SIRIKIT DAM
NAN RIVER PROJECT
THAILAND
OUTLET WORKS
HYDRAULIC MODEL STUDY

for

Engineering Consultants, Inc.
Denver, Colorado

by

Susumu Karaki
Professor of Civil Engineering

Civil Engineering Department
Colorado State University
Fort Collins, Colorado

May 1969

CER68-69SK38

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SIRIKIT DAM

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SUMMARY

A change in the outlet works for Sirikit Dam is proposed. Whereas originally the outflow was directed to the river through a separate tunnel, the current proposal is to reduce a substantial portion of that tunnel by directing the outlet flow into the spillway tunnel. A question thereby arises as to the most practical and adequate arrangement for the total outlet works. When the model study began, the single important criterion was to prevent erosion of the spillway tunnel because such erosion could be the origin of serious cavitation damage when spillway flows occurred. It was desirable, therefore, to dissipate some of the kinetic energy of the outlet flow before entry into the spillway tunnel. The problem was approached first by conducting small scale model tests of three basic schemes. As a consequence of these studies, scheme 2, involving a vertical chamber, was selected for further study in a large scale model

The hydraulic conditions, that is energy dissipation and flow velocities, were adequately controlled by the selected scheme, but the consequent vibration was of some concern. After many modifications an arrangement of guide blocks and deflectors were found to reduce vibration considerably. Whether the vibration would have serious consequences with respect to the rock in which the vertical chamber would be constructed remains as open question outside the scope of this report. A recommended vertical chamber is given within this report.

During the course of this study, a modification to the vertical curve of the spillway tunnel was proposed which would change the criterion upon which these studies were based. If the proposal is adopted, it would no longer become mandatory to dissipate the energy of the outlet flow before entry into the spillway tunnel. Accordingly a different outlet works arrangement, called scheme 4, is recommended conditionally if the spillway tunnel change is adopted.

INTRODUCTION

General Background

Sirikit Dam, Nan River Project, has been described adequately in other reports[1,2]. After completion of a general model study of the river diversion and spillway, a proposal was advanced by Engineering Consultants Inc. (ECI) to join the outlet tunnel with spillway tunnel 1. This proposal would accomplish two important objectives. (1) It would eliminate construction of a substantial portion of a fifth tunnel and thereby effect savings in construction costs. (2) It would eliminate the river outlet stilling basin, hence, make it possible to relocate the downstream cofferdam from its original restrictive location where the slopes are subject to erosion from river diversion flows.

Objectives of This Investigation

There are many possible alternative designs for joining the outlet tunnel with the spillway tunnel. It was considered necessary to dissipate part or all of the excess kinetic energy from the outlet flows before entry into the spillway tunnel, for, any erosion of the spillway tunnel surface by outlet flows could be the origin of serious cavitation damage with spillway flows.

There are three basic schemes possible to dissipate the excess energy. (1) Dissipate it at the level of the outlet tunnel downstream from the gates which is approximately 25 meters above the spillway tunnel floor and absorb the balance of kinetic energy in the spillway tunnel where the water depth would be about 7 to 9 m. (depending on discharge). (2) Spread the flow over a large area in the spillway tunnel so that the energy would be adequately dissipated by impact with the water in the spillway tunnel. (3) Dissipate the energy in a vertical chamber between the level of the outlet tunnel and the crown of the spillway tunnel.

Selecting and proportioning a satisfactory outlet works was approached in two steps. Initially a small scale model was constructed to compare the relative merit of the basic schemes mentioned above. The selected scheme was then subjected to further testing in a larger scale model to improve hydraulic performance.

Model Scales

The small scale refers to a model to prototype length ratio of 1:78.7 (1 in.:2 m.). This scale was essentially the same as that used for the general model study (1:80). The large scale had a length ratio of 1:39.4 (1 in.:1 m.).

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[1]Invitation for Bids No. C-1E. Contract Documents for Invitation, Proposal-Bill of Quantities, Contract, Instruction to Bidders, and Conditions for Phasom Dam and Appurtenant Structures, Nan River Multipurpose Project, Thailand. Volume I of III. Engineering Consultants, Inc., Denver. September 1967.

[2]Invitation for Bids No. C-1E. Contract Documents for Technical Specifications for Phasom Dam and Appurtentant Structures, Nan River Multipurpose Project, Thailand. Volume II of III. Engineering Consultants, Inc., Denver. September 1967.

SMALL SCALE MODEL TESTS

Scheme 1 - Dissipation in the Spillway Tunnel

A possible arrangement of this scheme is shown in figure 1. The outlet tunnel joins spillway tunnel 1 downstream from the P.T. of the vertical curve which is at Sta. 0+497.33 m. The principle objective of the arrangement was to spread the flow as much as possible within the confines of the tunnel with the intent that the water cushion within the spillway tunnel would absorb the kinetic energy of the flow. The 6 m. diameter tunnel downstream from the gates intersects the spillway tunnel at an angle of about 40 degrees. Although there can be some variation in this angle, there are construction limitations imposed.

There would be three sets of gates (for control and for emergency shut-down) to control the outlet flow, each 2.5 x 3.5 m. in size with the invert elevation at approximately 95 m. The maximum design outlet discharge was 400 m^3/sec and the three gates could be operated unsymmetically.

The model - The model included the outlet gates, the junction, and a short reach of spillway tunnel 1. The curved tunnel downstream from the gates was modeled with flexible pipe for ease of model construction. The spillway tunnel was made as an open channel to facilitate observations and photography. It was not considered important to close the top of the model spillway tunnel with a semi-circular section, although the sides and bottom were rounded to the proper dimensions.

Results - The series of photographs labelled as figures 2a through 2d depict the hydraulic conditions within the tunnel for discharges of 400, 300, 200 and 100 m^3/sec, respectively. The proposed outlet arrangement functioned most satisfactorily for discharges less than 200 m^3/sec. With 300 m^3/sec the velocities at the invert of the spillway tunnel were fairly large, but the energy was still adequately dissipated as manifested in the appearance of the water surface in the tunnel (see figure 2b). The total momentum of the flow for a discharge of 400 m^3/sec was great enough to sweep the water from the region of impact and cause a hydraulic jump downstream in the spillway tunnel. This resulted in the large energy flow impinging directly on the spillway tunnel floor, a condition which is considered desirable to avoid for reasons mentioned earlier.

The condition pictured in figure 2a for 400 m^3/sec meant simply that the momentum (M) of the flow entering the region of impact was greater than the force, F, plus M afforded by 9 meters of water depth with 400 m^3/sec flow downstream of the region of impact. Consequently, it is easy to reason that F+M for the entering flow must be distributed over a greater area in the spillway tunnel. This could be accomplished in two possible ways: (1) establish a better circumferential distribution of the flow in the outlet tunnel, and (2) reduce the angle of intersection of the outlet and spillway tunnels.

The first could be accomplished most easily by varying the horizontal angle of the outlet tunnel (approximately 25 degrees as shown on figure 1) to create a greater angle of outlet tunnel curvature so that the centrifugal force of the flow would better distribute the flow (greater swirling action). The arrangement shown and tested in figure 1 already caused swirl as the photographs in figure 2 show. A closer photograph for a flow of 400 m^3/sec is shown in figure 3. Several different angles were tested (which was easy to do because of the flexible pipe), but the effect was not manifestly different from that shown in figure 2a.

The second possibility was tested by simply elevating the terminus of the flexible pipe. While it was possible to bring the hydraulic jump closer and even into the region of impact, the large energy flow still swept the tunnel clear of "standing" water with consequent impact of the flow directly on the tunnel invert.

It was mentioned earlier that the outlet gates need not necessarily operate symmetrically. Tests with one gate open were recorded photographically in figures 4a, b, and c for the left, center and right gates, respectively (labeled in terms of the viewer looking downstream). The swirling action, hence the spread of flow, was definitely a function of the open gate, length of tunnel and tunnel curvature. For instance, it will be noted that flow (about 240 m^3/sec) from the right gate (figure 4c) caused a greater circumferential spread of flow than did the left or central gate. This resultant flow condition was neither beneficial nor detrimental, as it was already shown that for discharges less than 300 m^3/sec the hydraulics of the outlet flow were generally satisfactory. It will be mentioned, however, that the greater swirling action of the flow from the right gate subjected the spillway tunnel walls to more direct jet impingement than for flows from the other two gates (compare figure 4c with figures 4a and b).

Comments - The pertinent points to note from the results are that flows less than 300 m^3/sec can be satisfactorily discharged directly into the spillway tunnel, as the elevation of the flip bucket lip causes sufficient backwater depth within the tunnel to absorb the kinetic energy of the outlet flow in the form of turbulent diffusion of momentum. A discharge of 400 m^3/sec could cause erosion of the spillway tunnel lining through impact of the large velocity jet. It was not materially helpful to create a greater swirl in the outlet tunnel and it did not appear feasible to fully absorb the energy for the maximum design discharge. Although there are a large number of possible combinations of horizontal and inclined angles for the outlet tunnel that could be tried, and most assuredly it was not attempted to test more than a few of these, the author concludes (albeit subjectively) that erosion of the concrete surface from impingement of the jet on the spillway tunnel invert will be likely to occur for discharges near 400 m^3/sec.

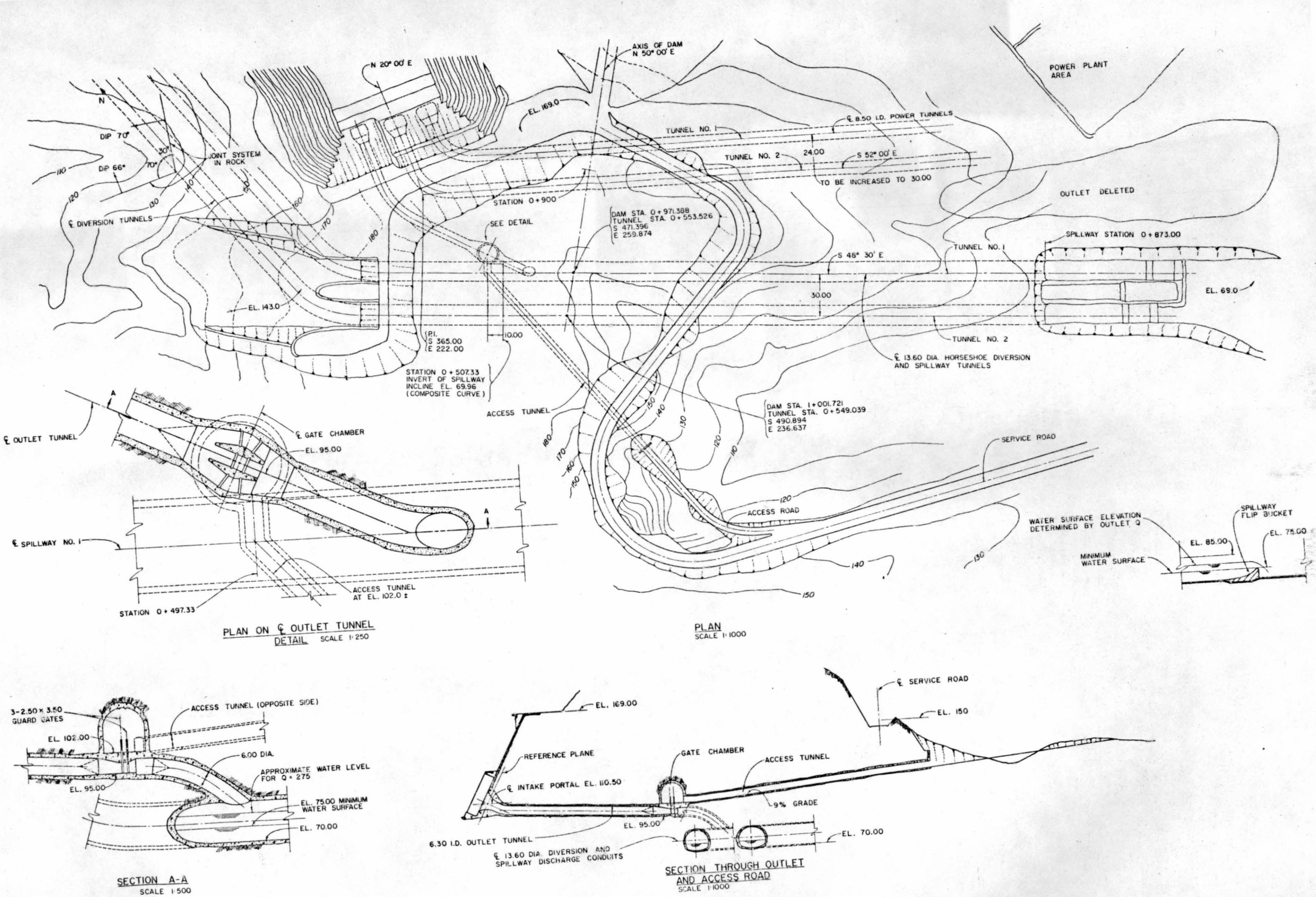
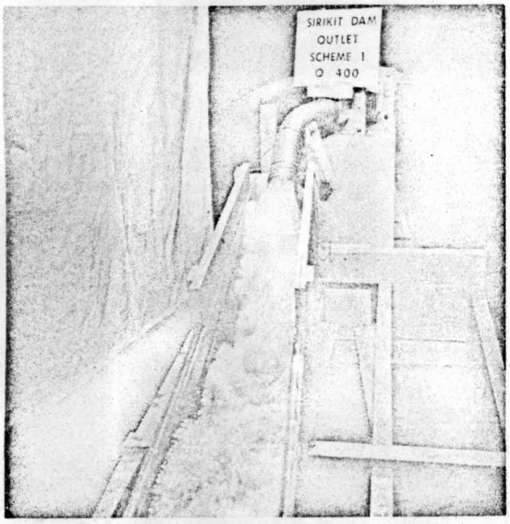


