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HYDRAULIC MODEL STUDY OF CHILI BAR DAM
SPILLWAY MODIFICATIONS

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Mr. Steve Peirano
Pacific Gas and Electric Company
77 Beale Street, Room 2600
San Francisco CA 94016

Dear Mr. Peirano:

Our laboratory study of the existing and modified spillways for Chili Bar Dam has been completed. I have enclosed the interim report covering the model studies conducted for Chili Bar Dam. The final report will also include Bureau of Reclamation research on hydraulic design of small radius flip bucket spillways and will be provided to Pacific Gas and Electric per the cooperative agreement later this year.

We have been pleased with the results of the study and hope they will meet the engineering needs of Pacific Gas and Electric.

Sincerely yours,

James R. Graham

James R. Graham, Acting Chief
Research and Laboratory
Services Division

Enclosure

Copy to: D-3750
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HYDRAULIC MODEL STUDY OF CHILI BAR DAM
SPILLWAY MODIFICATIONS

by

R. A. Dodge
B. W. Mefford

This study was conducted by the U. S. Bureau of Reclamation

in cooperation with Pacific Gas and Electric Company

under Cooperative Agreement No. 8-FC-81-12800

HYDRAULIC MODEL STUDY OF CHILI BAR DAM SPILLWAY MODIFICATIONS

Background of Structure

Chili Bar Dam is owned by PG&E (Pacific Gas and Electric) Company. The dam is a concrete gravity dam located on the South Fork of the American River near Placerville, California. The dam and adjacent powerhouse were built in 1965. The dam is approximately 120 ft high and 375 ft wide. The structure contains an uncontrolled ogee crest spillway 170 ft wide located 31 ft below the top of the dam, figure 1. The downstream side of the spillway follows a 7 on 10 slope until intersecting the ski jump radii. The spillway currently has three 45-ft-radius ski jumps terminating at the horizontal. All ski jumps are located at different elevations and span different widths of the spillway. From right to left (looking downstream) the ski jumps are as follows:

Toe elevation (ft)	Width (ft)
940	27.5
930	100.0
950	42.5

The spillway exits into an unlined natural rock basin. The downstream channel near the dam has, in general, had all overburden removed to bedrock from previous spillway operation. Since the dam was built the maximum daily average spillway discharge has been about 39,000 ft^3/s. The spillway design capacity was 100,000 ft^3/s.

The PMF (probable maximum flood) has since been increased to 250,000 ft^3/s. To pass the new PMF requires the dam be overtopped by approximately 15 ft.

Since the dam was completed in 1965, PG&E has reported a small amount of erosion under the toe of the dam due to spillway operation. Although the erosion is not currently serious, they are concerned about continued erosion.

Several alternatives were investigated by PG&E to repair the present erosion damage and prevent future erosion. These alternatives were:

1. Place tremie concrete to fill in the existing erosion holes. The bonding between the aquatic covered bedrock and the concrete was questionable for this alternative.

2. Build a cofferdam and dry up the dam toe to ensure a proper bond between the placed concrete and bedrock could be attained. The cofferdam would have to allow for powerplant operation.

3. Do not repair the existing erosion and install a flip bucket on the existing spillway structure which would halt further erosion.

PG&E decided the third alternative was preferable to the others which repair the erosion but do not prevent future erosion from taking place. They also estimated the third alternative to be less expensive than the second as the construction could be conducted without dewatering the dam's toe. The flip bucket design required by the third alternative does not fit into existing design criteria bounds for roller bucket radius or tailwater conditions. As such a physical model study was required. Both PG&E and the Bureau of Reclamation were interested in attaining research information that would allow for expanding the available design criteria for spillways similar to Chili Bar Dam. Therefore, PG&E and the Bureau of Reclamation entered into a cooperative research agreement to model study the proposed small radius flip bucket spillway.

Objectives of the Model Study

A 1:45 scale model was designed and tested to investigate flip bucket modifications aimed at reducing stilling basin scour near the toe of the dam. A moveable bed model of the structure was tested to:

1. Define relative scour patterns, particularly at the dam's toe, as a function of flip bucket geometry and bucket elevation. Relative erosion patterns were measured after passing discharges of 10 percent, 25 percent, 50 percent, 75 percent, and 100 percent of the PMF. Previous studies had shown that potential downstream damages caused by dam failure required that the dam be capable of passing the PMF without significant erosion at the toe. For the final bucket design, tests using flows of 2 percent and 4 percent of the PMF were also conducted.

2. Determine if a deflector wall placed on the bucket adjacent to the powerhouse would reduce local scour near the end of the tailrace wall. The deflector wall studies were conducted only on the final bucket geometry. A maximum design flow corresponding to the 65-year flood, 62,500 ft^3/s (25 percent of the PMF), was used in evaluating scour along the tailrace wall. Protecting the wall from bed erosion was not considered practical for larger flows. Relative bed erosion tests were conducted with and without the deflector on the bucket.

3. Measure reservoir elevation versus spillway/dam discharge capacity and spillway crest pressures.

Description of the Physical Model

A 1:45 scale model of Chili Bar Dam including reservoir approach topography, dam, spillway, powerhouse, abutments, and about 500 ft (prototype) of downstream channel topography was built for the study. The downstream channel was modeled using an erodible bed material. The bed material was contoured in the model by matching reverse templates representing channel cross sections spaced at about 40-ft intervals down the river channel. In the model, the dam abutments and the downstream canyon walls were considered nonerodible. They were geometrically modeled using a wire mesh molded over plywood forms. A concrete mortar was placed over the wire to give a finished surface. The spillway crest and the ski jump spillway were milled out of high density urethane. Six piezometer taps were placed in the crest to measure pressures. The taps were positioned down the crest along the spillway centerline, figure 2.

Model Similitude

General

For a model to truly represent actual conditions, it must be geometrically, kinematically, and dynamically similar to the prototype. If the model deviates from the prototype in any one of these three areas of similitude, then care must be taken to properly interpret the model results. However, if any one deviation is too large, or there are too many deviations, the model will not represent the prototype and no amount of interpretation will yield the correct results or conclusions.

Flow Similitudes

Similitude analysis and model design are best started by finding valid homogeneous equations and dimensionless functional relationships that apply to both the model and prototype. Selection of a set of equations and functions includes the requirement that they be checked for their model and prototype application range and limits.

Normalizing complete hydrodynamic equations for open channel flow opposed to tractive shear or friction and then extracting dimensionless parameters results in a Froude number squared F^2 or $(V^2/R_h g)$ and a product of the Darcy-Weisbach friction coefficient (f) times Froude number squared as the required parameters for scaling flow. The friction coefficient is a function of relative roughness (K_s) and Reynolds number (R) expressed as:

$$f = \Phi\ (K_s\ ,\ R)$$

where

K_s = $(k_s/4R_h)$
R = $(4R_h V/\nu)$
f = friction factor
R_h = hydraulic radius
V = velocity
g = gravitational constant
Φ = function operator
k_s = rugosity
ν = kinematic viscosity

A geometric or length scale ratio (L_r) of 45 was selected because of limited laboratory pump capacity. Based on Froude law alone,

Length ratio	$L_r = 45$
Velocity ratio	$V_r = 6.71$
Time ratio	$T_r = 6.71$
Discharge ratio	$Q_r = 13,584$
Unit discharge ratio	$q_r = 302$
Tractive shear ratio	$\tau_r = 45$
Pressure ratio	$P_r = 45$

Having selected the Darcy-Weisbach equation to normalize friction loss in the complete flow equation, the ratio of friction factors in model and prototype (f_r) must be made equal to 1 to produce similar vertical velocity distributions and secondary flows. The Darcy-Weisbach equation for open channel flow in slope (S) form is expressed as:

$$S = f\ (1/4R_h)\ (V^2/2g)$$

Since the friction factor (f) is a function of Reynolds number ($4R_hV/\nu$), and relative roughness ($k_s/4R_h$), the modeler must work within Moody-type friction curves. Reynolds number cannot be made the same for both a model and a prototype river. The model must be made to flow at water surface elevations according to a tailwater curve and produce the proper corresponding velocity. The modeler must find the rugosity that produces an equal (f) for both the model and prototype. Putting the previous scale relations into the Reynolds number results in a measure of Reynolds number distortion (R_{dr}) based on the selected model scale ratio expressed as:

$$R_{dr} = L_r^{3/2} = 302$$

A friction Reynolds number and relative roughness model to prototype comparison was done using the prototype tailwater curve and a Moody-type friction function for discharges from 5,000 to 250,000 ft^3/s. These comparisons showed that Reynolds number was sufficiently large for both model and prototype to be on the flat part of the friction function. Thus, model and prototype (f) are expected to be equal. It was also shown that relative roughness was sufficiently small (less than 1/10) such that Darcy-Weisbach equation applies to both the model and prototype. Because Reynolds numbers are large and model and prototype friction coefficients can be made the same, vertical geometric distortion of the model was not necessary. For example, for a prototype discharge of 125,000 ft^3/s the Reynolds number is 2.5×10^8 prototype and 8.3×10^5 model.

Sediment Similitude

In general, attempts to scale the structural integrity properties of bedrock are unsatisfactory. Therefore, it was decided that the grain distribution analyses would be used to provide friction scaling, indicate sizes that move and armor and determine a qualitative comparison of the scouring potential for flip bucket modifications relative to the existing spillway.

Fluid shear at the bed, lift, drag, secondary flow and turbulence are considered the main factors that initiate and maintain the transport of bed material. Particle settling velocity, shape, packing, and submerged weight govern resistance to motion.

Simple Froude law and frictional scaling do not assure that model sediment will transport similar to the prototype. Thus, further parameters need to be considered related to sediment entrainment and transport. If transport rate needs to be scaled, then a homogeneous transport equation must be selected or a dimensionless transport function must be used. The Bureau uses Taylor's dimensionless sediment discharge parameter (q_s/U_*d_s) denoted by (q_{s*}) that produces a set of curves approximately parallel to Shields' entrainment curve for constant values of (q_{s*}). Thus (q_{s*}) is a function of Shields' parameters for grain diameter-shear velocity Reynolds number R_{g*} or (U_*d_s/ν) and dimensionless shear T_* or ($\tau/(\gamma_s-\gamma_w)d_s$) expressed functionally as,

$$q_{s*} = \Phi\ (R_{g*}\ ,\ T_*)$$

where

q_{s*} = sediment discharge volume per unit width per second
d_s = sediment diameter
γ_s = specific weight of sediment
γ_w = specific weight of water
τ = tractive shear
ν = kinematic viscosity
U_* = shear velocity = $(\tau/\rho)^{1/2} = (SR_hg)^{1/2} = V(f/8)^{1/2}$
ρ = water density
S = slope

Transport scaling is accomplished by finding a model sediment diameter and specific gravity combination by trial and error that produces a model (q_{s*}) equal to prototype (q_{s*}). Analyses of Taylor's function and homogeneous transport equations show that noncohesive transport scales by $(L_r)^{3/2}$. Using cohesive sediment transport equations, transport scales by (L_r). Some model and prototype checks were done of Taylor's parameters and compared to existing velocity-diameter data. These checks and comparisons indicated that scaling the river part of the model could be done. Since the prototype material at the plunge area is bedrock, detailed transport analyses were not done. Bureau experience indicates that scaling by settling velocity alone produces near (q_{s*}) scaling, especially for large diameters. Scour in the plunge region is not expected to scale close to Taylor's relationship. Plunging jets scale closer according to pure Froude law for large particles geometrically scaled.

Settling velocity is considered an important sediment parameter since it relates to when sediment will remain at rest and how long it will travel once lifted into flow. To size model sediment, settling velocity is scaled by Froude law velocity scale ratio ($L_r^{1/2}$). Settling velocity for 1-mm particles and larger are proportional to diameter to the 1/2 power. Therefore, these model sizes scale settling velocity by Froude law and prototype diameters of 45-mm and greater scale both geometrically and by settling velocity. Settling velocity scaling has been successfully used for most of the Bureau's diversion dam model studies for relative comparisons of different test arrangements.

Expected Model Performance

Following are brief statements of the major results of the similitude and scaling analyses:

- In general, attempts to scale the structural integrity properties of bedrock are unsatisfactory. Therefore, it was decided that the grain distribution analyses would be used to provide friction scaling, indicate sizes that move and armor, and provide a qualitative comparison of the scouring potential for flip bucket modifications relative to the existing spillway.

- Because of the large Reynolds number, model and sediment diameter, it was possible to make the dimensionless parameters, Froude number, Darcy-Weisbach friction coefficient, and relative roughness the same for model and prototype. Therefore an undistorted model could be used for the river part of the model.

- Relative roughness ($k_s/4R_h$) was less than 1/10, thus the Darcy-Weisbach equation applied to both the model and prototype.

- Since the friction coefficient ratio (f_r) could be made equal to 1, vertical velocity distributions and secondary flow scale.

- Some Taylor-Shields scaling checks were made and indicated good sediment scaling of river part of the model.

- Settling velocity scaling of sediment diameter generally produces close Taylor-Shields scaling.

- Settling velocity scaling and geometric scaling produce the same diameter distribution down to 1-mm material in the model, thus geometric scaling was good down to the 20 percent passing size or the 45-mm prototype size.

- Verifying good river flow and sediment scaling without vertical geometric scale distortion, provides confidence of scaling in parts of the model where Darcy-Weisbach equation does not apply such as in the jet plunge region. Pure Froude law alone applies there with geometric diameter scaling. Larger sediment sizes than predicted, and scour assuming normal river flow, scour because of jet flow.

- Quantitative scour comparisons could not be made because loose bed material was used to represent bedrock regions of the prototype, and scour of the loose bed material would be affected by the more resistant exposed bedrock. It is believed that the model scour is conservative as compared to the prototype.

- The model is expected to provide good qualitative and relative comparisons of scouring potential of flip bucket modifications because the scour form did not vary much in shape and mainly changes of flip elevations were tested.

Bed Material

Pacific Gas and Electric provided four grain diameter distribution analyses of the river bottom material. The four samples came from an area of deposited transport material removed from the spillway plunge region. A field contour map, figure 3, of bars and sparsely distributed material remaining on poor bedrock near the plunge area was also provided. The material on the bedrock near the plunge area consisted of 1- to 15-ft boulders.

Figure 4 shows the cumulative distributions of prototype sediment provided by PG&E. In this figure, samples and distribution curves are identified by circled numbers. Divers obtained four distributions by measuring and counting individual boulders within four sample areas. Samples 1 and 2 were combined into a single curve and the remaining curves 3 and 4 were each separately plotted. Curve 1-2 weighted by two, curve 3 and curve 4 were averaged. The average, plotted as curve 5, represented the target sediment distribution to be modeled. Curve 6 defines the estimated grain distribution for isolated individual boulders near the spillway.

Prototype particle distributions were converted to model by geometric scaling and plotted in figure 5. Distribution 5, the long dashed line, is considered the upper bound for permissible geometrically scaled sediment for the model. The lower distribution 1-2, long dashed line, is considered the lower bound. The mean or target distribution is shown as the light solid line curve. The target distribution for settling velocity scaling plots on top of the curve for geometric scaling down to the 1-mm model size then deviates as shown. Thus geometric scaling is valid down to the 80 percent retained size. The heavy solid lined curve is distribution of a pit run material with some minor sieve separation used in the model.

Test Procedure

Prior to each new geometry tested, new bed material was placed in the downstream channel and the bed was contoured based on a prototype channel survey conducted in March 1988, figure 6. For each spillway geometry, the model bed was allowed to progressively scour as increased flows were tested. To prevent scouring of the bed during model startup, before each test the model tailwater was slowly raised by filling the model tailbox downstream of the dam. Each spillway geometry was tested for the same sequence of flows and for the same time of operation. After each flow the bed scour was contour mapped with string to show the erosion pattern for photographs. In addition to the qualitative string contours, the templates used to form the initial bed were reinstalled and quantitative measurements of changes in the bed elevation were made. The measurements were made in the same location for each test based on a preestablished grid pattern.

Bed Erosion Tests of As-Built Ski Jump Spillway

The as-built spillway geometry was placed in the model to determine the scour patterns developed for flows up to the PMF. Erosion tests of the as-built geometry established a comparative base for evaluating future scour patterns created with modified spillway geometries. The ski jumps operated either in a free discharge mode or in a tailwater sweep-out condition for all flows tested. The as-built ski jump spillway geometry generally created a scour pattern with scour holes downstream of the 940 and 950 ski jumps starting about midway down the tailrace wall, figures 7-11. During 10 percent PMF flows, fine bed material deposited against the spillway face. The material was drawn toward the spillway face by return flow along the bed. Along the spillway face, material generally moved from left to right (looking downstream). The flow moved the fines parallel to the face of the 930 bucket, forming a deposition peak in front of the 940 elevation bucket. Flows larger than 25 percent of PMF progressively eroded the bed at the toe of the spillway, figure 12.

Flip Bucket Modifications

The basic bucket designs tested in the model were developed by PG&E. The as-built ski jumps were modified by reducing the radius to 35 ft and extending the arc 30° beyond the horizontal, figure 13. The same bucket radius and arc length were used to modify the as-built geometry for all modified spillway tests. Using the set bucket geometry, model tests were then conducted for three different spillway designs. Spillway modifications tested were limited to designs which could be adapted to the prototype without requiring major concrete excavation of the existing spillway, figure 14A. First, a single-level bucket at invert elevation 952.6 ft was tested in the model, figure 14B. The 952.6-ft elevation was the lowest elevation at which a single-level bucket could be constructed due to the

950-ft elevation of the existing ski jump on the left side. For the second series of tests the spillway was modified by lowering the right 127.5 ft of the bucket to elevation 942.6 ft, figure 14C. Following testing on the two-level flip bucket spillway geometry, the spillway was changed to a three-level flip bucket design. The invert elevation for the middle portion of the bucket lying above the existing 930-ft ski jump was lowered to elevation 932.6 ft, figure 14D.

Model Tests of Single Bucket

The model spillway was changed to a single bucket 170 ft wide located on the spillway face at invert elevation 952.6 ft. The lip of the single bucket (elevation 957.25 ft) was above the tailwater for flows less than about 25 percent of PMF. For these flows the jet leaves the spillway bucket as a free jet, figure 15. At higher spillway discharges the jet sweeps out, with a partially aerated undernappe up to about 75 percent of PMF. At 100 percent of PMF the jet was fully suppressed. Erosion patterns produced were in general evenly distributed across the channel, figures 16A, 16B. The channel bed for the first 60 ft downstream of the bucket face showed only small changes in elevation from 10 percent PMF to 100 percent PMF. Just downstream of the toe of the spillway the steep portions of the bed below the old 940 and 950 ski jumps eroded to a near level profile, figure 17.

Model Tests of Two-Level Bucket

The two-level flip bucket spillway was tested for discharges of 10 percent PMF, figure 18, and 50 percent PMF. Scour patterns from flow over the two-level bucket were similar to the scour developed by the single, higher elevation configuration. After the 50 percent PMF test, an increase in the erosion was noted along the tailrace wall accompanied by greater deposition on the opposite side of the channel as compared to the single-bucket test results. Greater erosion also occurred below the toe of the higher bucket, figure 19.

Model Tests of the Three-Level Bucket

Bed erosion tests were run for the three-level bucket spillway at flows of 10 percent, 25 percent, and 50 percent of PMF. At 10 percent PMF, the outside buckets produce free impinging jets into the tailwater. The jet from the center flip bucket was partly suppressed, figure 20. After the 10 percent PMF test, less erosion had occurred along the tailrace wall as compared to the previous geometries tested, figure 21. Near the toe of the spillway the flows created only minor erosion of the channel bed on the steep slope below the high bucket, figure 22. At higher discharges deposition of fine bed material increased downstream of the two lower buckets, figures 23, 24. Fine material was carried from the downstream scour holes upstream to the toe of the spillway by the action of secondary return flows. The eddies moving material upstream along the bed are driven by the overlying high velocity surface jet. The material deposited in the model at the spillway toe was predominately very fine material.

