GR-79-3

MODEL STUDIES OF THE SUGAR PINE DAM ENERGY DISSIPATOR

Hydraulics Branch
Division of Research
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16. ABSTRACT

Due to the configuration of the dam relative to the drainage creek downstream, it was not feasible to construct a conventional hydraulic jump stilling basin for the spillway at Sugar Pine Dam. Also, the earth material of the opposite bank was highly erodible. An energy dissipator was developed that would adequately still the flow and also turn the flow 62.5° off the centerline of the chute into the original river channel. A hydraulic model study was used to develop a stilling basin that would create acceptable flow dissipation for the maximum discharge of 480 m^3/s, and desirable flow characteristics for lesser discharges. Chute blocks, directional vanes, sidewalls, end sill, and trapezoidal "vane" blocks placed at strategic locations separated, turned, and stilled the flow, and helped to force a hydraulic jump. Pressure measurements were made on the chute blocks, the left wall, and the vane blocks. Subatmospheric pressures occurred only at the maximum design discharge at the upstream end of the left wall near the floor. The tests showed that at maximum discharge, there would be severe river bank erosion downstream from the basin.

17. KEY WORDS AND DOCUMENT ANALYSIS

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by
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Denver, Colorado
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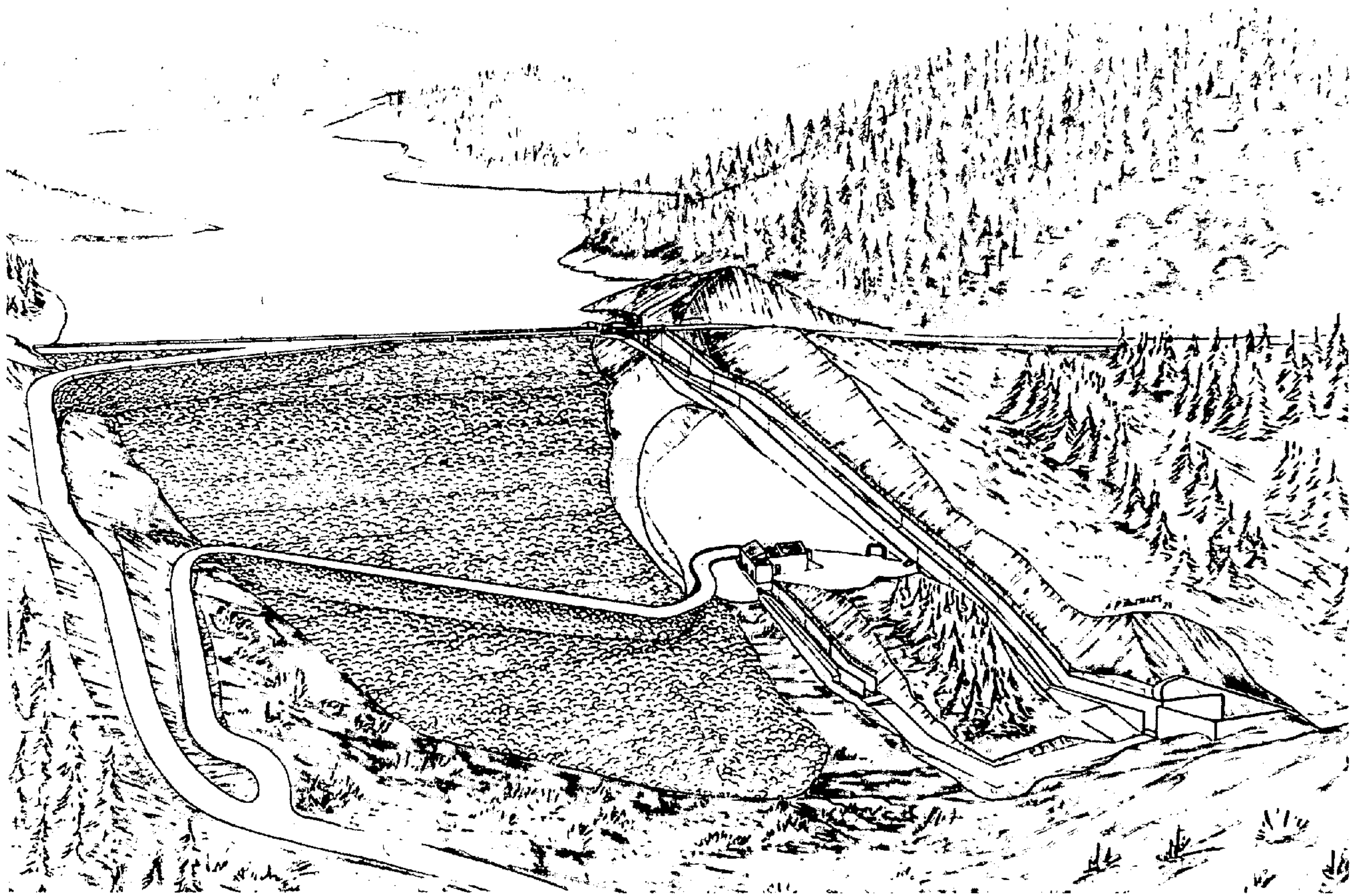
SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions—supplying water and power.

The text of this publication was prepared prior to adoption of the new name; all references to the Bureau of Reclamation or any derivative thereof are to be considered synonymous with the Water and Power Resources Service.



Conception of Sugar Pine Dam, spillway at right. (artist, Anthony Rozales)

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FIGURES

FIGURES - Continued

PURPOSE

Due to the orientation of the dam with respect to Shirttail Creek, an atypical spillway had to be designed. This required a special hydraulic model study, to develop an adequate stilling basin for the Sugar Pine Dam spillway. The stilling basin had to be designed to still and contain the flow, and turn it 62.5° off the centerline. The flow had to be completely contained within the sidewalls to prevent splashing which would erode the soft material of the stream banks. Several basin configurations were tested to create acceptable flow conditions for the maximum discharge of 480 m^3/s, and good flow conditions for lesser discharges. When a design which operated adequately to warrant recommendation was selected, pressures were tested for possible impact or cavitation problems.

INTRODUCTION

Sugar Pine Dam is located on the north fork of Shirttail Creek (fig. 1)[1] 14.5 km north of Foresthill, Placer County, California. It is a feature of the Auburn-Folsom South Unit, Central Valley Project. The earthfill dam would be approximately 55 m high and 181 m long at the crest, and would impound about 9×10^6 m^3 of water for irrigation, municipal and industrial use, and flood control. Principal hydraulic features include the spillway on the left abutment, and a gated outlet works at the base of the dam (fig. 2). This study is concerned with the hydraulic performance of the spillway stilling basin.

The spillway crest, an uncontrolled ogee type, (fig. 3) is set at the normal water surface elevation. The spillway at the crest is 13 m wide, has a 31-m-long transition to the 9-m-wide chute, which extends 123 m downstream to the stilling basin. The 0.53 slope of the spillway chute steepens in the latter 46 m of the chute, before the flow enters the stilling basin. The dam was positioned relative to the drainage creek in a manner that required the stilling basin centerline to veer to the left of the spillway chute centerline by

[1] All figures are at the end of the report.

62.5°. Thus, the stilling basin must both dissipate a large amount of energy, and turn the flow into the downstream channel. Preliminary design called for two directional vanes, high sidewalls in the basin, and several vane blocks.

CONCLUSIONS

1. Chute blocks, directional vanes, and vane blocks along the vanes and sidewall are required to achieve satisfactorily distributed flow within the stilling basin.

2. A vertical sill, rising 8.5 m from the stilling basin floor, is needed to maintain submergence of the spillway jet and to ensure sufficient energy dissipation.

3. Piezometric measurements in the stilling basin indicate that pressures may range from a positive head of 47 m of water to a subatmospheric level of 8 m of water in some areas. For discharges above 340 m^3/s, cavitation could occur near the base of the left wall immediately downstream from the point of curvature.

4. Turbulence within the basin produced high impact pressures, which suggested it would be desirable to add steel armor to the impact surfaces of the chute blocks, the vane blocks along the inside curvature of the directional vanes, and the top faces of the vanes along the curvature.

5. It would be advisable to widen the excavated river channel on the left channel bank downstream of the sill, because of severe washout potential of the riprap for flows greater than 340 m^3/s. Also, it might be well to rotate the right retaining wall outward, nearly perpendicular to the sill, or even eliminate the wall altogether.

6. Rocks, ranging in size from 0.25 to 3 m diameter, sometimes stay within the stilling basin for flows less than about 340 m^3/s. Flows of 175 m^3/s did not flush them out, but concentrated them near the left wall at the base of the sill. Some of the smaller rocks were

flushed out with a 225 m^3/s discharge, but the remainder stayed in the same location. Discharges of 340 m^3/s or more generally cleared the basin of all rocks.

7. Abrasive action caused by trees and rocks churning in the basin could be significant. Impact of such debris on the upstream ends of the directional vanes could be reduced by sloping the leading edge away from the flow. The test of this condition showed no adverse changes in the hydraulic performance. If this is done, the upstream end of the vanes should be closer to the chute to intercept the flow earlier.

TEST FACILITY

A 1:36 scale model (figs. 4 and 5) represented a portion of the spillway chute, the stilling basin, and a portion of the trapezoidal channel downstream from the sill. The basin, directional vanes, vane blocks, and sill are shown in figure 6. Maximum prototype discharge of 480 m^3/s was represented in the model by 0.062 m^3/s discharge.

A short portion of the spillway chute was modeled and the depth of flow into the basin was varied by adjusting a radial gate at the upper end of the chute, and each discharge was obtained by changing the head on the gate. The model stilling basin including the end sill was 1400 mm long, and the apron immediately downstream from the sill was 830 mm long. Downstream from the apron was an excavated channel bounded on the left by a 2:1 gravel slope representing riprap, and on the right by a converging vertical retaining wall. Channel floor width varied from 550 mm at the downstream edge of the sill to 150 mm at the downstream end of the retaining wall. In the 530-mm-long floor section, the elevation dropped 28 mm. Beyond the right retaining wall, a trapezoidal section 1500 mm long represented the natural river channel. The cross section was unsymmetrical because of a 3:1 left side slope and a 1.5:1 right side slope. The river channel grade was 4 percent.

THE INVESTIGATION

The model study was based on empirically evaluating the preliminary design and applying curative procedures to improve performance where necessary. When a workable design had seemingly been attained, pressure measurements were made at certain points along the curved portion of the left wall, on one vane block adjacent to a directional vane, and on a chute block at the toe of the chute. These measurements were made to detect possible subatmospheric pressures which would necessitate further design modifications.

Scheme 1 Preliminary Design

The preliminary stilling basin had a 6.4-m-high sill, 3-m-high directional vanes, and 1.5-m-high vane and baffle blocks (fig. 7). Six baffle blocks were placed near the downstream ends of the directional vanes, and three baffle blocks were placed near the upstream ends.

At 175-m^3/s discharge (fig. 8a), there was greater flow depth over the right side of the sill. While the basin performed satisfactorily up to 255 m^3/s, greater discharges dominated the directional vanes, the sill, and the vane and baffle blocks. Flows of 340 m^3/s and higher (figs. 8b, c) became more concentrated on the right side of the basin, intermittently overtopping the right retaining wall. Little energy dissipation was evident. Also, submergence at the toe of the chute was not maintained for discharges over 340 m^3/s apparently because the sill height was too low to force the hydraulic jump to occur over or upstream from the toe. Turbulence, strong surges, and reverse flow occurred along the left wall, and occasionally overtopped the wall. Performance at 495 m^3/s (fig. 8c), 15 m^3/s above maximum design discharge, was completely unsatisfactory. Distribution of flow over the sill was unsymmetrical, and flow consistently overtopped the right retaining wall.

Scheme 2

The original directional vanes were raised from 3 to 5 m for this scheme (fig. 9). The nine baffle blocks were eliminated, but the two vane blocks remained, and three additional vane blocks were installed. The block heights of 1.5 m and the sill height of 6.5 m, as well as the vanes and walls, were unchanged.

Flow performances are shown (figs. 10a, b, and c) for discharges of 175, 340, and 480 m^3/s, respectively. No discharge caused overtopping of either wall of the basin, but there was asymmetry of flow over the sill. Along the left wall between the transition curve and the sill turbulence, strong surges, reverse flow, and oscillations were again evident. The hydraulic jump was swept downstream from the chute toe for flows of 340 m^3/s and higher.

Scheme 3

The various features previously tested were retained and one baffle block and four concave floor blocks (fig. 11a) were added (fig. 12). The size and shape of the baffle block was the same as the vane blocks. The concave floor blocks [1, 2][2] were added to induce the hydraulic jump to remain upstream from the chute toe at all discharges. Height of the concave blocks was chosen to approximate twice the flow depth at the toe of the chute for the maximum discharge. The vanes and right wall were unchanged, but the sill height was increased to 7.5 m. The left wall was moved into the basin by 1.3 m to provide a radius at the transition instead of a sharp break. This wall extended the full height of the basin.

Flow conditions for three test discharges are shown (figs. 13, 14, and 15). (In the photographs facing upstream, a photographic illusion appears where the left wall seems to project into the flow. The photographs facing downstream and the plan drawing show the

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[2] Numbers in brackets refer to literature cited in the bibliography.

true position of the wall.) Hydraulic performance was improved considerably over the previous schemes. The hydraulic jump remained over or upstream from the chute toe, and the baffle block and redesigned left wall seemed to decrease the reverse flows along the wall between sill and transition curve.

Scheme 4

This scheme layout was identical to Scheme 3 except the concave floor block dimensions were decreased (figs 16 and 11b). This change was made to avoid difficulties in constructing the larger blocks. The basin controlled discharges at 175 m^3/s and 340 m^3/s, (figs. 17 and 18) but failed to control 480 m^3/s, shown in figure 19.

