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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

CALIBRATION OF HOLLOW-JET VALVES AND VIBRATION STUDIES OF OUTLET WORKS Y-BRANCH FALCON DAM

Hydraulic Laboratory Report No. Hyd-474

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
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474 Falcon Dam Hollow Jet Valves & Y-Branch 474

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Laboratory Report No. Hyd-474
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Subject: Calibration of hollow-jet valves and vibration studies of outlet works--Y-branch--Falcon Dam

PURPOSE

The purpose of the study was to obtain rating curves for the hollow-jet valves which had vertical convex bends immediately upstream, and to study the cause and remedy for vibration occurring in the Y-branch upstream from the hollow-jet valves in the Mexican outlet works.

SUMMARY

Investigation of pressure conditions at pressure taps located in the pipe walls just upstream from the valves of scale models (Figure 1) disclosed that the piezometric head differed as much as 30 percent from the top to the invert of the pipes which followed convex vertical bends. Pressure taps for indicating head from which the valve discharges could be determined were limited to the top portion of the pipe 45 degrees each side of the vertical centerline a short distance upstream from the valves. This limitation was imposed to guard against errors that might be introduced through changes in circulation through the pressure system by future corrosion within the system. The variation in pressure head from top to invert of the pipe immediately upstream from the valves and differences in the bends upstream from the pressure taps made calibration of the Mexican and United States outlet works separate problems and special model calibrations were made to obtain the rating curves of Figures 2 and 3.

Vibrations noted in the Y-branch of the prototype Mexican outlet works were also noted in the model. Investigation showed large fluctuations in pressure within the branch with instantaneous values equal to vapor pressure. Investigation showed that fillers placed in the turbulent area within the branch (Figure 4) decreased the magnitude of the fluctuations and kept the minimum instantaneous pressures well above vapor pressure (Figure 5) with a decided decrease in vibration tendencies.

ACKNOWLEDGMENT

The model tests and much of the analytical work pertaining to the valve calibration and Y-branch vibration for the Falcon Dam outlet works were performed by Don Colgate and W. P. Simmons, Jr. of the Hydraulic Laboratory staff.

INTRODUCTION

The studies described in this report were made for the International Boundary and Water Commission, United States and Mexico, in 1954. The material was first presented as memoranda in 1955. The results of the studies concerning the calibration of hydraulic models of the hollow-jet valves of the outlet works of Falcon Dam in their individual settings, and the vibration in the Y-branch and movement of the 102-inch butterfly valve in the left conduit of the Mexican outlet works, are now presented in report form because of the general interest and application of the results obtained. Hydraulic model studies of the spillway and outlet works stilling basins made prior to the studies covered in this report are presented in Hydraulic Laboratory Report No. Hyd-276.

During recent years there has been a trend to use outlet valves as devices for measuring releases of water from reservoirs. In instances where the field installations have been identical to those used in model studies, good accuracy has been obtained. In these cases there have been sufficient lengths of straight pipe upstream of the valves to assure good velocity and pressure distribution at the pressure measuring section arbitrarily selected at one pipe diameter upstream of the valve inlet. When the model tests were made it was realized that variations in approach piping would affect the head-discharge relationship, but such cases would not be standard and so would have special consideration as the designs were developed. The pressure taps upstream of the Falcon Dam outlet valves all being immediately downstream of bends made the calibration of the Falcon Dam hollow-jet valves a special problem. Models of the outlet valves and piping were therefore constructed and tested to provide accurate rating curves for determining outlet works discharges. After the outlet works at the Mexico side of the Rio Grande River was placed in operation, it was reported that there was vibration and noise in the Y-branch and a tendency for the No. 2 butterfly valve in the left branch to vibrate and move toward the closed position. Also, that certain corrective measures had been applied and found to be ineffective. Noise in the system and the movement of the piston-operating mechanism of the butterfly leaf were also described. The movements and sounds had a frequency of from 2 to 3 seconds. The sounds were referred to as cavitation sounds, having a rather loud and heavy thumping or slapping nature. The conditions were believed to result from turbulence originating at the Y junction, and it was proposed that the model used for calibration of the hollow-jet valves be used to investigate this possibility.

THE INVESTIGATION

The Models

Two hydraulic models and one aerodynamic model were used for the calibration tests on the Falcon Dam outlet valves. The aerodynamic model represented a portion of the piping upstream of the Y-branch in the United States outlet works. This model was used to determine to what extent the conduit system upstream of the Y-branch would have to be represented in the hydraulic models. The hydraulic models represented the United States and Mexican outlets. Since a 6-inch valve was used in both cases, the scale ratios were 1:12 and 1:15, respectively, for the United States and Mexican outlet works. The hydraulic models are shown on Figure 1.

Test Procedures

In order for calibration curves obtained from model valves to be applicable to the prototype valves, the model pressure heads and valve openings must correctly represent those of the prototype. The flow lines must be similar, particularly in the valve and in regions where pressure taps are located. Considerable preliminary testing was required on the models of the Falcon Dam outlet works valves and upstream piping to determine to what extent the prototype piping would have to be represented in order to fulfill these requirements. It was believed that the valves, the piping immediately upstream, the Y-branches, and a portion of the piping upstream of the branches would be needed. Because of the nearness of the pressure taps to bends in the prototype conduit system, it was considered important that they be located accurately in the model, so field locations were requested and the model taps installed accordingly.

