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Model Study of the SPILLWAY OF THE REZA SHAH KABIR PROJECT KHUZESTAN WATER AND POWER AUTHORITY MINISTRY OF WATER AND POWER - GOVERNMENT OF IRAN

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CONTENTS

PREFACE

A model of the spillway for the Reza Shah Kabir Project of the Khuzestan Water and Power Authority of the Government of Iran on the Karun River was constructed at a scale of 1:78.7 and tested at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. The purpose of the test was to examine the nature of the flow in the spillway and tailrace and to provide data for the structural design.

The experiments showed that a spillway could be proportioned that would effectively discharge the maximum design flow into the downstream river channel without causing scour to endanger the structure or to create currents in the pool that would adversely affect the operation of the powerhouse. Observations of the jet patterns suggested that the jet be deflected downstream approximately 25 degrees in order that the jet would more nearly impinge on the river and flow in the direction of the river channel.

Information was also provided regarding the nature of the flow in the approach channel and the suitability of raising the bed of the approach channel with a consequent reduction in excavation.

The model tests described in this report were sponsored by the Harza Engineering Company of Chicago, Illinois, which was represented initially by Dr. David Louie and later by Mr. H. Wayne Coleman, Assistant Head of the Hydraulics Department of Harza Engineering Company. The experiments were performed at the St. Anthony Falls Hydraulic Laboratory by Klaus E. Foerster under the general direction of Alvin G. Anderson. The models were fabricated in the laboratory shops.

Model Study of the
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I. INTRODUCTION

The Reza Shah Kabir Project consists of an arch dam and power generating facilities on the Karun River in Iran. The general layout of the project showing the dam and spillway is given in Chart 1. The outline of the model built to investigate the operation of the spillway has been superimposed. A portion of the arch dam, the entire spillway, and a portion of the downstream river has been included. The purpose of these experiments was to examine the hydraulic characteristics of the spillway as originally designed and to measure water surface profiles and pressures in the chutes and in the buckets, as well as to observe the flow approaching the crest and to establish its calibration curve for various conditions of flow.

The basic features of the spillway, the flip bucket, and the gate section, as originally designed, are given in Charts 2 and 3. The longitudinal profile of the spillway was fixed so that it would conform to the rock topography in this region, with the steepest portion conforming to the steeply sloping bedrock strata. The flip bucket at the end of the spillway was designed to direct the jets away from the spillway foundation and into the main river flow. At the crest, the discharge is controlled by three 15-meter-wide tainter gates. At the spillway, the bed of the sloping approach channel is only 20 meters below the crest. The normal headwater elevation in the upstream pool is 20 m above the crest; the maximum pool level at the design flood is 30 m above the crest.

A. A Description of Model and Appurtenances

The hydraulic model used in these studies incorporated an area of the approach channel, the spillway proper with its crest and flip bucket, and a portion of the Karun River downstream of the dam. Chart 4 is a layout of the model. The boundaries of the model have been superimposed on the general layout of the dam in Chart 1 in order to show the portions of the structure that were included in the model. The approach channel and the portion of the arch dam were modeled in concrete as shown in Photo 1. The spillway crest and the dividing piers were fabricated of a plastic, while the tainter gates were of sheet metal. The spillway chute and the original flip bucket were constructed of sheet metal to conform to the original design, while later modifications of the flip bucket were of concrete in order to provide the necessary warped surfaces. The more or less permanent bluffs that confine the river downstream of the dam and powerhouse were molded in concrete while provision was made to form the erodible bed of the river with relatively fine crushed rock with a mean size of 0.25 inches. The size of the crushed rock was chosen primarily on the basis of past experience; rock of this size allowed the erosion caused by the jets from the spillway to develop freely at a reasonable rate. Under these circumstances it is possible to delineate the scour pattern and to use it as a measure of the operation of the various spillway flip buckets.

Photo 2 is an overall view of the model from downstream showing the spillway, leading from the upper pool through the several gates down to the flip bucket and the river gorge, which forms the powerhouse discharge channel. Additional details of the simulated powerhouse and the spillway structure are shown in Photo 3. Photo 4 shows the flood plain of the river downstream of the spillway prior to a test with a bed configuration delineated by the superimposed contour lines. The water level in the river channel is at elevation 355 m.

The water supply for the model was taken directly from the Mississippi River through the laboratory supply channel and was measured by means of a calibrated orifice in either the 12-inch supply line or the 6-inch bypass line just prior to entering the headwater tank. After flowing through the model, it was discharged back into the river.

B. Scale Relationships for Hydraulic Similarity

The spillway structure represents a hydraulic system operating under the force of gravity and the velocities, pressures, and water surface elevations represent gravitational phenomena. For this kind of system, the model-prototype relationships are determined by the Froude law of similarity, giving rise to the following relationships for velocity, discharge, pressure, etc., in terms of the length-scale ratio, (L_r = 1:78.7):

$$V_p = V_m \, L_r^{1/2}$$

$$Q_p = Q_m \, L_r^{5/2}$$

$$P_p = P_m \, L_r$$

$$T_p = T_m \, L_r^{1/2}$$

where V is the velocity, Q is the discharge, P is the pressure, and T is the time. The subscripts p and m refer to the prototype and the model, respectively.

Because gravity is the predominating force acting in the flow on the spillway, a high degree of similarity can be expected between the measurements of velocity and pressure in the model and those which may be expected in the prototype. By utilizing the above equations, the model discharge can be determined and the pressures and velocities as measured in the model can be readily translated to the prototype values. The erosion pattern, as measured in the model for various conditions of operation, also can be translated to prototype dimensions by means of the length ratio. Since the crushed rock in the model does not simulate the rock and various materials found in the prototype, its rate of erosion will probably not be similar to that in the prototype; and consequently, the depth of erosion to be expected in the prototype cannot be predicted satisfactorily from the model experiments. However, since the erosion in the model is the result of the interaction of the jets with the bed, the qualitative aspects of the erosion pattern will be similar to those that can be expected in the prototype. For this reason the scour pattern observed in the model can be used to describe qualitatively the pattern to be expected in the prototype and to show the nature of the erosive forces generated by the various spillway buckets employed.

II. EXPERIMENTAL RESULTS

Of primary interest in these studies was the nature of the flow through the spillway chute and the flip bucket and the resulting scour pattern in the downstream river and flood plain. The majority of the tests were related to these aspects. In addition, spillway and crest pressures were measured, the spillway crest was calibrated for various operating conditions, and some observations were made of the flow in the approach channel, both for the sloping and the level approaches. The results of all of these tests are described in the following section.

A. Development of Spillway Flip Bucket Design

1. Tests on Original Design

The first tests were carried out with the model in accordance with the original spillway arrangement as shown in Chart 2. The tests were made with a discharge of 8,000 cms through the spillway. For the initial test all of the downstream river and flood plain within the confines of the model walls was erodible and was molded in accordance with the original contours. The erosion caused by the highly concentrated jets proceeded very rapidly and extended laterally almost to the confines of the model. This is shown in Chart 5.

In the prototype the river banks opposite the spillway and downstream of the spillway consist of rock which appeared to be more highly resistant to erosion than the material used in the model, so that normally the scour pattern would be limited by these rigid boundaries. Before the next test was performed, these banks were stabilized with concrete mortar to conform to the prototype topography. The test was repeated at 8,000 cms and run for a period of only 15 minutes.* This scour pattern, which is shown in Chart 6, shows that the erosion has been reduced in lateral extent. A second test was made with the same discharge for an additional 15 minutes in order to establish a reasonable test duration for equilibrium scour. A comparison of Charts 6 and 7 shows that relatively little change has occurred with the increased duration and that in a period of 30 minutes the scour pattern has essentially reached equilibrium. Charts 6 and 7

* All time measurements are in model dimensions.

show that the greatest scour occurred in the region of the jet impact and was confined to a relatively small area. The point of impact, however, was an appreciable distance from the lip of the spillway, so that there was relatively little scour at the toe of the chute.

One of the consequences of the concentrated jet impact area was the generation of relatively intense secondary reverse currents which swept around the side of the impact area and along the front of the spillway. These were caused primarily because of the direction of the spillway jets in relation to the general direction of the river channel. The secondary currents also transported sediment and formed a bar, which tended to infringe upon the channel leading from the powerhouse. This bar is shown by the closely-spaced contour lines on the upstream side of the impact area in Charts 6 and 7. In addition, the concentrated impact of the jets tended to create waves of considerable magnitude, so that the water surface was quite rough and irregular. Scour tests using the maximum discharge in the original flip bucket could not be conducted because the scour would be extremely heavy and rapid and because the model was not large enough to permit proper expansion of the high energy flow beyond the impact area.

2. Modifications of the Straight-Chute Spillway

It appears from the above tests that the concentration of flow from the original flip bucket design was responsible for the rather intense scour and secondary currents. In an attempt to spread the jet and to avoid the small impact area, the flip bucket was modified to Type B, shown in Chart 8. The sidewalls were flared outward and the lip of the bucket was cut back to make the shape somewhat spoon-like. The intermediate chute walls in the flip bucket proper were eliminated. In addition, the whole bucket structure was moved up the slope of the chute so that the lip was at elevation 410.2 m, approximately 15 m above the lip of the original flip bucket. Charts 9 and 10 show the scour pattern resulting from a flow of 15,500 cms through this structure. The tests shown on Chart 9 had a duration of 30 minutes, while for Chart 10, the test was continued for a total of 60 minutes. Here again, the resulting scour patterns were very similar in shape and extent. For this discharge, the maximum depth of scour was down to approximately elevation 335 m, and the sediment wave generated at the right of the point of impact by the secondary currents was quite extensive and nearly closed the channel from the powerhouse. The scour patterns were remarkably similar and indicate that the scour was in equilibrium.

It appeared that by spreading the jet, the intensity of the secondary currents was appreciably reduced and the depth of scour for a discharge of 15,500 cms was of the same order as the scour caused by discharge of 8,000 cms through the original flip bucket. The principal disadvantage of the Type B flip bucket was the complicated shape in relation to the improvement in the flow and scour pattern.

In an attempt to simplify the structure, the side flare of the Type B spillway was eliminated, but the lip elevation was kept at about the same level. These changes were made in the hope that the flow pattern could be improved in relation to the original design, by moving the point of impact back from the opposite wall and more nearly in the center of the river itself. The results of tests with a Type C flip bucket are given in Charts 11 through 15. Chart 11 shows the scour pattern for a discharge of 15,500 cms after 30 minutes of operation on a bed that was molded by a discharge of 8,000 cms for 60 minutes. It is apparent that for this discharge, the scour hole was drastically increased in depth and the bar generated by the reverse current almost closed the powerhouse channel. This demonstrated the effectiveness of the Type B spillway bucket as compared to Type C, as far as the scour characteristics were concerned. Moving the spillway up the chute to a higher elevation had practically no influence upon the depth of scour. This depth of scour appeared to be the consequence of the jet concentration which can attack the bed vigorously even after passing through considerable depth of water. Chart 12 shows the scour after a test with a discharge of 8,000 cms through the spillway. The results of this test are to be compared with the scour pattern in Chart 7, which is the result of the same discharge through the original bucket. The scour patterns were qualitatively similar, although the maximum depth of scour with the Type C flip bucket was somewhat greater than that shown in Chart 7. This may have been due to the greater duration of the flow shown in Chart 12, as compared to the earlier test.

Overall views of the Type C flip bucket in operation are shown in Photos 5 and 6, representing a discharge of 8,000 cms. Photo 7 shows the jet trajectory at the maximum discharge of 15,500 cms. The corresponding boil beyond the jet impact area and along the far shore is shown in Photo 8.

A test was also conducted to study the influence of powerhouse flow upon the bar formation near the exit of the powerhouse channel. Chart 13 shows the result of this test at a spillway flow of 8,000 cms and the maximum powerhouse flow of 730 cms. The powerhouse flow did not alter the secondary currents in the main tailwater pool sufficiently to prevent the formation of a bar similar to that shown in Chart 12. Further scour tests were conducted with reduced spillway discharges to determine whether the powerhouse channel would be further choked off during the period of decreasing discharges following the peak of a flood. Chart 14 shows a result of a discharge of 4,000 cms upon the bed that had been formed by a previous test of 8,000 cms. The duration of the test was for 2.5 hours and it appeared that the principal effect of this discharge was to move the point of maximum scour back towards the spillway. The reduced impact distance appeared to be the result of a rearrangement of the sediment in this area. A discharge of 2,000 cms following the preceding tests had the effect of moving the point of maximum scour slightly closer to the spillway bucket, as shown in Chart 15. The remainder of the scour pattern was qualitatively similar to those previously obtained. These experiments seemed to indicate that the scour pattern will be formed by the maximum discharge and remain relatively stable for all discharges less than the maximum. The smaller discharges can be accommodated by the scour pattern created by the peak discharge, provided, of course, that its duration is sufficiently long for the bed to reach equilibrium.

It appeared from the tests described in this section that the Type B spillway flip bucket was the most effective in reducing both the scour and the secondary currents. The Type B spillway bucket, however, did not eliminate the bar formation at the exit of the powerhouse channel and, in addition, was considerably more complicated than the original design. Two factors appeared to be relevant in the scour and secondary current patterns observed. For the original bucket and the Type C flip bucket the strong secondary currents were primarily the consequence of the direction of the jet relative to the mean direction of the river. Secondly, since the jet impinged on the pool far from the spillway bucket, the depth of scour was relatively unimportant as far as the safety of the structure was concerned. In order to reduce further the intensity of the secondary currents and improve the scour pattern, it was proposed that the flow be deflected by the flip bucket in a direction more nearly the same as that of the main river.

B. Tests of the Type D Spillway Bucket

The Type D spillway bucket design incorporated the idea that the flow pattern and the scour pattern would be improved with respect to the secondary currents and the deposition upstream of the point of impact by deflecting the jet downstream. This was done by providing an appropriate curvature of all of the walls and superelevation of the floor of the flip bucket between the walls. Chart 16 is a layout of the flip bucket and shows the profiles of the floor at their respective dividing walls. Photo 9 shows this flip bucket as built for the model.

The specific details of the Type D design are as follows:

1. The left outer wall forms a spiral in its horizontal projection. The spiral is defined as follows:

$$\Delta = \frac{L}{2\ R_{min}}\ ,\ R = \frac{L}{\ell} R_{min}$$

where Δ = horizontal deflection angle in radians.

L = total length of the spiral.

ℓ = distance along spiral to any point on the spiral.

R_{min} = terminal radius of curvature of the spiral.

R = radius of curvature of the spiral at distance ℓ.

2. All the other walls are parallel curves to the above spiral; i.e., they are always at equal horizontal distances from the left wall along lines drawn normal to the spiraled left wall.

3. The vertical profile of the chute floor along the left wall of each chute is a circular curve terminating with a 30 degree lip angle at the sill.

4. The transverse slope of each chute floor is defined by the following relationship:

$$\tan \theta = \frac{v^2/R}{g+v^2/r}$$

where θ = angle of superelevation with respect to the horizontal.

V = maximum velocity at the entrance to the flip bucket = 50 m/sec.

R = local radius of curvature of the left chute wall.

r = vertical radius of curvature of the chute floor along the left chute wall.

g = acceleration of gravity.

Values of tan θ must be calculated for each station along each left chute wall separately. The expression for the superelevation is an approximation of the forces acting on fluid particles, assuming that all particles move in parallel curved paths through the flip buckets.

The scour patterns for the Type D spillway bucket are shown for various increasing discharges in Charts 17 through 21. In general, there was a very significant improvement in the flow and scour pattern as a result of redirecting the jets. For a discharge of 2,000 cms, the scour was more or less restricted to the region just downstream of the spillway chute. At 4,000 cms, the point of greatest scour had moved outward from the spillway and a bar had developed on the right side of the point of impact. At 8,000 cms, the point of impact was in the middle of the river. The bar had been more fully developed, but it appeared that a channel of some sort was maintained under the spillway jet by the secondary current generated at the far bank. In the scour test shown in Chart 19, this channel was maintained despite the fact that the bar growth had been accelerated by adding bed material to the strong secondary currents along the far shore. The purpose of this procedure was to simulate the effect of strong erosion along the far shore in the event that erosion resistance in the prototype was low. Chart 20 shows the scour pattern resulting from a discharge of 8,000 cms on a bed which had been molded to the original contours. The scour pattern was very similar to that shown in Chart 19, except that the bar did not extend as far. When the discharge was increased to 15,500 cms, the scour pattern moved farther from the spillway and the channel from the powerhouse was more clearly defined, as shown in Chart 21. The bar that was formed on the right of the jet also extended farther upstream, but as it moved into the region of the powerhouse channel, the currents that transported the material were sufficiently strong as they were deflected downstream to maintain a channel from the powerhouse and transport the sediment which rolled over the edge of the bar back into the scour hole. The latter characteristic is also evident in Chart 19. It appeared that a considerable improvement in the nature of the scour, both with respect to its location and particularly with the maintenance of a channel from the powerhouse, was achieved by the revised flip bucket.

The points of impact of the jet on the tailwater surface and the secondary current generated by this flow are shown for various discharges in Chart 22. Normally, the impact of the jet in a large pool results in surface currents in both directions around the area of impact, as indicated by the currents for 4,000 cms. This condition was considerably modified when the discharge increased to 8,000 cms, because the secondary currents were deformed by the presence of the bank on the left side of the river. In this case, the principal secondary current was to the right, and appeared to flow completely around the area of impact and under the jet issuing from the spillway. It was this current which maintained an open channel from the powerhouse near the base of the spillway for the release of powerhouse discharges. A more detailed determination of the magnitudes of the secondary current for the several discharges are shown in Chart 23. Here the directions of the currents and estimates of their magnitude are shown at various points in the plunge pool. It is apparent that the velocities in the upstream direction along the bank of the river opposite the spillway were of a considerable magnitude, reaching a peak of approximately 14 m per second for the maximum flood flow. As the discharge decreased, these velocities also decreased. The effect of this flow on the erosion in this area depends to a large degree on the resistivity of this material in the prototype. The desirability of attempting to eliminate these currents also depends to a large degree upon the expected frequency of the floods which give rise to currents of this magnitude.

In addition to high velocities, large turbulence fluctuations and waves also existed as shown in Photos 10, 11, and 12 for discharges of 4,000 cms, 8,000 cms, and 15,000 cms, respectively. However, it should be observed that the area of maximum turbulence was well removed from the switchyard area, in comparison with the location of the boil caused by the Type C flip bucket shown in Photo 8.

The relationship of the tailwater level at the powerhouse to that downstream of the impact area could not be adequately determined in the model, because the flow discharging over the tailwater control gate had not fully expanded. It appeared, however, that the spillway discharge did cause some draw-down in the powerhouse channel, the magnitude of which will depend upon the scour conditions in the flood plain. At no time was there a measurable backwater effect.

The stability of the bar that tends to form in the powerhouse channel will depend upon the size of the sediment that is deposited. If it is sufficiently small, the powerhouse flow will be able to maintain a channel by scouring this material back into the scour hole. If the rock fragments are too large, they will resist scour and cause a partial closure of the powerhouse channel. Whatever occurs will depend upon the characteristics of the prototype channel bed and cannot be predicted in the model. In addition, a bar will tend to form downstream of the scour hole and its permanence will also depend upon the character of the rock and other sediment in the channel subject to the erosive attack of the jets.

C. Pressure and Water Surface Profiles on Spillway

The pressures and water surface profiles were measured along the spillway at several longitudinal sections. These data provided information regarding the depth of water to be expected at various points along the spillway as well as the corresponding pressures on the bottom. In the Type D flip bucket, wall pressures were measured, as well as those on the bottom, because of the centrifugal forces generated by the flow around the bend. Charts 24 through 26 show the water surface profiles for discharges of 8,000 cms and 15,500 cms in the three bays, respectively. The water surface profiles along the several longitudinal sections varied somewhat because of transverse water surface modification at the entrance to each chute, as shown in Photos 13 through 15, for discharges of 4,000, 8,000, and 15,500 cms, respectively. Time exposures of confetti particles floating on the water surface delineated the streamline pattern. The contraction of the flow in a lateral direction caused draw-down along the walls as the velocity of the flow increased. The greater the contraction in a given length the greater was the draw-down along that wall. This was indicated by the profiles given in the charts, which show the greatest draw-down along the outside walls.

The draw-down of the water surface in the crest section leads to standing waves in the spillway chute, which persist to some degree throughout its length. The standing waves fluctuate with respect to size and location. The profiles in the charts represent average water surface levels. Typical wave formations at the break in grade of the spillway chute are shown in Photos 16 through 18 for discharges of 4,000, 8,000, and 15,000 cms, respectively. The water surface at 8,000 cms was below the elevation of the divider walls, except for the region close to the junction between the divider walls and the piers. At 15,500 cms the water surface was above the divider wall, except at the very downstream end. In addition rooster tails formed at this discharge in the wake of the piers.

Pressures on the bottom of the spillway chute are given in Chart 27. These pressures were taken along the centerline of the center chute for various discharges. It is of interest to note that the pressures on the crest were positive for all discharges, although less than the corresponding hydrostatic pressure. In the convex portions of the spillway, the centrifugal forces were such that the pressure was reduced below the water surface elevation, while the pressures were greater than the hydrostatic pressure for the concave portions. At the second vertical curve, where the spillway chute becomes quite steep, the pressures on the bed were nearly zero. The data in Chart 27 suggest that the pressure conditions in the spillway proper are generally satisfactory for all discharges.

The transverse water surface profiles in the Type D flip bucket are shown in Chart 28, together with a plan view of the flip bucket showing the location of pressure taps. The corresponding pressure profiles on longitudinal sections and on the side walls are given in Charts 29 through 34. Longitudinal water surface profiles are presented along with the pressure profiles. These profiles show clearly the effect of the vertical curvature of the flip bucket and the effect of the centrifugal forces on the superelevated curve. The data show that there is some runup on the outside of the curves as the discharge increases, with the consequence that the pressure along the wall is not linearly distributed. The rapid increase in pressure as the bottom of the chute is approached is the result of the predominance of the centrifugal forces over the hydrostatic forces acting on the wall. Also indicated on the charts for comparison are the calculated pressures in the flip bucket for a discharge of 16,500 cms, which is somewhat greater than the maximum discharge that could be run through the model. The results indicate that the computed pressures correspond very well with those that were measured in the model.

Because the flip bucket will deflect the flow in the downstream direction, the thickness of the outer walls and the divider walls must be increased. This added thickness was not included in the model bucket, so that the chute width in the bucket proper was actually somewhat wider than it will be in the prototype. Since the velocity in the bucket depends primarily upon the head and the surface friction, the effect of the thicker walls will be a somewhat increased depth of flow. This in turn will increase the static pressure on the inside wall of each chute, but will have relatively little effect on the centrifugal forces on the channel floor or the outside wall, since these will depend primarily on the velocity and are large compared to the hydrostatic pressures.

The flow through the flip buckets and the resulting jet trajectory downstream is shown in Photos 19 through 21 for a discharge of 4,000 cms. A similar series of photographs for 8,000 cms is shown in Photos 22 through 26. Photo 22 shows the intermediate walls just containing the flow despite some runup. The wall height is uniform throughout the length of the buckets. Above discharges of 11,000 cms appreciable overtopping of the intermediate walls takes place. The behavior of the flip bucket at 15,000 cms is shown in Photos 27 through 30.

At very low discharges a hydraulic jump formed in the individual flip buckets. A discharge of approximately 250 cms per bay was required to sweep the hydraulic jump out of the bucket. The discharge could then be decreased to 150 cms per bay before the jump appeared again. Photos 31 and 32 show the flip bucket just before and after the jump occurs at approximately 150 cms per bay.

D. Calibration of Spillway Crest

In the course of the studies, the spillway crest was calibrated to relate the discharge to the reservoir pool elevation. In Chart 35 the calibration curve for the free crest is given. In these tests, the gates were wide open, so that they offered no control and the discharge varied with the reservoir elevation. The computed coefficient in terms of the reservoir elevation is also given on this chart. It shows the consistent increase in the discharge coefficient as the discharge increases, reaching a maximum value of about 4.0 when the pool is at approximately elevation 540 m. The corresponding discharge is 16,300 cms. In Charts 36 and 37 the calibration curves are given for a discharge at a constant pool elevation, but for various gate openings. In Chart 36 the data for a three-bay operation (with the gates in the three bays open equally) are given. In these tests, the gate opening was fixed and the discharge measured for various pool elevations. From these data, additional curves were drawn, showing how the discharge varies with the gate opening for a constant pool elevation. In Chart 37, the same data are given, based upon the calibration of the center gate only. Here, the discharge for a single bay is plotted in terms of gate opening and reservoir pool elevation. These data are for the center bay only. Also plotted on this graph for comparison are the data from Chart 36, reduced to discharge per bay. The difference in the curves illustrates the effect of end contraction. The flow contracts from the full width of the approach channel to the width of one bay in a relatively short distance. A sharper draw-down results around the pier noses, which is shown in Photo 33. A side bay, when operated alone, would discharge slightly more than the center bay operating alone, since only one sharp contraction exists in this case, as shown in Photo 34.

E. Tests in the Approach Channel

An examination was made to see if the bottom elevation of the approach channel could be modified and made level for some distance upstream of the crest for the benefit of the construction process. The original design of the approach channel sloped upward at a slope of 0.15 to reach a height of elevation 490 m at the spillway. It was proposed that the excavation for the approach channel be made level at elevation 490 m throughout its length in order to save on excavation costs. This geometry is shown in Photo 35. The cut along the face of the dam is part of the excavation for the foundation of the dam and will not be backfilled. The original approach channel in the model, shown in Photo 1, did not include this cut. The velocity profiles in the original approach channel are presented in Chart 38. It is significant to note that the velocities were quite uniform throughout the depth and were of the same order of magnitude in each cross-section. Because of the sloping approach channel, the average velocity increased as it approached the crest of the spillway. This is shown in the chart.

The distribution of surface velocities for the same approach channel are indicated by confetti streaks on the surface of the water in Photos 36 and 37 for discharges of 8,000 cms and 15,500 cms, respectively. The uneven velocity distribution inthe foreground of Photo 37 is due to the poor distribution of the incoming flow at maximum discharge.

The effect of changing the approach channel geometry was investigated by checking the discharge calibration for the free crest at several high discharges. The results are included in Chart 35 and show essentially no change from the original calibration. No measurable change in crest pressures occurred as a result of the modification of the approach channel. A comparison of photographs of surface velocities in the sloping and level approach channel indicates no marked change, either. Photos 38 and 39 present such a comparison at 15,000 cms.

F. Vortices at Partial Gate Openings

When spillway discharge control is of the sluice type, there exists the tendency for vortices to form above the gates near the walls of each bay. The strength and size of these vortices is related to the magnitude of the centrifugal forces that are generated in rapidly curving flow and the proximity of maximum streamline curvature to the free surface.

Flow contractions that bring about draw-down at free-crest discharge are also responsible for the generation of vortices under sluice discharge. The relative size of the vortices is directly comparable with the magnitude of the draw-down. Strong vortices can be expected to form when only one gate is partially raised. Photo 42 shows a pair of vortices in the center bay at a gate opening of 10 meters. A close-up of one such vortex is shown in Photo 43. When a second bay was opened to double the total discharge, the velocity of the approach flow increased and with it the magnitude of the centrifugal force in the contracting flow around the pier next to the closed bay. The resulting stronger vortex is shown in Photo 44. The magnitude of the vortices decreased as the gate opening was decreased and as the discharge was divided equally between the three bays.

III. SUMMARY

The results of the tests described in this report indicate that the spillway with the suggested modifications can function effectively at all discharges up to the maximum designed flood.

A. Tests on Spillway Flip Bucket

Tests were made on a number of suggested flip bucket arrangements. The alignment of the original bucket design is shown in Chart 2. The jets generated by the flow in the flip bucket landed approximately in the middle of the channel a considerable distance from the spillway structure. The penetration of the jets through the pool caused considerable scour at the point of impingement and the generation of strong secondary currents in an upstream direction along the far bank where the switchyard was to be located. These secondary currents transported the sediment from the scour hole in an upstream direction and tended to form a bar in the neighborhood of the powerhouse channel. The depth and the total volume of the sediment transported by the current was considerably reduced as the discharge decreased. A second test series involved a bucket with expanding sides in an attempt to spread the jet and thus reduce the scour depth and intensity of the secondary currents. It appeared that some improvement in the jet pattern was attained, but the bar, although smaller, still developed. Another disadvantage was its complicated shape in relation to the improvement of the flow and scour pattern.

In a third modification, the flip bucket reverted to the original geometry, but the lip was placed at a considerably higher elevation in an attempt to direct the jets more nearly into the center of the channel. No improvement was gained in the depth of scour or the strength of the secondary currents. The resultant sediment transport and bar deposition in the powerhouse channel was similar to the original design.

The Type D spillway bucket was designed to deflect the jet about 25 degrees in the downstream direction by providing an appropriate curvature of the wall and the superelevation of the floor between the walls. The experiments showed a significant improvement in the location of the plunge pool and a reduction in the strength of the secondary currents. The tendency for a bar to be deposited upstream of the impact area and in the powerhouse channel was somewhat reduced. Flow from the powerhouse was capable of maintaining a channel without an appreciable increase in the stage at the powerhouse. It appeared that a flip bucket which deflected the flow in the downstream direction was the most effective solution for energy dissipation of the very high and relatively infrequent flood flows.

B. Pressures and Water Surface Profiles

The crest control structure together with the level approach channel can pass the discharge of approximately 16,300 cms when the reservoir pool is at an elevation of 540 m. Pressures over the crest on the centerline of the chute are positive for all free crest discharges. Because of the curvature of the crest and the location of the gates with respect to this curvature, small negative pressures are experienced on the crest when the gate opening is very small, as the jets tend to separate from the spillway crest. In the area of the convex curvature of the chute downstream of the crest, the pressures do not fall appreciably below atmospheric pressure. The intermediate chute walls should be raised near their junction with the piers in order to contain the flow within the chute up to the maximum capacity that can be contained by the intermediate walls further downstream. Because of the vertical acceleration of the flow in the flip bucket, the pressures on the convex dividing walls are positive and generally immune from cavitation. Although the intermediate walls in the prototype will be thicker than those simulated in the model, the effect of this increased thickness will increase the depth of flow in proportion to the reduction in area with a corresponding increase in pressure. No tests were made in the model with the thickened intermediate walls.

C. Calibration of Spillway Crest and Flow in Approach Channel.

The tests included the calibration of the crest for both free flow and gate-controlled flow. The results of the calibration are shown in Charts 35 through 37. The alignment of the approach channel with respect to the spillway was such that the flow pattern was quite uniform with a smooth acceleration toward the gates. The tests showed that the bed of the approach channel could be horizontal without affecting the nature of the flow.

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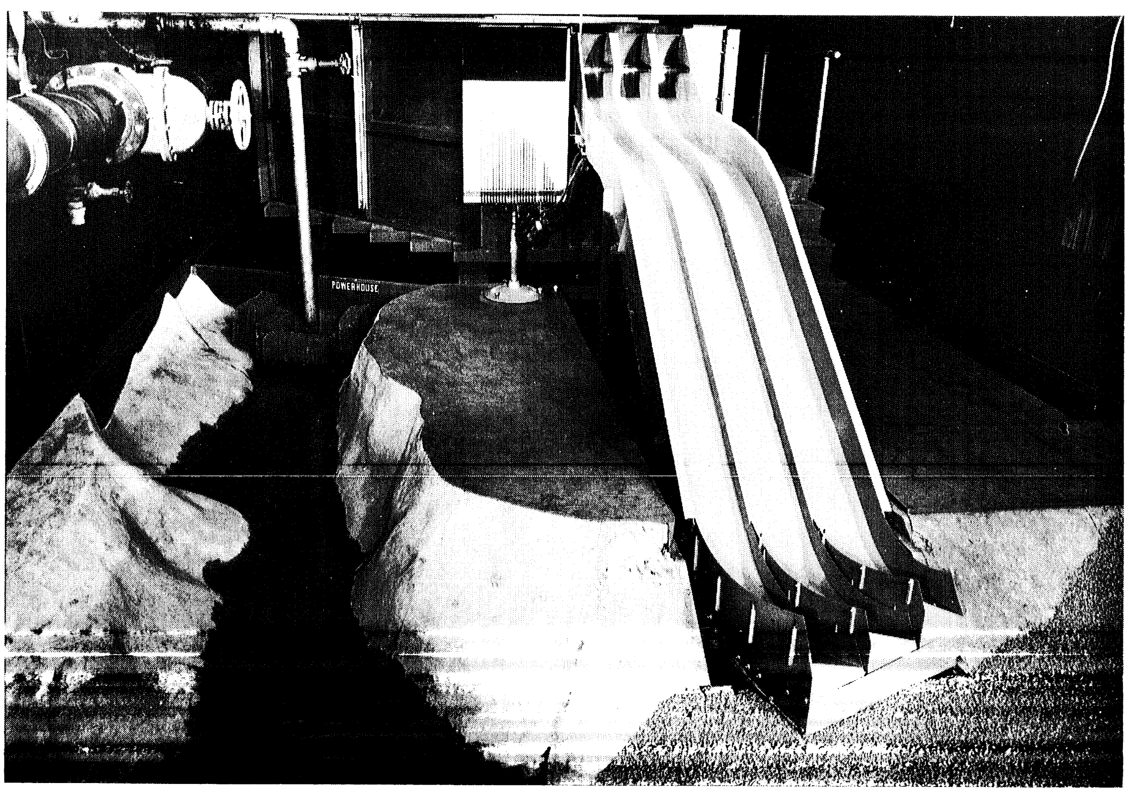

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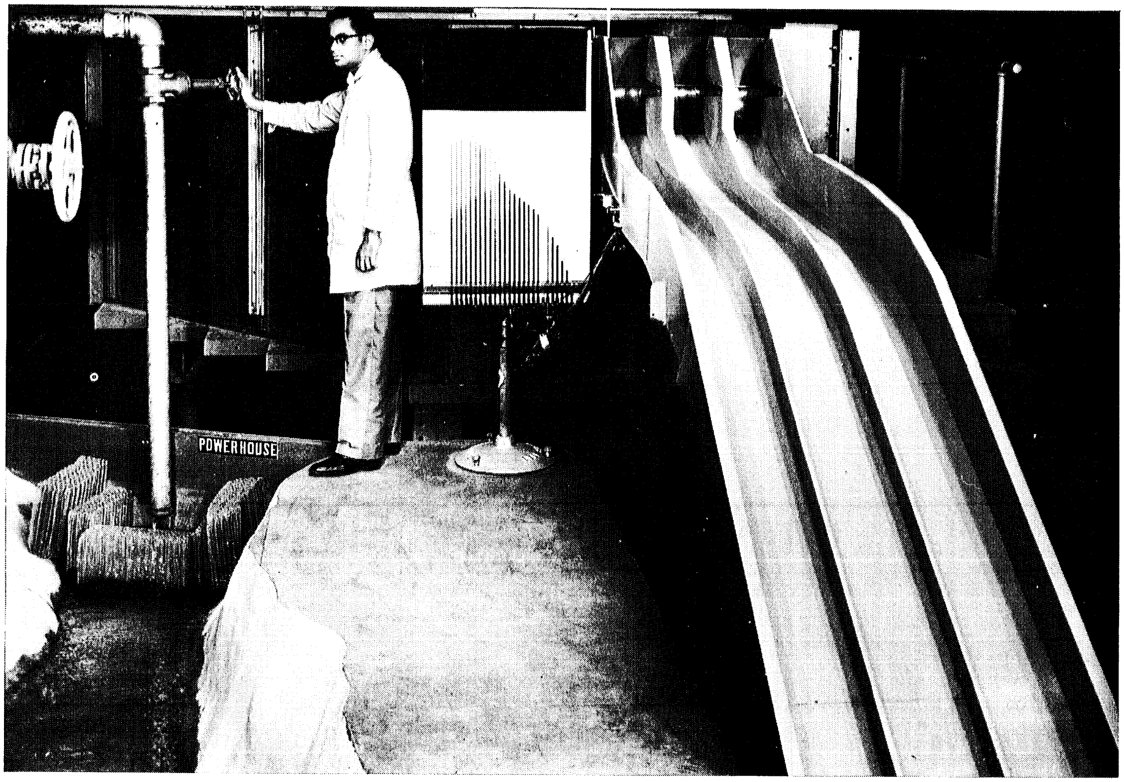