Three-Level Flip Bucket Spillway with Flow Deflector Wall

A wedge-shaped deflector wall was placed in the model along the powerhouse wall, figures 25A, 25B. The deflector was tested to determine if it would protect the tailrace training wall from scour for flows up to 25 percent of PMF. The wall was designed to divert the jet from the 942 level flip bucket away from the tailrace wall. Without the deflector wall, the outer edge of the jet impinges on the wall. Model tests with the deflector were conducted with 2 percent, 4 percent, 10 percent, 25 percent, 50 percent, 75 percent, and 100 percent of PMF. A comparison of erosion depths at several points near the tailrace wall shows the deflector wall only reduces the scour occurring around the very downstream end of the wall at 10 percent of PMF, figures 26-28. At 25 percent PMF little difference in the scour level occurs. Near the toe of the spillway, material was generally deposited against the center bucket and small amounts removed from the steep slopes in front of the two edge buckets, figure 29.

After the 2 percent of PMF, no definable erosion of the bed was apparent in the model. A discharge of 4 percent of PMF caused a small amount of erosion across the channel near the end of the tailrace, figure 30. The erosion was local to the area directly beneath the point of jet impingement. Some of the eroded material was deposited in the upstream river channel area. Overall river channel erosion was nearly the same for model tests with and without the deflector wall, figures 31-33. At 75 percent and 100 percent of PMF, the three-level flip bucket spillway developed much less erosion in the river channel between the toe of the dam and the end of the tailrace as compared to the as-built spillway, figures 34, 35.

Conclusions

Overall, the modified flip bucket spillways tested produced less bed scour within the reach from the toe of the spillway to the end of the tailrace wall when compared to the as-built spillway design. Of the three modified spillway geometries tested, the three-level arrangement produced the greatest deposition of fine bed material within the channel reach immediately downstream of the spillway and along the tailrace wall. Significant toeing of material occurred in the model for flows 25 percent of PMF and greater. Due to the large flows the spillway/dam is required to pass, the moving of material toward the toe of the dam is considered desirable. Although some abrasion to the concrete on the downstream face of the lower flip buckets could occur for the higher flows, the abrasion action is not expected to be significant. Visual observations made of the movement of bed material in the model indicated the tailwater velocities beneath the jet and next to the bucket faces were generally low. The deposition of very fine material along the toe in the model also suggests the hydraulic action next to the spillway is not extremely violent.

The implementation of the deflector wall in the right side bucket did not produce an overall improvement in the local scour along the tailrace wall. Scour at several locations along the wall increases slightly with addition of the flow deflector. The deflector did force the edge of the jet out from the wall thus preventing the edge of the jet from impinging directly above the wall.

Appendix

Reservoir elevation versus discharge was measured in the model, figure A1. Although no attempt was made to directly determine the maximum capacity of the spillway before overtopping of the dam occurred, overtopping was estimated to occur at 115,000 ft^3/s based on the model data. To pass the PMF required a reservoir elevation of 1043.5 ft. Flow overtopped the dam by 15 ft.

Pressures were measured on the spillway crest for discharges of 10, 25, 50, 75, and 100 percent of the PMF, figure A2. The pressures are listed in table 1. The pressures given are time averaged values. For the PMF a maximum negative pressure of 30.9 ft below atmospheric pressure was measured on the top of the crest. Pressures remained positive for all flows tested at piezometer location 6. The high negative pressures measured for the 75 percent and 100 percent of PMF are of a level that intermittent cavitation may occur. Due to the very low frequency of the events and the relatively short peak flow durations, severe cavitation damage is not probable.

The tailwater in the model was established for each test based on figure A3. The model tailwater was set in the model artificially by adjusting the height of a downstream overflow weir.

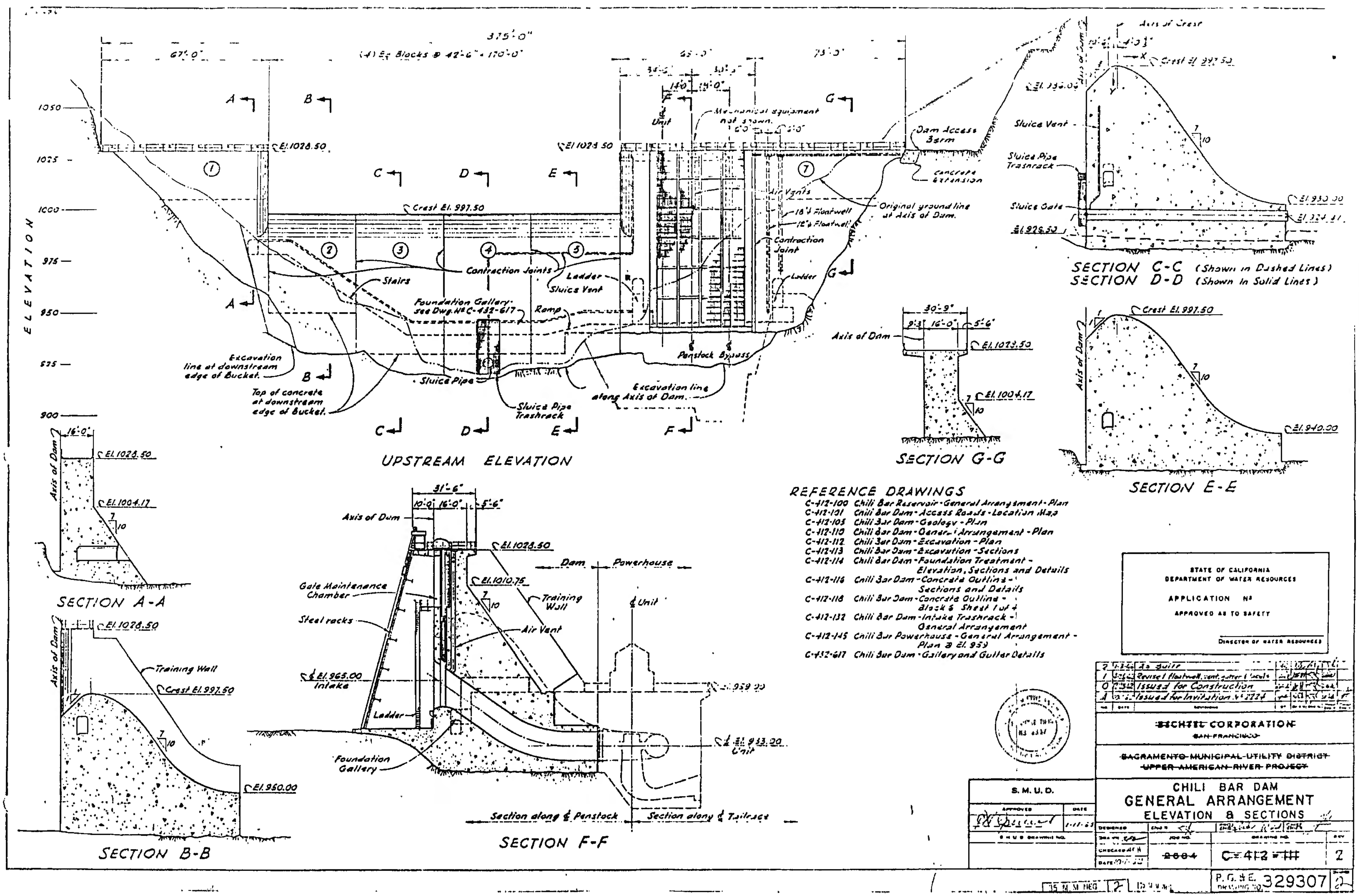


Figure 1. - Dam elevations.

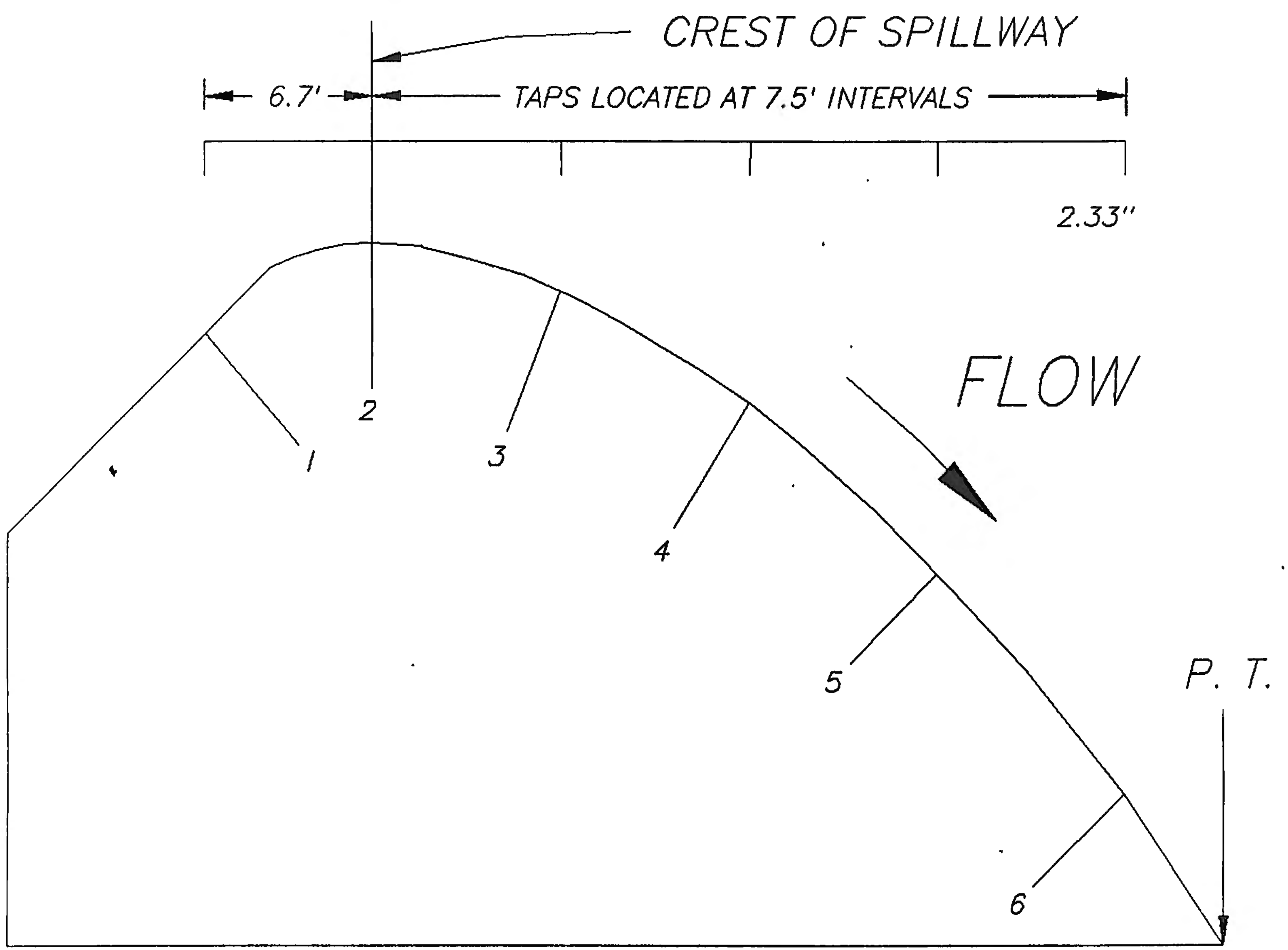


Figure 2. - Chili Bar spillway crest pressure tap locations.

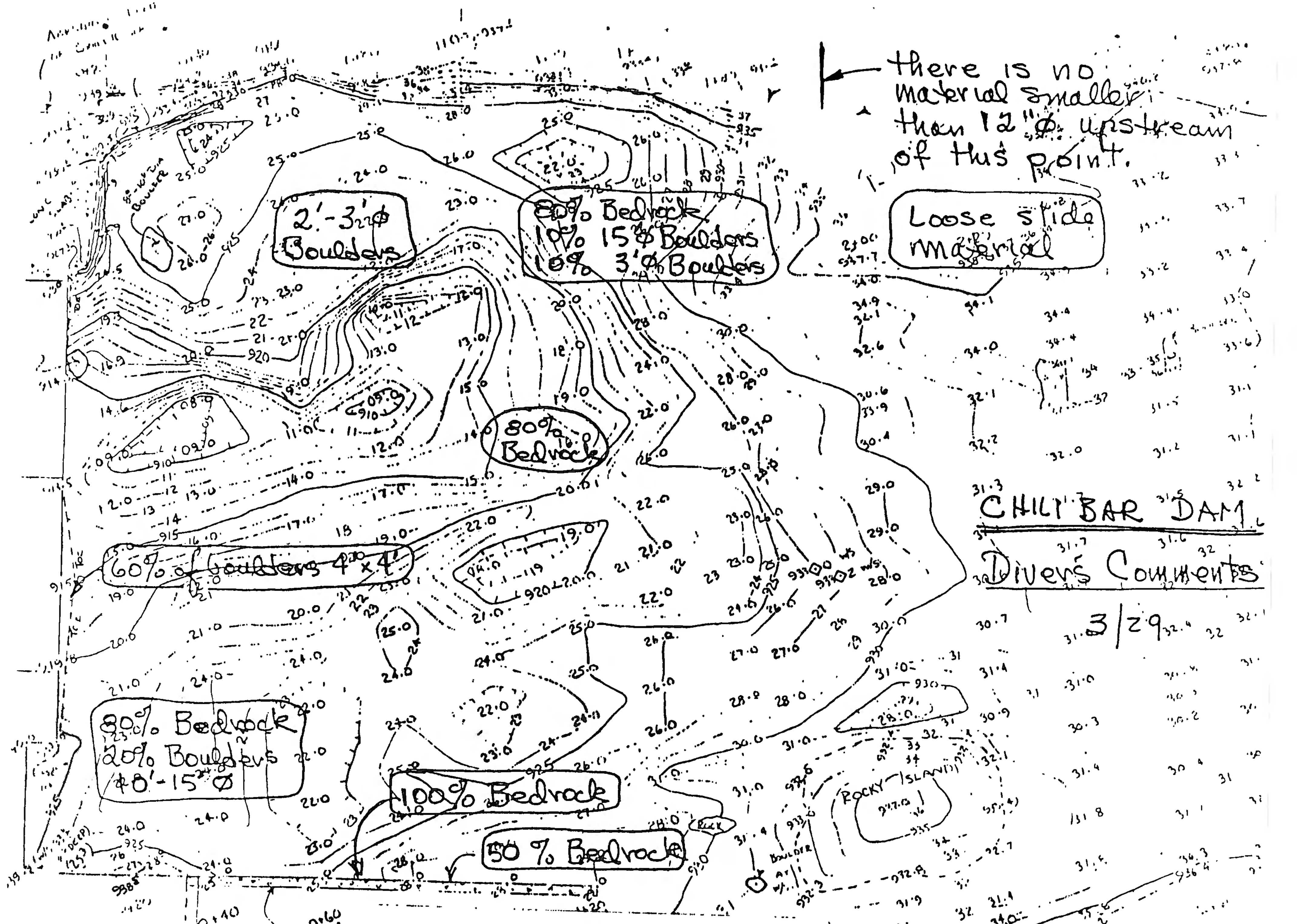


Figure 3. - Prototype bed material survey

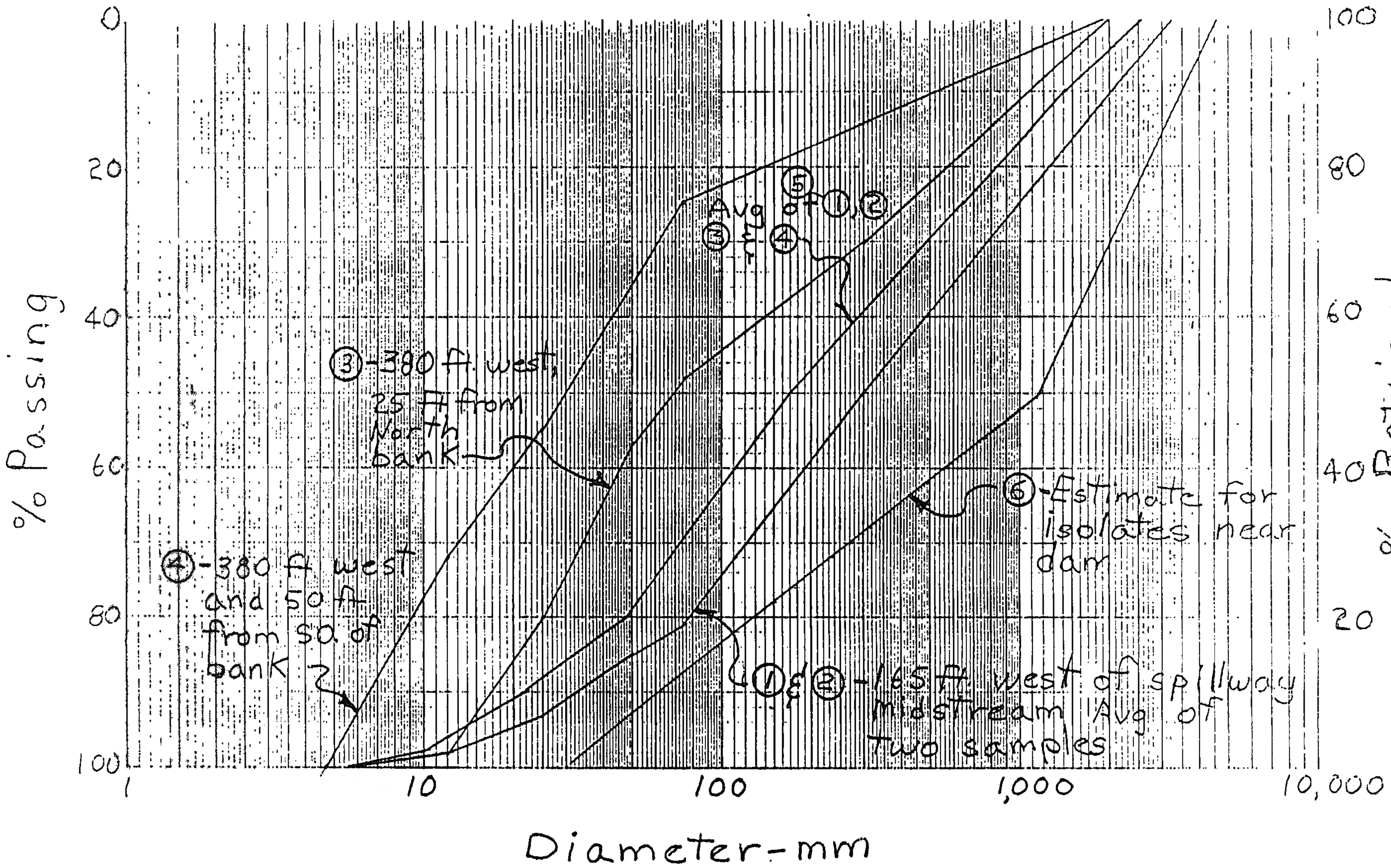


Figure 4. - Prototype bed material size distribution.