The approaches to the outlet branches were of first importance, since if the velocity distribution into them was quite symmetrical the penstock systems upstream could be represented by short sections of straight pipe. An examination of the two designs showed the United States side would be more likely to contain an unsymmetrical velocity pattern in the pipe ahead of the outlet branch than the Mexican side because of the type of branch connecting it to one of the turbine penstocks. A model was constructed of lightweight metal and tested, using air as a fluid to ascertain the velocity distribution entering the Y-branch. The model represented a part of the power penstock, the branch from the penstock, and the length of outlet pipe from this branch to a point a short distance above the outlet branch. From pitot traverses at the end of the model piping it was found that a very symmetrical velocity pattern existed. This was proof that a good velocity distribution would exist at the entrance of the Y-branch and that it would only be necessary to construct the piping of the hydraulic models to provide this type of distribution. From the tests it was concluded that conditions for the Mexican outlet works would be less severe than in the United States outlet works, and that its model could be constructed to give a good velocity pattern at the entrance of the Y-branch. Location of the models in the laboratory provided 8-1/2 feet of straight pipe upstream of the United States outlet works branch and 20 feet upstream of the Mexican outlet works branch. These lengths were considered more than adequate.

After the extent of the upstream piping had been established, tests were made to determine in what detail the piping, bends, and valves downstream of the branches would have to be represented for the calibration tests.

Tests were conducted on both models with one leg of the branch represented in its entirety including the valve, and the other with sufficient piping to contain a calibrated orifice. A study of the pressures just upstream of the valve for various discharges disclosed that operation of one leg of the branch would not affect the pressure discharge relationship in the other. These tests proved that a calibration of one valve with the other branch leg completely closed would apply for all flows.

Because of the location of the pressure taps near the downstream ends of pipe bends, it was expected that the pressure heads at the taps would vary with location on the periphery of the pipe. Heads at each of the taps were measured for all four valves. Since the taps were not located exactly symmetrical with the axes of the bends, the pressure heads at each were expected to be different, those to the outsides of the bends being higher than those to the insides. Initially, it was presumed that the average pressure at the section would be registered in the manifold and that this would permit use of calibration curves for similar valves connected to straight conduits. Measurements at the model taps of the United States outlet valves showed the pressures to the outside of the bend to be as much as 4 percent different from those to the inside of the bend, and those of the Mexican outlet valves to be as much as 31 percent different. It was found that the pressure head for the two top taps (on outside of bend) differed only slightly. The same was true of the two lower taps (those on the inside of the bend).

With a manifold connecting all four taps there would be flow from the higher to the lower pressure openings and the pressure within the manifold would be between the two extremes. The magnitude of this manifold pressure would vary depending on the size of the tap opening and other water passages. A calibration with this arrangement would be possible but would be applicable for only the particular arrangement and water passage size ratios. An accumulation of foreign material in any opening would change the pressure in the manifold and thus the pressure discharge relationship. This would decrease the measurement accuracy. Corrosion in the openings might result in the same type of action, thus the use of all four taps of a section connected to a manifold was not considered satisfactory. Since the pressure heads at the two taps on the inner curve of the bend were nearly the same and those at the two taps on the outer curve of the bend were nearly the same, the circulation within a manifold using either set of two taps would be small and excessive corrosion or blocking of a tap would not noticeably affect the accuracy. The use of the taps at the outer surface of the bend was recommended because heads of greater magnitude would be involved and it was felt that this would result in more accurate recordings of the head.

Calibration Tests

Calibration curves based on the pressure head at two top taps upstream from each valve were prepared from model data for the 72-inch United States valves and the 90-inch Mexican valves, Figures 2 and 3. The calibration curves are based on pressure heads above elevation 188.02 for the United States valves and above elevation 188.71 for the Mexican valves (centers of valve entrances), as registered in a manifold connecting the two top taps upstream from the valves, and on valve openings expressed in percent of a needle travel equal to one-third the valve entrance diameter. The calibration charts include valve openings in excess of 100 percent because the needle travel in these installations is greater than one-third of the valve entrance diameter.

Vibration Studies

Since pressure variations and intensities are important factors when vibration and noises are present, 32 piezometers were installed in critical pressure zones of the model representing the Mexican outlet works. Some of these piezometers are shown in Figure 4. The critical zones were : (1) the left inner wall of the left branch immediately downstream of its intersection with the upstream pipe, (2) the joint formed by the intersection of the two legs of the Y-branch, and (3) the butterfly valve stations.

An attempt was first made to measure transient pressures at each piezometer using an inductance-type pressure cell. The results obtained were erratic and inconsistent, and it was found necessary to change to a strain gage type of pressure cell. Oscillograph records were taken for nearly all piezometers with equal flows through both branches and with all flow through the left branch. A study of the oscillograph records showed pressure variations and instantaneous low pressures to be more severe when the flow was equally divided between the two legs of the branch than when it was confined to the left leg. With equally divided flow, substantial pressure variations occurred at the left butterfly valve. Much smaller variations occurred at the right butterfly valve. This was in agreement with prototype observations.

