PAP-800

Damage Assessment for the Choke Canyon Dam Outlet Works Stilling Basin

September 1998

by

Leslie Hanna

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RES-3.50

MEMORANDUM

To: Leon Esparza, OK-ESPARZA

From: Leslie Hanna
Hydraulic Engineer

Subject: Choke Canyon Dam Outlet Works Stilling Basin Damage Assessment

The attached report describes the results of our assessment of the cause of damage at the Choke Canyon Dam outlet works stilling basin. Brent Mefford, Technical Specialist at the Water Resources Research Laboratory (WRRL), provided technical expertise in the investigation and peer reviewed the attached document.

Please let us know if you have any questions or comments or if we can be of further assistance. Feel free to contact Leslie Hanna at (303) 445-2146 or Brent Mefford at (303) 445-2149.

Attachment

bc: D-8560 (Burgi, Hanna, Mefford)

WBR:LHanna:rlc:9/22/98:303/445-2146
(j:\wpfiles\hanna\chokmem.wpd)

Damage Assessment for the Choke Canyon Dam Outlet Works Stilling Basin

Background

The Choke Canyon Dam was examined on October 21, 1997, under the RO&M Program and SEED Program as required by the Reclamation Manual. The Choke Canyon Dam is the principle feature of the Nueces River Project and is located on the Frio River, 4 miles west of Three Rivers, Texas [1].

The river outlet works stilling basin was dewatered so that an inspection of the stilling basin and chute could be performed. The inspection revealed erosion of the concrete floor and side walls of the concrete outlet works chute. The estimated loss of concrete in the floor is 2 to 3 inches maximum and ½ to 1 inch maximum on the side walls. Rebar was exposed in the center energy dissipation block of the right bay.

A consultant was hired to do an evaluation of the cause of the damage so that repairs and necessary modifications could be made to eliminate reoccurrence of damage to the stilling basin. The consultant's report identified cavitation as the primary cause of the damage and recommended modifications that would address prevention of cavitation during future operations [2].

Reclamation's Water Resources Research Laboratory in Denver was requested to review the consultant's report as well as photos, and design and operation information, in order to make an independent assessment of the cause of the damage. The results of this study are presented herein.

Conclusions

1) Evidence indicates that the most probable cause of damage to the Choke Canyon Dam stilling basin chute, walls, and invert is abrasion damage. This assessment is based on the following:

> a) Pressure profiles determined from the finite element program FLOW 3D indicate that the lowest pressure experienced at the chute boundary is about -1.0 lb/in^2. This is well above the pressure required to produce cavitation damage along a smooth boundary (without regard to negative pressures caused by offsets in the chute).
>
> b) A program designed to compute cavitation characteristics was used to determine the cavitation index for the flow [3]. This value can be used to predict the occurrence of cavitation due to low pressures caused by local irregularities in the surface. The results from this program indicate that cavitation damage should not occur along the chute invert; with the possible exception of locations of very abrupt offsets.
>
> c) Photos of the damage indicate a pattern of damage that is consistent with that of abrasion damage. It shows a uniformly distributed roughness which is characteristic of this type of damage.

d) The abrasion high on the curved chute and side walls is characteristic of small flows where an unstable jet lifts off the invert, pulling material up the sides of the chute, then returning material down along the invert.

e) The removal of 55 gallons of round gravel, up to 1 inch in diameter, from the basin the last time the basin was dewatered demonstrates that a significant amount of material was drawn into the basin. In addition, the history of discharge operations shows that the basin is operated primarily at lower discharges and is rarely operated at high enough discharges to flush material out of the basin.

f) The high pressure gates are elevated, therefore the discharging jet will initially be aerated. As a result, although it is difficult to predict how far downstream the near-boundary flow remains aerated, our experience at other facilities suggests it is likely that sufficient air remains entrained to prevent cavitation damage.

Discussion of Investigations

Abrasion Characteristics

It is typical of many stilling basins to experience damage caused by rock, gravel, and sand brought into the basin by back flow over the stilling basin end sill. Normal operation of a hydraulic jump energy dissipation basin can cause a reverse flow eddy over the basin end sill and lower apron as shown in figure 1. This counter-rotating eddy is driven by a high velocity jet rising off the basin floor. Riprap placed on the apron downstream of the basin end sill is typically designed to be stable under this condition. However, small material, if available, can be transported into the basin and be trapped where turbulent flow continually moves the material about the surface, eroding the concrete. The photographs of the damage occurring at the Choke Canyon stilling basin (figure 2) show a similar pattern to the damage shown in figure 3 which shows abrasion damage that has occurred at the Hoover Dam spillway.

The following excerpts are paraphrased from Reclamation's Monograph No. 42 , "Cavitation in Chutes and Spillways" Chapter 3, under the heading of *Recognition of Cavitation Damage* :

> *Uniformly distributed roughnesses refer to variations occurring over a relatively wide area. This type of irregularity is caused by erosion of a concrete surface by sand or gravel in the water passing over the surface. The effect of cavitation bubble collapse perpendicular to a concrete surface produces a surface in which the individual pieces of aggregate are cleaned of the cement. However, deep crevices and holes can be found in the matrix. It almost appears as though worms bored into the concrete. The contrast between the texture of damage by cavitation and that caused by erosion with sand laden water is apparent in concrete. With cavitation, individual polished pieces of aggregate are exposed in the damaged zone as shown in figure 4. Whereas with erosion by sandladen water, individual pieces of aggregate are polished, as with cavitation, but the underlying surface is smooth and relatively even as shown on figure 3.*

Although we did not have the opportunity to inspect the basin ourselves, the description and photographs of the damage appear to match those of abrasion damage. In addition, the large amount of gravel (55 gallons) previously removed from the basin as well as material noted downstream of the basin indicates that there is an available source of materials to be drawn into the basin.

Cavitation Characteristics

The pressure profiles calculated from FLOW 3D indicate that pressures along the chute boundary are not low enough for cavitation to occur (appendix B). However, this ignores the fact that local irregularities can cause low pressures within the body of flow [3]. Therefore, cavitation can occur even though the boundary pressure is positive. The prediction of cavitation occurring at a boundary can best be accomplished by calculating the flow's cavitation index at the boundary and comparing this to the cavitation indices of surface irregularities which may be anticipated. To calculate the flow's cavitation index, the velocity and pressure conditions in the vicinity of the irregularities must be known. A computer program, published in Engineering Monograph No. 42, was designed to calculate the hydraulic and cavitation properties of free water surface flows. This program was used to model the Choke Canyon Dam outlet works stilling basin to determine the potential for cavitation along the curved chute and basin invert. The four flow conditions modeled were 200 ft^3/s, 400 ft^3/s, 600 ft^3/s, and 1000 ft^3/s. Appendix A gives the results from this program. The stations and elevations designated in the results were computed from drawing 1012-D-100 and were converted directly from meters to feet so that station 1152.92 represents station 3+51.5 on the drawing. The initial velocity discharging from the gate was computed from the Choke Canyon Dam outlet works discharge curves (drawing 1012-D-359) based on a reservoir elevation of 65 meters (see appendix C for drawings).

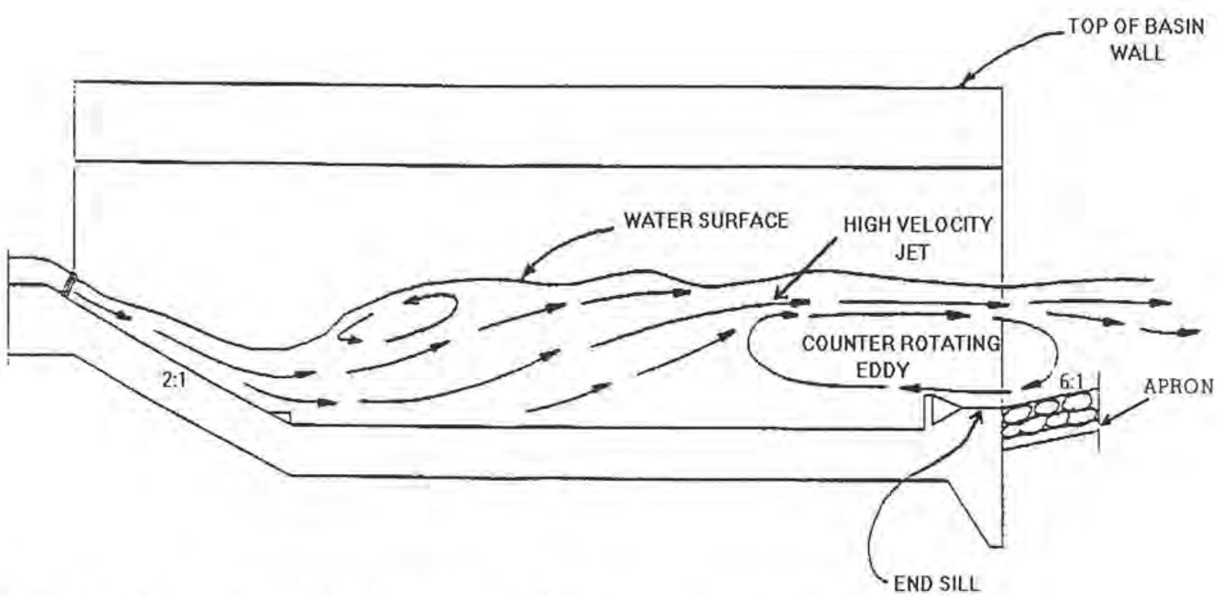


Figure 1. Counter-rotating eddy typical of hydraulic jump stilling basins.

