UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE FLOW CHARACTERISTICS AND AIR ENTRAINMENT IN THE CHECK TOWERS OF THE MAIN AQUEDUCT, CANADIAN RIVER PROJECT TEXAS

Report No. Hyd-555

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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CONTENTS

Page

Table

Figure

ABSTRACT

Head losses, air entrainment characteristics, and air venting requirements were determined from hydraulic model studies of proposed check towers for the Canadian River Aqueduct, Texas. The aqueduct flows 160 mi by gravity, drops 701 ft in elevation, and is constructed of 54-, 60-, 66-, and 72-in.-dia reinforced concrete pipe. Conduit wall pressures will be maintained at about 60-ft head by the check towers, each of which consists of 2 vertical sections of pipe connected at the top by a vented 180-deg return bend. The design discharge will be controlled by friction alone, and lesser flows will be controlled automatically in each pipe reach by the downstream check towers whose top inner radius serves as a crest for the water to flow over. Air will be entrained in the downstream leg of each tower during less than normal flows. This air will be removed from the aqueduct by a 36-in.-dia air vent located 100 ft downstream from each tower. Laboratory model studies showed that these check towers will operate satisfactorily for all discharges, preventing overpressures and water hammer during other than normal operation, and when running full flow will maintain the proper hydraulic gradient in the pipeline.

DESCRIPTORS-- *aqueducts/ *check structures/ distribution systems/ *surges/ pressure pipes/ standpipes/ flow resistance/ *head losses/ *hydraulic gradients/ hydraulic models/ *pressure conduits/ unsteady flow/ flow control/ air entrainment/ hydraulic conduits/ closed conduits/ concrete pipes/ water hammer/ model tests/ laboratory tests
IDENTIFIERS-- Canadian River Aqueduct/ Canadian River Project, Tex/ Texas/ hydraulic design

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Office of Chief Engineer	Report No. Hyd-555
Division of Research	Author: D. Colgate
Hydraulics Branch	Checked by: W. P. Simmons
Denver, Colorado	Reviewed by: W. E. Wagner
June 1, 1966	Submitted by: H. M. Martin

HYDRAULIC MODEL STUDIES OF THE FLOW CHARACTERISTICS AND AIR ENTRAINMENT IN THE CHECK TOWERS OF THE MAIN AQUEDUCT, CANADIAN RIVER PROJECT TEXAS

PURPOSE

Model studies were made of the Main Aqueduct check towers to determine head losses with the system flowing full, and the air entrainment and air-venting requirements with the system flowing partially full.

CONCLUSIONS

1. A check tower configuration consisting of a 90° bend to turn the flow vertically upward to the desired height of the tower, a 180° return bend opened to atmosphere at the top, and a 90° bend at the bottom of the downstream leg to return the conduit to the original alinement (Figure 14) will operate satisfactorily for all discharges.

2. The hydraulic head loss caused by the three bends of the tower will be $0.562\ V^2/2g$ feet of water when the conduit is flowing full. (V is the average velocity in the conduit.)

3. Air entrained in the downstream leg of a tower will, under certain flow conditions, be carried into the downstream horizontal conduit. This air will rise to the top of the conduit within about 15 conduit diameters.

4. An air vent 36 inches in diameter placed in the crown of the conduit 100 feet downstream from each check tower will satisfactorily release the air moving along the crown of the conduit.

5. The fluctuations of the water column in the air vent as air passes up through it will pump some air back into the main conduit. The conduit downstream from the vent should be constructed on a downward slope of 0.08 or greater for about 50 feet to allow the small amount of air so entrained to work back upstream and escape through the vent.

INTRODUCTION

Sanford Dam on the Canadian River, about 40 miles northeast of Amarillo, Texas, is the primary storage facility for the Canadian River Project (Figure 1). Lake Meredith, impounded by Sanford Dam, will provide 103,000 acre-feet of water annually for municipal and industrial uses for 11 cities: Borger, Pampa, Amarillo, Plainview, Lubbock, Levelland, Brownfield, Slaton, Tahoka, O'Donnell, and Lamesa. Use of the regulated flows from the Canadian River will decrease demands on underground reserves, thereby increasing the supplies available for irrigation from wells.

Facilities required for the project include an aqueduct system of about 322 miles of pipeline, 10 pumping plants, 2 regulating reservoirs, and chlorinating facilities to prevent algae growth in the pipelines. All of the cities directly benefited by the project are at a higher elevation than Sanford Dam, necessitating pumping of water from the reservoir. Borger and Pampa are 9 and 36 miles, respectively, southeast of the reservoir and will be furnished water directly by pumping. Amarillo is 40 miles southwest of the reservoir and 864 feet in elevation above the reservoir. The remaining 8 cities in the project are south of and at a lower elevation than Amarillo. The most distant city, Lamesa is 160 miles south of Amarillo and 701 feet lower.

Water from Lake Meredith will pass through four pumping plants in the Main Aqueduct to a regulating reservoir at Amarillo, and flow by gravity south to another regulating reservoir at Lubbock. Two aqueducts flow from the regulating reservoir at Lubbock--the Main Aqueduct continues south by gravity flow to Lamesa, and the southwest aqueduct, aided by four pumping plants, flows to Levelland and Brownfield.

The gravity flow pipeline between Amarillo and Lubbock will be reinforced precast concrete pipe varying from 54 to 72 inches in diameter.

The pipeline is so designed that, at normal flow, the hydraulic gradient will parallel the average ground profile producing a pipe wall pressure not exceeding 100 feet of water. While filling or draining the pipeline, or discharging less than normal flow through the system there is a danger of surging, air entrainment and water hammer.

A tower-type check structure was designed to prevent adverse conditions such as overpressures and water hammer during other than normal operation, and still maintain the proper hydraulic gradient during normal operation. Each tower consists of a 90° bend to turn the water vertically upward from the conduit, a 180° return bend (with air vent) at the top of the tower, and a 90° bend at the bottom of the downstream leg to return the flow to the main conduit alinement. Check towers will be installed at intervals along the conduit where the ground profile has dropped in elevation not exceeding 60 feet from the adjacent tower upstream. The top of each tower will be slightly below the normal hydraulic gradient, but will have a pipe, open to the atmosphere, extending above the hydraulic gradeline from the top of the tower. The bottom of each tower will be slightly lower in elevation than the top of the adjacent tower downstream. Thus, during normal flows the hydraulic gradient will be slightly above the top of each tower causing the system to flow full, and at flows less than normal, or no flow, the conduit between towers will remain full. The pipe extension open to the atmosphere at the top of the tower will prevent damaging overpressures in the event of surging in the conduit during changing flows.

Model tests were conducted to determine head losses, flow conditions, and air entrainment in the basic check tower design, and to devise a vent structure capable of removing the air carried into the conduit downstream from a check tower with the tower flowing partially full.

THE MODEL

The model was constructed of transparent plastic to facilitate observation of flow conditions and air bubble movement (Figure 2). Commercially available 11-1/2-inch-inside-diameter, 1/4-inch wall pipe was used for the straight sections, and four 90° bends, 11-1/2-inch centerline radius, were constructed in the laboratory shop. Water entered the model through a vaned elbow and 11 feet of 11-1/2-inch-inside-diameter pipe before reaching the first vertical bend of the check tower. A slat-type gate at the downstream end of the conduit controlled the back pressure or water depth in the downstream leg of the check tower.

Three piezometer rings were installed in the conduit for line loss measurements. The head at the various stations was measured with a single leg water manometer, and discharge was determined with the laboratory Venturi meters.

The pattern of flow over the crest of the check tower with the system flowing partially full was determined by sighting through a grid drawn on the outside of the transparent return bend. Air bubble concentration, location, and movement were determined visually.

The Main Aqueduct will include conduits with diameters of 72, 66, 60, and 54 inches depending on the natural ground slope in the area and the amount of water the conduit must pass. The model study was made with a single tower 11-1/2 inches in diameter, therefore the scale ratio depended upon the diameter of the prototype pipe to be considered. The following table may be used for computations.

Table 1

MODEL-PROTOTYPE RELATIONSHIPS

Conduit diameter (inches)	Scale ratio (N)	Conduit area (square feet)	Velocity (feet per second)	Discharge (cubic feet per second)
11.5	1	0.7215	V_m*	Q_m
54	4.696	15.904	2.165 V_m	47.80 Q_m
60	5.220	19.635	2.284 V_m	62.22 Q_m
66	5.740	23.758	2.393 V_m	78.95 Q_m
72	6.260	28.274	2.503 V_m	98.10 Q_m

*The subscript "m" denotes the model.

THE INVESTIGATION

Check Tower Head Losses

The head loss caused by a single check tower with the system flowing full was determined for a range of discharges. An initial loss measurement was made with a straight run of pipe (without a check tower) with a length of 38 feet 10-3/8 inches (40.6 pipe diameters) between piezometer rings (Figure 2A). A check tower was then installed in the system with one piezometer ring 1 diameter upstream from the first vertical bend, and a second ring 40.6 pipe diameters downstream from the first ring, measured along the conduit centerline (Figure 2B). The head loss caused by the four 90° bends of the check tower was the difference between the losses with and without the tower.

The results of the model head loss studies are shown in Figure 3. Head losses for various check towers, as determined from model data, are shown in Figure 4. The losses for any discharge in any size similarly designed check tower flowing full may be computed from the formula:

$$H_L = 0.565 \frac{V^2}{2g}$$

Where H_L is the head loss caused by the tower, and
V is the average velocity in the conduit.

Free Flow over the Crest

Water spills over the crest formed by the return bend at the top of the tower when the conduit flows partially full. Two factors became evident as this free water surface flow was viewed through the transparent conduit walls. First, a measurement of the head required on the upstream leg to pass specific flows was needed for computations regarding overall aqueduct performance*, and secondly, air entrained in the downstream leg required study since it was evident that air entrainment would be a major problem.

