UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE SOLDIER CANYON DAM OUTLET WORKS COLORADO-BIG THOMPSON PROJECT

Hydraulic Laboratory Report No. Hyd. 334

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

February 12, 1953

FOREWORD

Hydraulic model studies of the outlet works for the Soldier Canyon Dam, Colorado-Big Thompson Project were conducted in the Hydraulic Laboratory of the Bureau of Reclamation at Denver, Colorado, during the period October 1946 to August 1949.

The final plans, evolved from these studies, were developed through the cooperation of the staffs of the Outlet Works Section of the Dams Division, and the Hydraulic Laboratory.

During the course of the model studies, Messrs. H. W. Tabor, I. B. Kirkwood, and R. W. Winnerah, of the Outlet Works Section frequently visited the laboratory to observe the model studies and to discuss the test results.

These studies were conducted by W. E. Wagner, L. R. Thompson, R. H. Slykehouse and T. J. Rhone under the supervision of Messrs. J. N. Bradley and A. J. Peterka of the Hydraulic Laboratory staff.

Reference is also made to the paper "Progress in New Designs for Outlet Works Stilling Basins" by A. J. Peterka and H. W. Tabor which was presented at the Fourth International Congress on Large Dams at New Delhi, India, in February 1951.

Excerpts from Field Trip Report No. 1191, a report on field tests performed on the prototype outlet works by B. R. Blackwell in September 1951, are included as an appendix to this report.

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Laboratory Report No. Hyd-334
Hydraulic Laboratory Section
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Subject: Hydraulic Model Studies of the Soldier Canyon Dam Outlet Works, Colorado-Big Thompson Project

SUMMARY

The hydraulic model studies discussed in this report were made to determine the operating characteristics of the Soldier Canyon Dam Outlet Works and to develop a stilling basin that performed satisfactorily for a particular type of valve control. The stilling basin to be satisfactory not only had to provide effective energy dissipation but also negligible wave action in the unlined canal section.

The results and recommendations contained herein were determined from studies on 1:4.67 and 1:6 scale models of the control valve, stilling basin, and a section of the downstream canal. Tests were made using hollow-jet, butterfly, and pivot valves for the outlet works control on basins using the hydraulic jump and dispersion devices for energy dissipation.

The preliminary design used a hollow-jet valve discharging horizontally onto a curved trajectory floor leading to a long, narrow stilling basin and utilizing the hydraulic jump as an energy dissipator. The tests made on the jump basin showed that a long trajectory was necessary to spread the jet from the valve and that even then there were large boils and surges in the stilling basin that carried down into the canal section, causing high velocity surface flow and damaging wave action, Figure 5B. When the valve was depressed a small amount, the basin was still unsatisfactory, Figures 5 and 6. A longer stilling basin might have quieted the water surface sufficiently to make the performance satisfactory, but since almost one-half of the length of this basin consisted of the trajectory curve, it was felt that better use of the basin length could be realized by using some other method of energy dissipation.

The trajectory floor was then removed and tests were made with the valve depressed at various angles up to 45°. The tests showed that the high velocity jet from the valve did not penetrate into the pool sufficiently to produce satisfactory energy dissipation.

At this point in the studies a lower cost butterfly valve was substituted for the hollow-jet valve. The studies were continued using the basin that had been developed for the hollow-jet valve.

The jet leaving the butterfly valve was dispersed in such a wide variety of patterns for different heads and degree of openings that it became necessary to use a hood to insure a uniform flow pattern entering the stilling basin at all discharges. Accordingly, the basin was developed for use with a hood or discharge guide on the valve. A basin that operated satisfactorily with the butterfly valve and discharge guide was developed and submitted to the designers so that the prototype basin could be constructed, Figure 4.

Several months after the prototype stilling basin had been constructed, increased discharge requirements made it necessary to use a larger valve, and an 18-inch commercial pivot valve was specified for the outlet works control. Since this valve had operating characteristics similar to the butterfly valve, minor modifications permitted the use of the same type of hood.

The stilling basin was rebuilt to a scale of 1:6, Figure 15, and the modified hood tested and developed, Figure 23. Operating tests showed that the stilling basin was adequate and that the energy dissipation was sufficient to provide a smooth water surface in the canal section, Figures 25 and 26. Piezometers placed in critical areas on the hood, Figure 29, indicated that the pressures were above atmospheric and that there was no danger from either cavitation or from excessively high pressures.

Calibration of the model valve confirmed that the required discharges could be attained at the available heads, Figures 30 and 31. Piezometers placed in the invert of the valve indicated that the pressures in that area were also safe, Figure 16. However, no attempt was made to prove or disprove that the entire valve was safe from cavitation.

In September 1951 tests on a limited scale were perfomed on the prototype of the Soldier Canyon Dam Outlet Works. The results of these tests were reported in Field Trip Report No. 1191. The essential parts of this report are included as an Appendix to this report.

The prototype tests showed that the model and prototype stilling basin performances are similar and that the pressures in the hood and wave heights in the canal compare favorably.

Two prototype calibration points obtained for the pivot valve indicated that the prototype coefficient of discharge is lower than that obtained from the model valve. This discrepancy cannot be explained at the present time.

INTRODUCTION

Soldier Canyon Dam is one of four earth-fill dams impounding water in Horsetooth Reservoir, approximately 10 miles west of Fort Collins, Colorado, Figures 1 and 2. Soldier Canyon Dam is approximately 1,400 feet long with crest elevation 5440 feet, and rises 150 feet above the original ground surface. The maximum water surface of the reservoir is elevation 5430.

The principal hydraulic feature of Soldier Canyon Dam is the outlet works which consist of the outlet conduit, the stilling basin, and the 18-inch pivot valve for releasing the water through a supply canal for irrigation purposes.

Water from the reservoir flows through a 5-foot-diameter circular concrete conduit, 550 feet in length, to the gate chamber which encloses a 24-inch wedge gate valve. From the gate chamber the water passes through a 30-inch circular steel conduit, 722 feet in length, to the pivot valve and thence to the stilling basin.

The hydraulic model tests discussed in this report were confined to studies of the entry of the jet from the valve into the stilling basin, the stilling basin performance, and the flow into the canal.

As originally designed, the outlet works control and regulation was accomplished with a 14-inch hollow-jet valve. During the course of the stilling basin studies, an economic analysis by the designers brought forth that considerable savings could be realized by the use of a 14-inch butterfly valve. Accordingly, the laboratory was requested to develop a stilling basin that would be satisfactory for this type of valve. Still later developments increased the maximum discharge from 60 to 100 second feet, and since the 14-inch butterfly valve could not pass this quantity at the available head, it was necessary to use a larger valve. An 18-inch pivot valve was found to be available and was specified for use. Before the type of control valve to be used was definitely decided, the prototype construction schedules made it necessary for the designers to issue drawings of the stilling basin outline to the contractor. The stilling basin developed for the 14-inch butterfly valve was recommended for construction since its performance was satisfactory, and it was believed that it could be made satisfactory if another type valve were used. Tests from this point on, therefore, used the recommended basin outline and changes were confined to the valve hood.

THE MODELS

The 1:4.67 model. A 3-inch hollow-jet valve and sections of 3-inch pipe were both available in the laboratory. Therefore, a scale ratio of 1:4.67 was selected for the model studies. This model of the outlet works consisted of a straight section of 3-inch steel pipe, the

3-inch hollow-jet valve representing the 14-inch prototype valve, the stilling basin, and a section of the canal. Figure 3 shows the model lay-out, giving the actual model dimensions.

Water was supplied directly to the 3-inch pipe by a laboratory pump through a Venturi orifice meter for accurate measurement of discharge. One diameter upstream from the valve a piezometer was installed to measure the head on the valve.

The connection between the straight pipe and the valve was constructed so that wedge-shaped shims could be installed to depress the valve from the horizontal to 10° in increments of $2\text{-}1/2^{\circ}$

The hollow-jet valve was accurately machined from brass stock and constructed so that it could be opened and closed in a manner similar to the prototype valve.

The trajectory apron under the valve and the transition leading to the canal section were of concrete screeded to sheet metal templates. The stilling basin and canal section were constructed of wood lined with galvanized sheet metal. The canal section was molded in pea gravel about 3 inches thick, as shown in Figure 3.

The tailwater elevation was measured by a staff gage in the canal section and controlled by a tail gate installed at the lower end of the canal section. The tailwater elevations for the discharges used in this study are shown in Figure 29.

The 1:6 model. The stilling basin outline had been submitted for field construction and the 1:4.67 model dismantled when the laboratory was informed that an 18-inch pivot valve had been specified to meet increased discharge requirements. As a result of this information, the stilling basin model was rebuilt for further study and a scale of 1:6 selected so that a 3-inch model pivot valve could be used.

The second model was constructed similar to the 1:4.67 model with the exceptions that the trajectory floor under the valve was of wood covered with sheet metal and one side of the basin was made of glass panels, Figure 15.

The valve was constructed with a transparent plastic barrel with machined-brass leaf and operating mechanism, from drawings furnished by the valve manufacturer, Figure 16. The hood or discharge guide was constructed of galvanized sheet metal and was part of the laboratory development. Piezometers connected to open-tube glass manometers were placed in both the valve and discharge guide, Figures 16 and 23.

THE INVESTIGATION

1:4.67 Model, Hollow-jet Valve Stilling Basin Studies

For all studies made to develop a stilling basin for use with the hollow-jet valve, a maximum discharge of 60 second feet at reservoir elevation of 5430 was used, resulting in a head of approximately 200 feet at the valve which was the maximum expected head. This combination of head and discharge provided the severest operating condition. The tailwater elevation at this discharge was 5225.0.

For each stilling basin the model was operated at the above discharge; then on a basis of visual observations confirmed by photographs, measurement of the magnitude of the surges and waves, and from the movement of the riprap in the canal section, the effectiveness of the basin, and the probable changes needed to improve the basin were determined.

Preliminary basin. The control valve for the preliminary design was a 14-inch hollow-jet valve that could be depressed from the horizontal to 10° in increments of 2-1/2°. The stilling basin was 111 feet long and 6 feet wide, with a depth of 13.5 feet. Under the valve was a parabolic trajectory floor 60 feet long, Figure 7. Figure 3 shows the preliminary basin with model dimensions.

The model was operated for this design with the valve in a horizontal position and depressed 2-1/2°, 5°, 7-1/2°, and 10°. In each of the valve positions, the flow spread uniformly on the trajectory, but the hydraulic jump formed on the lower part of the trajectory apron. There were excessive disturbances in the form of large boils in the upstream portion of the jump, causing surges in the pool and movement of the riprap in the canal section. In the downstream part of the stilling basin, all of the flow was in the upper 2 to 3 feet of the pool making the surface velocity excessively high, Figures 5 and 6.

It was apparent that the basin in this form was not satisfactory, primarily because the jet from the valve did not penetrate sufficiently deep into the basin to obtain good energy dissipation.

Basin No. 2. For Basin No. 2 the preliminary basin was altered so that there was a deeper pool for energy dissipation and the valve was moved close to the water surface so that the jet could penetrate the pool. This was accomplished by lowering the floor of the basin 2 feet and the center line of the valve 1.4 feet, Figure 7. The parabolic trajectory under the valve was changed to a straight line slope of about 10° below horizontal. The 0.6-foot relative change in elevation of the valve and the basin floor combined with the changes in the trajectory floor increased the total length of the stilling basin by 2 feet. Other features of the stilling basin and the canal remained unchanged. The axis of the hollow-jet valve was depressed 10° from the horizontal, Figure 7.

The appearance of the stilling action for 60 second feet was not improved with this basin. The outflow was still confined to the upper 2 to 3 feet of the pool and the surges were even more pronounced than for the previous basin, Figure 8. The surges in the stilling pool caused waves of a choppy nature that extended down into the canal section, and in a short period of time, moved the riprap on the banks of the canal for several feet downstream.

The trajectory apron under the valve was removed, and with the valve depressed 10°, the jet was allowed to plunge into the pool. With this arrangement the jet did not penetrate into the pool but skipped along the surface of the water with no energy dissipation. This high velocity of flow extended down into the canal section causing considerable damage to the riprap banks.

The valve was then depressed 30°. At this angle the jet plunged into the pool but the width and depth of the pool was not adequate to absorb the energy, with the result that the jet struck the floor of the basin and was deflected back to the pool surface causing large boils and surges with some of the flow near the surface directed back toward the valve. The return flow interfering with the jet from the valve resulted in an even greater amount of surging accompanied by large quantities of splashing and spray that covered a considerable area around the model. The mist and spray occurring with this operation was an additional undesirable feature that could not be tolerated in the prototype structure, indicating a definite need for improvement. However, it was noticed that in the extreme downstream end of the basin the flow had become nearly uniform, and the wave action in the canal was smoother than for the previous tests. It was concluded that this type of energy dissipation might perform satisfactorily with a wider and deeper stilling pool.

Basin No. 3. Since it was felt that a wider basin would dissipate more energy, the model was altered so that the sides of the basin diverged from a width of 6 feet at the valve, to a width of 12 feet in a length of 37 feet. The basin was 12 feet wide for a length of 55 feet and then had a 20-foot transition leading to the canal. The floor of the diverging section was sloped about 10° below horizontal. The valve was depressed 10° but the elevations of the valve and the basin floor were the same as in Basin No. 2, Figure 7.

The model was operated with this design but the jet did not penetrate the pool. The flow skipped along the surface of the pool, creating considerable spray and disturbance, Figure 9. Since there was no improvement over Basin No. 2 and since the jet from the valve did not penetrate the pool, the valve was depressed below 10°.

The method of depressing the valve was made simpler by using a section of flexible rubber hose in place of the pipe upstream from the valve. With a tilt slightly greater than 10° the jet penetrated the pool to a greater depth and the energy from the jet seemed to be better dissipated, but the trajectory floor was too flat and the valve could not be depressed much below 10°. Therefore, the trajectory floor was removed and the jet allowed to plunge directly into the pool. This arrangement resulted in better stilling action, but the elevation of the valve was too low and it became submerged at all flows.

The valve and connecting pipe were raised to eliminate this submergence. The model was then operated at a discharge of 60 second feet with the valve depressed at several different angles to determine the most satisfactory angle of depression. For 24° the jet dived under the water surface and resulted in the best stilling pool action observed so far. However, due to the entrained air and the concentration of the jet in a small area, large boils and unsymmetrical flow prevailed in the basin, Figure 9-C. The boils and unsymmetrical flow were confined to the upstream portion of the stilling basin and the flow had become more or less stable by the time it entered the canal section, although the surface velocity was still too great.

Basin No. 4. During the previous tests it was observed that most of the stilling action was confined to the upstream portion of the basin with very little use being made of the downstream half. Also, the stilling action that did occur was not thorough and the flow in the downstream part had a high surface velocity that carried over into the canal section, causing damage to the riprap. Therefore, it was decided that with a deeper pool a more complete dissipation of energy could occur and the length of the stilling basin could be shortened. On this basis, for Basin No. 4, Basin No. 3 was made 4.5 feet deeper and shortened by 18.62 feet, Figure 7.

The model was operated at 60 second feet with the valve depressed 24°. The stilling action was much improved, there was better distribution of the flow, but large surges and waves were still present indicating that the jet was not penetrating to the bottom of the pool. The waves extended down into the canal section and caused some movement of the riprap banks.

HOOD STUDIES

Deflectors. The best stilling action obtained so far had been with the jet plunging directly into the pool. However, the energy dissipation had not been complete, indicating that there might not be sufficient penetration and spreading of the jet into the pool. It was thought that a device which protected the jet from the tailwater until the jet was close to the floor of the stilling basin would provide the penetration necessary to distribute the flow evenly and to obtain a more thorough energy dissipation.

A flat sheet, the full width of the diverging section of the basin, called a deflector, was placed over the valve and parallel with the angle of tilt of the valve. The deflector extended to within 2 feet of the floor of the pool. For a discharge of 60 second feet, the stilling action was greatly improved over the previous tests. However, the flow from under the deflector was not evenly distributed and rose to the surface of the pool in surges that shifted from one side of the basin to the other. This action was reflected in waves that carried down into the canal section causing movement of the riprap banks.

The deflector was then extended to within 13 inches of the stilling basin floor. The deflector then exerted more control over the jet from the valve, and consequently the distribution of the flow emerging from under the deflector was more evenly distributed across the basin. The surges were dampened to the extent that the waves resulting from the surges caused only a slight movement of the riprap banks in the canal section. Whereas the improvement in the stilling action was noticeable, it was still not sufficient to give the best possible energy dissipation.

Discharge guide. Since there was a definite improvement with the use of a deflector over the top of the valve, it seemed likely that better control of the jet could be obtained by using a device that would confine the jet entirely until it had penetrated to the floor of the basin.

The first device tried was an 8-inch-diameter pipe, representing a 37-inch-prototype pipe, placed so that the jet discharged directly into it and was carried to the bottom of the pool. It was apparent that this device was not adequate. At the 60-second-foot discharge there were large boils and surges that shifted from one side of the basin to the other, producing unsymmetrical flow in the basin and damage to the riprap in the canal. At flows less than 60 second feet, the jet did not force the flow out of the lower end of the pipe. Consequently, the water backed up in the pipe and flowed out of the upper end with considerable splashing.

The next device tried was a transition box 28 feet long, with the upstream opening 3 feet 10.67 inches square and the downstream opening 1 foot 2 inches high by 6 feet 3 inches wide. The box was inclined the same as the valve and was placed directly in front of, but not touching, the valve. The performance of the basin with this type of guide was very poor. The concentrated jet was not distributed across the basin and therefore rose to the surface in a series of shifting surges with very little energy having been dissipated. When the height of the downstream opening of the chute was reduced to 7 inches, the stilling action was improved for the larger flows; however, for the lower flows, the water backed up in the guide and flowed out the upstream end.

14-INCH BUTTERFLY VALVE

At this point in the study it was decided to use a 14-inch butterfly valve instead of the hollow-jet valve because of the economies which could be realized, since a butterfly valve may be obtained commercially where the hollow-jet valve must be made to order.

Preliminary studies. During the initial studies the butterfly valve without a hood or guide was used in conjunction with Stilling Basin No. 4.

The flow from the butterfly valve was entirely different than the flow from the hollow-jet valve. Where the flow from the hollow-jet valve was annular in shape at all heads and valve openings, Figure 11-A, the flow from the butterfly valve consisted of two jets whose pattern varied considerably with either a change in head or degree of opening, Figure 11-B. The two jets from the butterfly valve issued from the upper and lower part of the valve and were separated by the leaf, Figure 10. When the leaf was closed in a counter-clockwise manner, Figure 10-A, the upper jet formed a large fin that arched high above the basin and extended far down into the canal section. When the valve was turned so that the leaf closed in a clockwise manner, Figure 10-B, the large fin was directed into the stilling pool and the part of the jet that now was on top fell well within the stilling basin. However, in neither position was there appreciable stilling action or dissipation of the jet energy. The jet struck the surface of the pool and skipped along the surface creating a high surface velocity in the canal section accompanied by large waves that destroyed the riprap banks.

The valve was then depressed 30^{o} and allowed to plunge directly into the pool. The jet was now confined in the stilling basin, but there was not enough penetration into the pool due to the wide divergence of the jet, and consequently all of the flow was along the surface.

Basin No. 5. All of the previous tests showed that a deep basin cannot be fully utilized if the jet does not penetrate the water. Since in the last test the jet had not penetrated to the bottom of the pool, two possible solutions were proposed; either a device to carry the jet to the bottom of the basin could be developed or the floor of the basin raised so that the ordinary penetration of the jet without a protecting device would reach the floor.

The latter solution was the most economical so it was tried first. The floor of Stilling Basin No. 4 was raised to elevation 5215.5 by placing a wooden false floor 4.5 feet above the existing floor.

When the model was operated the extreme dispersion of the jet at small openings prevented appreciable penetration into the pool, and at the larger openings the depth was not adequate for energy dissipation. This basin was also tried with two types of deflectors on the valve, Figure 13. These tests are described in greater detail in the section under "Hood Studies." Briefly, however, the stilling action was very inadequate for valve openings of one-third or less, making it apparent that the deeper basin was necessary.

When the false floor was removed to revert to the deeper basin, the side rails that supported the false floor were not removed. When some of the earlier tests were repeated to obtain photographs, it was noticed that the stilling action was improved. Further investigation showed that the rails assisted in turning under the boils which formerly had risen to the surface next to the walls. Figure 12 shows a comparison of the flow appearance with and without the side rails. This feature was incorporated in the basin with the addition of 45° fillets on the top and bottom of the rail to facilitate field construction, since tests had shown that the fillets did not reduce the effectiveness of the rails. Stilling Basin No. 5 consists of Stilling Basin No. 4 with the addition of the side rails.

Recommended basin outline. At this point in the investigation, it became necessary to submit a stilling basin outline to the field so that the first stage concrete could be poured and the basin used for diversion purposes. However, the type of valve to be used had not definitely been decided and consequently the final basin could not be recommended. The investigation had shown, however, that some type of hood would be necessary on the valve and that the basin as developed to this point had the proper over-all dimensions. Since the performance of Stilling Basin No. 5 was satisfactory, it was submitted to the designers.

The recommended basin outline had a valve chamber 6 feet wide and 8 feet long, a diverging section 37 feet long with the maximum width 12 feet, a 12-foot-wide section 36 feet 4 inches long, and a 19-foot transition leading to the canal section. The floor of the pool was at elevation 5211.0, with the lower edge of the rails 2 feet 10 inches above this. The rails started 3 feet upstream from the end of the trajectory and were each 34.6 feet long, Figure 4.

Tests from here on had to be made using the basin outline which was now under construction. Therefore, all changes and additions had to be compatible with this design.

HOOD STUDIES

Deflectors. Because of the extreme divergence of the jet of the butterfly valve at partial openings, it was apparent that in order to obtain the desired stilling action it would be necessary to develop a guide to carry the flow to the bottom of the stilling pool for the most effective energy dissipation. For all of the following tests the valve was depressed 30°.

The first type of guide tested was a semicircular hood 3.5 feet long, fastened over the top of the valve, Figure 13, Deflector No. 1. This hood caused the jet to plunge into the basin, but the jet divergence was such that the penetration was not sufficient, and consequently there were large boils and surges in the stilling basin causing wave action in the canal section that moved the riprap from the banks.

A curved deflector, the width of the stilling basin, was then developed to attempt to confine the divergence of the jet, Figure 13, Deflector No. 2. With this design the operation in the stilling basin was good at the larger discharges. For a valve opening of one-third or less the jet's divergence was so great that its energy was diminished to the extent that the jet did not penetrate into the pool but hit the surface of the water and caused a considerable amount of spray and splashing to be present. This spray backed up over the valve, causing the valve to be partially submerged intermittently, resulting in very poor basin operation. Side walls were placed under the deflector to further control the divergence of the jet at the small openings, but there was no improvement in the stilling action, so further study on this type of hood was discontinued.

Discharge guides. Deflectors No. 1 and 2 as described above were of the same general type, but differed in size and in the method of attaching them to the structure. Whereas neither of the deflectors were entirely satisfactory, some features of both showed promise that warranted further development. It was believed that if the jet could be carried to the bottom of the pool as by Deflector No. 2, but at the same time be fastened directly to the valve as Deflector No. 1, better control of the jet could be obtained and consequently a better stilling action.

The first discharge guide developed along this line consisted of a length of 14-inch pipe bolted to the downstream flange of the valve. The pipe was 11.67 feet long and inclined 30° below the horizontal.

The operation with this type of guide was exceptionally good; the energy dissipation was accomplished with no disturbances in the form of visible surges, boils, or wave action, although some eddies were noticeable. However, this lack of a visible stilling action can be explained as follows: In fastening the guide directly to the valve it was not possible for the valve to receive air, and consequently there was no air carried into the stilling basin as in all of the previous tests. The lack of air, however, caused subatmospheric pressures in the pipe and valve, and the use of this device could not be recommended.

Two air vents, about 5 inches in diameter, were then placed in the sides of the guide, directly downstream from the flange. With air provided, the turbulence in the basin increased considerably. Also, part of the flow from the valve was discharged through the vents, causing objectionable spray and splashing. To eliminate this feature a pipe 18.67 inches in diameter was used in place of the 14-inch pipe. The larger pipe was fastened to the valve in the same manner as the smaller pipe, and two air vents, the same size and location, were also provided. The larger pipe provided the additional area needed to prevent flow out of the air vents, but the circular pipe did not exert enough control over the dispersion of the jet and the flow in the basin was unsymmetrical with large shifting boils and surges.

To obtain better dispersion, a circle-to-rectangle transition, 11 feet 9 inches long, was used in place of the circular pipe. The upstream end of the transition was circular, 18.67 inches in diameter, and fastened directly to the valve by a flange. Air vents were provided immediately downstream from the flange. The lower end was rectangular, 5.17 inches high and 4 feet 5 inches wide, giving the same area at the entrance and exit of the transition, Figure 14.

With the valve fully open, the transition helped to provide good operation in the stilling pool; however, as the valve was closed, shifting boils caused excessive waves in the transition and canal.

To eliminate the poor stilling basin appearance at the smaller discharges, two methods of reducing the area at the end of the transition were tried. For the first a wedge-shaped divider, 8.17 inches wide and 23.35 inches long, was placed in the center of the rectangular opening. This split the jet and directed the two parts against the basin walls. The reduced area resulted in better stilling action but the splitting of the jet and its consequent striking of the walls with considerable force made the use of the dividing wedge undesirable.

The area was then reduced by an amount equal to the wedge by reducing the height of the rectangular opening to 4.2 inches. When the model was operated with this arrangement, the action in the stilling pool was improved with the jet plunging sufficiently deep into the pool to give thorough energy dissipation.

At this point in the model studies the testing was discontinued because there was still considerable doubt as to the type and size of control valve that was to be used in the outlet works; and therefore it was not practical to develop a final discharge guide until a definite decision was made.

1:6 MODEL--COMMERCIAL PIVOT VALVE

Introduction. The model studies were resumed after a lapse of several months. An 18-inch commercial pivot valve had been selected for the outlet works; the 18-inch valve had become necessary when the maximum discharge requirements had been increased to 100 second feet.

The pivot valve is similar in performance to the butterfly valve in that the flow issues from the valve in two jets whose characteristics vary considerably with both head and degree of opening. At small openings the jet diverges, with the smallest openings giving the greatest divergence, Figure 11-C; at the larger openings the jets are concentrated and difficult to spread. These features made the control of the jet a problem similar to that encountered with the butterfly valve. Consequently, the same manner of overcoming the difficulty was used.

Several months had elapsed since the model studies were discontinued and the 1:4.67 model had been dismantled to make room for more active studies. The model was rebuilt to a scale of 1:6 so that a 3-inch model of the pivot valve could be used. The recommened basin, Figure 4, was rebuilt to this scale in the same manner as in the 1:4.67 model, with the exception that in one side of the 1:6 model, glass panels were installed. Figure 15 shows the model installation. With the panels it was possible to see how deep the jet was penetrating and the effectiveness of any device used to obtain a better dispersion of the jet.

The model valve was constructed of brass and transparent plastic. The valve leaf and operating mechanism were machined from brass stock, and the barrel molded in transparent plastic, Figures 16, and 17. Piezometers were installed on the invert of the valve barrel.

The prototype stilling basin had already been accepted and constructed in the field; therefore, any changes necessary to obtain proper operation would have to be made with a hood or discharge guide used in conjunction with the valve.

In the preliminary tests the pivot valve was depressed 30° and discharged directly into the basin, Figure 17-A. The jet did not penetrate the pool, and as a result there were large boils and shifting surges in the basin, with high velocity surface flow and large waves in the canal. Figures 18 and 19 show the action at two different discharges and reservoir elevations. It was apparent from this test that a hood or discharge guide was necessary to enable the jet to penetrate the pool for any effective energy dissipation.

