ENGINEERING MONOGRAPH No. 9

United States Department of the Interior
BUREAU OF RECLAMATION

DISCHARGE COEFFICIENTS FOR IRREGULAR OVERFALL SPILLWAYS

By J. N. Bradley

Denver, Colorado

March 1952

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DISCHARGE COEFFICIENTS FOR IRREGULAR 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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APPENDIX

Engineering Monograph No. 9 was written in 1952. Its methods for estimating the values of discharge coefficients for overfall spillways have been largely supplanted by newer methods described in ***Design of Small Dams*** (1st ed. 1960, 2nd ed. 1977, 3rd ed. 1987).

EM-9 summarized results of tests on a range of ogee-type spillway crests. The monograph describes a procedure for estimating discharge coefficients that begins with comparison of the spillway shape to that of previously tested designs. The design discharge coefficient is then set to that of the matching previously tested or calibrated design. Once the design discharge coefficient is set, discharge coefficient adjustments for operation at other heads (different from the design head, Ho) are made by deciding whether the spillway shape is "unsuppressed" (free discharge) or suppressed (affected by a raised elevation of the discharge apron) using either Figure 34 or Figure 35, respectively. Clear criteria for making this decision are not given, but it is suggested that low Ho/(P+E) values indicate free flow, while high values indicate suppressed flow. In the range of 1.3-2.2, it is not clear which curve should be used. Figure 35 shows that operation at reduced heads will cause less reduction of discharge for a crest that is suppressed, which is at first counterintuitive, but makes sense when one considers that overfall suppression has already been accounted for in the shape matching process (especially if matching the downstream apron level is emphasized, as suggested by EM-9), and there are probably "degrees" of suppression, so reducing the operating head probably leads a suppressed crest to be less suppressed and behave more like a free-flow crest.

Design of Small Dams takes a different approach. The design head of a given shape can be determined by curve matching to ideal nappe shapes (Fig. 9-21A or Fig. 9-22). Next, a base coefficient can be determined by use of Figs. 9-23 (vertical upstream face) and 9-25 (inclined upstream faces). The effects of operation at other heads are then accounted for with Fig. 9-24. Finally, effects of overfall suppression by the downstream apron AND tailwater submergence are evaluated with Figs. 9-26 (combined apron and tailwater effects), 9-27 (apron effects only) or 9-28 (submergence only). This approach allows the effects of overfall suppression to vary by degree, and incorporates tailwater effects that are not considered at all in the EM-9 method. Hydraulic Laboratory Report HYD-182 (Bradley 1945) provides an early version of Fig. 9-26.

Tony Wahl - Bureau of Reclamation Hydraulics Laboratory - September 27, 2019

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_o 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_o coefficient of discharge for the designed head, H_o

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 continously 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_o). 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 $H_o \div (P + E)$ 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:

Dam spillway	Figure	Coefficient of discharge
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_o is the ratio of any total head to the total designed head, while the abscissa, C/C_o is the ratio of the corresponding coefficient of discharge for the head H to the coefficient for the designed head, H_o. 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_o. 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_o 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 spillway as to type, it may be helpful to observe the values of

$$\frac{H_o}{P + E} \text{ and } \frac{(h_d + d) \text{ actual}}{(h_d + d) \text{ experimental}}$$

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	0.2	0.843	2.26	3.00
	0.4	0.900	4.52	3.19
	0.6	0.940	6.79	3.33
$H_o = 11.3$	0.8	0.975	9.05	3.46
$C_o = 3.55$	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	0.2	0.910	1.60	3.18
	0.4	0.948	3.20	3.32
	0.6	0.974	4.80	3.41
$H_o = 8.0$	0.8	0.992	6.40	3.47
$C_o = 3.50$	1.0	1.000	8.00	3.50
	1.2	1.003	9.60	3.51

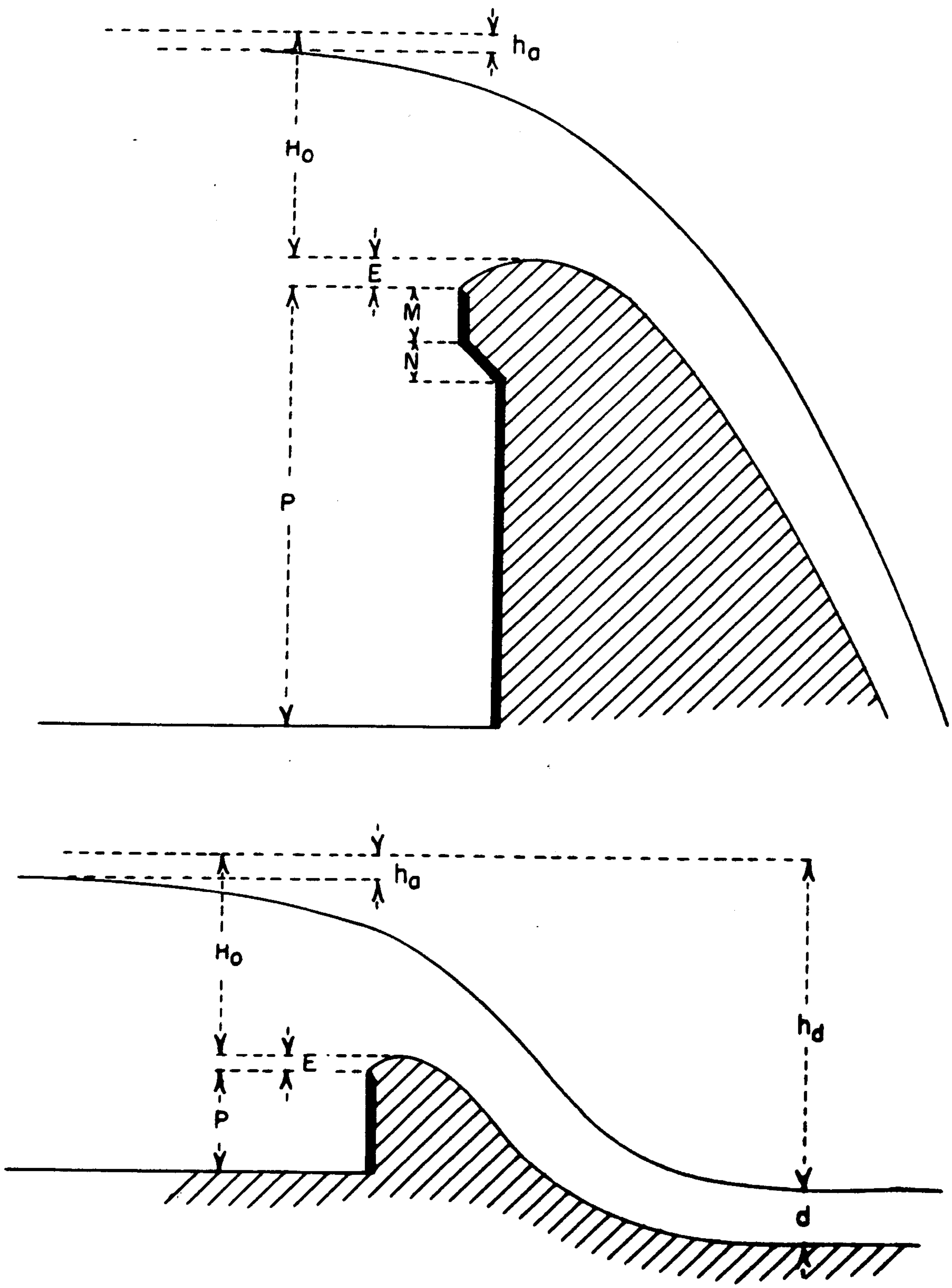
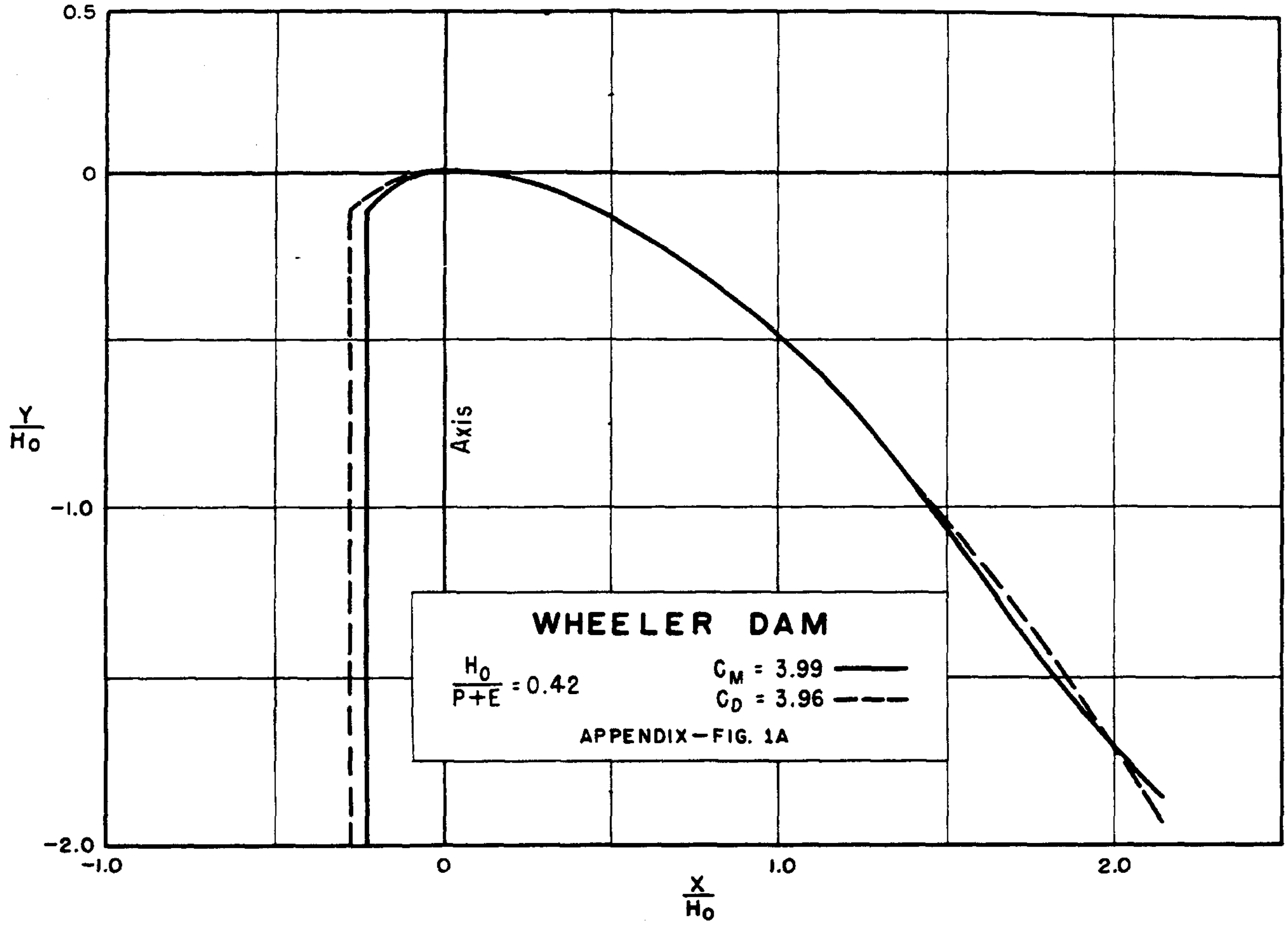


FIGURE 1 - Identification of symbols.



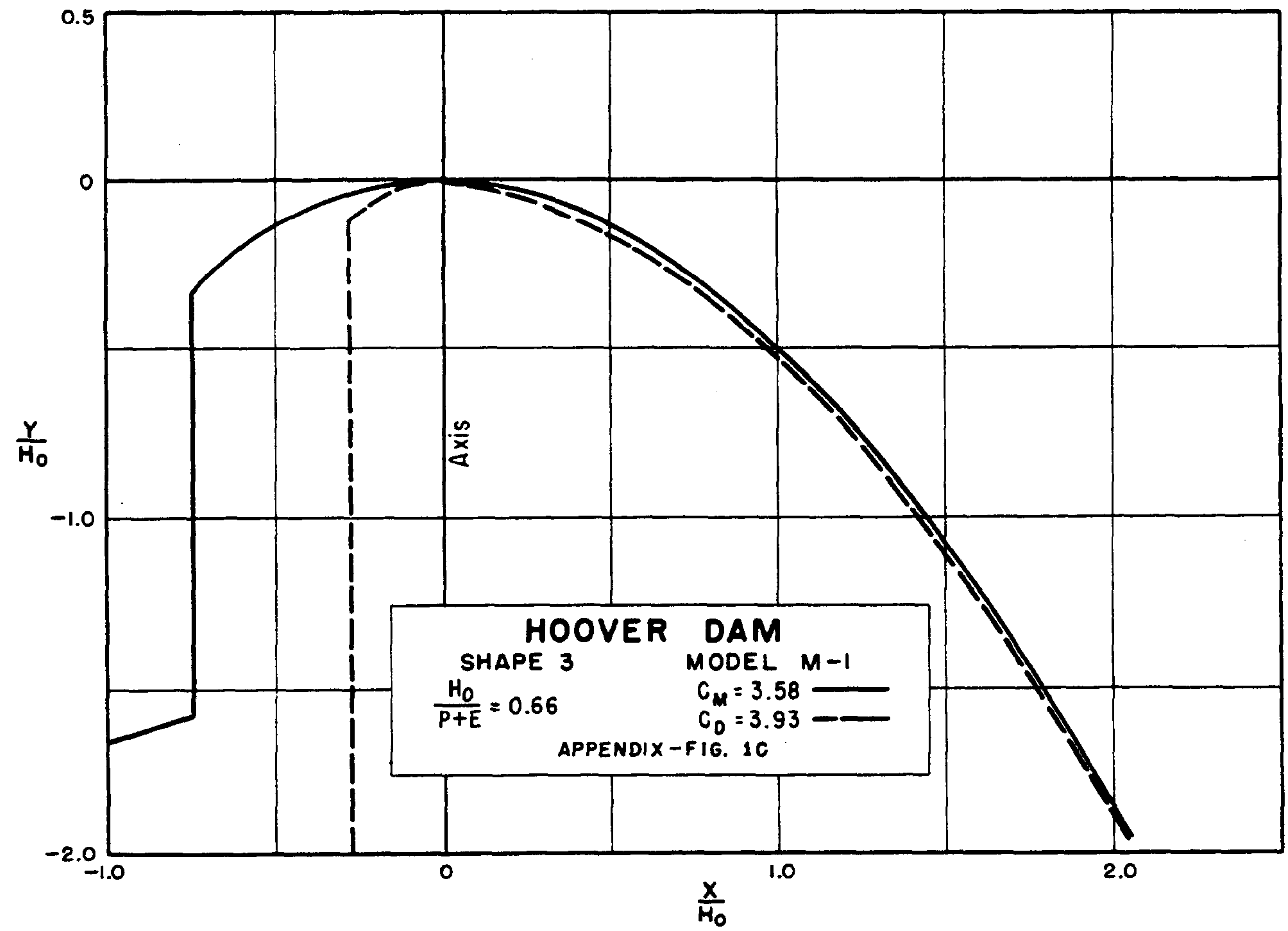


FIGURE 2 - Spillways with vertical upstream face.

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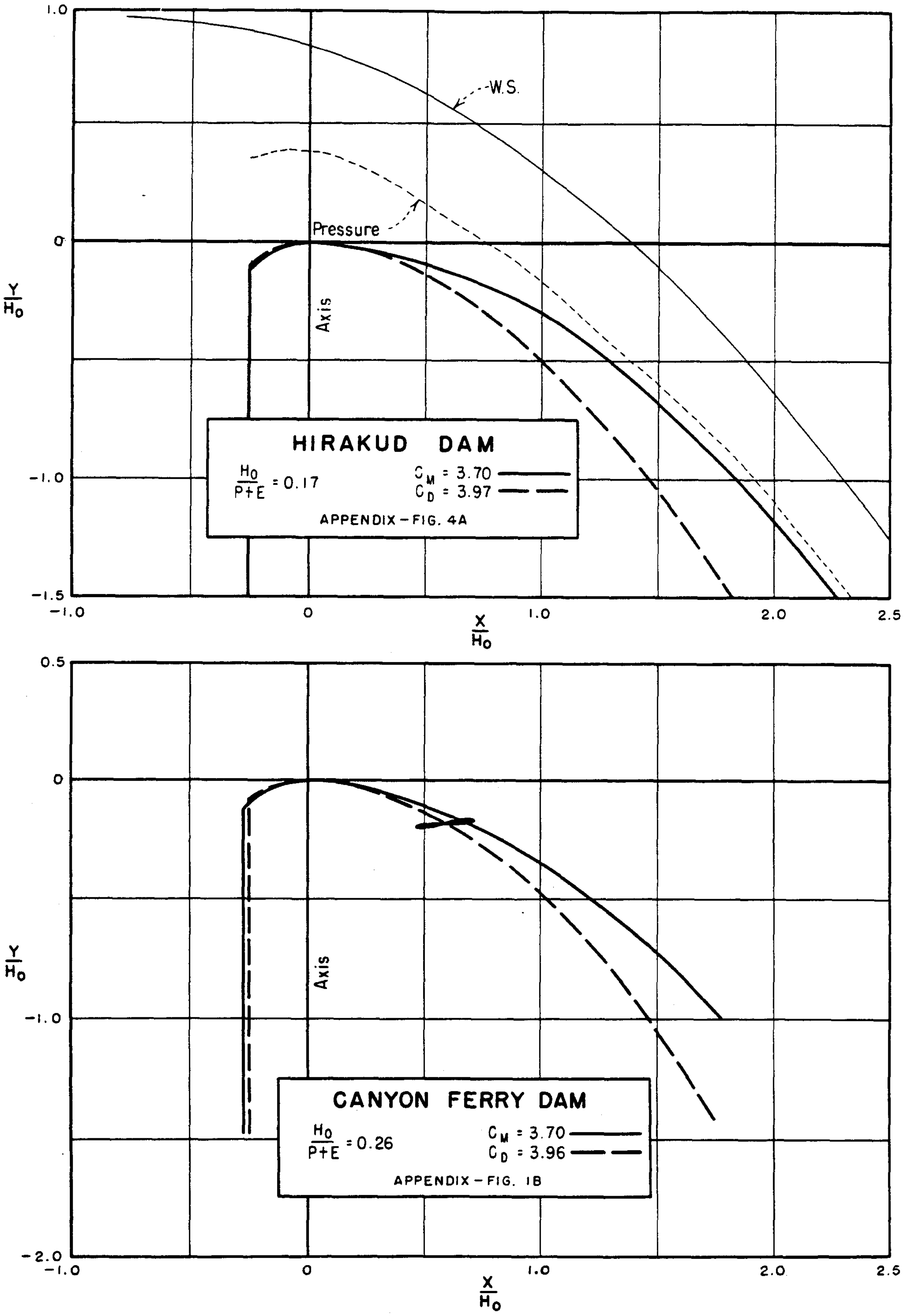

FIGURE 3 - Spillways with vertical upstream face.

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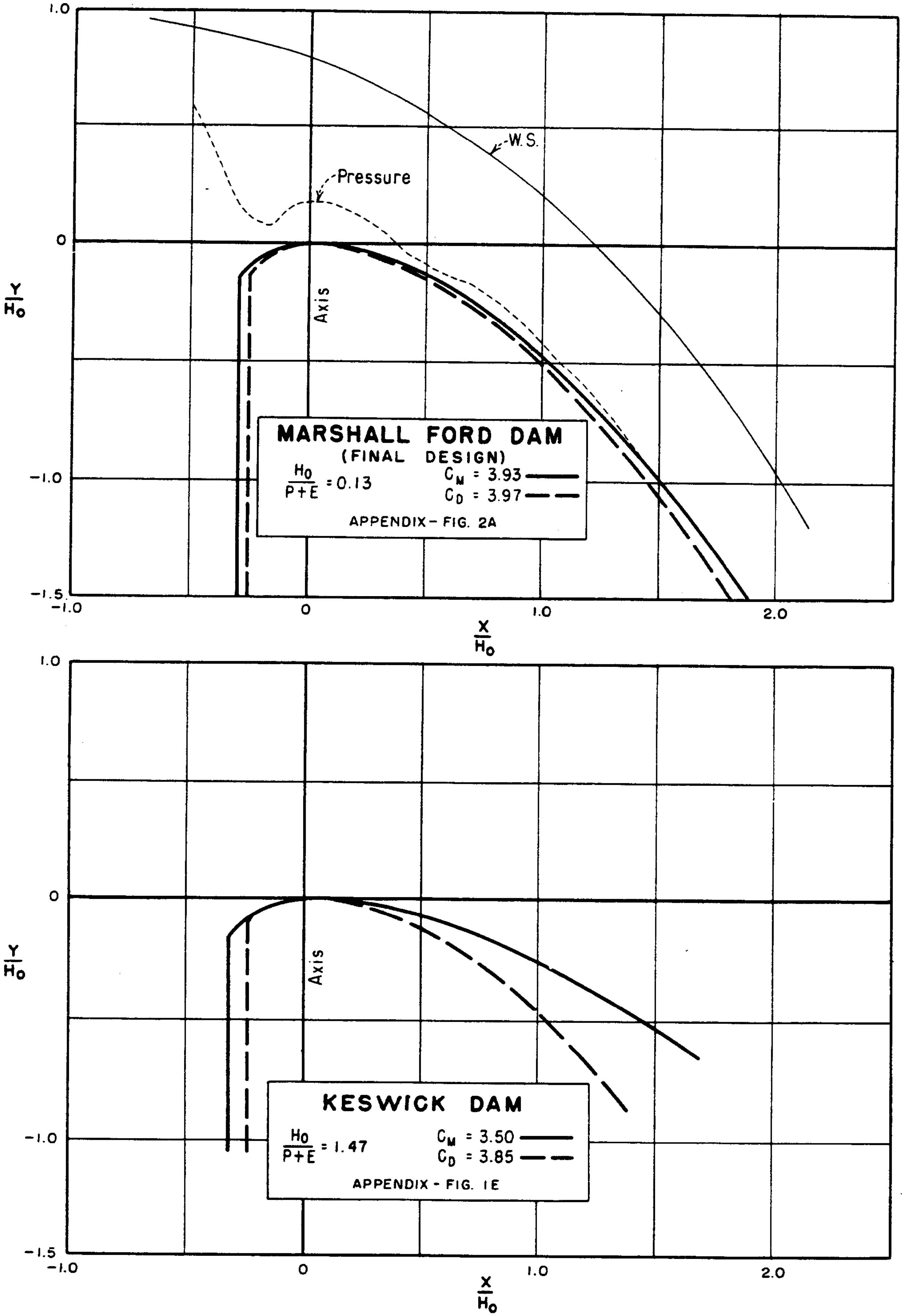

FIGURE 4 - Spillways with vertical upstream face.