The results indicate that the flow cavitation index is greater than 1.0 for all flows modeled. In general only minor cavitation damage, if any, would be expected to occur at abrupt offsets on the flow boundary for the condition of no air entrainment. FLOW 3D was used to more precisely define the velocity and pressure profiles for the flow conditions modeled (see appendix B). The results from this program concur reasonably with the results computed from the cavitation program.

Adequacy of Curved Chute Design

The jet profiles entering the curved section of the chute were estimated based on the trajectory of a free-discharging jet from

$$-y = x \tan\theta + \{x^2/[k(4*(d+hv)) \cos\theta^2]\}$$

Where θ = slope angle of the floor upstream of the curve
d = depth of flow
hv = velocity head ($V^2/2g$)

This equation was used to determine the tendency of the jet to lift off the chute invert. Reclamation's "Design of Small Dams" specifies that to avoid the tendency for the water to spring away from the floor the curvature should be made slightly flatter than the trajectory of a free charging jet [4]. To ensure positive pressure along the entire contact surface of the curve, K should be equal to or greater than 1.5. Figures 5a and 5b show the jet profiles calculated with a factor of safety or K value of 1.5 and 2.0 respectively for four discharges ranging from 200 to 1000 ft^3/s, compared to the actual invert profile of the curved chute. The velocity head was based on the velocity entering the curved chute (calculated from FLOW 3D). Figure 5a demonstrates that for each case where K= 1.5 the invert profile is flatter than the jet profile and therefore meets design criteria. However, figure 5b shows that with a safety factor of K = 2, at the lower discharges the jet no longer lies inside the invert profile. This may indicate the possibility that under certain operating conditions, the jet may become unstable and lift off the chute invert at the lower discharges. This possibility was confirmed with FLOW 3D which shows instability and the breaking up of the jet at 200 ft^3/s (figure B-5). Although under this condition pressures are still not low enough to cause a significant amount of cavitation damage, this condition can result in material being pulled up the sides of the chute then returning material down the invert. This will produce abrasion damage in those areas.

Recommendations

Abrasion damage is a common problem associated with hydraulic jump energy dissipation stilling basins. In order to minimize damage to the basin the following steps can be taken:

1) The source of material entering the basin should be identified and cleaned from the riprap apron downstream of the basin. It may be necessary to remove the existing riprap and have it replaced to meet original design specifications.

2) Cleaning the basin at regular intervals will help to minimize damage caused by abrasion.

3) The basin should be monitored to prevent materials from being deposited onto the riprap apron during activities such as construction.

4) If it is not possible to clean smaller material out of the area, grouting the material downstream of the basin can help minimize the amount of material being drawn into the basin. The downstream distance affected by the reverse flow can be as great as 50 to 100 ft. A physical model study would be required to determine the exact distance and nature of the hydraulics bringing material into the basin under normal operating conditions.

5) Install a flow deflector in the basin to suppress the return flow eddy that moves material into the basin. Previous model studies conducted in our laboratory, and limited field applications have demonstrated that the installation of flow deflectors can improve a basin's flow distribution significantly, greatly reducing the potential for movement of material into a basin. However, this solution would also require a model study to ensure deflector effectiveness and proper deflector design.

Finally, we do recommend the basin be studied with a physical model. A model would help resolve the differing opinions as to the primary cause of the damage and would provide the data necessary to identify the most cost effective alternatives to minimize damage.

References

[1] "1997 Periodic Facility Review Report," Choke Canyon Dam Nueces River Project, Texas, Bureau of Reclamation, U. S. Department of the Interior, November 24, 1997.

[2] "Choke Canyon Dam Outlet Works Investigation," City of Corpus Christi, Russell-Veteto Engineering, Inc., March 1998.

[3] "Cavitation in Chutes and Spillways," Engineering Monograph No. 42, Bureau of Reclamation, U.S. Department of the Interior, April 1990.

[4] "Design of Small Dams", Bureau of Reclamation, U.S. Department of the Interior, 1987.

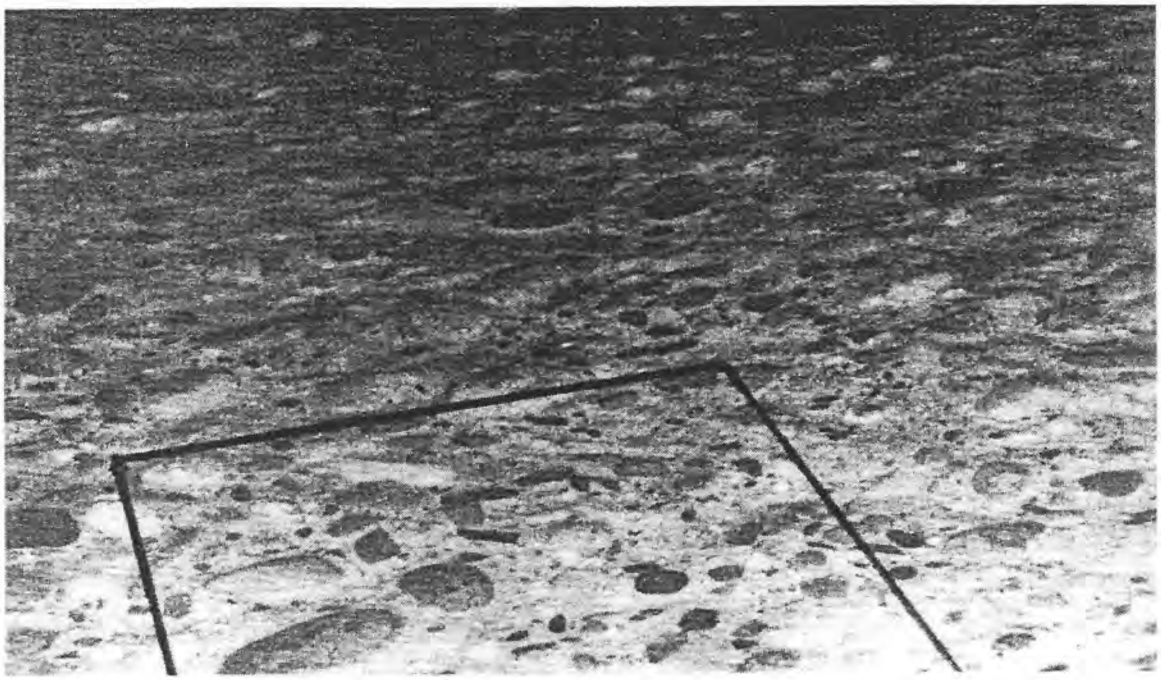
Photo No. 5

South chute exposed aggregate/rebar, looking upstream.

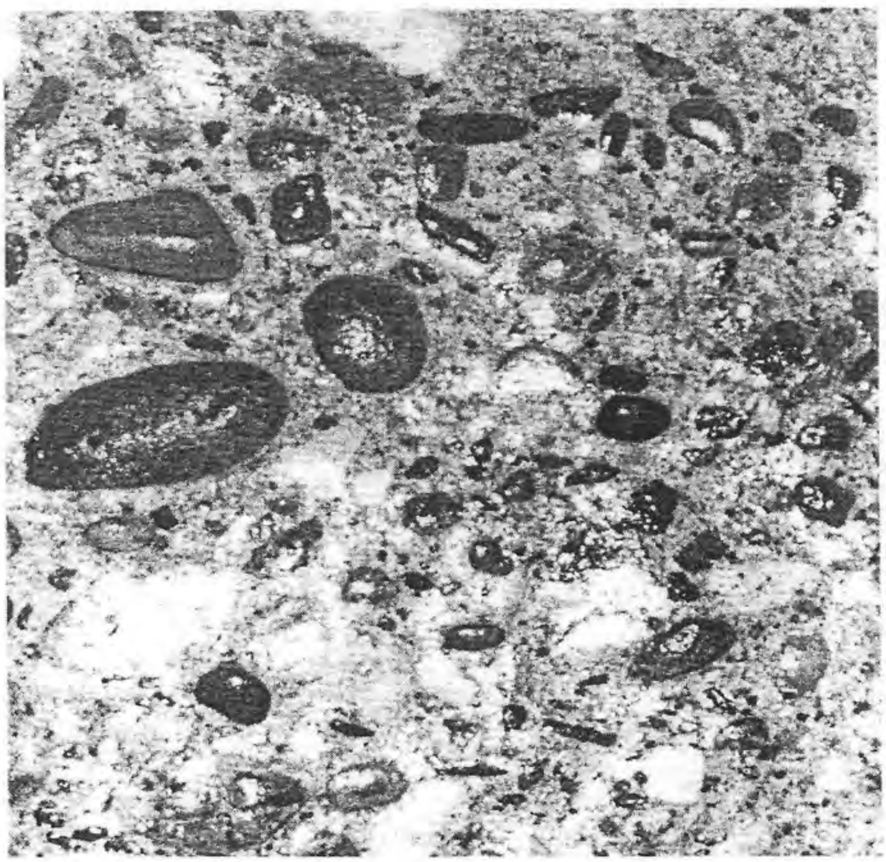
Photo No. 6

Damaged chute floor slope, looking upstream.