Scheme 5

Because the hydraulic jump continued to be swept downstream from the chute toe during maximum discharge, three baffle beams and a wave suppressor were positioned across the full width of the channel below the chute toe (fig. 20). The baffle beam and wave suppressor design evolved from studies of other energy dissipators and modification of the dissipator proposed for the Friant-Kern Canal headworks [3, 4]. The vanes and sidewalls remained unchanged from Scheme 2, but two baffle blocks were added and the sill height was decreased to 6.5 m. The baffle blocks were the same size and relative position, across the basin, as the block added for Scheme 3.

This scheme generally confined flows successfully within the basin up to 480 m^3/s (figs. 21, 22, and 23); however, above 425 m^3/s, energy dissipation at the beam suppressor was sufficiently violent to cause splashing over the basin walls (fig. 23). Although significantly more turbulence was evident near the chute toe, rather stable and smooth flows were noted in the wider downstream section of the basin.

Scheme 6, Recommended Design

This scheme, considerably simplified from scheme 5, would result in more economical prototype construction and fewer maintenance problems (fig. 24). The directional vanes were reduced to 3 m high, and the baffle blocks, baffle beams, and wave suppressor were removed. Five chute blocks were installed at the chute toe; the sill height was increased to 8.5 m; and the left wall was curved with a 10-m radius to provide a much more gradual change of direction.

The combination of the chute blocks and the higher sill caused submergence of the jet at the chute toe, up to the 480-m^3/s discharge (figs. 25, 26, and 27). The chute blocks helped to corrugate the jet, lifting a portion of it from the floor to provide less jet concentration. Strong boils were noted immediately upstream from the sill, and some return flow continued along the left wall. Because of the higher end sill, energy dissipation was well confined within the stilling basin, although considerable turbulence occurred downstream from the sill until it reached the downstream channel section that widens into the stream bed.

Pressure Measurements

Having a seemingly acceptable design in Scheme 6, piezometers were installed in the chute blocks, along the toe of the chute, in a vane block, and along the left wall (figs. 28, 29, and 30). Pressure measurements were made for five discharges as shown in the tables accompanying the figures. Downstream from the point of curvature on the left wall and immediately above the floor (piezometer No. 9, fig. 29) pressures dropped significantly below atmospheric for discharges above 400 m^3/s. Comparison of pressures on piezometer No. 9 with pressures on piezometers No. 10 and 11, indicates that subatmospheric pressures will probably be experienced only in a small area near the basin floor.

Only on piezometer No. 7 (fig. 30) were other subatmospheric pressures encountered, but the magnitude was not large enough to be of concern. Protecting the leading edge of the vane block with angle iron should be considered since subatmospheric pressures at the edge may be somewhat less than at the location of piezometer No. 7.

Erosion and Debris Tests

Observation of the various tests indicated that erosion was more likely to occur downstream from the sill on the left side. On that side, return flows behind the retaining wall were possible in contrast to the right side where a wingwall projecting into the flow prevented similar flow.

Gravel was placed on the left channel slope to simulate 2-m-thick riprap. A variety of discharges were then run through the Scheme 6 model, starting with 175 m^3/s, rising to 480 m^3/s for several minutes, and then decreasing gradually to no flow. Much of the gravel slope was eroded. Similar action could be expected in the prototype.

Several tests were made to study debris accumulation in the stilling basin. Various size riprap, from 0.25 to 3 m, was dropped into the basin, allowing different discharges to continue for about 2 minutes each (equivalent to 12 minutes prototype). The sizes and locations of the pieces of gravel were then noted. Generally, most debris was removed by turbulence for discharges above 255 m^3/s. Below that rate of flow, accumulations occurred near the left retaining wall at the base of the sill.

To test abrasive action of timber in the stilling basin, dowels were randomly dropped in the chute. The dowels represented tree sections ranging from 0.25 m in diameter and 3 m long to 1 m in diameter and 9 m long. For all discharges the dowels churned in the hydraulic jump, eventually being ejected downstream. Considerable noise of impacting dowels was heard, suggesting that damage to concrete surfaces could take place. To minimize damage to the directional vanes from this hazard, the upstream ends of both vanes were sloped 1:1 away from the flow. No adverse reactions in the hydraulic performance were noted; however, the slope should probably not exceed 1:1, because this could lessen the ability of the vanes to redirect the flows. Also, if this is done, the upstream end of the vanes should be closer to the chute to intercept the flow earlier.

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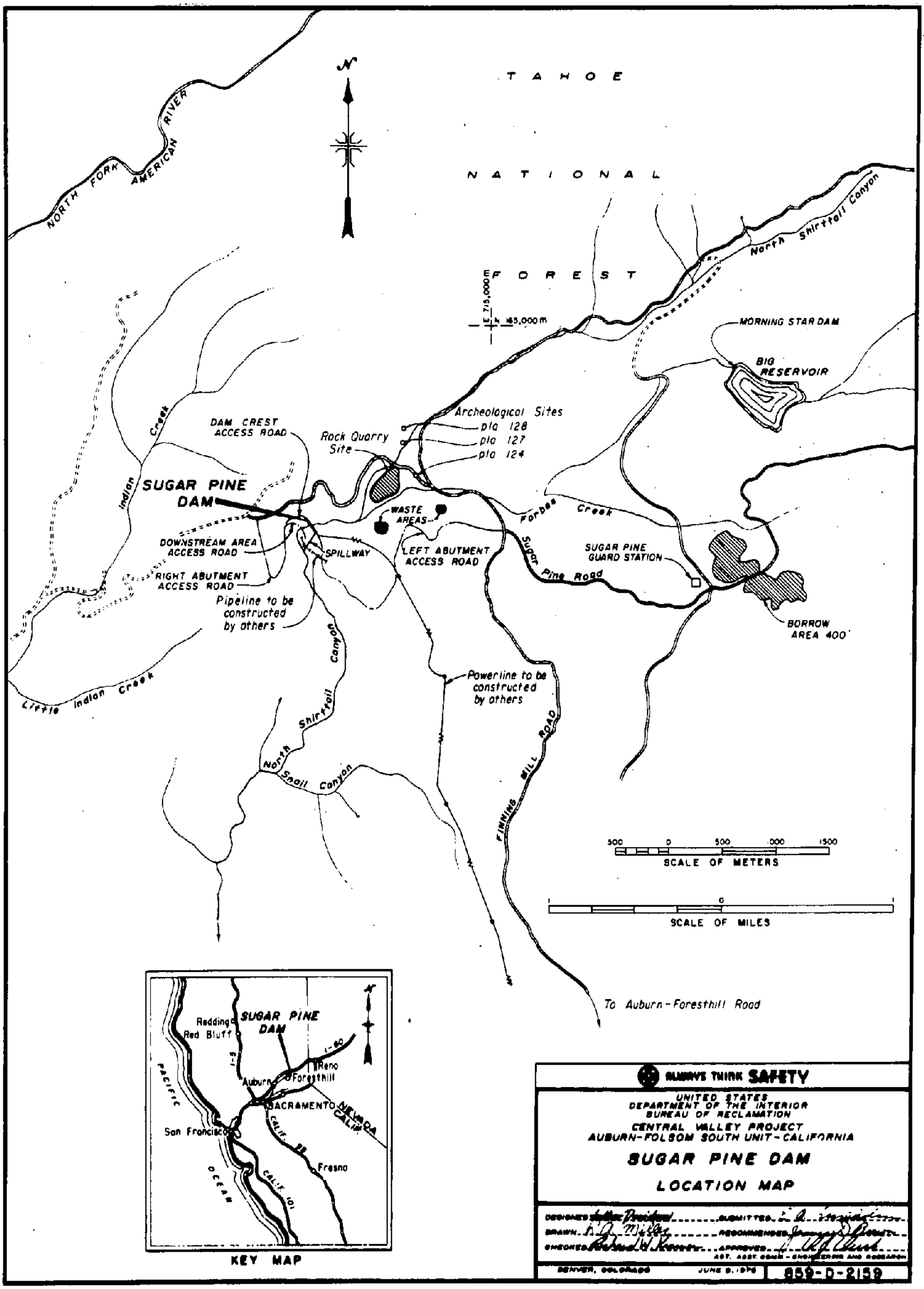
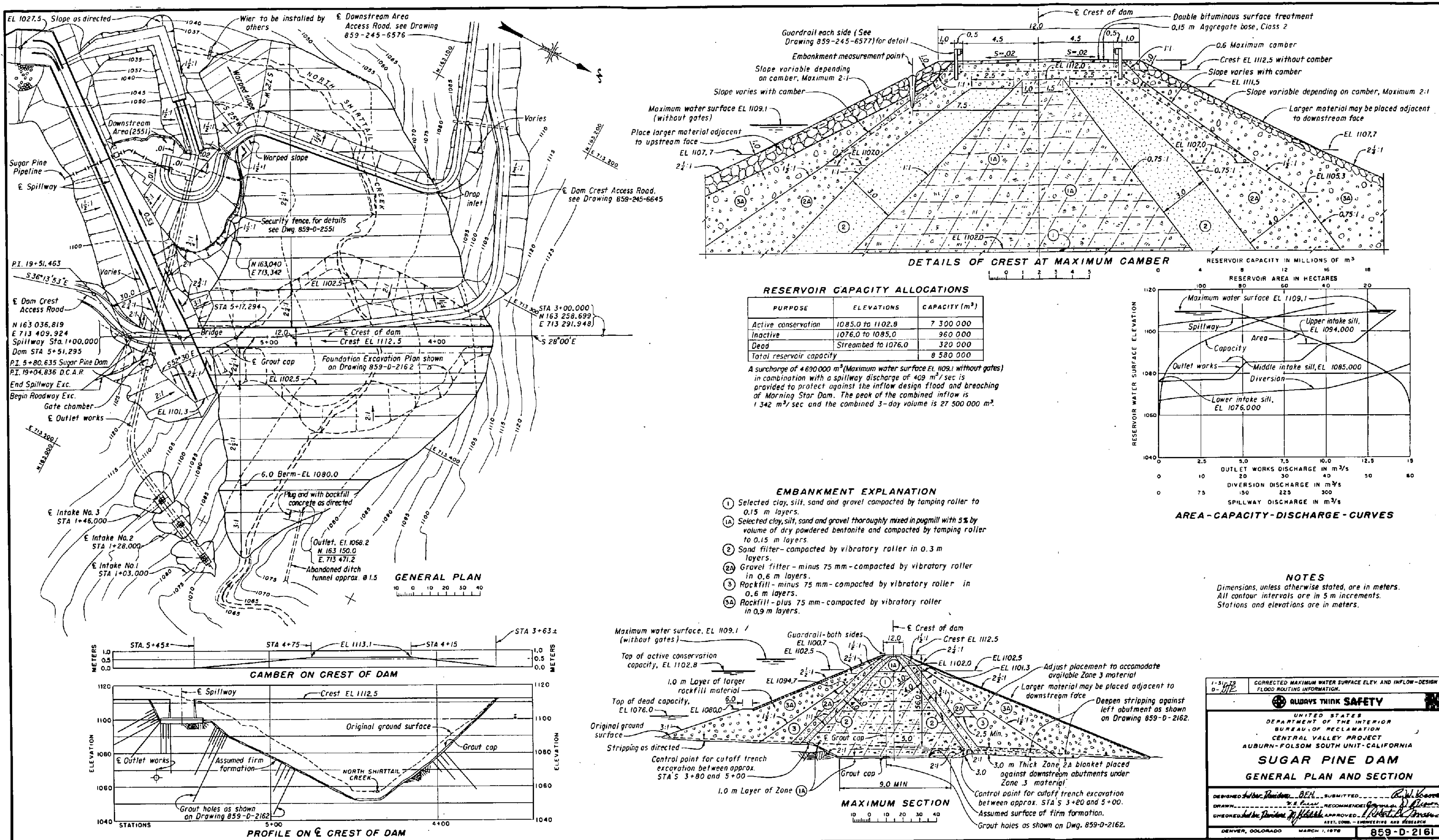


Figure 1. — Location map.



PURPOSE	ELEVATIONS	CAPACITY (m^3)
Active conservation	1085.0 to 1102.8	7 300 000
Inactive	1076.0 to 1085.0	960 000
Dead	Streambed to 1076.0	320 000
Total reservoir capacity		8 580 000

Figure 2. — General plan and sections.