To determine the relationship of upstream head versus discharge, the model was operated at various rates of flow with free fall over the return bend. Measurements were recorded of the free water surface, particularly the maximum surface at the top of the "boil" and the water depth over the invert or crest. The plot in Figure 5 shows the results of this study.

Water flowing over the crest may, under certain conditions, entrain air. To determine these conditions, a study was made simulating the design discharge of 92 cfs (cubic feet per second) in the 60-inch conduit with the water level in the downstream leg controlled by varying the back pressure. With small back pressures a large quantity of air was entrained in the downstream leg of the check tower (Figure 7A). As the back pressure was increased, raising the elevation of the water surface in the downstream leg (Figure 6A), the amount

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*These values are to be used in a later study of surges in the aqueduct.

of entrained air decreased until, at a water depth over the crest of 3 feet (0.6 D), the small amount of air circulating in the jump was no longer carried through the downstream leg of the tower (Figure 6B). With a further increase in back pressure the free water surface in the return bend became tranquil (Figure 6C) and finally filled the bend and entered the free surface tube (Figure 6D).

Air Vent Structure

If the free water surface in the downstream leg of the check tower is relatively low (1 pipe diameter or so above the horizontal conduit downstream), a discharge of about 8 to 10 percent of the maximum will entrain considerable air and carry it into the horizontal conduit. At these small discharges with low water velocities in the pipeline, the air passing the downstream bend will collect at the top of the conduit. Some air will bubble back into the check tower and some will work slowly downstream. For larger discharges and higher water velocities in the conduit, more air will become entrained and carried into the horizontal conduit to be swept downstream (Figure 7B).

At a model discharge of 1.478 cfs (92 cfs for the 60-inch conduit) all entrained air which passed the downstream bend rose to the top of the horizontal conduit in a distance of 10-1/2 pipe diameters downstream from the check tower and continued on downstream. The air which entered the horizontal conduit and was swept along by the flowing water was compressed by the ambient water pressure in the system and presented the possibility of uncontrolled explosive releases of air. It was apparent that this air would have to be vented downstream from the check tower after collecting at the top of the conduit.

To be certain the air vent structure was located a sufficient distance downstream so all entrained air had collected at the top of the conduit before reaching the vent, the vent was installed 18 conduit diameters downstream from the check towers. To aid air movement from the check tower to the air vent structure, and to retard air movement downstream from the air vent, the conduit was sloped upward on a 0.01 slope from the check tower to the air vent structure, and downward on a 0.01 slope downstream from the air vent (Figure 8). The initial model air vent structure was transparent pipe, 3-5/8-inch-inside diameter, extending 8 feet vertically upward (Figure 9).

Generally for the studies concerning the air vent structure, a discharge representing 92 cfs in the 60-inch conduit was maintained and the pool in the downstream leg of the check tower was held about

3 conduit diameters above the centerline of the horizontal conduit. These conditions were practical from a prototype-operating standpoint and forced a large amount of air to enter the conduit downstream from the check tower.

From observation of the action of the fluid flow at the air vent structure, it was concluded that:

1. The location of the vent was good; all air collected at the top of the conduit before reaching the vent structure (Figure 10A).

2. The vent entrance port was too small; portions of the larger bubbles passed on either side of the vent opening and continued on down the conduit (Figure 10B).

3. Air was pumped from the vent back into the conduit due to large water surface fluctuation in the vent pipe (Figure 10C).

4. The upslope of the conduit upstream from the vent contributed little to the operation, and the minus 0.01 slope downstream from the vent was not sufficiently steep to cause air to flow back upstream by buoyancy against the downstream drag of the water. (There was very little difference in the movement of air at the top of the conduit upstream and downstream from the vent structure.)

Using the results of these tests as a guide, the conduit from the tower to the vent was made horizontal, and provisions were made to permit adjustment of the slope of the conduit downstream from the vent. A 5-1/2-inch-inside-diameter air vent replaced the 3-5/8-inch vent, and the conduit downstream from the air vent structure was adjusted to a slope of minus 0.03 (Figure 11A).

Air movement upstream from the vent was satisfactory and similar to that in the preceding test. More air passed into the larger vent, but the sides of some of the larger bubbles still moved past the vent to continue on down the conduit. The pumping action of fluctuating water in the vent forced air back into the stream where it was swept down the conduit. A portion of the air downstream from the vent collected at the top of the conduit and worked upstream to the vent and bubbled out; the remainder swept on downstream.

It appeared that a wider vent entrance port was needed to trap more of the air as it reached the vent. Therefore, a conical section 11-1/2 inches in diameter at the centerline of the conduit, 3-5/8 inches in diameter at the top, and 23 inches long was installed in the model. A 3-5/8-inch-diameter vent pipe was attached to the top of the cone. The slope of the conduit downstream from the vent was increased to minus 0.05.

The wide mouth of the vent caught all of the air approaching from the check tower, but the fluctuation water in the vent created a pumping action which forced air back into the conduit where it was swept downstream (Figure 11B). About one-fourth of the air collecting on the top of the downward sloping conduit traveled downstream; the remainder worked back upstream against the current and again entered the air vent.

The conical section did not appear to have any desirable features which could not be achieved with a less expensive cylindrical section. Therefore, a 7-1/2-inch-inside-diameter air vent structure was mounted in the horizontal conduit 17 conduit diameters downstream from the check tower. The vent was moved to the upstream side of the adjustable flanged joint so the vent would remain vertical while the slope of the downstream conduit was varied. The downstream conduit was placed on a downward slope of 0.08 for this series of tests.

All air approaching this vent structure from upstream entered the vent (Figure 12A). Pumping action was present and forced some air into the downstream conduit (Figure 12B). All air which was pumped into the sloping conduit worked back upstream and bubbled out of the air vent (Figure 12C).

With the 7-1/2-inch-diameter vent pipe all air entering the sloping conduit downstream from the vent was furnished by pumping action in the vent pipe. In an effort to eliminate the pumping action, a vent 11-1/2 inches in diameter was installed in the model (Figure 13A). The bubbles in the comparatively large cross-sectional area of the 11-1/2-inch vent pipe were relatively small and uniformly dispersed (Figure 13B). This factor tended to decrease the pumping action; however, some air was still pumped into the sloping conduit downstream.

From the preceding tests it was apparent that under certain conditions, some air would pass beyond the air vent and into the conduit downstream. The tests with the largest vent (11-1/2 inches) indicated that only a small amount of air would be forced into the downstream conduit by pumping, however, in the prototype structure, with pipe stands and check towers in series, additional surging will exist in the system tending to add to the pumping action. Since some air will pass any vertical-pipe-type vent structure, and the conduit downstream must be sloped sufficiently to allow the air to return to the vent by buoyancy, it was felt that a vent pipe about 36 inches (5.75 to 7.67 model) in diameter, available commercially and therefore relatively inexpensive, would be adequate. This vent pipe size seemed satisfactory according to the model results.

Design personnel stated that a bend of 5° could be achieved in the conduit without special forming of the joints. Since such a bend would produce a downward slope of 0.087, and in the model a 0.080 slope was sufficient to allow air to return upstream by buoyancy, the 5° slope was deemed satisfactory.

Accordingly, the recommended check tower and vent design for the Canadian River Main Aqueduct is as shown in Figure 14. The bends in the check tower are short-radius bends (centerline radius equal to the conduit diameter). The conduit is horizontal from the check tower to the vent and the vent is 36 inches in diameter and about 100 feet downstream from the tower. The conduit downstream from the vent slopes downward 5° for about 50 feet.

AIR ENTRAINMENT RELATIONSHIPS

The following discussions explain the uncertainties regarding model studies concerned with entrained air, and the methods and reasoning employed to arrive at the installation recommendations included in this report.

Air Vent Location

The bubbles downstream from the model check tower rose to the top of the conduit in about 10 feet, or 10-1/2 conduit diameters. Flow turbulence caused by the vertical bend at the bottom of the downstream leg of the tower held air bubbles to the bottom of the conduit for about 5 conduit diameters (Figure 7B), and all air rose to the top of the conduit in an additional 5-1/2 diameters. This implies that a 52.5-foot length of 60-inch conduit would be needed to achieve full bubble rise when the discharge was 92 cfs. Actually, however, the rate of rise of a given size bubble in water is a constant and scale factors are not applicable.

Assuming a constant rate of rise of 0.4 fps (feet per second) for 0.05-inch-diameter bubbles in water flowing 4 fps*, and allowing 5 pipe diameters for the flow turbulence to release the bubbles from the bottom of the conduit, computation indicates a rise distance of 83.6 feet for the 60-inch conduit discharging 92 cfs.

Table 2 lists the results of the computations for the bubble rise distance in various conduits based on 5 conduit diameters of

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*Snowy Mountain Hydroelectric Authority chart 8-6-60.

turbulent mixing length and thereafter a bubble rise velocity of 0.4 fps.

Table 2

BUBBLE RISE DISTANCE IN HORIZONTAL CONDUIT

Conduit diameter (inches)	Q (cubic feet per second)	Velocity (average) (feet per second)	Seconds to rise 1 diameter at 0.4 feet per second	Bubble rise distance (feet)	Total rise distance from elbow (feet)
11.5	1.478	2.05	2.40	4.92	1/9.71
54	92	5.78	11.25	65.0	87.5
60	92	4.69	12.50	58.6	83.6
66	92	3.87	13.75	53.2	80.7
72	92	3.25	15.00	48.8	78.8

1/Measured model distance = 10 feet.

It would thus appear that a distance of 100 feet from a check tower to the air vent structure would be adequate for all considered conduit sizes.

