UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

THE SALT LAKE AQUEDUCT MAXIMUM CAPACITY TEST RESULTS PROVO RIVER PROJECT, UTAH

Report No. HYD-585

HYDRAULICS BRANCH
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

AUGUST 1968

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values. A table of conversion factors--BRITISH TO METRIC UNITS OF MEASUREMENT--is provided at the end of this report.

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by
R. B. Dexter

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FOREWORD

The investigation reported herein was a cooperative effort of many persons. Facilities and personnel for assistance in the field measurements were provided by the Central Utah Projects Office, Provo, Utah and the Metropolitan Water District of Salt Lake City (MWD). Mr. C. G. Bargeron of the Projects Office coordinated activities of all parties concerned with the field test. Mr. W. C. Hague, General Manager and Chief Engineer, MWD, arranged for use of MWD personnel and equipment necessary to operate the aqueduct for test purposes. Mr. F. C. Greenwood, Engineer-Superintendent, MWD, applied his knowledge of the aqueduct system to assure maximum benefit from personnel and facilities involved in test activities. R. L. Hansen, Chemical Engineering Branch, provided technical assistance for color-velocity discharge measurements. W. A. Sattler, Mechanical Branch, completed the hydraulic friction computations while on assignment to the Hydraulics Branch. The investigation was coordinated in the Office of the Chief Engineer by personnel of the Canals Branch and Hydraulics Branch.

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ABSTRACT

Field tests were performed on the upstream 32-mi portion of the Salt Lake Aqueduct to determine the safe capacity above the design value of 150 cfs. The section, consisting of 17 reaches of 5.75-ft-dia precast pipe and 6 reaches of 6.5-ft-dia concrete-lined free-flow horseshoe tunnels, safely conveyed 174 cfs. Water surface elevations were measured at 24 open-vent structures and discharges were measured by the color-velocity method. Tables are included of Darcy, Scobey, and Manning coefficients for 16 pipeline reaches and Manning coefficients for 6 tunnels. Friction coefficients indicate excellent hydraulic characteristics of flow surfaces. This was verified by inspecting the tunnels; pipelines were not inspected. Discharge measurement results and coefficients of a 69-in. by 34.5-in. Herschel-type Venturi meter are included.

DESCRIPTORS--/ hydraulics/ *closed conduits/ *tunnel hydraulics/ flow resistance/ *roughness coefficients/ field tests/ surface properties/ Reynolds number/ *discharge measurement/ pipelines/ fluid friction/ *Venturi meters/ Manning formula/ standing waves/ closed conduit flow/ head losses
IDENTIFIERS--/ color-velocity method/ Salt Lake Aqueduct, Utah/ flow measurement/ friction coefficient (hyd)

INTRODUCTION

In connection with studies for supplying municipal and industrial water to the Salt Lake Valley under the Bonneville Unit of the Central Utah Project, the need arose to determine the maximum safe capacity of the upstream 32-mile portion of the Salt Lake Aqueduct. The Regional Director, Salt Lake City, Utah, requested assistance to plan and conduct a capacity test. Personnel and equipment were furnished from the Division of Research to assist the Central Utah Projects Office, Provo, Utah, in accomplishment of the required test measurements which were made in 1966.

The Salt Lake Aqueduct was constructed to divert a maximum flow of 150 cubic feet per second (cfs) from the outlet works stilling basin of Deer Creek Dam, on the Provo River northeast of Provo, Utah, to a terminal reservoir near Salt Lake City for municipal use. The geographical location and route of the aqueduct are shown on Figure 1. The aqueduct was put into service during 1951. Operational experience prior to 1966 indicated that the aqueduct might safely convey appreciably more than 150 cfs. The aqueduct is about 42 miles long and the maximum safe capacity of only the first 32 miles of the system was of concern. A description of components of the aqueduct and pertinent physical characteristics of the components are presented under the subheading "Description of the Aqueduct."

Hereafter, in this report "capacity of the aqueduct" will by synonymous with "maximum safe capacity of the aqueduct."

SUMMARY

Test discharges of 151 cfs, 174 cfs and 185 cfs were used to determine the capacity of the Salt Lake Aqueduct from the headworks to a point downstream of the 6 tunnels in the system. Measurements along the test reach of the aqueduct revealed that the system would safely convey appreciably more than the design capacity of 150 cfs. At a discharge of 186 cfs, the friction head of several inverted siphon pipeline reaches created excessive water depths in tunnel outlet vent structures that resulted in submergence of 4 of the 6 freeflow tunnels. The system safely conveyed 174 cfs. Water surfaces in excess of design gradient elevations, for a discharge of 174 cfs, were of minor magnitude and occurred only at the first 2 vent structures in the system where freeboard is not critical.

Analysis of hydraulic data obtained during the 3 test discharges revealed that hydraulic frictional resistance of the precast concrete pipeline reaches and concrete lined tunnels in the aqueduct were in a low range that could only be provided by excellent flow surfaces. The excellent quality of flow surfaces in the tunnels and vent structures was confirmed

by inspection, but the pipelines were not drained for examination. The high quality of flow surfaces and design characteristics of structures contributed to the ability of the aqueduct system to safely convey about 25 cfs more than the design discharge.

APPLICATIONS

The direct application of reported results may be the future utilization of a portion of the Salt Lake Aqueduct to transport water quantities in excess of the original design capacity. This extra capacity will be beneficial when the time arrives to deliver Central Utah Project water to Salt Lake County, Utah. The low frictional resistance of pipelines and tunnels in the aqueduct show that construction practices may provide better flow surfaces than can reasonably be anticipated in design and that age does not necessarily decrease the high quality of flow surfaces. The overall satisfactory operation of aqueduct components could encourage consideration for use of similar components in the future. The consistency of test results is encouraging and provides confidence for future use of field test methods and equipment employed for this investigation. A research program for determination of hydraulic characteristics of existing pipelines and tunnels will benefit from the results of this study.

FIELD MEASUREMENTS

Description of the Aqueduct

The 32-mile long reach of the aqueduct that was tested for maximum capacity extended from the headworks at Deer Creek Dam stilling basin to the third vent structure downstream of Alpine-Draper tunnel. When the aqueduct is used to deliver Central Utah Project water to Salt Lake County, delivery of this water will be made at or near the upstream end of Alpine-Draper Tunnel. Figure 2 is a schematic profile of the tested portion of the aqueduct. This portion of the single conduit system contains 6 concrete-lined, free-flow tunnels. All of the tunnels have a horseshoe section diameter of 6.5 feet, invert slope of -0.0008, design flow depth of 5.36 feet for a discharge of 150 cfs.

Vent structures are located at tunnel portals and at high points along the aqueduct where the pipeline approaches the design hydraulic gradient and where, for partial flows, the hydraulic gradient falls below the crown of the pipe. A typical vent structure located in series with siphons is shown by Figure 3, and a vent structure at a tunnel portal is shown by Figure 4. The vent structures divide the aqueduct into inverted siphons in series with the six tunnels as indicated by Figure 2. The cross section dimensions of the tunnels are shown by Section F-F, Figure 4.

The siphon pipelines and two constant slope pipelines, were constructed of 69-inch inside-diameter precast concrete pipe sections with bell-and-spigot joints except steel pipe was installed at locations where the hydrostatic head exceeded 165 feet. The annular grooves at bell-and-spigot joints inside the pipelines were filled with hand tamped mortar and the mortar was trowled smooth during construction of the pipelines. The steel pipe has an inside diameter of 70 inches, welded longitudinal and girth joints, and the flow surfaces are coated with coal tar enamel. Steel pipe portions of inverted siphons are identified in Table 4 in connection with hydraulic friction coefficients of the pipelines.

Hydraulic Gradient Measurements

The maximum capacity test of a portion of the aqueduct afforded the opportunity to measure water surface elevations in vent structures, during steady flow conditions, with reference to a common datum as opposed to measurement of freeboard only in the vent structures and tunnels. These water surface elevations, along with accurate measurement of discharge and known physical features of the inverted siphons and tunnels, were used to compute hydraulic characteristics of the system. This information, especially hydraulic friction coefficients of siphons and tunnels and depth of flow in tunnels, provided a basis for interpolation of the capacity of the aqueduct. This procedure eliminated numerous tests that would have been required to determine the maximum capacity of the aqueduct.

During steady flow conditions with 3 different discharges, water surface elevations were manually measured and recorded with respect to an established benchmark at all except one vent structure in the test reach. Measurements were not practical at the Station 357+30 vent structure between Tunnels No. 3 and No. 4. This vent structure was enclosed except for a vertical rectangular opening on the side that was covered with a nonremovable screen. This structure was observed by listening and looking through the side screen while the aqueduct was carrying 185 cfs and the water surface was not close to the bottom of the screened opening. Since 185 cfs is in excess of the capacity of the aqueduct, sufficient freeboard would exist in this structure for smaller discharges.

In addition to water surface elevation measurements in the vent structures, depths of flow were measured inside Alpine-Draper Tunnel with two Prandtl-type static-head probes. To avoid water-depth fluctuations immediately downstream from the transition at the tunnel inlet, the upstream water depth probe was located 117 feet downstream of the tunnel inlet transition where water surface marks on the tunnel lining indicated the water surface was free of waves. A downstream static-head or water depth probe was installed 66 feet upstream of the tunnel outlet transition to avoid water surface drawdown at the tunnel outlet. Pressure tranmission tubes were extended from each probe to a manometer at each end of the tunnel. These pressure-head probe installations are shown by Figure 5.

Color Velocity Method Discharge Measurements

The color-velocity method provides a fast and economical means of discharge measurements in long pipelines. This method is based upon the phenomenon that a slug or cloud of tracer injected into a conduit will travel at the mean velocity of the transporting medium provided two requirements are fulfilled. These requirements are; that there is not a significant difference in specific gravity of the tracer and the transporting medium, and that the flow path is long (hundreds of pipe diameters) so the length of the flow path required to accomplish lateral diffusion of the injected tracer over the flow cross section is short compared to the total length of the flow path. Also, a long flow path will provide a long tracer flow time so the effect of a small time error will be minimized. Water soluable dyes, with good fluorescence properties, can be used in quantities so small that a suitable tracer cloud has essentially the same specific gravity as the transporting water. A nontoxic dye, Pontacyl Brilliant Pink, was used in the aqueduct and 47 to 54 grams of dye, dissolved in water, was poured into the flow for each discharge measurement. Fluorometers, which have become available in recent years, that can detect very low concentrations of dye traces and produce an electrical signal proportional to dye concentraction have provided the final link for practical application of the color-velocity method of discharge measurements.

