

**United States Department of the Interior
BUREAU OF RECLAMATION**

**DISCHARGE COEFFICIENTS
FOR IRREGULAR
OVERFALL SPILLWAYS**

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OVERFALL SPILLWAYS**

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On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions—supplying water and power.

The text of this publication was prepared prior to adoption of the new name; all references to the Bureau of Reclamation or any derivative thereof are to be considered synonymous with the Water and Power Resources Service.

ENGINEERING MONOGRAPHS are published in limited editions for the technical staff of the Bureau of Reclamation and interested technical circles in government and private agencies. Their purpose is to record developments, innovations, and progress in the engineering and scientific techniques and practices that are employed in the planning, design, construction, and operation of Reclamation structures and equipment. Copies may be obtained from the Bureau of Reclamation, Denver Federal Center, Denver, Colorado, and Washington, D. C.

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INTRODUCTION

In 1948, the Bureau of Reclamation published Bulletin 3, Part VI, a Boulder Canyon Project Final Report, titled "Studies of Crests for Overfall Dams." This work was based on an extensive series of experiments on weirs with sharp crests for the purpose of defining the natural nappe shapes, both upper and lower, and determining the resulting discharge coefficients. These natural nappe shapes and discharge coefficients, recorded in the above bulletin, are termed "datum profiles" and "datum discharge coefficients" to distinguish them from those which will be presented in this monograph.

By datum shape is meant the shape of spillway cross section which corresponds to or coincides with the natural (basic) profile of the lower nappe surface for the design discharge condition. This will be the smallest cross section, as well as the most efficient shape, on which no significant negative pressures will exist for the design discharge. For discharges less than the design discharge, pressures on the face will be greater than atmospheric and discharge coefficients will be smaller than for the design discharge. For discharges greater than the design discharge, subatmospheric pressures will exist on the downstream face and discharge coefficients will be greater. The terms "datum shape" and "datum coefficient" represent a definite basis from which the designer may work, even though he may deviate from the datum shape in any particular design.

Datum shapes are included in this monograph for the purpose of comparison. It is suggested that the reader become familiar

with Bulletin 3, Part VI, of Boulder Canyon Project Final Reports, because much of the material in the monograph is supplementary to that in the bulletin.

Coefficient of discharge information is quite complete for the datum shapes. There is, however, much to be desired in the way of reliable data on coefficients of discharge for sections that differ from the datum shape.

The monograph deals with overfall spillway sections which differ from the datum shape. For lack of a better descriptive term, these are referred to as "irregular" shapes. Irregular shapes are the ones most likely to be encountered in practice. This is true for several reasons: (1) sufficient information for the design of datum shapes has not been available until recently; (2) where radial or vertical slide gates are used for regulation, it has been customary to shape the overfall section to fit the trajectory issuing from a small gate opening. This gives a broader section than the datum shape. Such practice is losing ground in favor of the datum shapes; and (3) where drum gates are provided on a spillway, a broad overfall section is usually required for structural reasons. For these reasons, true datum shapes are not as common in practice as the irregular shapes.

This monograph was written for the express purpose of providing the designer with experimental information by which he may determine, with a fair degree of accuracy, the coefficient of discharge at any head for irregular overfall spillway shapes.

DEFINITIONS OF SYMBOLS

The symbols will be the same as those used in Bulletin 3, Part VI, Boulder Canyon Project Final Reports. Symbols appearing in this monograph are as follows: (See Figure 1.)

H_0 total head for which spillway section was designed (including velocity head of approach)

H any other total head measured above high point of crest

h_a velocity head of approach

$P + E$ the average depth of approach channel

C_0 coefficient of discharge for the designed head, H_0

C coefficient of discharge for other than the designed head, H

C_M coefficient of discharge obtained from model at designed head

C_D coefficient of discharge for corresponding datum shape at designed head

h_d drop headwater to tail water elevation (low dams)

d tail water depth (low dams)

EXTENT OF INVESTIGATION

The Hydraulic Laboratory of the Bureau of Reclamation has been continuously experimenting, collecting, and compiling data on flow over both high and low overfall dams since its inception. It is now felt that sufficient information has been accumulated to warrant a compilation of coefficient data for spillways of irregular shape (those differing from the datum shape).

The information stems from model studies performed on spillways of dams designed by the Bureau during the past 20 years, model studies of spillways for several Tennessee Valley Authority dams, and model studies of spillways for three dams for the Government of India, performed at the Colorado A and M College at Fort Collins. Coefficients of discharge are included for high dams with free overfall, as well as for the shallow earth dam type of spillway where free flow is suppressed by insufficient getaway downstream.

Considering the information collectively, it will be found that, for high dams, Figures

2 through 5 pertain to spillways having vertical upstream faces; Figures 6 through 12 represent spillways with sloping upstream faces; and Figures 13 through 18 are for spillways having offsets, or corbels, on the upstream face. Figures 21 through 31 apply to earth dam spillways. The charts on the foregoing figures will be referred to as stock shapes. All charts are plotted to the same scale, an ordinate or abscissa value of 1.0 on any chart being equal to 100 of the smallest divisions on a 60 engineer's scale. This scale will be referred to hereinafter as the "standard scale."

The discussion first shows how to obtain the coefficient of discharge, at the designed head, for a spillway section in question. This is done for both the free overfall spillway and for one in which free overfall is suppressed (earth dam type). Then it is shown how the curve showing coefficient of discharge for various heads may be established from a single point. Examples are included to illustrate the procedures.

SPILLWAYS WITH FREE OVERFALL

Method of Procedure

The solid lines on Figure 2 represent two spillway shapes with free overfall which were tested by means of hydraulic models. These cross sectional shapes and the ones that follow are plotted to the same scale, which is dimensionless (both X and Y distances are divided by the total designed head, H_0). By this method of plotting, similar shapes with similar heads will coincide. The coefficient of discharge for each shape at its respective designed head (as determined from a model) is listed opposite the symbol C_M . The model coefficient for the Wheeler Dam, C_M is 3.99 while the much broader section for the Hoover Dam shows C_M is 3.58, Figure 2.

For the purpose of comparison, datum shapes, computed for the same heads and approach conditions, are also plotted on Figure 2 for the two spillway sections and are identified by the heavy dash lines. The datum coefficient C_D is 3.96 for the Wheeler Dam and 3.93 for the Hoover Dam. In making a comparison of this kind, it is necessary to match either the upstream faces of the actual and datum sections or their axes. Neither method is altogether satisfactory. In this comparison of free overfall shapes, however, the axes of the actual and datum shapes are made

to coincide so that the crest, or high point, of each shape constitutes a common point. The values $H_0 \div (P + E)$ on Figure 2 indicate the ratio of the total designed head to the approach depth.

The method consists simply of comparing an irregular shape in question with a corresponding, or closely corresponding, shape for which the coefficient of discharge is known. Considering the number of variables involved, the procedure is perhaps the best that can be devised at the present stage of the study. The accuracy obtainable is well within the limit of practical design.

Dimensions and details have been omitted from the charts as it was desired to present these in as simplified a form as possible. Prototype dimensions can be found in the Appendix by observing the reference on each chart. For example, the prototype dimensions of the Wheeler Dam Spillway Section, shown on Figure 2, can be found in Figure 1A of the Appendix.

Application of Results

The most effective way to explain the use of the charts on Figures 2 through 18 is to present an example.

Example 1: Spillway with free overfall

From the elevation and section of the American Falls Dam spillway, shown on Figure 19, determine the coefficient of discharge for the designed head of 11.3 feet. This spillway has never been rated, so this serves as a practical application as well as an example.

First, all dimensions of the crest profile, Figure 19, are divided by the total designed head which is 11.3 feet. The resulting dimensionless values are then plotted, to the standard scale, as shown on Figure 20A, but transparent paper should be used so that this shape may be readily superimposed on the stock shapes. As the shape in question has a vertical upstream face, it should be superimposed on the charts of Figures 2 through 5 until a satisfactory comparison is obtained with an actual shape or a datum shape--either will do. It is not necessary to match the axes in this process, rather it is much more important to match the upstream and downstream faces simultaneously.

The American Falls Spillway profile compares favorably with the profile for the Keswick Dam Spillway, Figure 4. The model coefficient C_M for the Keswick Spillway is 3.50.

As the experimental work was performed in several laboratories by different personnel over a period of years, inconsistencies in the results may be expected. Therefore, it is desirable to obtain as many comparisons as possible. By checking with Figures 2 through 18, it is found that the shape for the Davis Dam Spillway (Figure 15) also compares favorably with the American Falls shape. The model coefficient for the Davis shape is 3.59. It was previously demonstrated in the Boulder Bulletin 3, that spillways with straight vertical offsets in the upstream face perform very much the same as though the upstream face of the offset was continuous. The Davis Dam Spillway can, therefore, also be considered. From the two comparisons, the coefficient of discharge for the total designed head of 11.3 feet will be chosen as 3.55 for the American Falls Dam Spillway.

It is evident that a large variety of stock shapes is necessary in a compilation of this type. It is to be understood that the charts do not include all spillway shapes that may be encountered in practice; however, they do include the majority of cross sections used by the larger design offices.

SPILLWAYS WITH OVERFALL SUPPRESSED

Method of Procedure

Earth dam spillways usually follow closely the downstream profile of the dam; consequently, they are not steep and the approach depth is shallow. In the case of the free overfall dam sections just presented, the only important factor affecting the coefficient of discharge was the shape of the overfall section. Three factors, however, affect the coefficient of discharge on the earth dam type of spillway: (1) the depth of the approach channel; (2) the shape of the overflow or gate section; and (3) the elevation of the floor of the channel or chute immediately downstream from the gate section. The individual effects of each factor are evaluated in Boulder Canyon Bulletin 3, Part VI, but when combinations of the three factors must be considered simultaneously, the following procedure is the best for determining over-all discharge coefficients.

From Figure 21, it can be seen that the efficiency of three flat spillways shown thereon can be increased considerably by making use of a small ogee, or overflow crest, at the gate section and providing a free getaway downstream. The solid lines represent the

actual shapes of the spillways, while the dash lines are datum shapes. The method of plotting is different than for the previous free overfall shapes, principally to illustrate a point. For flat spillways, the shapes are plotted with a common vertical axis, but due to the better efficiency of the datum shape, its crest has been elevated to show that each spillway section will pass the same discharge for the maximum reservoir elevations. Should the more efficient datum shapes on Figure 21 be used, it would be possible to either reduce the height of the gates or, by holding the crests at their original elevations, shorten the width of the gate sections. The datum shapes, as drawn, will have atmospheric pressure over the face of the overfalls proper for the maximum discharge condition, while the chute floor downstream has been dropped to an elevation where it will have no effect on the discharge coefficient. In actual design, the layout of the gate section will depend on existing topography and other practical considerations as well as efficiency.

Figures 21 through 31 all represent earth dam spillways in which the discharge is retarded by the position of the chute floor immediately downstream from the gate section

and by the shallow depth of approach. These are dimensionless plottings in which the X and Y distances are related to the total design head. The scale is the same as in the previous charts. The prototype dimensions for these spillways can be found in the Appendix by means of the reference number under each chart.

Application of Results

Example 2: Spillway with overfall suppressed

Determine the discharge coefficient for the Kachess Dam Spillway, shown on Figure 32, for the total designed head of 8.0 feet. This spillway has not been rated previously.

The procedure to follow to obtain the coefficient of discharge for this flat profile spillway is the same as described in Example 1.

The dimensions of the overfall portion should be divided by the designed head, and the spillway in question should be drawn to the standard scale on a piece of transparent paper. A dimensionless plot of the Kachess Spillway is shown on Figure 33A. The transparent plot is superimposed on the stock shapes of Figures 21 through 31 until one, or preferably more than one, shape is found to be comparable. Either actual or datum shapes

may be used, as the discharge coefficients are listed for each. It will be found that a reasonable agreement exists between the Kachess Spillway shape and the following:

<u>Dam spillway</u>	<u>Figure</u>	<u>Coefficient of discharge</u>
Boca	25	3.50
Scofield	25	3.44
Unity	26	3.48
Deer Creek	28	3.46
Keyhole	29	3.56
Average		3.49

It will, therefore, be assumed that the coefficient of discharge for the Kachess Spillway for the total design head of 8.0 feet is 3.50.

When using the stock shapes of Figures 21 through 31, it should be kept in mind that the flat portion of a chute immediately downstream from a gate section can have a more marked effect on the discharge coefficient than the approach depth upstream. Thus, it is more important to match the chute floor immediately downstream from the overfall than the approach floor upstream. The general effect of the position of the chute floor on the coefficient of discharge can be readily observed from Figure 44 of the Boulder Canyon Bulletin 3, previously mentioned.

DETERMINATION OF COEFFICIENT OF DISCHARGE CURVE

Spillways With Free Overfall

The coefficient of discharge curves obtained from the free overfall models of Figures 2 through 18 are shown plotted in a dimensionless form on Figure 34. The ordinate, H/H_0 is the ratio of any total head to the total designed head, while the abscissa, C/C_0 is the ratio of the corresponding coefficient of discharge for the head H to the coefficient for the designed head, H_0 . A single curve was drawn through the mass of points, as there was no logical order to those that scattered. The scattering is therefore considered experimental error. When one considers the number of models involved, varying in size and scale, and considers that the testing was performed in several laboratories by a number of individuals, the agreement is all that can be expected.

Spillways With Overfall Suppressed

The same method of plotting was used for the earth dam spillways of Figures 21 through

31 and these results are shown on Figure 35. It was again possible to draw a single curve through the points. The curve is steeper than the free overfall curve and does not show as much variation in the value of C/C_0 . As the coefficient of discharge is usually lower for this type of spillway, it cannot vary as much as for the free overflow. It can be noted that the curve doubles back for heads greater than 1.2 times the design head and the maximum value of C/C_0 is slightly more than 1.0. This is explained by the fact that, as the head increases over one of these flat spillways, the floor effect downstream becomes more pronounced. The result is a decrease in the coefficient of discharge.

As there is no particular order to the points on either Figures 34 or 35, there is no basis for drawing intermediate curves between the two lines already established. Thus, it appears that the discharge coefficients considered in this monograph fall into one type or the other. In attempting to classify a spill-

way as to type, it may be helpful to observe the values of

$$\frac{H_o \text{ and } (h_d + d) \text{ actual}}{P + E} \frac{(h_d + d) \text{ experimental}}{\text{tabulated in Figures 34 and 35.}}$$

Application of Results

Example 3: Coefficient curve for free overfall spillway

Determine the entire head versus coefficient of discharge curve for the American Falls Dam Spillway from the one point obtained in Example 1, where $H_o = 11.3$ feet and $C_o = 3.55$.

Values of C/C_o for corresponding values of H/H_o are read from the curve on Figure

34. These values are tabulated as shown in Table 1A. With H_o and C_o known, values of H and C are computed. The resulting head versus coefficient of discharge curve is plotted on Figure 20B.

Example 4: Coefficient curve for spillway with overfall suppressed

Determine the complete head versus coefficient of discharge curve for the Kachess Dam Spillway from the one point determined in Example 2, where $C_o = 3.50$ for the designed head of 8.0 feet.

The procedure is the same as for Example 3 except that in this case the H/H_o and C/C_o values were obtained from Figure 35. The computation is tabulated in Table 1B and the resulting head-coefficient of discharge curve is shown on Figure 33B.

WATER SURFACE AND PRESSURE PROFILES

Where the experimental information was available, average water surfaces and pressures have been plotted on the charts of Figures 2 through 18 and 21 through 31. The water surface and pressure profiles are for the actual overfall shapes operating at their respective designed heads. Water surfaces for the datum shapes are not shown as these can be computed from Bulletin 3, Part VI, Boulder Canyon Project Final Reports. The water surface profiles will be found useful where the designer desires to locate gate pins or counterweights in close proximity to the maximum water surface. They may also be useful in determining the height of training walls. One should be reminded, however, that a water surface profile is not nearly as easy

to define as the profile of the lower nappe, because piers and entrance conditions can produce diagonal surface waves and fins of appreciable magnitude.

Pressures are more or less indicative of the coefficient of discharge. Generally speaking, if the pressures are appreciable and positive, over the overfall face, the coefficient of discharge will be low. Conversely, subatmospheric pressures generally distributed over the overfall face are conducive to high discharge coefficients. The pressures are plotted using the overfall face as a zero reference line, thus pressures above the line are positive and those falling below the line are negative.

Table 1

COEFFICIENT OF DISCHARGE COMPUTATIONS FOR EXAMPLES 3 AND 4

A	H/H _o	C/C _o	H	C
American Falls Dam Spillway H _o = 11.3 C _o = 3.55	0.2	0.843	2.26	3.00
	0.4	0.900	4.52	3.19
	0.6	0.940	6.79	3.33
	0.8	0.975	9.05	3.46
	1.0	1.000	11.30	3.55
	1.2	1.025	13.57	3.64
B	H/H _o	C/C _o	H	C
Kachess Dam Spillway H _o = 8.0 C _o = 3.50	0.2	0.910	1.60	3.18
	0.4	0.948	3.20	3.32
	0.6	0.974	4.80	3.41
	0.8	0.992	6.40	3.47
	1.0	1.000	8.00	3.50
	1.2	1.003	9.60	3.51

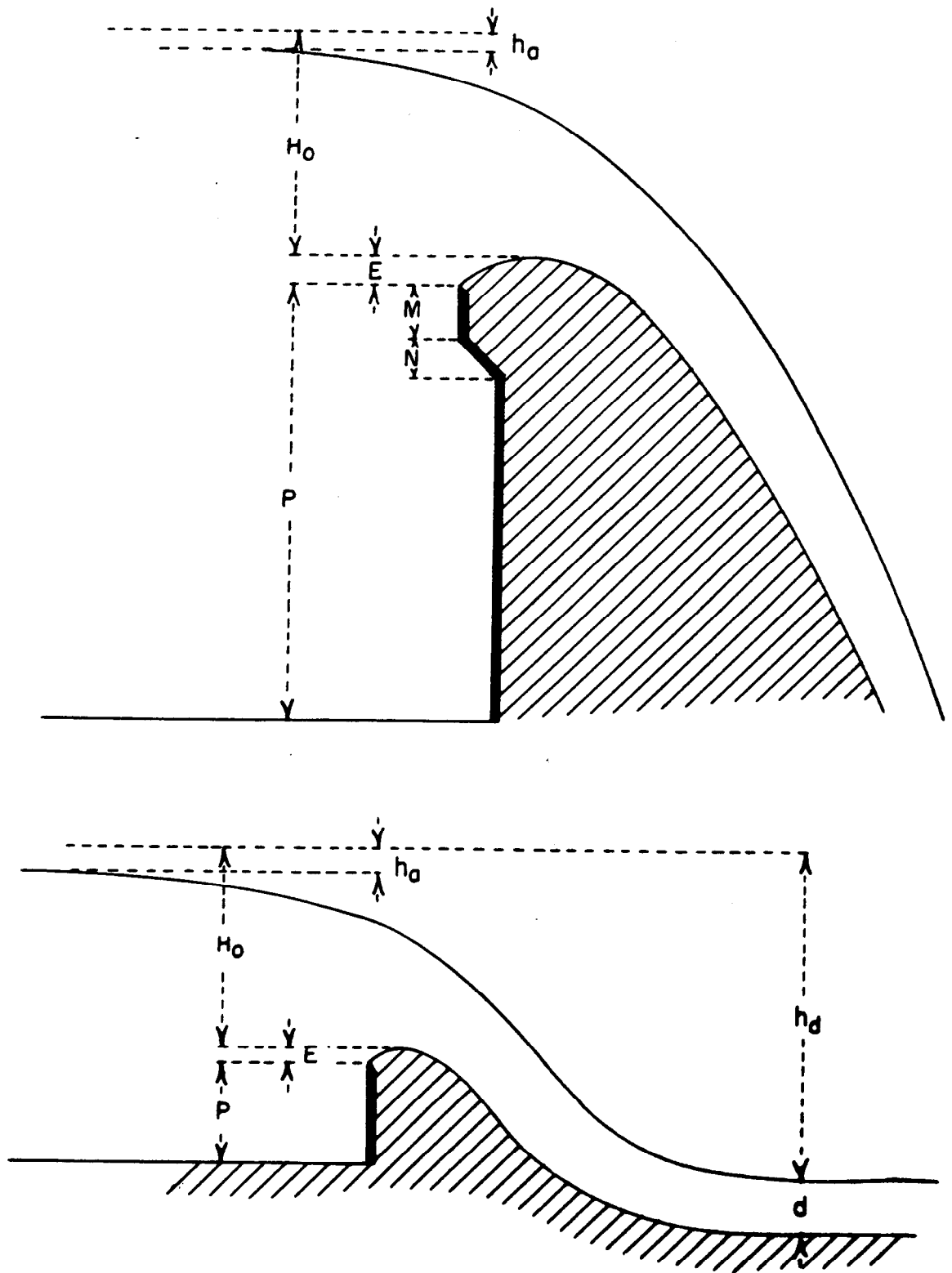


FIGURE 1 - Identification of symbols.

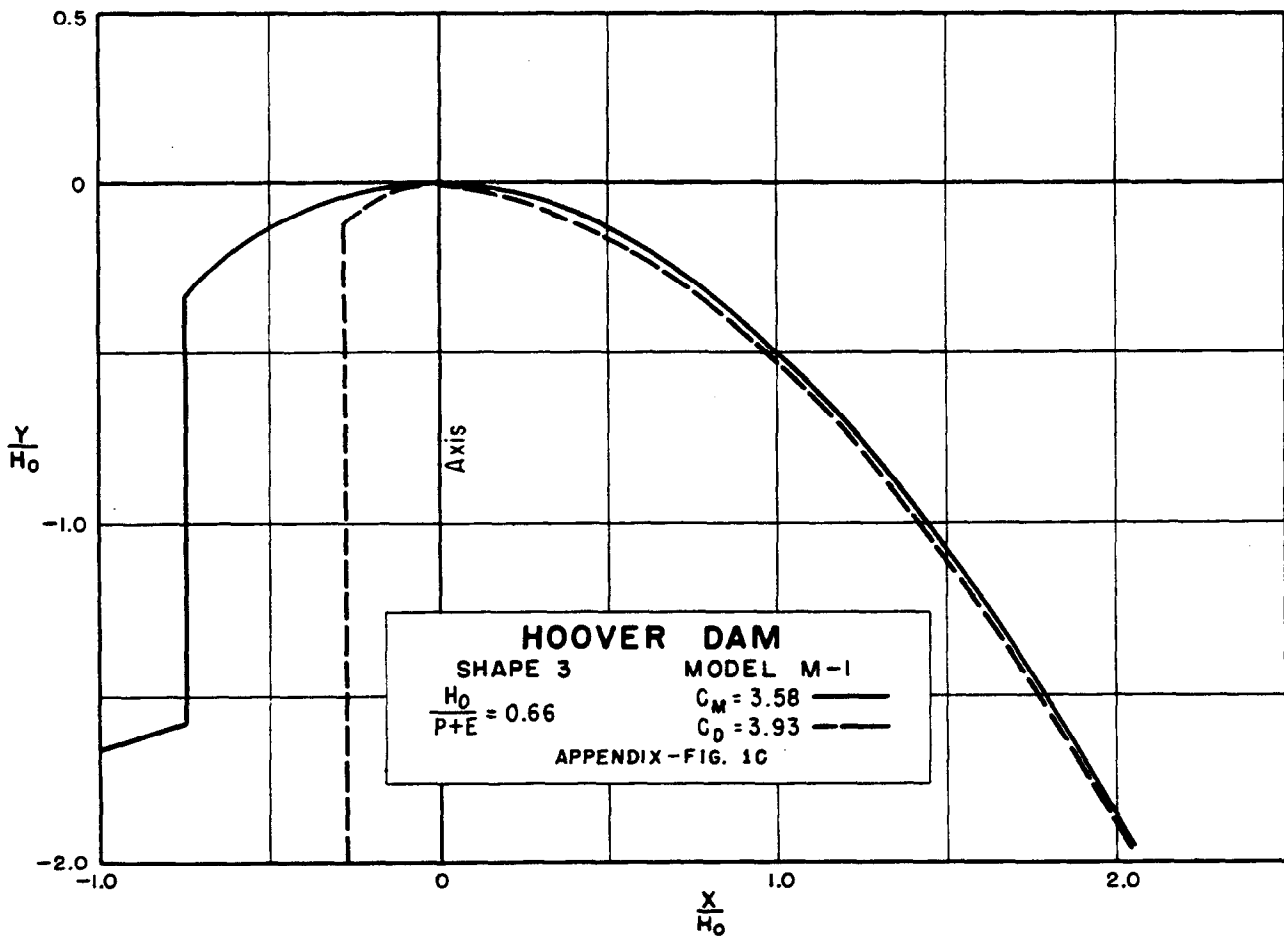
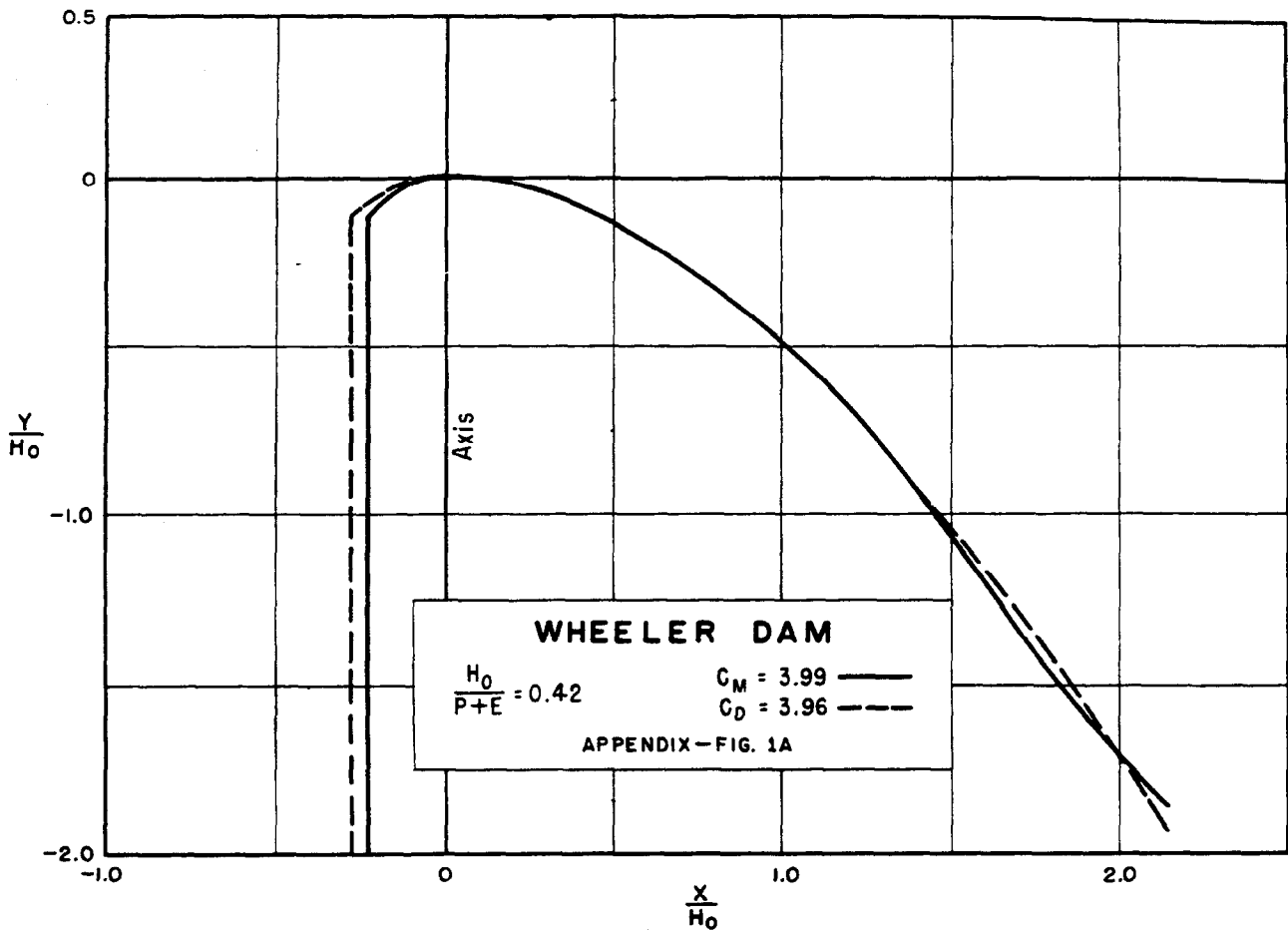


FIGURE 2 - Spillways with vertical upstream face.

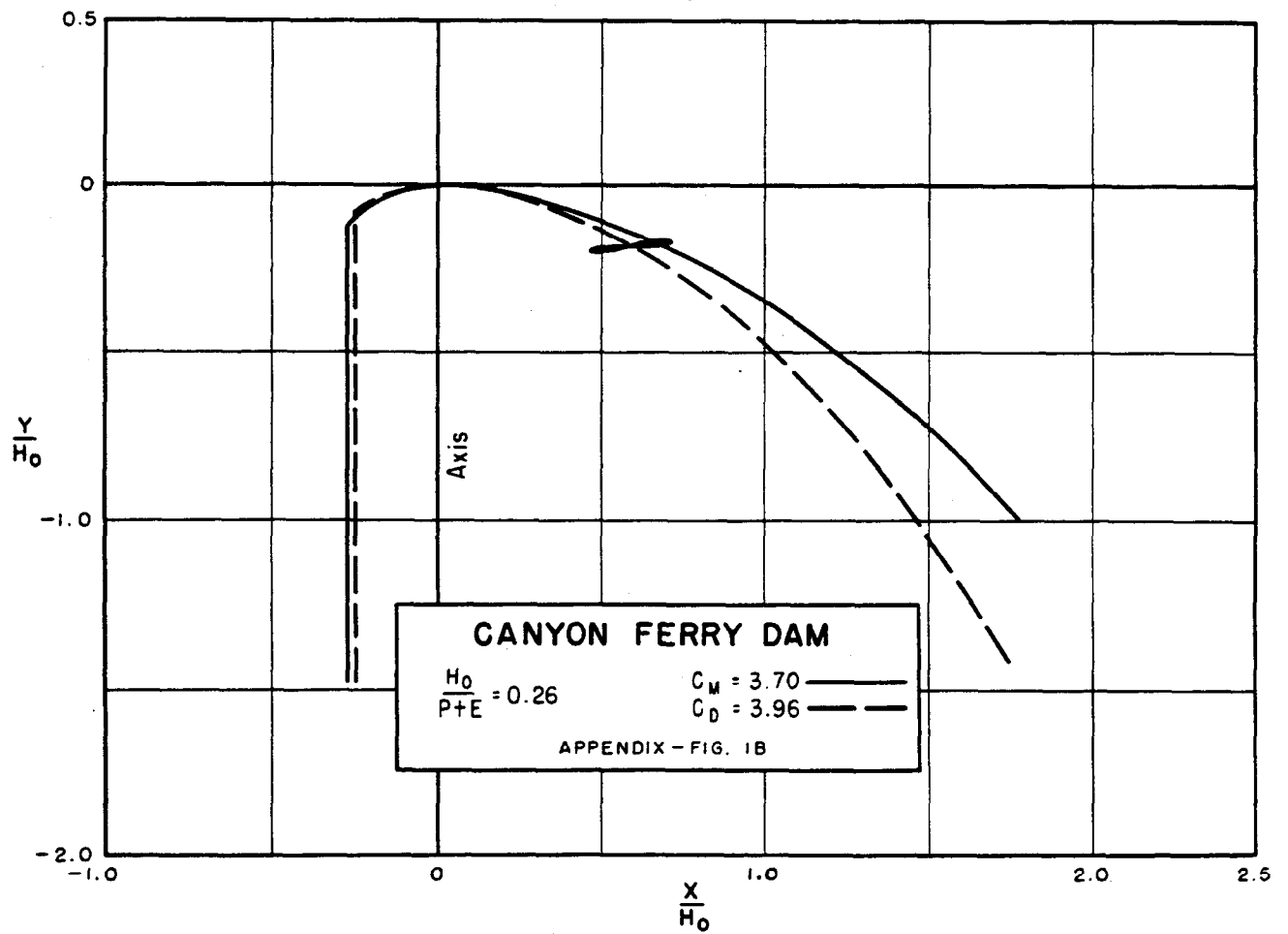
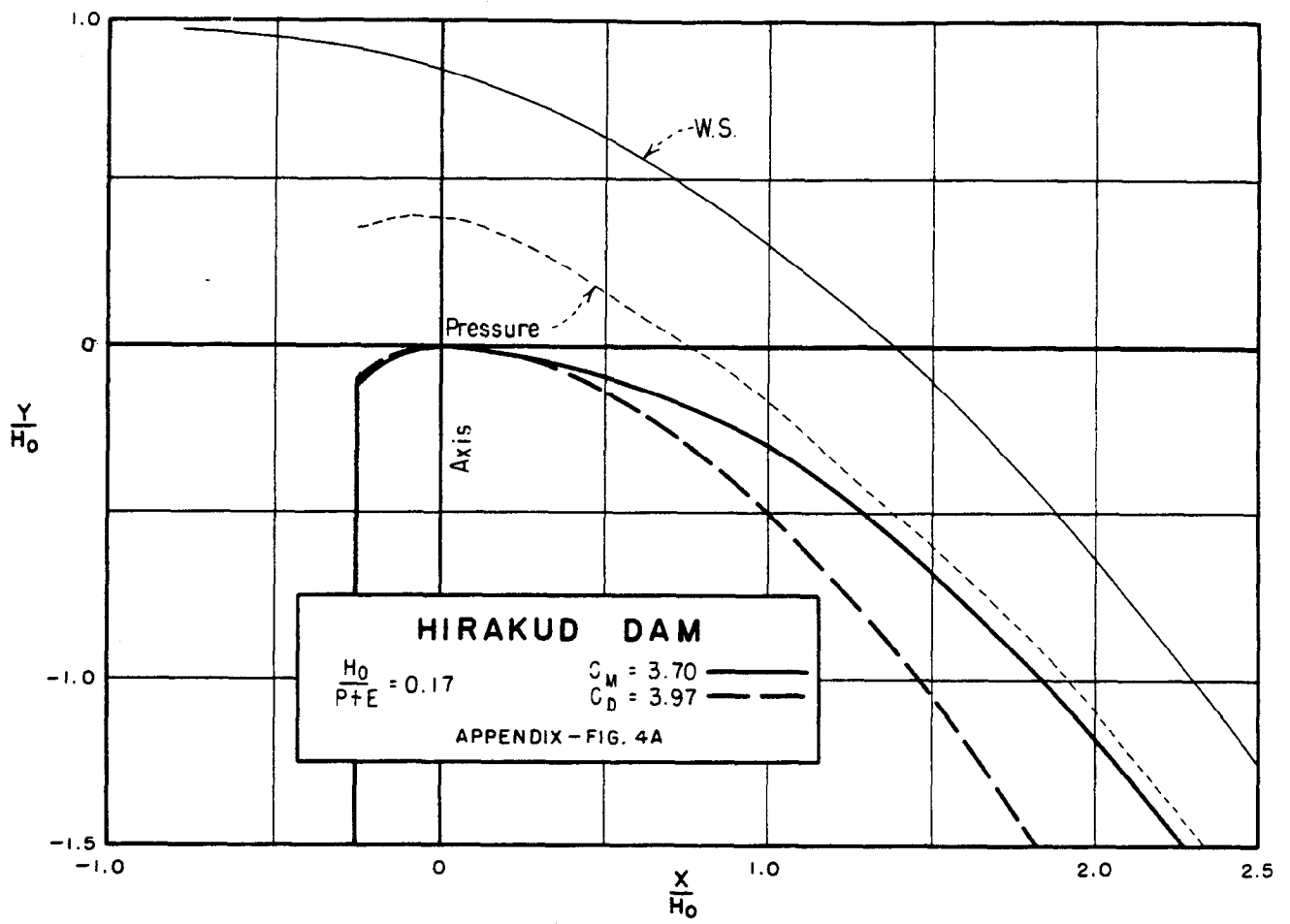


FIGURE 3 - Spillways with vertical upstream face.