Surging in the Air Vent

With the same discharge and back pressure in the model, and thus the same amount of entrained air, the action of the air in four vent pipe sizes was observed. In the smallest pipe (3-5/8-inch diameter) a pocket of air would rise as a large bubble allowing a thin sheet of water to pass between the bubble and the pipe walls (Figure 15A). The surges in this pipe tended to be sluggish, damped somewhat by the air bubble almost filling the pipe. Some air was pumped back into the conduit as the water surface in the vent pipe fluctuated. In the 5-1/2-inch-diameter pipe, the largest bubbles were unstable tending to flutter as they progressed up the pipe. These bubbles rose quite rapidly causing large undulations in the water surface in the vent pipe and pumping considerable amounts of air into the conduit (Figure 15B). The 7-1/2-inch vent pipe acted in a similar manner to the 5-1/2-inch one, but with smaller undulations of the water surface and consequently less pumping of air into the downstream conduit (Figure 15C). The bubble in this case did not remain intact, thereby being unable to lift and rapidly release a large volume of water. In the 11-1/2-inch vent pipe the individual air bubbles remained fairly small rising uniformly in the pipe (Figure 15D). The water surface here was relatively stable with only small amounts of air being pumped into the conduit downstream. It is believed that bubbles in the 36-inch air vent structure in the field would break up in a manner similar to that shown in Figure 15D and there would not be as violent a pumping action as the model pipe indicated.

Air Downstream from the Vent

Air which collected at the top of the sloping conduit downstream from the vent in the model formed individual bubbles or strings (Figure 10). The shearing action of the flow tended to break up bubbles larger than about 4 inches wide (42° included angle at the conduit centerline). The movement of bubbles upstream due to buoyancy, or downstream due to the drag of the flowing water, was dependent on the slope of the conduit, the discharge, and the bubble size.

A previous study by Kalinski and Bliss1/ concerned bubbles at the zenith of a sloping pipe. In the Kalinski study, the discharge at which the drag of the flowing water was equal to the buoyancy of an air bubble (causing the bubble to remain stationary) was determined for various pipe slopes. It was found that the ratio $\frac{Q^2}{gD^5}$ varied linearly with the pipe slope (S) for the condition of stationary bubbles. (Q = discharge, g = acceleration of gravity, and D = pipe diameter.) Since these parameters ($\frac{Q^2}{gD^5}$ and S) are dimensionless, prototype behavior may be predicted from model data in geometrically similar installations.

In this check tower study, the bubbles downstream from the air vent remained stationary when the model conduit was sloped downward 0.080, and the discharge was 1.875 cfs. The slope (S), discharge (Q), and pipe diameter (D) were related thus:

$$KS = \frac{Q^2}{gD^5} = \frac{(1.875)^2}{(32.2)(11.5/12)^5} = 0.135$$

$$K(0.080) = 0.135; \; K = 16.87$$

$$16.87S = \frac{Q^2}{gD^5} \text{ for stationary bubbles.}$$

1/A. A. Kalinski and P. H. Bliss--"Removal of Air from Pipelines by Flowing Water," Civil Engineering, Volume 13, No. 10, 1943.

In a conduit with a slope of 0.087; air bubbles will remain stationary when:

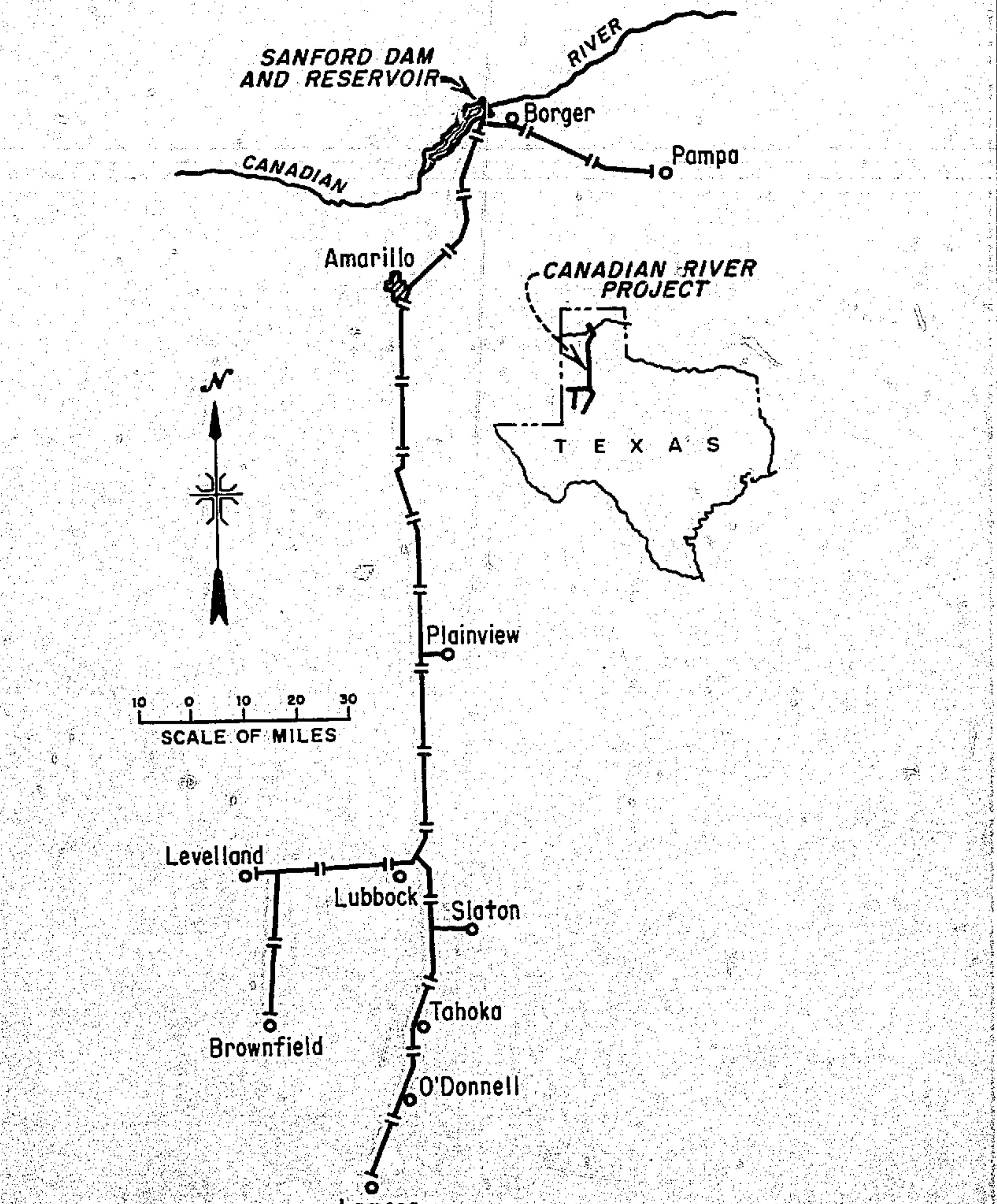
$$(16.87)\ (0.087) = \frac{Q^2}{g^{D5}} = 0.1468$$

Therefore, for a conduit slope of 0.087, a value of $\frac{Q^2}{g^{D5}}$ greater than 0.1468 would indicate that air bubbles would move downstream, while a value smaller would indicate that bubbles would move upstream.

Computed values for the Canadian River Aqueduct, which has a slope of 0.087 downstream from the vent, are:

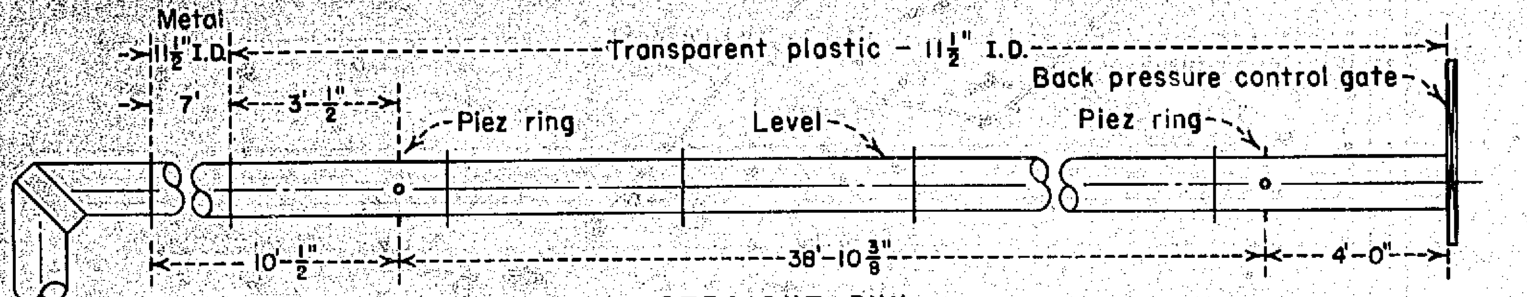
Pipe diameter (inches)	Q	$\frac{Q^2}{g^{D5}}$
11.5	1.478	0.0841
54	92	0.1420
54	85	0.1210
60	92	0.0841
66	92	0.0491
72	92	0.0338

It would thus appear that the 0.087 downward slope downstream from the vent will insure the return upstream of the small amount of air which will pass the air vent, or be pumped into the conduit from the vent, for any of the installed conduits with up to maximum design discharge.

