HYDRAULIC MODEL STUDY OF THE OUTLET WORKS IN DIVERSION TUNNEL NO. 2 FOR BHUMIPHOL DAM

Prepared for

Engineering Consultants, Inc.

Denver, Colorado

by

Susumu S. Karaki

Research Foundation
Colorado State University
Fort Collins, Colorado
January 1960

CER60SSK5

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PREFACE

The hydraulic model study of the diversion outlet works in tunnel No. 2 of the Bhumiphol Dam was conducted in the hydraulics laboratory of Colorado State University for Engineering Consultants Inc., Denver, Colorado.

Bhumiphol Dam, a concrete arch dam, will be located in the northwestern sector of Thailand, across the Ping River near the junction of the Wang and Ping Rivers. The dam will be approximately 154 meters high with a crest length of about 470 meters, and it will contain a reservoir with a capacity of approximately 12.2 billion cubic meters of water. The dam is part of the multipurpose Yanhee project for power development, flood control, irrigation and navigation improvement.

The temporary outlet works, with which this model study was concerned, will be constructed in river diversion tunnel No. 2 after the tunnel is no longer needed for diversion. The tunnel will be plugged and 2-1.25 x 1.80-meter high-pressure gates will be installed to control the flow. The outlets are needed to pass minimum river flow requirements before, and during installation of the initial generator units and to provide means for draining the reservoir.

The purpose of this model study was to determine flow characteristics of the high velocity flow discharging from the high-pressure outlet gates into the tunnel, and by experimentation, to develop a structure to adequately control or dissipate the kinetic energy in the flow to minimize damage in the tunnel.

The model was constructed by the shop staff of the Hydraulics Laboratory and the studies were conducted by F. Videon and F. Trelease,

graduate students in Civil Engineering under the direction of S. Karaki, Assistant Research Engineer. Acknowledgments are due Dr. A. R. Chamberlain, Acting Dean of Engineering and Chief of Engineering Research, and Dr. M. L. Albertson, Director of Colorado State University Research Foundation for their administrative and technical assistance.

The writer wishes to express his appreciation for the cooperation of the staff of Engineering Consultants, Inc., in providing prints of drawings, prototype construction data, and for their helpful suggestions during model testing.

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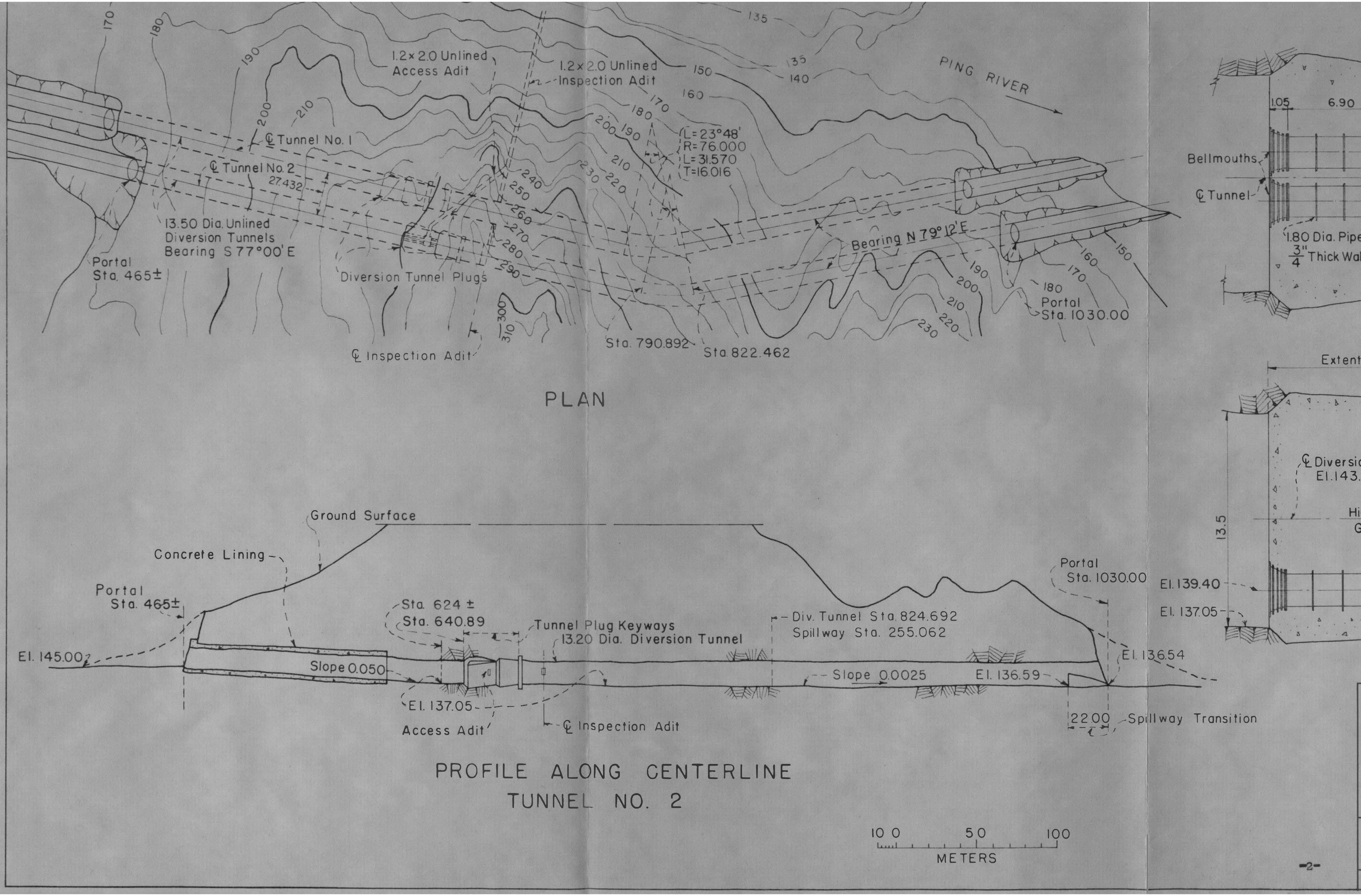
I. INTRODUCTION

The temporary river outlet works will be constructed in diversion tunnel No. 2 after necessity for river diversion has ended and before the spillway is completed. This will be accomplished by constructing within the tunnel a concrete plug with two high pressure rectangular gates 1.25 x 1.80 meters in size installed in the tunnel plugs as shown in Fig 1. The temporary outlets will be used during construction of the dam and power house for a period of approximately two years. After completion of the generator units the outlet works will no longer be functional. The tunnel will be plugged at the junction with the spillway tunnel and the gates may be removed.

Need for the outlet works arises from irrigation requirements in the Ping River Valley and the gates will operate at maximum opening most of the time. When the head is near maximum in the reservoir and the gates are fully open, discharge will be approximately 180 cubic meters per second, and the velocity at the gate will be about 42 meters per second. With this high velocity, considerable erosion damage was expected along the invert of the tunnel, especially in the upstream sections of the tunnel and also at the tunnel bend.

The purpose of the model study was to determine the flow characteristics in the tunnel for the high velocity flow, and to experimentally develop a structure which would control the flow and prevent damage to the tunnel. A deflector was tested at the bend to deflect the flow from the wall. Because of the limitations of the deflector to adequately control all discharges, a stilling basin, immediately downstream from the outlet gates was developed to dissipate the kinetic energy in the flow.