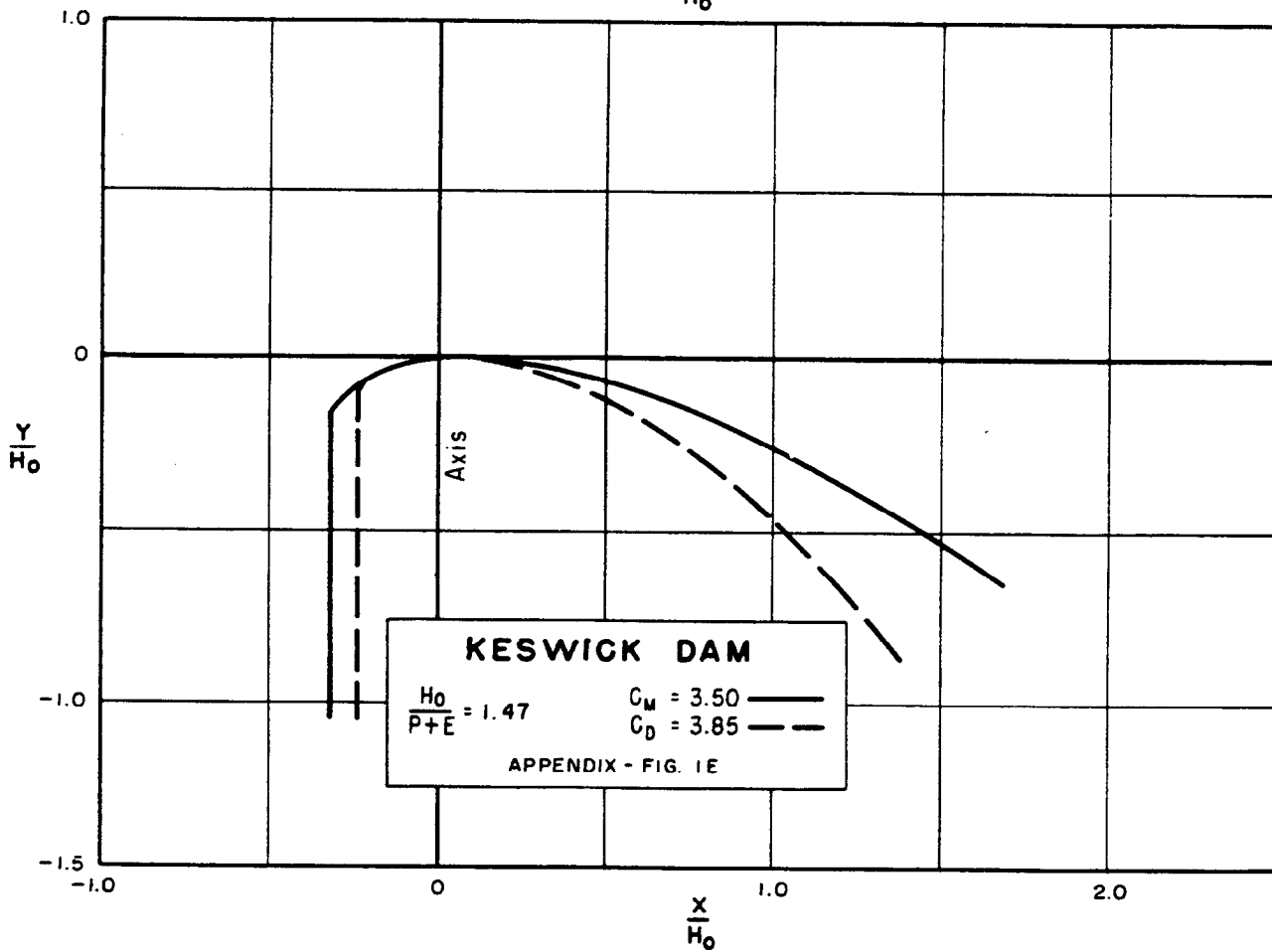
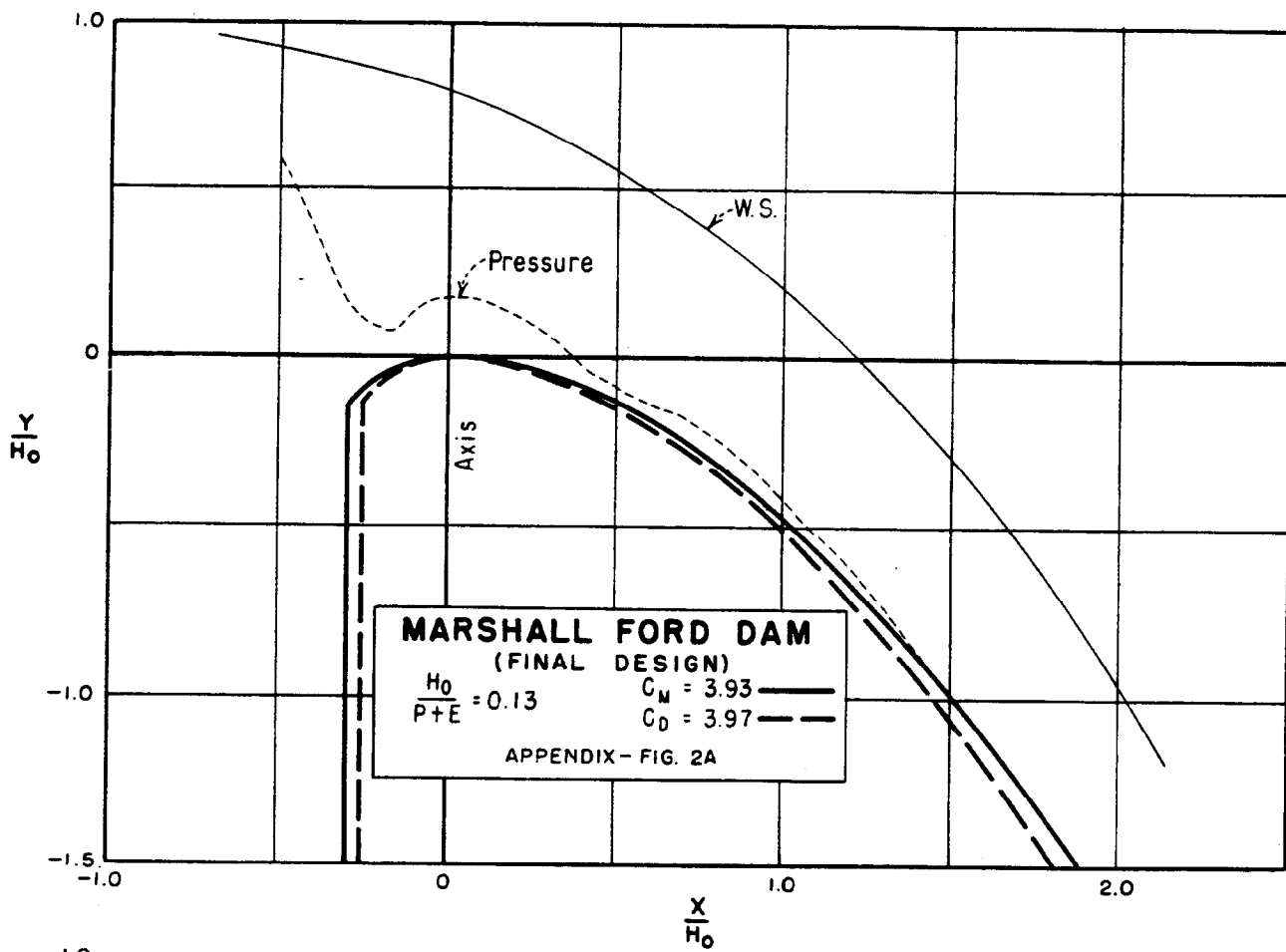


FIGURE 4 - Spillways with vertical upstream face.

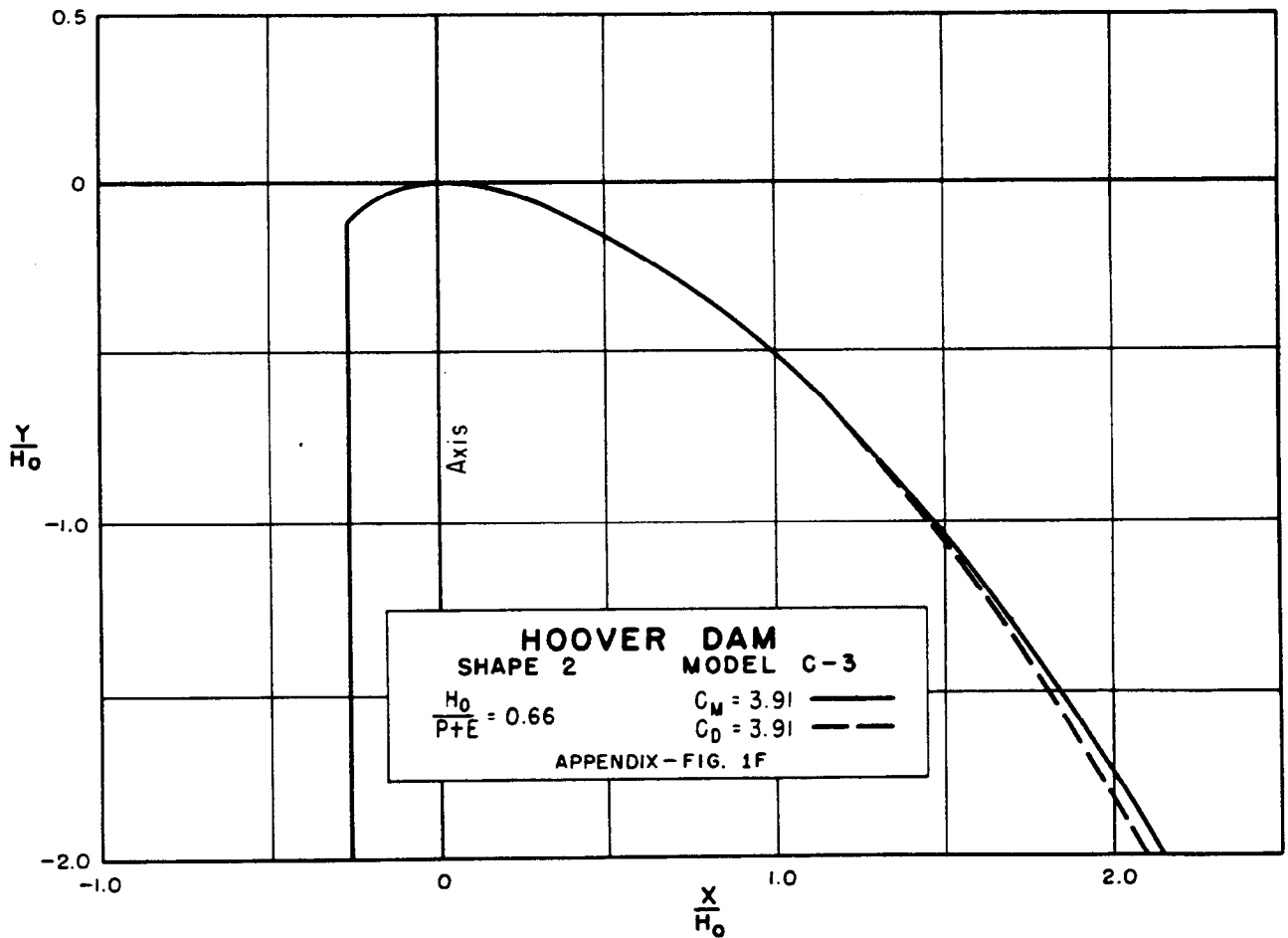
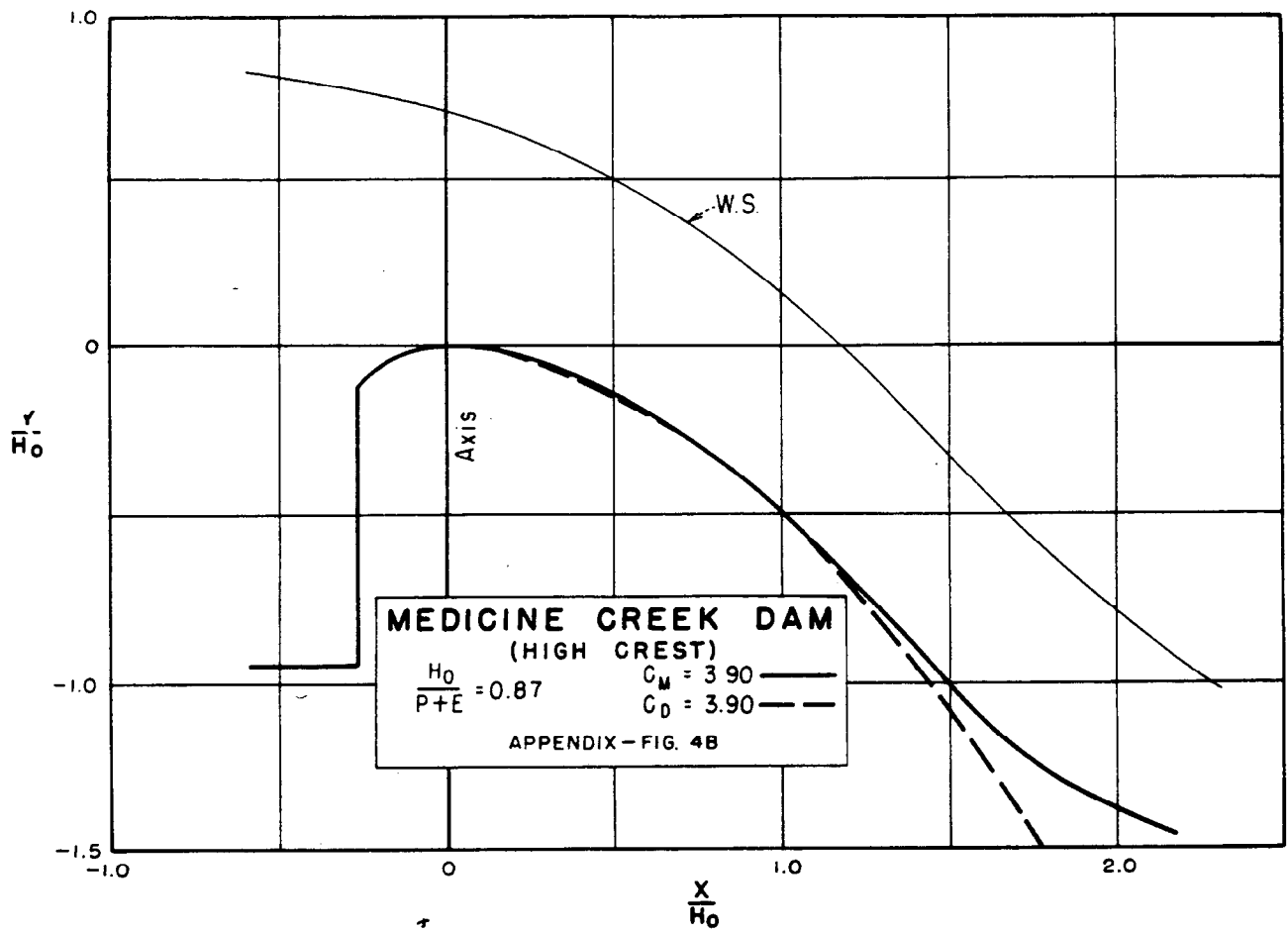


FIGURE 5 - Spillways with vertical upstream face.

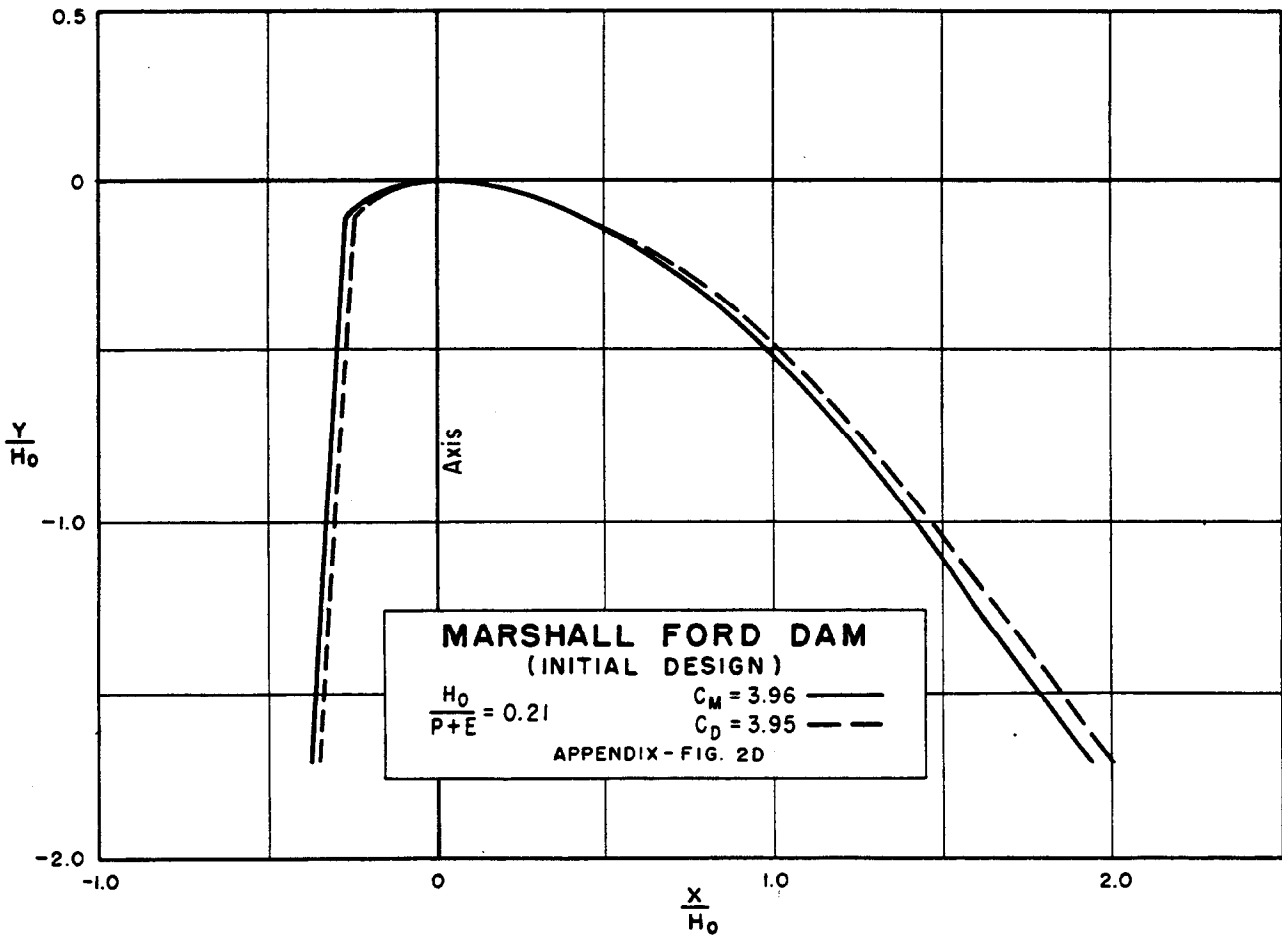
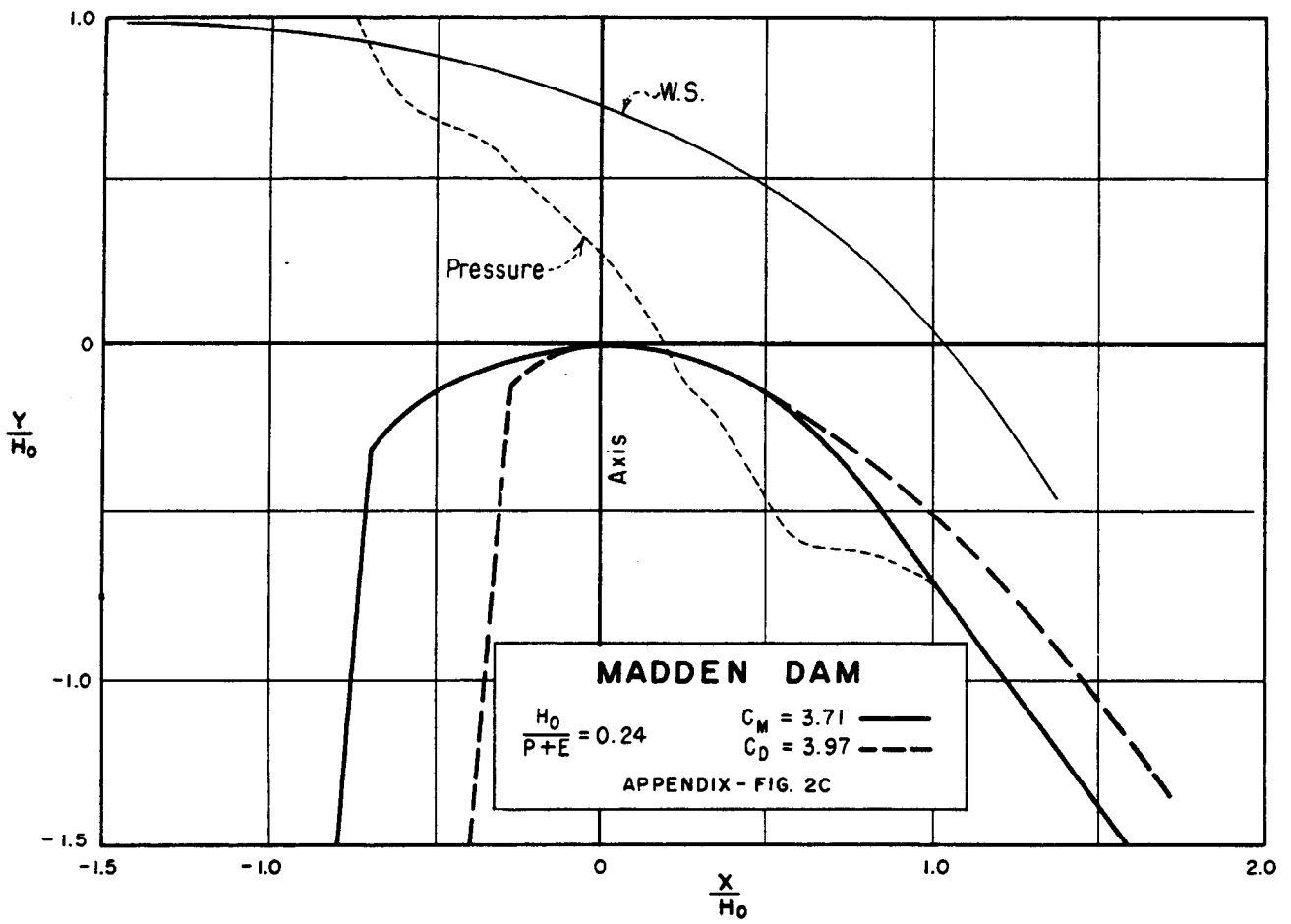


FIGURE 6 - Spillways with sloping upstream face.

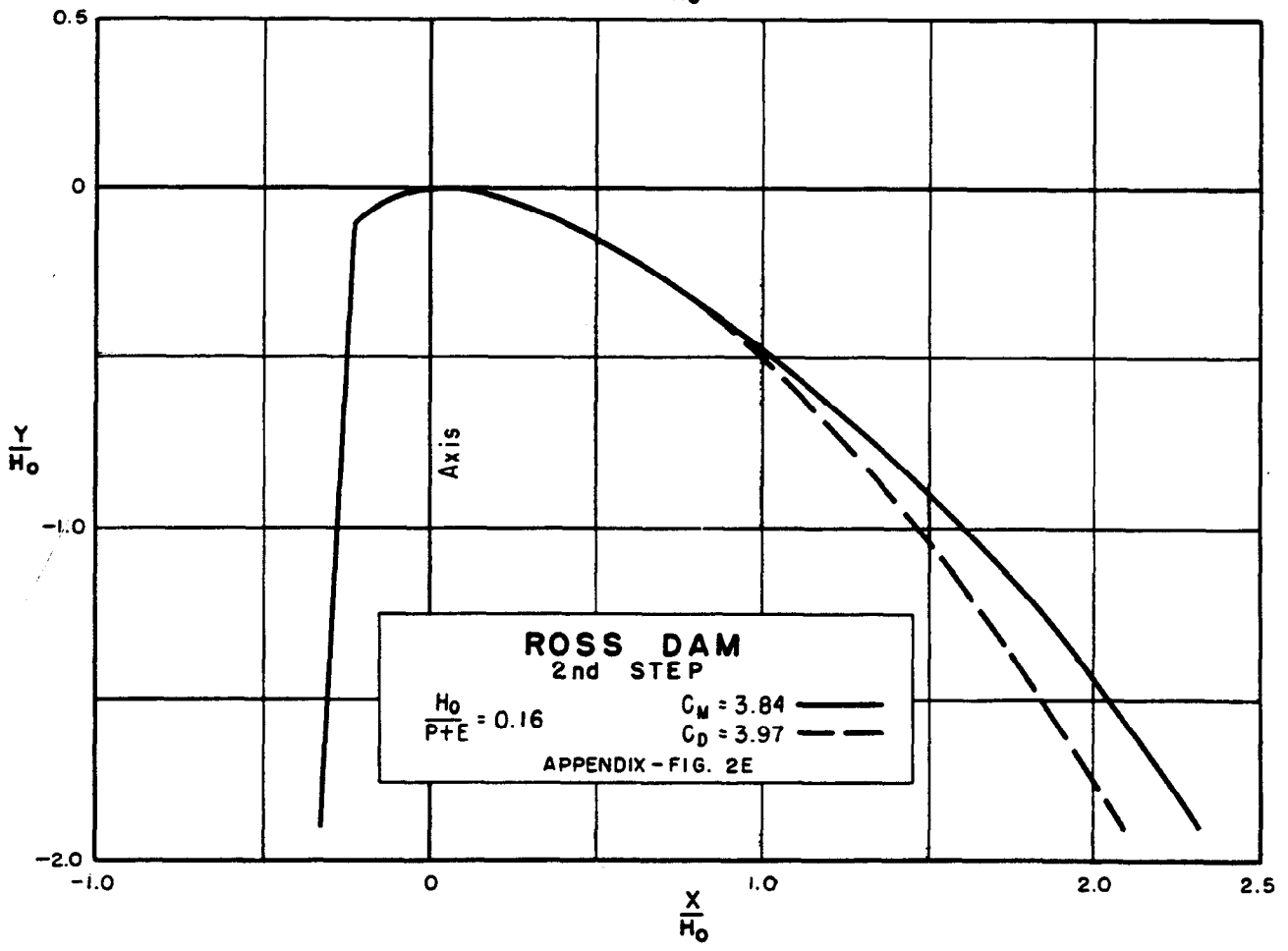
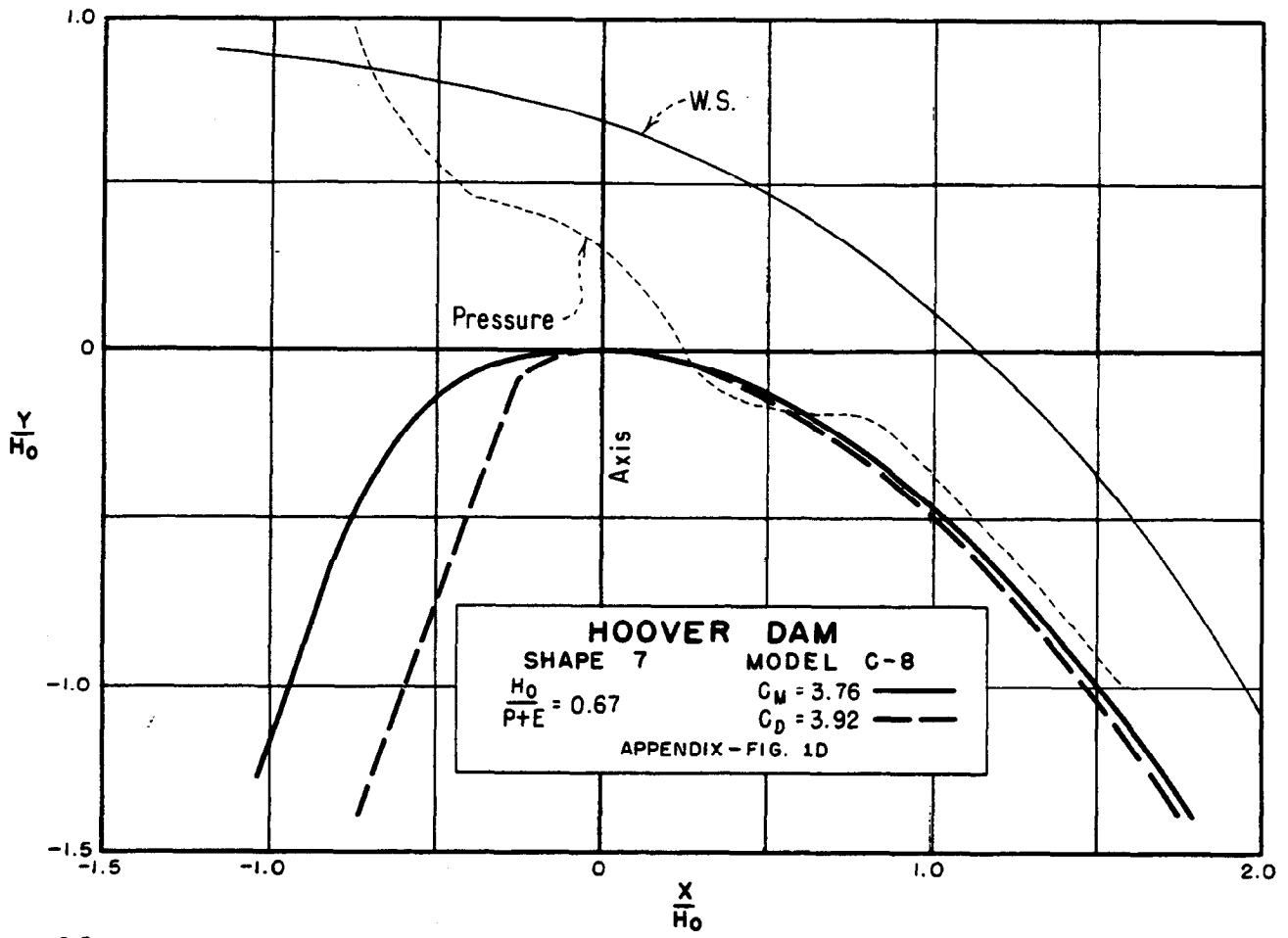


FIGURE 7 - Spillways with sloping upstream face.

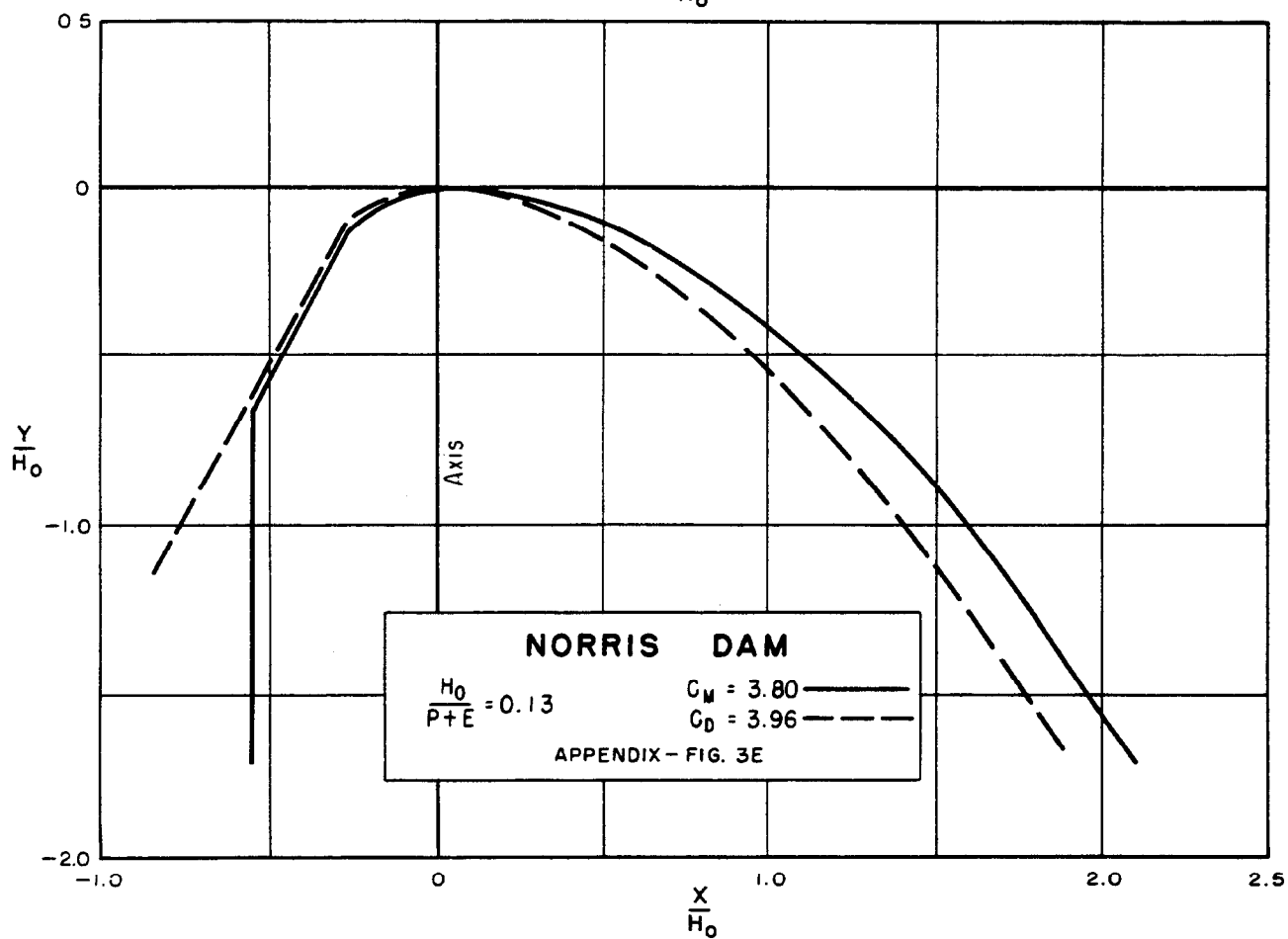
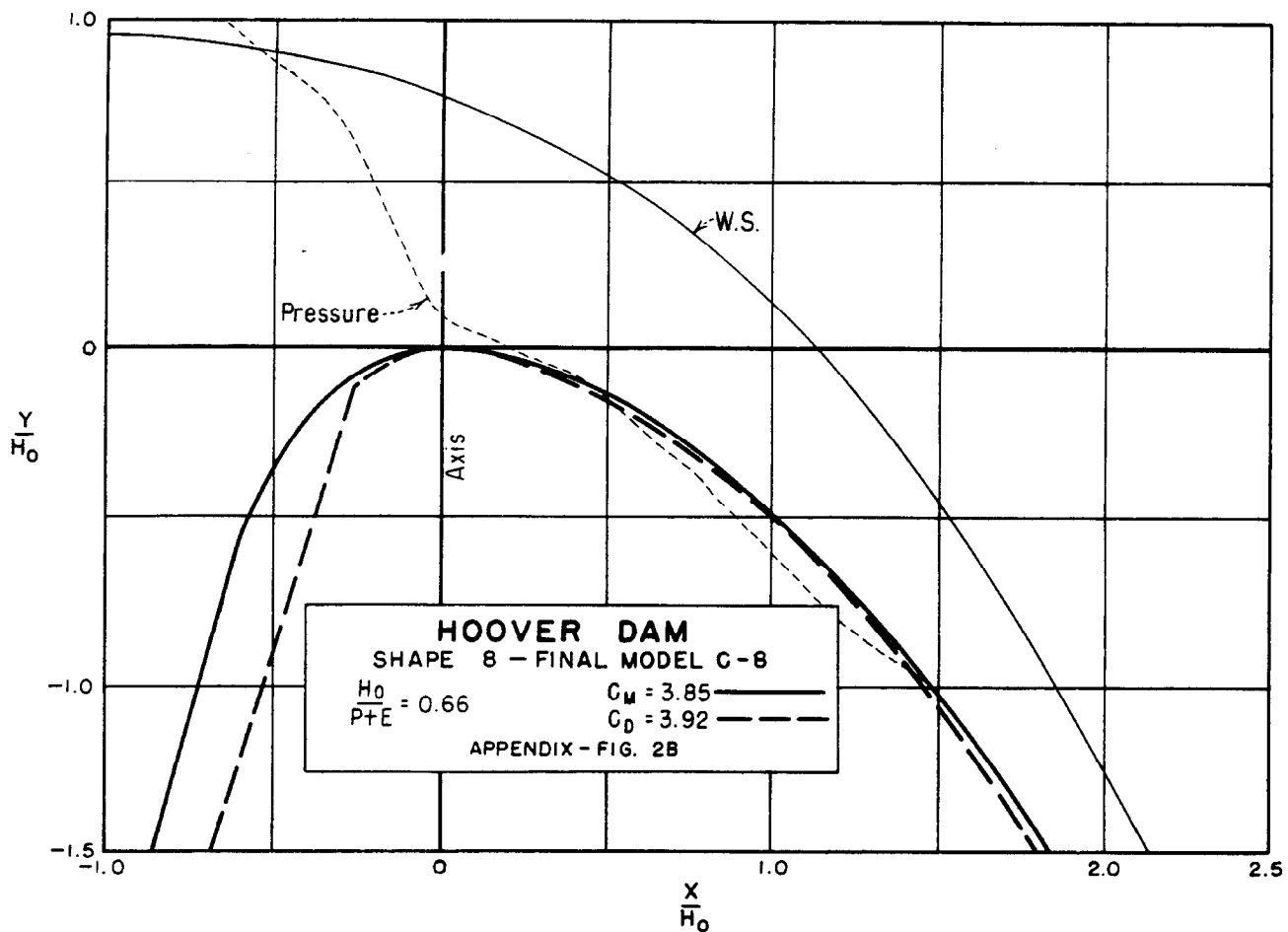


FIGURE 8 - Spillways with sloping upstream face.