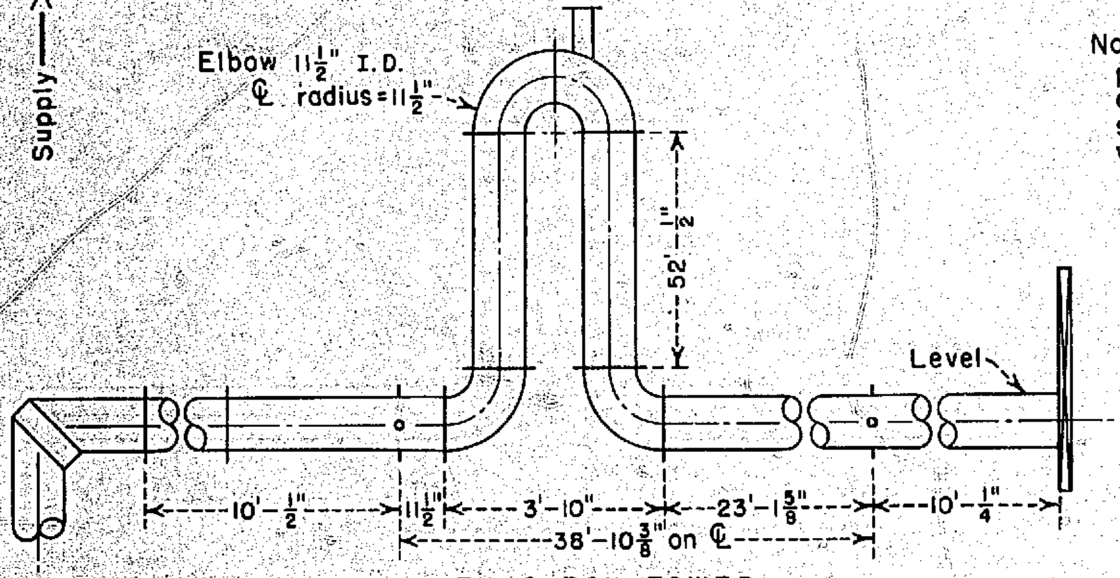


CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS
LOCATION MAP

FIGURE 2
REPORT HYD-555



A. STRAIGHT RUN

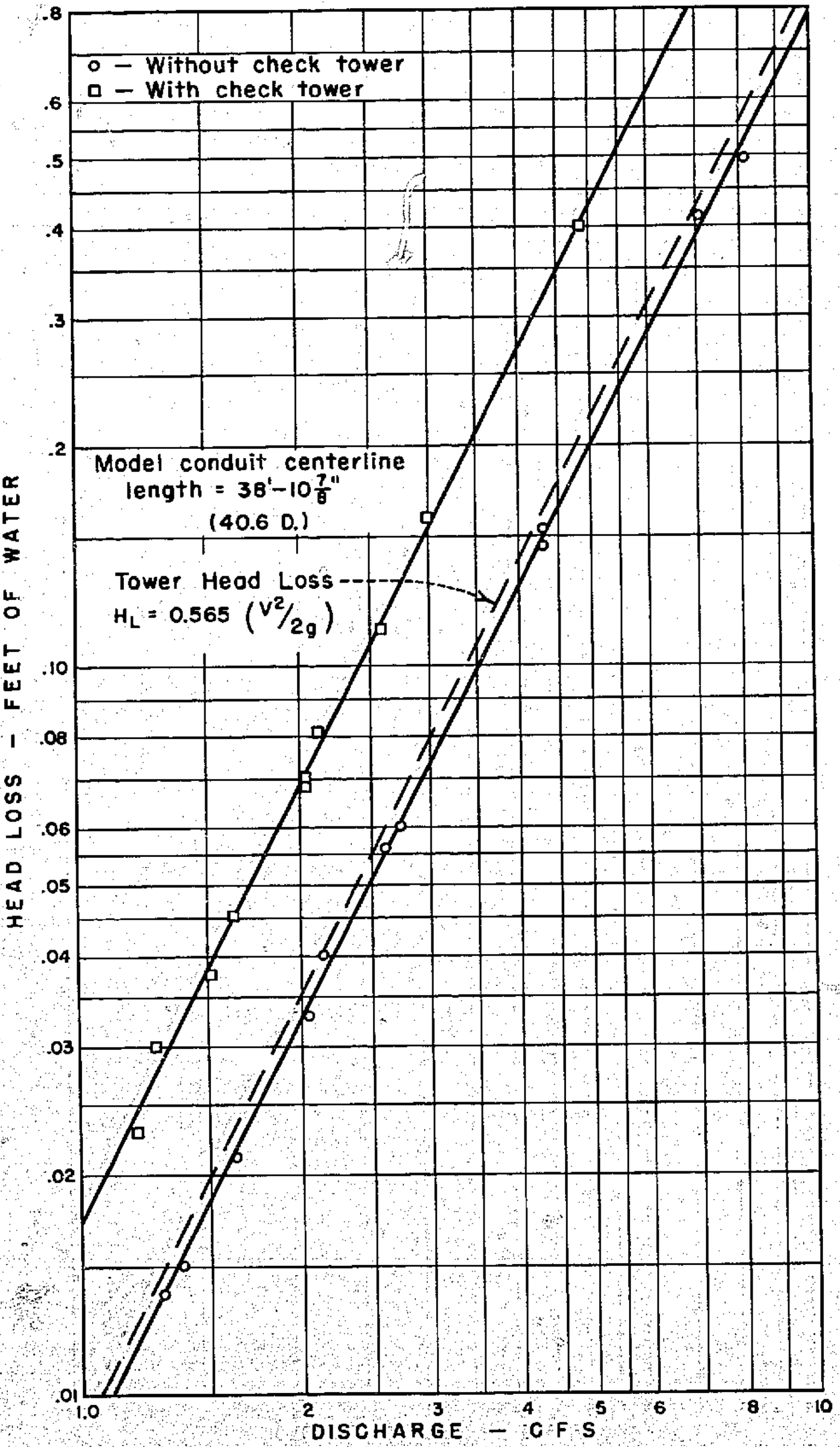


B. WITH CHECK TOWER

Note: Distance between piezometer rings, measured along conduit ℄'s, is the same in the straight run and with the check stand in place.

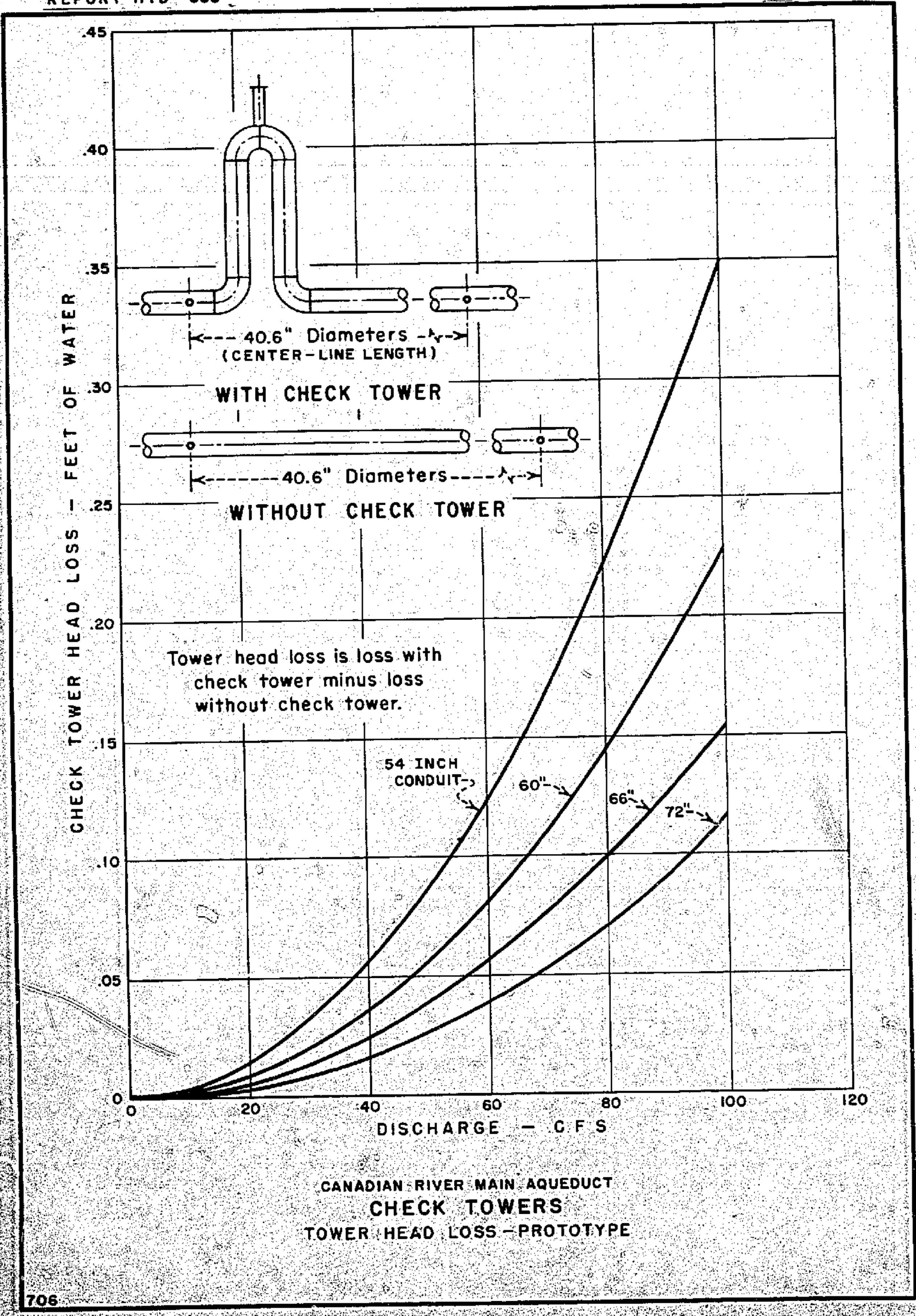
CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS
MODEL INSTALLATION FOR LOSS MEASUREMENTS