The surges at the left valve were most pronounced on the invert and left side and appeared to be the result of a zone of turbulence along the upstream left side of the left branch. The frayed condition of the jet from an orifice placed at the No. 2 butterfly valve position during the calibration tests showed that turbulence from the Y-branch extends downstream to the butterfly valve. The maximum pressure variation recorded in the initial tests, 48 feet of water prototype and the minimum instantaneous pressure, -16.5 feet of water prototype, were measured in this zone (Piezometer No. 5). Such pressure variations undoubtedly exist in the prototype and are responsible for the vibration in the structure and for the forces which tended to close the left butterfly leaf. It is possible that more severe subatmospheric pressures than measured exist momentarily and that these low pressures may reach vapor pressure causing cavitation. There was indication that this was the case when tests were made later with the addition of Piezometers A, B, C, D, E, and F (Figures 4 and 5).

Operation of the valves simultaneously at small openings, or confining the flow to one valve until it reaches full opening before opening the second valve might be used to minimize the pressure fluctuations and vibration. Limitations of this type are not conducive to efficient operation so further study of the problem seemed desirable. It is believed that converging instead of expanding water passage areas within the Y-branch would have given better conditions. The sum of the areas of the two branch legs of the Mexican outlet works is greater than the area of the passage at the branch entrance. While this condition may not be a major influence on the pressure surges and vibration, it is decidedly a contributing factor.

A review of test results obtained from models of the penstock branches for Hoover Dam (Part VI, Bulletin 2, Boulder Canyon Project Final Reports) disclosed that much was accomplished toward eliminating zones of turbulent flow in the branches when filler blocks were placed to occupy the turbulent zones. Because of the effectiveness of these filler blocks, a decision was made to install one at the left wall of the left branch and study its influence on the pressure surges. It was hoped that the Hoover tests would indicate the shape of block required and data from the bulletin was plotted. It was found, however, that because of the difference in shapes of the Y-branches the data could serve only as a general guide, and a modified shape was developed. The shape is shown in Figure 4 as the 8.9-inch filler block. The block was placed with the upstream end at the intersection of the branch leg with the main pipe and extended into the pipe to occupy the turbulent zone indicated by the initial pressure records. The inner surface of the block (flow surface) was made using straight, vertical elements because of simplicity of construction for the prototype structure. Piezometers A, B, C, D, E, and F were placed in the filler block and pipe walls at the locations shown in Figure 4 and pressure records (using a strain gage type pressure cell) were taken with an oscillograph. Records were taken both with and without the filler block in place.

An examination of the oscillograph records disclosed that an extensive reduction in pressure fluctuations had been accomplished by installing the filler block (Figure 5). There seemed also to be a decided reduction in the noise and vibration of the model. The fluctuation in pressure at the No. 2 butterfly valve location was reduced considerably (Piezometer 32, Figure 5). Because of the pronounced effectiveness of the filler block in reducing the pressure fluctuations and vibration it seemed desirable to determine the effectiveness of a smaller filler block. A similar, but smaller, filler block was installed (Figure 4). A comparison of the oscillograph records for this filler block showed it to be much less effective.

After a study of the records for conditions with and without the blocks, it was believed that improvement could be obtained in the region of Piezometers B, C, D, and E by using a block that was longer and thicker than the 8.9-inch one. The 10.9-inch long block was, therefore, installed. Pressure fluctuations along the block were still somewhat larger than those at the branch entrance, or those at the butterfly valve, and further improvement might be accomplished by a still longer block. The added length was not considered justified in this case since the maximum fluctuation was 19.5 feet compared with 4.0 feet at the branch entrance. The following table of pressure fluctuations shows the relative effectiveness of the filler blocks.

Table 1

	Without filler block	Short (6") filler block	Intermediate (8.9") filler block	Long (10.9") filler block
Location of max. surge	Piezometers D and E	Piezometer C	Piezometer C	Piezometer B
Magnitude of max. surge	62.0	63.0	19.5	19.5
Location lowest pressure	Piezometer 5	Piezometer C	Piezometer A	Piezometer A
Magnitude lowest pressure	-16.5	-27.3	7.2	2.8

Pressures given in feet of water, prototype.

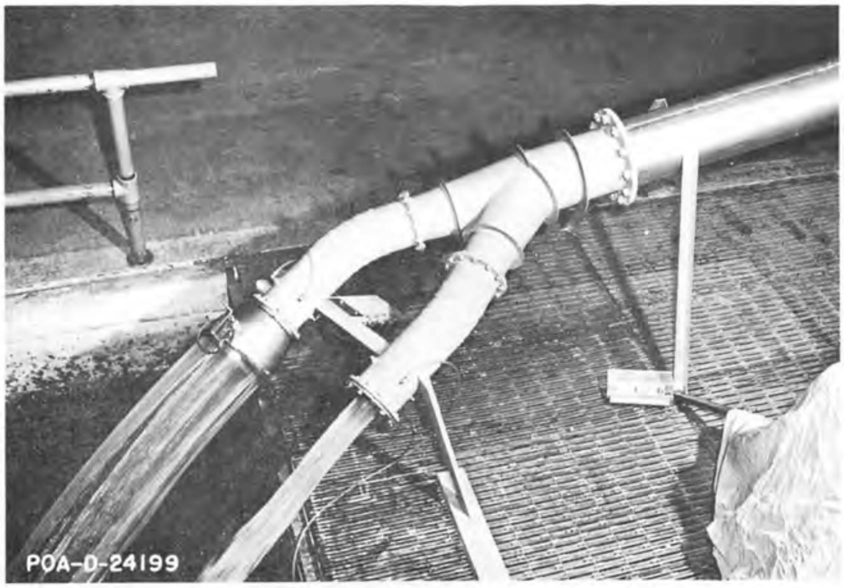
The following table gives the average pressure at the various piezometers for the maximum head and both valves fully open.