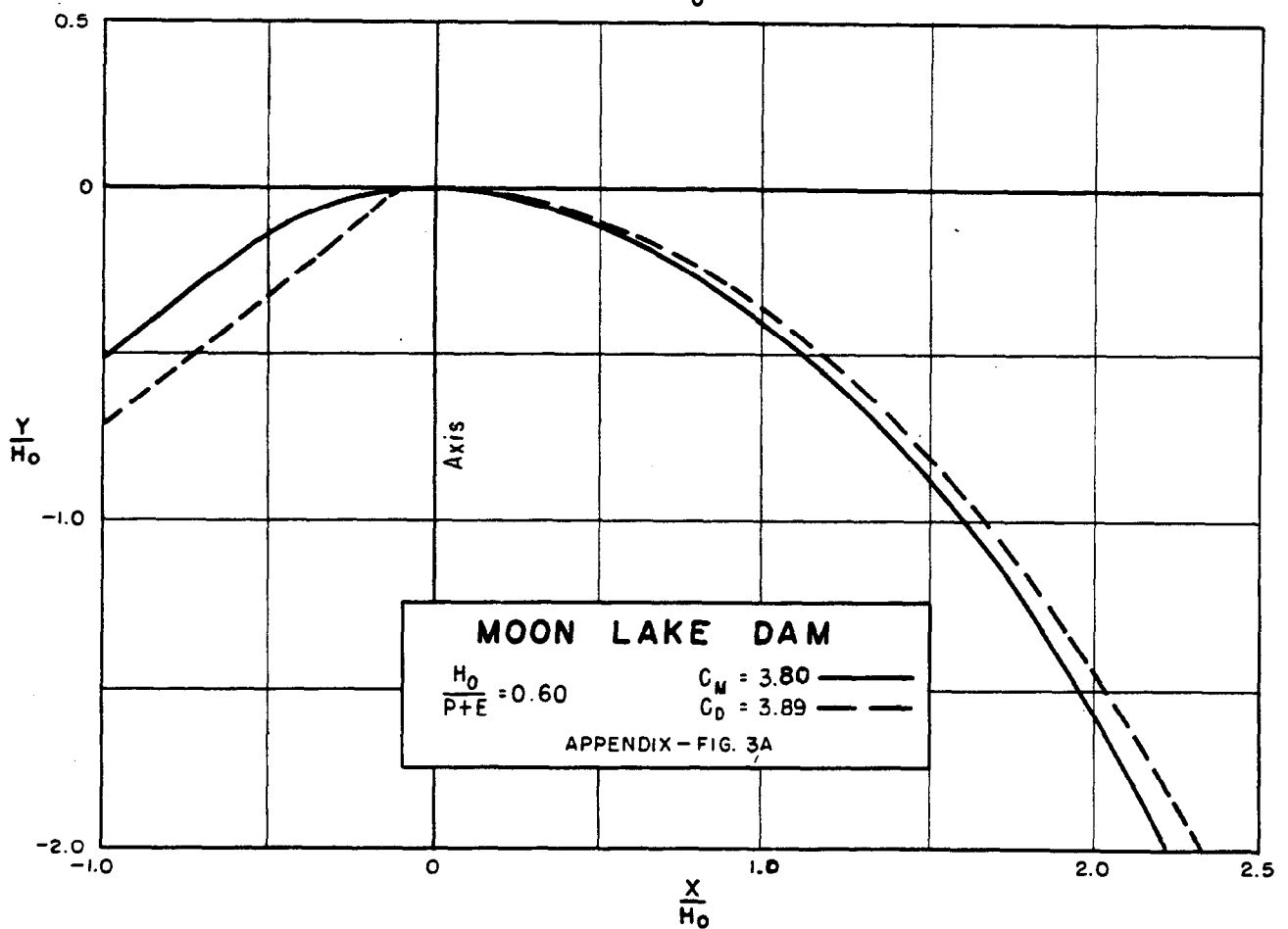
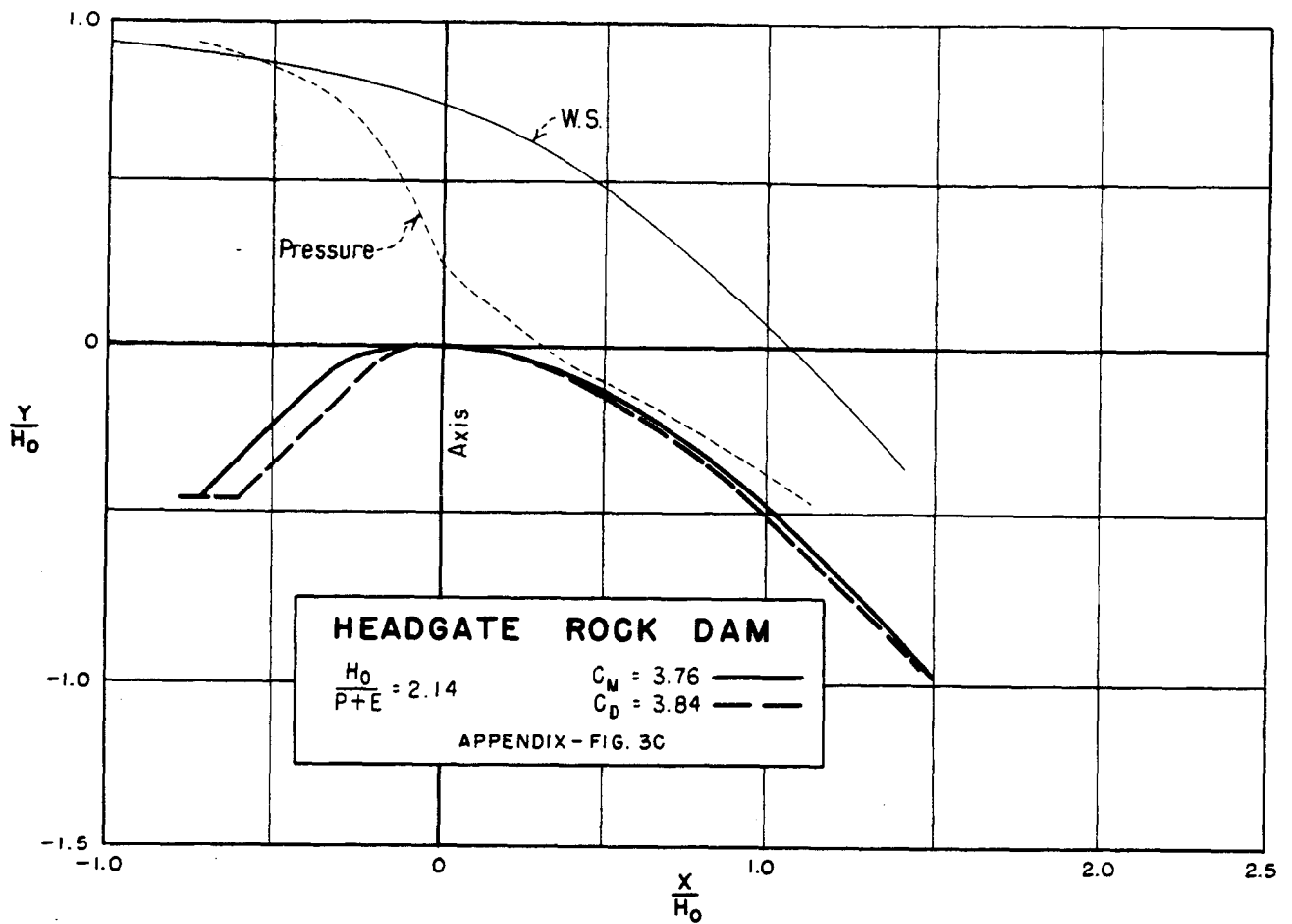


FIGURE 9 - Spillways with sloping upstream face.

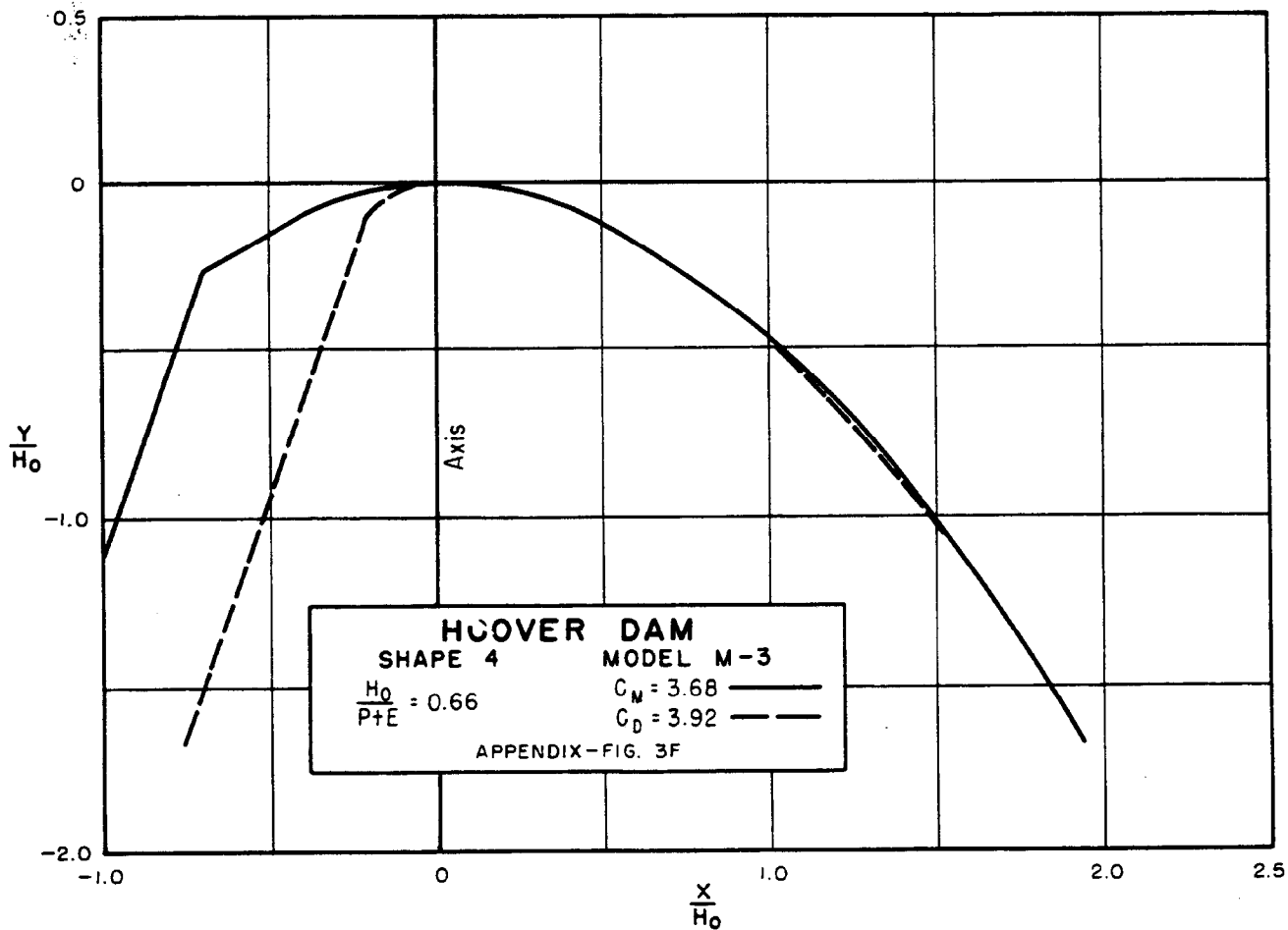
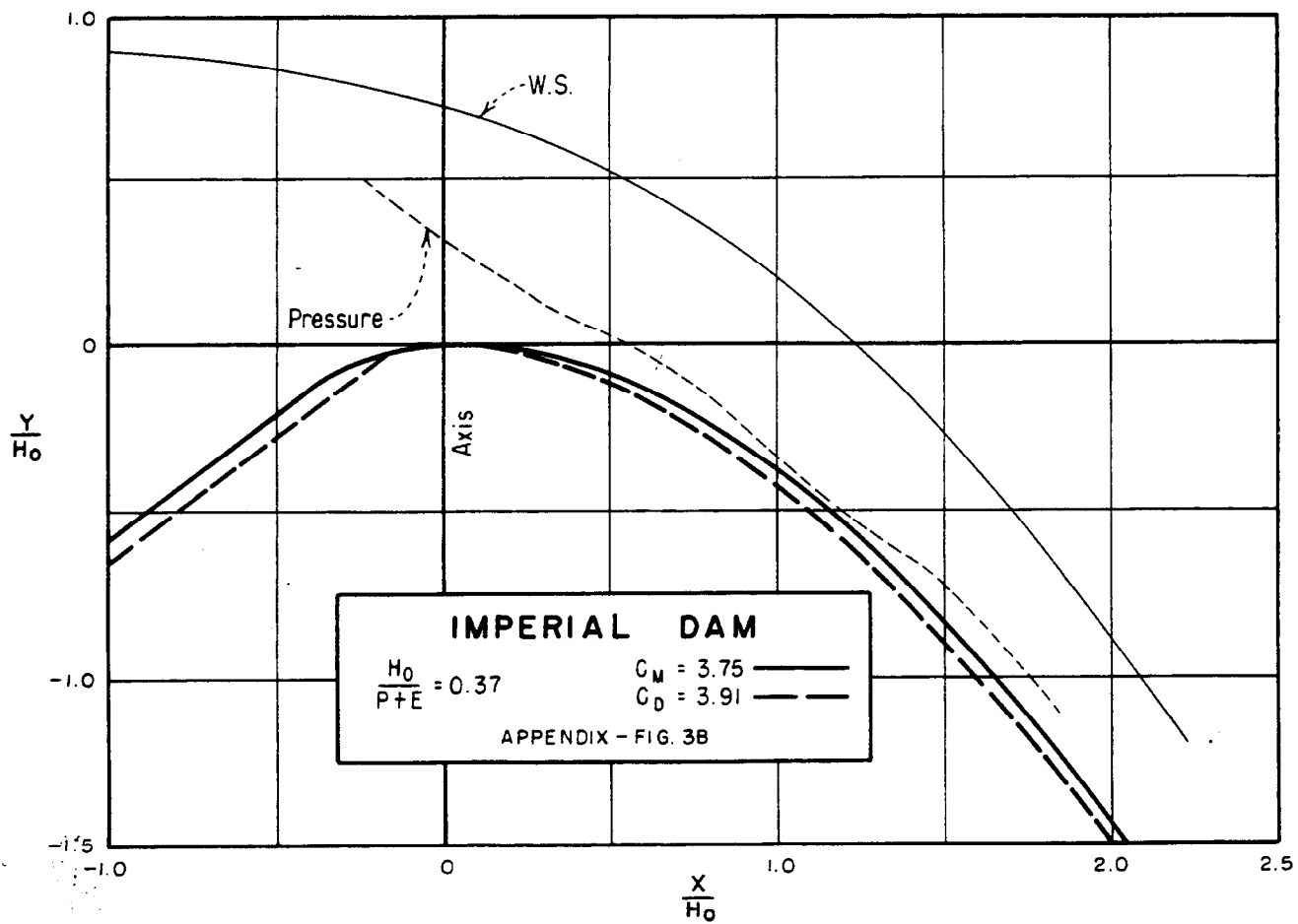


FIGURE 10 - Spillways with sloping upstream face.

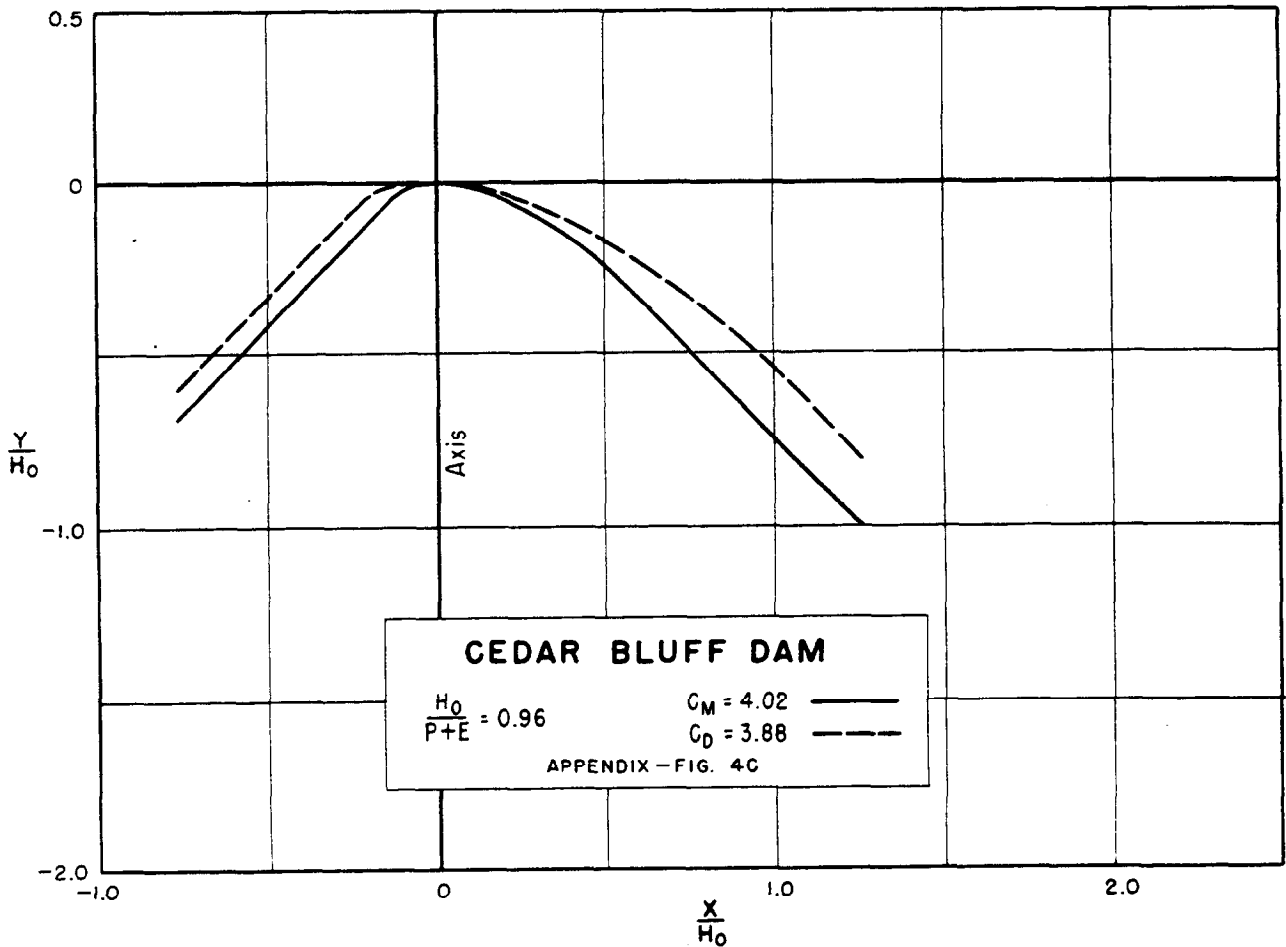
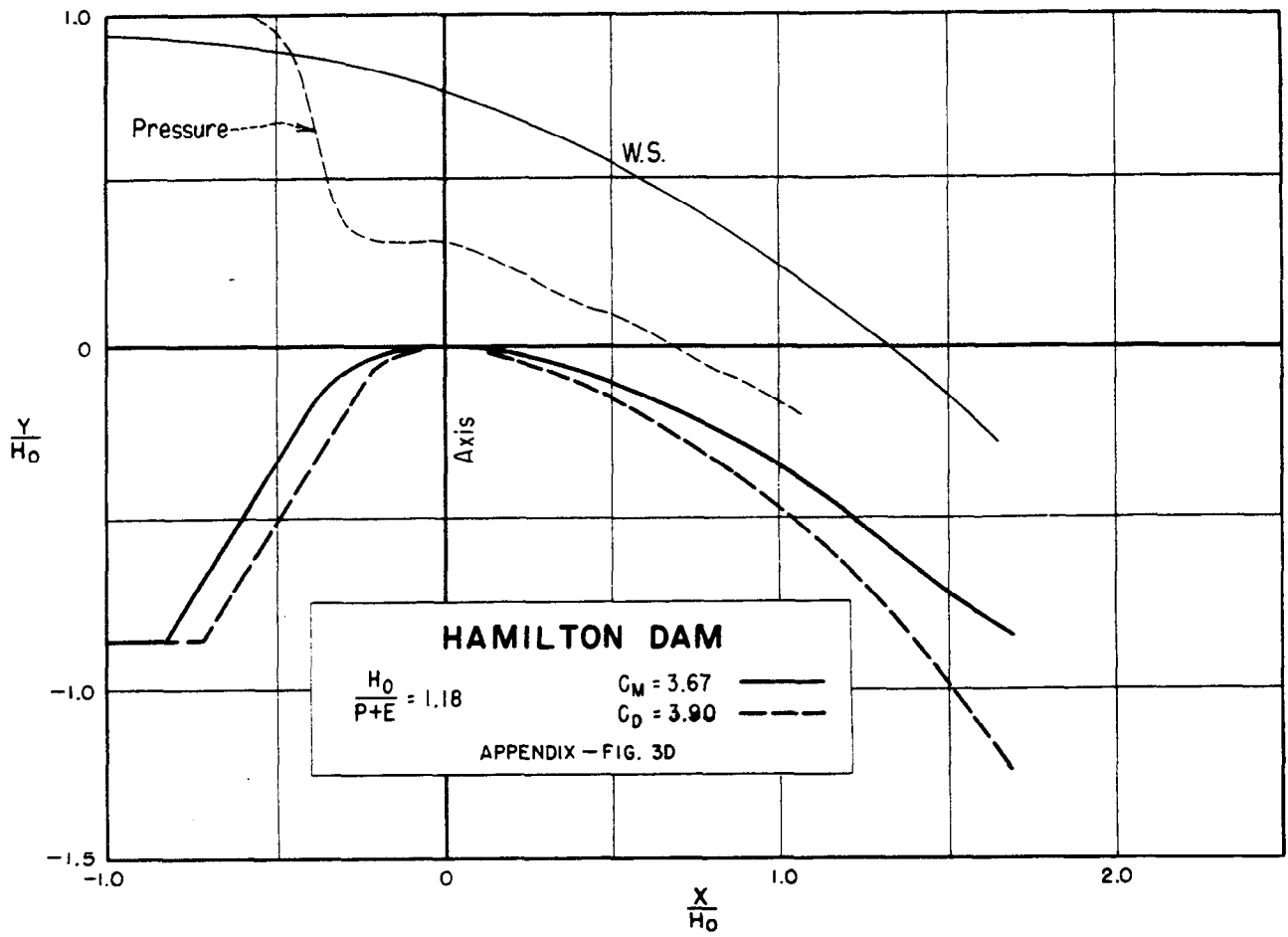


FIGURE 11 - Spillways with sloping upstream face.

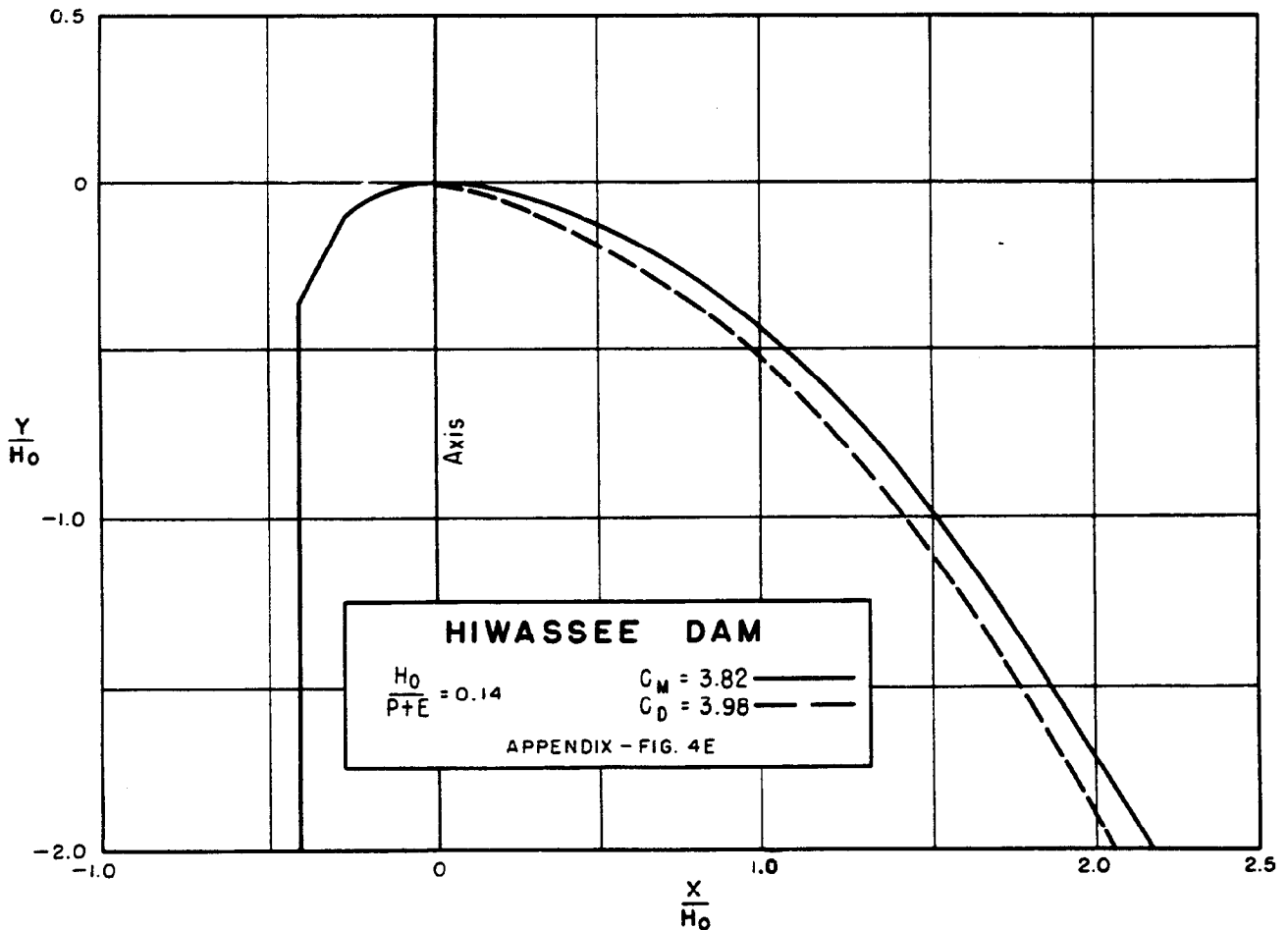
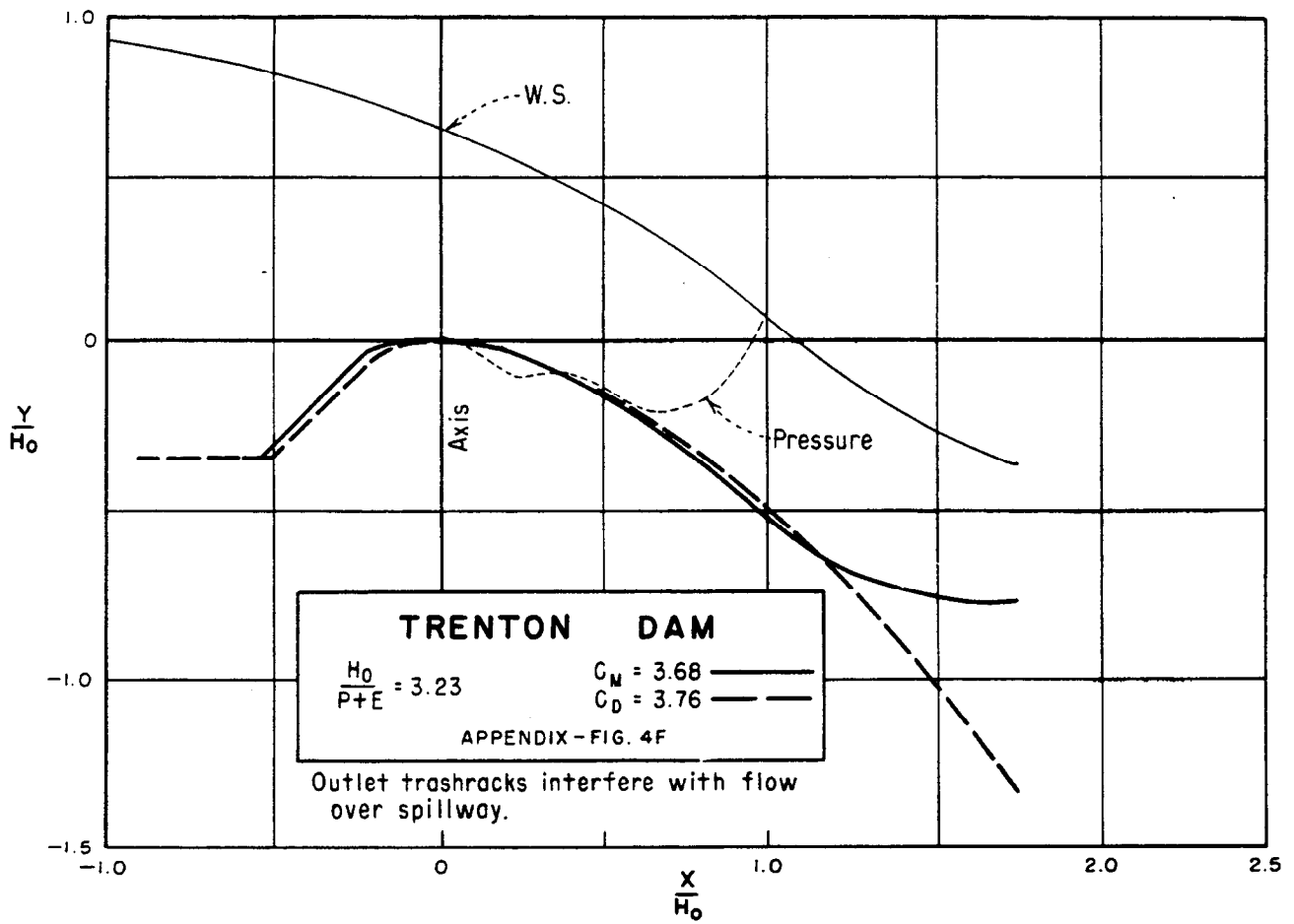


FIGURE 12 - Spillways with sloping upstream face.

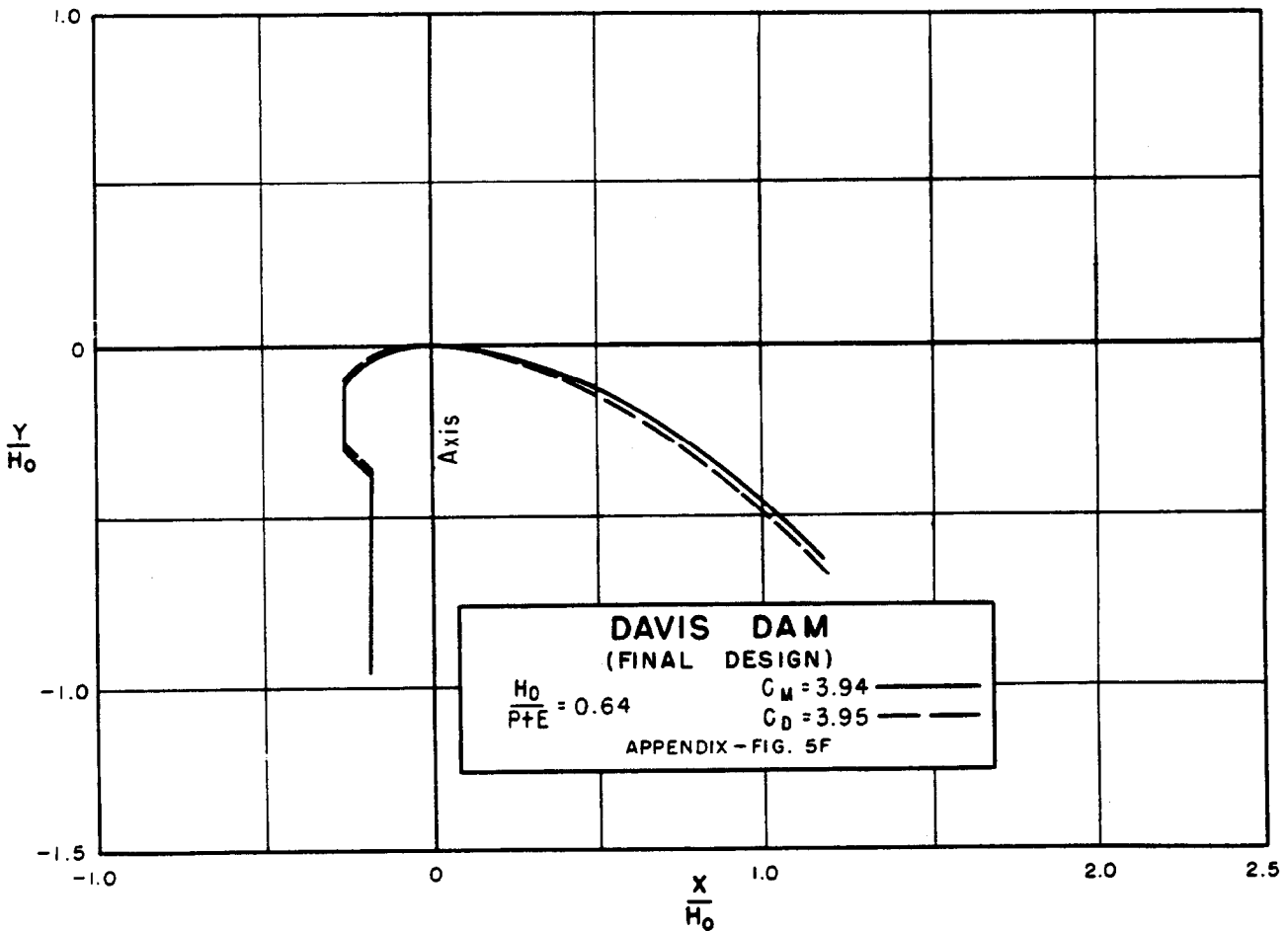
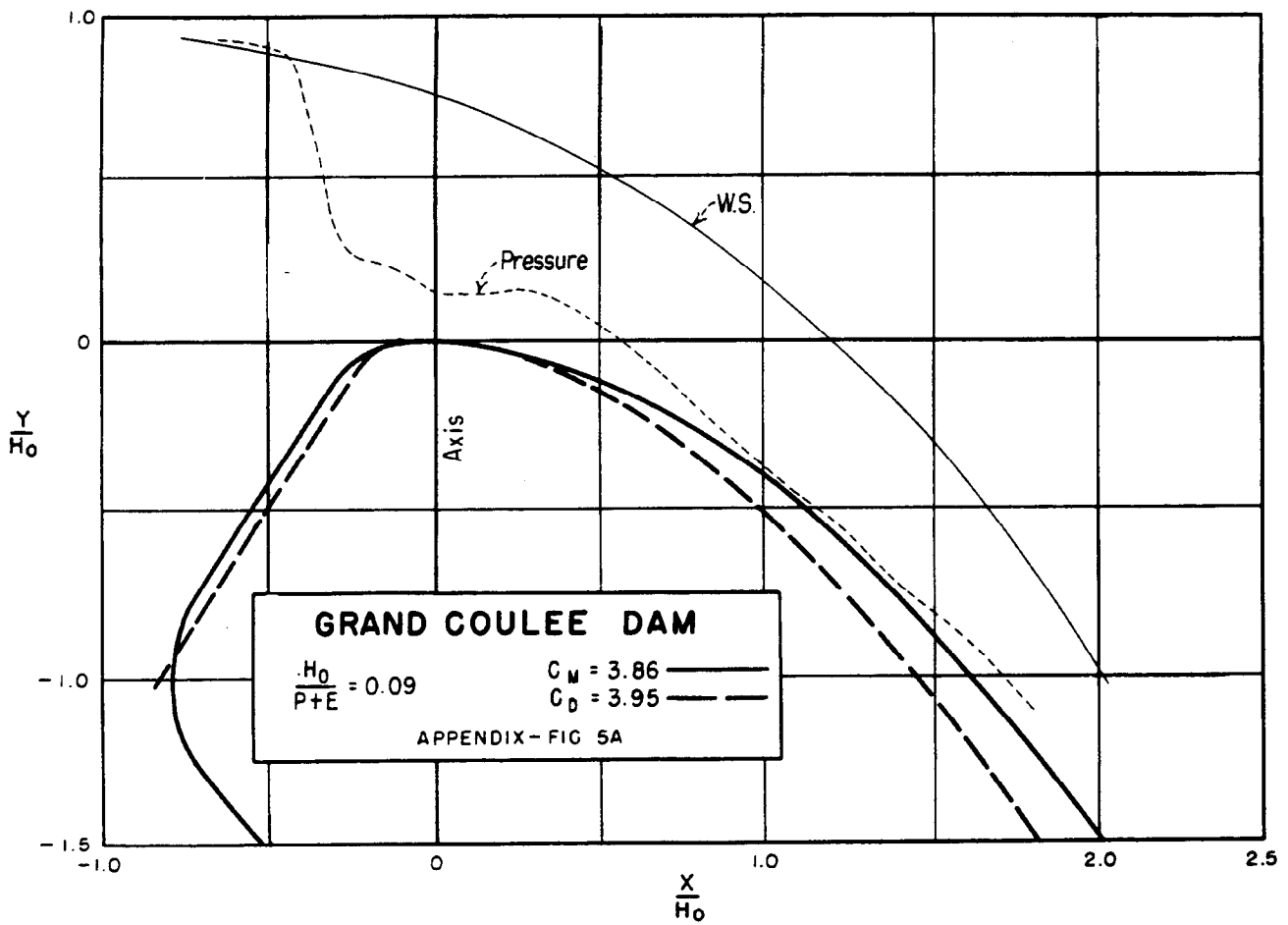


FIGURE 14 - Spillways with offset in upstream face.