7.06

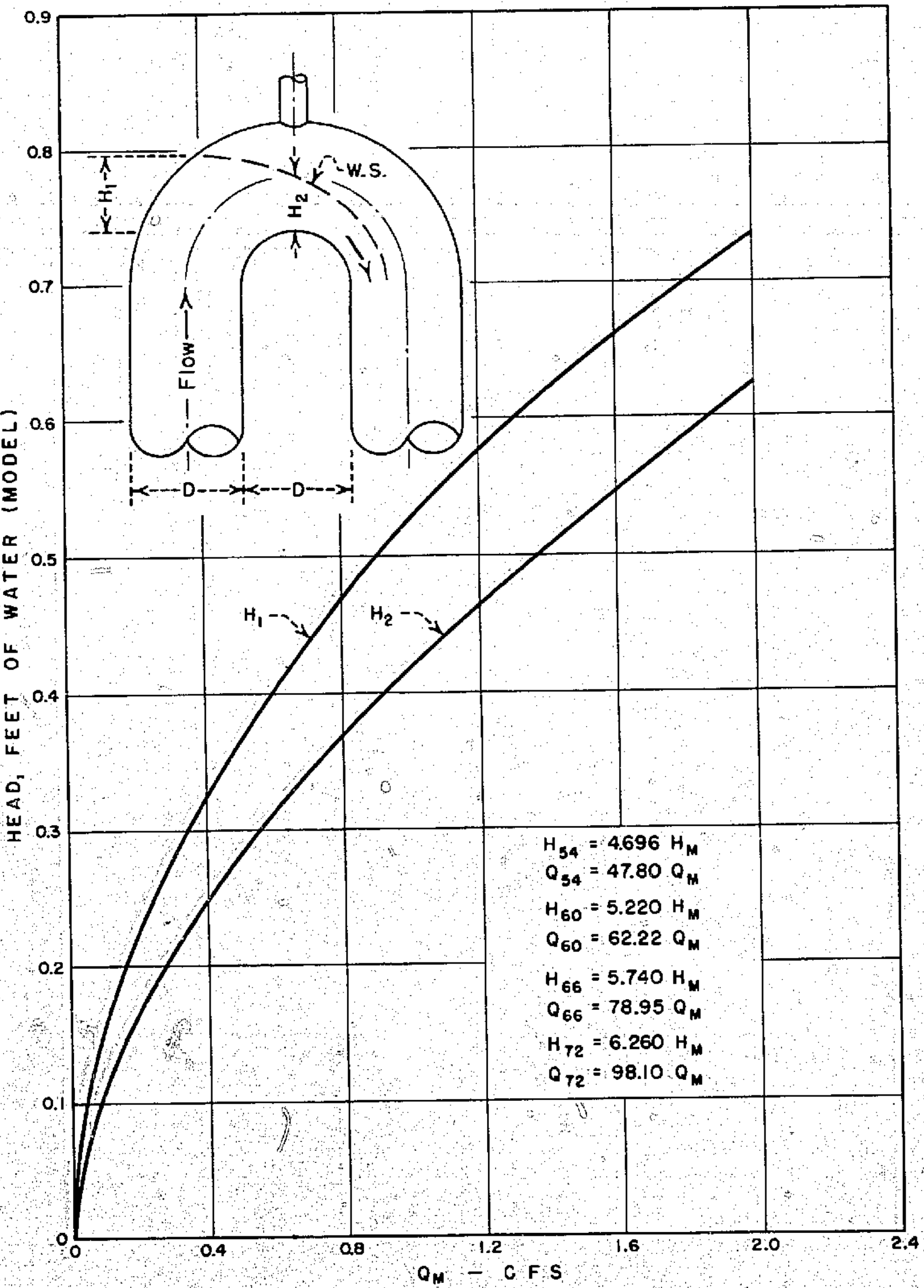


CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS
CONDUIT HEAD LOSS—MODEL

FIGURE 4
REPORT HYD-555

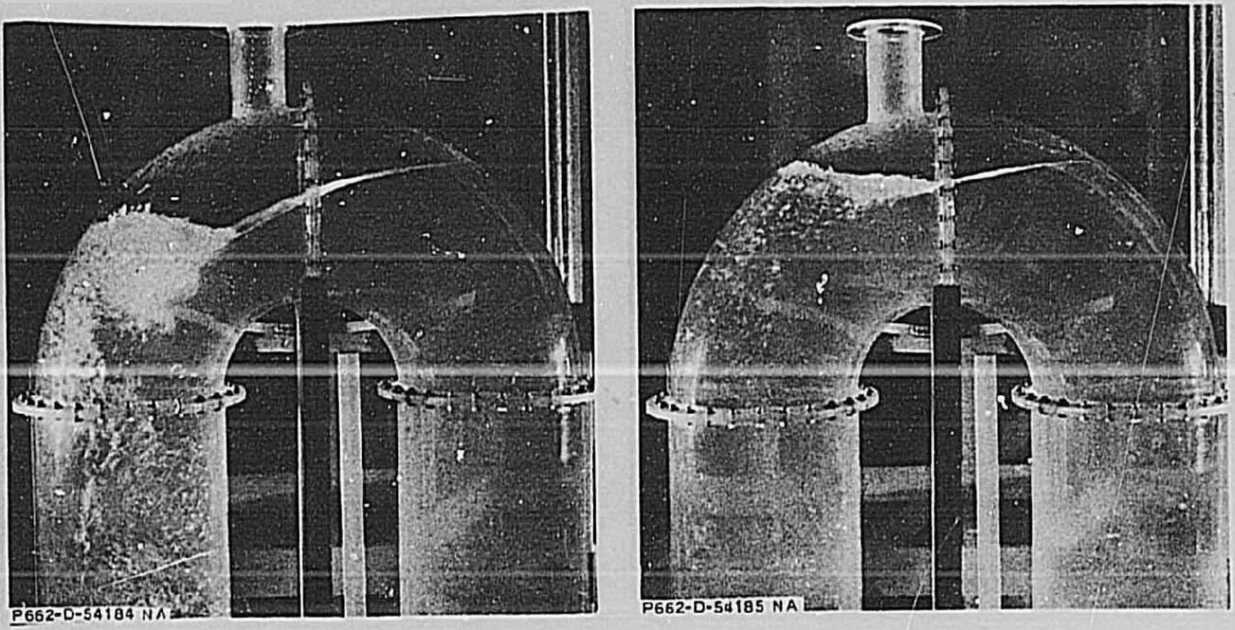


CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS
TOWER HEAD LOSS-PROTOTYPE



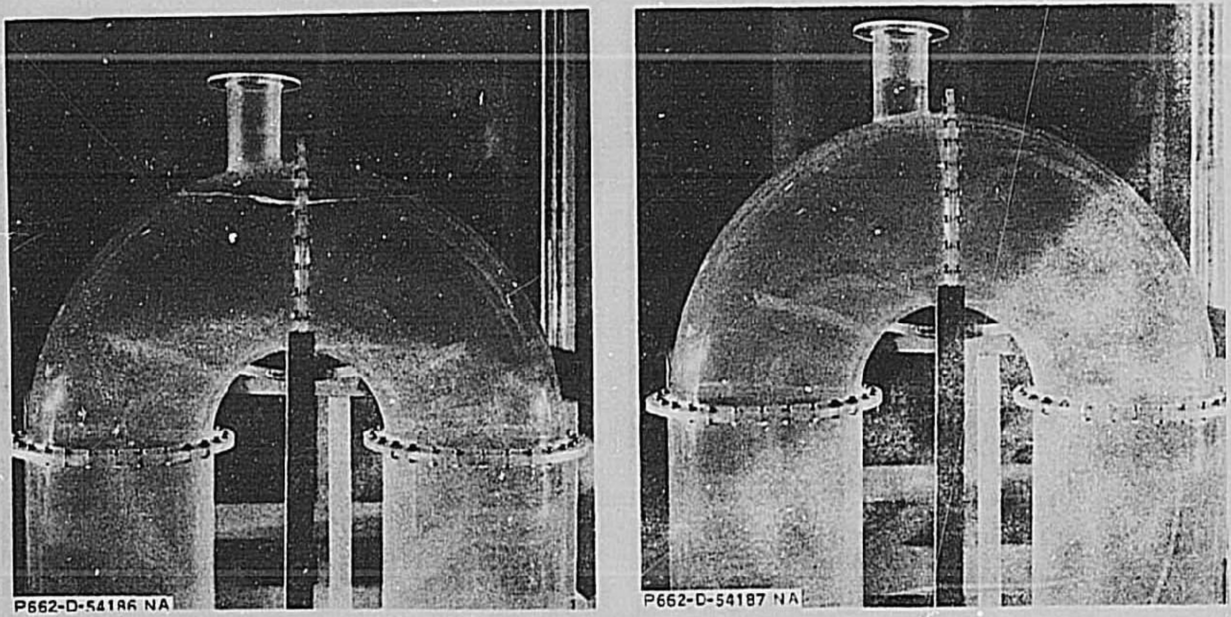
CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS
FREE FLOW OVER THE RETURN BEND

Figure 6
Report Hyd-555



A. Air entrained in the jump continues down the downstream leg.

B. Air entrained in the jump enters the downstream leg, but rises back to the free water surface.

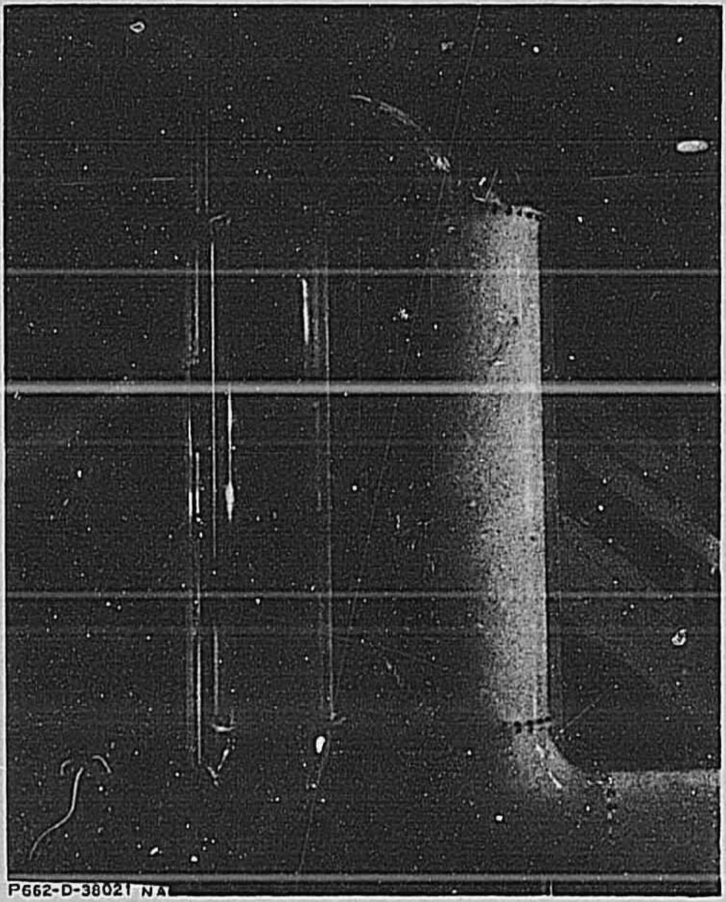


C. No air entrained - flow tranquil with bend partially full.

D. Normal operation - water surface in open pipe.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS

Controlled flow over the return bend.
Model discharge - 1.478 cfs.