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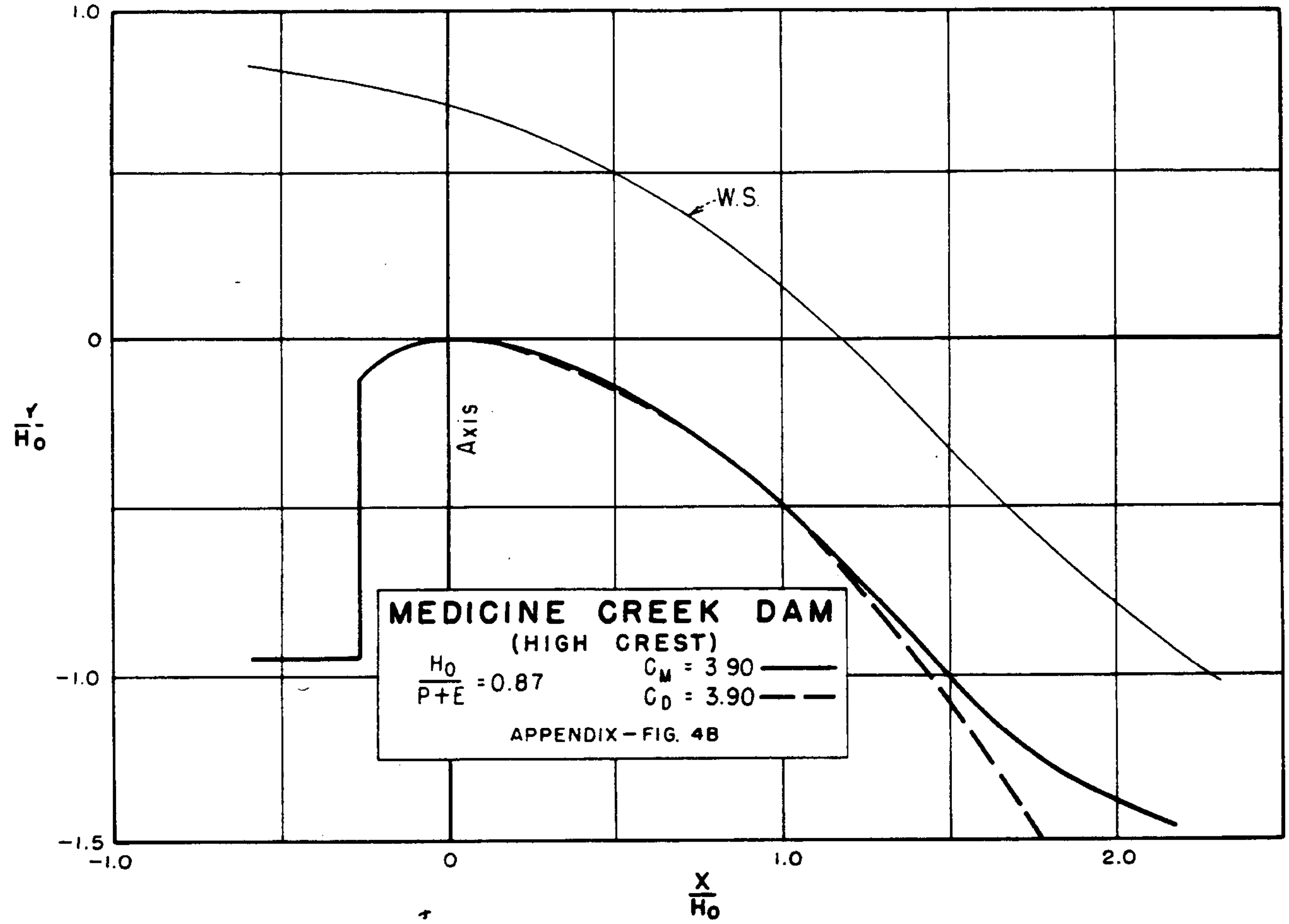

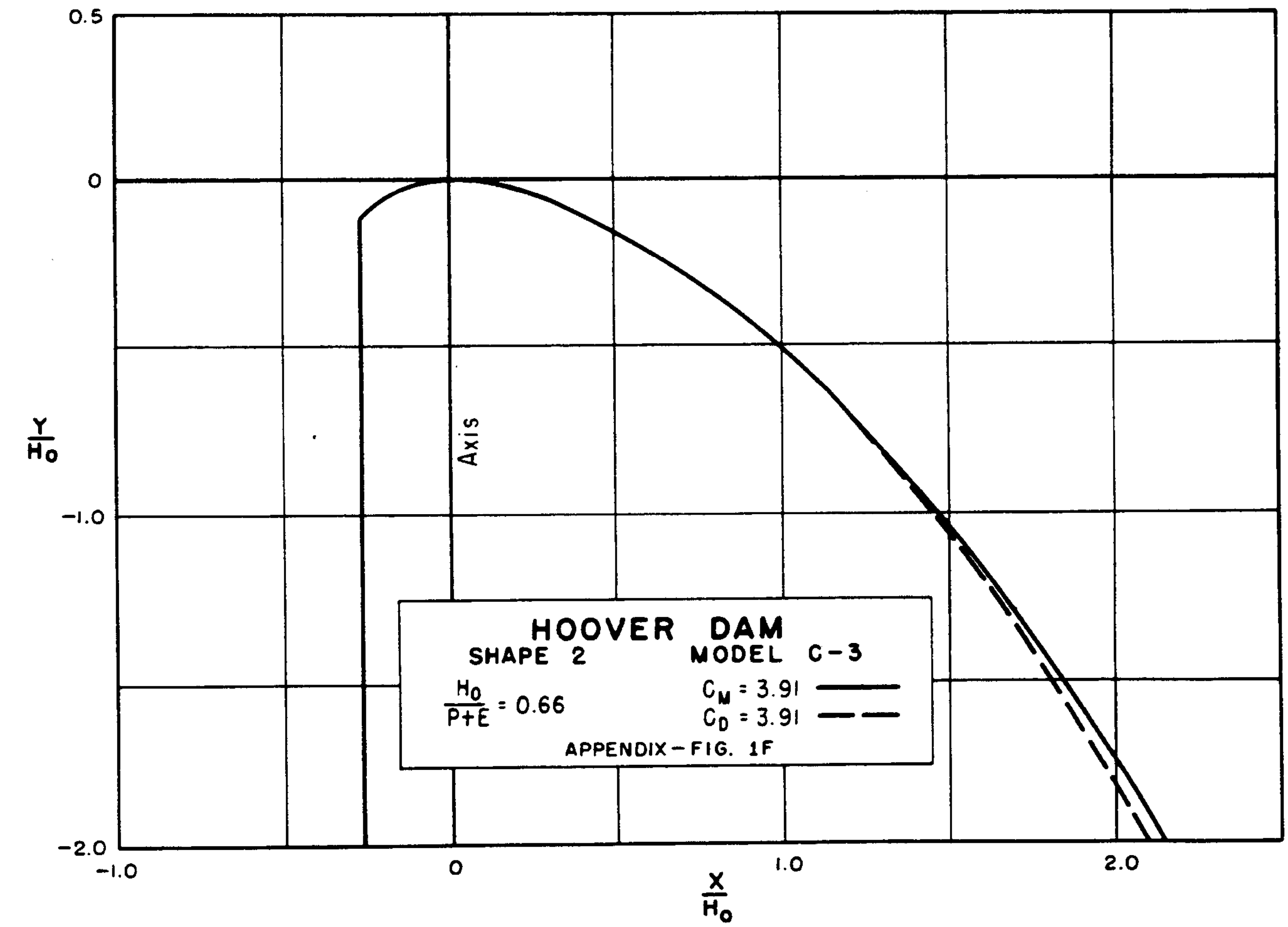

FIGURE 5 - Spillways with vertical upstream face.

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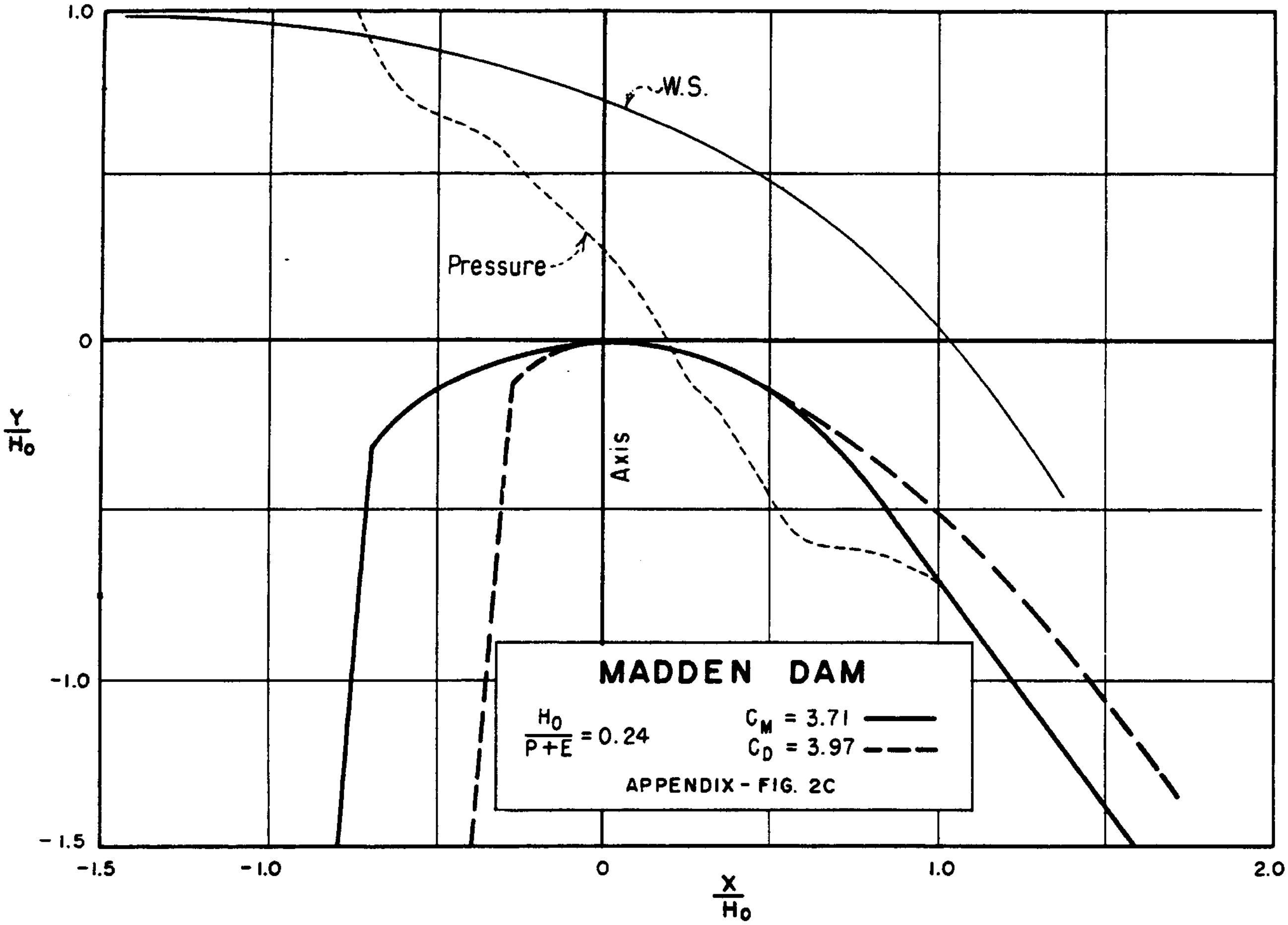

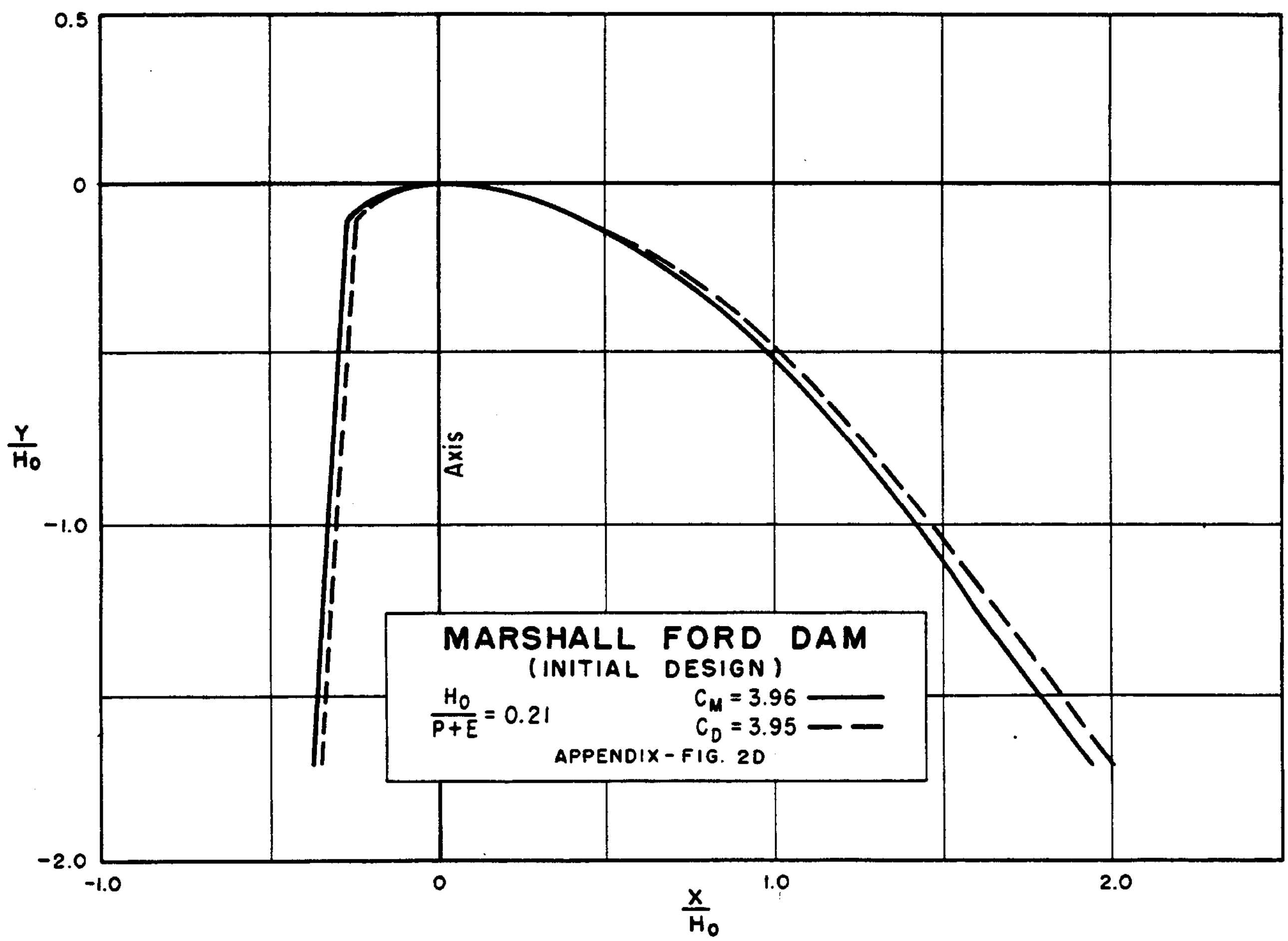

FIGURE 6 - Spillways with sloping upstream face.

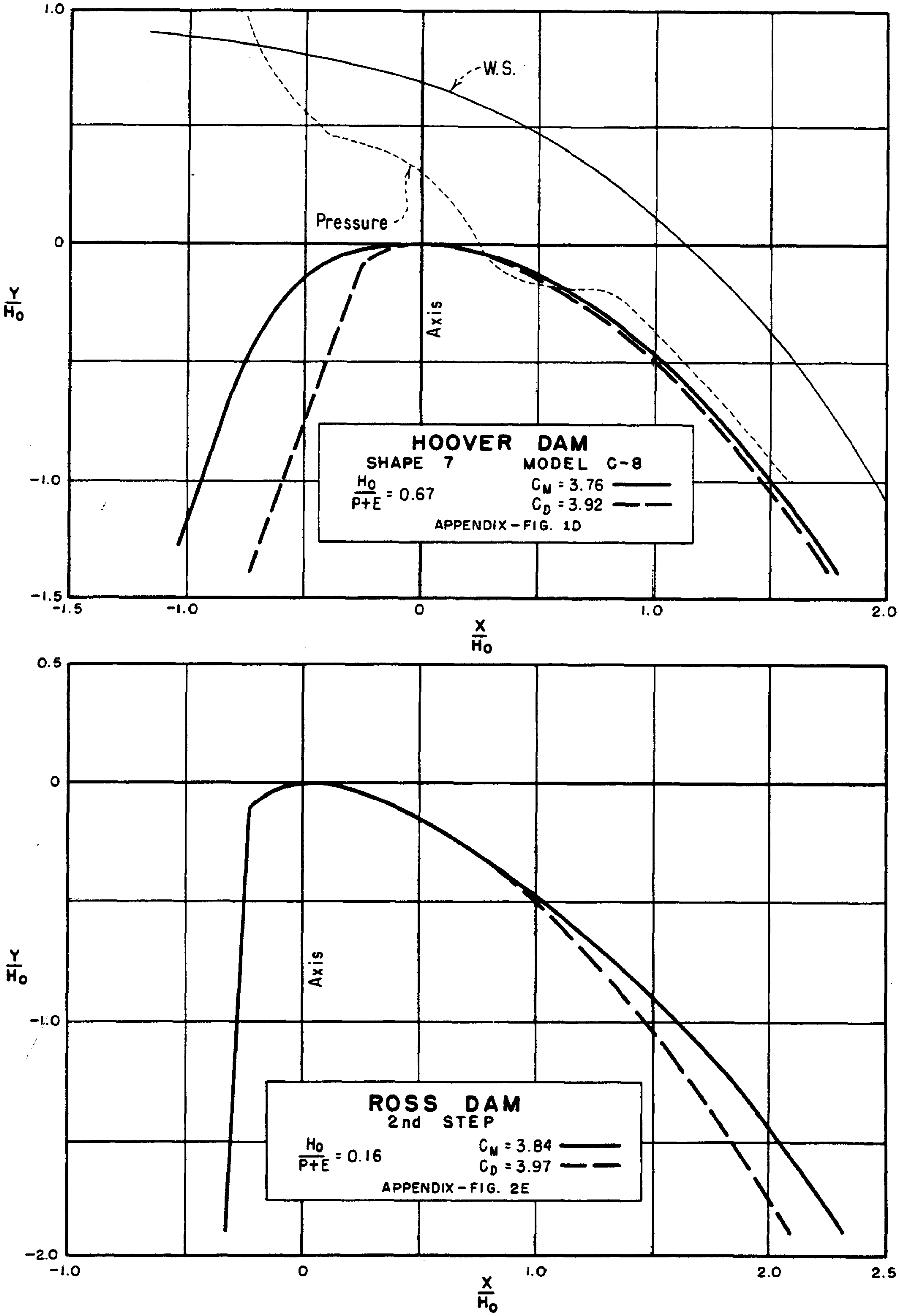

FIGURE 7 - Spillways with sloping upstream face.

