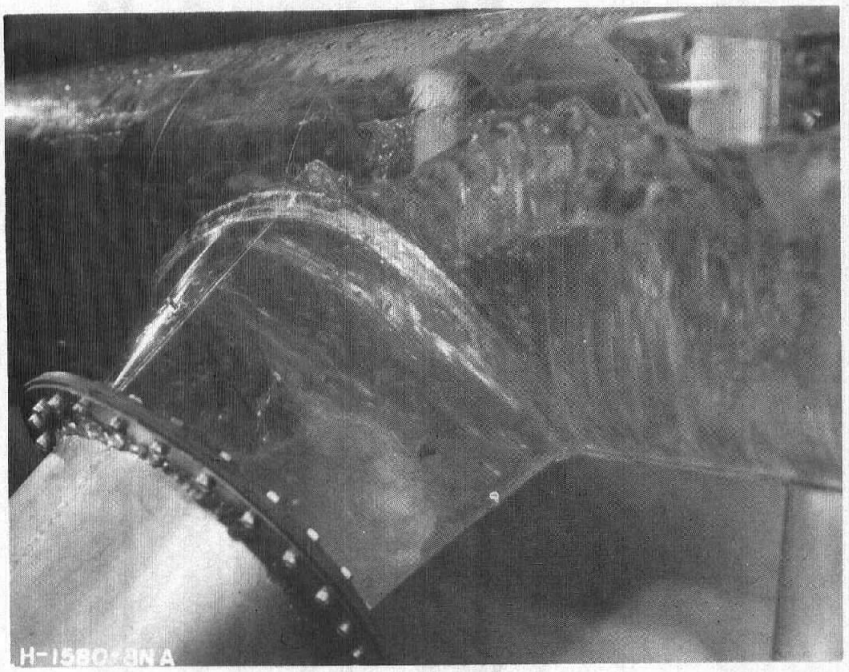
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design
Photo P800-D-65468



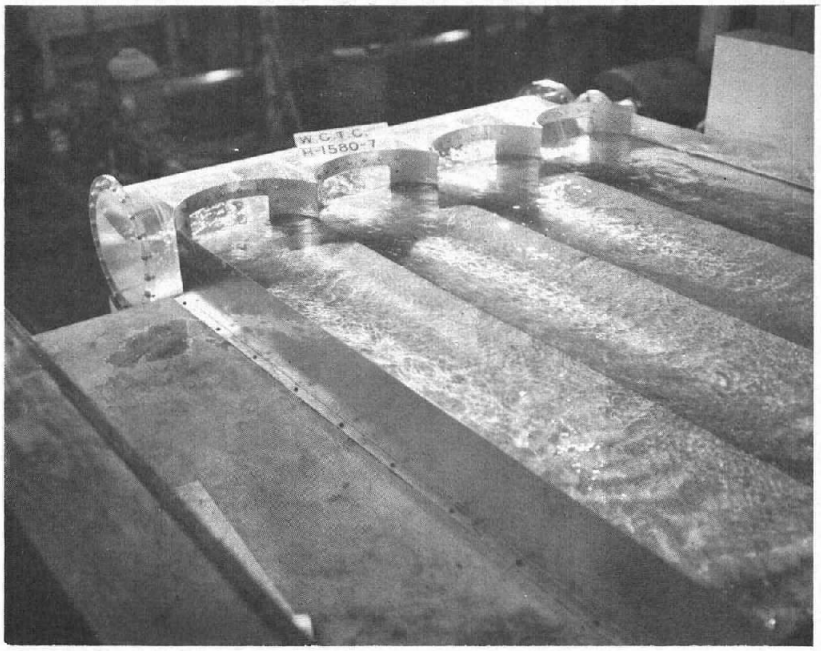


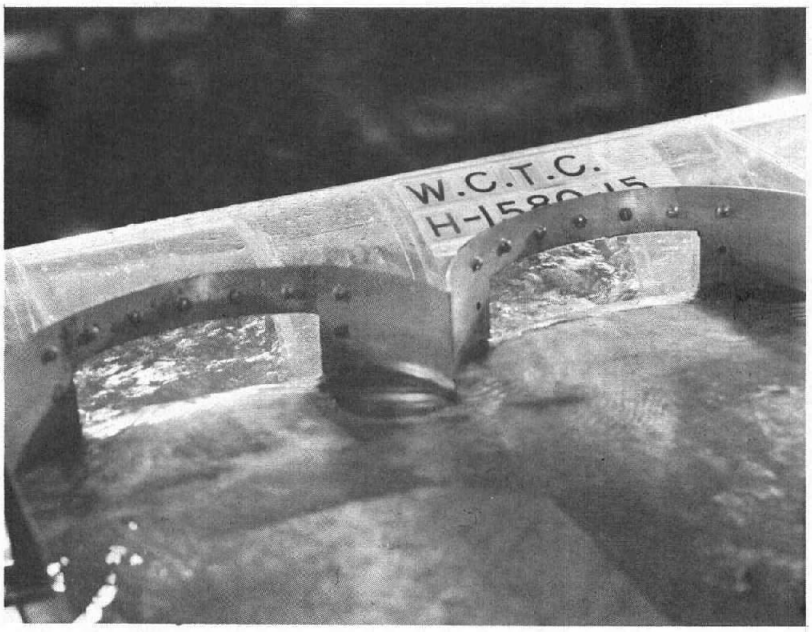
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design
Manifold Depth = 5 feet
Q = 171.5 cfs
Top Photo P800-D-65469
Bottom Photo P800-D-65470