The numerous long inverted siphons along the aqueduct, with open vent structures at both ends where dye could be injected and sampled, provided excellent facilities for color-velocity discharge measurements. While plans for the capacity test were being made, it became apparent that the discharge should be measured near both the upstream end and downstream end of the test reach in the event there was a significant loss of water in this 32-mile long section of the aqueduct. Upstream and downstream discharge measurements were made additionally desirable by the location of the longest tunnel in the system near the downstream end of the test reach and by the operational Venturi meter installation at the upstream end of the system. In the event the tunnel proved to be the limiting structure for maximum capacity, it would be beneficial to know the discharge at the tunnel. The upstream discharge measurement could be used to check the accuracy of the Venturi meter at Station 2+90. Also independent discharge measurements at two locations would reinforce the validity of the measurements.

The two pipeline reaches used for discharge measurements are indicated on Figure 2. The upstream reach extended from Station 49+00 to Station 98+21 (upstream headwall of the Station 98+29 vent structure). The downstream discharge test reach consisted of a single inverted siphon from Station 1523+60 to Station 1641+00. The color-velocity dye solution was poured into the flowing water at the upstream end of the test reach, and a "zero" time signal was transmitted to the fluorometer operator by radio. At the downstream end of the test reach, a sample of the aqueduct water was continuously pumped through the fluorometer. As a dye cloud passed, the output signal of the fluorometer was used to operate an electrical recorder that produced an analog trace of dye concentration with respect to time.

The dye cloud flow time was taken as the elapsed time from injection of the dye to the peak of the cloud at the sampling station as illustrated by Figure 6. This flow time was corrected by subtraction of the time required for the pumped sample of water to travel from the aqueduct to the fluorometer at the sampling site. The aqueduct discharge was computed by dividing the pipeline test reach volume, in cubic feet, by the corrected flow time, in seconds.

The volume of the downstream color-velocity test reach was composed of 9,670 lineal feet of 69-inch inside diameter concrete pipe and 2,180 lineal feet of 70-inch inside diameter steel pipe. The upstream test reach contained 4,932 lineal feet of 69-inch concrete pipe. The nominal diameters of these pipelines were used to compute volumes. A portion of the upstream test reach pipe was not full during the 151 cfs and 174 cfs tests and the volume of the pipeline was decreased for the computation of discharges. The volume of pipe not filled was determined from measured water surface elevations and pipe slope. Individual and average discharge measurement results are listed in Table 1.

Calibration of Venturi Meter at Station 2+90

A Herschel-type or long-form Venturi meter, located immediately downstream of the aqueduct headworks at Station 2+90 is used to establish the desired discharge in the aqueduct. The characteristics of this type Venturi meter are long, small-angle inlet and exit cones, and high coefficient of discharge values. Details of the meter, which is a reinforced concrete monolithic structure, are shown by Figure 7. The meter discharge, in cfs, was continuously recorded on a circular chart and indicated by a pointer and scale.

Prior to the aqueduct capacity test, the Venturi meter was unwatered and the flow surfaces of the brass inlet and throat rings and adjacent concrete were cleaned. The differential pressure head piping and piezometer openings in the brass rings were back flushed. Four diameter measurements were made with an inside pipe caliper near the plane of the piezometer taps in the inlet and throat rings.

A two tube water column manometer, with both tubes open to the atmosphere, was connected to the Venturi meter piping for measurement of differential head. The diameters measured inside the meter, differential head readings, flow chart record, flow indicator readings and discharge measurements by the color-velocity method provided all the information needed to determine the accuracy of the meter readout system and to determine meter discharge coefficients.

MAXIMUM CAPACITY RESULTS

Freeboard In Vent Structures and Tunnels

The aqueduct was operated at three discharges for test purposes. During steady flow conditions, discharge measurements were made by the color-velocity method at the two locations discussed above. Individual and average discharge measurement results are shown in Table 1. Discharge measurements at the upstream location were consistently larger, by small amounts, than those measured at the downstream location. A major portion of these differences can be attributed to water loss along the 27 miles of the aqueduct system between discharge measurement sites. However, no visible loss of water was discovered except minor splashes out of vent structures during the test at 185 cfs.

Averages of upstream and downstream discharge measurements, Table 1, rounded off to the nearest whole cfs result in discharges of 151 cfs during the first test, 185 cfs during the second test, and 174 cfs during the third and last test.

Data recorded during the 151 cfs aqueduct operation revealed that the system would safely convey a significantly larger discharge. Water surface elevation measurements and visual observations revealed that the inlet ends of the siphons were not full, the water was flowing above critical velocity as it left the vent structures and flowed down into the siphons, and hydraulic jumps existed in the sloping pipes. This condition precluded measurement of friction heads across any of the siphons that could have been used to compute capacity of the siphons within design head limits.

Water surface elevations in vent structures at both ends of all tunnels indicated that the flow depths in the tunnels were 1-foot or more below design depth with the 151 cfs flow. Also, excellent correlation between water surface elevation in the vent structure at the Alpine-Draper tunnel inlet and the water surface elevation measurement with the depth of flow probe inside the tunnel revealed that the measurement in the vent structure was a very good indication of the water surface elevation inside the tunnel. The measurement in the vent structure showed the water surface to be 1.0 foot below design depth at the tunnel inlet portal and the probe measurement showed a corresponding difference of 1.1 feet below design depth at the probe.

A summary of water surface elevations in vent structures is presented in Column 5, Table 2. Freeboard values for all structures in the test reach, except the Station 357+30 vent, are tabulated in Column 4, Table 2. These freeboard values are the vertical distance from the water surface to the top of the vent structure walls, that is, to the height at which water would spill from the structure. Water surface elevations were not measured at Station 357+30 because of the enclosed box-type design of this structure that was provided to withstand potential rockslides. Visual and sound observations were made at the screen covered opening in this structure and there was no indication of lack of freeboard during any of the test discharges.

The freeboard values in Column 4, Table 2 show that there was more than 6 feet of freeboard in all vent structures, except at Station 1706+10 at the downstream end of the test reach, for a discharge of 151 cfs. The water surface elevation at this location was controlled by the depth of flow over the vertical standpipe overflow at Station 1746+60 which is the next freeflow structure downstream of Station 1706+10. The depth of flow over the top of the standpipe was a function of the amount of water turned out to a water treatment plant immediately downstream of the standpipe. During the 151 cfs test, nearly all the flow in the aqueduct was passing over the top of the standpipe and this increased the head in the Station 1706+10 vent structure. During the other two tests at larger discharges, less flow occured out of the vertical standpipe. Since this portion of the aqueduct was downstream of the portion considered for additional capacity, the only concern here was to maintain reasonable freeboard in the Station 1706+10 structure by control of the head over the downstream standpipe.

Design hydraulic gradient elevations at all freeflow structures are listed in Column 6, Table 2. At locations where vent structures are common with tunnel inlets and outlets, the tabulated design hydraulic gradient elevation is the design water surface elevation at the tunnel portal which is within a few feet, horizontally, of the vent structure. Because of the close agreement between water surface elevations measured inside Alpine-Draper tunnel and in the inlet vent structure, the test water surface elevation, Column 5, Table 2, can be compared with the tunnel portal design water surface elevation, Column 6, to show that water surfaces were well below design for a discharge of 151 cfs. Water surface drawdown existed in the vent structure at tunnel outlets and water surface elevation measurements were made at the upstream end of these vents to minimize this effect and to obtain a measurement representative of the tunnel portal water surface elevation.

The only location where the measured water surface elevation exceeded the design value was in the Station 1+95 vent structure just upstream of the Venturi meter. The water surface elevation at this point is a function of the head required to maintain a given discharge through the meter and this tall structure did not present any problems during any of the test discharges.

Information obtained during the second test with a discharge of 185 cfs conclusively showed that the aqueduct would not safely carry this flow. This discharge was the computed capacity at design depth of Alpine-Draper Tunnel; the computation was based upon the hydraulic gradient slope measured in the tunnel during the 151 cfs test. The tunnel discharge was 146 cfs due to a 6 cfs turnout delivery upstream of the tunnel. However, with a discharge of 185 cfs, it became evident that the friction heads of some of the siphon pipelines would be the factor that controlled the maximum capacity of the aqueduct. The pressure head required to force 185 cfs through several of the siphons created excessive water surface elevations at four of the six tunnel outlet vent structures. As water surface elevations increased in these vent structures, the outlets of the tunnels became submerged then backwater progressed upstream through the tunnels and the tunnel inlets also became submerged. As a consequence, Tunnels No. 1, 2, 3, and Alpine-Draper were submerged and operated as pressure conduits during the 185 cfs test. Freeboard in six vent structures was 2 feet or less with a minimum of 0.5 of a foot in the Station 1369+63 structure at the outlet of Alpine-Draper Tunnel. With freeboard of 2 feet or less, water occasionally splashed out of the vent structures due to turbulence but there was no sustained overflow in the test reach.

During the 185 cfs test, the depth of water was sufficient in all vent structures to submerge the inlet and outlet pipes. This condition afforded the opportunity to measure the hydraulic gradient of each pipeline reach. The hydraulic gradient of the siphons that created excessive depths at the siphon inlets and the test discharge of 185 cfs were used to compute the discharge that each siphon might carry within limits of design hydraulic gradient slope. These computations indicated a maximum safe capacity of about 170 cfs.

The third test was performed with a discharge of 174 cfs. Comparison of measured water surface elevation, Column 5, Table 2, and design hydraulic gradient elevation, Column 6, show that with the exception of the Station 1+95 vent structure all measured elevations were at or below the design values. The measured elevations show a minimum freeboard value of 5.3 feet at Station 80+20 except in the structures at Station 1641+00 and Station 1706+10 where the freeboard values were 3.8 feet and 3.6 feet, respectively. Here again these minimum freeboard values were influenced by the flow out of the vertical standpipe at the downstream end of the test reach and these structures are downstream of the portion of the aqueduct under consideration for maximum safe capacity.

Two pipeline sections of the aqueduct were constant slope reaches. One of these reaches extended from Station 10+04 to Station 49+00 and was designed for freeflow; measurements showed that water surface elevations were at or below design hydraulic gradient values in this reach for a discharge of 174 cfs. The other constant slope reach extended from the wasteway structure at Station 64+79 to the vent at Station 80+20, and water surface elevations at both ends of this reach were below design values with a discharge of 174 cfs. Therefore, the water surface was well below the wasteway crest at Station 64+79.