Table 2

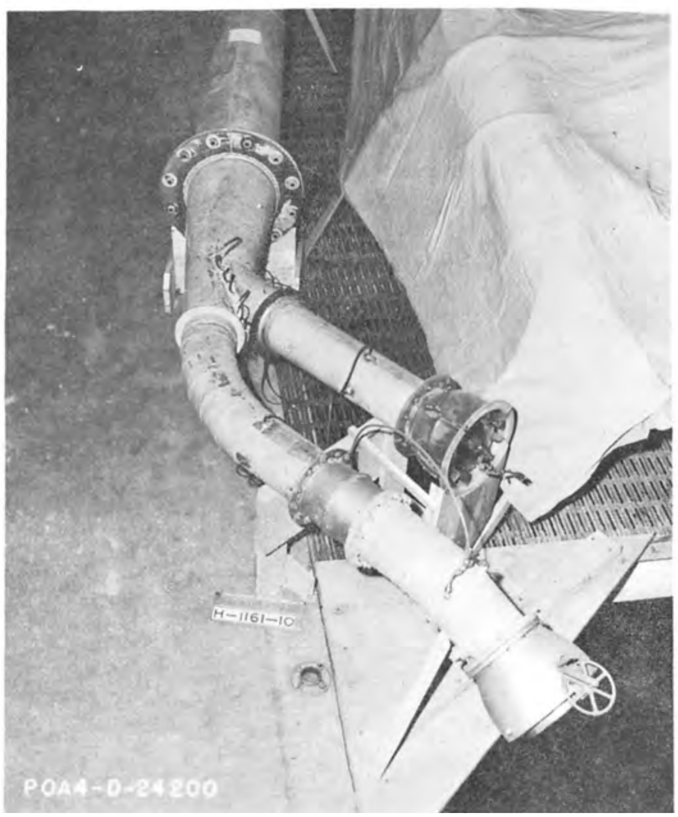
Piezometer Number	Without block	With 6" block	With 8.9" block	With 10.9" block
6	57.5	55.3	56.3	53.4
7	62.3	61.4	60.0	60.0
1	22.5	10.7	13.5	16.7
A	7.8	28.8	11.0	6.6
B	7.2	37.5	38.3	36.5
C	15.6	58.2	49.8	49.5
D	32.4	61.5	61.5	57.2
E	52.8	57.0	65.3	--
F	53.7	57.0	62.4	61.8
29	53.3	54.2	56.0	55.7
30	56.9	58.5	58.8	58.8
31	57.0	58.2	59.9	60.6
32	56.9	57.9	59.7	59.0
12	83.6	86.0	89.0	86.3
13	88.5	96.8	94.5	94.5
16	--	95.7	97.5	100.7
17	--	117.0	111.0	117.0

Because of the effectiveness of the two long filler blocks in reducing the vibration and pressure fluctuations in the model, it is recommended that consideration be given to installing a similar shape in the Y-branch of the Mexican outlet works. The filler could be formed of flat plate stock to shape and welded to the pipe walls. The length should be at least that of the 8.9-inch block (13.4 feet proto) and preferably should be longer. The space between the plate and pipe walls might be filled with concrete. It is believed that the vibration described in a report by the Mexican engineers will be reduced to an acceptable amount by the installation of the filler block.

Figure 1



United States Outlets
Right Outlet Complete
Orifice replacing left hollow-jet valve
Model scale 1:12



Mexican Outlets
Right Outlet Complete
Left outlet--Laboratory control valve in position of left butterfly valve
Model scale 1:15