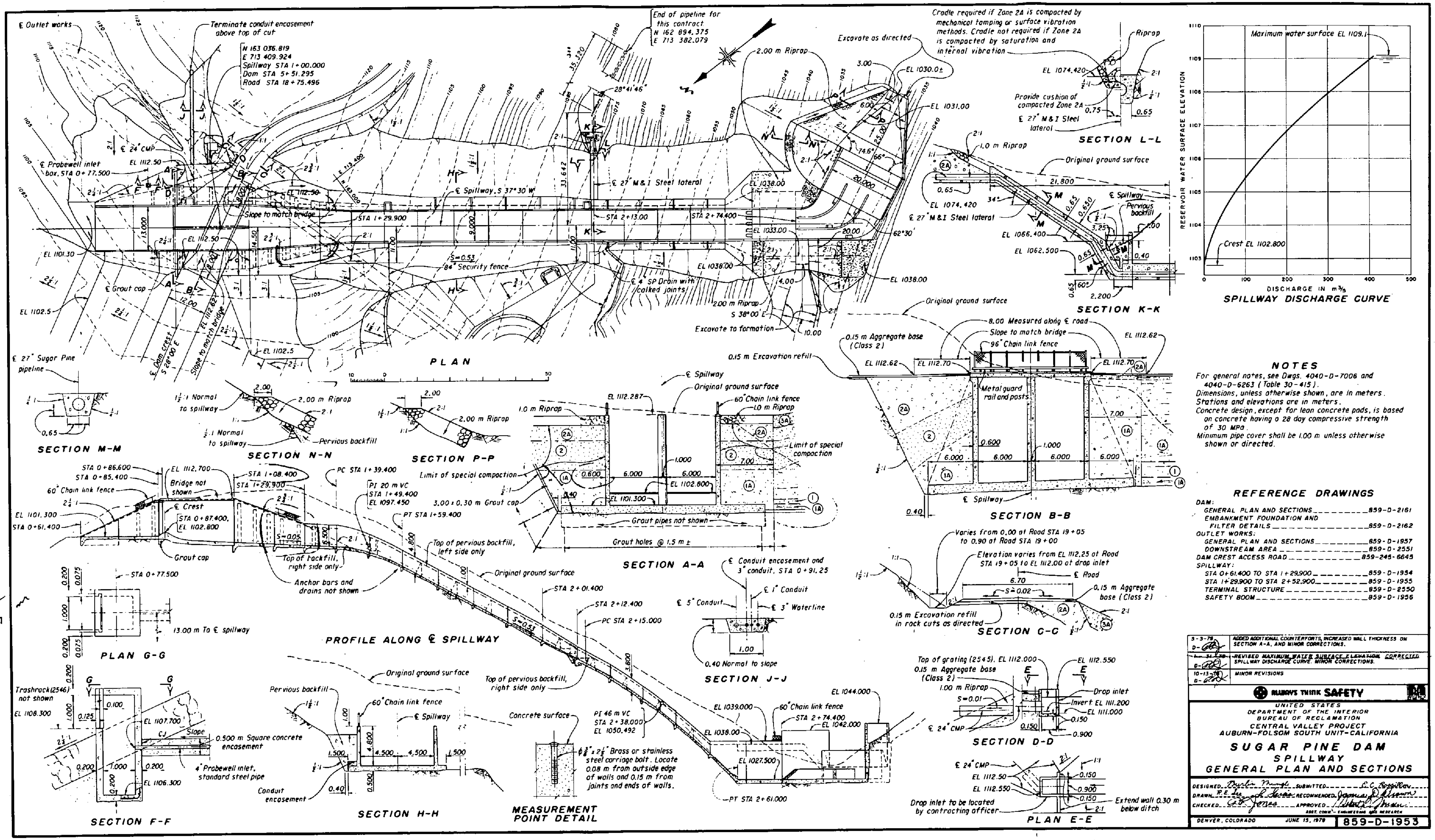


Figure 3. — Spillway, general plan and sections.

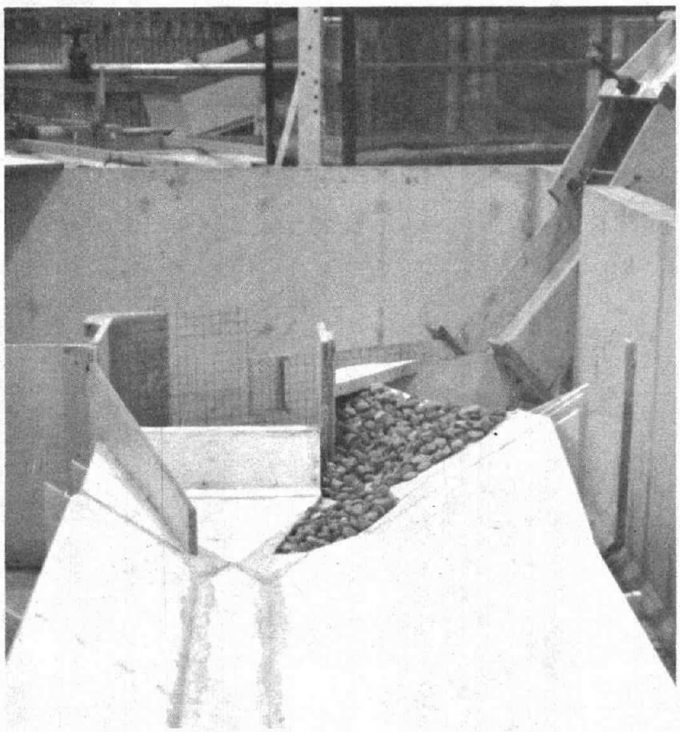


Figure 4. — Overall view of the 1:36 model. (Note the spillway chute on the right, stilling basin in center, and trapezoidal downstream channel in foreground). Photo P801-D-79100

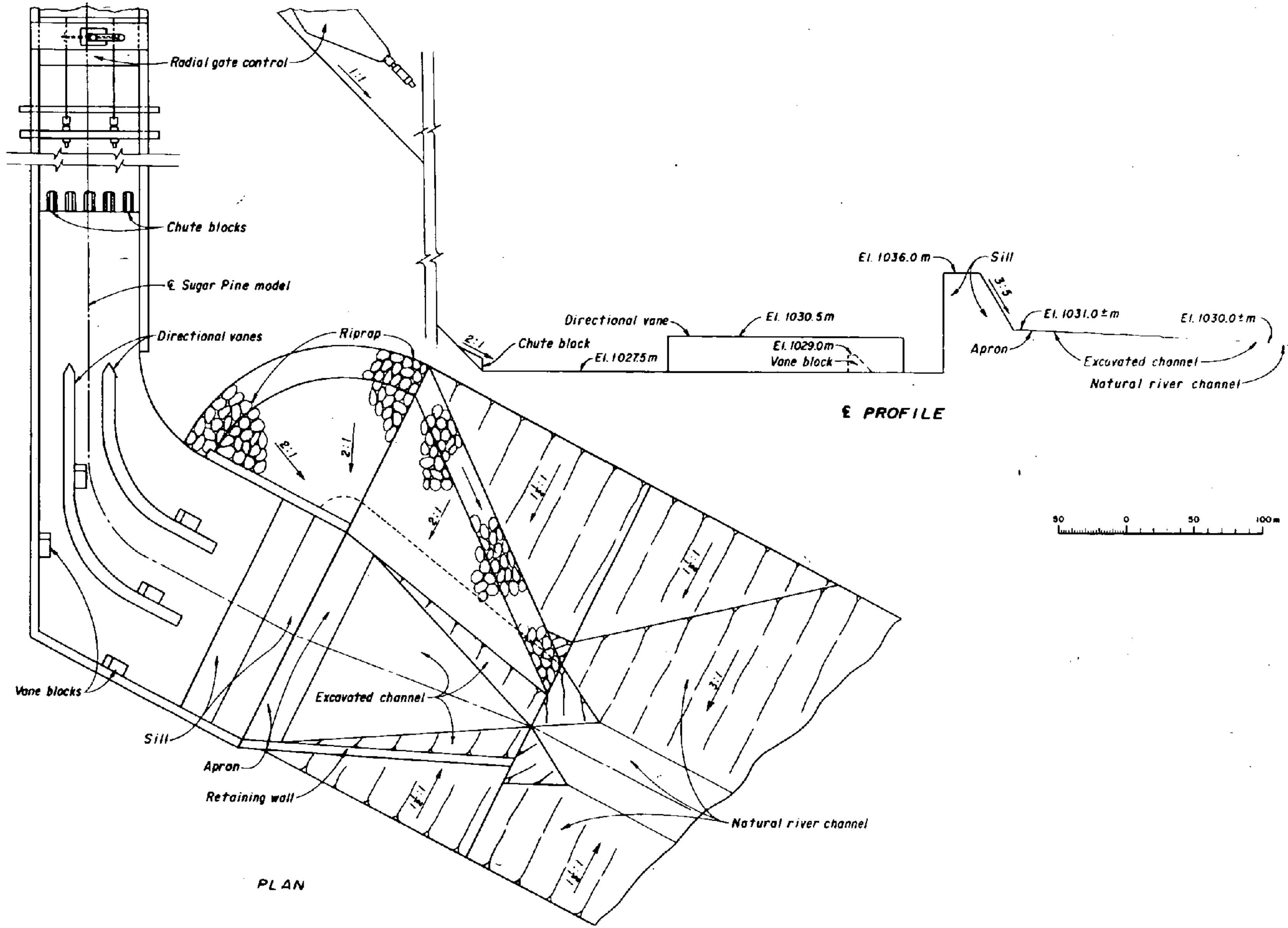


Figure 5. — Spillway model energy dissipator.

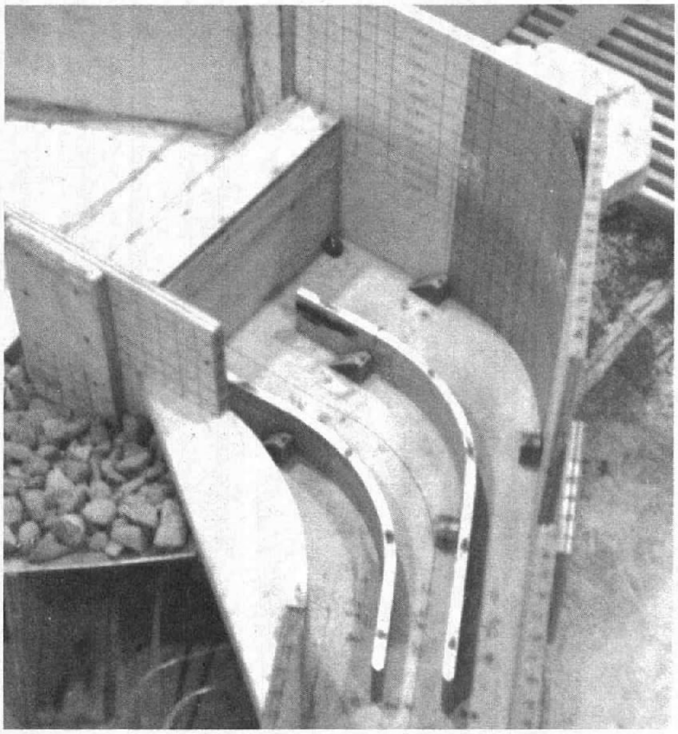


Figure 6. — View of preliminary design stilling basin. (Note directional vanes, vane blocks, and sill). Photo P801-D-79101

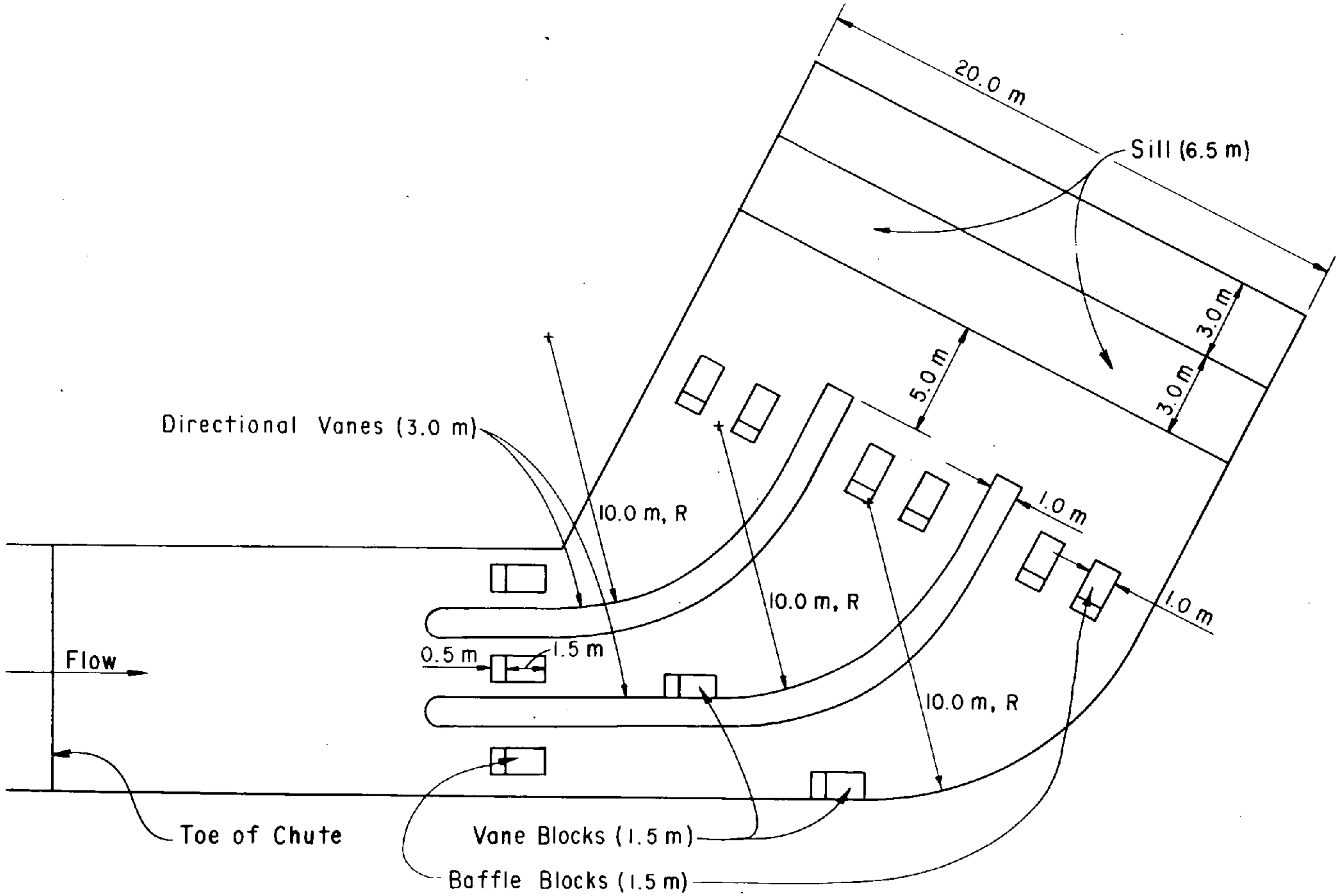
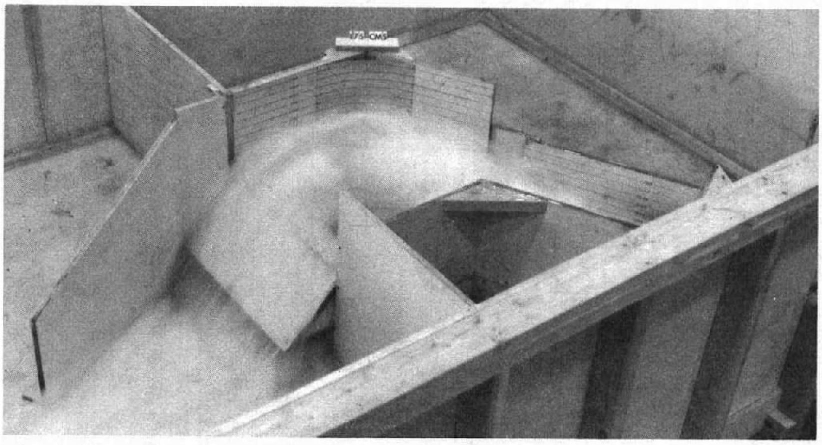
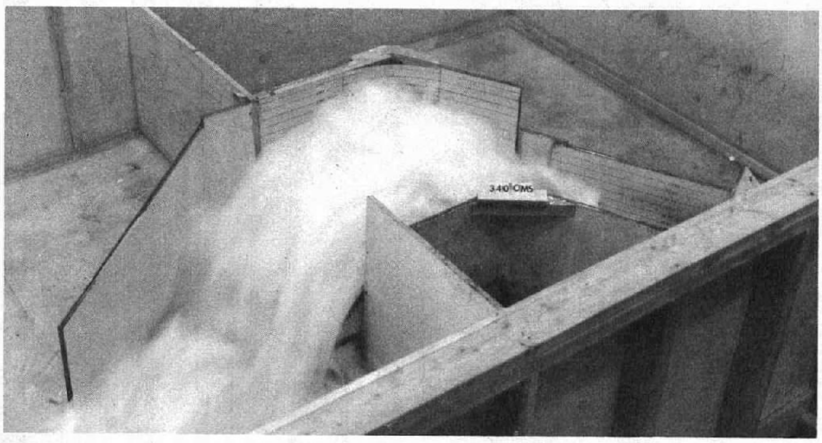