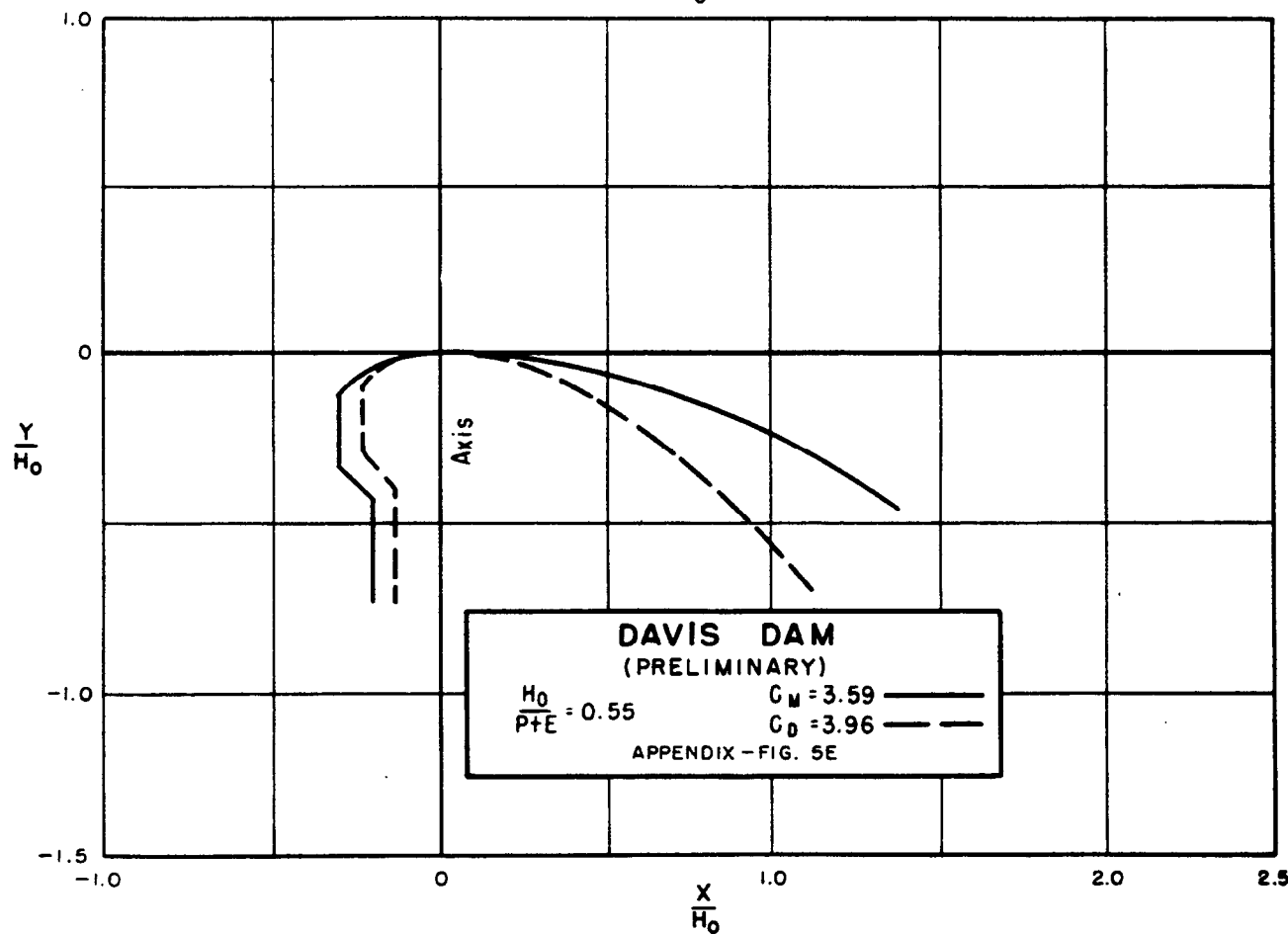
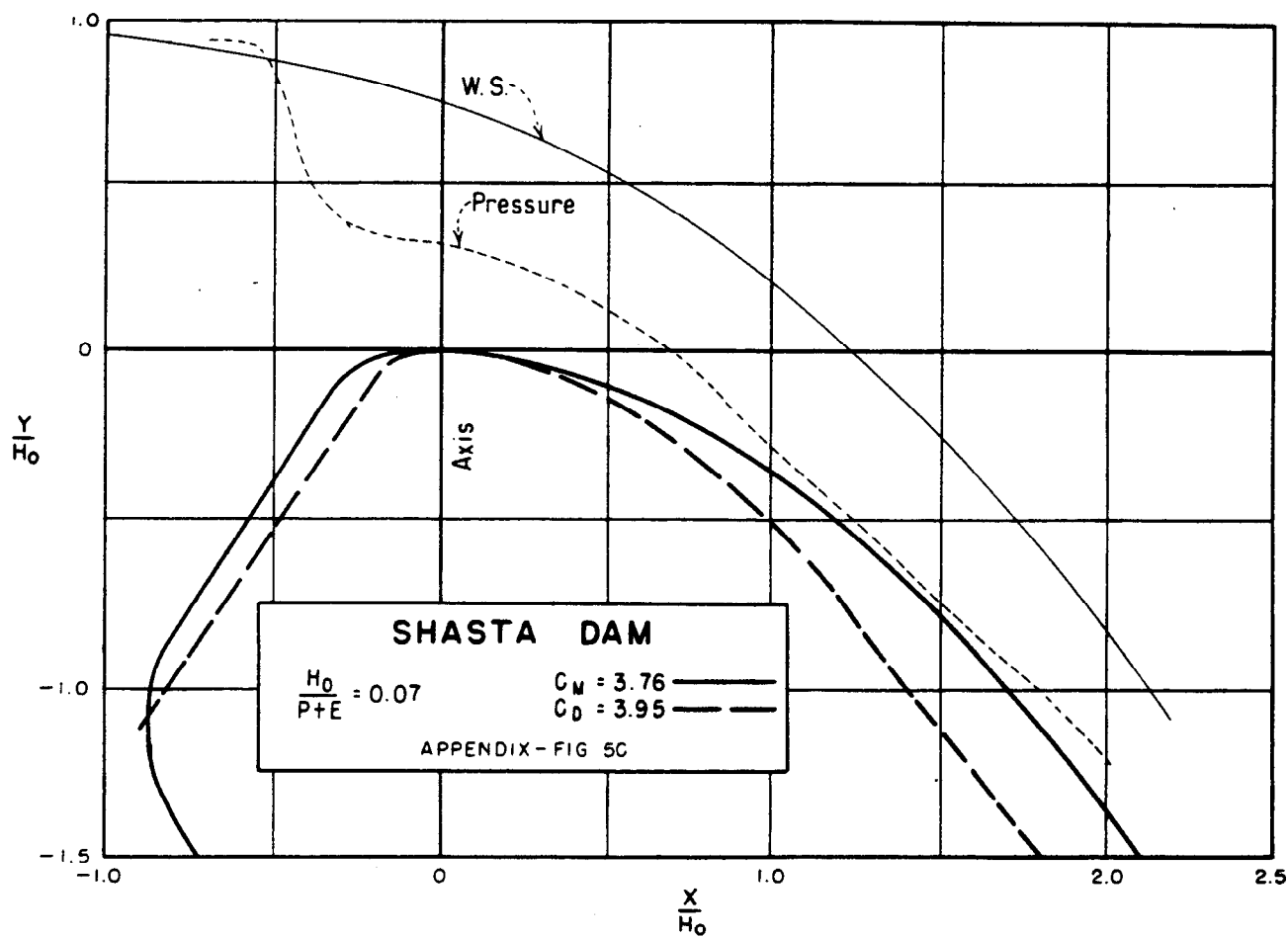


FIGURE 15 - Spillways with offset in upstream face.

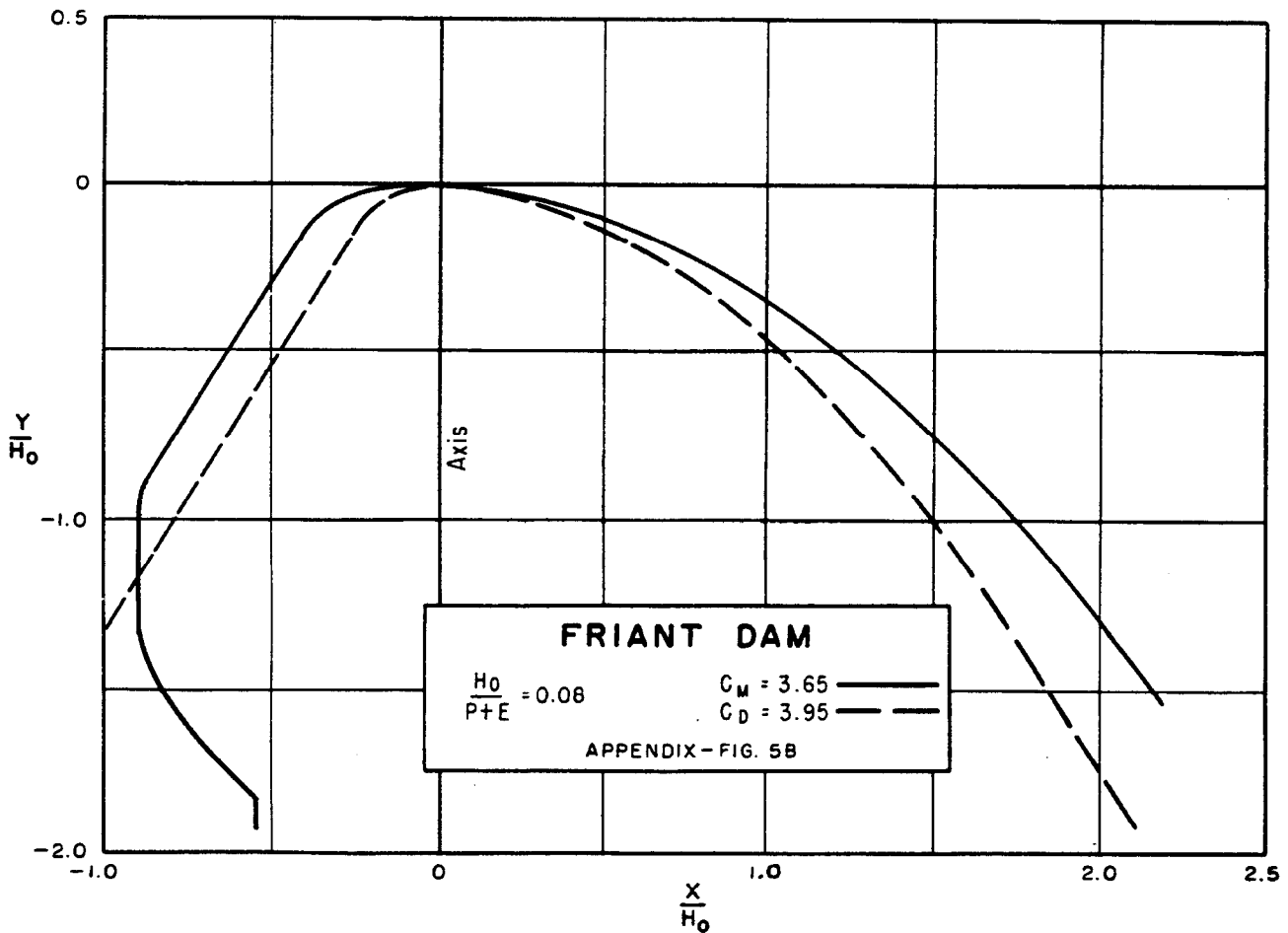
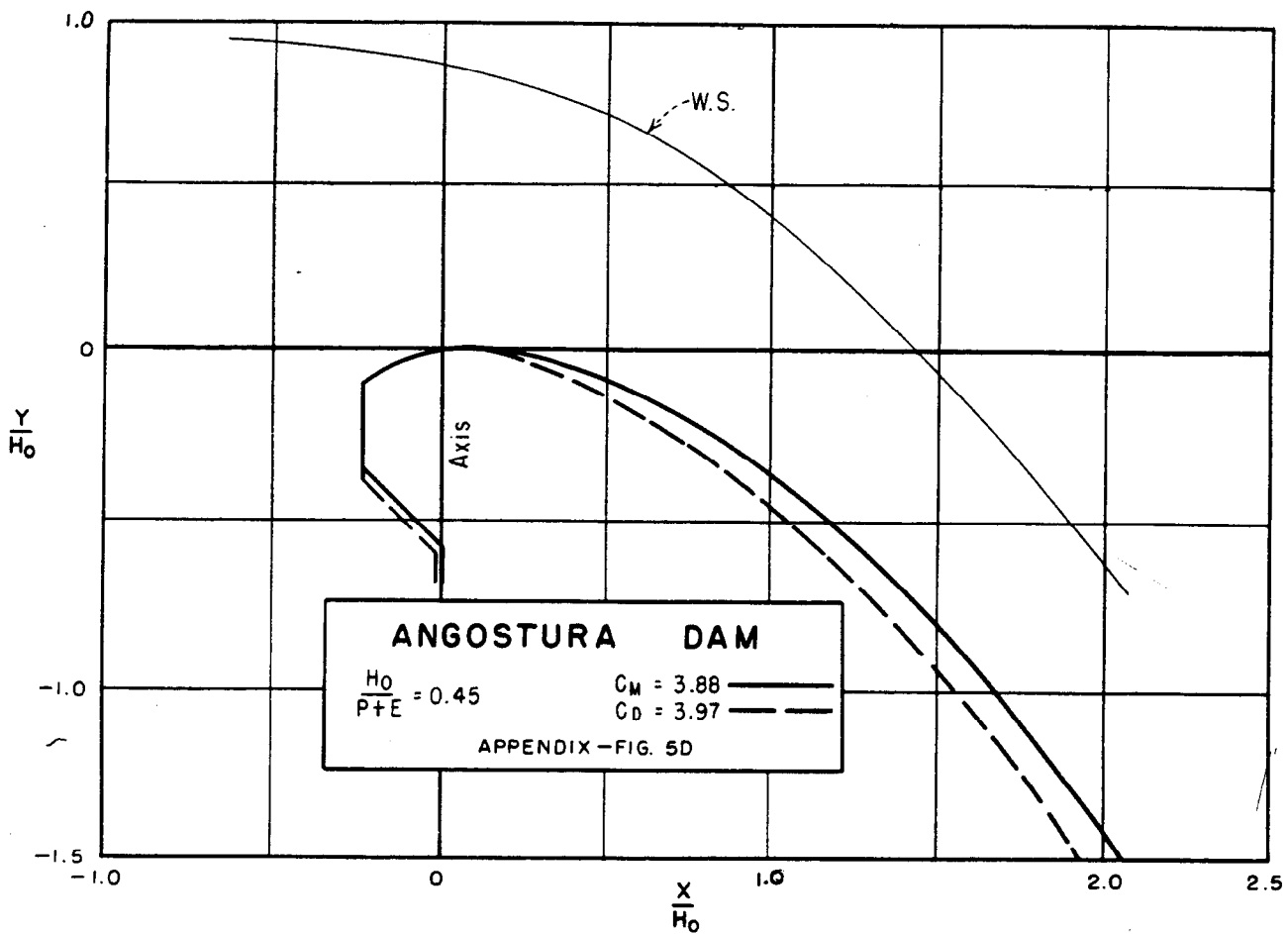


FIGURE 16 - Spillways with offset in upstream face.

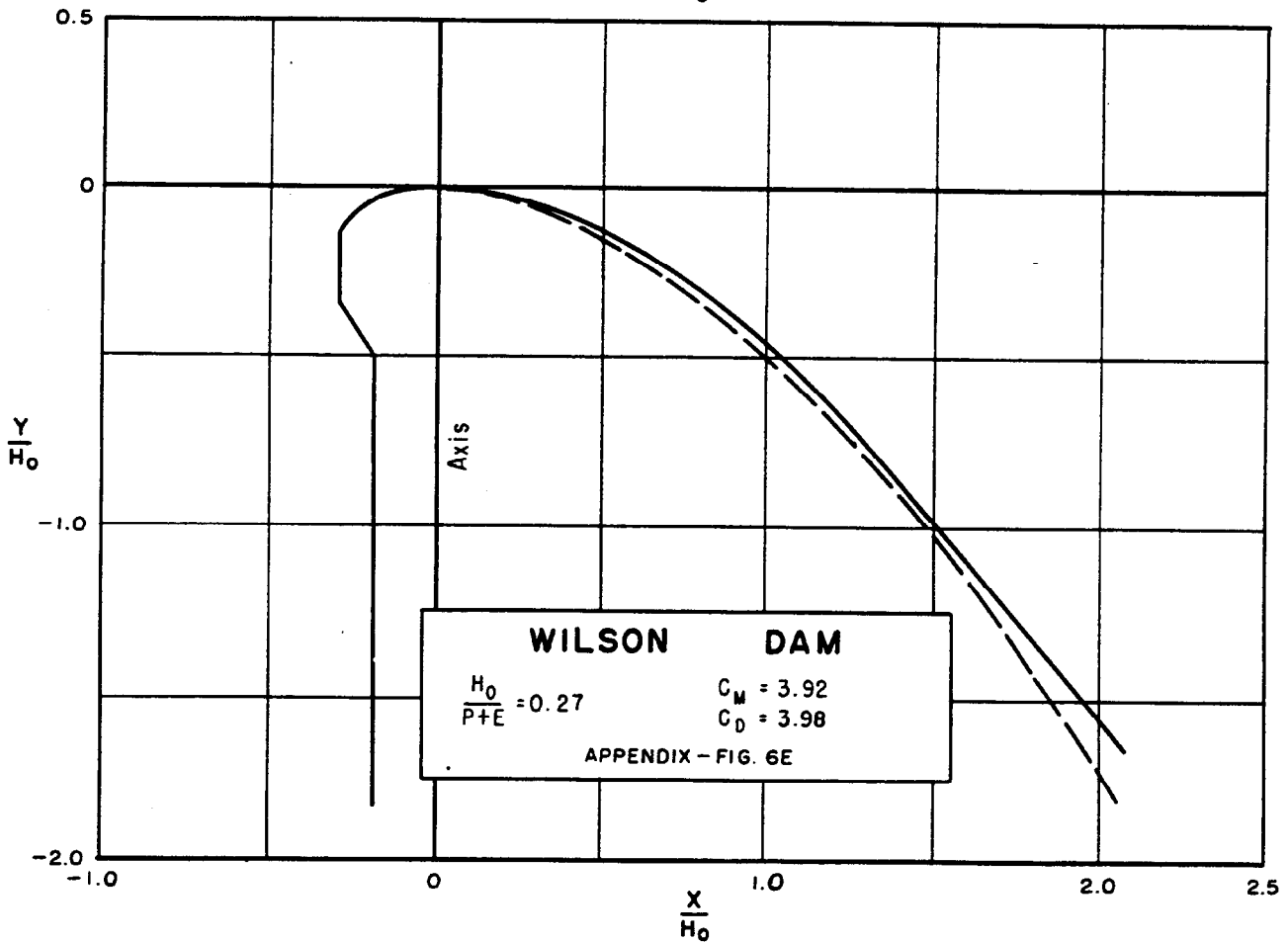
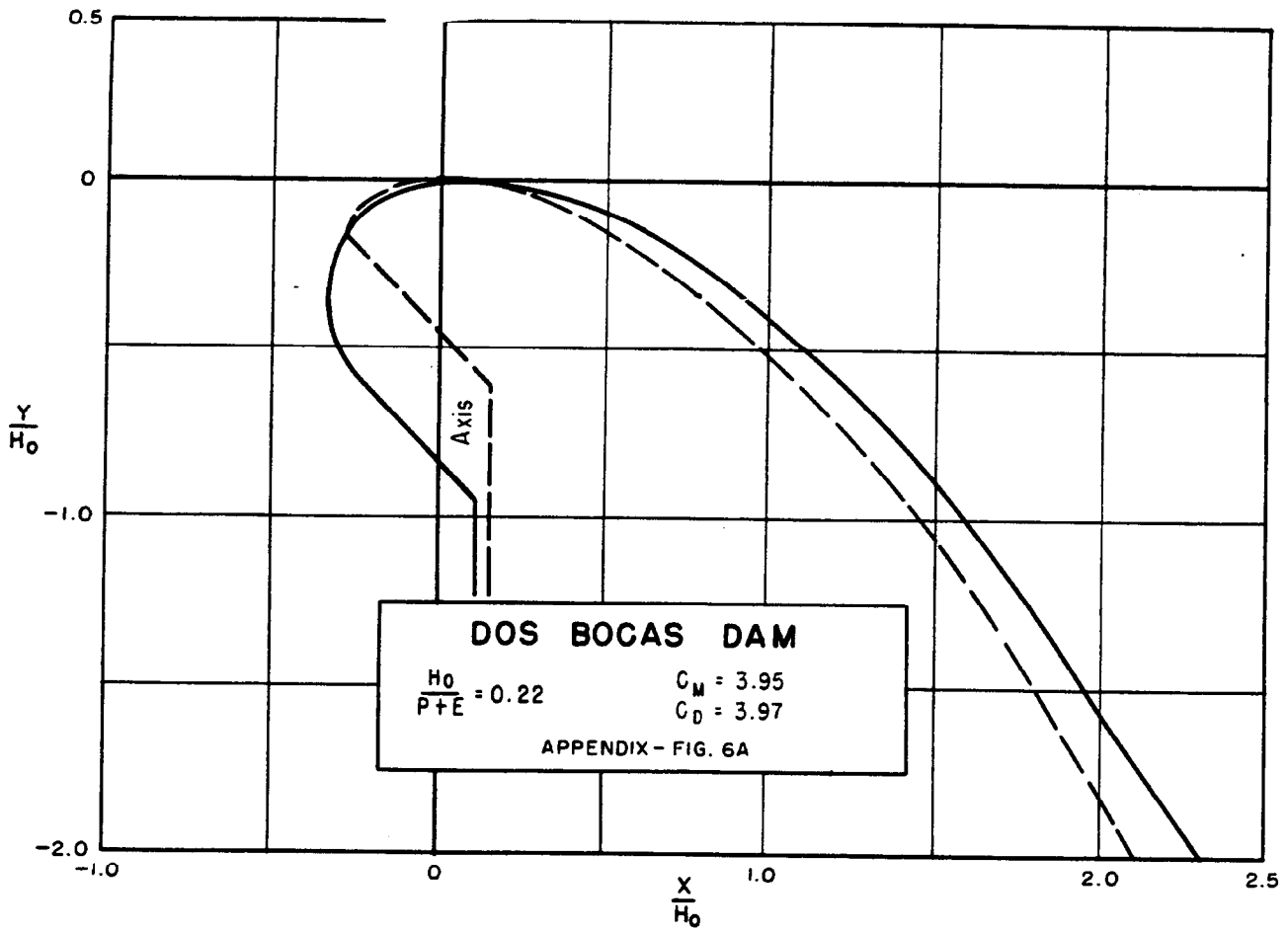
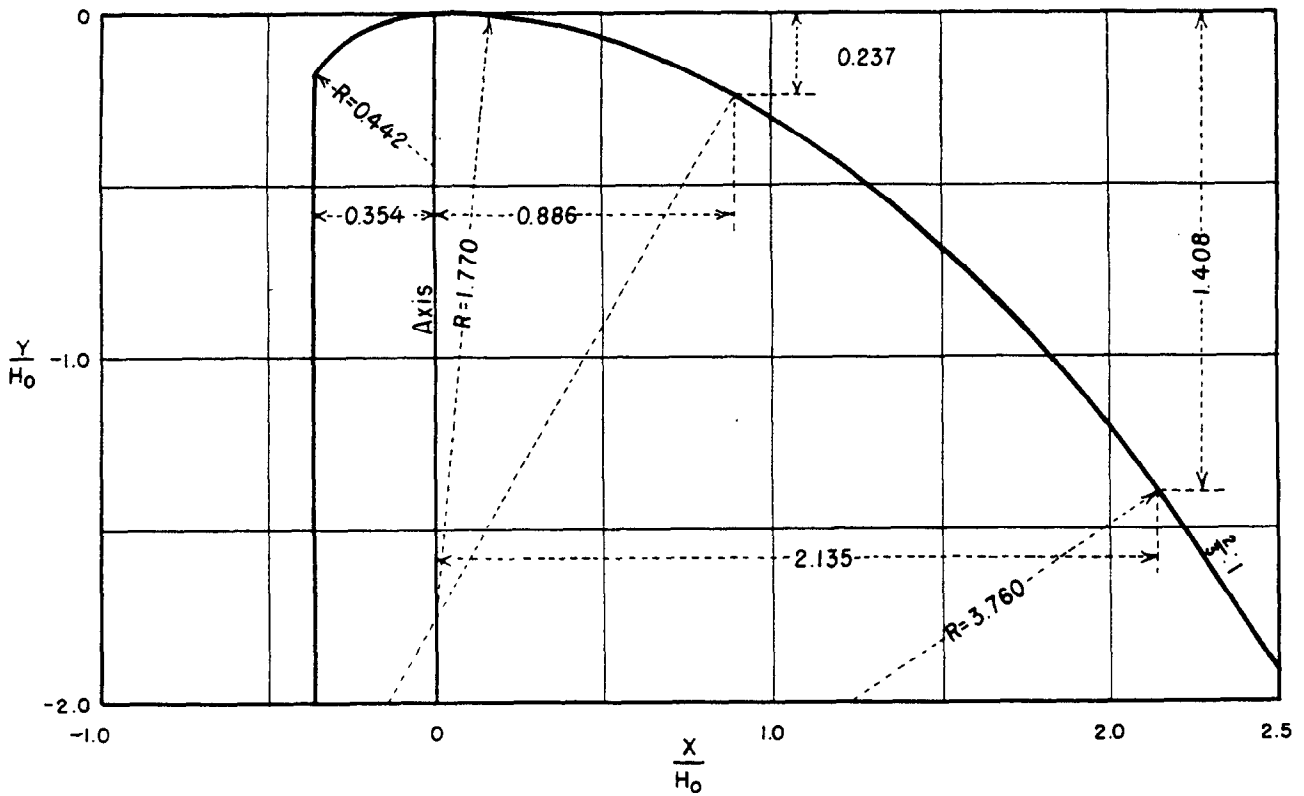
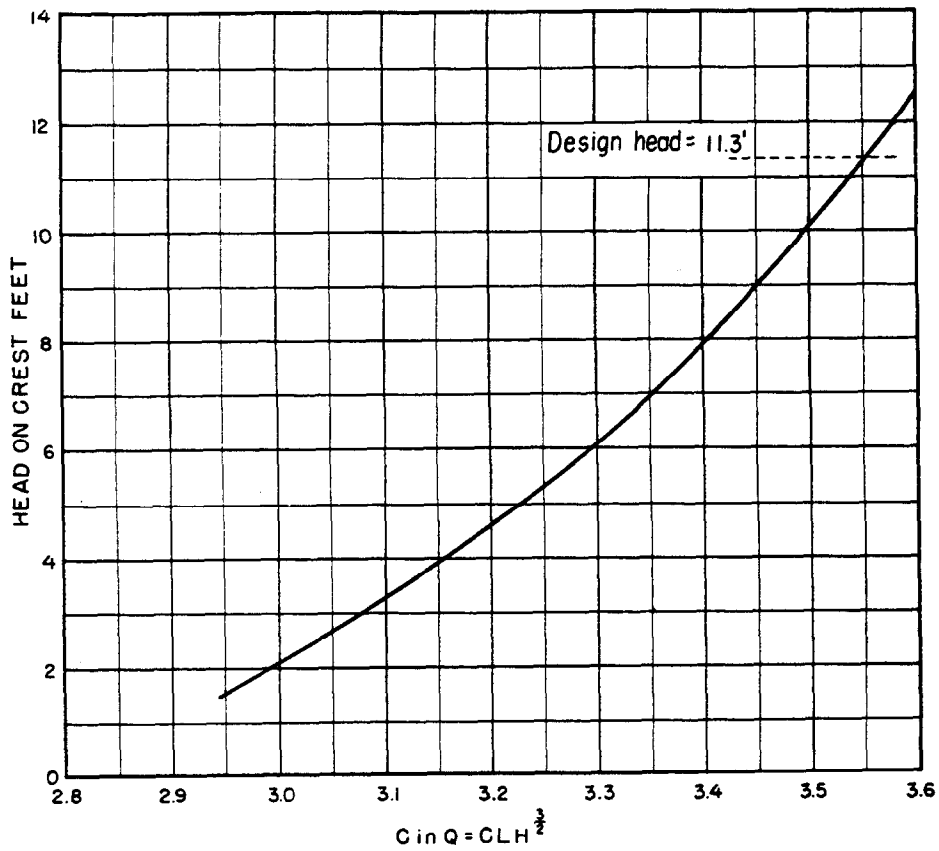


FIGURE 18 - Spillways with offset in upstream face.

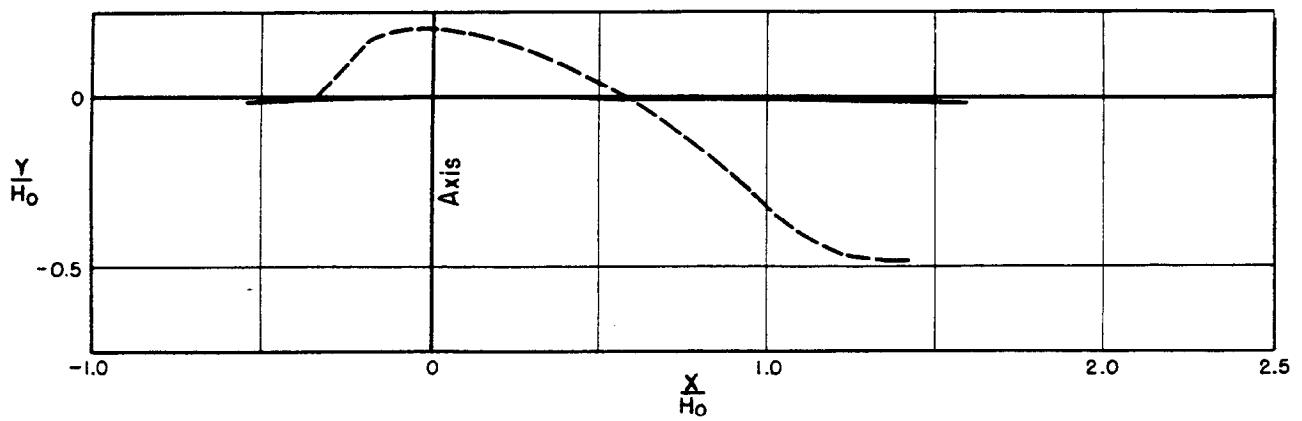


A- OVERFALL CREST SECTION



B- HEAD-COEFFICIENT CURVE

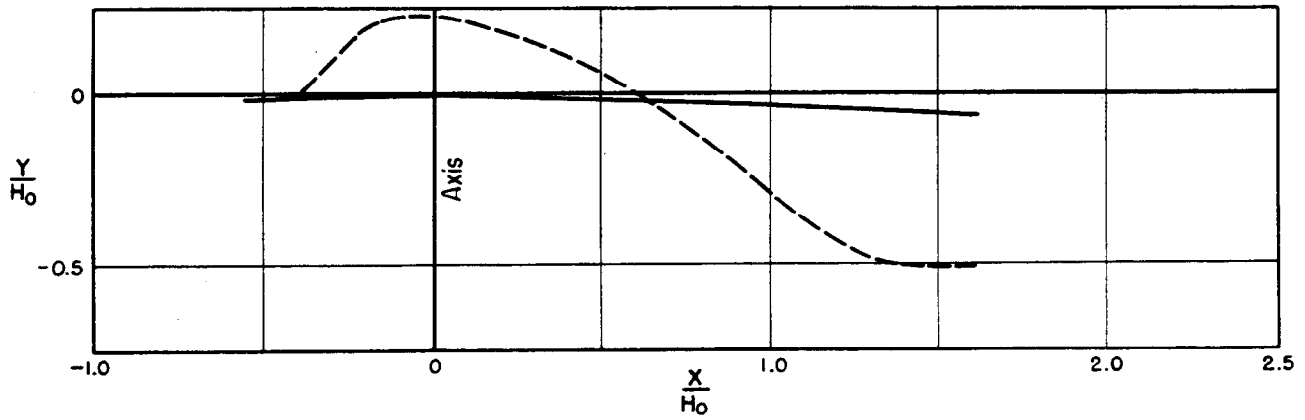
FIGURE 20 - American Falls Dam Spillway (Examples 1 and 3).



RYE PATCH DAM

$\frac{H_0}{P+E} = 17$ $C_M = 2.81$ ———
 $\frac{H_0}{P+E} = 3.53$ $C_D = 3.77$ - - -

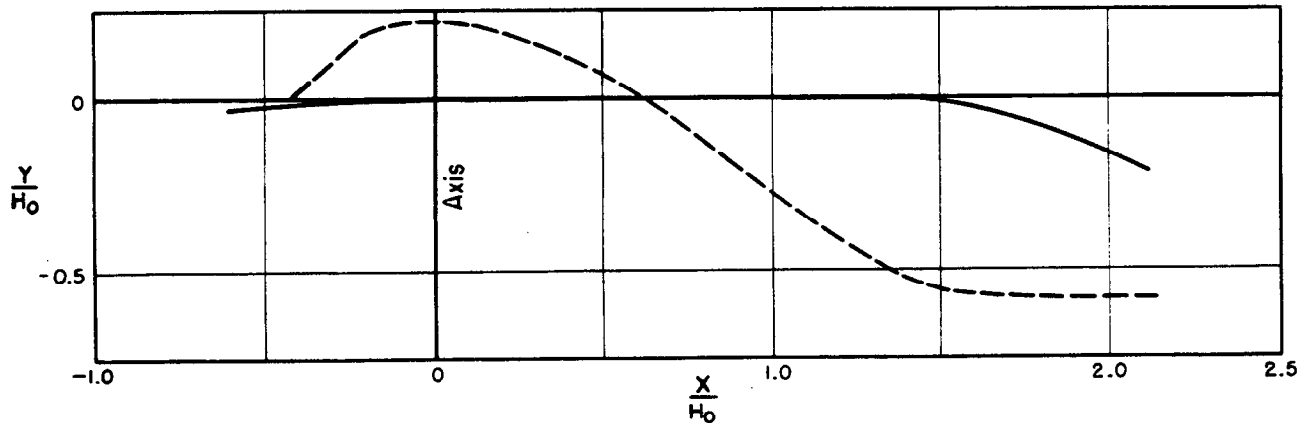
APPENDIX—FIG. 7A



AGENCY VALLEY DAM

$\frac{H_0}{P+E} = 17$ $C_M = 2.73$ ———
 $\frac{H_0}{P+E} = 3.23$ $C_D = 3.78$ - - -

CONTRACTION IN CHUTE D.S.
APPENDIX—FIG. 7D



PINE VIEW DAM

$\frac{H_0}{P+E} = 4$ $C_M = 2.74$ ———
 $\frac{H_0}{P+E} = 1.81$ $C_D = 3.86$ - - -

CONTRACTION IN CHUTE D.S.
APPENDIX—FIG. 7C

FIGURE 21 - Spillways with overfall suppressed.