FIGURE 3
REPORT HYD-597



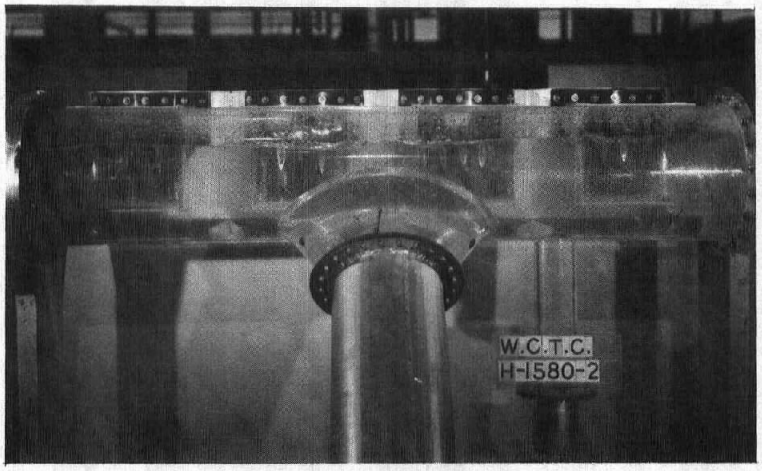
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design
Manifold Depth = 5 feet
Q = 171.5 cfs
Photo P800-D-65471

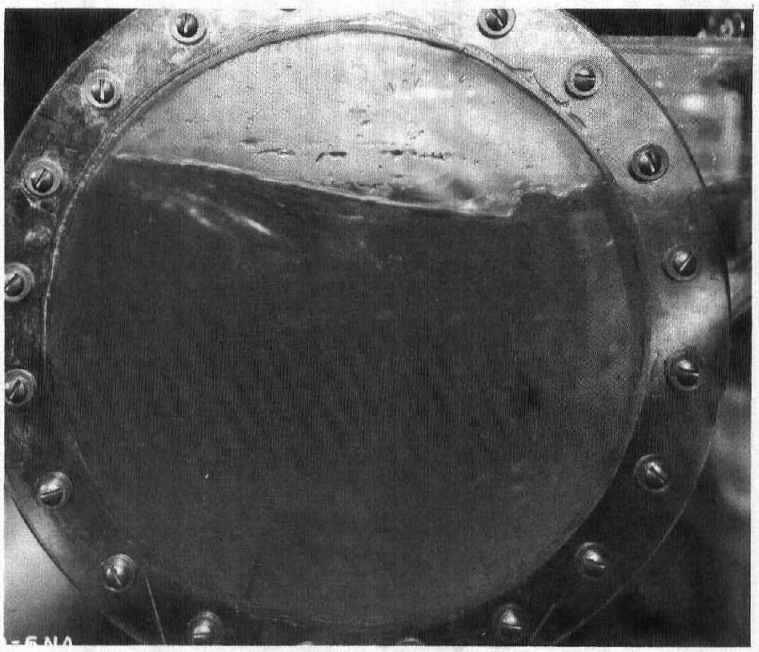




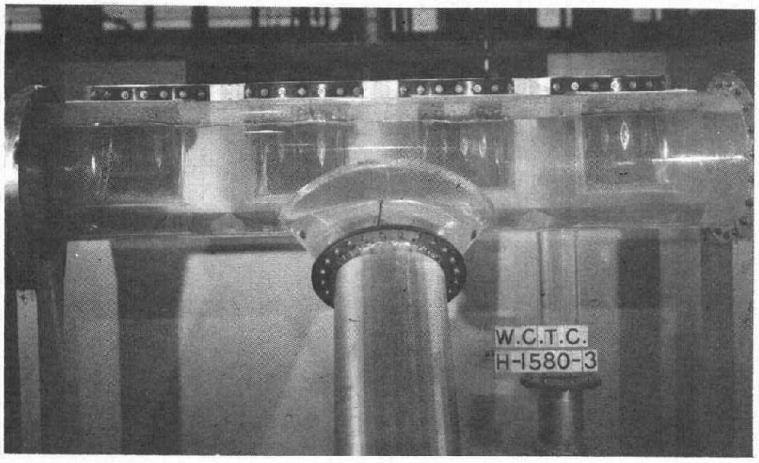
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design
Manifold Depth = 5 feet
Q = 171.5 cfs
Top Photo P800-D-65472
Bottom Photo P800-D-65473