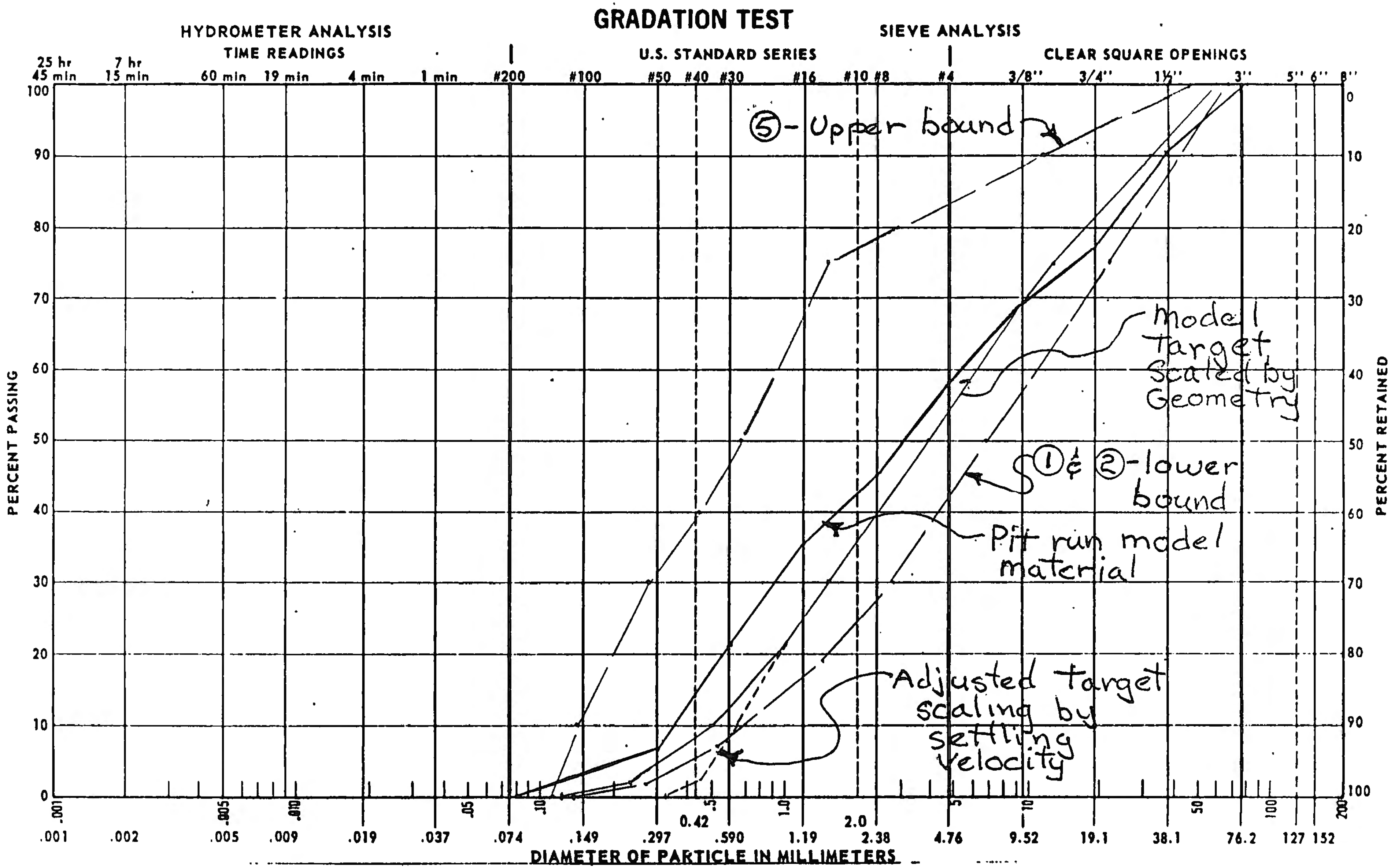


Figure 5. - Model bed size distributions.

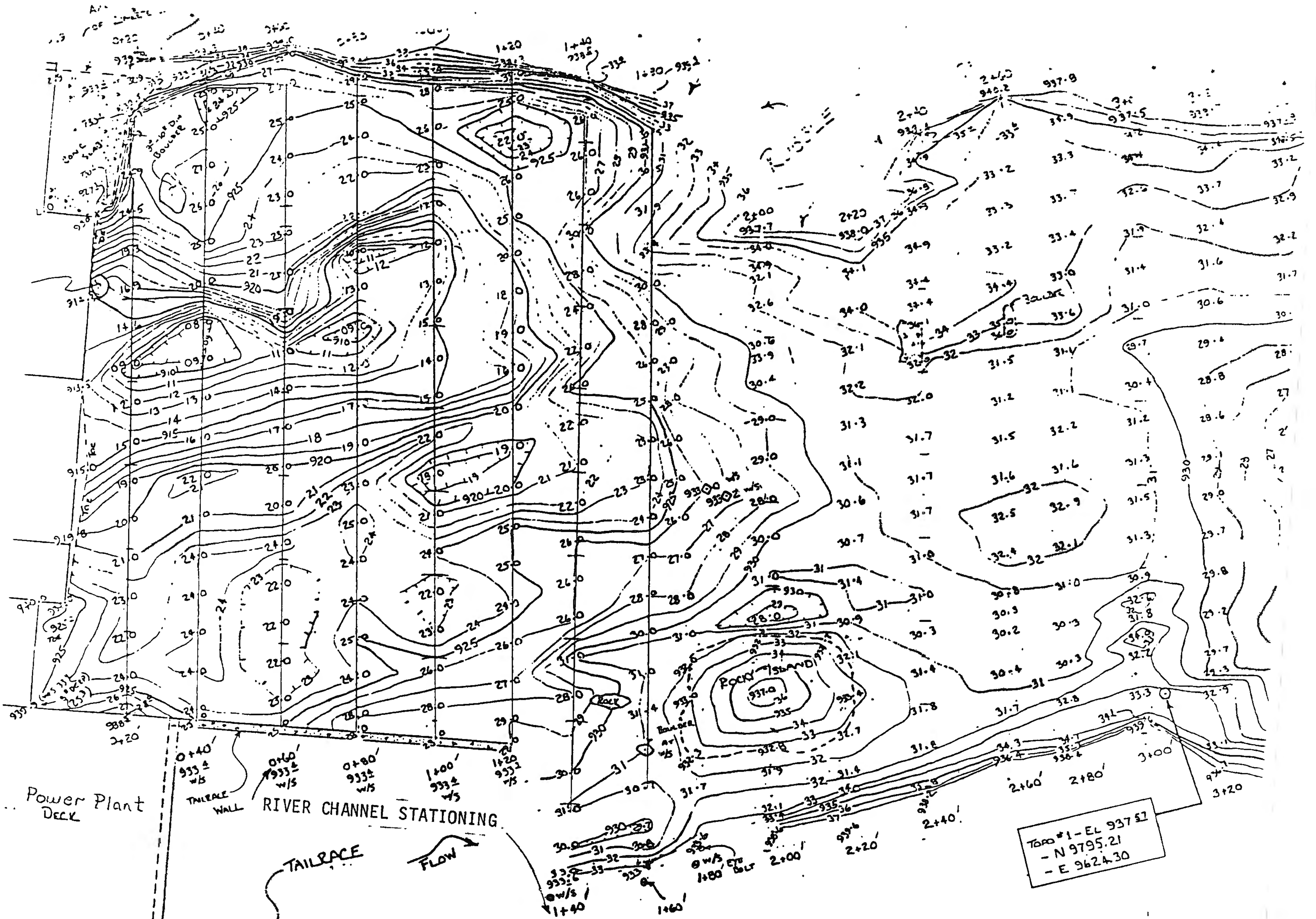


Figure 6. - Prototype channel contours.

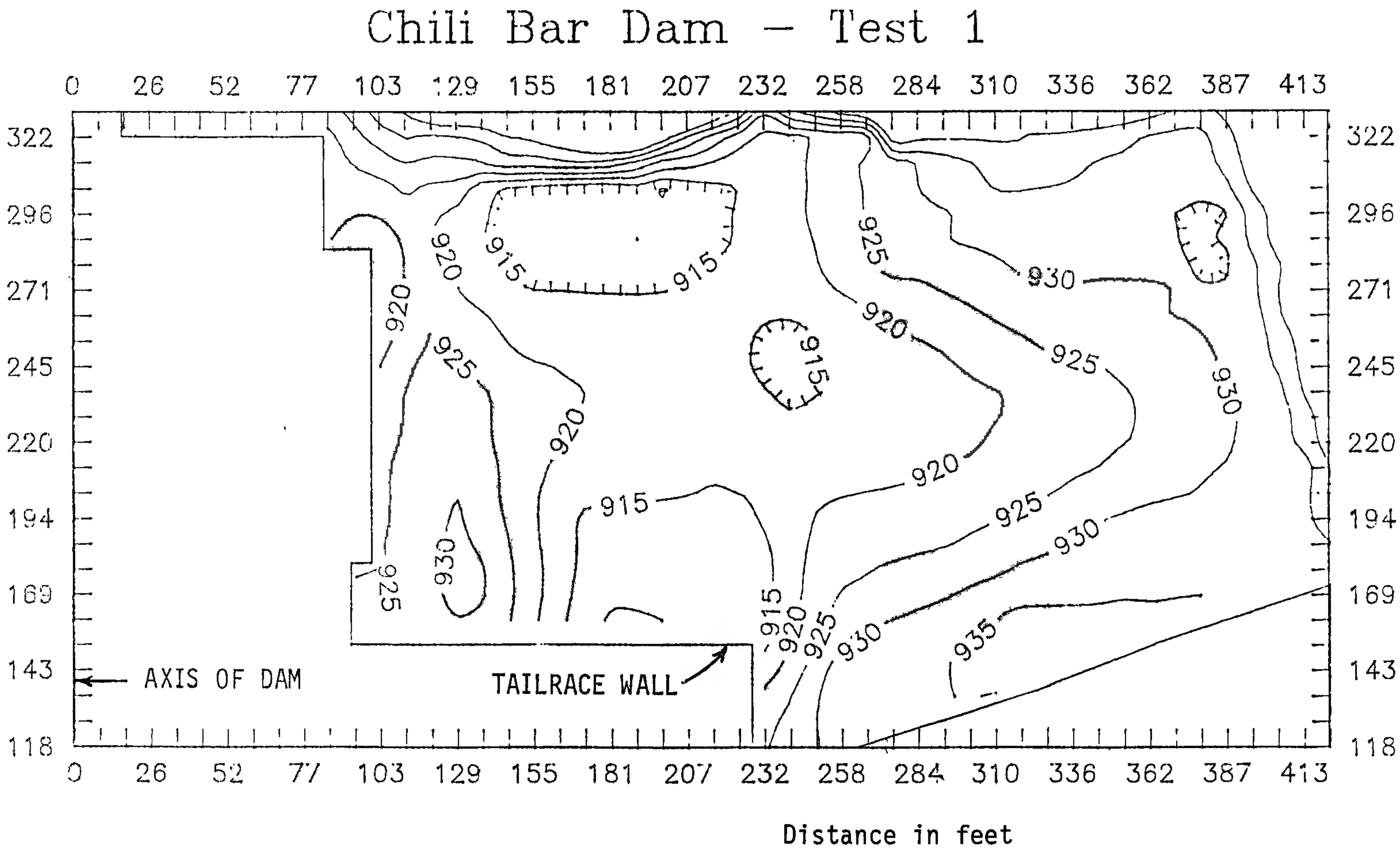


Figure 7. - As-built bed scour after 10 percent of PMF.

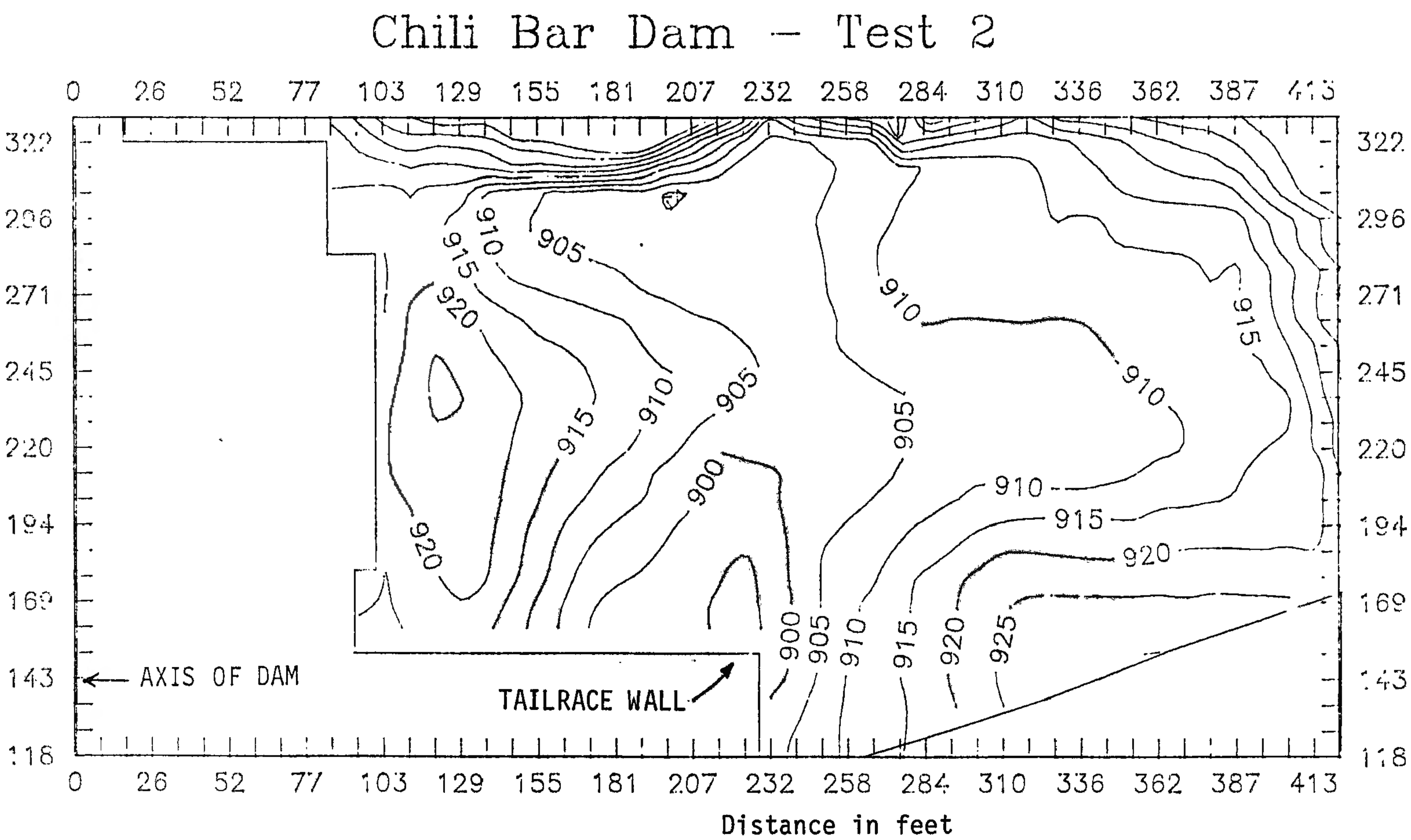


Figure 8. - As-built bed scour after 25 percent of PMF.

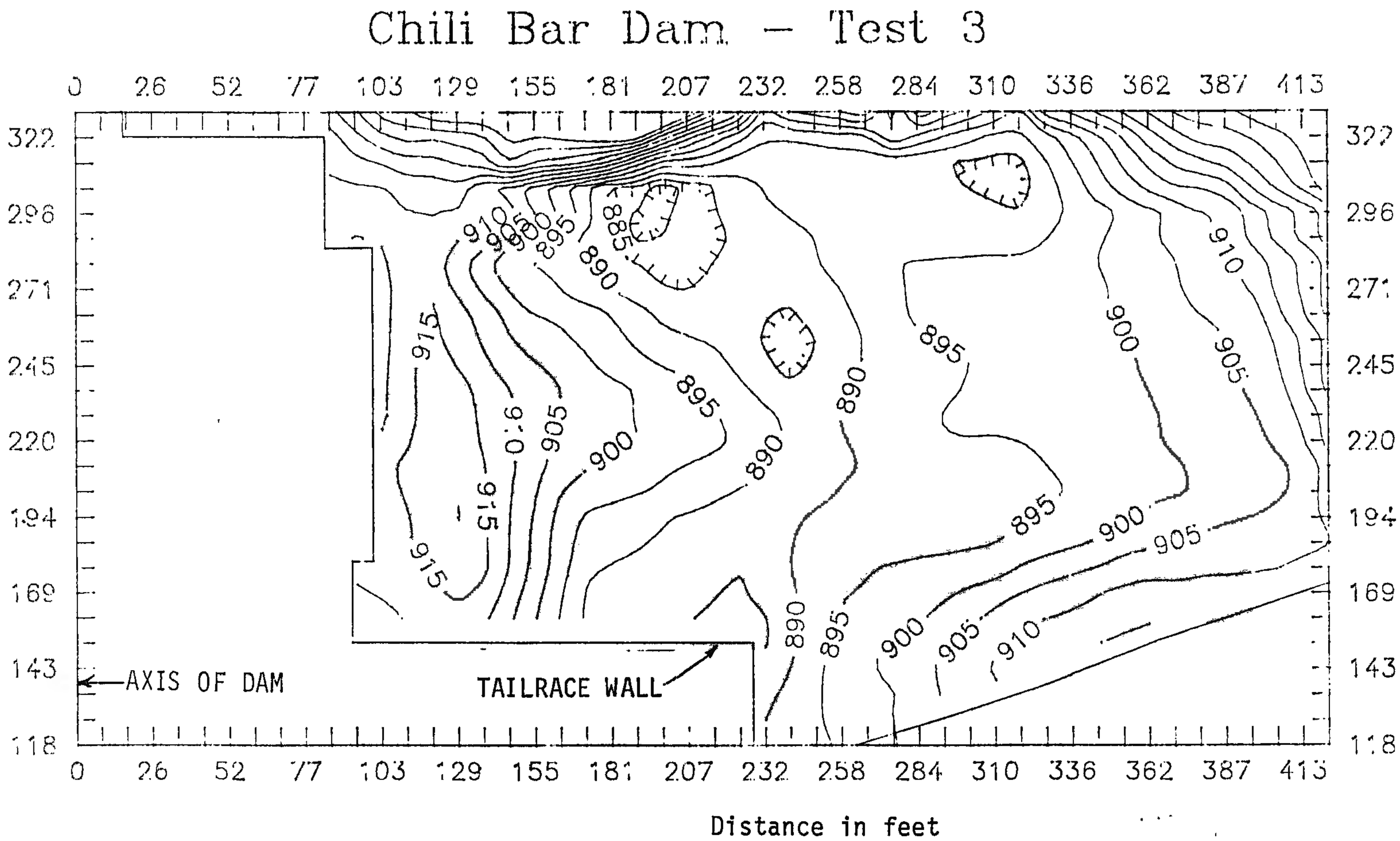


Figure 9. - As-built bed scour after 50 percent of PMF.

Chili Bar Dam – Test 4

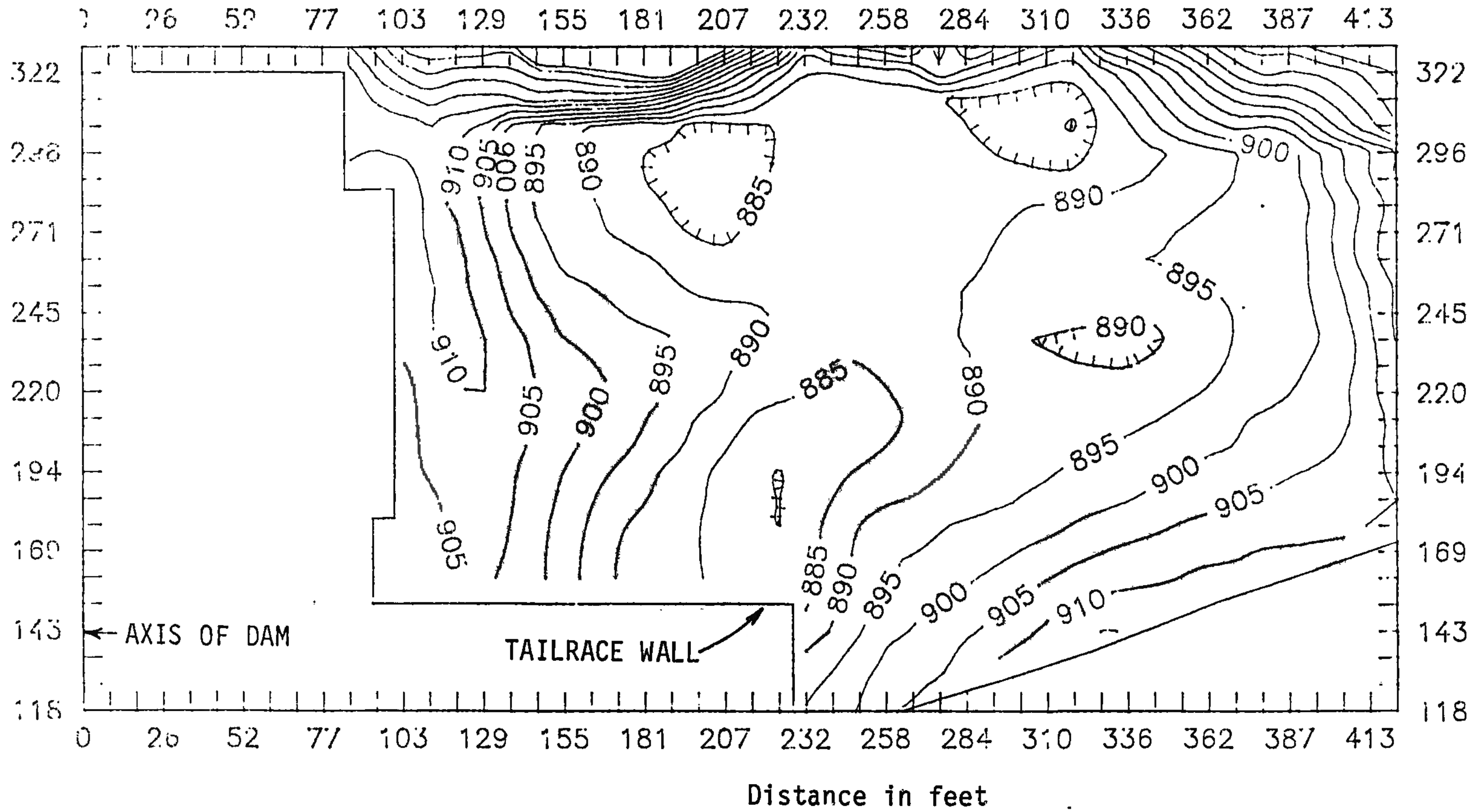


Figure 10. - As-built bed scour after 75 percent of PMF.