FALCON DAM HOLLOW JET VALVE CALIBRATION

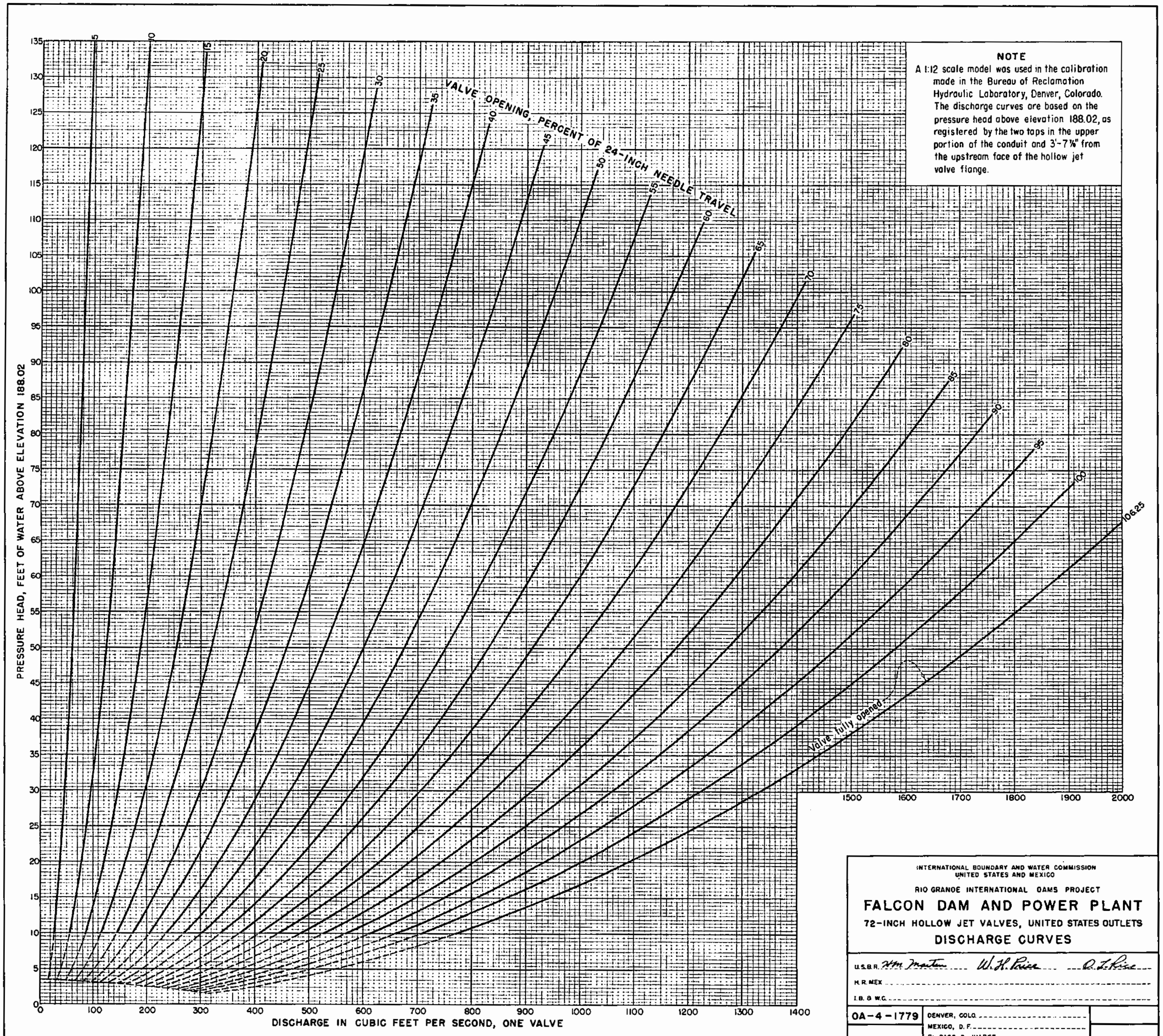
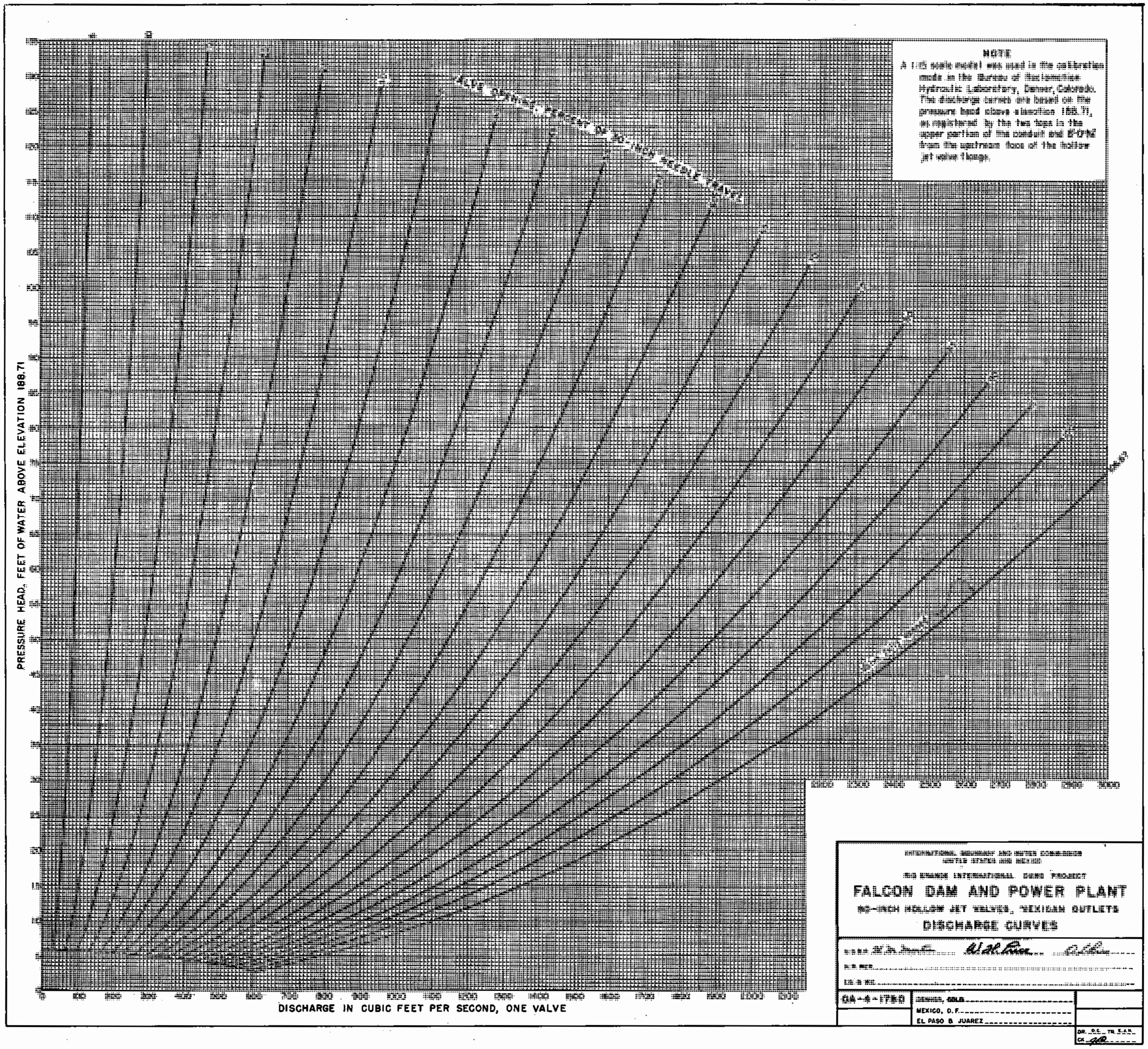