HOOD STUDIES

Preliminary hoods. To provide information to determine the type of discharge guide that was necessary for the pivot valve, the hood that had been used on the 1:4.67 scale model, Figure 14, was fastened to the pivot valve, Figure 17-B. The 4-inch-diameter entrance of the model hood when scaled up for the 1:6 model represented a 24-inch-diameter opening on the prototype. This entrance was slightly larger than the diameter of the valve, but flanges on the valve and hood were matched so that they could be fastened together concentrically. Two 6-inch-diameter air vents, one on each side of the hood immediately downstream from the flange, provided ventilation for the valve.

Operation with this hood was satisfactory with the air vents open. The stilling pool operation was adequate with the stilling action well distributed throughout the basin, Figures 20 and 21. Pressure measurements obtained in the valve and hood for several discharges were all above atmospheric. When the air vents were closed, the appearance in the stilling pool was much better since there was no entrained air, but pressures in the valve and hood dropped to below atmospheric, which increased the discharge. This was an undesirable feature, and because of the comparatively small openings for the air vents, it was possible that at some time they might become closed off in the prototype structure.

Because of this uncertain ventilating factor and because of possible damage to the valve from vibration in the hood, it was decided to position the hood in such a way that the hood and valve would not be attached.

The same hood was used, but instead of being fastened to the valve it was fastened to the side walls and floor of the stilling basin. There was a 4-1/2-inch clearance between the valve and hood. This arrangement was satisfactory at the larger discharges, but as the valve was closed and the jet began to disperse, part of the jet did not enter the hood, showing a need for a larger entrance to the hood.

Another hood was constructed with the entrance diameter increased to 30 inches and the rectangular exit dimensions increased to 7 inches high by 4 feet 10 inches wide. The length was increased to 12 feet 6 inches, Figure 22. This hood was also placed 4-1/2 inches from the valve and parallel to the sloping basin floor.

Operation with this design was satisfactory at all flows. The jet penetrated to the bottom of the stilling basin and there was good dissipation of the jet energy. However, there were still some boils and surges present in the lower end of the stilling basin and they had a tendency to shift from one side of the basin to the other.

Two alterations to the hood were made in an attempt to reduce the slightly unstable flow in the basin. For the first alteration a sheet metal slide gate was placed on the rectangular exit. The gate could be raised or lowered by means of a threaded crank while the model was in operation. It was anticipated that the unstable condition in the lower end of the stilling basin might be controlled if the flow emerged from the hood through a smaller area. At a discharge of 60 second feet the unstable condition had been most prevalent. Therefore, the model was operated at this discharge, and the slide gate slowly closed. The gate could be closed only three-eighths of an inch before the water backed up in the hood and started coming out of the entrance. It was decided to accept the original 7-inch height for this opening in order to provide for any inconsistencies between the model and prototype.

The second alteration was to increase the length of the discharge guide by 6 feet in order to bring the jet closer to the floor of the pool before releasing it. This did not improve the stilling action and there was a tendency for the water to choke up in the hood, although none came out the entrance. Since these alterations did not improve the flow conditions, neither was incorporated in the recommended design.

Recommended hood. The hood recommended for prototype construction is shown in Figure 23. The slight differences between this hood and that shown in Figure 22 were made to eliminate sharp corners where there was flowing water and for ease of prototype construction. A 1:6 model was constructed of the recommended hood and installed for further testing. The model hood installation is shown in Figures 4 and 17-C.

The model was operated over the full range of discharges at reservoir elevations 5340 and 5430. Three features: (1) stilling basin appearance, (2) wave action and its effect in the canal section, and (3) pressure measurements in the hood, were then checked for a final evaluation of the design.

Stilling Basin Appearance

The model was operated at discharges ranging from 5 to 100 second feet at reservoir elevations of 5340 and 5430. The appearance of the flow in the basin was satisfactory. The water surface in the basin at 100 second feet was comparatively rough, but since it was an infrequent operating condition, the basin was believed to be adequate. For a flow of 15 second feet at reservoir elevation 5430, the jet leaving the valve and entering the hood was dispersed to such an extent that it tended to choke up the hood, causing some water to splash back into the valve chamber; however, the amount of the water splashed back was small enough that a 1/8-inch drain hose could keep the chamber siphoned dry while the model was operating, and therefore the splash was not considered dangerous. (This backflow was also encountered during the prototype tests, see Appendix.)

The hood did not choke up at any of the other discharges, indicating that it was a specific head and valve opening that caused the jet to disperse and would occur in the prototype only under the same conditions. Figures 25, 26, and 28 are photographs showing the appearance of the stilling basin for several different operating conditions. Figure 3 of the Appendix shows the prototype stilling basin at a discharge of 30 second feet.

Wave Heights

The wave heights in the canal section were measured by means of a staff gage located about 2 feet downstream from the end of the concrete transition. The wave height was determined by recording the maximum and minimum water surface that occurred in a period of 1 minute. Several such readings were obtained and averaged for the height that has been tabulated in the table below.

The wave heights were measured at four discharges for the recommended stilling basin both with and without the side rails. The wave heights at 15 second feet were negligible under both conditions. At all other discharges except 100 second feet, the waves were less in magnitude with the rails in place; at 100 second feet the rails seemed to lose their dampening effect. Figures 26 and 27 are a comparison of the appearance in the stilling basin with and without the side rails.

WAVE HEIGHTS IN CANAL SECTION

Q	Reservoir elevation	Wave heights	
		W/o rails	W/rails
30	5340	0.22 foot	0.11 foot
30	5430	.22 foot	.10 foot
60	5340	.28 foot	.19 foot
60	5430	.25 foot	.07 foot
100	5430	.63 foot	.66 foot

Wave heights obtained during the prototype tests showed that at 15 second feet the waves were about 0.05 foot in magnitude, and at 30 second feet were 0.1 foot in magnitude both of which compare favorably with the model measurements.

Pressure Measurements

Thirty-two piezometers were placed in critical areas on the model hood, Figure 23. Pressure measurements obtained from these piezometers at discharges of 15, 30, 45, and 60 second feet with reservoir elevations of 5340 and 5430 were atmospheric or above at every discharge with one exception. When the discharge was 30 second feet at reservoir elevation 5340, the pressure at Piezometer No. 7 was 0.4 foot of water below atmospheric. Since this pressure was not excessively low nor the others too high, the hood design was considered adequate. Figure 29 is a graphical representation of the pressure readings.

The prototype structure has 12 piezometers that correspond to the following numbered model locations: Nos. 2, 3, 6, 8, 11, 13, 16, 18, 21. 23, 27, and 30. Figure 24 shows the location and installation of the prototype piezometers. Pressure measurements made on the prototype structure were all higher than corresponding pressures determined from the model. The tailwater elevations during the prototype tests were about 1-1/2 feet higher than the tailwater used for the model tests, which might account for the discrepancy. Figure 2 of the Appendix is a comparison of the prototype and model pressure readings.

VALVE STUDIES

Discharge characteristics. To determine the discharge characteristics of the pivot valve, tests were made on the 1:6 model valve.

The information thus obtained was used to determine the coefficient of discharge, C_D, for the valve at any opening and to determine the discharge in cubic feet per second for any valve opening and pressure head at the valve, Figures 30 and 31.

The model discharge was measured by an orifice Venturi meter and the pressure head at the valve was measured by a piezometer placed 1 diameter upstream from the 30° bend.

Two approach conditions were used for the tests; in the first the valve and a short section of the approach pipe were depressed 30° to represent the prototype arrangement; for the second condition the valve and approach pipe were horizontal.

For the first condition the maximum C_D is 0.658 occurring at a valve opening of 89.6 percent; for larger valve openings the coefficient decreases rapidly.

For the second condition C_D was the same for valve openings up to 75 percent; for openings greater than 75 percent C_D was larger than it had been for corresponding openings under the first condition. The maximum C_D with the horizontal approach was 0.63 and was attained when the valve was 82-percent open; for valve openings greater than 82 percent the C_D decreased, but not as rapidly as under the first condition, Figure 30.

Tests with the valve and a short section of the approach pipe depressed 30° showed that the maximum required discharge can be obtained at normal reservoir elevations with this valve. The discharge in second feet for valve openings at 10-percent intervals has been plotted against pressure head in Figure 31.

The coefficient of discharge was obtained for the two discharges used during the prototype tests, see Appendix. For both discharges the prototype coefficient was smaller than the coefficient determined from the model studies. This difference cannot be explained at the present time.

Pressures. Four piezometers were placed in the valve so that pressure measurements could be obtained under the most common operating conditions. These piezometers were located on the bottom of the valve, two on each side of the invert, Figure 16. Since this was not a comprehensive study of a pivot valve, no piezometers were placed in the gate leaf or operating stem housing.

Pressure readings were taken for discharges of 30 and 60 second feet at reservoir elevations of 5340 and 5430. No subatmospheric pressures were found for these discharges. On Figure 16 the pressure readings at each piezometer location are shown in tabular form.

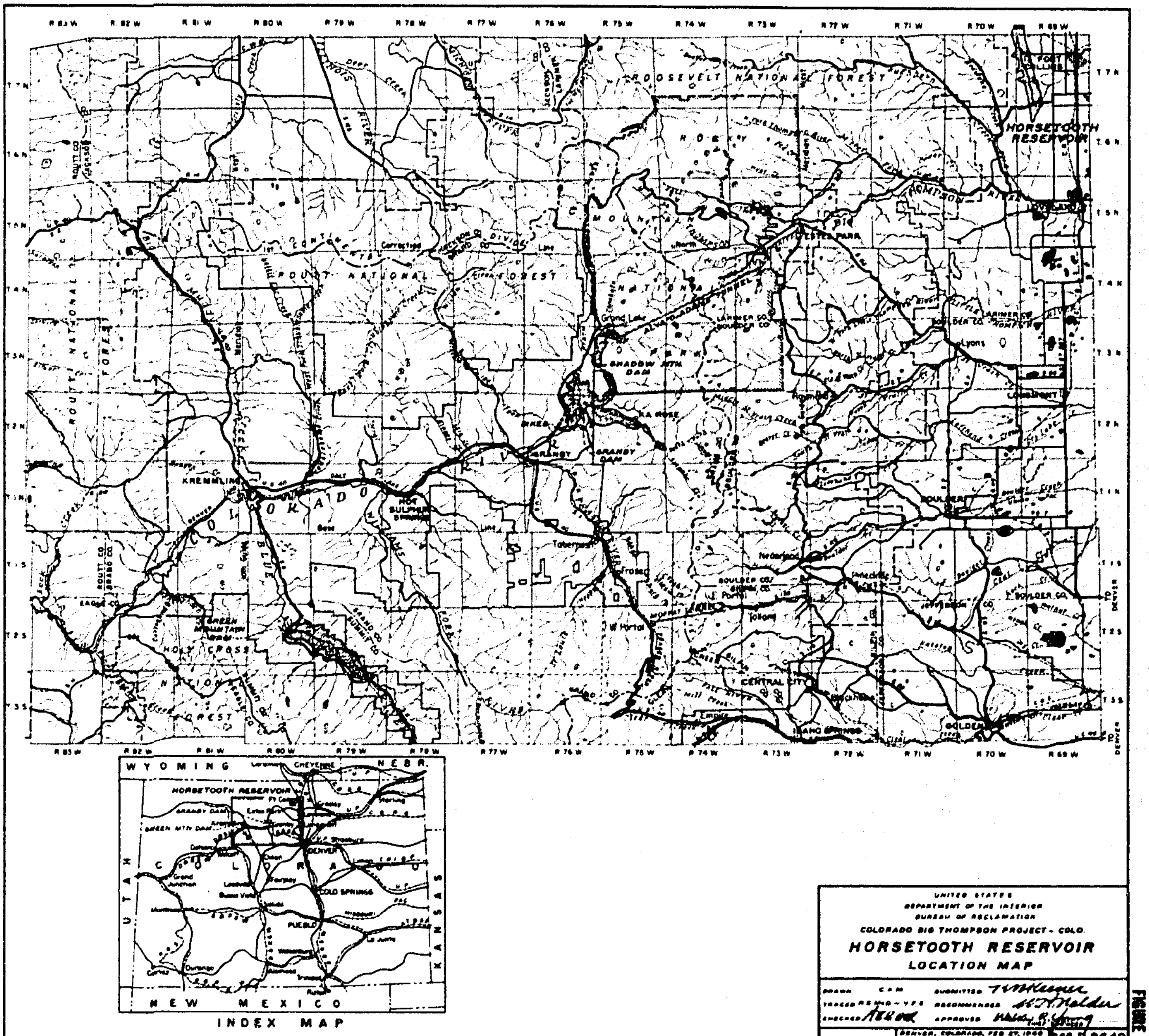
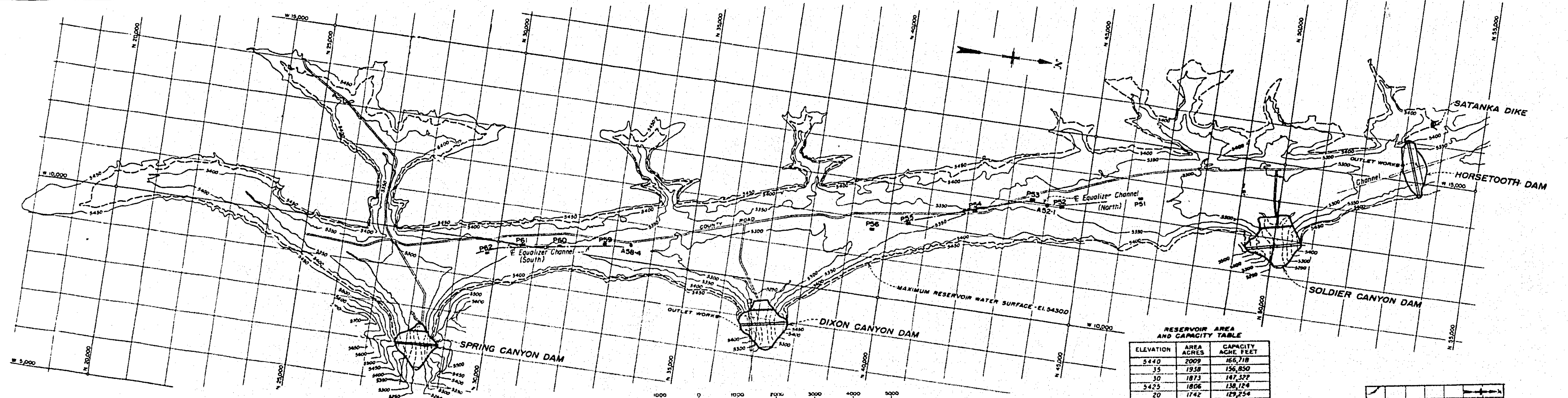
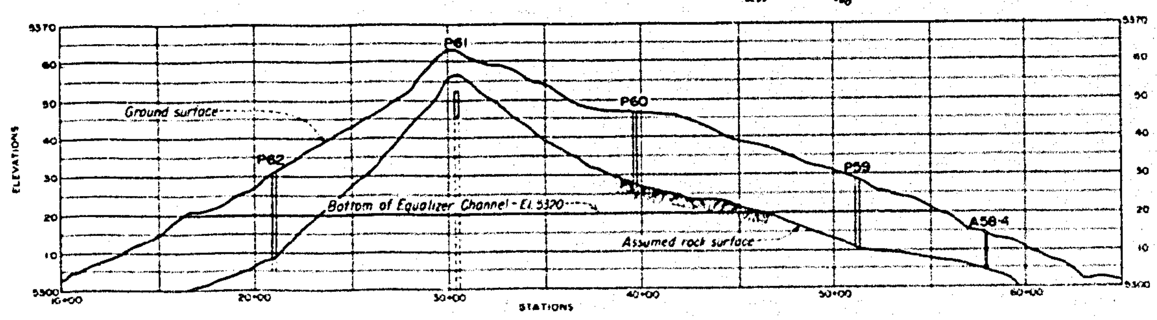
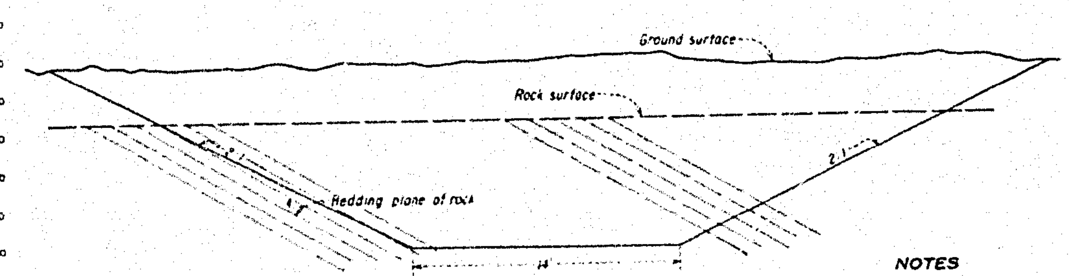

ROOSEVELT NATIONAL FOREST
HORSETOOTH RESERVOIR
ROUTT NATIONAL FOREST
ESTES PARK
LOVELAND
Grand Lake
SHADOW MTN. DAM
GRANBY
GRANBY DAM
KREMMLING
HOT SULPHUR SPRINGS
COLORADO
Lyons
BOULDER
Nederland
Fraser
Tabernash
W Portal
CENTRAL CITY
IDAHO SPRINGS
GOLDEN
HOLY CROSS
INDEX MAP
WYOMING
NEBR.
UTAH
KANSAS
NEW MEXICO
CHEYENNE
DENVER
COLO SPRINGS
PUEBLO
Grand Junction
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO BIG THOMPSON PROJECT - COLO.
HORSETOOTH RESERVOIR
LOCATION MAP
DENVER, COLORADO
245-D-2640
FIGURE 1

FIGURE 2





PROFILE ON ℄ SOUTH CHANNEL



CROSS SECTION OF CHANNEL

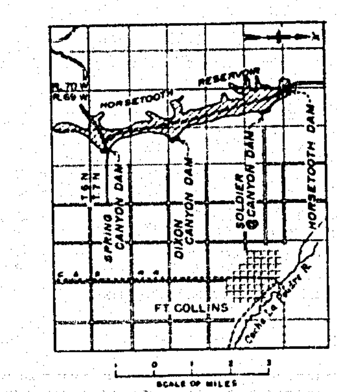
NOTES

P57 Indicates Test Pit

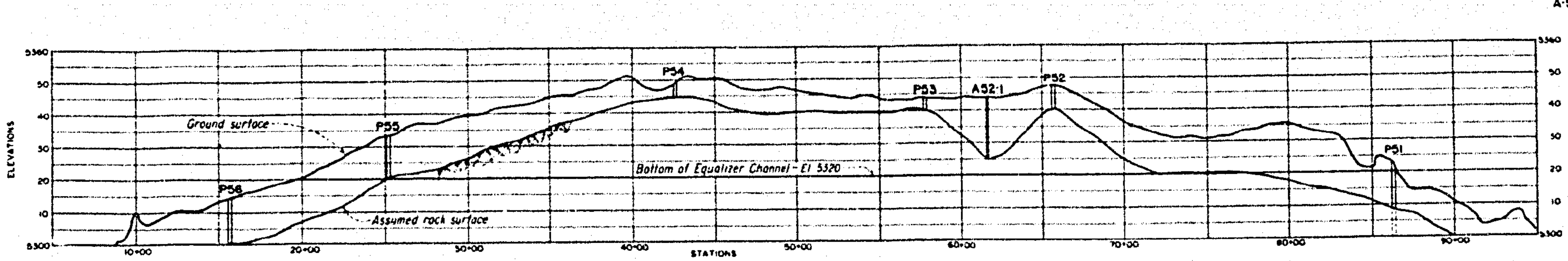
A-58-1 Indicates Auger Hole

RESERVOIR AREA AND CAPACITY TABLE

ELEVATION	AREA ACRES	CAPACITY ACRE FEET
5440	2009	166,718
35	1938	156,850
30	1873	147,322
5425	1806	138,124
20	1742	129,254
15	1676	120,709
10	1625	112,456
05	1569	104,471
5400	1513	96,761
95	1457	89,386
90	1399	82,246
85	1343	75,449
80	1282	68,885
5375	1222	62,624
70	1162	56,659
65	1107	50,987
60	1045	45,607
55	977	40,549
5350	913	35,825
45	837	31,445
40	757	27,460
35	700	23,814
30	635	20,475
5325	580	17,437
20	525	14,675
15	471	12,184
10	419	9,959
05	372	7,982
5300	322	6,247
95	270	4,768
30	220	3,544
85	176	2,555
80	132	1,784
5275	96	1,183
70	75	754
65	47	448
60	30	255
55	19	132
5250	11	58
45	4	19
40	1	5
5235	03	1



LOCATION MAP



PROFILE ON ℄ NORTH CHANNEL

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO BIG THOMPSON PROJECT - COLO.