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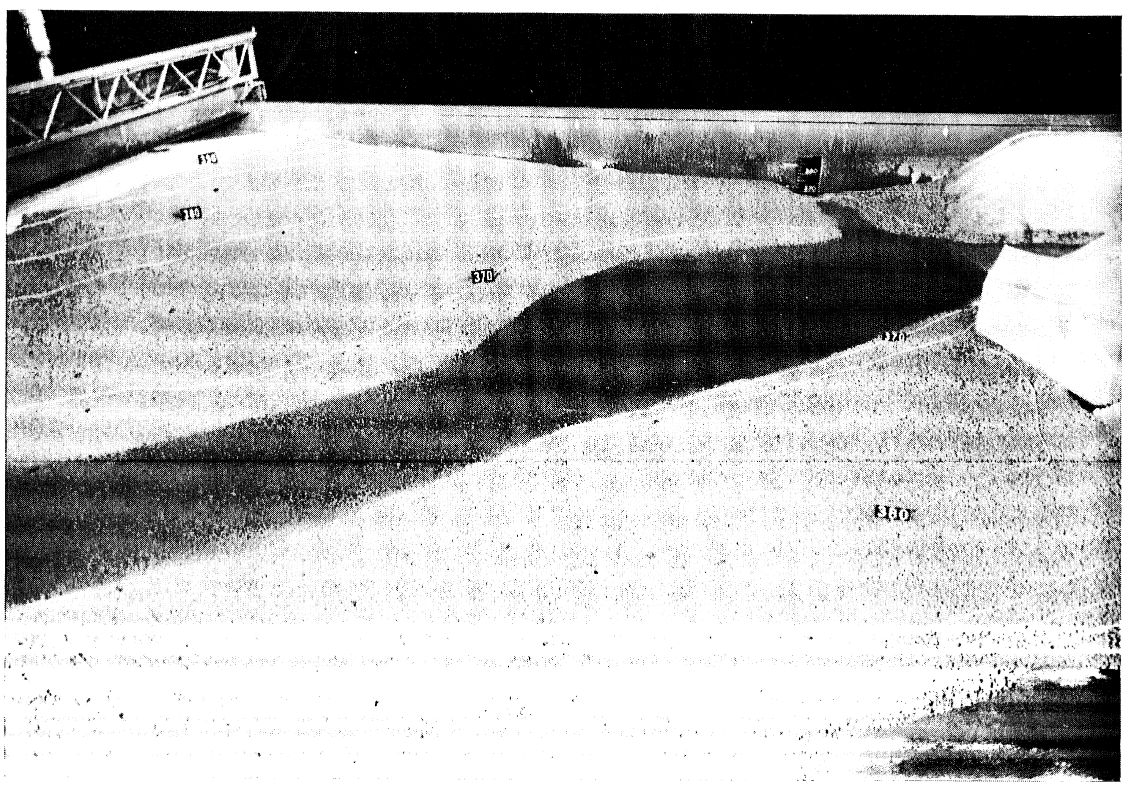

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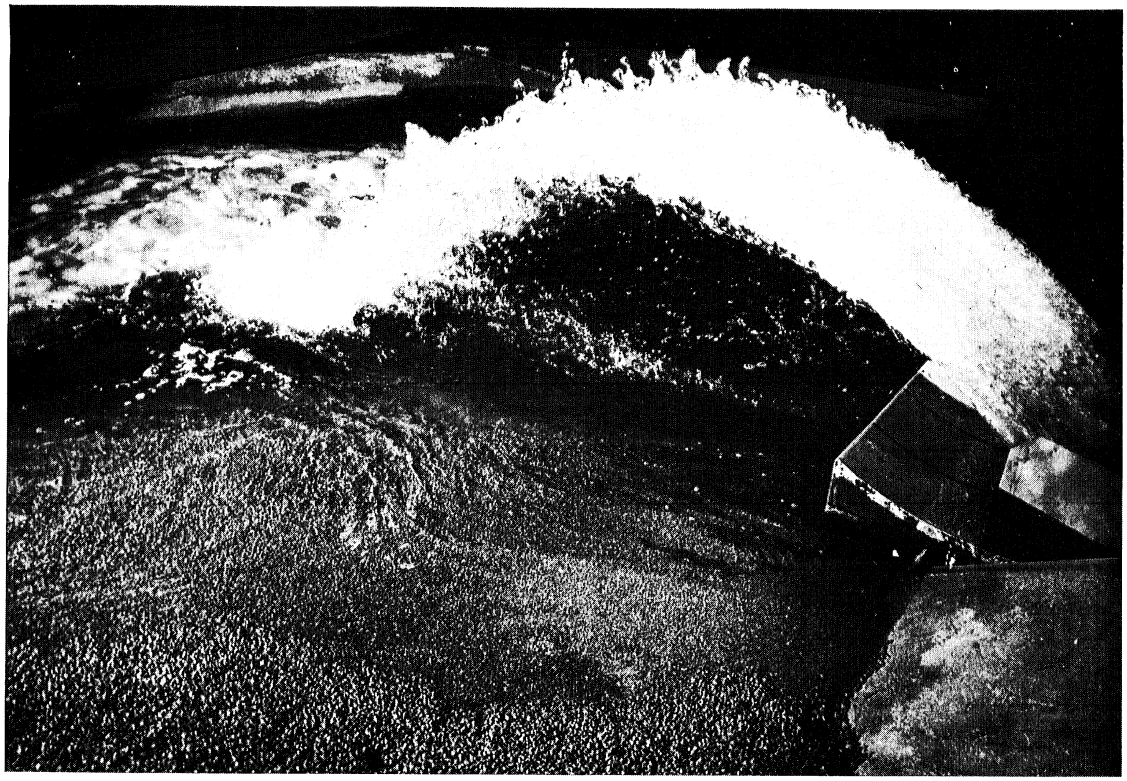

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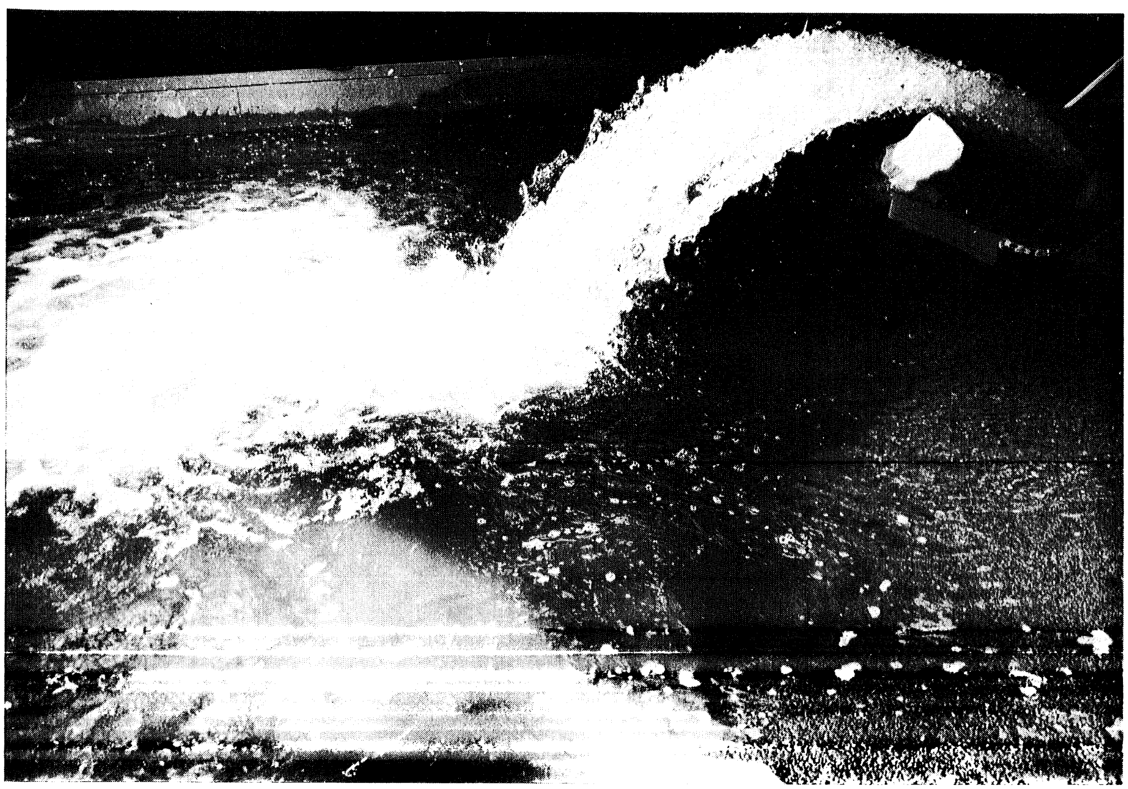

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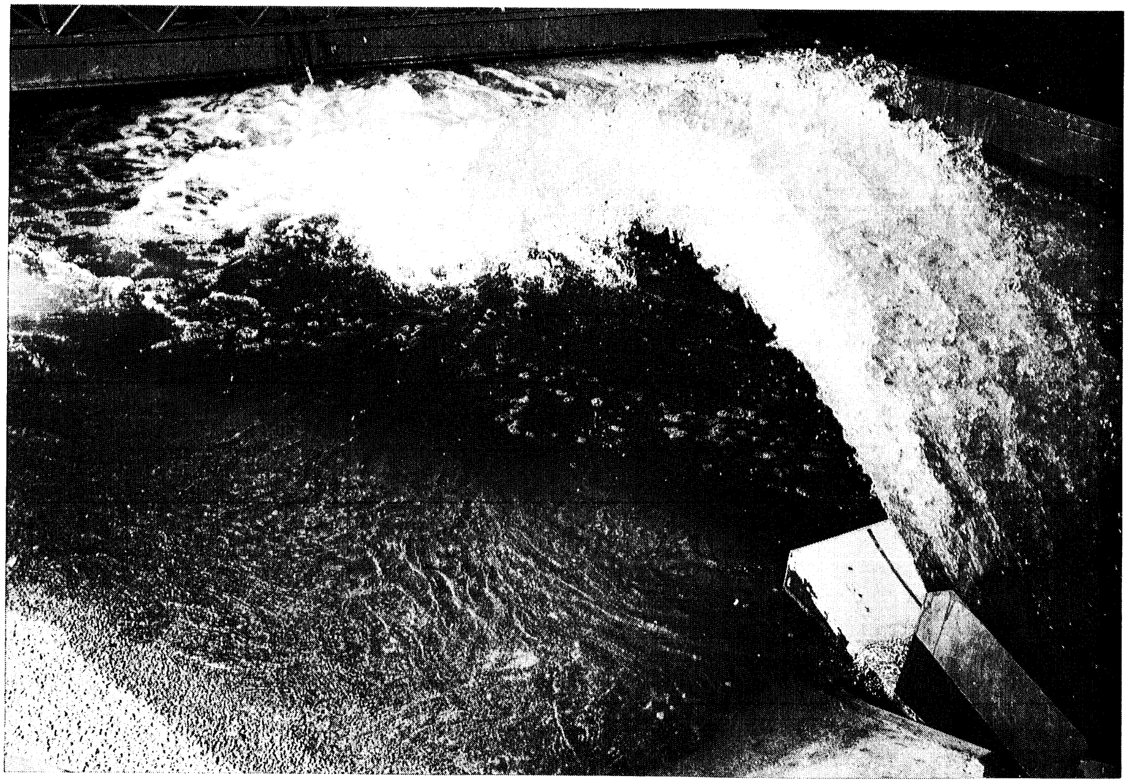

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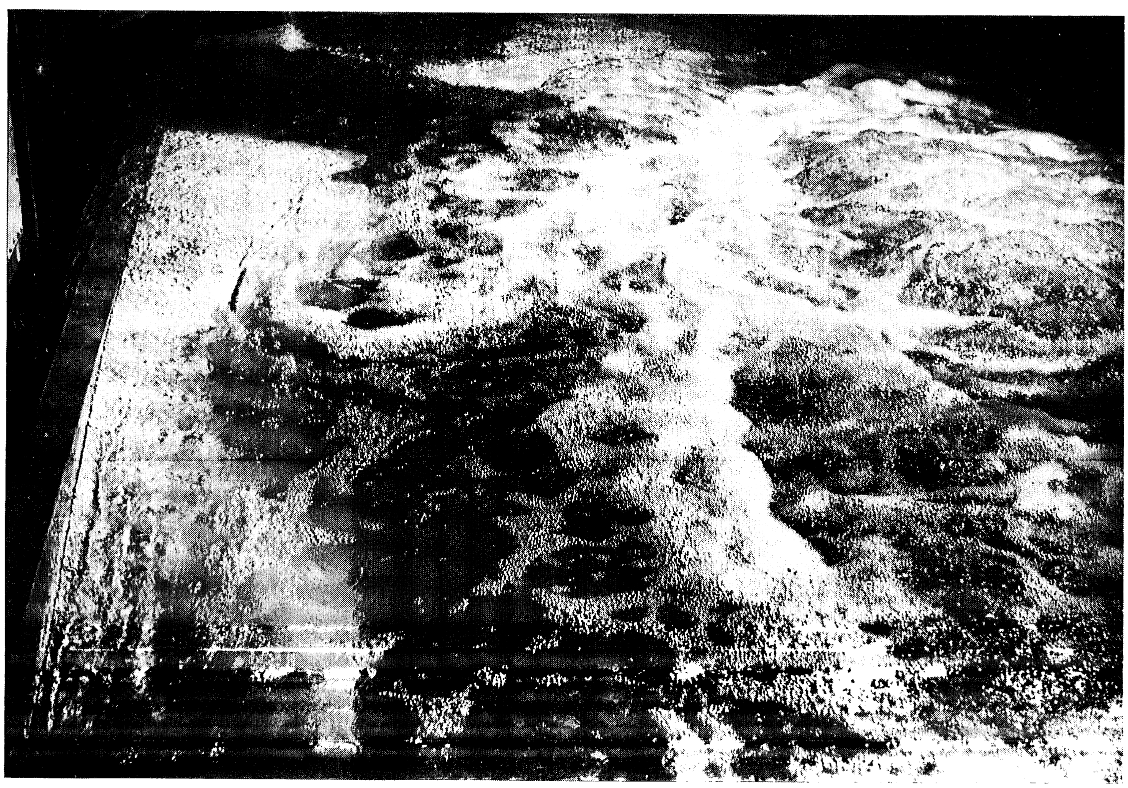

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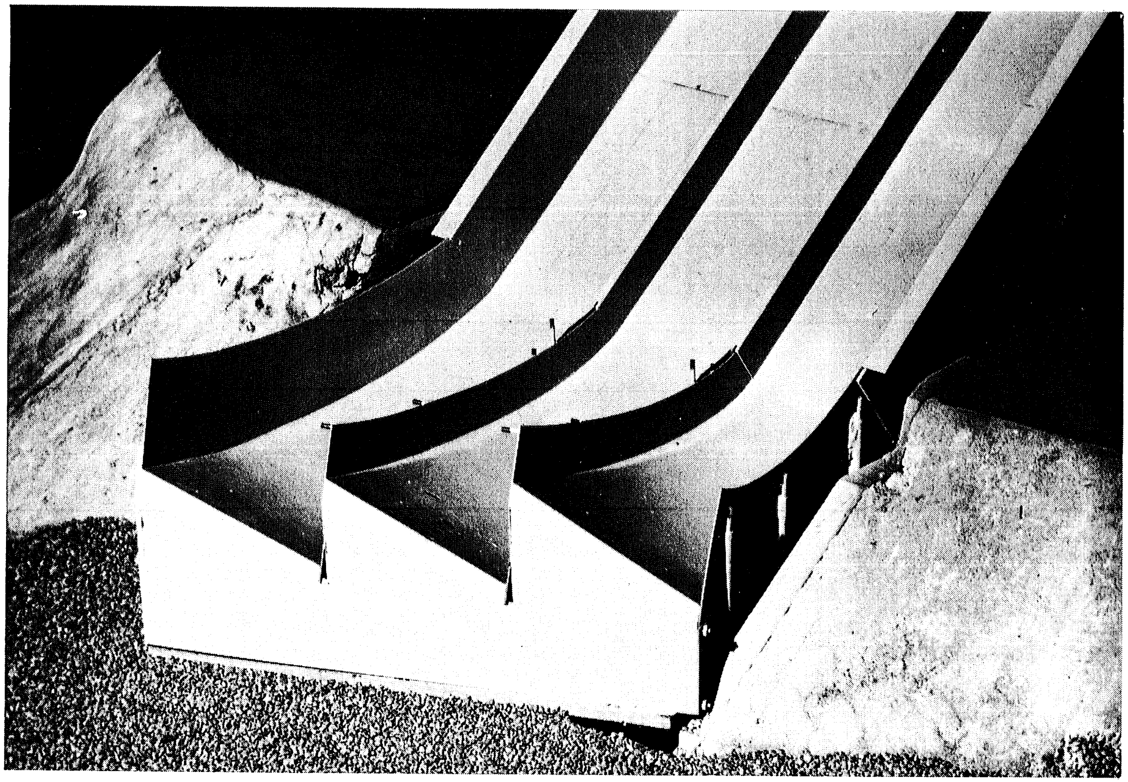

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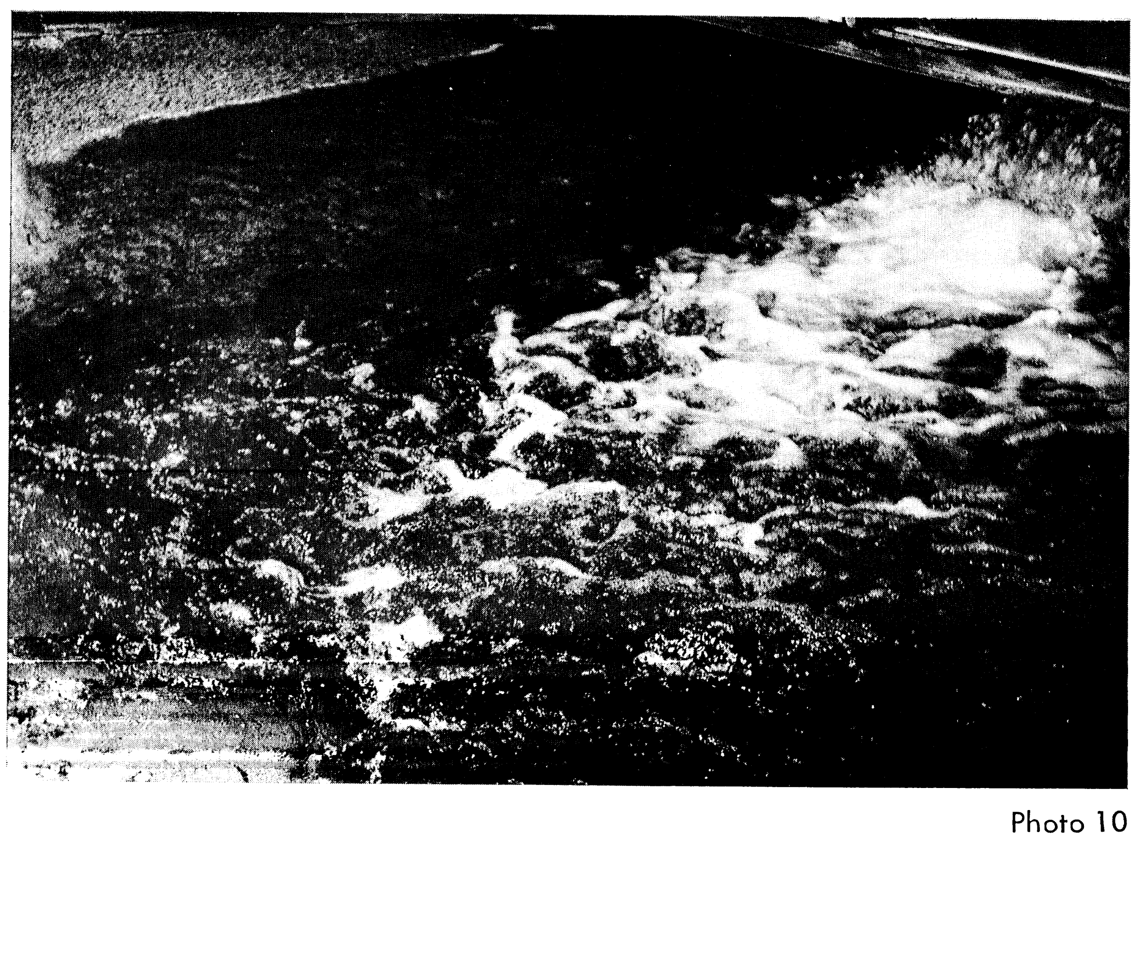

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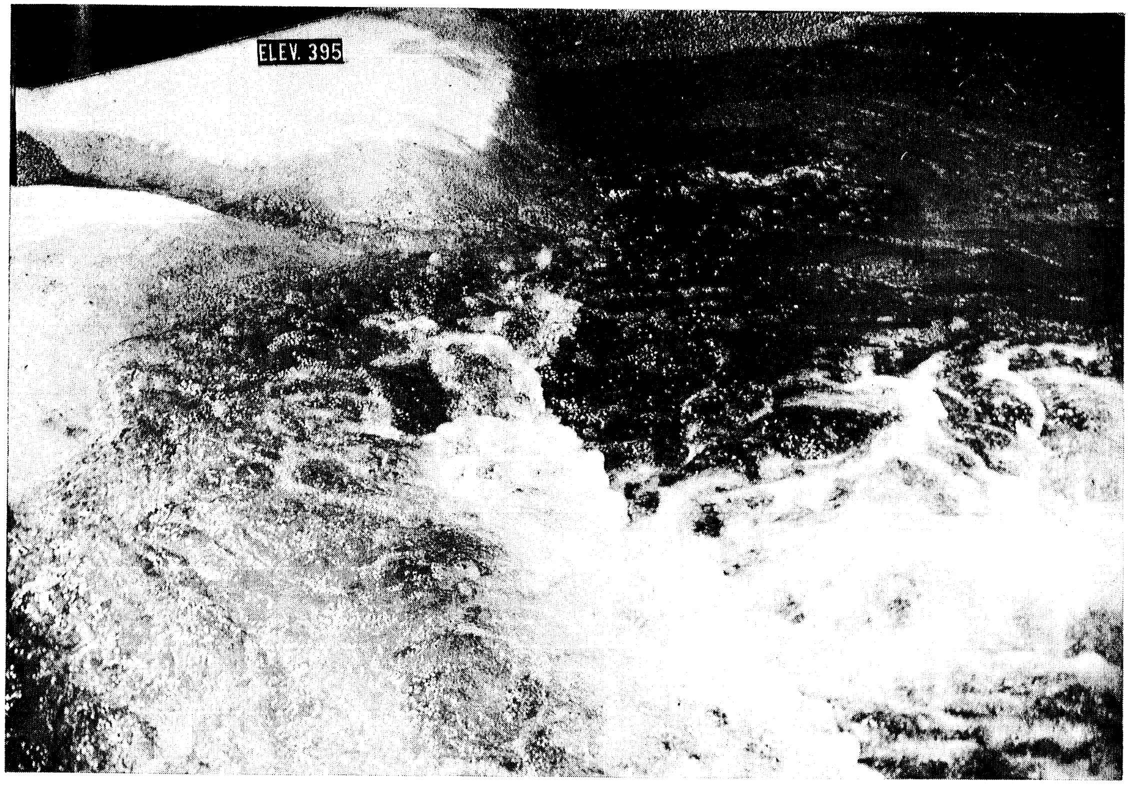

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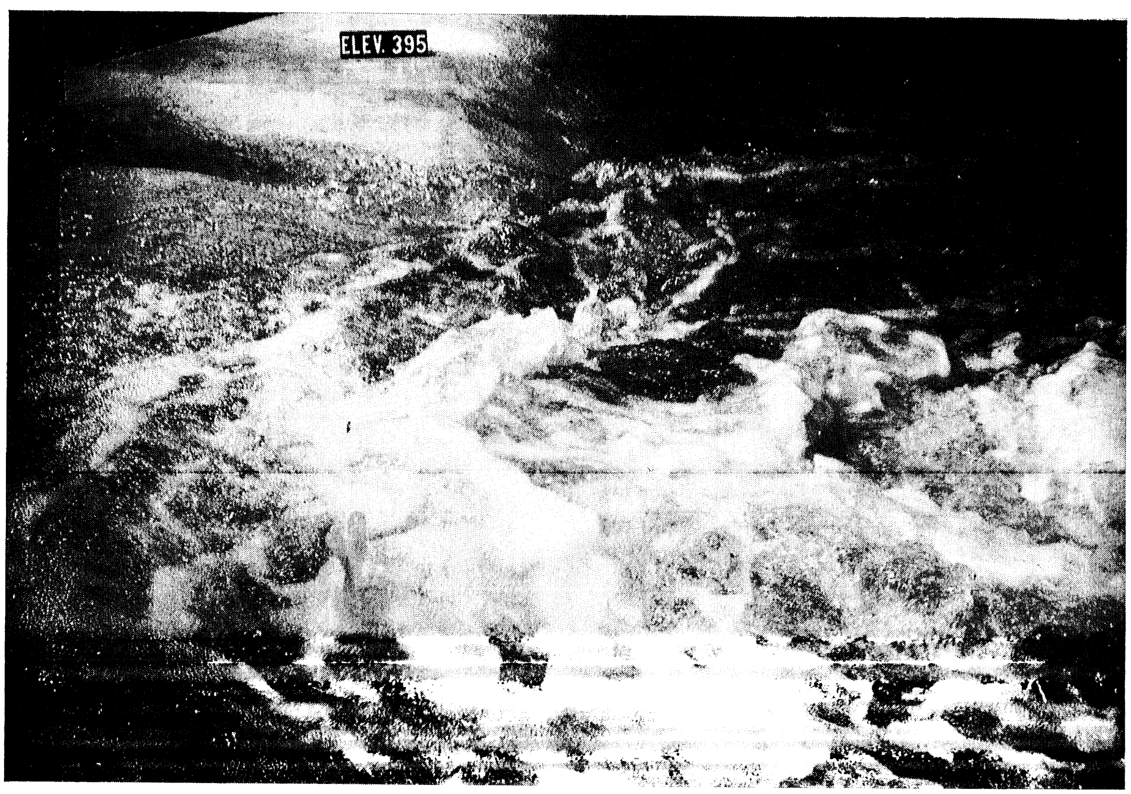

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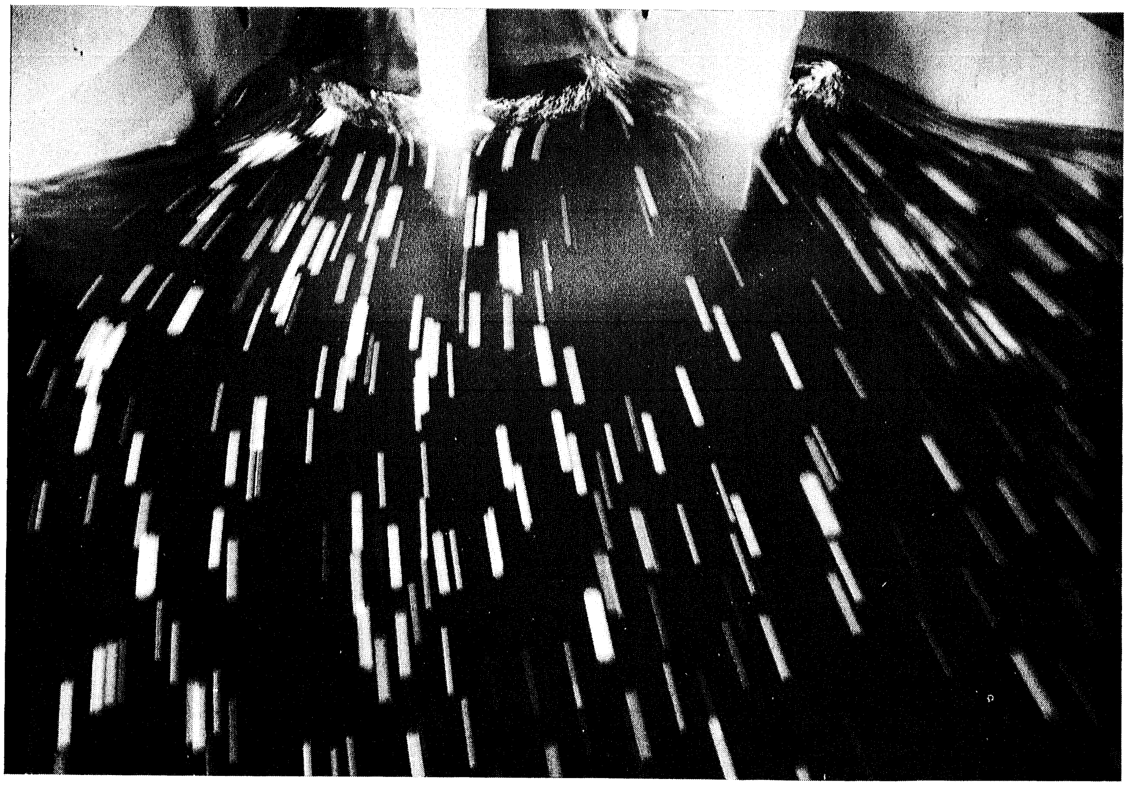

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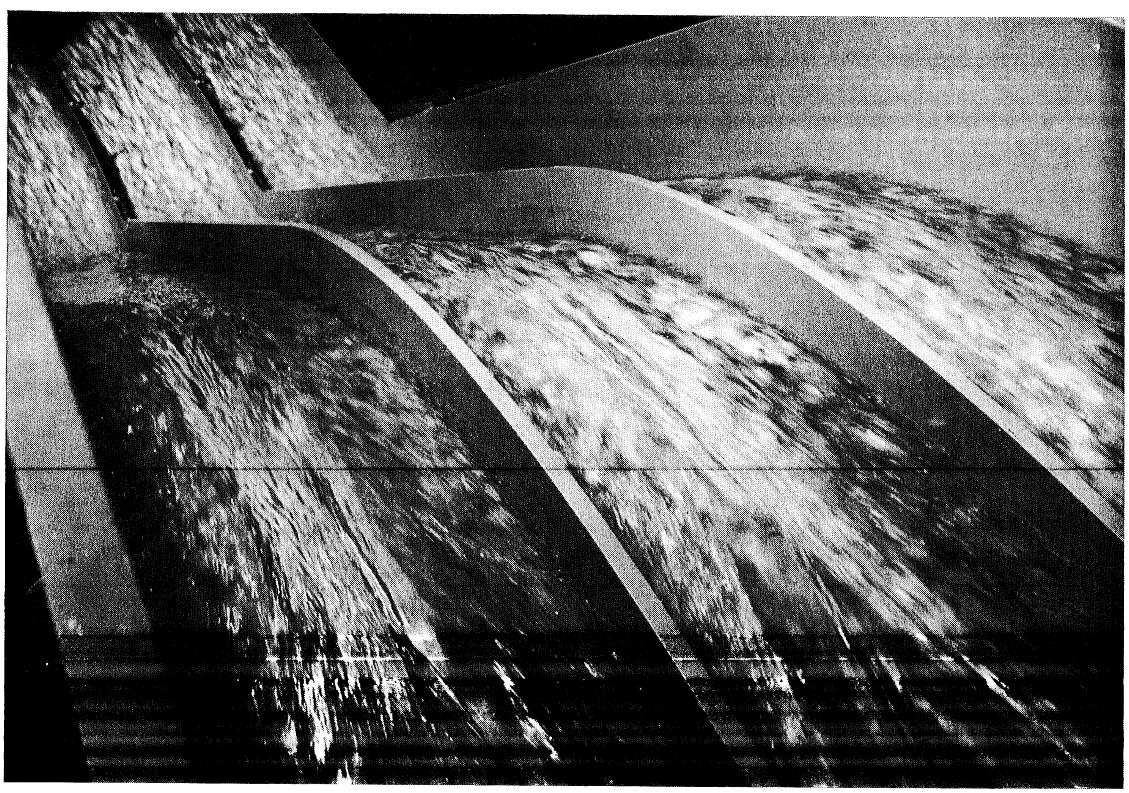

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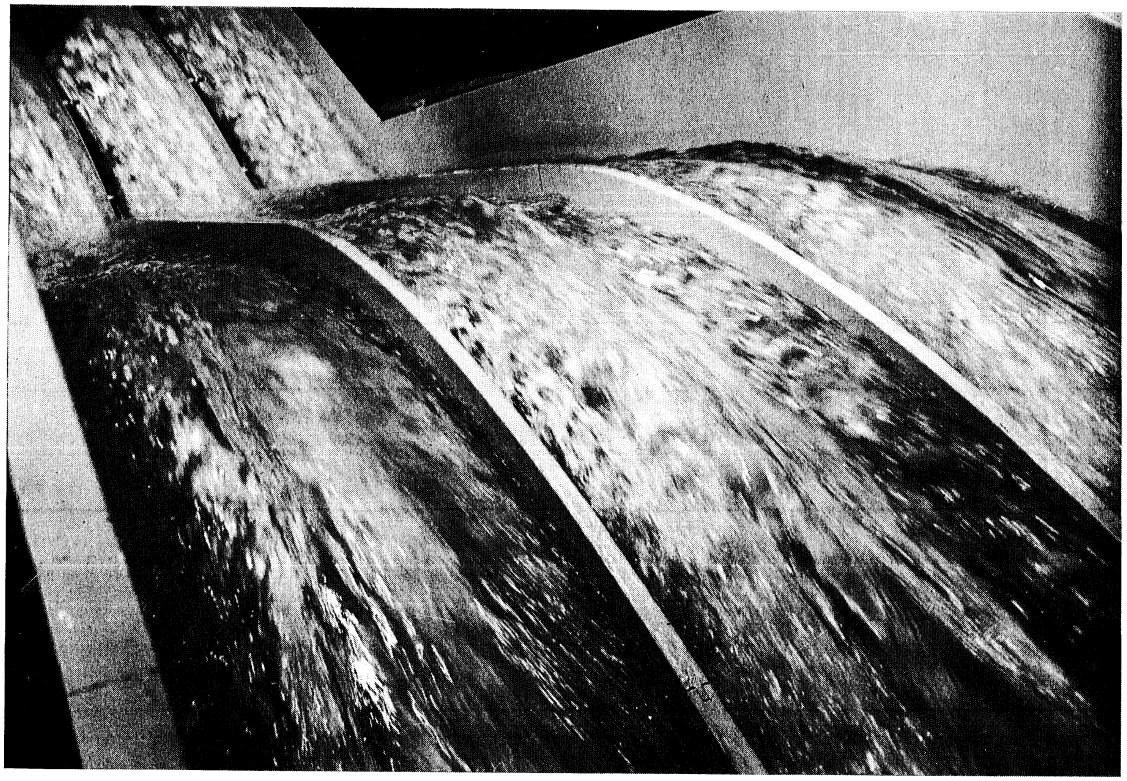

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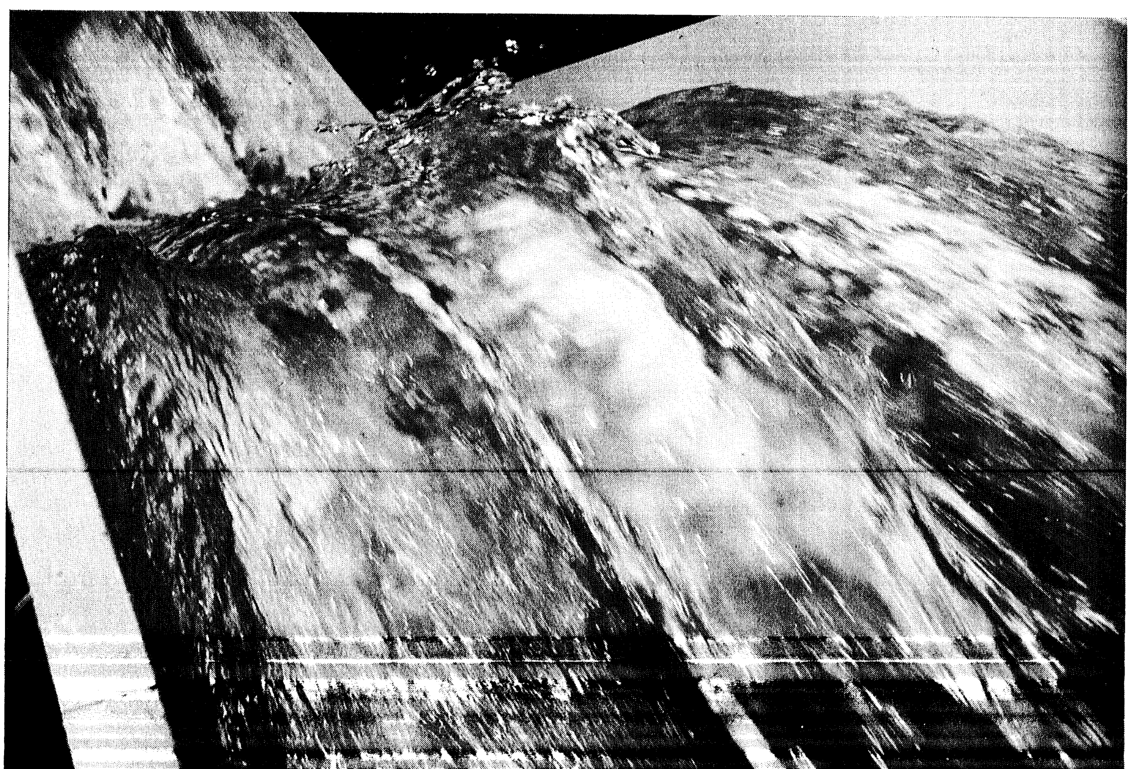