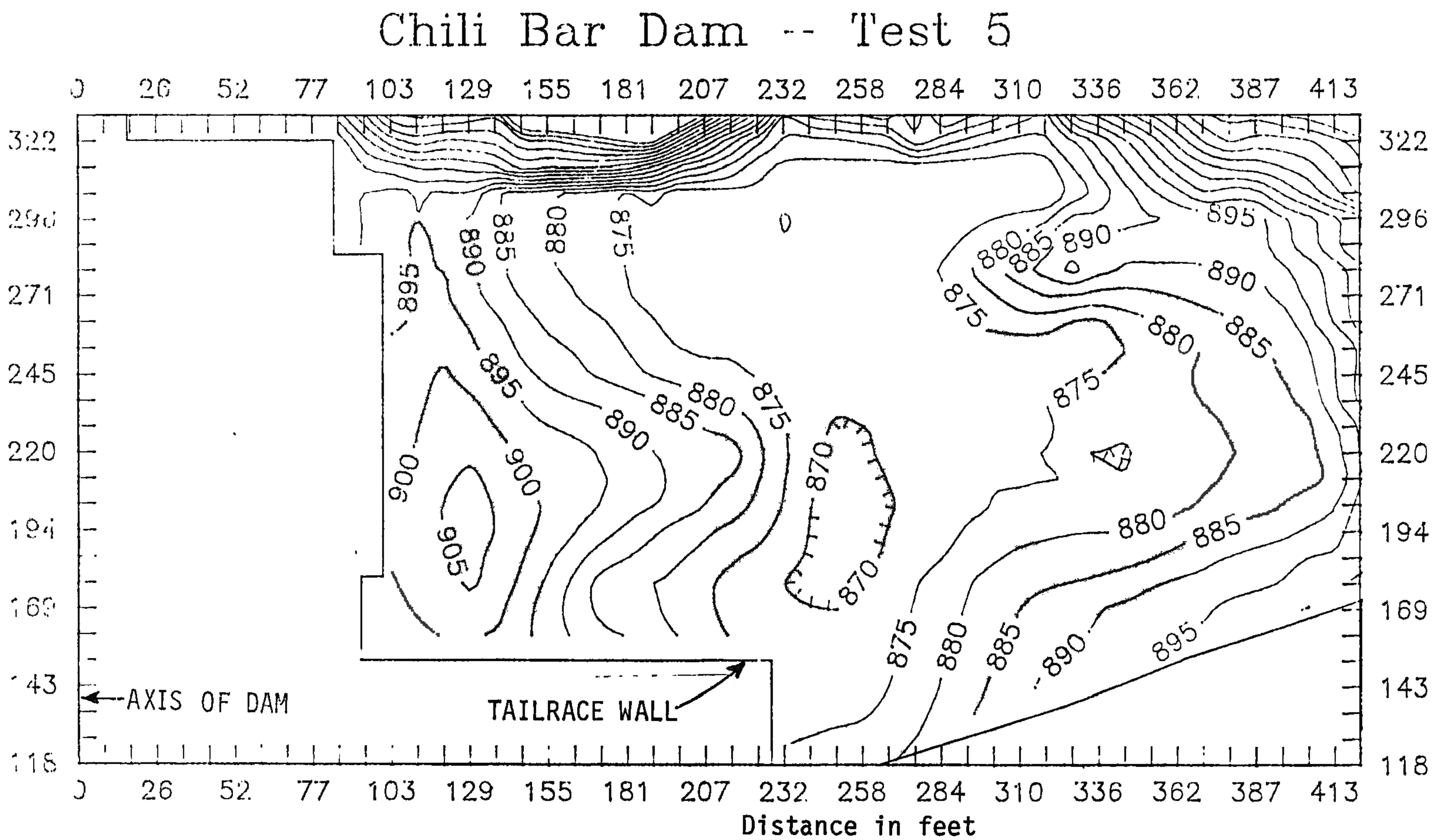


Figure 11. - As-built bed scour after 100 percent of PMF.

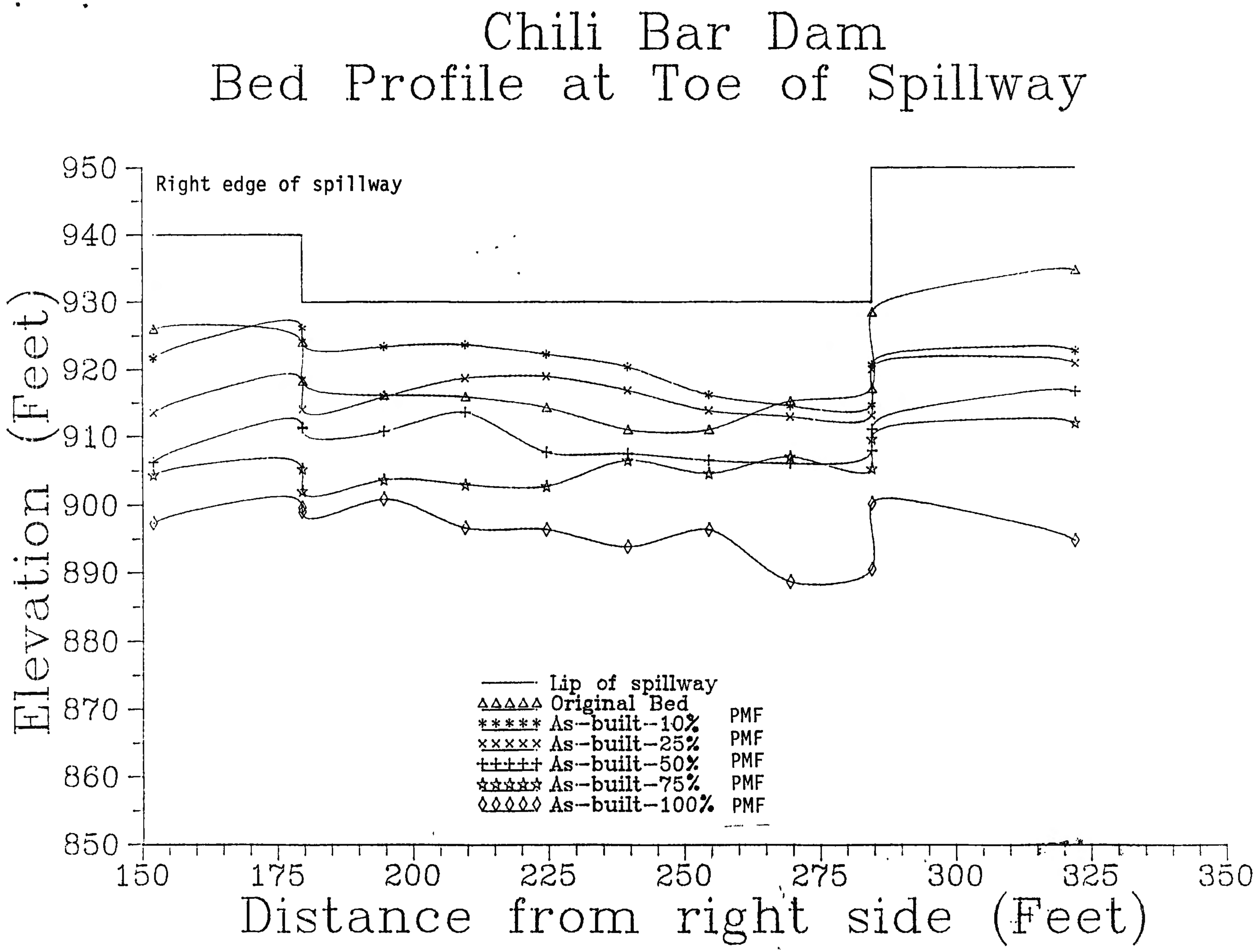


Figure 12. - As-built spillway bed profiles at toe of spillway.

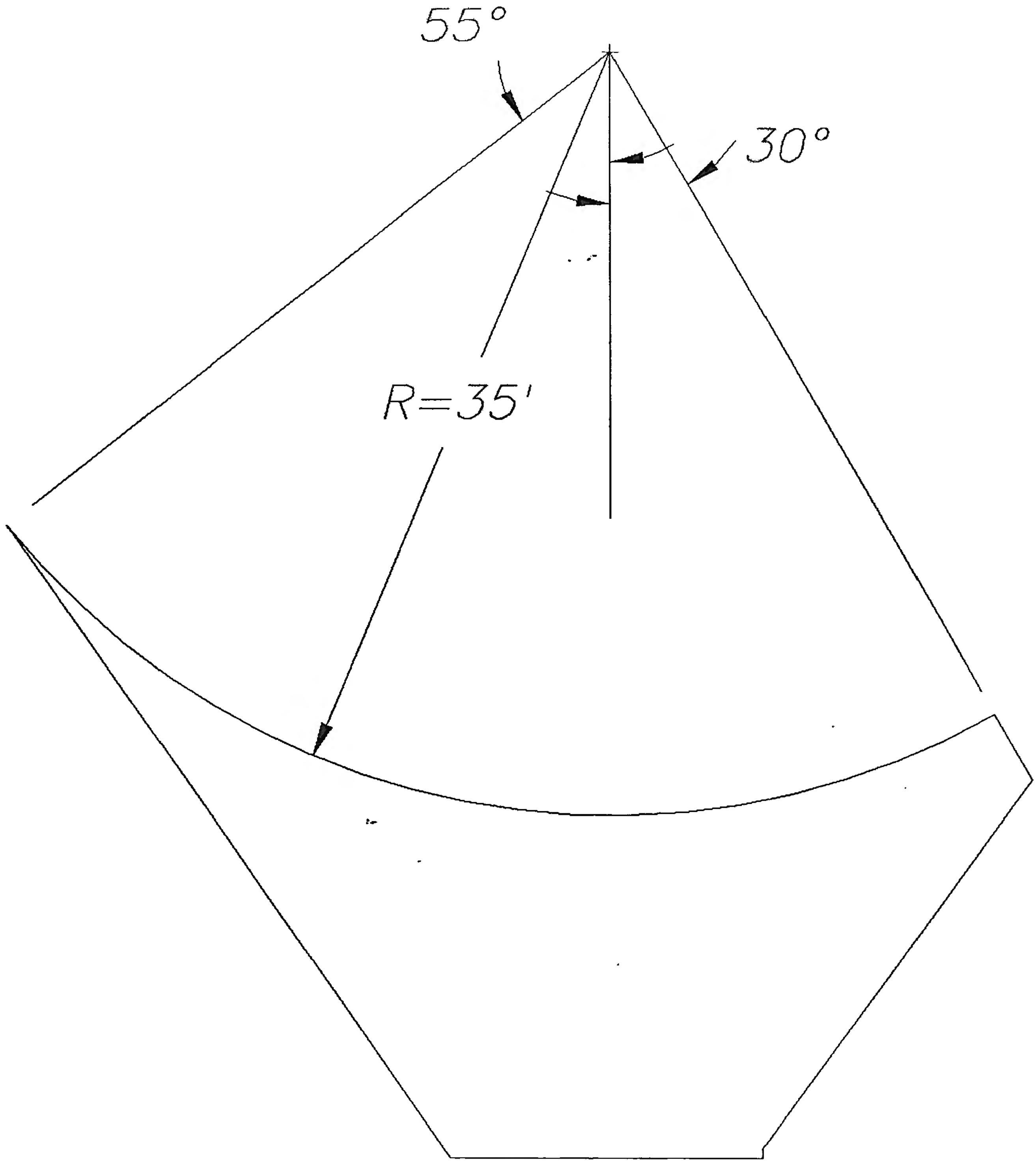


Figure 13. - Modified flip bucket geometry.

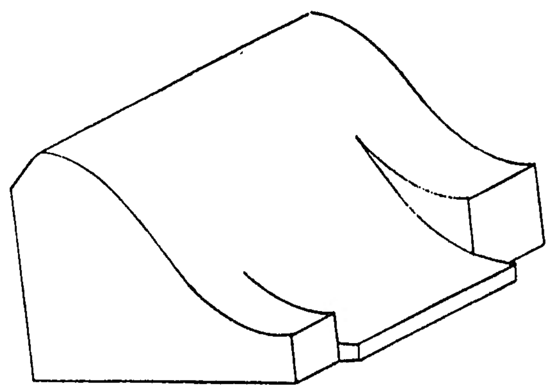


Figure 14A. - As-built spillway.

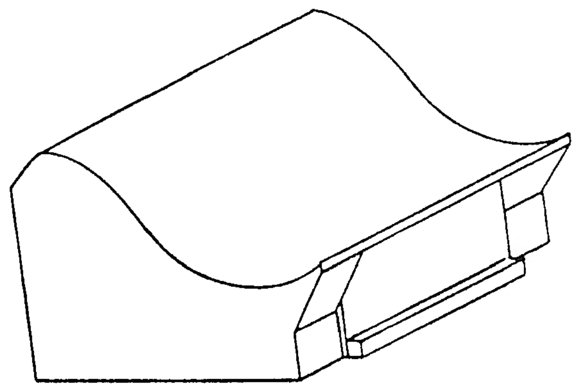


Figure 14B. - Single level flip bucket spillway.

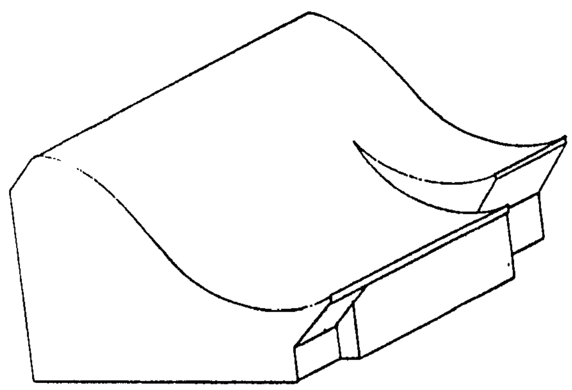


Figure 14C. - Two level flip bucket spillway.

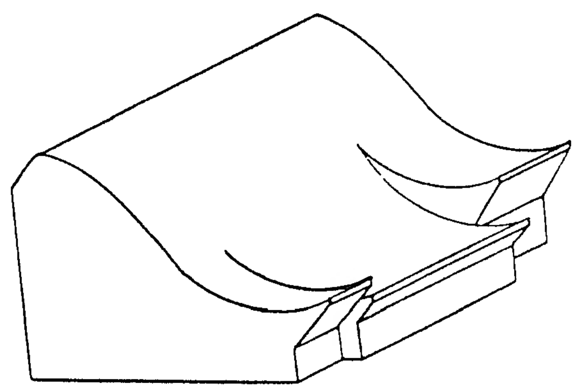


Figure 14D. - Three level flip bucket spillway.

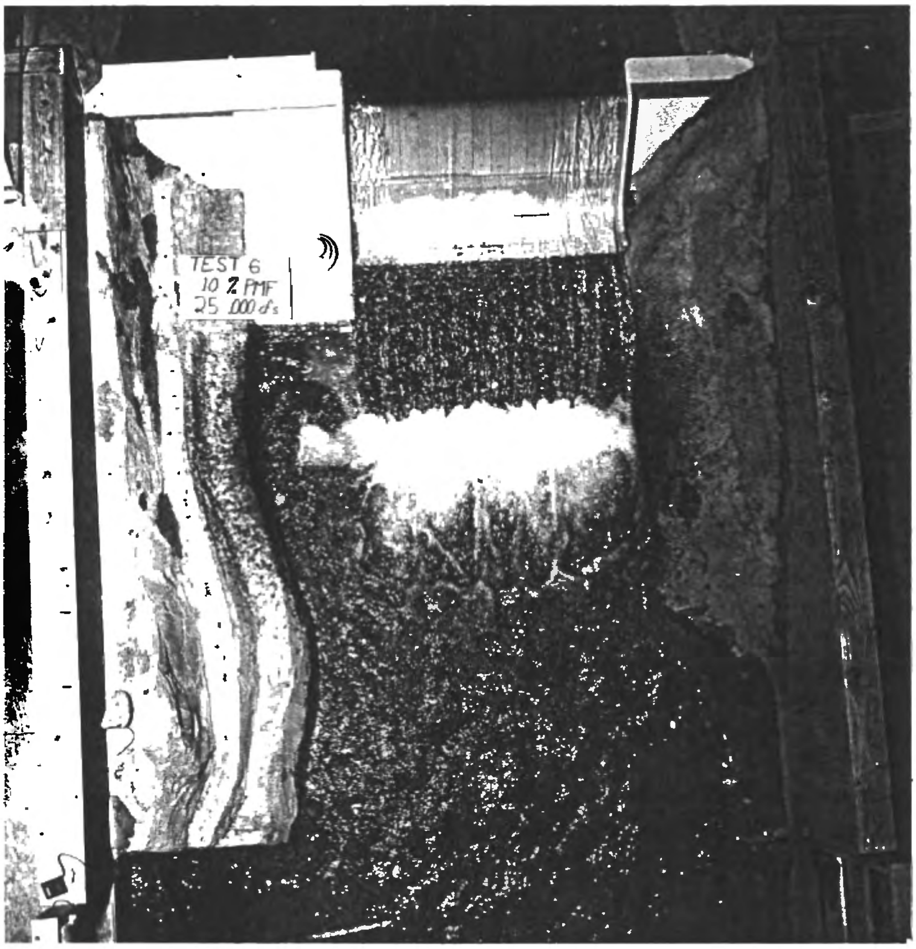


Figure 15. - Single level flip bucket spillway.

Figure 16A. - Single level flip bucket bed scour after 10 percent of PMF.

Figure 16B. - Single level flip bucket bed scour after 50 percent of PMF.