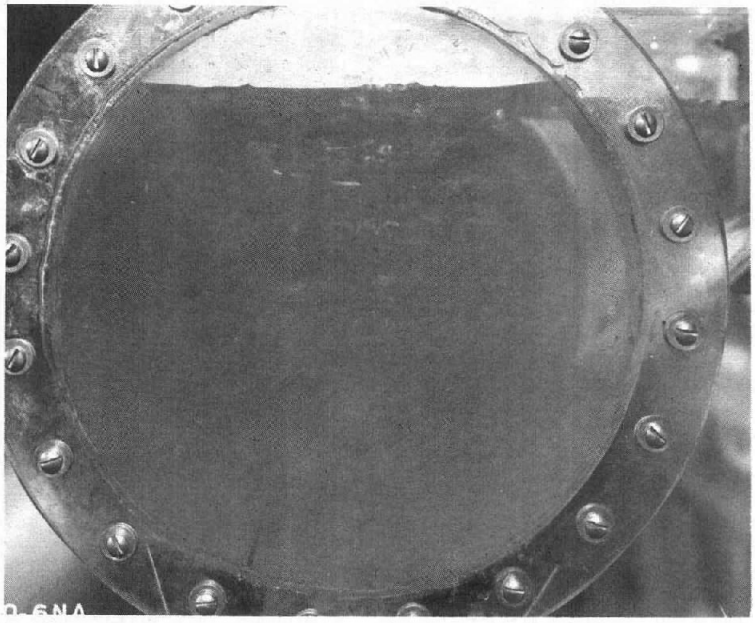
FIGURE 5
REPORT HYD-597



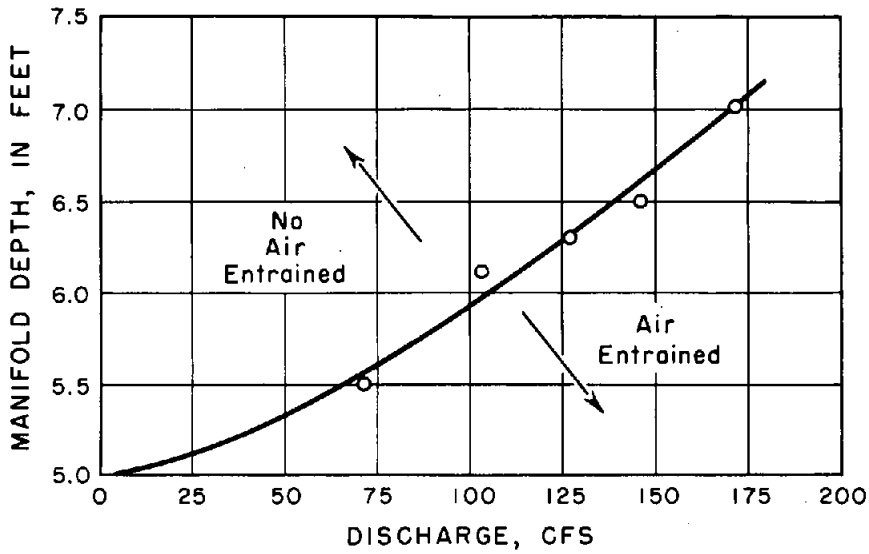


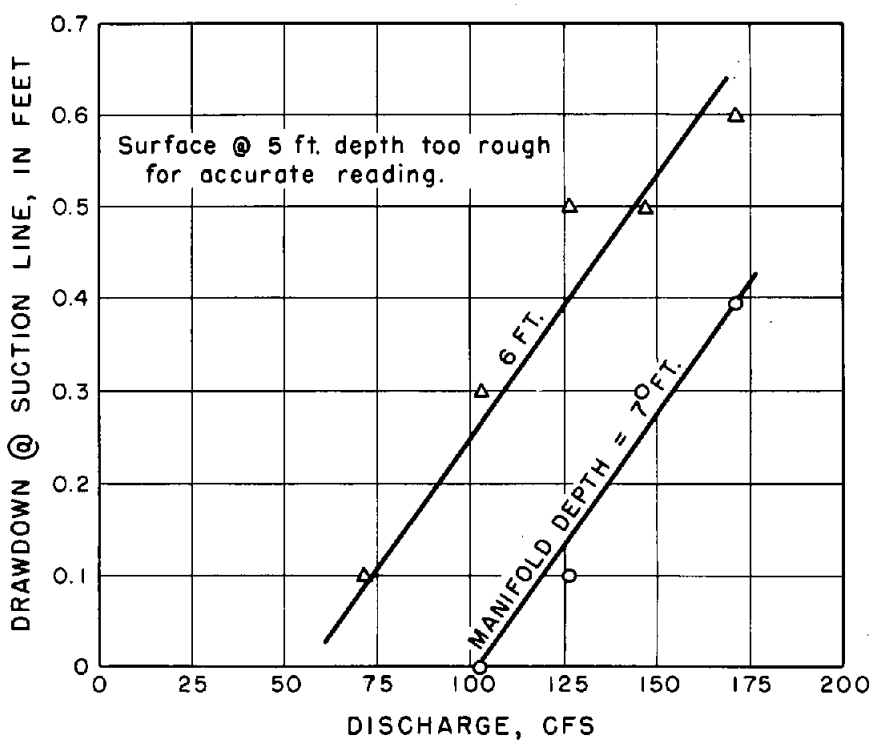
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design
Manifold Depth = 6 feet
Q = 171.5 cfs
Top Photo P800-D-65474
Bottom Photo P800-D-65475