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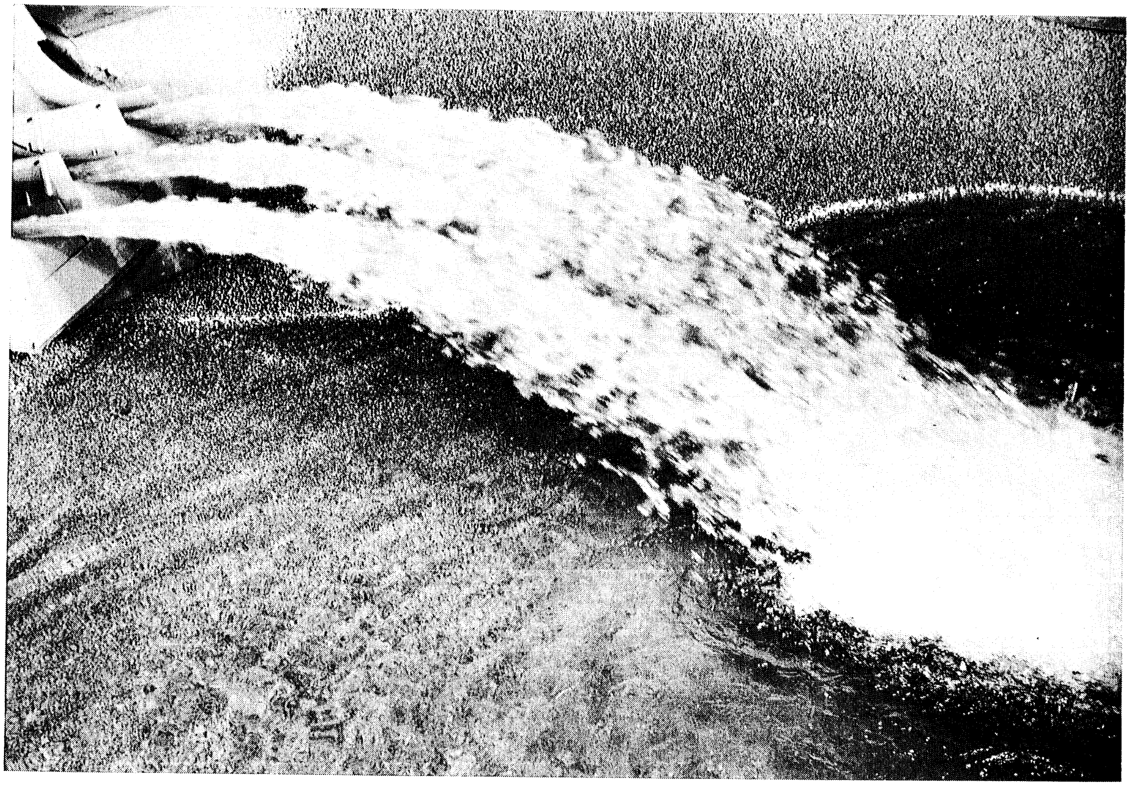

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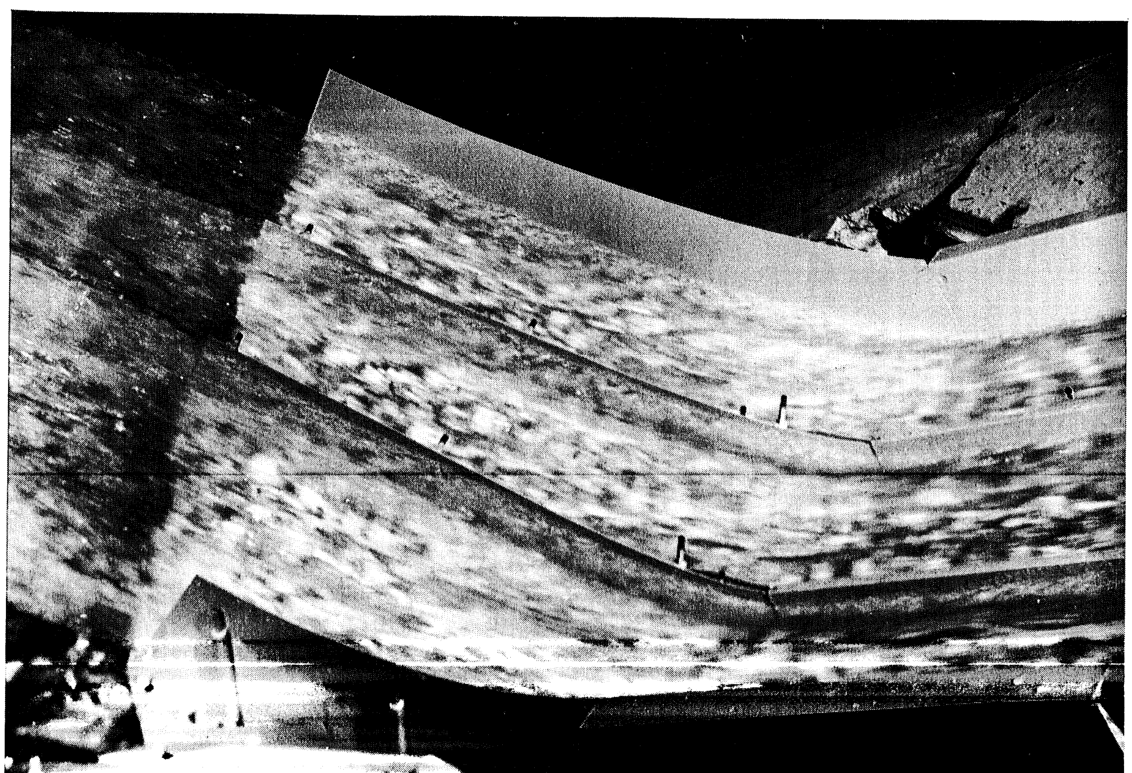

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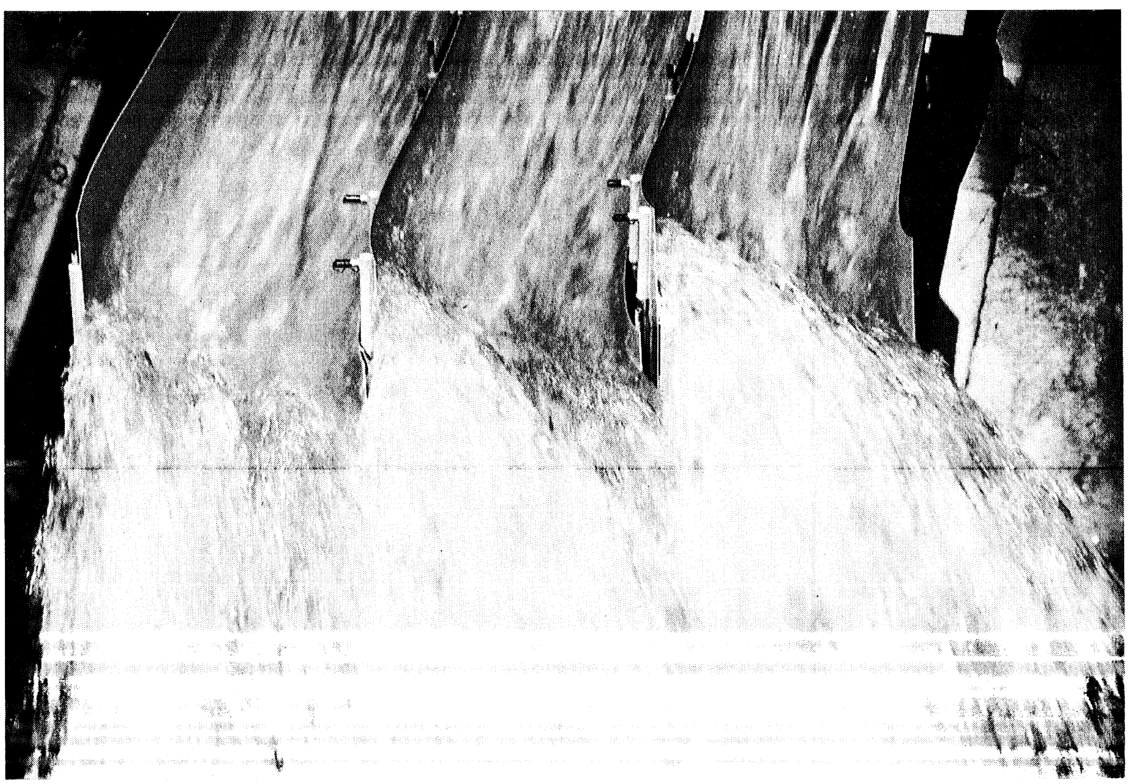

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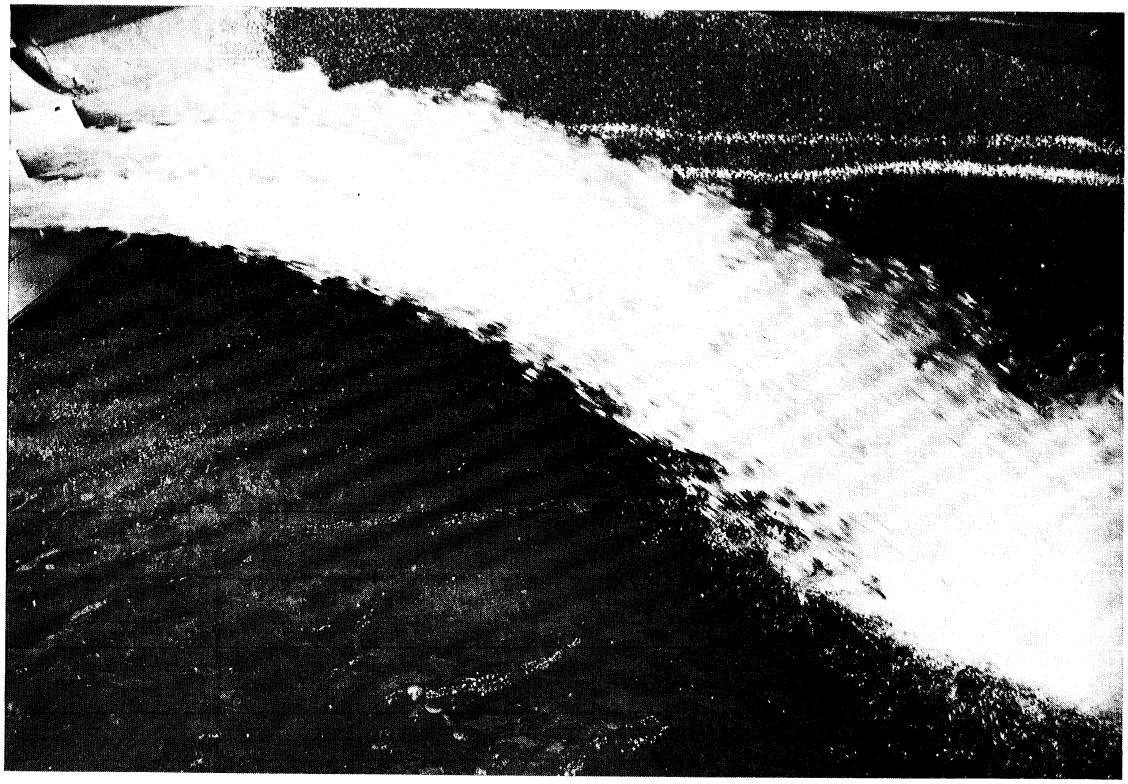

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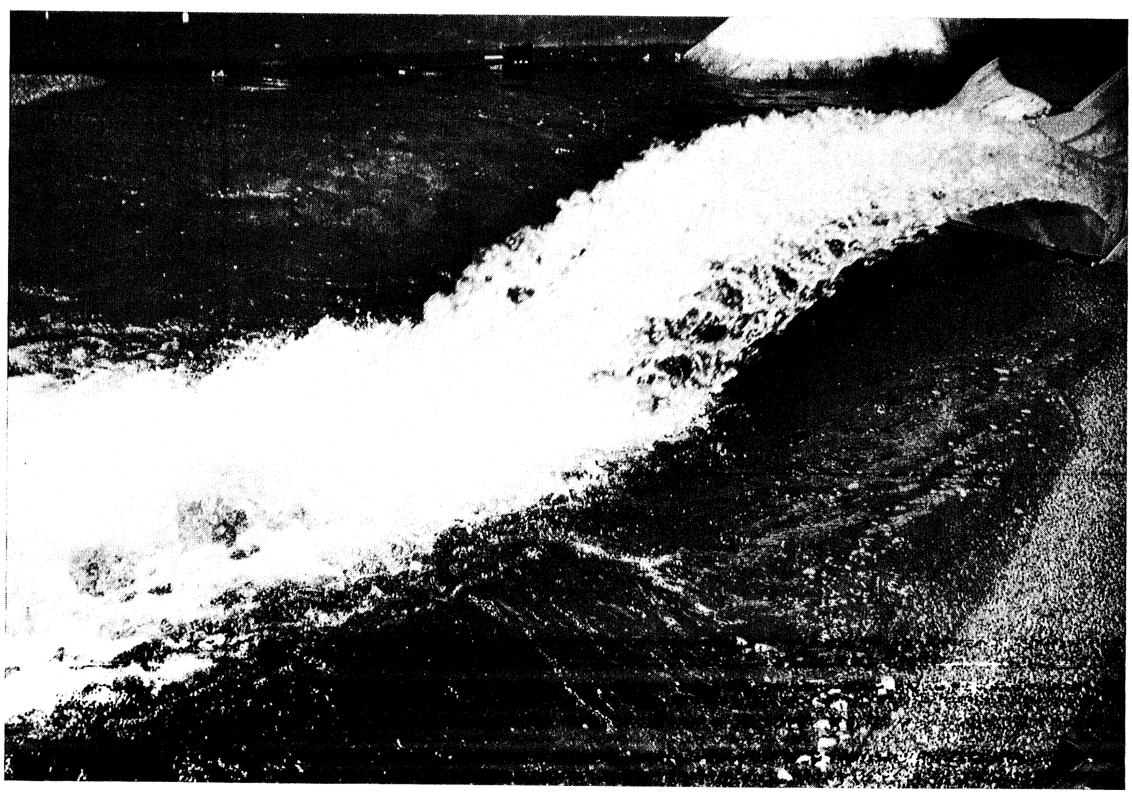

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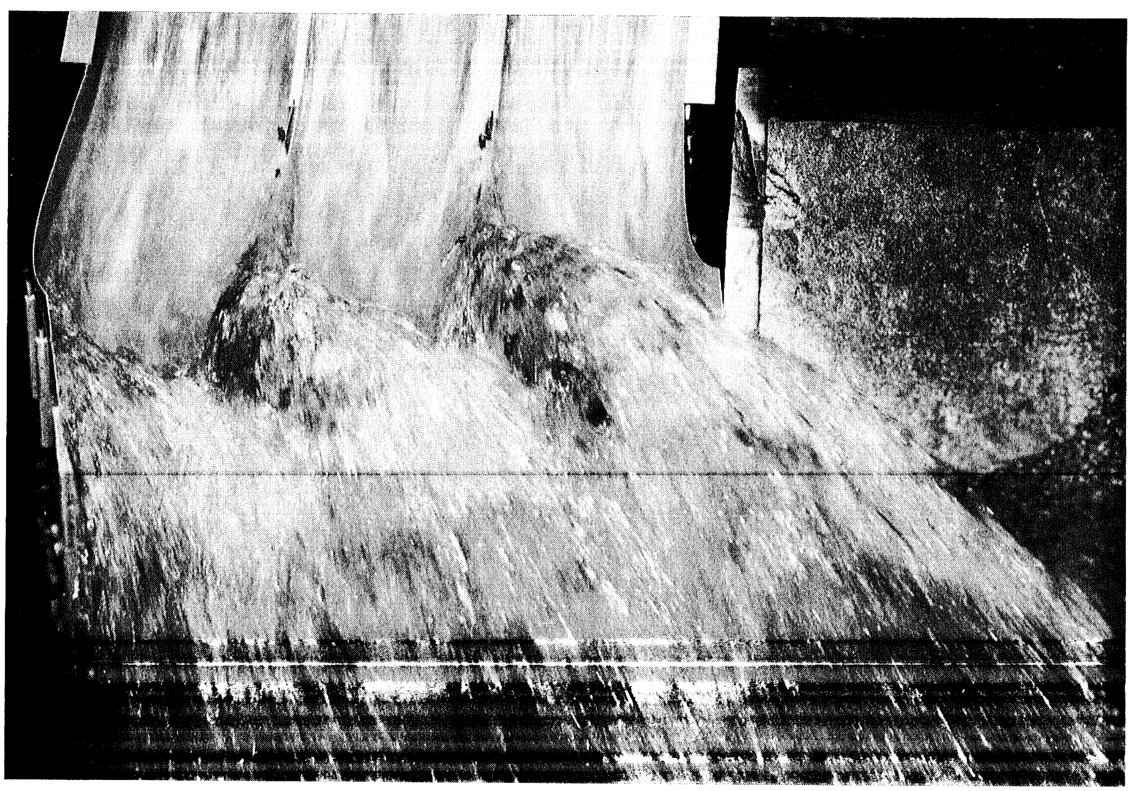

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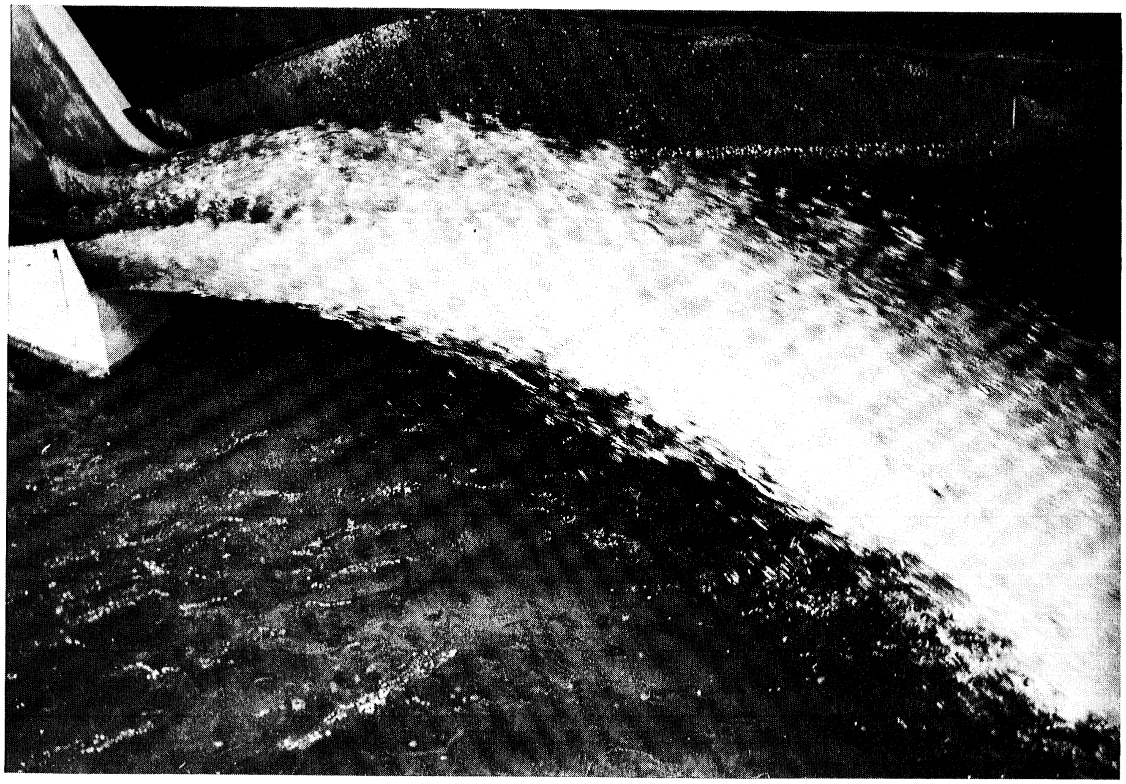

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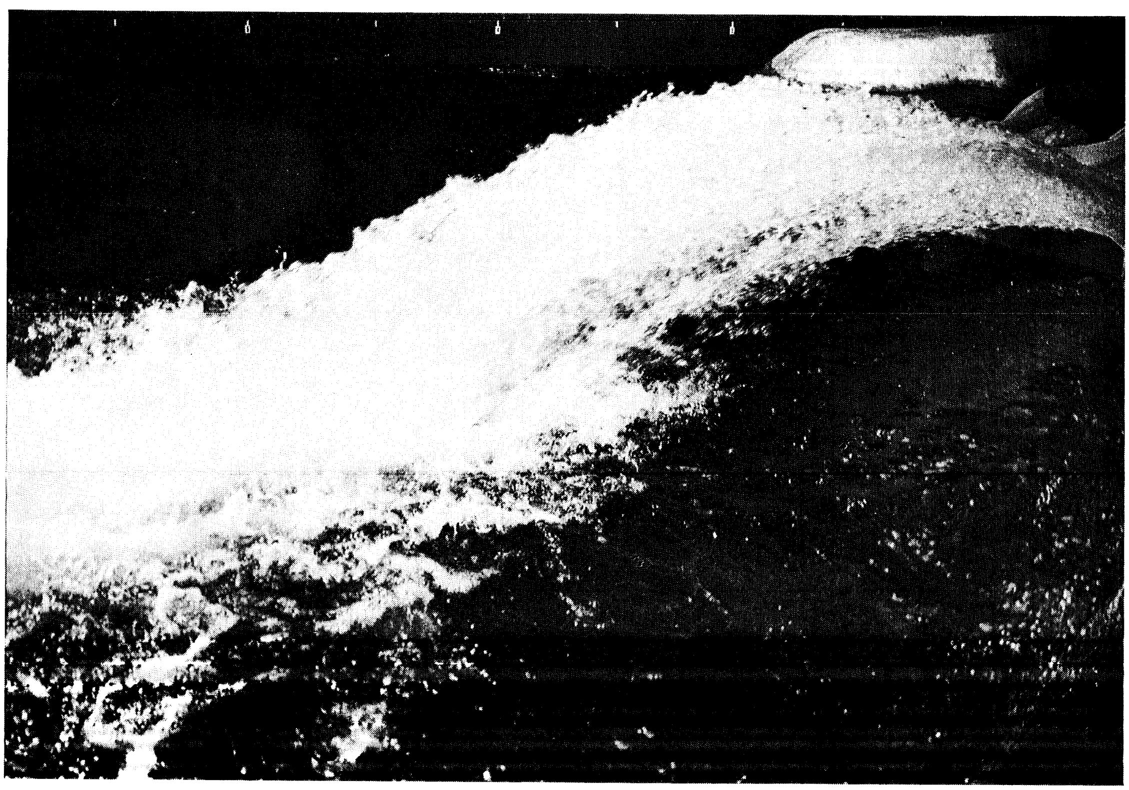

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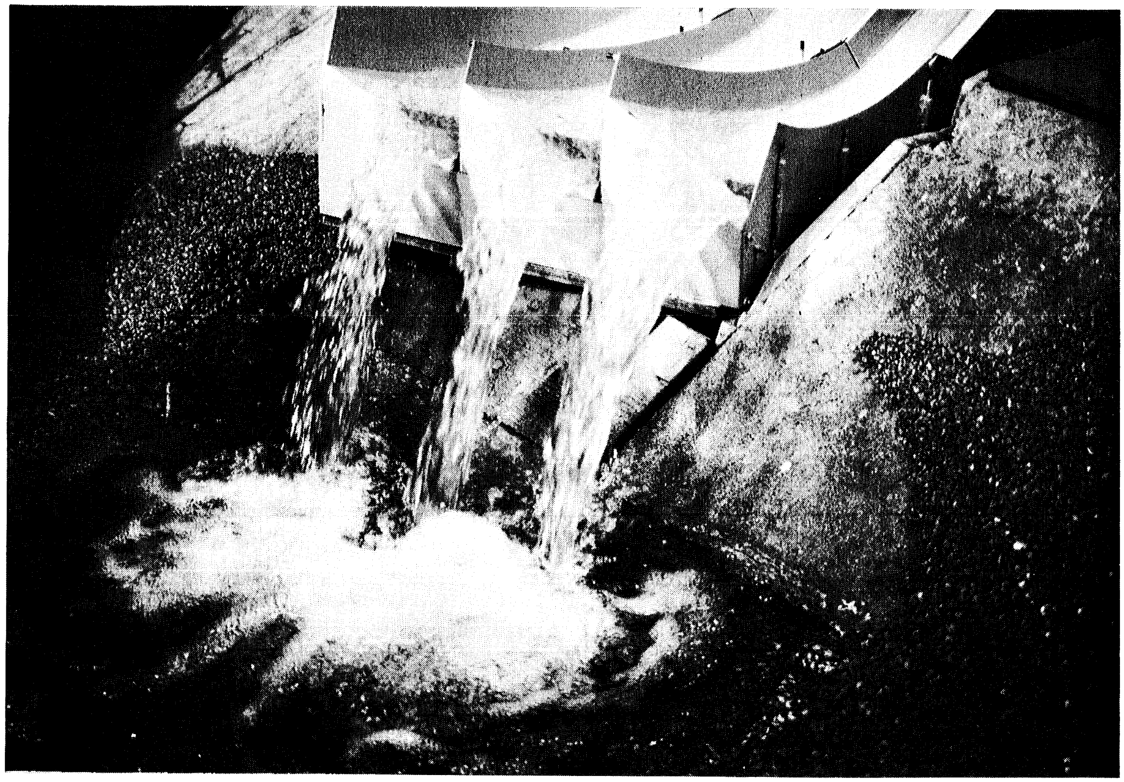

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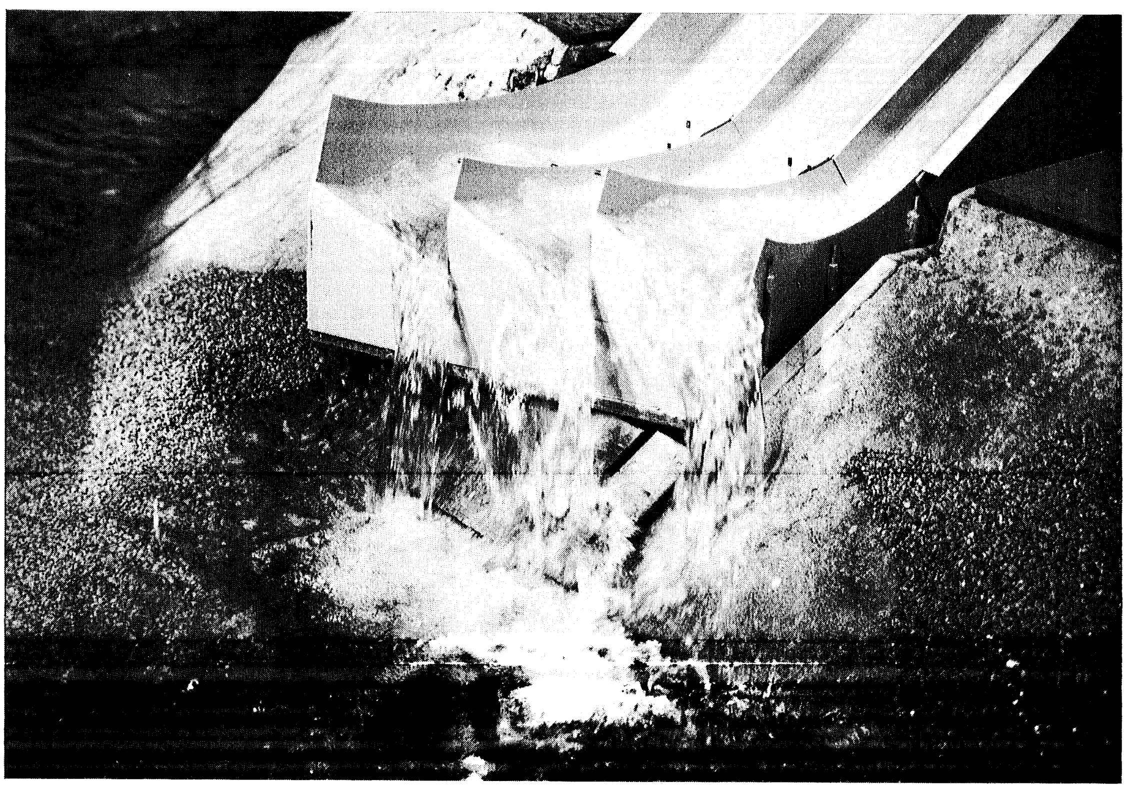

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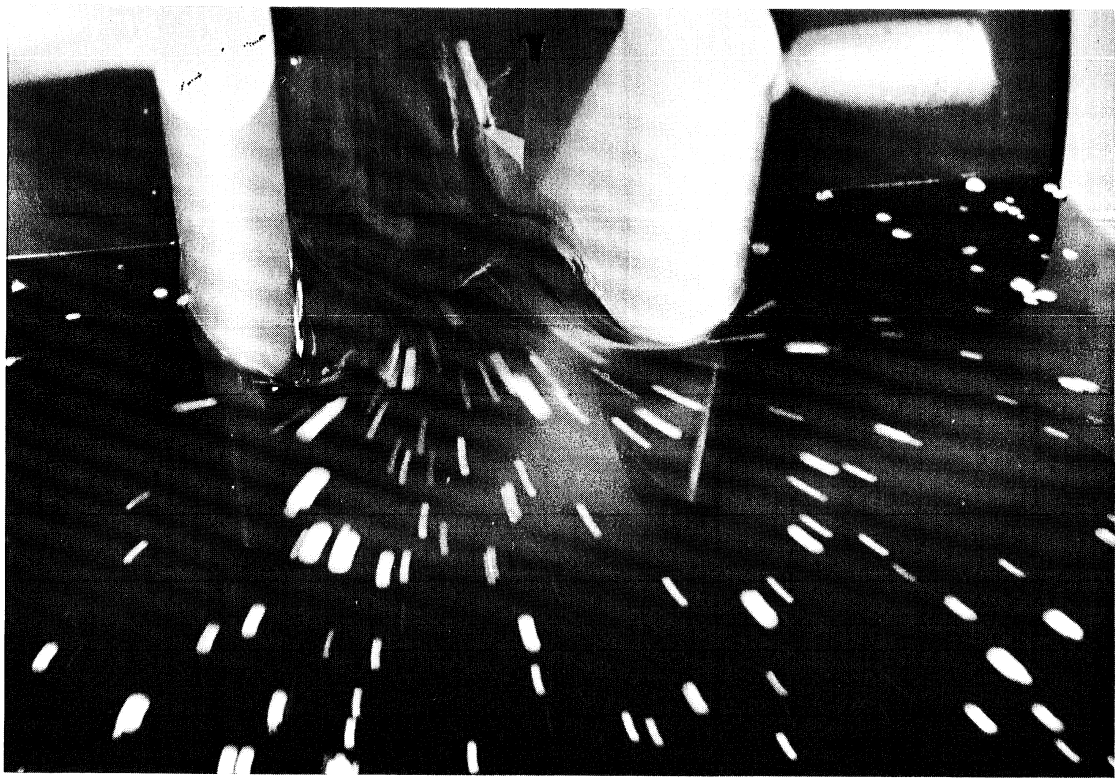

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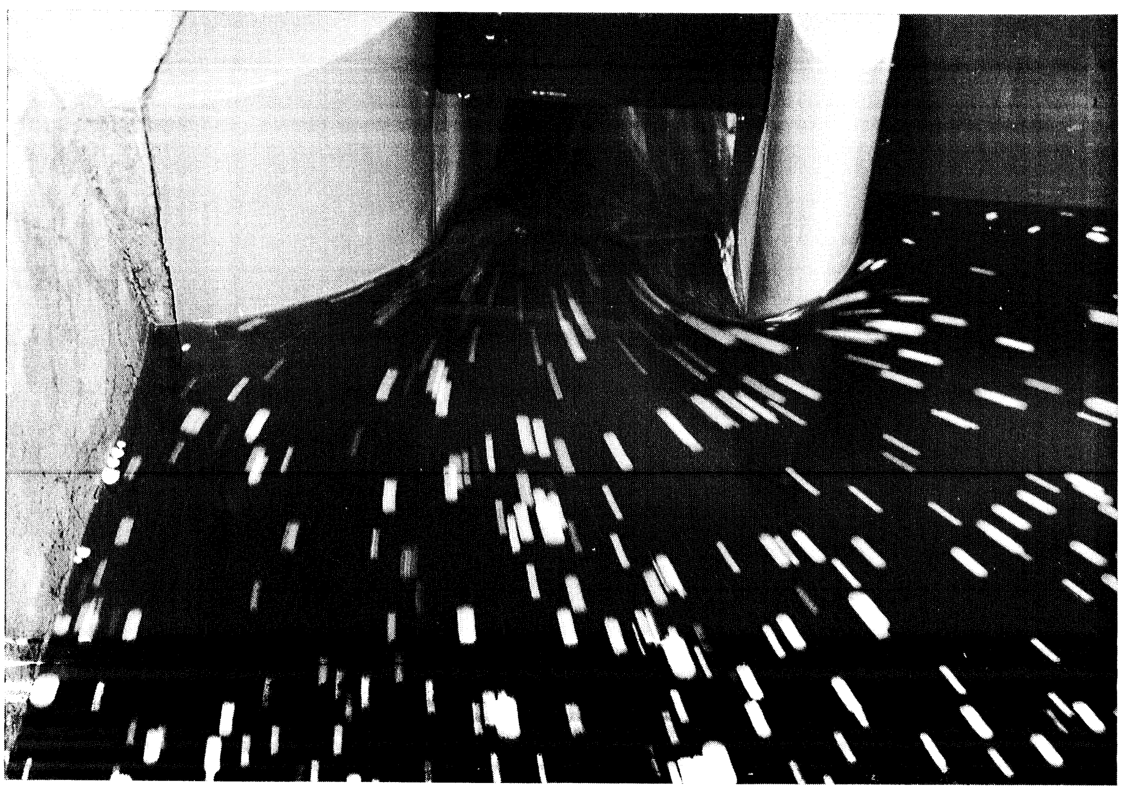

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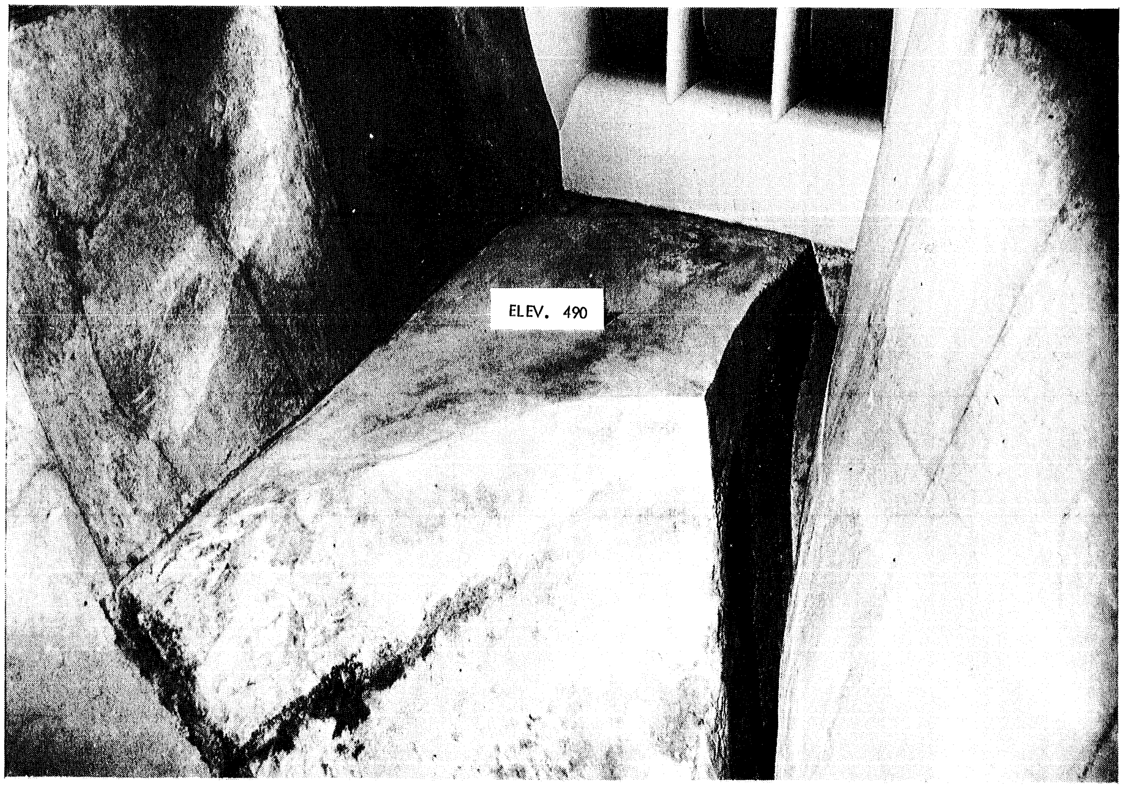

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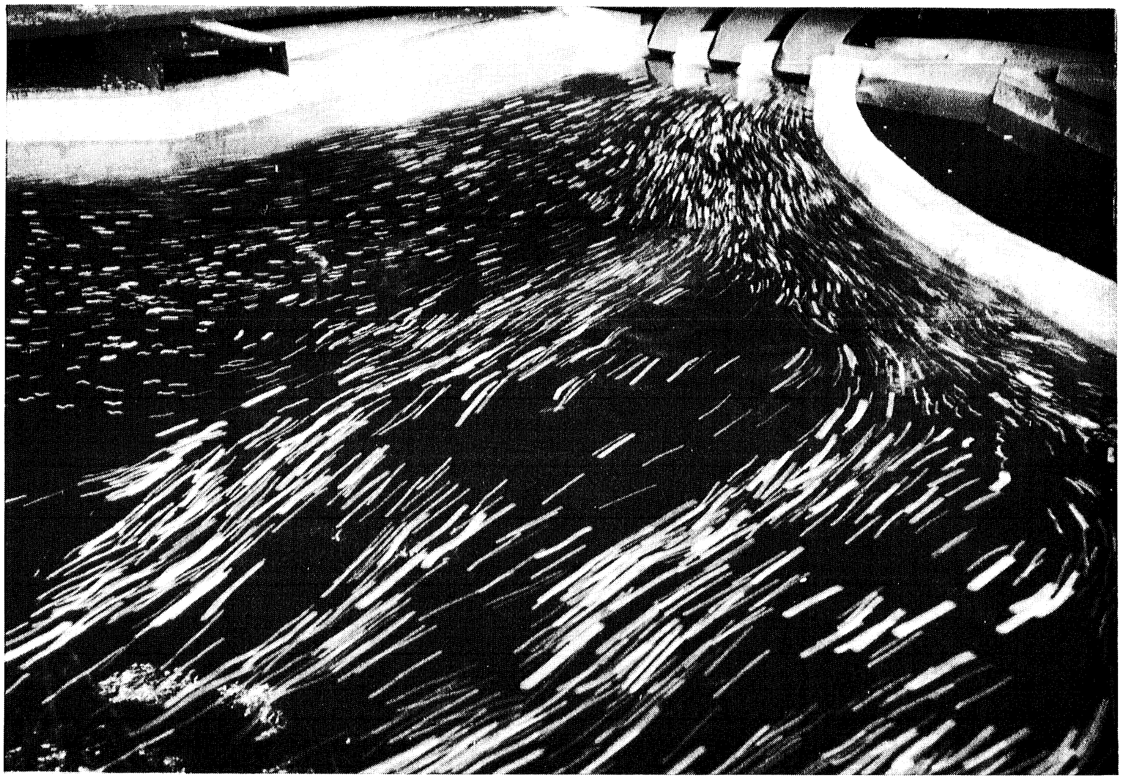

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Photo 40

PHOTO 41 (Serial No. 180-153) The relative surface velocity distribution in the approach channel with level floor at a discharge of 15,000 cms.