Figure 2. Choke Canyon outlet works stilling basin, dewatered for inspection [2].

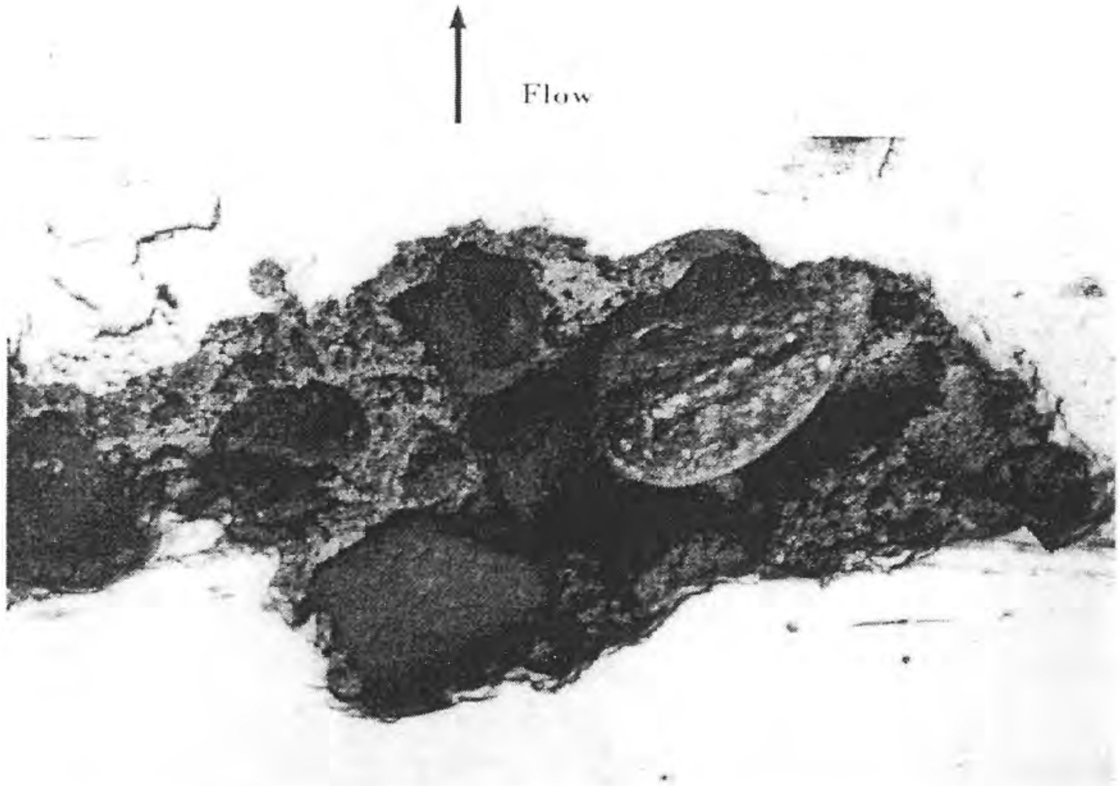


a. View of invert



b. Invert closeup

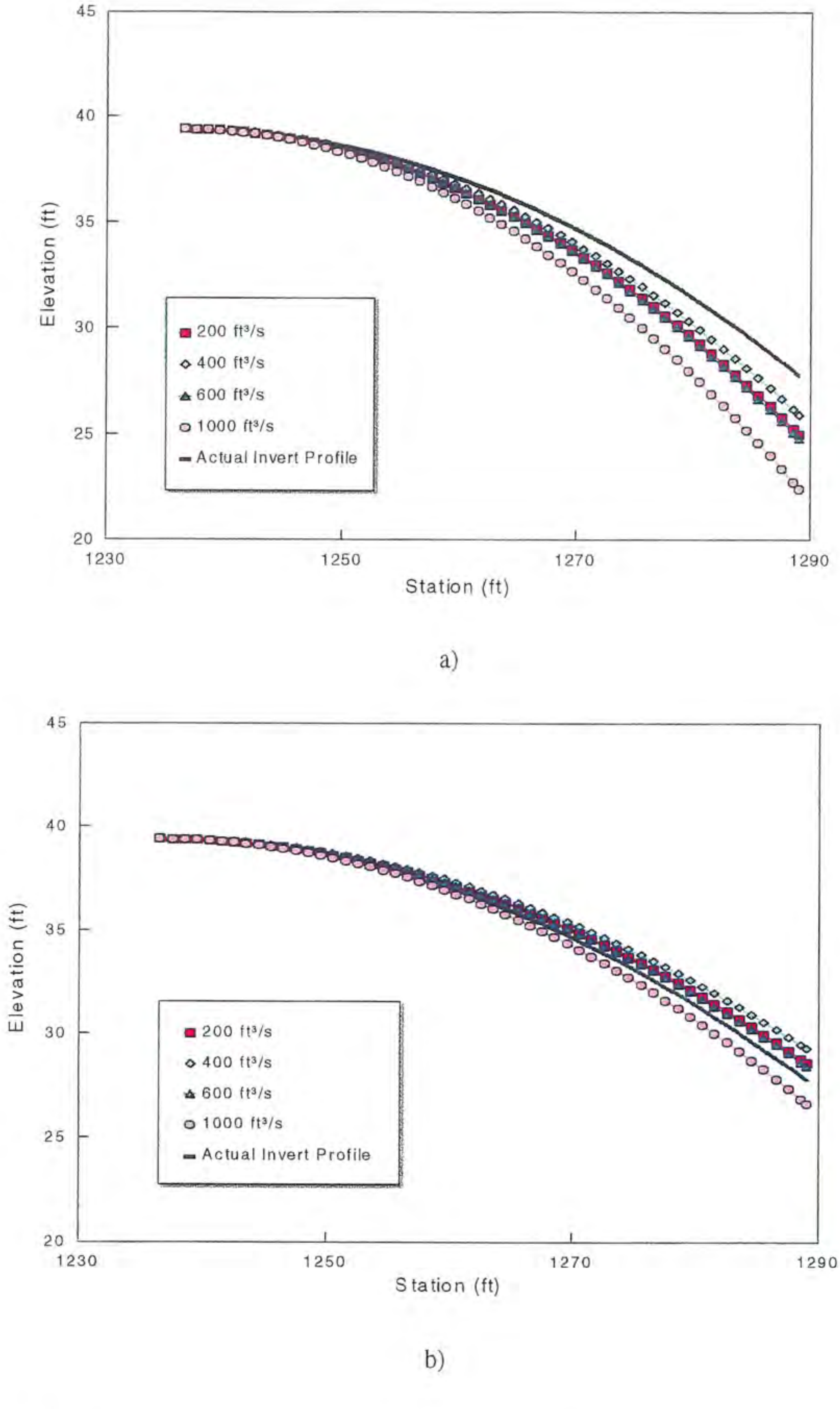
Figure 3. Abrasion damage in concrete at the Hoover Dam spillway [3].



a. Cavitation damage produced in a venturi cavitation test facility

b. Hoover Dam, Nevada spillway tunnel — initiation of damage

Figure 4. Cavitation damage in concrete [3].



a)

b)

Figure 5. Chute curvature required to prevent jet from lifting from invert with factor of safety of a) $K = 1.5$ and b) $K = 2.0$.