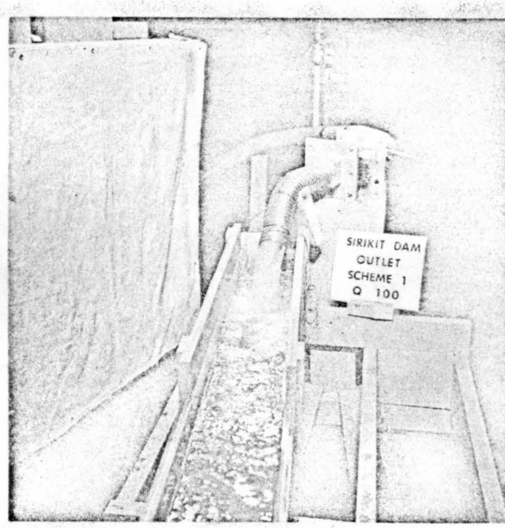
Figure 1. Scheme 1. Possible arrangement of outlet works.



2a. Q = 400 m^3/sec. Note that the tunnel invert is swept clear.

2b. Q = 300 m^3/sec. The tunnel invert is not swept clear. Conditions are considered marginally satisfactory.

2c. Q = 200 m^3/sec. Energy of flow is adequately dissipated in the impact region. Conditions are satisfactory.



2d. Q = 100 m^3/sec. Conditions are satisfactory.

Figure 2. Flow conditions for scheme 1.

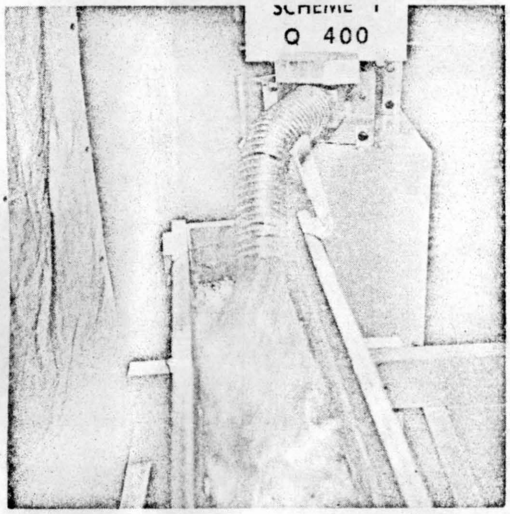
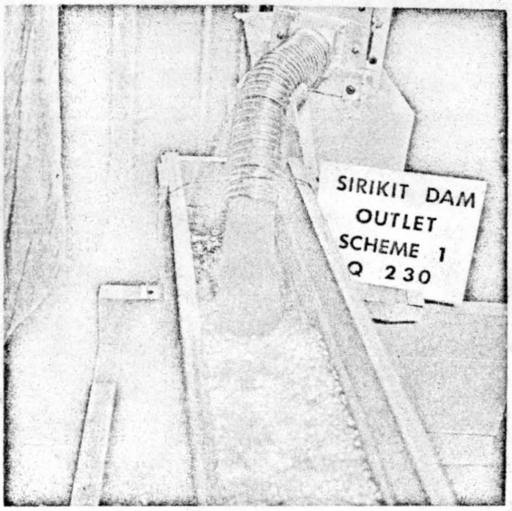
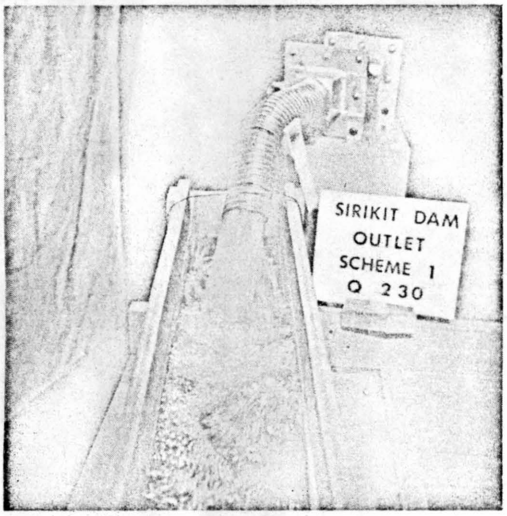


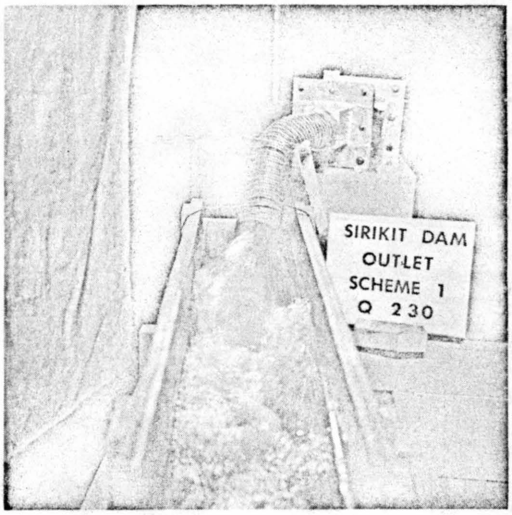
Figure 3. Swirling action caused by the bend in the outlet tunnel.



4a. Left gate only is open.



4b. Center gate only is open.



4c. Right gate only is open.

Figure 4. Flow conditions with unsymmetrical gate operation.

Scheme 2 - Vertical Dissipation of Energy

A feasible arrangement of this outlet works scheme is shown as figure 5. The gate structure would be the same as for scheme 1 and the outlet tunnel diameter would be the same size (6 m. diameter). A vertical chamber connects the outlet and spillway tunnels in which the kinetic energy of the flow would be dissipated, ideally with little excess. It was planned that the vertical chamber would be basically an impact type, as opposed say, to a vortex chamber. Although vortex chambers have been successfully constructed and operated, they have been used for much smaller total heads and discharges. Proportionally a larger diameter and longer (vertical dimension) chamber would be necessary for the heads and discharges considered here. It was thought that a maximum chamber diameter would be about 10 meters, considering the geology of the site and problems of construction. This dimension is only 1.7 times the diameter of the outlet tunnel.

The model - The model was again restricted to the outlet gates, the vertical chamber and a limited reach of the spillway tunnel.

Results - The test results of the vertical chamber with discharges of 400, 300, 200 and 100 m^3/sec are shown in figures 6a through 6d, respectively. The velocities at the outlet of the chamber were satisfactorily small for discharges less than 300 m^3/sec. At 400 m^3/sec the momentum of the flow swept the spillway tunnel clear of "standing" water. Part of the reason for this was the 6 m. diameter opening at the bottom of the chamber, the same size as the outlet tunnel. It was thought that a velocity of 14 m/sec through a 6 m. aperture would be satisfactorily dissipated by the water depth in the spillway tunnel of approximately 9 meters. The results proved, however, that there was an imbalance in flow momentum which caused the condition shown in figure 6a. This could be rectified most easily by increasing the size of the opening at the bottom of the chamber.

Comments - The vertical chamber works satisfactorily for discharges less than 300 m^3/sec as noted in the photographs of figures 6b, c and d. The question of satisfactorily discharging 400 m^3/sec is answered, in part, by requiring a larger aperture at the bottom of the chamber. However, careful balance of the size of that aperture to chamber diameter would have to be observed in order to make the chamber fully effective.

Scheme 3 - Horizontal Chamber

There are many possible arrangements for dissipating the energy in a horizontal chamber at the level of the outlet gates. A hydrualic jump basin, an impact basin and a diffusion chamber are three that could be suggested. An underground hydraulic jump basin was ruled out on the basis of size. In order to perform adequately, the stilling basin would have to be of comparable size to the original basin designed for the outlet at the river. For an underground installation this would be too large. An impact basin would be a possibility, but inherent problems of cavitation would introduce maintenance difficulties, and vibration could not be overlooked. It was decided, therefore, to test a diffusion chamber of the type shown on figure 7.

The elevation of the gate structure would be lower by approximately 15 meters as compared to that of the other two schemes. Although the diffusion chamber is shown to be rectangular in form, it could, without hydraulic difficulty, be the same shape and dimension as the horseshoe-shaped spillway tunnel 13.6 m. in diameter. It will be noted that the diffusion chamber is parallel to the spillway tunnel and the flow spills over the sides of the stilling basin and through two vertical ports at the crown of the spillway tunnel.

The model - The model was restricted to the outlet gates, the diffusion chamber (manifold stilling basin) and a short reach of the spillway tunnel. The top of the chamber was left open for photographic purposes, although some tests were conducted with the roof (rectangular and semi-circle) placed over the chamber.

Results - The test results with the manifold stilling basin are shown photographically in figures 8 through 11, inclusively, for discharges of 400, 300, 200 and 100 m^3/sec. The basin was very effective in dissipating energy for all discharges. There is some asymmetry of flow for Q of 200 and 100 m^3/sec, in that there is greater flow at the downstream end of the basin than there is at the upstream end (see figures 10b and 10c). This causes no essential difficulty however with basin performance and the energy is adequately dissipated.

Comments - This scheme works satisfactorily for the whole range of discharges up to the design discharge. It has already been mentioned that instead of the flat roof of the chamber shown in figure 7, a more practical semi-circular roof could be used. In fact, the entire chamber size above the diffusion blocks could be the same dimension as the spillway tunnel. In that event, the vertical support columns shown in figure 7 could be eliminated.