PHOTO 42 (Serial No. 180-69) The formation of vortices at partial gate opening. Strong vortices form from maximum flow contraction when single bays are operated alone. Gate opening is 10 m.

Photo 41

Photo 42

PHOTO 43 (Serial No. 180-78) Close-up view of a strong vortex next to a pier. Center bay is operating alone at a gate opening of 10 m and a discharge of 2,000 cms.

PHOTO 44 (Serial No. 180-80) Close-up view of a very strong vortex next to a pier adjoining a closed bay when gates in two adjacent bays are raised 10 m.

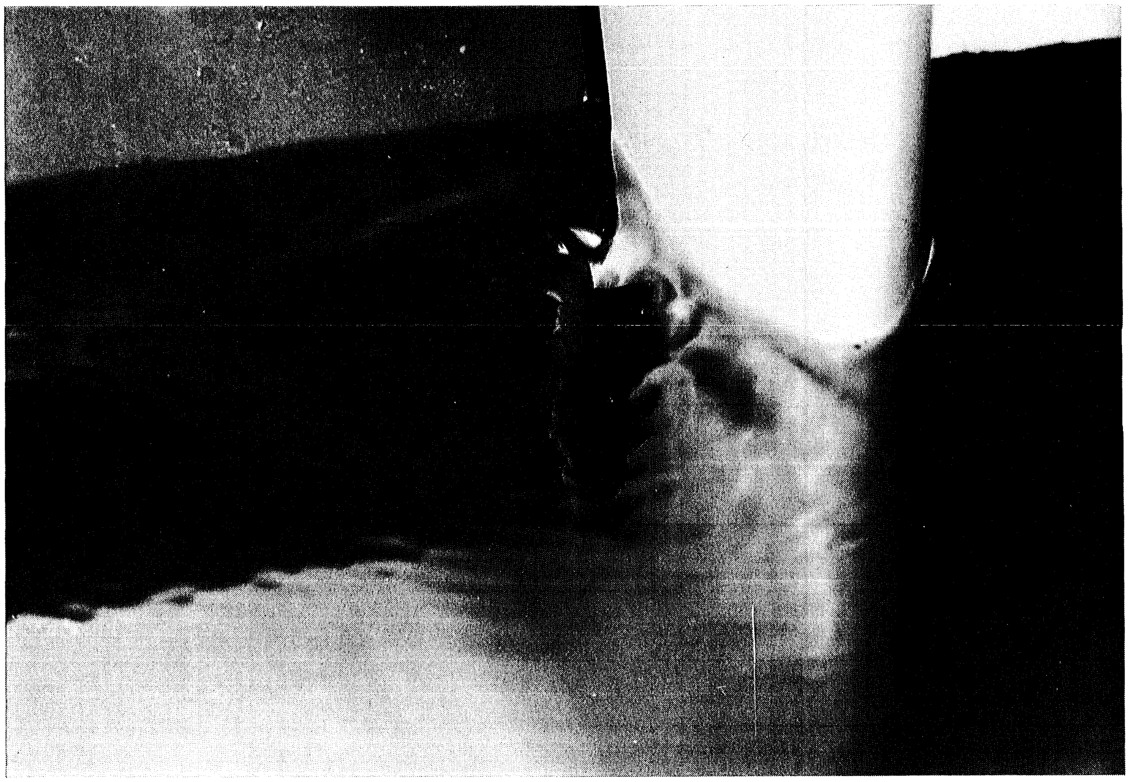


Photo 43

Photo 44

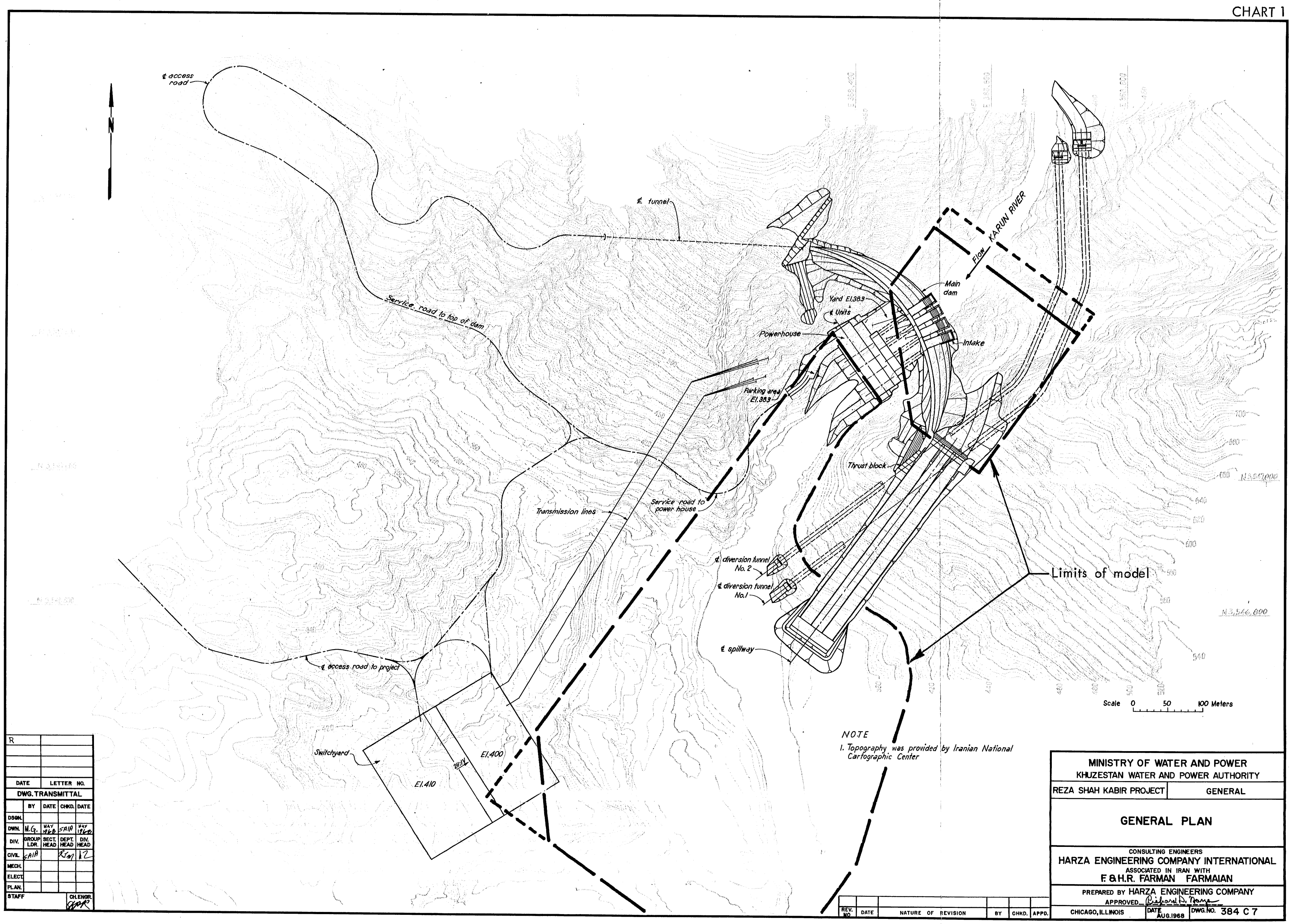
LIST OF CHARTS

CHART 36 (180B476-15) Spillway calibration for uniform partial gate openings in all bays.

CHART 37 (180B476-16) Spillway calibration for partial gate openings in the center bay only.

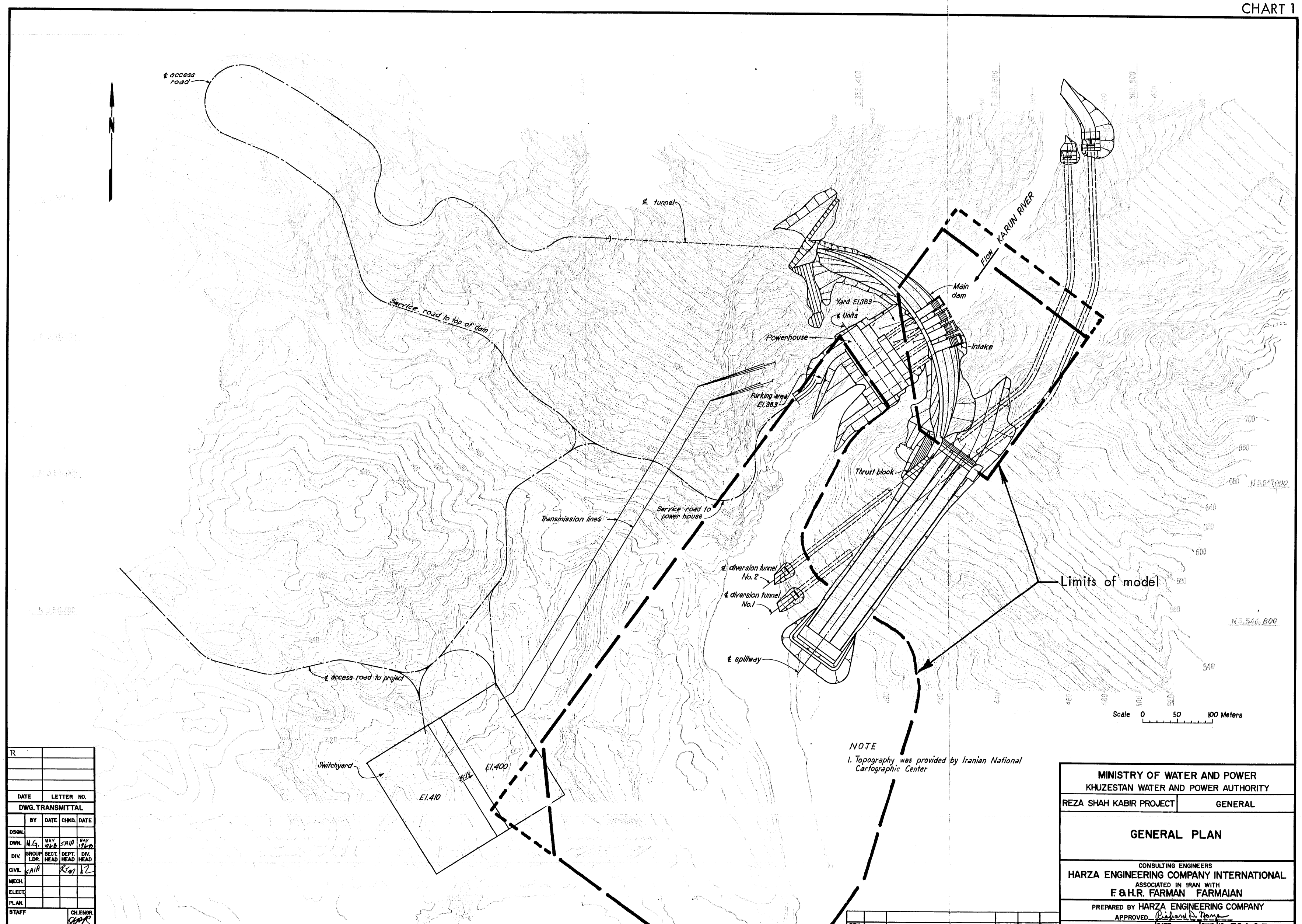
CHART 38 (180B 476-28) Velocity profiles in the approach channel.

CHART 1



N
℄ access road
℄ tunnel
Service road to top of dam
Flow KARUN RIVER
Main dam
Yard El.383
℄ Units
Powerhouse
Intake
Parking area El.383
Thrust block
Service road to power house
Transmission lines
℄ diversion tunnel No. 2
℄ diversion tunnel No.1
Limits of model
℄ spillway
℄ access road to project
Switchyard
El.400
El.410
N3,547,000
N3,546,800
Scale 0 50 100 Meters
NOTE
1. Topography was provided by Iranian National Cartographic Center
MINISTRY OF WATER AND POWER
KHUZESTAN WATER AND POWER AUTHORITY
REZA SHAH KABIR PROJECT
GENERAL
GENERAL PLAN
CONSULTING ENGINEERS
HARZA ENGINEERING COMPANY INTERNATIONAL
ASSOCIATED IN IRAN WITH
F. & H.R. FARMAN FARMAIAN
PREPARED BY HARZA ENGINEERING COMPANY
APPROVED
CHICAGO, ILLINOIS
DATE AUG.1968
DWG.NO. 384 C 7
REV. NO.
DATE
NATURE OF REVISION
BY
CHKD.
APPD.
DATE
LETTER NO.
DWG. TRANSMITTAL
BY
DATE
CHKD.
DATE
DSGN.
DWN.
M.G.
MAY 1968
MAY 1968
DIV.
GROUP LDR.
SECT. HEAD
DEPT. HEAD
DIV. HEAD
CIVIL
MECH.
ELECT.
PLAN.
STAFF
CH. ENGR.

CHART 1



N
℄ access road
℄ tunnel
Service road to top of dam
Flow
KARUN RIVER
Main dam
Yard El.383
℄ Units
Powerhouse
Intake
Parking area El.383
Thrust block
Transmission lines
Service road to power house
℄ diversion tunnel No. 2
℄ diversion tunnel No. 1
℄ spillway
Limits of model
℄ access road to project
Switchyard
El.400
El.410
Scale 0 50 100 Meters
NOTE
1. Topography was provided by Iranian National Cartographic Center
N 3,566,800
MINISTRY OF WATER AND POWER
KHUZESTAN WATER AND POWER AUTHORITY
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PREPARED BY HARZA ENGINEERING COMPANY
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DWG. NO. 384 C 7
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DATE
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BY
CHKD.
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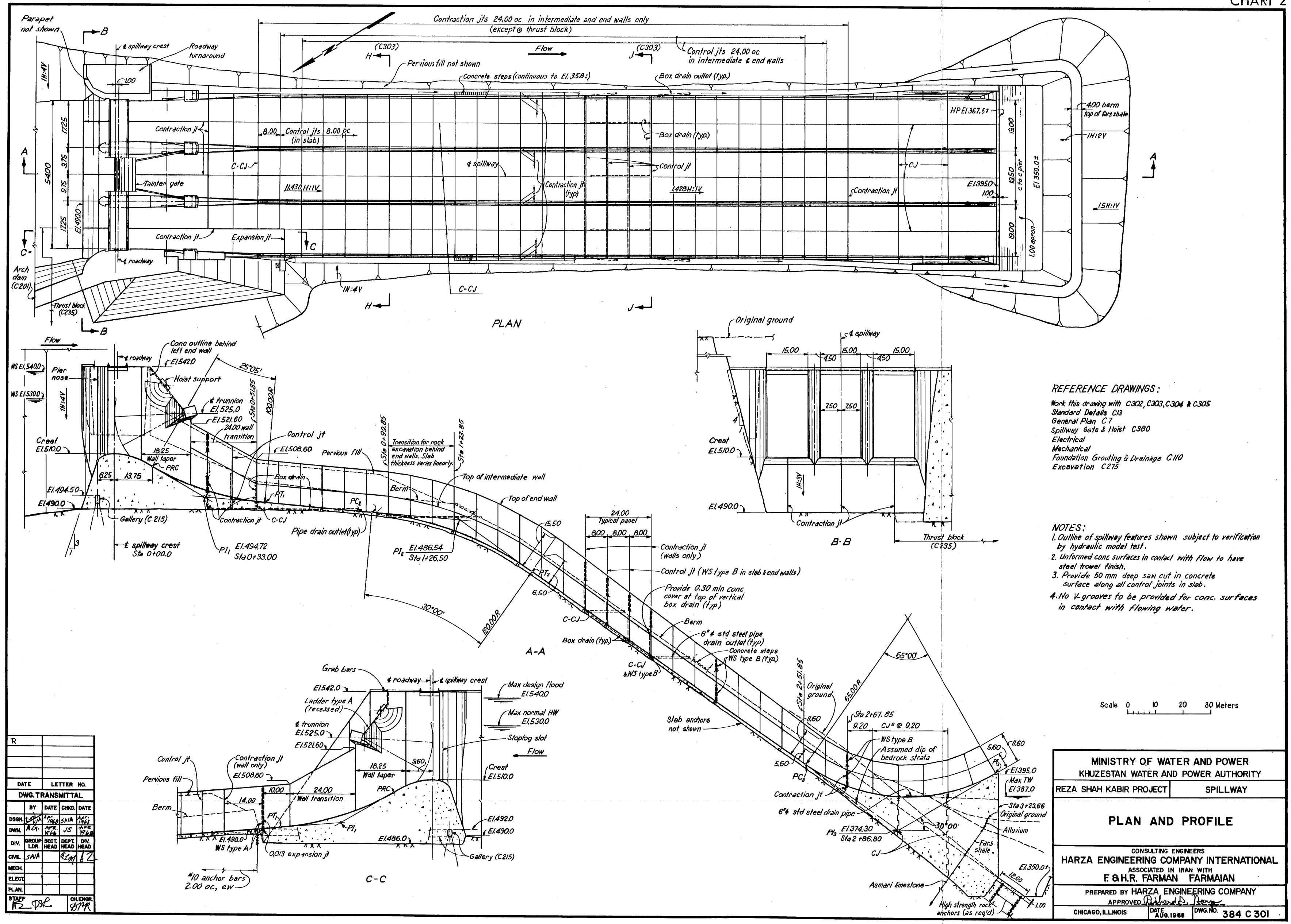
DATE
LETTER NO.
DWG. TRANSMITTAL
BY
DATE
CHKD.
DSGN.
DWN.
DIV.
GROUP LDR.
SECT. HEAD
DEPT. HEAD
DIV. HEAD
CIVIL
MECH.
ELECT.
PLAN.
STAFF
CH.ENGR.


PLAN
A-A
B-B
C-C
Contraction jts 24.00 oc in intermediate and end walls only (except @ thrust block)
Control jts 24.00 oc in intermediate & end walls
Parapet not shown
℄ spillway crest
Roadway turnaround
Pervious fill not shown
Concrete steps (continuous to El.358±)
Box drain outlet (typ)
Flow
Contraction jt
Control jts 8.00 oc (in slab)
Box drain (typ)
Tainter gate
℄ spillway
Control jt
Contraction jt (typ)
Expansion jt
Arch dam (C201)
Thrust block (C235)
℄ roadway
HP El.367.5±
El.395.0
El.350.0±
1.00 apron
4.00 berm top of Fars shale
Original ground
Typical panel
Contraction jt (walls only)
Control jt (WS type B in slab & end walls)
Provide 0.30 min conc cover at top of vertical box drain (typ)
6" ⌀ std steel pipe drain outlet (typ)
Concrete steps WS type B (typ)
Slab anchors not shown
Max design flood El.540.0
Max normal HW El.530.0
Stoplog slot
Crest El.510.0
Gallery (C215)
Ladder type A (recessed)
Grab bars
Wall transition
Wall taper
#10 anchor bars 2.00 oc, e.w.
0.013 expansion jt
Assumed dip of bedrock strata
Alluvium
Fars shale
Asmari limestone
High strength rock anchors (as req'd)
REFERENCE DRAWINGS:
Work this drawing with C302, C303, C304 & C305
Standard Details C13
General Plan C7
Spillway Gate & Hoist C380
Electrical
Mechanical
Foundation Grouting & Drainage C110
Excavation C215
NOTES:
1. Outline of spillway features shown subject to verification by hydraulic model test.
2. Unformed conc surfaces in contact with flow to have steel trowel finish.
3. Provide 50 mm deep saw cut in concrete surface along all control joints in slab.
4. No V-grooves to be provided for conc. surfaces in contact with flowing water.
Scale 0 10 20 30 Meters
MINISTRY OF WATER AND POWER
KHUZESTAN WATER AND POWER AUTHORITY
REZA SHAH KABIR PROJECT
SPILLWAY
PLAN AND PROFILE
CONSULTING ENGINEERS
HARZA ENGINEERING COMPANY INTERNATIONAL
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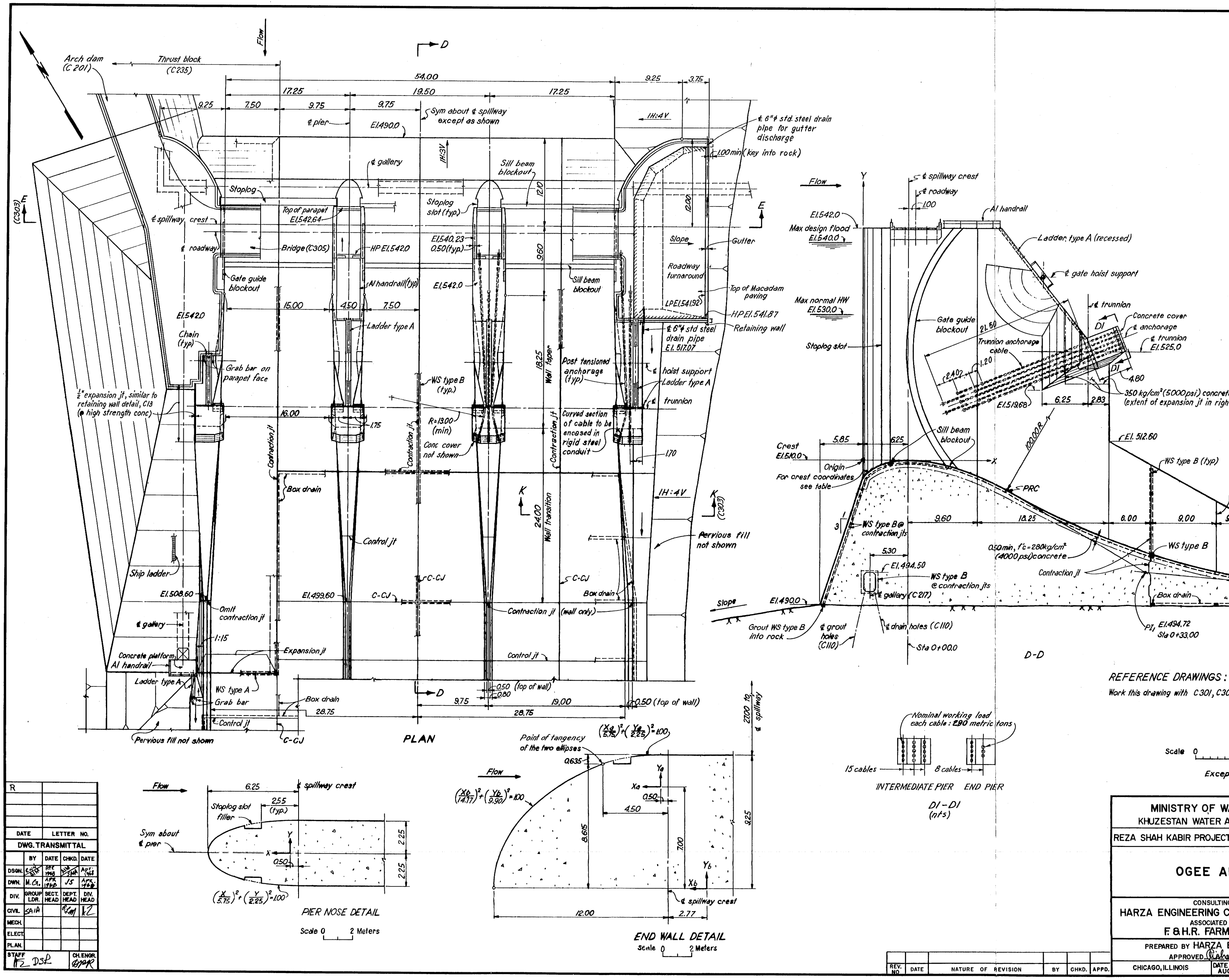
PREPARED BY HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS
DATE AUG.1968
DWG.NO. 384 C 301
DWG. TRANSMITTAL



X	Y
0.0	-2.45
1.25	-1.28
2.50	-0.65
3.75	-0.28
5.00	-0.08
6.25	0.0
7.50	-0.03
8.75	-0.13
11.25	-0.55
12.50	-0.88
15.00	-1.73
20.00	-4.13 PRC

CREST COORDINATES

REFERENCE DRAWINGS:

Work this drawing with C301, C303, C304 & C305

MINISTRY OF WATER AND POWER
KHUZESTAN WATER AND POWER AUTHORITY
REZA SHAH KABIR PROJECT — SPILLWAY

OGEE AND PIERS

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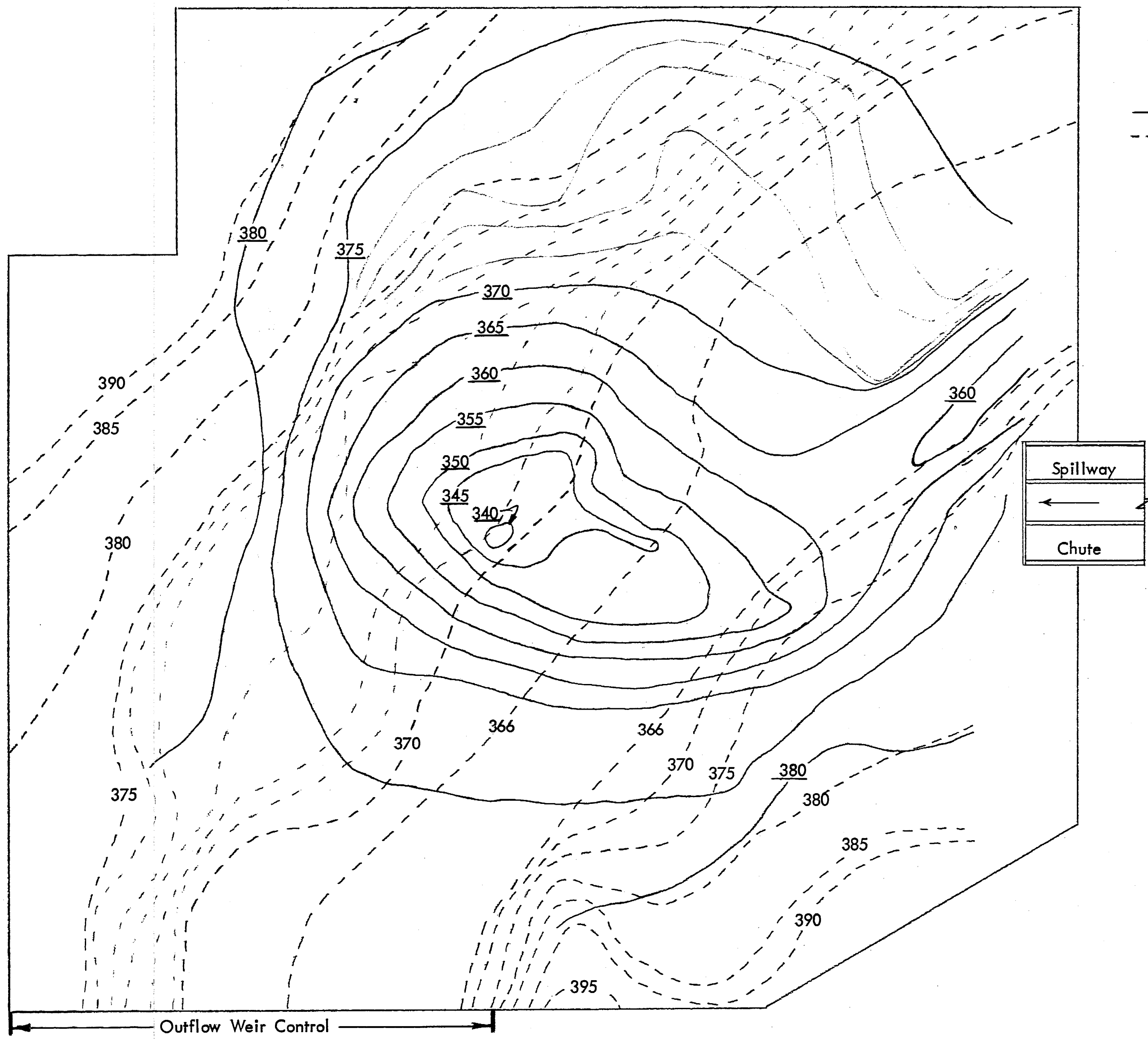
APPROVED
CHICAGO, ILLINOIS — DATE AUG. 1968 — DWG. NO. 384 C 302



LEGEND

380 — Scour contours

- - - 380 - - - Original contours

ORIGINAL SKI JUMP BUCKET

Preliminary Scour Test without Bank Stabilization

Duration: 30 min

Q: 8000 cms

T. W. Elev.: 380 meters

0 50 100

Scale in Meters

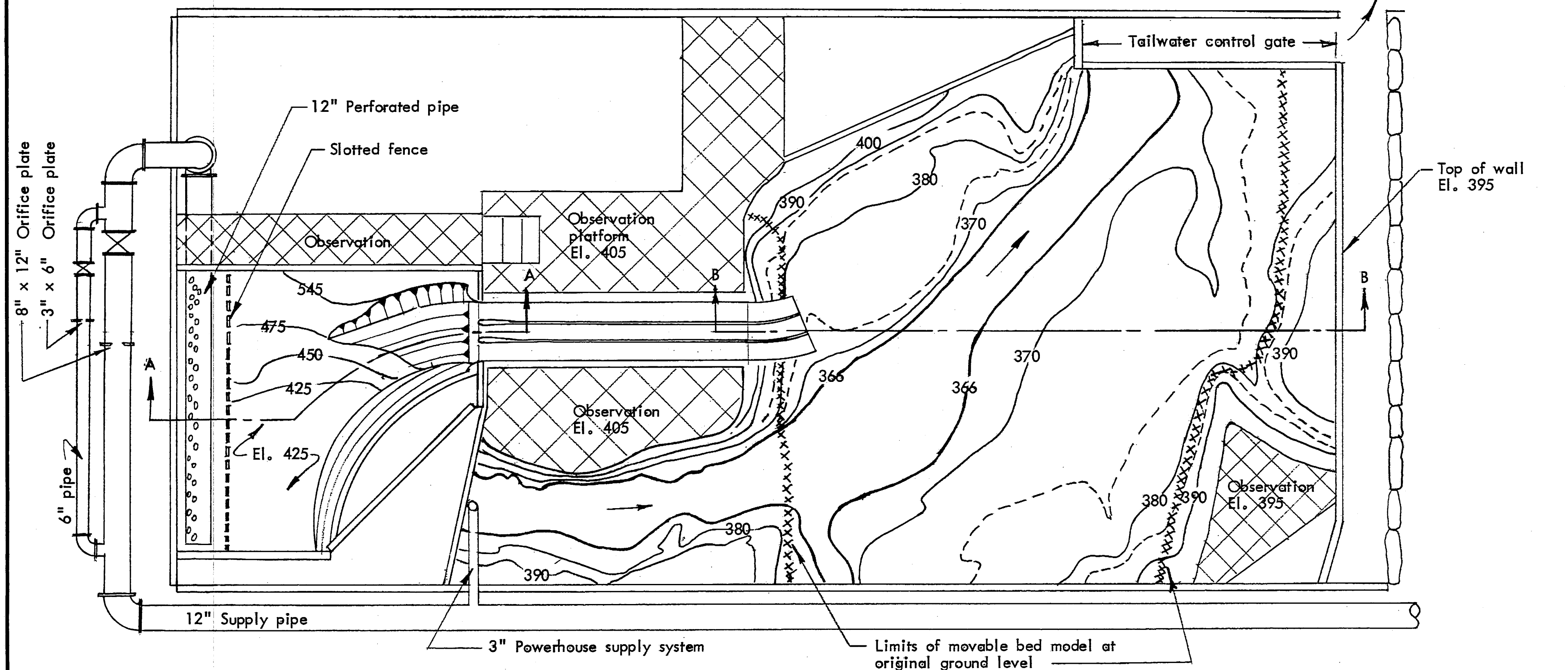
Model Scale 1:78.7

KARUN SPILLWAY MODEL STUDIES
Government of Iran
Harza Engineering Company
Chicago, Illinois
PLUNGE POOL SCOUR STUDIES

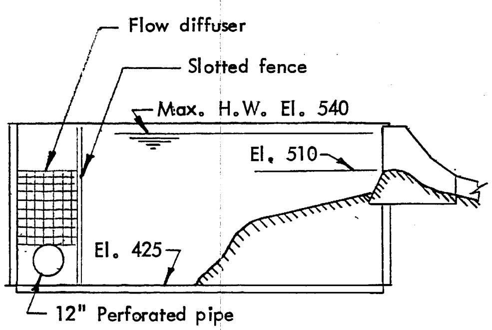
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN PF	CHECKED KF	APPROVED
SCALE Graphic	DATE 6-28-68	NO. 180B-476-1

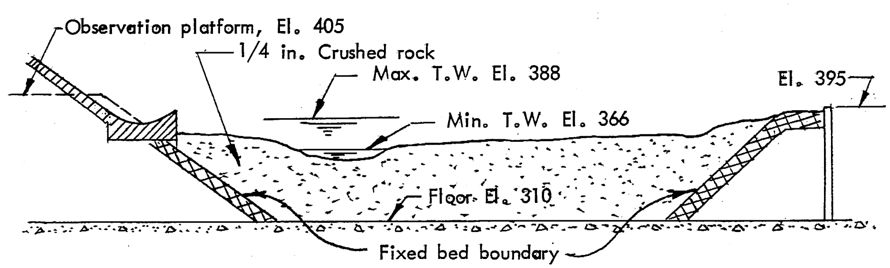
CHART 5



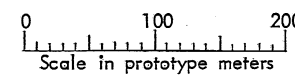
PLAN LAYOUT



SECTION A-A



SECTION B-B



Scale of drawing: 1/4 in. = 1 ft
Model scale: 1 in. = 2 meters (1:78.7)

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Chicago, Illinois
SCHEMATIC MODEL LAYOUT

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DRAWN KF	CHECKED	APPROVED
SCALE noted	DATE 4-5-69	NO. 180B476-36