Of particular importance were the water surface elevations at all tunnel inlets during the 174 cfs flow. Comparison of values in Columns 5 and 6, Table 2, show the water surface elevations were below design value at all tunnel inlet portals for flow of 174 cfs. However, standing waves at tunnel inlets, described below, tended to decrease the apparent freeboard. All test measurements made during flows of 151 cfs, and 174 cfs revealed the water surface slope in all tunnels to be greater than the design slope of -0.0008 so the freeboard below design water surface at tunnel outlets was greater than at tunnel inlets.

Standing Waves at Tunnel Inlet Portals

A hydraulic phenomenon of significance occurred at the tunnel inlet portals in the form of standing waves created by recovery of velocity head as the flow passed from a vent structure into a horseshoe-shaped tunnel. This phenomenon is shown by the photographs of the entrances of Tunnels No. 1 and 2, Figure 8. The photographs were taken the day after the 151 cfs test, and examination of all tunnel inlets revealed similar conditions. The first wave crest in the high-water mark occurred immediately upstream of the horseshoe flow section. The wave had an amplitude, peak to trough, of about 12 inches and a crest-to-crest wave length of about 3 feet at the tunnel portals. These remarks pertain to the high-water marks in the photographs of Figure 8; the pattern of darker, lower elevation, water marks in the photographs was influenced by drying of the concrete flow surfaces at the tunnel inlets where water was in contact with the flow surfaces during a discharge of 151 cfs the day prior to exposure of the photographs. The discharge that created the high-water mark is not known.

Although water-surface elevation measurements in tunnel inlet vent structures, during a discharge of 174 cfs, indicated freeboard below all tunnel inlet design water-surface elevations, the standing waves at the inlet portals diminished the apparent portal freeboard. The test results for a discharge of 174 cfs show that the crest of a wave with an amplitude of 1 foot above the water-surface elevation in the tunnel inlet vent structure would encroach a maximum of 0.55 of a foot on the design freeboard of the Alpine-Draper Tunnel inlet. Corresponding wave peak encroachment upon design freeboards would be less than 0.55 of a foot at all other tunnel inlet portals.

Consideration of Flow Surface Conditions

Initial operation of the aqueduct occurred in 1951. A tabulation of cleaning operations of the test reach from Station 10+04 to the inlet of Alpine-Draper Tunnel, furnished by the Central Utah Projects Office, is contained in Table 3. This information reveals that no cleaning operations were performed downstream of Station 10+04 after 1959, thus 7 years elapsed between the last cleaning operation and the year in which the test being reported was performed. The 69-inch diameter concrete pipe reach from the Venturi meter at Station 2+90 to Station 10+04 was hand cleaned in 1966 prior to the capacity test.

The water surface elevation at Station 1+95, upstream of the Venturi meter, was the only location along the test reach where the water surface was up to design hydraulic gradient elevation for a discharge of 151 cfs. The hydraulic gradient at this location is controlled by the head required to force a given discharge through the Venturi meter, but freeboard in the Station 1+95 vent and access structure is not a problem because the top of the structure is above the intake water surface.

Flow surfaces of pipeline reaches were not examined prior to the capacity test except for areas that were exposed adjacent to vent structures when the tunnels were unwatered for inspection prior to the test. The inverted siphon pipeline reaches were not drained and the opportunity to inspect the two constant slope reaches near the upstream end of the aqueduct had to be passed because of time limitations. However, the concrete pipe flow surfaces that were observed adjacent to vent structures appeared similar to the tunnel flow surfaces in regard to smoothness and freedom from significant deposits.

All 6 tunnels in the aqueduct test reach were unwatered and inspected throughout their entire lengths prior to the capacity test. The only material on the tunnel flow surfaces was a dark brown, slick (when wet) film, where water had been in contact with the concrete flow surfaces. This film was tenaciously bonded to the concrete and could appropriately be considered a stain as opposed to an accumulation of any significant thickness. The extreme slickness of this wet film hindered walking on the slight circular arc slope adjacent to the tunnel invert. This film possibly presented less frictional resistance to the flow of water than a clean concrete surface.

The concrete lining in all tunnels was essentially in "as built" condition and the quality of the flow surfaces was excellent as illustrated by the photograph of Figure 5A. The excellent quality of concrete and concrete workmanship; that is, high strength, lack of spalling, minimum form offsets and minimum air voids on flow surfaces in pipelines, tunnels, and vent structures of this system is well known by persons familiar with the aqueduct.

Apparently frequent cleaning of the aqueduct pipeline reaches and tunnels has not been necessary because the system conveyed 174 cfs down to the standpipe wasteway at Station 1746+60 within the limits of design hydraulic gradient elevations established for a discharge of 150 cfs. The only exception was the water surface elevation in the Station 1+95 vent structure at the headworks. There evidently has not been any significant deterioration of flow surfaces to creat undue hydraulic frictional resistance. Gaseous state chlorine is injected into the aqueduct flow at the Station 2+90 Venturi meter to control bacterial organisms and this possibly inhibits accumulation of other organisms. There were no filamentatious type growths in evidence on any of the flow surfaces.

<u>Operational Procedures and Related Observations</u>

Designers' Operating Criteria instructions for the aqueduct were followed to establish test discharges in the system and no difficulties were experienced. Discharges larger than 150 cfs were established by flow rate increases of 3 cfs per hour.

The three air vent pipes at siphon inlets with long, relatively steep inlet reaches, shown by Figure 3, performed their intended function satisfactorily during all test operations of the aqueduct. A hydraulic jump formed down inside the 69-inch entrance pipe of the siphons while test discharges were being established. Air entrained in the jump was effectively released through the vent pipes and prevented any appreciable air blow-back in the 69-inch aqueduct pipe. As a hydraulic jump progressed upstream during flow increases, one or two vent pipes released air and occasional spurts of water. The small quantities of water expelled from the vent pipes fell down into the vent structure without consequence.

RESULTS OF HYDRAULIC ANALYSES

Friction Coefficients of Concrete Pipelines

Friction coefficients of pipeline reaches, computed from test data and design diameter and slope lengths of the lines, are shown by Columns 3, 4, and 5, Table 4. These coefficients for pipelines could be computed only for the test discharge of 185 cfs when the pipe reaches were full and the effective head on each pipeline could be measured.

The following equations were used for computation of the friction coefficients:

(1) $$f = \frac{H_f\ D}{h_v\ L}$$

where f = Darcy coefficient
H_f = measured friction head (feet)
L = length of pipe (feet)
D = pipe diameter (feet)
h_v = velocity head in the pipe (feet)

(2) $$Cs = \frac{Q}{0.00546\ d^{2.625} H^{0.5}}$$

where C_s = Scobey coefficient
Q = discharge (cfs)
d = pipe diameter (inches)
H = friction head per 1,000 feet of pipe (feet)

(3) $$n = \frac{1.486}{V}\ r^{2/3}\ s^{1/2}$$

where n = Manning coefficient
V = average velocity in the pipe (feet per second)
r = hydraulic radius (feet)
s = energy granient slope

The friction coefficients in Table 4 indicate exceptionally low resistance pipelines. The exception to this statement is the friction coefficient for the 1,600-foot-long pipe between the vent structure at Station 49+00 and the combination vent and wasteway structure at Station 64+79. The wasteway structure inlet includes a circular to square transition that would create a small head loss (all other vent structures have a semi-circular invert that is alined with the lower one-half of the inlet pipe), but not enough to account for an overall friction loss of 1.85 feet per 1,000 feet of pipe in this reach compared to an average of 1.52 feet per 1,000 feet for all other pipeline reaches at a discharge of 185 cfs.

The Reynolds number of the pipelines was 3.15×10^6 for a discharge of 186 cfs. The Darcy "f" value for smooth pipe, at a Reynolds number of 3.15×10^6 is 0.0097 on the Moody diagram. The average "f" value of 0.0111 for the aqueduct pipelines indicates very smooth precast concrete pipelines.

A comparison of the average Scobey coefficient of 0.409, for the aqueduct pipeline reaches, with Mr. Scobey's initial, or early publication of his studies of friction coefficients for concrete pipelines is worthwhile.[1/] Mr. Scobey developed Equation (2) as the result of head loss measurements of 41 different concrete pipelines that ranged from 8 inches to 216 inches in inside diameter. Although the publication by Mr. Scobey contains results in which the values of "C_s" exceed 0.400, he concluded that a "C_s" value of 0.370 should be used for design of concrete pipelines even when construction practices necessary to provide the smoothest possible flow surfaces could be anticipated. To quote from page 8 of the publication by Mr. Scobey:

> "A few of the pipes upon which experiments were made appear to have coefficients higher than 0.370, but the writer wishes to be conservative in recommending a coefficient that necessitates a surface so nearly ideal. That is to say, a better surface may be attained in construction than should be anticipated in design."

The average C_s value of 0.409 for the Salt Lake Aqueduct pipeline reaches indicates excellent construction results. These 69-inch inside-diameter pipelines were constructed of 20-foot long precast sections with bell and spigot joints. The inside surfaces of the pipe sections were cast against oiled steel forms and the form joints were in the longitudinal direction only; that is, parallel to the flow of water in the pipe. Specifications for manufacture of the pipe sections required that a special tool be worked up and down next to the form until the coarser material was forced back and a layer of mortar brought next to the form. When the pipelines were constructed, not more than a 1/8-inch offset of flow surfaces at joints was allowed, and the annular groove at each bell and spigot joint was filled with hand-tamped mortar and the mortar was troweled smooth. The above requirements evidently provided extremely smooth and practically continuous flow surfaces in the pipelines as indicated by low Darcy and Manning coefficients and a high Scobey coefficient.

All of the pipeline reaches contained horizontal bends of either 200-foot or 400-foot radius. All, except two reaches, contained small-angle vertical bends. These two constant slope reaches are indicated on Figure 2. The largest angle vertical bends are in the pipeline reach that crosses the Provo River between the outlet

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1/Fred C. Scobey, the Flow of Water in Concrete Pipe, United States Department of Agriculture Bulletin No. 852, October 28, 1920 of Tunnel No. 4 and the inlet of Olmstead Tunnel. Bend losses were evidently not an appreciable factor in pipeline head losses as evidenced by the low frictional resistance of the lines.