HORSETOOTH RESERVOIR

GENERAL MAP OF RESERVOIR AREA

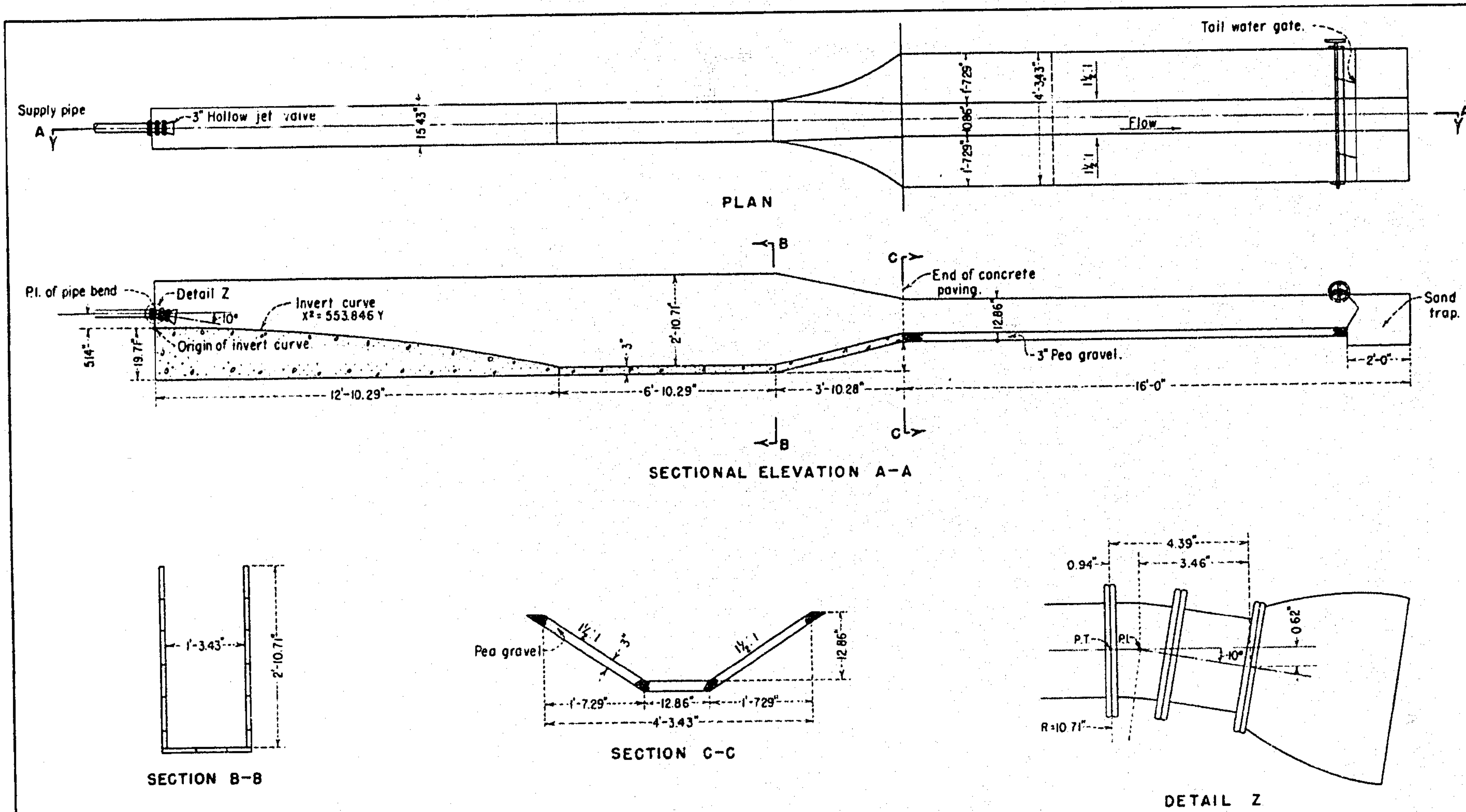
DRAWN J.O.O.-C.A.M. SUBMITTED

TRACED W.L.A. RECOMMENDED

CHECKED APPROVED

DENVER, COLORADO FEB. 27, 1946

245-D-2641

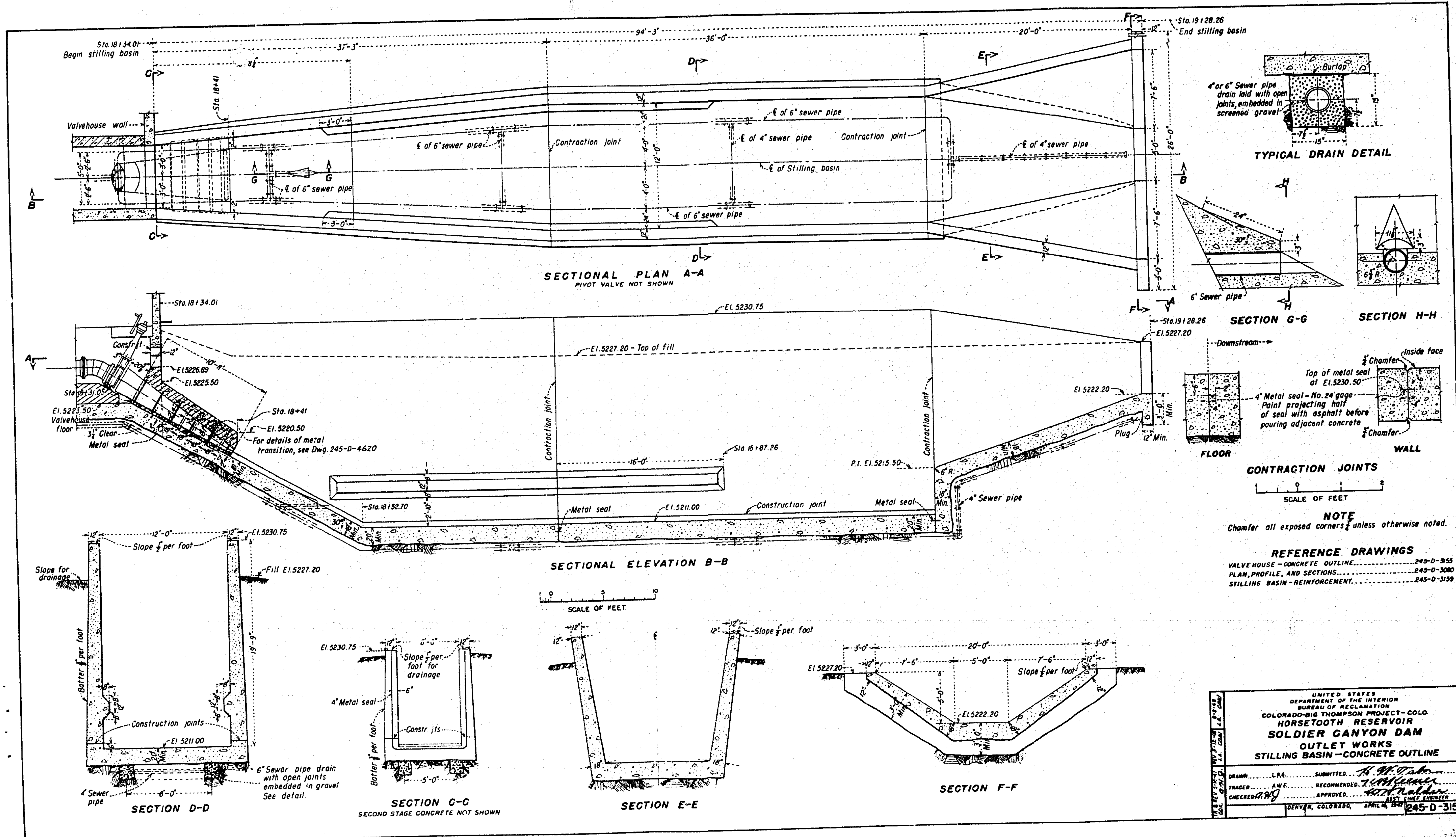


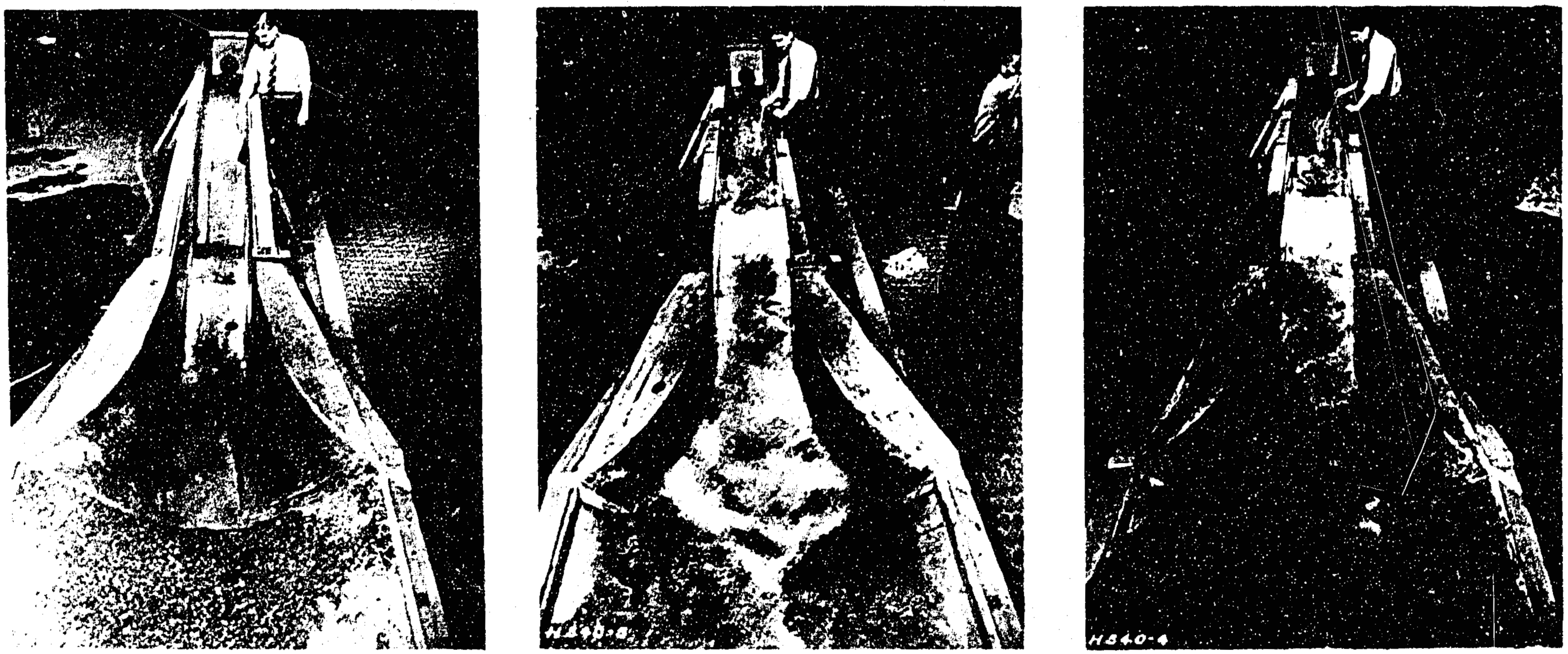
SOLDIER CANYON DAM
OUTLET WORKS
PRELIMINARY STILLING BASIN
1:4.67 SCALE MODEL

246
6-15-50

FIGURE 3

FIGURE 4


SECTIONAL PLAN A-A
PIVOT VALVE NOT SHOWN
Sta. 18+34.01 Begin stilling basin
Sta. 19+28.26 End stilling basin
94'-3"
36'-0"
20'-0"
Valvehouse wall
Contraction joint
℄ of 6" sewer pipe
℄ of 4" sewer pipe
℄ of Stilling basin
SECTIONAL ELEVATION B-B
El. 5230.75
El. 5227.20 - Top of fill
El. 5222.20
El. 5211.00
Sta. 18+87.26
Sta. 18+52.70
Sta. 18+41
P.I. El. 5215.50
Construction joint
Metal seal
4" Sewer pipe
Valvehouse floor
For details of metal transition, see Dwg. 245-D-4620
TYPICAL DRAIN DETAIL
4" or 6" Sewer pipe drain laid with open joints, embedded in screened gravel
Burlap
SECTION G-G
6" Sewer pipe
SECTION H-H
CONTRACTION JOINTS
Top of metal seal at El. 5230.50
4" Metal seal - No. 24 gage. Paint projecting half of seal with asphalt before pouring adjacent concrete
3/4" Chamfer
Inside face
Downstream
FLOOR
WALL
SCALE OF FEET
NOTE
Chamfer all exposed corners 3/4" unless otherwise noted.
REFERENCE DRAWINGS
VALVE HOUSE - CONCRETE OUTLINE 245-D-3155
PLAN, PROFILE, AND SECTIONS 245-D-3080
STILLING BASIN - REINFORCEMENT 245-D-3159
SECTION D-D
Slope for drainage
Slope 1/4" per foot
Fill El. 5227.20
Batter 1/8" per foot
Construction joints
6" Sewer pipe drain with open joints embedded in gravel See detail.
4" Sewer pipe
SECTION C-C
SECOND STAGE CONCRETE NOT SHOWN
4" Metal seal
Constr. jts.
SECTION E-E
SECTION F-F
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT-COLO.
HORSETOOTH RESERVOIR
SOLDIER CANYON DAM
OUTLET WORKS
STILLING BASIN-CONCRETE OUTLINE
DENVER, COLORADO, APRIL 16, 1947
245-D-3158



A. Basin, No Flow
Valve tilted 5°

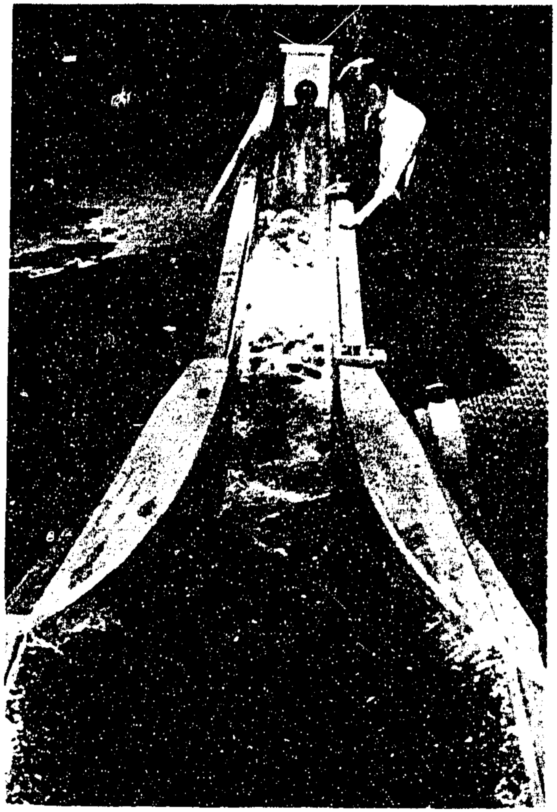
B. Discharge 60 cfs
Valve Horizontal

C. Discharge 60 cfs
Valve tilted $2\frac{1}{2}$°

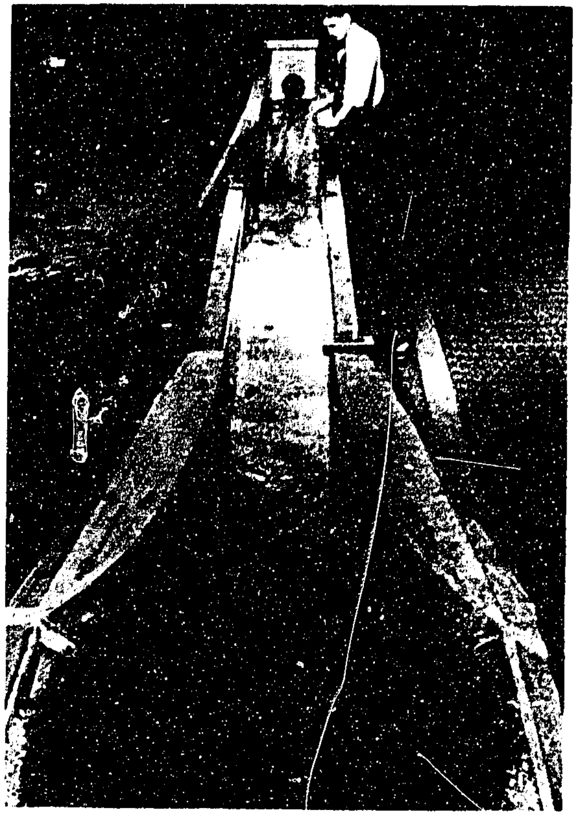
SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Preliminary Basin

Figure 5

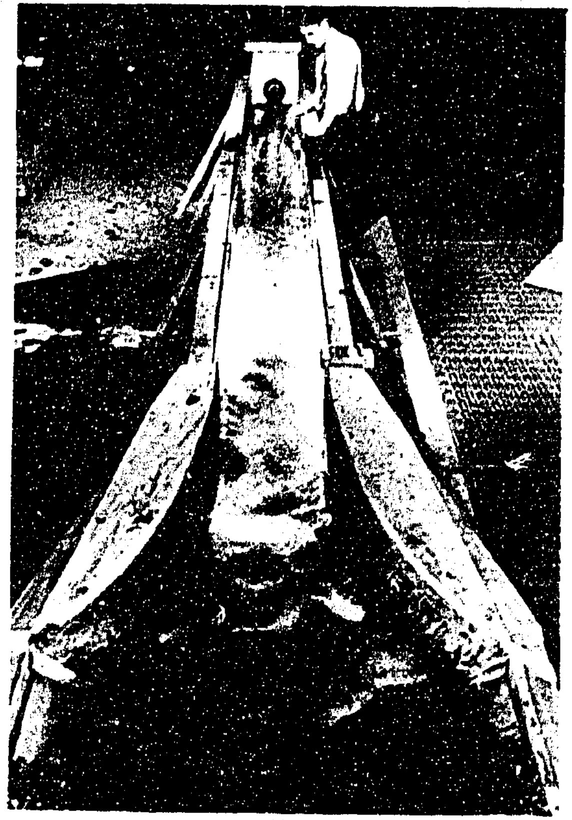
Figure 6



A. Valve Tilted 5°

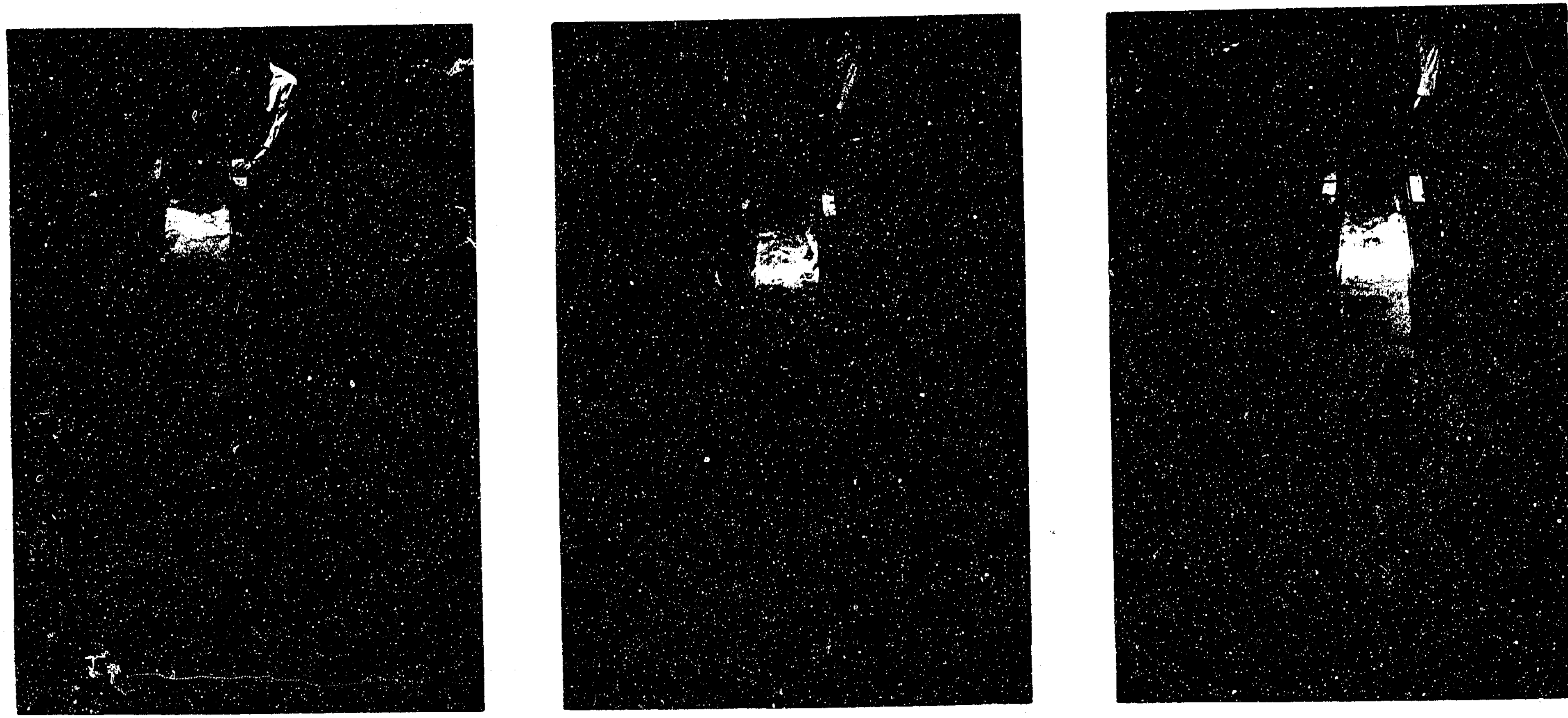


B. Valve Tilted $7\frac{1}{2}^{\circ}$



C. Valve Tilted 10°

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Preliminary Basin
Discharge 60 cfs



A. Valve Tilted 5°

B. Valve Tilted 7½°

C. Valve Tilted 10°

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Preliminary Basin
Discharge 60 cfs

Figure 6

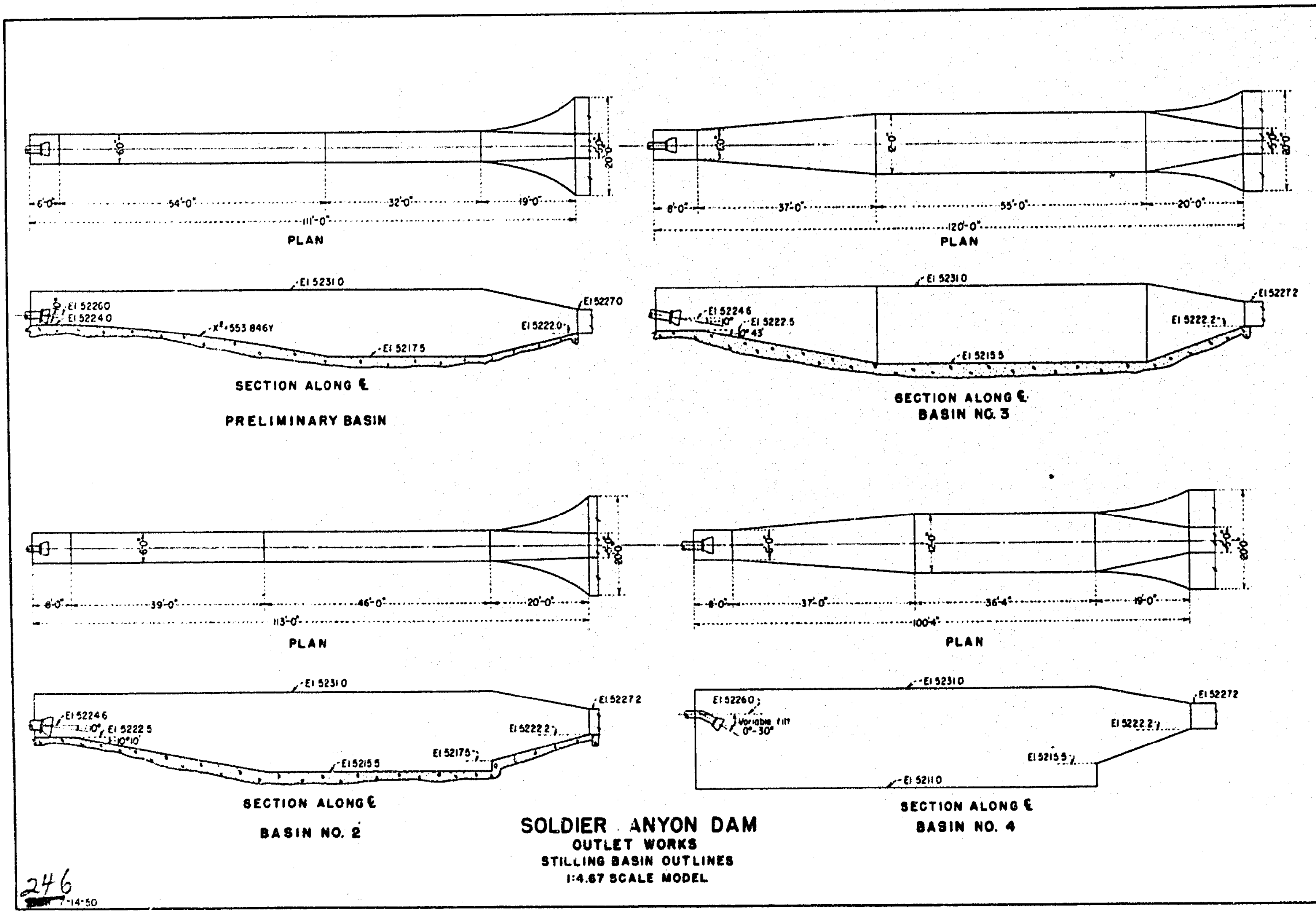
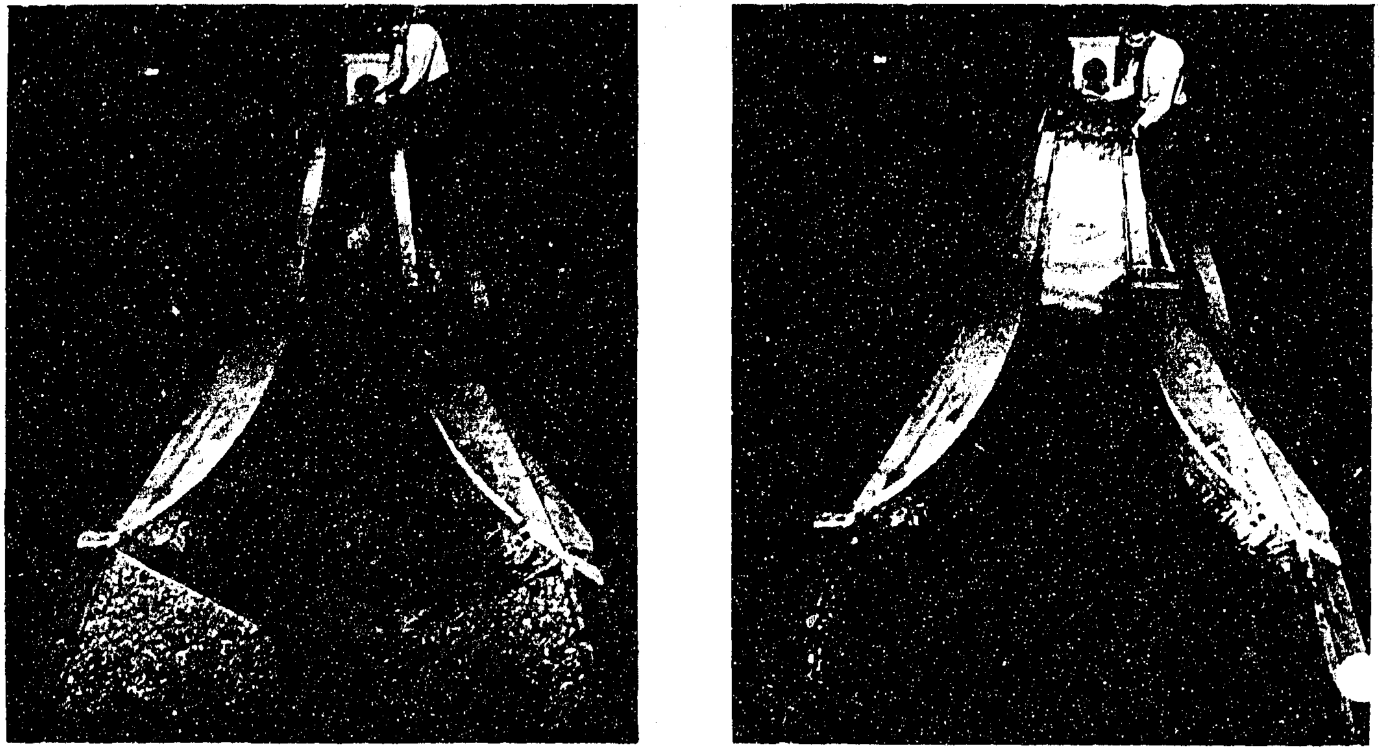

PLAN
SECTION ALONG ℄
PRELIMINARY BASIN
PLAN
SECTION ALONG ℄
BASIN NO. 3
PLAN
SECTION ALONG ℄
BASIN NO. 2
PLAN
SECTION ALONG ℄
BASIN NO. 4
El 5231.0
El 5227.2
El 5215.5
SOLDIER ANYON DAM
OUTLET WORKS
STILLING BASIN OUTLINES
1:4.67 SCALE MODEL
246
7-14-50

FIGURE 7

Figure 8



Dry Model | Discharge 60 cfs

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Basin No. 2

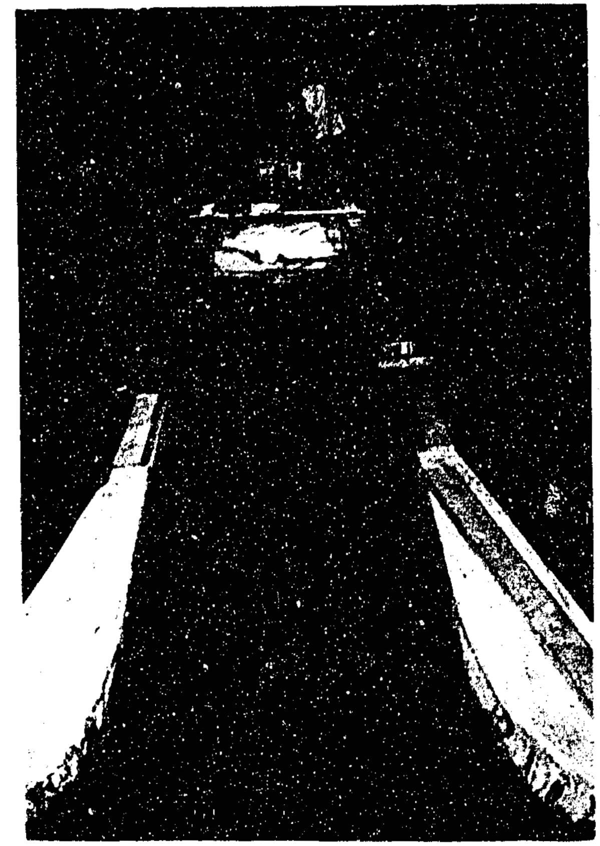
Dry Model

Discharge 60 cfs

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Basin No. 2

A. Dry Model
Valve depressed 10°

B. Discharge 60 cfs
Trajectory Apron in place
Valve depressed 10°

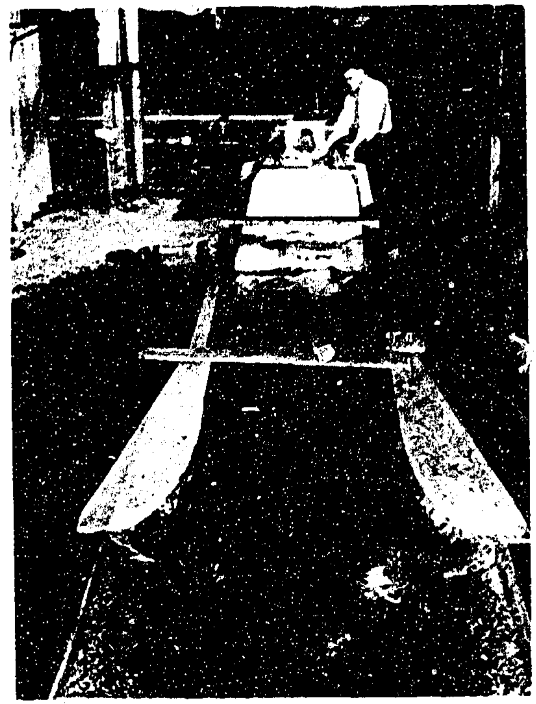


C. Discharge 60 cfs
Trajectory Apron Removed
Valve depressed 24°

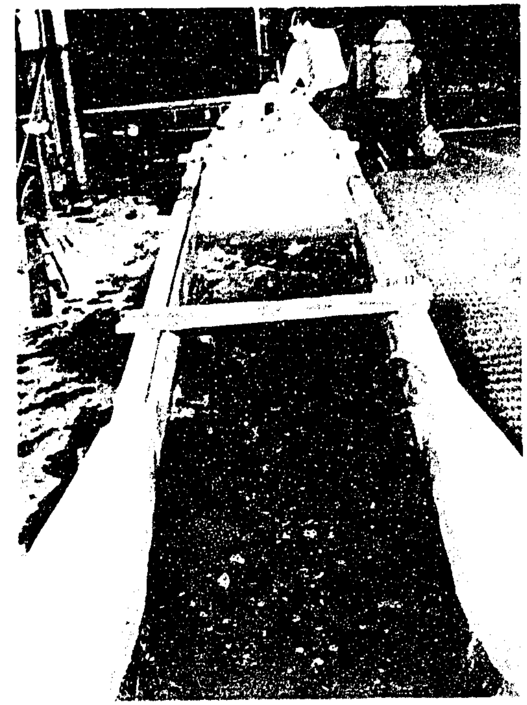
SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Basin No. 3

Figure 9

A. Dry Model
Valve depressed 10°



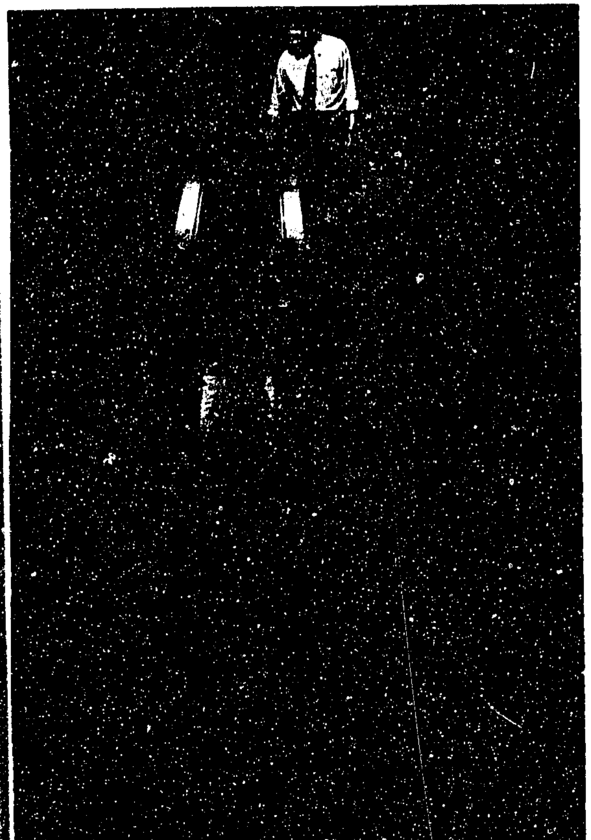
B. Discharge 60 cfs
Trajectory Apron in place
Valve depressed 10°