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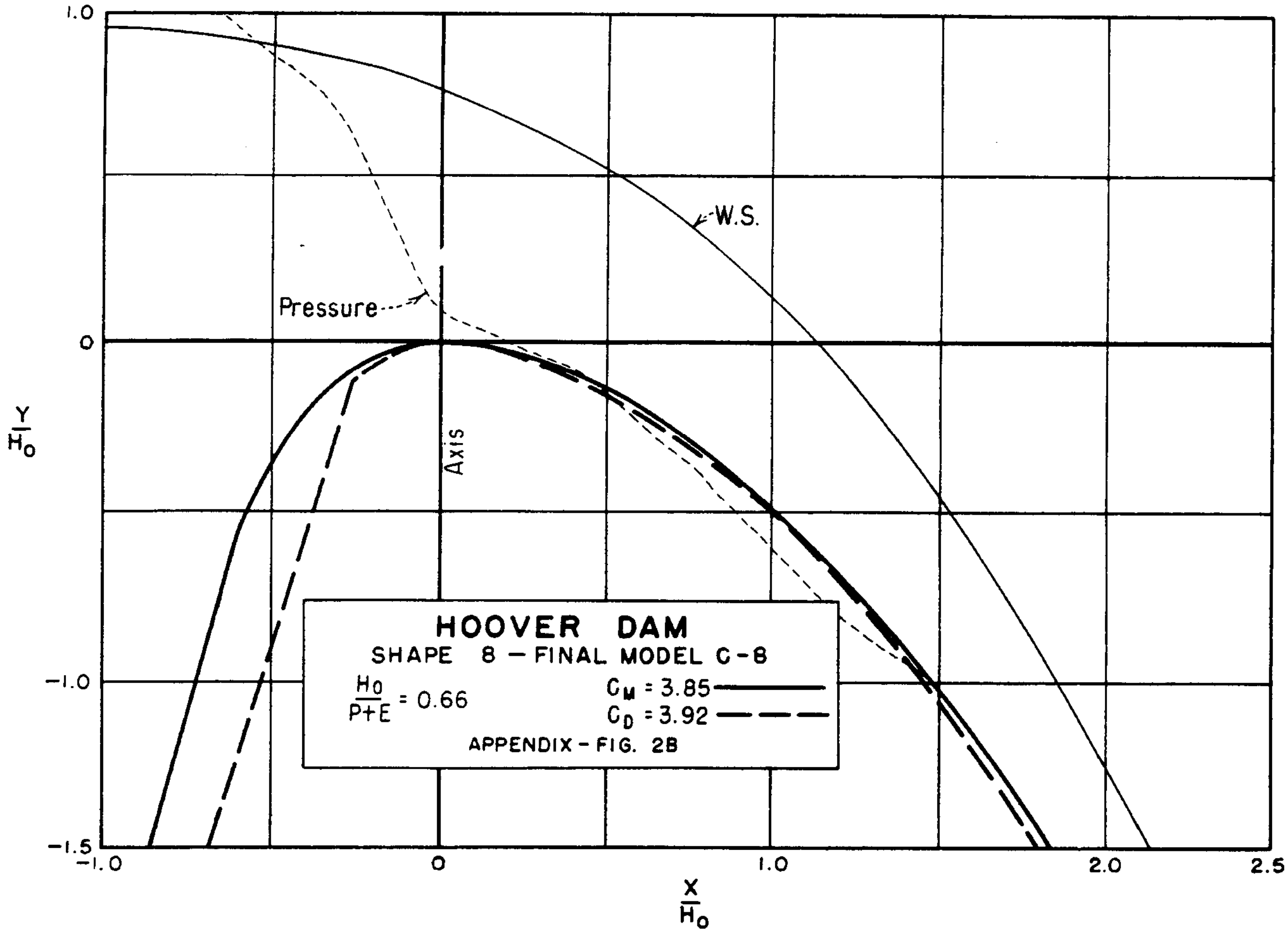

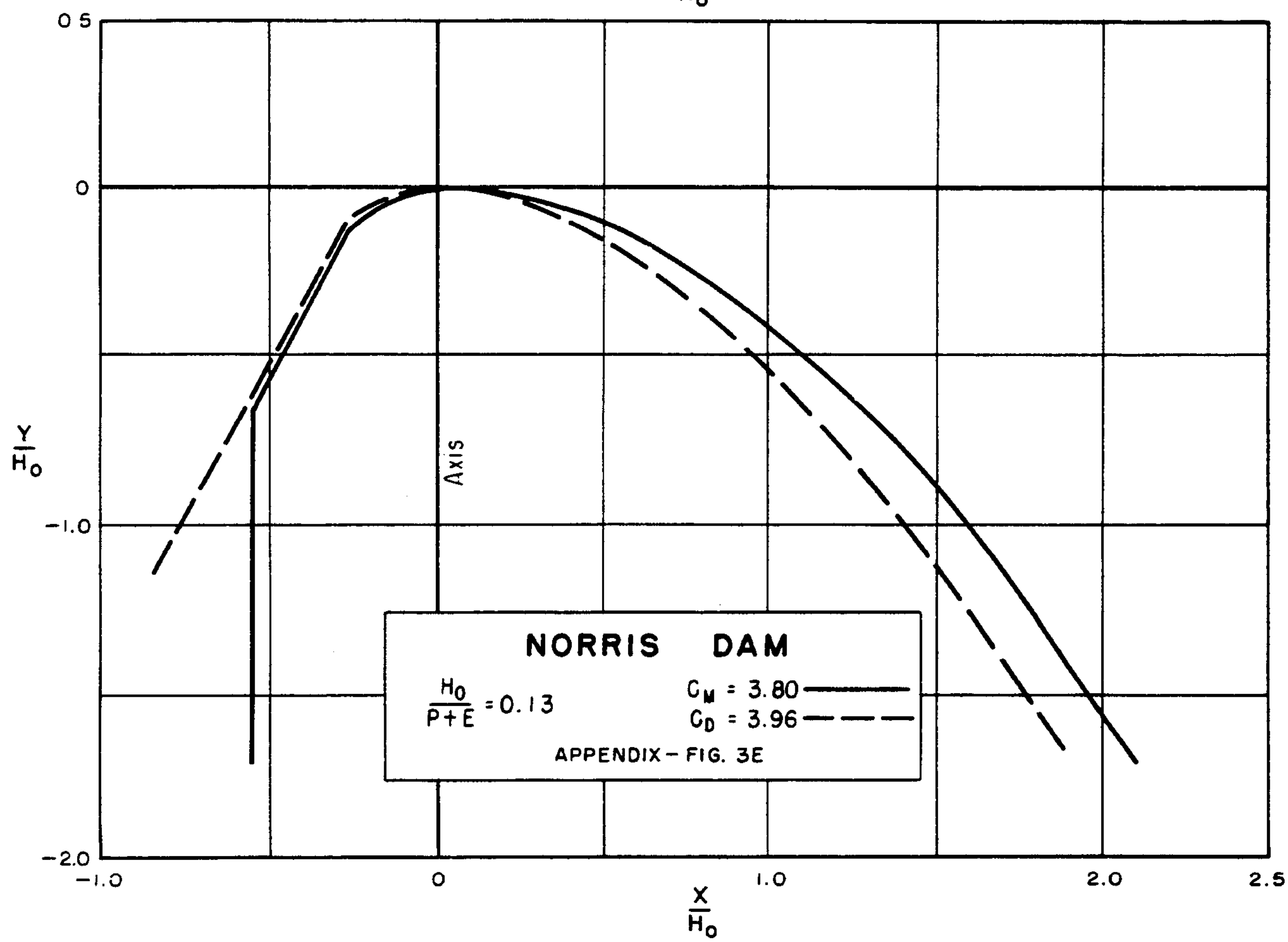

FIGURE 8 - Spillways with sloping upstream face.

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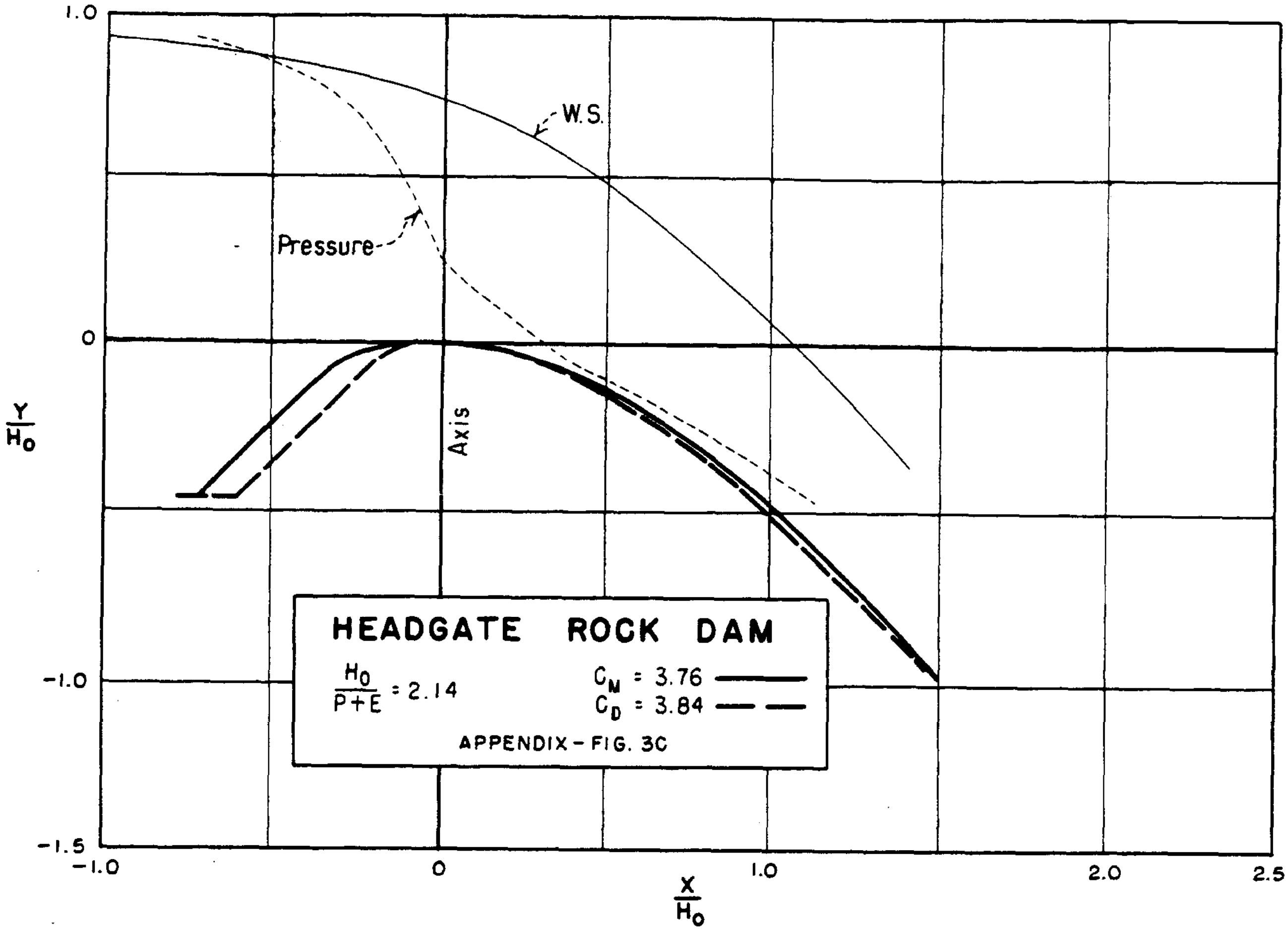


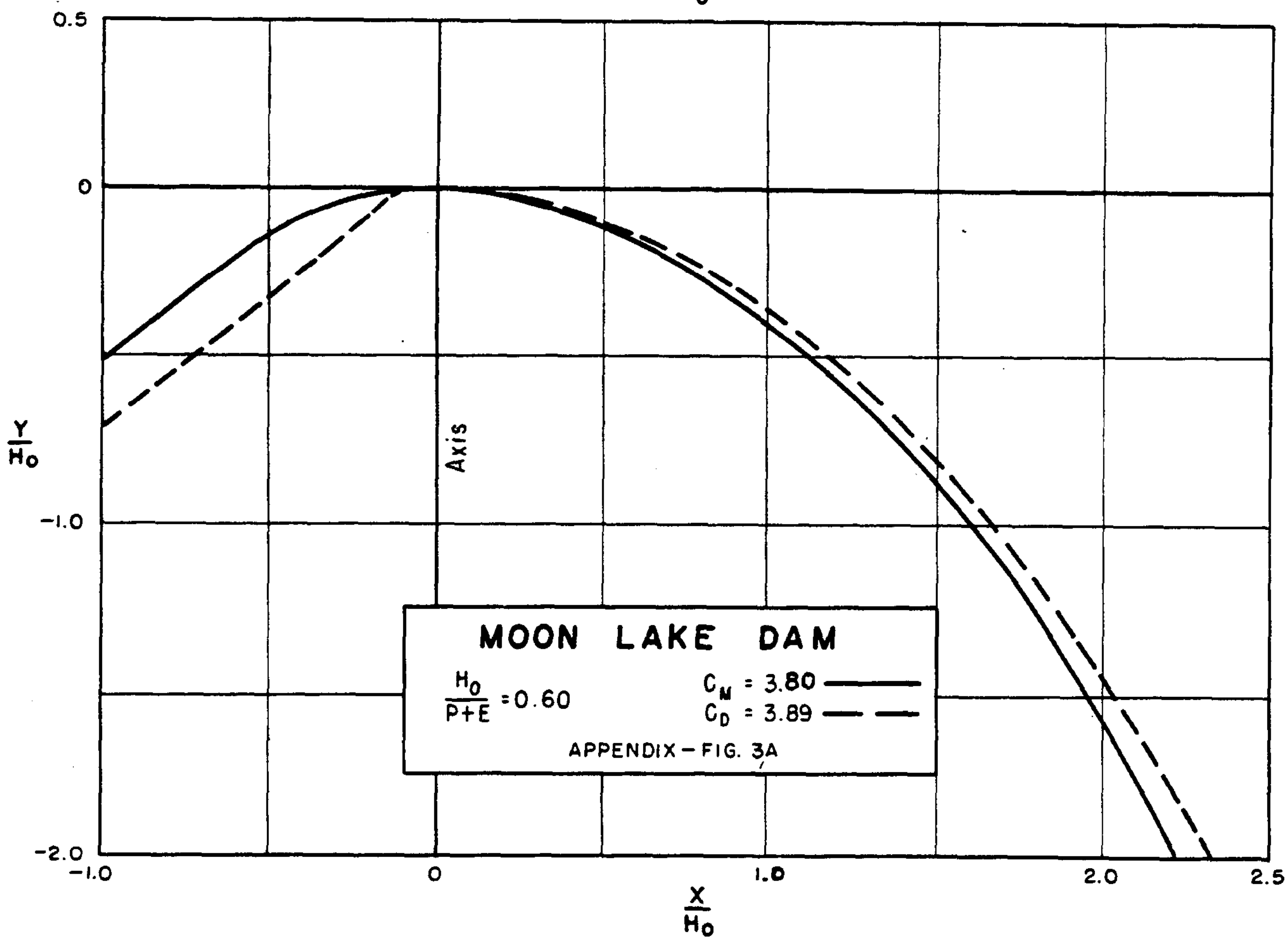
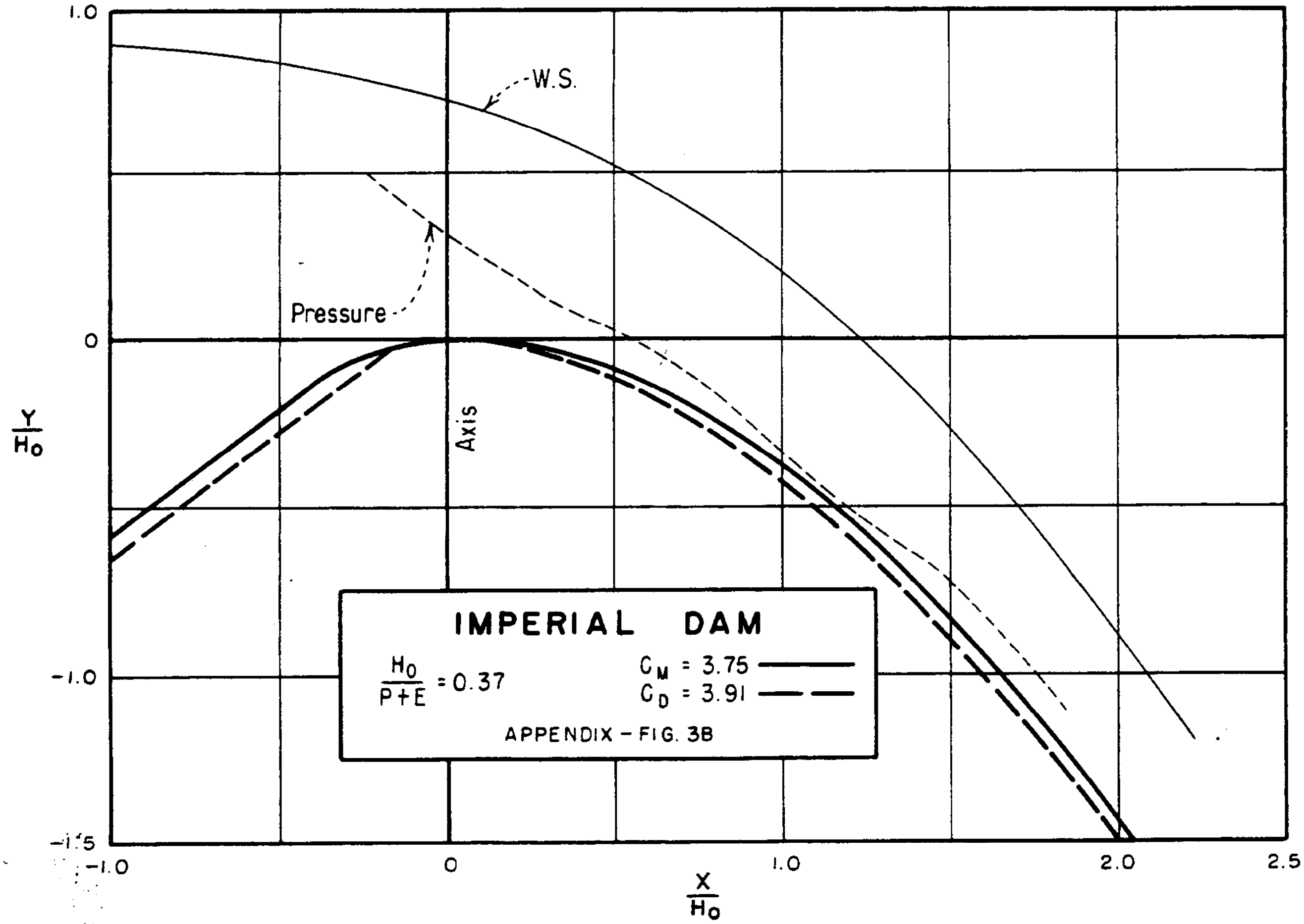


FIGURE 9 - Spillways with sloping upstream face.