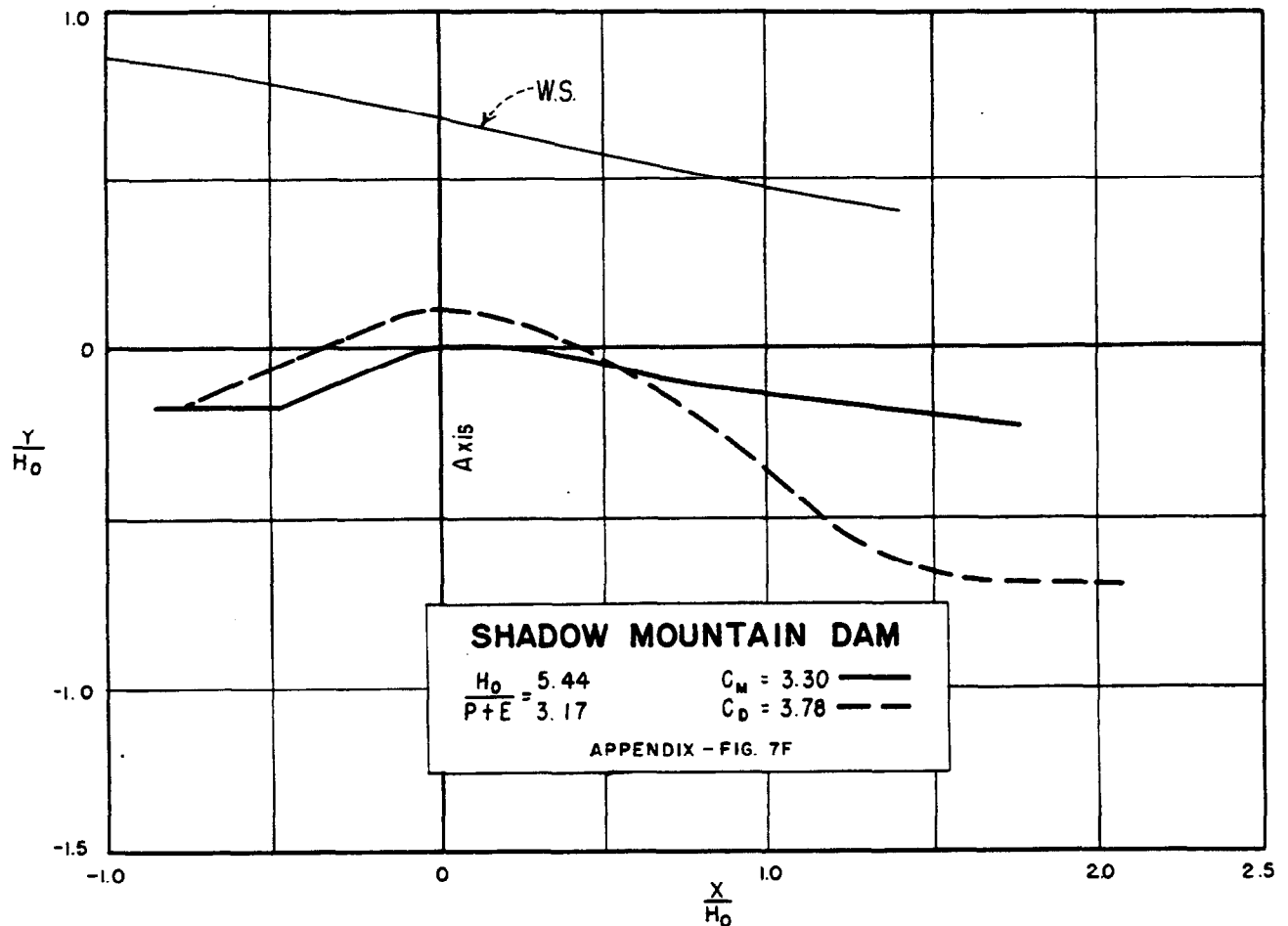
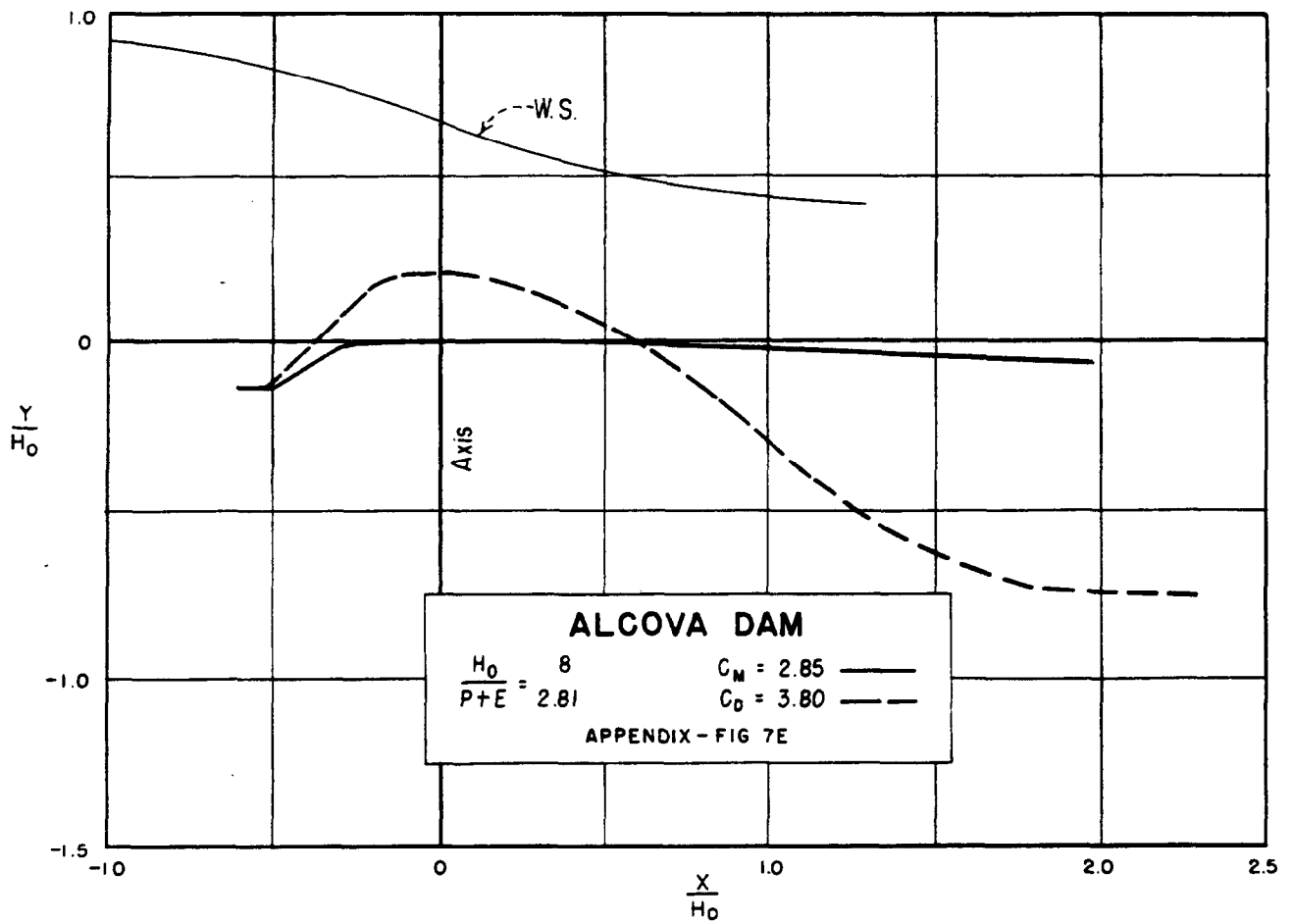
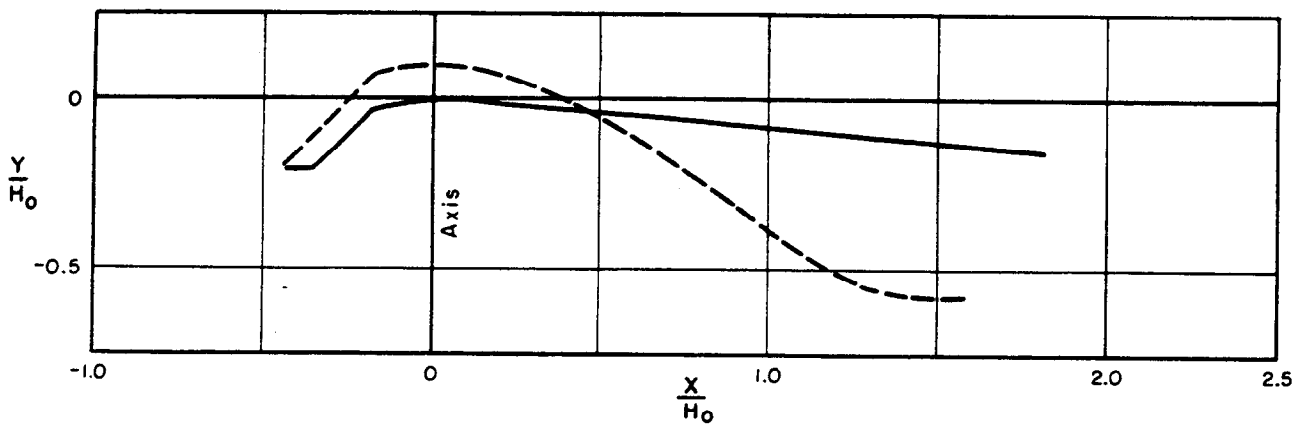


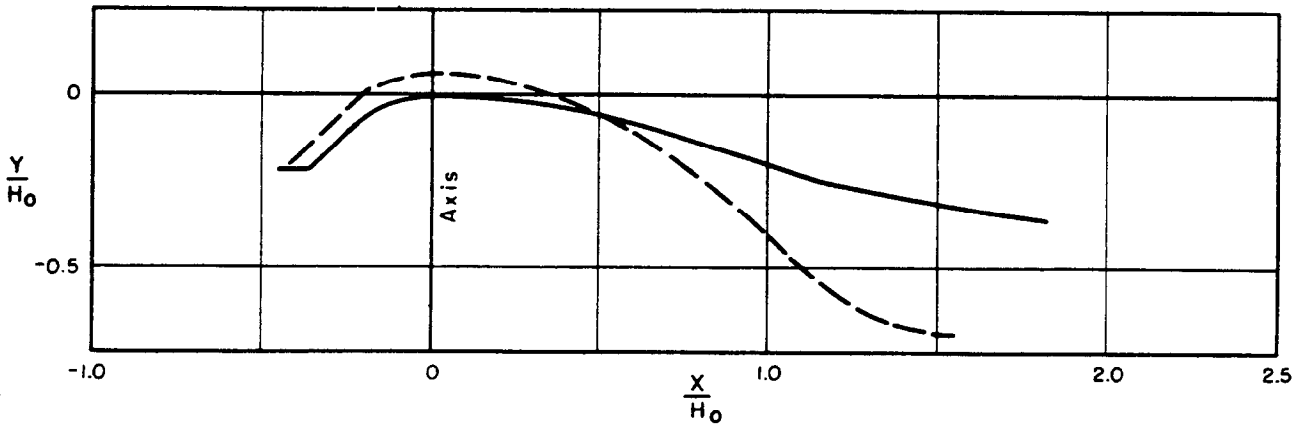
FIGURE 22 - Spillways with overfall suppressed.



GREEN MOUNTAIN DAM

$H_0 = 5.5$ $C_M = 3.21$ ———
 $\frac{P+E}{H_0} = 3.16$ $C_D = 3.78$ - - - -

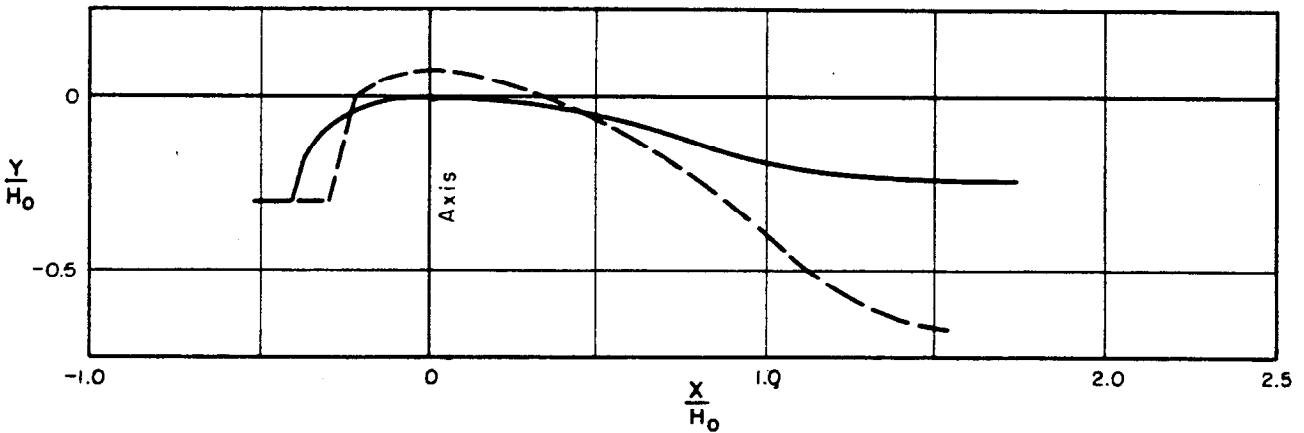
CONTRACTION IN CHUTE D.S.
 APPENDIX - FIG. 7B



ANDERSON RANCH DAM

$H_0 = 3.80$ $C_M = 3.40$ ———
 $\frac{P+E}{H_0} = 3.46$ $C_D = 3.76$ - - - -

APPENDIX - FIG. 8A

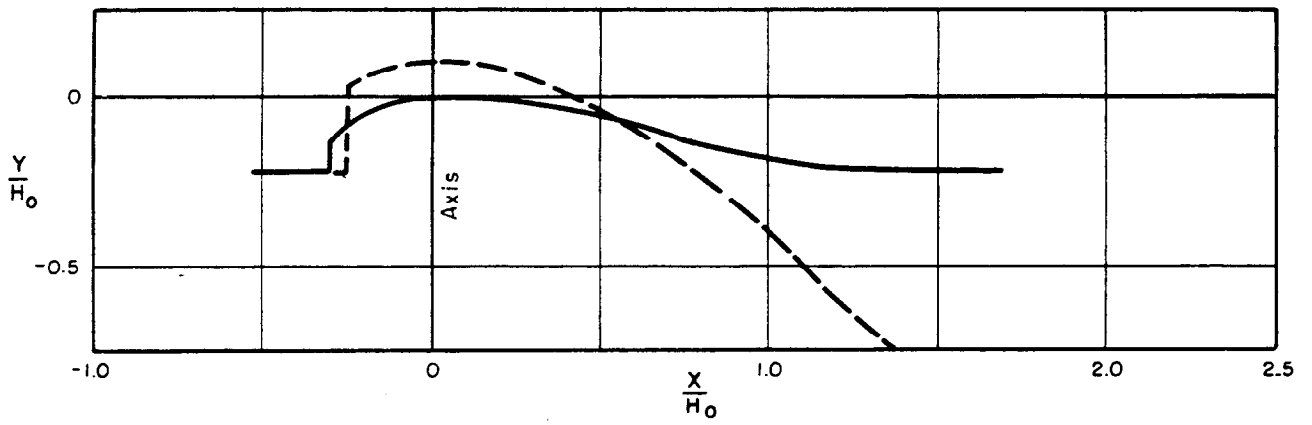


BARTLETT DAM

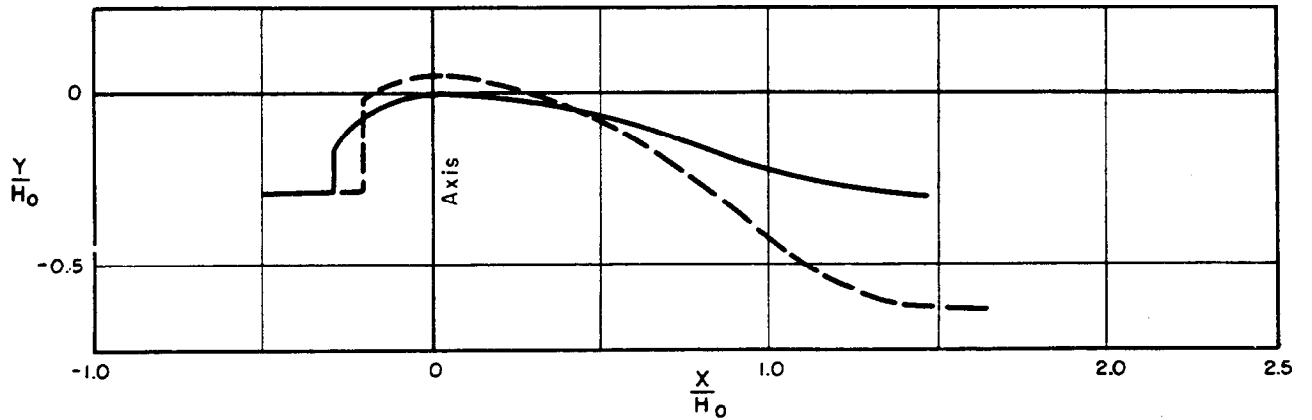
$H_0 = 3.57$ $C_M = 3.48$ ———
 $\frac{P+E}{H_0} = 2.64$ $C_D = 3.76$ - - - -

APPENDIX - FIG. 8B

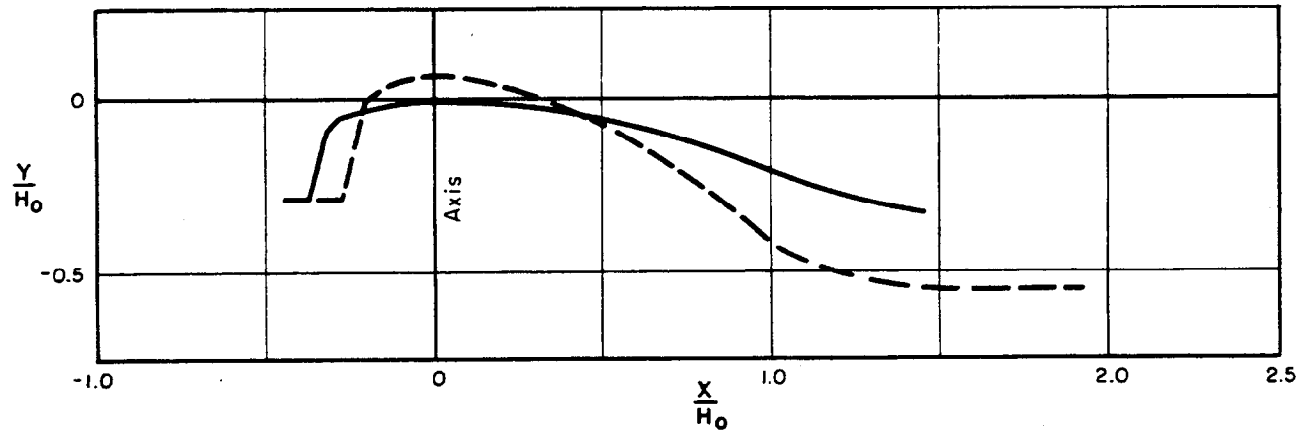
FIGURE 23 - Spillways with overfall suppressed.



GRANBY DAM
 $H_0 = 5.0$ $C_M = 3.20$ ———
 $\frac{P+E}{H_0} = 3.1$ $C_D = 3.71$ - - -
 APPENDIX - FIG. 8C



VALLECITO DAM
 $H_0 = 3.8$ $C_M = 3.42$ ———
 $\frac{P+E}{H_0} = 3.0$ $C_D = 3.72$ - - -
 CONTRACTION IN CHUTE D.S.
 APPENDIX - FIG. 8F



BOYSEN DAM
 (PRELIMINARY DESIGN)
 $H_0 = 3.71$ $C_M = 3.37$ ———
 $\frac{P+E}{H_0} = 2.74$ $C_D = 3.76$ - - -
 APPENDIX - FIG. 8E

FIGURE 24 - Spillways with overfall suppressed.

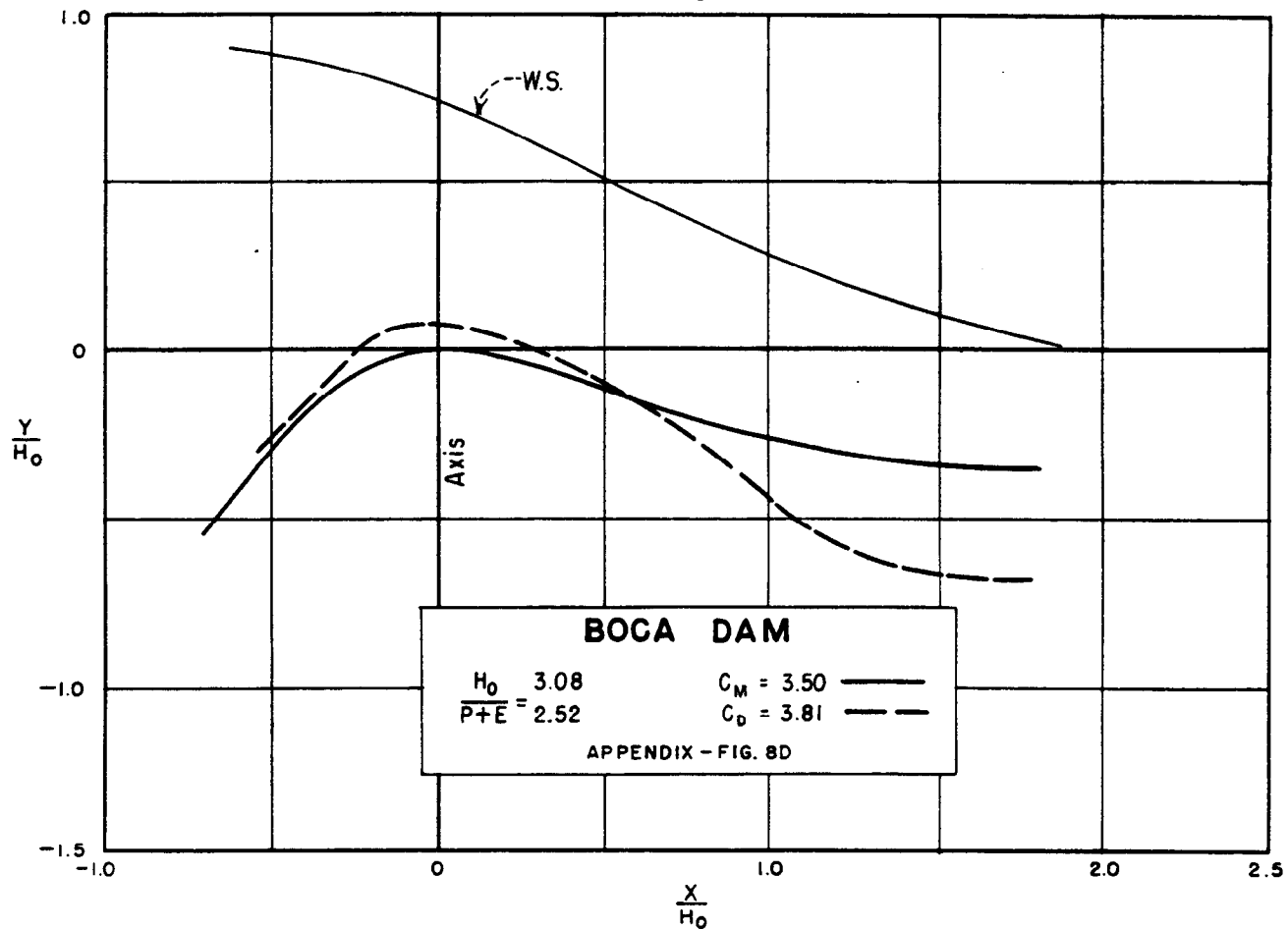
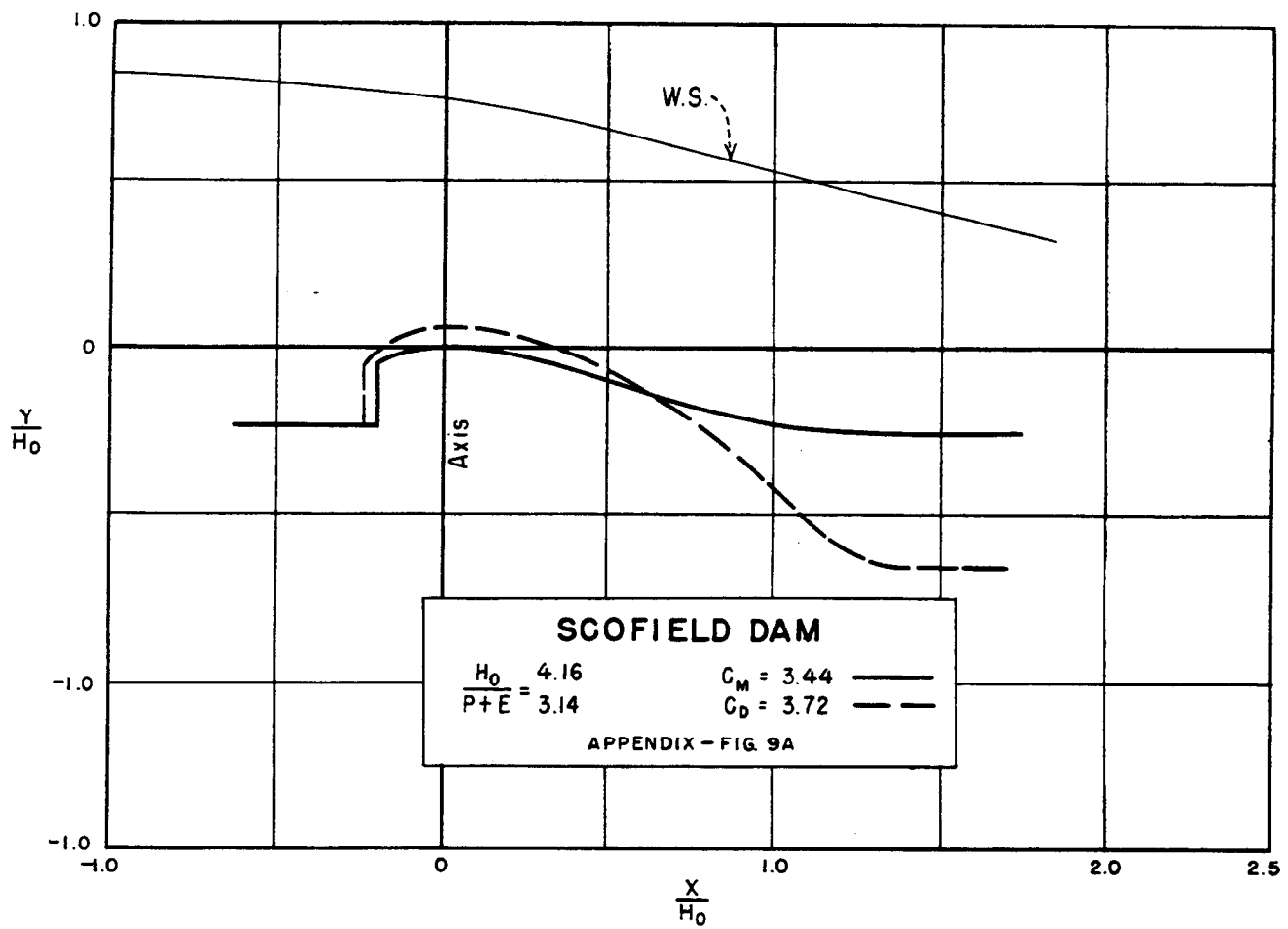


FIGURE 25 - Spillways with overfall suppressed.

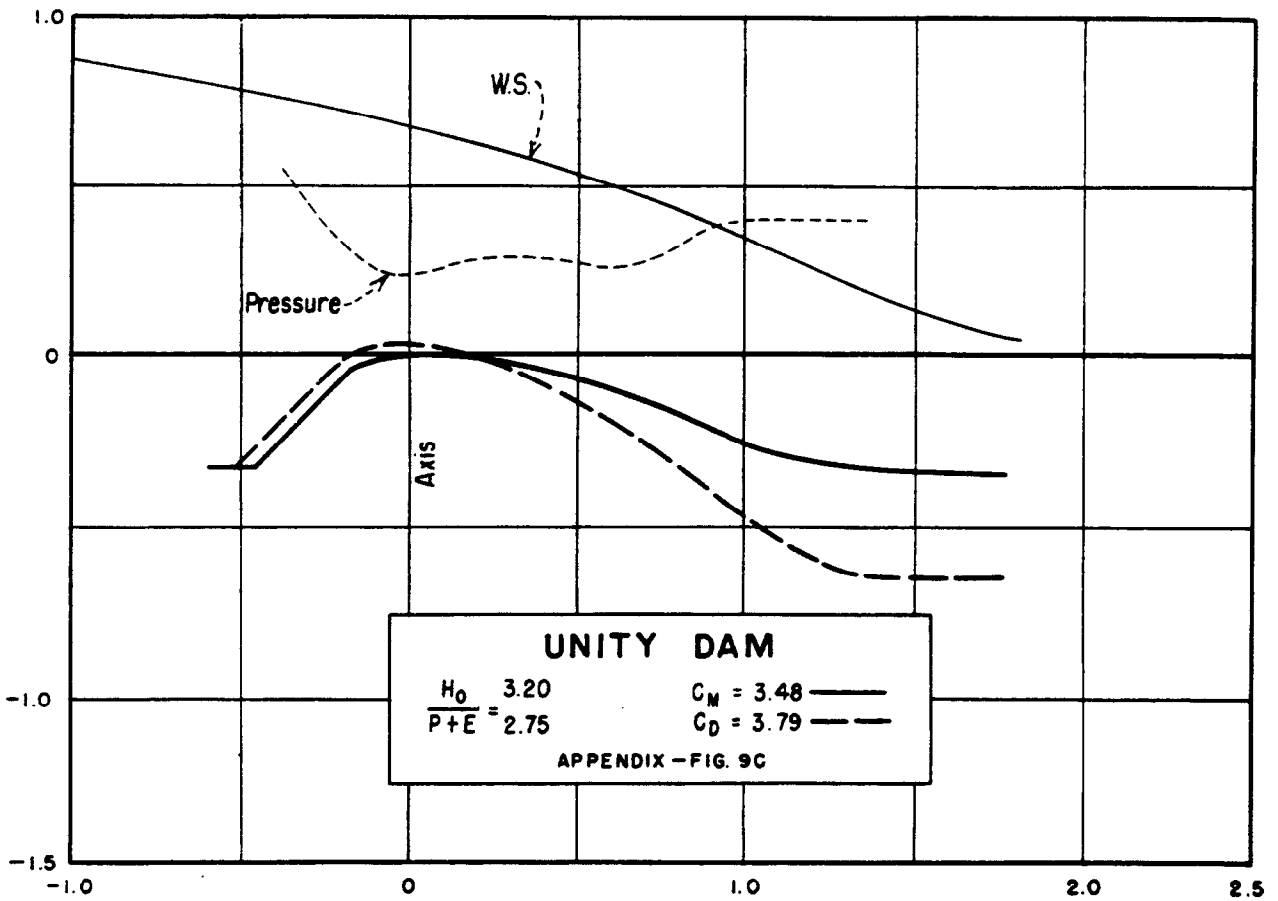
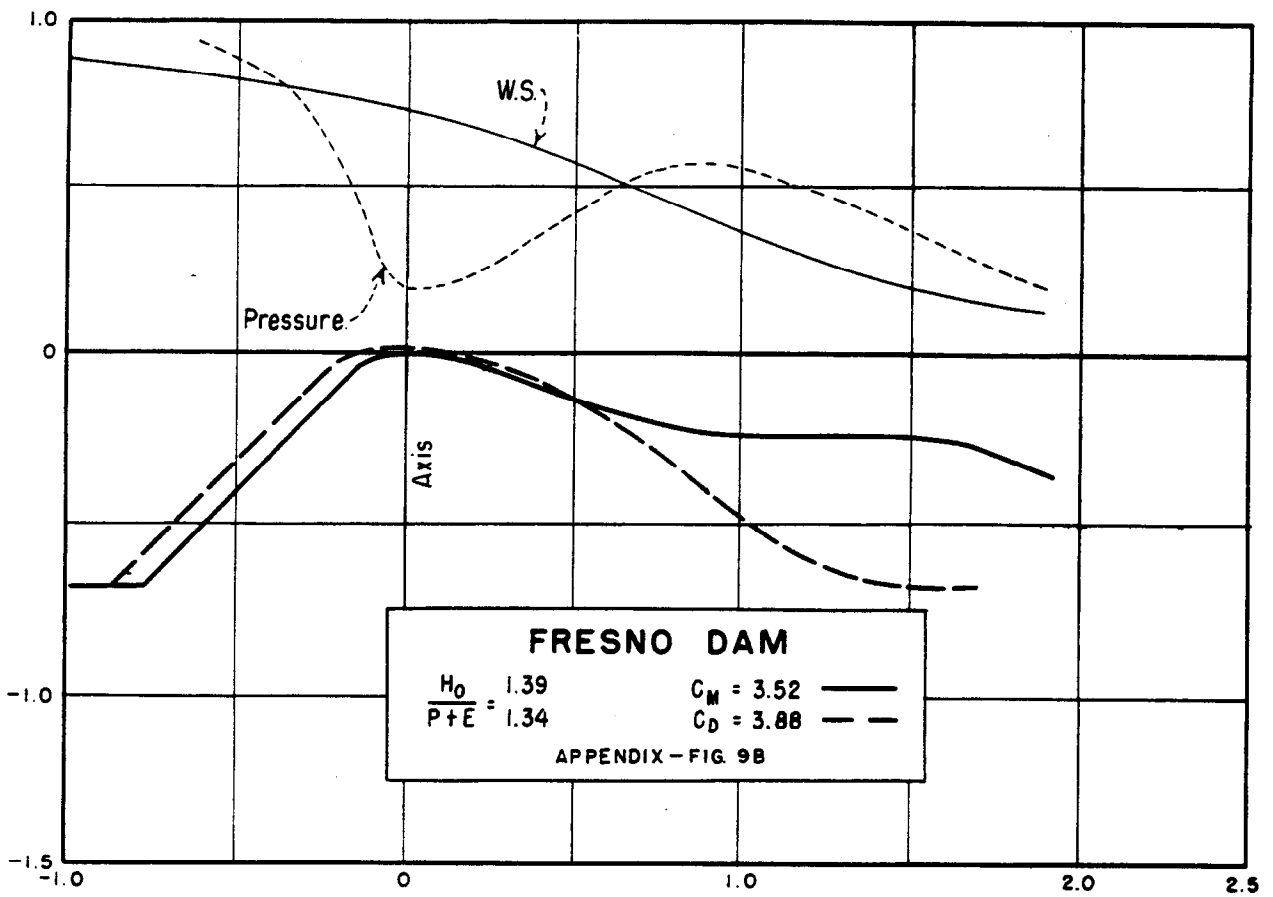


FIGURE 26 - Spillways with overfall suppressed.