CHART 4

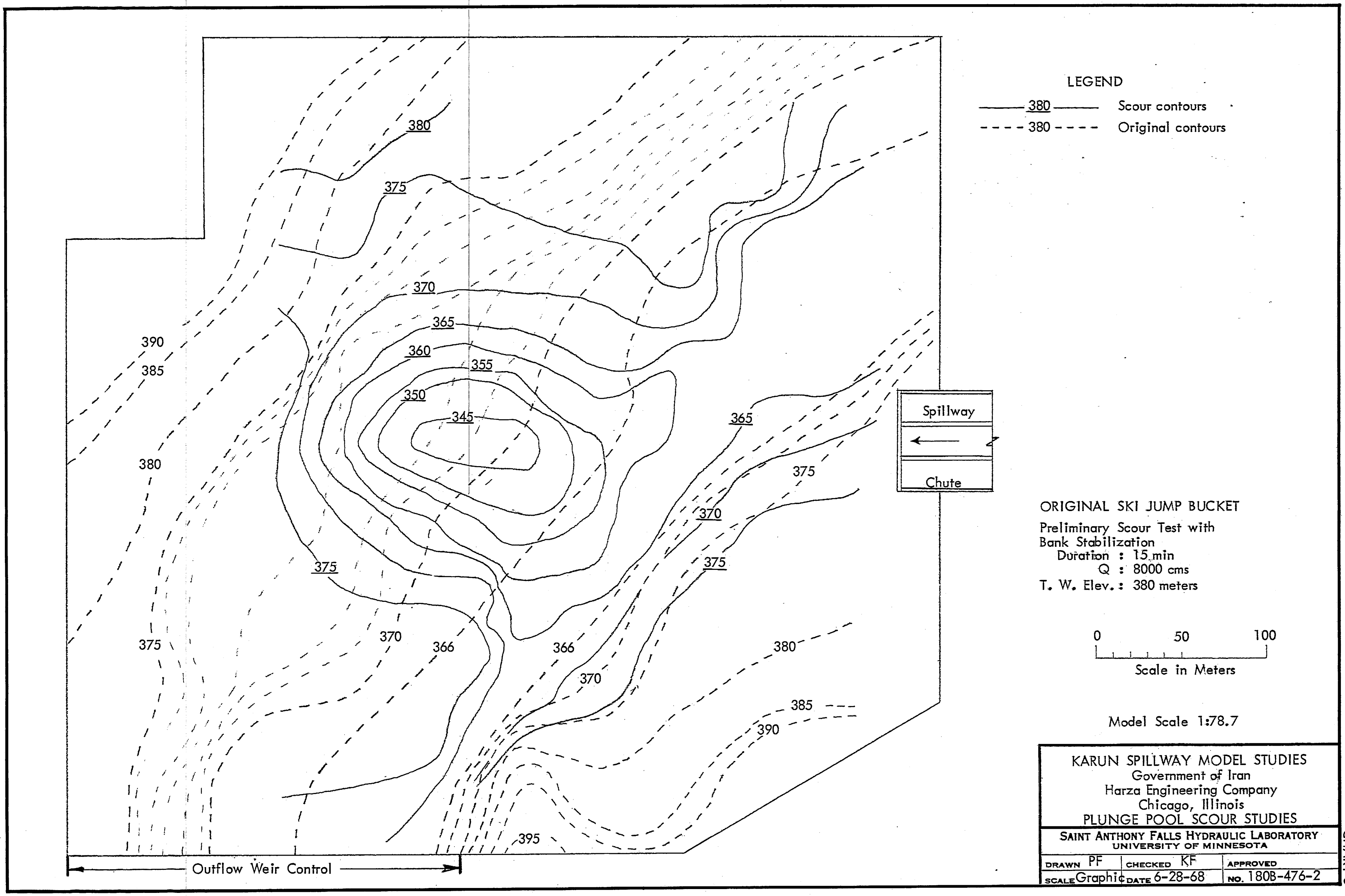
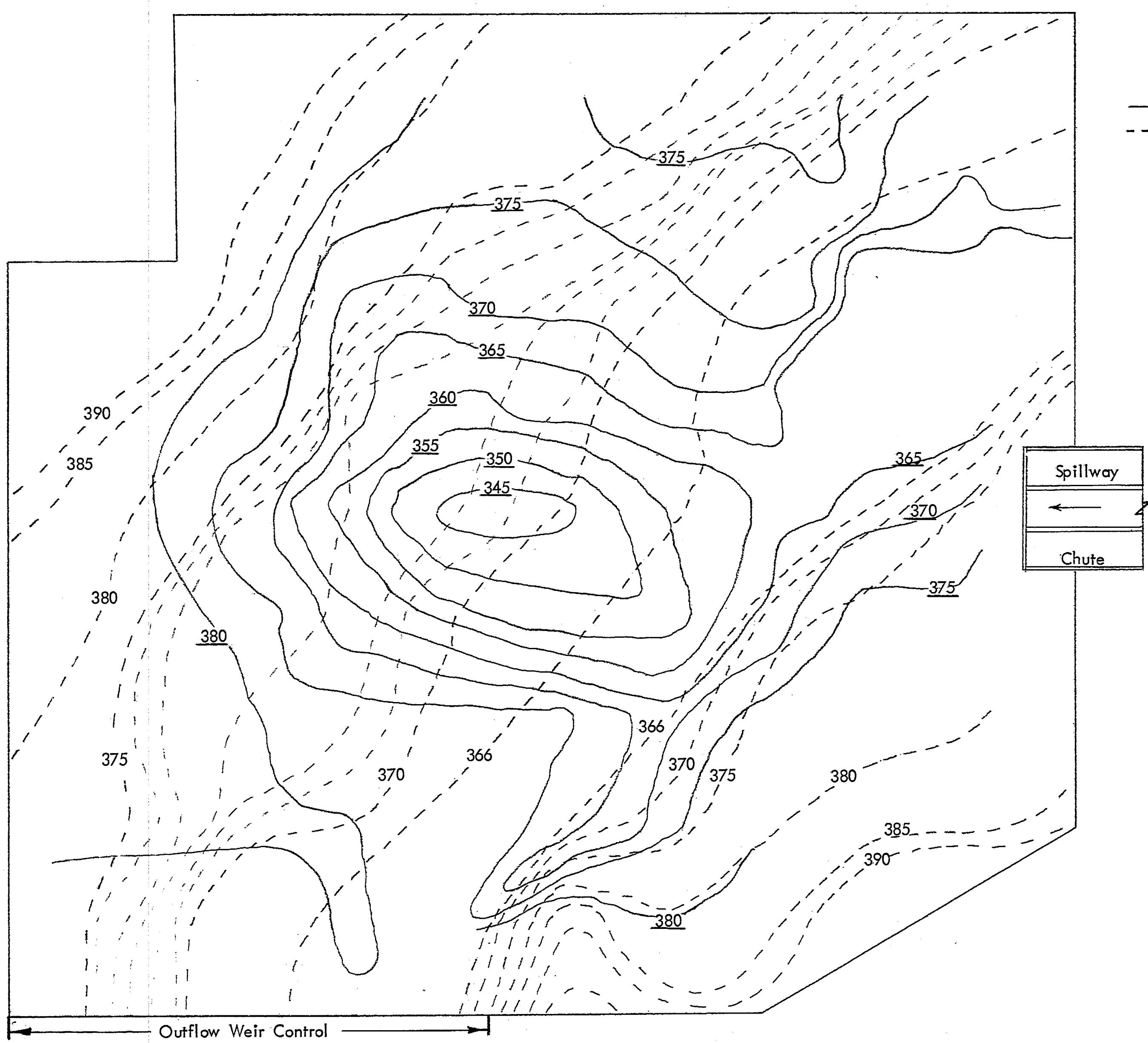

LEGEND
380 Scour contours
380 Original contours
Spillway
Chute
ORIGINAL SKI JUMP BUCKET
Preliminary Scour Test with
Bank Stabilization
Duration : 15 min
Q : 8000 cms
T. W. Elev. : 380 meters
0 50 100
Scale in Meters
Model Scale 1:78.7
KARUN SPILLWAY MODEL STUDIES
Government of Iran
Harza Engineering Company
Chicago, Illinois
PLUNGE POOL SCOUR STUDIES
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN PF CHECKED KF APPROVED
SCALE Graphic DATE 6-28-68 NO. 180B-476-2
Outflow Weir Control
380
375
370
365
360
355
350
345
390
385
380
375
365
375
370
375
370
366
366
370
380
385
390
395

CHART 6



LEGEND

—— 380 —— Scour contours
- - - 380 - - - Original contours

ORIGINAL SKI JUMP BUCKET

Preliminary Scour Test with Bank Stabilization

Duration : 30 min
Q = 8000 cms
T. W. Elev.: 380 meters

0 50 100
Scale in Meters

Model Scale 1:78.7

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PLUNGE POOL SCOUR STUDIES

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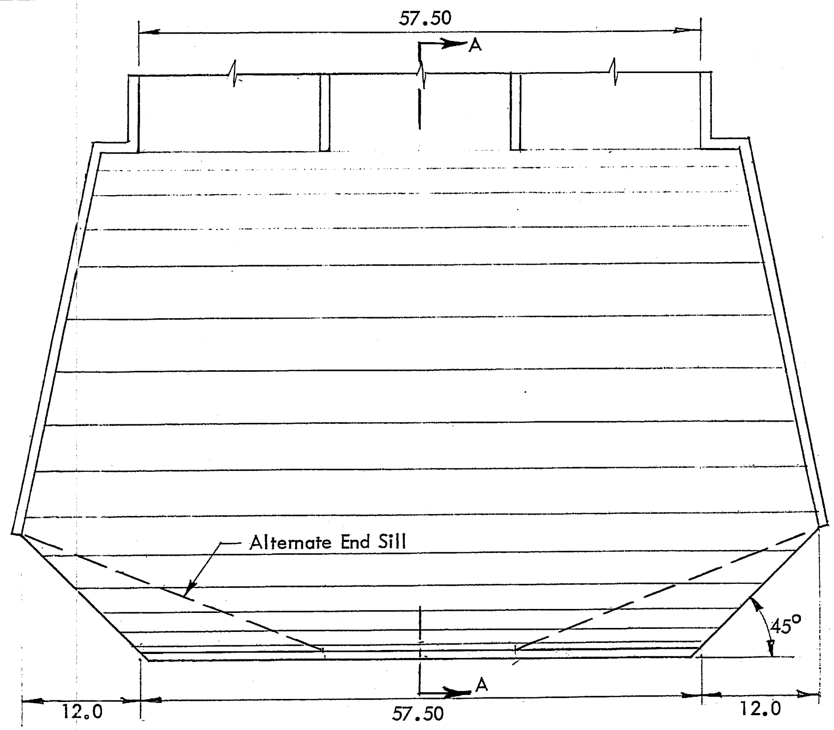
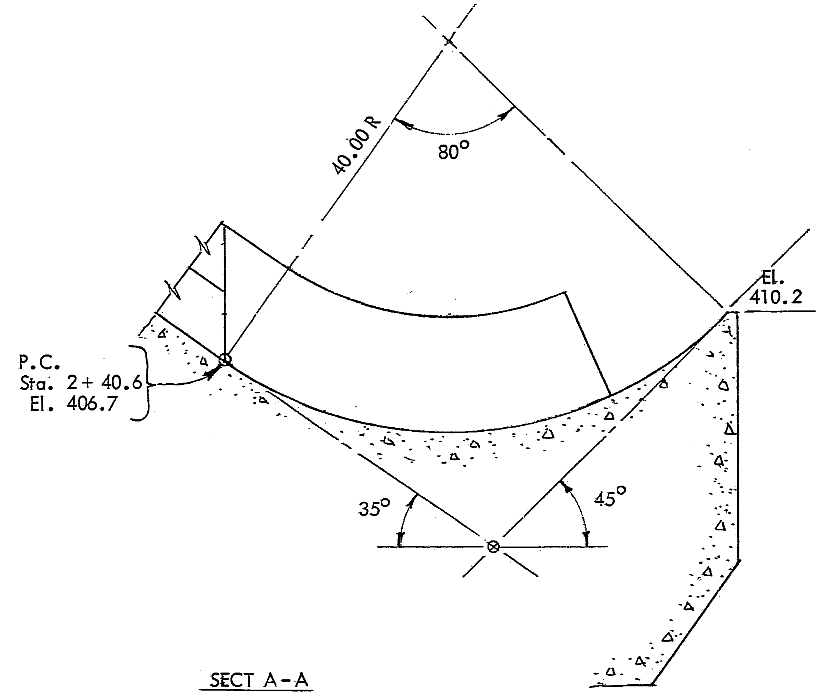
UNIVERSITY OF MINNESOTA

DRAWN PF	CHECKED KF	APPROVED
SCALE Graphic	DATE 6-28-68	NO. 180B-476-3

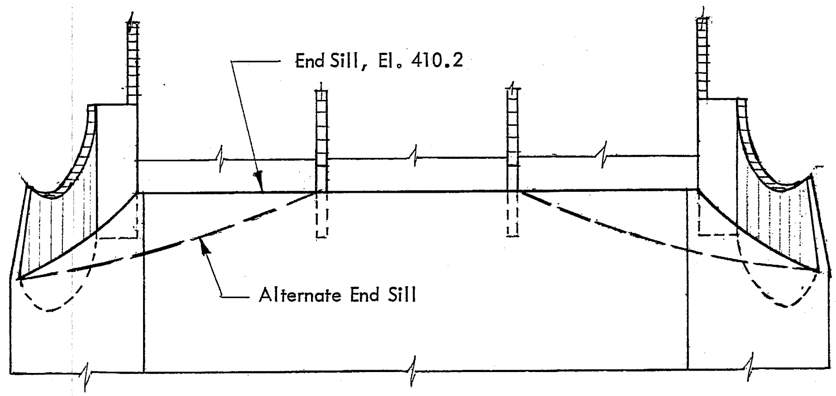
CHART 7



PLAN

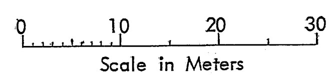


SECT A-A



END ELEVATION

PROPOSED TYPE B FLIP BUCKET



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Chicago, Illinois
SKI JUMP STUDIES

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DRAWN KF	CHECKED	APPROVED
SCALE Graphic	DATE 8-5-68	NO. 180B476-6

CHART 8

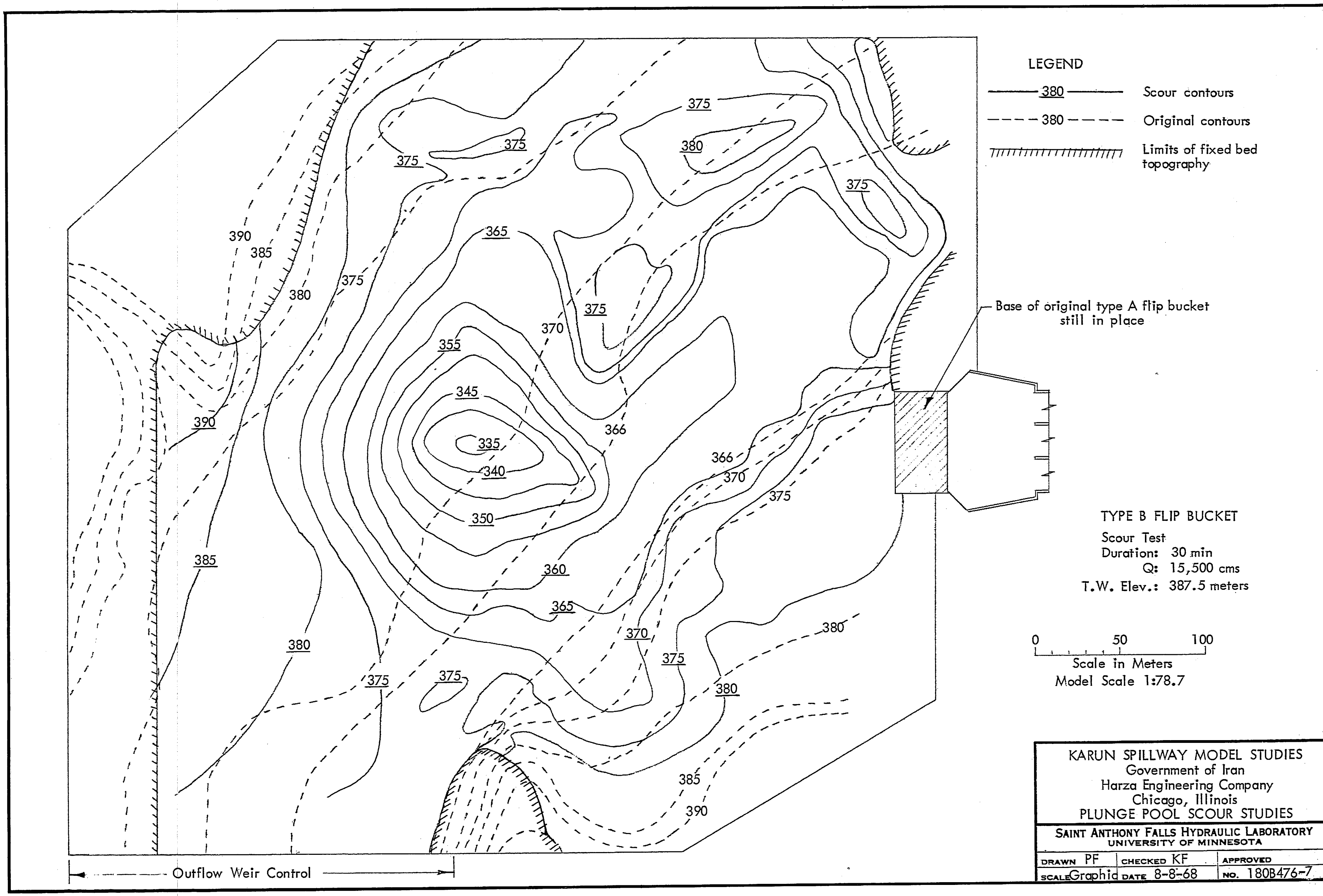
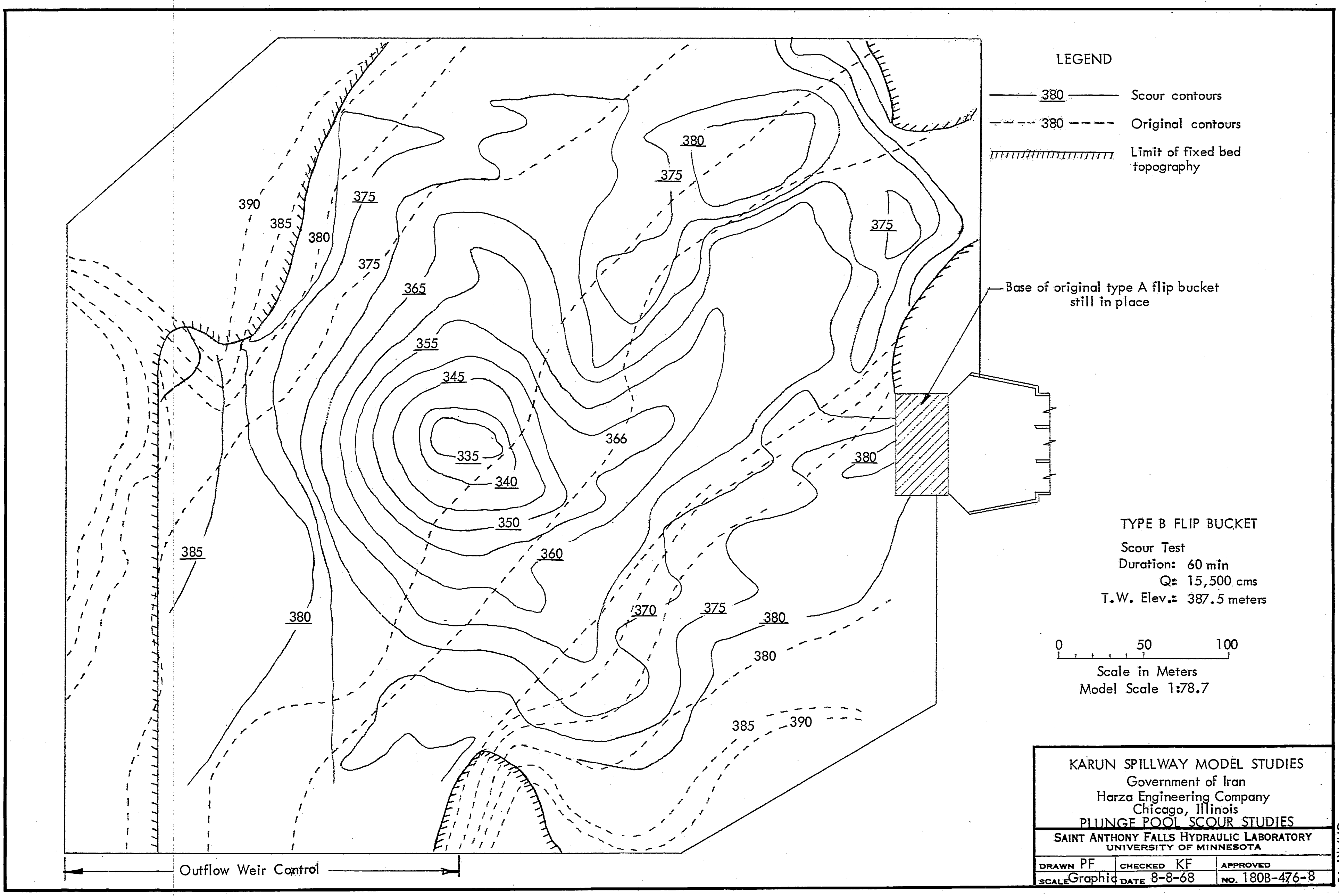

LEGEND
380 Scour contours
380 Original contours
Limits of fixed bed topography
Base of original type A flip bucket still in place
TYPE B FLIP BUCKET
Scour Test
Duration: 30 min
Q: 15,500 cms
T.W. Elev.: 387.5 meters
0 50 100
Scale in Meters
Model Scale 1:78.7
Outflow Weir Control
390
385
380
375
370
366
365
360
355
350
345
340
335
KARUN SPILLWAY MODEL STUDIES
Government of Iran
Harza Engineering Company
Chicago, Illinois
PLUNGE POOL SCOUR STUDIES
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN PF
CHECKED KF
APPROVED
SCALE Graphic
DATE 8-8-68
NO. 180B476-7

CHART 9


LEGEND
380 Scour contours
380 Original contours
Limit of fixed bed topography
Base of original type A flip bucket still in place
TYPE B FLIP BUCKET
Scour Test
Duration: 60 min
Q= 15,500 cms
T.W. Elev.= 387.5 meters
0 50 100
Scale in Meters
Model Scale 1:78.7
Outflow Weir Control
KARUN SPILLWAY MODEL STUDIES
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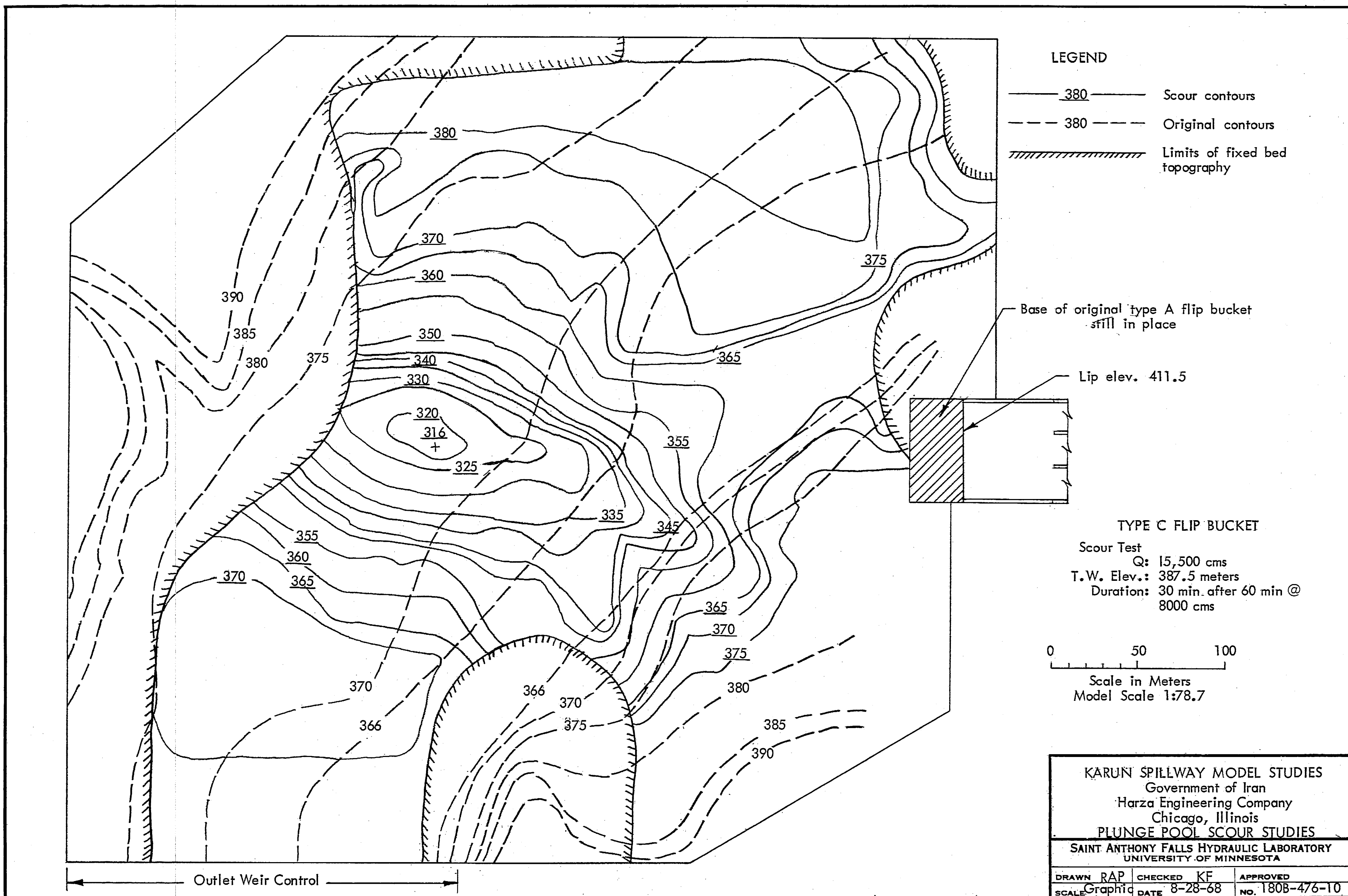
DRAWN PF
CHECKED KF
APPROVED
SCALE Graphic
DATE 8-8-68
NO. 180B-476-8
CHART 10


LEGEND
380 Scour contours
380 Original contours
Limits of fixed bed topography
Base of original type A flip bucket still in place
Lip elev. 411.5
TYPE C FLIP BUCKET
Scour Test
Q: 15,500 cms
T.W. Elev.: 387.5 meters
Duration: 30 min. after 60 min @ 8000 cms
0 50 100
Scale in Meters
Model Scale 1:78.7
Outlet Weir Control
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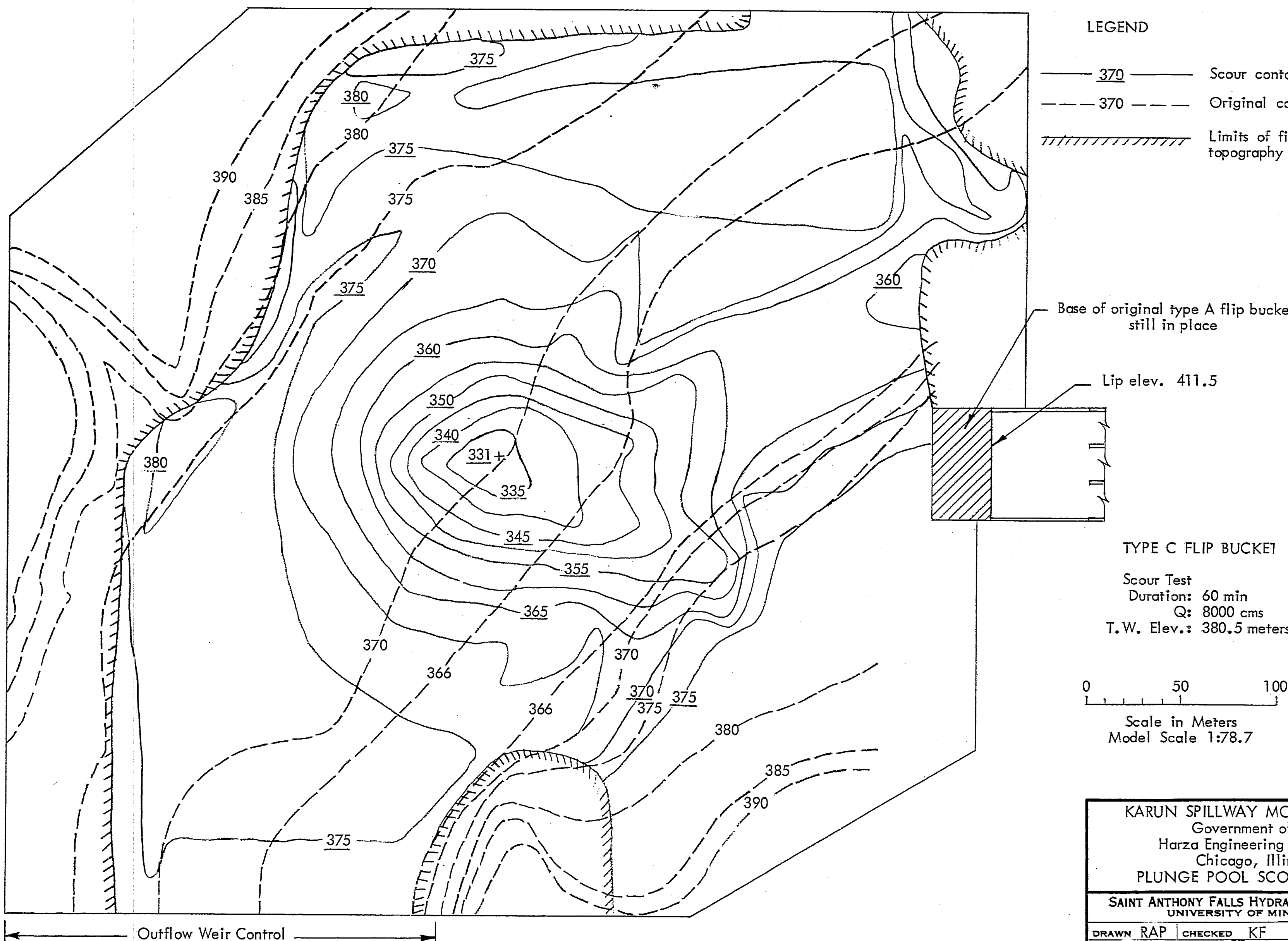
UNIVERSITY OF MINNESOTA
DRAWN RAP
CHECKED KF
APPROVED
SCALE Graphic
DATE 8-28-68
NO. 180B-476-10

CHART 11



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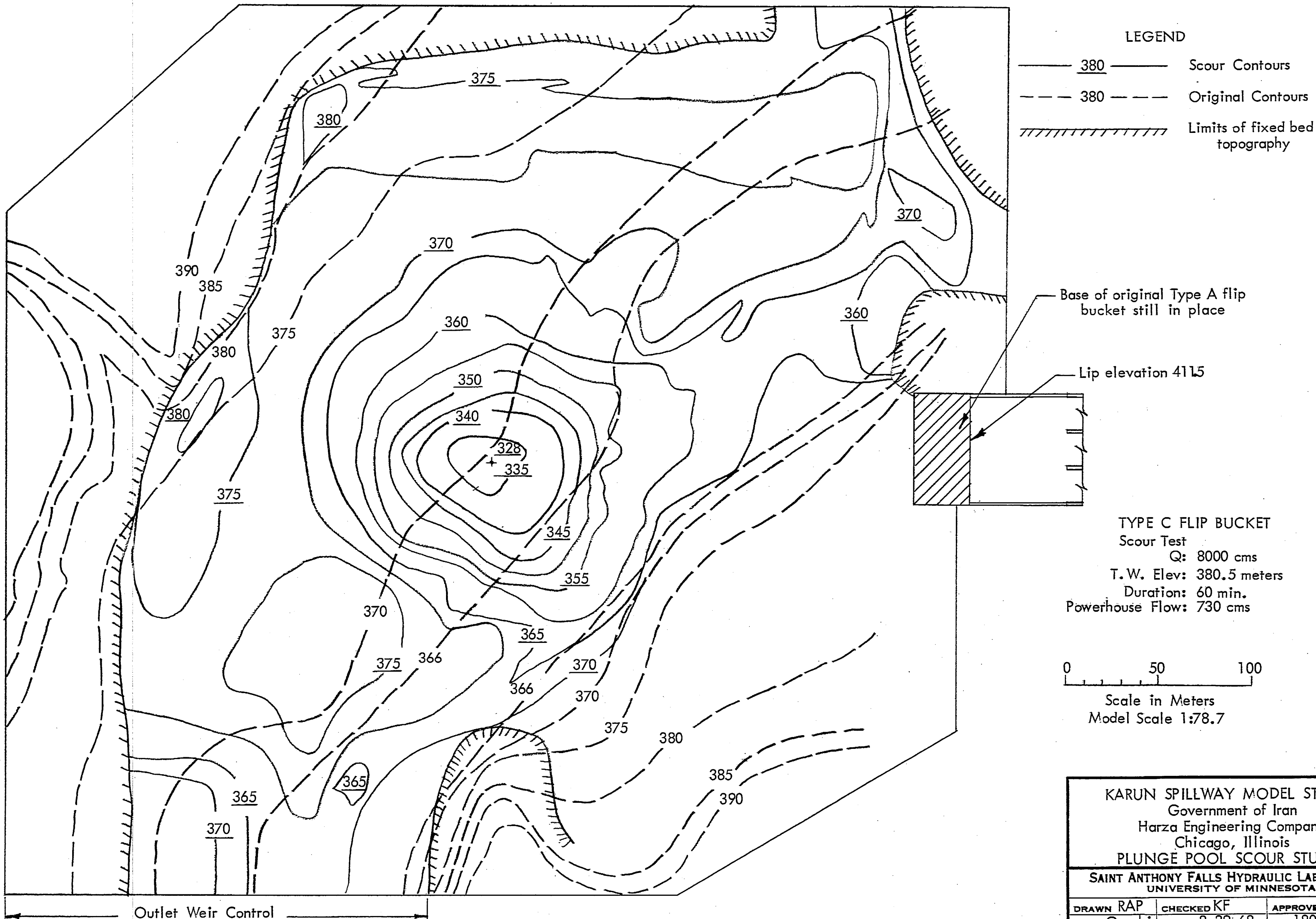
DRAWN RAP	CHECKED KF	APPROVED
SCALE Graphic	DATE 8-27-68	NO. 180B476-9

CHART 12



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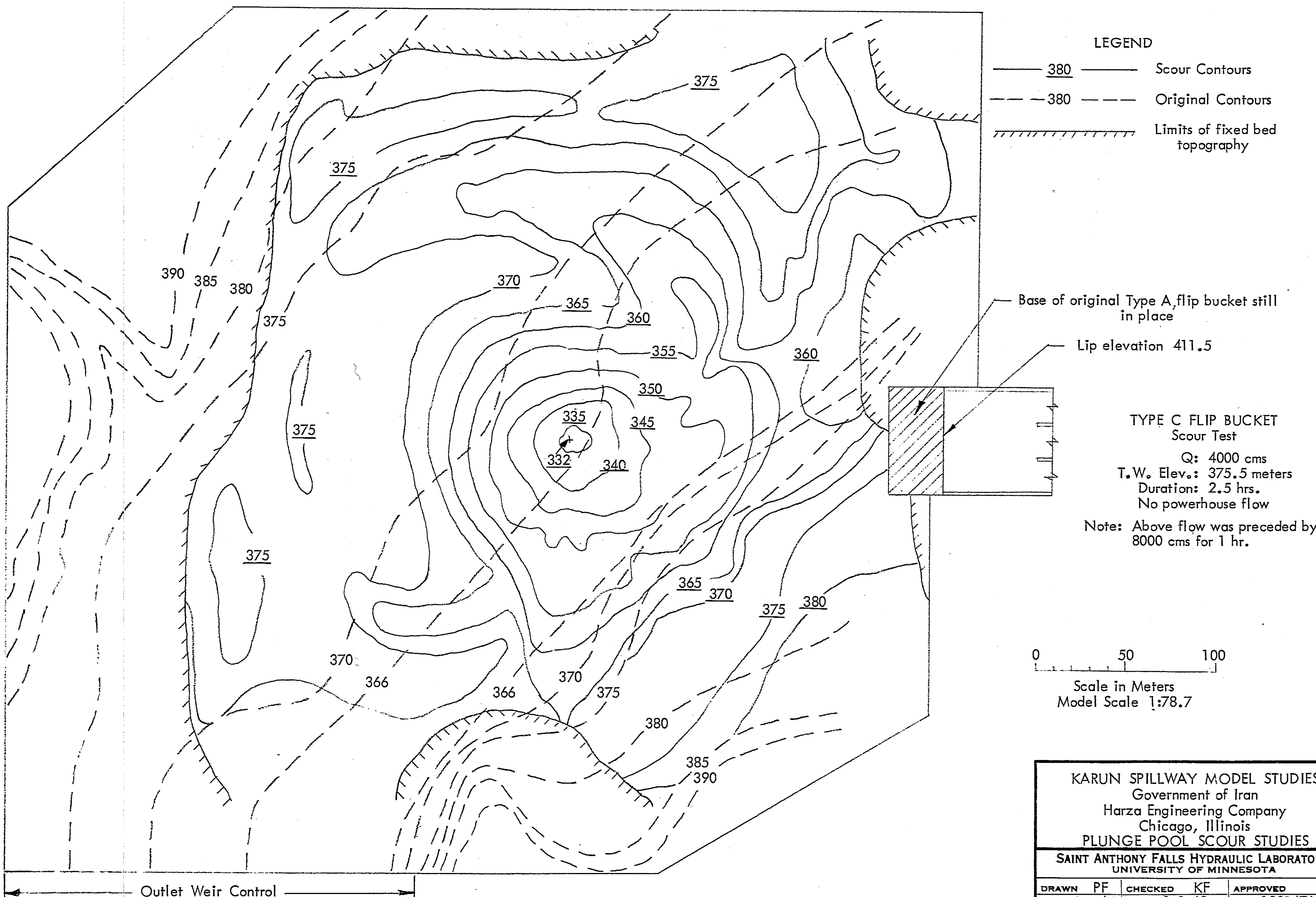
DRAWN RAP	CHECKED KF	APPROVED
SCALE Graphic	DATE 8-29-68	NO. 180B476-11