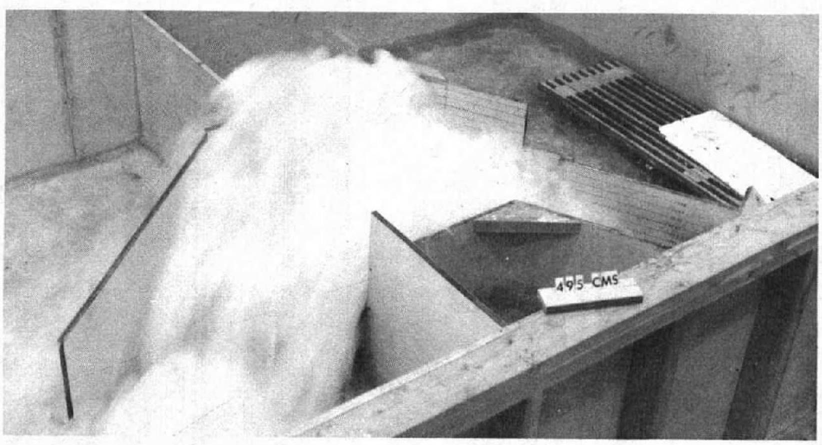
Figure 7. — Scheme 1.



a.—175 m³/s. Photo P801-D-79102.



b.—340 m³/s. Photo P801-D-79103.



c.—495 m³/s. Photo P801-D-79104.

Figure 8. — Flow in basin, scheme 1.

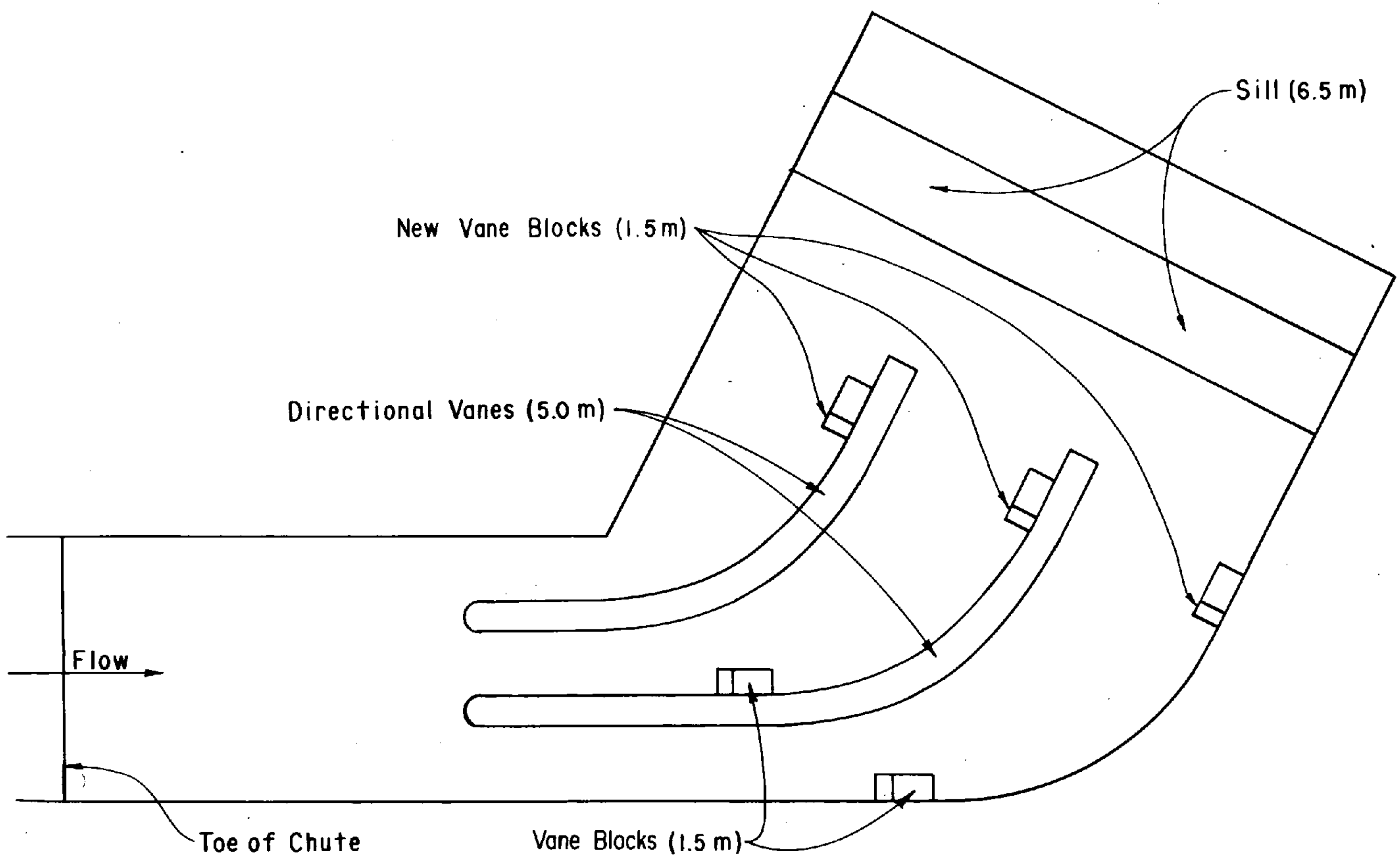
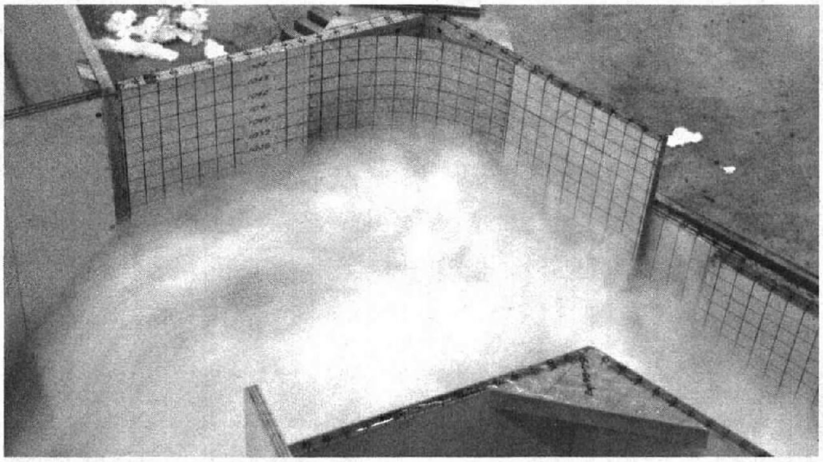
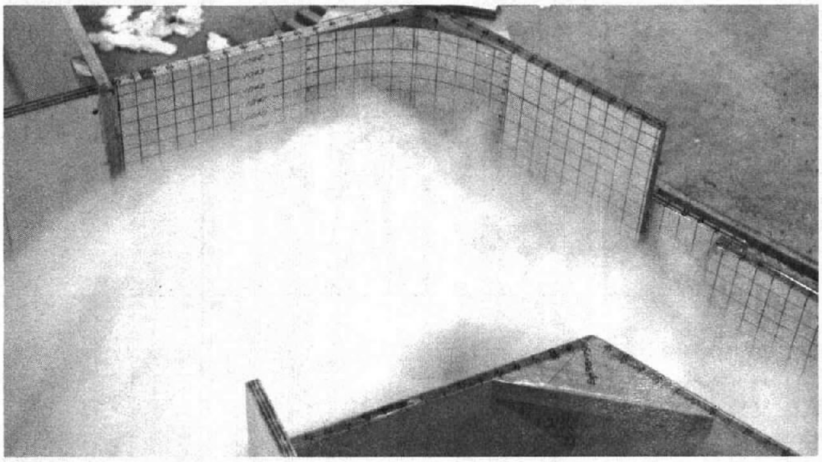


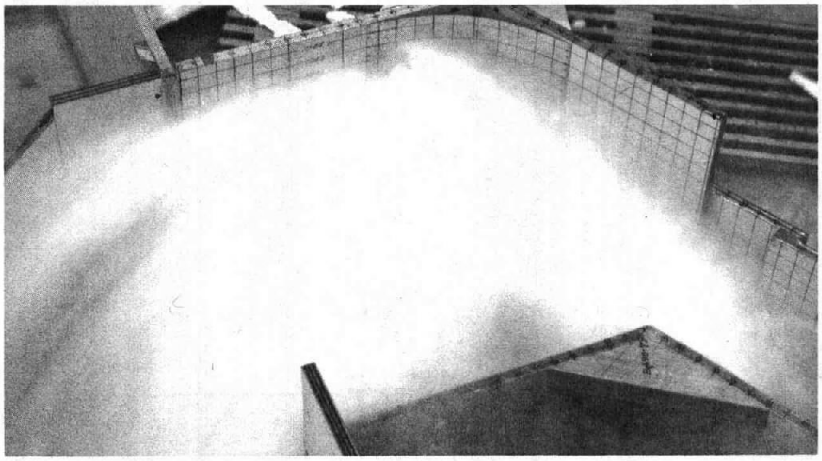
Figure 9. — Scheme 2.



a.—175 m³/s. Photo P801-D-79105.

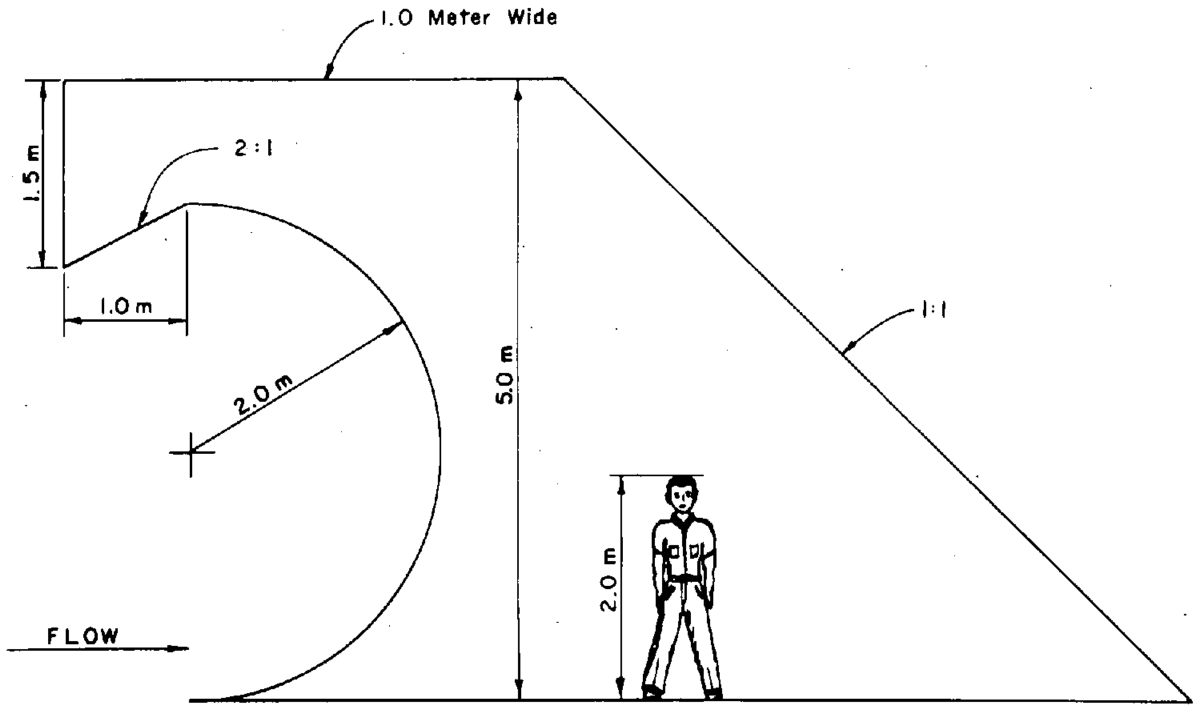


b.—340 m³/s. Photo P801-D-79106.