Appendix A

Cavitation Characteristics Results

Choke Canyon Stilling Basin

Q = 200.0 CFS INITIAL DEPTH = .30 FT RUGOSITY = .001500 FT N = .0112 R = 135.6

STATION FT	INVERT ELEV FT	SLOPE	DEPTH FT	VELOCITY FT/SEC	PIEZ FT	ENERGY GRADE LINE FT	Q AIR/Q WATER	PROFILE	DEPTH NORMAL FT	DEPTH CRITICAL FT	THICKNESS BOUNDARY LAYER FT
1152.9	129.23	.0100	.300	66.667	.300	172.890	.000	S3	1.479	2.316	.003
1175.9	129.00	.0100	.378	52.935	.378	172.890	.000	S3	1.479	2.316	.229
1205.9	128.70	.0100	.481	41.547	.481	156.965	.000	S3	1.479	2.344	.481
1236.6	128.39	.0101	.584	34.222	.584	148.978	.000	S3	1.473	2.391	.584
1246.6	127.97	.0420	.602	33.238	.434	147.274	.192	S3	.915	2.377	.602
1256.6	126.70	.1270	.606	32.998	.435	145.733	.000	S3	.639	2.383	.606
1266.6	124.59	.2110	.598	33.461	.416	144.131	.000	S2	.545	2.394	.598
1276.6	121.63	.2960	.580	34.479	.382	142.318	.000	S2	.492	2.410	.580
1286.6	117.83	.3800	.557	35.915	.340	140.202	.000	S2	.458	2.430	.557
1289.0	116.76	.4315	.551	36.325	.323	139.621	.000	S2	.443	2.445	.551

ENERGY GRADE LINE AT BEGINNING OF BOUNDARY LAYER
198.544

Choke Canyon Stilling Basin

Q = 200.0 CFS INITIAL DEPTH = .30 FT RUGOSITY = .001500 FT N = .0112 R = 135.6

CAVITATION CHARACTERISTICS

STATION	FLOW SIGMA	SIGMA OF UNIFORM ROUGHNESS	REQUIRED CHAMFER TO STOP CAVITATION	DAMAGE POTENTIAL CIRCULAR ARC 1/4-IN 5-MM	CIRCULAR ARC 1/2-IN 10-MM	CIRCULAR ARC 1-IN 25-MM	90-DEGREE OFFSET 1/4-IN 5-MM	90-DEGREE OFFSET 1/2-IN 10-MM	90-DEGREE OFFSET 1-IN 25-MM	TURBULENCE INTENSITY
1152.92	.488	.089	1 TO 7	.103E+02	.251E+02	.577E+02	.110E+03	.251E+03	.559E+03	.0928
1175.92	.775	.084	1 TO 4	.100E-01	.221E+00	.117E+01	.379E+00	.168E+01	.501E+01	.0383
1205.92	1.262	.080	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.235E-01	.0349
1236.56	1.866	.077	1 TO 1	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0341
1246.56	1.970	.076	1 TO 1	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0340
1256.56	1.998	.076	1 TO 1	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0340
1266.56	1.943	.076	1 TO 1	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0340
1276.56	1.828	.077	1 TO 1	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0342
1286.56	1.683	.077	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0343
1289.04	1.644	.077	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0344

Choke Canyon Stilling Basin

Q = 400.0 CFS INITIAL DEPTH = .70 FT RUGOSITY = .001500 FT N = .0116 R = 135.6

STATION FT	INVERT ELEV FT	SLOPE	DEPTH FT	VELOCITY FT/SEC	PIEZ FT	ENERGY GRADE LINE FT	Q AIR/Q WATER	PROFILE	DEPTH NORMAL FT	DEPTH CRITICAL FT	THICKNESS BOUNDARY LAYER FT
1152.9	129.23	.0100	.700	57.143	.700	172.123	.000	S3	2.391	3.676	.003
1175.9	129.00	.0100	.766	52.228	.766	172.123	.000	S3	2.391	3.676	.229
1205.9	128.70	.0100	.854	46.829	.854	163.911	.000	S3	2.391	3.687	.485
1236.6	128.39	.0101	.948	42.191	.948	157.868	.000	S3	2.381	3.715	.728
1246.6	127.97	.0420	.973	41.123	.573	156.349	.000	S3	1.453	3.714	.806
1256.6	126.70	.1270	.979	40.841	.572	154.949	.000	S3	1.005	3.734	.883
1266.6	124.59	.2110	.974	41.087	.546	153.479	.000	S2	.854	3.765	.959
1276.6	121.63	.2960	.958	41.774	.498	151.858	.000	S2	.769	3.809	.958
1286.6	117.83	.3800	.928	43.117	.433	150.017	.000	S2	.715	3.844	.928
1289.0	116.76	.4315	.919	43.521	.405	149.518	.000	S2	.690	3.867	.919

ENERGY GRADE LINE AT BEGINNING OF BOUNDARY LAYER
180.634

Choke Canyon Stilling Basin

Q = 400.0 CFS INITIAL DEPTH = .70 FT RUGOSITY = .001500 FT N = .0116 R = 135.6

CAVITATION CHARACTERISTICS

STATION	FLOW SIGMA	SIGMA OF UNIFORM ROUGHNESS	REQUIRED CHAMFER TO STOP CAVITATION	DAMAGE POTENTIAL CIRCULAR ARC 1/4-IN 5-MM	CIRCULAR ARC 1/2-IN 10-MM	CIRCULAR ARC 1-IN 25-MM	90-DEGREE OFFSET 1/4-IN 5-MM	90-DEGREE OFFSET 1/2-IN 10-MM	90-DEGREE OFFSET 1-IN 25-MM	TURBULENCE INTENSITY
1152.92	.672	.074	1 TO 5	.152E+01	.453E+01	.115E+02	.239E+02	.566E+02	.129E+03	.0919
1175.92	.805	.072	1 TO 4	.100E-01	.127E+00	.892E+00	.255E+00	.132E+01	.407E+01	.0383
1205.92	1.005	.071	1 TO 3	.100E-01	.100E-01	.136E-01	.100E-01	.306E-01	.558E+00	.0349
1236.56	1.241	.069	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0332
1246.56	1.292	.069	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0329
1256.56	1.310	.069	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0325
1266.56	1.293	.069	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0322
1276.56	1.250	.069	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0322
1286.56	1.171	.070	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.166E-02	.0323
1289.04	1.148	.070	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.229E-01	.0324

Choke Canyon Stilling Basin

Q = 600.0 CFS INITIAL DEPTH = 1.30 FT RUGOSITY = .001500 FT N = .0119 R = 135.6

STATION FT	INVERT ELEV FT	SLOPE	DEPTH FT	VELOCITY FT/SEC	PIEZ FT	ENERGY GRADE LINE FT	Q AIR/Q WATER	PROFILE	DEPTH NORMAL FT	DEPTH CRITICAL FT	THICKNESS BOUNDARY LAYER FT
1152.9	129.23	.0100	1.300	46.154	1.300	160.495	.000	S3	3.201	4.817	.003
1175.9	129.00	.0100	1.362	44.052	1.362	160.495	.000	S3	3.201	4.817	.237
1205.9	128.70	.0100	1.444	41.539	1.444	157.019	.000	S3	3.201	4.822	.499
1236.6	128.39	.0101	1.532	39.175	1.532	154.036	.000	S3	3.187	4.837	.745
1246.6	127.97	.0420	1.536	39.067	.985	153.216	.000	S3	1.919	4.797	.824
1256.6	126.70	.1270	1.526	39.320	.958	152.357	.000	S2	1.317	4.817	.902
1266.6	124.59	.2110	1.495	40.142	.892	151.377	.000	S2	1.116	4.848	.979
1276.6	121.63	.2960	1.448	41.442	.794	150.236	.000	S2	1.004	4.894	1.056
1286.6	117.83	.3800	1.392	43.108	.677	148.897	.000	S2	.932	4.951	1.132
1289.0	116.76	.4315	1.384	43.366	.635	148.530	.000	S2	.899	5.000	1.152

ENERGY GRADE LINE AT BEGINNING OF BOUNDARY LAYER
163.607

Choke Canyon Stilling Basin

Q = 600.0 CFS INITIAL DEPTH = 1.30 FT RUGOSITY = .001500 FT N = .0119 R = 135.6

CAVITATION CHARACTERISTICS

STATION	FLOW SIGMA	SIGMA OF UNIFORM ROUGHNESS	REQUIRED CHAMFER TO STOP CAVITATION	DAMAGE POTENTIAL CIRCULAR ARC 1/4-IN 5-MM	CIRCULAR ARC 1/2-IN 10-MM	CIRCULAR ARC 1-IN 25-MM	90-DEGREE OFFSET 1/4-IN 5-MM	90-DEGREE OFFSET 1/2-IN 10-MM	90-DEGREE OFFSET 1-IN 25-MM	TURBULENCE INTENSITY
1152.92	1.048	.065	1 TO 3	.100E-01	.156E+00	.846E+00	.231E+01	.633E+01	.157E+02	.0906
1175.92	1.152	.065	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.399E+00	.0381
1205.92	1.299	.064	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0347
1236.56	1.464	.064	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0331
1246.56	1.449	.064	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0328
1256.56	1.429	.064	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0324
1266.56	1.369	.064	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0321
1276.56	1.281	.064	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0319
1286.56	1.180	.065	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0316
1289.04	1.164	.065	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0316