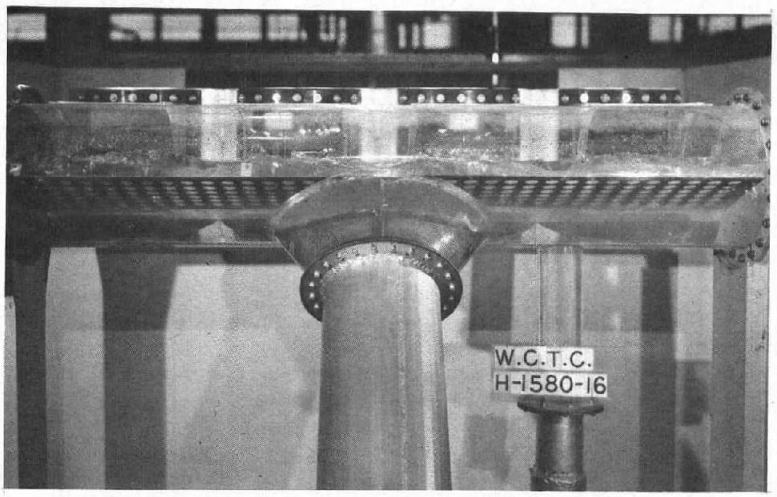


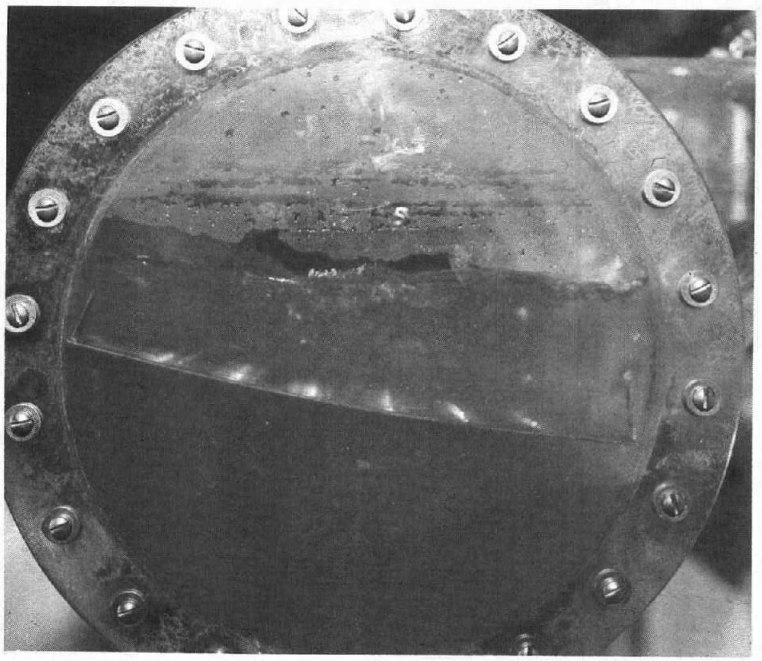
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design
Manifold Depth = 7 feet
Q = 171.5 cfs
Top Photo P800-D-65476
Bottom Photo P800-D-65477





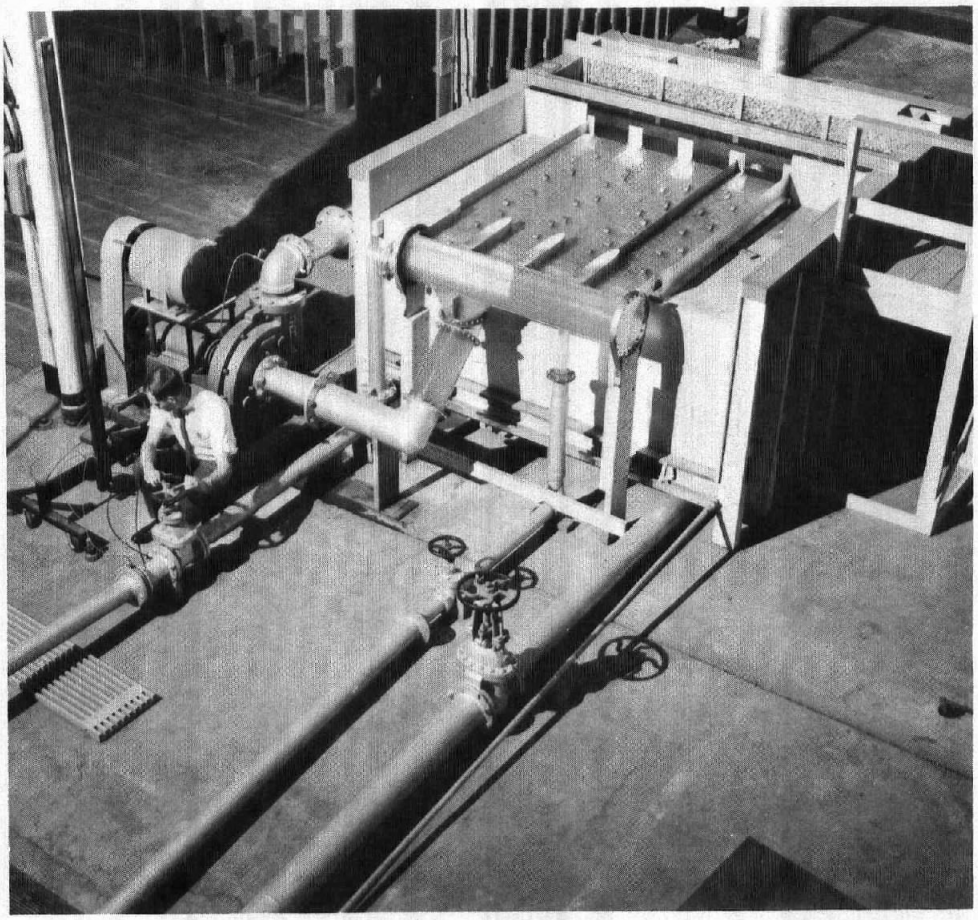
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design
Air-entrainment and Drawdown Tests