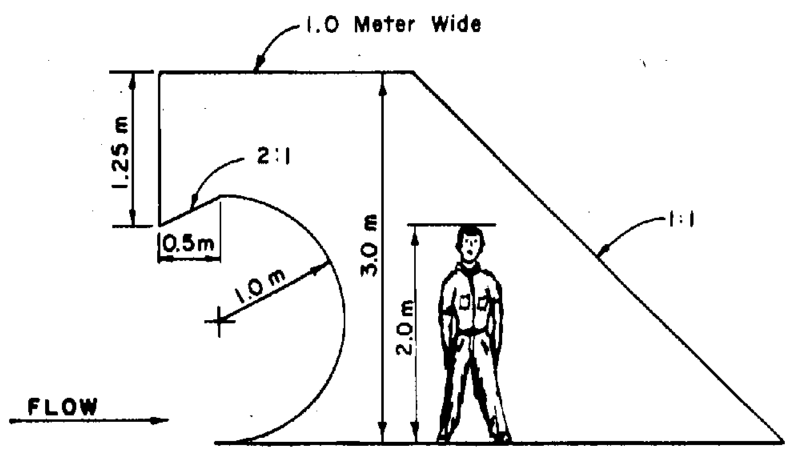


c.—480 m³/s. Photo P801-D-79107.

Figure 10. — Flow in basin, scheme 2.



a. – Scheme 3



b. – Scheme 4

Figure 11. — Concave floor blocks.

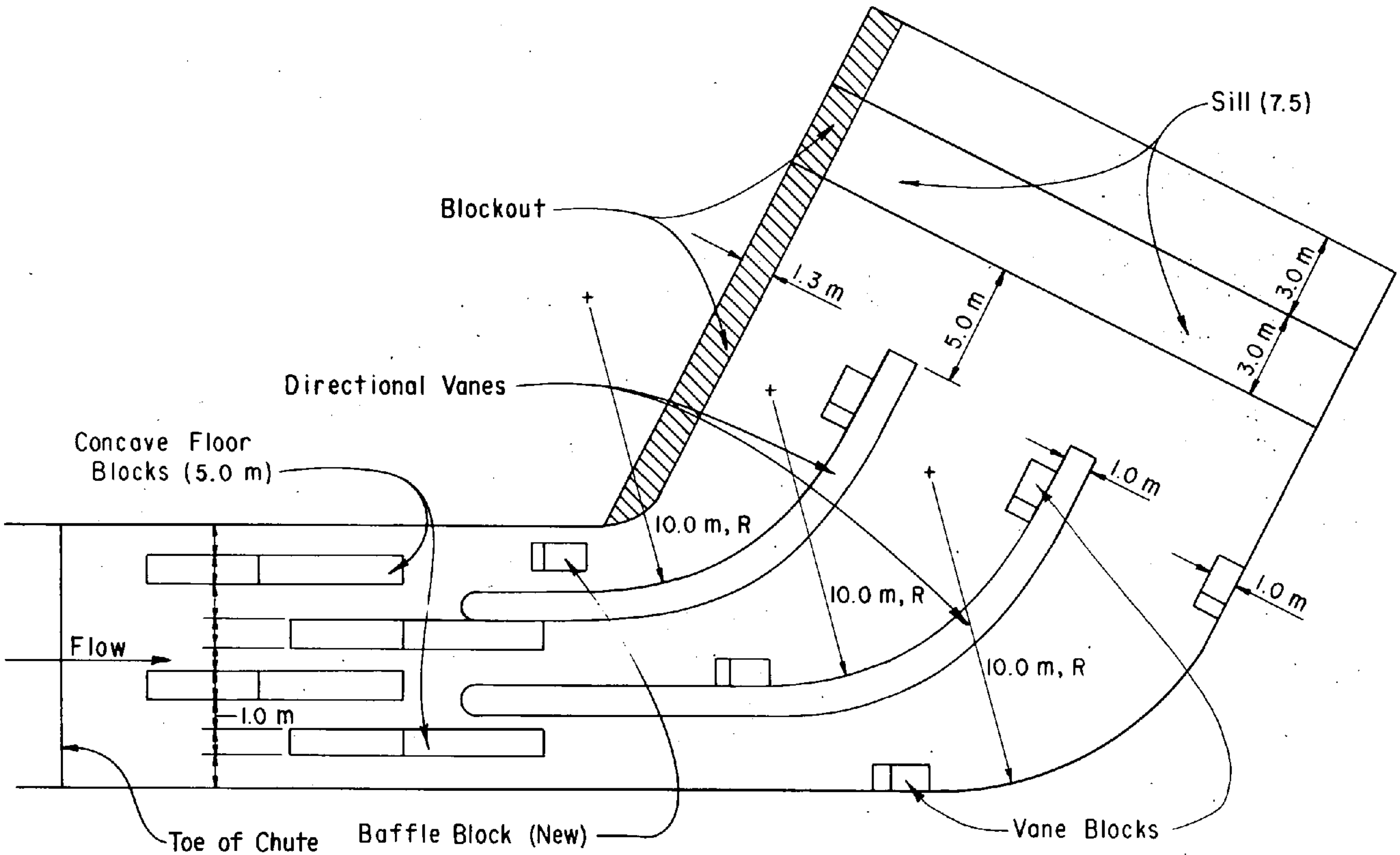
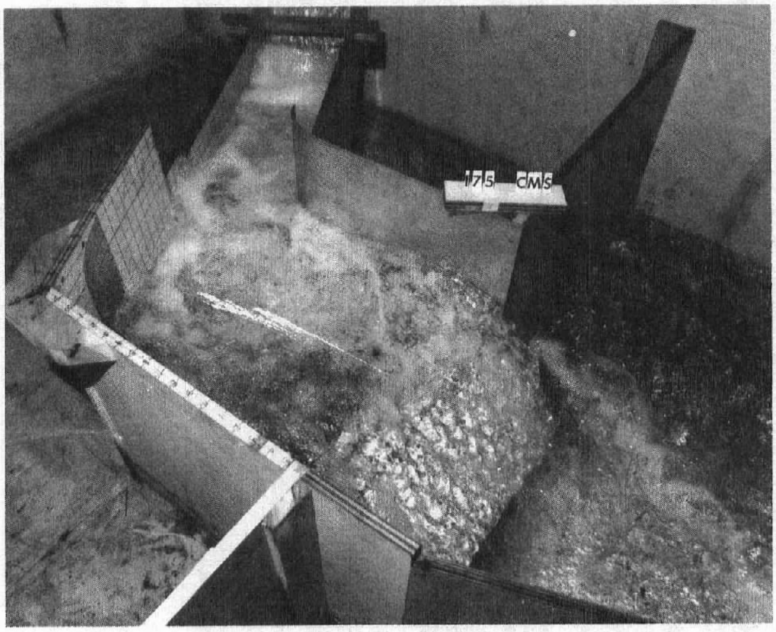


Figure 12. — Scheme 3.



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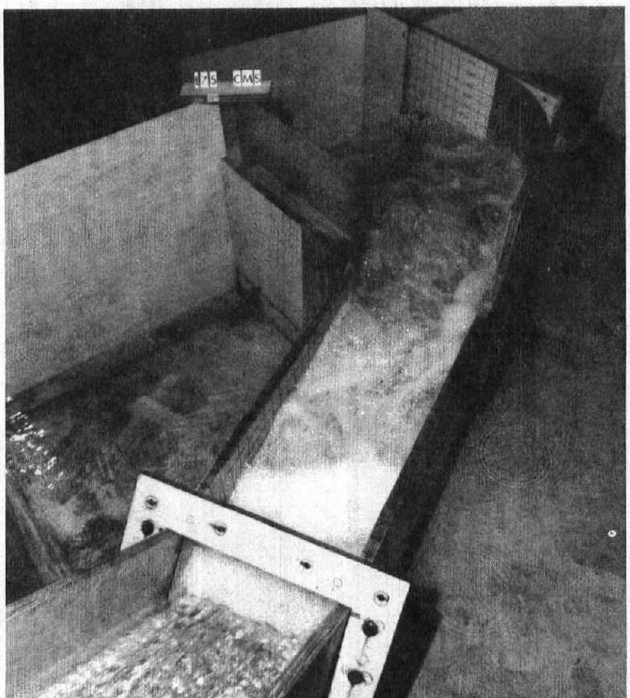

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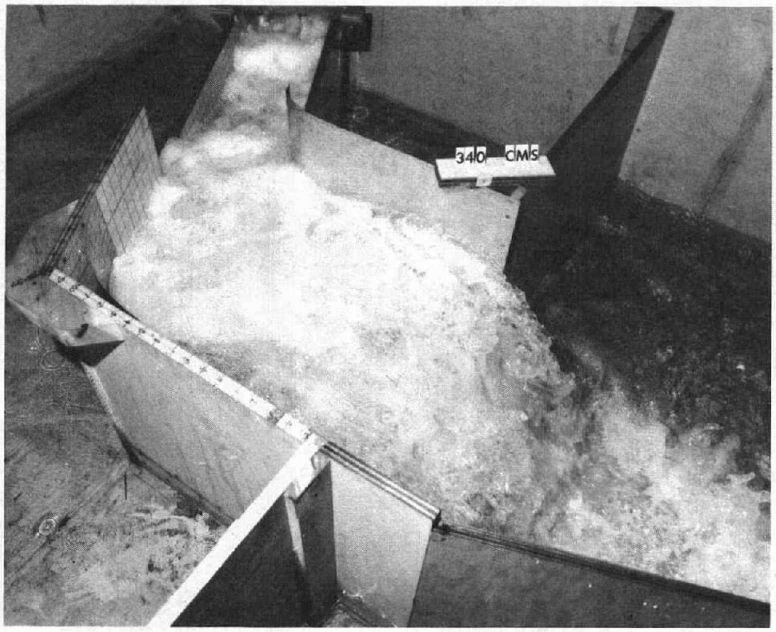
Figure 13. — Flow in basin, scheme 3, 175 m^3/s.



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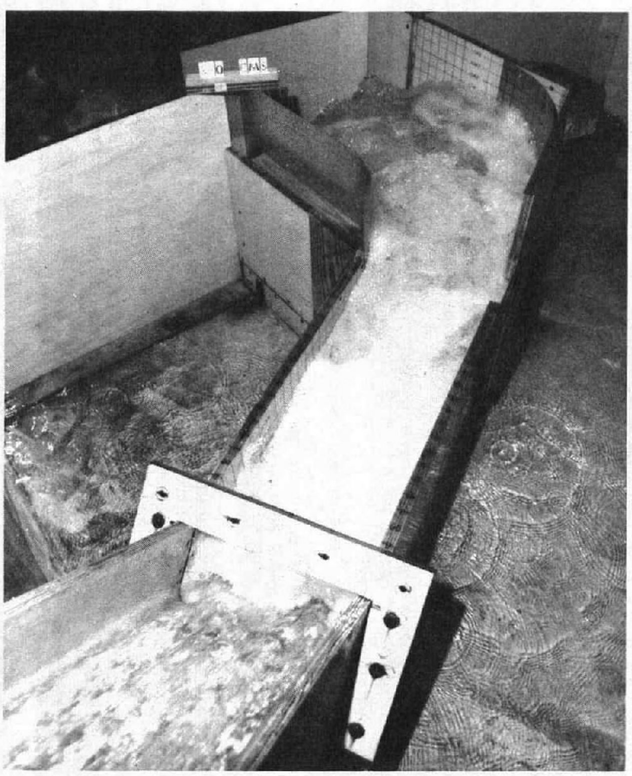

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Figure 14. — Flow in basin, scheme 3, 340 m^3/s.

Photo P801-D-79112.

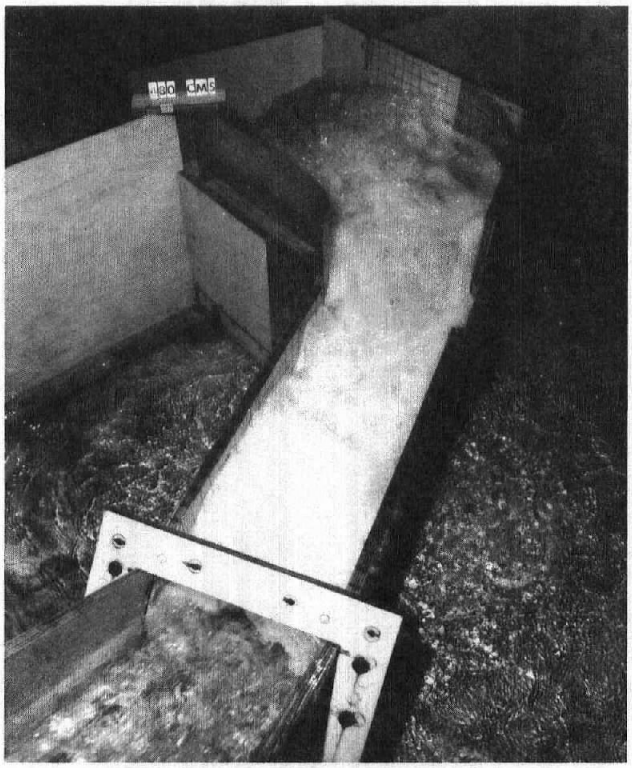


Photo P801-D-79113.