CHART 13



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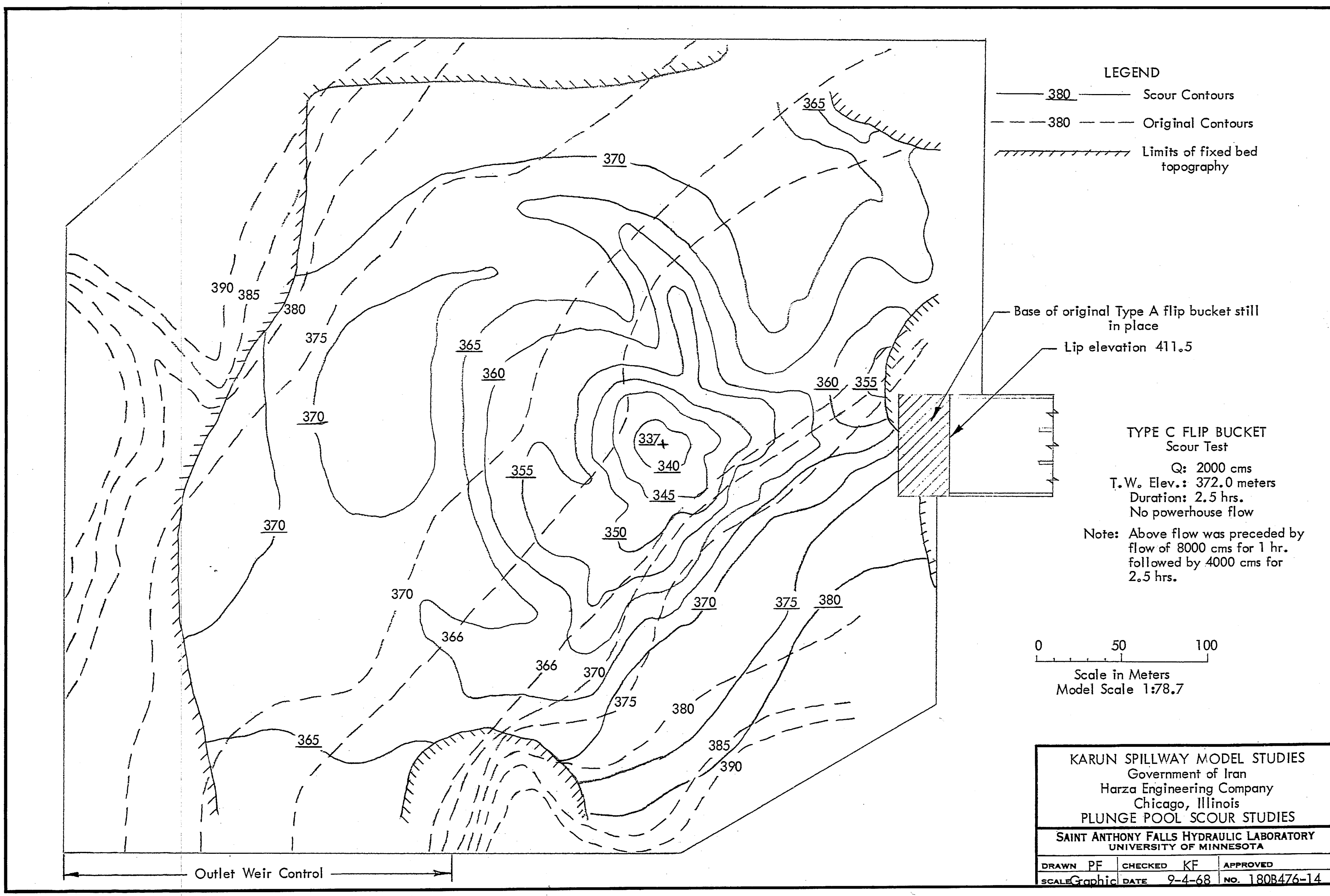
DRAWN PF	CHECKED KF	APPROVED
SCALE Graphic	DATE 9-3-68	NO. 180B476-13

CHART 14



LEGEND
380 Scour Contours
380 Original Contours
Limits of fixed bed topography
Base of original Type A flip bucket still in place
Lip elevation 411.5
TYPE C FLIP BUCKET
Scour Test
Q: 2000 cms
T.W. Elev.: 372.0 meters
Duration: 2.5 hrs.
No powerhouse flow
Note: Above flow was preceded by flow of 8000 cms for 1 hr. followed by 4000 cms for 2.5 hrs.
0 50 100
Scale in Meters
Model Scale 1:78.7
365
370
390 385
380
375
365
360
370
355
337
340
345
350
360 355
370
370
366
366
370
375
380
375 380
370
365
385
390
Outlet Weir Control
KARUN SPILLWAY MODEL STUDIES
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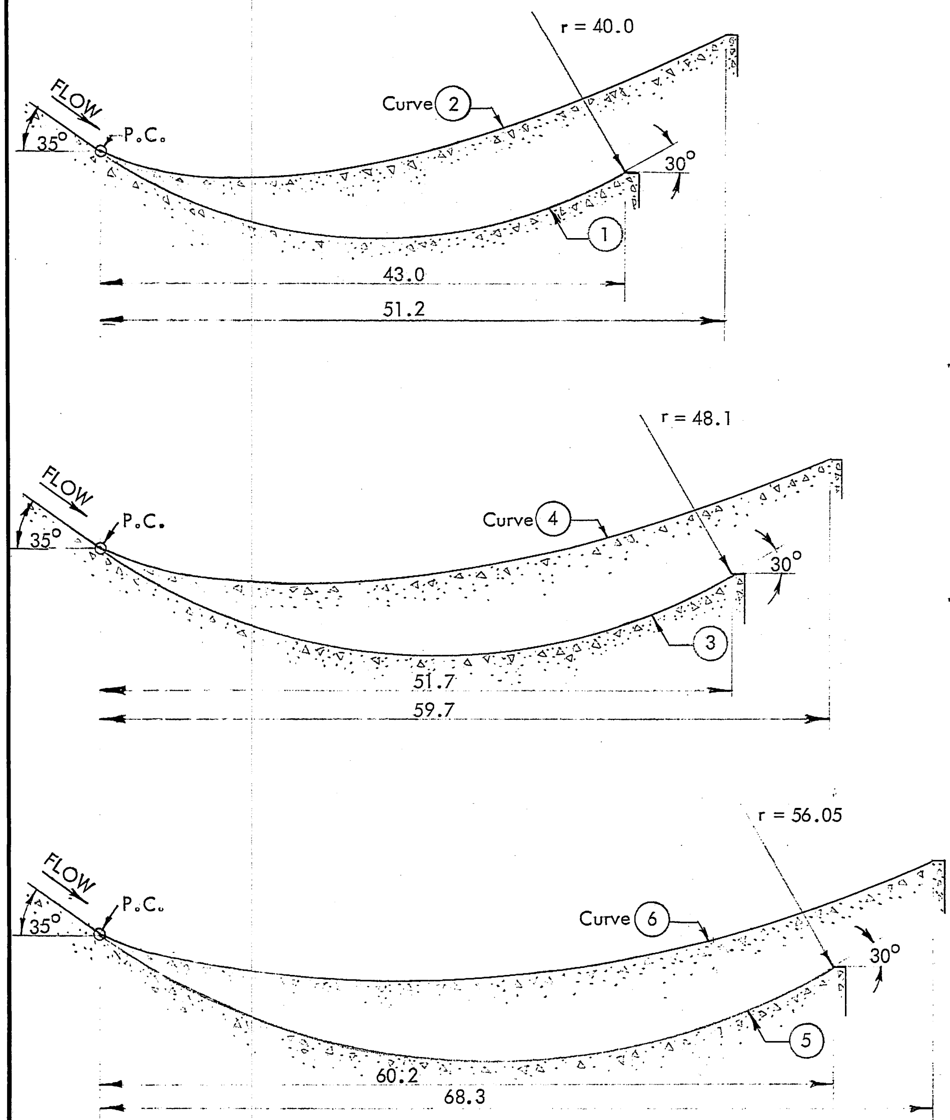
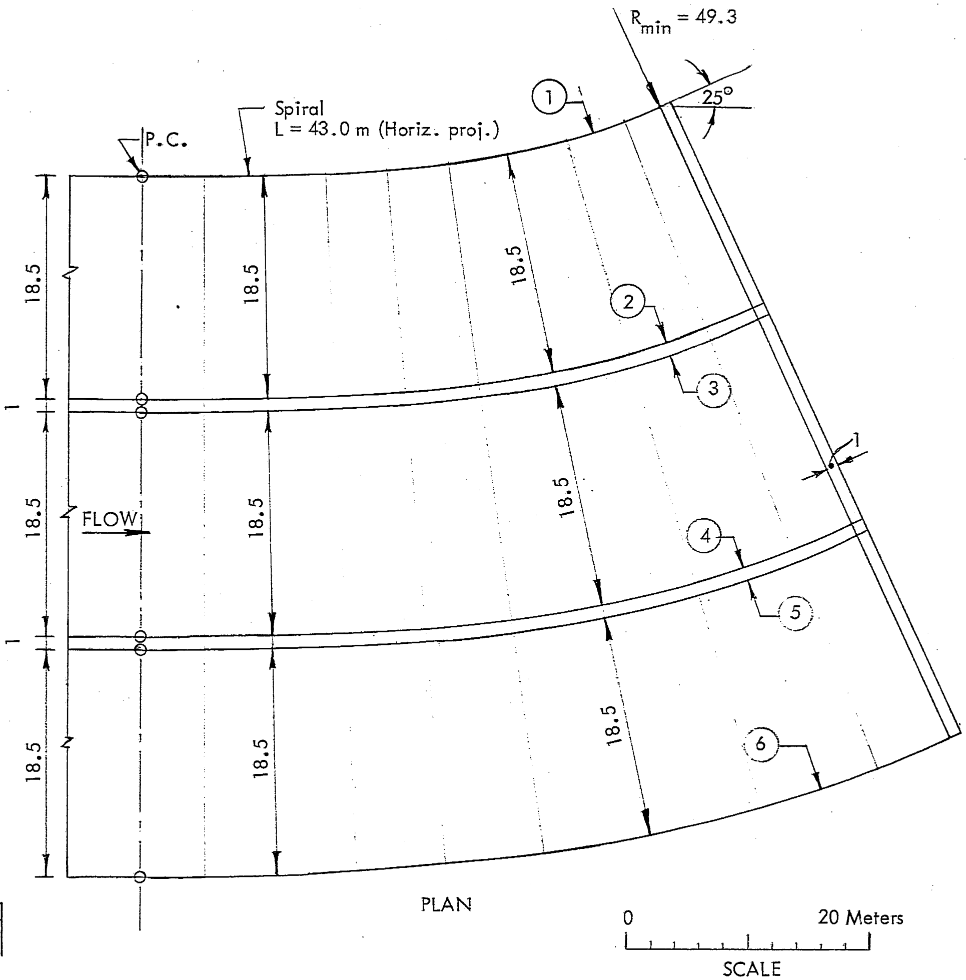
UNIVERSITY OF MINNESOTA
DRAWN PF
CHECKED KF
APPROVED
SCALE Graphic
DATE 9-4-68
NO. 180B476-14

CHART 15



VERTICAL SECTIONS ALONG CHUTE WALLS



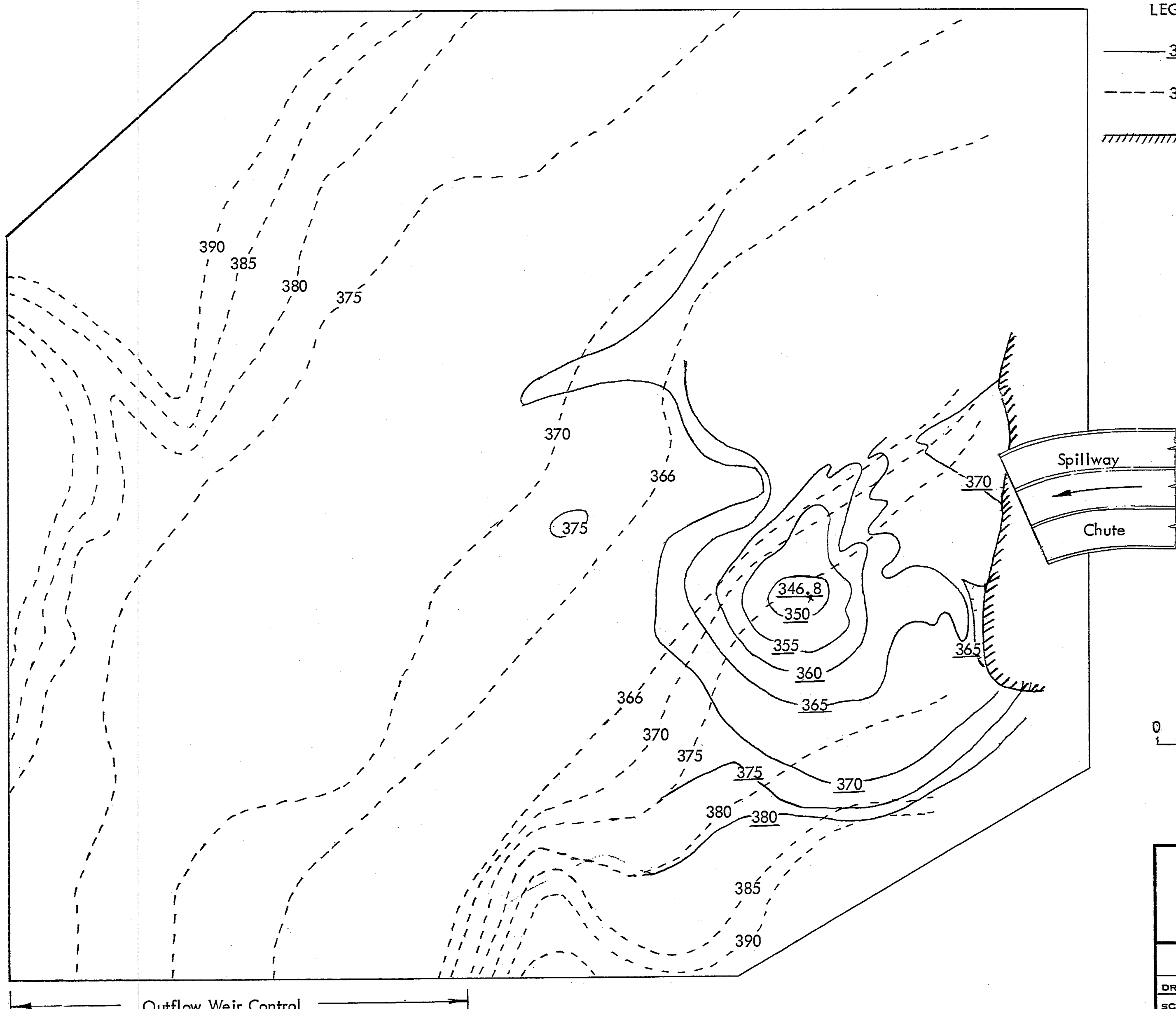
PLAN

Notes:

1. Curve (1) is a spiral.
2. Curves (2) thru (6) are laid out from curve (1), as shown.
3. Elevations are to be determined later. Initial trial with P.C. at El. 398.05 and Sta. 2 + 52.92.

KARUN SPILLWAY MODEL STUDIES Government of Iran Harza Engineering Company Chicago, Illinois TYPE D FLIP BUCKET		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN AH	CHECKED KF	APPROVED
SCALE Graphic	DATE 9-20-68	NO. 180B476-12

CHART 16



LEGEND

380 — Scour contours

- - - 380 - - - Orignial contours

/////////// Limits of fixed bed topography

TYPE D FLIP BUCKET
Scour Test

Q : 2000 cms
T. W. Elev. : 372.0 meters
Duration : 2 1/3 hrs
No powerhouse flow

0 50 100
Scale in Meters
Model Scale 1:78.7

KARUN SPILLWAY MODEL STUDIES
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Chicago, Illinois
PLUNGE POOL SCOUR STUDIES

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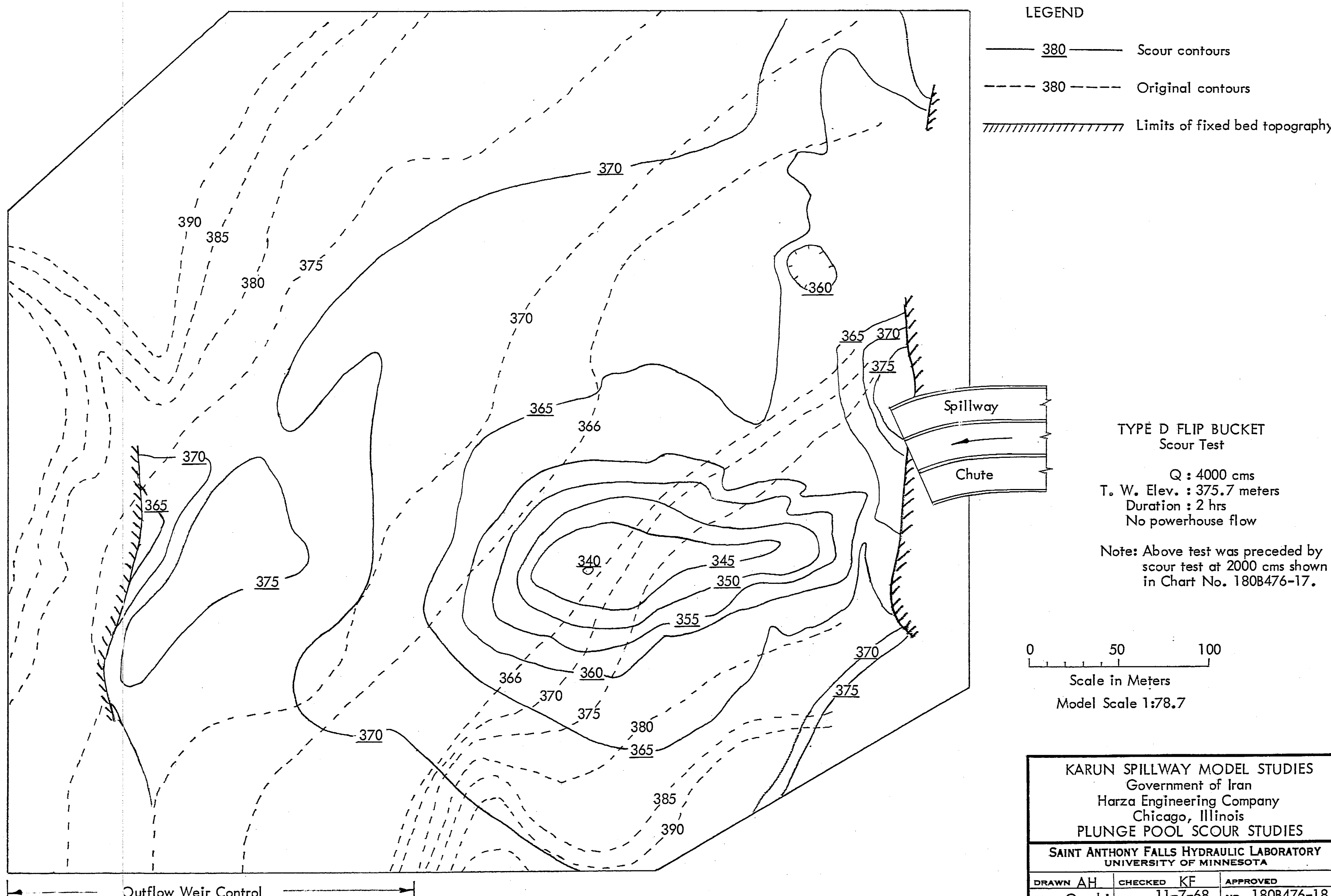
UNIVERSITY OF MINNESOTA

DRAWN AH	CHECKED KF	APPROVED
SCALE Graphic	DATE 11-7-68	NO. 180B476-17

CHART 17



TYPE D FLIP BUCKET
Scour Test

Q : 4000 cms
T. W. Elev. : 375.7 meters
Duration : 2 hrs
No powerhouse flow

Note: Above test was preceded by scour test at 2000 cms shown in Chart No. 180B476-17.

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PLUNGE POOL SCOUR STUDIES

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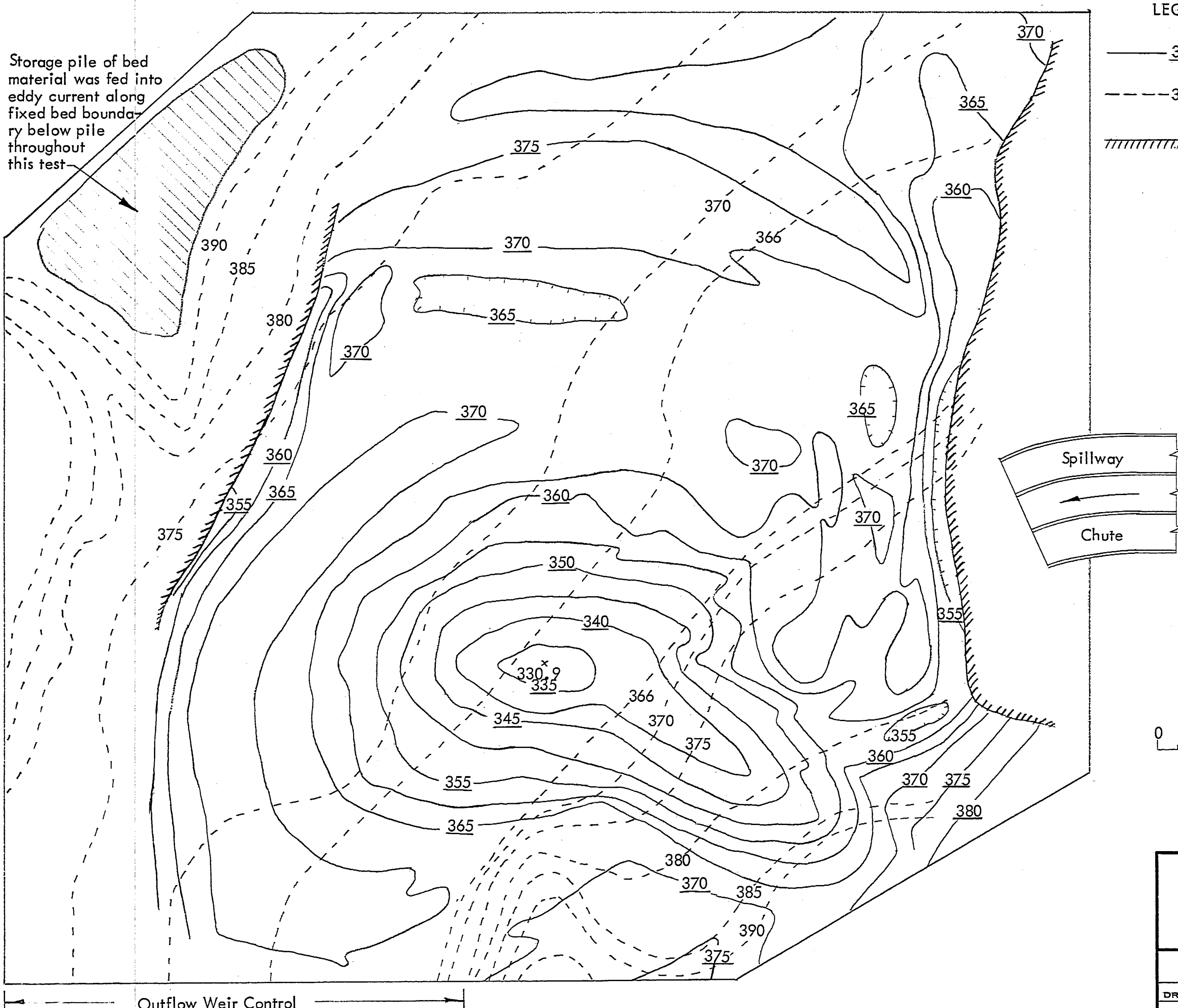
DRAWN AH	CHECKED KF	APPROVED
SCALE Graphic	DATE 11-7-68	NO. 180B476-18

CHART 18



LEGEND

——380—— Scour contours

- - - -380- - - - Original contours

/////////// Limits of fixed bed topography

TYPE D FLIP BUCKET
Scour Test

Q : 8000 cms
T. W. Elev. : 380.5 meters
Duration : 2 1/2 hrs
No powerhouse flow

Note: Above test was preceded by scour test at 4000 cms shown in Chart No. 180B476-18.

0 50 100
Scale in Meters
Model Scale 1:78.7

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PLUNGE POOL SCOUR STUDIES

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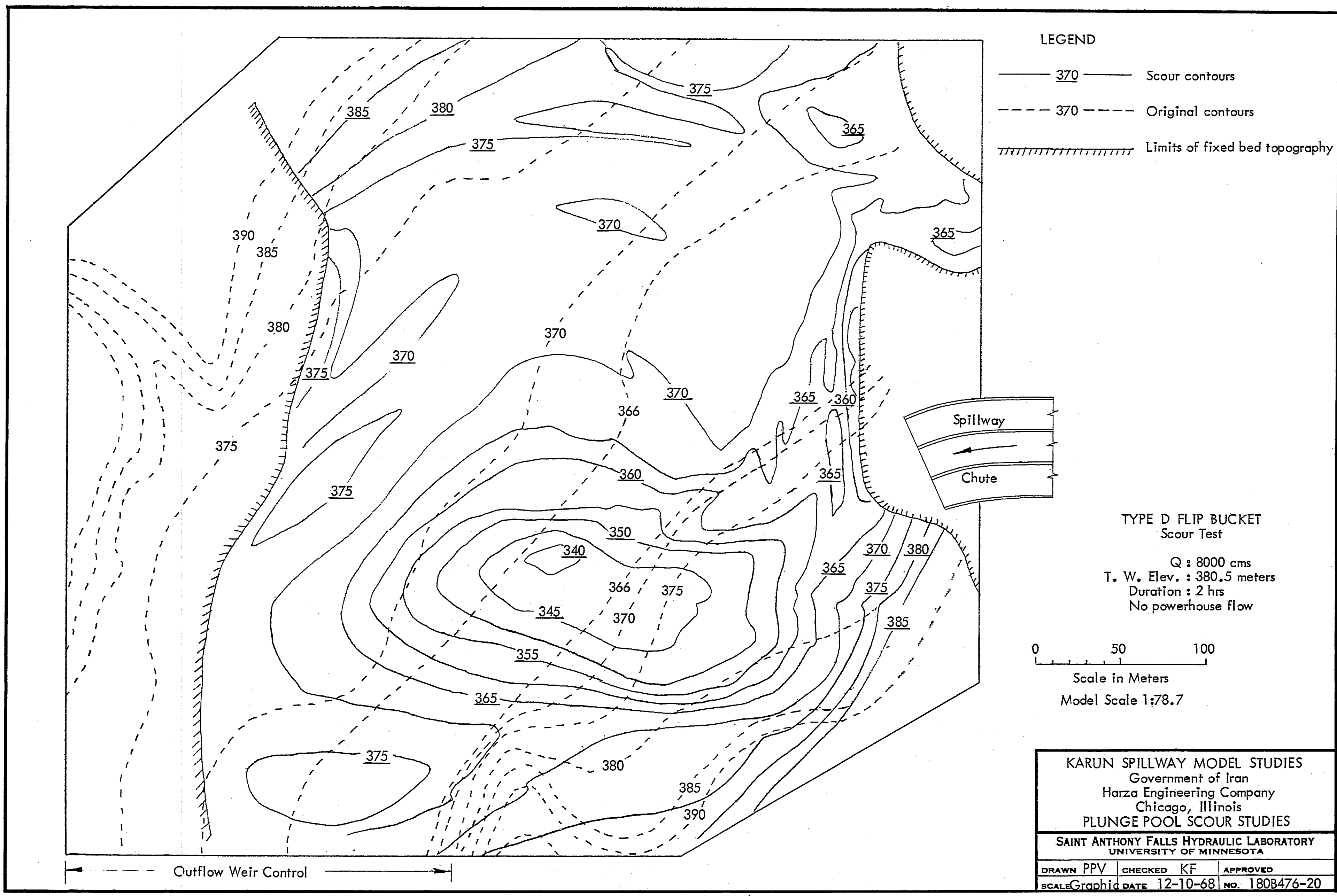
DRAWN AH	CHECKED KF	APPROVED
SCALE Graphic	DATE 11-8-68	NO. 180B476-19

CHART 19


LEGEND
370 Scour contours
370 Original contours
Limits of fixed bed topography
Spillway
Chute
Outflow Weir Control
TYPE D FLIP BUCKET
Scour Test
Q : 8000 cms
T. W. Elev. : 380.5 meters
Duration : 2 hrs
No powerhouse flow
0 50 100
Scale in Meters
Model Scale 1:78.7
KARUN SPILLWAY MODEL STUDIES
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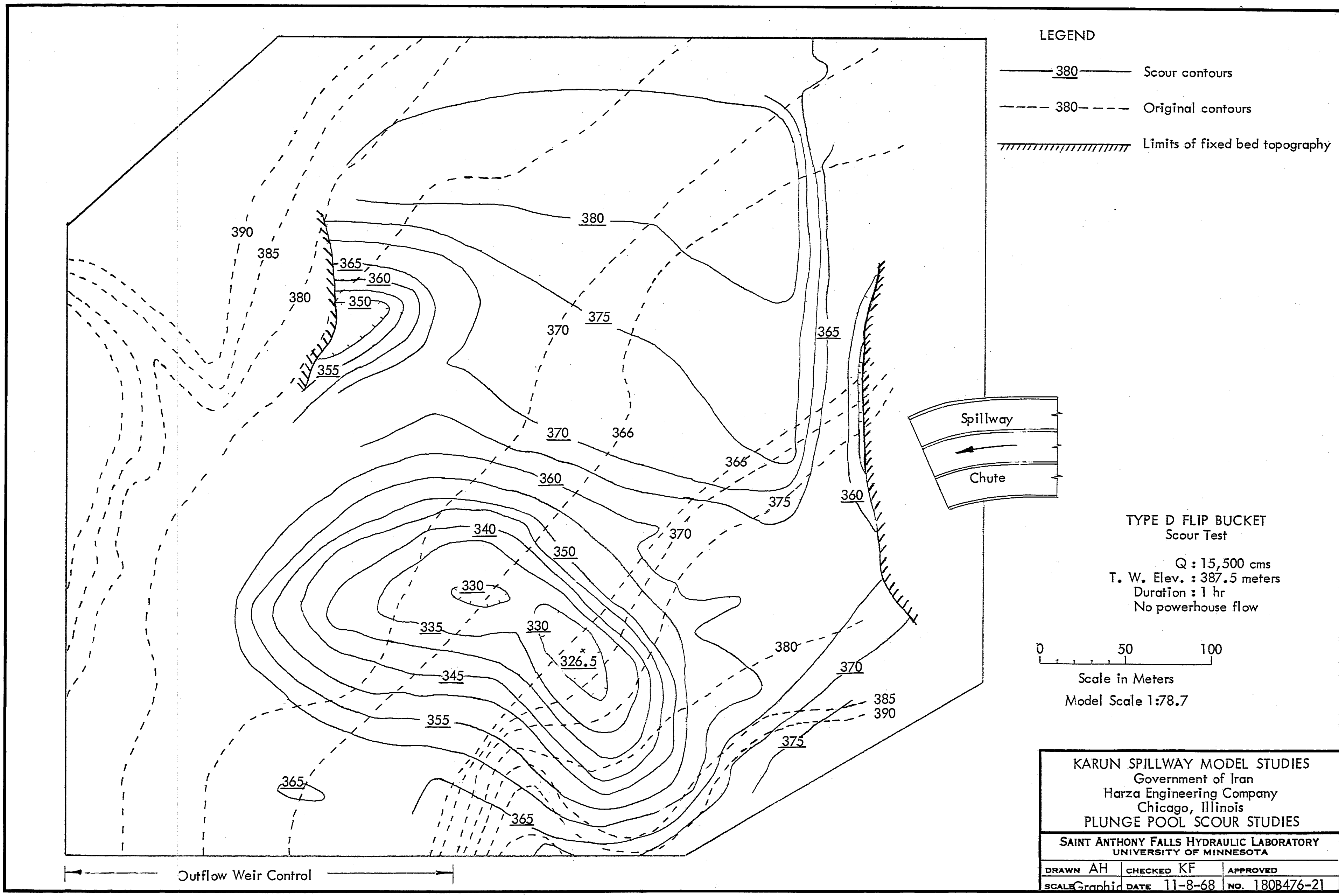
UNIVERSITY OF MINNESOTA
DRAWN PPV
CHECKED KF
APPROVED
SCALE Graphic
DATE 12-10-68
NO. 180B476-20
CHART 20



LEGEND
380 Scour contours
380 Original contours
Limits of fixed bed topography
Spillway
Chute
TYPE D FLIP BUCKET
Scour Test
Q : 15,500 cms
T. W. Elev. : 387.5 meters
Duration : 1 hr
No powerhouse flow
0 50 100
Scale in Meters
Model Scale 1:78.7
390
385
380
365
360
350
355
380
375
370
370
366
365
366
360
375
360
370
340
350
330
335
330
326.5
345
355
380
370
385
390
375
365
365
Outflow Weir Control
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PLUNGE POOL SCOUR STUDIES
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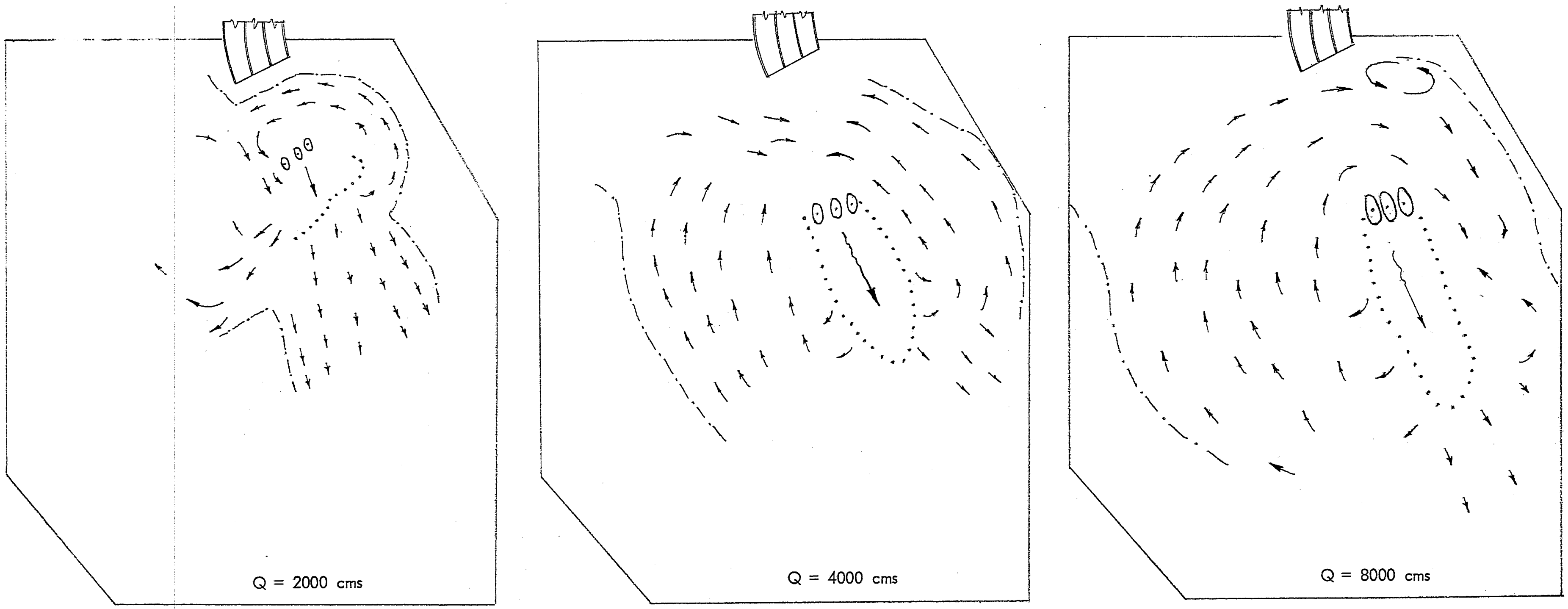
UNIVERSITY OF MINNESOTA
DRAWN AH
CHECKED KF
APPROVED
SCALE Graphic
DATE 11-8-68
NO. 180B476-21

CHART 21



LEGEND

- Impact area
- Flow direction
- Shore line
- Approx. limit of extremely turbulent zone