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MODEL STUDY
BHUMIPHOL OUTLET WORKS
PLANS AND PROFILES OF
TUNNEL AND OUTLET WORKS

Drawn by ---- H.A.
Traced by -- H.A., R.P.M.
Checked by --- S.K.
Approved

2008	DECEMBER 1959	FIG. 1

II. THE MODEL

Design

Model simulation of a channel with free surface flow is dependent upon the Froude criterion because the principle predominating force controlling the flow is gravity. The Froude law states that if gravitational forces predominate, the Froude numbers for the flow in the model must be the same as that in the prototype to achieve model-prototype conformity. Using this criterion, certain basic relationships are established for geometric, kinematic and dynamic similarity as listed in Table I. The assumptions used to establish the relationships are that the force of gravity is the same in the model as that for the prototype and water is a common fluid.

TABLE I.

RELATIONSHIPS FOR MODEL-PROTOTYPE CONFORMITY
ACCORDING TO THE FROUDE LAW

Item	Ratio
Length	L_r
Area	$(L_r)^2$
Volume	$(L_r)^3$
Time	$(L_r)^{1/2}$
Velocity	$(L_r)^{1/2}$
Discharge	$(L_r)^{5/2}$
Pressure Intensity	L_r

The prototype tunnel was reproduced from the face of the tunnel plug to the portal, with provision for the junction with the spillway tunnel. The selection of model scale was based upon a convenient size of plastic pipe commercially available, which could be used to represent the tunnel. The size of pipe selected was 8.75 inches inside diameter which was large enough to make the effect of surface tension negligible. As the model studies progressed, it became necessary, actually, to use three model scales to study flow phenomena for three different tunnel conditions. Scales were changed simply as an economic expedient. The three conditions were:

1. Flow in the unlined tunnel. The effective diameter of the unlined tunnel was 13.2 meters. The model scale with plastic pipe 8.75 inches inside diameter was 1:59.38.
2. Flow in the lined tunnel with a diameter of 11.3 meters. The model scale was 1:50.83.
3. Flow in the lined tunnel with a diameter of 12.0 meters. The model scale was 1:53.98.

Although the Froude criterion must be used to establish model conformity because the gravitational and inertial forces predominate, fluid friction in the model is also an important factor and is reflected in the water surface slope. Viscous forces are simulated by Reynolds criterion. Modelling by both Froude and Reynolds Laws is impossible however, because there exists no fluid having the viscosity and density required in the theoretical relationship which satisfies both laws. Therefore, simulation of water surface slope in the model was controlled by adjusting the channel roughness in the model and verifying the measured water surface slope with the calculated water surface of the prototype tunnel. Because prototype data for the water surface in the tunnel was obviously not available, verification was assumed if the model water surface conformed to calculated values for the prototype. In general, the verification process reverts to a trial and error process. To establish a rational approach to the problem, however, by using certain assumptions the scale ratio of friction slopes can be related to channel roughness coefficients. Among the most important assumptions used are:

(a) The channel boundaries are rough.

(b) The Reynolds number of the flow is sufficiently large so that the roughness coefficient is dependent only on the relative roughness.

If Powells Formulation is used (1)* the value of Chezys C is made identical in both model and prototype and by calculating the value of the Reynolds number for the model, the relative roughness required for the model is determined from a set of empirical curves.

In using Mannings equation, it can be shown that the required ratio between n in the model and prototype is equal to the one-sixth power of the length ratio.

The approach used for this model study was the latter, in which artificial roughness in the form of hardware cloth was used to establish similarity in water surface slopes. The basic values of n for the prototype were 0.014 for concrete surfaces and 0.035 for unlined rock surfaces irrespective of flow depth.

---

* Number in parenthesis is a reference number of the Bibliography.

For the lined tunnels, the model scales being 1:50.83 and 1:53.98, the model n values should be about 0.0075. The measured value of n for the plastic pipe flowing full was approximately 0.008 for velocities near 7 ft per second. Under model test conditions, flow velocities in the model would vary from about 8 to 20 ft per second. At the higher velocities, the roughness value n would decrease slightly and should approach 0.0075. Therefore, it was considered satisfactory to use the unaltered plastic surface to represent lined tunnel conditions.

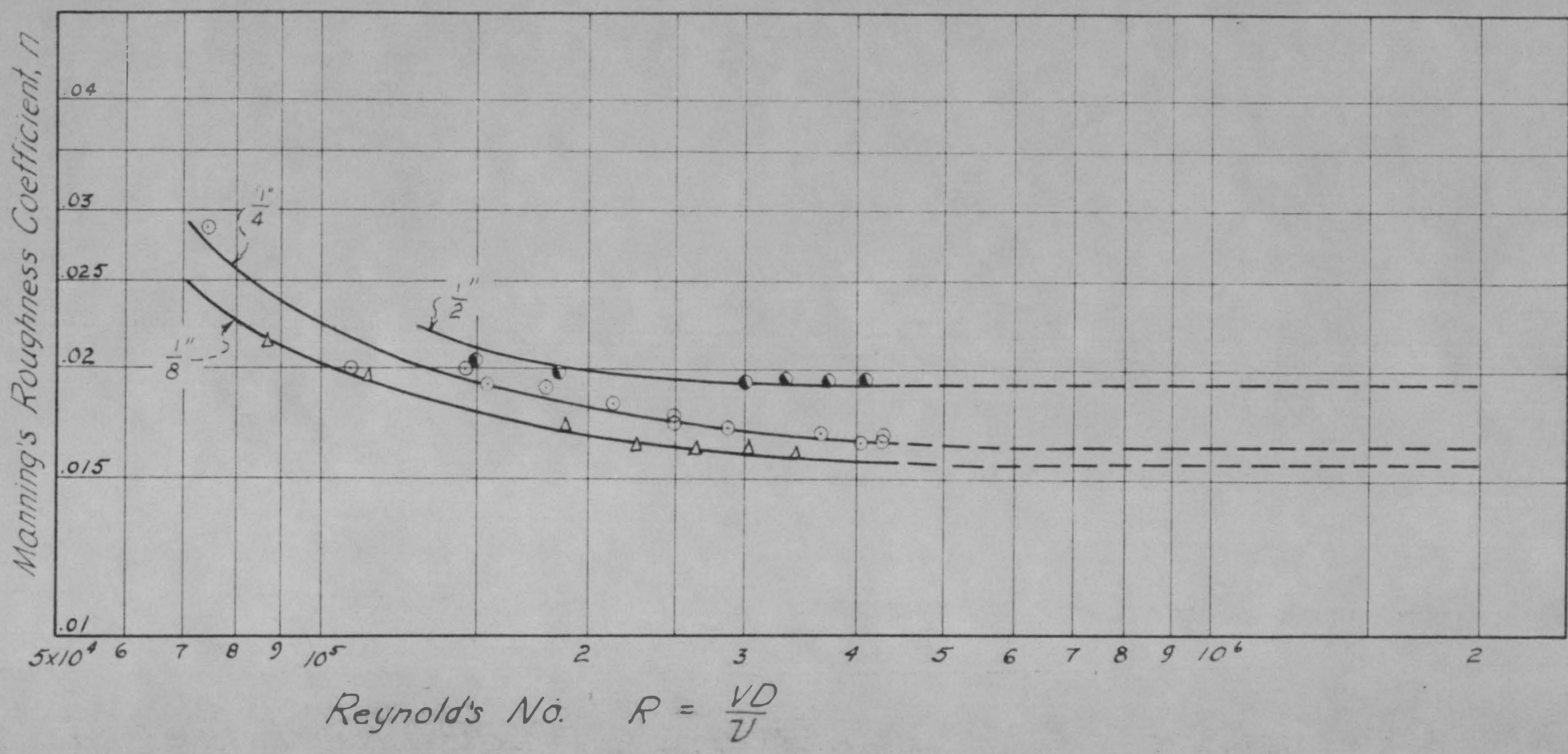
The model coefficient n for the unlined tunnel must be approximately 0.017, using the relationship of

$$n_r = (L_r)^{1/6} .$$

In order to determine the amount of artificial roughness required in the model to attain this value, preliminary tests were made with 1/8-in., 1/4-in. and 1/2-in. hardware cloths placed as sleeves inside the plastic pipe. The test results are shown in Fig 2 with dashed lines extending the curves beyond the limits of actual data. In the range of Reynolds numbers from 4×10^5 to 2×10^6 (velocities of from 8 to 20 ft per second) the 1/4-in. hardware cloth gave the approximate required value. The model water surface obtained with this roughness is compared to the calculated water surface in another section of this report.