Choke Canyon Stilling Basin

Q = 1000.0 CFS   INITIAL DEPTH = 2.50 FT   RUGOSITY = .001500 FT   N = .0122 R = 135.6

STATION FT	INVERT ELEV FT	SLOPE	DEPTH FT	VELOCITY FT/SEC	PIEZ FT	ENERGY GRADE LINE FT	Q AIR/Q WATER	PROFILE	DEPTH NORMAL FT	DEPTH CRITICAL FT	THICKNESS BOUNDARY LAYER FT
1152.9	129.23	.0100	2.500	40.000	2.500	155.236	.000	S3	4.686	6.772	.003
1175.9	129.00	.0100	2.561	39.047	2.561	155.236	.000	S3	4.686	6.772	.243
1205.9	128.70	.0100	2.641	37.861	2.641	153.619	.000	S3	4.686	6.774	.509
1236.6	128.39	.0101	2.725	36.701	2.725	152.108	.000	S3	4.665	6.780	.759
1246.6	127.97	.0420	2.679	37.323	1.815	151.584	.000	S3	2.753	6.678	.839
1256.6	126.70	.1270	2.634	37.966	1.735	151.037	.000	S2	1.867	6.698	.917
1266.6	124.59	.2110	2.549	39.236	1.584	150.369	.000	S2	1.575	6.733	.995
1276.6	121.63	.2960	2.437	41.033	1.383	149.555	.000	S2	1.413	6.785	1.071
1286.6	117.83	.3800	2.313	43.235	1.153	148.570	.000	S2	1.310	6.851	1.148
1289.0	116.76	.4315	2.285	43.756	1.072	148.294	.000	S2	1.263	6.902	1.167

ENERGY GRADE LINE AT BEGINNING OF BOUNDARY LAYER
156.575

Choke Canyon Stilling Basin

Q = 1000.0 CFS   INITIAL DEPTH = 2.50 FT   RUGOSITY = .001500 FT   N = .0122 R = 135.6

CAVITATION CHARACTERISTICS

STATION	FLOW SIGMA	SIGMA OF UNIFORM ROUGHNESS	REQUIRED CHAMFER TO STOP CAVITATION	DAMAGE POTENTIAL: CIRCULAR ARC 1/4-IN 5-MM	CIRCULAR ARC 1/2-IN 10-MM	CIRCULAR ARC 1-IN 25-MM	90-DEGREE OFFSET 1/4-IN 5-MM	90-DEGREE OFFSET 1/2-IN 10-MM	90-DEGREE OFFSET 1-IN 25-MM	TURBULENCE INTENSITY
1152.92	1.443	.059	1 TO 2	.100E-01	.100E-01	.100E-01	.263E+00	.107E+01	.308E+01	.0898
1175.92	1.517	.059	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0380
1205.92	1.617	.059	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0346
1236.56	1.725	.058	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0331
1246.56	1.626	.058	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0327
1256.56	1.568	.059	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0324
1266.56	1.462	.059	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0321
1276.56	1.329	.059	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0318
1286.56	1.189	.060	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0316
1289.04	1.158	.060	1 TO 2	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.100E-01	.0315

Appendix B

FLOW 3D Results

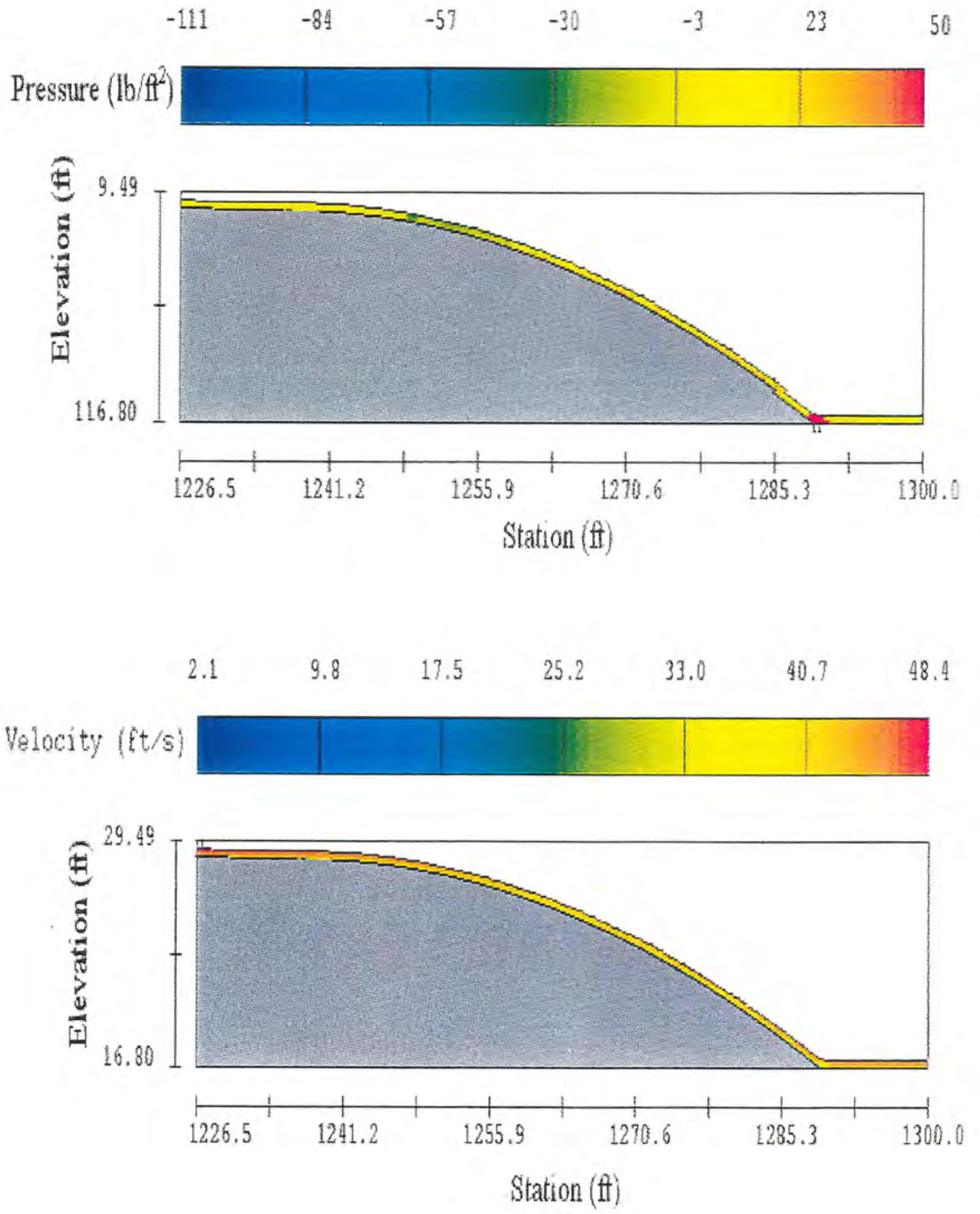


Figure B-1. Pressure and velocity profiles along the curved chute for a discharge of 200 ft^3/s (from FLOW 3D)