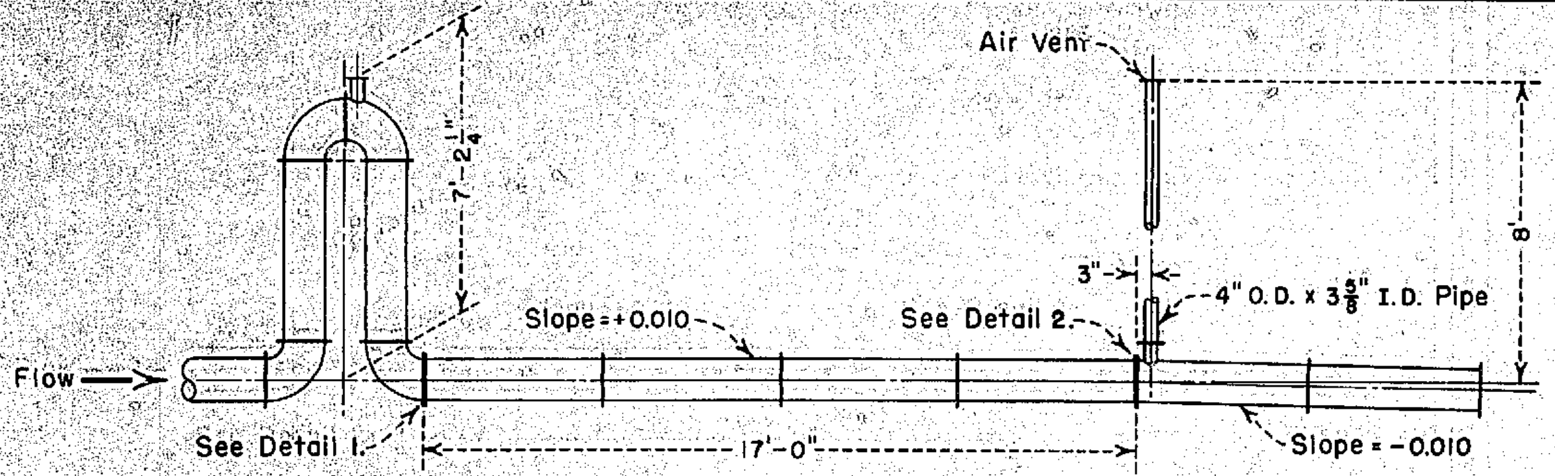
A. Entrained air in the downstream leg.

B. Air rising to the top of the horizontal conduit.

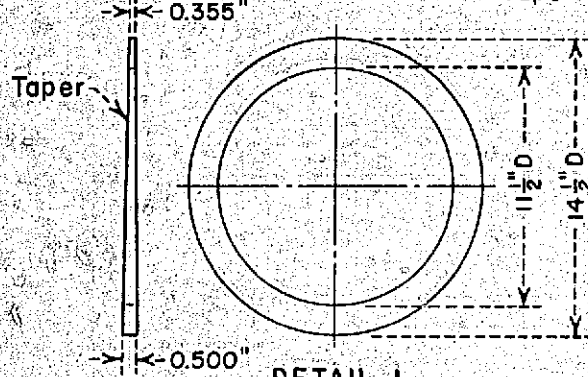
CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS

Entrained air downstream from the check tower crest (Q = 1.478 cfs).

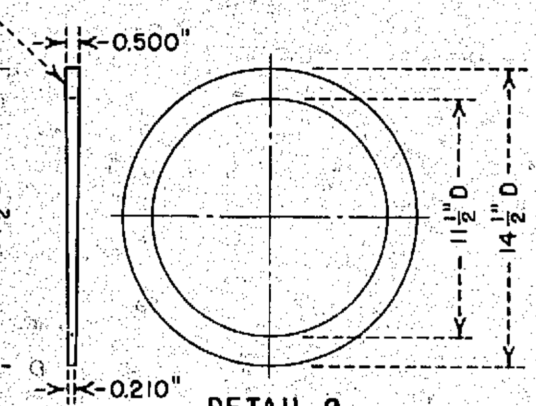
706



ASSEMBLED PIPE STAND AND AIR VENTS



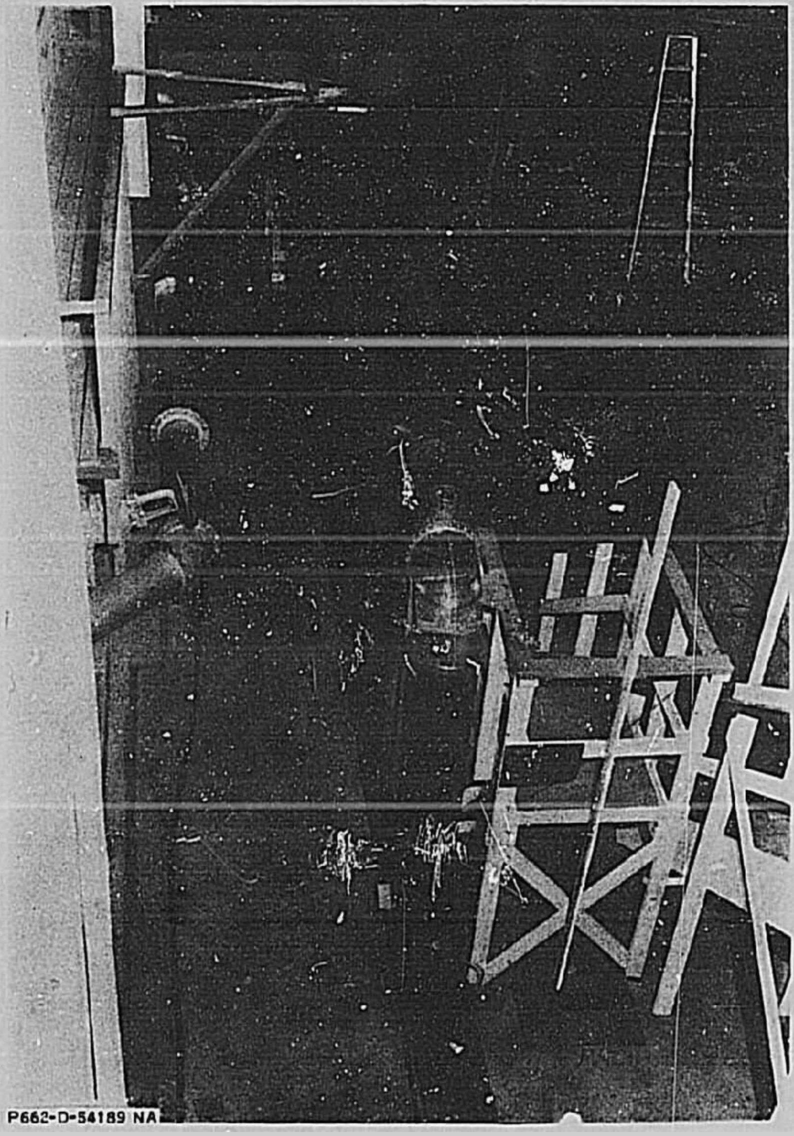
DETAIL 1.



DETAIL 2.

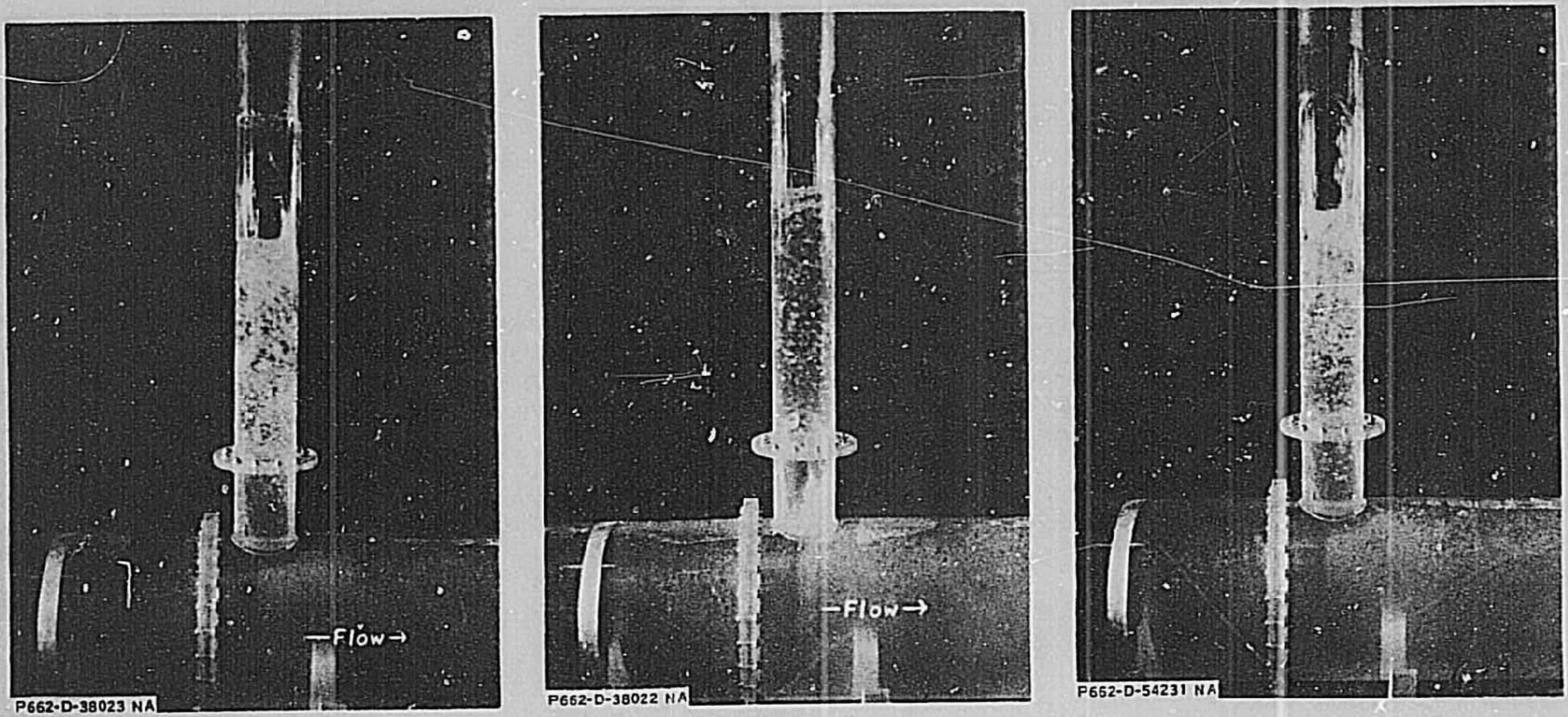
Fabricate wedge flanges from $\frac{1}{2}$" plastic.
Drill 28 - $\frac{17}{64}$" holes on 1.47" centers, straddle ℄.
13.10" Bolt circle.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS
CHECK TOWER AND AIR VENT STRUCTURE
MODEL INSTALLATION