Construction

A schematic drawing of the model is shown in Fig 3. The water supply for the model was from the municipal system of the City of Fort Collins. Water was pumped from the head box through a 4-inch centrifugal pump with a valve in the discharge line to control the flow and an orifice with a differential air-water manometer to measure the flow rate. Gates



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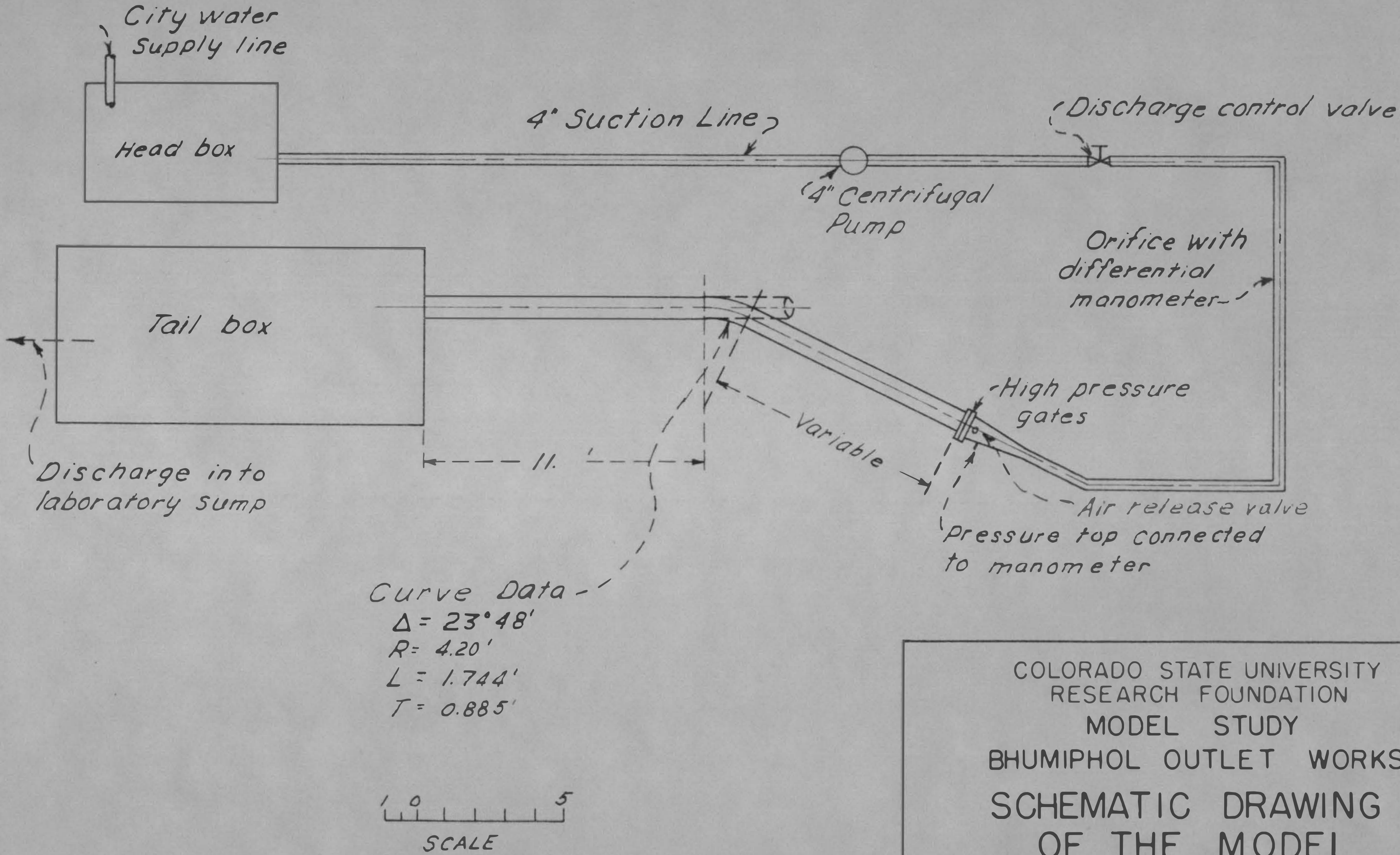
MODEL ROUGHNESS COEFFICIENT FOR HARDWARE CLOTH

Drawn by____R.P.M. Traced by____R.P.M. Checked by____S.K.	Approved S. Karaki

2008	DECEMBER 1959	FIG. 2



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MODEL STUDY

BHUMIPHOL OUTLET WORKS

SCHEMATIC DRAWING OF THE MODEL

Drawn by ___ R.P.M. Traced by ___ R.P.M. Checked by ___ S.K.	Approved S. S. Karaki

2008	DECEMBER 1959	FIG. 3

were constructed for the model to regulate the head and the velocity of the flow in the tunnel. The tunnel section, as mentioned previously was constructed with clear plastic pipe, 8.75 inches inside diameter. A tail box was used to collect the flow at the tunnel outlet and discharge it into the laboratory sump.

Operation

The success of the model in predicting prototype flow phenomena depended upon accurate model representation of discharge, velocity and head losses. Model discharge was relatively easy to determine and regulate. Tunnel surface resistance was not as easy to control, but verification was achieved using the 1/4-inch hardware cloth as artificial roughness in the model tunnel. The verification results are shown in Table 2 and plotted in Fig 4.

Discharge and velocity in the model could be controlled independently; therefore, the head upstream from the model gates was used as an indicator of model velocity. There was no attempt to model the high pressure gates in exact geometric proportions with the prototype. It was necessary only that the relative location and rectangular shape of the jet issuing from the model gates be maintained in the proper relationship.

Values of velocities through the high pressure gates were determined from data provided by Engineering Consultants, Inc., and are given in Table 3. To calculate these velocities, a discharge coefficient of 0.95 was assumed. Discharge coefficient can be thought of as a product of the coefficient of contraction and the coefficient of velocity. The coefficient of velocity is largely a function of the flow and fluid properties. Because

TABLE 2.

CALCULATED AND MEASURED WATER SURFACE PROFILES
Q = 170 c.m.s.

Critical depth was assumed at the downstream tunnel portal for the calculated values. Artificial roughness with 1/4-in. hardware cloth was used for the measured values.

Calculated		Measured	
x*	y+	x*	y+
0	3.96	0	-
12.2	4.11	3.8	3.7
18.2	4.27	22.3	4.4
29.7	4.42	40.8	4.6
47.1	4.57	59.3	4.7
70.0	4.72	77.7	4.8
110	4.88	96.4	5.2
165.5	5.03	115.0	5.0
248	5.18	170.5	5.0
		207.5	4.8

* x is the distance upstream from the tunnel portal in meters.