TYPE D FLIP BUCKET
Flow Patterns in Plunge Pool

0 100 200 300
Scale in Meters
Model Scale 1:78.7

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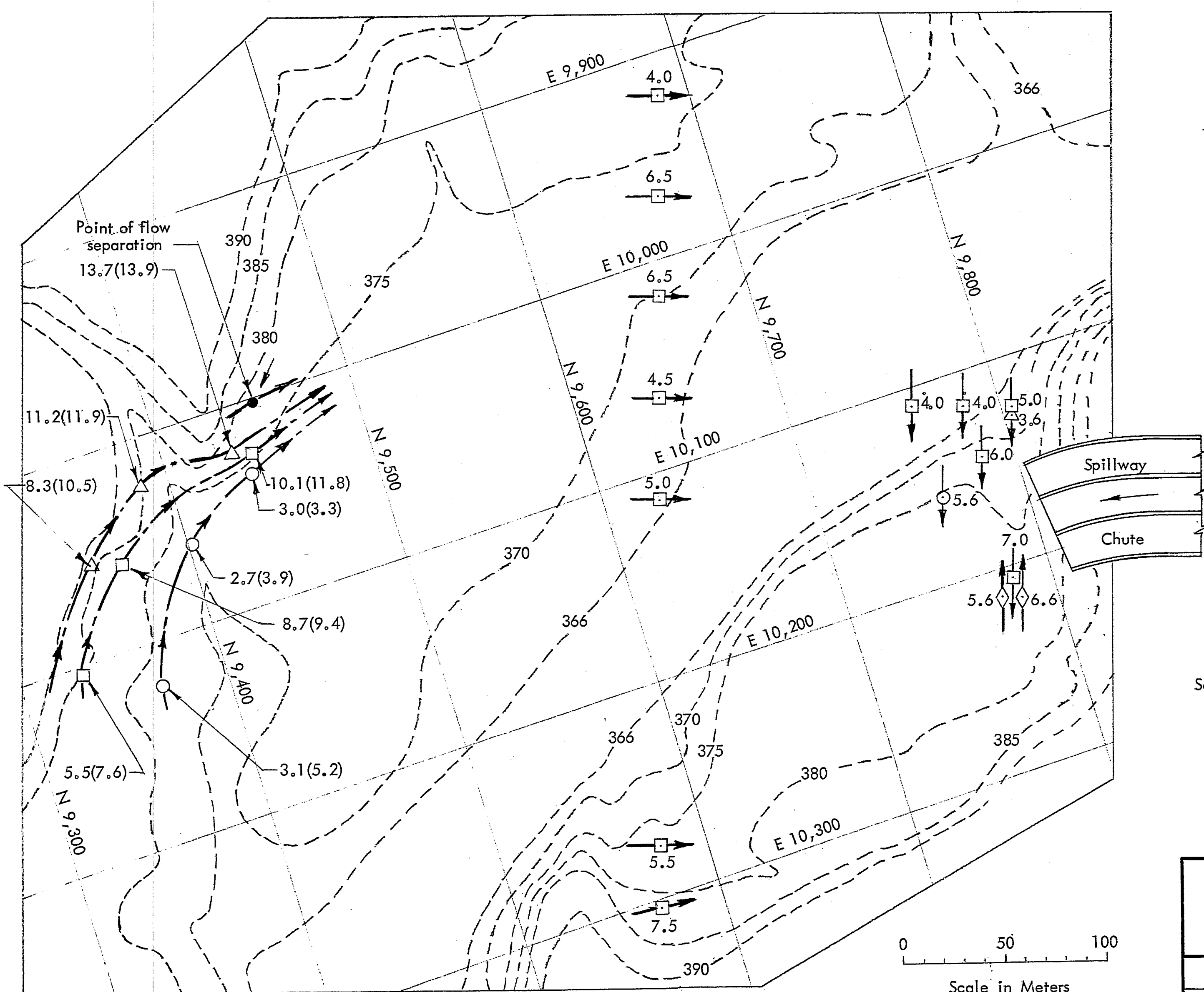
DRAWN PPV	CHECKED KF.	APPROVED
SCALE Graphic	DATE 12-18-68	NO. 180B476-22

CHART 22



LEGEND

- - - - - -	Ground contours before erosion
——►- - - ►	Flow direction
◊	Q = 2,000 cms
⊙	Q = 4,000 cms
⊡	Q = 8,000 cms
△	Q = 15,500 cms
2.7(3.9)	Velocity in meters/sec
	Avg. peak velocity
	Long-term avg. velocity

TYPE D FLIP BUCKET
Selected Velocities in Plunge Pool Area

0 50 100
Scale in Meters
Model Scale 1:78.7

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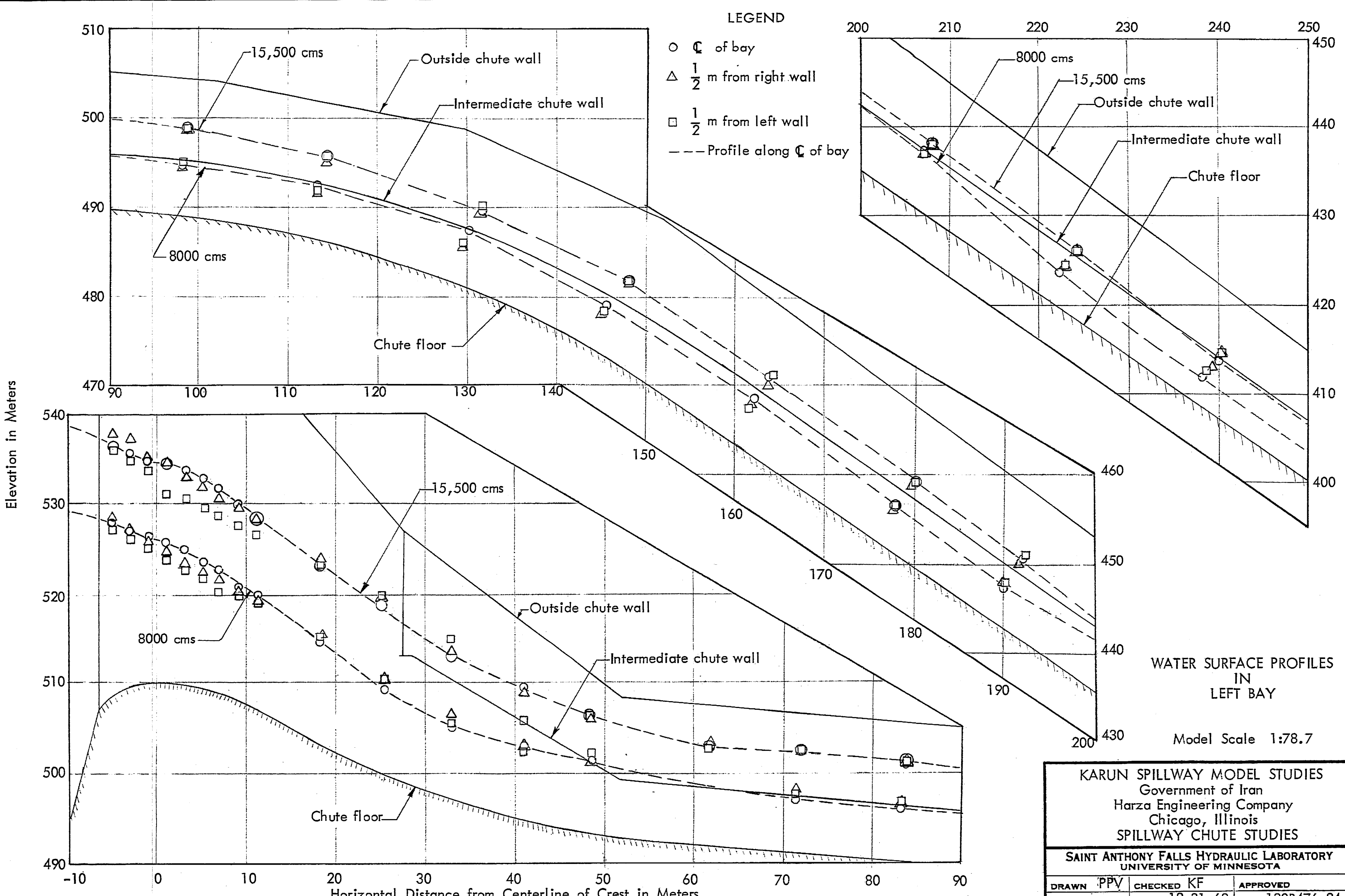
DRAWN WD	CHECKED KF	APPROVED
SCALE Graphic	DATE 12-20-68	NO. 180B476-23

CHART 23



WATER SURFACE PROFILES
IN
LEFT BAY

Model Scale 1:78.7

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SPILLWAY CHUTE STUDIES

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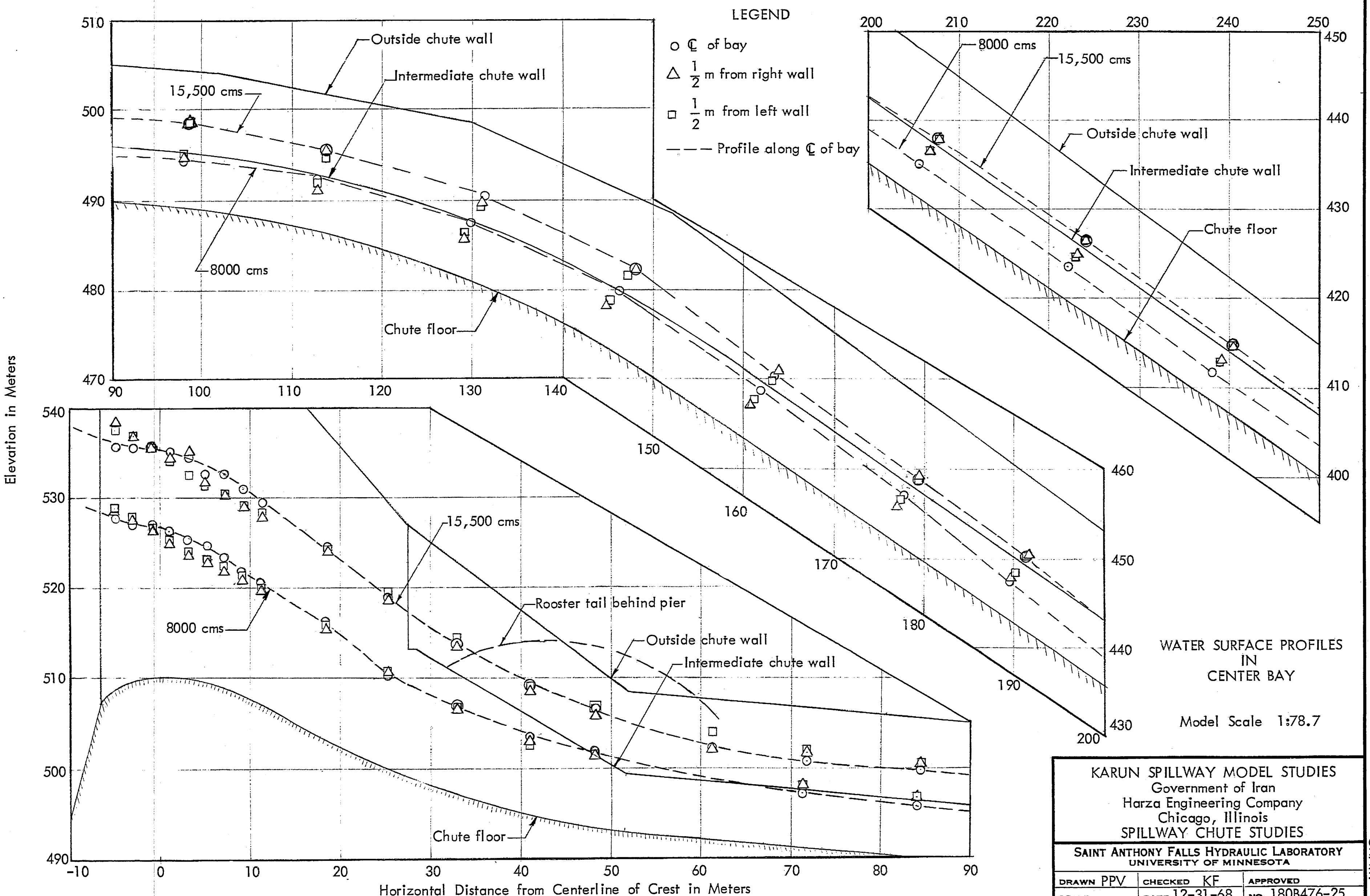
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 12-31-68	NO. 180B476-24

CHART 24



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SPILLWAY CHUTE STUDIES

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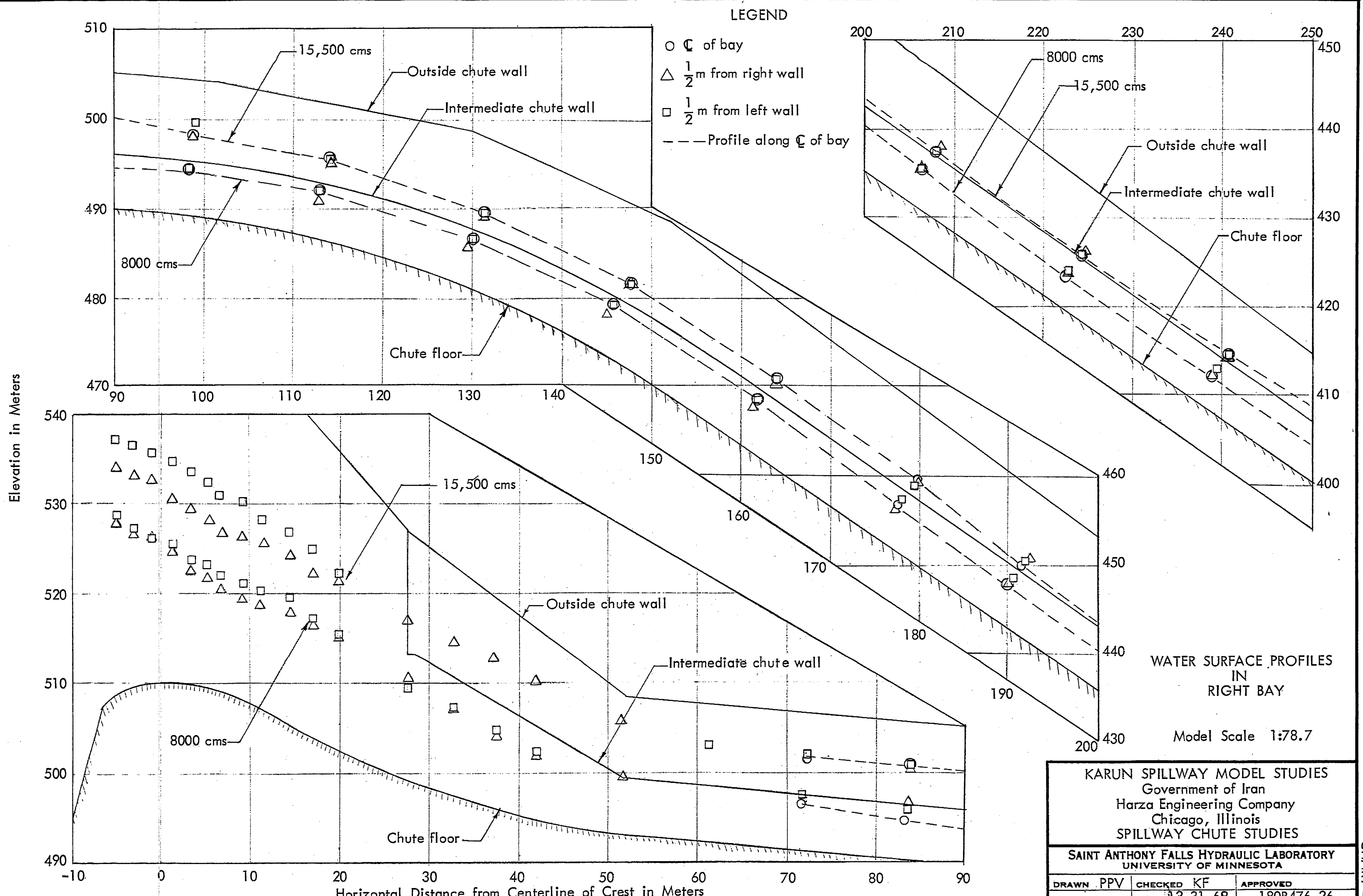
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 12-31-68	NO. 180B476-25

CHART 25



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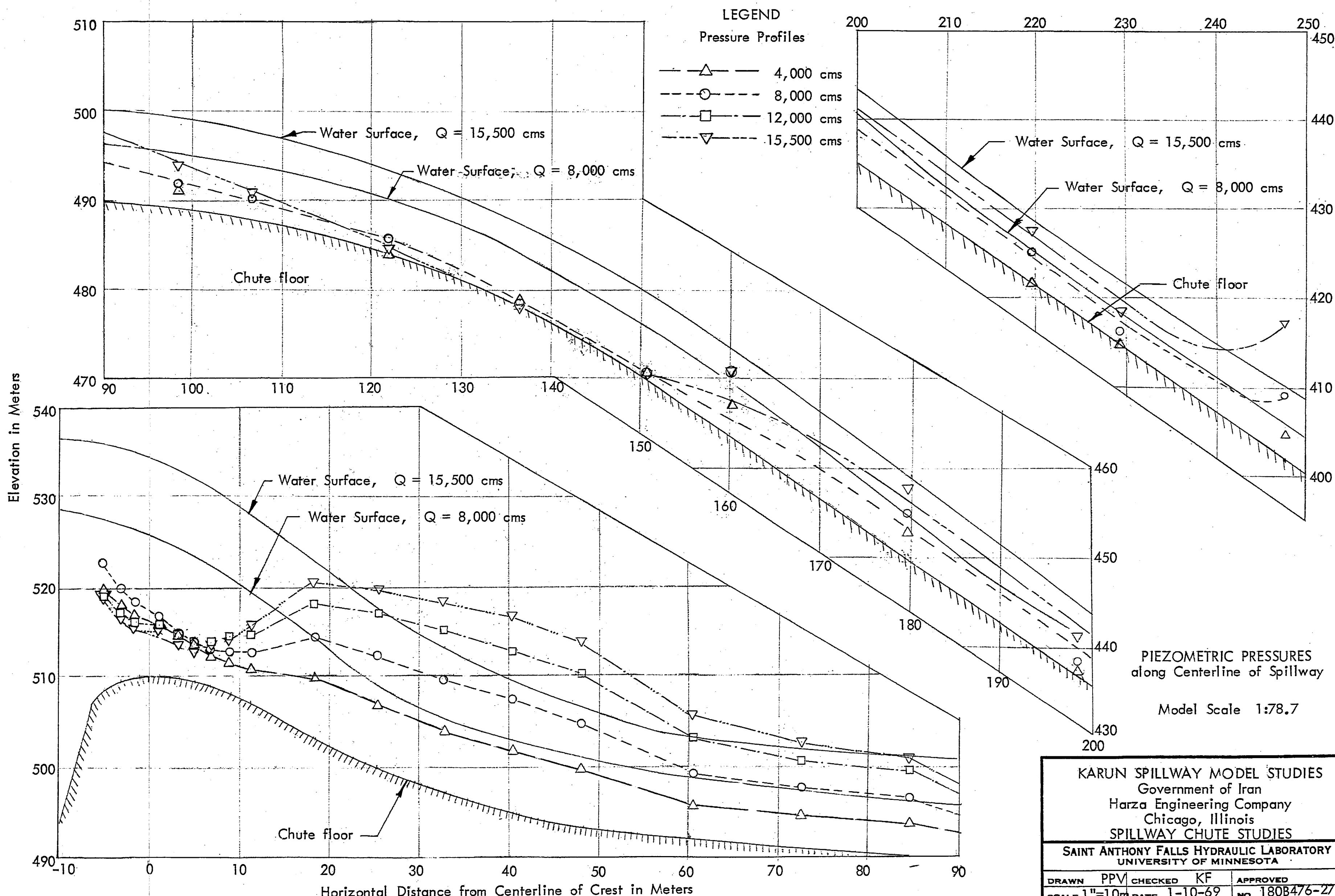
DRAWN PPV	CHECKED KF	APPROVED
SCALE:	DATE 12-31-68	NO. 180B476-26

CHART 26



PIEZOMETRIC PRESSURES
along Centerline of Spillway

Model Scale 1:78.7

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SPILLWAY CHUTE STUDIES

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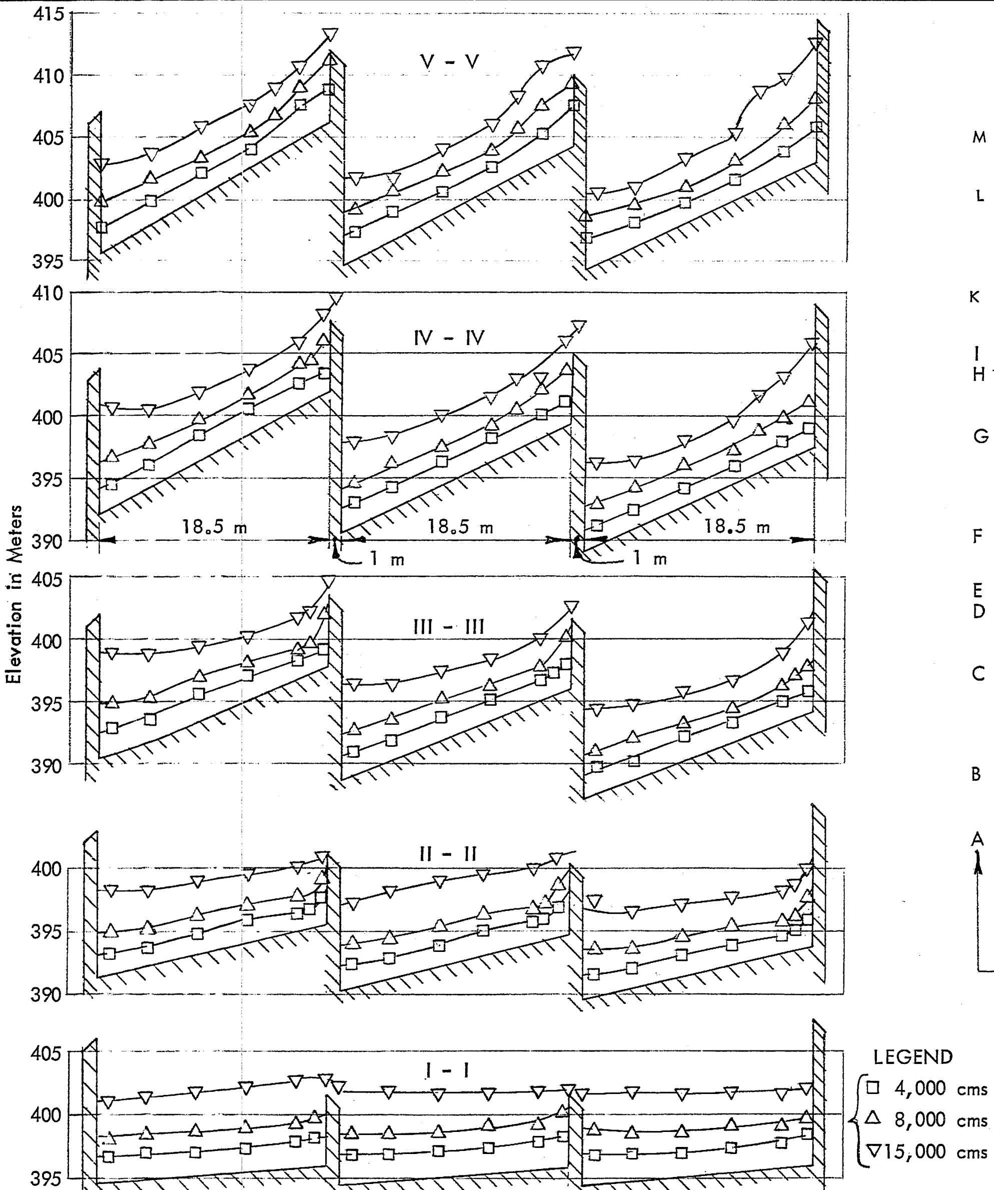
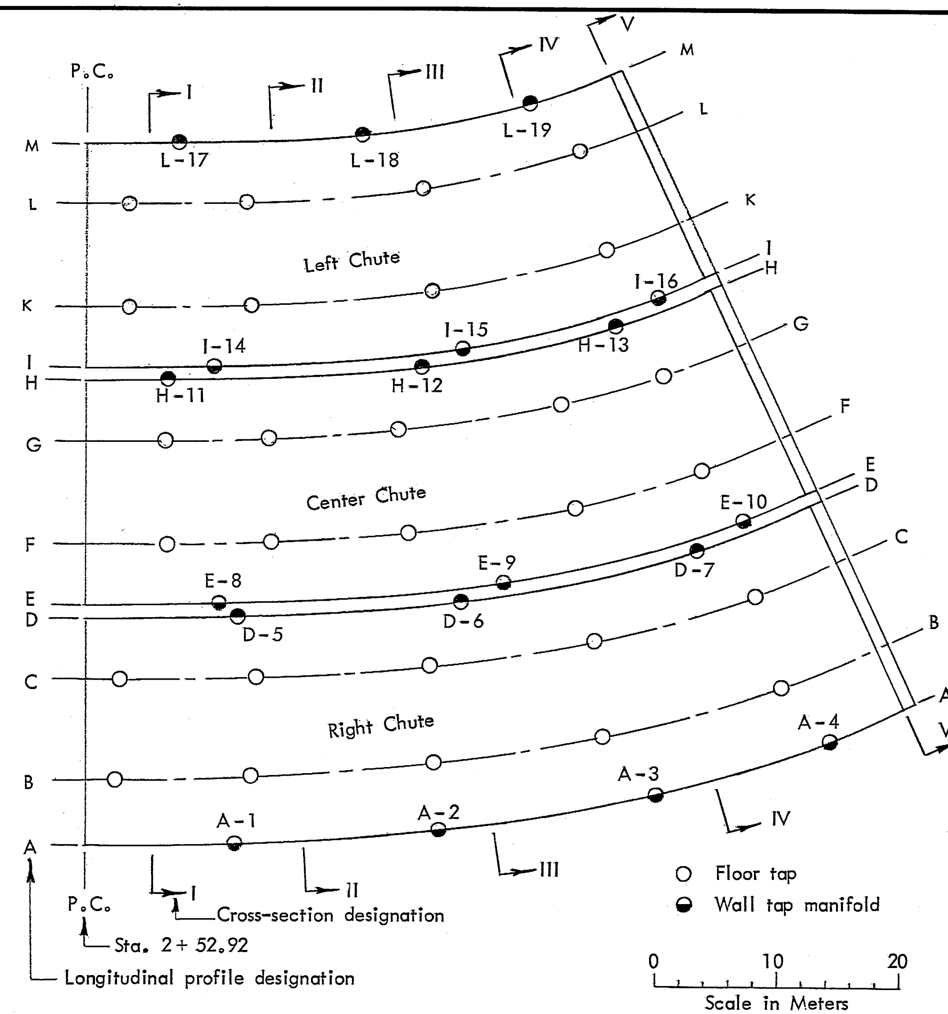
DRAWN PPV	CHECKED KF	APPROVED
SCALE 1"=10m	DATE 1-10-69	NO. 180B476-27

CHART 27



CROSS-SECTIONAL WATER SURFACE PROFILES



PRESSURE TAP LOCATION CHART

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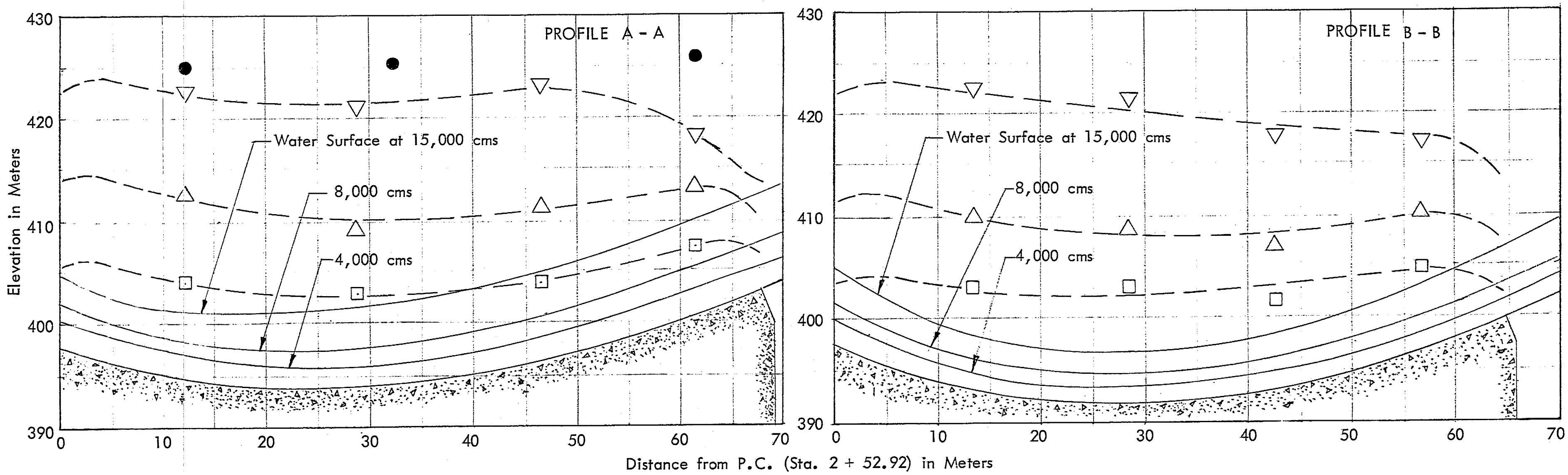
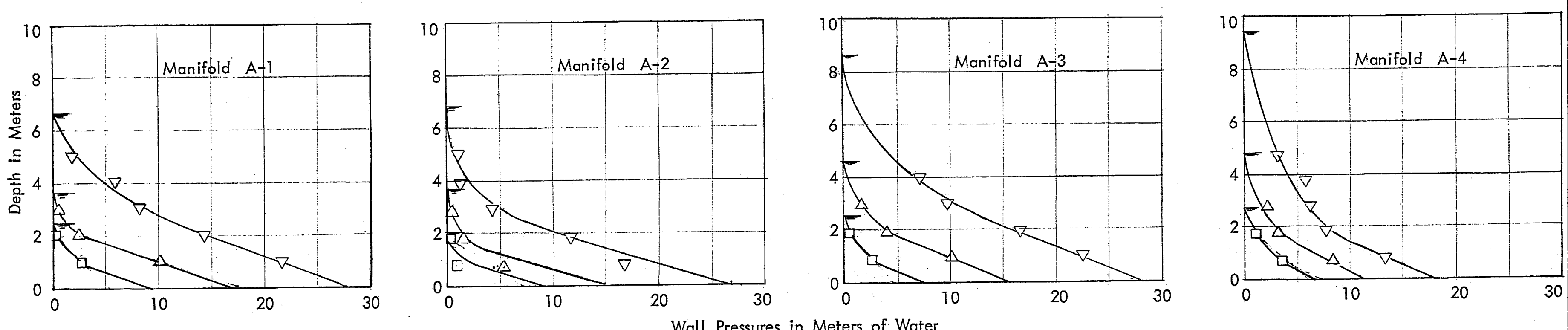
DRAWN KF	CHECKED	APPROVED
SCALE	DATE 4-3-69	NO. 180B476-29



LONGITUDINAL WATER SURFACE AND FLOOR PRESSURE PROFILES



Legend: Pressure Data

- □ 4,000 cms
- △ 8,000 cms
- ▽ 15,000 cms
- ● Calculated pressure at 16,500 cms

Note: For location of pressure taps and profiles see also Chart No. 180B 476-29.

PRESSURE AND WATER SURFACE PROFILES IN THE RIGHT FLIP BUCKET

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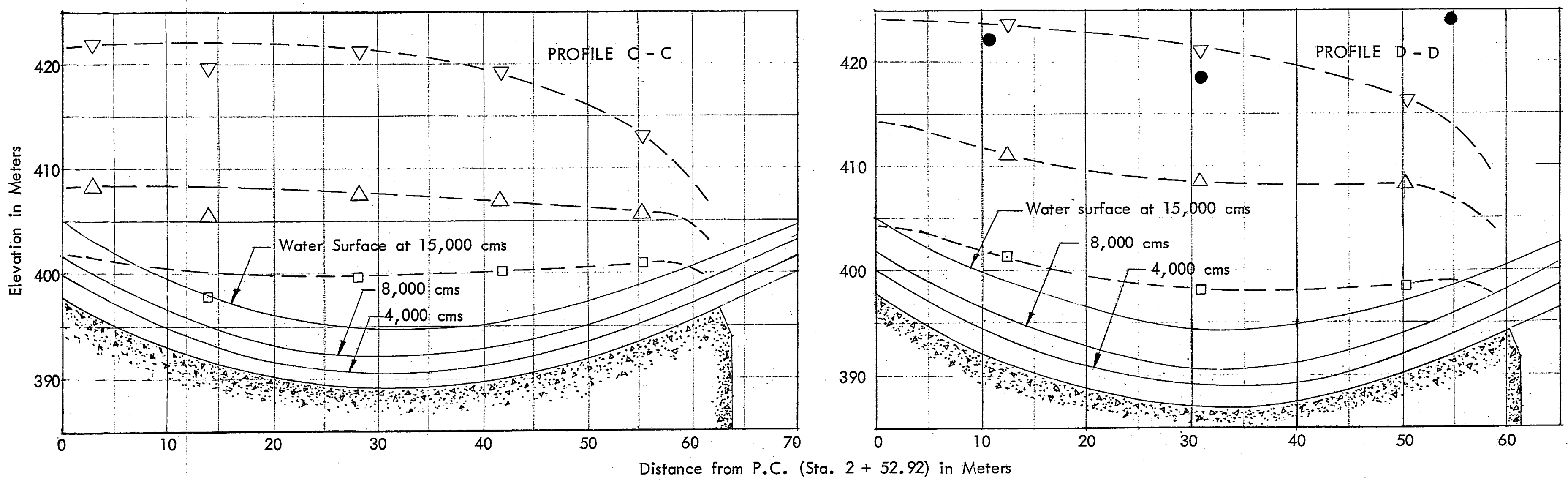
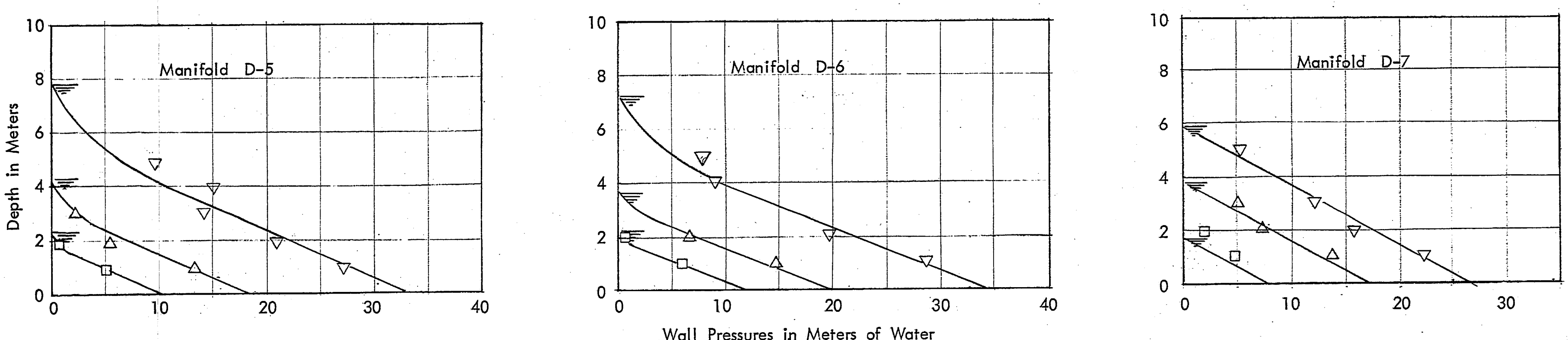
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 3-19-69	NO. 180B-476-30

CHART 29



LONGITUDINAL WATER SURFACE AND FLOOR PRESSURE PROFILES



Legend: Pressure Data

- □ 4,000 cms
- △ 8,000 cms
- ▽ 15,000 cms
- ● Calculated pressure at 16,500 cms

Note: For location of pressure taps and profiles see also Chart No. 180B 476-29.