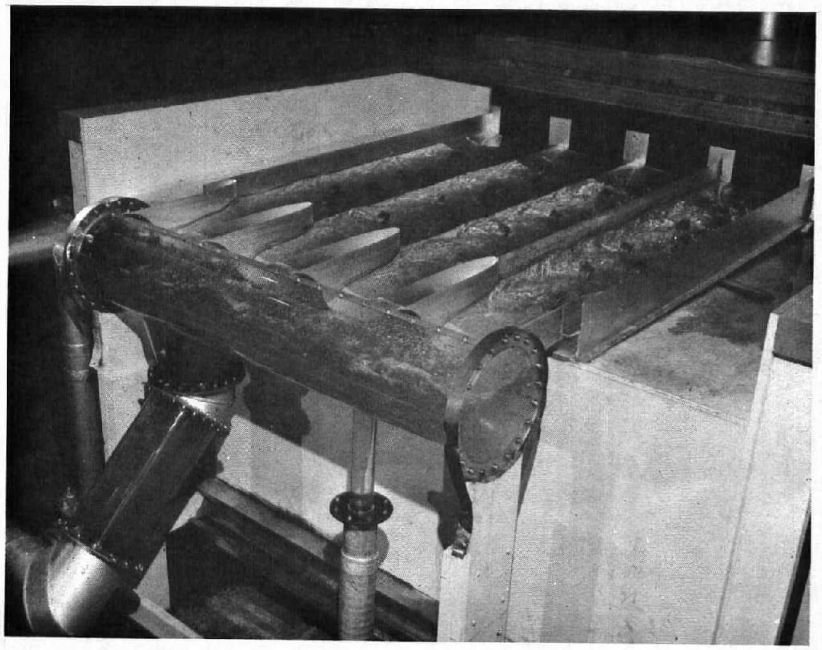


SALINE WATER TEST FACILITY
1:8.93 Scale Model
Preliminary Design with
Horizontal Perforated Baffle
Manifold Depth = 5 feet
Q = 171.5 cfs
Top Photo P800-D-65478
Bottom Photo P800-D-65479

FIGURE 9
REPORT HYD-597

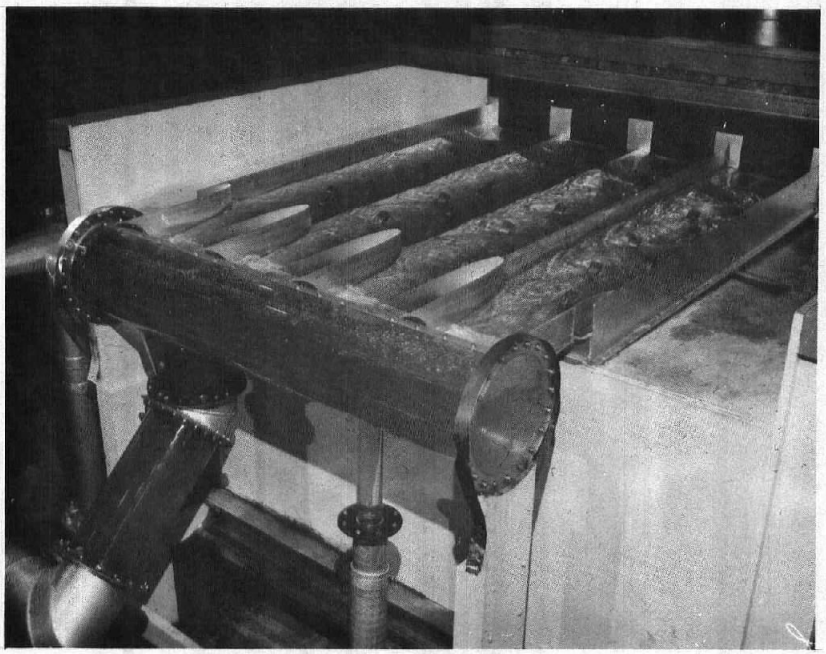


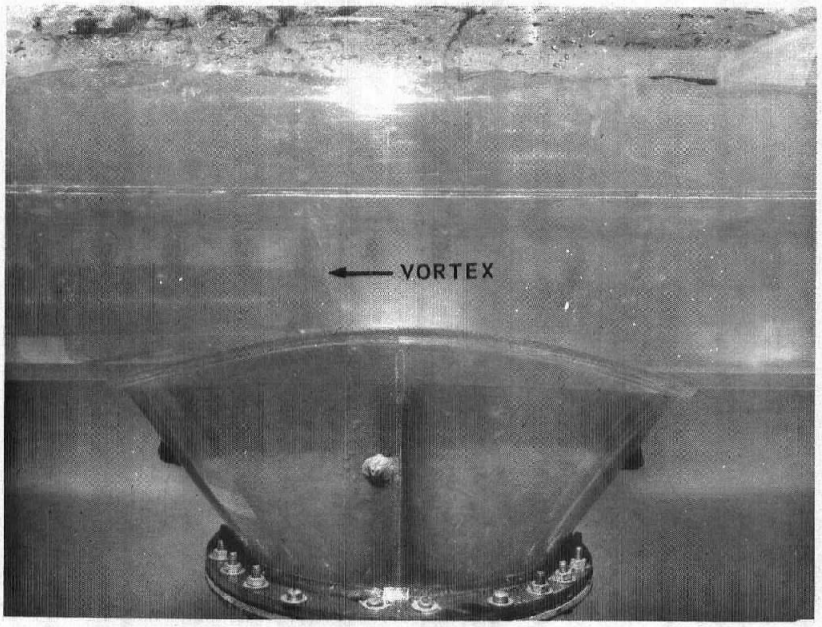
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Modified Design
Photo P800-D-65480