\+ y is the depth of flow measured from the water surface to the tunnel invert in meters.

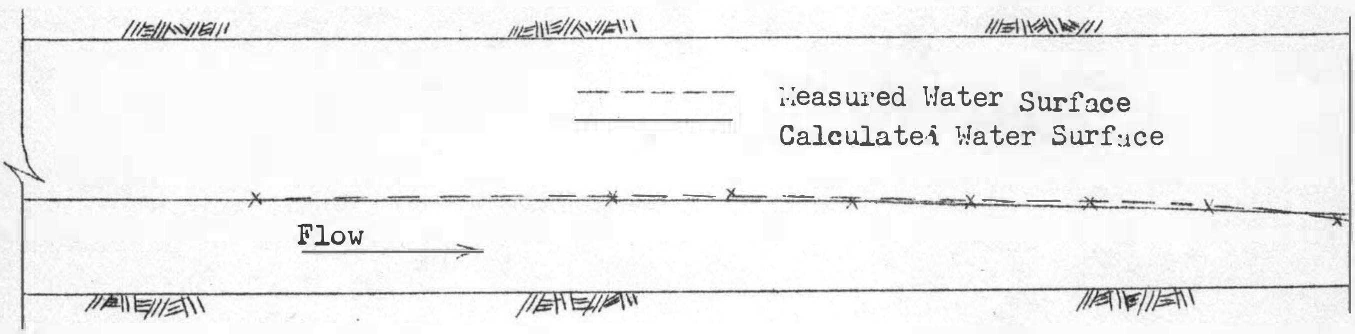


Fig. 4. Model Verification of Water Surface Slope

of the large size of the prototype gates, the effects of viscosity, density and surface tension are negligible. Thus, the coefficient of velocity is near 1.0 and the coefficient of discharge is approximately equal to the coefficient of contraction.

Table 3 also gives velocities required in the model for the three model scales. For any fixed discharge, the head upstream from the gates and the velocity of flow through the gates varied with the opening at the model gates. Because of the small size of the model gate openings, the coefficient of velocity is not equal to 1.0 as assumed for the prototype. Values of 0.96 and 0.97 were used for velocity coefficients for the smaller and larger gates respectively. These values were selected from results of tests made by Smith and Walker (4), with orifices varying in size from 0.75 to 2.5 inches in diameter. The two sizes of model gates were considered desirable when model scales were changed. The smaller gates were used when the model scale was 1:59.38 and the larger gates were used with model scales of 1:53.98 and 1:50.83.

TABLE 3.

MODEL HEAD REQUIRED TO SIMULATE PROTOTYPE VELOCITIES

		Small Gates			Large Gates			Large Gates		
		Model Scale 1:59.38			Model Scale 1:50.83			Model Scale 1:53.98		
		27,100	7.72		18,420	7.14		21,400	7.35	
Q_p	V_p	Q_m	V_m	H_m	Q_m	V_m	H_m	Q_m	V_m	H_m
cms	m/sec	cfs	ft/sec	ft	cfs	ft/sec	ft	cfs	ft/sec	ft
180	42.1	.234	17.9	5.40	.345	19.4	6.20	.297	18.8	5.83
160	37.4	.208	15.9	4.26	.306	17.2	4.88	.264	16.7	4.60
140	32.75	.182	13.9	3.26	.268	15.1	3.76	.231	14.6	3.52
120	28.10	.156	11.9	2.39	.230	12.9	2.74	.198	12.5	2.58
100	23.40	.130	9.9	1.65	.192	10.8	1.93	.165	10.4	1.78
85	19.90	.111	8.5	1.22	.163	9.2	1.40	.140	8.9	1.31
80	18.70	.104	7.9	1.05	.153	8.6	1.22	.132	8.3	1.14
60	14.02	.078	6.0	0.61	.115	6.4	0.68	.099	6.3	0.66
40	9.35	.052	4.0	0.27	.076	4.3	0.31	.066	4.2	0.29

III. MODEL INVESTIGATION

Tunnel Without Structures

The model studies were concerned with protection of the bend in the tunnel from erosion and cavitation due to the high velocity flow from the high-pressure gates. With velocities at about 42 meters per second at the upstream end, the tunnel would require a concrete lining along the invert. Figs 5 and 6 show the conditions of flow at the gate outlet and at the tunnel bend respectively. The discharge was 170 cubic meters per second at reservoir elevation of 220 meters, representing prototype gates fully open. The flow is forced high up on the wall in the circular tunnel at the bend in a spiraling motion and undulates downstream. The profile of the flow is shown in Fig 7. Tests were also made at a discharge of 85 cubic meters per second with corresponding reservoir elevation of 166.5 meters. The results are shown in the photographs of Figs 8 and 9 and the water surface profile is shown in Fig 7. These tests show that at a large discharge, the high velocity is maintained in the flow at the bend. This high velocity could cause extensive erosive damage and cavitation of the concrete surface of the tunnel lining, which could lead to expensive maintenance.

A discussion was held with the engineers of Engineering Consultants, Inc., from which it was concluded that a structure would probably be required in the tunnel to prevent contact of the flow with the tunnel wall at the bend at high velocities to avoid erosion and cavitation. Accordingly, a deflector was installed in the model and tested.

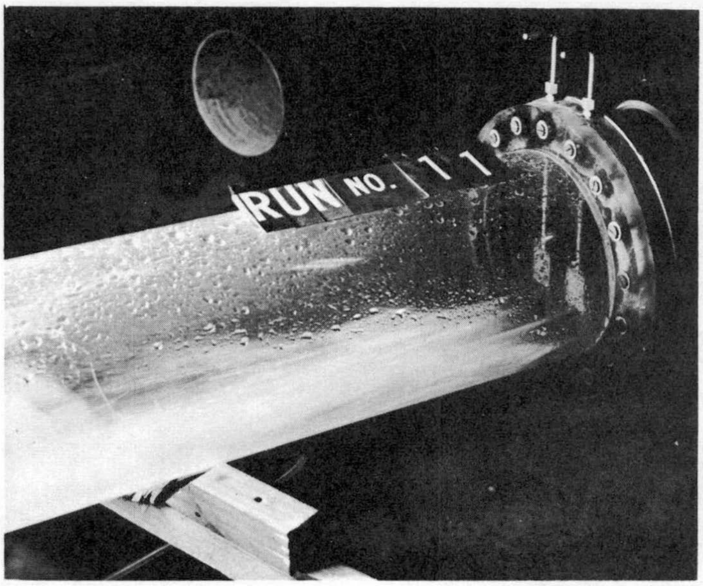


Fig 5. Flow through the high pressure gates at Q = 170 c.m.s. V = 39.8 m/sec. Model scale 1:50.83