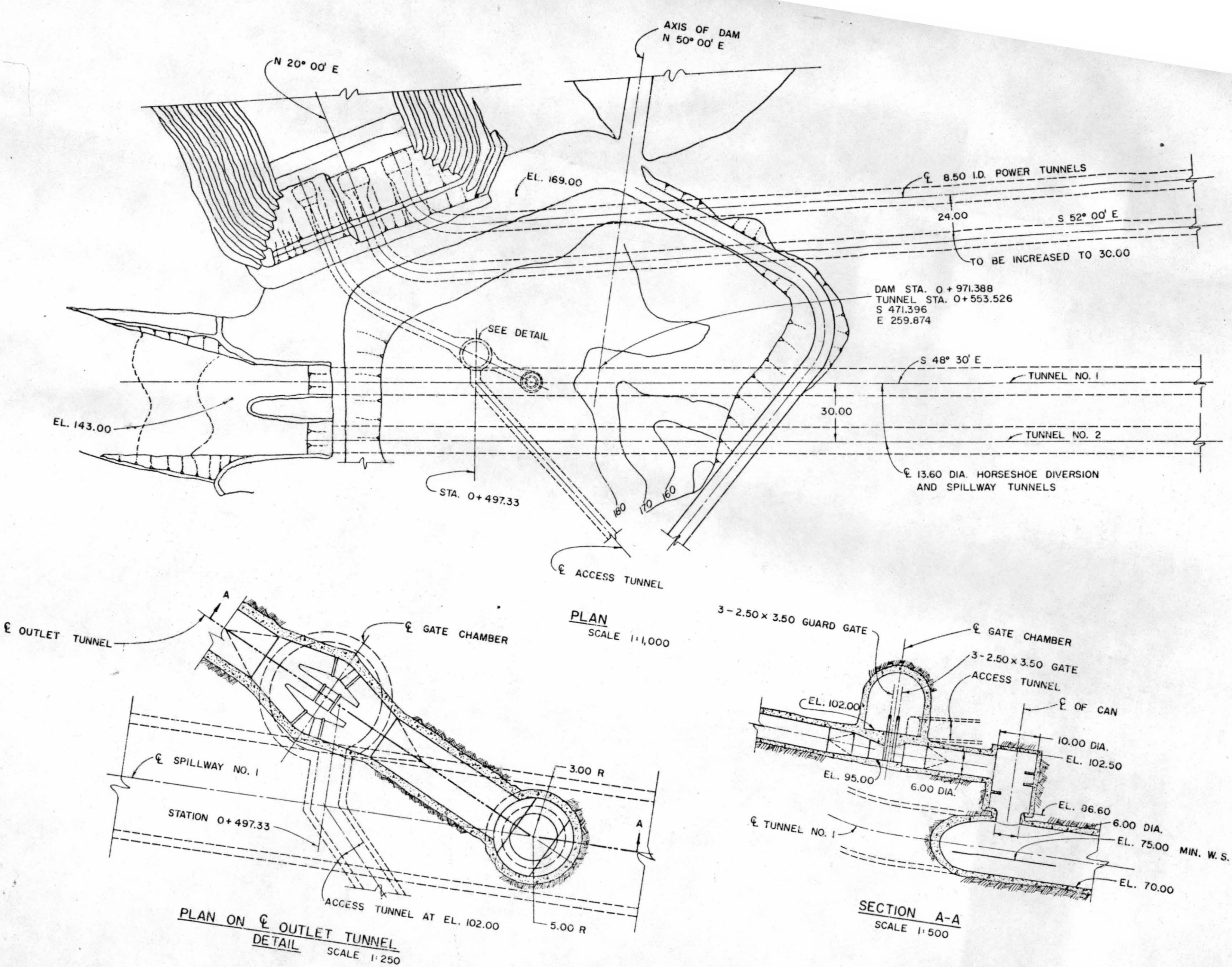


Figure 5. Scheme 2. Possible arrangement of outlet works.

6a. Q = 400 m^3/sec. Tunnel invert is swept clear.

6b. Q = 300 m^3/sec. Although much turbulence exists in the region of impact, conditions are satisfactory.

6c. Q = 200 m^3/sec. Flow conditions are entirely satisfactory.

6d. Q = 100 m^3/sec. Flow conditions are satisfactory.

Figure 6. Flow conditions for scheme 2.

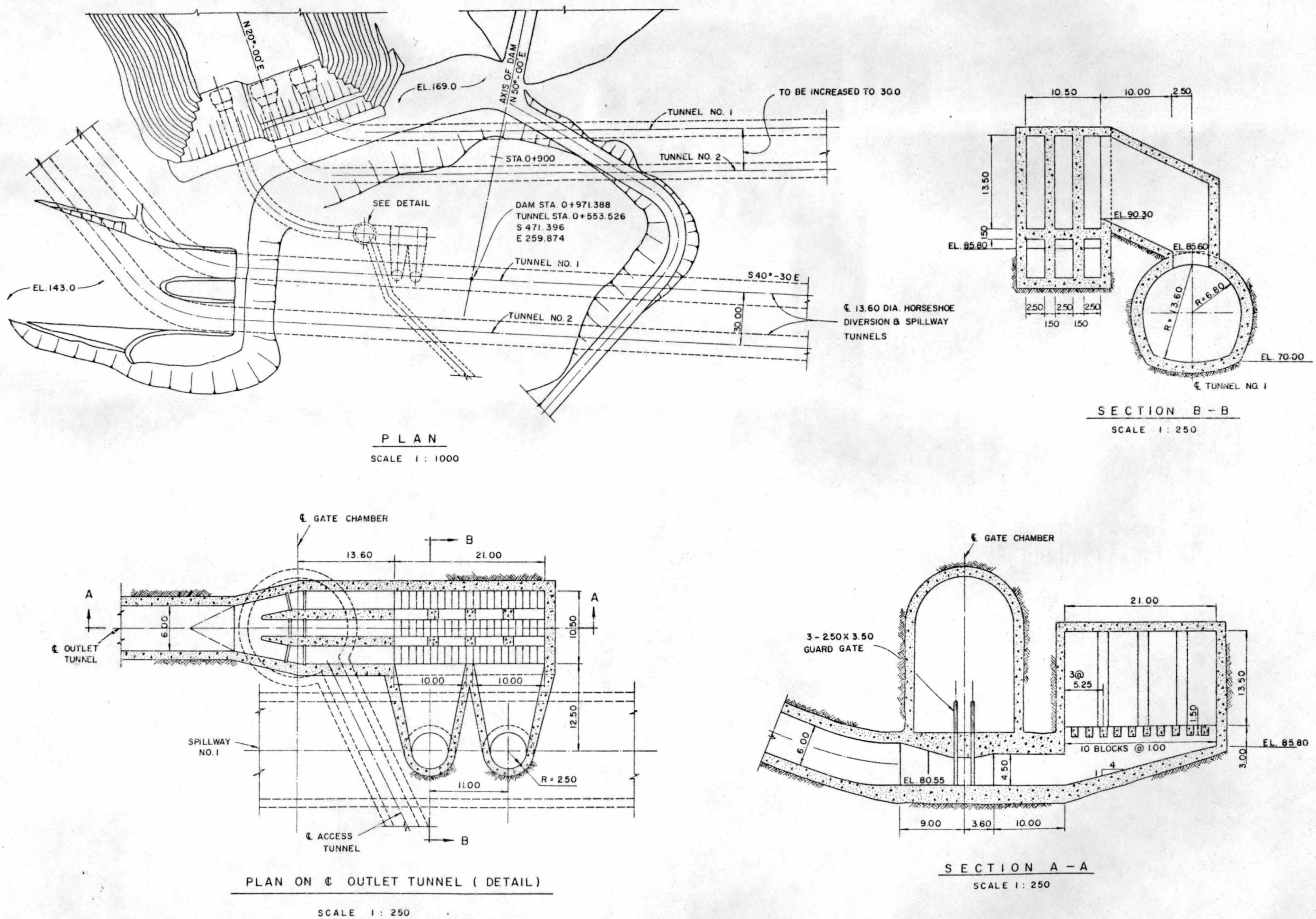
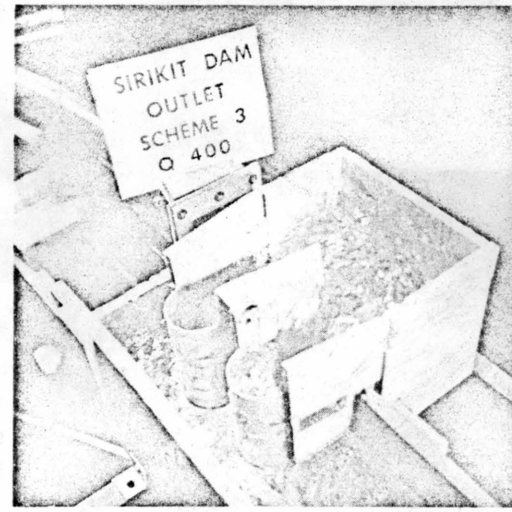


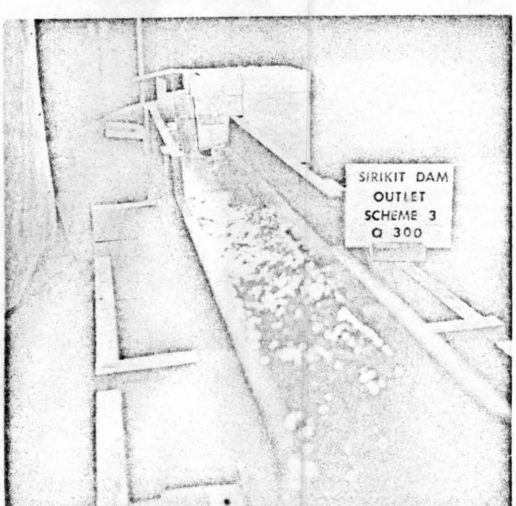
Figure 7. Scheme 3. Possible arrangement for outlet works.

8a. Water surface is relatively smooth.

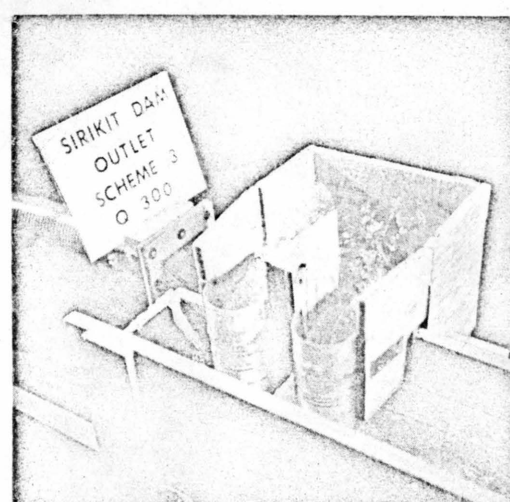


8b. Dissipation of energy is satisfactory.

Figure 8. Scheme 3. Flow conditions for Q = 400 m^3/sec.

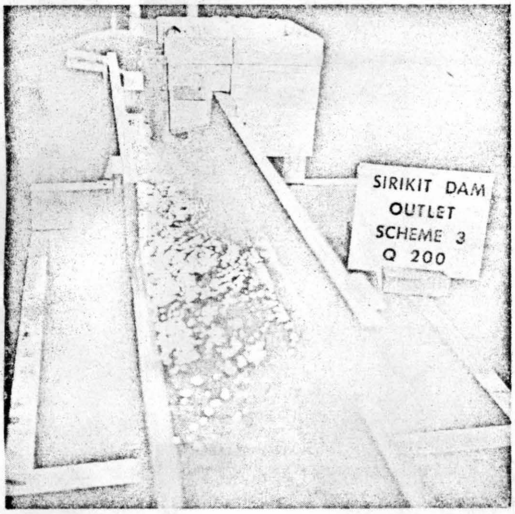


9a. Flow into the tunnel is satisfactory.



9b. Some uneven flow distribution occurs in the diffusion chamber.