To verify that the friction coefficients that resulted from test measurements are not a product of erroneously high discharge measurements, an examination of discharge measurements and related discharge coefficients of the Venturi meter was made.

Venturi Meter Accuracy and Discharge Coefficients

The equation for Venturi meter flow is:

$$Q = \frac{CA_1A_2}{(A_1^2 - A_2^2)^{1/2}} (2g\ \Delta h)^{1/2}$$

where Q = discharge (cubic feet per second)
C = coefficient of discharge
A_1 = inlet area (square feet)
A_2 = throat area (square feet)
g = gravitational acceleration constant = 32.14 feet per second squared at the test site
Δh = differential pressure head in feet of flowing fluid

Four inside-diameter measurements were made at the inlet pressure ring and at the throat pressure ring of the Station 2+90 Venturi meter. These measured diameters and averages have been entered on Figure 7. The average diameters and A_1 and A_2 values are:

average diameter at inlet pressure ring = 5.750 feet
A_1 = 25.97 square feet

average diameter at throat pressure ring = 2.874 feet
A_2 = 6.487 square feet

Therefore,

$$C = \frac{Q(A_1^2 - A_2^2)^{1/2}}{A_1A_2(2g\,\Delta h)^{1/2}} = 0.01861 \frac{Q}{\Delta h^{1/2}}$$

The discharges measured a short distance downstream of the meter by the color-velocity method, water manometer differential head values, and computed Venturi meter discharge coefficients are:

Q (cfs)	Δh (ft)	C
151.9	8.20	.0987
174.1	10.75	.0988
186.2	12.48	.0981

The Venturi meter had a throat to inlet diameter ratio of 0.500. The Reynolds number at the meter throat for all the discharges shown above was in excess of 4×10^6 or well into the turbulent flow-range. An authorative reference[2/] reveals that a Herschel-type Venturi meter of the size under discussion, constructed of cast iron, would have a turbulent flow-range discharge coefficient of 0.99. The concrete flow surfaces in the Station 2+90 Herschel-type Venturi meter were smooth and in excellent condition and the 4-foot radius tangential curved surfaces at both ends of the throat section were well formed and uniform. It would be reasonable to expect that this Venturi meter would have a turbulent flow-range coefficient very close to 0.99. The three discharge coefficient values tabulated above, based entirely upon test data obtained during the aqueduct capacity test are in good agreement with the expected discharge coefficient of this Venturi meter. This agreement of discharge coefficients verifies that the test discharge measurements were of sufficient accuracy to serve as a basis for pipeline and tunnel friction coefficients.

Comparison of test discharges measured at the upstream color-velocity site and discharges shown by the Station 2+90 Venturi meter readout system can be made with the results shown in the bottom three lines of Table 1. The meter recorder-chart and indicator values were both low by small amounts, except the indicator overregistered slightly during a discharge of 186 cfs.

Friction Coefficients of Tunnels

Manning friction coefficients for the six concrete lined, free-flow, horseshoe cross section tunnels, with nominal diameter of 6.5 feet, are shown in Table 5. The Manning coefficients were computed with equation (3).

Depth of flow at each tunnel inlet and outlet were used to determine an average depth of flow in a tunnel and the hydraulic radius and average

2/A. L. Jorrissen, Discharge Coefficients of Herschel-Type Venturi Tubes, and discussion by W. S. Pardoe, Transactions of the ASME, Volume 74, August 1952 velocity were determined from average depth for the horseshoe section. Velocity head at water surface elevation measuring points at each end of the tunnels was added to the measured water surface elevations to arrive at energy gradient elevations. The values of energy gradient slopes were taken as the difference in energy gradient elevations divided by the invert slope length between water surface measurement points.

The Manning "n" values of the tunnels range from 0.0105 to 0.0112 and average 0.0108 for a discharge of 151 cfs and average 0.0105 for a discharge of 174 cfs and indicate exceptionally low-resistance flow surfaces in the tunnels. The Manning "n" values of 0.0106 and 0.0105, based upon water depths measured with pressure-head probes inside Alpine-Draper Tunnel, spaced 14,857 feet apart, can be considered as the most reliable frictional resistance coefficients for the tunnels. The discharge through Alpine-Draper Tunnel was 145 cfs during the lowest test discharge, because 6 cfs was turned out upstream of the tunnel. By way of comparison the design Manning "n" values for all the tunnels was 0.014 for a discharge of 150 cfs. The excellent quality and slickness of the tunnel flow surfaces are described under the heading "Consideration of Flow Surface Conditions."

Conclusions

A maximum capacity test of the Salt Lake Aqueduct, from the headworks to the standpipe overflow at Station 1746+60, was performed with discharges of 151 cfs, 174 cfs, and 185 cfs. The design capacity of this system is 150 cfs. Data necessary to document hydraulic performance of this system were obtained under steady flow conditions with each test discharge. Test discharges were measured at two widely separated locations in the test reach of the aqueduct by the color-velocity method. The discharges measured near the operational control Venturi meter and corresponding measured differential heads of the meter resulted in discharge coefficients for the meter that agreed with the established coefficient for this particular type of Venturi meter. This agreement would not have resulted from inaccurate discharge measurements. Water surface elevation measurements and observation throughout the test reach revealed that the system would safely convey appreciably more than 151 cfs. A second test with a discharge of 186 cfs resulted in submergence of four of the six free flow tunnels due to backwater created by inverted siphon pipeline reaches. The tested portion of the aqueduct safely conveyed 174 cfs within the limits of design hydraulic gradient at all water surface locations as far downstream as the Station 1706+10 vent structure with two minor exceptions. These exceptions were the first two vent structures in the system at Station 1+95 and Station 10+04 where freeboard is not critical.

The flow surfaces in the six free-flow horseshoe tunnels were examined and found to be in excellent condition and of a nature to provide minimum resistance to flow. The inside of pipeline reaches were not examined but analysis of test data revealed that the hydraulic friction coefficient of both the tunnels and pipelines were in a range that would result only from uniform flow surfaces in excellent condition. Absence of energy dissipation-type turbulance in the 24 vent structures of the system undoubtedly contributed to the ability of the system to convey 174 cfs without creation of any problems.

The system conveyed 174 cfs even though cleaning of the pipeline reaches upstream of Alpine-Draper Tunnel was discontinued after 1959. From the viewpoint of practical operational considerations of the tested portion of the aqueduct, a discharge of 175 cfs would not be distinguishable from the 174 cfs used for test purposes.

TABLE 1

The Salt Lake Aqueduct
Maximum Capacity Test - 1966
Discharge Measurement Results

Color velocity measurements	Discharges in second-feet First test	Second test	Third test
Upstream Sta. 49+00	152.0	185.6	174.0
to Sta. 98+20	151.8	186.7	174.2
		186.4	174.2
Upstream average	151.9	186.2	174.1
Downstream Sta. 1523+60	*150.4	184.3	173.3
to Sta. 1641+00	*150.6	183.6	173.1
Downstream Average	*150.5	184.0	173.2
Average of upstream and downstream	151.2	185.1	173.7
Venturi Meter at Sta. 2+90			
Recorder	148.	185.	170.
Indicator	150.	187.	172.
Color velocity, upstream	151.9	186.2	174.1

*6.0 cfs added to measured discharge to compensate for metered turnout delivery at Sta. 551+18.

TABLE 2

The Salt Lake Aqueduct - Provo River Project
Maximum Capacity Test - 1966
Freeboard in Vent Structures and at Tunnel Portals

Feature 1	Aqueduct station 2	Discharge (cfs) 3	Freeboard (feet) 4. (A)	Test water surface elevation 5	Design hydraulic gradient elevation 6 (B)	Remarks
Vent and access	1+95	151	15.1	5270.95	5270.89	
		174	13.8	72.25		
		185	11.2	74.80		
Vent	10+04	151	17.8	5268.20	5268.69	
		174	17.2	68.74		
		185	14.7	71.33		
Vent	49+00	151	8.1	5261.56	5263.00	
		174	8.3	61.41		Test w.s. questionable
		185	3.7	65.97		
Wasteway	64+79	151	2.2	5258.68	5260.65	Freeboard below wasteway crest.
		174	1.3	59.60		
		185	-2.3	63.22		Crest blocked.
Vent	80+20	151	7.0	5255.45	5258.40	
		174	5.3	57.16		
		185	1.7	60.71		
Vent and Tunnel No. 1 inlet	98+29	151	6.5	5254.25	5255.63	
		174	6.1	54.63	(B)	
		185	2.7	58.02		Tunnel submerged at 185 cfs

(A) Freeboard: Vertical distance from water surface to elevation at which water would spill.
(B) At tunnel inlet and outlet the design hydraulic gradient elevation at tunnel portal is listed but water surface elevation was measured in adjacent vent structure.

(Continued)

TABLE 2 - Continued

Feature 1	Aqueduct station 2	Discharge (cfs) 3	Freeboard (feet) 4	Test water surface elevation 5	Design hydraulic gradient elevation 6 (B)	Remarks
Vent and	108+79	151	7.3	5252.62	5254.83	
Tunnel No. 1		174	6.9	52.93	(B)	
outlet		185	2.8	5257.12		Submerged at 185 cfs
Vent and	140+84	151	6.9	5248.40	5250.06	
Tunnel No. 2		174	6.5	48.78	(B)	
inlet		185	3.2	52.08		Submerged at 185 cfs
Vent and	146+30	151	7.1	5247.86	5249.68	
Tunnel No. 2		174	6.8	48.16	(B)	
outlet		185	3.2	51.71		Submerged at 185 cfs
Vent and	195+44	151	6.4	5241.24	5242.45	
Tunnel No. 3		174	5.9	41.72	(B)	
inlet		185	3.6	44.09		Submerged at 185 cfs
Vent and	222+13	151	7.0	5238.58	5240.35	
Tunnel No. 3		174	6.8	38.82	(B)	
outlet		185	3.5	42.10		Submerged at 185 cfs
Vent	357+30	(water surface not measured, no water spilled with 185 cfs flow)				
Vent and	452+72	151	7.2	5201.31	5203.30	
Tunnel No. 4		174	6.5	02.01	(B)	
inlet		185	5.2	03.31		
Vent and	456+87	151	7.9	5200.28	5203.00	
Tunnel No. 4		174	7.1	01.08	(B)	
outlet		185	5.0	03.13		

(B) At tunnel inlet and outlet the design hydraulic gradient elevation at tunnel portal is listed but water surface elevation was measured in adjacent vent structure.