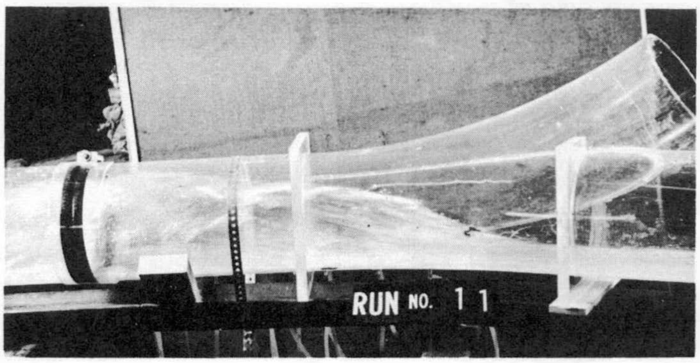
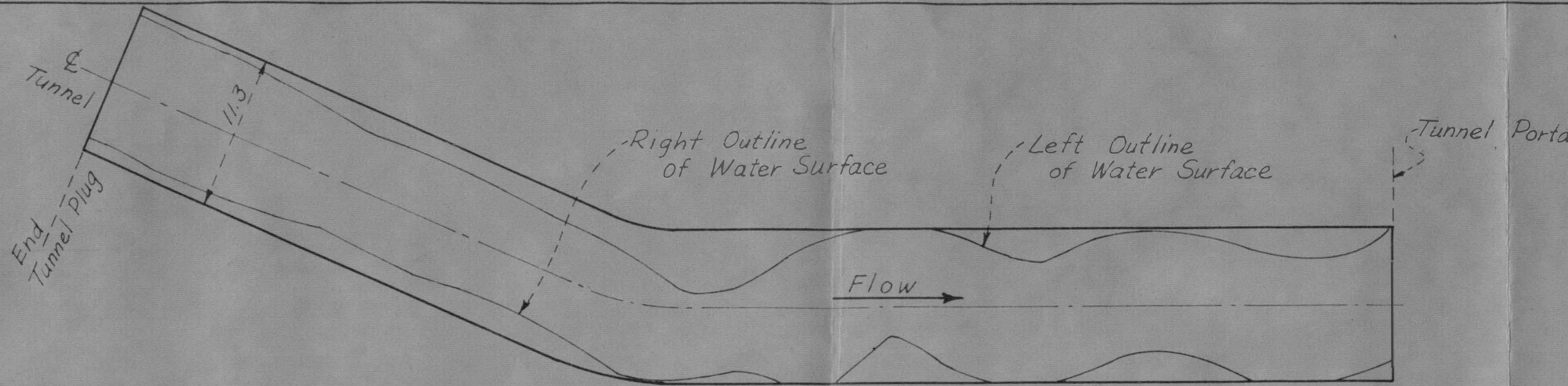
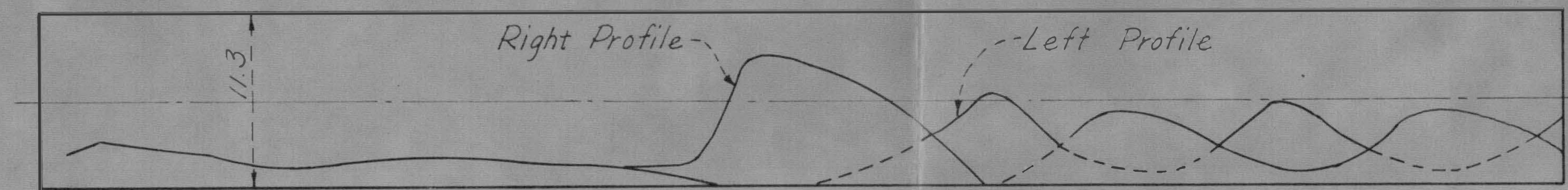


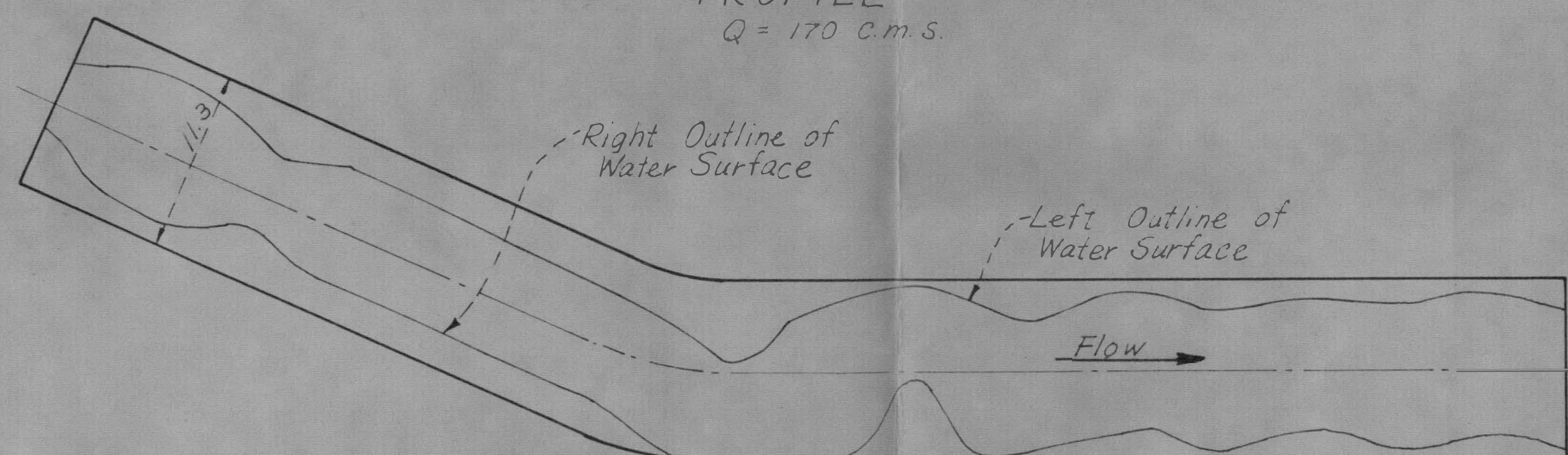
Fig 6. Flow at the bend in the tunnel. Q = 170 c.m.s. The tunnel invert is assumed to be lined. Model scale 1:50.83



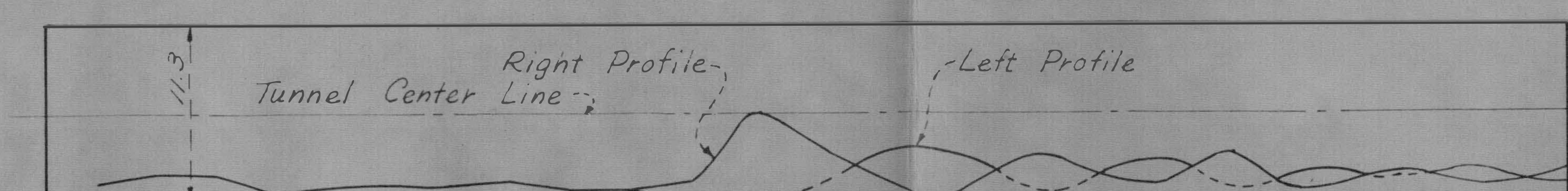
PLAN
Q = 170 c.m.s.



PROFILE
Q = 170 c.m.s.



PLAN
Q = 85 c.m.s.



PROFILE
Q = 85 c.m.s.