NOTE
A 1:12 scale model was used in the calibration made in the Bureau of Reclamation Hydraulic Laboratory, Denver, Colorado. The discharge curves are based on the pressure head above elevation 188.02, as registered by the two taps in the upper portion of the conduit and 3'-7¼" from the upstream face of the hollow jet valve flange.
VALVE OPENING, PERCENT OF 24-INCH NEEDLE TRAVEL
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
106.25
Valve fully opened
PRESSURE HEAD, FEET OF WATER ABOVE ELEVATION 188.02
DISCHARGE IN CUBIC FEET PER SECOND, ONE VALVE
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
INTERNATIONAL BOUNDARY AND WATER COMMISSION
UNITED STATES AND MEXICO
RIO GRANDE INTERNATIONAL DAMS PROJECT
FALCON DAM AND POWER PLANT
72-INCH HOLLOW JET VALVES, UNITED STATES OUTLETS
DISCHARGE CURVES
U.S.B.R.
H.R. MEX
I.B. & W.C.
OA-4-1779
DENVER, COLO.
MEXICO, D.F.
EL PASO & JUAREZ

FIGURE 2



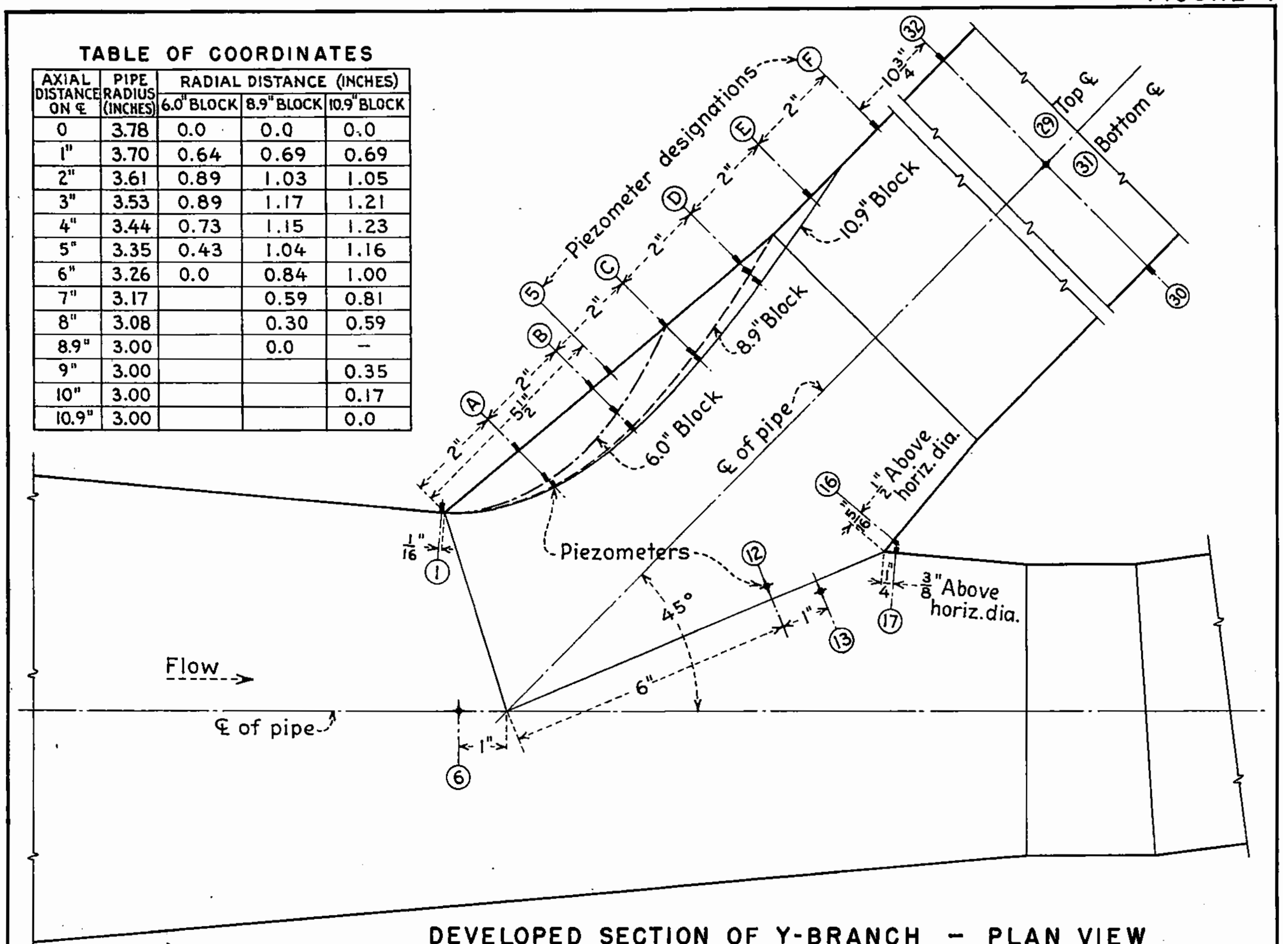
NOTE