PRESSURE AND WATER SURFACE PROFILES IN THE RIGHT FLIP BUCKET

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FLIP BUCKET STUDIES

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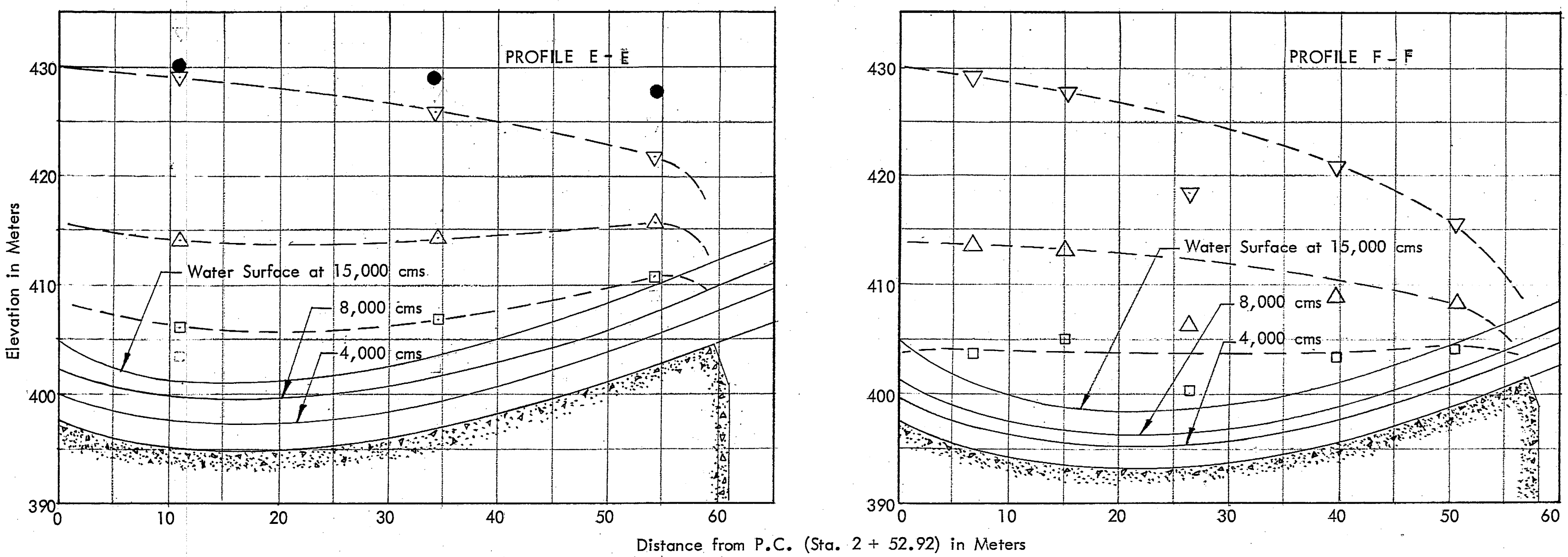
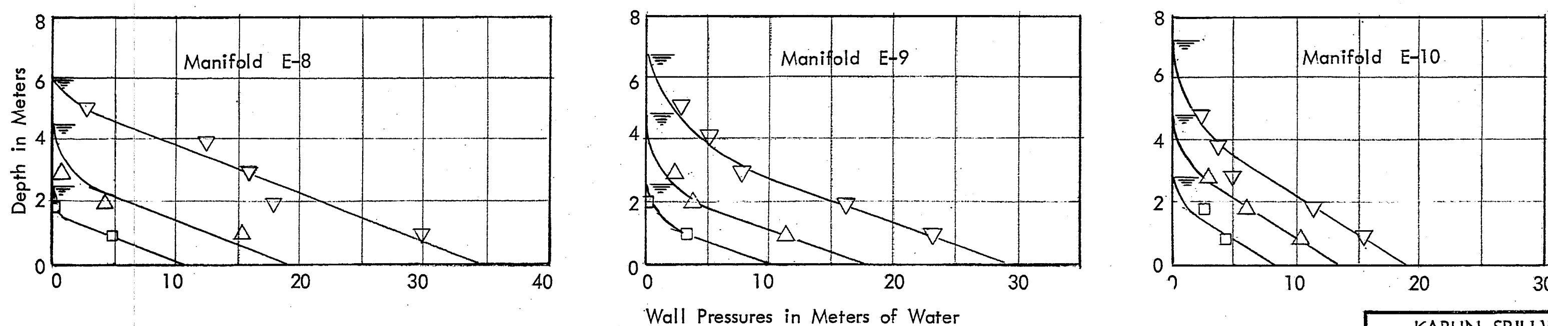
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 3-19-69	NO. 180B476-31

CHART 30



LONGITUDINAL WATER SURFACE AND FLOOR PRESSURE PROFILES



Legend: Pressure Data

- □ 4,000 cms
- △ 8,000 cms
- ▽ 15,000 cms
- ● Calculated pressure at 16,500 cms

Note: For location of pressure taps and profiles see also Chart No. 180B 476-29.

PRESSURE AND WATER SURFACE PROFILES IN THE CENTER FLIP BUCKET

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FLIP BUCKET STUDIES

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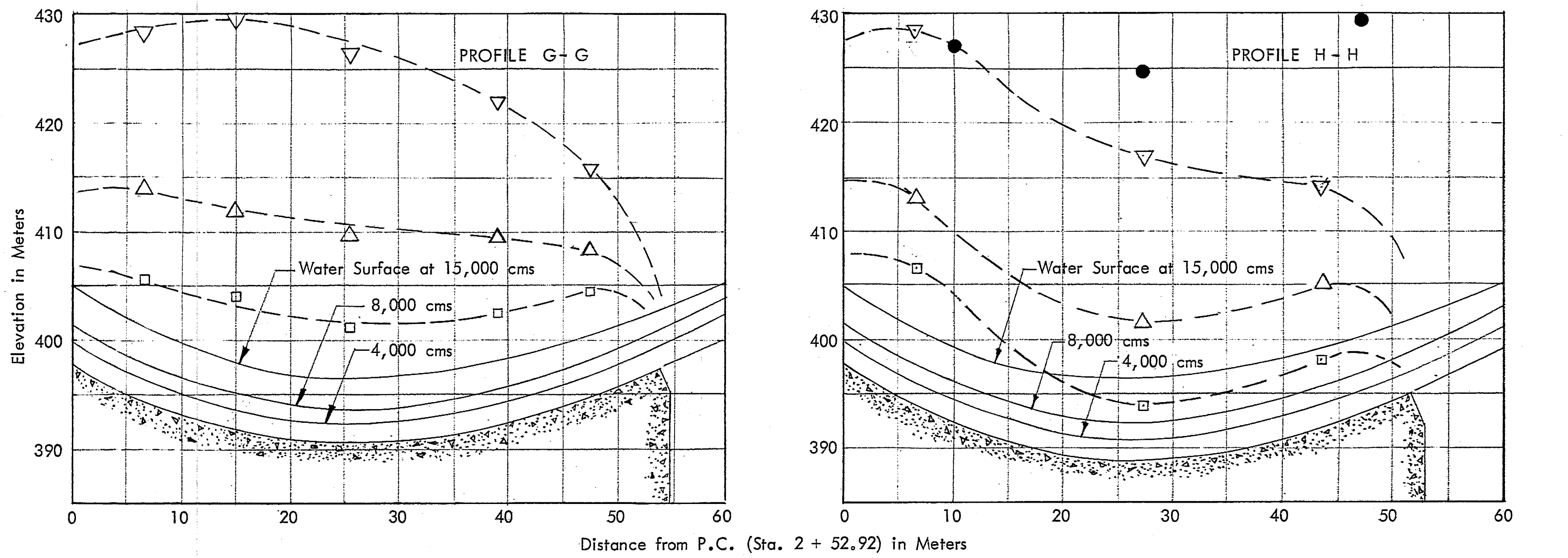
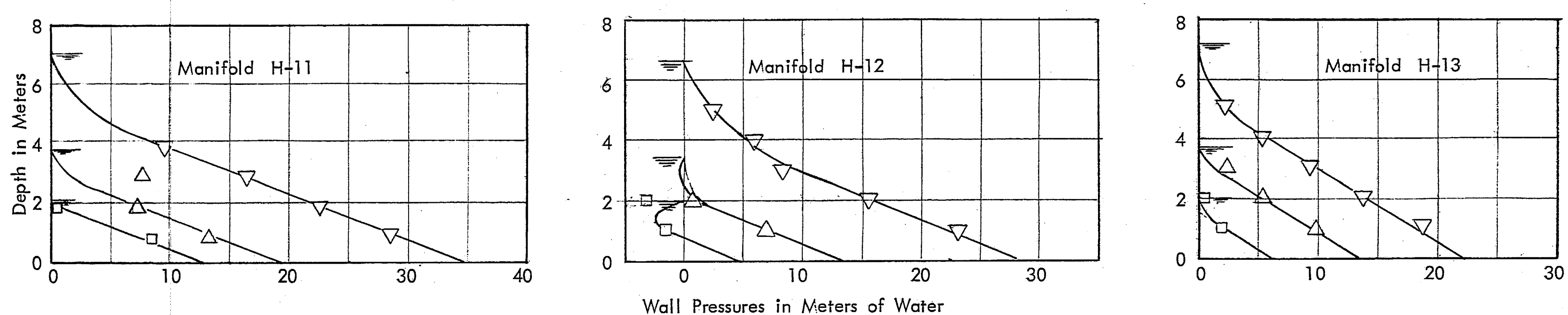
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 3-19-69	NO. 180B476-32

CHART 31



LONGITUDINAL WATER SURFACE AND FLOOR PRESSURE PROFILES



Legend: Pressure Data

- □ 4,000 cms
- △ 8,000 cms
- ▽ 15,000 cms
- ● Calculated pressure at 16,500 cms

Note: For location of pressure taps and profiles see also Chart No. 180B 476-29.

PRESSURE AND WATER SURFACE
PROFILES IN THE CENTER
FLIP BUCKET

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FLIP BUCKET STUDIES

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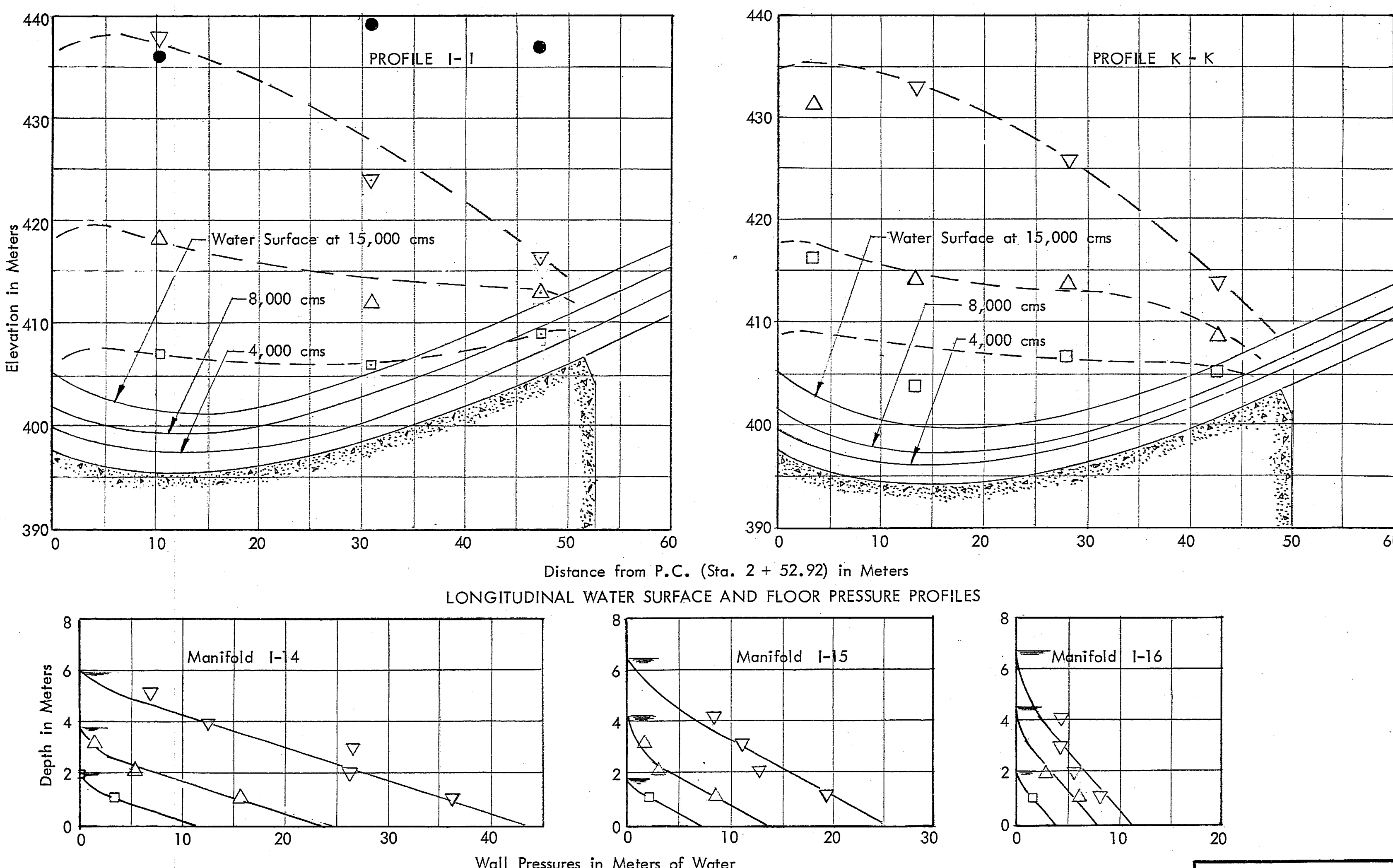
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 3-19-69	NO. 180B474-33

CHART 32



Legend: Pressure Data

- □ 4,000 cms
- △ 8,000 cms
- ▽ 15,000 cms
- ● Calculated pressure at 16,500 cms

Note: For location of pressure taps and profiles see also Chart No. 180B 476-29.

PRESSURE AND WATER SURFACE PROFILES IN THE LEFT FLIP BUCKET

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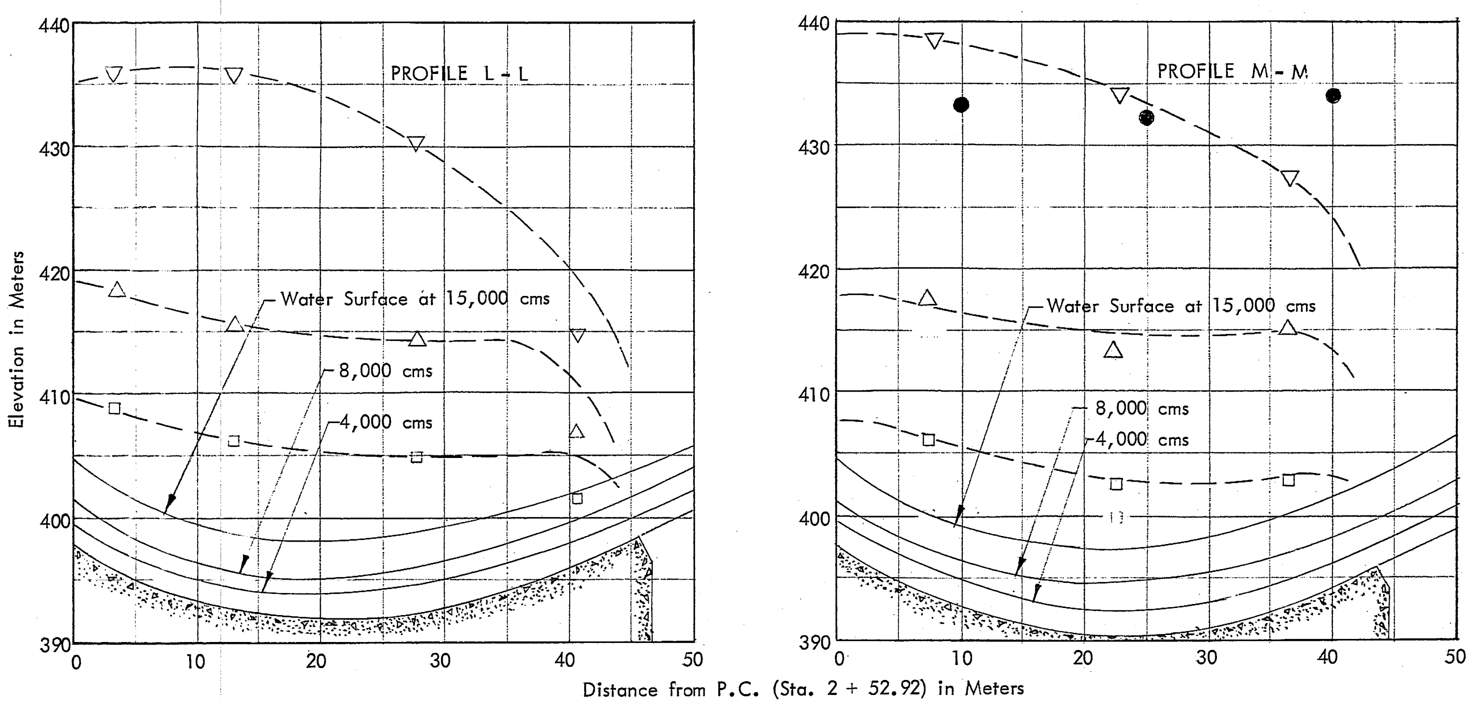
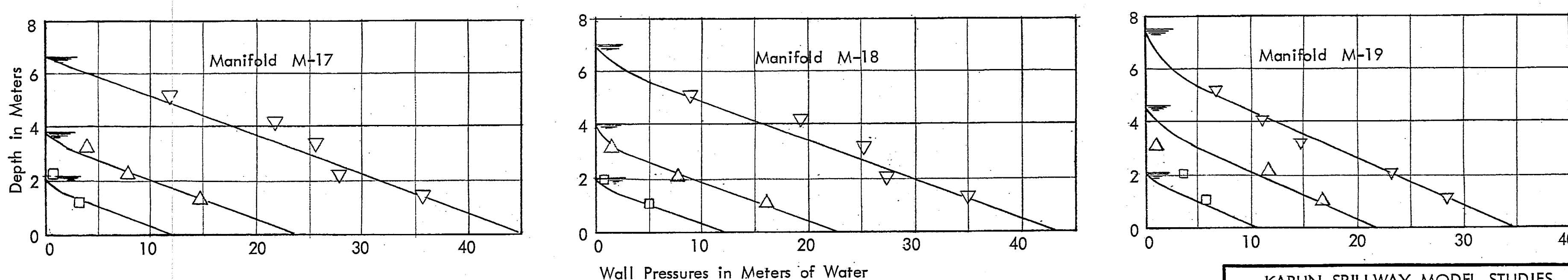
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 3-25-69	NO. 180B476-34

CHART 33



LONGITUDINAL WATER SURFACE AND FLOOR PRESSURE PROFILES



Legends: Pressure Data

- □ 4,000 cms
- △ 8,000 cms
- ▽ 15,000 cms
- ● Calculated pressure at 16,500 cms

Note: For location of pressure taps and profiles see also Chart No. 180B 476-29.

PRESSURE AND WATER SURFACE PROFILES IN THE LEFT FLIP BUCKET

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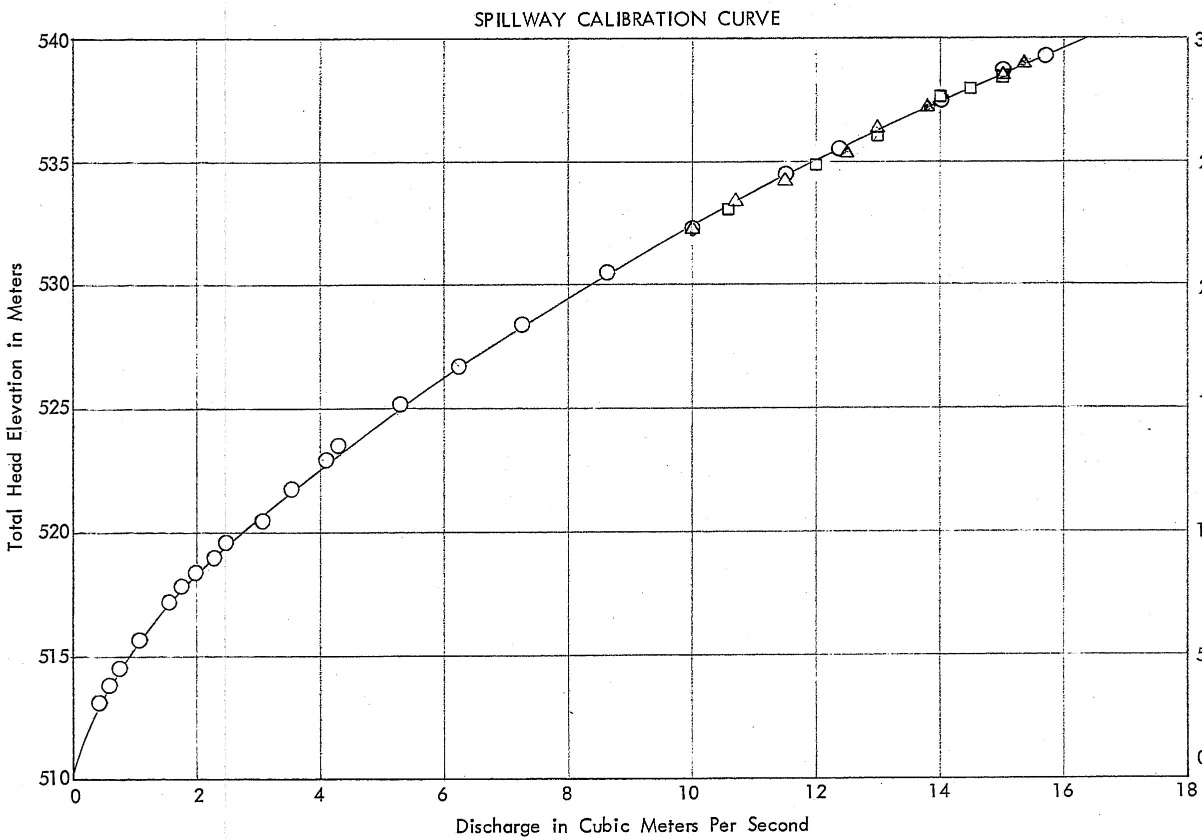
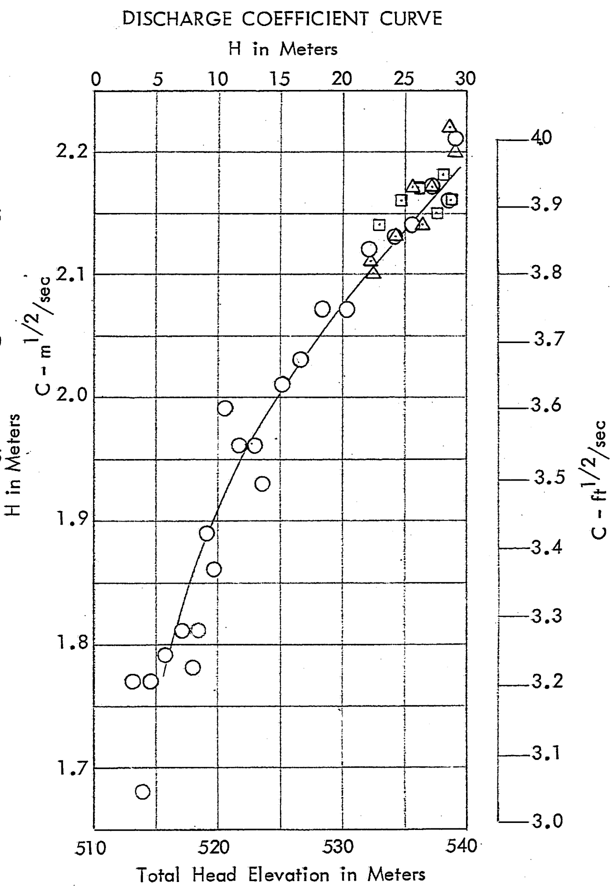
DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 3-25-69	NO. 180B476-35

CHART 34





○ Sloping approach channel floor

△ Sloping floor with cut along dam face

□ Approach channel floor at elev. 490 and cut along dam face

Note: $C = \frac{Q}{LH^{3/2}}$

where

Q = Discharge

L = Net crest length

H = Total head

SPILLWAY CHARACTERISTICS OF FREE CREST

Spillway Calibration and Discharge Coefficients

Model Scale 1:78.7

KARUN SPILLWAY MODEL STUDIES Government of Iran Harza Engineering Company Chicago, Illinois SPILLWAY CREST HYDRAULIC STUDIES		
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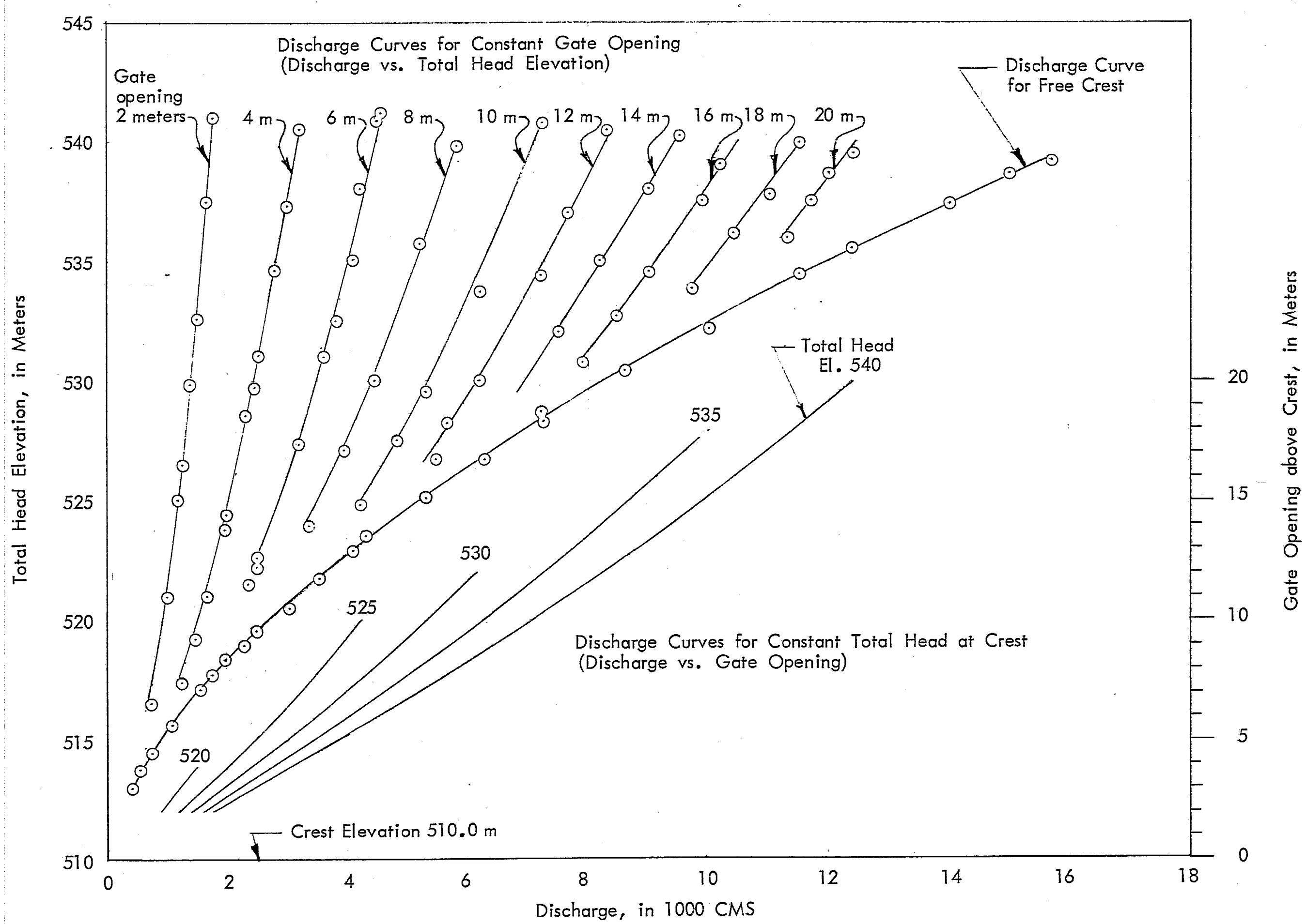
DRAWN PF	CHECKED KF	APPROVED
SCALE Graphic	DATE 8-1-68	NO. 180B476-4

CHART 35



Notes:

1. Gate opening is vertical distance between crest elevation and bottom lip of gate.

2. Curves are based on tests with all three gates open equal amounts.

Model Scale 1:78.7

SPILLWAY CALIBRATION CURVES
3-BAY OPERATION

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SPILLWAY CREST CHARACTERISTICS

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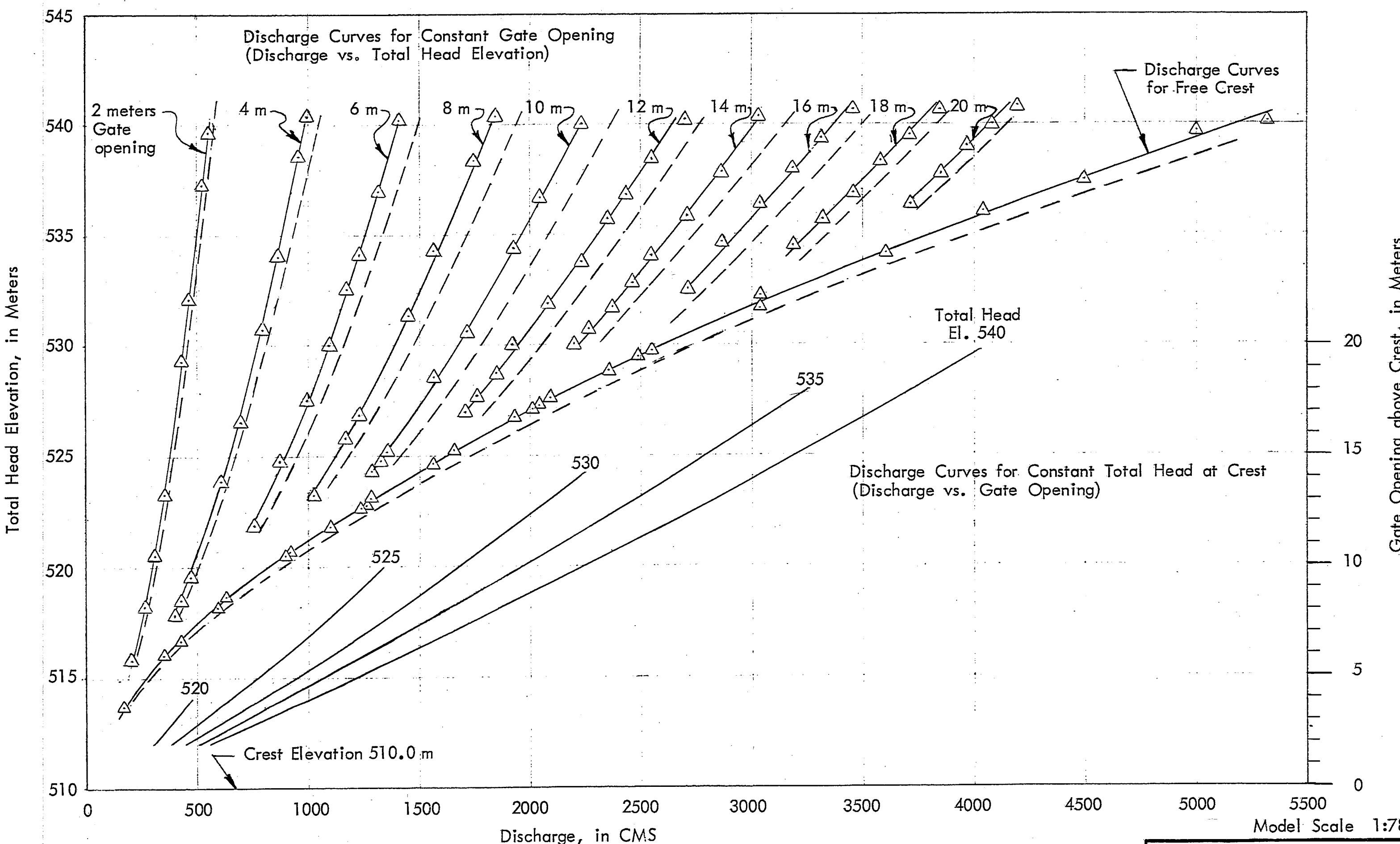
UNIVERSITY OF MINNESOTA

DRAWN AH	CHECKED KF	APPROVED
SCALE Graphic	DATE 10-15-68	NO. 180B-476-15

CHART 36



Model Scale 1:78.7

Notes:

1. ——△—— Discharge data for center bay operating alone.

2. – – – – – – Discharge per bay from uniform gate operation data. (See also Chart No. 180B-476-15.)

3. Gate opening is vertical distance between crest elevation and bottom lip of gate.

SPILLWAY CALIBRATION CURVES
SINGLE BAY OPERATION

KARUN SPILLWAY MODEL STUDIES Government of Iran Harza Engineering Company Chicago, Illinois SPILLWAY CREST CHARACTERISTICS		
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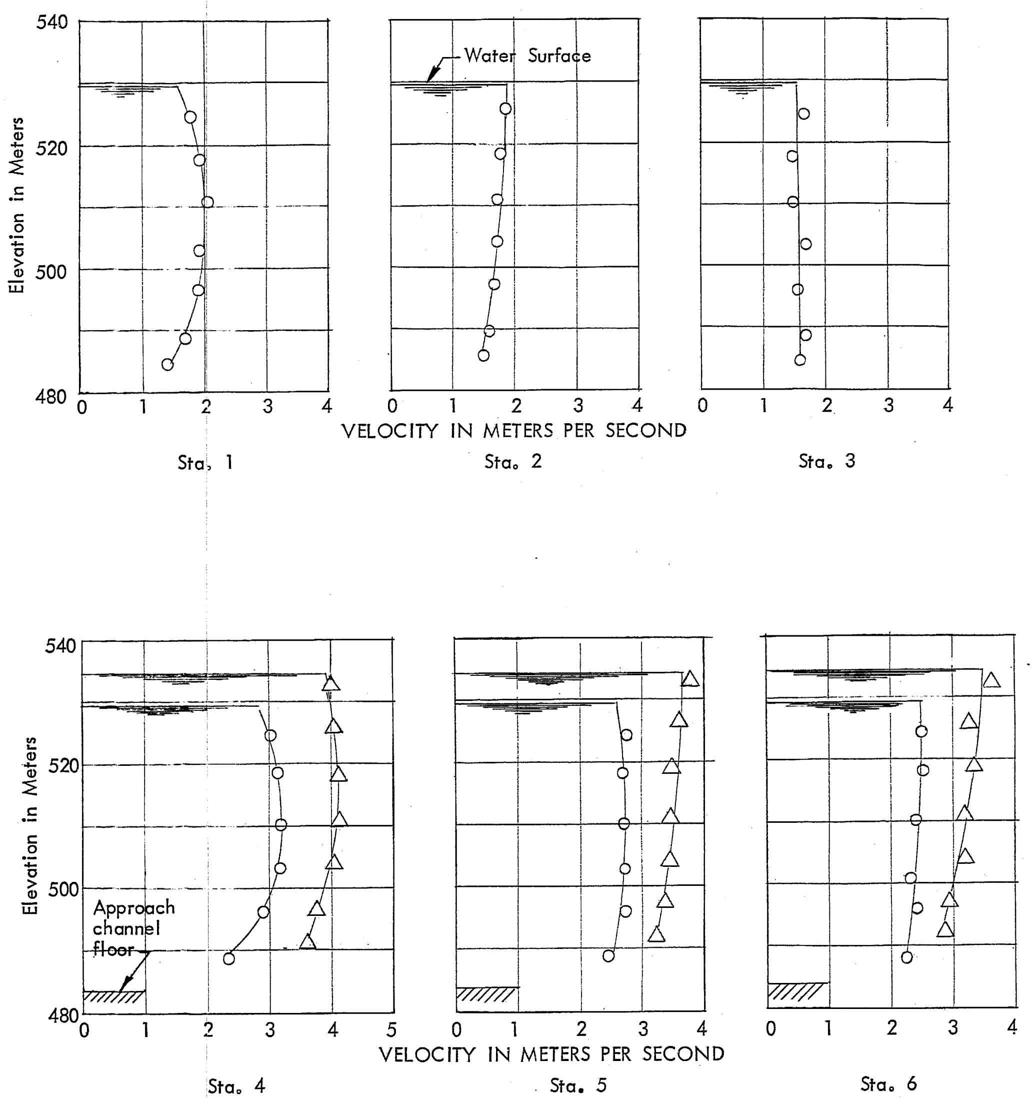
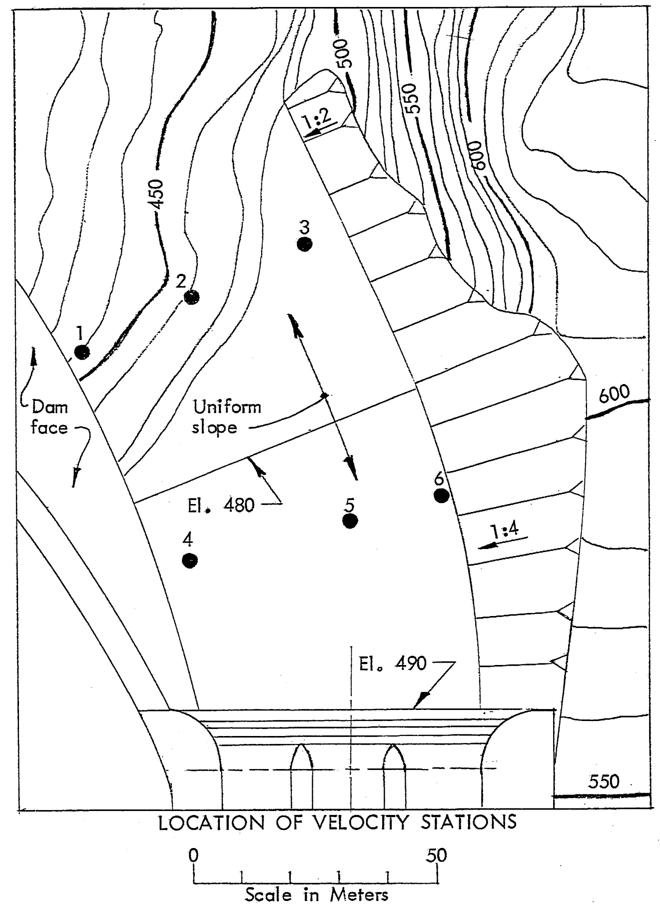
DRAWN AH	CHECKED KF	APPROVED
SCALE Graphic	DATE 10-3-68	NO. 180B-476-16

CHART 37



LEGEND: ○ 8,000 cms
△ 15,000 cms

Note: Approach channel geometry as shown in location map above.



VELOCITY DISTRIBUTIONS
IN THE APPROACH CHANNEL

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Government of Iran
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Chicago, Illinois
APPROACH CHANNEL STUDIES

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DRAWN PPV	CHECKED KF	APPROVED
SCALE	DATE 1-13-69	NO. 180B476-28

CHART 38