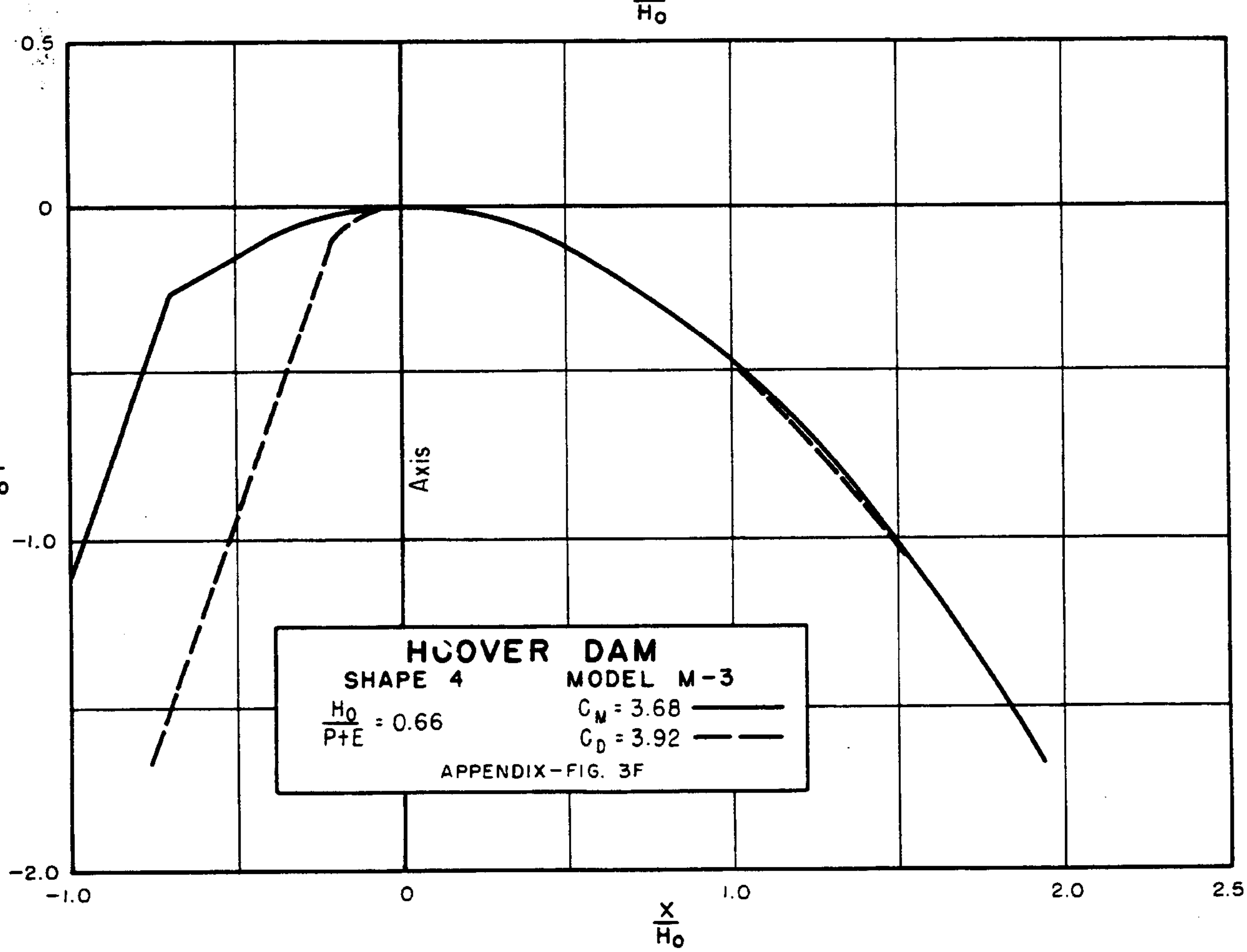
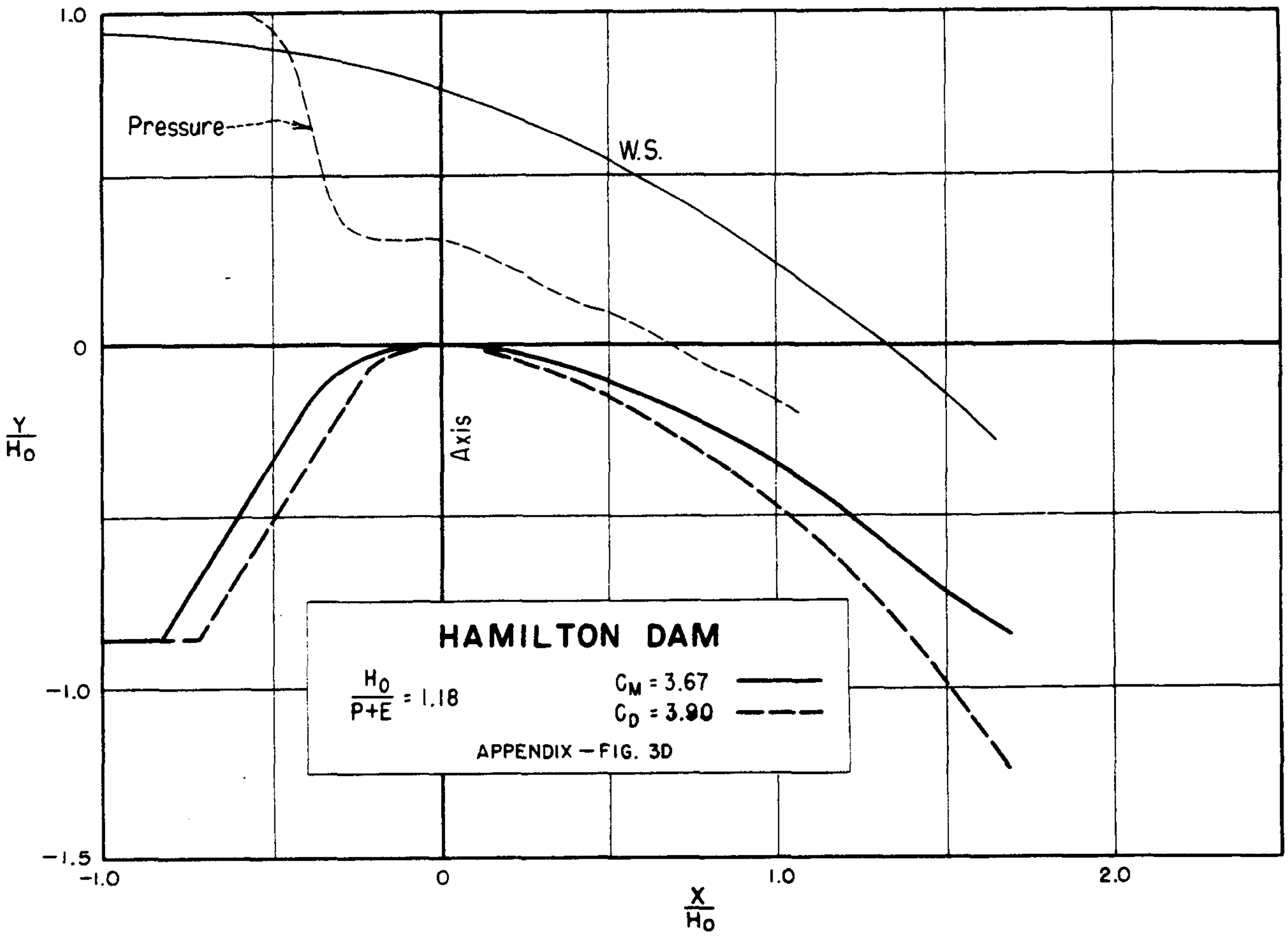


FIGURE 10 - Spillways with sloping upstream face.



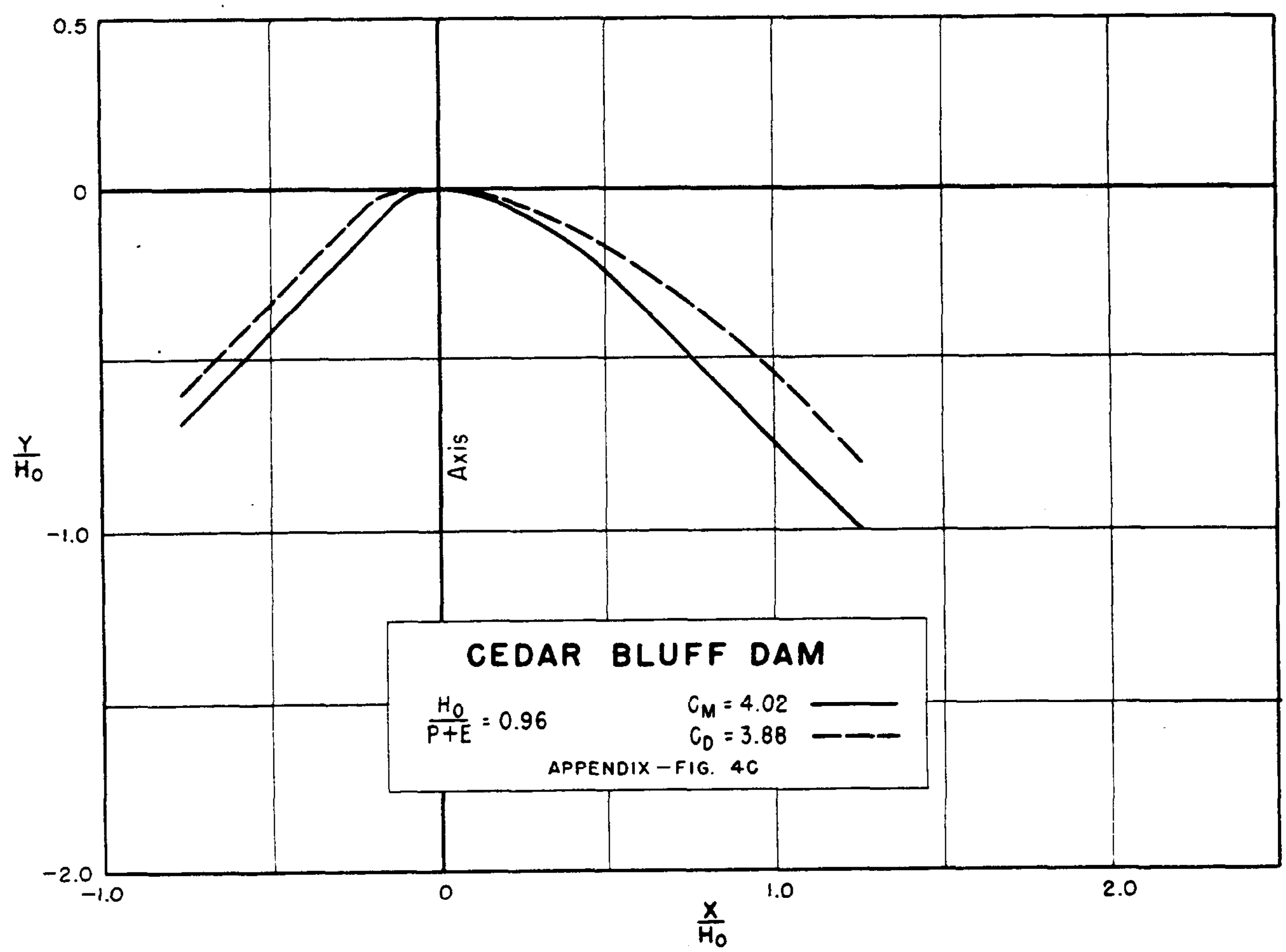
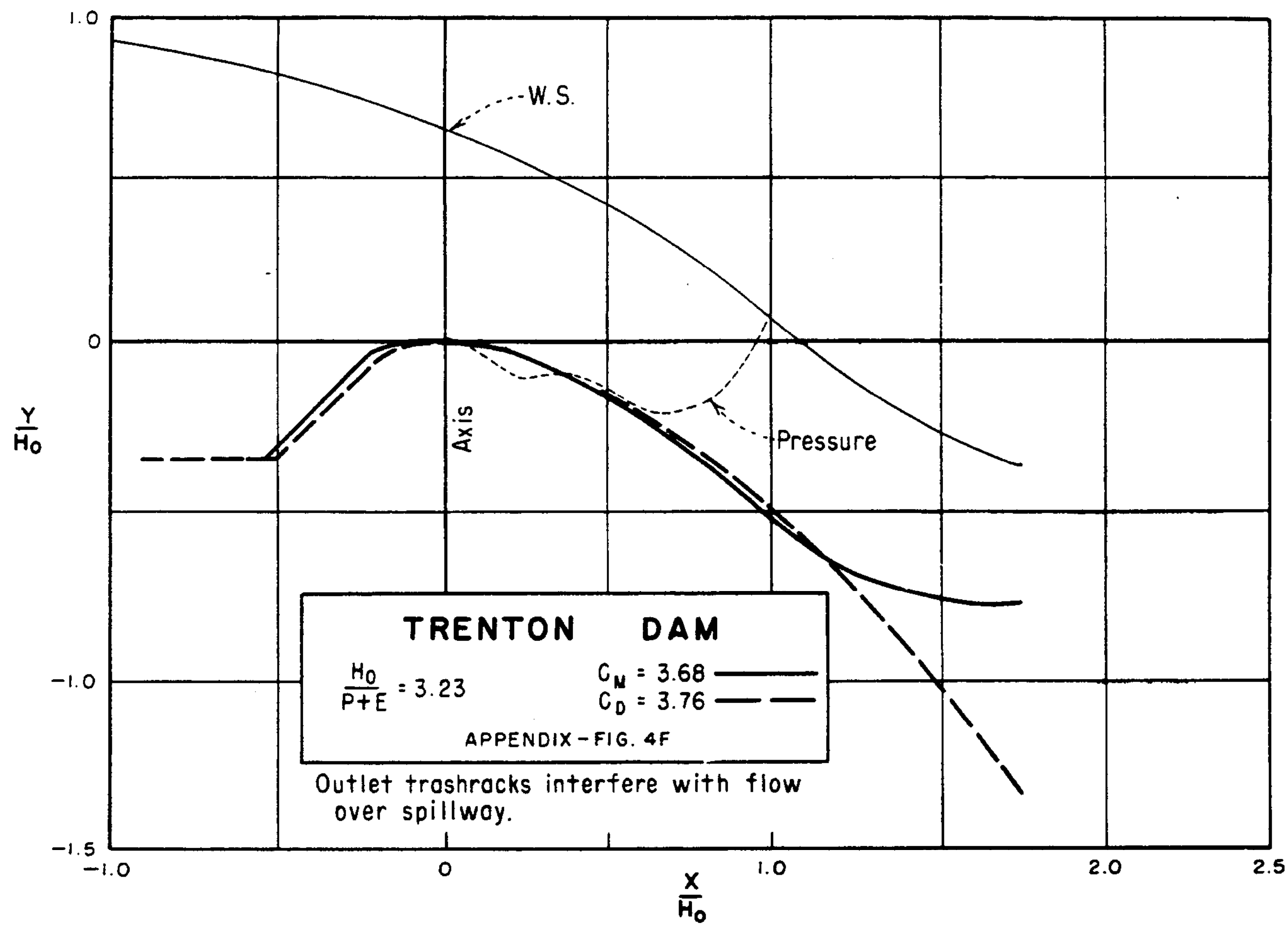


FIGURE 11 - Spillways with sloping upstream face.



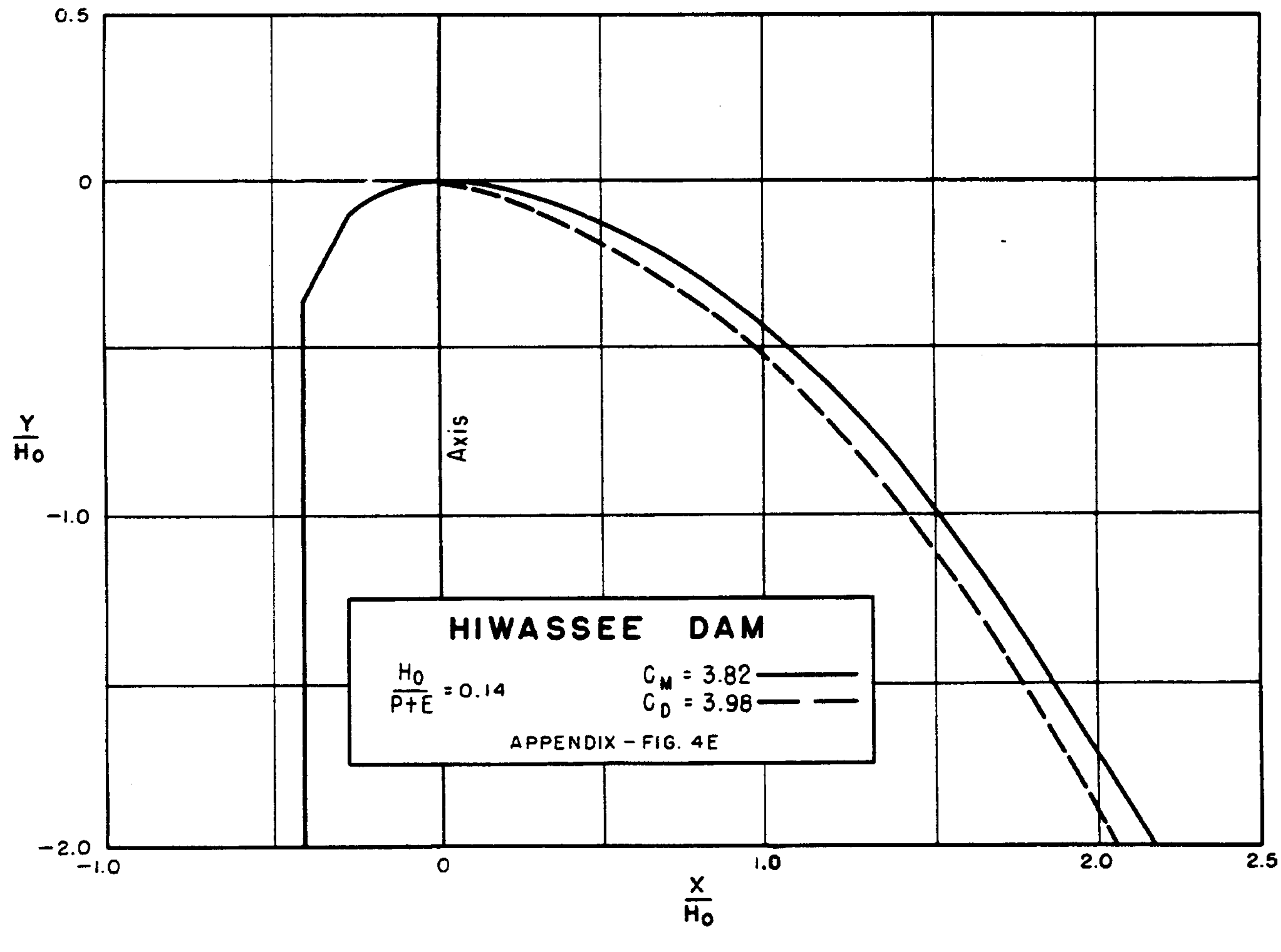
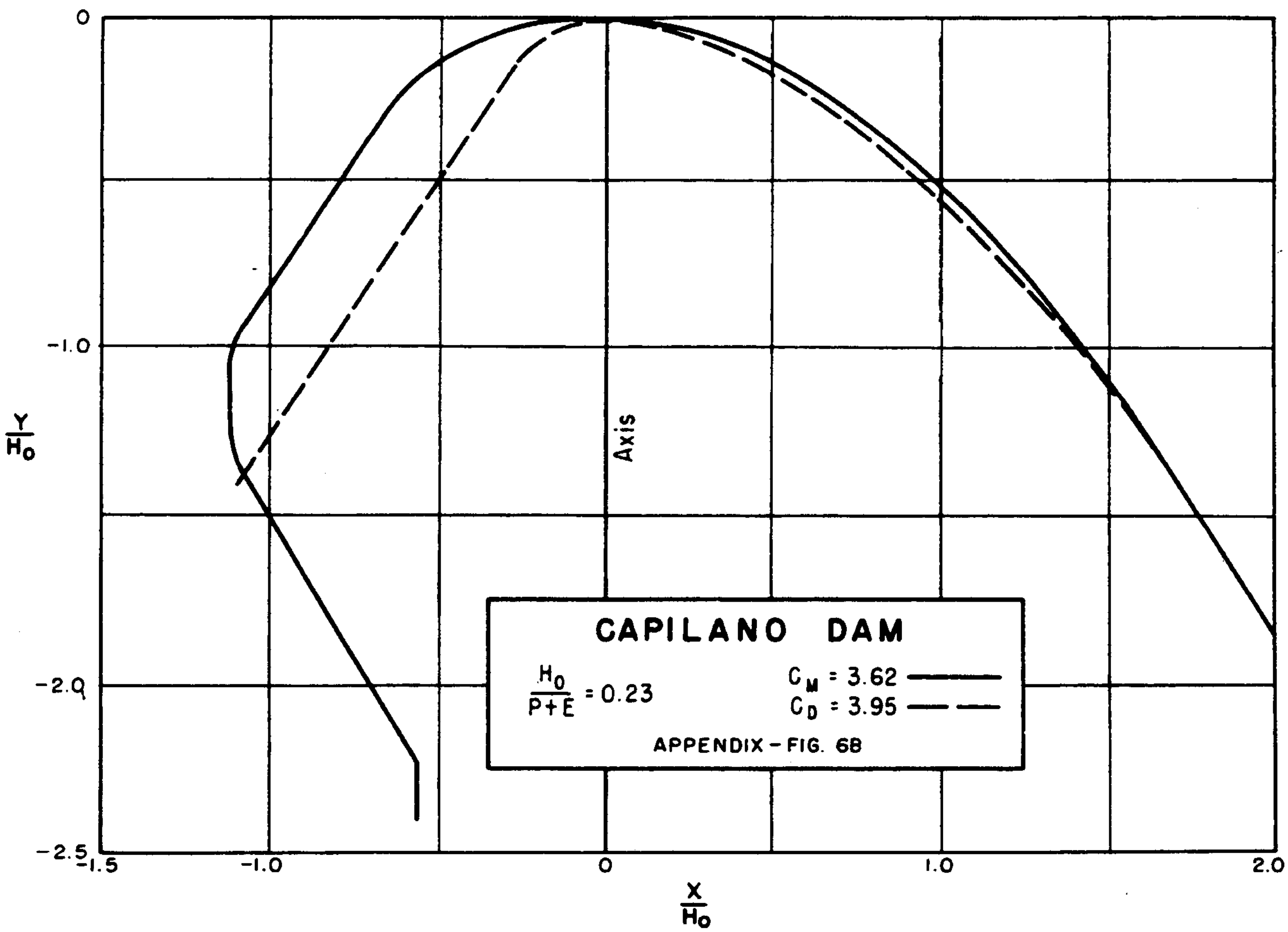


FIGURE 12 - Spillways with sloping upstream face.



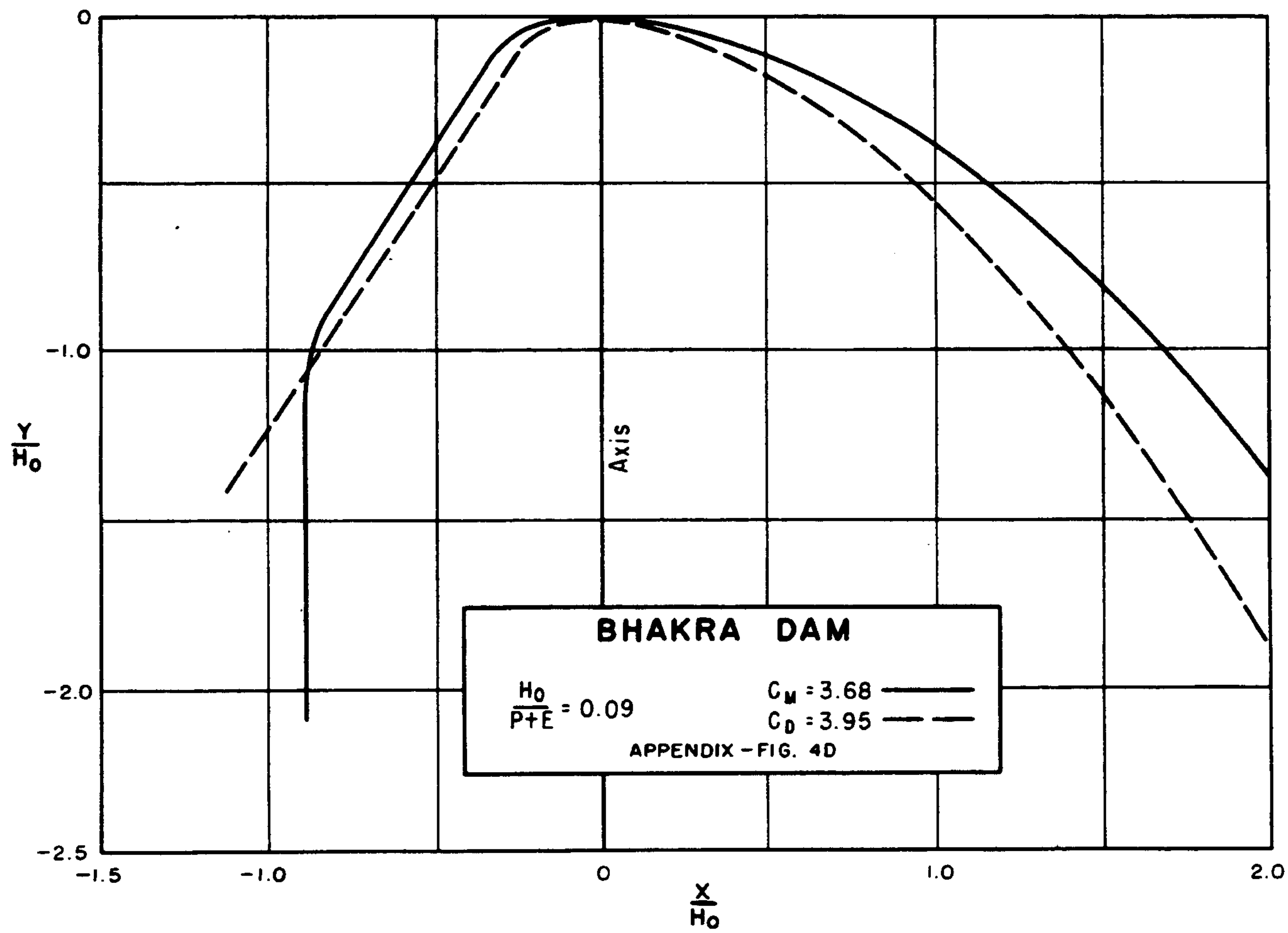


FIGURE 13 - Spillways with sloping and offset upstream face.