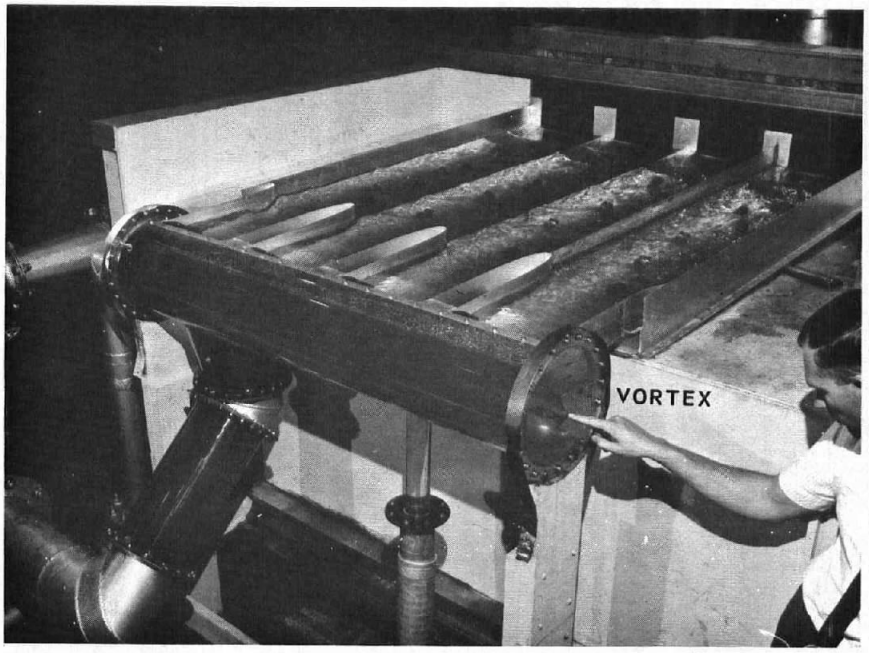
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Modified Design
Manifold Depth = 5 feet
Q = 171.5 cfs
Top Photo P800-D-65481
Bottom Photo P800-D-65482

FIGURE 11
REPORT HYD-597



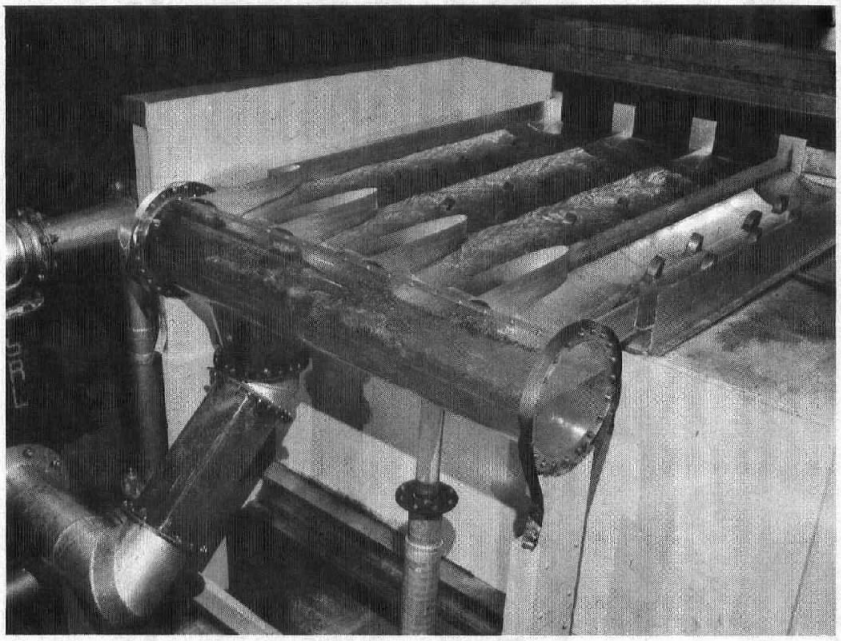


SALINE WATER TEST FACILITY
1:8.93 Scale Model
Modified Design
Manifold Depth = 6 feet
Q = 171.5 cfs
Top Photo P800-D-65483
Bottom Photo P800-D-65484