P662-D-54189 NA

Overall view of model with check tower and air vent structure.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS



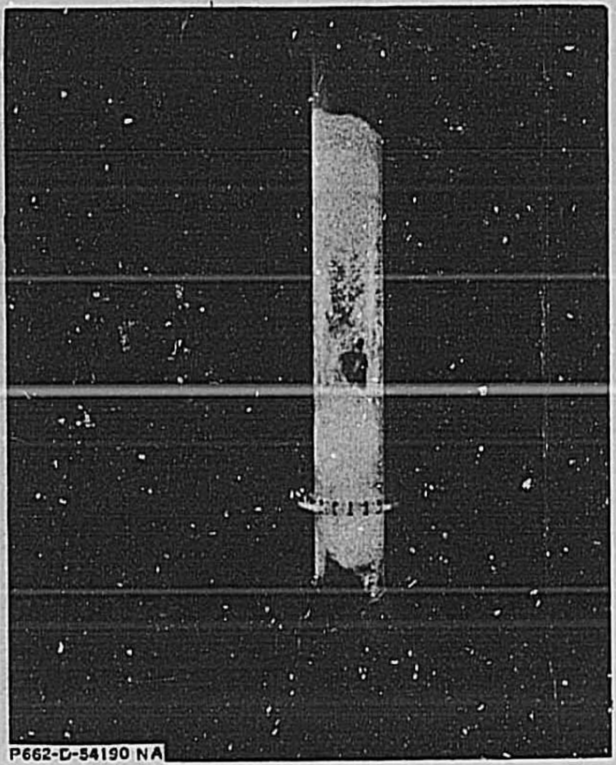
A. Large air pocket approaching the vent.

B. Part of air pocket has entered the vent; part has passed the vent.

C. Small air pockets continue to travel downstream. (Note the large air pocket supporting a solid slug of water.)

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS

Trapped air release, 3-5/8-inch air vent, Q = 1.478 cfs, -0.010 downstream slope.

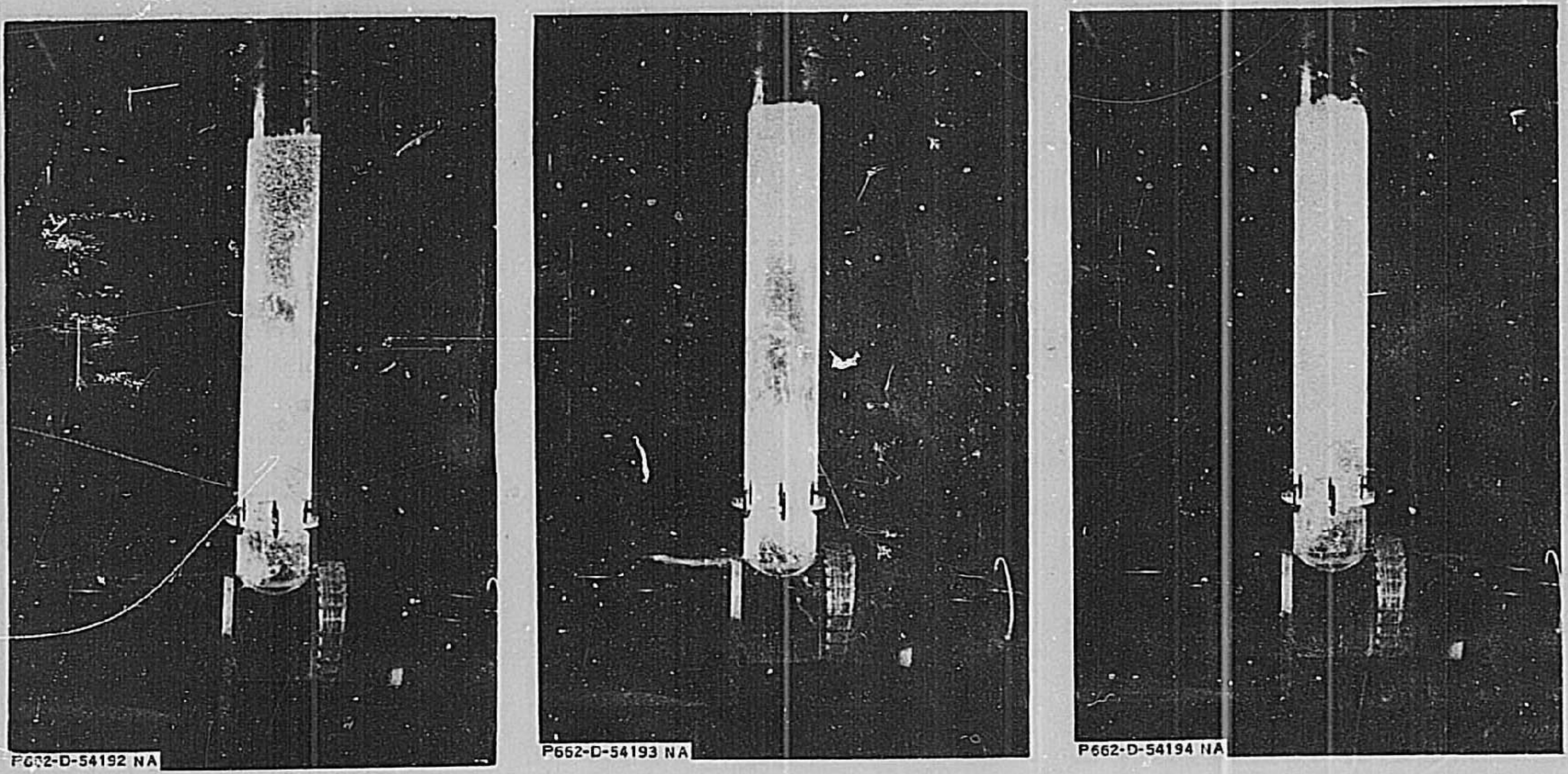


A. Air pumped from 5-1/2-inch air vent -0.030 downstream slope.

B. Air pumped from 11-1/2 by 3-5/8-inch cone -0.050 downstream slope.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS

Air pumped into downstream conduit from air vents (Q = 1.478 cfs).



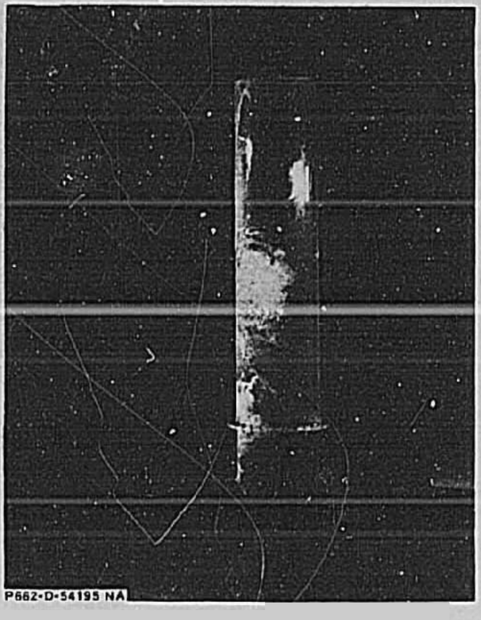
A. Air entering the vent from upstream.

B. Air being pumped from the vent into the conduit by vent water surface fluctuations.

C. Air returning to the vent from downstream.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS

Trapped air release, 7-1/2-inch air vent, Q = 1.478 cfs, 0.080 downstream slope.