NOTES:

The Tunnel Plans and Profiles are drawn to exaggerated scales of:
Horizontal Scale - 1 in = 40 m
Vertical Scale - 1 in = 10 m

The terms Left and Right are referenced to views looking downstream

For detailed dimensions of the tunnel see Fig. 1

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FLOW PROFILES
LINED TUNNEL INVERT

Drawn by - - - - H.A. Traced by - - - - H.A. Checked by - - - - S.S.K.	Approved S.S. Karaki

2008	DECEMBER 1959	FIG. 7

Fig 8. Flow through the high pressure gates at Q = 85 c.m.s. V = 19.9 m/sec. Model scale 1:50.83

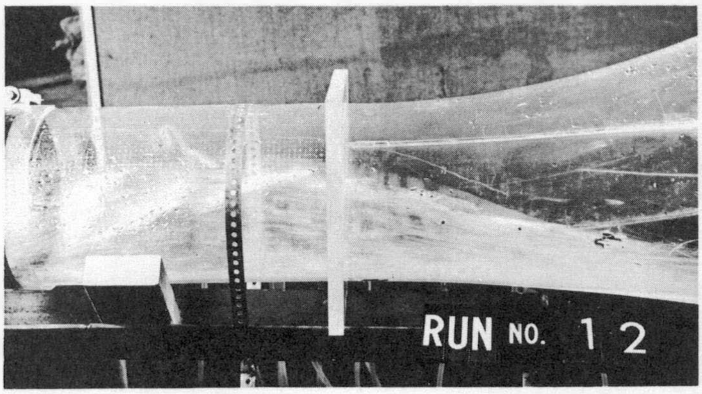


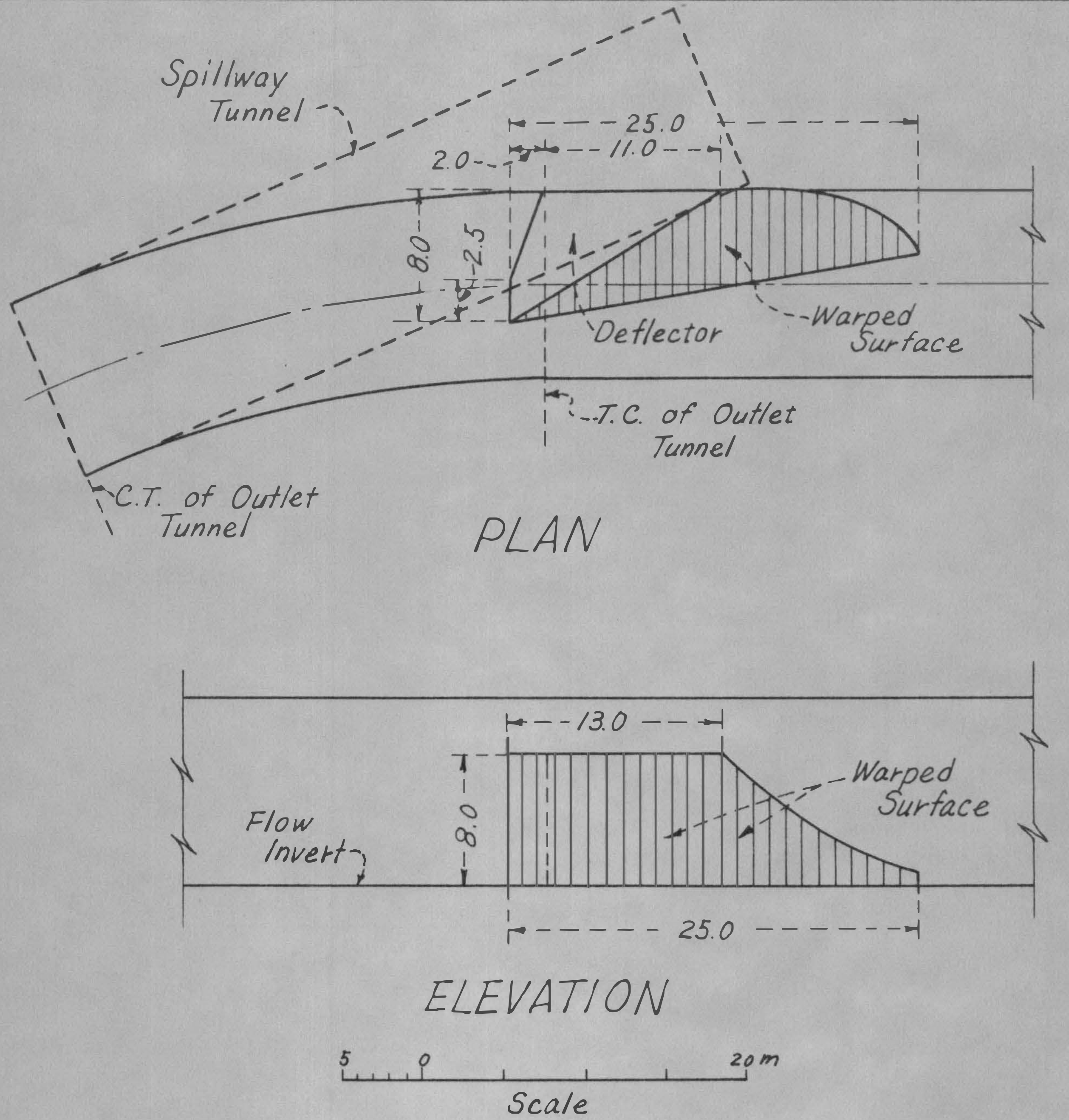
Fig 9. Flow at the bend in the tunnel. Q = 85 c.m.s. The tunnel invert is assumed to be lined. Model scale 1:50.83

Deflector

The deflector was designed so that the trajectory of the jet was in line with the downstream channel, so that not only was flow kept from contact with the tunnel wall at the bend, but the undulation of the flow was minimized. A trial and error method was used to establish the final deflector size and shape. General features of the deflector were:

1. The deflector extended beyond the center of the tunnel in order to be effective in keeping the flow from contacting the bend.
2. The warped surface of the deflector terminated vertically at the downstream end.
3. The height of the deflector was about 3/4 the diameter of the tunnel.

A sketch showing the position and size of the deflector is shown in Fig 10. Photographs of the flow at the deflector for discharges of 170 and 85 cubic meters per second are shown in Figs 11 and 12. For these discharges the deflector performed satisfactorily. However, when the discharge was reduced to about 70 cubic meters per second, flow resistance at the deflector caused a hydraulic jump to form upstream from the deflector as shown in Fig 13. Although this did not create any problem at the bend, the turbulence in the hydraulic jump would necessitate protection of the tunnel wall in the zone of the hydraulic jump. As the jump could form at any location upstream from the deflector, depending upon the discharge and velocity, the entire upstream length would have to be lined at least to a height of about one-half the diameter of the tunnel. On the basis of these tests, it seemed desirable to establish a structure to dissipate the energy upstream at the gate outlet and confine the hydraulic problems within a relatively short section of the tunnel.



NOTES:

1. Tunnel Lining is not Shown
2. Dimensions of the deflector are shown in meters
3. The warped surface of the deflector is the development of a straight line begining from on angle tangent to the tunnel curvature and ending vertically

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MODEL STUDY
BHUMIPHOL OUTLET WORKS

FLOW DEFLECTOR

Drawn by-- R.P.M. S.S.K. Traced by--- H.A. Checked by--- S.S.K	Approved S. S. Karaki

2008	DECEMBER	1959	FIG. 10

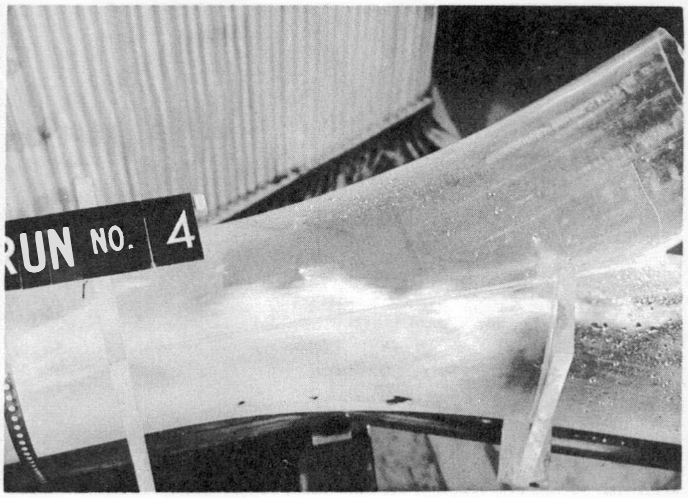


Fig 11. Photographs of the flow at the deflector for Q = 170 c.m.s.