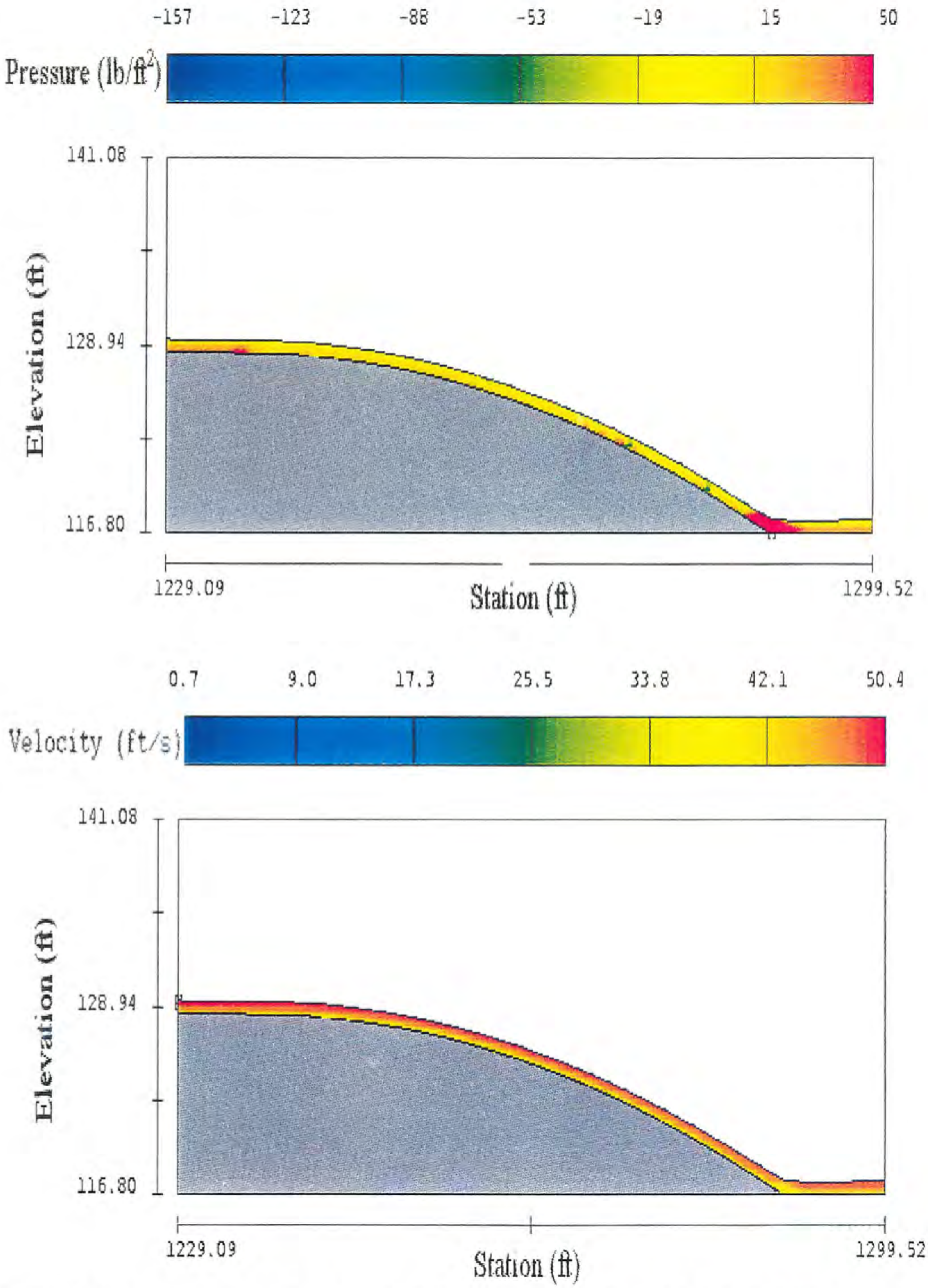


Figure B-2. Pressure and velocity profiles along the curved chute for a discharge of 400 ft^3/s (from FLOW 3D).

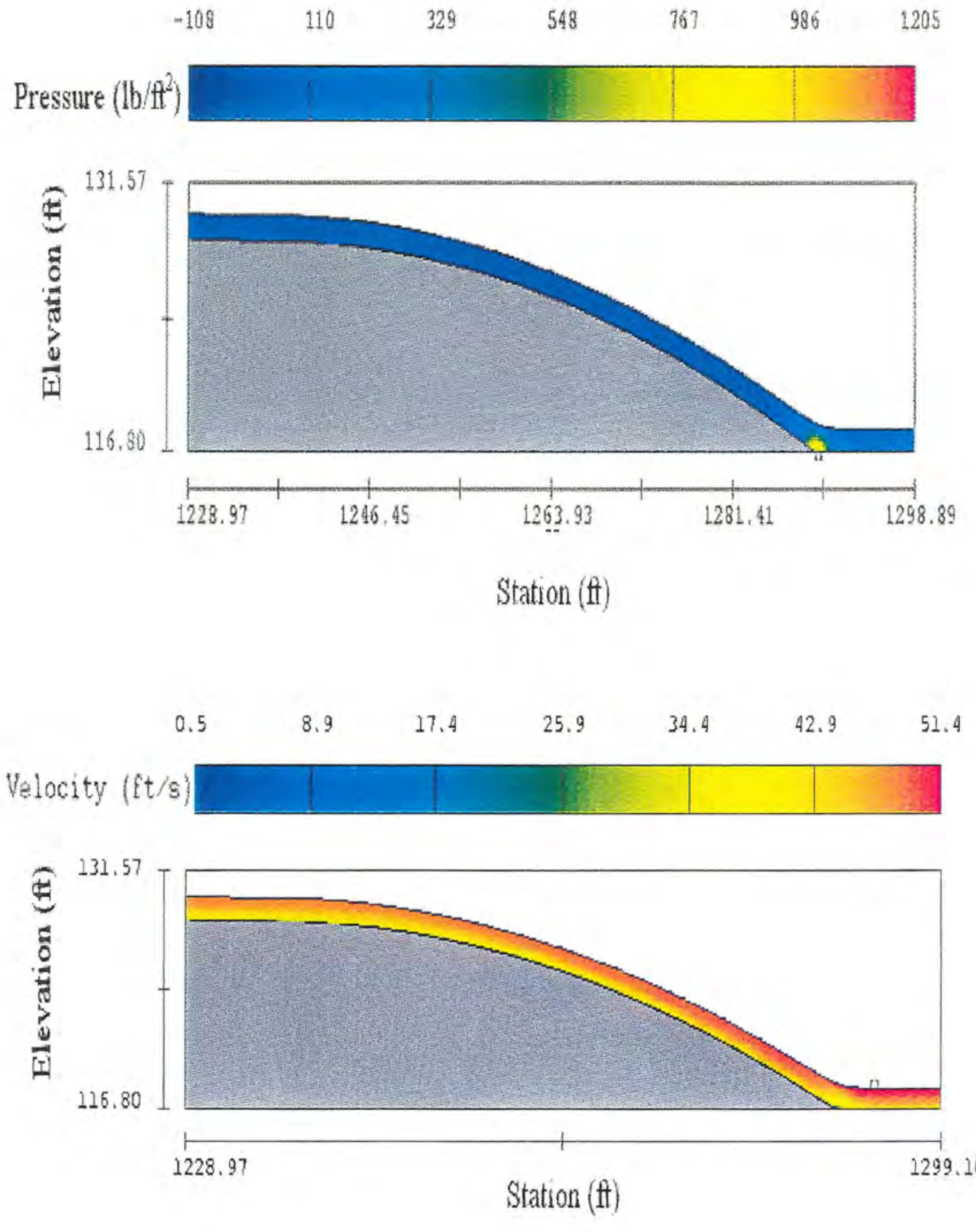


Figure B-3. Pressure and velocity profiles along the curved chute for a discharge of 600 ft^3/s (from FLOW 3D)