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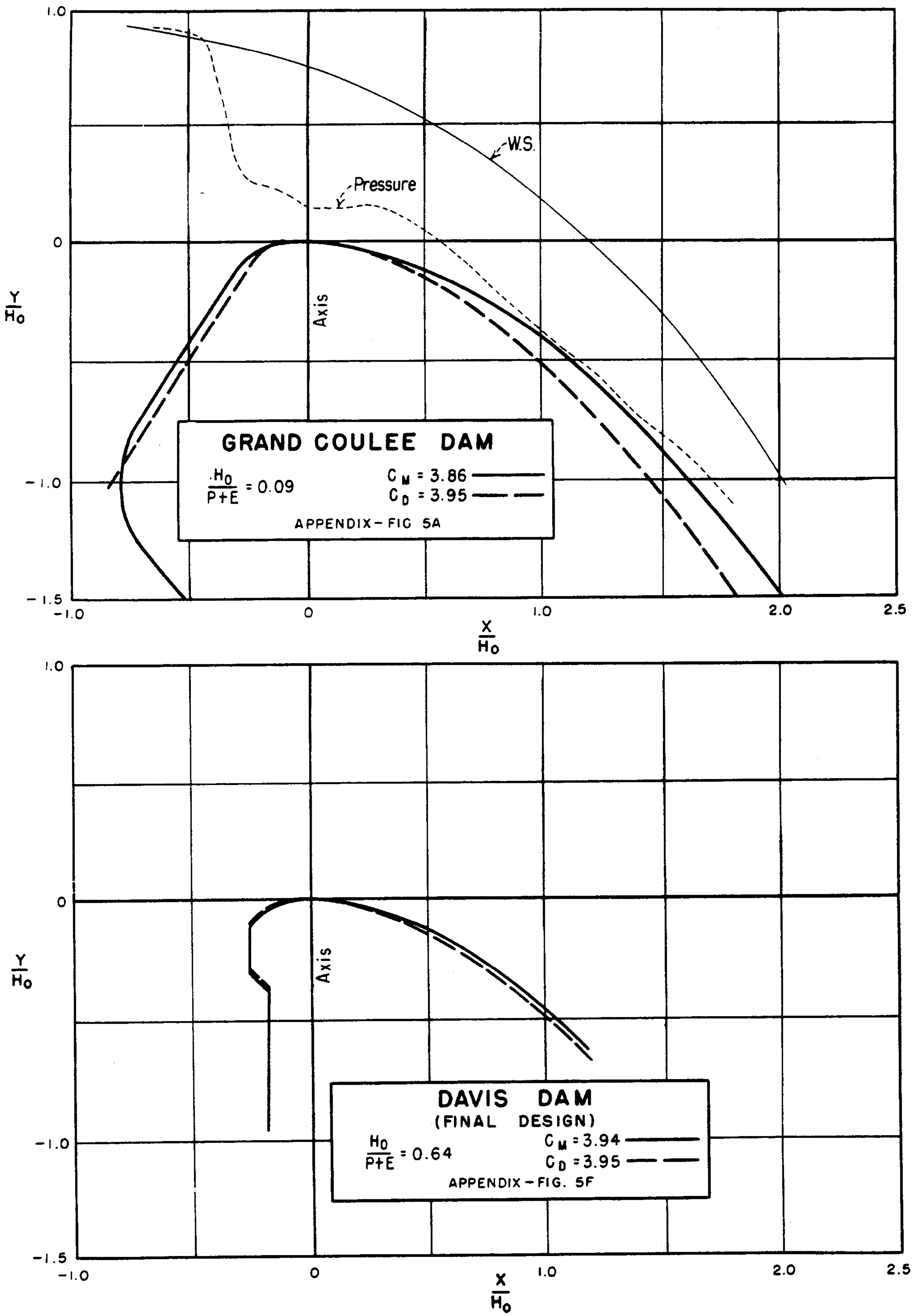
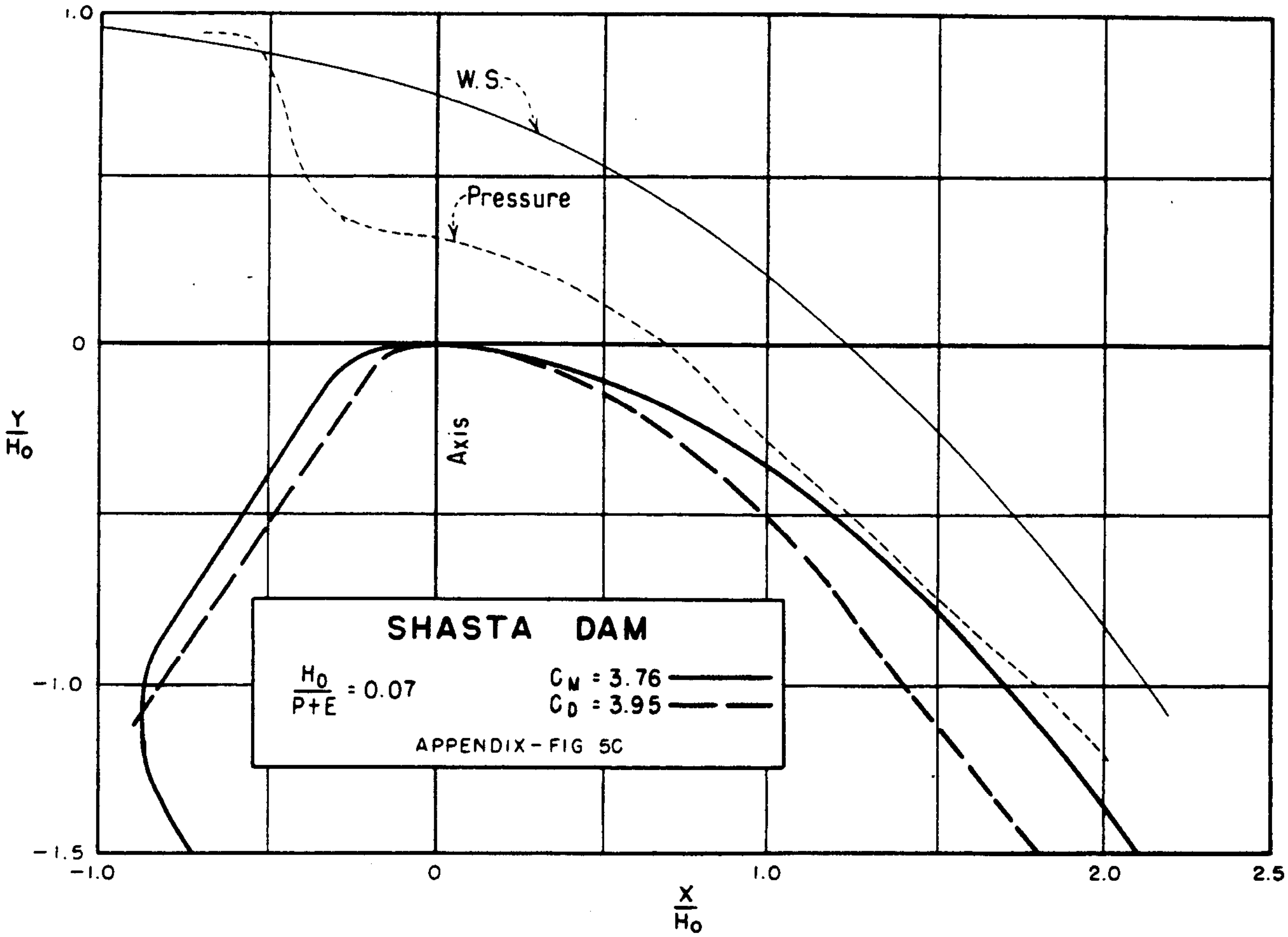


FIGURE 14 - Spillways with offset in upstream face.

SHEET 2 OF 6



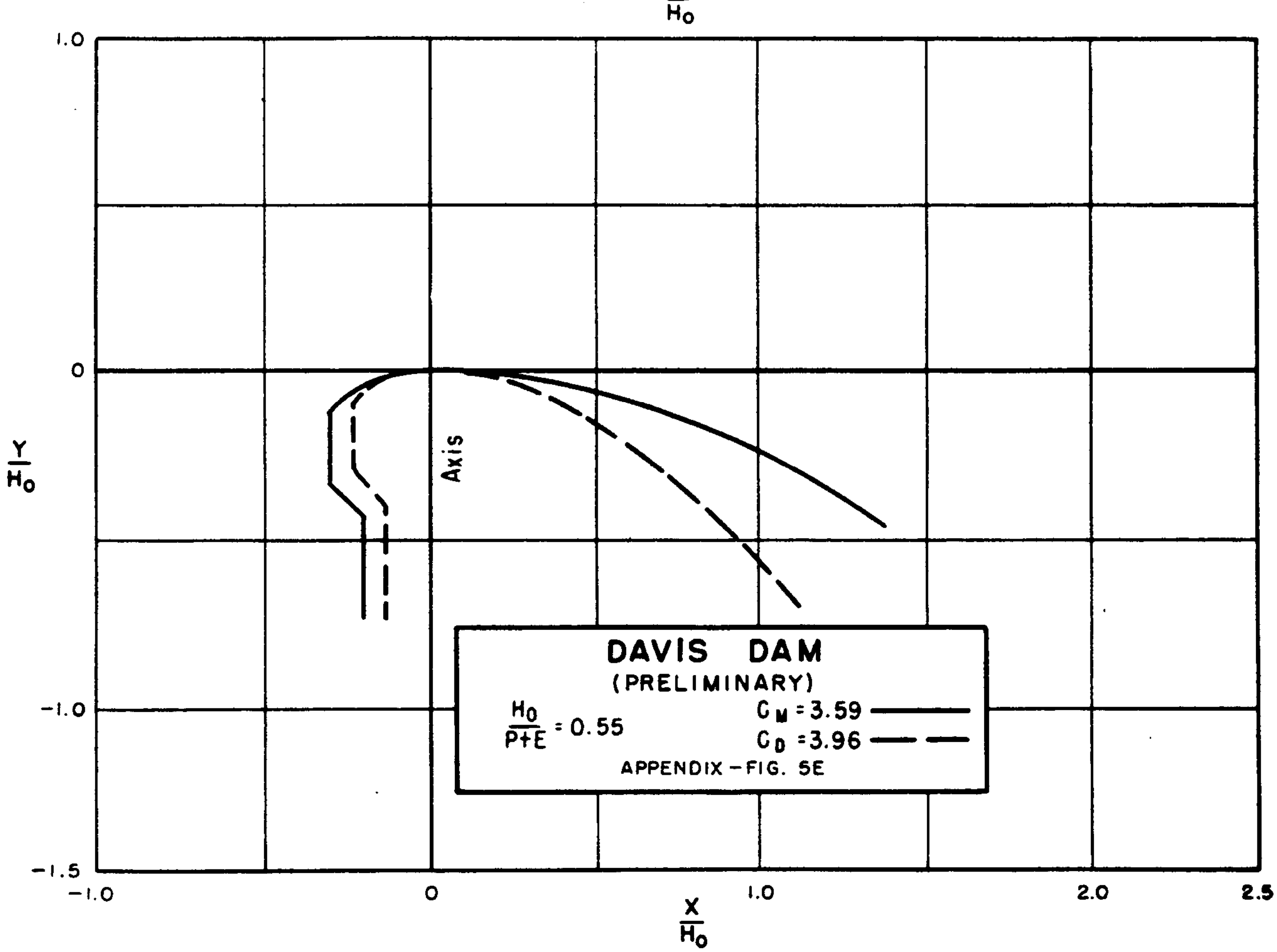
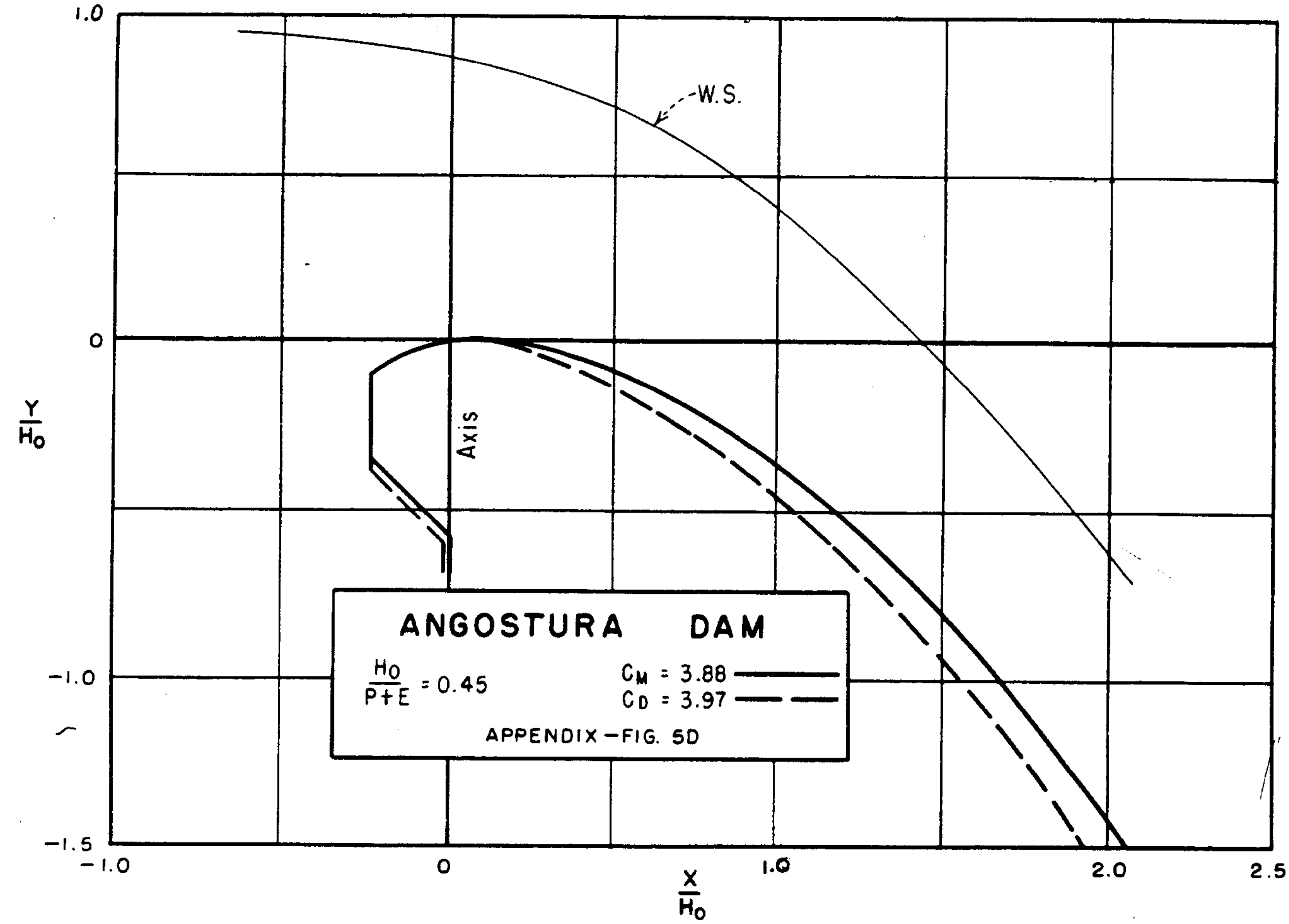


FIGURE 15 - Spillways with offset in upstream face.

SHEET 3 OF 6



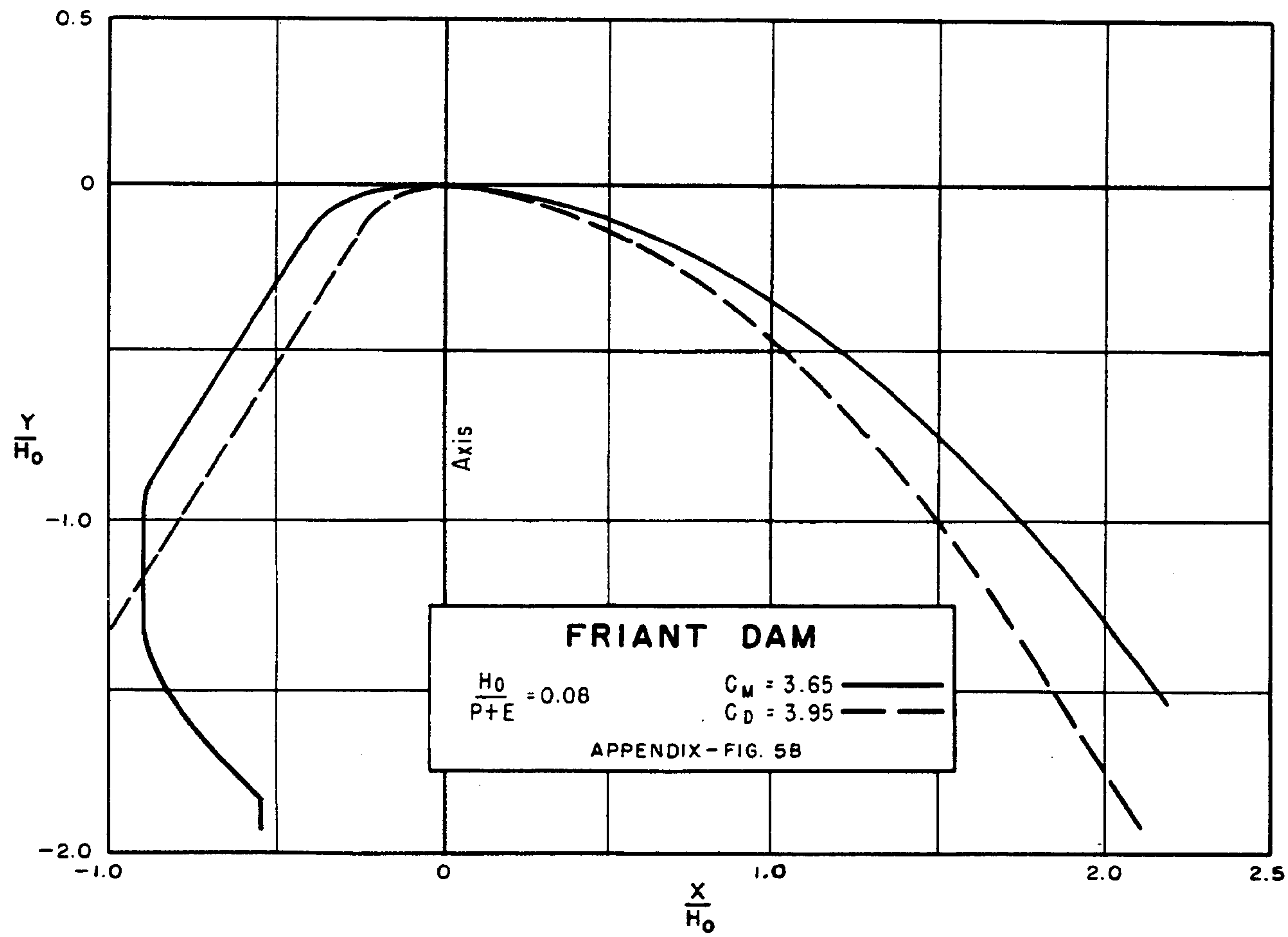
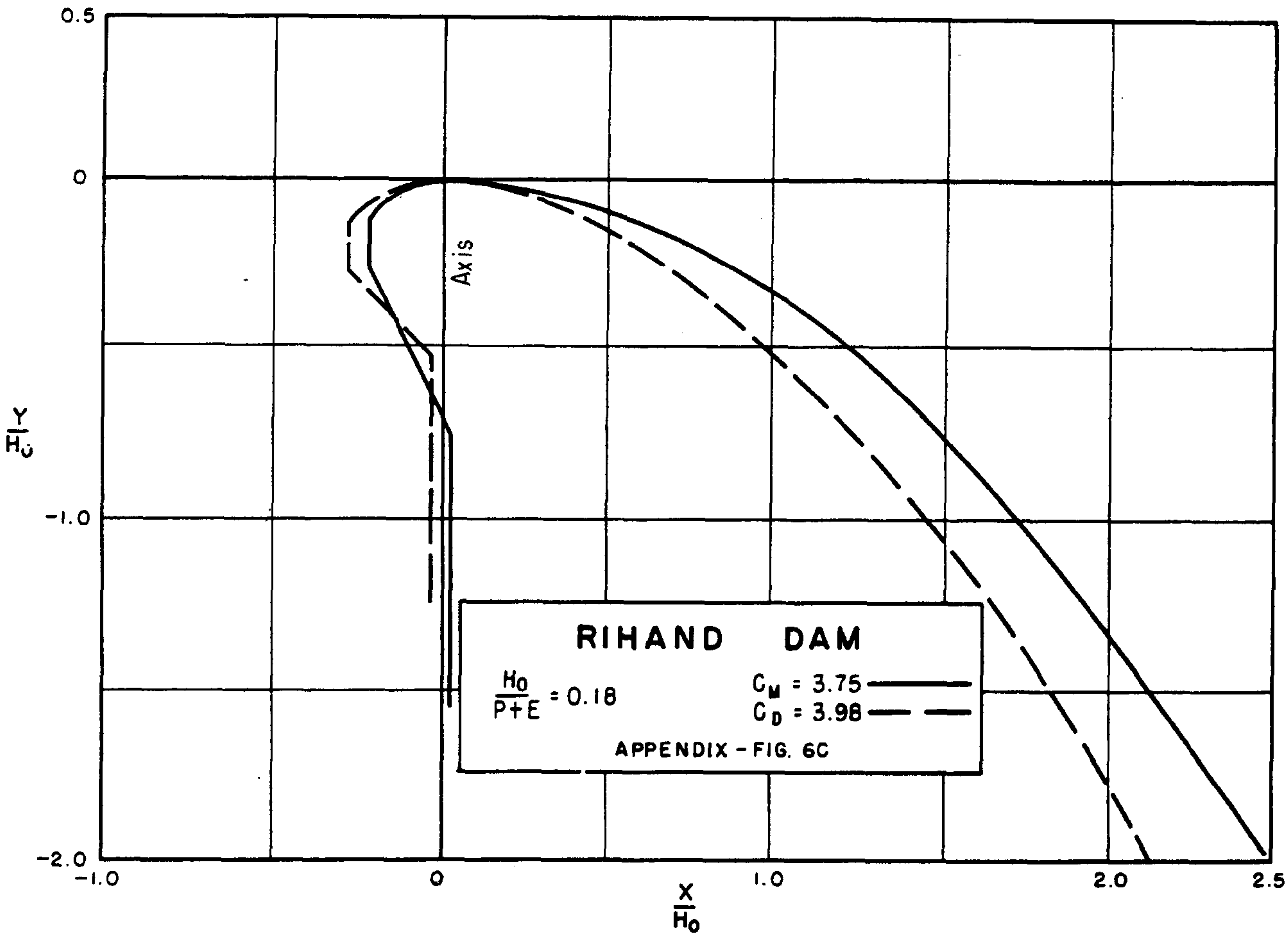


FIGURE 16 - Spillways with offset in upstream face.