Figure 15. — Flow in basin, scheme 3, 480 m³/s.

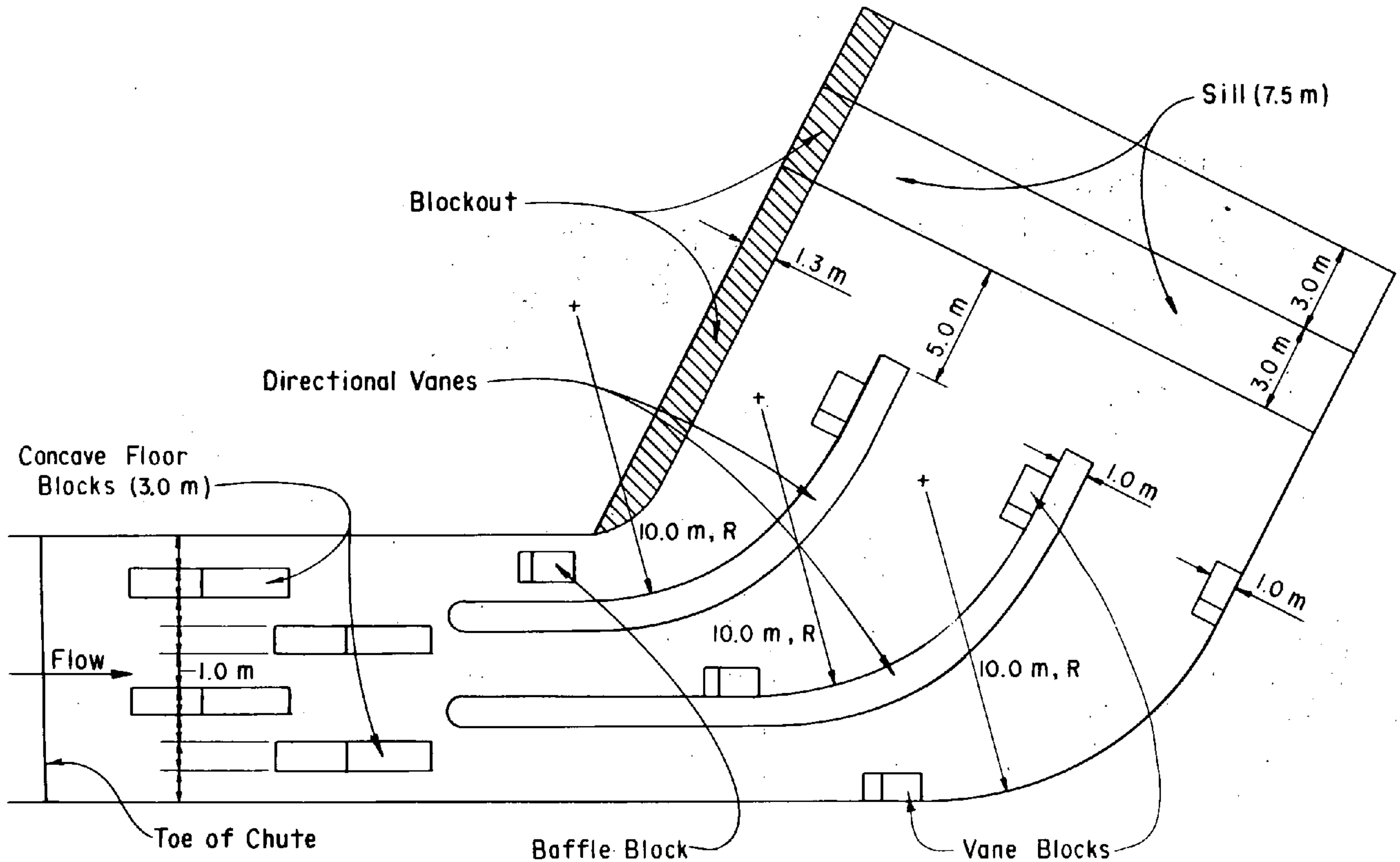
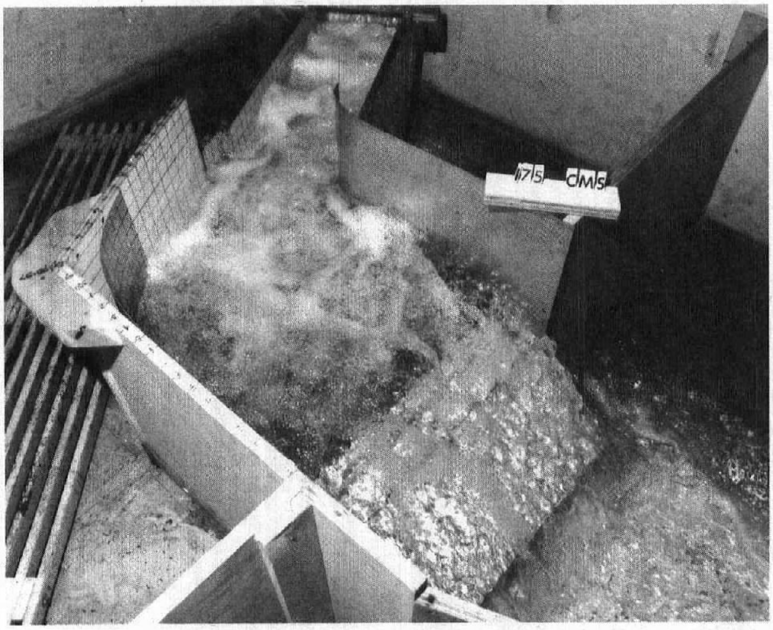


Figure 16. — Scheme 4.



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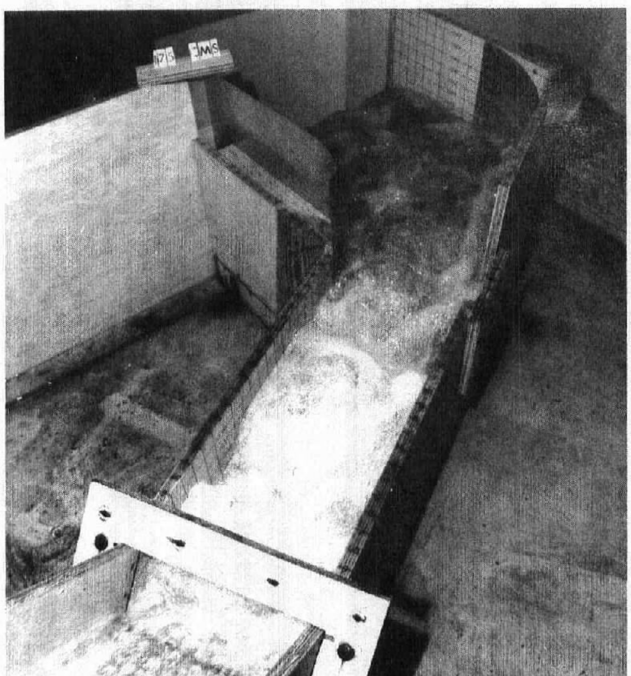

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Figure 17. — Flow in basin, scheme 4, 175 m^3/s.

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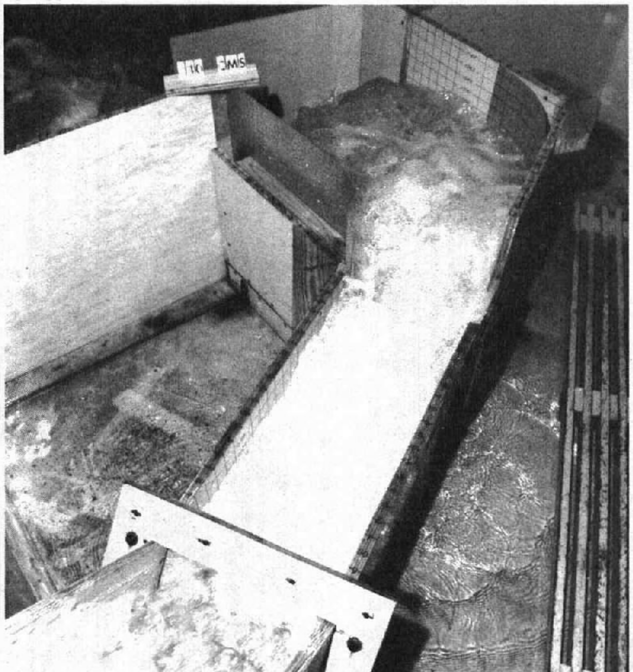

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Figure 18. — Flow in basin, scheme 4, 340 m³/s.

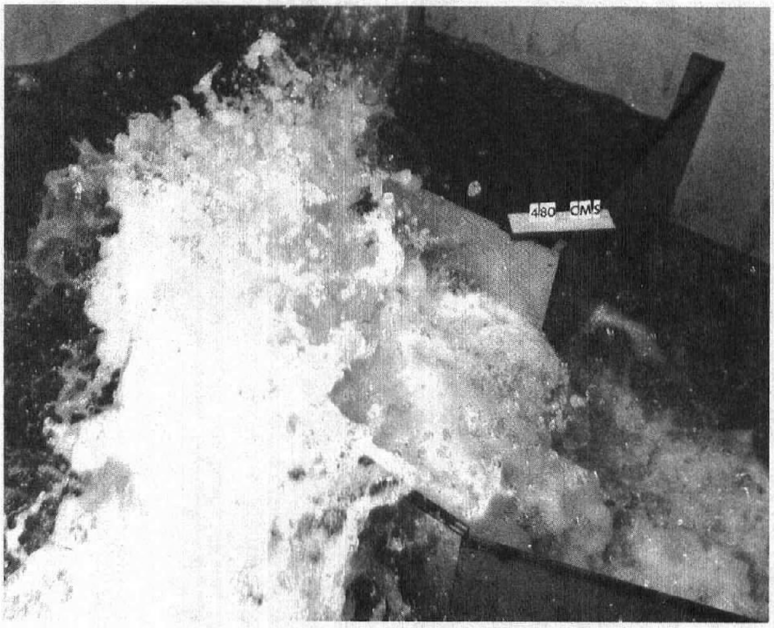


Photo P801-D-79118.

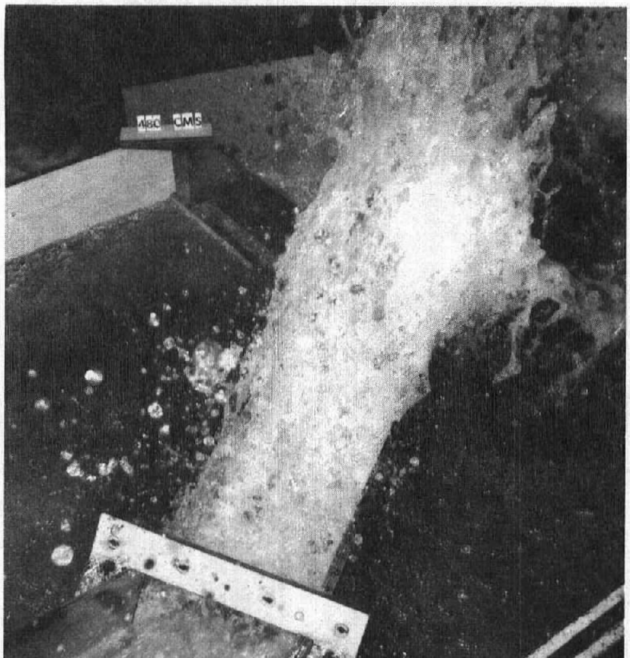


Photo P801-D-79119.

Figure 19. — Flow in basin, scheme 4, 480 m^3/s.