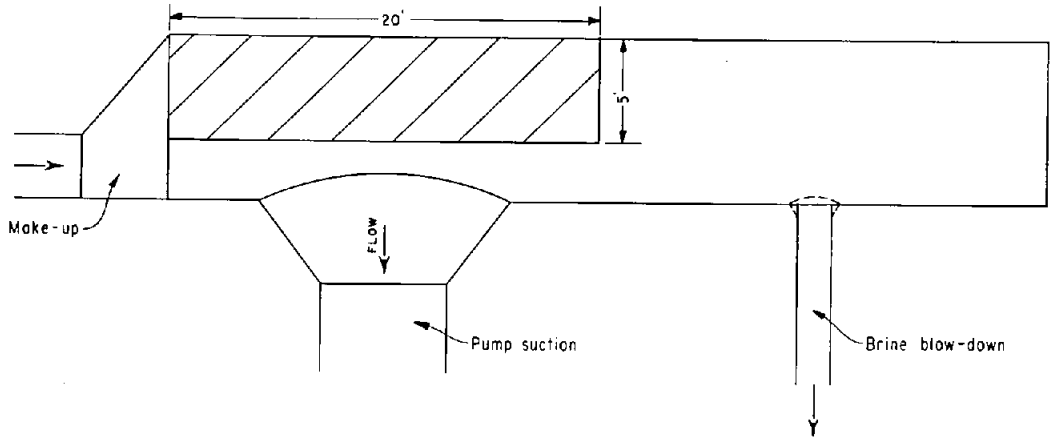


SALINE WATER TEST FACILITY
1:8.93 Scale Model
Modified Design
Manifold Depth = 7 feet
Q = 171.5 cfs
Photo P900-D-65485

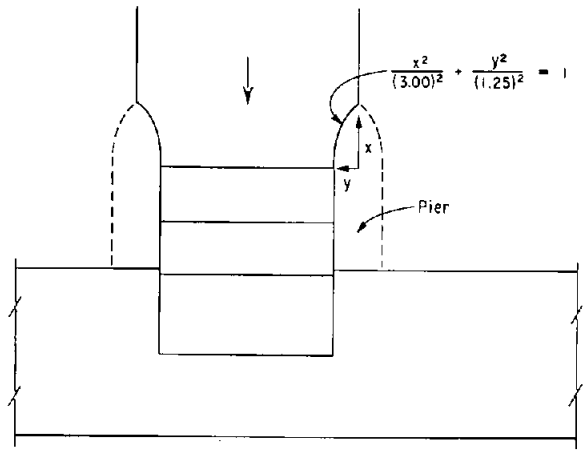
FIGURE 13
REPORT HYD-597



SALINE WATER TEST FACILITY
1:8.93 Scale Model
Modified Design
Manifold Depth = 5 feet
Q = 128.6 cfs
Photo P800-D-65486



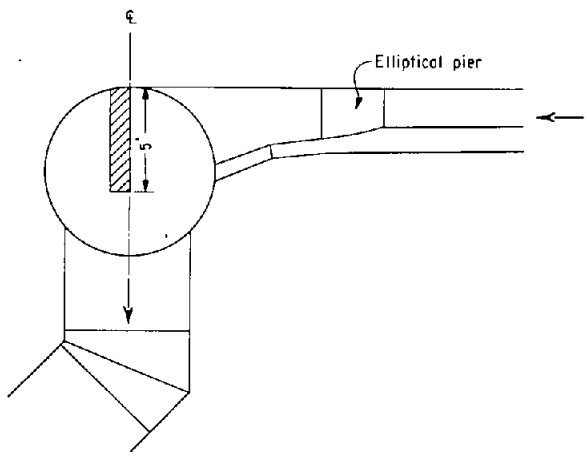
FRONT VIEW OF MANIFOLD SHOWING
TENTATIVE BAFFLE ARRANGEMENT



PLAN VIEW OF TYPICAL TRANSITION SECTION
SHOWING EQUATION OF PIER SHAPE

NOTE

Baffle arrangement shown was effective in eliminating the vortex above the pump suction, but had little effect on air entrainment at the minimum manifold depth.