(Continued)

TABLE 2 - Continued

Feature 1	Aqueduct station 2	Discharge (cfs) 3	Freeboard (feet) 4	Test water surface elevation 5	Design hydraulic gradient elevation 6	Remarks
Vent and Olm- stead tunnel inlet	498+02	151	6.4	5196.01	5197.17	
		174	5.9	96.51	(B)	
		185	5.3	97.06		
Vent and Olm- stead tunnel outlet	541+19	151	7.1	5192.41	5194.29	
		174	6.8	92.75	(B)	
		185	5.6	93.90		
Vent	630+35	145	6.6	5179.14	5181.1	6 cfs T.O. at Station 551+18
		174	6.3	79.42		
		185	6.2	79.52		
Vent	763+46	145	7.3	5158.57	5162.0	
		174	6.8	58.98		
		185	5.3	60.50		
Vent	834+10	145	7.1	5147.98	5150.8	
		174	7.0	48.08		
		185	4.8	50.23		
Vent	1039+70	145	8.4	5116.59	5119.3	
		174	8.2	16.85		
		185	1.7	23.28		
Vent and A-D tunnel inlet	1218+74	145	6.3	5094.34	5095.39	
		174	5.7	94.95	(B)	
		185	1.9	98.72		Submerged at 185 cfs

(B) At tunnel inlet and outlet the design hydraulic gradient elevation at tunnel portal is listed but water surface elevation was measured in adjacent vent structure.

(Continued)

TABLE 2 - Continued

Feature 1	Aqueduct station 2	Discharge (cfs) 3	Freeboard (feet) 4	Test water surface elevation 5	Design hydraulic gradient elevation 6	Remarks
US probe in A-D tunnel	1220+17	145	--	5094.20	5095.30	
		174	--	94.86		
		185	--	---		Submerged at 185 cfs
DS probe in A-D tunnel	1368+74	145	--	5081.94	5083.26	
		174	--	82.36		
		185	--	---		Submerged at 185 cfs
Vent and A-D tunnel outlet	1369+63	145	7.0	5081.23	5083.21 (B)	
		174	6.7	81.55		
		185	0.5	87.77		Submerged at 185 cfs
Vent	1523+60	145	6.5	5058.19	5060.2	
		174	5.4	59.31		
		185	1.3	63.38		
Vent	1641+00	145	7.2	5039.99	5043.7	
		174	3.8	43.42		
		185	2.3	44.92		
Vent	1706+10	145	4.7	5033.27	5034.4	
		174	3.6	34.44		
		185	3.3	34.72		

(B) At tunnel inlet and outlet the design hydraulic gradient elevation at tunnel portal is listed but water surface elevation was measured in adjacent vent structure.

TABLE 3

Provo River Project
Salt Lake Aqueduct
Inverted Siphon Pipelines
Station 10+04 to Station 1706+10
Aqueduct Cleaning History

Pipeline Reach Station	to Station	Date cleaned	Remarks
10+04	49+00	March 16, 1959	The aqueduct between Station 10+04 and 1218+74 has been cleaned four different times with a water propelled cleaning tool designed specially for the aqueduct size pipe of 69" - diameter.
49+00	64+79	March 16, 1959	
64+79	80+20	March 16, 1959	
80+20	98+29	March 16, 1959	
108+79	140+84	March 16, 1959	The first cleaning was April 21 to April 30, 1954; second cleaning - April 26 and 27, 1955; third cleaning - March 1956; and fourth cleaning March 16 and 17, 1959.
146+30	195+44	March 16, 1959	
222+13	452+72	March 16, 1959	The first cleaning is described in the Bureau's "Operation and Maintenance Equipment and Procedures" Release No. 15 for January, February and March 1956.
456+87	498+02	March 16, 1959	
541+19	630+35	March 16, 1959	
630+35	763+46	March 16, 1959	* Beyond Station 1218+74 the only cleaning of the aqueduct has been flushing with water flows up to 105 cfs between stations 1218+74 and 1746+60 following each of the four cleanings mentioned above.
763+46	834+10	March 16, 1959	
834+10	1039+70	March 17, 1959	
1039+70	1218+74	March 17, 1959	
1369+64	1523+60	* Flushings	
1523+60	1641+00	Flushings	
1641+00	1706+10	Flushings	

TABLE 4

The Salt Lake Aqueduct - Provo River Project
Maximum Capacity Test - 1966
Hydraulic Friction Coefficients of Pipelines

Conditions: 69-inch I.D. precast concrete pipe discharge = 185 cubic feet per second, Reynolds Number = 3.15×10^6

Aqueduct stations 1	Slope length (feet) 2	Darcy f 3	Scobey Cs 4	Manning n 5	Remarks
10+04 to 49+00	3,896	.0101	.428	.0099	
49+00 to 64+79	1,600	.0135	.371	.0114	
64+79 to 80+20	1,543	.0113	.405	.0105	
80+20 to 98+29	1,797	.0106	.418	.0102	
108+79 to 140+84	3,175	.0115	.402	.0106	
146+30 to 195+44	4,922	.0112	.397	.0104	
222+13 to 452+72	25,477	.0110	.410	.0103	
456+87 to 498+02	4,105	.0106	.418	.0102	2,315 feet (56 percent) 70-inch steel pipe
541+19 to 630+35	8,943	.0110	.410	.0103	
630+35 to 763+46	13,230	.0110	.410	.0103	
763+46 to 834+10	7,084	.0105	.420	.0101	

(Continued)

TABLE 4 - Continued

Aqueduct stations 1	Slope length (feet) 2	Darcy f 3	Scobey Cs 4	Manning n 5	Remarks
834+10 to 1039+70	19,105	.0105	.420	.0101	
1039+70 to 1218+74	17,860	.0100	.431	.0098	13,860 feet (77 percent) 70-inch steel pipe
1369+63 to 1523+60	15,445	.0115	.402	.0106	5,563 feet (36 percent) 70-inch steel pipe
1523+60 to 1641+00	11,850	.0113	.405	.0105	2,180 feet (18 percent) 70-inch steel pipe
1641+00 to 1706+10	6,556	.0113	.405	.0105	
Averages		.0111	.409	.0104	