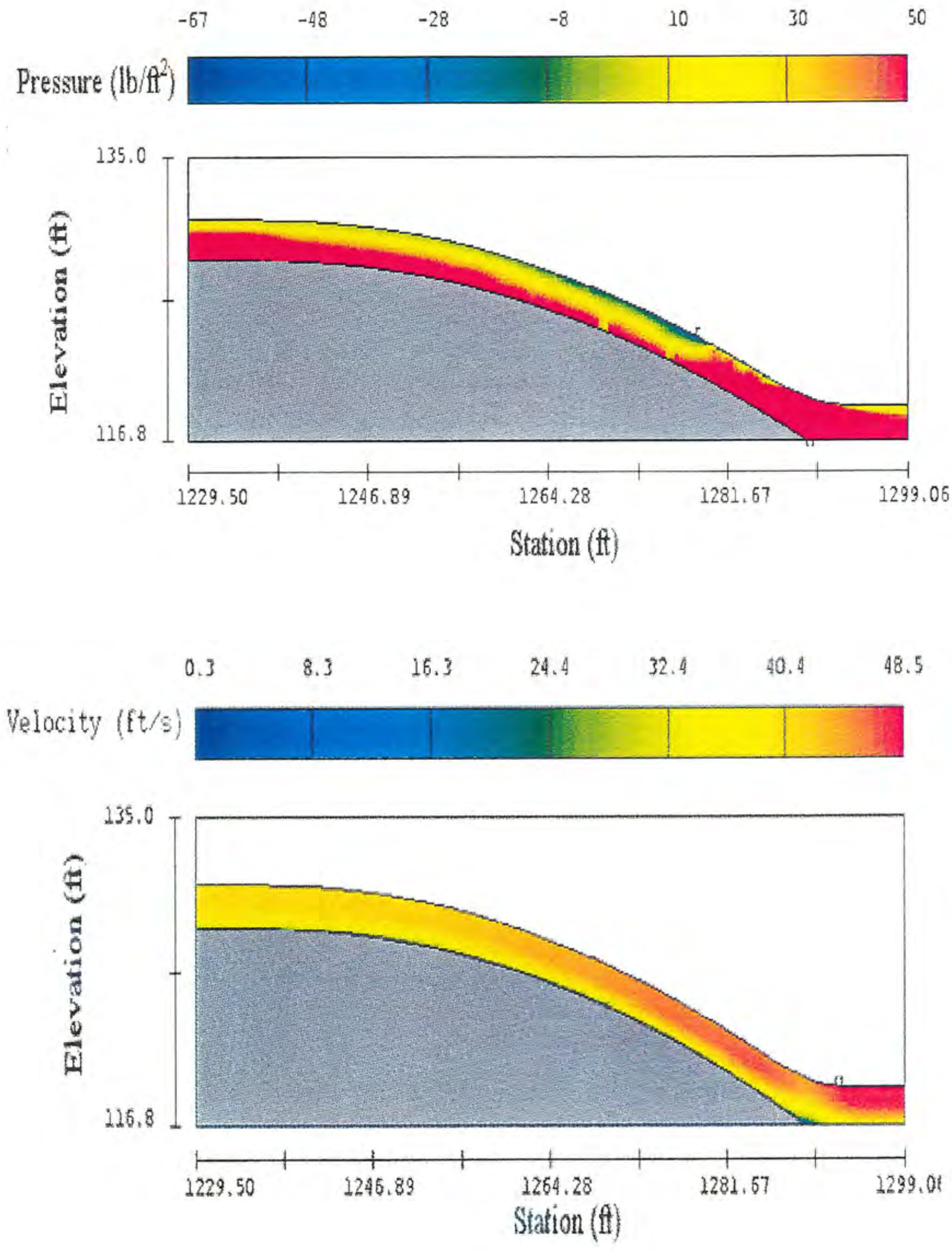
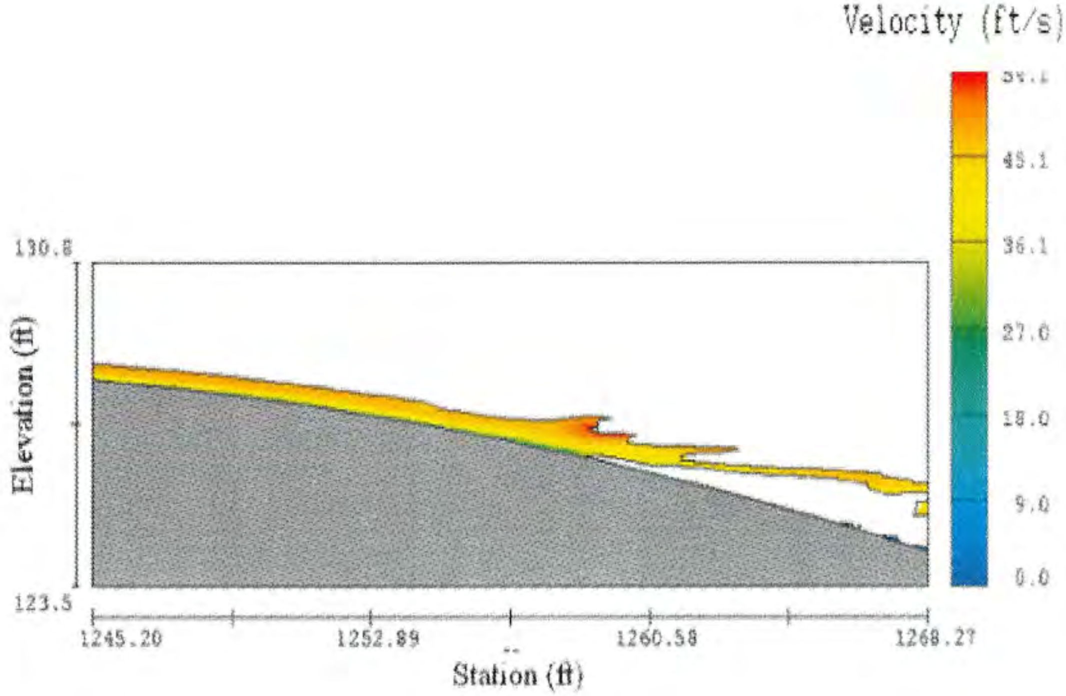


Figure B-4. Pressure and velocity profiles along the curved chute for a discharge of 1000 ft^3/s (from FLOW 3D)