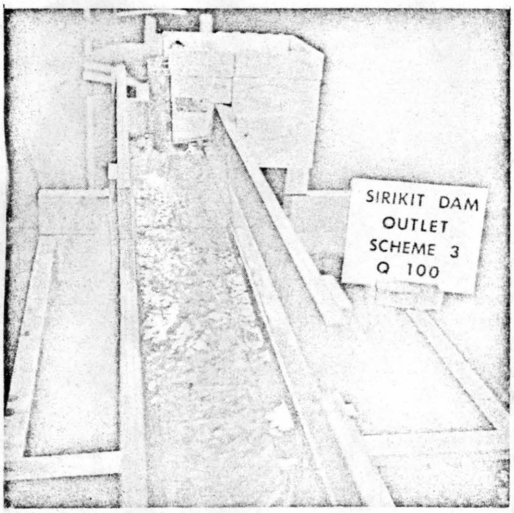
Figure 9. Scheme 3. Flow conditions for Q = 300 m^3/sec.



10a. Flow in the tunnel is satisfactory.

10b. Uneven distribution of flow exists in the diffusion chamber.

Figure 10. Scheme 3. Flow conditions for Q = 200 m^3/sec.



11a. Flow in the tunnel is satisfactory.

11b. Distribution of flow in the diffusion chamber is uneven but satisfactory.

Figure 11. Scheme 3. Flow conditions for Q = 100 m^3/sec.

Comparisons of the Three Schemes and Recommendations

From the small scale model studies it can be concluded that any of the three basic schemes could be used if the outlet discharges are less than 300 m^3/sec. However, the design discharge is 400 m^3/sec, and problems arise in adequately discharging this flow into the spillway tunnel. In scheme 1, where the flow is directly into the spillway tunnel, there is a probability of erosion of the concrete surface, which in times of spillway flow, could cause further damage to the lining because of cavitation. In scheme 2 part of the kinetic energy of flow is dissipated in the vertical chamber, but at 400 m^3/sec the dissipation is not adequate and the hydraulic conditions are similarly unacceptable. However, it is considered possible to modify the chamber to yield satisfactory results. Scheme 3 is satisfactory for all discharges.

From the standpoint of construction, scheme 1 is the simplest followed by schemes 2 and 3 in that order. Therefore, in overall consideration it was recommended that scheme 2 be selected for further study. Construction of a vertical chamber 10 m. in diameter was considered to offer no special difficulty. The intricacy and large size of scheme 3 is a distinct disadvantage from the viewpoint of construction.

Conclusions of ECI

The essential observations from the model tests and the recommendation stated above was submitted to the consulting engineers (ECI). After due consideration, they also decided that scheme 2 was the most consistent with hydraulic desirability, ease of construction considering geology of the site and with cost. Therefore, this scheme, the vertical chamber, was selected for further development and study in a large scale model.

LARGE SCALE MODEL TESTS

The larger scale model was twice the geometric size of the small scale models. This afforded a better opportunity to study the flow in the various parts of the model, including the gates. It will be recalled that scheme 2 was selected for further study, so that the tests described hereafter are confined to that outlet arrangement. An overall possible arrangement was shown in figure 5.

The model - The model was constructed of clear plexiglass so that the flow inside the tunnels and the chamber could be seen. In the small scale studies a metal chamber was used; thus, internal flow conditions could not be inspected. Some modifications were made to the geometry of the vertical chamber. These modifications can be seen by comparing figure 12 with figure 5. The changes consisted of the following: (1) A semi-circular dome was considered to be more structurally desirable than a flat roof for the vertical chamber. (2) The bottom aperture to the vertical chamber was increased in size to 7 meters in diameter from the 6-meter size in the small model. (3) The shapes of the horizontal splitter baffles were modified to provide positive pressure surfaces. (4) The lower baffle on the same side as the outlet tunnel was omitted initially and included in later tests.

Results - The arrangement of the vertical chamber as shown in figure 12 was tested initially and the results are shown in the sequence of photographs in figures 13 through 16 for discharges of 400, 300, 200 and 100 m^3/sec, respectively. At a discharge of 400 m^3/sec, the chamber was essentially completely full. It will be noted in figure 13a that white water (air entrained water) is backed up into the outlet tunnel. This was not a hydraulic jump but the consequence of violent turbulence in the vertical chamber. The top baffle essentially divided the flow, directing half of the flow upward into the domed cavity, and around the circumference of the chamber. The lower half of the flow was directed towards the lower baffle and also around the chamber. The lower baffle then redirected the flow against the upper flow which was now falling vertically in a turbulent chaotic movement. Although the chamber was full, the flow is essentially in a free fall condition so that a low pressure cavity was formed below the lower baffle. This low pressure cavity could be eliminated by either filling the cavity with concrete (or perhaps simply by not excavating there) or, by providing air inlets immediately below the baffle to alleviate potential cavitation. Pressure readings at 400 m^3/sec flow were about -6 m. of head, with large fluctuations about that head. Air inflow conditions will be discussed with later modifications.

The vibration of the chamber, because of the impact and turbulence, was noticeable. Modifications were therefore tested in an effort to reduce or eliminate it. Those tests will be discussed subsequently. As it might be imagined, after some thoughtful study of the photographs, discharges of 300 m^3/sec and less were adequately accommodated by this energy dissipator. The outlet flow of 400 m^3/sec was satisfactory insofar as input velocities in the spillway tunnel were concerned. However, efforts to reduce vibration were considered necessary.

Flow through the gates and outlet tunnel were satisfactory. Air inlets will, of course, be required downstream from the gates and it is suggested that the air supply ducts be of the order of 0.6 m. in diameter or greater. It is suggested also that the downstream nose of the piers separating the gates be rounded rather than terminated with a square end to avoid cavitation there; otherwise provide air vents near the bottom of each pier if the ends are flat. Supercritical waves are generated at the ends of the piers, but the resulting rooster-tail did not close off the tunnel for any discharge as is evident in figures 13 through 16.

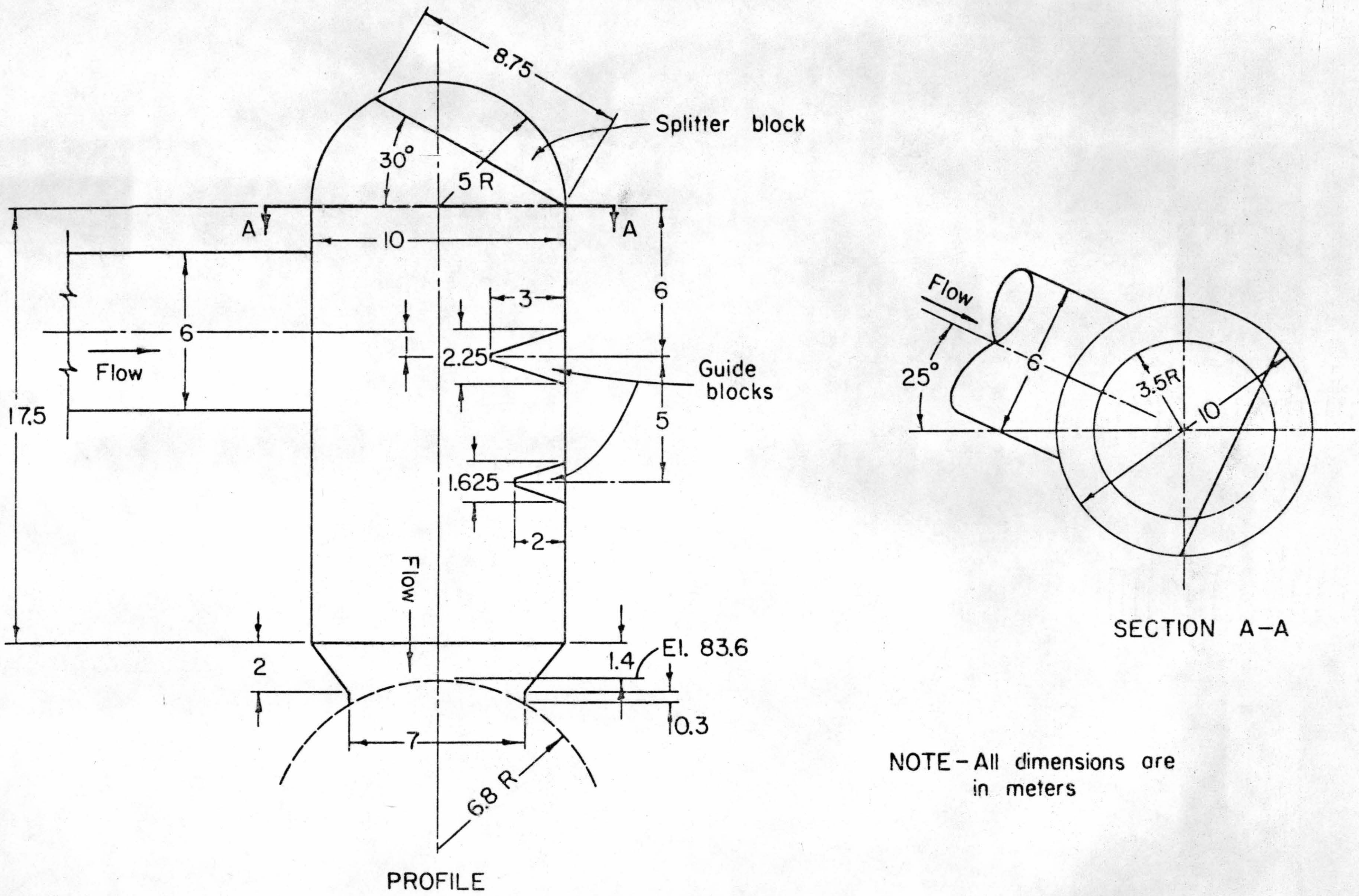
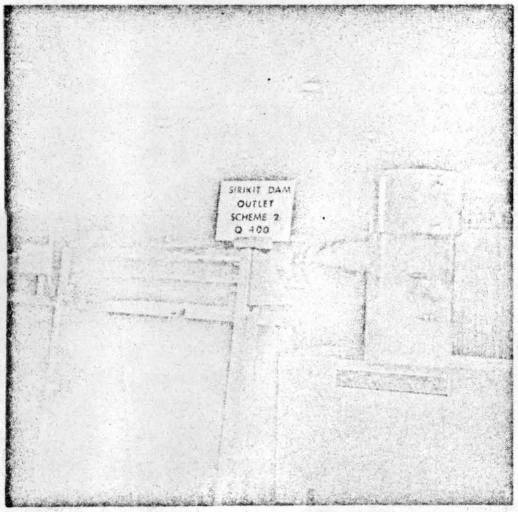


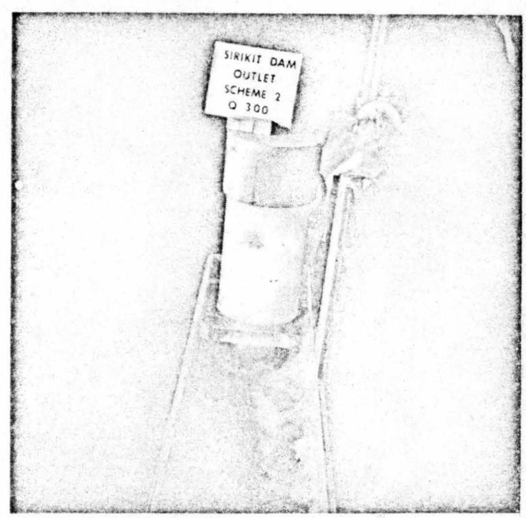
Figure 12. Scheme 2 as tested in the large scale model.



13a. Flow through the outlet tunnel and vertical chamber. Note turbulence in the vertical chamber.

13b. Flow emanating from the vertical chamber did not sweep the flow out of the tunnel as it did in the small scale model.