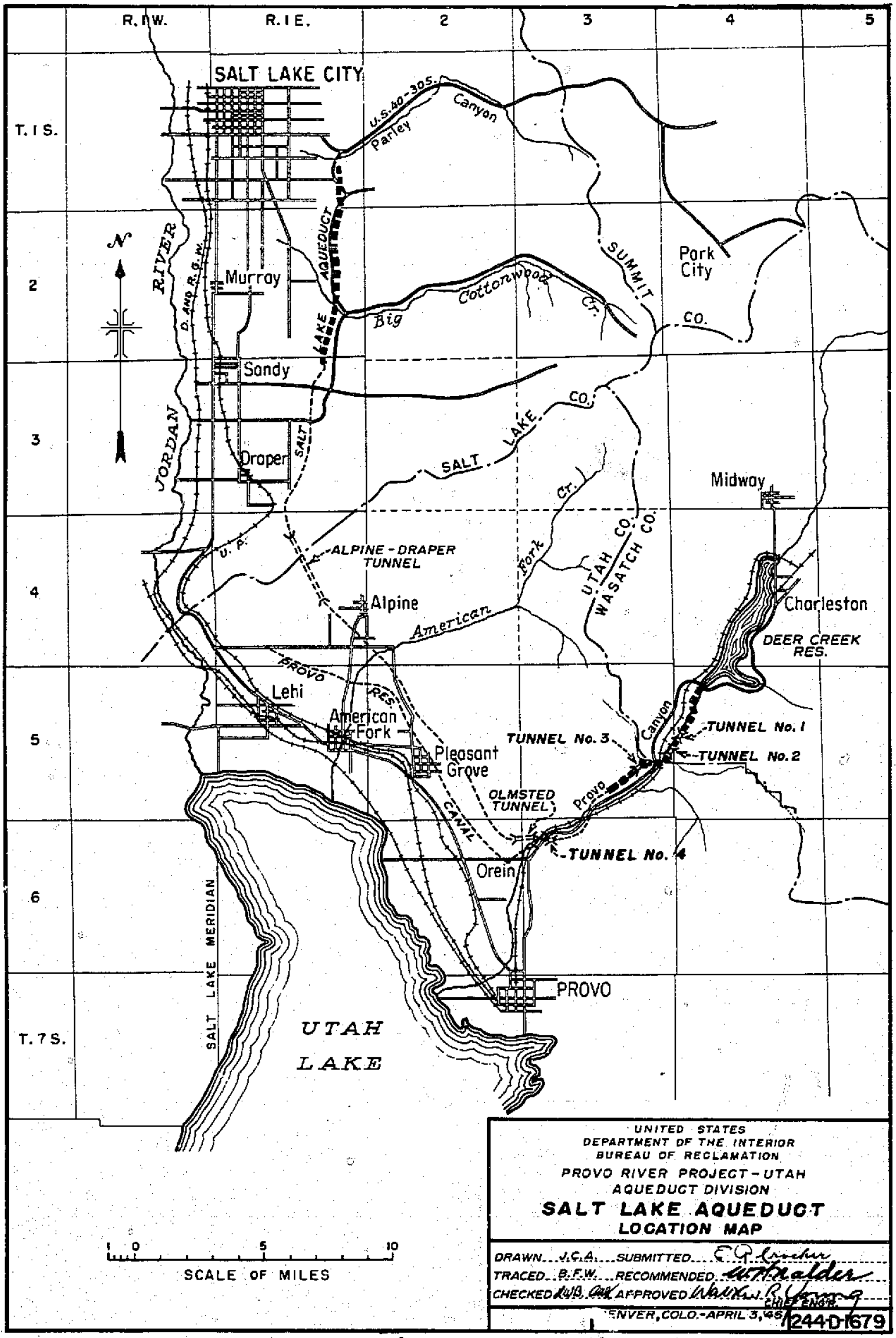
TABLE 5

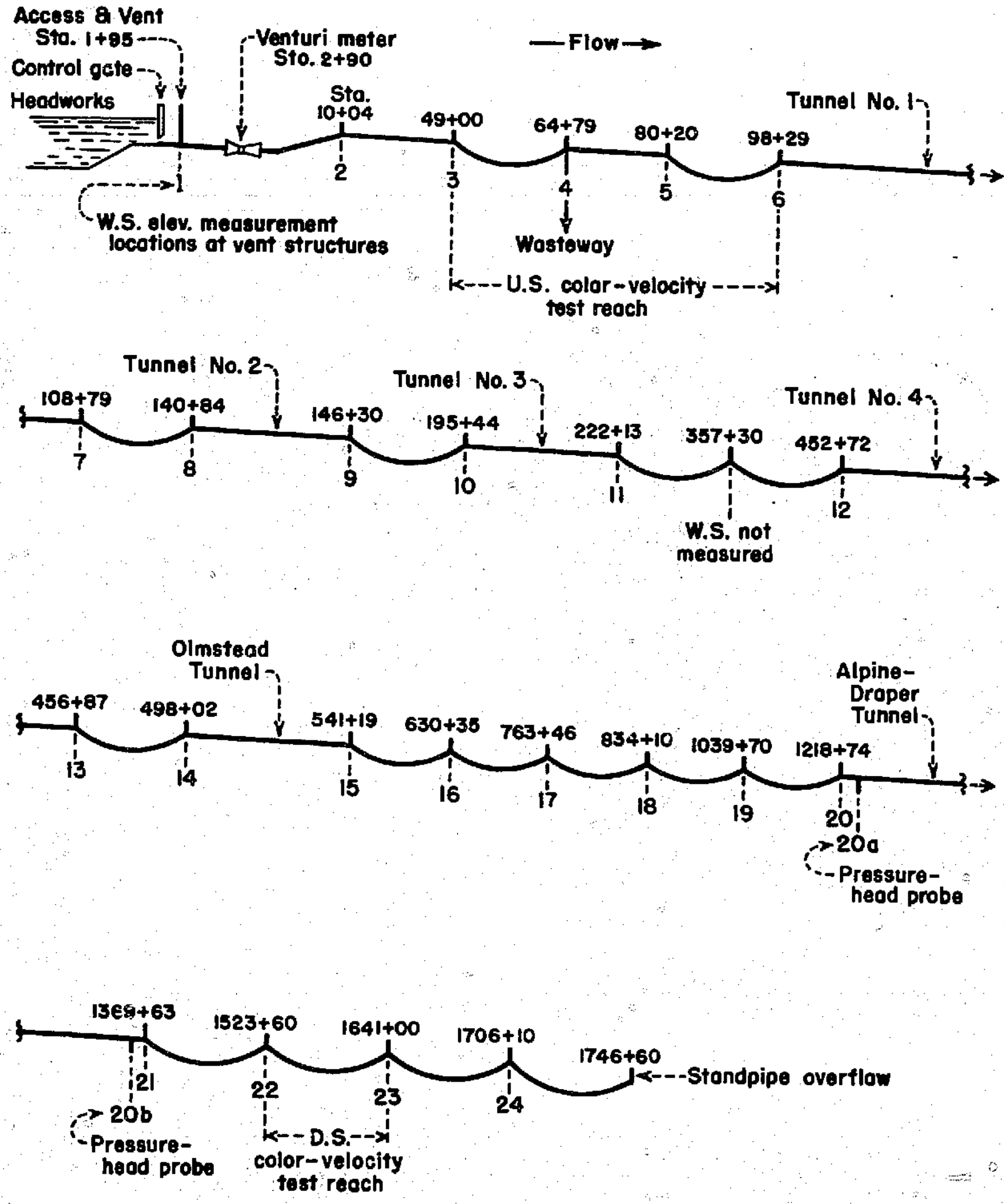
The Salt Lake Aqueduct - Provo River Project
Maximum Capacity Test - 1966
Manning Friction Coefficients of Tunnels

Description: Free flow, Concrete-lined Horseshoe Cross Section, 6.5-foot diameter, Invert Slope = 0.0008

Tunnel designation	Slope length (feet)	Discharge (cfs)	Manning n	Remarks
No. 1	1,050	151	.0112	
		174	.0109	
No. 2	547	151	.0107	
		174	.0105	
No. 3	2,697	151	.0110	
		174	.0107	
No. 4	435	151	.0105	
		174	.0103	
Olmstead	3,657	151	.0110	
		174	.0106	
Alpine-Draper	15,090	146	.0107	Inlet to outlet
		174	.0102	
Alpine-Draper	14,857	146	.0106	Between water depth probes
		174	.0105	

FIGURE 1
REPORT HYD-585



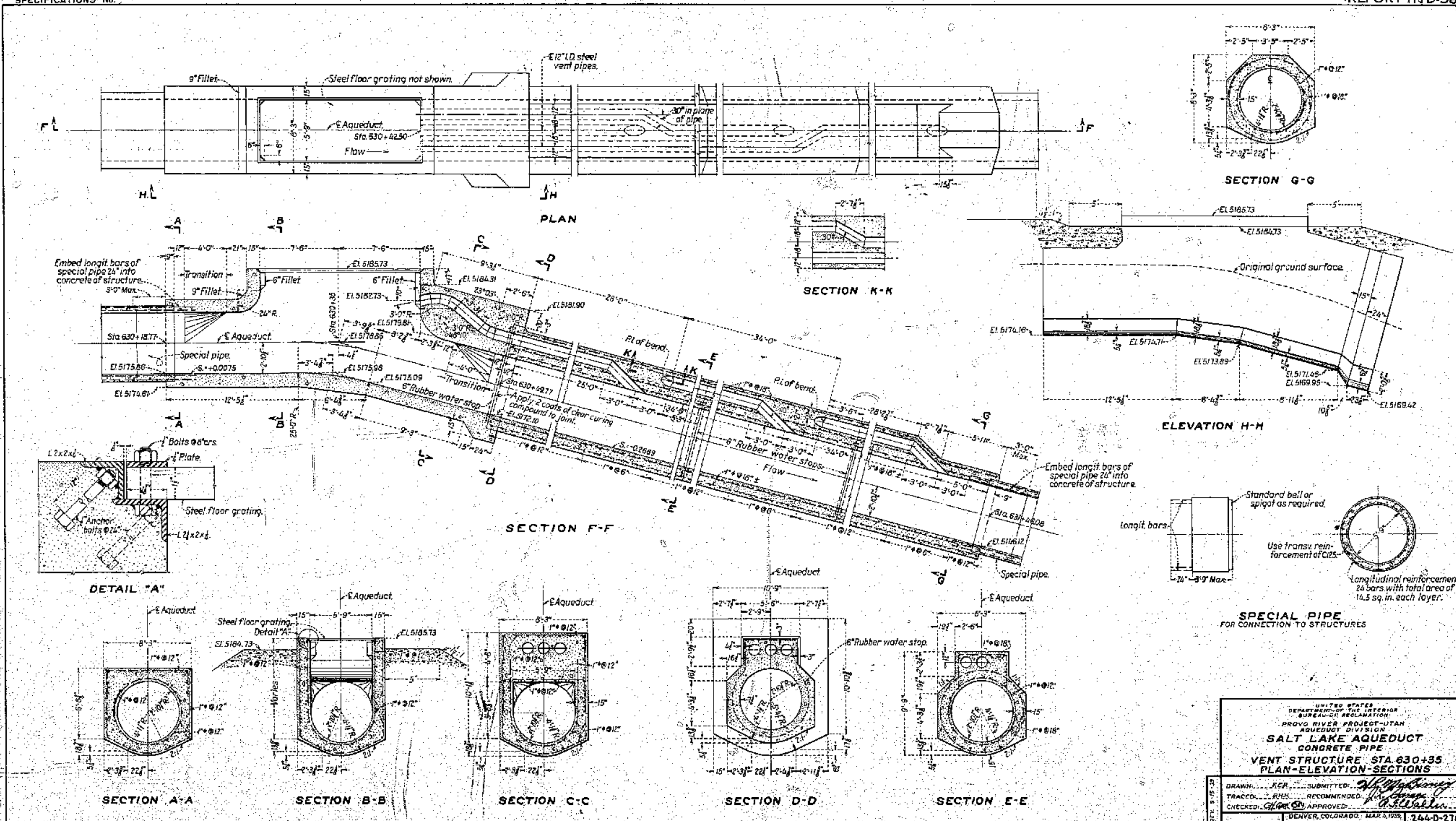


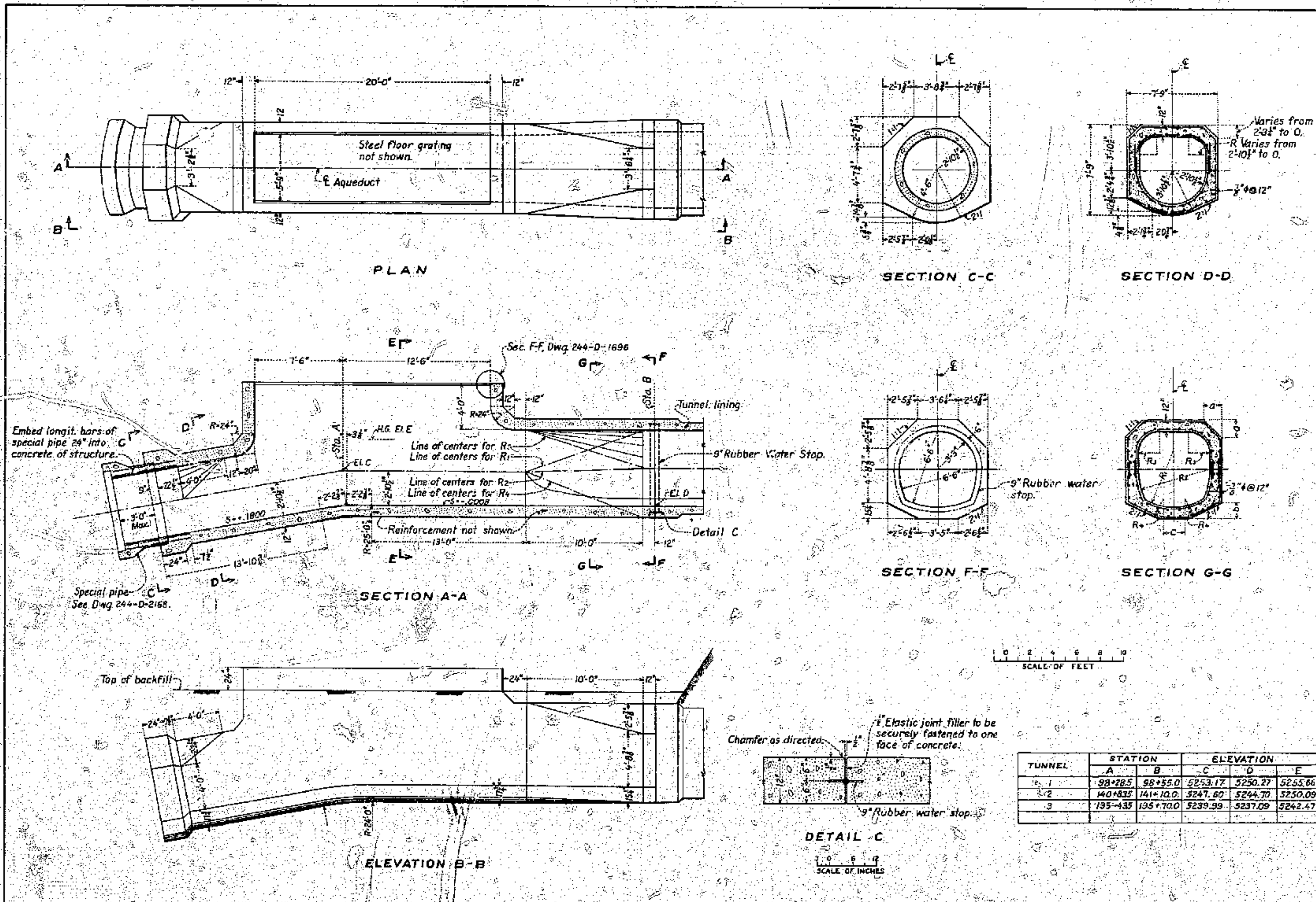
SALT LAKE AQUEDUCT - PROVO RIVER PROJECT
MAXIMUM CAPACITY TEST - 1966
SCHEMATIC PROFILE OF TEST REACH