C. Discharge 60 cfs
Trajectory Apron Removed
Valve depressed 24°

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Basin No. 3

Figure 9



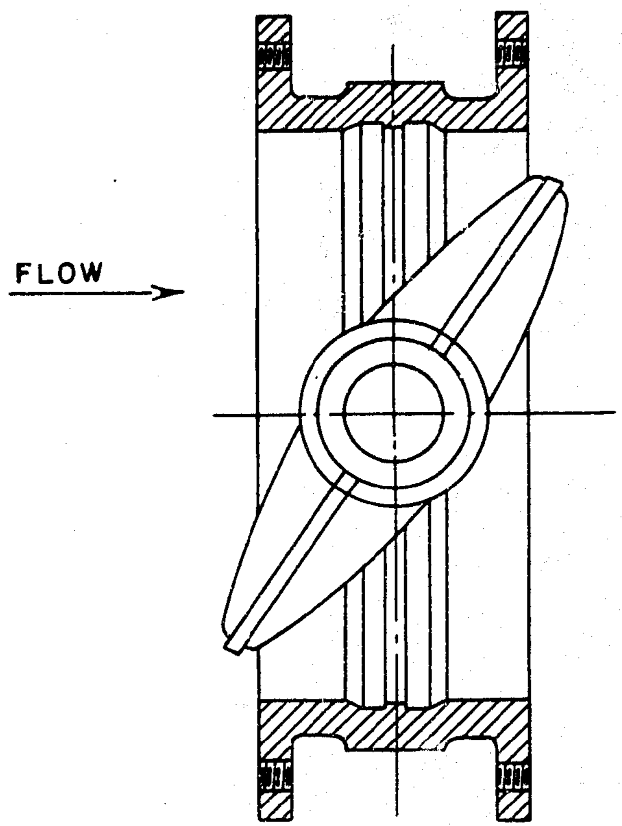
A. Basin, No Flow
Valve tilted 5°

B. Discharge 60 cfs
Valve Horizontal

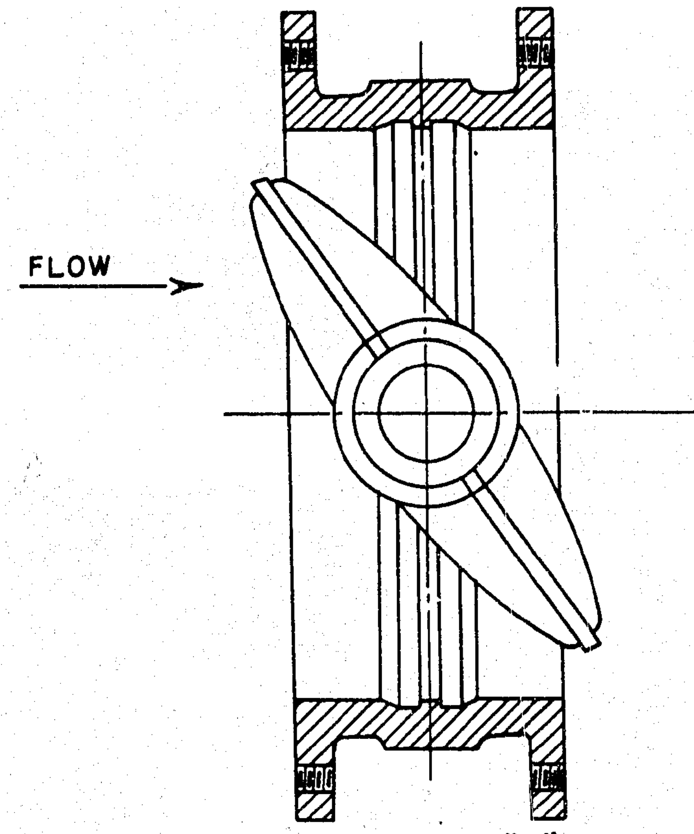
C. Discharge 60 cfs
Valve tilted $2\frac{1}{2}°$

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Preliminary Basin

Figure 5



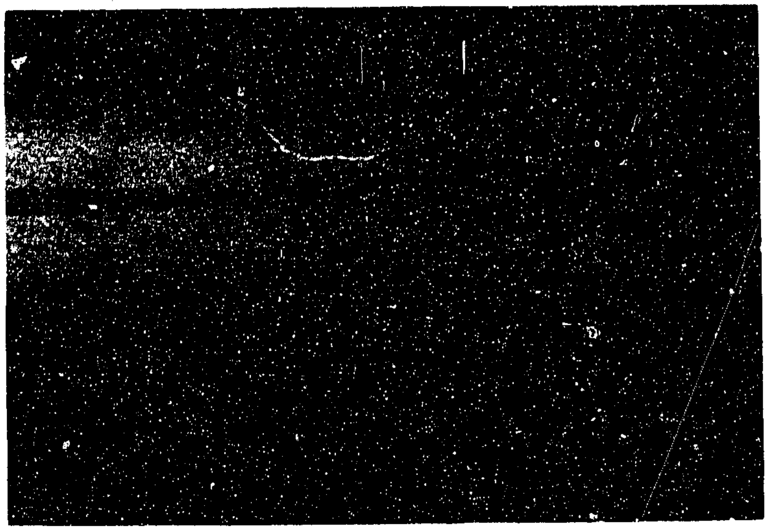
POSITION "A"
LEAF CLOSES IN A
COUNTERCLOCKWISE DIRECTION



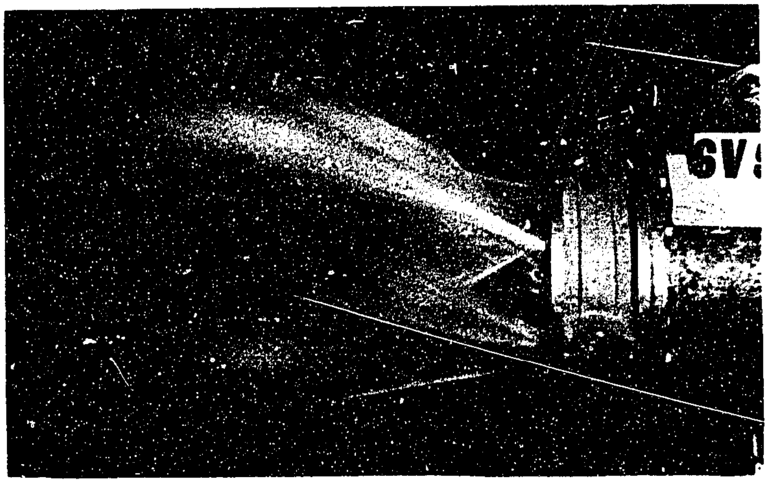
POSITION "B"
LEAF CLOSES IN A
CLOCKWISE DIRECTION

SOLDIER CANYON DAM
OUTLET WORKS
14" BUTTERFLY VALVE

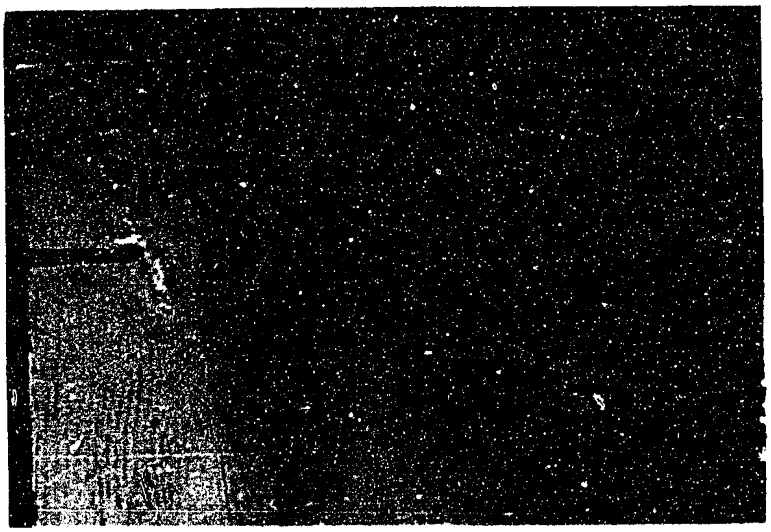
246
R. 2-14-50



A. HOLLOW-JET VALVE
Operating at a small opening and large head, note symmetry of the jet.

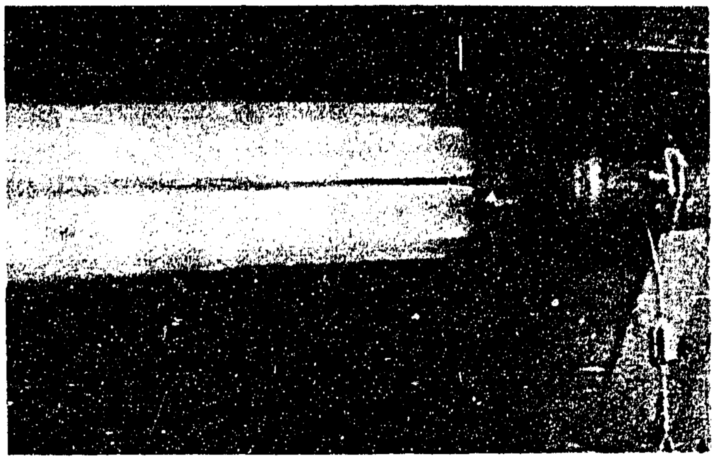


B. BUTTERFLY VALVE
Operating at a small opening and large head, note the large fin on the top of the jet, also the extreme divergence.

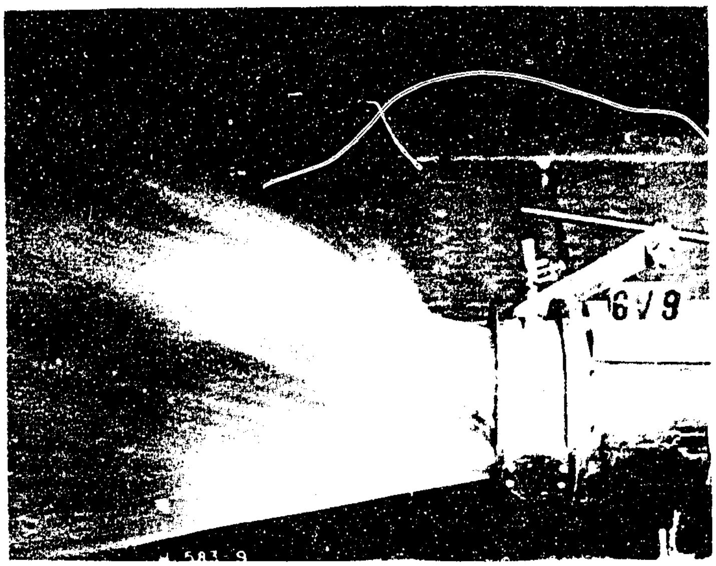


C. COMMERCIAL PIVOT VALVE
Operating at a small opening and large head, note the divergence of the jet.

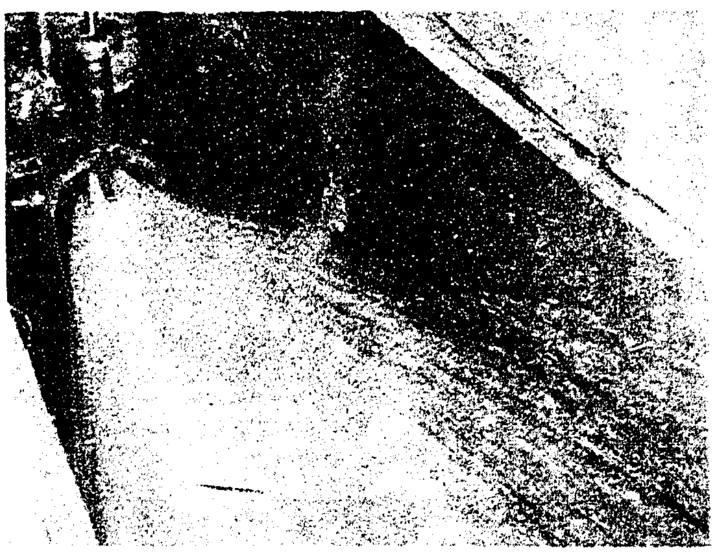
SOLDIER CANYON DAM
Outlet Works
Model Studies
Flow patterns for three types of control valves.



A. HOLLOW-JET VALVE
Operating at a small opening and large head, note symmetry of the jet.



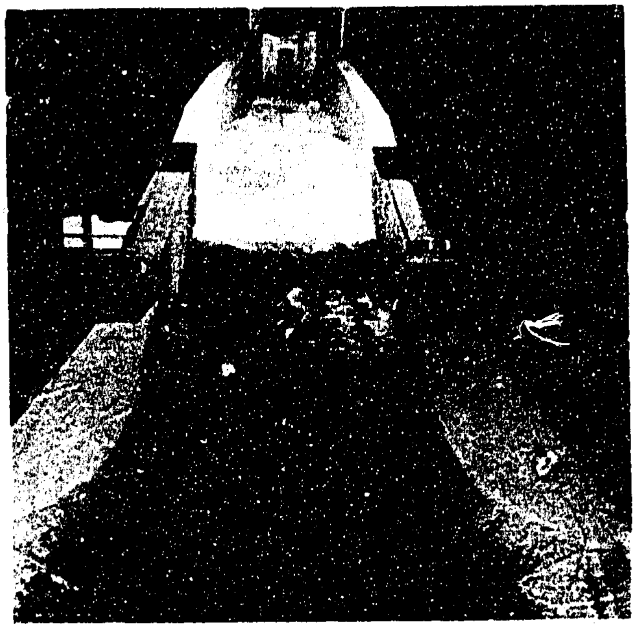
B. BUTTERFLY VALVE
Operating at a small opening and large head, note the large fin on the top of the jet, also the extreme divergence.



C. COMMERCIAL PIVOT VALVE
Operating at a small opening and large head, note the divergence of the jet.

SOLDIER CANYON DAM
Outlet Works
Model Studies
Flow patterns for three types of control valves.

Figure 12



Without side rails

With side rails

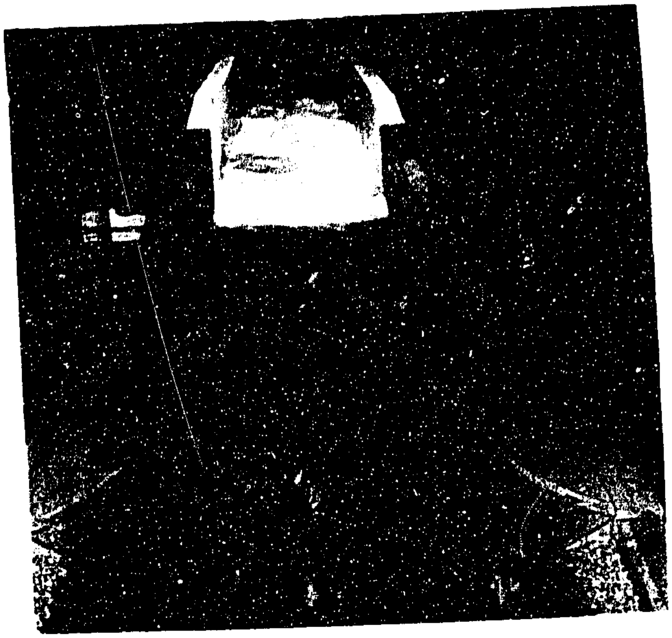
Discharge 45 cfs
Reservoir elevation 5430

Without side rails

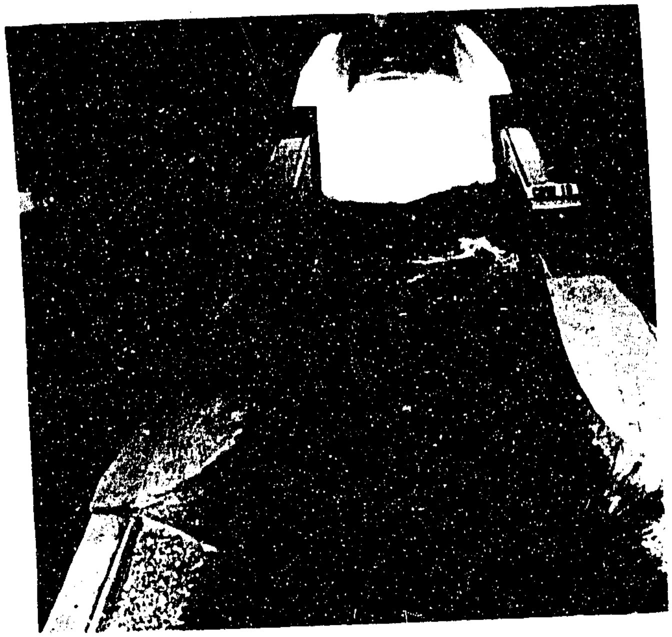
With side rails

Discharge 60 cfs
Reservoir elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Basin with and without side rails

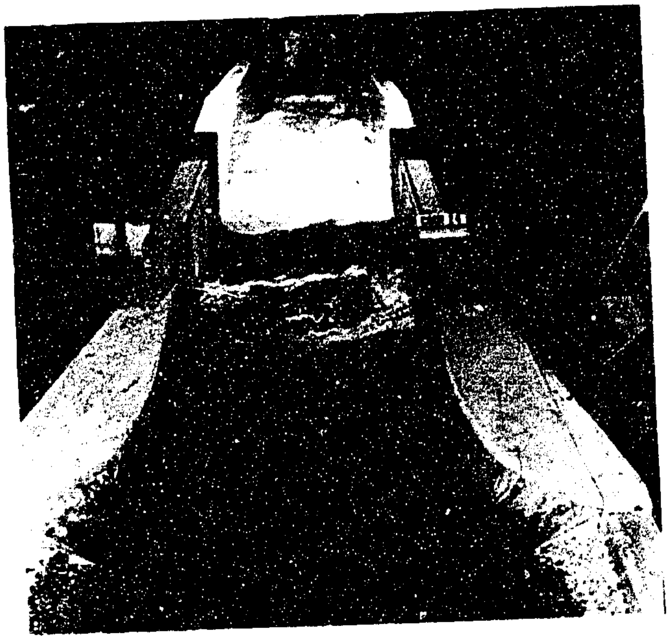


Without side rails

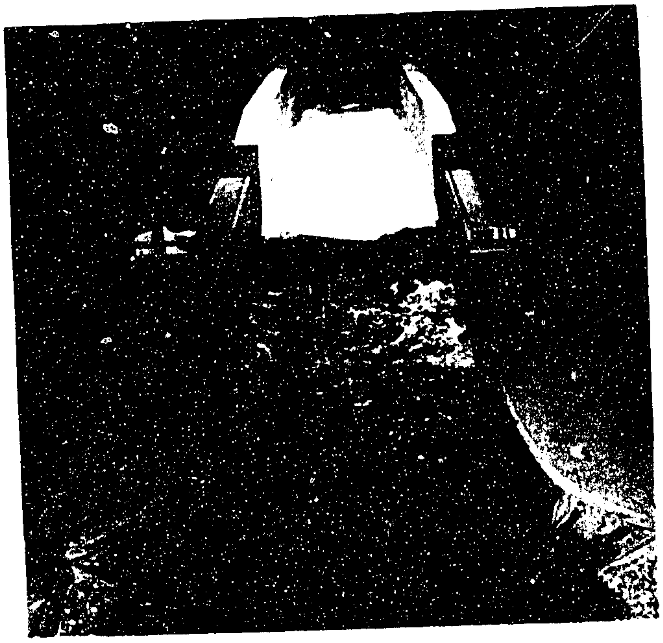


With side rails

Discharge 45 cfs
Reservoir elevation 5430



Without side rails

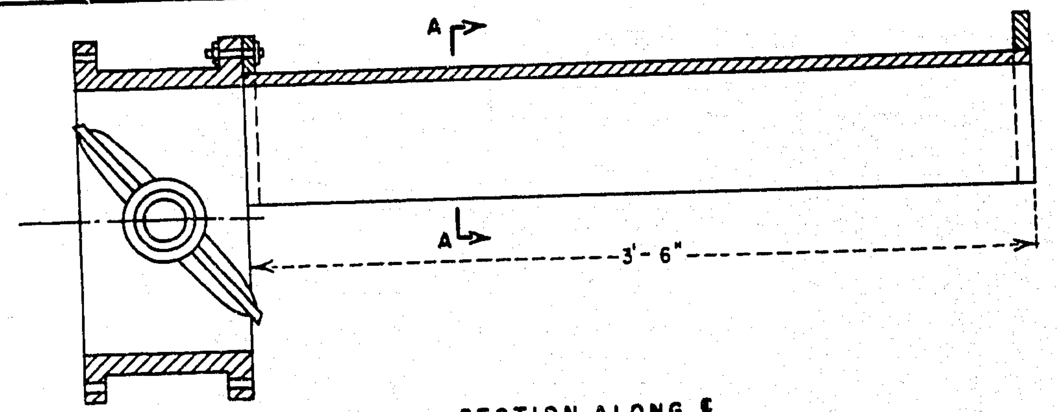


With side rails

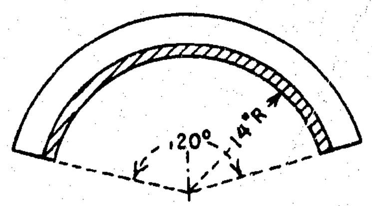
Discharge 60 cfs
Reservoir elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:4.67 scale model
Stilling Basin Studies
Basin with and without side rails