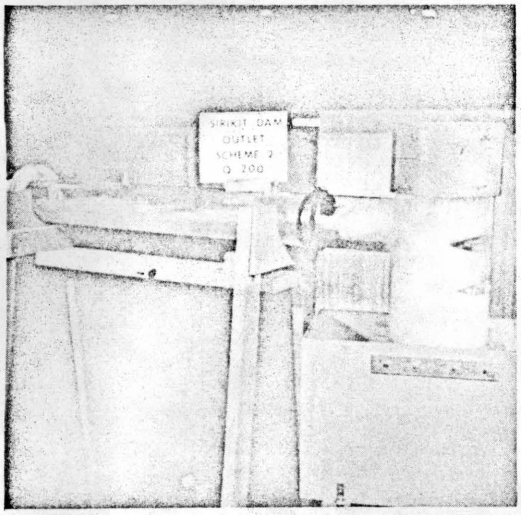
Figure 13. Flow conditions for Q = 400 m^3/sec.

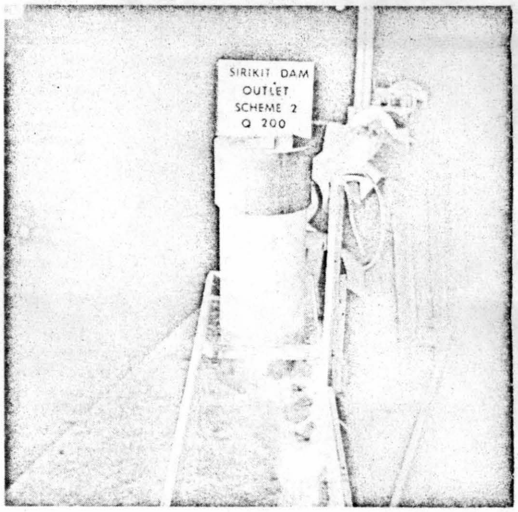


14a. Turbulence in the vertical chamber is fairly effective in dissipating the kinetic energy of flow.

14b. Outlet flow into the tunnel is turbulent but satisfactory.

Figure 14. Flow conditions for Q = 300 m^3/sec.

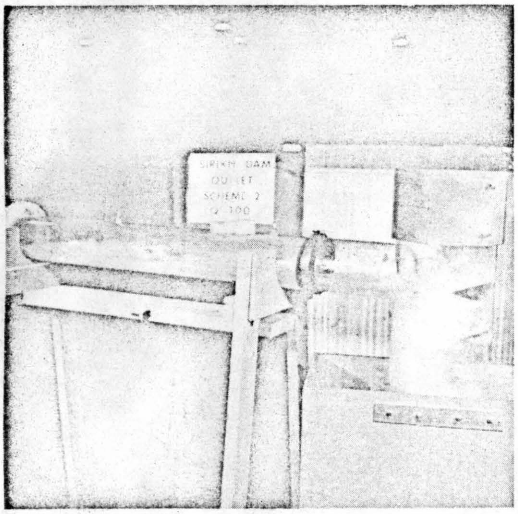




15a. Small amount of rooster tail in the outlet tunnel can be noted.

15b. Flow into the spillway tunnel is satisfactory.

Figure 15. Flow conditions for Q = 200 m^3/sec.



16a. Chamber is not full. A large cavity can be seen below the low baffle.

16b. Flow into the tunnel is satisfactory.

Figure 16. Flow conditions for Q = 100 m^3/sec.

Unsymmetrical gate openings were also tested. In figures 17, 18 and 19 various combinations of two-gate operation are photographed. The flow within the vertical chamber appeared to be satisfactory. There was no essential difference of flow condition manifest there. However, in the outlet tunnel downstream from the gates, the flow swept fully over the crown of the tunnel. This can be seen in figure 17 for the left and right gates open, to a lesser extent in figures 18 and 19 with the left and center gates and right and center gates, respectively. No difficulty arose from the condition, however, as the tunnel was never closed off by the water turning over the tunnel crown.

Single gate openings were also tested for the left, center and right gates and are shown in figures 20, 21 and 22, respectively. Flow overturning occurred only for the center gate open. Rather than overturning, the condition in figure 21 resulted as a consequence of the flow spreading from the ends of the piers in the gate chamber and impinging on the sides of the transition which caused the flow to rise upward toward the tunnel crown. With flow from either the left or right gates the geometry of the transition guided the flow more smoothly into the outlet tunnel.

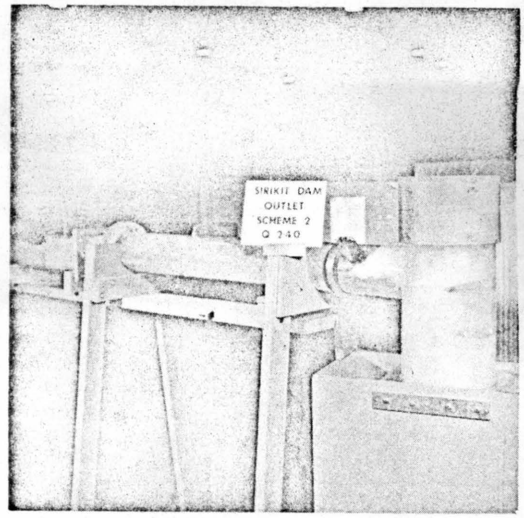


Figure 17. Left and right gates open. Note flow over outlet tunnel crown.

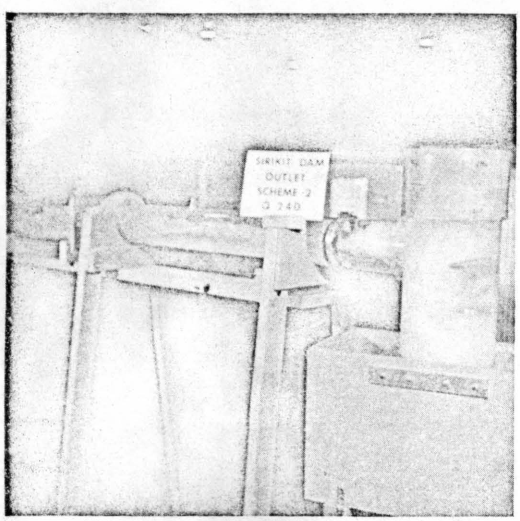


Figure 18. Left and center gates open. Some flow occurs over the crown of the tunnel.

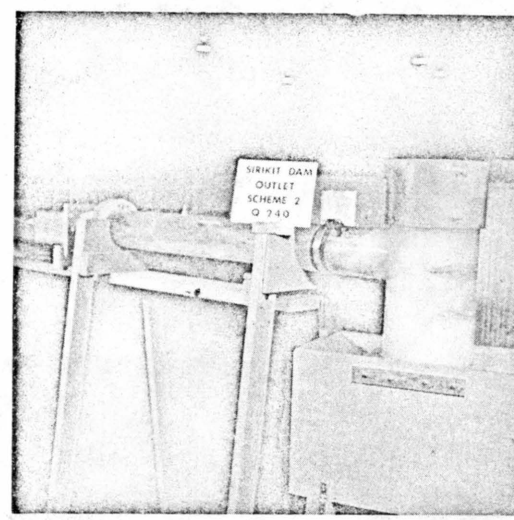


Figure 19. Right and center gates open. The condition is the reverse of figure 18.

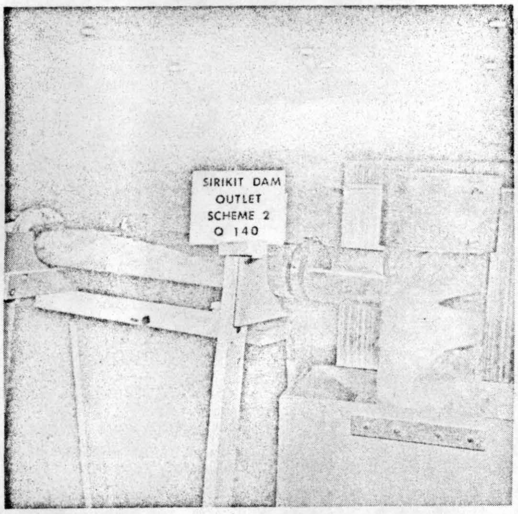


Figure 20. Flow from the left gate only.

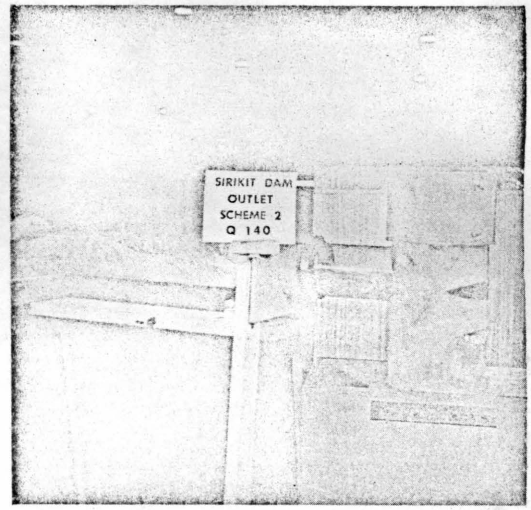


Figure 21. Flow from the central gate only.

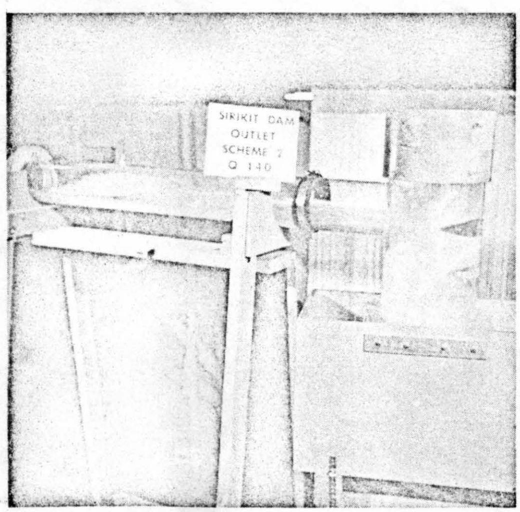


Figure 22. Flow from the right gate only.

Modifications - The principle reason for conducting tests of several modifications was to reduce the vibration of the vertical chamber. It should be made quite clear here that this model was designed only to determine the kinematic and dynamic conditions of the outlet flows into the spillway tunnel. Although vibration is a consequence of the dynamics of the flow, it is in total a hydro-elastic problem and a true representation of the vibrational consequence of the flow would require adherence to structural similitude laws as well. Such a model would require much greater attention to the mechanics of the rock in which the chamber would be constructed. For example, if the model were constructed with very rigid supports, as opposed to the manner in which the model was supported (later modified) as shown in all the preceding photographs and through figure 26, less noticeable vibration would have resulted. Nevertheless, the following modifications give, comparably, the effects of the changes to the vertical chamber. Even though the statements related to vibration are subjective, they have relative value, comparing the merits of one modification with another.

The first modification (1) involved simply removal of the lower horizontal baffle. It was thought that the vibration could be reduced by changing the direction of the lower half of the outlet flow so that it would not impinge against the opposite side of the vertical chamber. Change in resultant vibration was not apparent. There was however a greater velocity of a portion of the flow through the bottom chamber aperture with marked concentration toward the downstream side of the chamber. The photographs for 400 m^3/sec are shown in figure 23.

In modification 2 the lower baffle was reinserted with the cavitating space below filled in with "concrete" as shown in figure 24. The purpose was to eliminate the fluctuating cavity which was thought to be perhaps contributing to vibration. No apparent improvement resulted excepting to eliminate the region of negative pressure.