735

SPECIFICATIONS No.

FIGURE 3
REPORT HYD-585





DIMENSION	VARIES	
	FROM	TO
a	0	2'-5⅞"
b	17½"	15⅛"
c	0	3'-5"
R₁	2'-10½"	6'-6"
R₂	5'-9"	6'-6"
R₃	0	3'-3"
R₄	3'-10½"	0

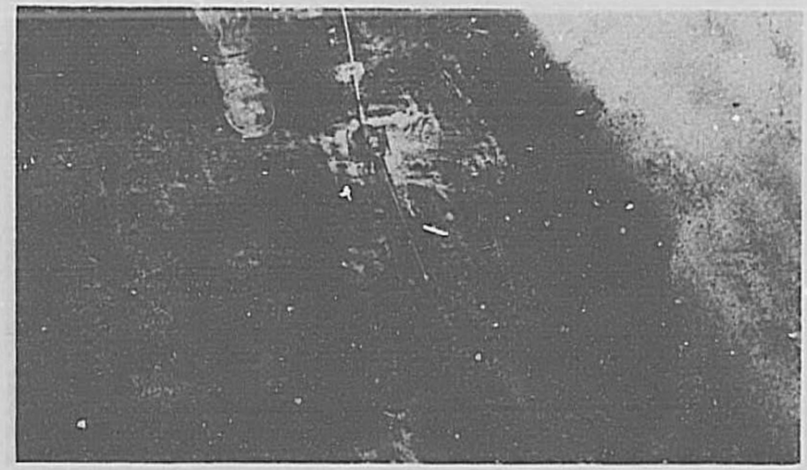
TUNNEL	STATION		ELEVATION		
	A	B	C	D	E
1	98+28.5	98+55.0	5253.17	5250.27	5255.66
2	140+83.5	141+10.0	5247.60	5244.70	5250.09
3	195+43.5	195+70.0	5239.99	5237.09	5242.47

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT—UTAH
AQUEDUCT DIVISION

SALT LAKE AQUEDUCT
TUNNEL INLET VENT STRUCTURES
STA'S. 98+28.5, 140+83.5 AND 195+43.5
PLAN, ELEVATIONS, SECTIONS

DRAWN: T.E.S. SUBMITTED:
TRACED: H.W.B. RECOMMENDED:
CHECKED: APPROVED:
DENVER, COLORADO, MAY 21, 1948
244-D-1700

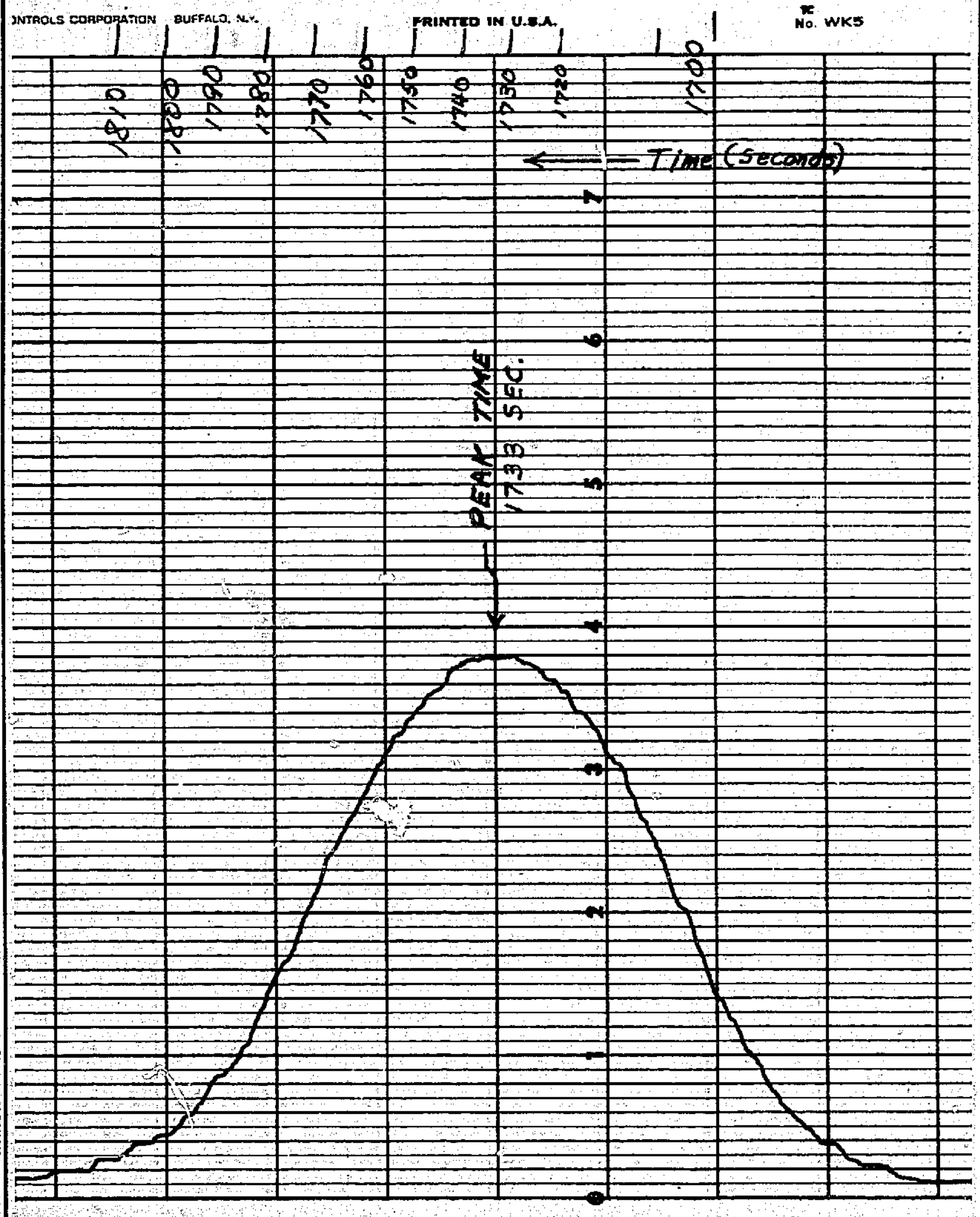
A. Upstream view toward inlet of Alpine-Draper Tunnel. Prandtl-type pressure head probe and manometer connection tube anchored at the left of the tunnel invert. Photograph P66-418-2687



B. Close view of pressure head probe installed near the outlet of Alpine-Draper Tunnel for water depth measurements. Photograph P66-418-2691

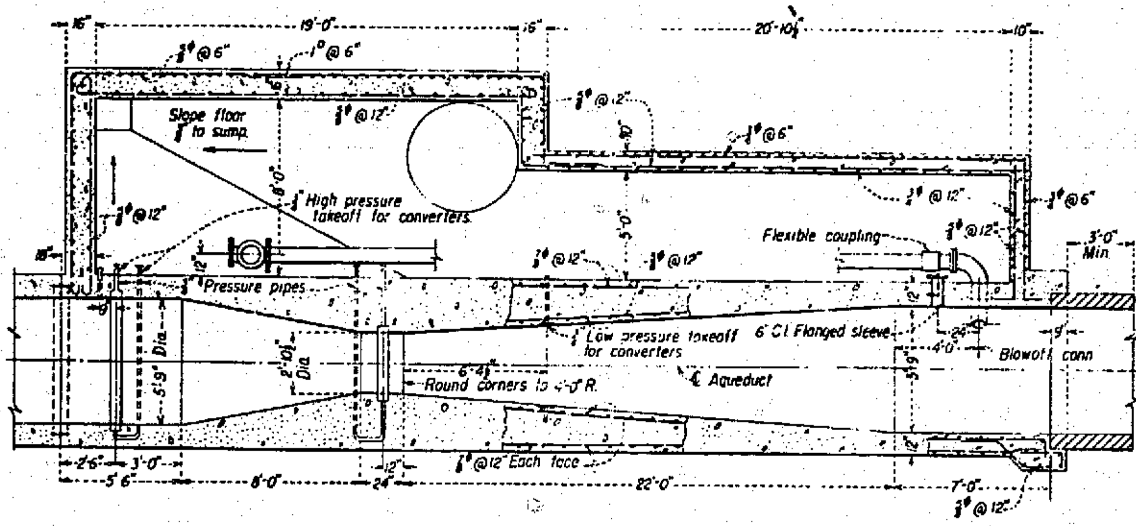
Salt Lake Aqueduct - Provo River Project
Maximum Capacity Test - 1966
Pressure Head Probes in Alpine-Draper Tunnel

FIGURE 6
REPORT HYD-585



SALT LAKE AQUEDUCT — PROVO RIVER PROJECT
MAXIMUM CAPACITY TEST — 1966
COLOR VELOCITY DYE CLOUD TRACE
STA. 1641+00 RUN 2-1 D.S.