SECTION SHOWING TENTATIVE
BAFFLE ARRANGEMENT

SAN DIEGO SALINE WATER TEST FACILITY

TENTATIVE MANIFOLD BAFFLE ARRANGEMENT
AND TRANSITION PIER SHAPE

1 : 8.93 SCALE MODEL

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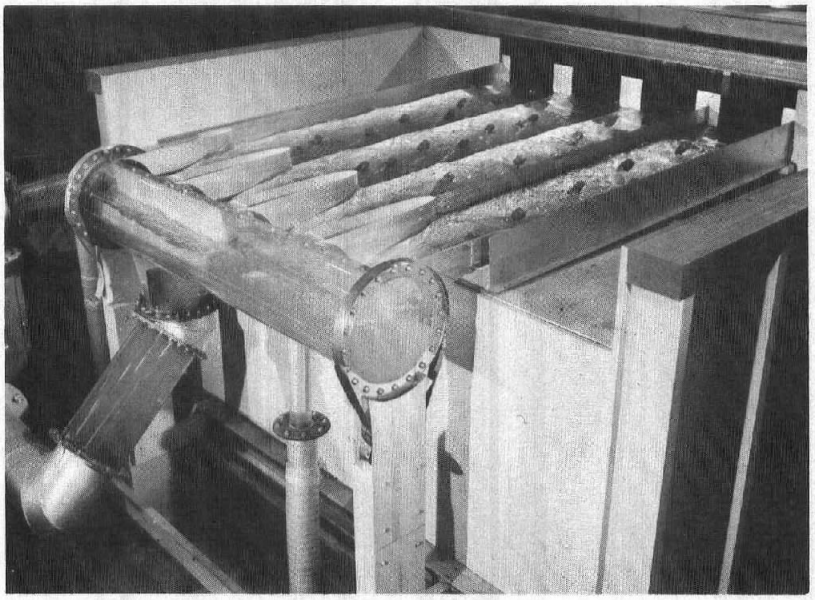
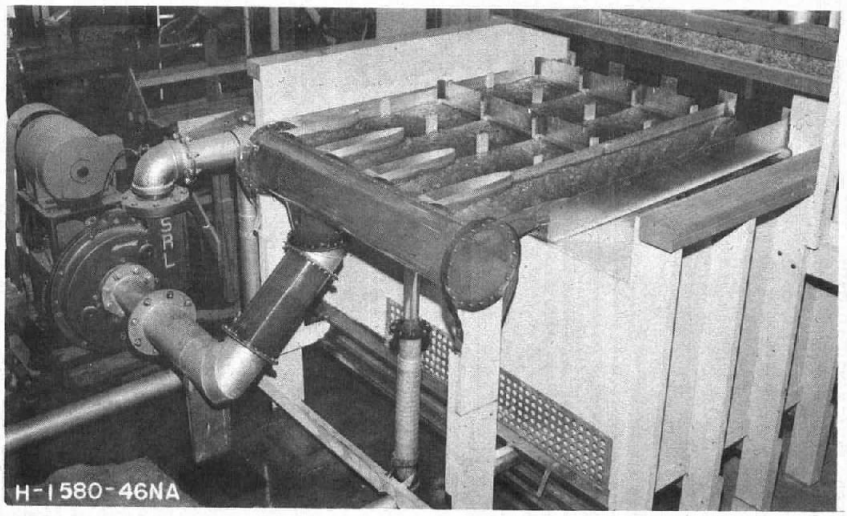
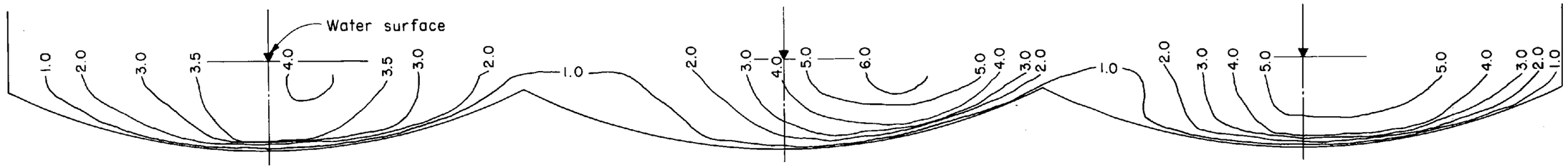
FIGURE 15
REPORT HYD-597



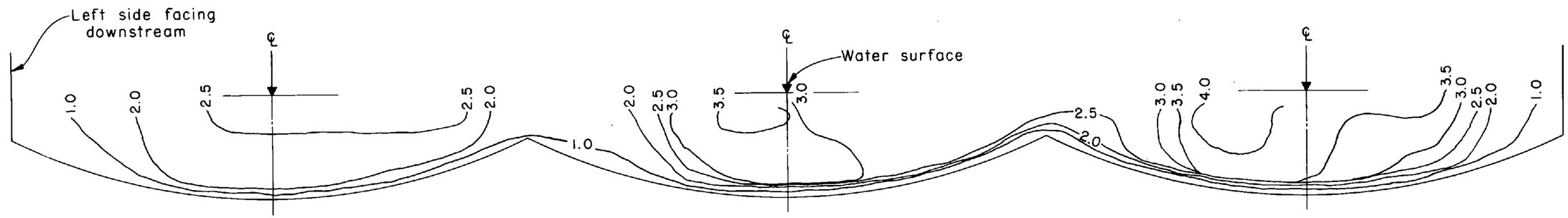
SALINE WATER TEST FACILITY
1:8.93 Scale Model
Flow Conditions with Manifold
Baffle
Manifold Depth = 5 feet
Q = 171.5 cfs
Photo P800-D-65487



SALINE WATER TEST FACILITY
1:8.93 Scale Model
Evaporation Tray Mixing Devices
Photo P800-D-65488



WITHOUT OVERFLOW WEIRS



WITH OVERFLOW WEIRS

NOTES

Discharge = 820,000 #/hr/ft
Orifice Hgt = 16" above invert
Velocities in feet / sec.
Manifold Depth = 7.0'

SALINE WATER TEST FACILITY
1:8.93 Scale Model
Velocity Distribution in
Evaporation Trays
(14 feet Downstream from start
of Stage 9)

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CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

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

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

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

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

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

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ABSTRACT

The San Diego Saline Water Test Facility includes a test module to aid designing a multistage flash distillation desalting plant. The module contains evaporation, collection, and recirculation components. Design of the intake for recirculation pumps required special attention to maintain sufficient net positive suction head on the pumps while operating with a fluid near the flashing point. With improper intake design, vortex formation or water surface drawdown could result in reduction of suction head, cavitation on pump impellers, and severe pump vibration from entrainment of vapor. Tests performed on a 1:8.93 hydraulic model of a pump intake manifold enabled recommendations for several modifications to the preliminary design, alleviating vortex formation and vapor entrainment. Brine mixing devices in the last 2 stages of the evaporation trays were tested for effects on velocity distribution.

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DESCRIPTORS–/ *pump intakes/ centrifugal pumps/ open channels/ velocity distribution/ hydraulic models/ hydraulics/ *model tests/ vortices/ open channel flow/ distillation/ appurtenances/ flash distillation/ desalination
IDENTIFIERS–/ *intake systems & manifolds/ Office of Saline Water/ San Diego Saline Fac, Calif/ multistage flash distill

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