FIGURE 13

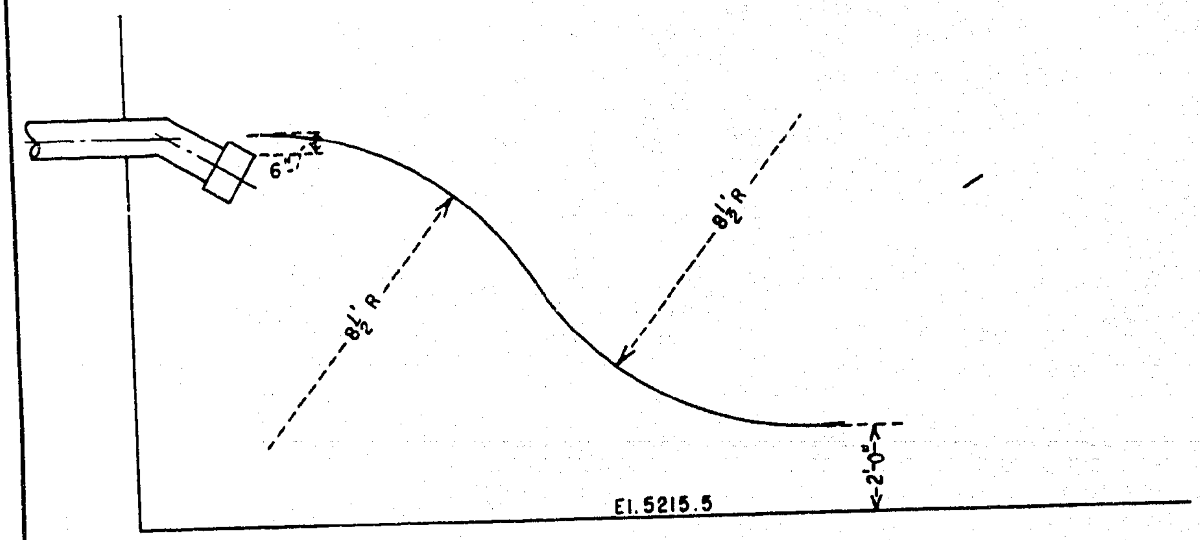


SECTION ALONG ℄



SECTION A-A

DEFLECTOR NO. 1

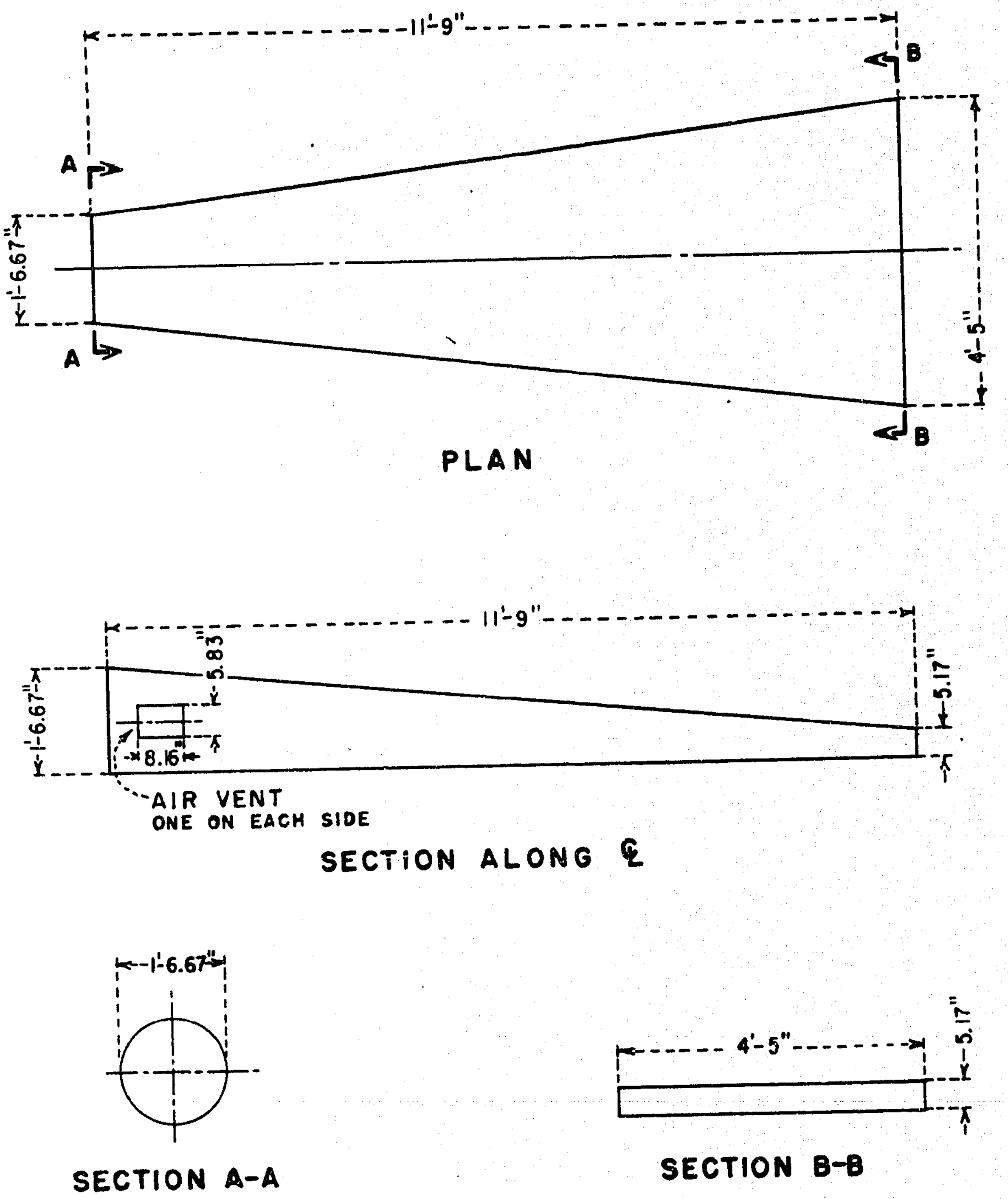


DEFLECTOR NO. 2

SOLDIER CANYON DAM
OUTLET WORKS
14" BUTTERFLY VALVE
DEFLECTORS

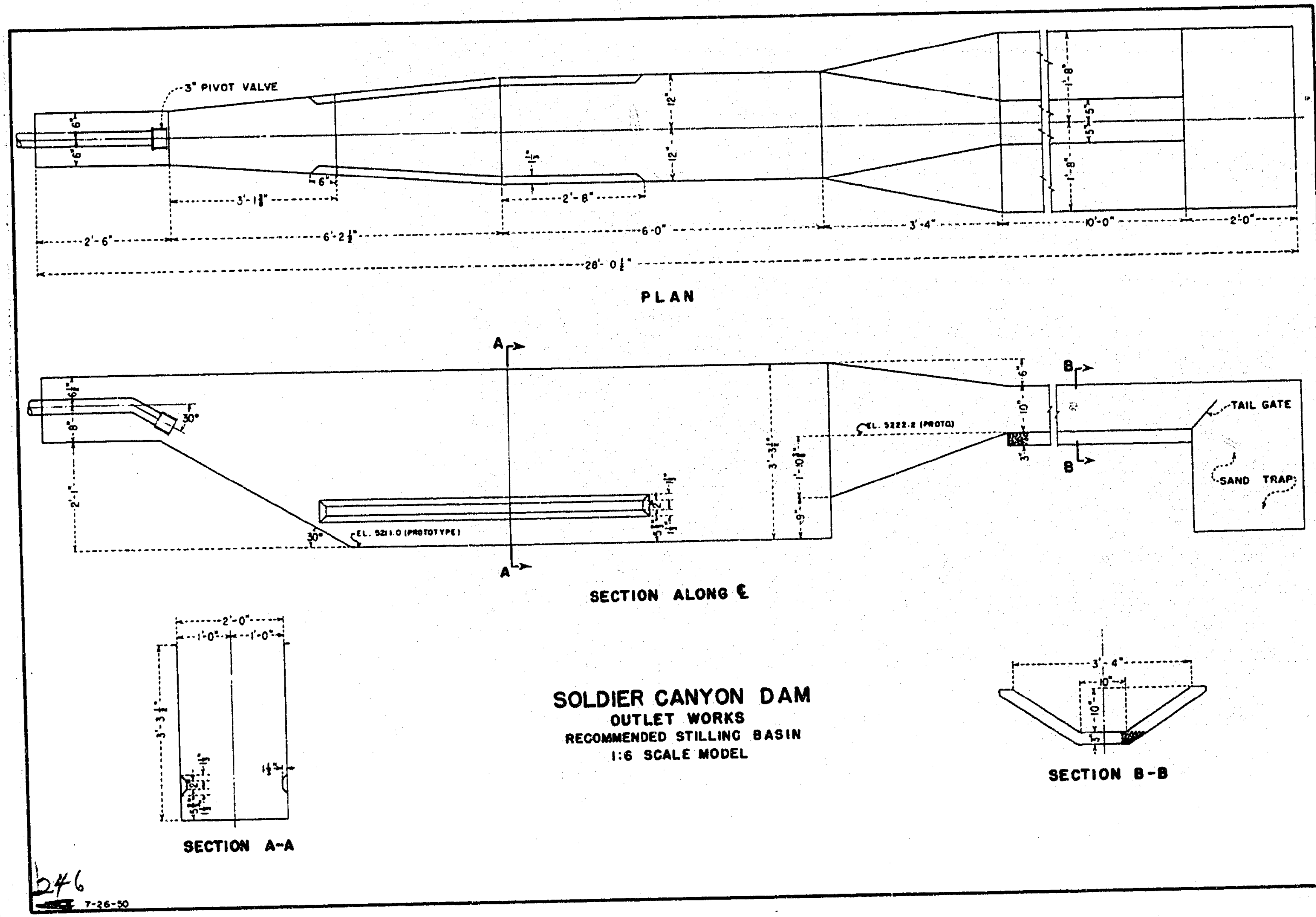
24b
7-27-50

FIGURE 14



SOLDIER CANYON DAM
OUTLET WORKS
HOOD FOR BUTTERFLY VALVE
1: 4.67 SCALE MODEL

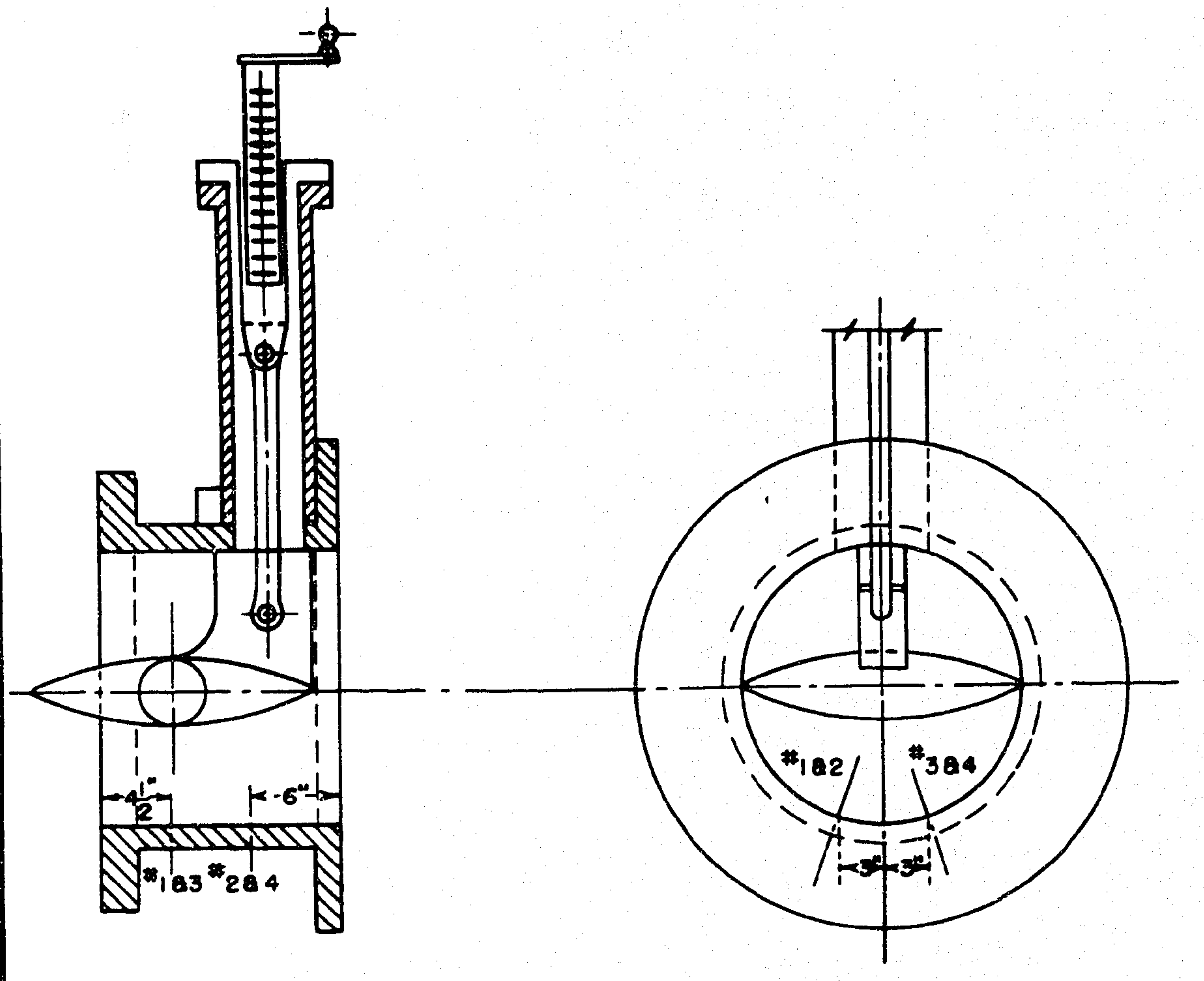
246
~~T.J.R.~~ - 2-23-51



3" PIVOT VALVE
PLAN
SECTION ALONG ℄
EL. 5222.2 (PROTO)
EL. 5211.0 (PROTOTYPE)
TAIL GATE
SAND TRAP
SECTION A-A
SECTION B-B
SOLDIER CANYON DAM
OUTLET WORKS
RECOMMENDED STILLING BASIN
1:6 SCALE MODEL
7-26-50

FIGURE 15

FIGURE 16

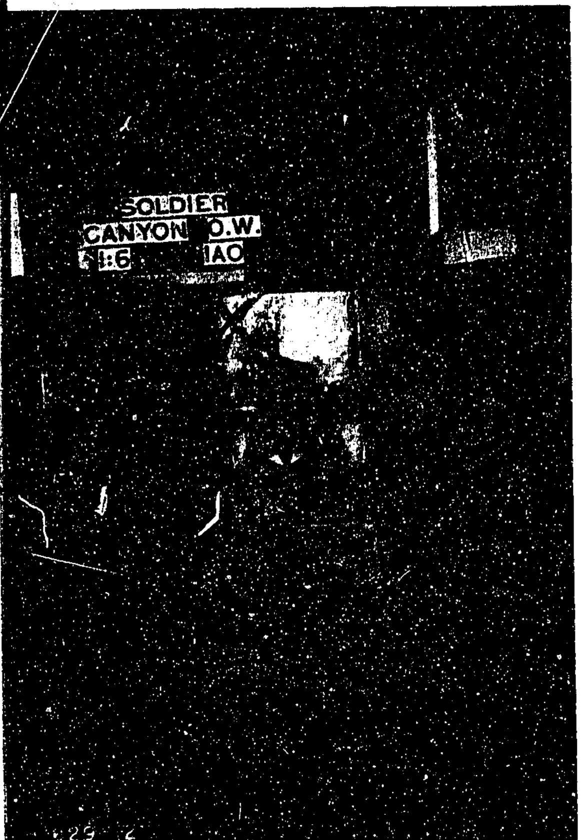


PRESSURES
FEET OF WATER

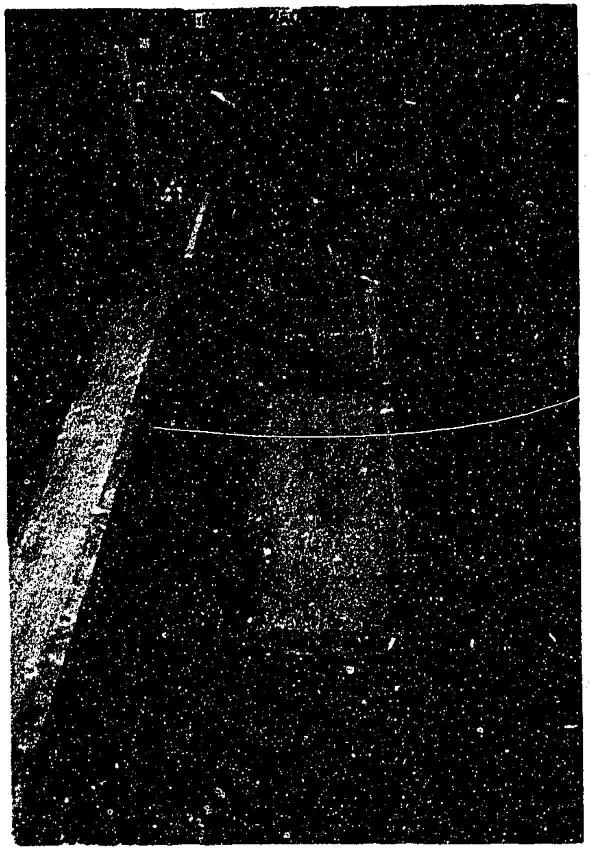
	RESERVOIR ELEVATION 5340		5430	
DISCHARGE	30 C.F.S.	60 C.F.S.	30 C.F.S.	60 C.F.S.
PIEZ #1	86 FT.	24 FT.	176 FT.	112 FT.
PIEZ 2	43 FT	8.7 FT.	70 FT.	59 FT.
PIEZ 3	84 FT.	21 FT.	173 FT.	108 FT.
PIEZ 4	45 FT.	9.4 FT.	77 FT.	61 FT.

SOLDIER CANYON DAM
OUTLET WORKS
18-INCH COMMERCIAL PIVOT VALVE
PIEZOMETER LOCATIONS AND PRESSURES
1:6 SCALE MODEL

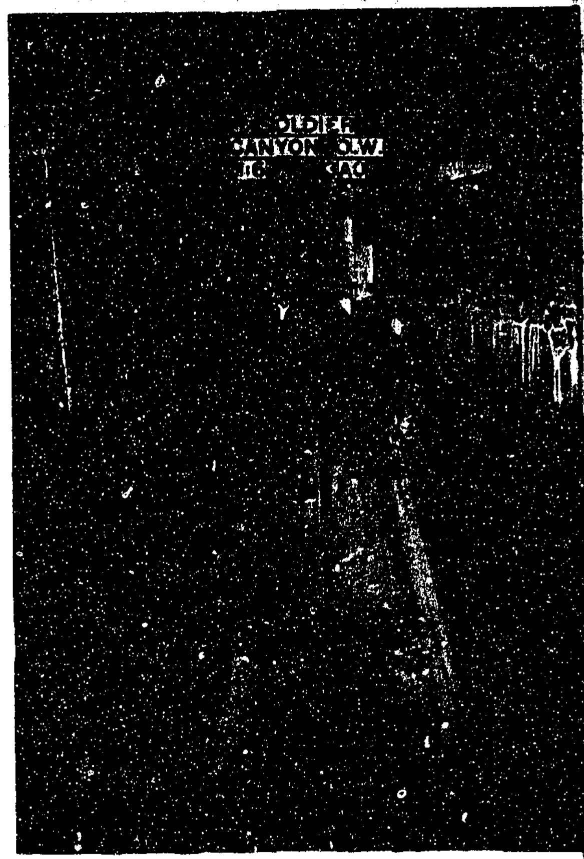
246
2-27-51



A. Model of commercial pivot valve installed in model.



B. Hood designed for Butterfly valve fastened directly to pivot valve. Note piezometers in hood, and side rails in basin.

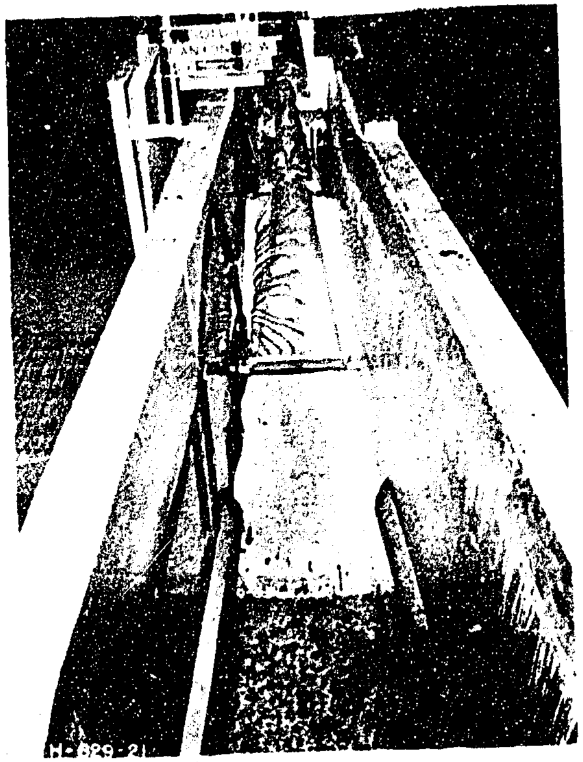


C. Recommended hood installed 4-1/2-inches in front of valve

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Pivot valve and Hoods

Figure 17

A. Model of commercial pivot valve installed in model.



B. Hood designed for Butterfly valve fastened directly to pivot valve. Note piezometers in hood, and side rails in basin.

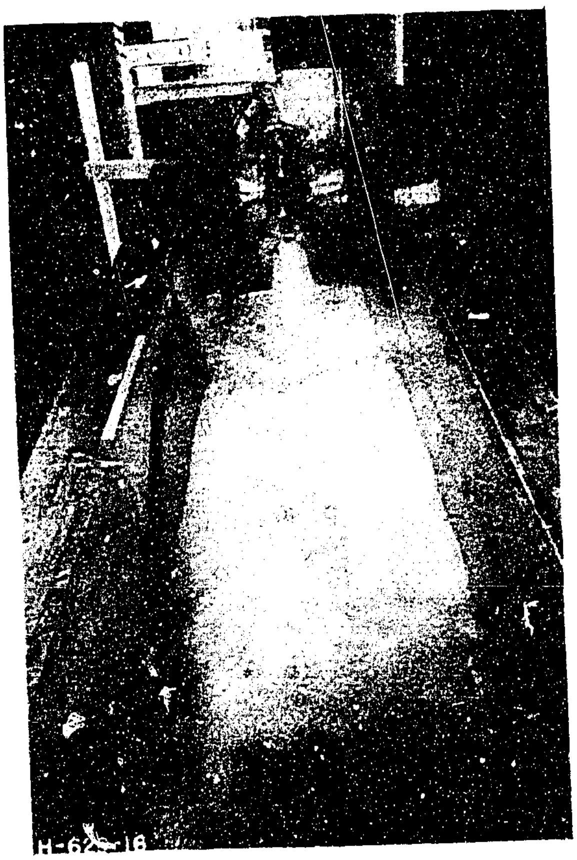
C. Recommended hood installed 4-1/4-inches in front of valve.

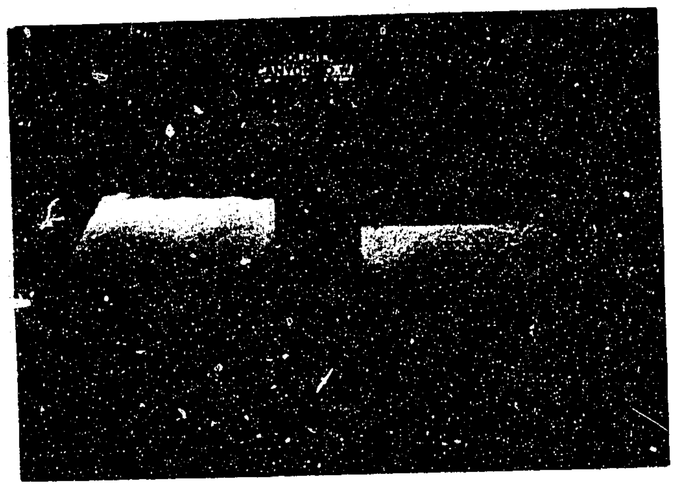
SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Pivot valve and Hoods

Figure 17

Figure 18

Reservoir Elevation 5430

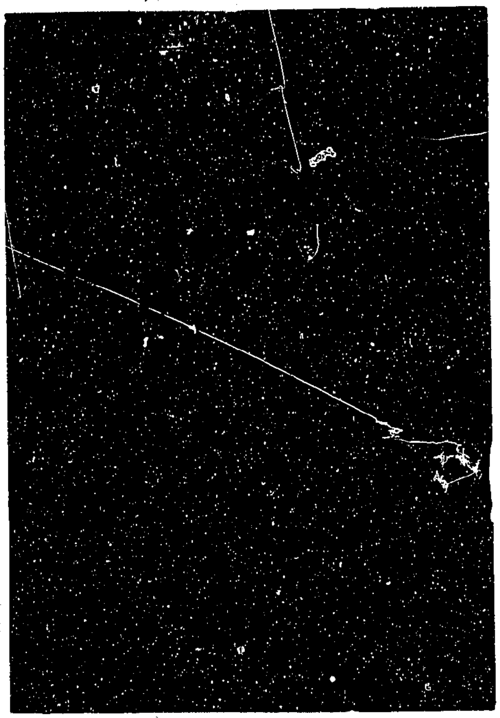


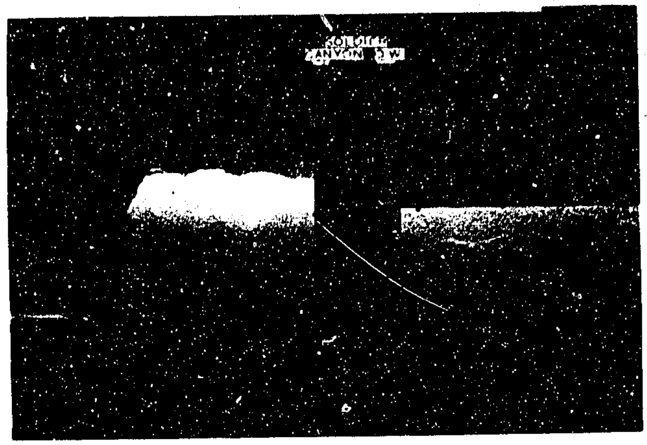


Reservoir Elevation 5340

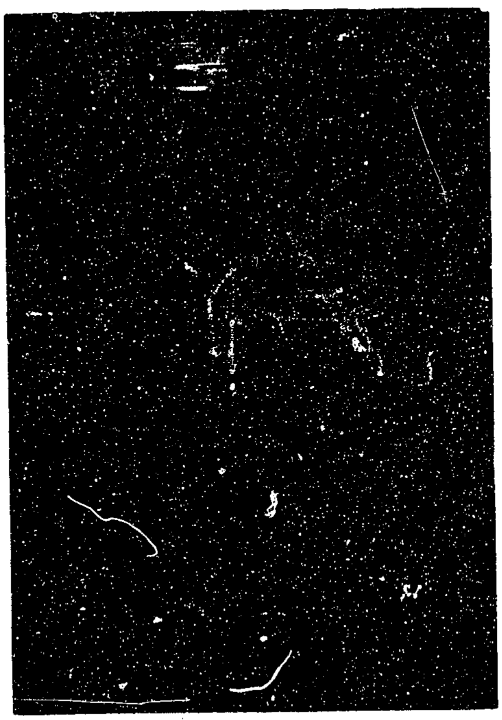
SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Performance of 18-inch
Pivot valve without hood
Discharge 30 cfs

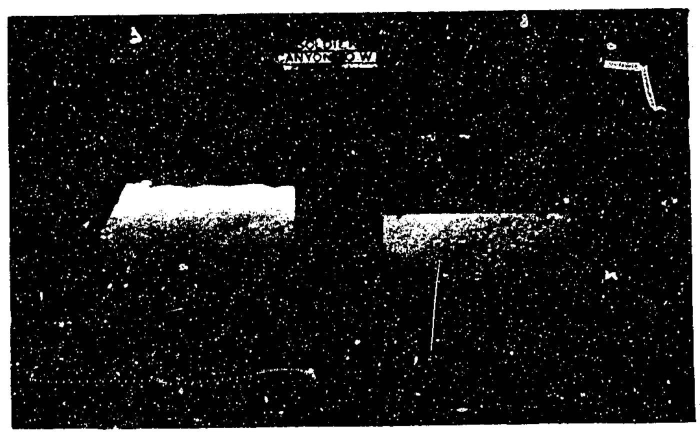
Figure 18





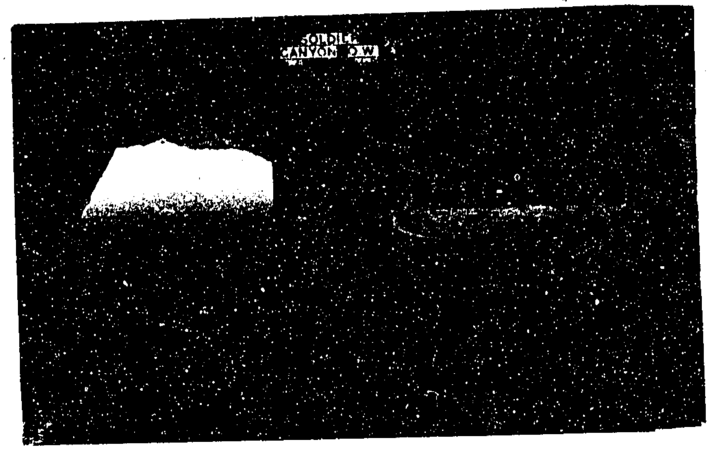
Reservoir elevation 5430



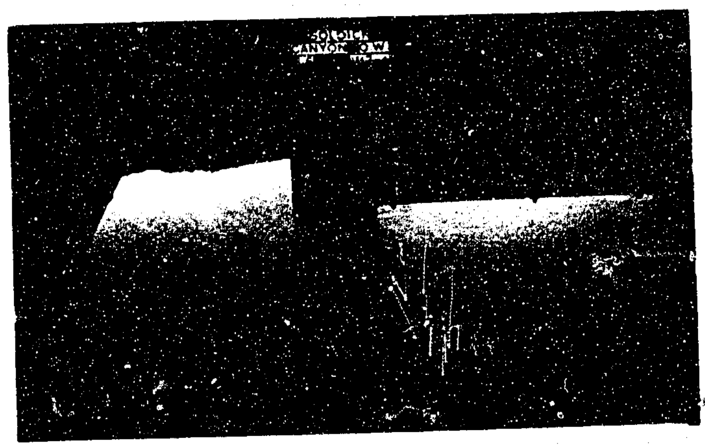


Reservoir elevation 5340

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Performance of 18-inch
Pivot valve without hood
Discharge 30 cfs



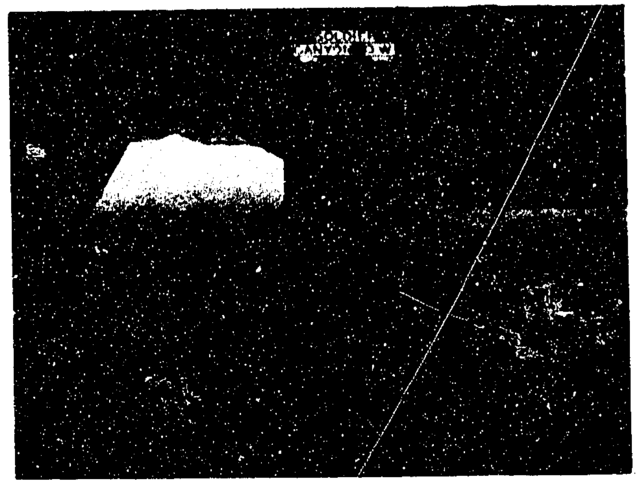
Reservoir elevation 5430



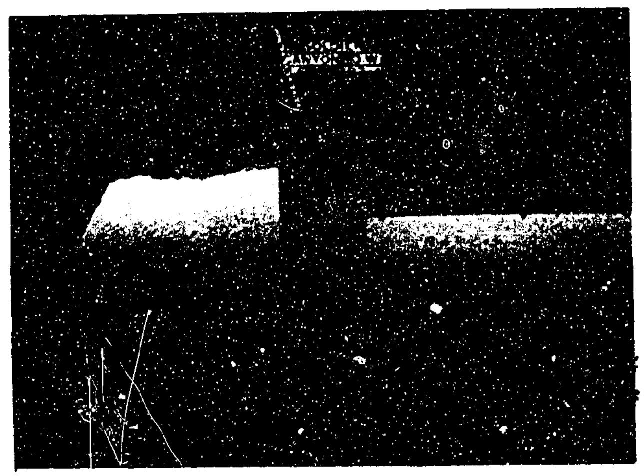
Reservoir elevation 5340

SOLDIER ÇANYON DAM
Outlet Works
1:6 scale model
Hood studies
Performance of 18-inch
Pivot valve without hood.
Discharge 60 cfs.