SHEET 4 OF 6



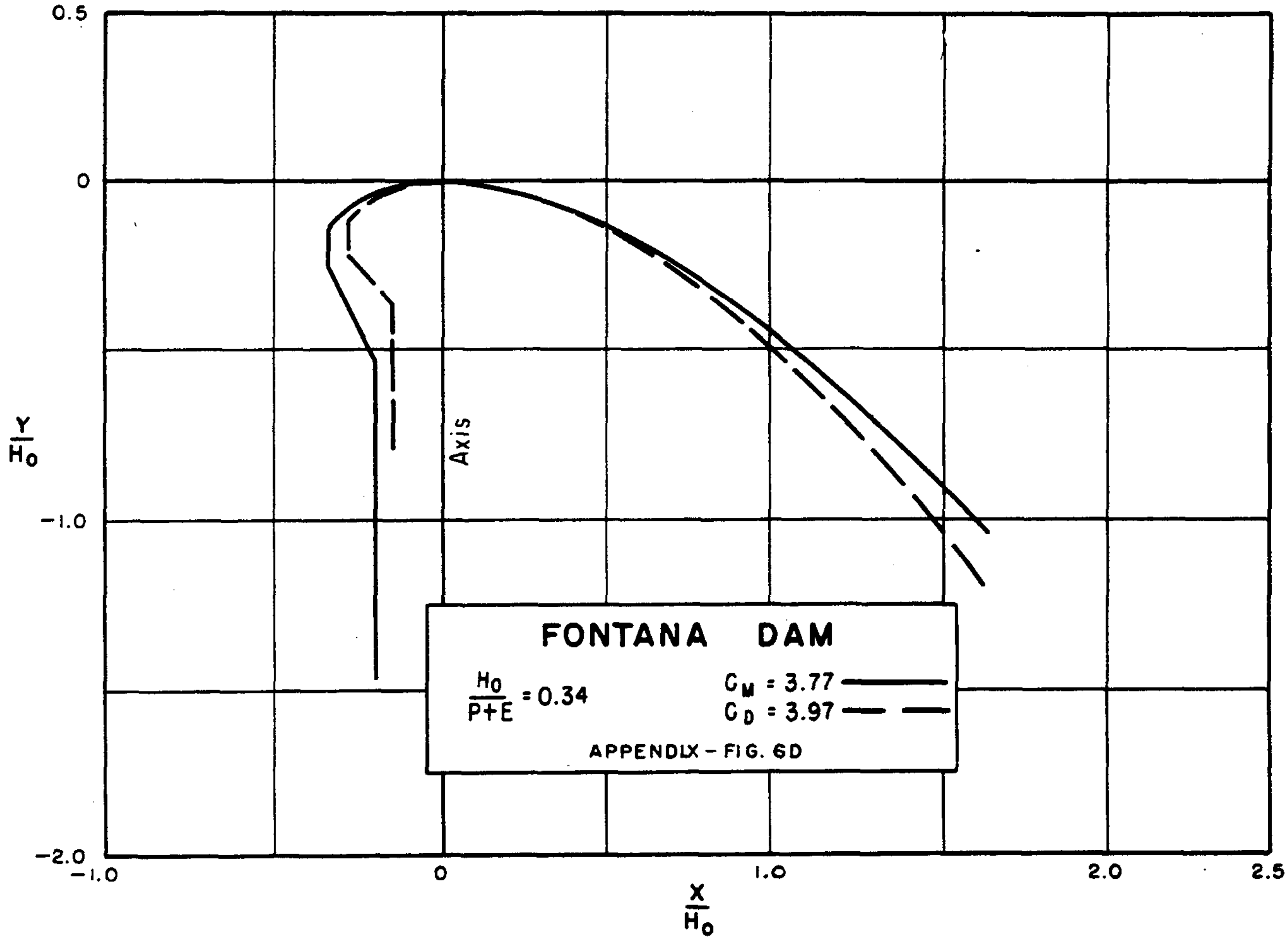
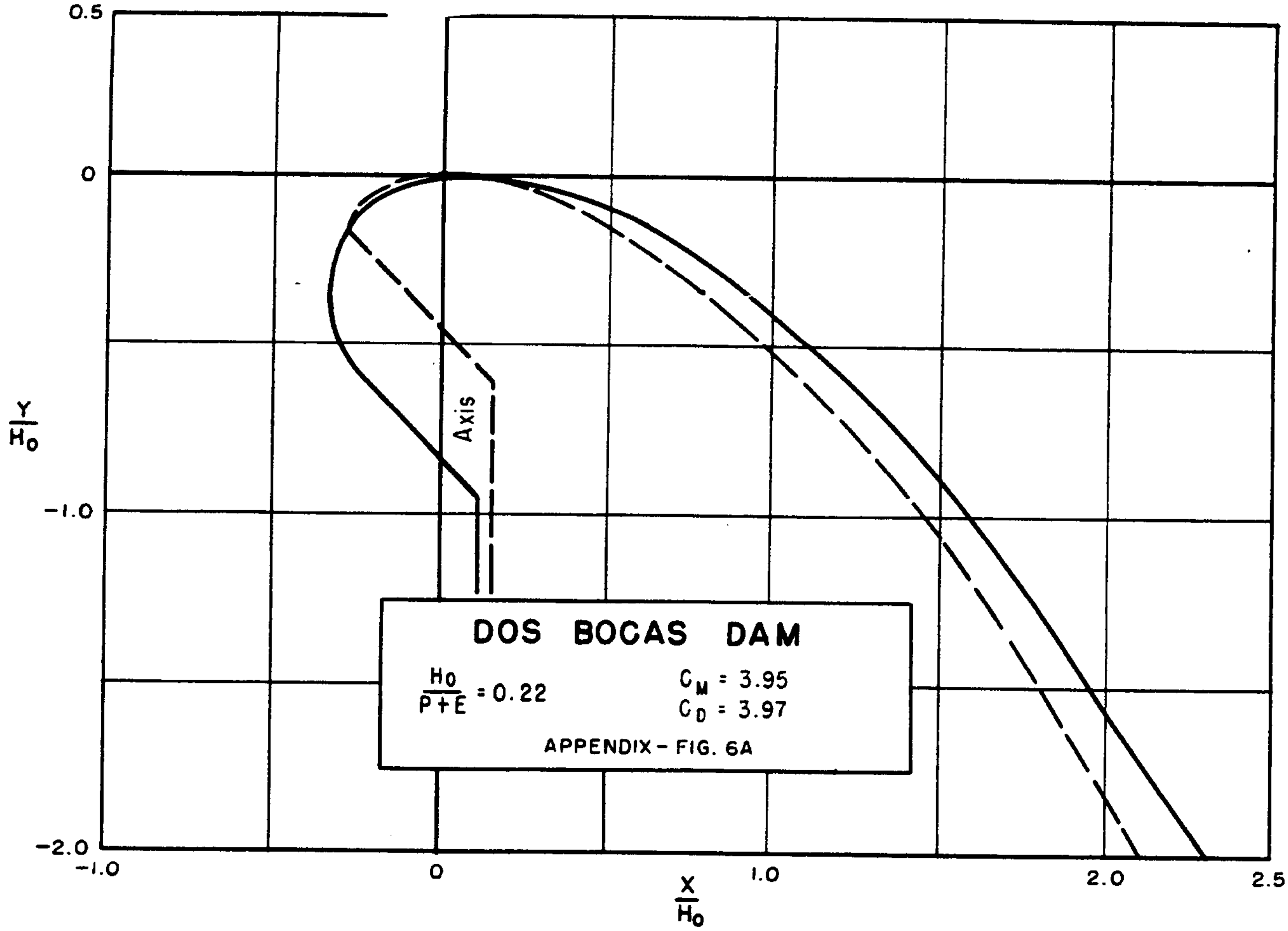


FIGURE 17 - Spillways with offset in upstream face.



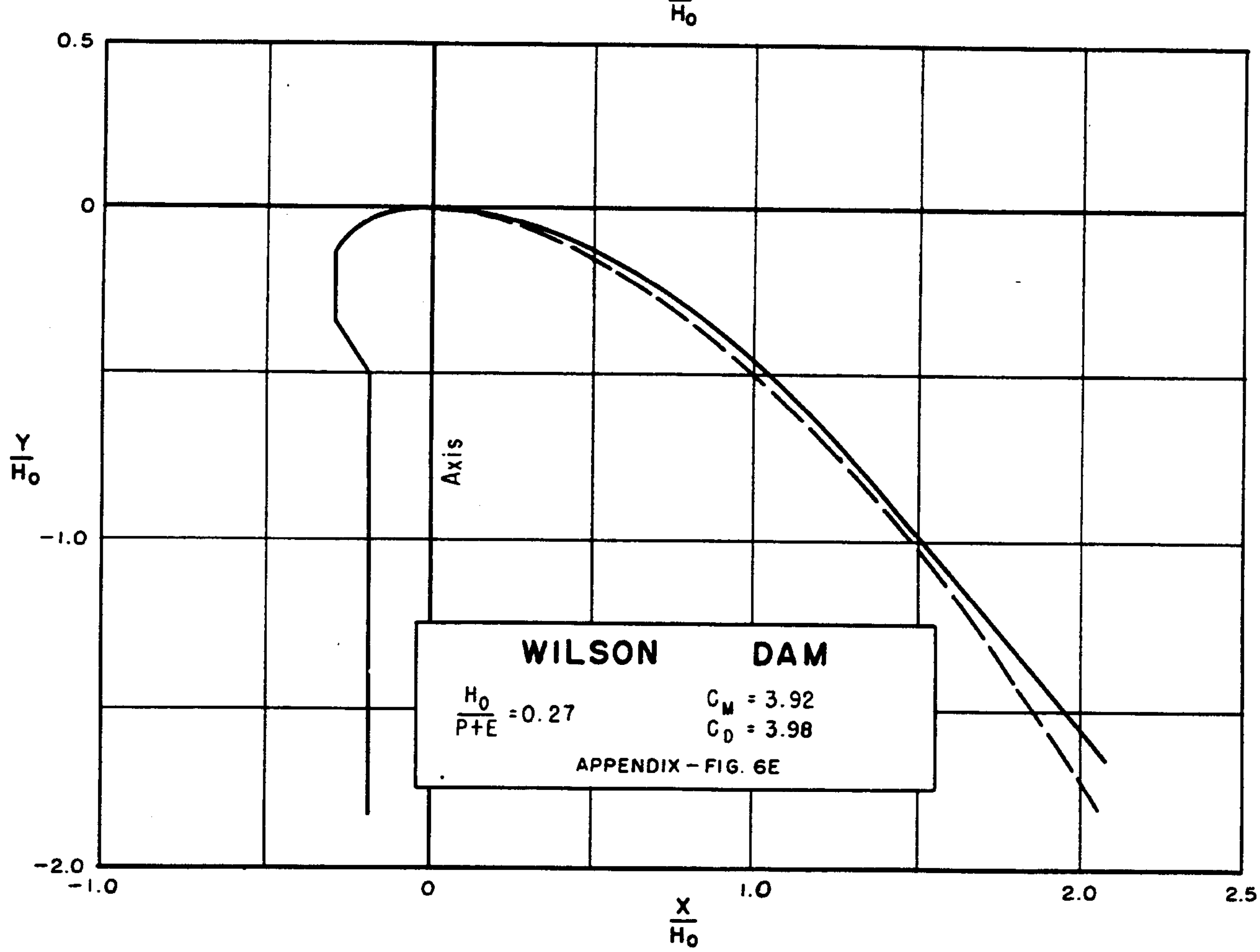


FIGURE 18 - Spillways with offset in upstream face.

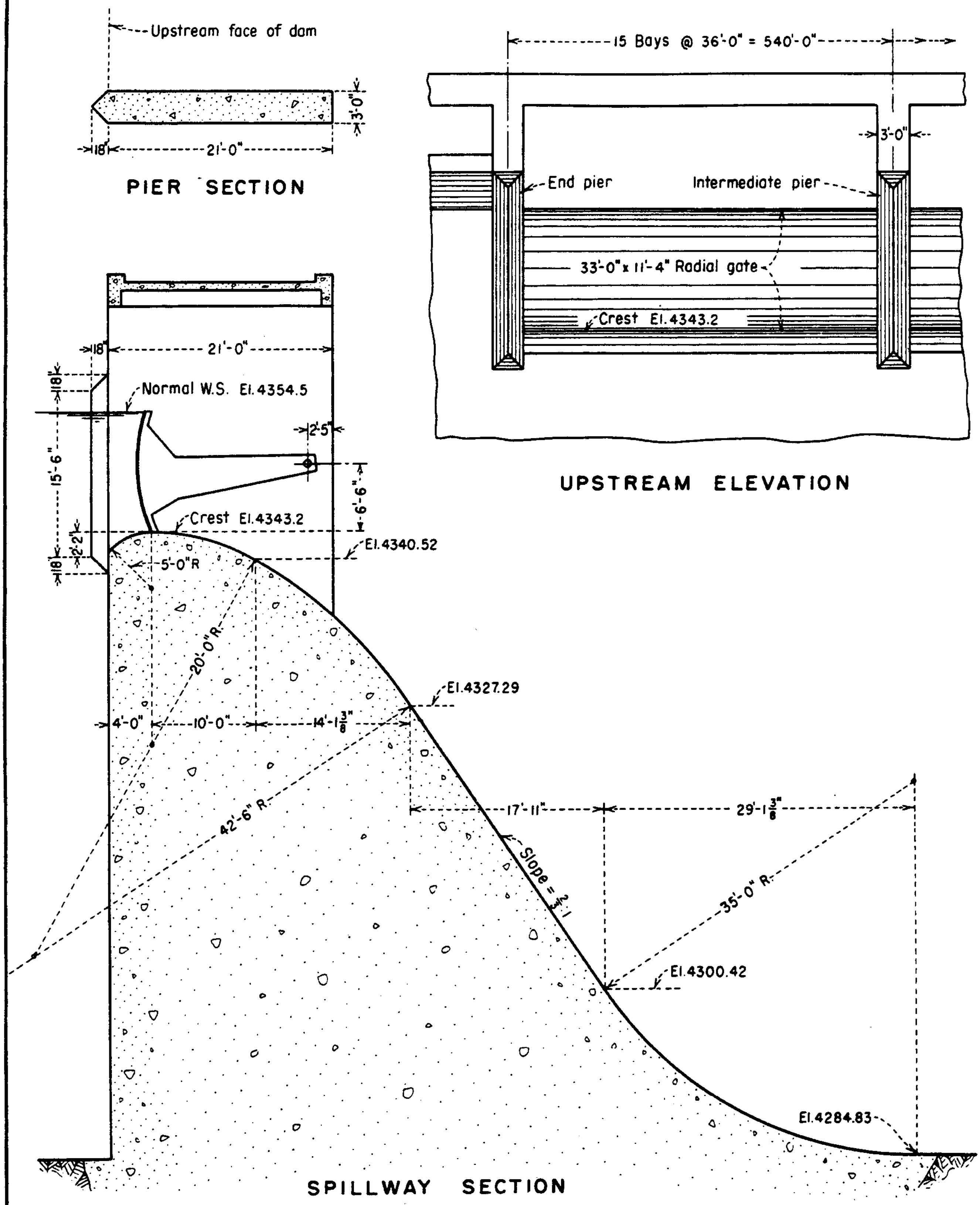
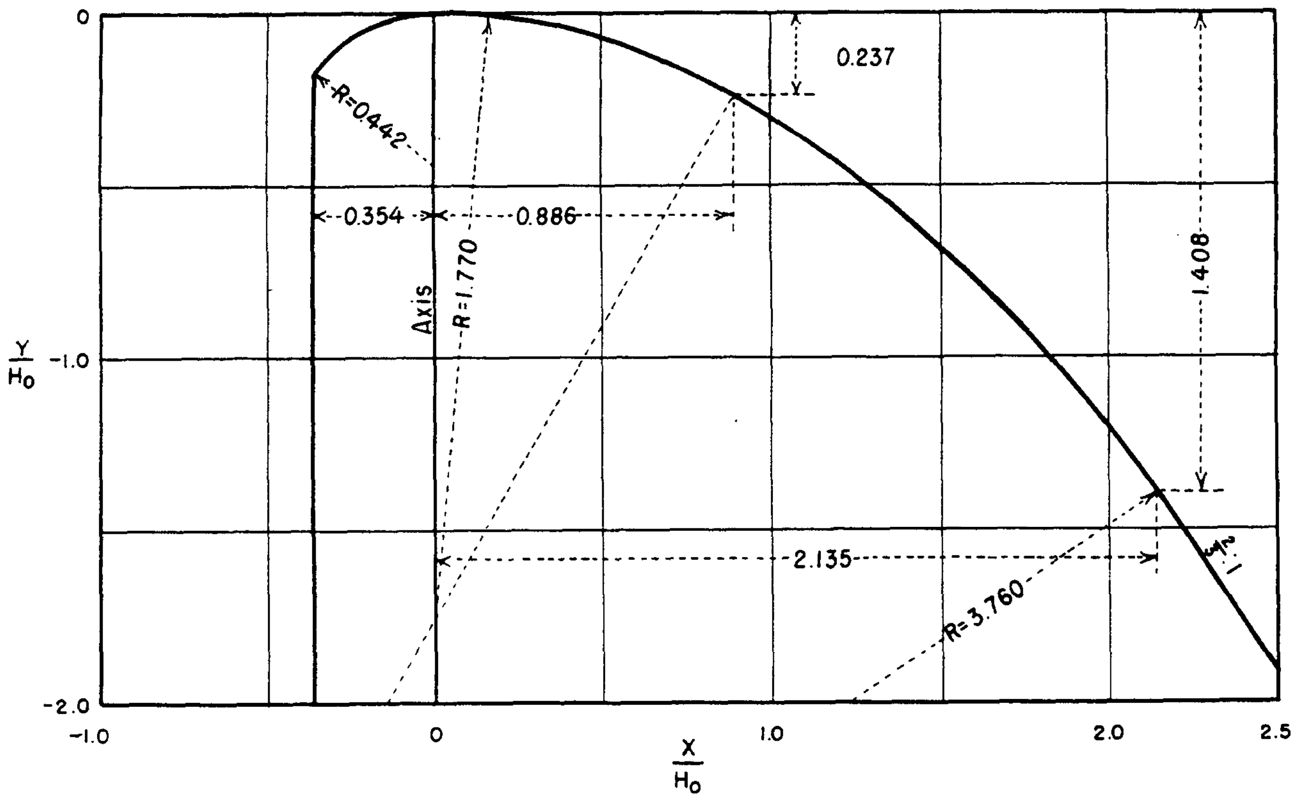
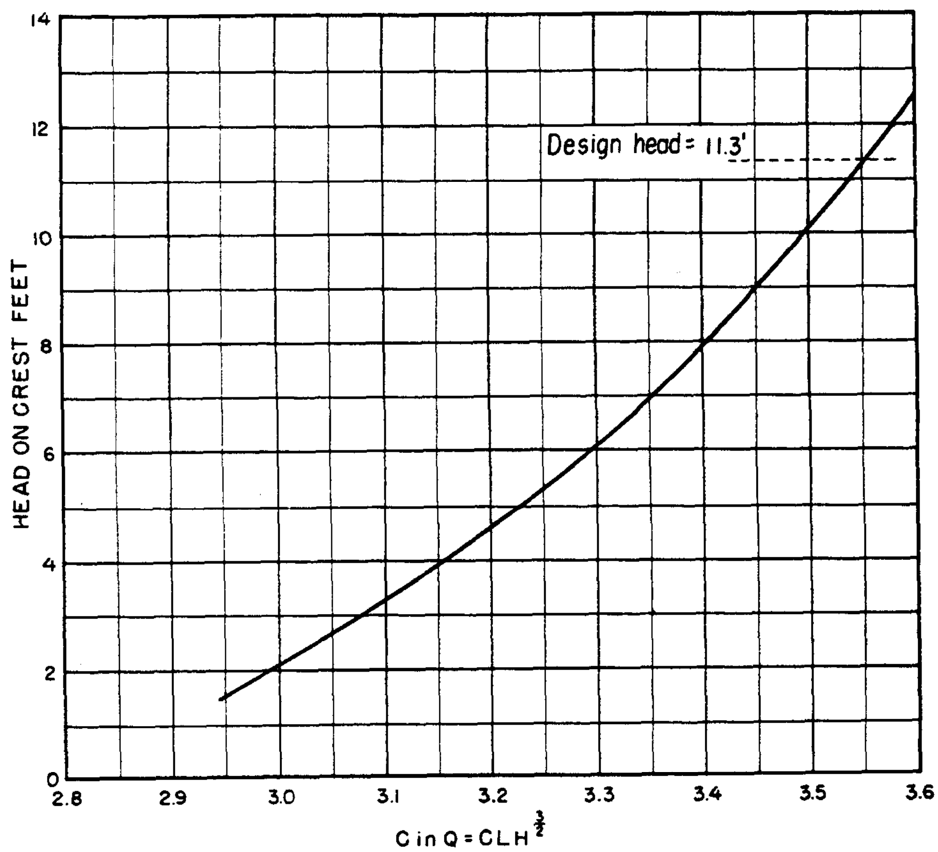


FIGURE 19 - Elevation and section American Falls Dam Spillway.