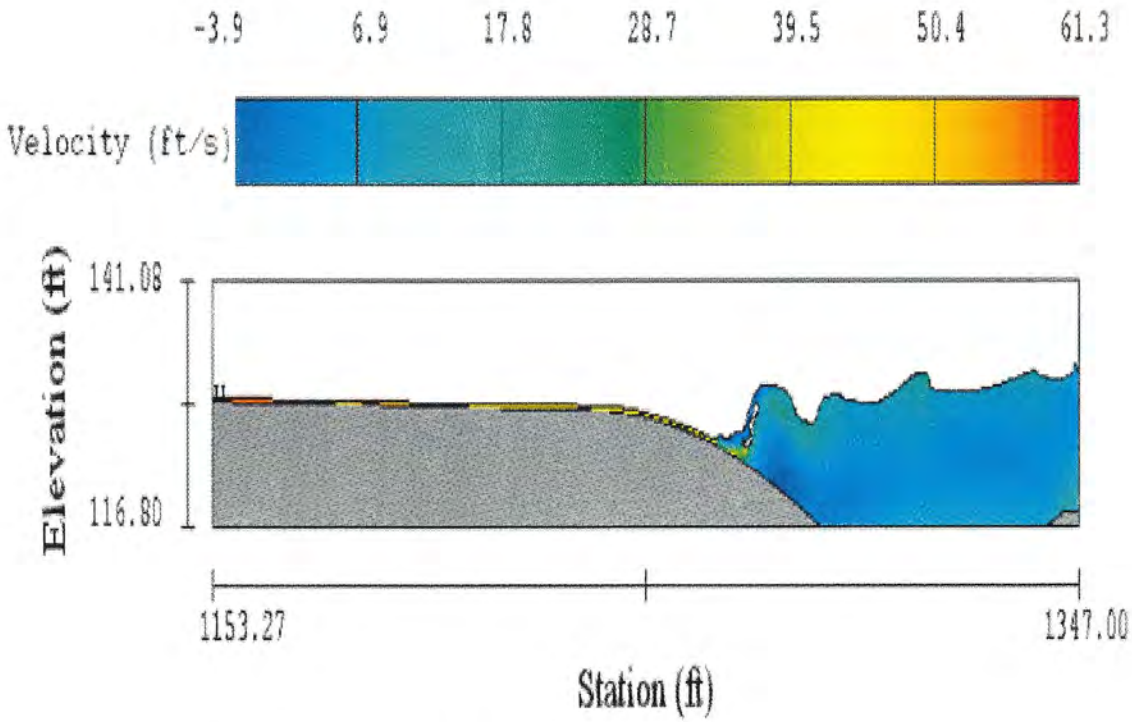
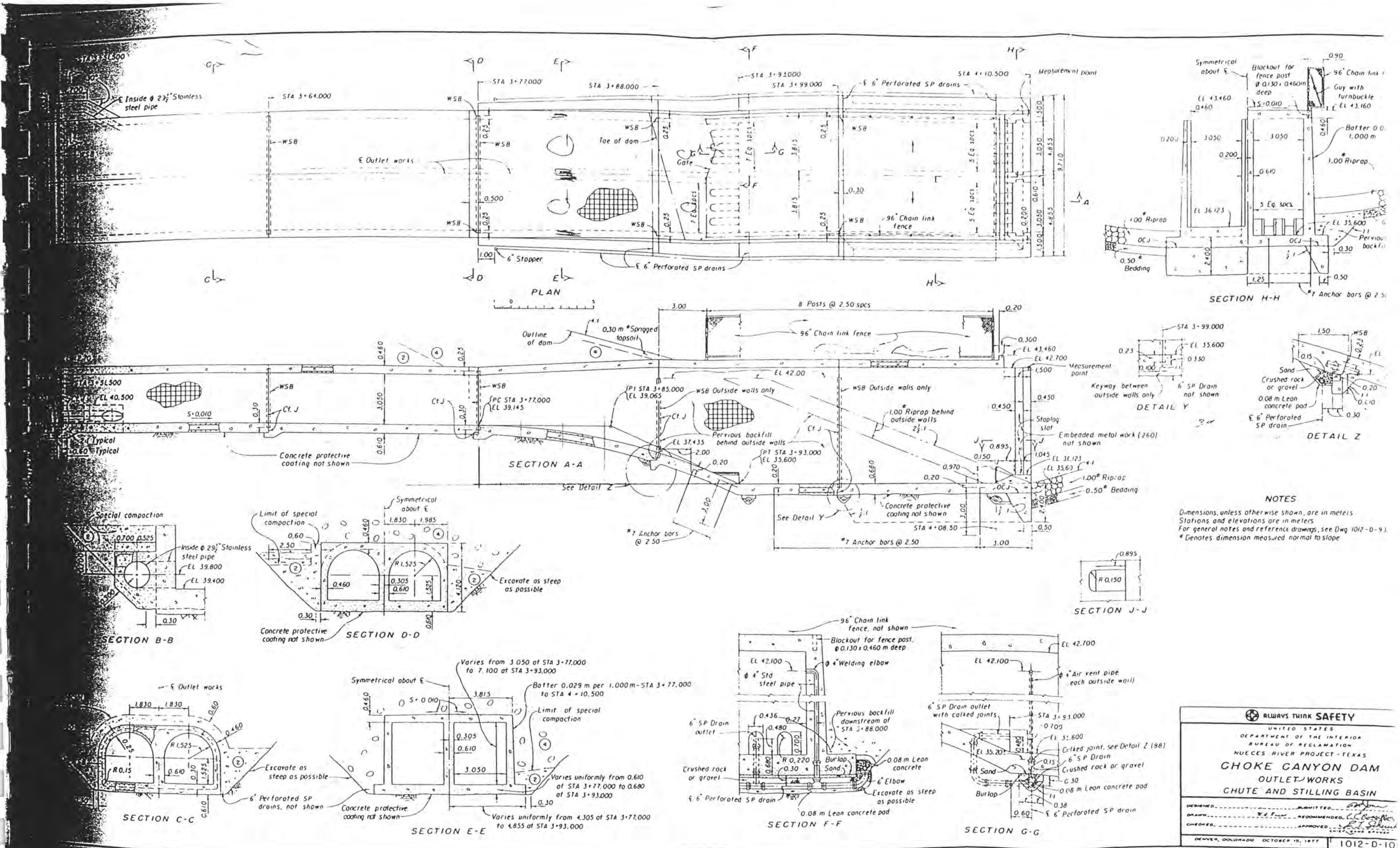
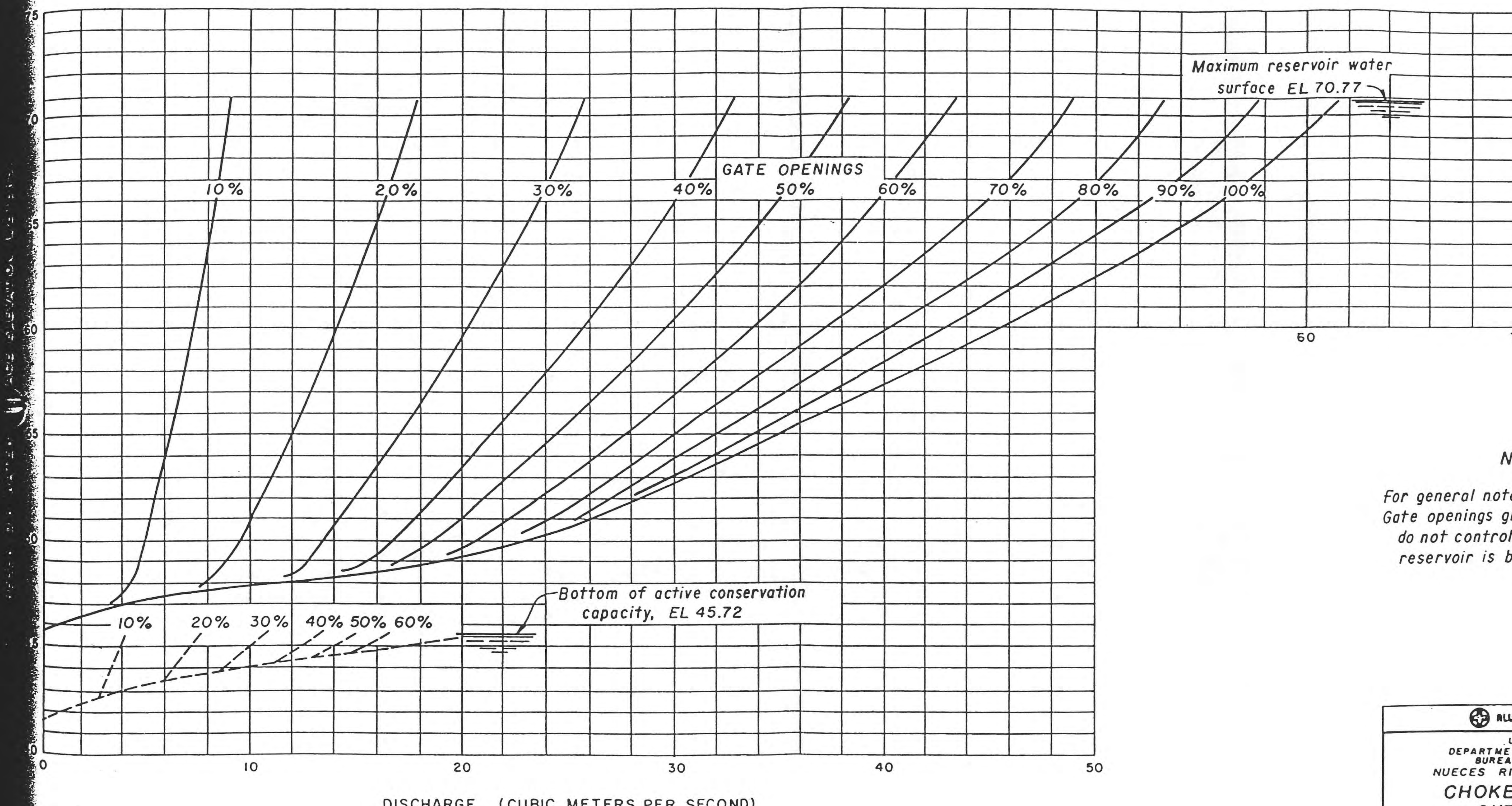


Figure B-5. Jet shown lifting from chute invert during early tme step, then shown with upstream velocities along chute invert with tailwater at conjugarte depth, for a discharge of 200 ft^3/s (from FLOW 3D)

Appendix C

Choke Canyon Drawings


PLAN
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
DETAIL Y
DETAIL Z
℄ Outlet works
℄ Inside ϕ 29½" Stainless steel pipe
96" Chain link fence
8 Posts @ 2.50 spcs
℄ 6" Perforated SP drains
6" Stopper
Toe of dam
Gate
Measurement point
Outline of dam
0.30 m *Sprigged topsoil
Pervious backfill behind outside walls
1.00* Riprap behind outside walls
Concrete protective coating not shown
Embedded metal work (260) not shown
Stoplog slot
0.50* Bedding
1.00* Riprap
#7 Anchor bars @ 2.50
See Detail Z
See Detail Y
Keyway between outside walls only
6" SP Drain not shown
Limit of special compaction
Excavate as steep as possible
Varies from 3.050 at STA 3+77.000 to 7.100 at STA 3+93.000
Batter 0.029 m per 1.000 m - STA 3+77.000 to STA 4+10.500
Varies uniformly from 0.610 at STA 3+77.000 to 0.680 at STA 3+93.000
Varies uniformly from 4.305 at STA 3+77.000 to 4.855 at STA 3+93.000
Blockout for fence post, ϕ 0.130 x 0.460 m deep
ϕ 4" Welding elbow
ϕ 4" Std steel pipe
Pervious backfill downstream of STA 3+88.000
0.08 m Lean concrete
6" Elbow
0.08 m Lean concrete pad
Crushed rock or gravel
4" Air vent pipe each outside wall
6" SP Drain outlet with calked joints
Calked joint, see Detail Z (88)
NOTES
Dimensions, unless otherwise shown, are in meters
Stations and elevations are in meters
For general notes and reference drawings, see Dwg 1012-D-93
* Denotes dimension measured normal to slope
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NUECES RIVER PROJECT - TEXAS
CHOKE CANYON DAM
OUTLET WORKS
CHUTE AND STILLING BASIN
DESIGNED
DRAWN
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO OCTOBER 15, 1977
1012-D-10



TWO 1.524 X 1.524 METER H.P. GATES EQUALLY OPEN

NOTES

For general notes, see Dwg. 1012-D-
Gate openings greater than 60% do not control discharges when reservoir is below EL 45.72

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NUECES RIVER PROJECT – TEXAS

CHOKE CANYON DAM
OUTLET WORKS
DISCHARGE CURVES

DESIGNED S. Lau ___ TECHNICAL APPROVAL
DRAWN S. Lau ___ SUBMITTED R.O. ...
CHECKED D.J. Kowell ___ APPROVED C.C. Ross
CHIEF, DAMS BR.

DENVER, COLORADO MAR. 27, 1981 SHEET 3 OF 3 1012 – D –