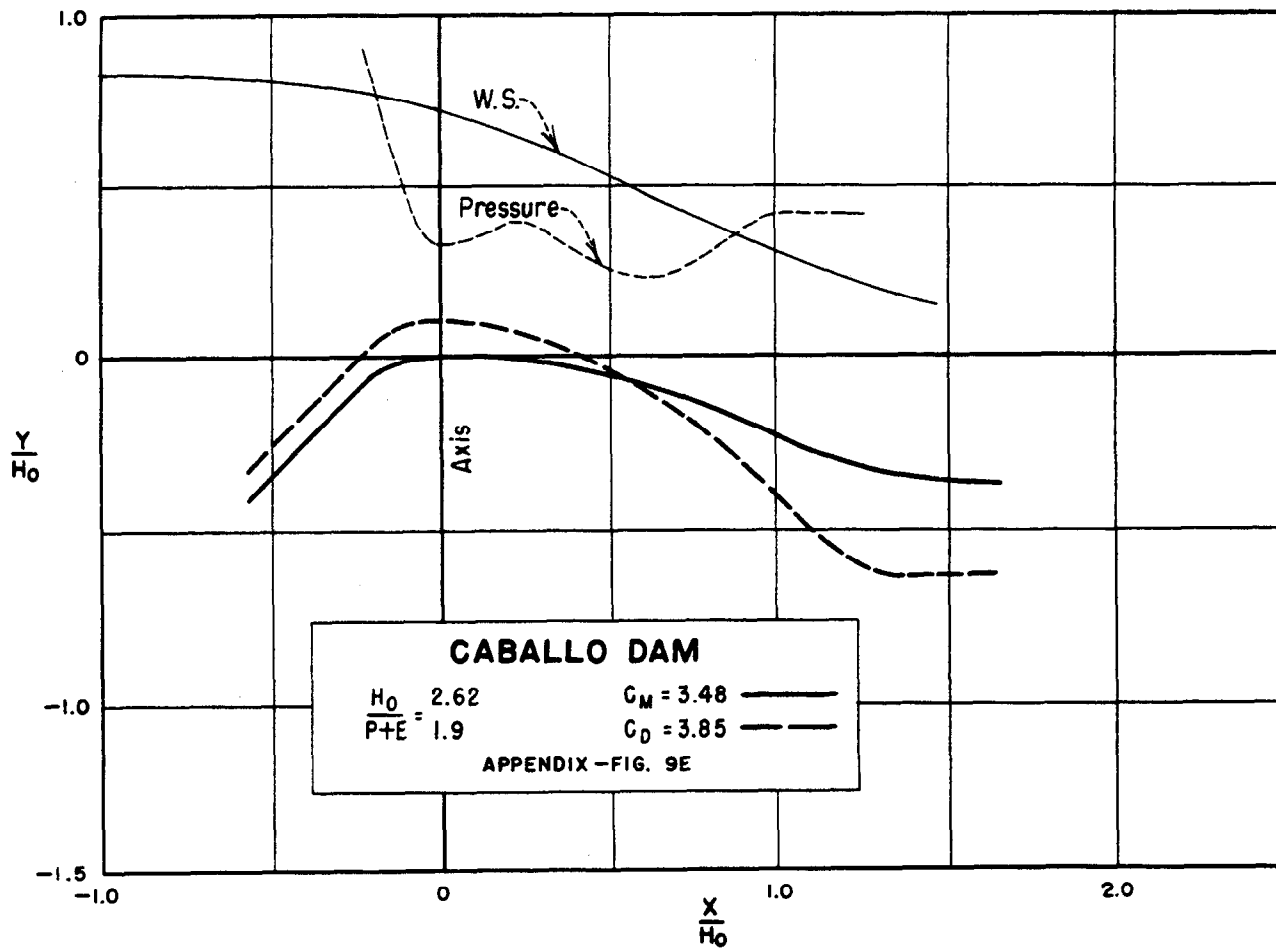
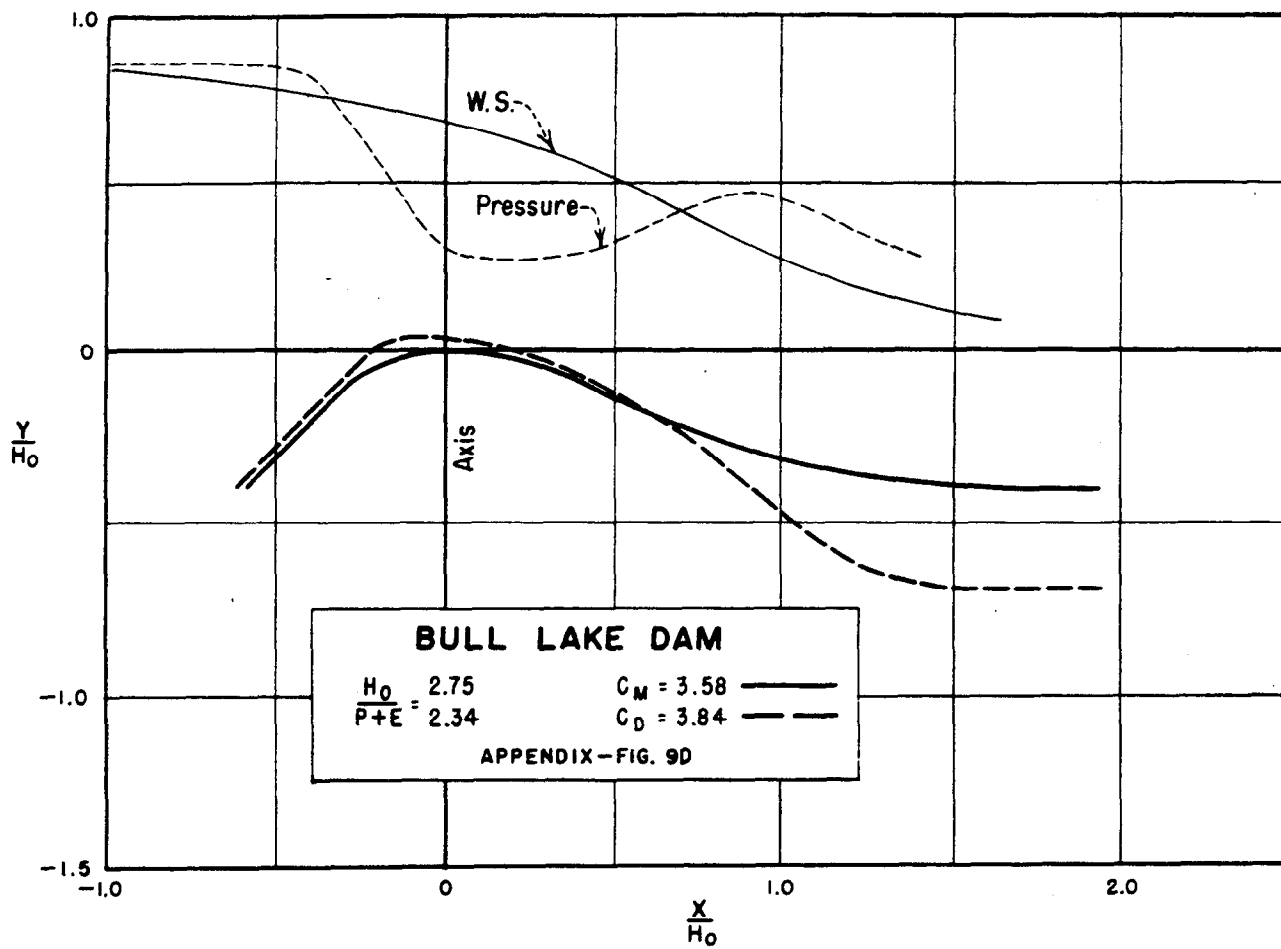
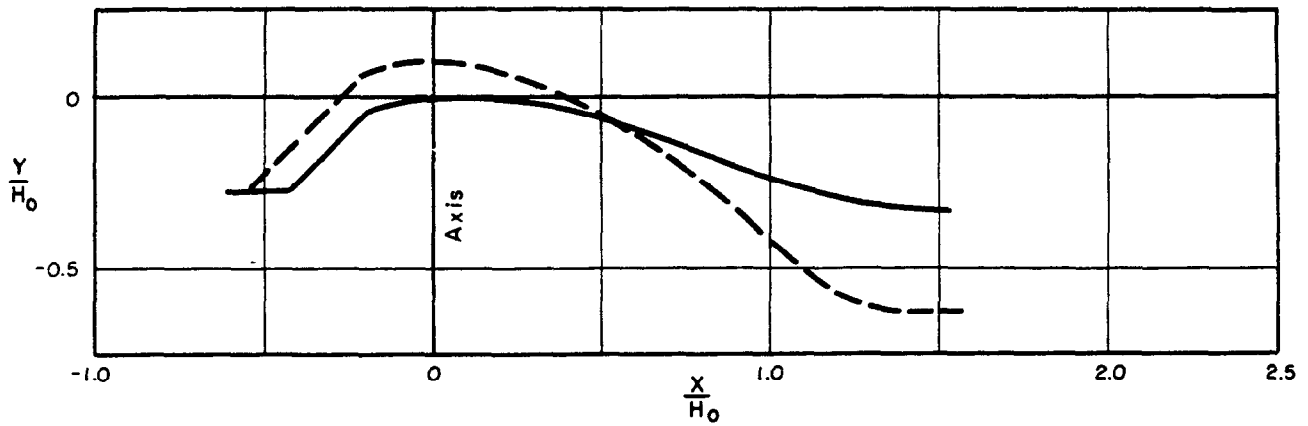
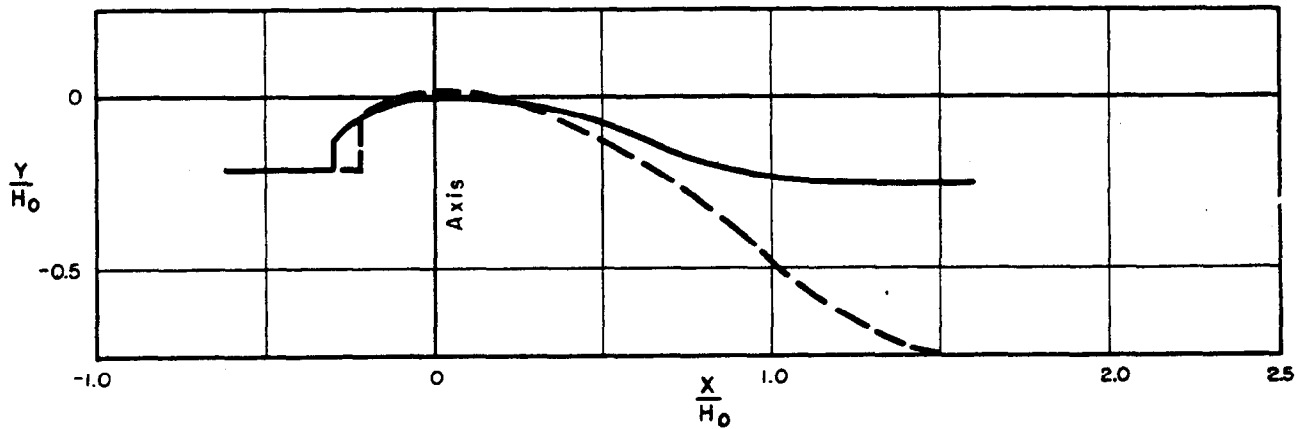


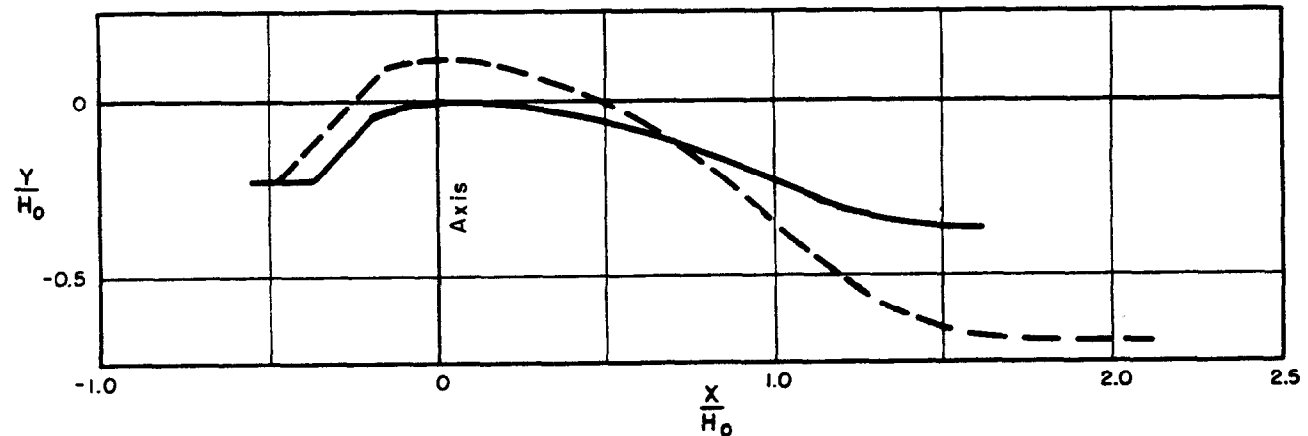
FIGURE 27 - Spillways with overfall suppressed.



MOON LAKE DAM
 (FINAL DESIGN)
 $H_0 = 4.0$ $C_M = 3.28$ ———
 $P+E = 2.57$ $C_D = 3.80$ - - -
 CONTRACTION IN CHUTE D.S.
 APPENDIX - FIG. 9F

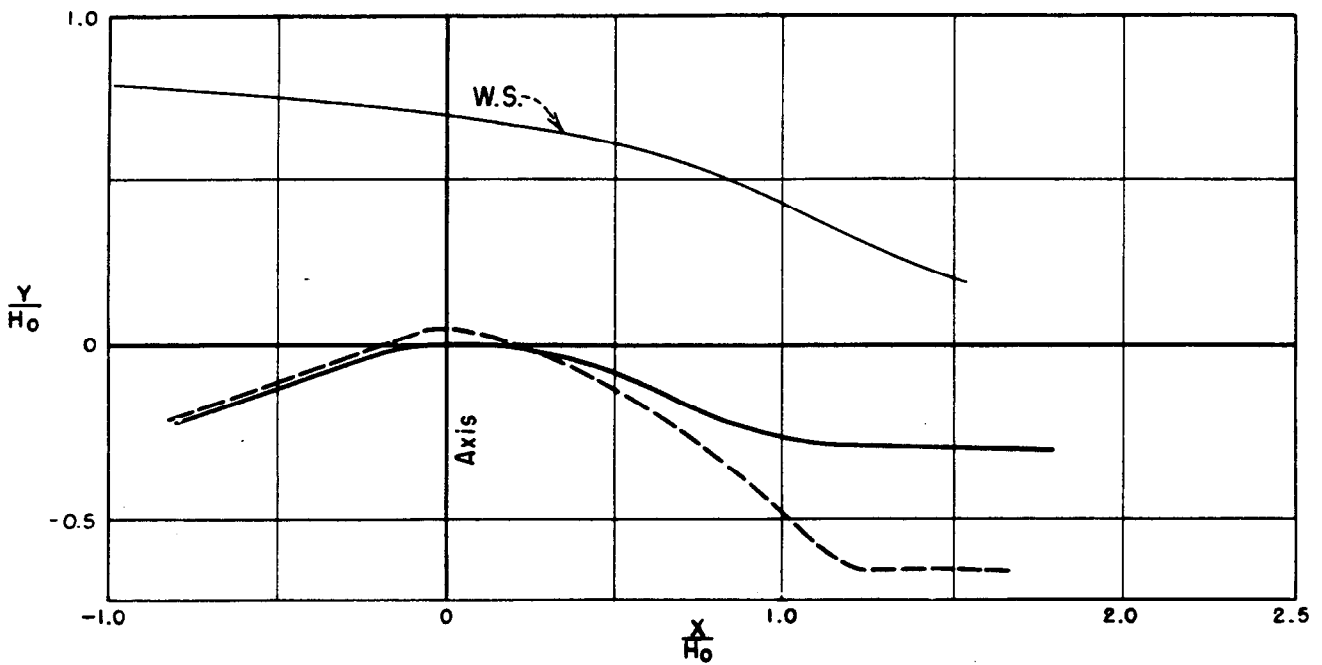


DEER CREEK DAM
 $H_0 = 5.0$ $C_M = 3.46$ ———
 $P+E = 4.22$ $C_D = 3.61$ - - -
 CONTRACTION IN CHUTE D.S.
 APPENDIX - FIG. 9G



ALAMOGORDO DAM
 $H_0 = 5.2$ $C_M = 3.18$ ———
 $P+E = 2.82$ $C_D = 3.79$ - - -
 CONTRACTION IN CHUTE D.S.
 APPENDIX - FIG. 9H

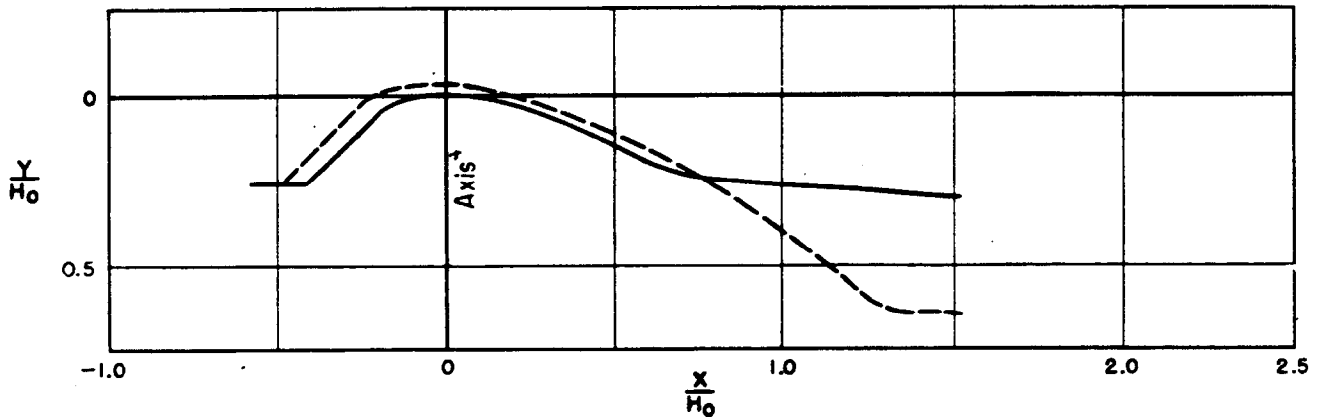
FIGURE 28 - Spillways with overfall suppressed.



MEDICINE CREEK DAM (LOW CREST)

$\frac{H_0}{P+E} = 4.53$ $C_M = 3.54$
 $P+E = 3.74$ $C_D = 3.73$

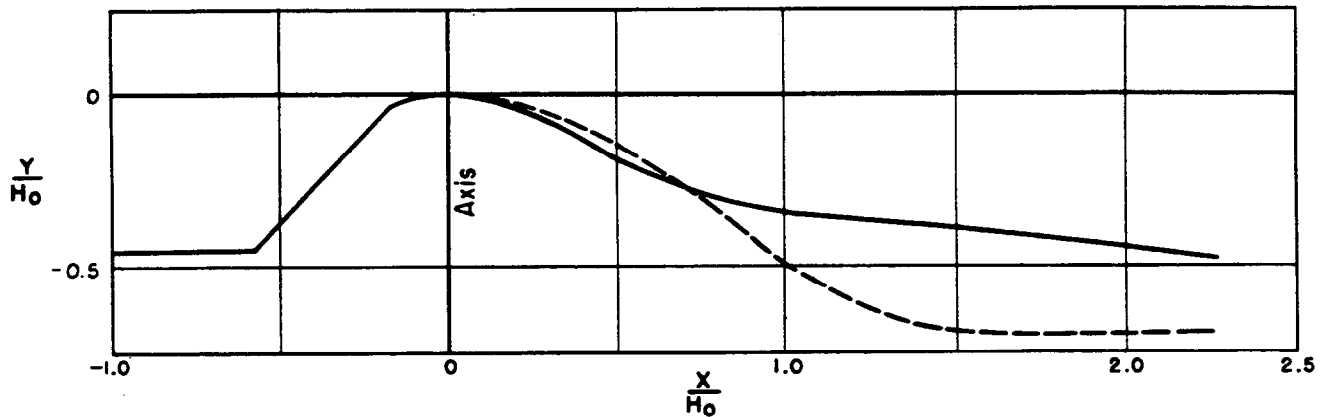
APPENDIX - FIG. 10C



KEYHOLE DAM

$\frac{H_0}{P+E} = 4.0$ $C_M = 3.56$
 $P+E = 3.3$ $C_D = 3.76$

APPENDIX - FIG. 10D

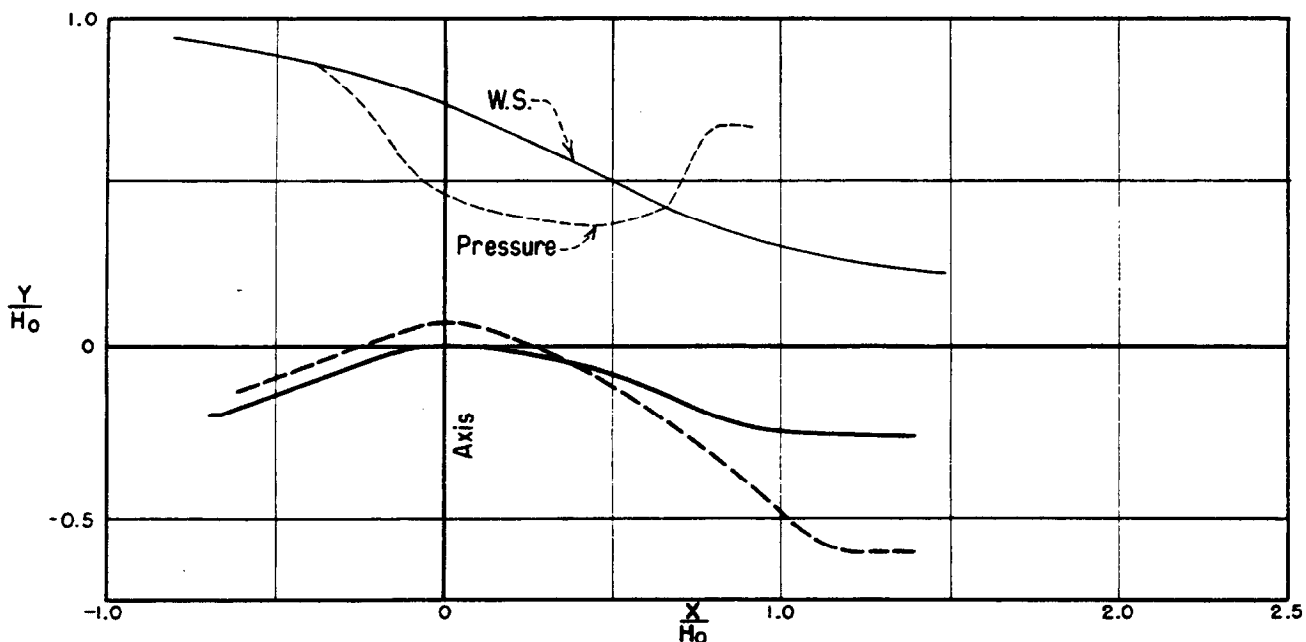


DICKINSON DAM

$\frac{H_0}{P+E} = 2.75$ $C_M = 3.75$
 $P+E = 2.75$ $C_D = 3.80$

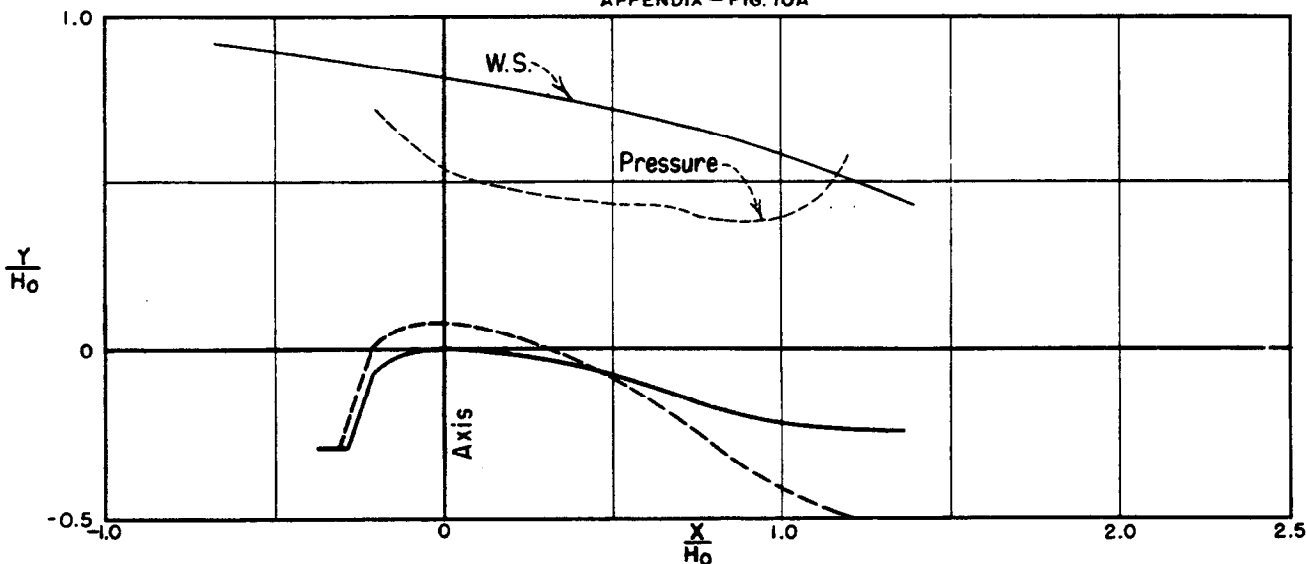
APPENDIX - FIG. 10B

FIGURE 29 - Spillways with overfall suppressed.



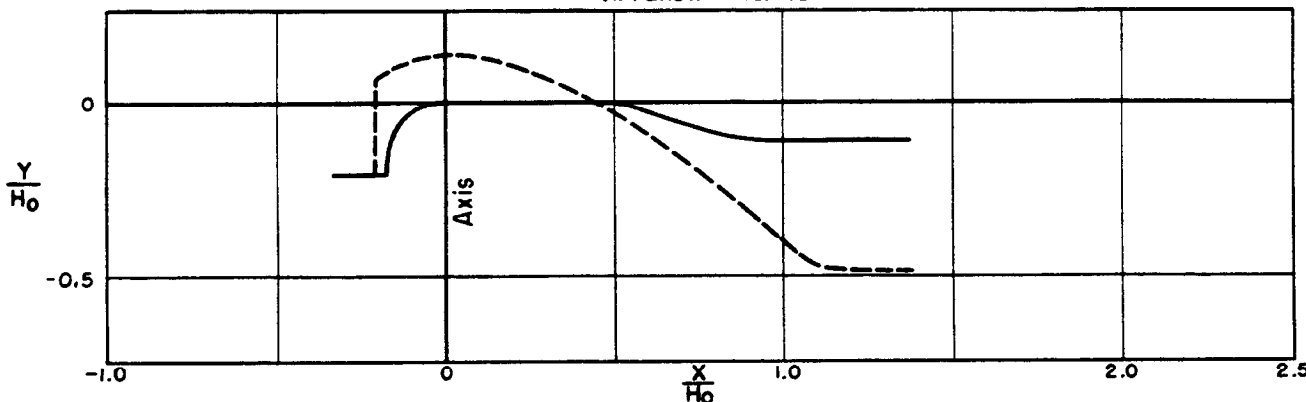
CACHUMA DAM
 $\frac{H_0}{P+E} = 3.55$ $C_M = 3.42$ —
 $C_D = 3.76$ - -

APPENDIX - FIG. 10A



FALCON DAM
 $\frac{H_0}{P+E} = 2.50$ $C_M = 3.33$ —
 $C_D = 3.78$ - -

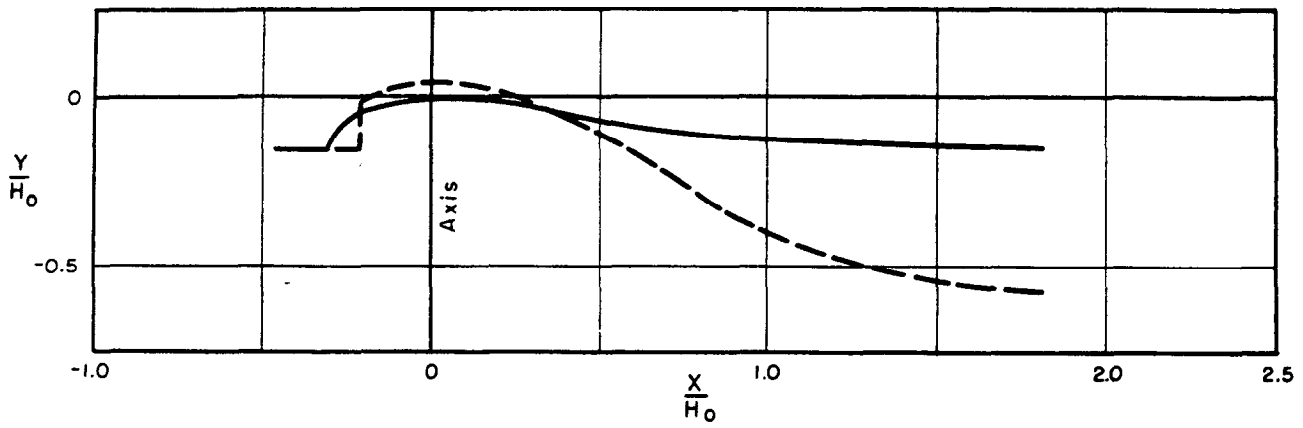
APPENDIX - FIG. 11D



HORSESHOE DAM
 $\frac{H_0}{P+E} = 2.54$ $C_M = 3.20$ —
 $C_D = 3.74$ - -

APPENDIX - FIG. 11B

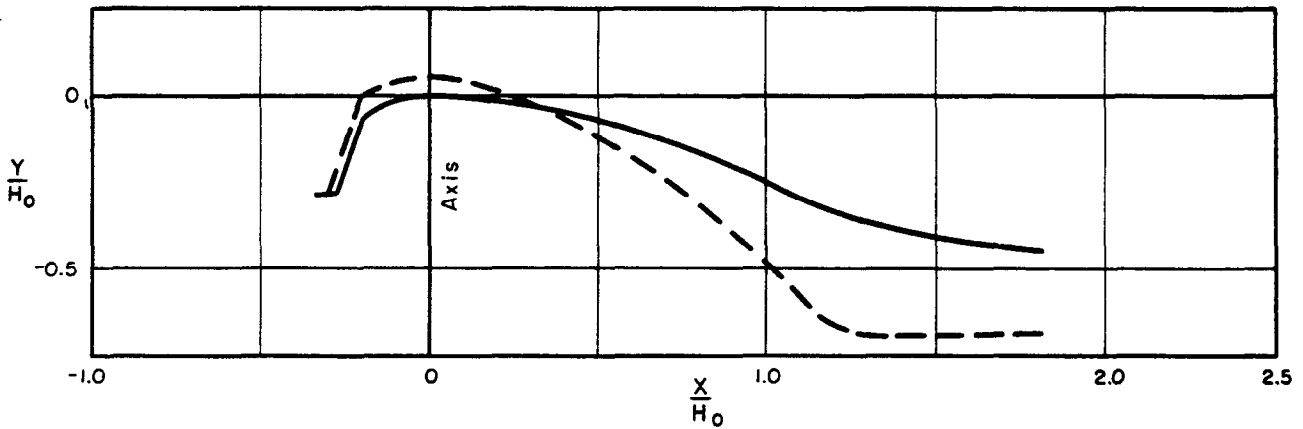
FIGURE 30 - Spillways with overfall suppressed.



CASCADE DAM

$H_0 = 6.67$ $C_M = 3.38$ ———
 $P+E = 4.75$ $C_D = 3.57$ - - -

APPENDIX - FIG. IIE

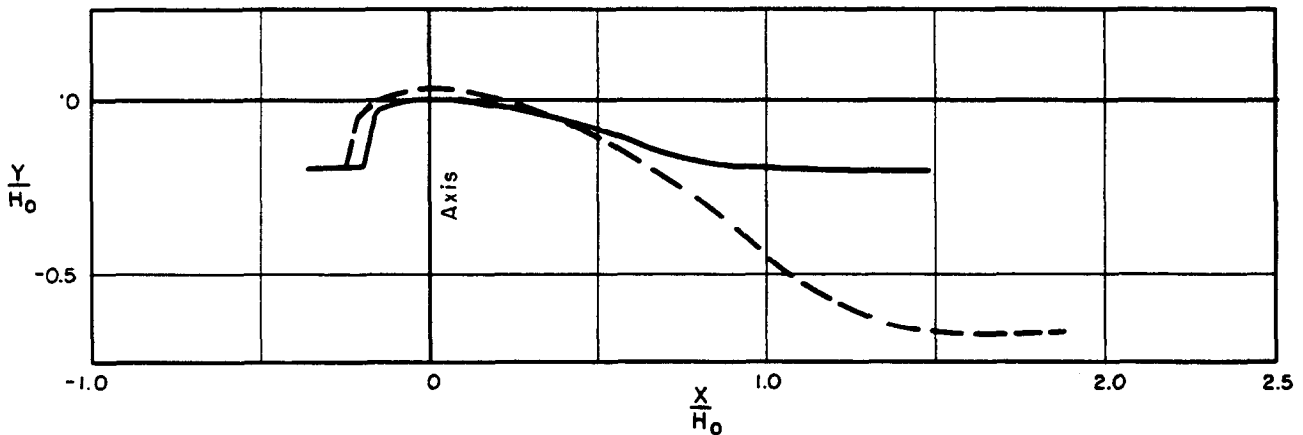


TIBER DAM

(WITHOUT CURTAIN WALL)

$H_0 = 3.49$ $C_M = 3.49$ ———
 $P+E = 2.77$ $C_D = 3.77$ - - -

APPENDIX - FIG. IIA



BOYSEN DAM

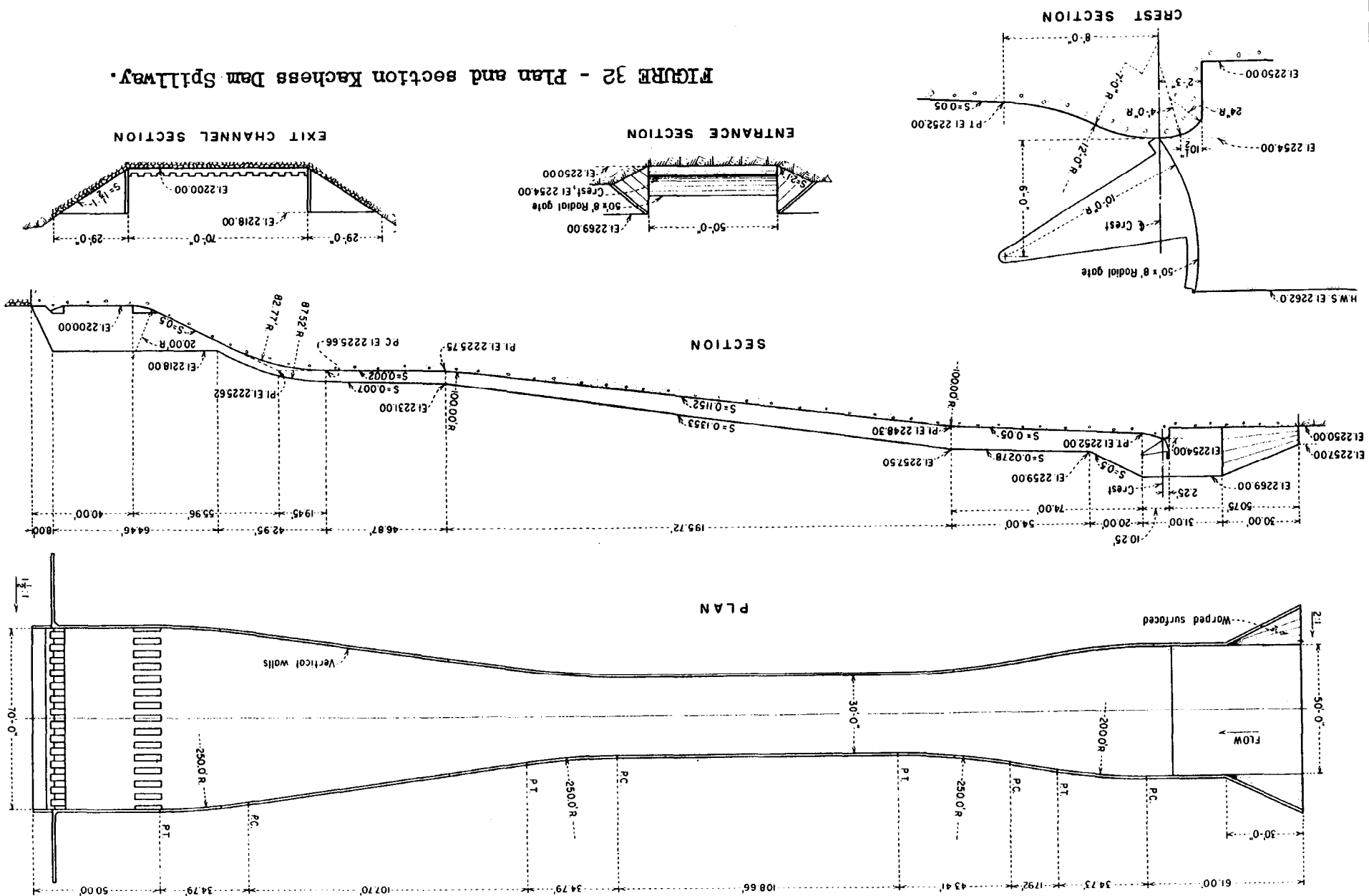
(FINAL DESIGN)

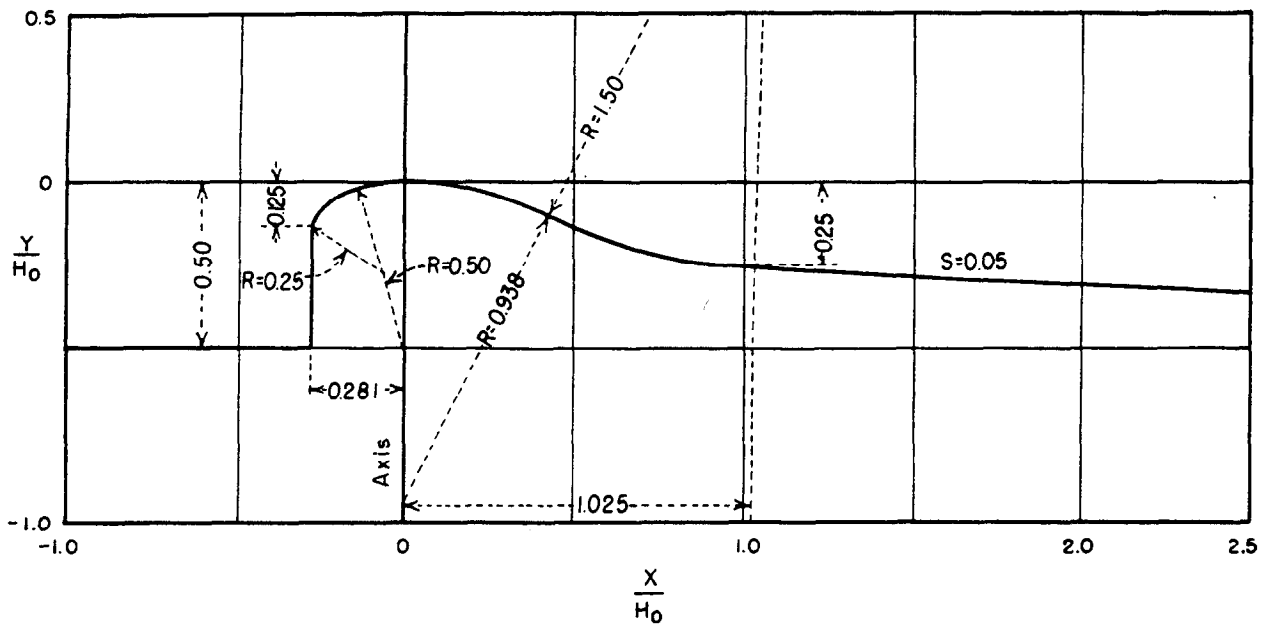
$H_0 = 5.20$ $C_M = 3.45$ ———
 $P+E = 4.51$ $C_D = 3.57$ - - -

APPENDIX - FIG. IIC

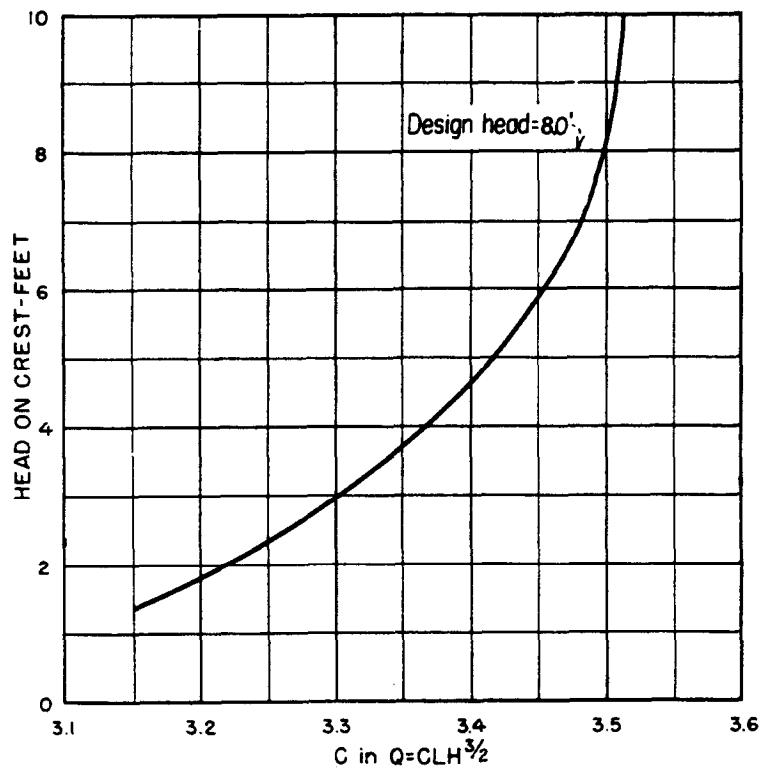
FIGURE 31 - Spillways with overfall suppressed.