Figure 19



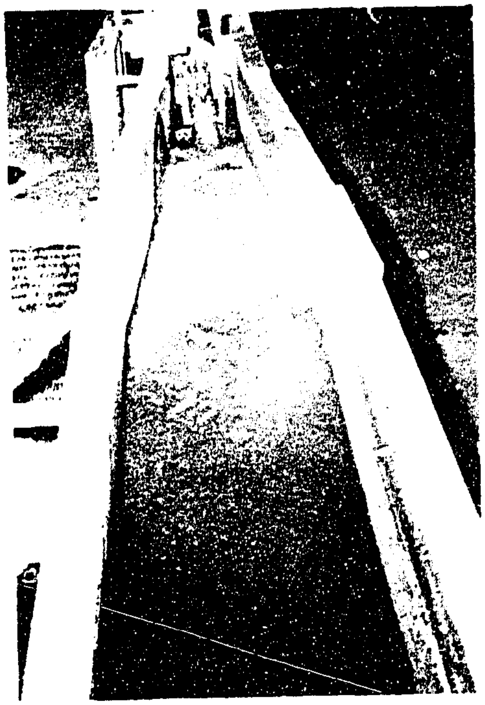
Reservoir elevation 5430



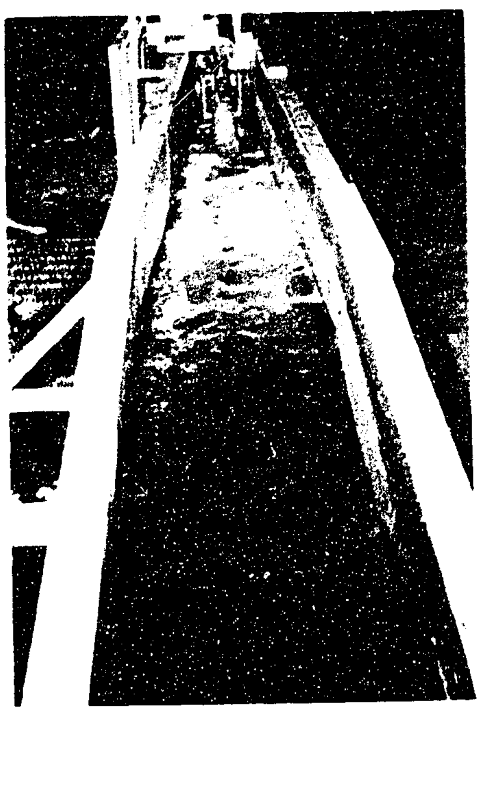
Reservoir elevation 5340

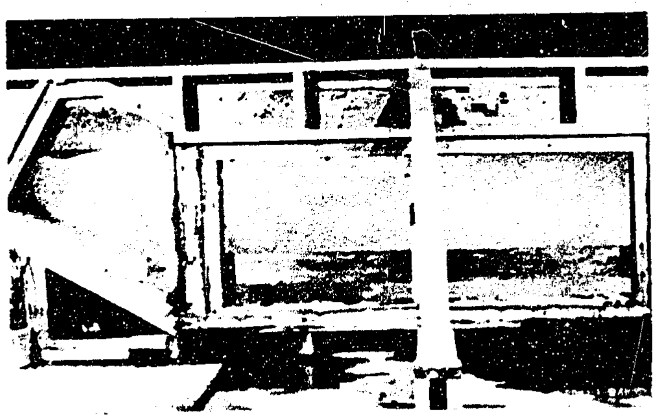
SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood studies
Performance of 18-inch
Pivot valve without hood.
Discharge 60 cfs.

Figure 20



Reservoir elevation 5430

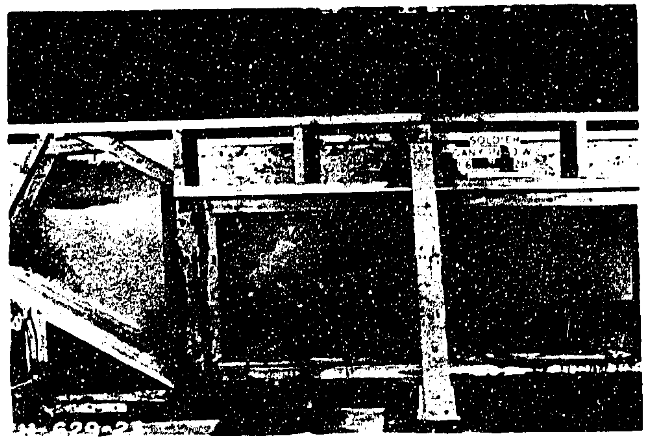




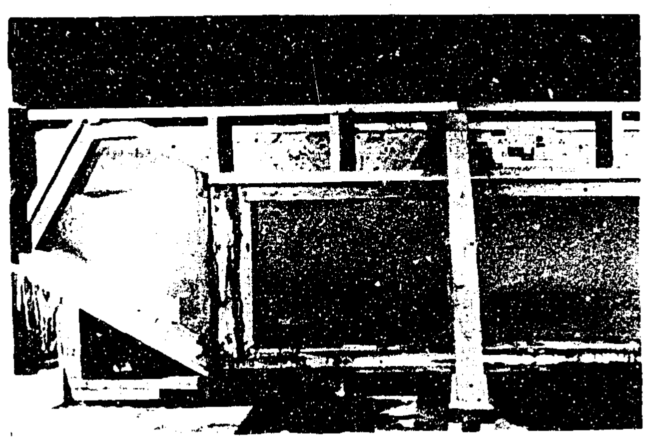
Reservoir elevation 5340

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Performance of 18-inch
Pivot valve with preliminary hood.
Discharge 60 cfs

Figure 20

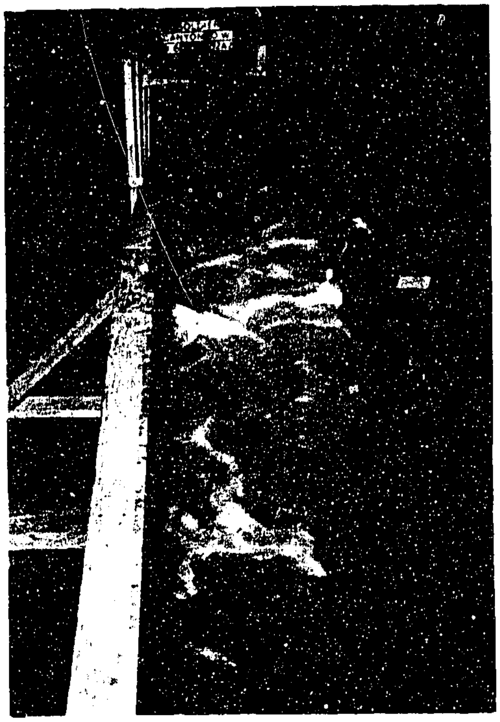


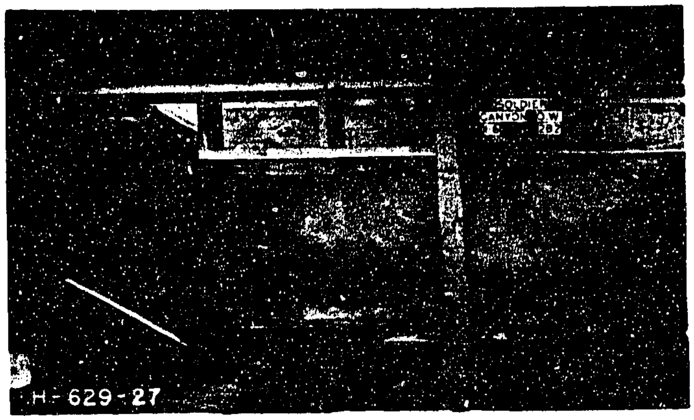
Reservoir elevation 5430



Reservoir elevation 5340

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Performance of 18-inch
Pivot valve with preliminary hood.
Discharge 60 cfs



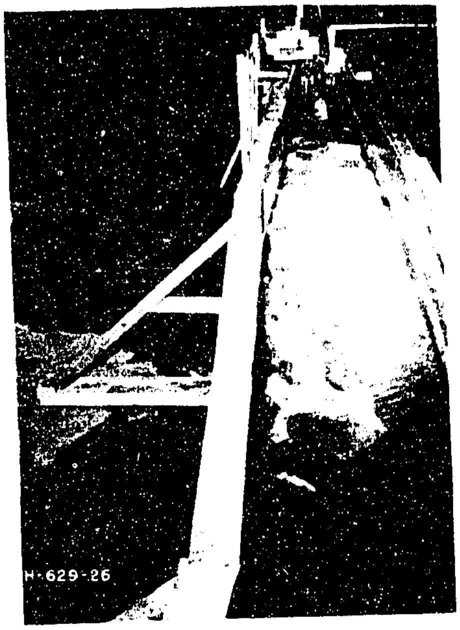


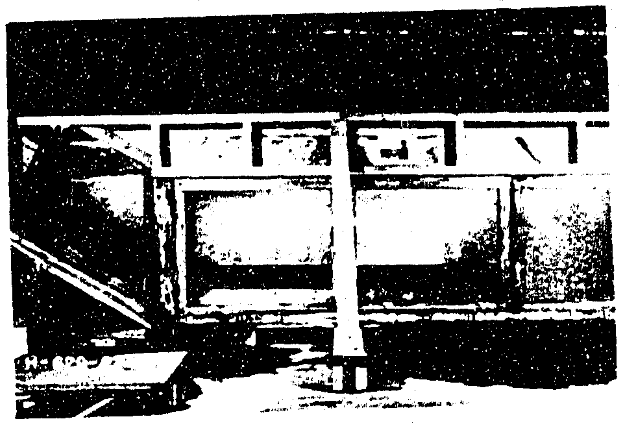
Reservoir elevation 5430

Reservoir Elevation 5340

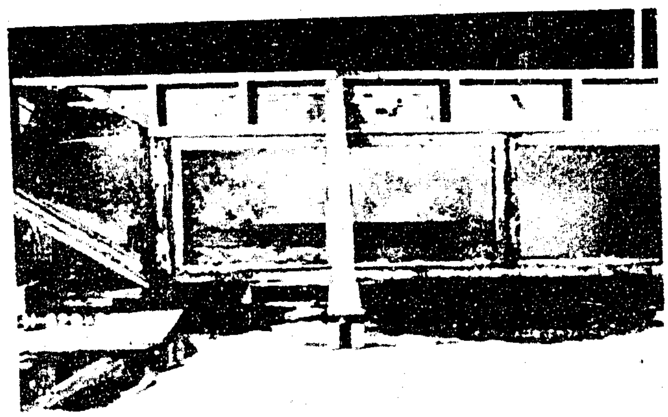
SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Hood as designed for Butterfly
valve fastened to 18-inch Pivot
Valve. Discharge 60 cfs.

Figure 21





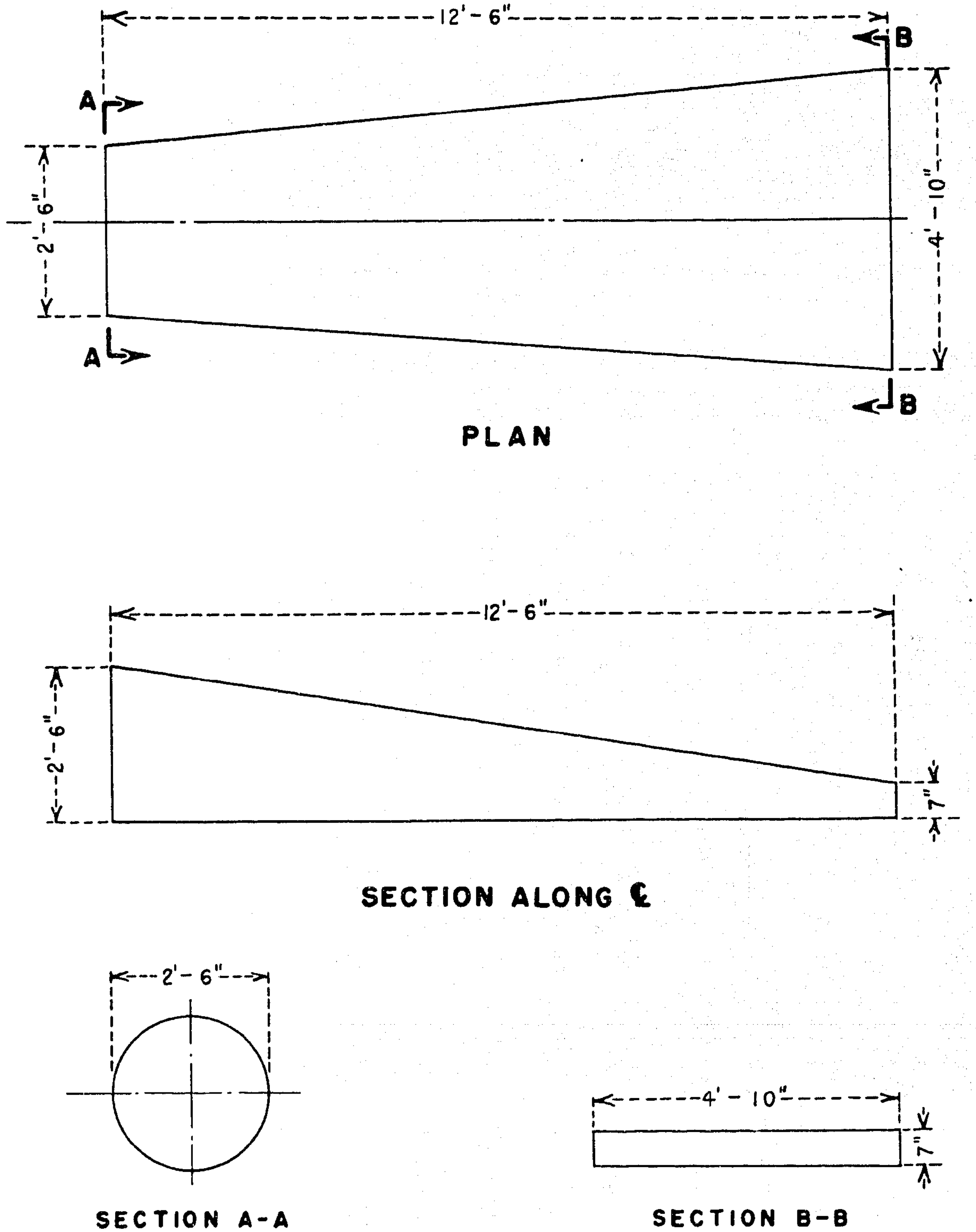
Reservoir elevation 5430



Reservoir elevation 5340

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Hood as designed for Butterfly
valve fastened to 18-inch Pivot
Valve. Discharge 30 cfs.

FIGURE 22

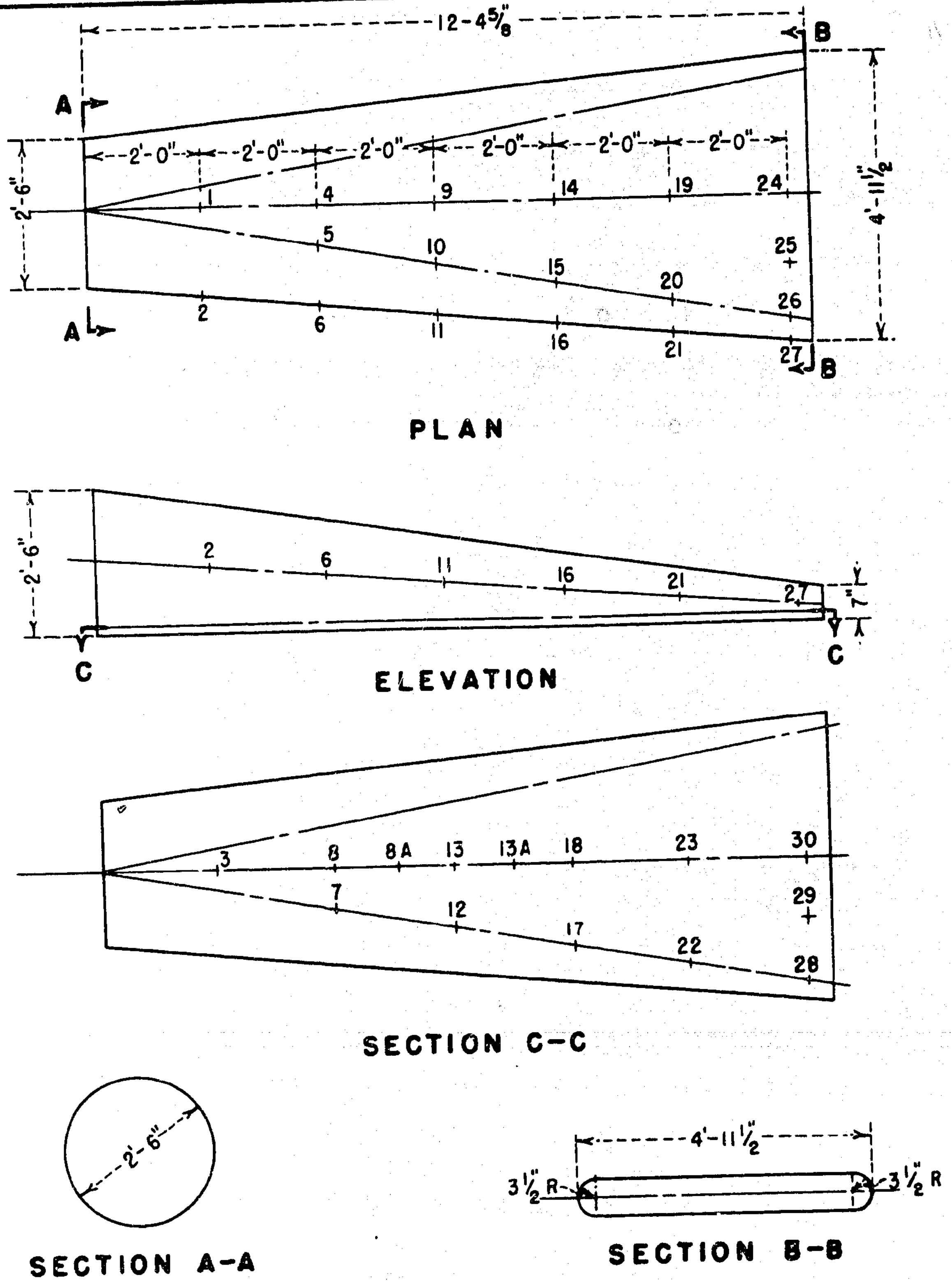


SOLDIER CANYON DAM
OUTLET WORKS
PRELIMINARY HOOD FOR PIVOT VALVE
1:6 SCALE MODEL

246

2 - 26 - 51

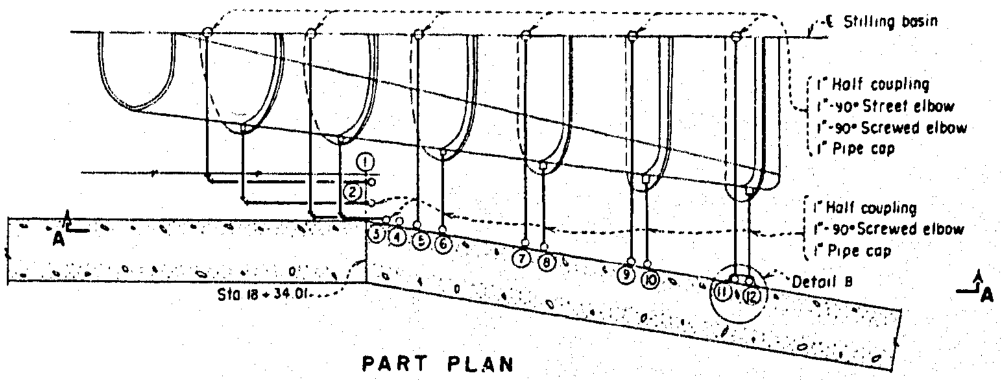
FIGURE 23



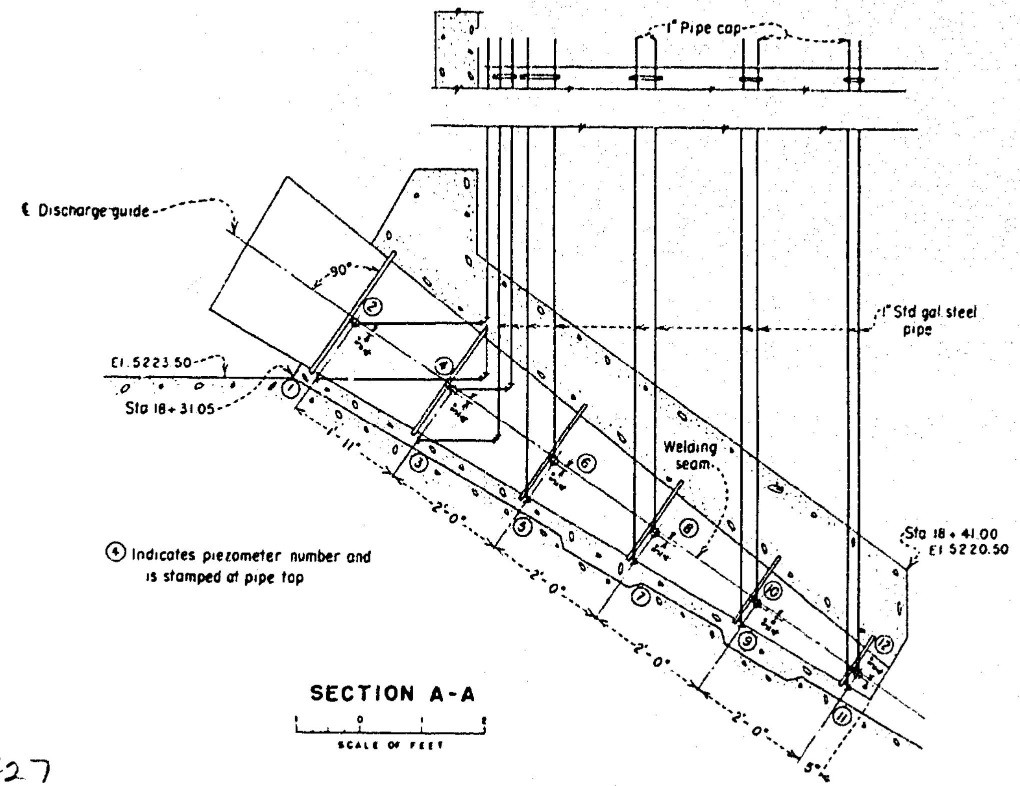
SOLDIER CANYON DAM
OUTLET WORKS
RECOMMENDED HOOD FOR PIVOT VALVE
SHOWING PIEZOMETER LOCATIONS
1:6 SCALE MODEL

246
R.-2-27-51

FIGURE 24



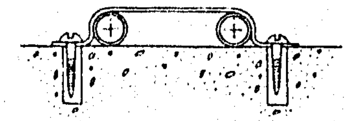
PART PLAN



④ Indicates piezometer number and is stamped at pipe top

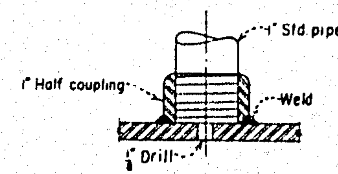
SECTION A-A

SCALE OF FEET

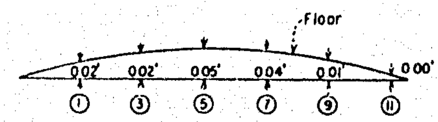


DETAIL B

TYPICAL PIPE SUPPORT



TYPICAL PIEZOMETER CONNECTION



BEND IN FLOOR OF DISCHARGE GUIDE

(REFER TO SECTION A-A)

REFERENCE DRAWINGS

VALVE HOUSE - CONCRETE OUTLINE	245-D-3155
STILLING BASIN - CONCRETE OUTLINE	245-D-3158
VALVE HOUSE - DISCHARGE GUIDE	245-D-4620

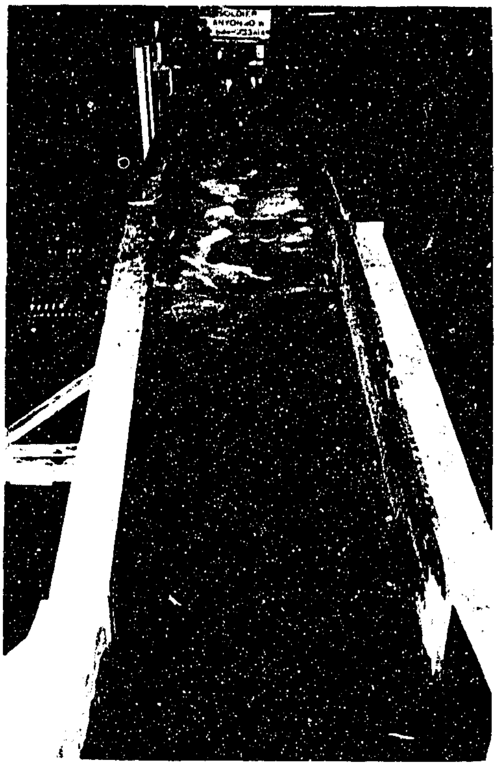
NOTE - All fittings malleable iron

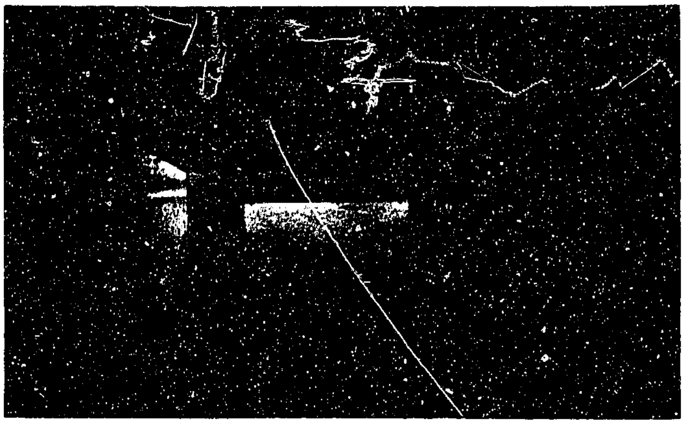
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT - COLO.
HORSETOOTH RESERVOIR

SOLDIER CANYON DAM
OUTLET WORKS
PIEZOMETER TIPS AS INSTALLED

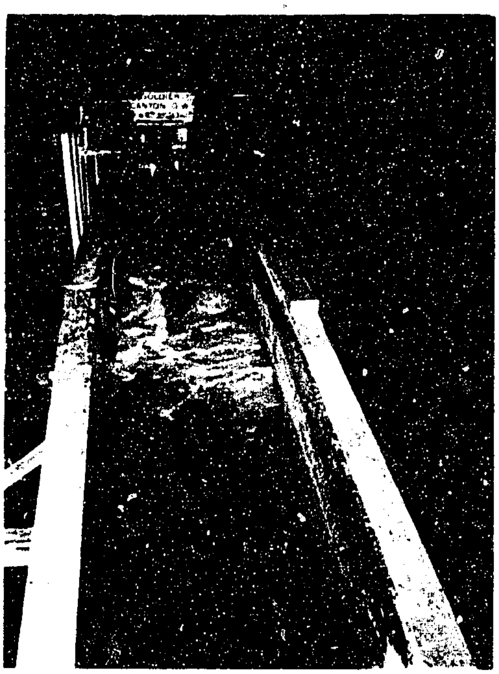
DRAWN .... SUBMITTED ....
TRACED. L.O.B. .... RECOMMENDED ....
CHECKED .... APPROVED ....