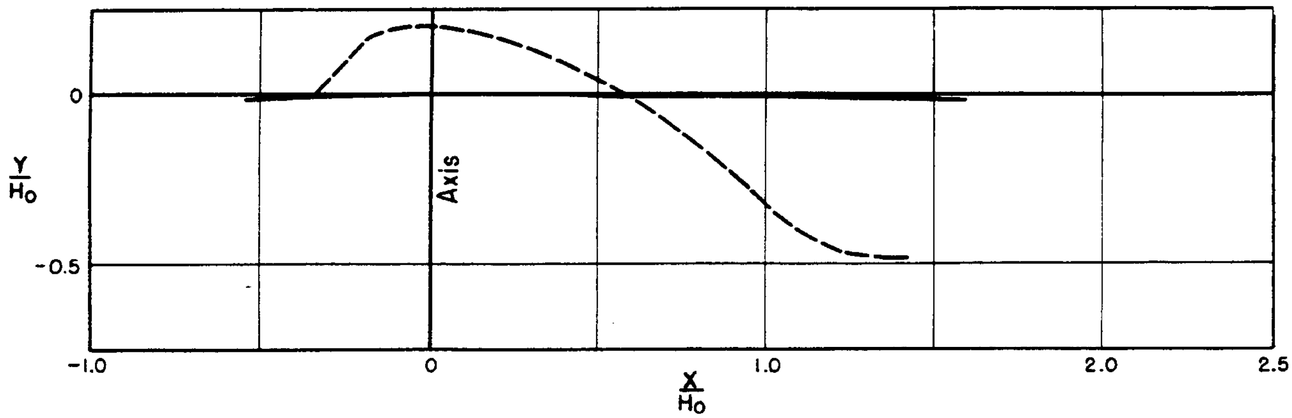


A- OVERFALL CREST SECTION



B- HEAD- COEFFICIENT CURVE

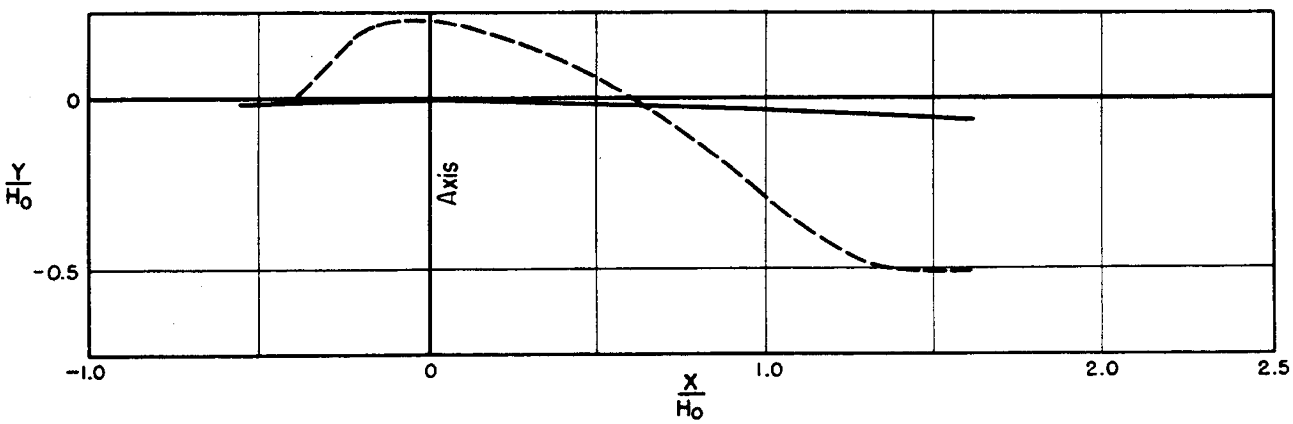
FIGURE 20 - American Falls Dam Spillway (Examples 1 and 3).



RYE PATCH DAM

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

APPENDIX—FIG. 7A

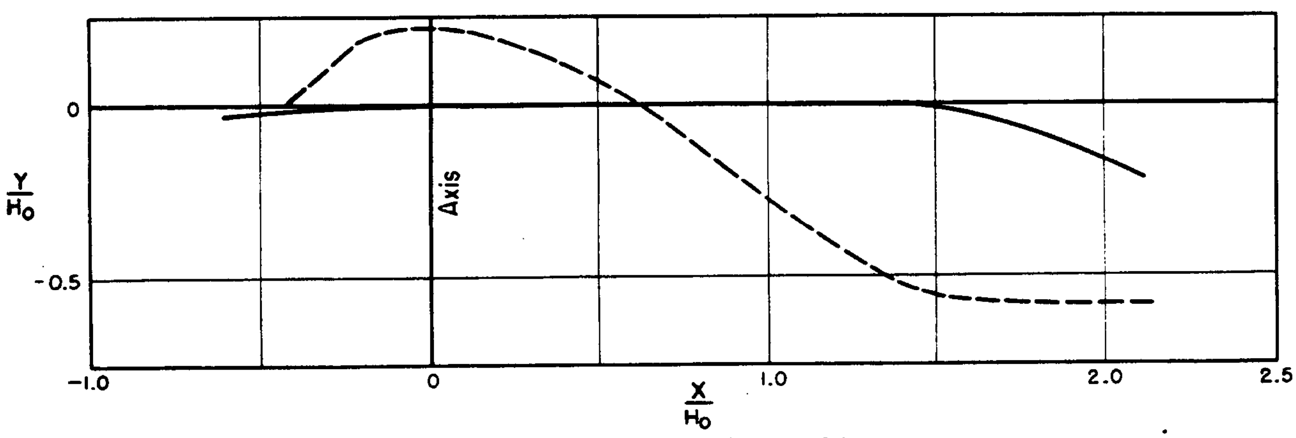


AGENCY VALLEY DAM

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

CONTRACTION IN CHUTE D.S.

APPENDIX—FIG. 7D



PINE VIEW DAM

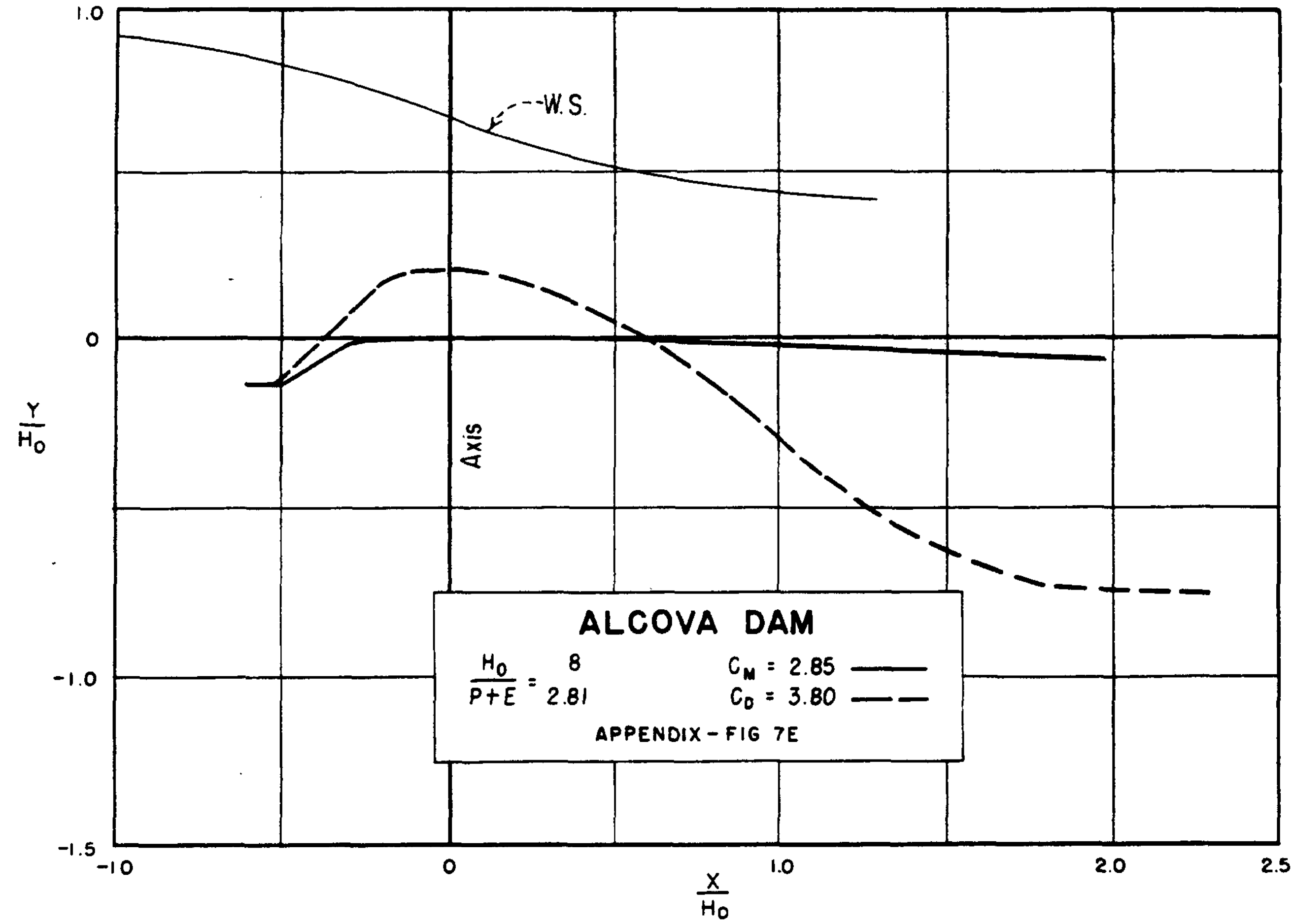
$\frac{H_0}{P+E} = \frac{4}{1.81}$ $C_M = 2.74$ ——— $C_D = 3.86$ — —

CONTRACTION IN CHUTE D.S.

APPENDIX—FIG. 7C

FIGURE 21 - Spillways with overfall suppressed.

SHEET 1 OF 11



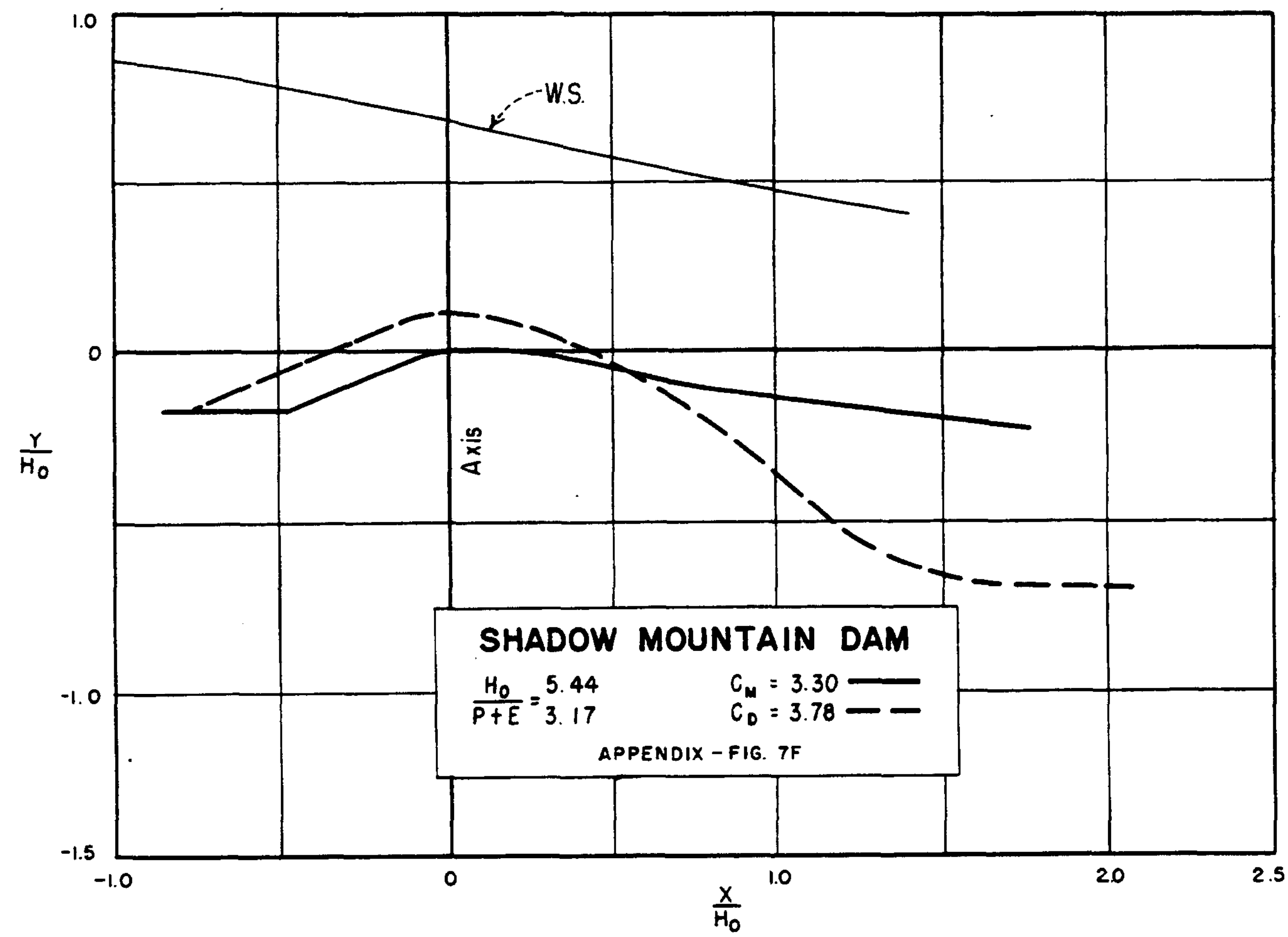
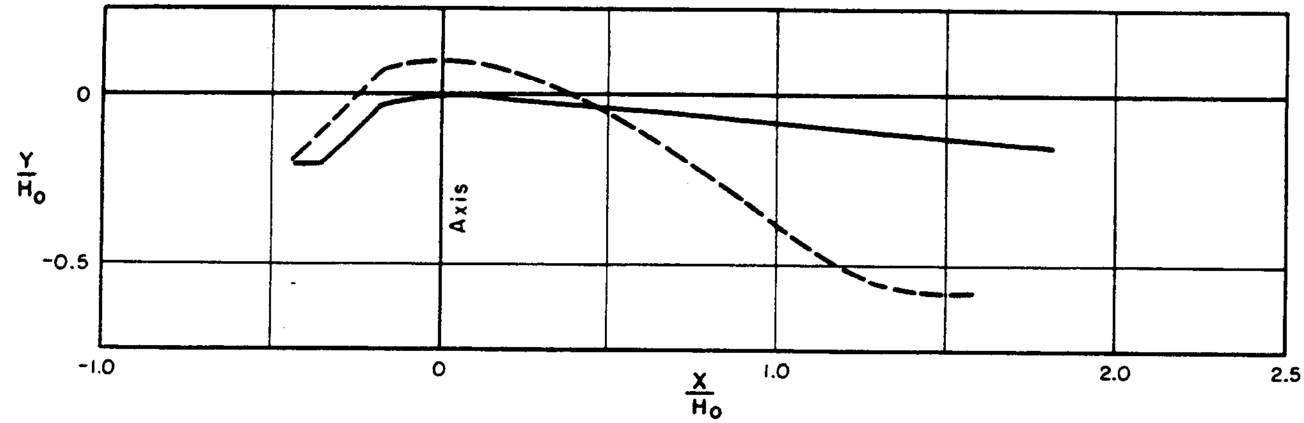


FIGURE 22 - Spillways with overfall suppressed.

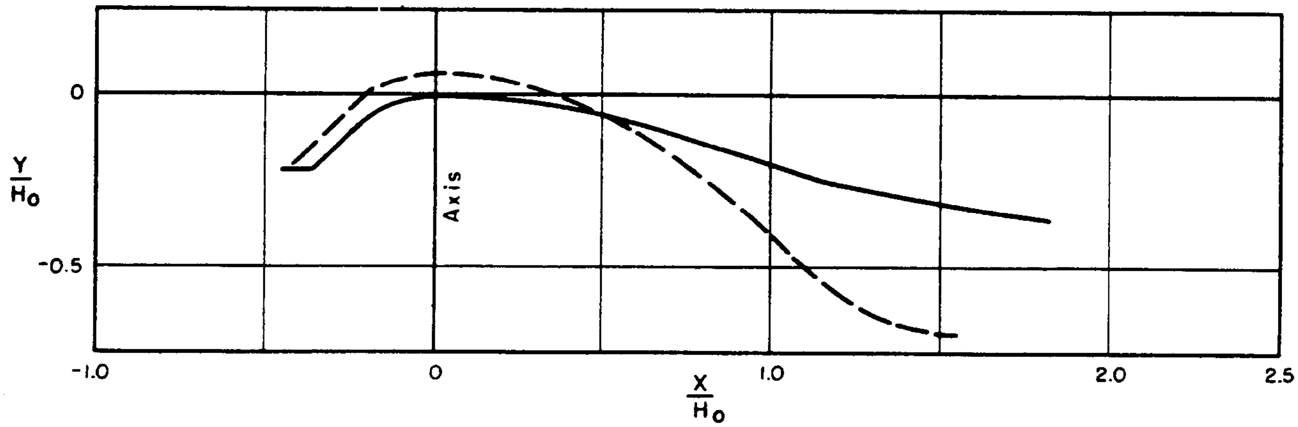
SHEET 2 OF 11



GREEN MOUNTAIN DAM

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

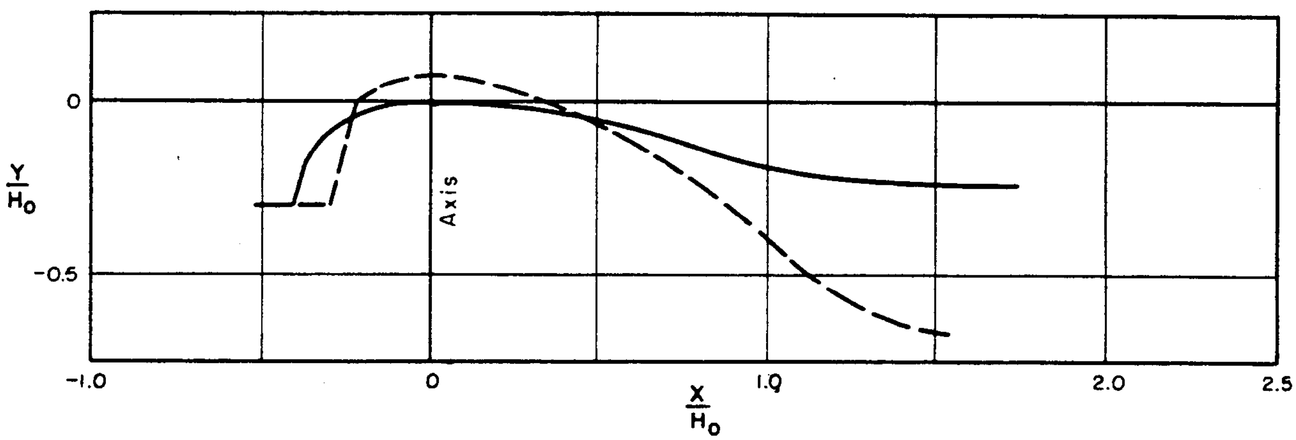
CONTRACTION IN CHUTE D.S.
APPENDIX - FIG. 7B