A 1:15 scale model was used in the calibration made in the Bureau of Reclamation Hydraulic Laboratory, Denver, Colorado. The discharge curves are based on the pressure head above elevation 188.71, as registered by the two taps in the upper portion of the conduit and from the upstream face of the hollow jet valve flange.
PRESSURE HEAD, FEET OF WATER ABOVE ELEVATION 188.71
DISCHARGE IN CUBIC FEET PER SECOND, ONE VALVE
FALCON DAM AND POWER PLANT
MEXICAN OUTLETS
DISCHARGE CURVES
MEXICO, D. F.
EL PASO & JUAREZ

FIGURE 3

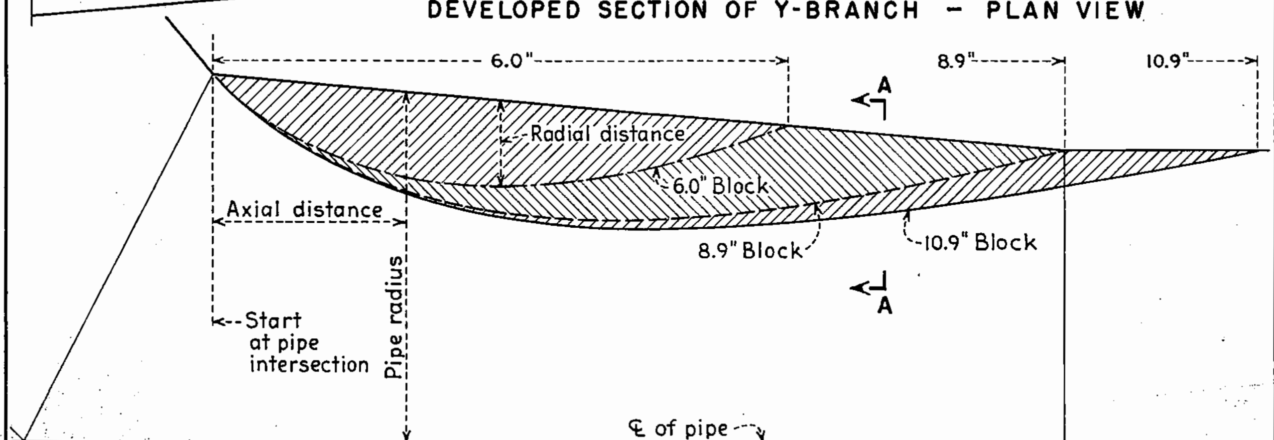
FIGURE 4

TABLE OF COORDINATES

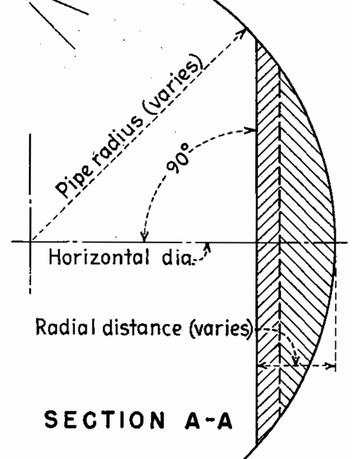
AXIAL DISTANCE ON ℄	PIPE RADIUS (INCHES)	RADIAL DISTANCE (INCHES)		
		6.0" BLOCK	8.9" BLOCK	10.9" BLOCK
0	3.78	0.0	0.0	0.0
1"	3.70	0.64	0.69	0.69
2"	3.61	0.89	1.03	1.05
3"	3.53	0.89	1.17	1.21
4"	3.44	0.73	1.15	1.23
5"	3.35	0.43	1.04	1.16
6"	3.26	0.0	0.84	1.00
7"	3.17		0.59	0.81
8"	3.08		0.30	0.59
8.9"	3.00		0.0	–
9"	3.00			0.35
10"	3.00			0.17
10.9"	3.00			0.0