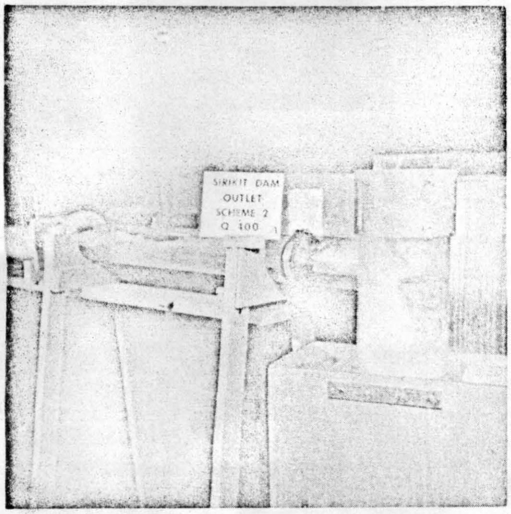
Inasmuch as the principle source of vibration seemed to be with impact of the outlet flow on the opposite side of the chamber, reduction of that impact should therefore result in reduction of vibration. Thus, a vortex chamber was created by placing the tunnel outlet so that one side was tangent to the vertical chamber as shown in figures 25 and 26. The consequence, as noted in figure 25, was induced vorticity in the chamber, reduction of effective outlet flow capacity through the bottom aperture and backing-up the flow into the outlet tunnel. This in turn reduced the capacity of the outlet works to about 320 m^3/sec. (Note the identification label in figure 25a is marked as 400 m^3/sec which may be misleading.) There was greater velocity through the aperture as less energy was dissipated in the chamber and greater velocities into the spillway tunnel resulted. Figure 26 shows the condition for 200 m^3/sec. Although the outlet tunnel did not flow full, a hydraulic jump was created near the entrance to the chamber. This is evident in figure 26a.

Because the principle source of vibration seemed to stem from impact, a shock absorbing recess in the chamber opposite the outlet tunnel was considered as a means to reduce vibration and to dissipate the energy as well. The arrangement tested and the resulting conditions are shown in figure 27. Some of the kinetic energy was indeed dissipated, but there was no apparent reduction of vibration. An air surge chamber was added, as in figure 28, with little effectiveness. The size (length) of the shock recess was reduced as in figure 29 with filler (styrofoam) material. In this case less energy was dissipated and vibration increased, indicating some effectiveness of the recess and air surge chamber for damping the forces of impact.

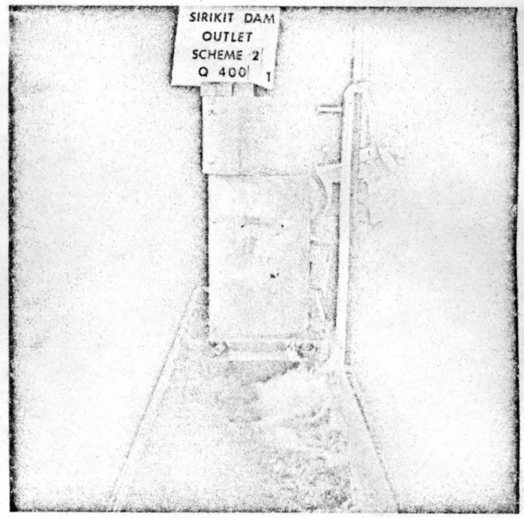
The greatest improvement to reduction in vibration resulted from stabilization of the horizontal oscillation of the flow within the chamber. This was accomplished by placing vertical splitter baffles above the upper horizontal guide block and between the upper and lower horizontal guide blocks. Air vents were added below the lower guide block, and although little benefit to the vibration problem resulted from these vents, the cavitation problem was eliminated. One final modification tested was the addition of a small (0.75 in. high by 0.75 in. wide) curved deflector on the invert of the outlet tunnel at the entrance to the chamber and inclusion of the horizontal baffle on the side of the outlet tunnel which was included in the small scale model but eliminated earlier in this large scale model. The intent of the deflector was to break up the flow entering the chamber so as to distribute the impact over a larger area of the chamber wall. The resulting flow condition for 400 m^3/sec is shown in figure 30 and a drawing for the arrangement is shown in figure 31.

Comments - Of the various modifications tested, the final one shown on figure 31 is the best arrangement both from the standpoint of the hydraulics of the flow and vibration. Some of the kinetic energy of the outlet flow is dissipated within the chamber so that the velocities at various discharges are reduced as the flow enters the spillway tunnel. As noted before, the statements in reference to vibration are subjective. Vibration within the chamber occurs because of the turbulent activity associated with energy dissipation. Structurally, the vertical chamber can be designed to withstand the forces and the vibration. Whether the rock can also be made to withstand vibration is left as an open question insofar as this report is concerned. Ideally, of course, it would be desirable to eliminate vibration, or make it negligible, but this is not consistent with dissipation of energy within the chamber.

Air vents should be provided at the downstream end of the deflector in the outlet tunnel and below the guide blocks on the sides of the chamber. The vent for the deflector should be about 0.45 m in diameter, and below the guide blocks the vents should be 1 m diameter.



23a. Flow in the tunnel remained essentially unaltered.



23b. Flow was concentrated along the downstream end of the chamber and velocities were greater.

Figure 23. Modification 1. The lower guide block was removed.

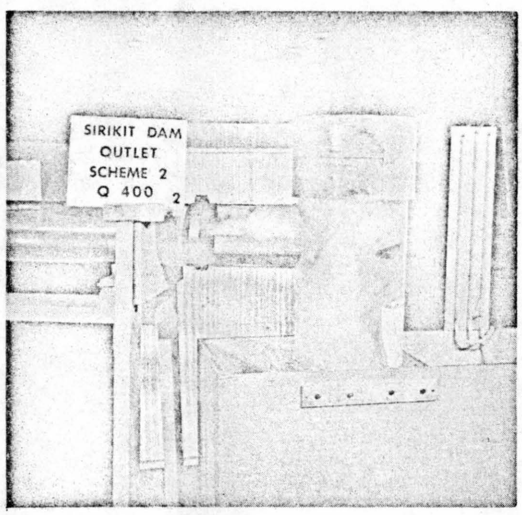
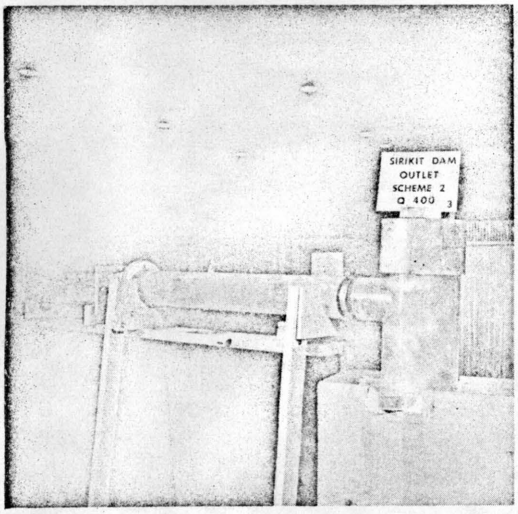
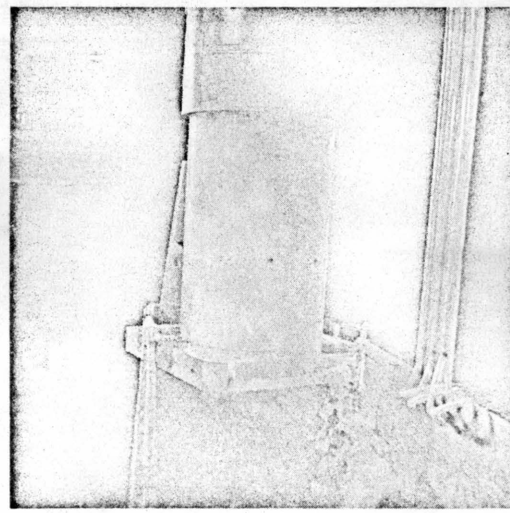


Figure 24. Modification 2. The region below the lower guide block was filled in to eliminate the cavity.

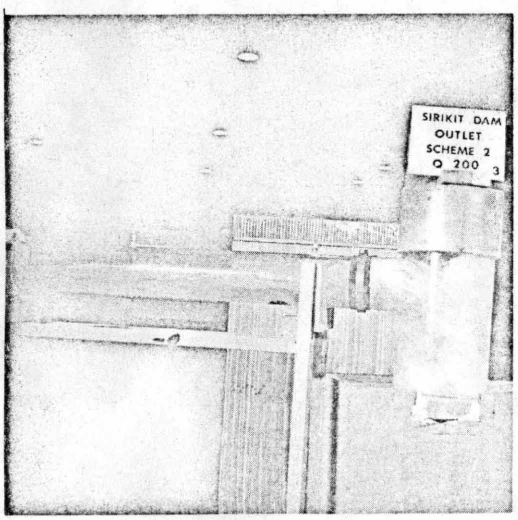




25a. Outlet tunnel filled and backed up into the gate opening.

25b. Vertical chamber was filled.

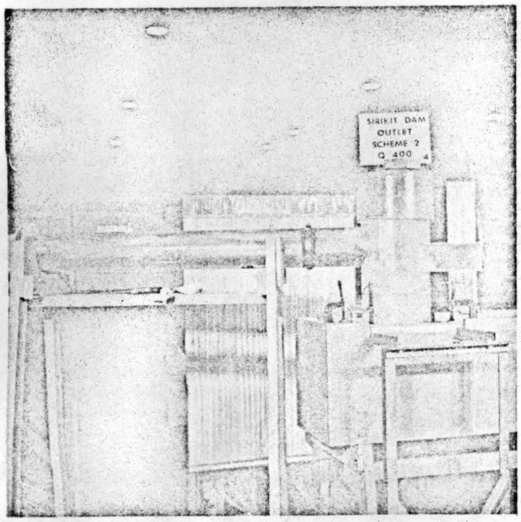
Figure 25. Modification 3. Vortex chamber. Q = 320 ± m^3/sec.

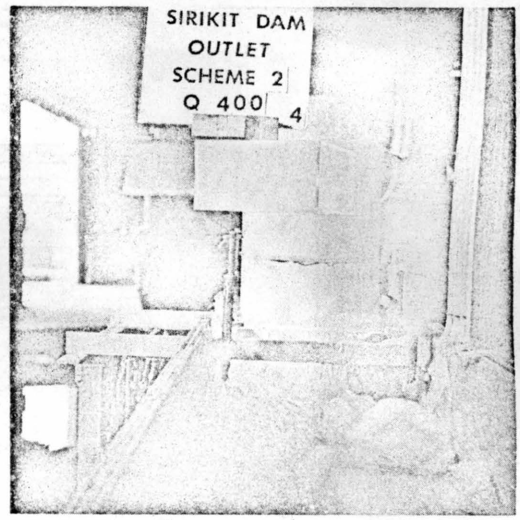


26a. Outlet tunnel flows freely at this discharge but a hydraulic jump is formed.

26b. Note the vortex action traced by the air bubbles entrained in the flow.

Figure 26. Vortex chamber. Q = 200 m^3/sec.





27a. Q = 400 m^3/sec. Note the chamber supporting sub-structure was modified to be separated from the spillway tunnel.

27b. Flow into the spillway tunnel.

Figure 27. Modification 4. Shock absorbing recess added to the chamber.

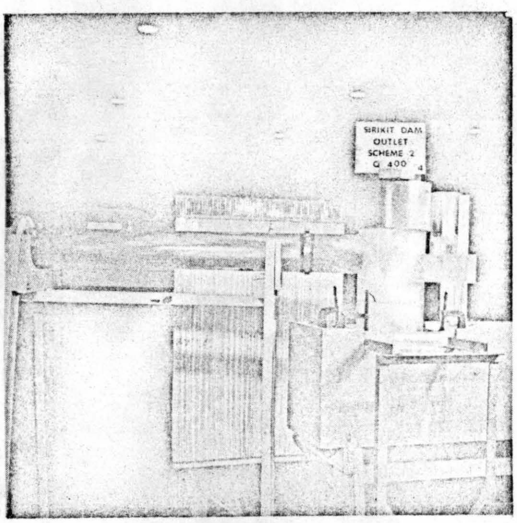


Figure 28. Modification 5. Air "surge" chamber added to the shock recess.