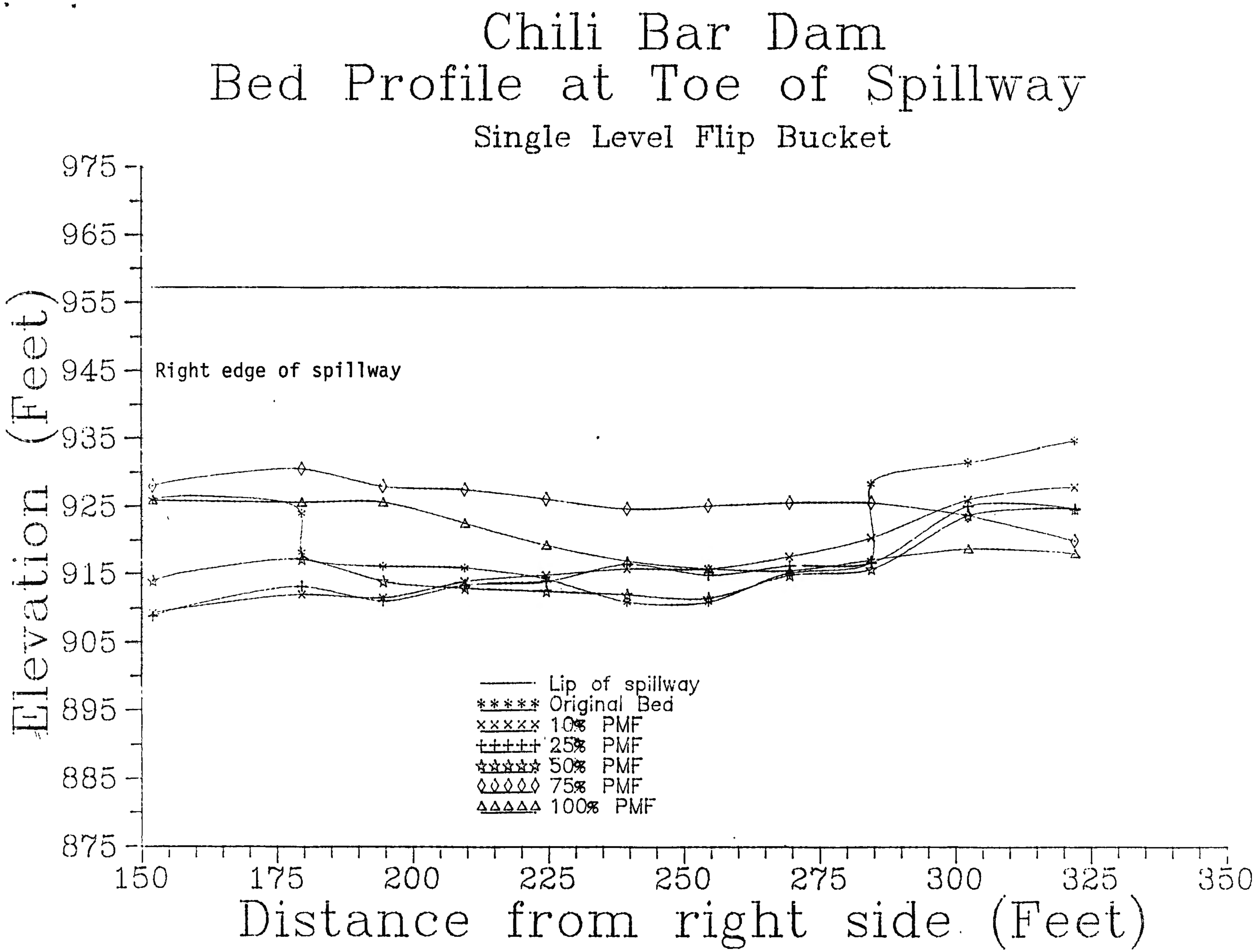


Figure 17. - Single level flip bucket - bed profiles at toe of spillway.

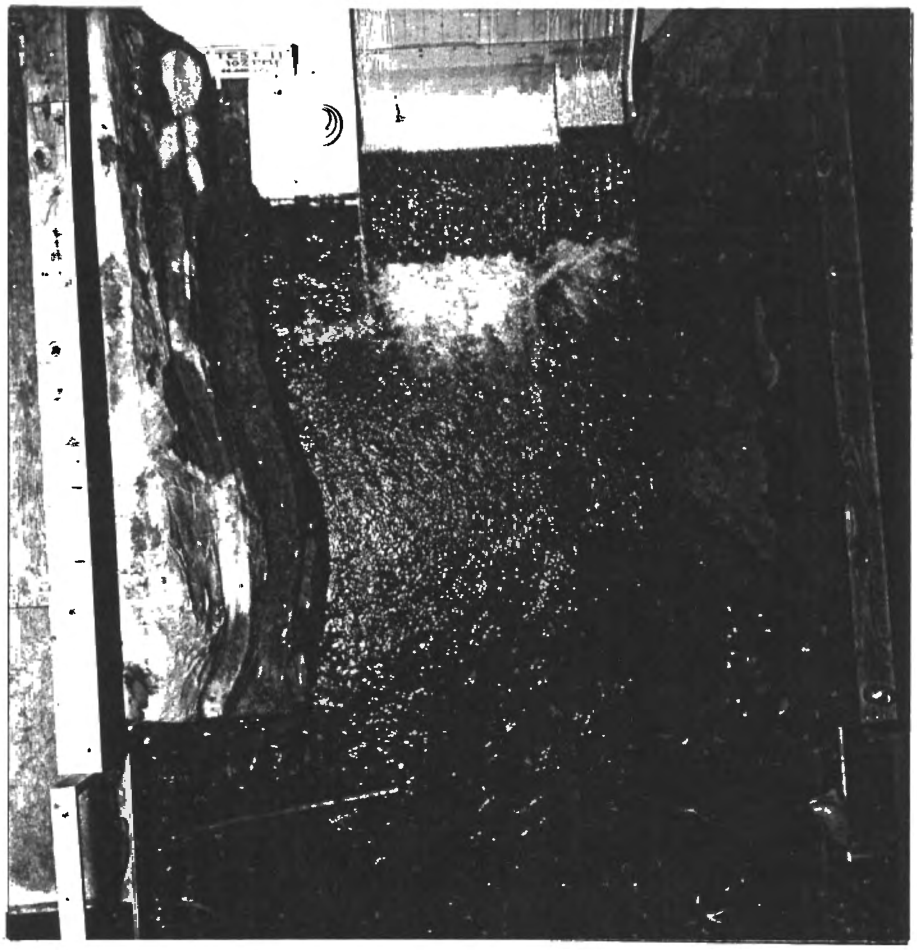


Figure 18. - Two level flip bucket - flow = 10 percent of PMF.

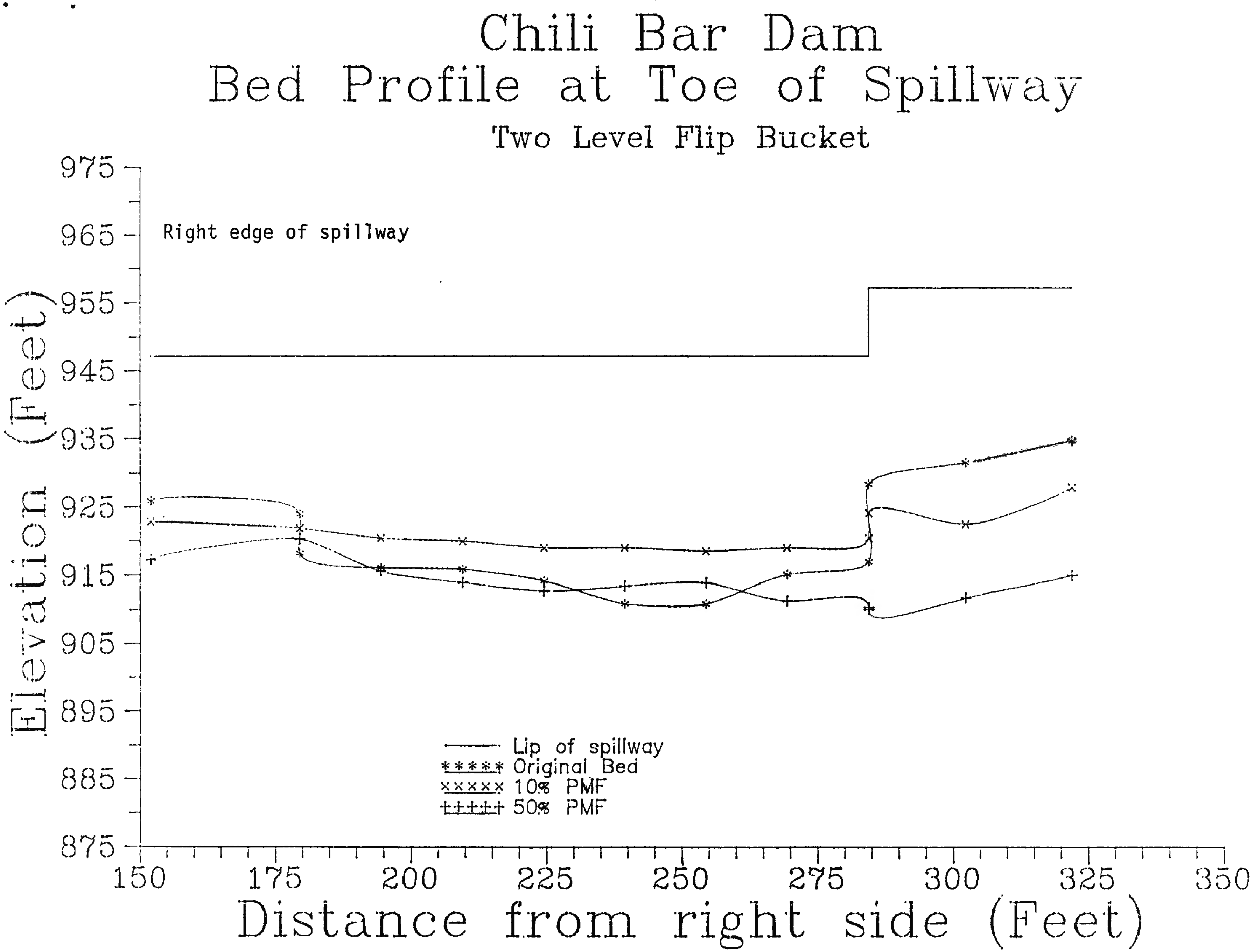


Figure 19. - Two level flip bucket - bed profiles at toe of spillway.

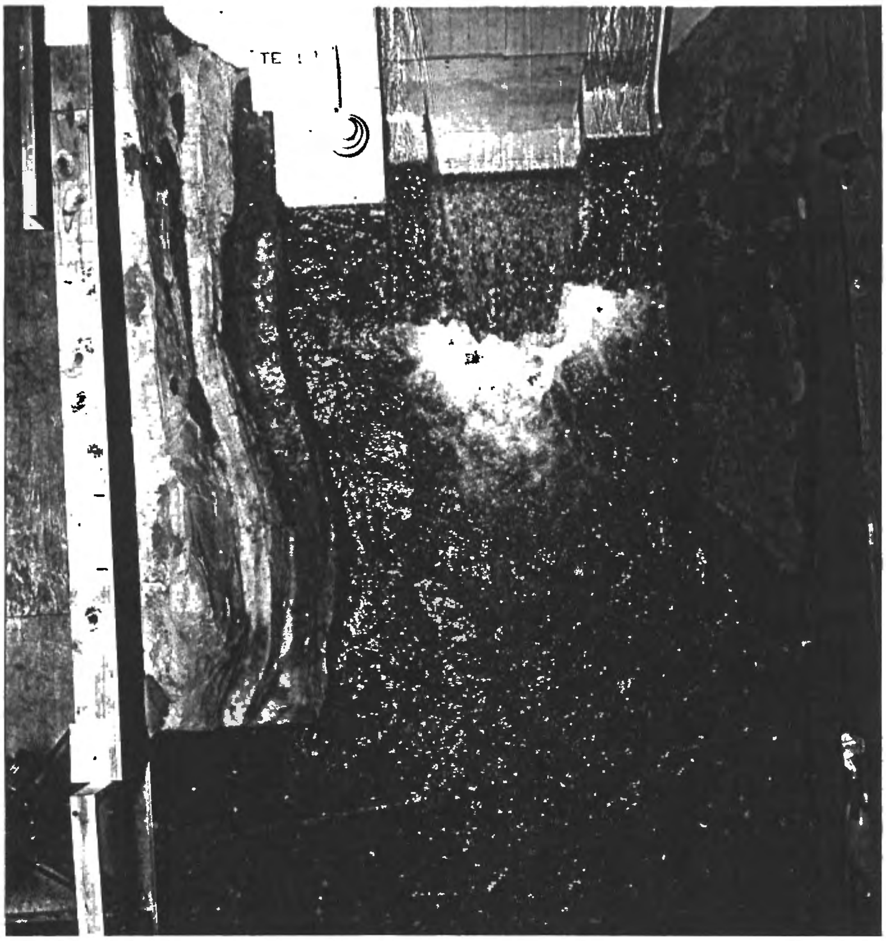


Figure 20. - Three level flip bucket - Flow = 10 percent of PMF.

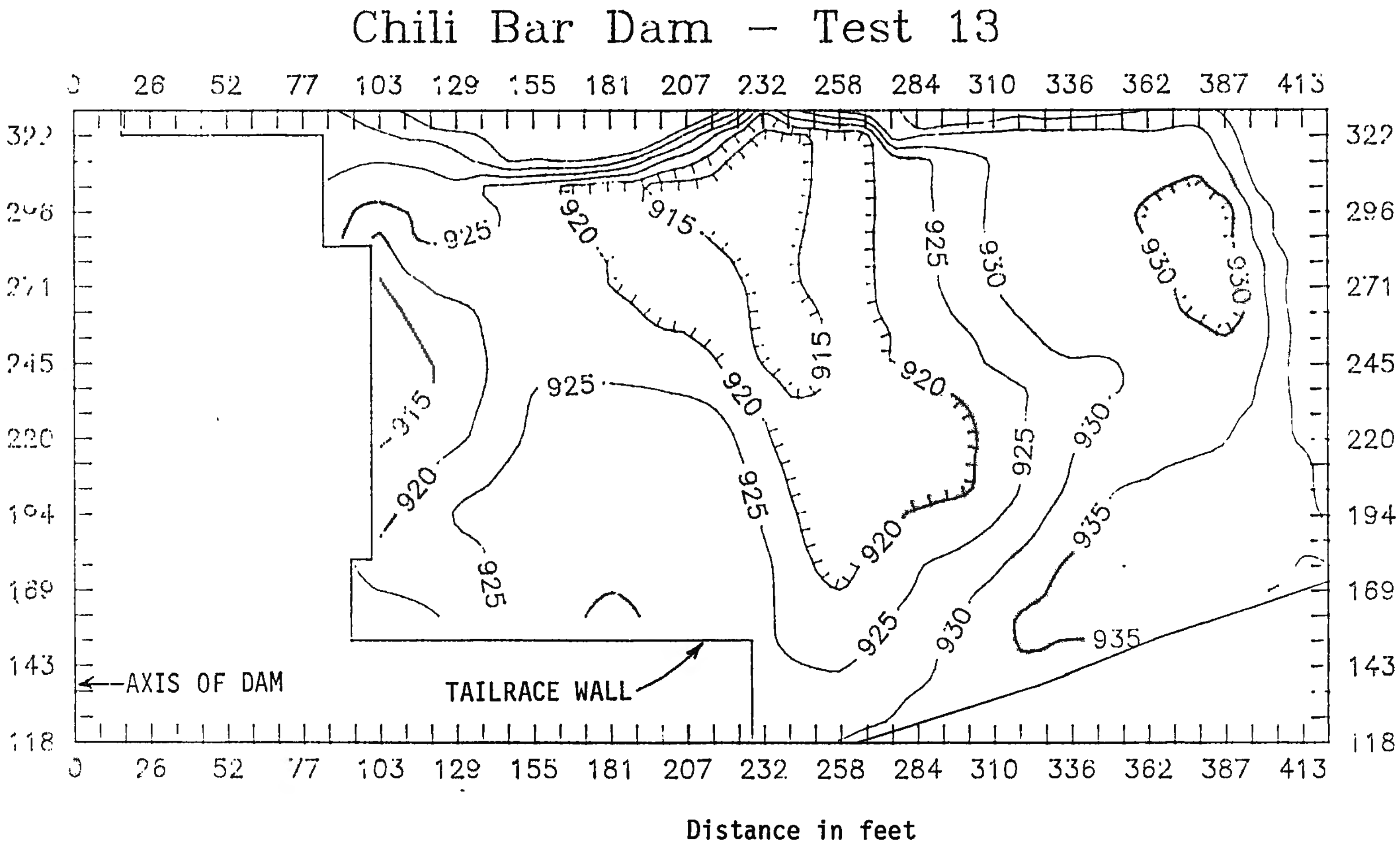


Figure 21. - Three level flip bucket spillway - bed contours after 10 percent of PMF.

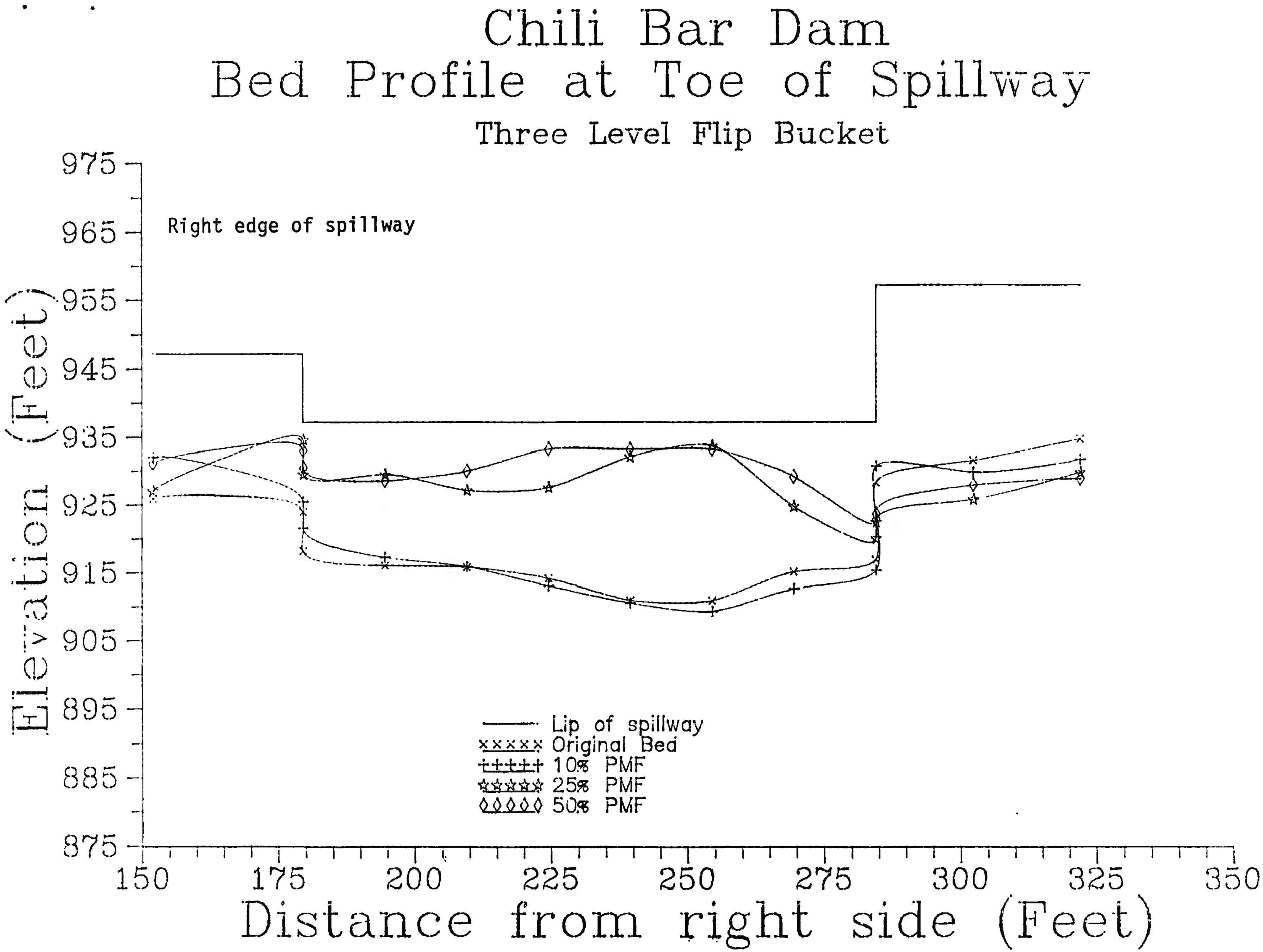


Figure 22. - Three level flip bucket - bed profiles at toe of spillway.