DEVELOPED SECTION OF Y-BRANCH - PLAN VIEW



ENLARGED SECTION OF BLOCKS

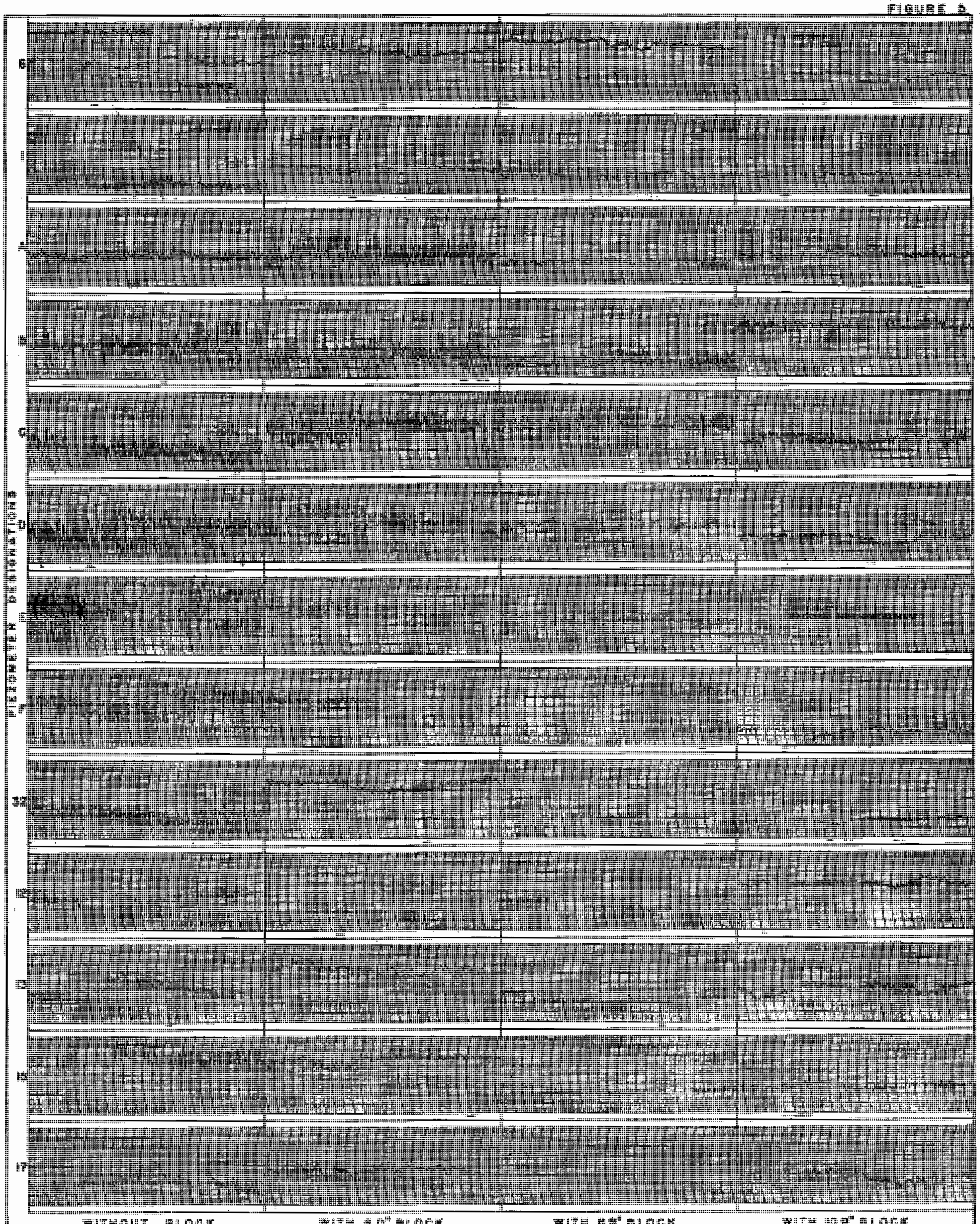


SECTION A-A

FALCON DAM
OUTLET WORKS - MEXICAN SIDE
PRESSURE VARIATIONS IN Y-BRANCH

PIEZOMETER LOCATIONS AND FILLER BLOCKS
1:15 SCALE MODEL

522



Horizontal scale:- lines at $\frac{1}{5}$ second intervals, Vertical scale:- heavy lines at 0.5" H_2O model intervals

NOTES

See Figure 4 for piezometer locations and block shapes.
Both 90-inch hollow jet valves fully opened - maximum head.
Rate of flow - 6.68 c.f.s. (5820 c.f.s. prototype)

FALCON DAM
OUTLET WORKS — MEXICAN SIDE
PRESSURE VARIATIONS IN Y-BRANCH

PRESSURE TRACES
1:15 SCALE MODEL