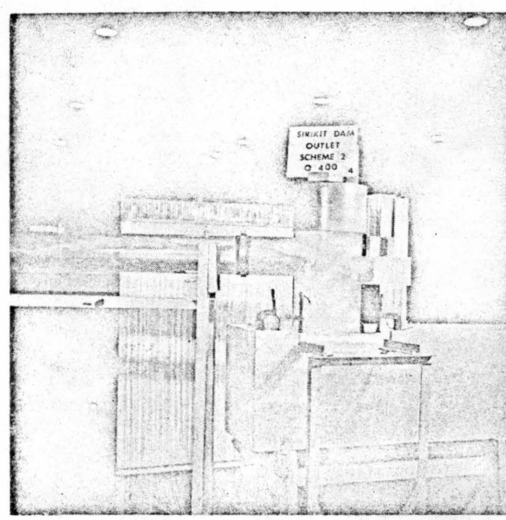
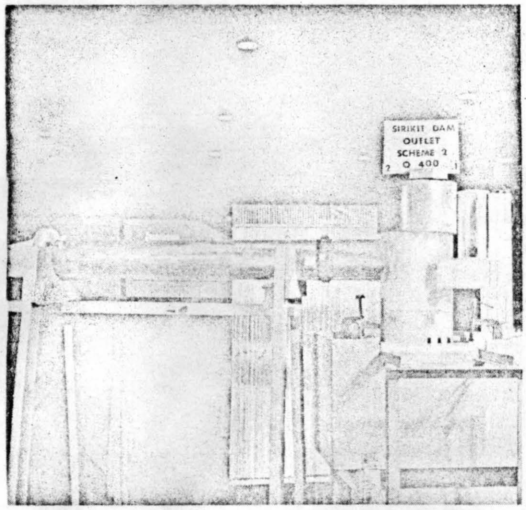


Figure 29. Modification 6. Shock recess was reduced in size.



30a. Final modification to chamber.

30b. Resulting outlet flow.

Figure 30. Q = 400 m^3/sec. Final modification of the vertical chamber. (The shock recess and air surge chamber are not effective. Note that the interior has been filled in.)

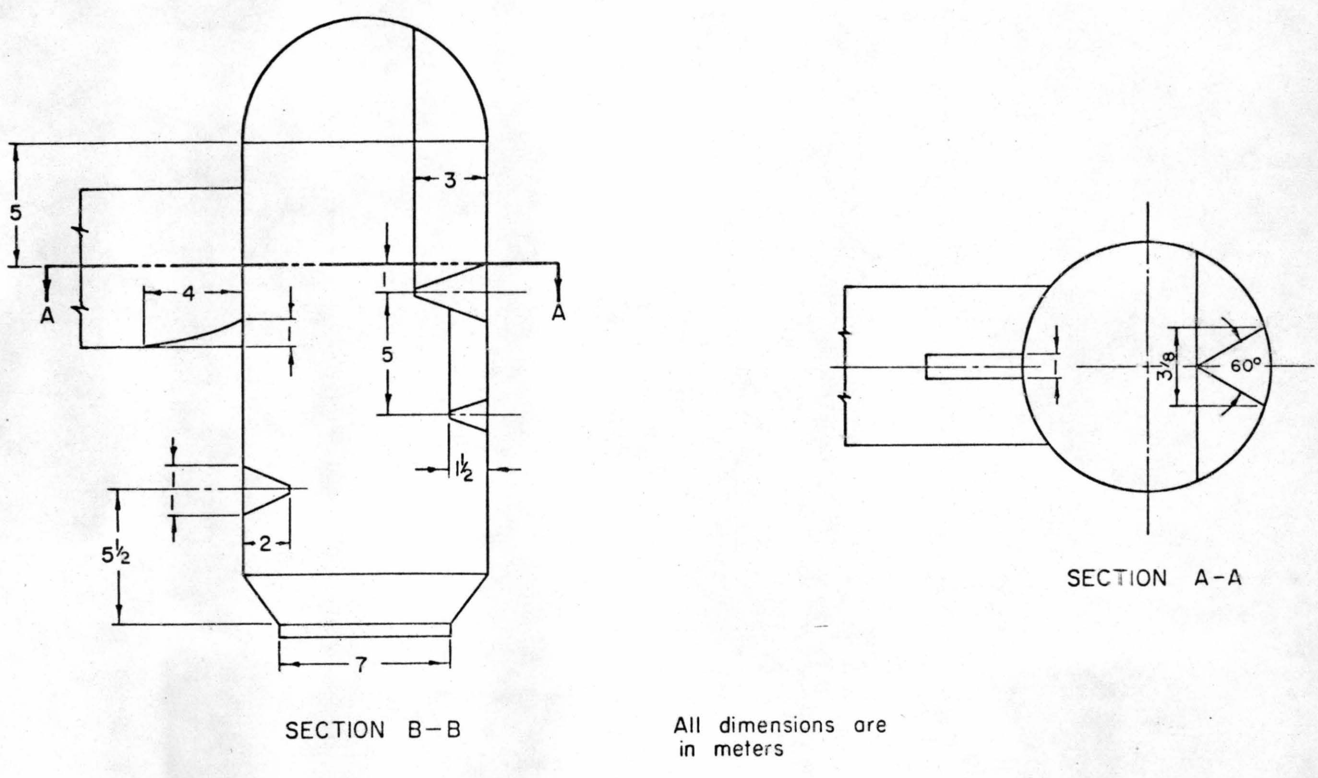


Figure 31. Final arrangement of the vertical energy dissipation chamber.

RECOMMENDED OUTLET ARRANGEMENT

Background - During the time these model tests were being conducted, ECI considered the possibility of modifying the vertical curve of the spillway tunnel so as to create an offset between the P.T. of the curve and the invert of the horizontal tunnel. This, it was believed, would eliminate the difficulty which could arise because of the sudden change in pressures along the invert near the P.T. of the curve. This point was discussed in an earlier report[3]. It is envisioned that this could be done most simply by having a smaller sized inclined shaft and curve so that the crown of the tunnels at the P.T. of the curve would be aligned, thus creating the offset at the invert. This arrangement is to be subjected to additional model studies.

If this arrangement for the spillway tunnel is adopted, then the basic criterion for the outlet works is affected. It will be recalled that the choice of the vertical chamber (scheme 2) was predicated upon the desire to avoid erosion of the concrete surface in the spillway tunnel. The eroded surface would most surely be the origin of serious cavitation during spillway flows. With the offset arrangement, however, avoiding the erosion is no longer a valid criterion, for the outlet flow can enter the spillway tunnel in a region where the spillway flow will jet over the invert. Thus, in this region the spillway tunnel may be lined and reinforced without concern of the spillway flows. Combined spillway and outlet flows are most unlikely.

Scheme 4 - The large scale model was used to test a different outlet works arrangement, called scheme 4, which is drawn on figure 32. The intent was simply to deflect the horizontal flow from the outlet tunnel vertically into the spillway tunnel. To accomplish this, a sudden expansion section was provided downstream from the outlet tunnel and joined with an inclined rectangular shaft, 60 degrees from horizontal. The shaft and expansion sections are 10 m wide to provide opportunity for flow to spread. Aeration will, of course, be required where the boundary deviates from the flow line. That is, air vents will be required below the outlet tunnel invert, and at the top of the inclined shaft, at or near the centerline.

Results - The outlet flows through the entire arrangement are shown in figures 33 through 36 for discharges of 400, 300, 200 and 100 m^3/sec, respectively. Negative pressures on the sides of the expansion chamber were noted for discharges of 400, 300 and 200 m^3/sec as recorded in the table below. The piezometer numbers and location are shown in figure 32.

Vibration of the entire structure is reduced compared to the vertical chamber, primarily as a result of reduced turbulence within the deflector. The velocities of the flow entering the tunnel are greater than those from the vertical chamber, but as is noted in figure 33b the water is not swept clear within the tunnel. It might be recalled that in the small scale models at a discharge of 400 m^3/sec, the tunnel floor was swept clear and a jump formed downstream. The greater angle of flow entry for scheme 4 as compared to scheme 1 (60 degrees as compared to 40 degrees) is in part responsible for the difference of flow in the tunnel. In any event, the flow in the tunnel is relatively smooth and if the spillway tunnel can be lined for a short distance in the region of impact, no difficulty will result.

Asymmetric gate openings were also tested with no consequent irregularity within the structure. Photographs of the consequence of one gate operation are shown in figures 37, 38 and 39 for the left, center and right gates, respectively.

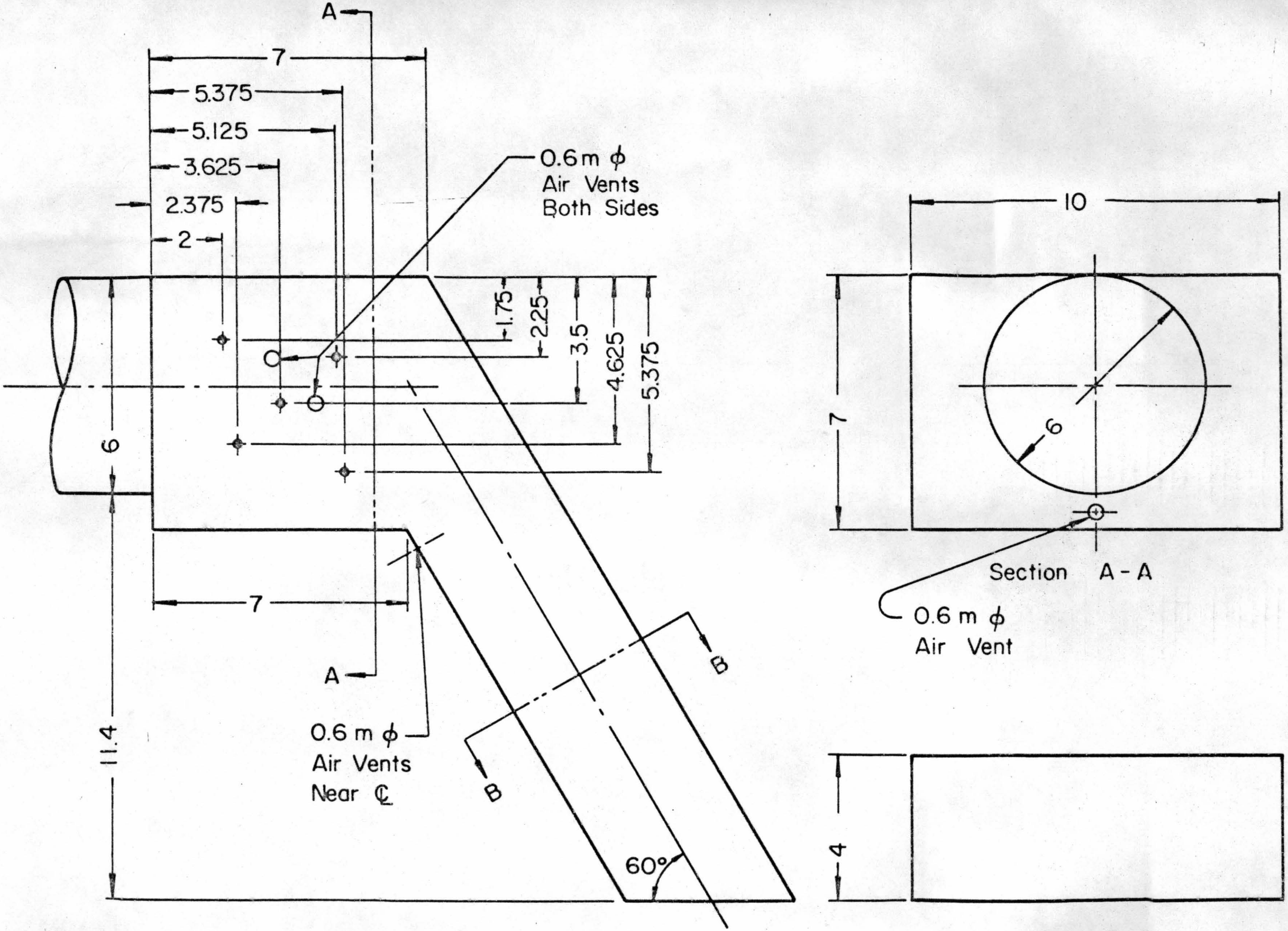
Comments - Should the proposed change in the spillway tunnel be adopted, then it is recommended that this structure be used to direct the outlet flow into the spillway tunnel. The 10 m width of the expansion chamber should not be reduced. Sufficient space should be allowed for circulation of the flow which results from impact. If the chamber size is reduced, the recirculating flow will affect the flow in the outlet tunnel with consequent reduction of the capacity of the outlet works.