Fig 12. Photograph of the flow at the deflector for Q = 85 c.m.s.

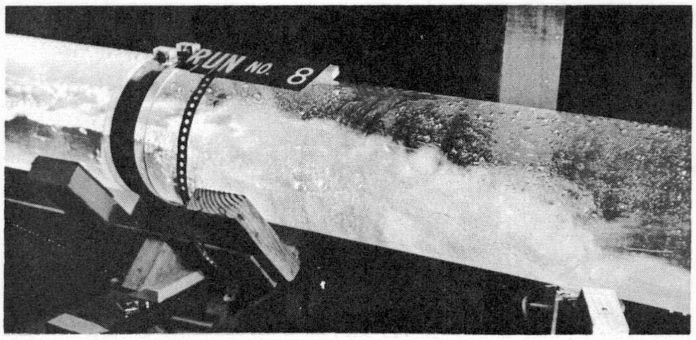


Fig 13. Hydraulic jump forms upstream of deflector for Q = 70 c.m.s.

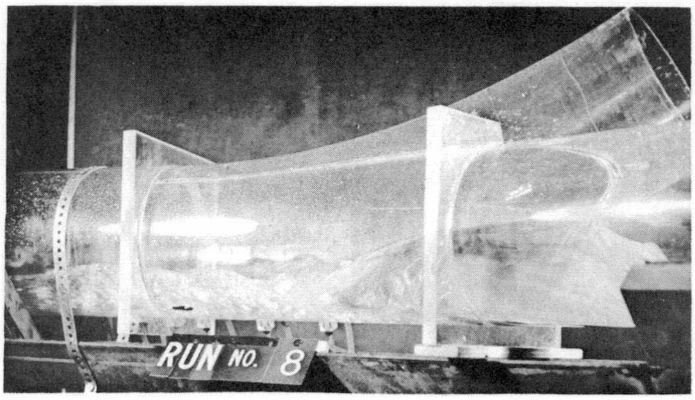


Fig 14. Flow at the bend for Q = 70 c.m.s. with a hydraulic jump upstream of the deflector

Stilling Basin

The stilling basin was studied as an alternative structure to protect the tunnel from damage that could be caused by the supercritical flow. Since it was undesirable, from the standpoint of construction and cost to alter the shape of the outlet tunnel, a stilling basin formed by an impact wall was designed and tested in the model.

The preliminary design was made so that the sequent depth at maximum flow was less than the diameter of the tunnel. Assuming critical flow over the wall, the height of the impact wall was computed to be 4.6 meters and the necessary distance downstream from the gate at 35 meters. The design was tested and the result is shown in Fig 15 for a discharge of 185 cubic meters per second. Because of the large Froude number of the approaching flow a stable jump could not be formed within the calculated distance. Successive trials of longer stilling basins and higher sills were made. Ultimately, a sill height of 7 meters was established and located 45 meters downstream from the face of the tunnel plug. Flow conditions in the selected structure are shown for discharges of 185, 140 and 90 cubic meters per second in Figs 16 to 18.

The impact wall for the selected stilling basin was designed so that some amount of flow could pass through the wall to alleviate the negative pressures that could be created behind the nappe of the overflow. Measurements of pressure were made in the model for discharges of 185, 140 and 90 cubic meters per second with the impact wall design shown in Fig 19. Negative pressures were not measurable using an air-water differential manometer. The conduits in the impact wall also reduce the total static and dynamic forces against the wall and provide drainage for the stilling basin.

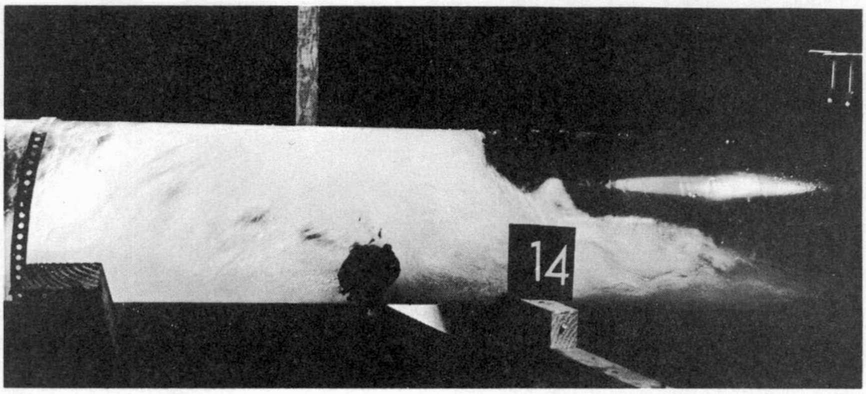


Fig 15. Hydraulic jump in the preliminary stilling basin for Q = 185 c.m.s. Model scale 1:53.98

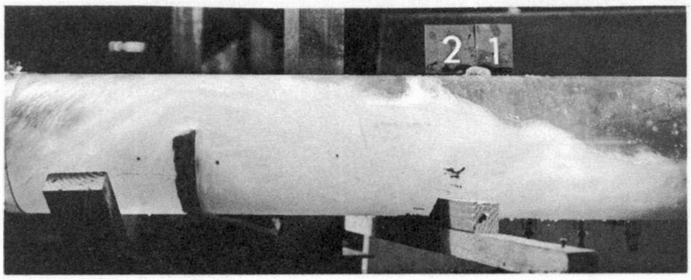


Fig 16. Hydraulic jump in the recommended stilling basin for Q = 185 c.m.s. Model scale 1:53.98

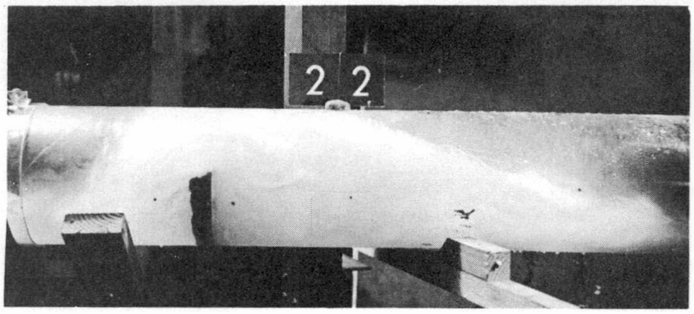


Fig 17. Hydraulic jump in the recommended stilling basin for Q = 140 c.m.s. Model scale = 1:53.98