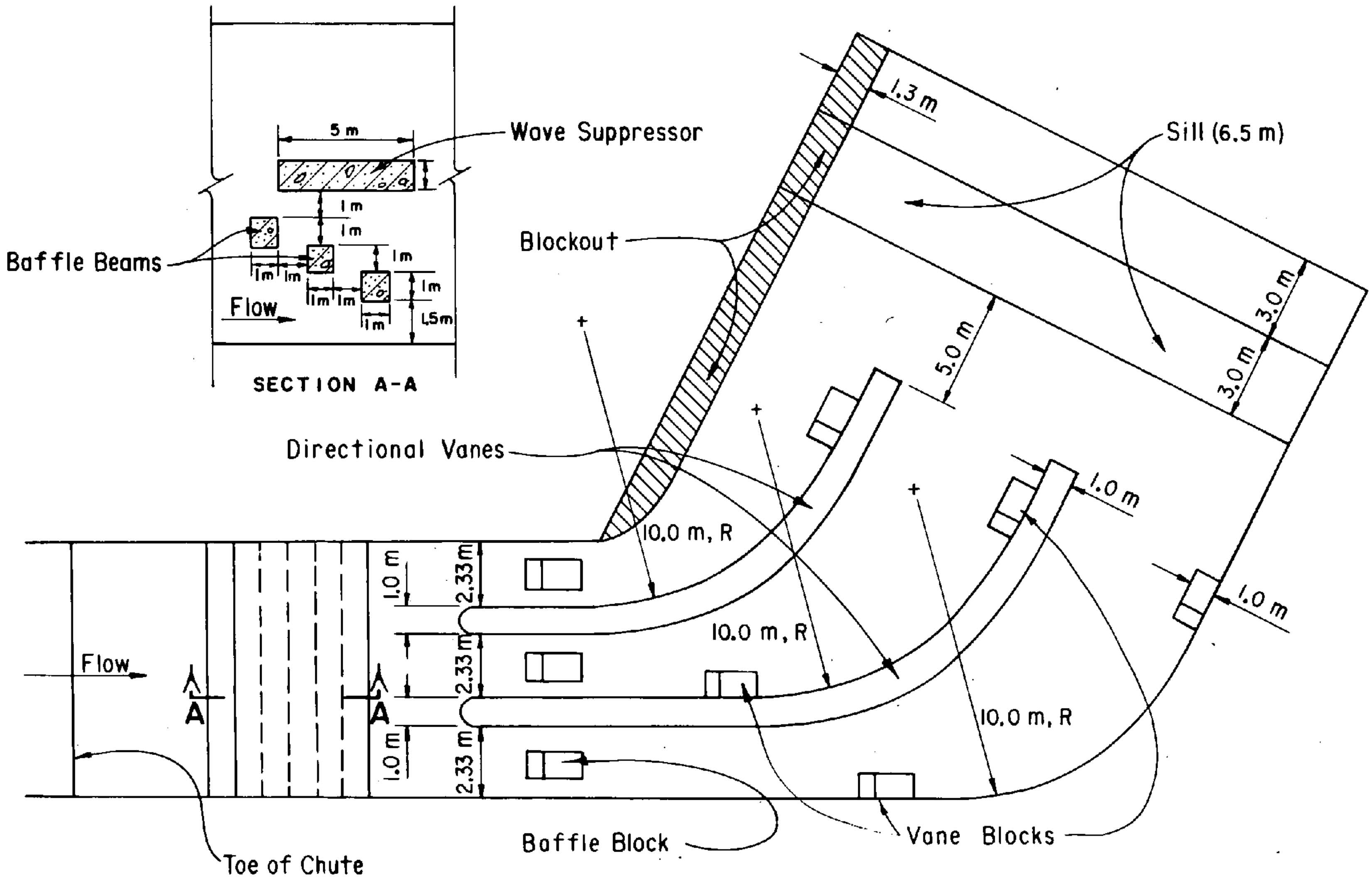


Figure 20. — Scheme 5.

Photo P801-D-79120.

Photo P801-D-79121,

Figure 21. — Flow in basin, scheme 5, 175 m^3/s.

Photo P801-D-79122.

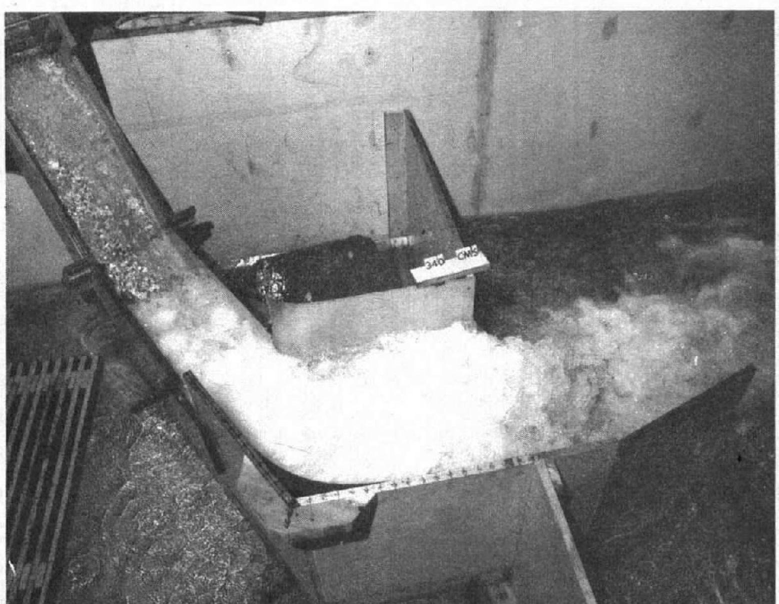


Photo P801-D-79123.

Figure 22. — Flow in basin, scheme 5, 340 m³/s.

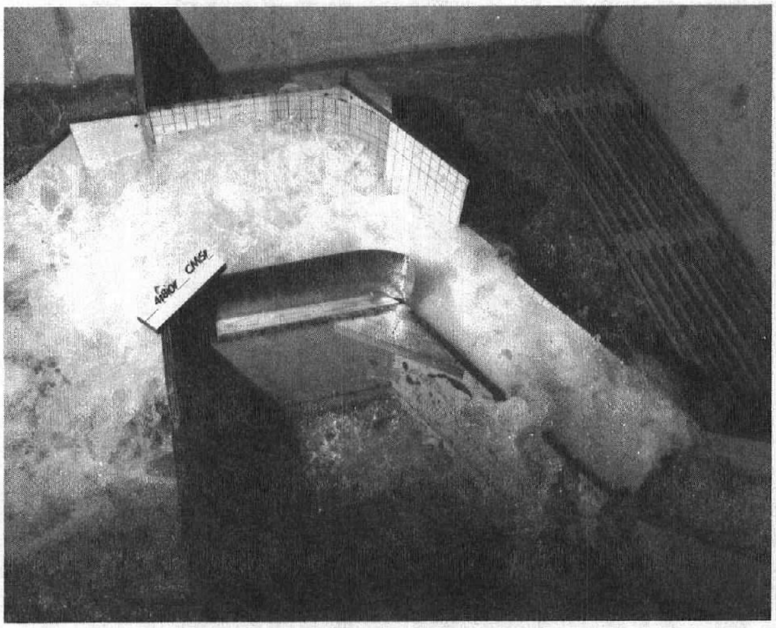


Photo P801-D-79124.

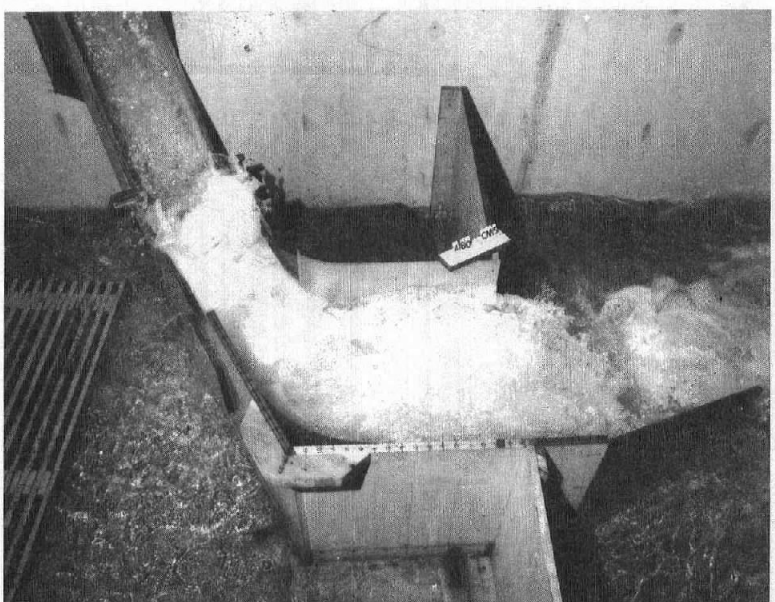


Photo P801-D-79125.

Figure 23. — Flow in basin, scheme 5, 480 m³/s.

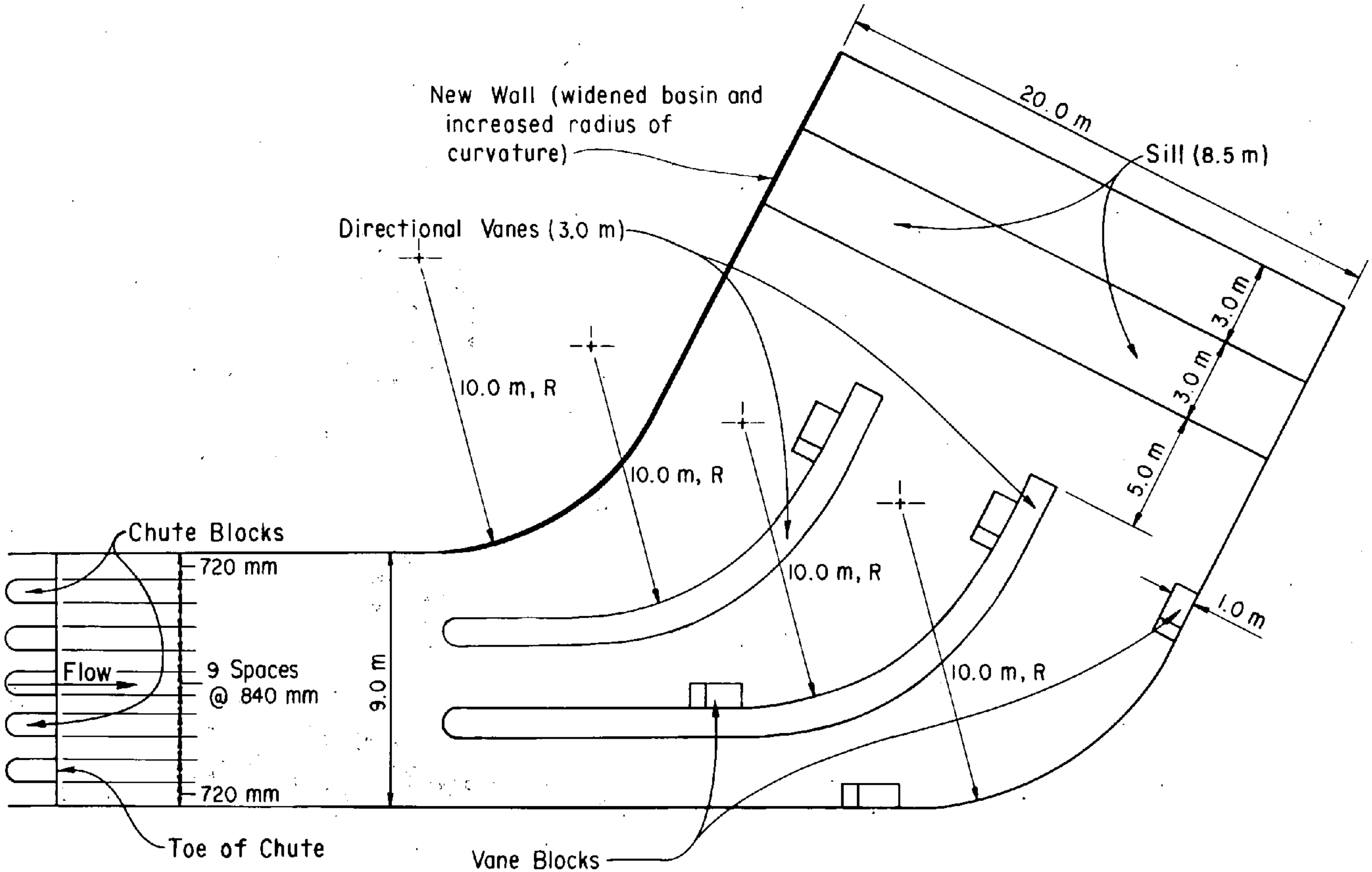


Figure 24. — Scheme 6, recommended design.

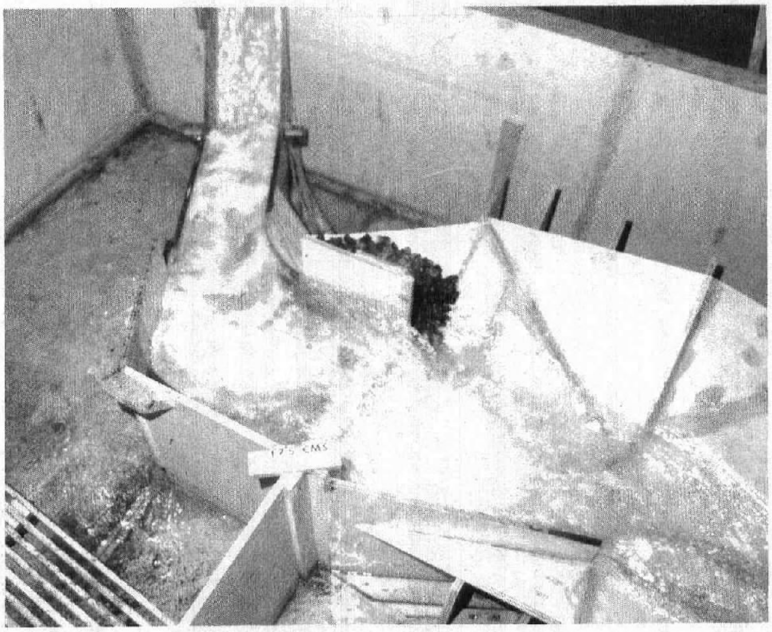


Photo P801-D-79126.

Photo P801-D-79127.

Figure 25. — Flow in basin, scheme 6, 175 m^3/s.

Photo P801-D-79128.