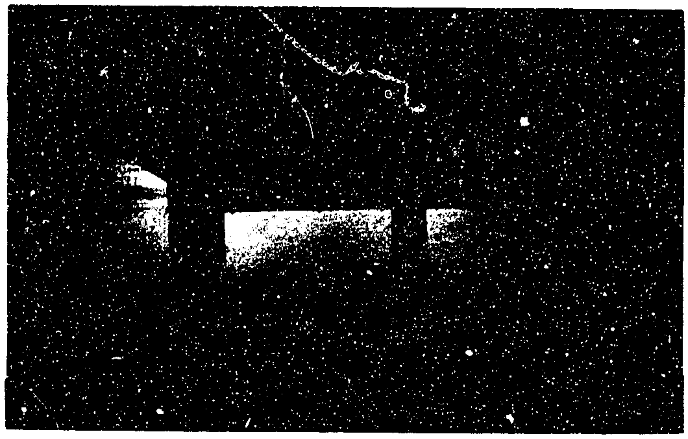
221.2-30 | FORT COLLINS COLO DEC. 2, 1948





Reservoir elevation 5430

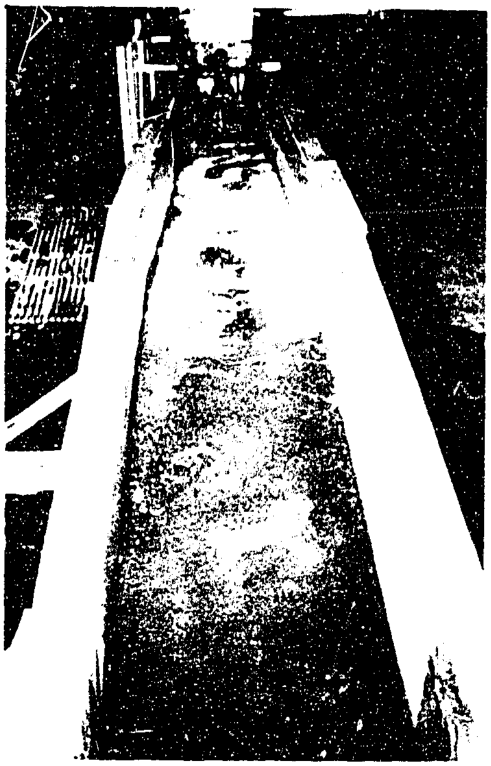


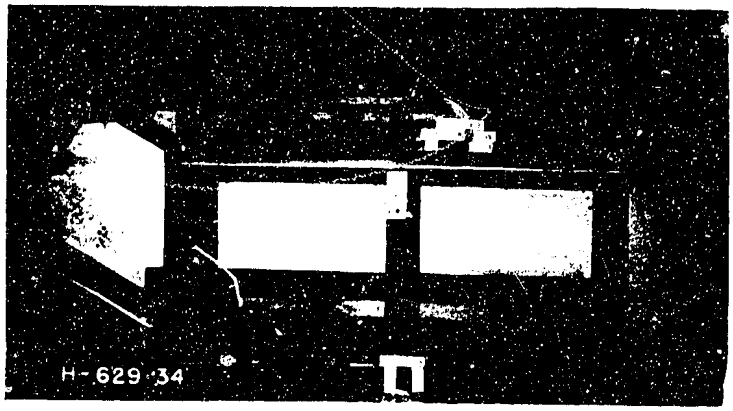


Reservoir elevation 5340

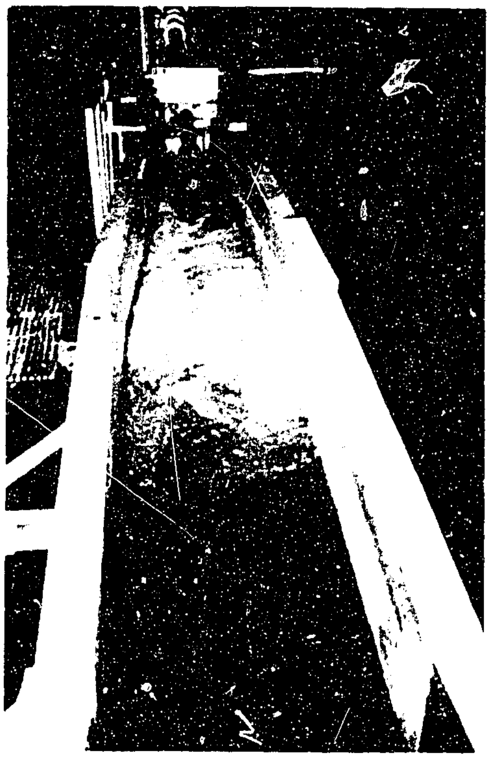
SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Recommended stilling basin and hood.
Discharge 30 cfs

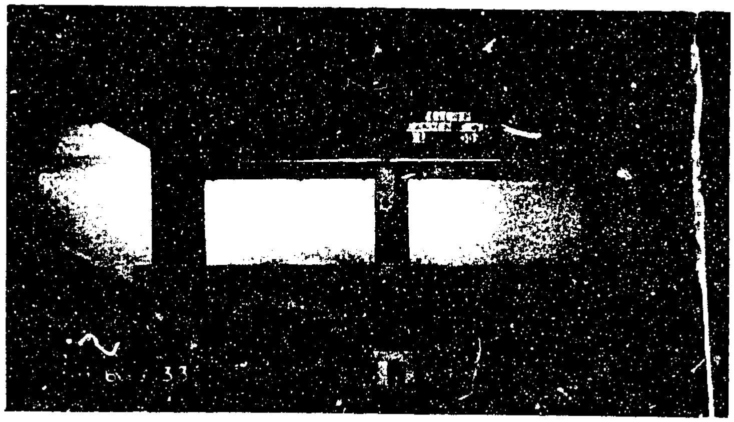
Figure 25





Reservoir elevation 5340

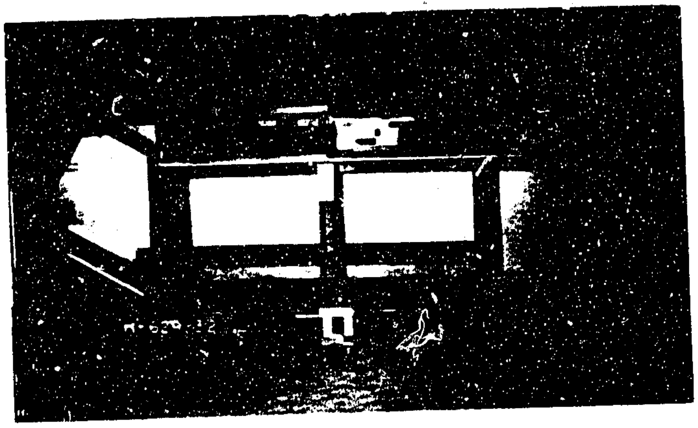




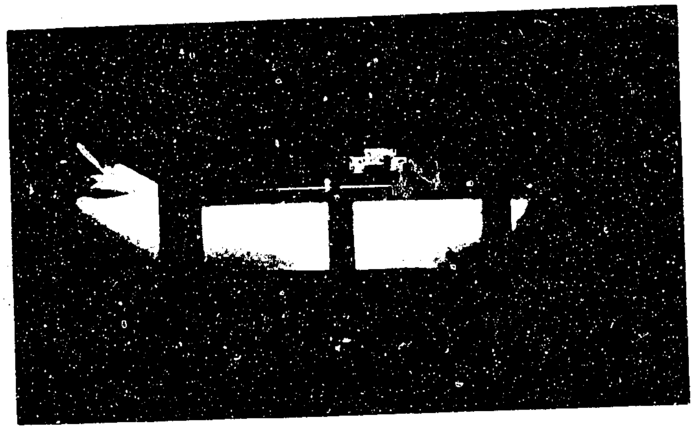
Reservoir elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Recommended stilling basin and hood.
Discharge 30 cfs

Figure 26

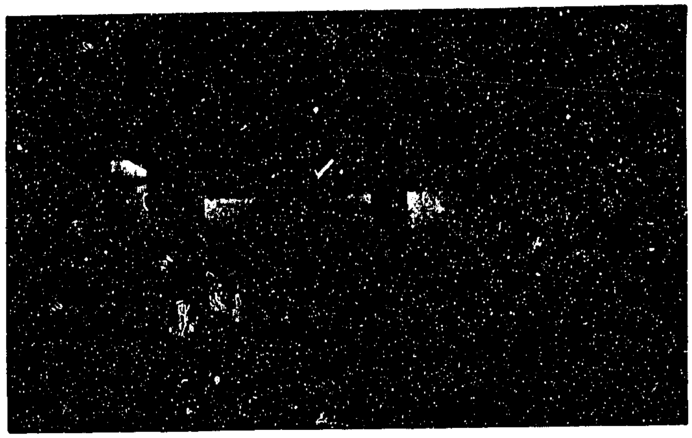


Reservoir elevation 5340

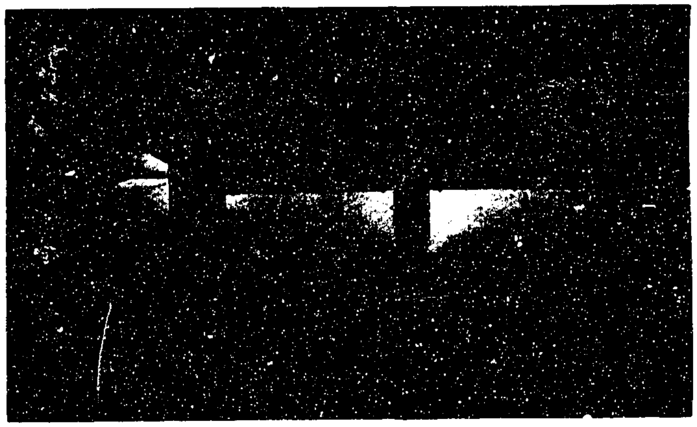


Reservoir elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Recommended stilling basin and hood.
Discharge 60 cfs.



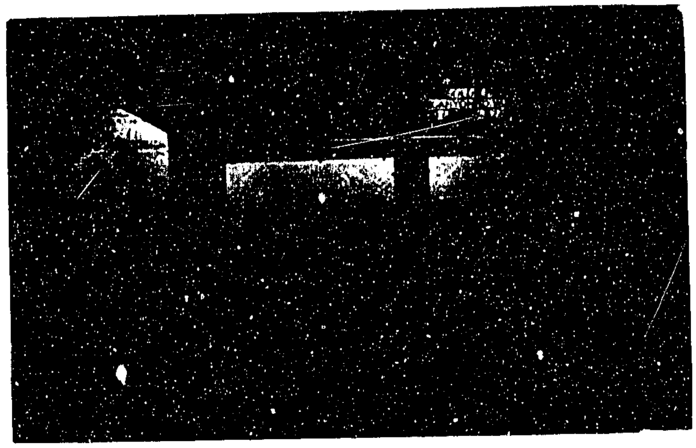
Reservoir elevation 5340



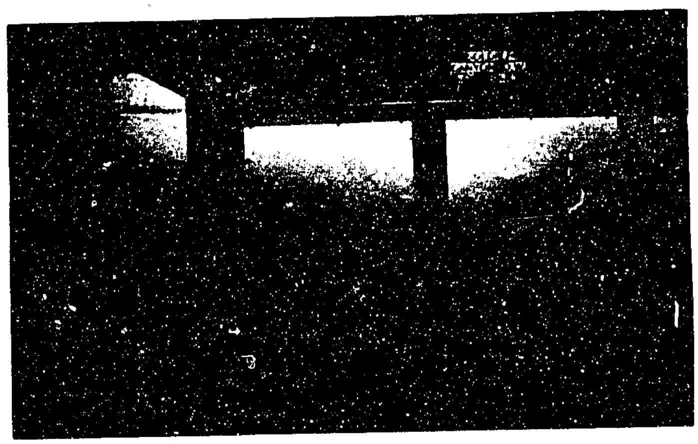
Reservoir Elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Hood Studies
Recommended stilling basin and hood.
Discharge 60 cfs.

Figure 27

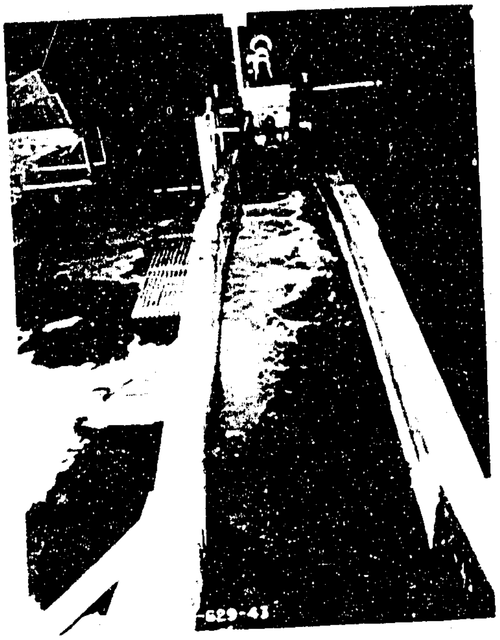


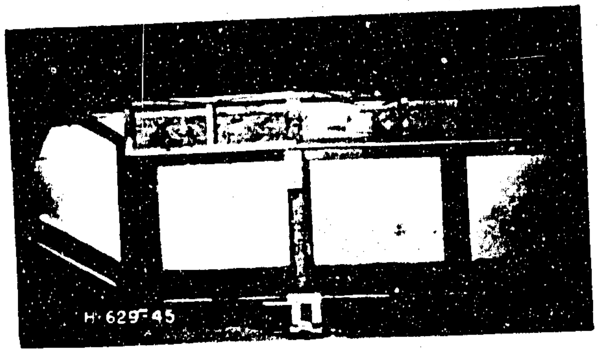
Reservoir elevation 5340



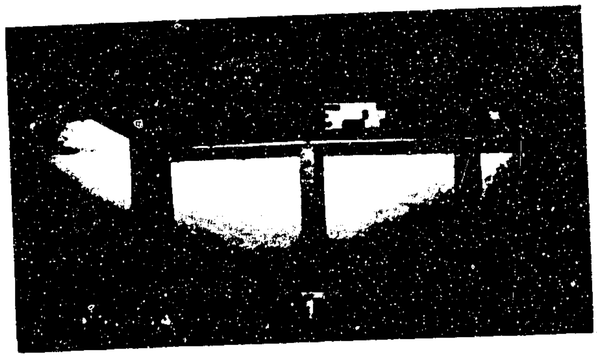
Reservoir elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Stilling Basin Studies
Recommended Basin with
side rails removed.
Discharge 60 cfs.





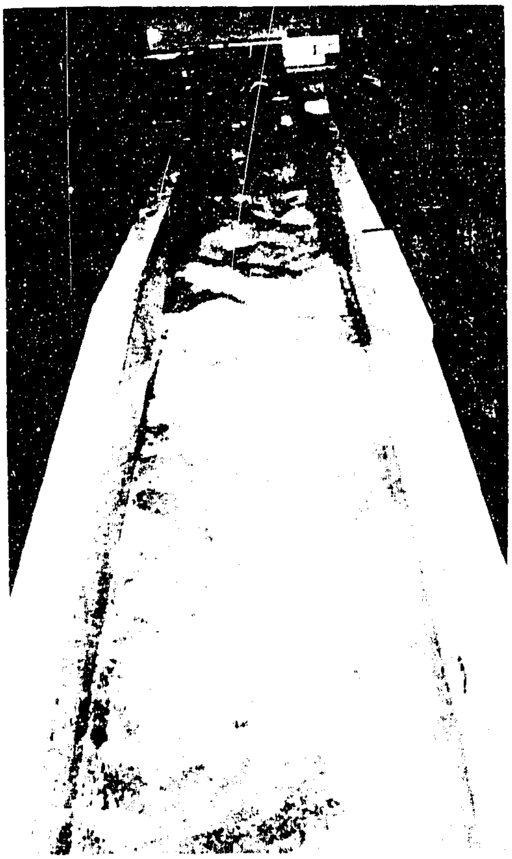
Reservoir elevation 5340

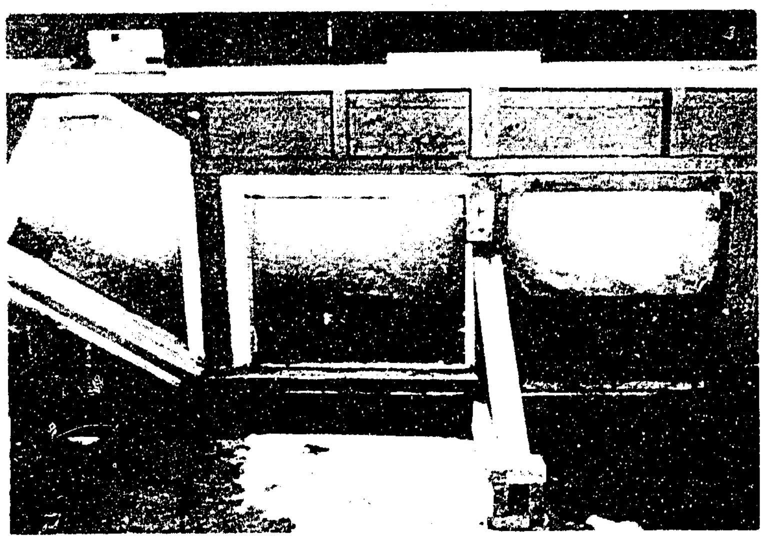


Reservoir elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Stilling Basin Studies
Recommended Basin with
side rails removed.
Discharge 60 cfs.

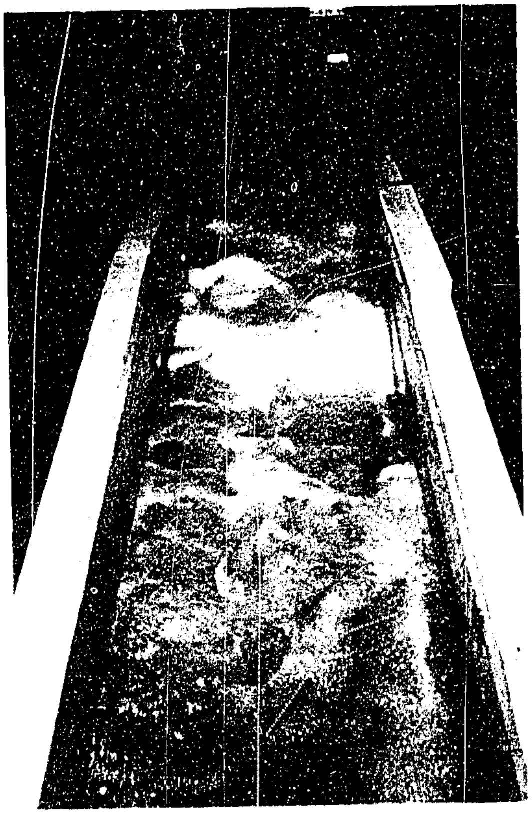
Figure 28

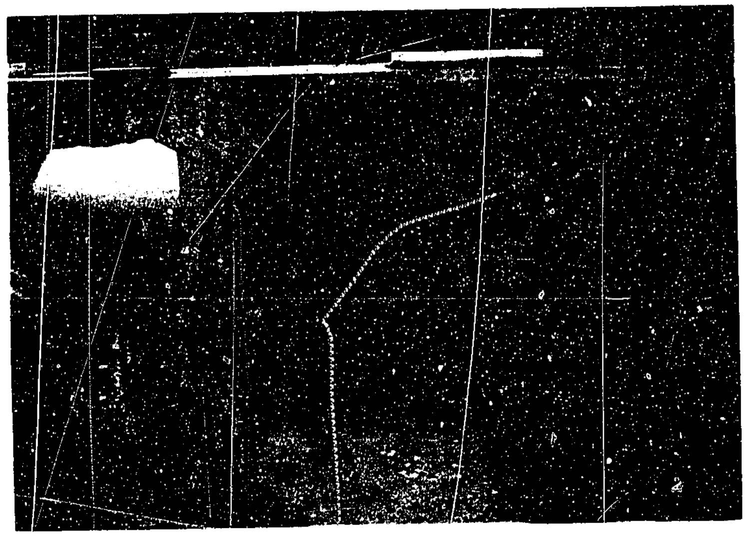




Reservoir elevation 5430

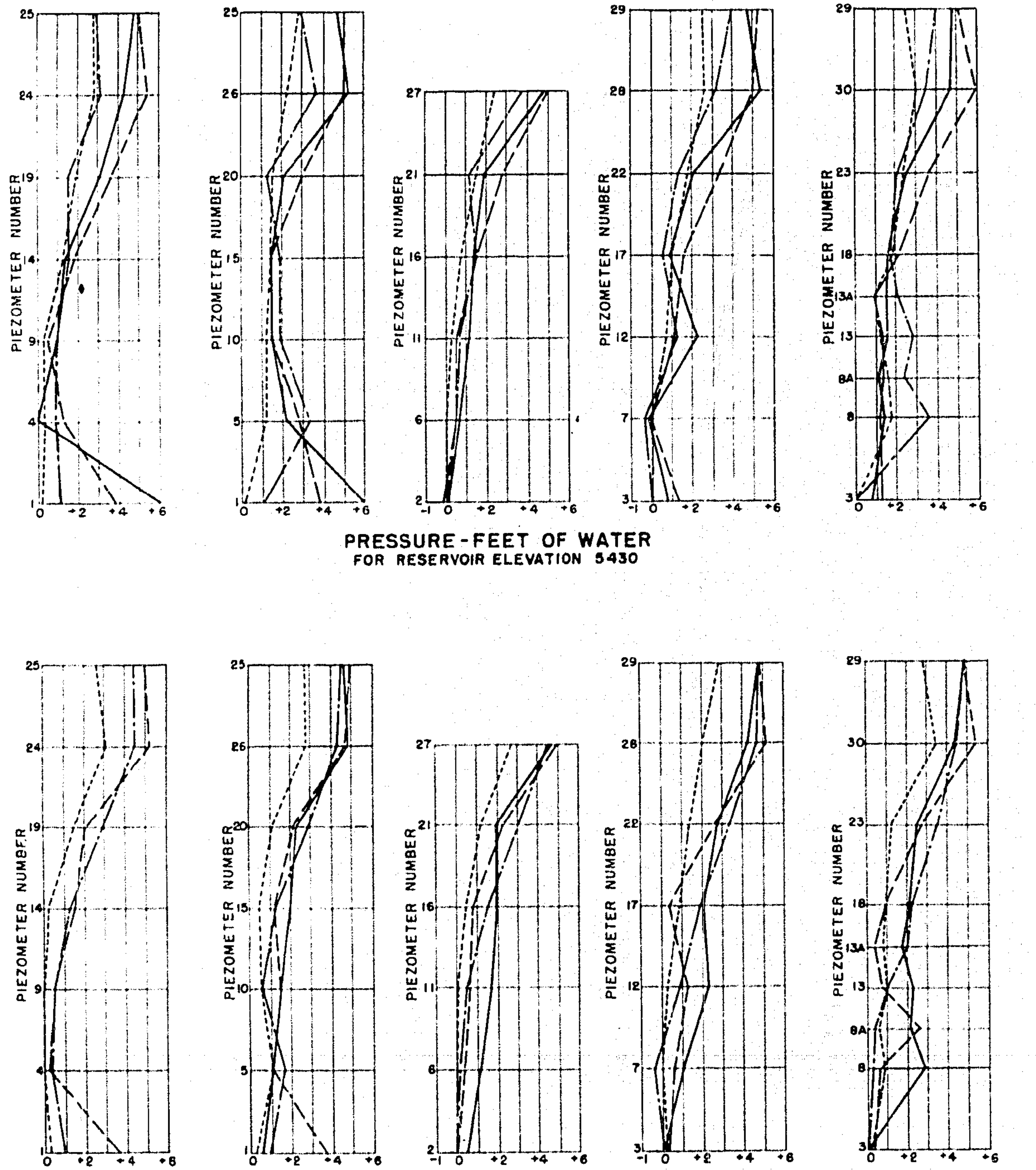
SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Stilling Basin Studies
Recommended Basin and Hood.
Discharge 100 cfs





Reservoir elevation 5430

SOLDIER CANYON DAM
Outlet Works
1:6 scale model
Stilling Basin Studies
Recommended Basin and Hood.
Discharge 100 cfs



TAILWATER ELEVATIONS

DISCHARGE	ELEVATION
15 C.F.S.	5223.5
30 "	5224.1
45 "	5224.6
60 "	5225.0
100 "	5225.8

KEY

- ——— 60 - SECOND - FEET
- — — 45 - SECOND - FEET
- —·— 30 - SECOND - FEET
- ------ 15 - SECOND - FEET

SOLDIER CANYON DAM

OUTLET WORKS

PRESSURES IN RECOMMENDED HOOD
1:6 SCALE MODEL

246
[illegible] 2-20-51

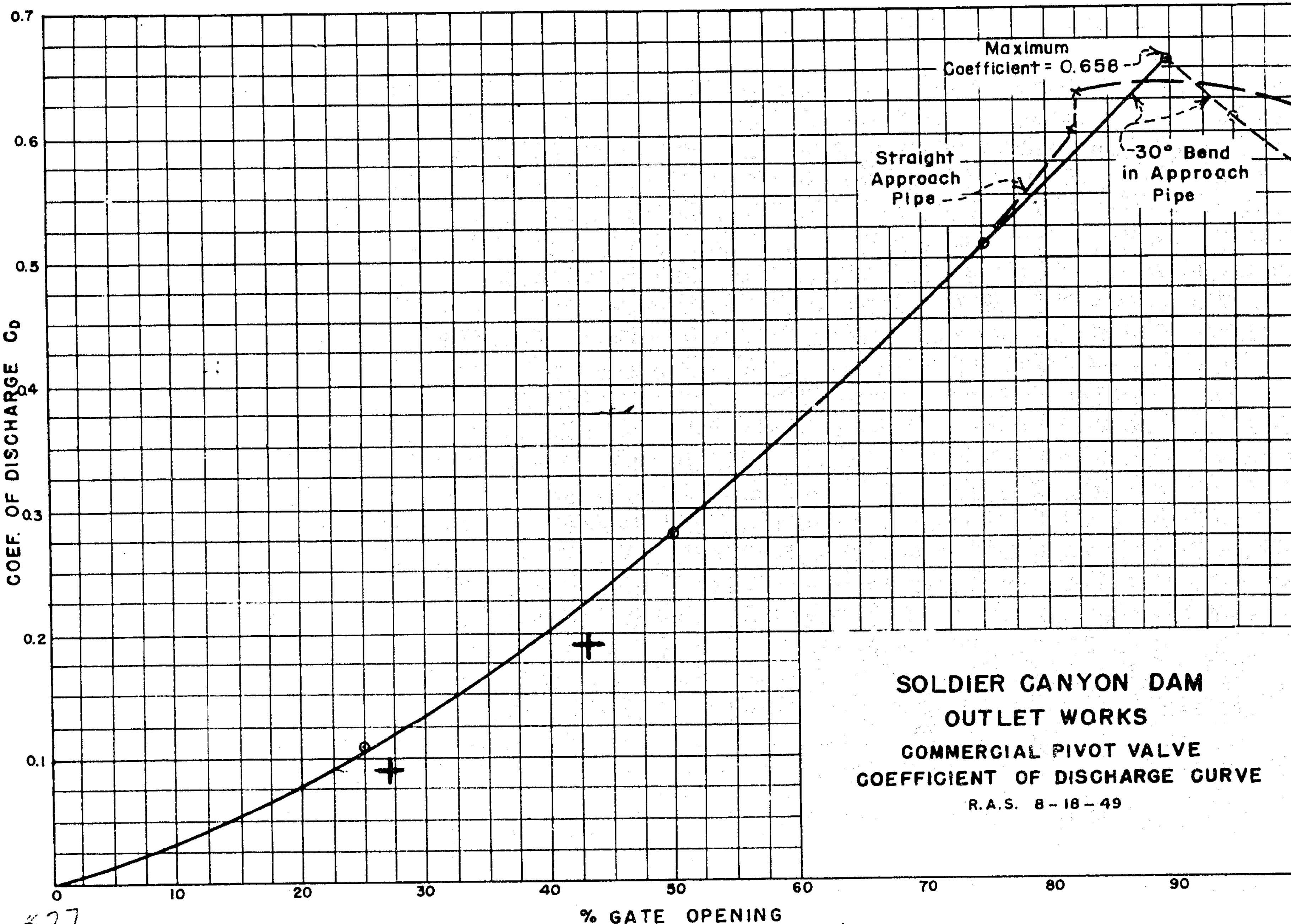
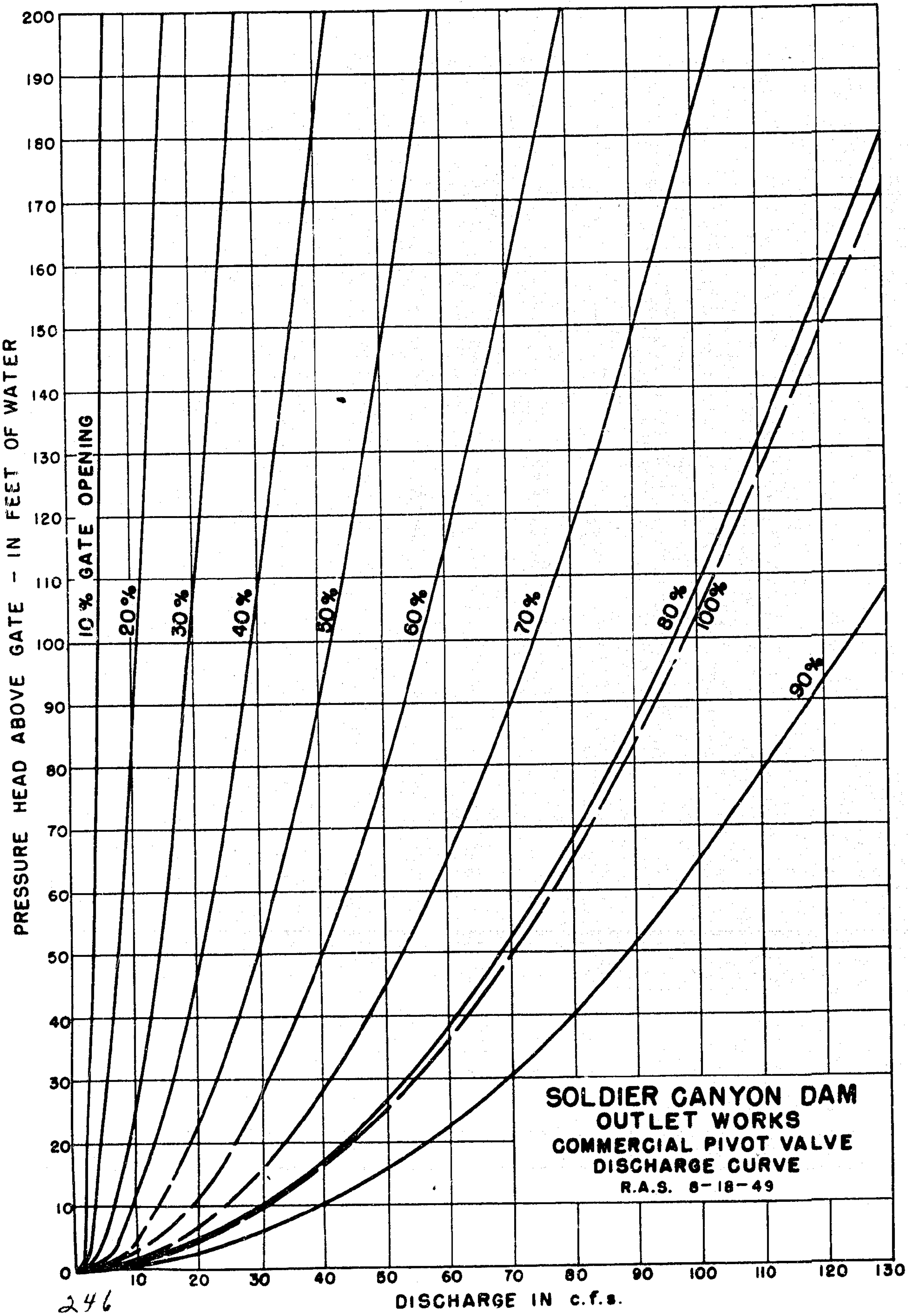