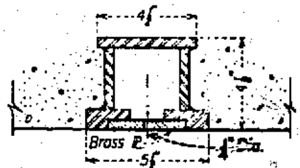
735



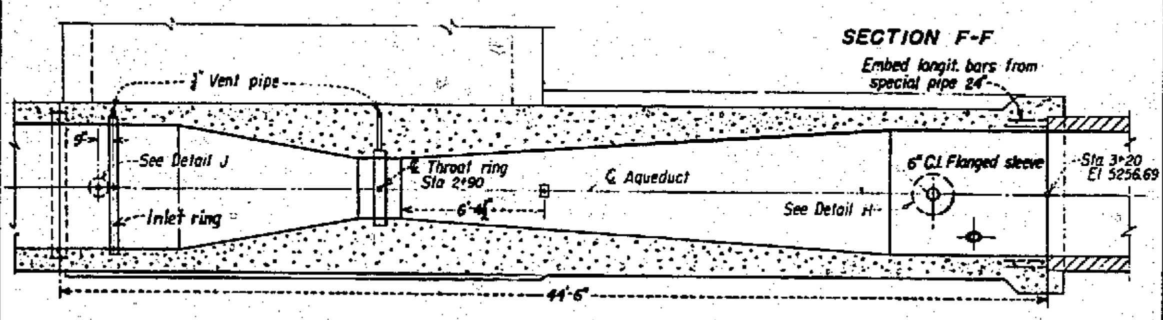
HORIZONTAL SECTION

MEASURED DIAMETERS (FT.) MAY 1966

	Inlet	Throat
Vert. ℄	5.750	2.874
Horiz. ℄	5.749	2.874
45° dia.	5.751	2.873
45° dia	5.750	2.874
Averages	5.750	2.874



TYPICAL SECTION
VENTURI RINGS

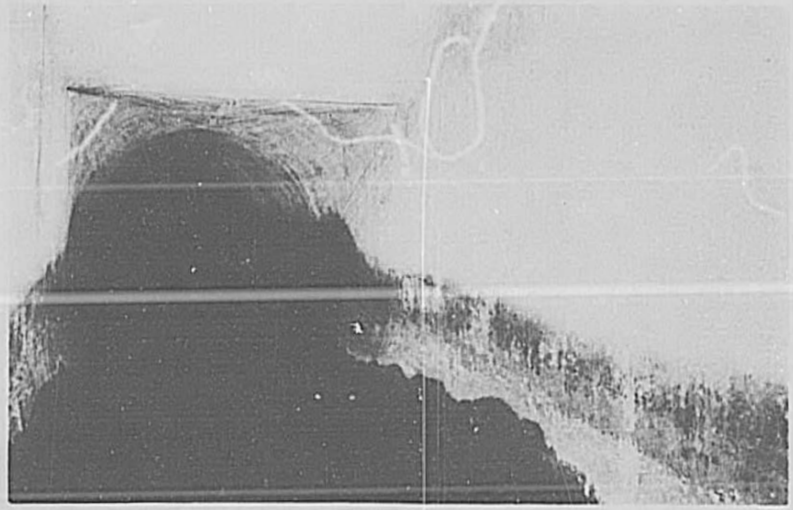


LONGITUDINAL SECTION

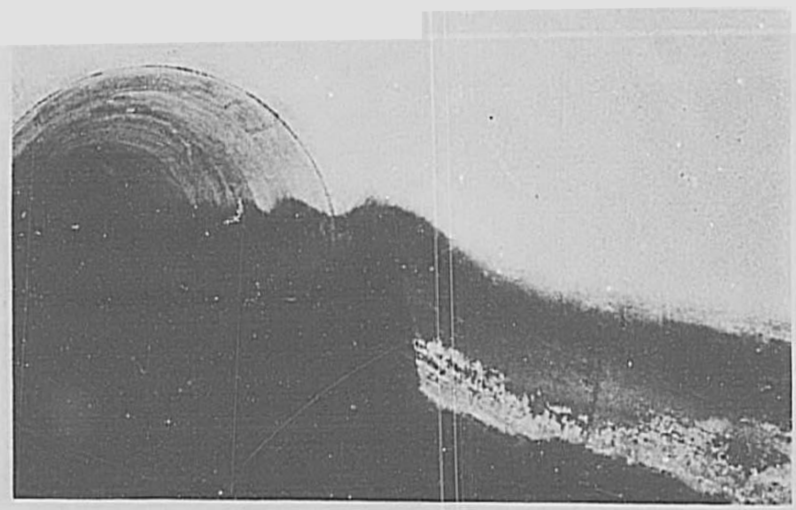
SALT LAKE AQUEDUCT – PROVO RIVER PROJECT

VENTURI METER, STA. 2+90

735

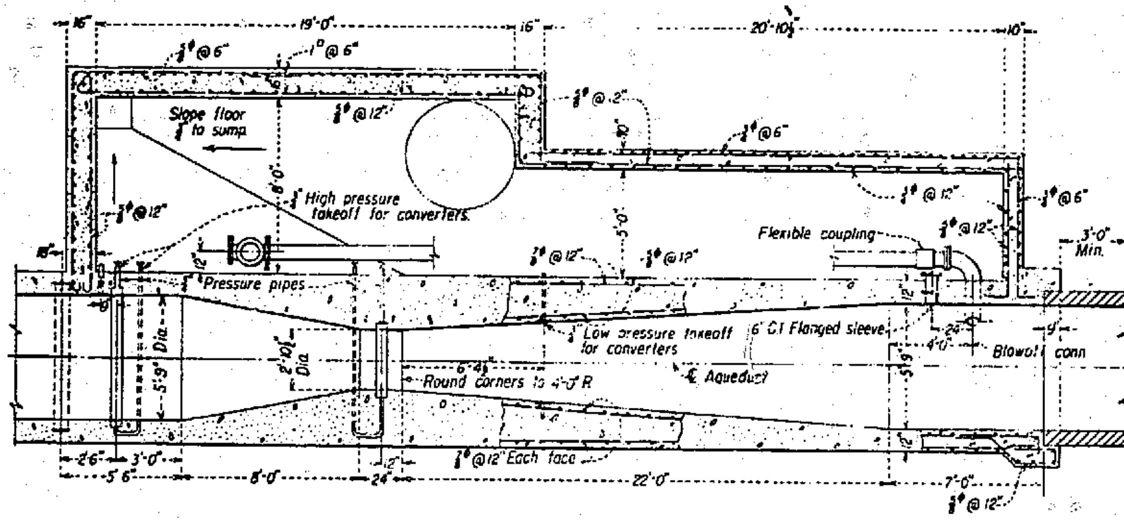


A. Downstream view of Tunnel No. 1 inlet from the Station 98+29 vent structure. A standing wave profile is shown by the high water mark along the right wall of the inlet transition and tunnel. Photograph P244-D-61629



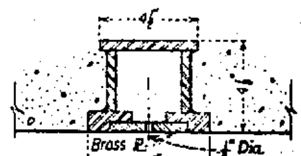
B. Downstream view of Tunnel No. 2 inlet from the Station 140+84 vent structure. The first wave crest in both photos is immediately upstream of the tunnel portal where velocity head recovery occurs. Darker lower elevation water marks were drying and do not indicate true water surface marks. Photograph P244-D-61628

Salt Lake Aqueduct - Provo River Project
Maximum Capacity Test - 1966
Waves at Tunnel Inlet Portals



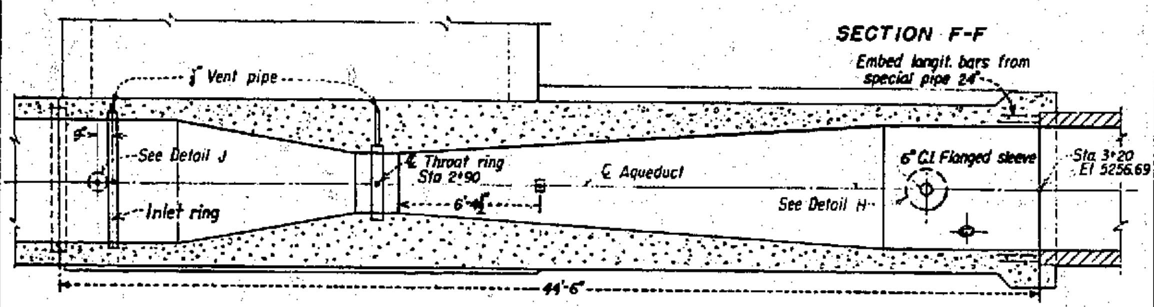
HORIZONTAL SECTION

MEASURED DIAMETERS (FT.) MAY 1966	Inlet	Throat
Vert. ℄	5.750	2.874
Horiz. ℄	5.749	2.874
45° dia.	5.751	2.873
45° dia	5.750	2.874
Averages	5.750	2.874



TYPICAL SECTION
VENTURI RINGS

SECTION F-F



LONGITUDINAL SECTION

SALT LAKE AQUEDUCT – PROVO RIVER PROJECT

VENTURI METER, STA. 2+90

7-1750
(2-67)
Bureau of Reclamation

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 I

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*	Square centimeters
	0.092903	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	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.)	946.358*	Cubic centimeters
	0.946331*	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

Multiply	By	To obtain
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)	0.092903*	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

ABSTRACT

Field tests were performed on the upstream 32-mi portion of the Salt Lake Aqueduct to determine the safe capacity above the design value of 150 cfs. The section, consisting of 17 reaches of 5.75-ft-dia precast pipe and 6 reaches of 6.5-ft-dia concrete-lined free-flow horseshoe tunnels, safely conveyed 174 cfs. Water surface elevations were measured at 24 open-vent structures and discharges were measured by the color-velocity method. Tables are included of Darcy, Scobey, and Manning coefficients for 16 pipeline reaches and Manning coefficients for 6 tunnels. Friction coefficients indicate excellent hydraulic characteristics of flow surfaces. This was verified by inspecting the tunnels; pipelines were not inspected. Discharge measurement results and coefficients of a 69-in. by 34.5-in. Herschel-type Venturi meter are included.

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