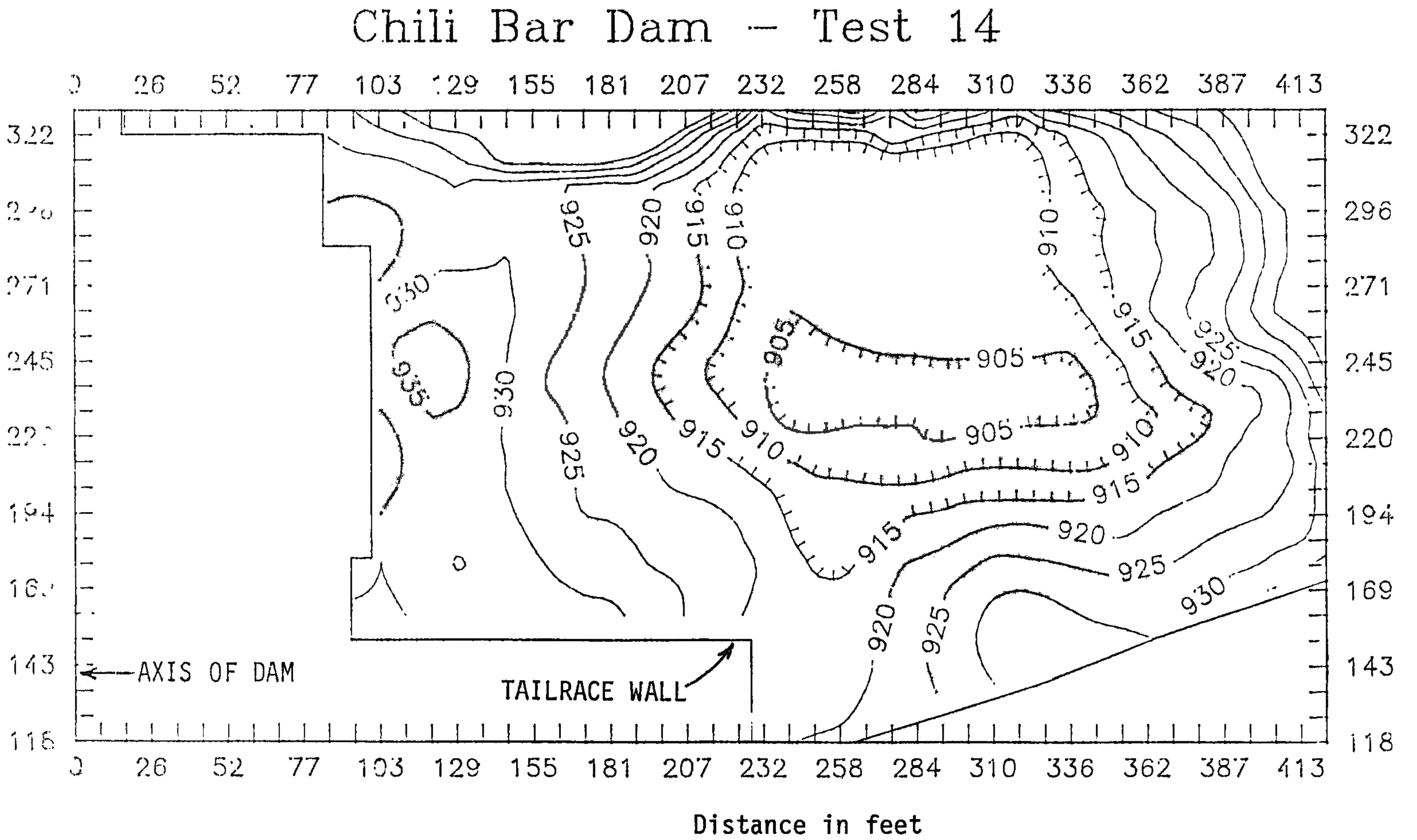
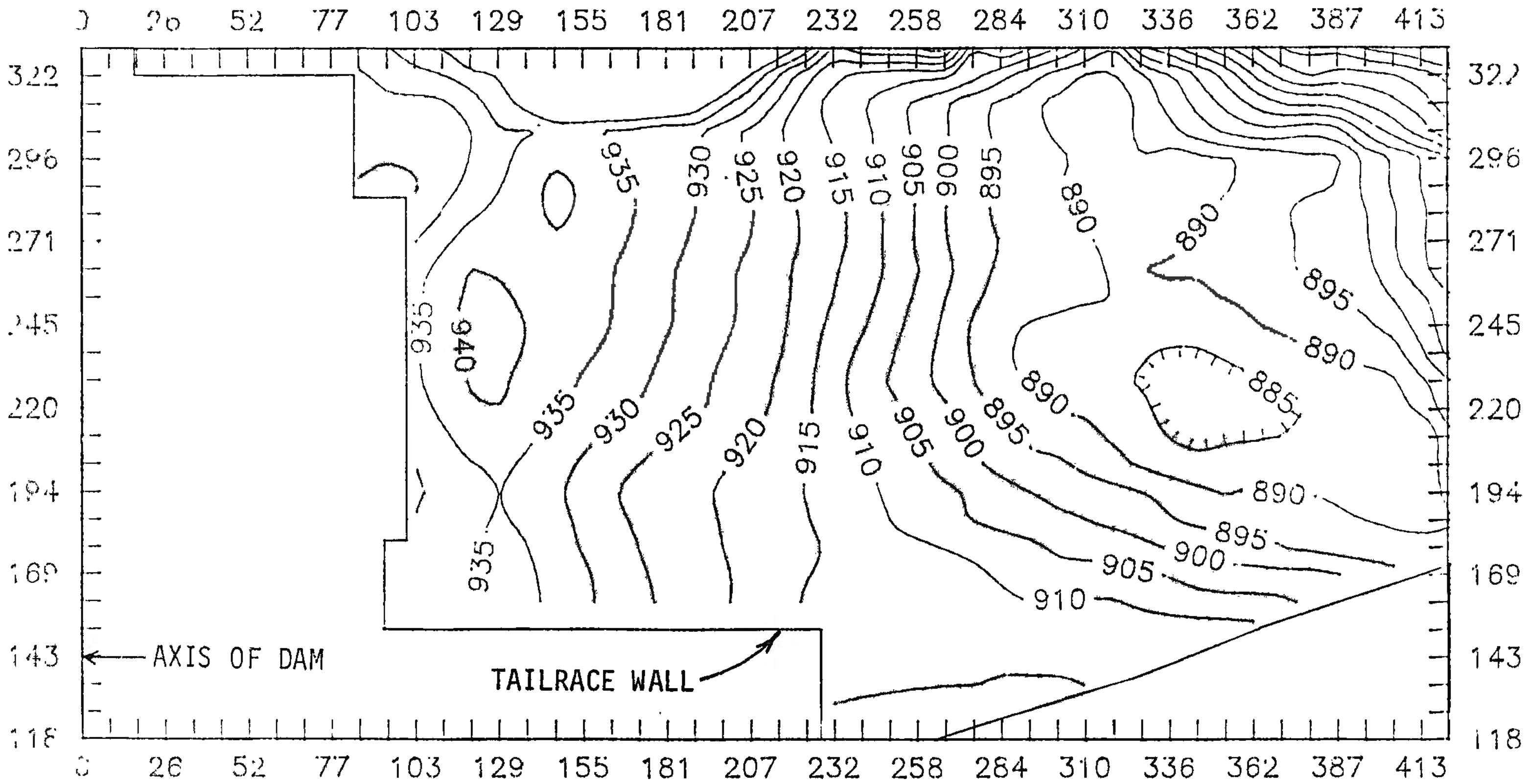


Figure 23. - Three level flip bucket spillway - bed contours after 25 percent of PMF.

Chili Bar Dam - Test 15



Distance in feet

Figure 24. - Three level flip bucket spillway - bed contours after 50 percent of PMF.

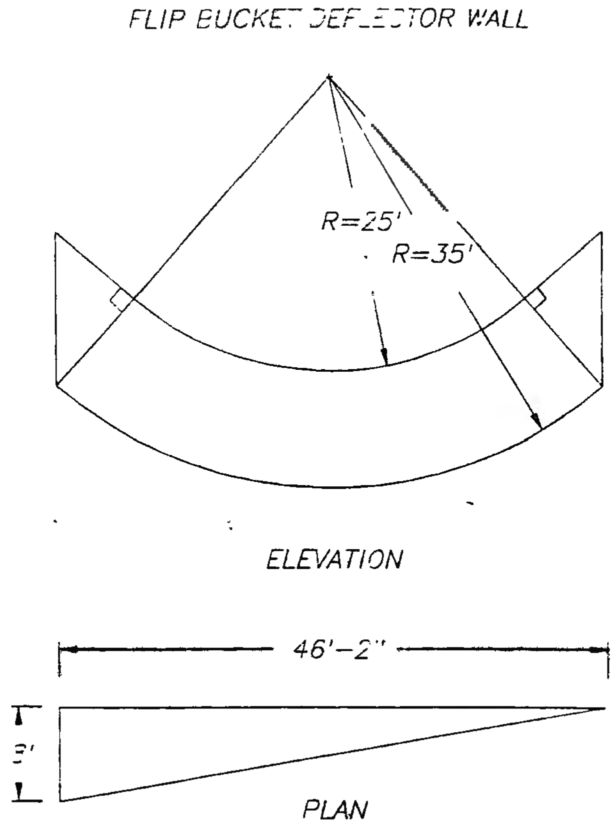


Figure 25A - Deflector wall geometry.

Figure 25B. - Three-level flip bucket spillway with deflector wall (25 percent of PMF).

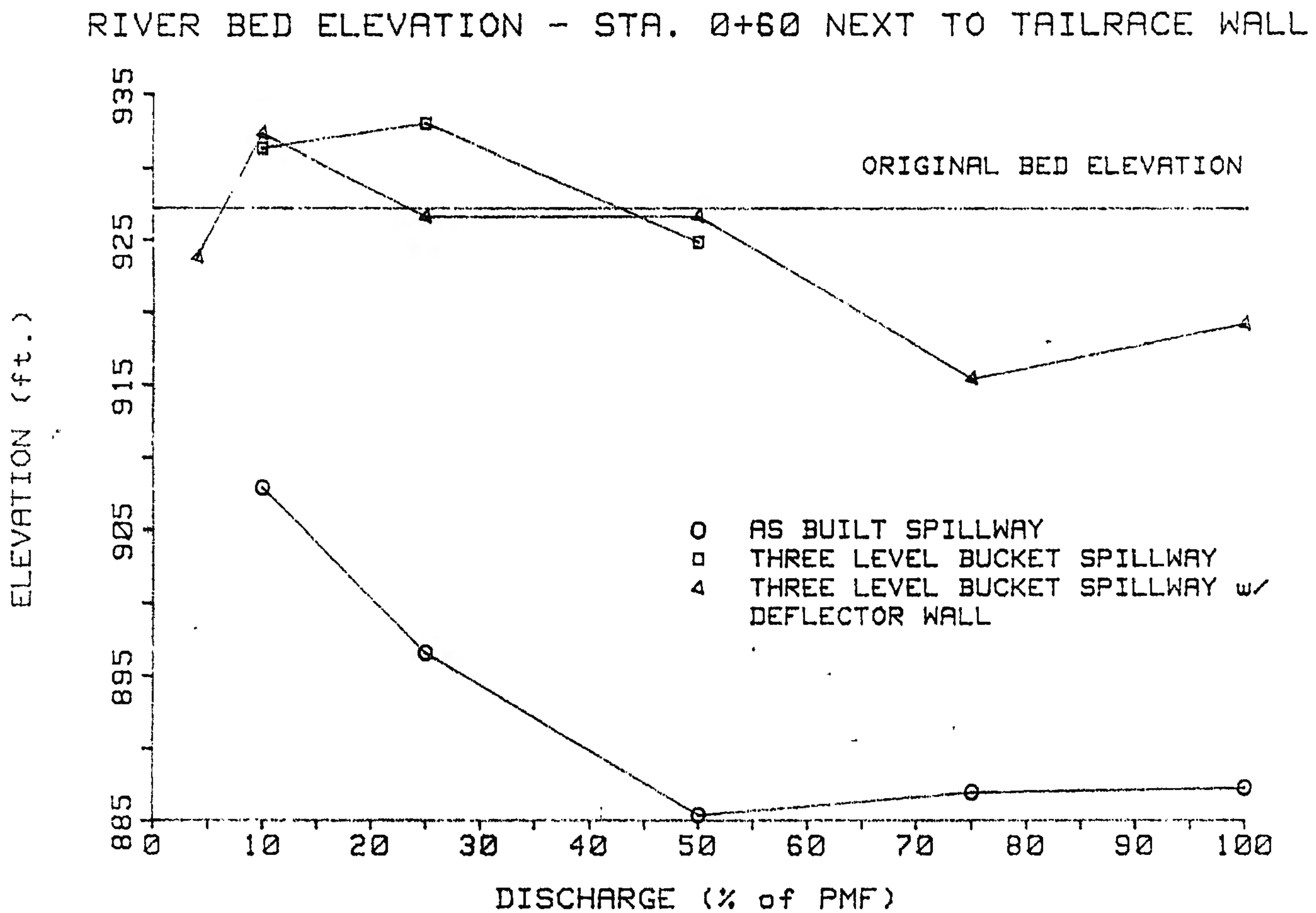


Figure 26. - Bed scour next to tailrace wall, station 0+60 (refer to figure 6).

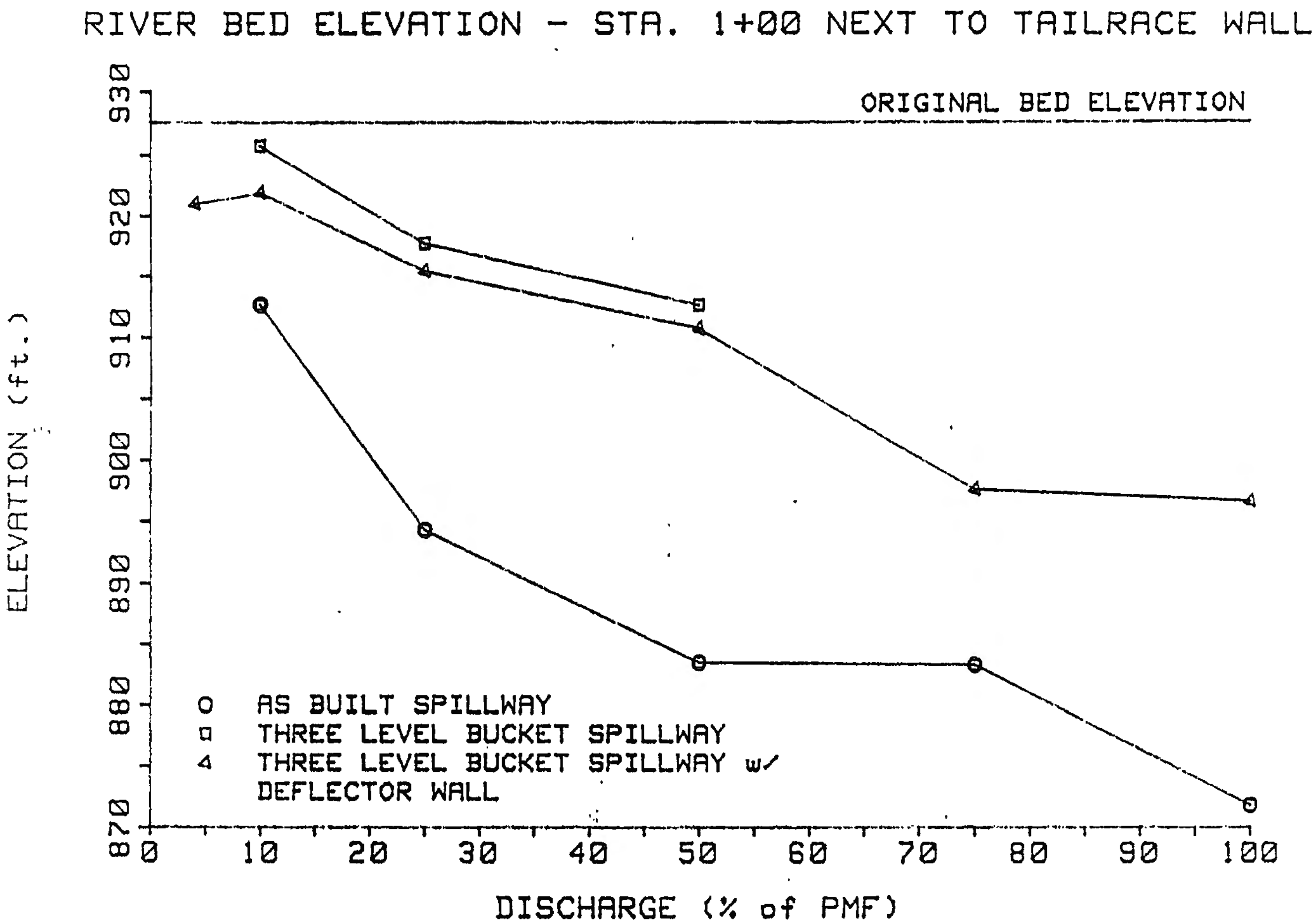


Figure 27. - Bed scour next to tailrace wall, station 1+00 (refer to figure 6).

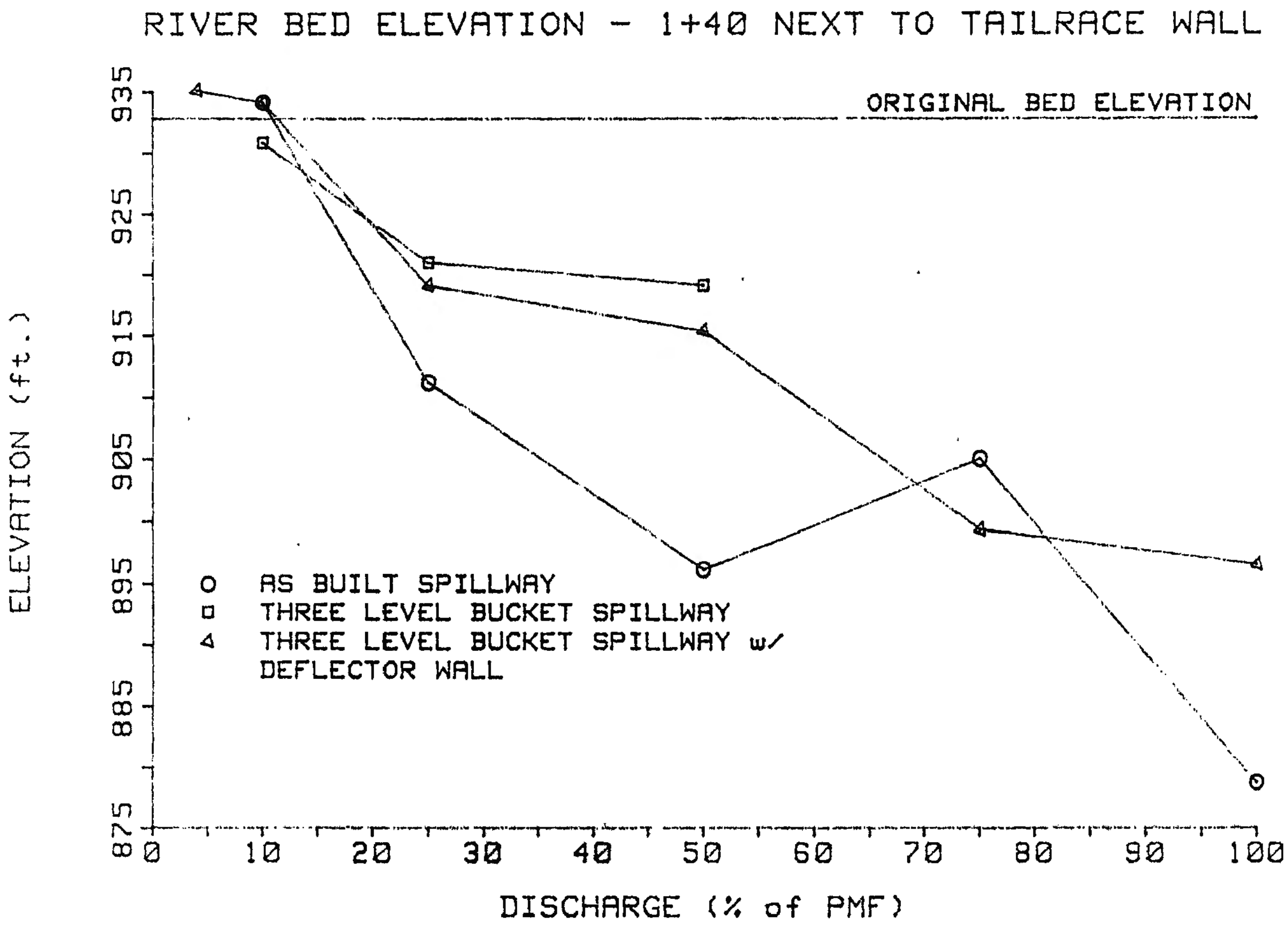


Figure 28. - Bed scour next to tailrace wall, Station 1+40 (refer to figure 6).