SOLDIER CANYON DAM
OUTLET WORKS
COMMERCIAL PIVOT VALVE
COEFFICIENT OF DISCHARGE CURVE
R.A.S. 8-18-49
Maximum Coefficient = 0.658
Straight Approach Pipe
30° Bend in Approach Pipe
COEF. OF DISCHARGE C_D
% GATE OPENING
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
70
80
90
100

FIGURE 30

#27

FIGURE 31


SOLDIER CANYON DAM
OUTLET WORKS
COMMERCIAL PIVOT VALVE
DISCHARGE CURVE
R.A.S. 8-18-49
PRESSURE HEAD ABOVE GATE - IN FEET OF WATER
DISCHARGE IN c.f.s.
10% GATE OPENING
20%
30%
40%
50%
60%
70%
80%
100%
90%
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

APPENDIX

December 19, 1951

Field Trip Report No. 1191

To: Chief Engineer

Through: Chief, Engineering Laboratories Branch

From: Engineer Ben R. Blackwell

Subject: Field Trip to obtain hydraulic measurements--Soldier Canyon Outlet Works--Colorado-Big Thompson Project

Introduction

1. September 26 and 27, 1951, were spent at Soldier Canyon Outlet Works obtaining hydraulic measurements utilizing special equipment installed in the discharge guide during construction. The very best of cooperation was received from L. R. Fossett, Maintenance Superintendent, ably assisted by H. J. Barber and G. H. Burkard, all of the Loveland, Colorado office. These men adjusted the outlet works discharge as required by the test schedule, they assisted in running levels, and did everything in their power to bring the testing program to a successful conclusion.

Purpose of the Trip

2. The primary purpose of the trip was to obtain pressure measurements in the discharge guide of the Soldier Canyon Outlet Works and compare these pressures with those predicted from hydraulic model studies. Secondary purposes include (1) partial calibration of the 18-inch pivot valve, (2) wave height observations in the canal downstream from the stilling basin, (3) observations on the severity of the ejection of water out of the upstream end of the discharge guide into the valve house, and (4) observations on the hydraulic performance of the stilling basin.

This study is of special interest due to the departure from standard design practice by having the valve discharge into a submerged discharge guide. The purpose of this guide is to convey the water from the valve to the bottom of the stilling basin where maximum energy dissipation is possible with a minimum length of basin. This new design concept was discussed in detail in the paper "Progress in New Designs for Outlet Works Stilling Basins" by A. J. Peterka and H. W. Tabor which was presented at the Fourth International Congress on Large Dams at New Delhi, India, in February 1951.

Operating Range of the Outlet Works

3. The outlet works was designed for a maximum capacity of 100 cubic feet per second. This capacity anticipates greatly expanded deliveries in the Fort Collins area. At the present time the capacity of the outlet works is limited by the capacity of the available canal system. A 2-foot Parshall flume limits the flow to College Reservoir to about 30 cubic feet per second while the canal to Dixson Reservoir will handle approximately 8 cubic feet per second. Model data were obtained at discharges of 15, 30, 45, 60, and 100 cubic feet per second. At the time of the tests the head on the valve was approximately 130 feet while the maximum available head, when Horsetooth Reservoir is full, will be about 203 feet. Model data were obtained for heads of 35, 75, 113, 160, and 203 feet prototype. The actual model heads were one-sixth of these values.

Model Pressure Measurements

4. Model data were obtained from a 1 to 6 scale hydraulic model in the Denver Hydraulic Laboratory. Model pressures were measured on a manometer board. Since one of the purposes of the model tests was to evolve a design for the discharge guide without negative pressures, the low point of the surge in the manometers was recorded as the pressure in the discharge guide. Neither the average pressure nor the magnitude of the pressure surge as shown by the manometer was recorded. Apparently the surge was not large enough to give concern.

Prototype Pressure Measurements

5. Prototype pressure measurements were obtained at discharges of 15 and 30 cubic feet per second at the 12 piezometer locations in the discharge guide shown in Figure 1. The reservoir for these tests was at elevation 5358.8 feet, resulting in a head of approximately 130 feet on the valve. Two techniques were used in obtaining the pressures, namely, (1) an electric "well" gage, and (2) a gas pressure system. The tops of the 1-inch vertical pipe leads from the piezometer openings were all appreciably above the hydraulic gradient in the discharge guide, thereby permitting the use of the pipes as manometers. The well gage probe was used to locate the water surface in the opaque pipes. Both of these methods of measuring pressures indicate the average pressure at the piezometer since most of the pressure fluctuations are absorbed in the large volume in the 1-inch riser pipes in conjunction with the small 1/8-inch piezometer openings.

Comparison of Model-Prototype Pressures

6. In addition to the fact that the prototype data indicated average pressures and the model data indicated a minimum pressure, the prototype tailwater elevations were about 1.5 feet higher than those tested in the model. Both of these factors tend to result in higher prototype pressures than were indicated by the model. The model data for the prototype head tested were obtained from a cross plot of the model results. The final results showing (1) model data, (2) prototype data using the well gage, and (3) prototype data using the N_2 gas setup is included in this report as Figure 2. From an examination of this figure it may be clearly seen that the prototype pressures are consistently higher than the model pressures extended to the prototype level.

Backflow out of the Discharge Guide

7. In both the model and the prototype small amounts of water were ejected back out of the upper end of the discharge guide into the valve house area. In both the model and the prototype this action was more severe at 15 cubic feet per second than at the higher discharges. At 15 cubic feet per second in the prototype the ejected water was sufficient to wet the valve house floor immediately above the valve. No damage was done.

Stilling Basin Operation

8. Model and prototype stilling basin operation were both similar and satisfactory. The energy of the water was dissipated within the confines of the basin and wave heights in the canal, as discussed elsewhere in this report, were small. Figure 3 shows the prototype operation at 15 and 30 second feet and the model operation at 30 second feet. Due to the high tailwater elevation in the field, caused by the backwater from the 2.0 foot Parshall flume downstream from the outlet works, there was some flow back over the head wall at the upstream end of the stilling basin into the valve house structure, Figure 3. In the prototype, as well as in the model, the energy dissipating boils shifted from side to side as well as longitudinally within the confines of the stilling basin.

Wave Action in the Canal

9. Wave action in the canal downstream from the outlet works was observed in both the model and in the prototype. These observations were made about 50 feet downstream from the end of the stilling basin. Model wave heights expressed in prototype feet were as follows:

Discharge	Wave Heights
15 c.f.s.	Negligible
30 c.f.s.	0.1 feet
60 c.f.s.	0.2 feet
100 c.f.s.	0.7 feet

Prototype observations indicated wave heights of less than 0.05 feet at 15 cubic feet per second and less than 0.1 feet at 30 cubic feet per second. This prototype wave action at the lower discharges compares favorably with predictions from the model studies. The model studies, however, indicated greatly increased wave action below the stilling basin for the higher flows. This increased wave action at the higher flows should be carefully checked in the prototype.

Calibration of the Pivot Valve

10. A careful calibration of the pivot valve was made in the hydraulic laboratory on a 1 to 6 scale model. The laboratory coefficient curve together with the two prototype calibration points are shown in Figure 4. The prototype discharges were measured through a 2-foot Parshall flume, while the gate opening was obtained from measurements of the valve stem travel. The coefficient of discharge was obtained from the formula

$$Q = CA\sqrt{2gh}$$

where A = area of an 18-inch circle
and h = total head at the valve in feet

The calibration data are summarized in the following table:

Discharge	Gate Opening	Proto. Coeff.	Model Coeff.
15 c.f.s.	27%	0.09	0.117
30 c.f.s.	43%	0.19	0.226

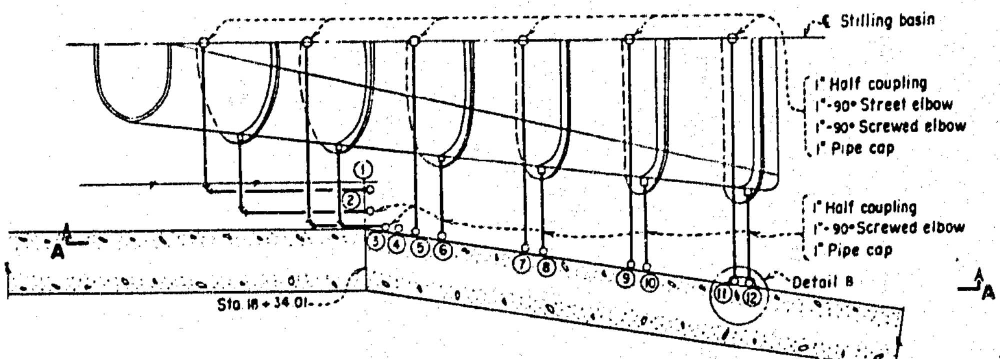
The prototype coefficients are 77% and 84% respectively of the model results. This difference between model and prototype, much greater than would normally be expected, cannot be explained at the present time. Further study will be given to this problem in order to locate the cause of the discrepancy.

Future Tests

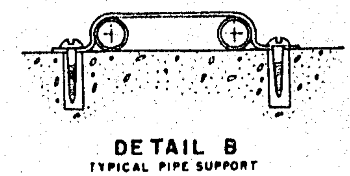
11. Since the present tests were limited to the lower range of discharges, at some future date when field conditions are appropriate, application will be made for another field trip to the Soldier Canyon

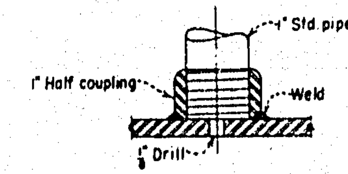
Outlet Works for obtaining more data at higher heads and discharges. At this time average pressures will be obtained in the outlet works discharge guide as was done in the tests discussed in this report and the results will be compared with the model study test results. In addition to these tests an effort will be made to obtain data on pressure surges in the discharge guide using a pressure cell with suitable electronic recording equipment. The tests should be made at discharges approaching the maximum capacity of the outlet works. Experience has shown that in some cases the pressure surges in hydraulic structures must be given primary design consideration when the average hydraulic pressures may be of minor importance.

/S/ Ben R. Blackwell

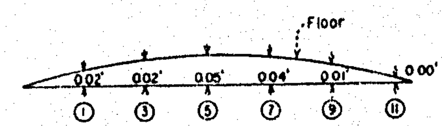


PART PLAN

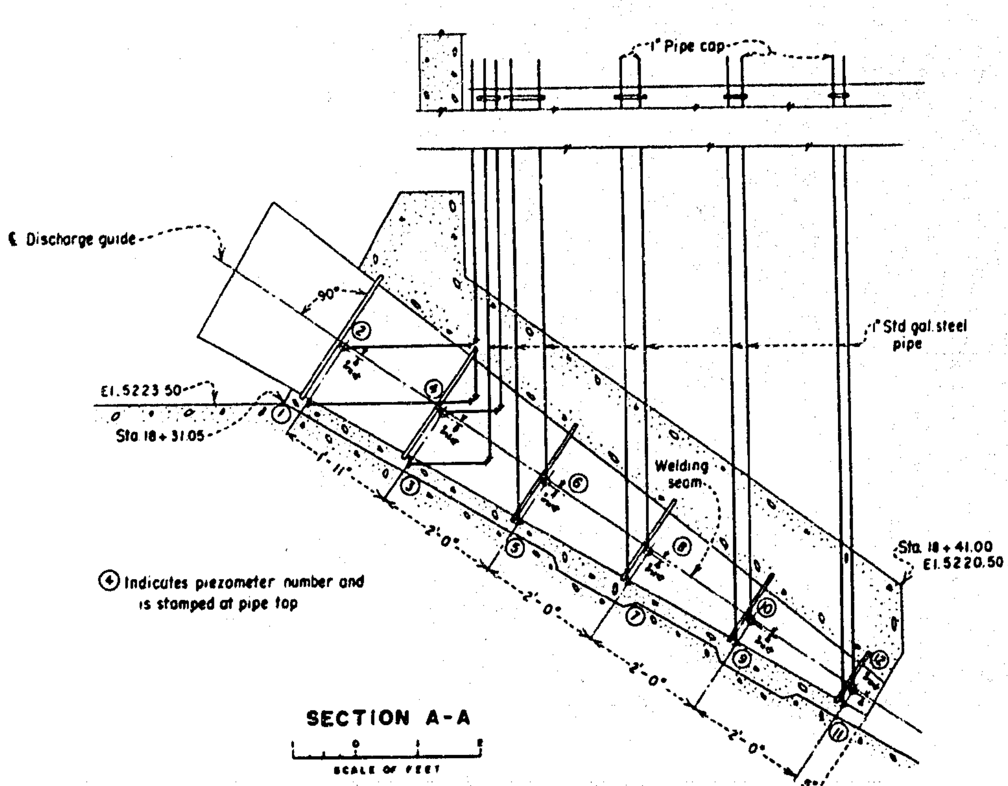




TYPICAL PIEZOMETER CONNECTION



BEND IN FLOOR OF DISCHARGE GUIDE
(REFER TO SECTION A-A)



SECTION A-A

REFERENCE DRAWINGS

VALVE HOUSE - CONCRETE OUTLINE	245-D-3155
STILLING BASIN - CONCRETE OUTLINE	245-D-3156
VALVE HOUSE - DISCHARGE GUIDE	245-D-4620

NOTE: All fittings malleable iron

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT - COLO.
HORSETOOTH RESERVOIR

SOLDIER CANYON DAM
OUTLET WORKS
PIEZOMETER TIPS AS INSTALLED

DRAWN............ SUBMITTED............
TRACED. L.O.B. .... RECOMMENDED............
CHECKED............ APPROVED............

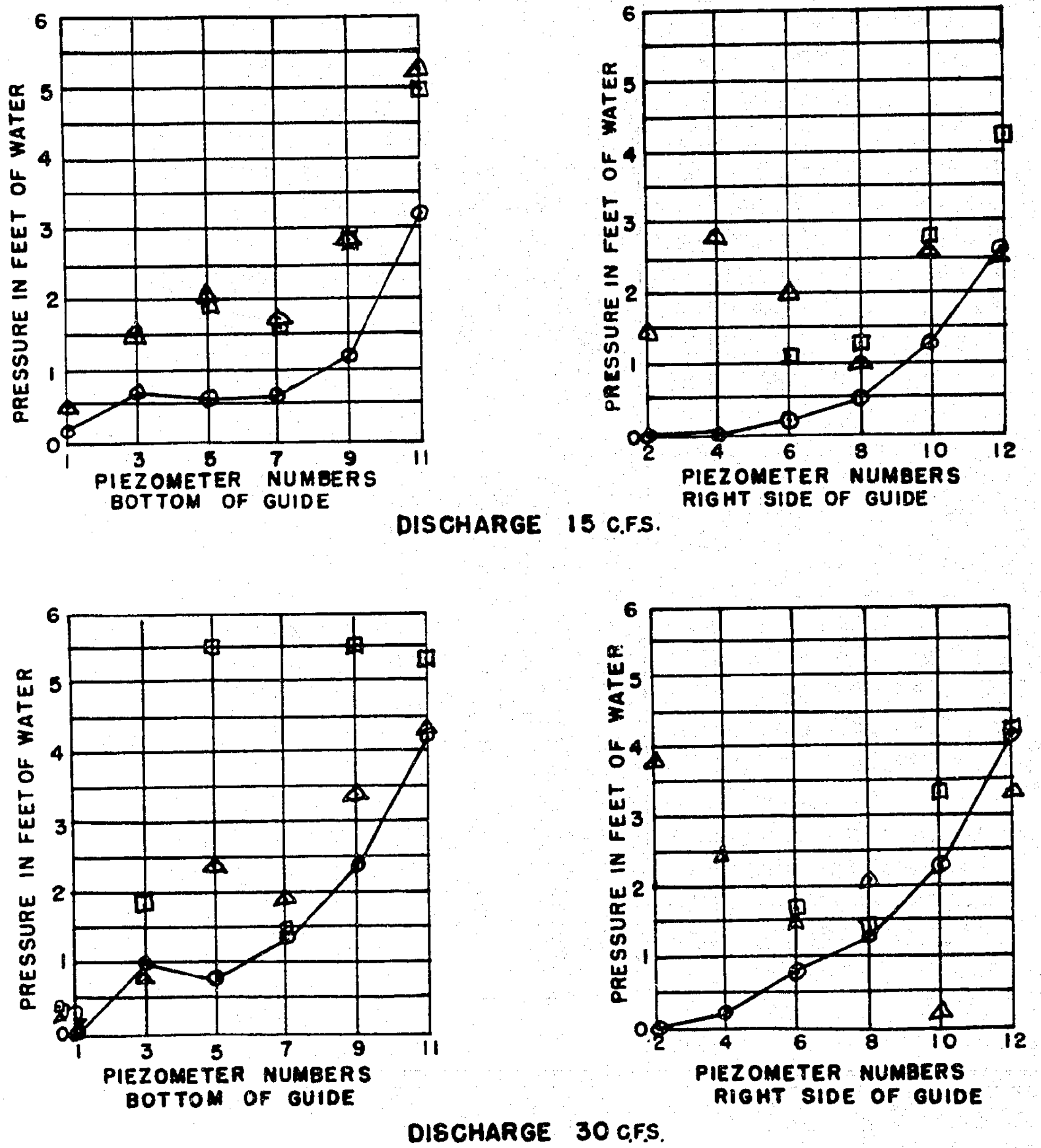
221.2-30 | FORT COLLINS COLO. DEC. 2, 1948

FIGURE 1

427

FIGURE 2

FTR 1191



EXPLANATION:

⊙ MODEL STUDIES

⊡ PROTOTYPE- WELL GAGE

△ PROTOTYPE- N_2 SETUP

NOTE: PIEZOMETER LOCATIONS ARE SHOWN IN FIGURE 1.

SOLDIER CANYON DAM

OUTLET WORKS

DISCHARGE GUIDE

MODEL-PROTOTYPE PRESSURES

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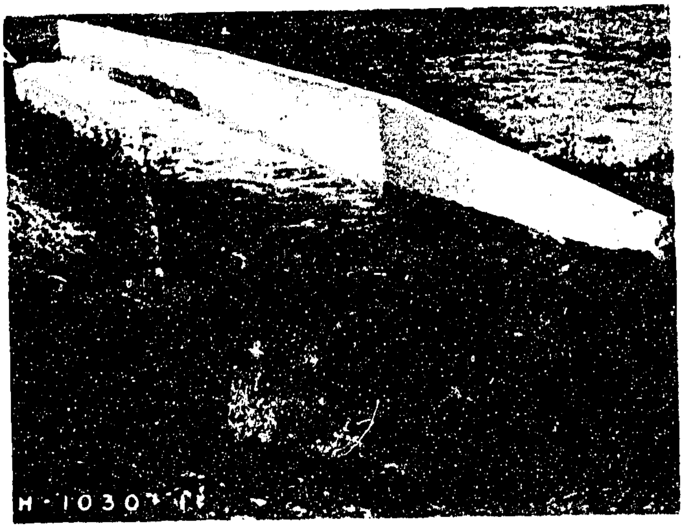
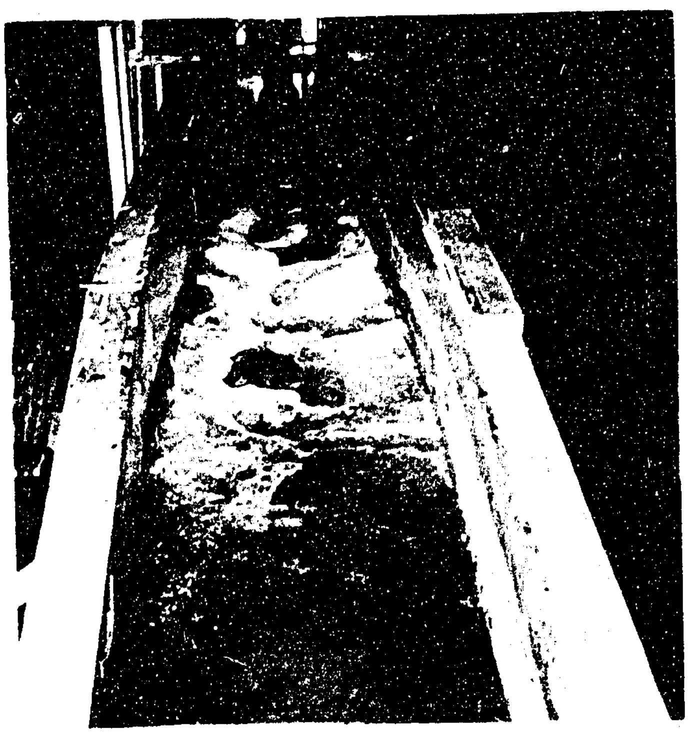


Prototype Basin
Discharge 30 cfs.
Reservoir elev. 5358.8
Tailwater elev. 5225.7

Discharge 15 cfs.
Reservoir elev. 5358.8
Tailwater elev. 5224.9



Model Basin
Discharge 30 cfs.
Reservoir elev. 5340
Tailwater elev. 5224.1

Discharge 30 cfs.
Reservoir elev. 5358.8
Tailwater elev. 5225.7

SOLDIER CANYON DAM
Outlet Works Stilling Basin
Model-Prototype Photographs

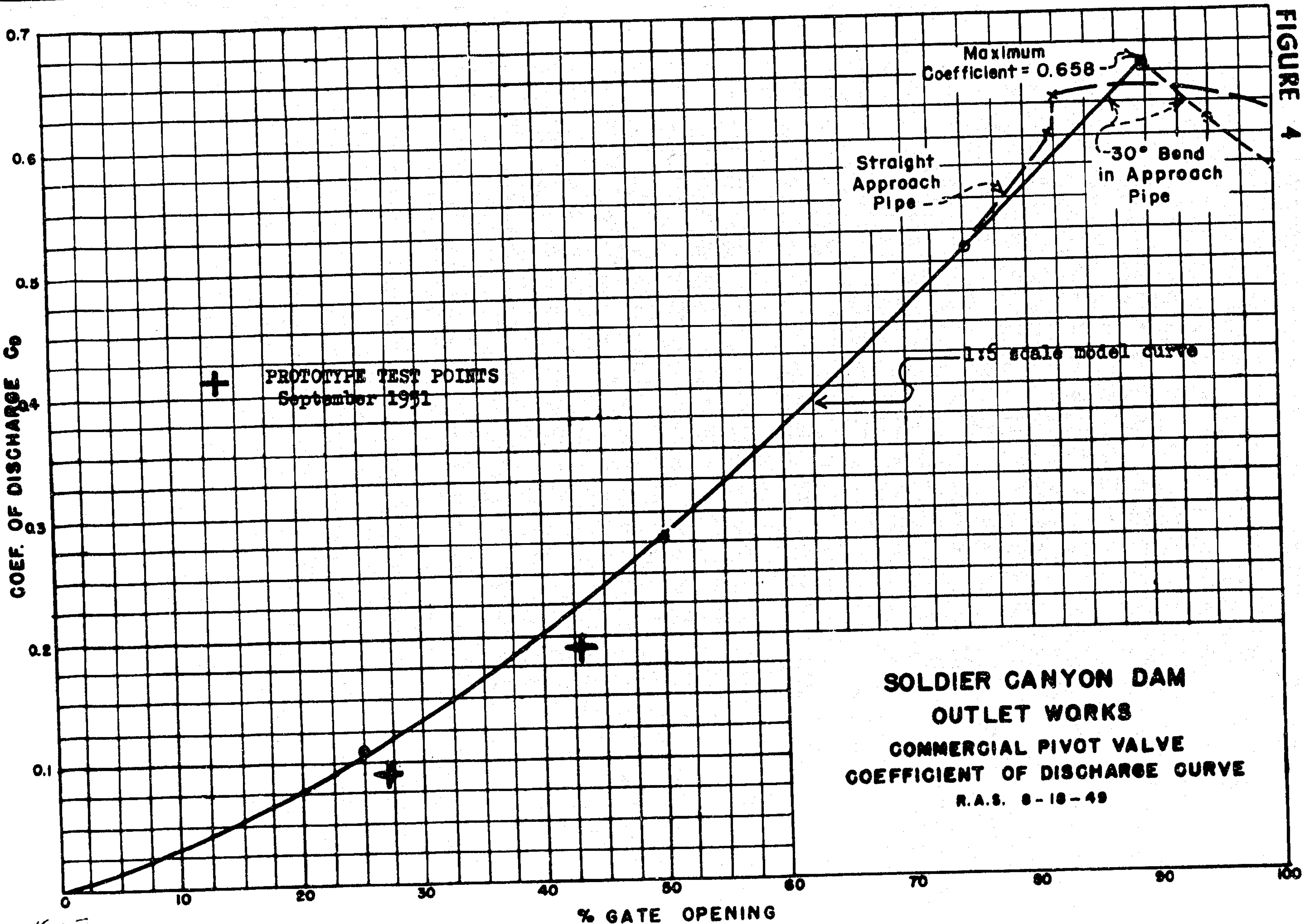


FIGURE 4
Maximum Coefficient = 0.658
Straight Approach Pipe
30° Bend in Approach Pipe
1:5 scale model curve
PROTOTYPE TEST POINTS September 1951
COEF. OF DISCHARGE C_D
% GATE OPENING
0
10
20
30
40
50
60
70
80
90
100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
SOLDIER CANYON DAM
OUTLET WORKS
COMMERCIAL PIVOT VALVE
COEFFICIENT OF DISCHARGE CURVE
R.A.S. 8-18-49

#27