FIGURE 32 - Plan and section Kachess Dam Spillway.



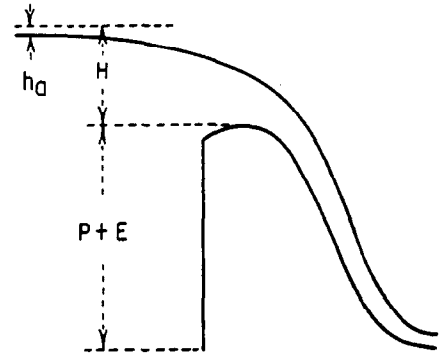
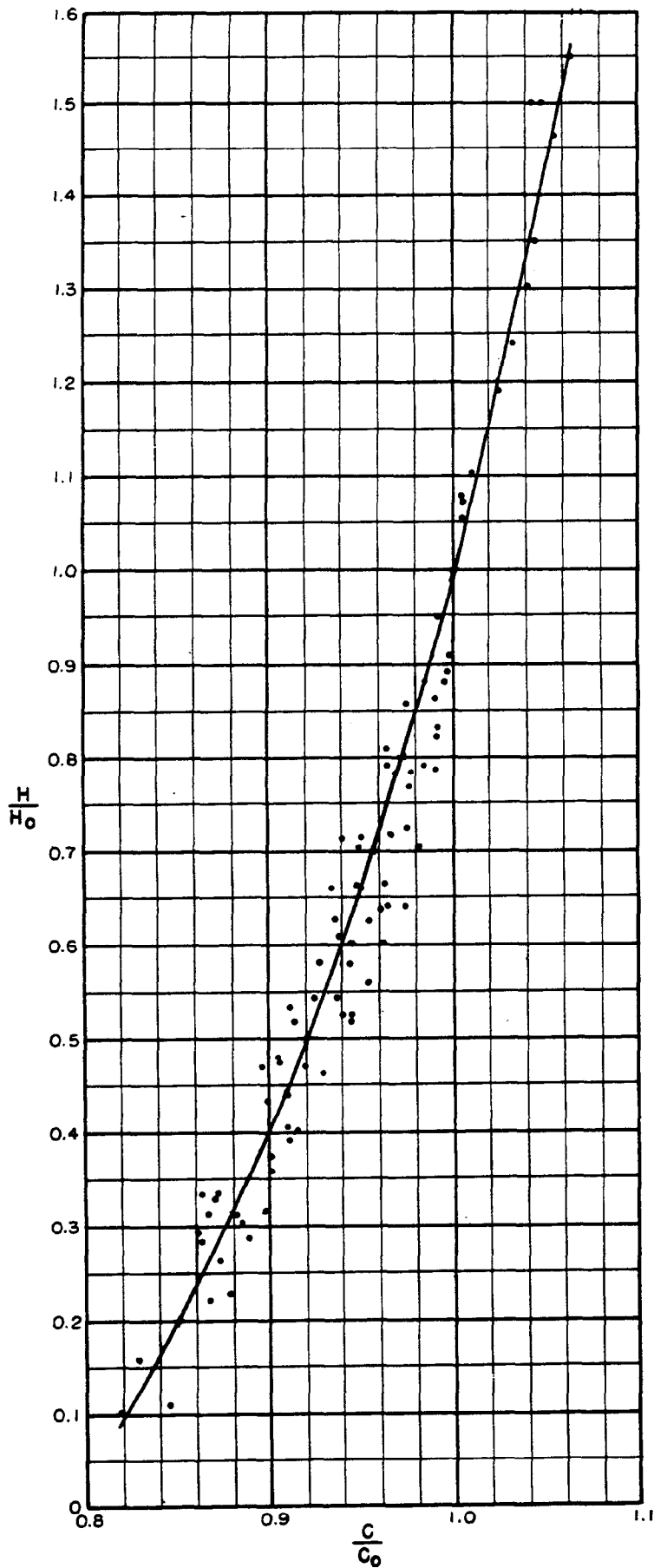


A- PROFILE OF GATE SECTION



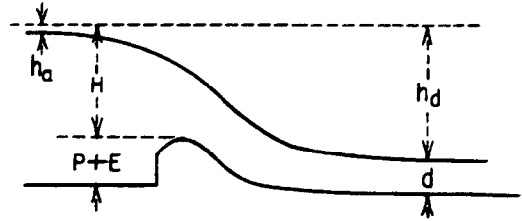
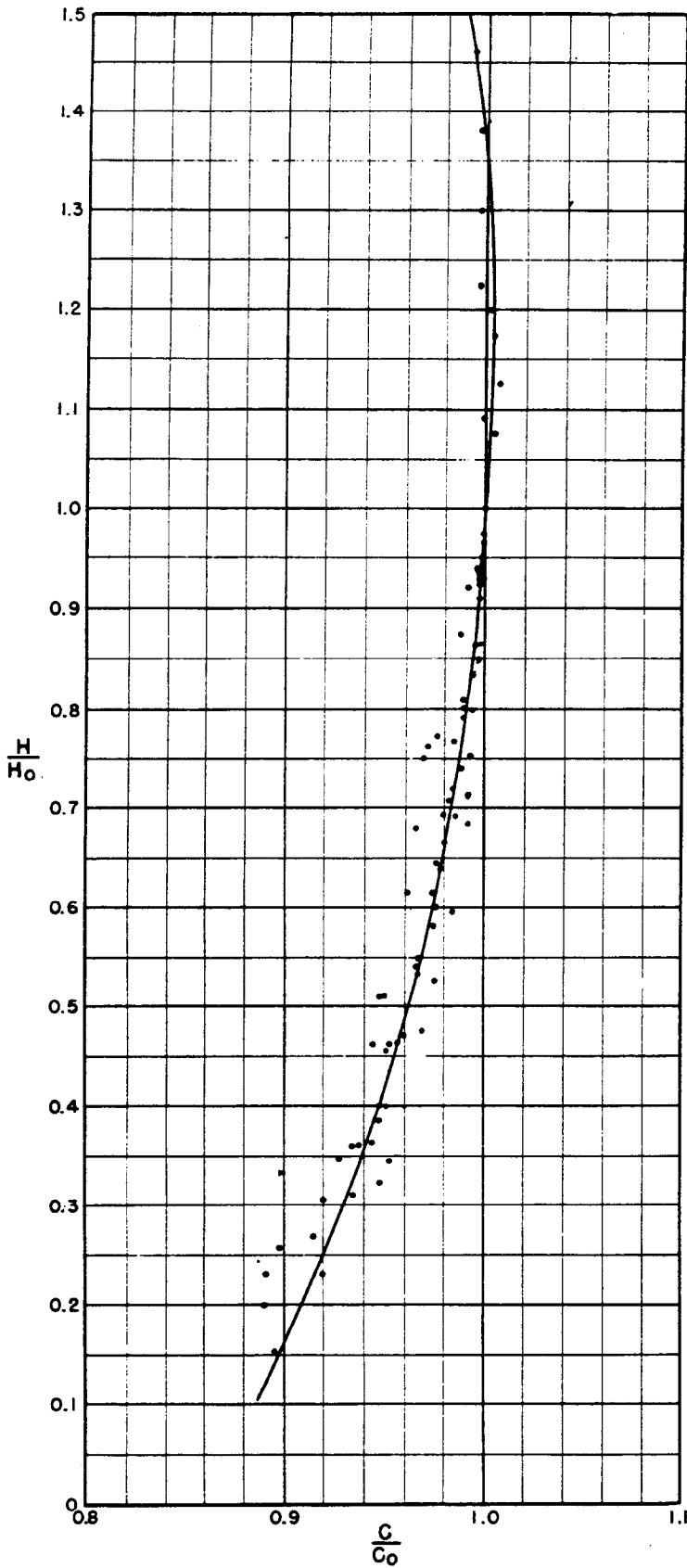
B- HEAD - COEFFICIENT CURVE

FIGURE 33 - Kachess Dam Spillway (Examples 2 and 4).



$\frac{H_0}{P+E}$	SPILLWAY
0.07	Shasta
.08	Friant
.09	Grand Coulee
.09	Bhakra
.09	Hoover S2-C3
.13	Norris
.14	Hiwassee
.22	Dos Bocas
.23	Capilano
.24	Madden
.26	Canyon Ferry
.27	Wilson
.31	Marshall Ford (Prelim)
.31	Marshall Ford (Final)
.37	Imperial
.42	Wheeler
.45	Angostura
.65	Moon Lake
.65	Davis (Prelim)
.65	Davis (Final)
.67	Hoover S7-C8
.67	Hoover S3-M1
.67	Hoover S8-C8
.67	Hoover S4-M3
.87	Medicine Creek (High)
.96	Cedar Bluff
1.20	Hamilton
1.50	Keswick
3.20	Trenton

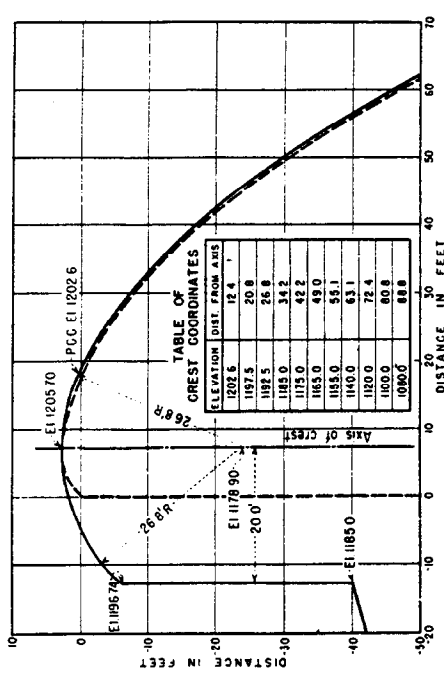
FIGURE 34 - Coefficients of discharge for other than the design head (free overfall spillways).



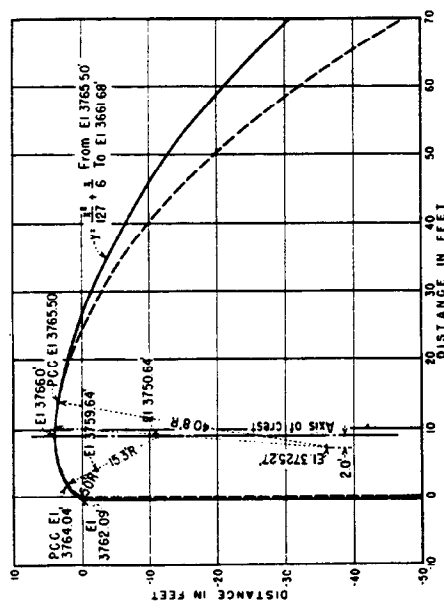
$\frac{H_0}{P+E}$	SPILLWAY	$\frac{h_d+d}{h_d+d}$ (Actual)	$\frac{h_d+d}{h_d+d}$ (Experimental)
17	Rye Patch		0.71
8	Alcova		.71
5.2	Boysen (Final)		.72
5.5	Green Mountain		.75
3.1	Scofield		.76
3.6	Bartlett		.76
4.8	Anderson Ranch		.76
5.0	Cachuma		.78
3.4	Falcon		.79
2.8	Unity		.79
2.8	Dickinson		.80
4.5	Medicine Creek (Low)		.80
2.4	Boca		.83
1.3	Fresno		.84
3.7	Boysen (Prelim.)		.85
2.6	Caballo		.86

FIGURE 35 - Coefficients of discharge for other than the design head (spillways with overfall suppressed).

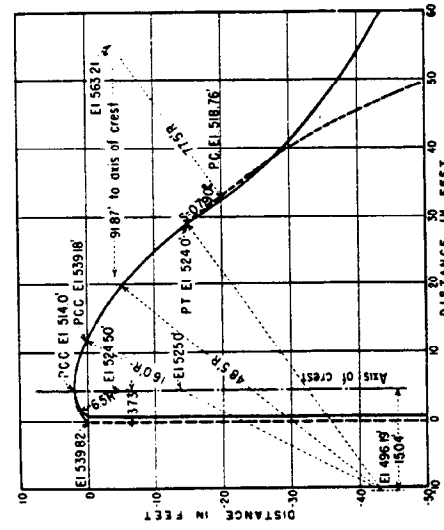
APPENDIX



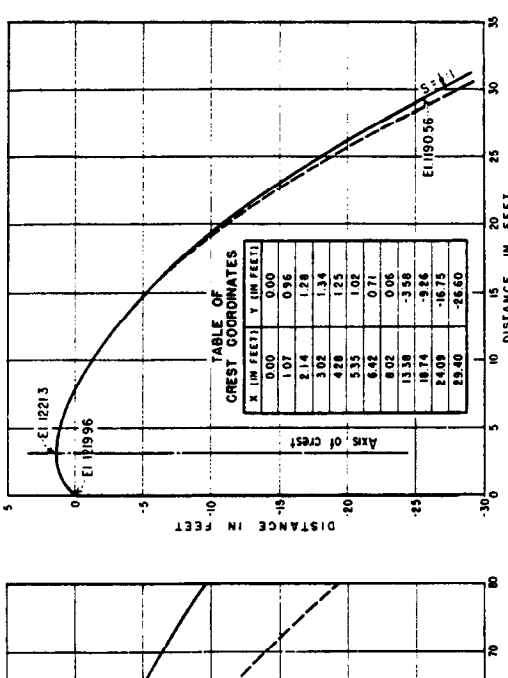
A. WHEELER DAM SPILLWAY
 MODEL SCALE 1:36
 RES. ELEV. 556.0
 $C_d = 3.99$ --- MODEL
 $C_d = 3.99$ --- DATUM
 $P \cdot E = 40.0'$
 $H_0 = 17.0'$



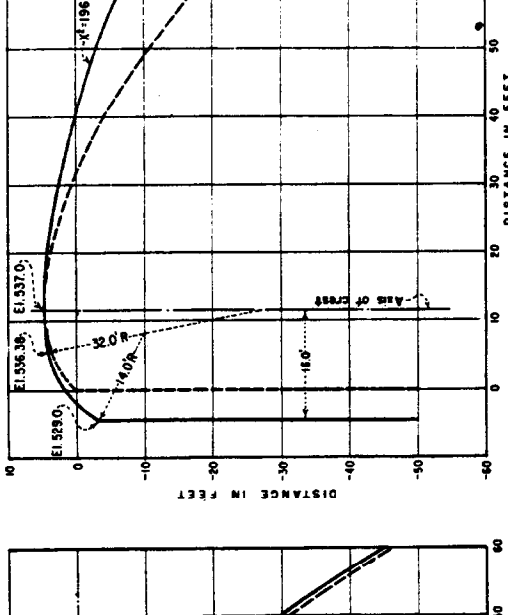
B. CANYON FERRY DAM SPILLWAY
 MODEL SCALE 1:80
 RES. ELEV. 3800.0
 $C_d = 3.70$ --- MODEL
 $C_d = 3.98$ --- DATUM
 $P \cdot E = 130.0'$
 $H_0 = 34.0'$



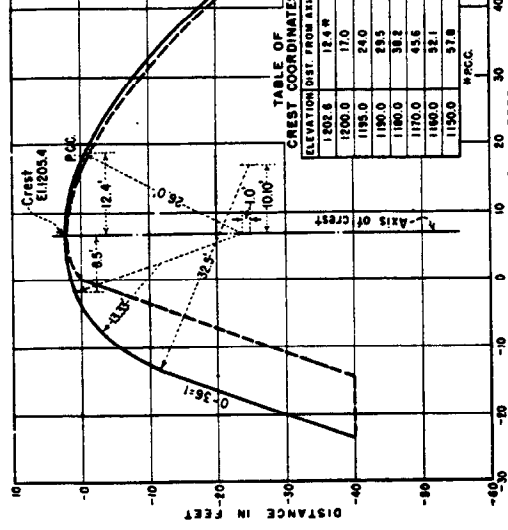
C. HOOVER DAM SPILLWAY
 SHAPE 2 SCAL MODEL W1
 RES. ELEV. 1232.00
 $C_d = 5.58$ --- MODEL
 $C_d = 5.93$ --- DATUM
 $P \cdot E = 40.0'$
 $H_0 = 26.6'$



D. HOOVER DAM SPILLWAY
 SHAPE 7 MODEL C-8
 MODEL SCALE 1:20
 RES. ELEV. 1232.0
 $C_d = 3.99$ --- MODEL
 $C_d = 3.99$ --- DATUM
 $P \cdot E = 40.0'$
 $H_0 = 26.6'$

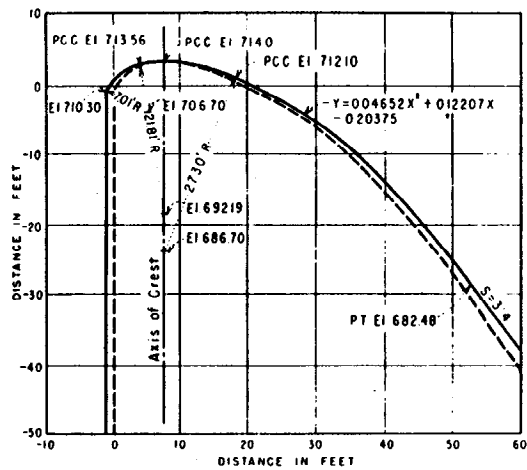


E. KESWICK DAM SPILLWAY
 MODEL SCALE 1:80
 RES. ELEV. 1370.0
 $C_d = 3.88$ --- MODEL
 $C_d = 3.88$ --- DATUM
 $P \cdot E = 134.0'$
 $H_0 = 30.0'$



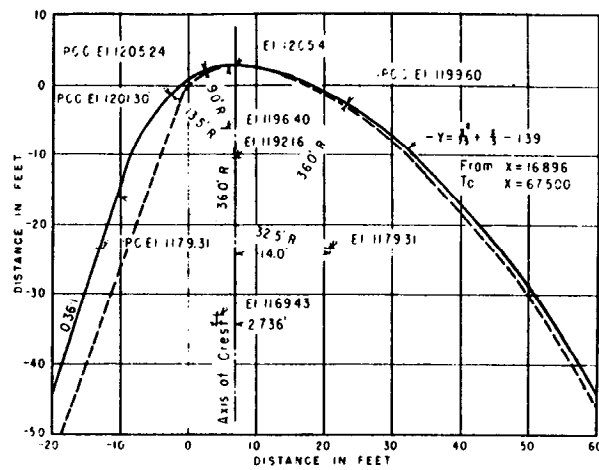
F. HOOVER DAM SPILLWAY
 SHAPE 2 SCAL MODEL C-3
 MODEL SCALE 1:20
 RES. ELEV. 1232.00
 $C_d = 5.58$ --- MODEL
 $C_d = 5.93$ --- DATUM
 $P \cdot E = 40.0'$
 $H_0 = 26.6'$

**FIGURE 1 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 for spillways with vertical upstream face**



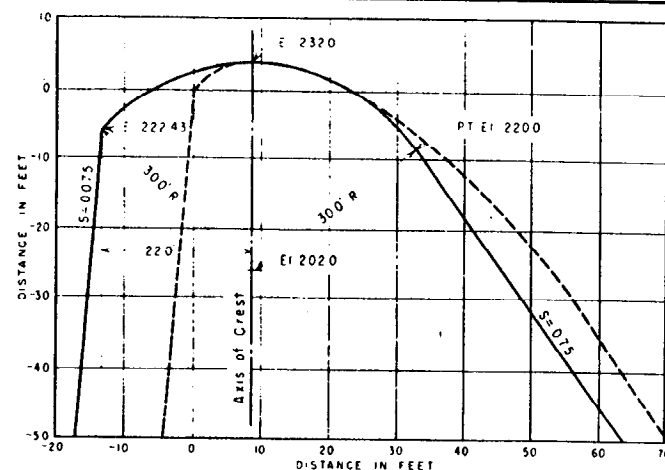
A. MARSHALL FORD DAM SPILLWAY

(FINAL DESIGN)
 MODEL SCALE 1:408
 RES. ELEV. 742.0
 P+E = 214.0' C_d = 1.93 — MODEL
 H_o = 26.0' C_d = 3.97 — DATUM



B. HOOVER DAM SPILLWAY

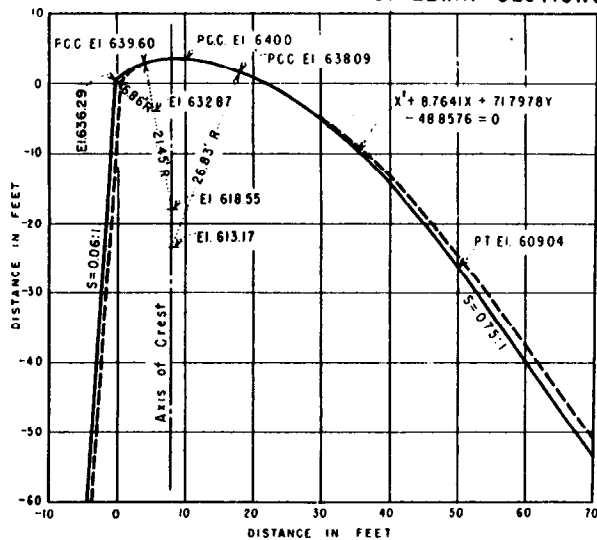
SHAPE B — FINAL MODEL C-8
 MODEL SCALE 1:220
 RES. ELEV. 1232.0
 P+E = 400' C_d = 3.85 — MODEL
 H_o = 26.6' C_d = 3.92 — DATUM



C. MADDEN DAM SPILLWAY

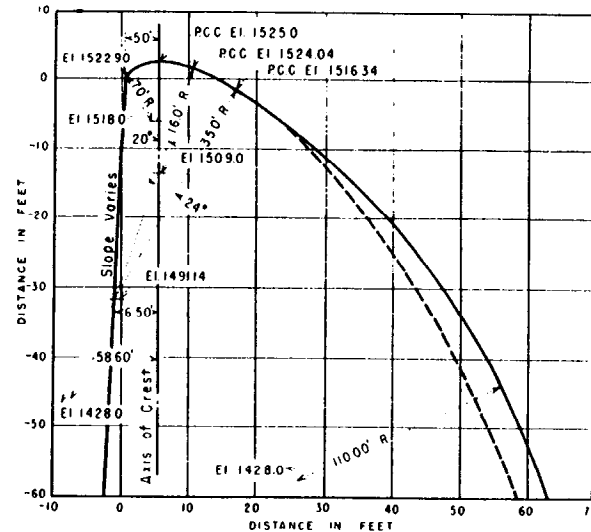
MODEL SCALE 1:72
 RES. ELEV. 263.4
 P+E = 132.0' C_d = 3.71 — MODEL
 H_o = 31.4' C_d = 3.97 — DATUM

SPILLWAY SECTIONS WITH VERTICAL UPSTREAM FACE



D. MARSHALL FORD DAM SPILLWAY

(INITIAL DESIGN)
 MODEL SCALE 1:408
 RES. ELEV. 670.0
 P+E = 140.0' C_d = 3.96 — MODEL
 H_o = 30.0' C_d = 3.95 — DATUM



E. ROSS DAM SPILLWAY

(2nd STEP)
 MODEL SCALE 1:60
 RES. ELEV. 1545.0
 P+E = 125.0' C_d = 3.84 — MODEL
 H_o = 20.0' C_d = 3.97 — DATUM

SPILLWAY SECTIONS WITH SLOPING UPSTREAM FACE

**FIGURE 2 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 for spillway sections with vertical and
 sloping upstream faces**

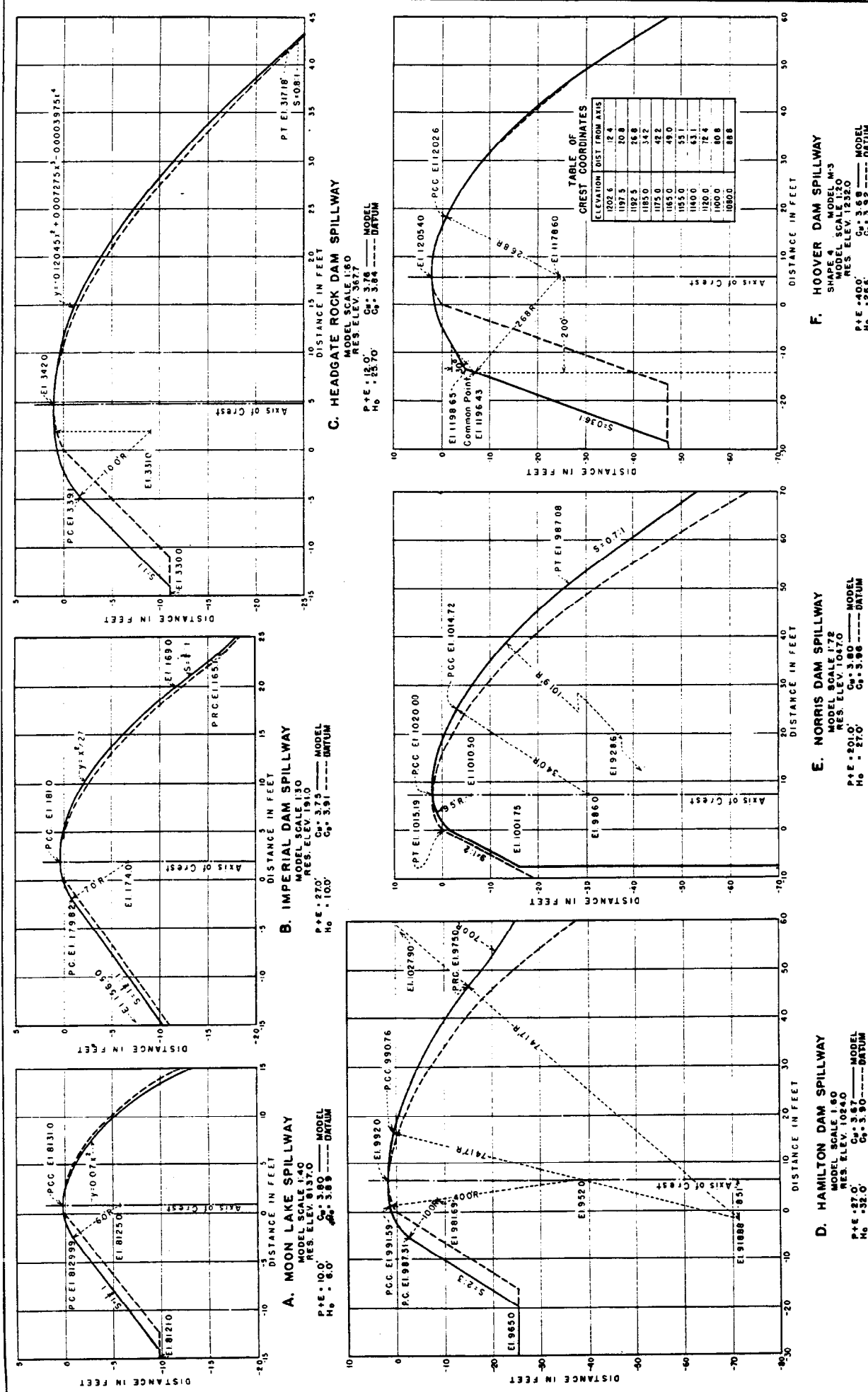
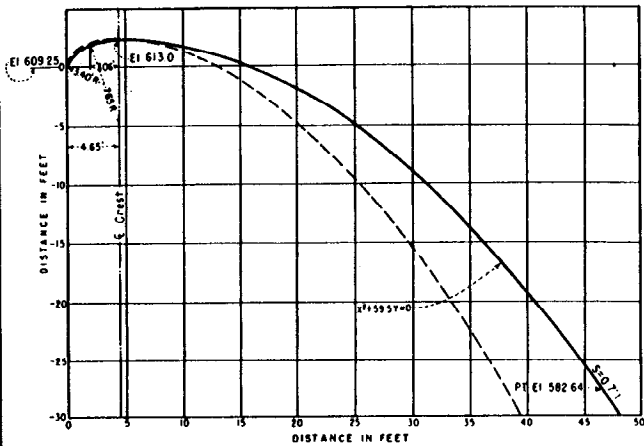
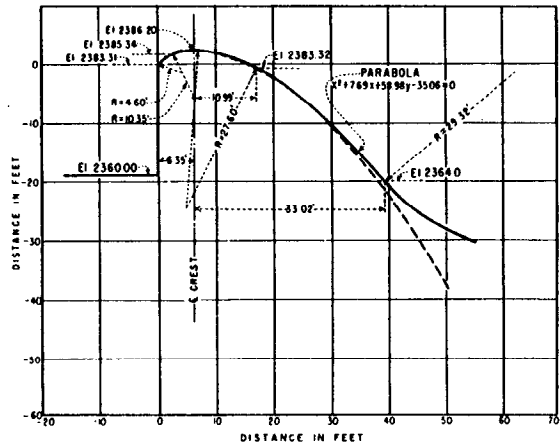


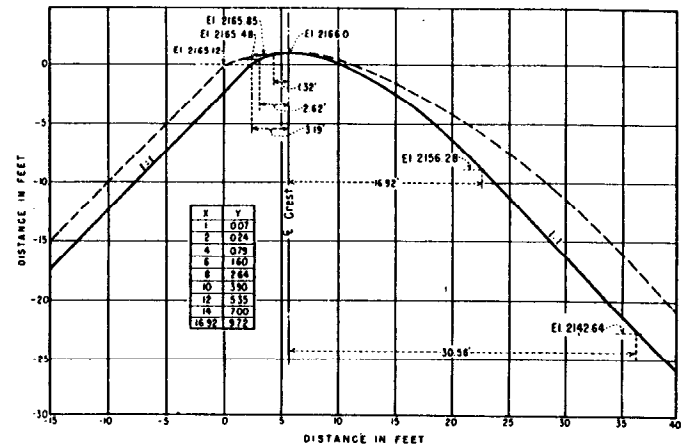
FIGURE 3 - Comparison of discharge coefficients Model coefficient versus datum coefficient for spillways with sloping upstream faces



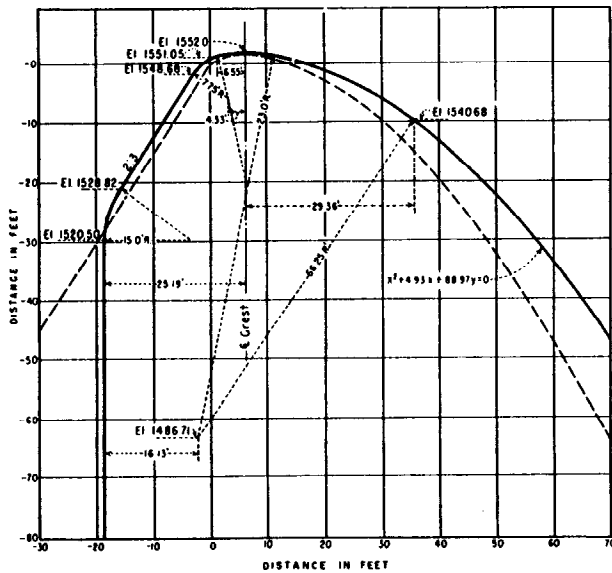
A. HIRAKUD DAM SPILLWAY
 MODEL SCALE 1:40
 RES. ELEV. 830.0
 $H_0 = 17.0'$ $C_m = 3.70$ — MODEL
 $P+E=103'$ $C_d = 3.97$ — DATUM



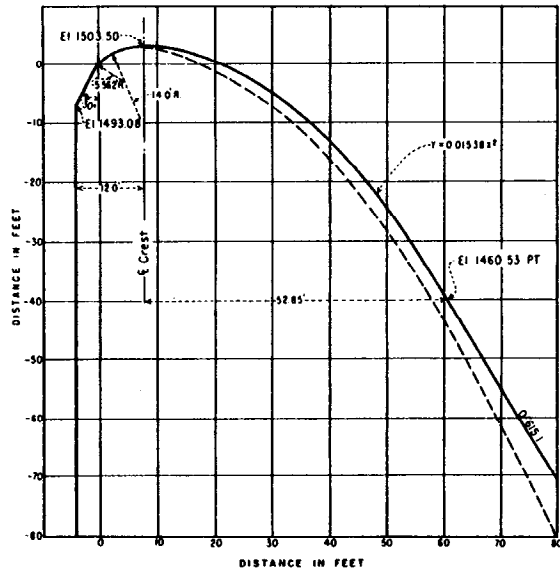
B. MEDICINE CREEK DAM SPILLWAY (HIGH CREST)
 MODEL SCALE 1:60
 RES. ELEV. 2408.90
 $H_0 = 22.7'$ $C_m = 3.90$ — MODEL
 $P+E=26.2'$ $C_d = 3.90$ — DATUM



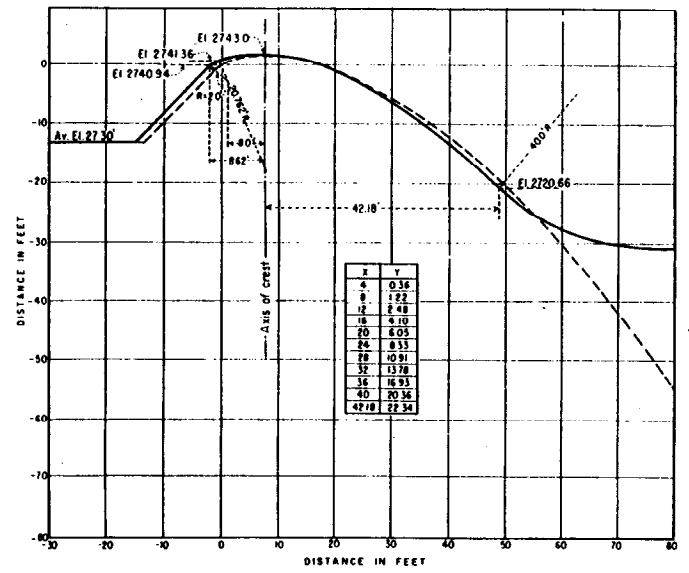
C. CEDAR BLUFF DAM SPILLWAY
 MODEL SCALE 1:48
 RES. ELEV. 2193.0
 $H_0 = 27'$ $C_m = 4.02$ — MODEL
 $P+E=28'$ $C_d = 3.88$ — DATUM



D. BHAKRA DAM SPILLWAY (PUNJAB PROVINCE INDIA)
 MODEL SCALE 1:32
 RES. ELEV. 1590.0
 $H_0 = 28.0'$ $C_m = 3.68$ — MODEL
 $P+E=302'$ $C_d = 3.95$ — DATUM