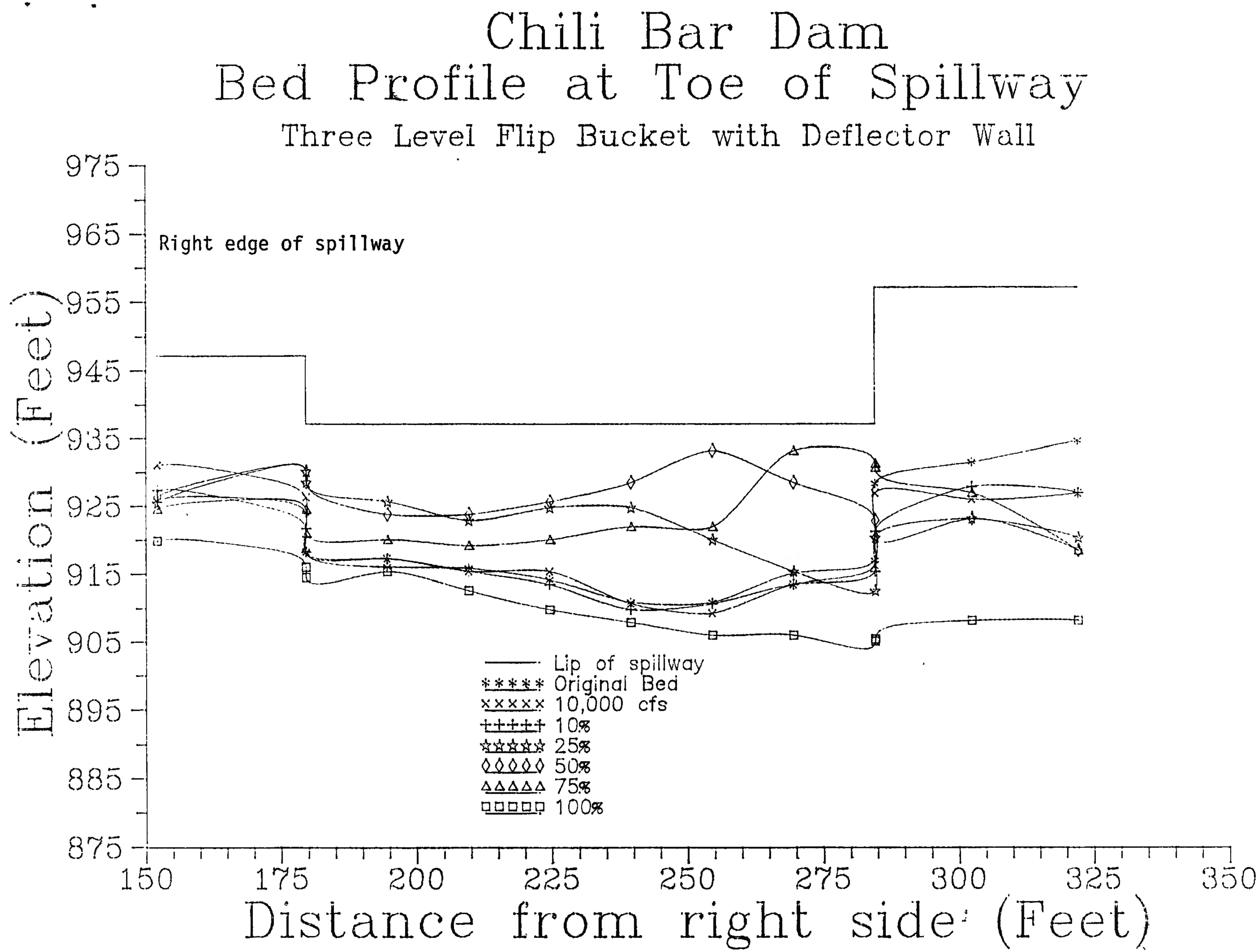


Figure 29. - Three level flip bucket with deflector wall - bed profiles at toe of spillway.

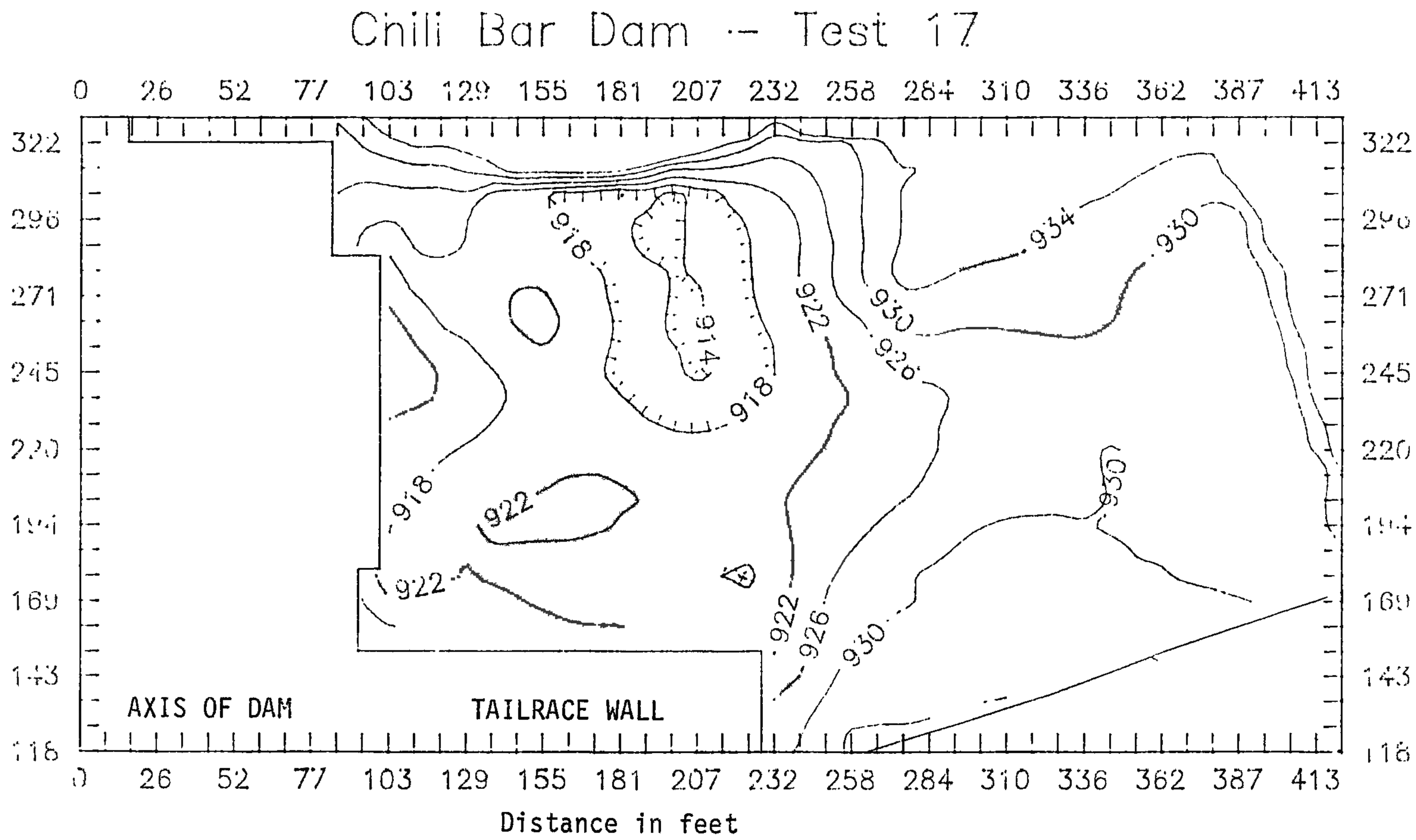


Figure 30. - Three-level flip bucket with deflector wall - bed contours after 4 percent of PMF.

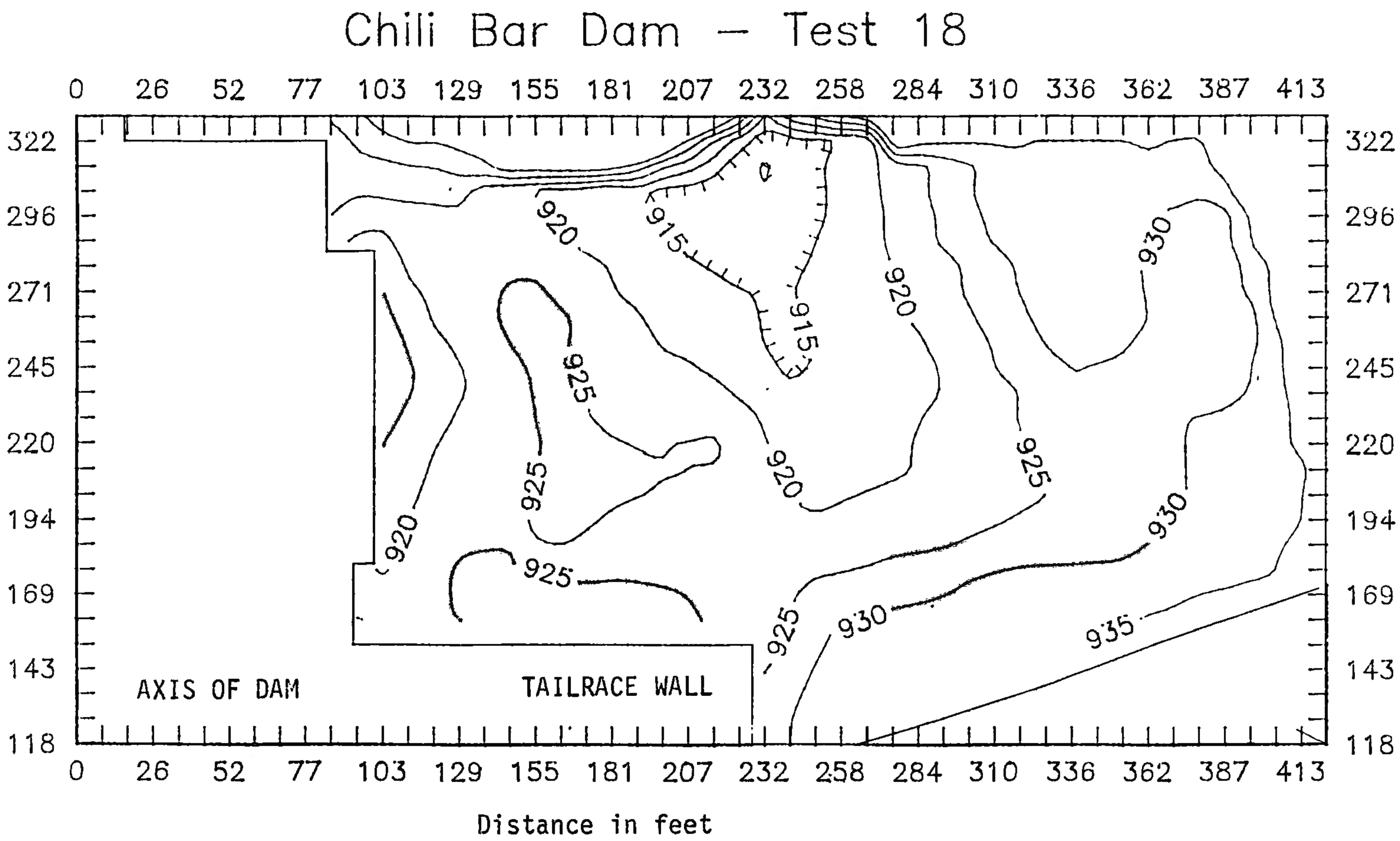


Figure 31. - Three-level flip bucket with deflector wall - bed contours after 10 percent of PMF.

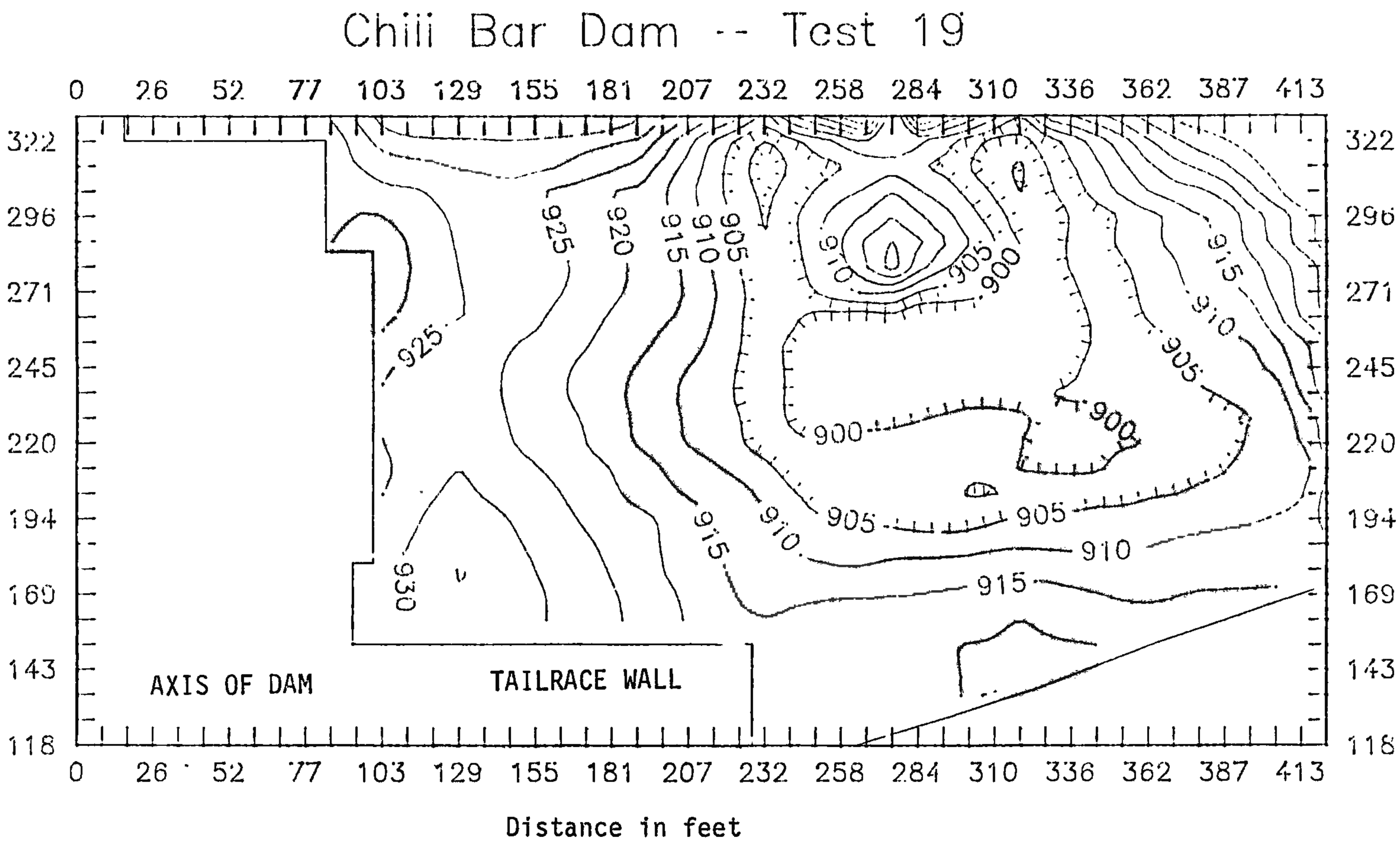


Figure 32. - Three-level flip bucket with deflector wall - bed contours after 25 percent of PMF.

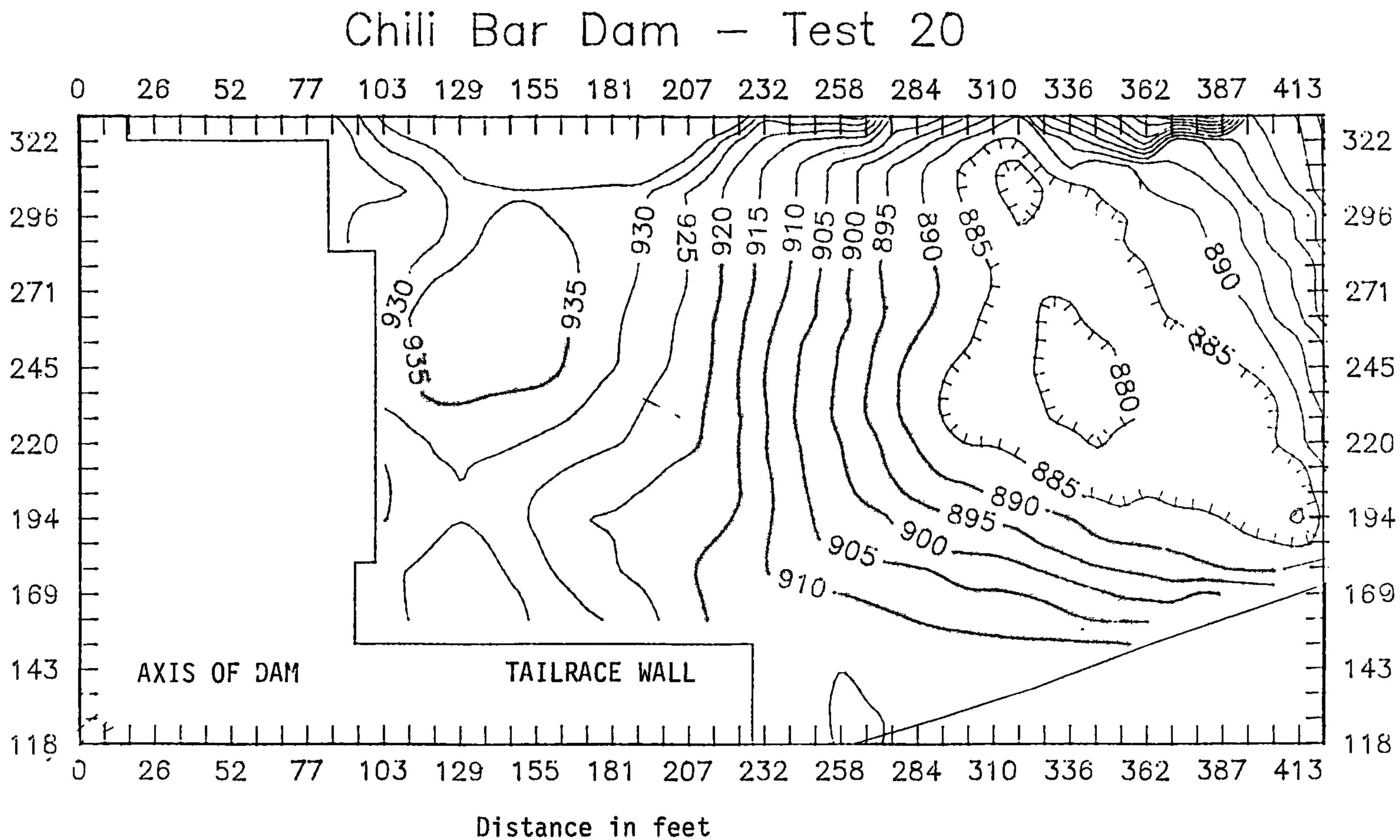


Figure 33. - Three-level flip bucket with deflector wall - bed contours after 50 percent of PMF.