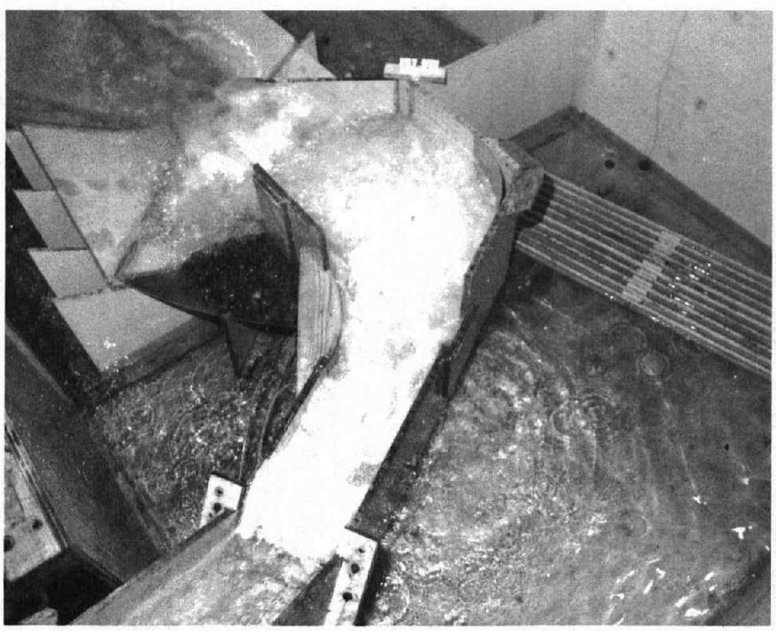


Photo P801-D-79129.

Figure 26. — Flow in basin, scheme 6, 340 m³/s.

Photo P801-D-79130.

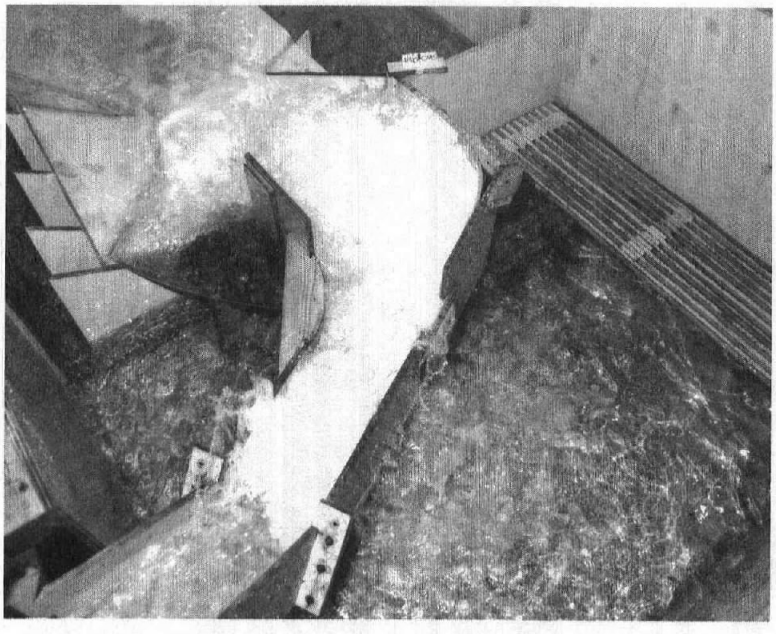
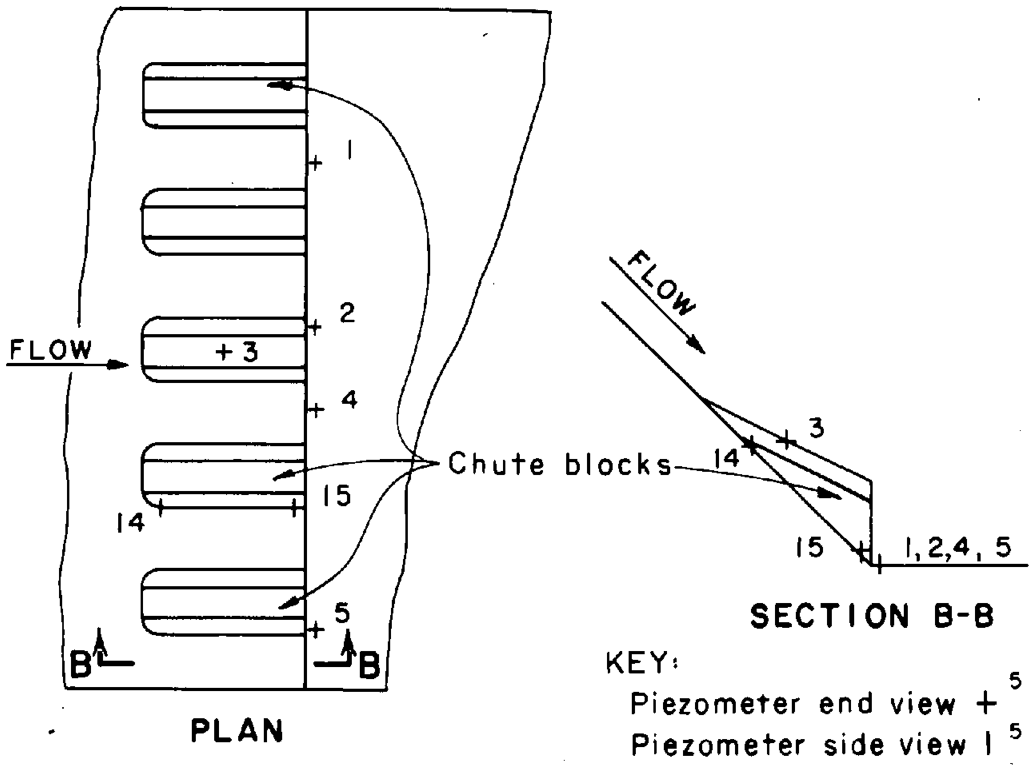


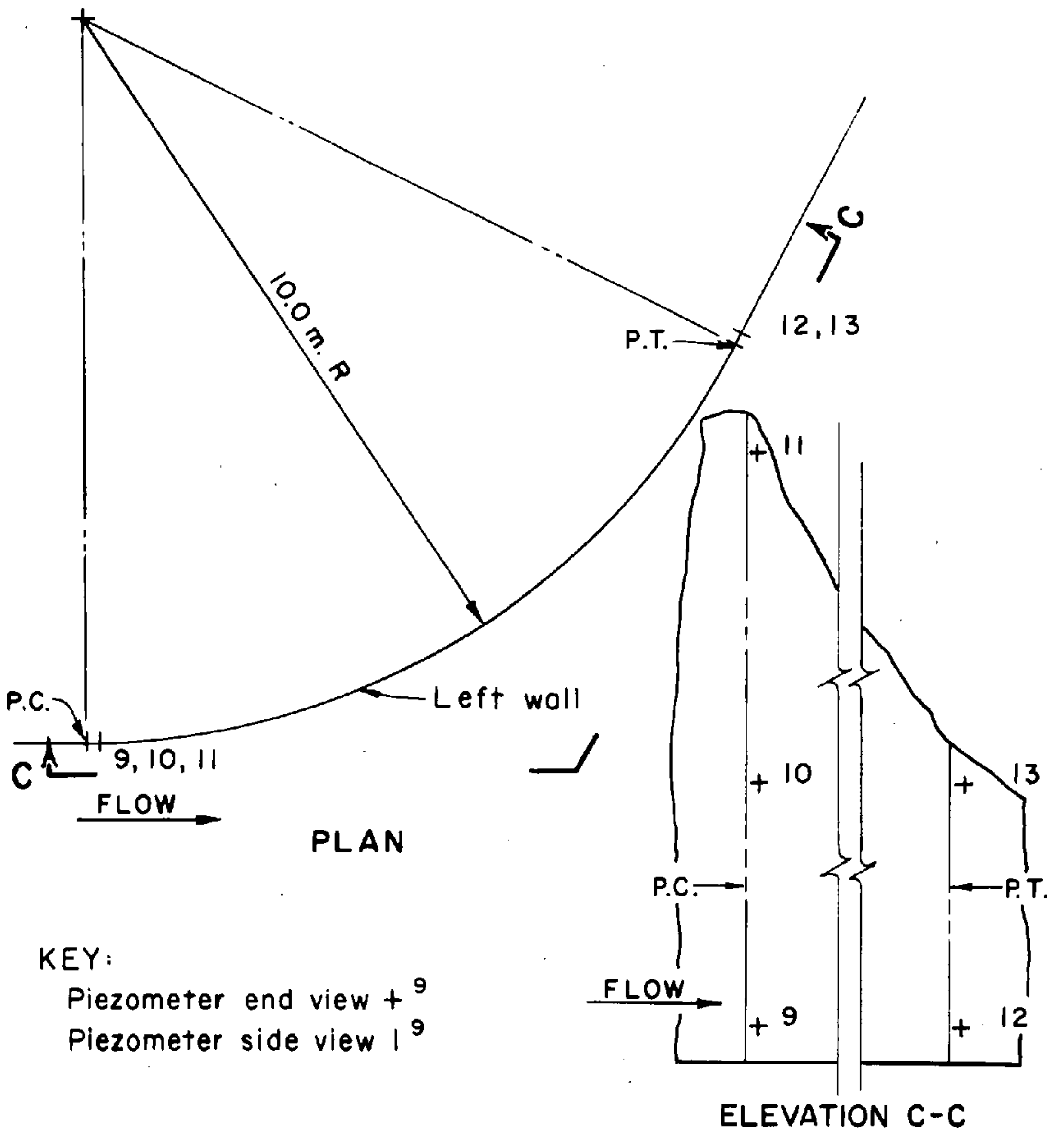
Photo P801-D-79131.

Figure 27. — Flow in basin, scheme 6, 480 m³/s.



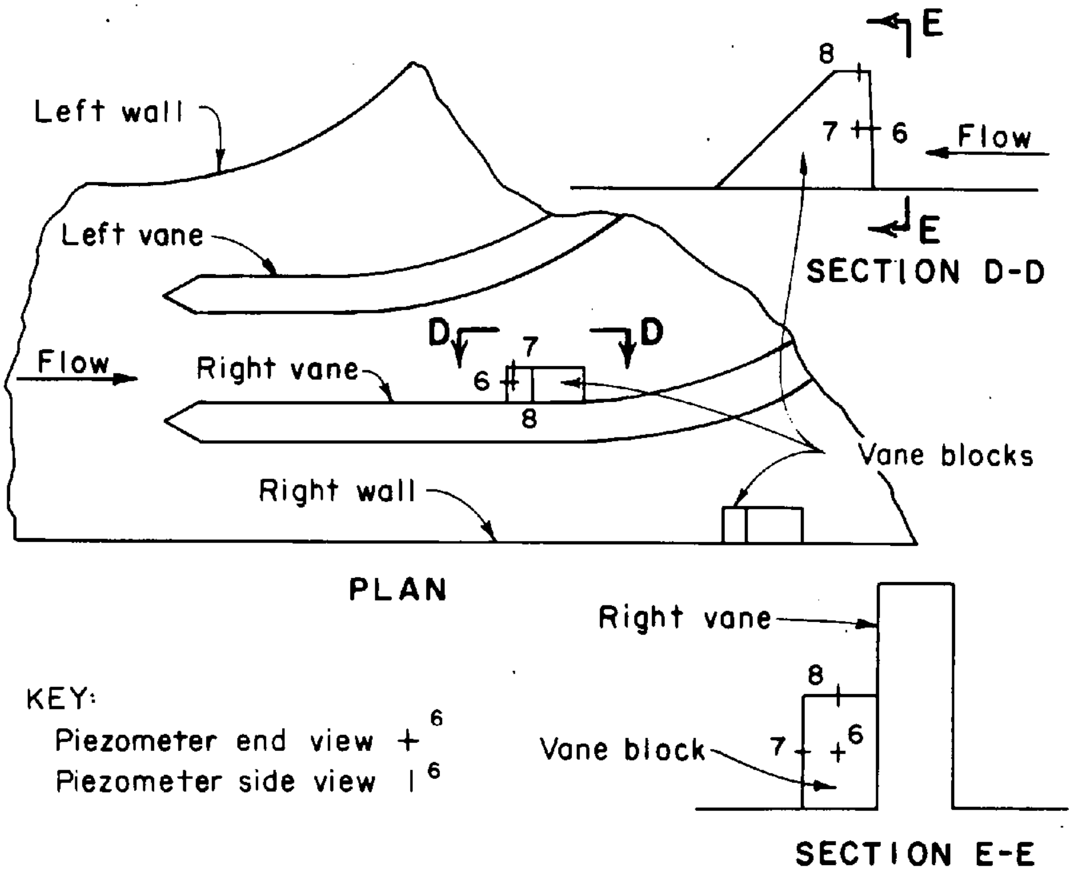
DISCHARGE (m^3/s)	175	255	340	425	480
PIEZOMETER NUMBER	PROTOTYPE PRESSURE HEAD (m of water)				
1	27.68	36.17	38.69	43.23	44.18
2	9.58	11.66	15.76	21.39	24.94
3	12.47	16.09	19.53	24.43	27.03
4	26.26	33.97	37.34	42.09	43.04
5	11.08	12.76	16.42	20.26	23.55
14	7.55	9.47	11.66	14.41	16.99
15	13.33	16.51	20.30	25.62	27.98

Figure 28. — Chute block piezometer locations and pressure data.



DISCHARGE (m^3/s)	175	255	340	425	480
PIEZOMETER NUMBER	PROTOTYPE PRESSURE HEAD (m of water)				
9	3.45	-0.94	-2.81	-7.01	-7.70
10	3.93	2.45	2.09	1.39	1.06
11	0.19	0.81	0.63	0.45	0.52
12	9.74	9.30	8.75	8.86	9.30
13	5.53	5.34	5.16	5.26	5.01

Figure 29. — Left wall piezometer locations and pressure data.



DISCHARGE (m^3/s)	175	255	340	425	480
PIEZOMETER NUMBER	PROTOTYPE PRESSURE HEAD (m of water)				
6	18.30	26.78	33.37	42.86	47.23
7	6.70	3.89	1.73	-0.94	-1.67
8	6.29	4.61	2.71	0.95	0.18

Figure 30. — Vane block piezometer locations and pressure data.

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