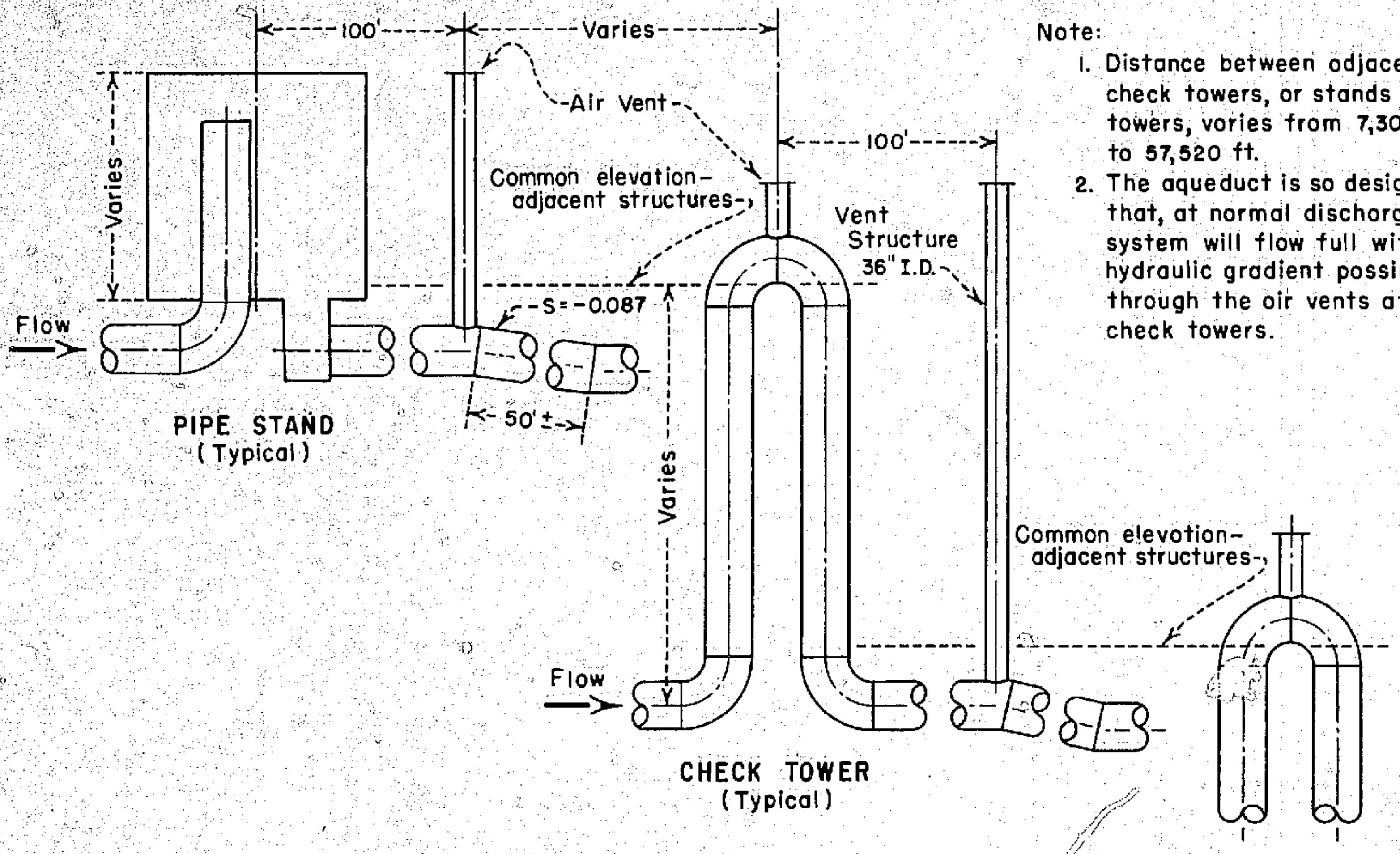


A. Vent air furnished from upstream only.

B. Vent air furnished from both upstream and downstream.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS

11-1/2-inch air vent structure, Q = 1.478 cfs, downstream slope = 0.080



Note:

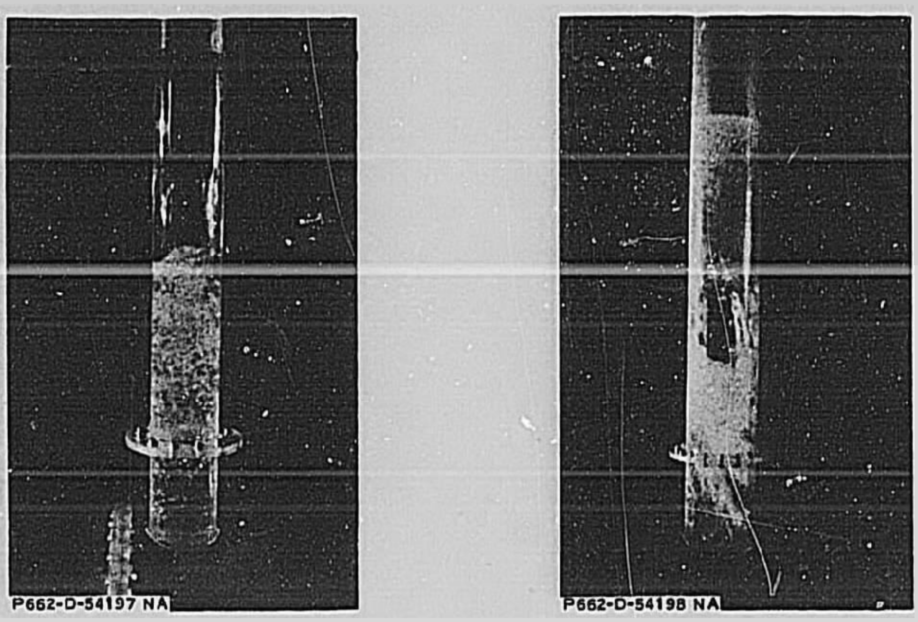
1. Distance between adjacent check towers, or stands and towers, varies from 7,300 ft. to 57,520 ft.
2. The aqueduct is so designed that, at normal discharge, the system will flow full with the hydraulic gradient passing through the air vents atop the check towers.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS
RECOMMENDED CHECK TOWER AND VENT STRUCTURE

706

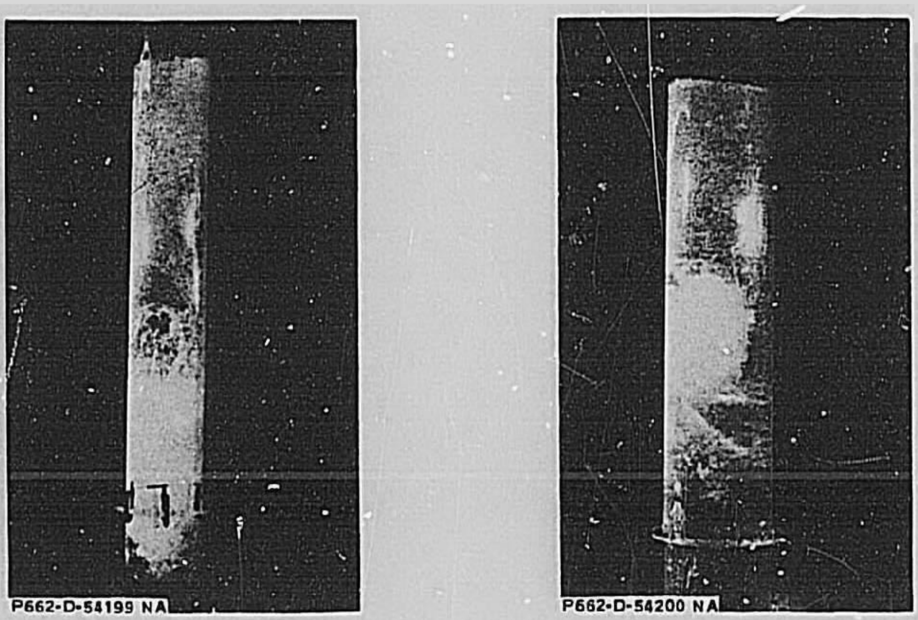
GPO 858-590

Figure 15
Report Hyd-555



A. 3-5/8-inch-diameter vent. Large homogeneous air cylinder rising slowly and evenly causing small water surface fluctuations.

B. 5-1/2-inch-diameter vent. Large ragged air pockets rising rapidly causing large water surface fluctuations.



C. 7-1/2-inch-diameter vent. Disintegrating air pocket rising rapidly causing relatively small water surface fluctuations.

D. 11-1/2-inch-diameter vent. Small air bubbles rising uniformly. Small water surface fluctuations are caused primarily by pressure surges.

CANADIAN RIVER MAIN AQUEDUCT
CHECK TOWERS

Air action in various air vent structures

7-1750
(10-64)

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 x 10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582 x 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 x 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 x 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

ABSTRACT

Head losses, air entrainment characteristics, and air venting requirements were determined from hydraulic model studies of proposed check towers for the Canadian River Aqueduct, Texas. The aqueduct flows 160 mi by gravity, drops 701 ft in elevation, and is constructed of 54-, 60-, 66-, and 72-in.-dia reinforced concrete pipe. Conduit wall pressures will be maintained at about 60-ft head by the check towers, each of which consists of 2 vertical sections of pipe connected at the top by a vented 180-deg return bend. The design discharge will be controlled by friction alone, and lesser flows will be controlled automatically in each pipe reach by the downstream check towers whose top inner radius serves as a crest for the water to flow over. Air will be entrained in the downstream leg of each tower during less than normal flows. This air will be removed from the aqueduct by a 36-in.-dia air vent located 100 ft downstream from each tower. Laboratory model studies showed that these check towers will operate satisfactorily for all discharges, preventing overpressures and water hammer during other than normal operation, and when running full flow will maintain the proper hydraulic gradient in the pipeline.

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Hyd-555
Colgate, D
HYDRAULIC MODEL STUDIES OF THE FLOW CHARACTERISTICS AND AIR ENTRAINMENT IN THE CHECK TOWERS OF THE MAIN AQUEDUCT, CANADIAN RIVER PROJECT, TEXAS. USBR Lab Rept Hyd-555, Hyd Br, June 1966. Bureau of Reclamation, Denver, 12 p, 15 fig, 2 tab, 1 ref

DESCRIPTORS-- *aqueducts/ *check structures/ distribution systems/ *surges/ pressure pipes/ standpipes/ flow resistance/ *head losses/ *hydraulic gradients/ hydraulic models/ *pressure conduits/ unsteady flow/ flow control/ air entrainment/ hydraulic conduits/ closed conduits/ concrete pipes/ water hammer/ model tests/ laboratory tests
IDENTIFIERS-- Canadian River Aqueduct/ Canadian River Project, Tex/ Texas/ hydraulic design

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