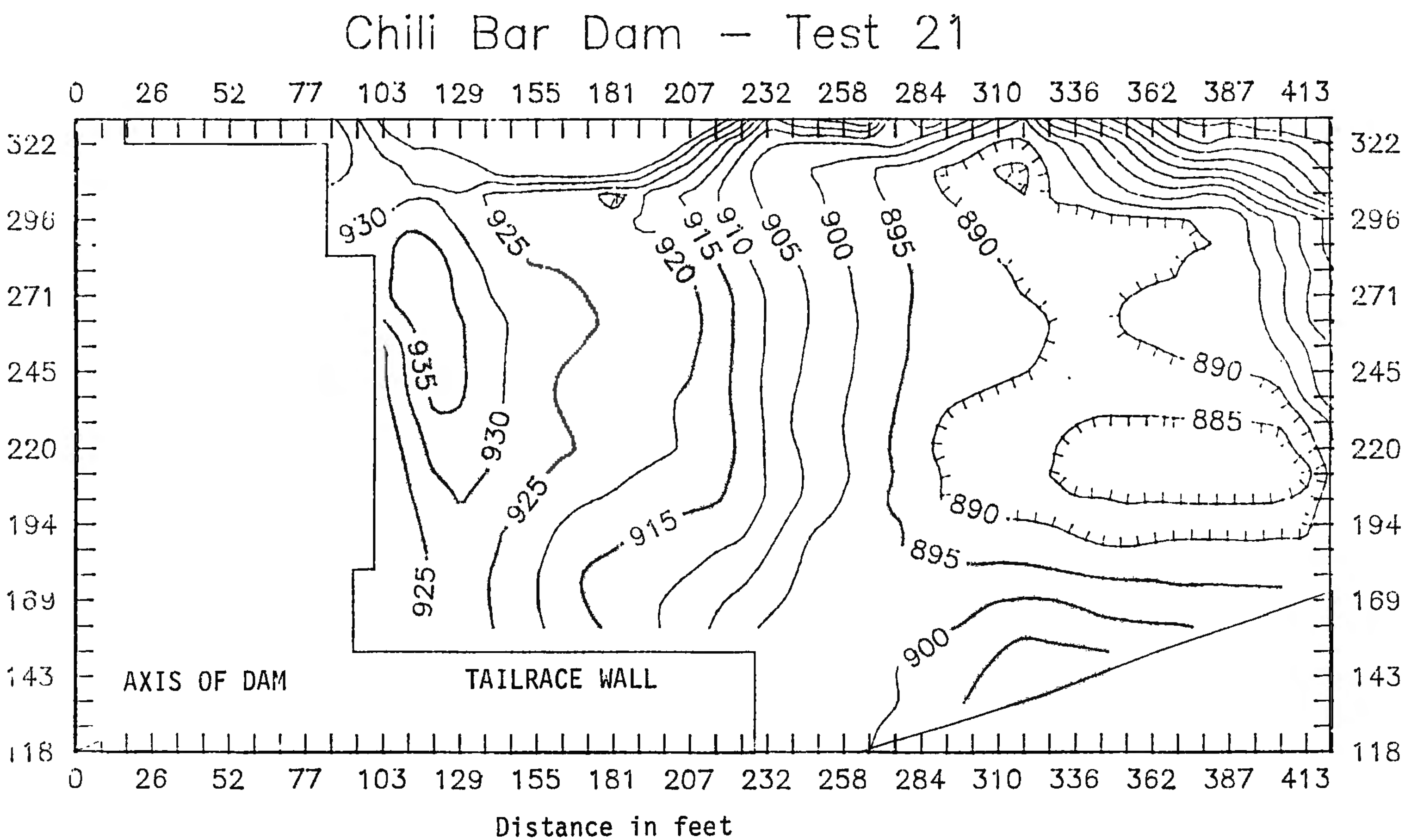


Figure 34. - Three-level flip bucket with deflector wall - bed contours after 75 percent of PMF.

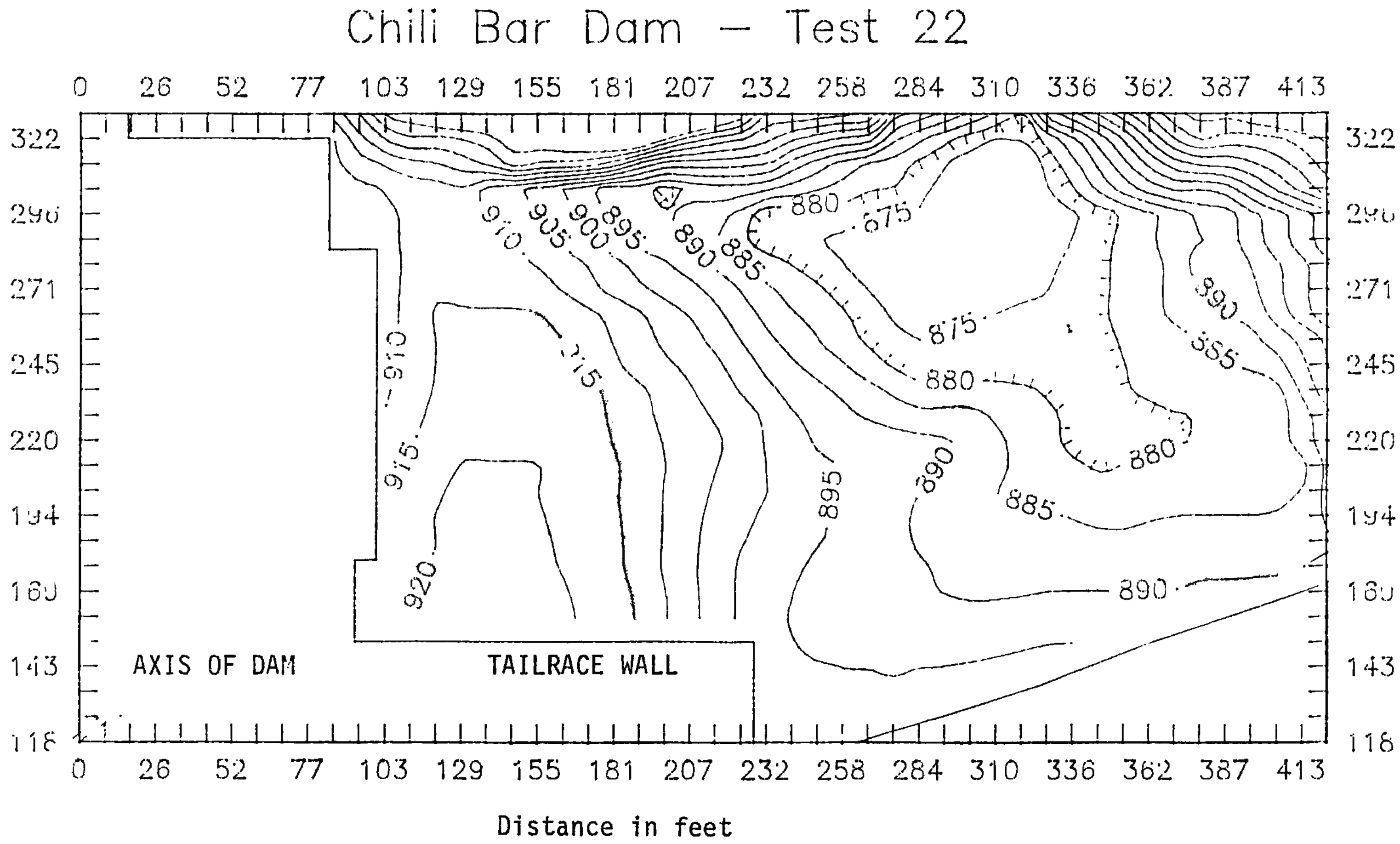


Figure 35. - Three-level flip bucket with deflector wall - bed contours after 100 percent of PMF.

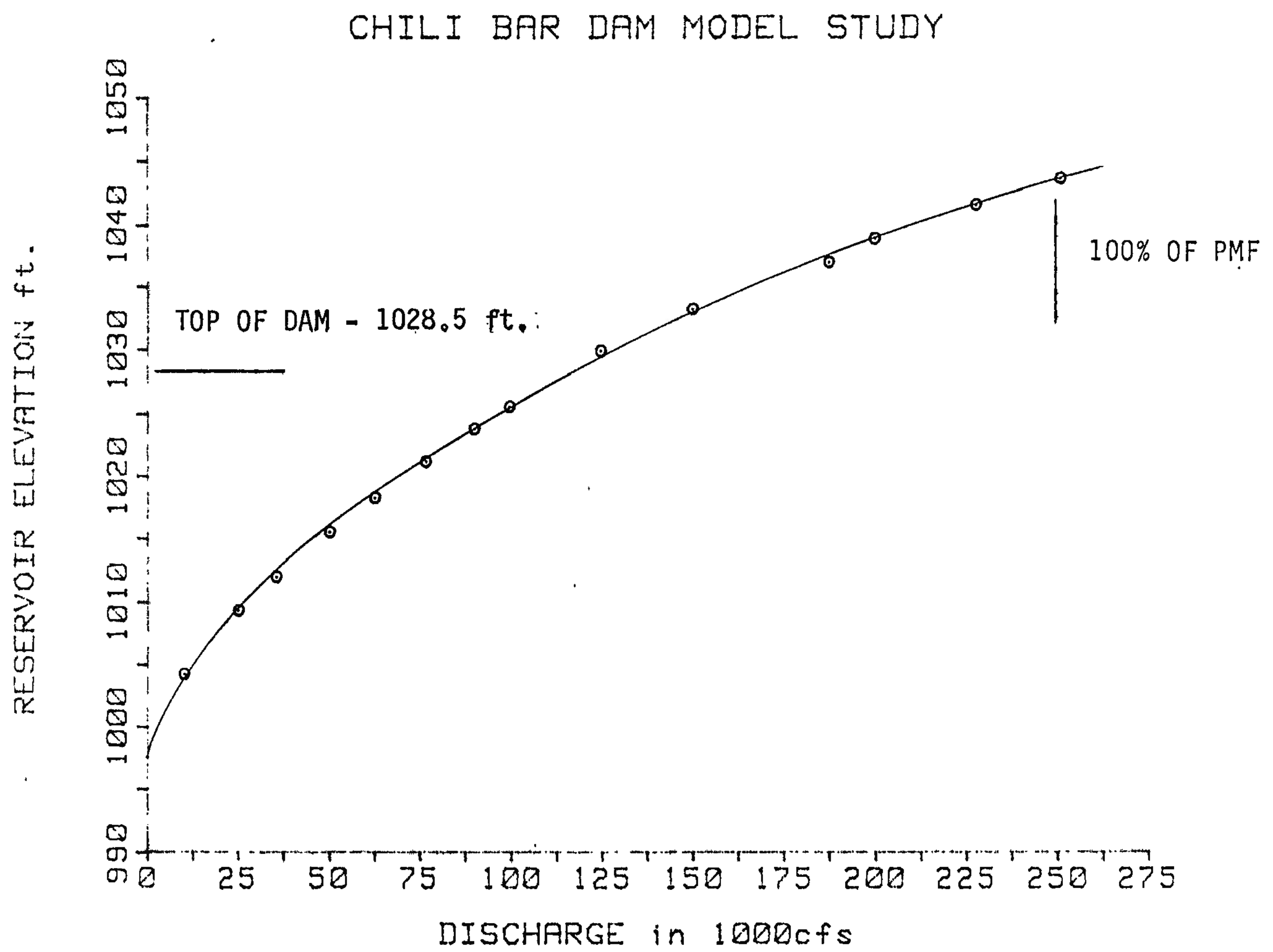


Figure A1. - Spillway/dam discharge rating curve.

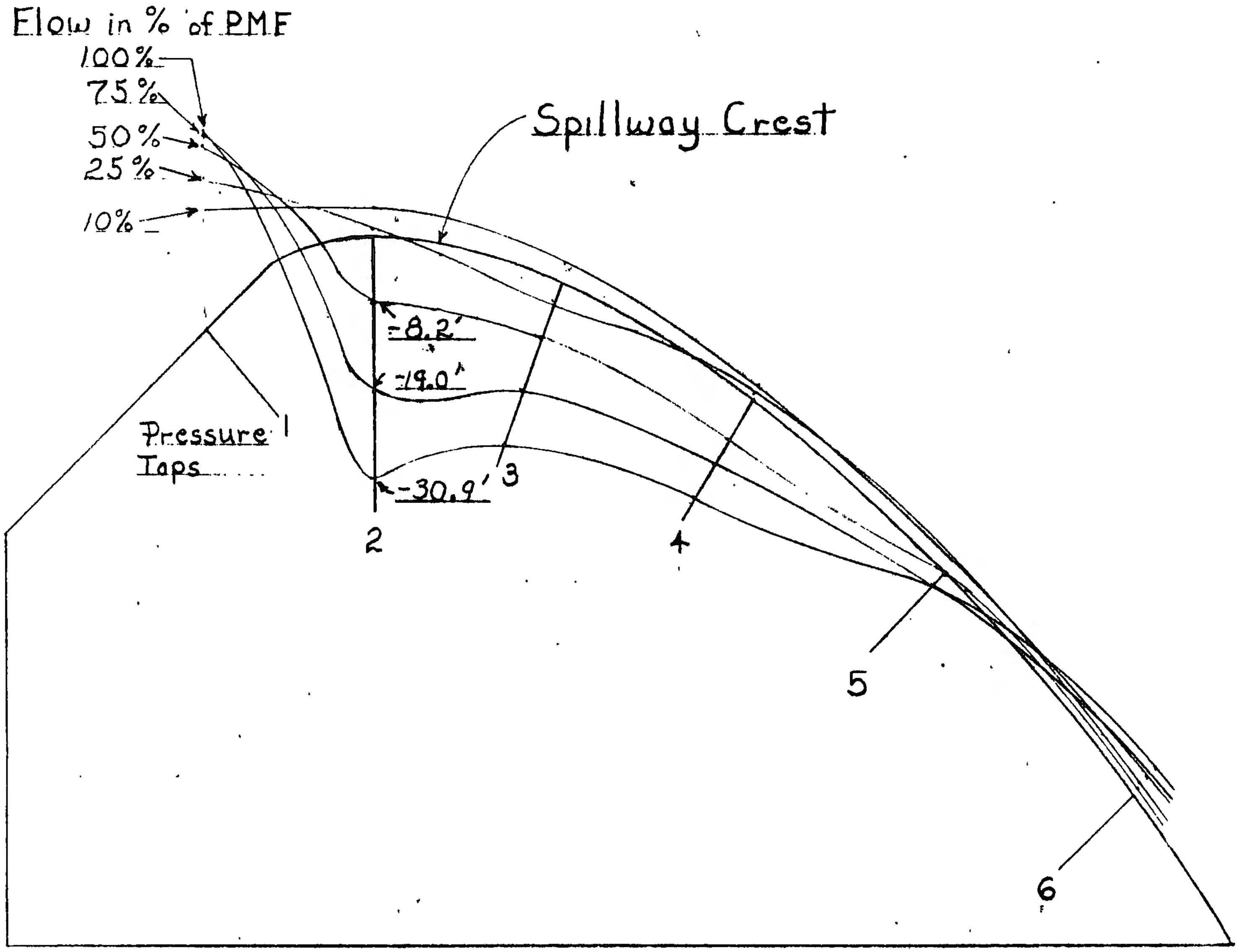
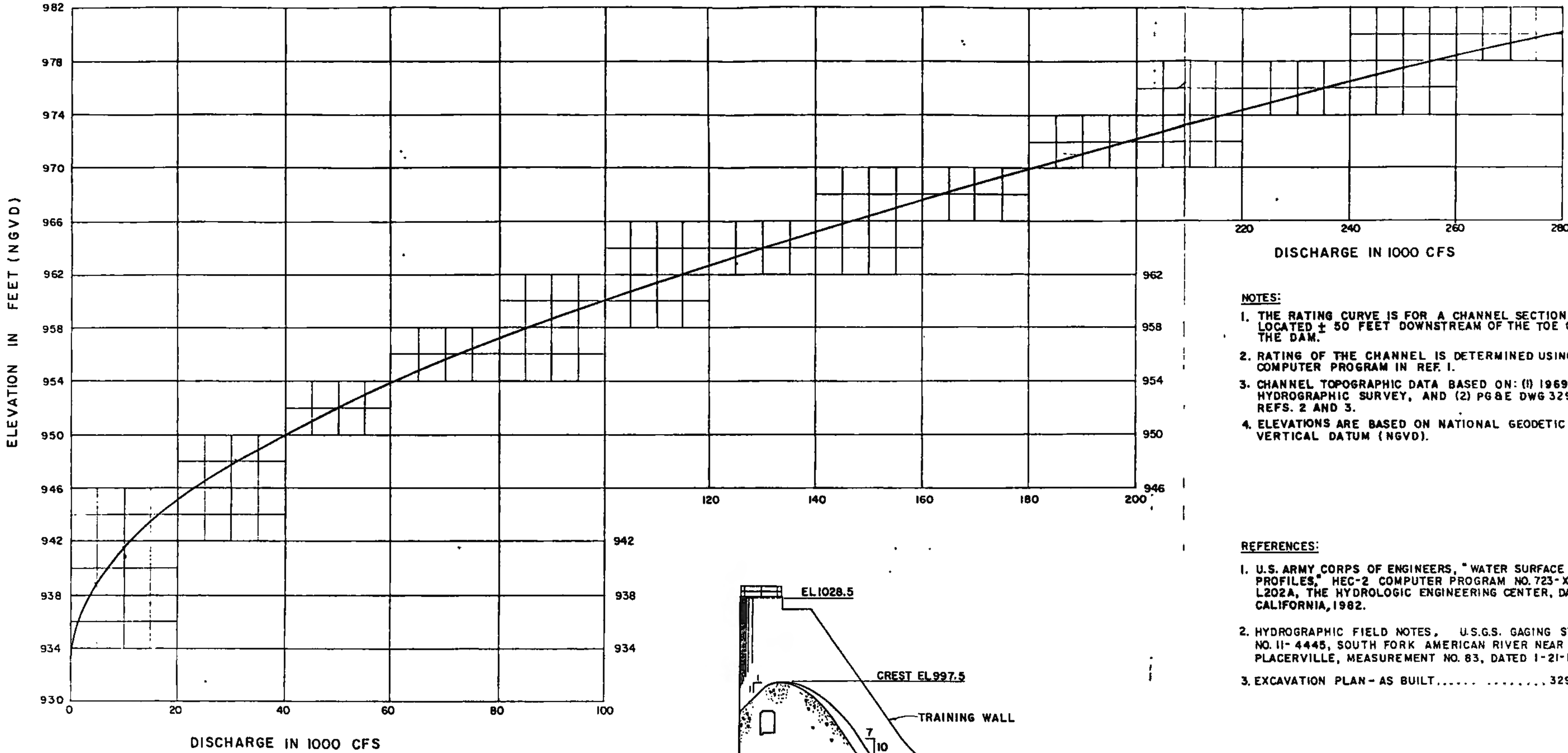


Figure A2. - Spillway crest pressures.

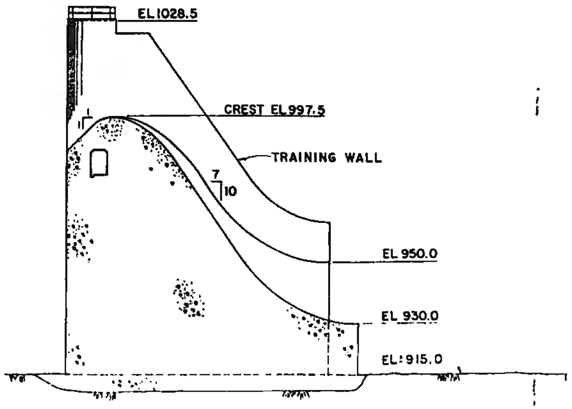


NOTES:

1. THE RATING CURVE IS FOR A CHANNEL SECTION LOCATED ± 50 FEET DOWNSTREAM OF THE TOE OF THE DAM.
2. RATING OF THE CHANNEL IS DETERMINED USING COMPUTER PROGRAM IN REF. 1.
3. CHANNEL TOPOGRAPHIC DATA BASED ON: (1) 1969 HYDROGRAPHIC SURVEY, AND (2) PG&E DWG 329305 REFS. 2 AND 3.
4. ELEVATIONS ARE BASED ON NATIONAL GEODETIC VERTICAL DATUM (NGVD).

REFERENCES:

1. U.S. ARMY CORPS OF ENGINEERS, "WATER SURFACE PROFILES," HEC-2 COMPUTER PROGRAM NO. 723-X6-L202A, THE HYDROLOGIC ENGINEERING CENTER, DAVIS CALIFORNIA, 1982.
2. HYDROGRAPHIC FIELD NOTES, U.S.G.S. GAGING STA. NO. 11-4445, SOUTH FORK AMERICAN RIVER NEAR PLACERVILLE, MEASUREMENT NO. 83, DATED 1-21-1969.
3. EXCAVATION PLAN - AS BUILT.............329305



DAM PROFILE (ALONG RIVER ℄)

NTS

CIVIL-HYDROLOGIC ENGINEERING
TAILWATER RATING CURVE
CHILI BAR DAM
SOUTH FORK AMERICAN RIVER
DEPARTMENT OF ENGINEERING
PACIFIC GAS AND ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

DIV SACRAMENTO

341552

Table 1. - Spillway crest pressures.

Pressure tap	Discharge in percent of PMF				
	10	25	50	75	100
	Pressures in feet of water				
1	13.5	18.5	22.1	24.4	24.2
2	3.9	0.3	- 8.1	-19.0	-30.9
3	2.5	- 2.4	- 7.2	-14.3	-21.3
4	1.8	0.4	- 5.1	- 9.6	-13.8
5	1.8	1.6	- 0.1	- 1.9	- 3.3
6	2.6	1.5	1.4	2.9	4.5