The negative pressures on the sides of the expansion chamber are not of serious concern, especially if the expansion chamber is to be lined. There is no real need to steel-line the expansion chamber, however. The flow is adequately aerated as is evident in the photographs so that aeration at the sides of the expansion chamber is not essential. If, however, air vents are to be provided to alleviate the local negative pressures, they should be placed at the locations shown on figure 32. The recommended size of the air ducts in that event is 0.6 m in diameter.

TABLE OF PRESSURES

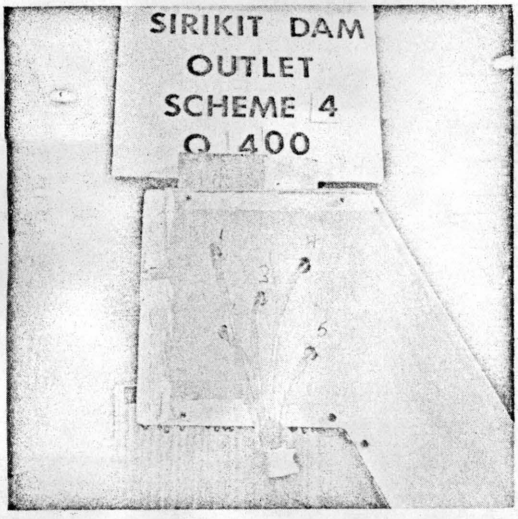
Discharge	Piezo. Nos. - Readings are in meters of head					Comments
m^3/sec	1	2	3	4	5	
400	-2.0	-1.0	-2.0	0	-1.5	fluctuates
300	-1.5	-1.5	-2.0	-1.0	-1.0	fluctuates
200	-0.25	-0.5	-0.25	-0.5	-0.5	steady
100	0	0	0	0	0	steady

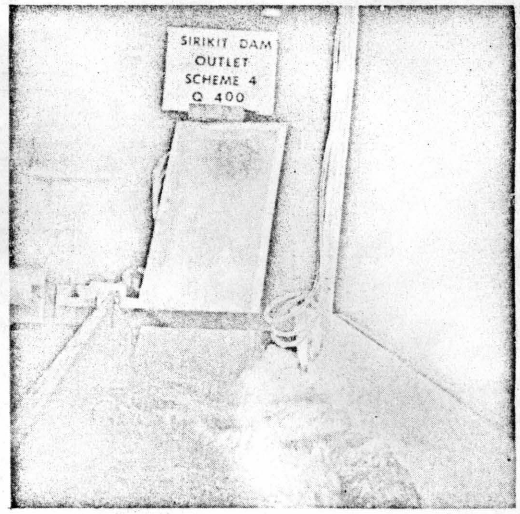
[3]Sirikit Dam River Diversion and Spillway Hydraulic Model Studies, Nan River Multipurpose Project, Thailand. Prida Thimakorn and Susumu Karaki for Engineering Consultants, Inc., Denver. January 1969.



All Dimensions in Meters.

Figure 32. Scheme 4. Outlet flow deflector.

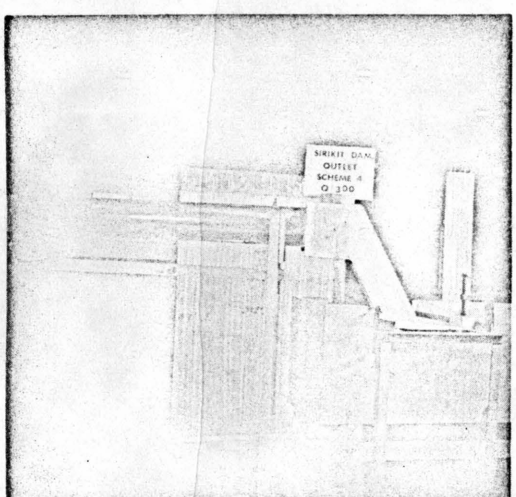


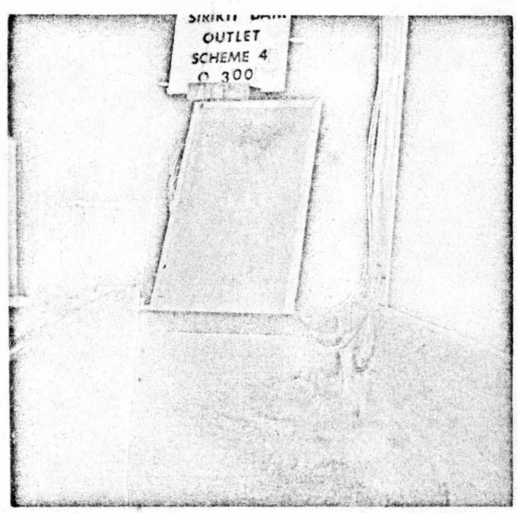


33a. Some circulation of flow occurs in the expansion chamber.

33b. Resultant flow into the tunnel.

Figure 33. Q = 400 m^3/sec.

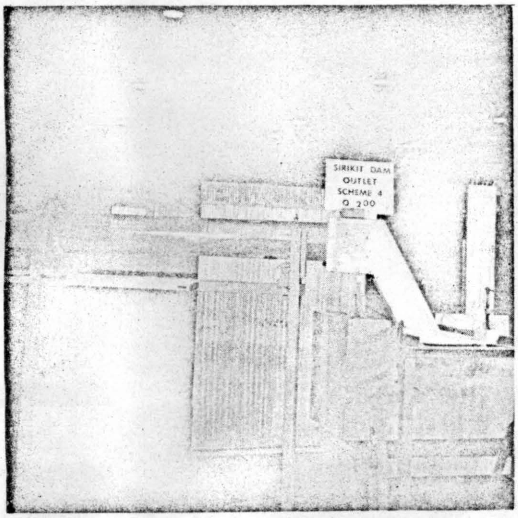




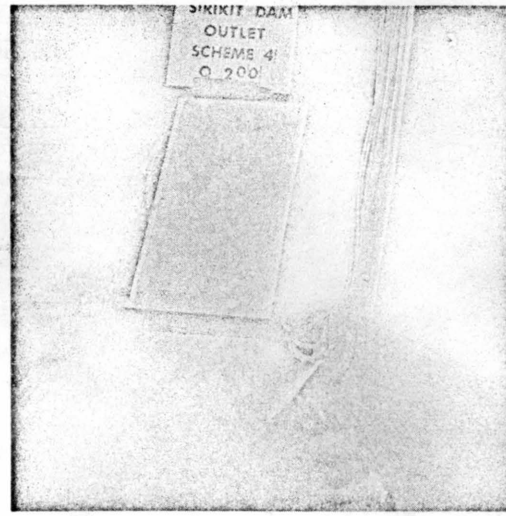
34a. Side view.

34b. Flow into the tunnel.

Figure 34. Q = 300 m^3/sec.

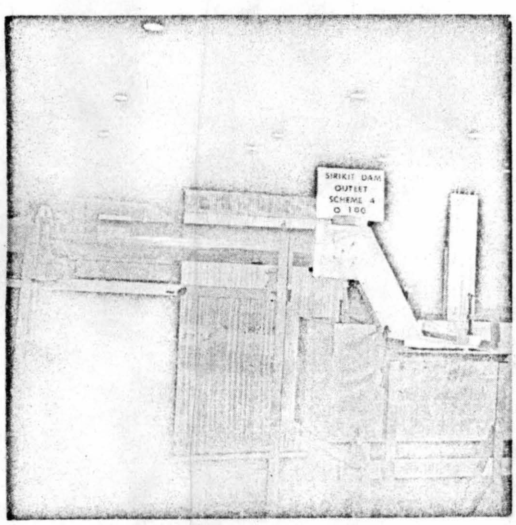


35a. Side view.

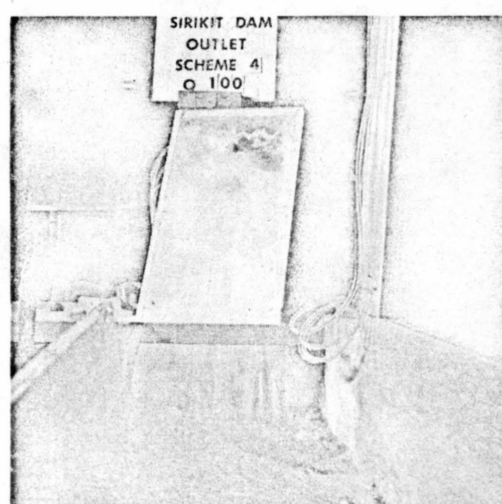


35b. Flow into the tunnel.

Figure 35. Q = 200 m^3/sec.



36a. Side view.



36b. Flow into the tunnel.

Figure 36. Q = 100 m^3/sec.

Figure 37. Left gate open. Q = 140 m^3/sec.

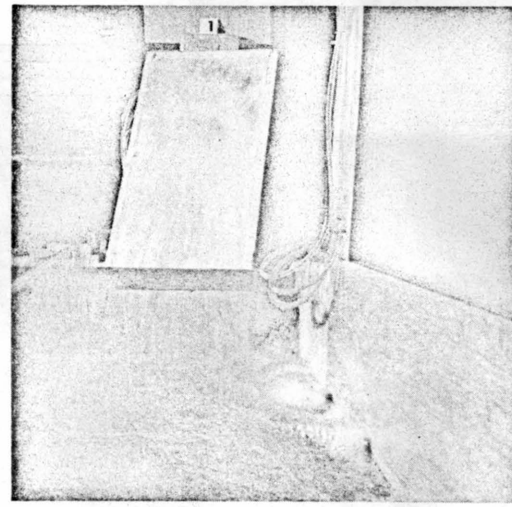


Figure 38. Center gate open. Q = 140 m^3/sec.

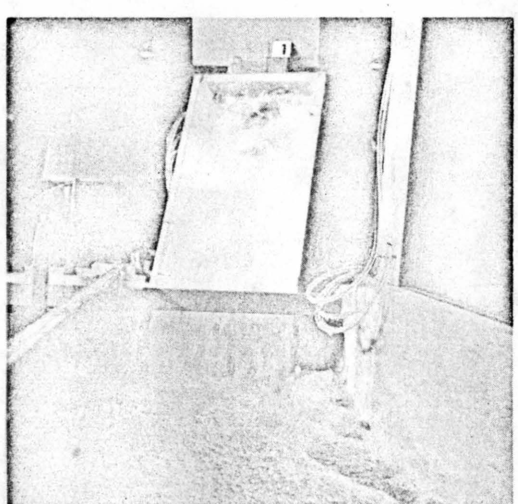


Figure 39. Right gate open. Q = 140 m^3/sec.