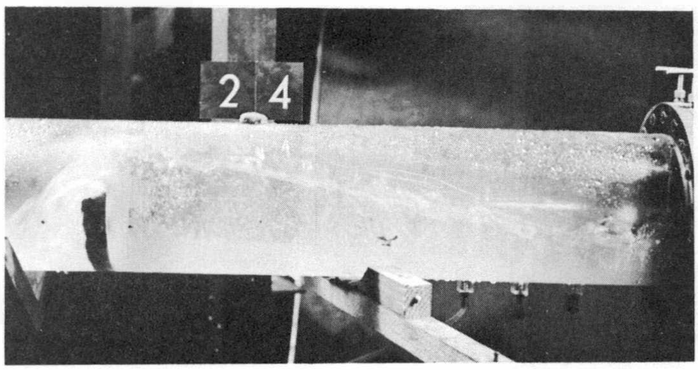
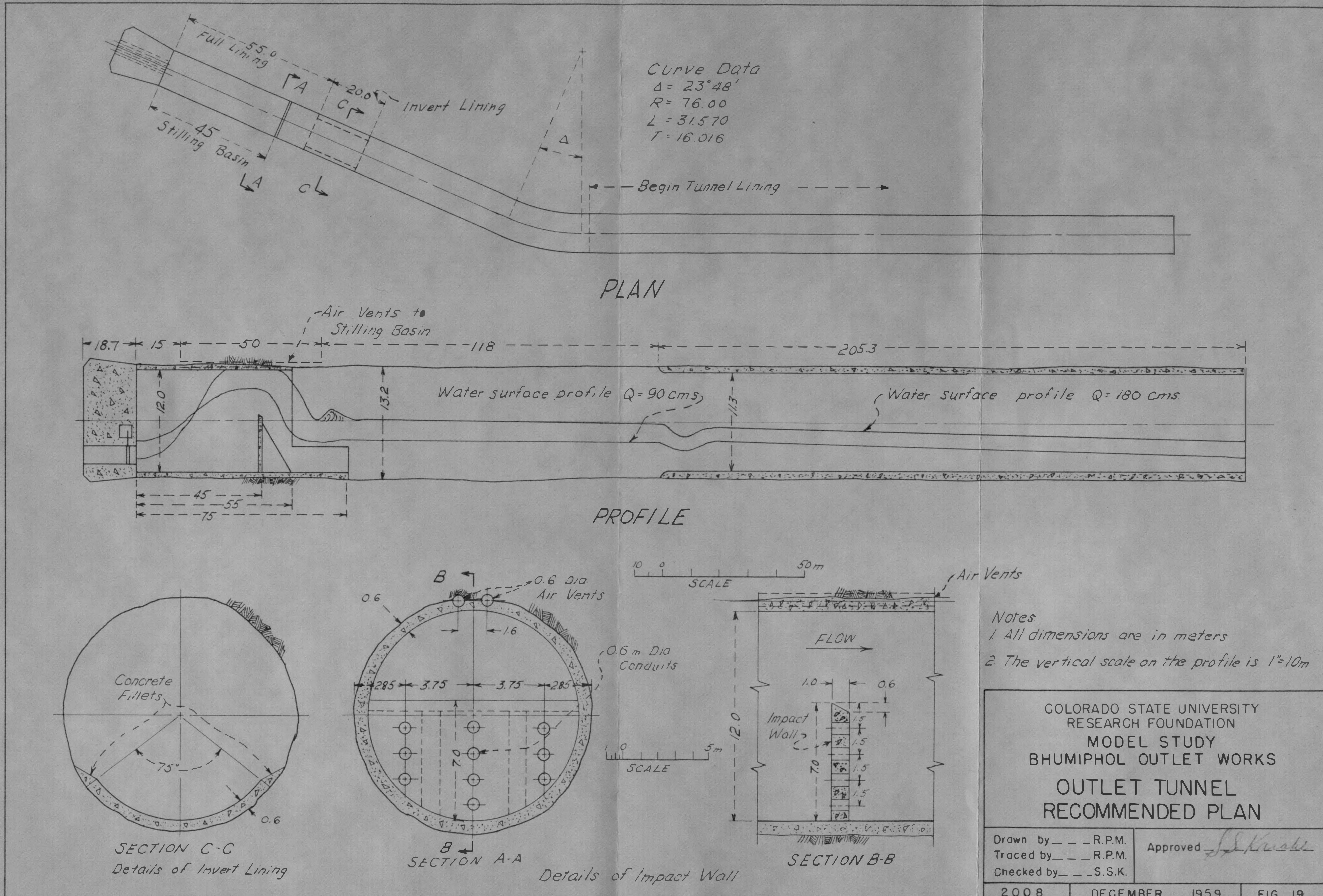


Fig 18. Hydraulic jump in the final stilling basin for Q = 90 c.m.s. Model scale = 1:53.98

In Fig 18, for a discharge of 90 cubic meters per second, it will be noted that the gate outlets are submerged. The submergence, of course, would reduce the effective discharge head from the reservoir surface to the outlet, but because the reduction is only a small percentage of the total head, the decrease in discharge will probably not be significant. The major difficulty created by this submergence is in the design of the air vent system in the gate chamber, since it was originally designed so that the circulation of air would be maintained by passage of air through the vent into the tunnel. A suggested modification would be to add vent pipes embedded in the concrete tunnel plug with the inlet located high on the wall of the gate chamber.

It will be noted in Fig 16 that at the maximum discharge of 185 c.m.s. the hydraulic jump which formed, filled the tunnel at the downstream end. Under this condition free passage of air from the downstream end is inhibited. Because it is essential that air be provided to the upstream end of the jump, air vents through the stilling basin will be necessary. These air vents can be embedded in the tunnel lining in the crown of the tunnel so that air from downstream will be drawn into the upstream end of the stilling basin. Qualitative tests of air demand at maximum discharge showed that two 24-in. vent pipes constructed in the manner discussed should provide sufficient ventilation. The required lengths of vent pipes are shown in Fig 19. Recommended dimensions of the stilling basin are also shown in the figure.

The tunnel as shown in Fig 19 was tested in the model for hydraulic conditions. From these tests it was determined that an apron below the nappe of the flow over the impact wall of the stilling basin would be necessary to prevent scour. This apron should be along the invert of the



COLORADO STATE UNIVERSITY
RESEARCH FOUNDATION
MODEL STUDY
BHUMIPHOL OUTLET WORKS

OUTLET TUNNEL
RECOMMENDED PLAN

Drawn by _ _ _ R.P.M. Traced by _ _ _ R.P.M. Checked by _ _ _ S.S.K.	Approved S.S. Karaki

2008	DECEMBER 1959	FIG. 19

tunnel as shown in the figure and should extend for a distance of at least 30 meters beyond the impact wall.

Flow beyond the stilling basin should not cause any problem in the tunnel. Profiles of the flow for 185 and 90 cubic meters per second discharges are shown in the longitudinal section of the tunnel in Fig 19.

SUMMARY

The model study of the outlet tunnel No. 2 of the Bhumiphol Dam showed that a satisfactory flow control is effected by a stilling basin in the circular conduit. Although minor modifications of the gate chamber and vent system may be necessary, such modifications should be of little economic significance. Overall, the hydraulic performance of the stilling basin when compared to the deflector is better when considering the total range of flows. Certain economic advantages are implicated by use of the stilling basin, but is beyond the scope of this report and will not be discussed. On the basis of this model study, it is recommended that the stilling basin of the dimensions given in Fig 19 be designed for construction.

BIBLIOGRAPHY

1. Powell, R. W., "Resistance to Flow in Rough Channels," Trans. A.G.U. Vol. 31, No. 4, August, 1950.

2. Liu, H. K., and Albertson, M. L., "Significance and Application of Froude and Reynolds Numbers as Criteria for Similitude," unpublished paper presented at the Hydraulics Conference of A.S.C.E. in Fort Collins, Colorado. July, 1959. Colorado State University, Civil Engineering Report No. CER59HKL20.

3. Foster, James E., "Fixed-Bed River Models," unpublished paper presented at the A.S.C.E. Convention in Washington, D. C., October, 1959.

4. Russell, George E., Hydraulics 5th Ed. Henry Holt and Co. New York, August 1948.