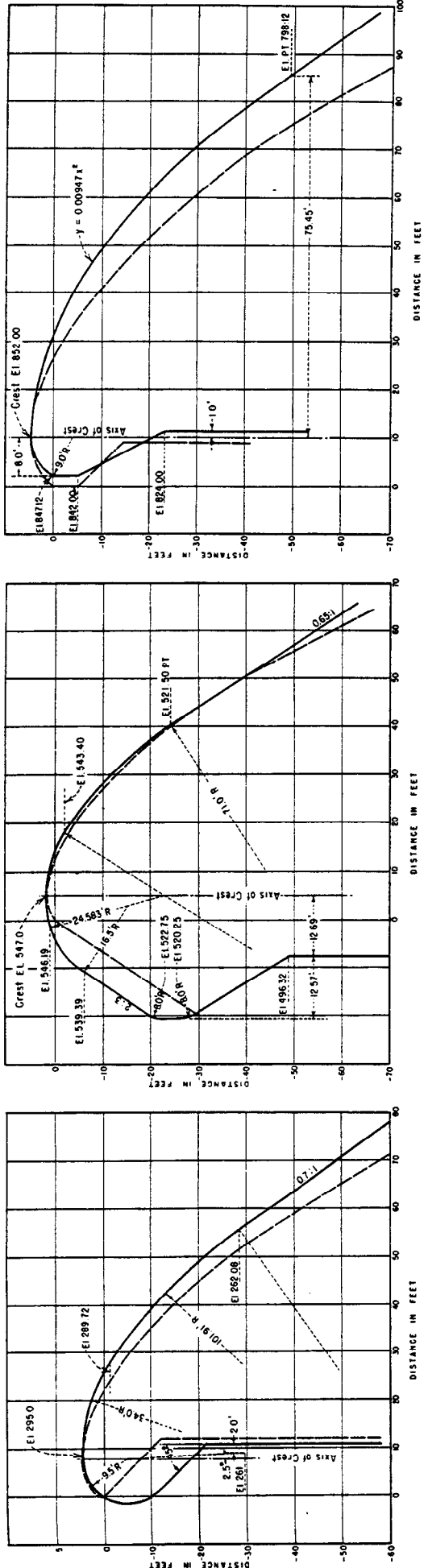


E. HIWASSEE DAM SPILLWAY
 MODEL SCALE 1:55
 RES. ELEV. 1532.00
 $H_0 = 28.5'$ $C_m = 3.82$ — MODEL
 $P+E=203.5'$ $C_d = 3.88$ — DATUM

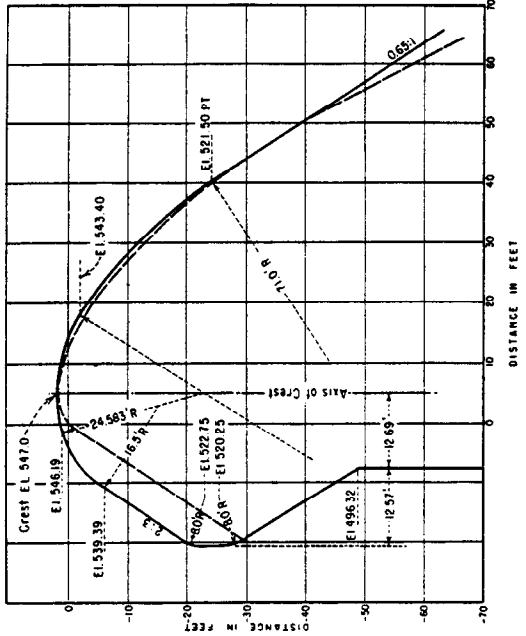


F. TRENTON DAM SPILLWAY
 MODEL SCALE 1:54
 RES. ELEV. 2785.00
 $H_0 = 42'$ $C_m = 3.68$ — MODEL
 $P+E=15'$ $C_d = 3.76$ — DATUM

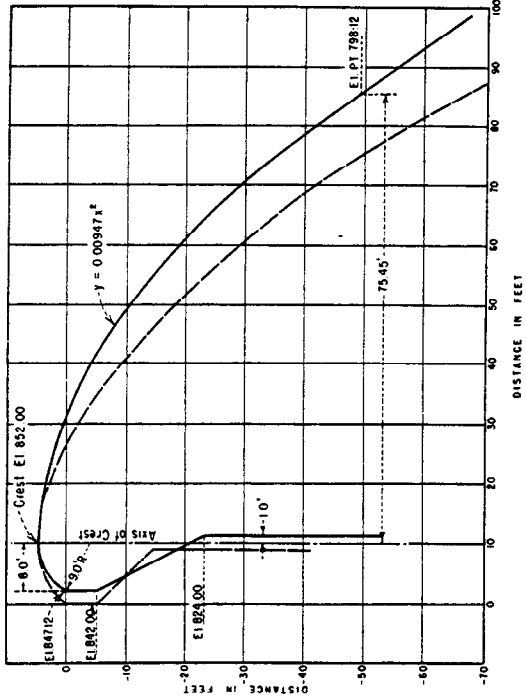
**FIGURE 4 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 Miscellaneous spillway shapes**



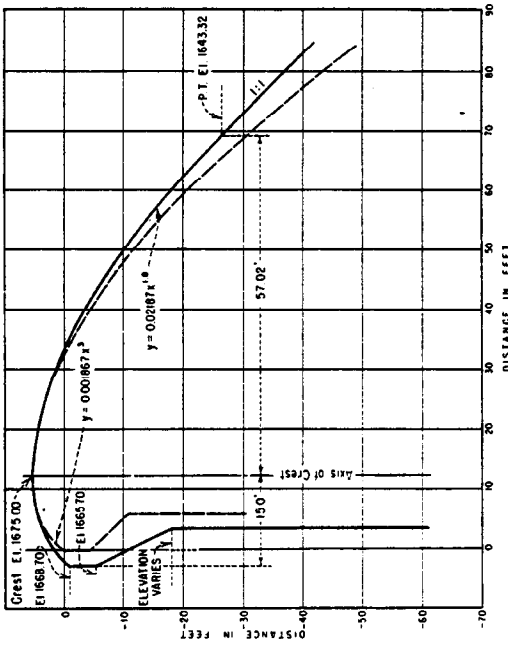
A. DOS BOGAS DAM SPILLWAY
 MODEL SCALE 1:30
 RES. ELEV. 2950.00
 $P + E = 155'$ $C_m = 3.95$ $C_b = 3.97$ MODEL
 $H_0 = 27.85'$ DATUM



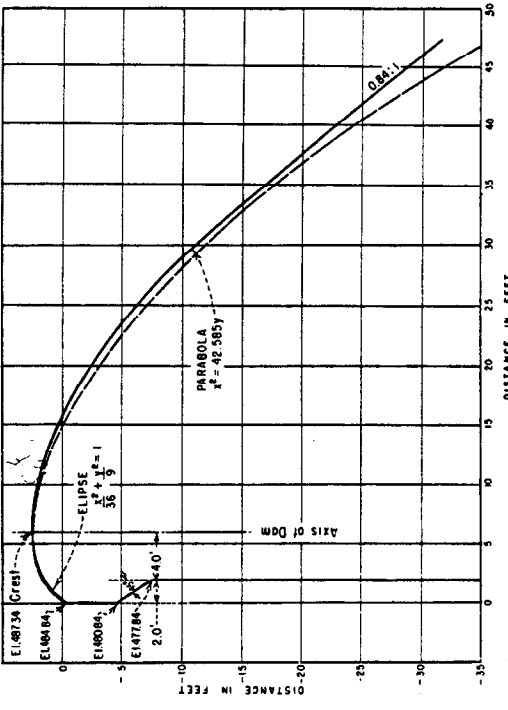
B. CAPILANO DAM SPILLWAY
 MODEL SCALE 1:30
 RES. ELEV. 5470.00
 $P + E = 100$ $C_m = 3.62$ $C_b = 3.50$ MODEL
 $H_0 = 23.0'$ DATUM



C. RIHARD DAM SPILLWAY
 MODEL SCALE 1:72
 RES. ELEV. 866.00
 $P + E = 202'$ $C_m = 3.75$ $C_b = 3.98$ MODEL
 $H_0 = 36'$ DATUM

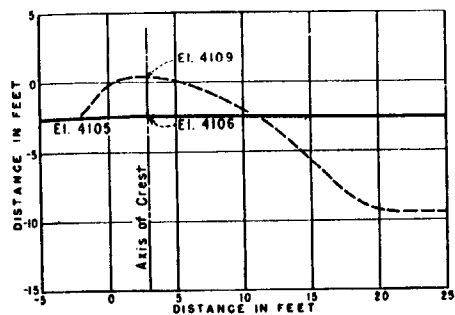


D. FONTANA DAM SPILLWAY
 MODEL SCALE 1:31
 RES. ELEV. 1720.00
 $P + E = 130'$ $C_m = 3.77$ $C_b = 3.97$ MODEL
 $H_0 = 45.0'$ DATUM



E. WILSON DAM SPILLWAY
 MODEL SCALE 1:30.4
 RES. ELEV. 507.88
 $P + E = 77.3$ $C_m = 3.92$ $C_b = 3.98$ MODEL
 $H_0 = 20.54'$ DATUM

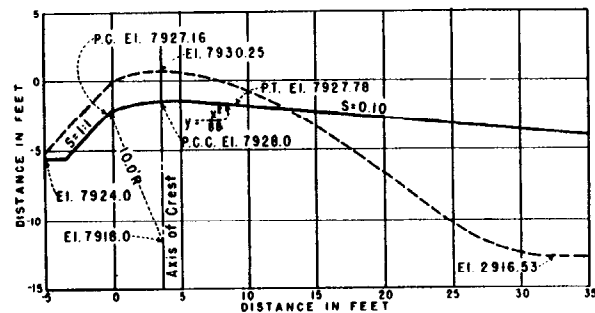
**FIGURE 6 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 for spillways with offset in upstream face**



A. RYE PATCH DAM SPILLWAY

MODEL SCALE 1:50
RES. ELEV. 4123.0

H_0	P+E	C_d	MODEL
17	1	2.81	MODEL
14.1	4	3.77	DATUM



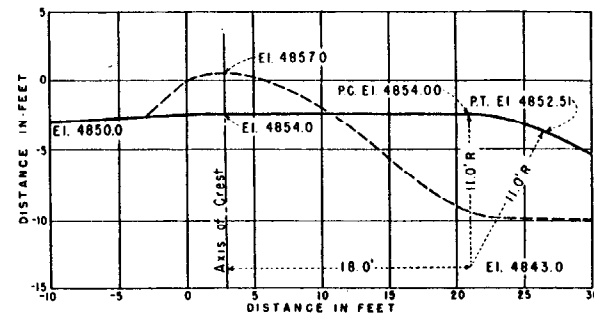
B. GREEN MOUNTAIN DAM SPILLWAY

(FINAL DESIGN)

MODEL SCALE 1:40
RES. ELEV. 7950.0

H_0	P+E	C_d	MODEL
22.0	4.0	3.21	MODEL
19.75	6.25	3.78	DATUM

CONTRACTION D.S. FROM GATE SECTION

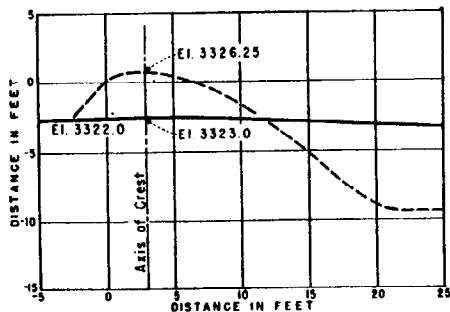


C. PINE VIEW DAM SPILLWAY

MODEL SCALE 1:30
RES. ELEV. 4870.0

H_0	P+E	C_d	MODEL
16	4	2.74	MODEL
12.9	7.1	3.86	DATUM

CONTRACTION D.S. FROM GATE SECTION

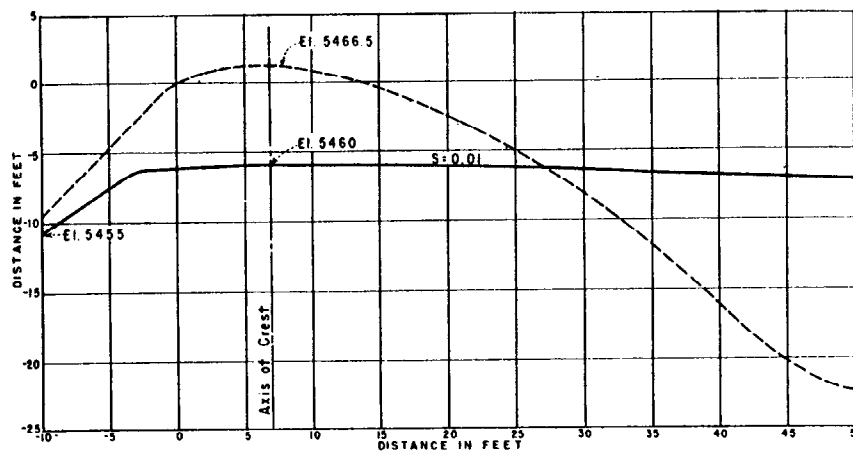


D. AGENCY VALLEY SPILLWAY

MODEL SCALE 1:30
RES. ELEV. 3340.0

H_0	P+E	C_d	MODEL
17	1	2.73	MODEL
13.75	4.25	3.78	DATUM

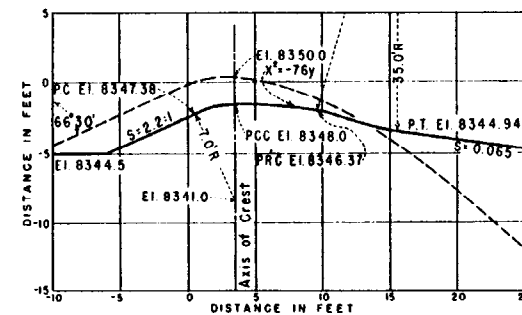
CONTRACTION D.S. FROM GATE SECTION



E. ALGOVA DAM SPILLWAY

MODEL SCALE 1:72
RES. ELEV. 5500.0

H_0	P+E	C_d	MODEL
40	5	2.85	MODEL
33.5	11.5	3.80	DATUM

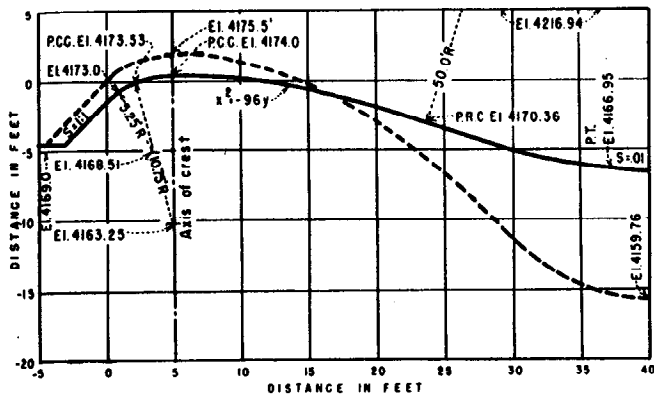


F. SHADOW MOUNTAIN DAM SPILLWAY

MODEL SCALE 1:30
RES. ELEV. 8367.0

H_0	P+E	C_d	MODEL
19	3.5	3.30	MODEL
17.1	5.4	3.78	DATUM

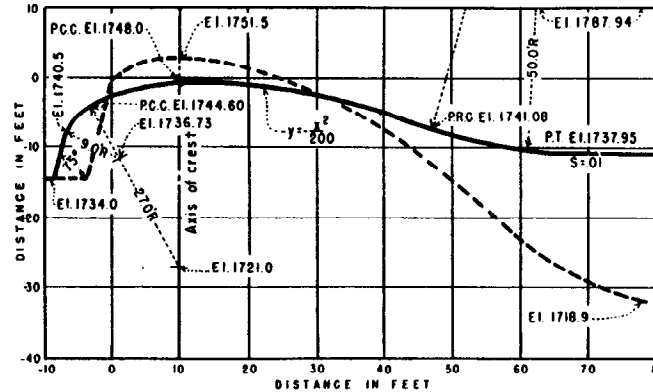
**FIGURE 7 - Comparison of discharge coefficients
Model coefficient versus datum coefficient
for earth dam spillway sections with
shallow approach depth**



A. ANDERSON RANCH DAM SPILLWAY

(FINAL DESIGN)
 MODEL SCALE 1:48
 RES. ELEV. 4196.0

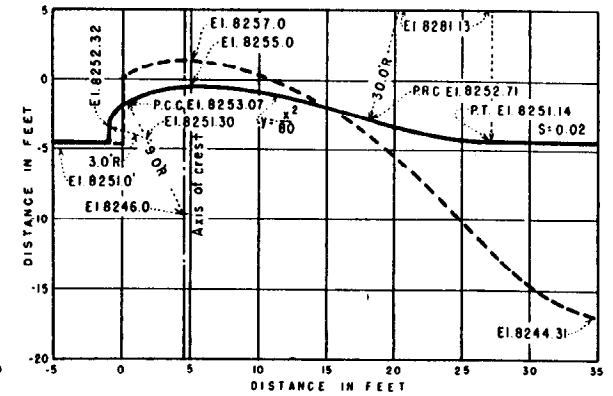
H_0	P+E	C_d	MODEL
24	5	3.40	—
22.5	6.5	3.76	- - - DATUM



B. BARTLETT DAM SPILLWAY

(FINAL DESIGN)
 MODEL SCALE 1:100
 RES. ELEV. 1798.0

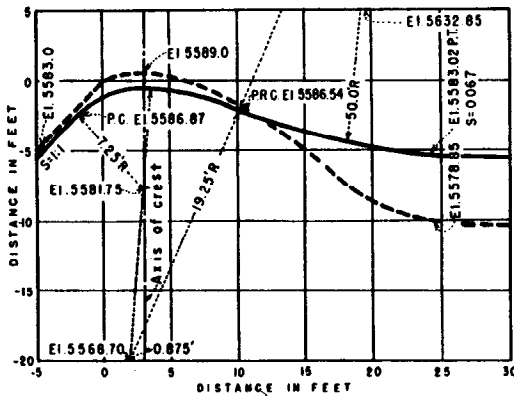
H_0	P+E	C_d	MODEL
50	14	3.48	—
48.4	17.6	3.76	- - - DATUM



C. GRANBY DAM SPILLWAY

(FINAL DESIGN)
 MODEL SCALE 1:48
 RES. ELEV. 8273.0

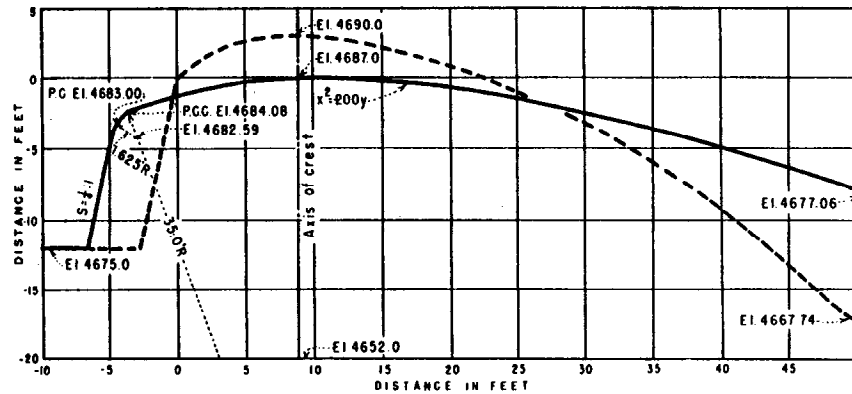
H_0	P+E	C_d	MODEL
20	4	3.20	—
18.1	5.9	3.71	- - - DATUM



D. BOCA DAM SPILLWAY

(FINAL DESIGN)
 MODEL SCALE 1:48
 RES. ELEV. 5603.40

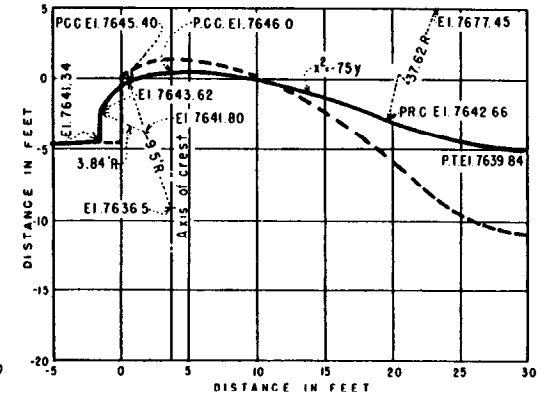
H_0	P+E	C_d	MODEL
19.4	8	3.50	—
14.6	8.8	3.81	- - - DATUM



E. BOYSEN DAM SPILLWAY

(PRELIMINARY DESIGN)
 MODEL SCALE 1:60
 RES. ELEV. 4731.5

H_0	P+E	C_d	MODEL
44.5	12	3.37	—
41.4	15.1	3.76	- - - DATUM



F. VALLECITO DAM SPILLWAY

(FINAL DESIGN)
 MODEL SCALE 1:60
 RES. ELEV. 7665.0

H_0	P+E	C_d	MODEL
19	5	3.42	—
18	6	3.72	- - - DATUM

CONTRACTION D.S. FROM GATE SECTION

**FIGURE 8 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 for earth dam spillway sections with
 shallow approach depth**

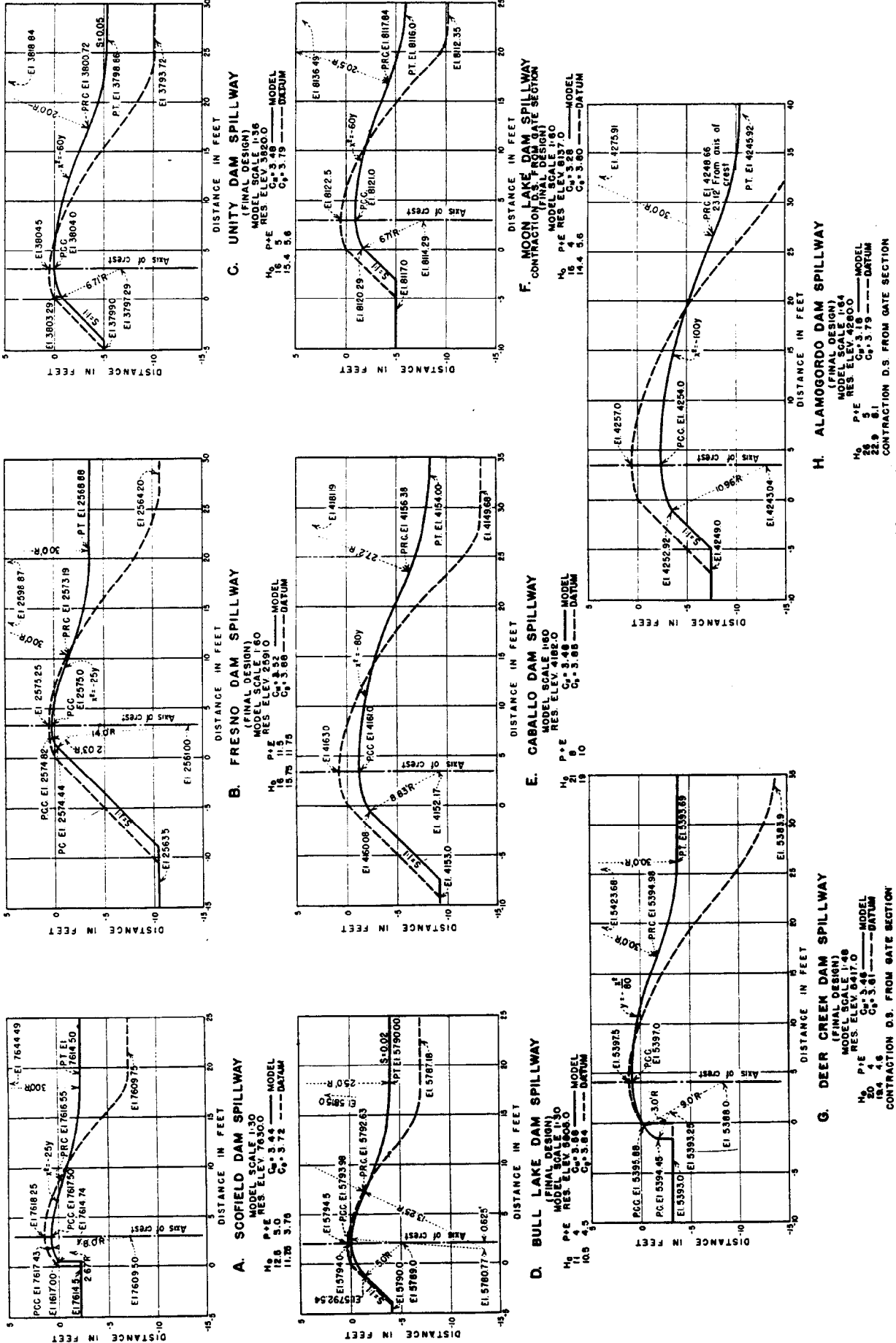
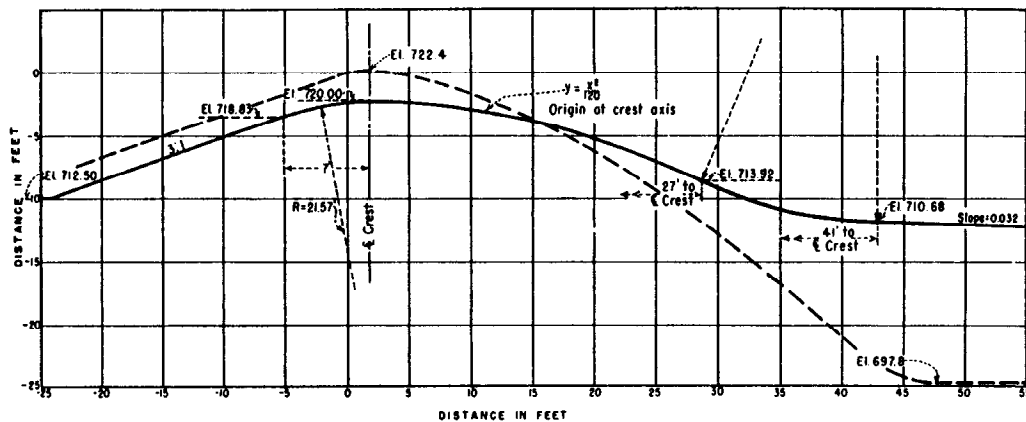
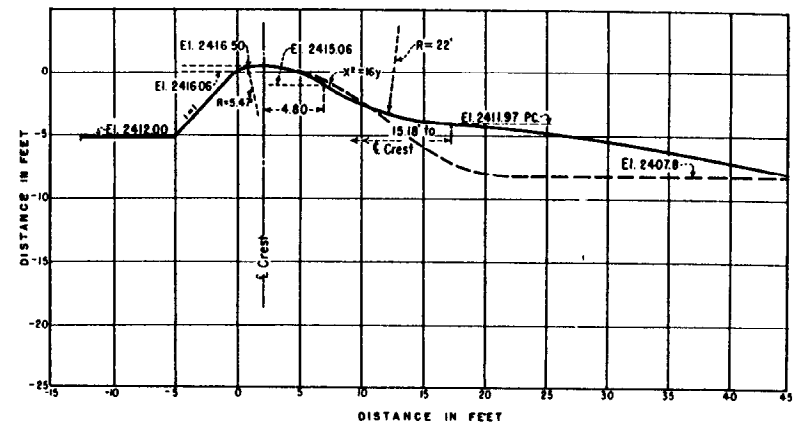


FIGURE 9 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 for earth dam spillway sections with
 shallow approach depth



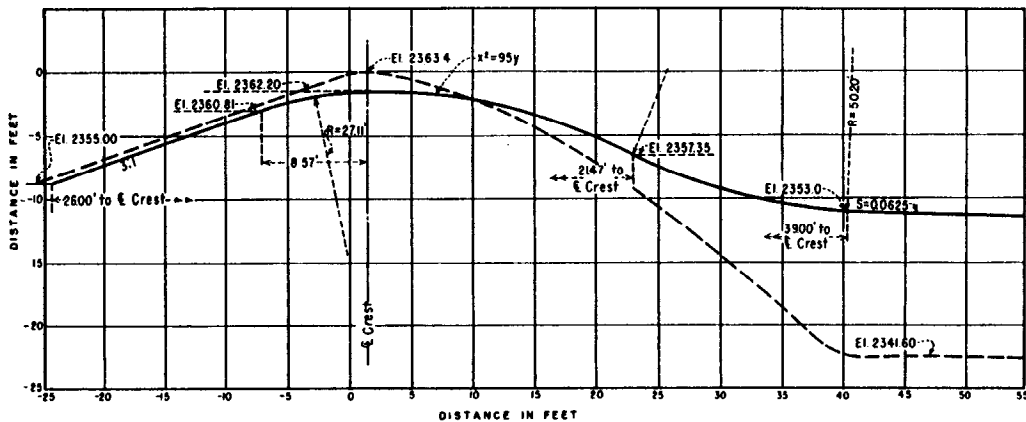
A. CACHUMA DAM SPILLWAY
 MODEL SCALE 1:60
 RES. ELEV. 757.6

H ₀	P+E	C _m	MODEL
37.6'	7.5'	3.42	—
38.2'	9.9'	3.76	- - - DATUM



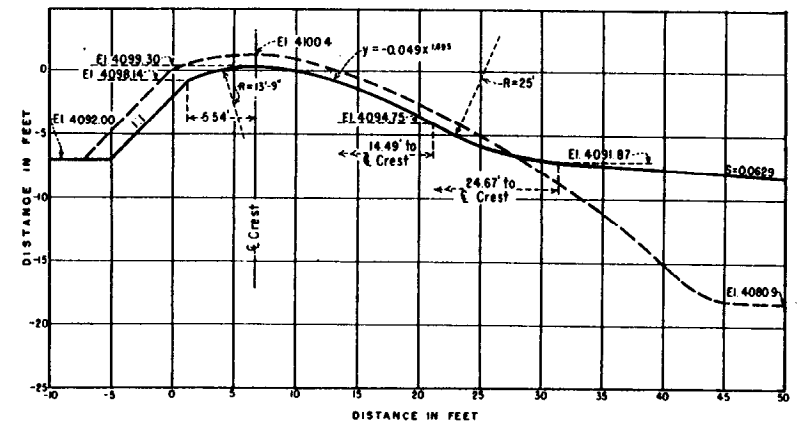
B. DICKINSON DAM SPILLWAY
 MODEL SCALE 1:36
 RES. ELEV. 2428.90

H ₀	P+E	C _m	MODEL
12.4	4.5	3.75	—
12.4	4.5	3.80	- - - DATUM



C. MEDICINE CREEK DAM SPILLWAY (LOW CREST)
 MODEL SCALE 1:60
 RES. ELEV. 2394.80

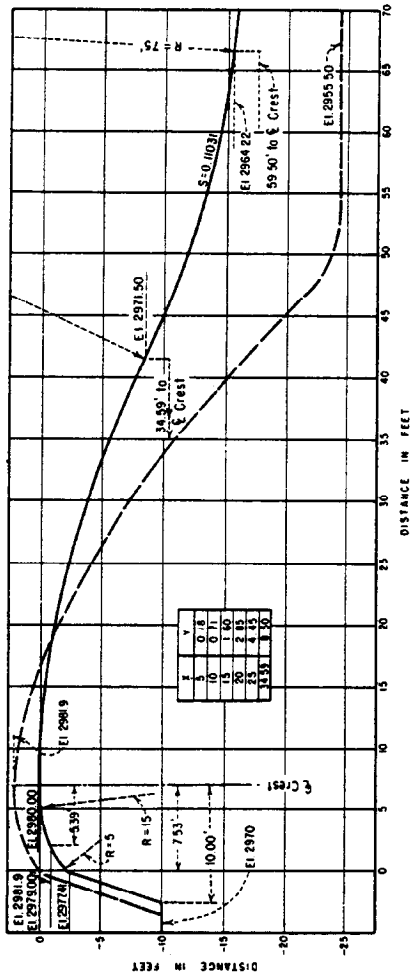
H ₀	P+E	C _m	MODEL
32.6	7.2	3.64	—
31.4	6.4	3.73	- - - DATUM



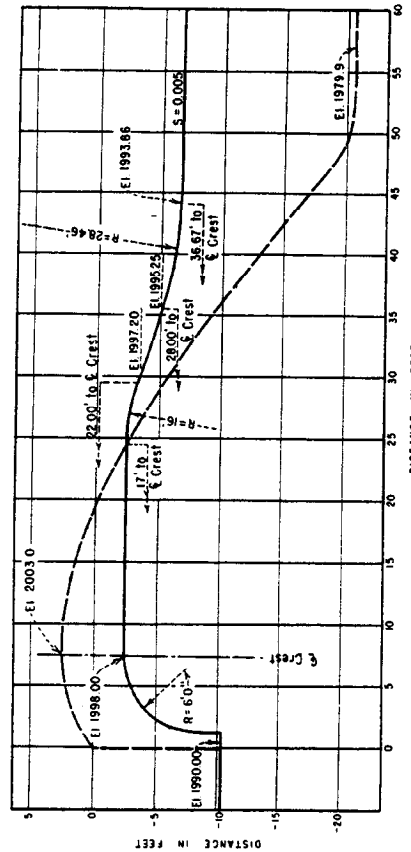
D. KEYHOLE DAM SPILLWAY
 MODEL SCALE 1:24
 RES. ELEV. 4128.20

H ₀	P+E	C _m	MODEL
28.9	7.3	3.58	—
27.8	6.4	3.73	- - - DATUM

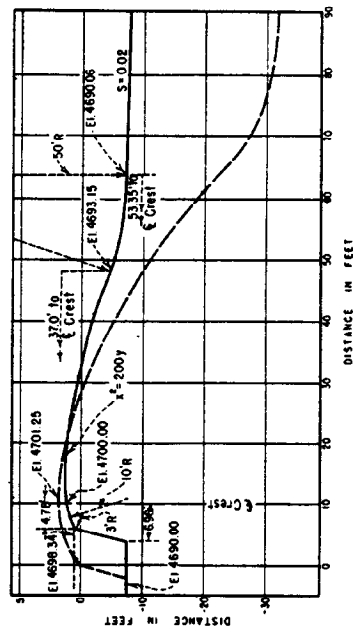
**FIGURE 10 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 for earth dam spillway sections with
 shallow approach depth**



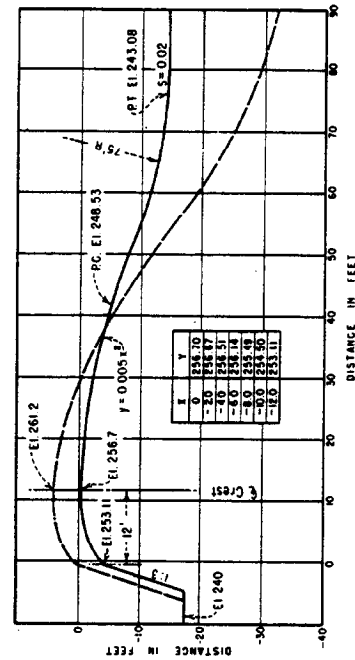
A. TIBER DAM SPILLWAY (WITHOUT CURTAIN WALL)
 MODEL SCALE 1:48
 RES. ELEV. 3014.90
 No. 34.9 P+E 10 Cm = 3.49 Model 33.0 Datum 11.9 Cb = 3.77



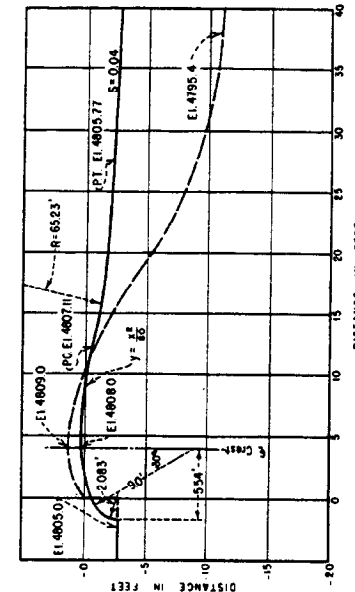
B. HORSESHOE DAM SPILLWAY
 MODEL SCALE 1:60
 RES. ELEV. 2036.0
 No. 38.0 P+E 8.0 Cm = 3.20 Model 33.0 Datum 13.0 Cb = 3.74



C. BOYSER DAM SPILLWAY
 MODEL SCALE 1:48
 RES. ELEV. 4752.0
 No. 52.0 P+E 10.0 Cm = 3.45 Model 50.75 Datum 11.25 Cb = 3.37



D. FALCON DAM SPILLWAY
 MODEL SCALE 1:130
 RES. ELEV. 314.2
 No. 57.0 P+E 21.2 Cm = 3.33 Model 53.0 Datum 21.2 Cb = 3.78



E. CASCADE DAM SPILLWAY
 MODEL SCALE 1:30
 RES. ELEV. 4828.0
 No. 19.0 P+E 3.0 Cm = 3.38 Model 20.0 Datum 4.0 Cb = 3.57

**FIGURE 11 - Comparison of discharge coefficients
 Model coefficient versus datum coefficient
 for earth dam spillway sections with
 shallow approach depth**