ANDERSON RANCH DAM

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

APPENDIX - FIG. 8A

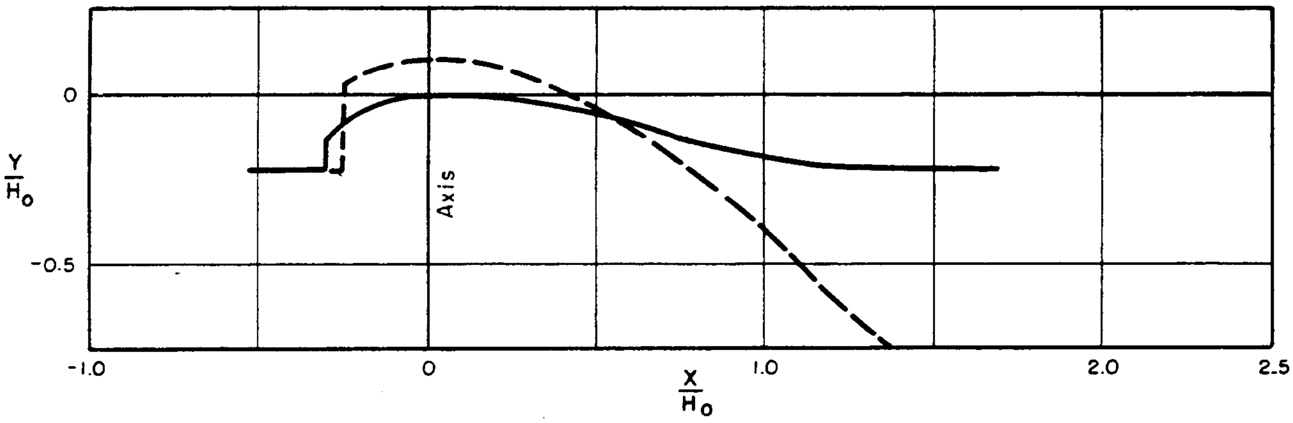


BARTLETT DAM

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

APPENDIX - FIG. 8B

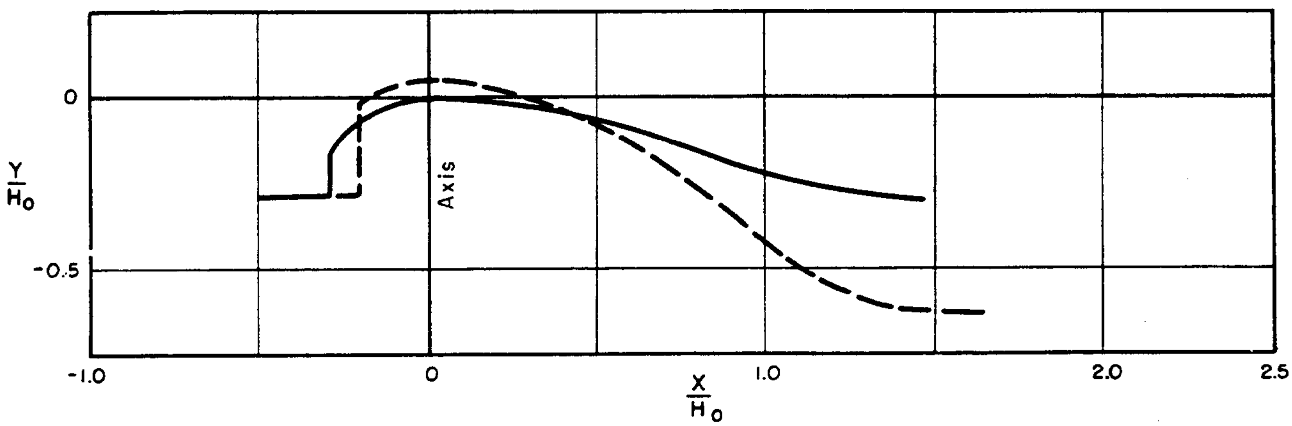
FIGURE 23 - Spillways with overfall suppressed.



GRANBY DAM

$\frac{H_0}{P+E} = \frac{5.0}{3.1}$ C_M = 3.20 ——— C_D = 3.71 – – –

APPENDIX - FIG. 8C

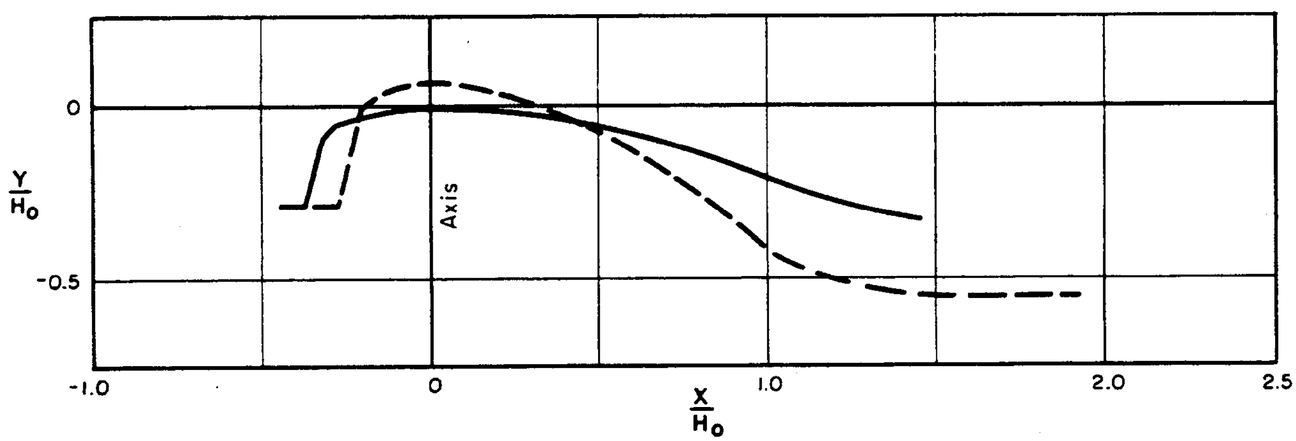


VALLECITO DAM

$\frac{H_0}{P+E} = \frac{3.8}{3.0}$ C_M = 3.42 ——— C_D = 3.72 – – –

CONTRACTION IN CHUTE D.S.

APPENDIX - FIG. 8F



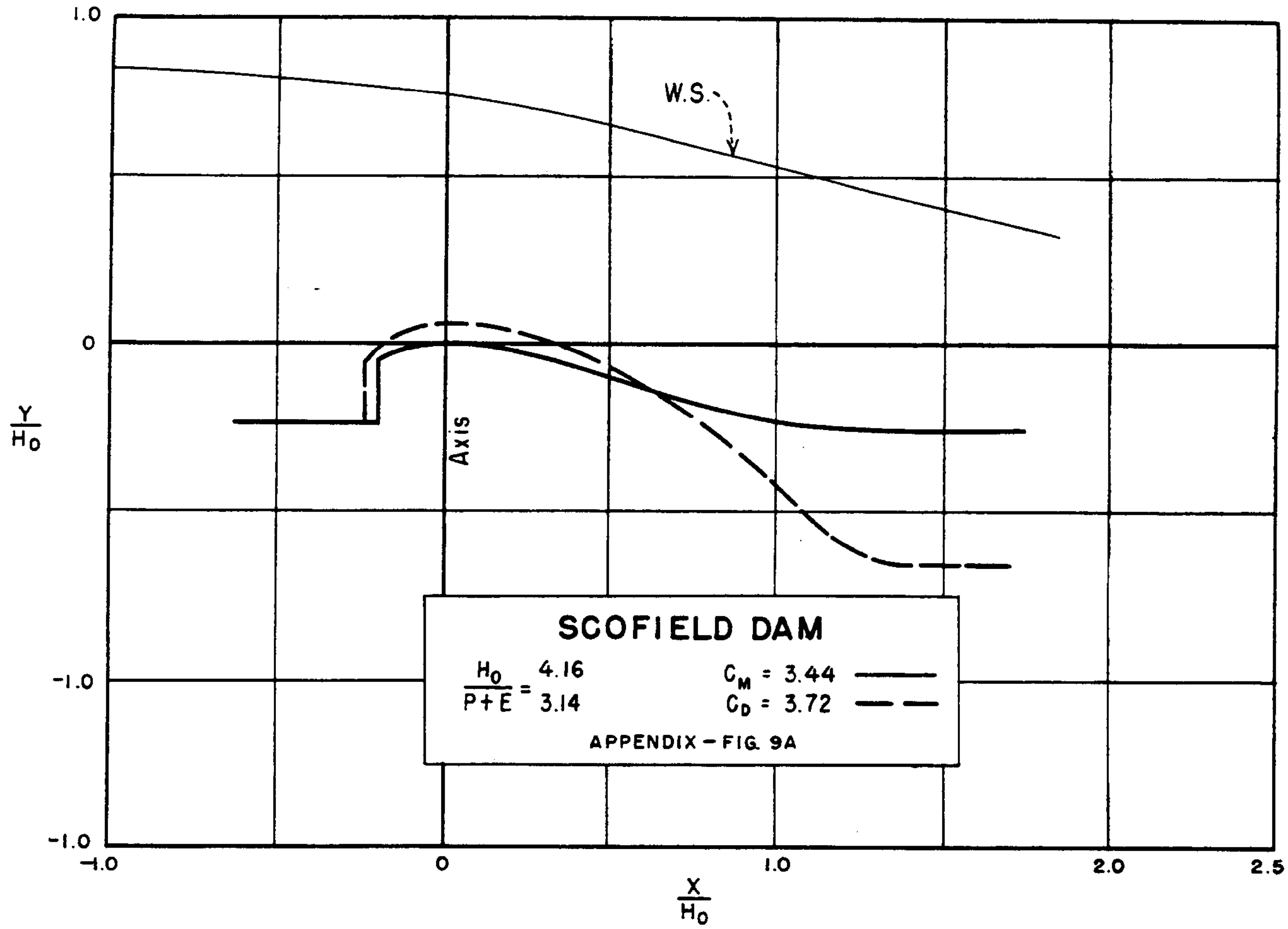
BOYSEN DAM

(PRELIMINARY DESIGN)

$\frac{H_0}{P+E} = \frac{3.71}{2.74}$ C_M = 3.37 ——— C_D = 3.76 – – –

APPENDIX - FIG. 8E

FIGURE 24 - Spillways with overfall suppressed.



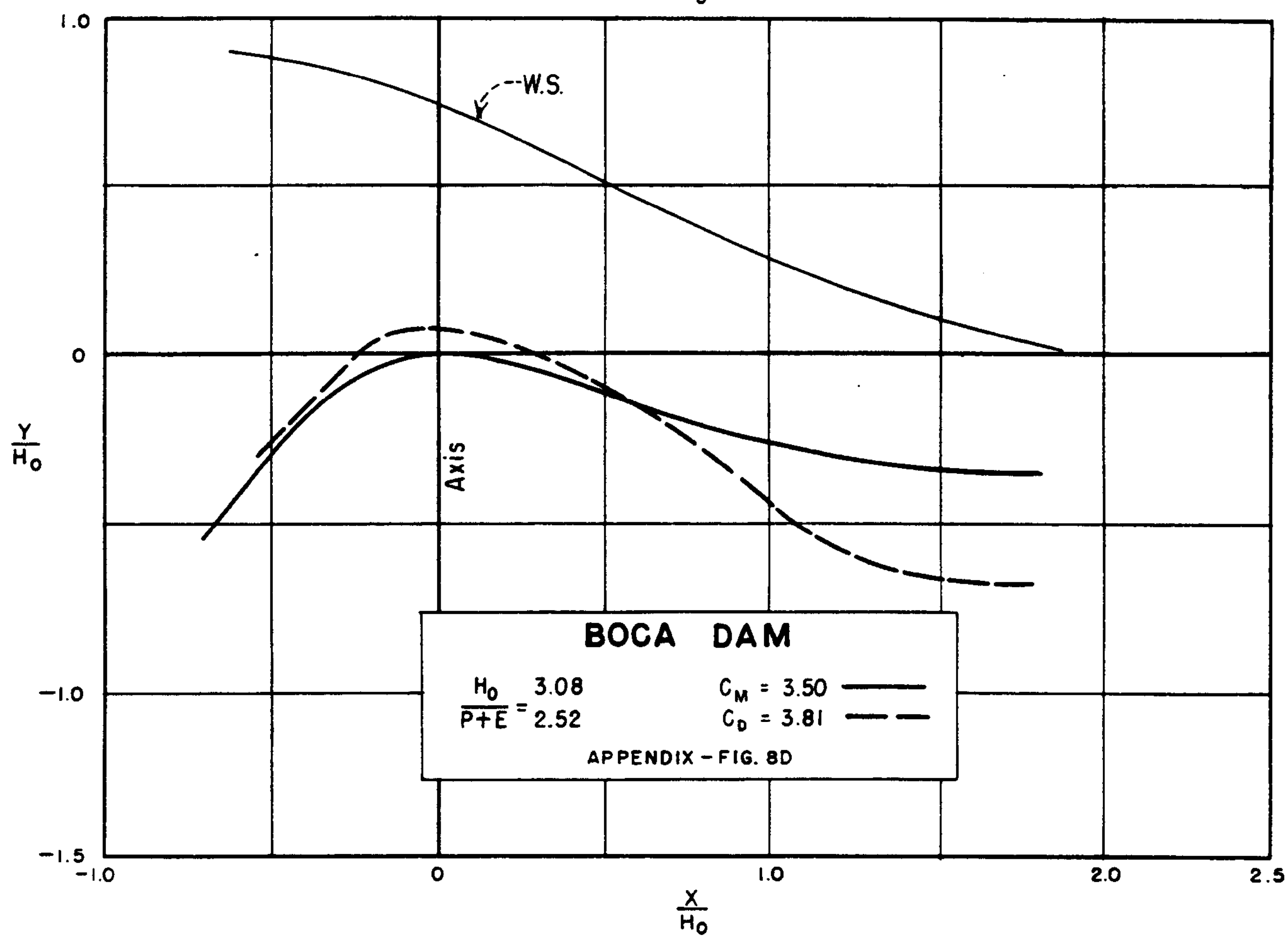
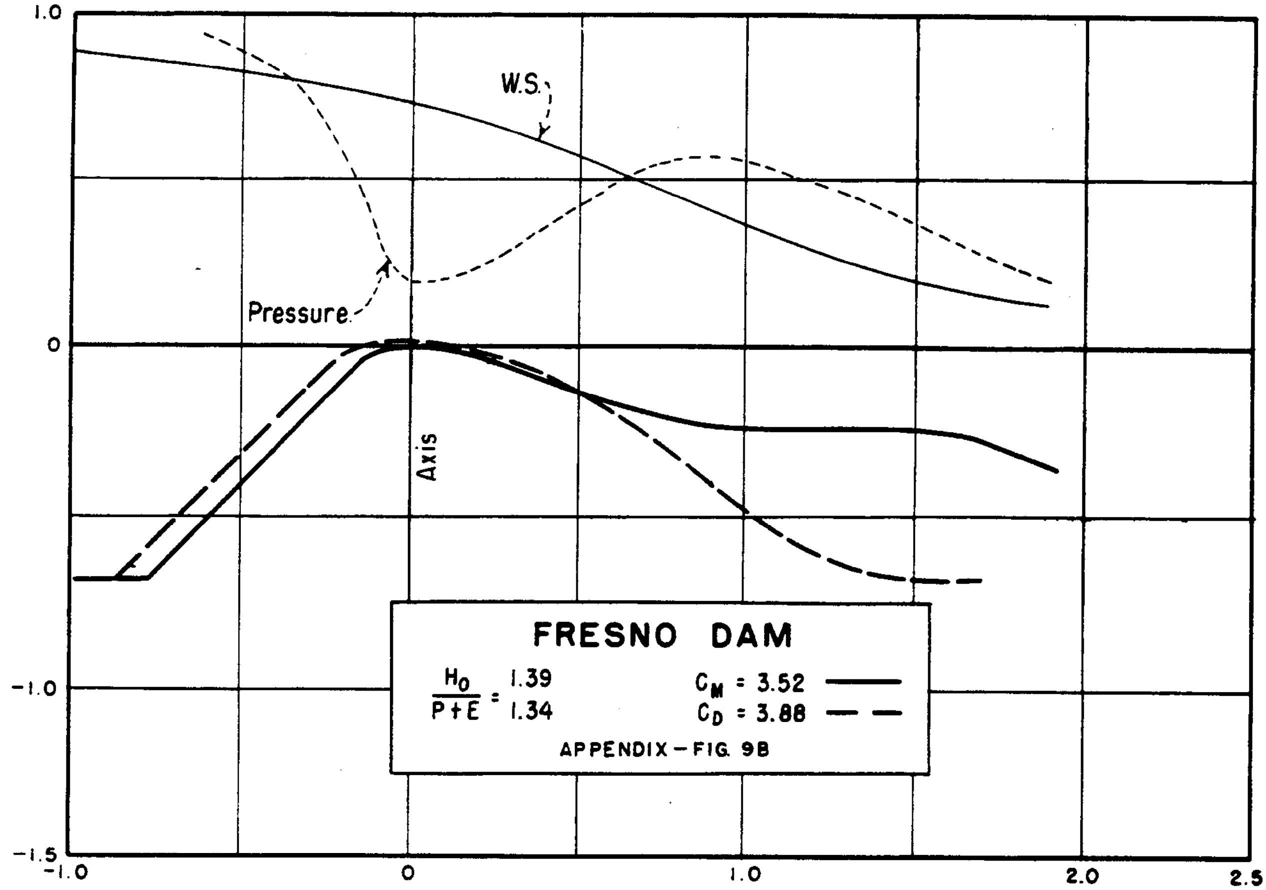


FIGURE 25 - Spillways with overfall suppressed.



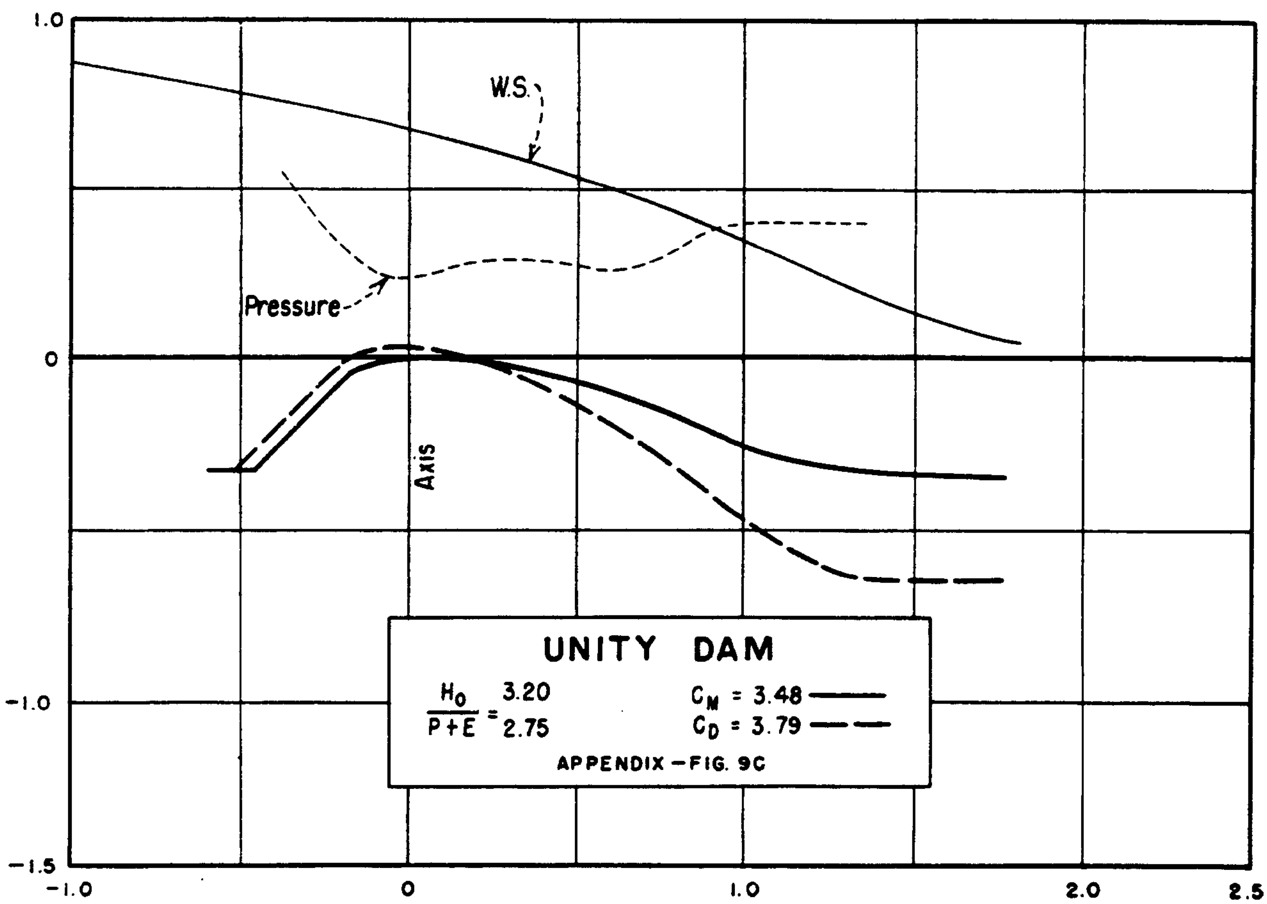
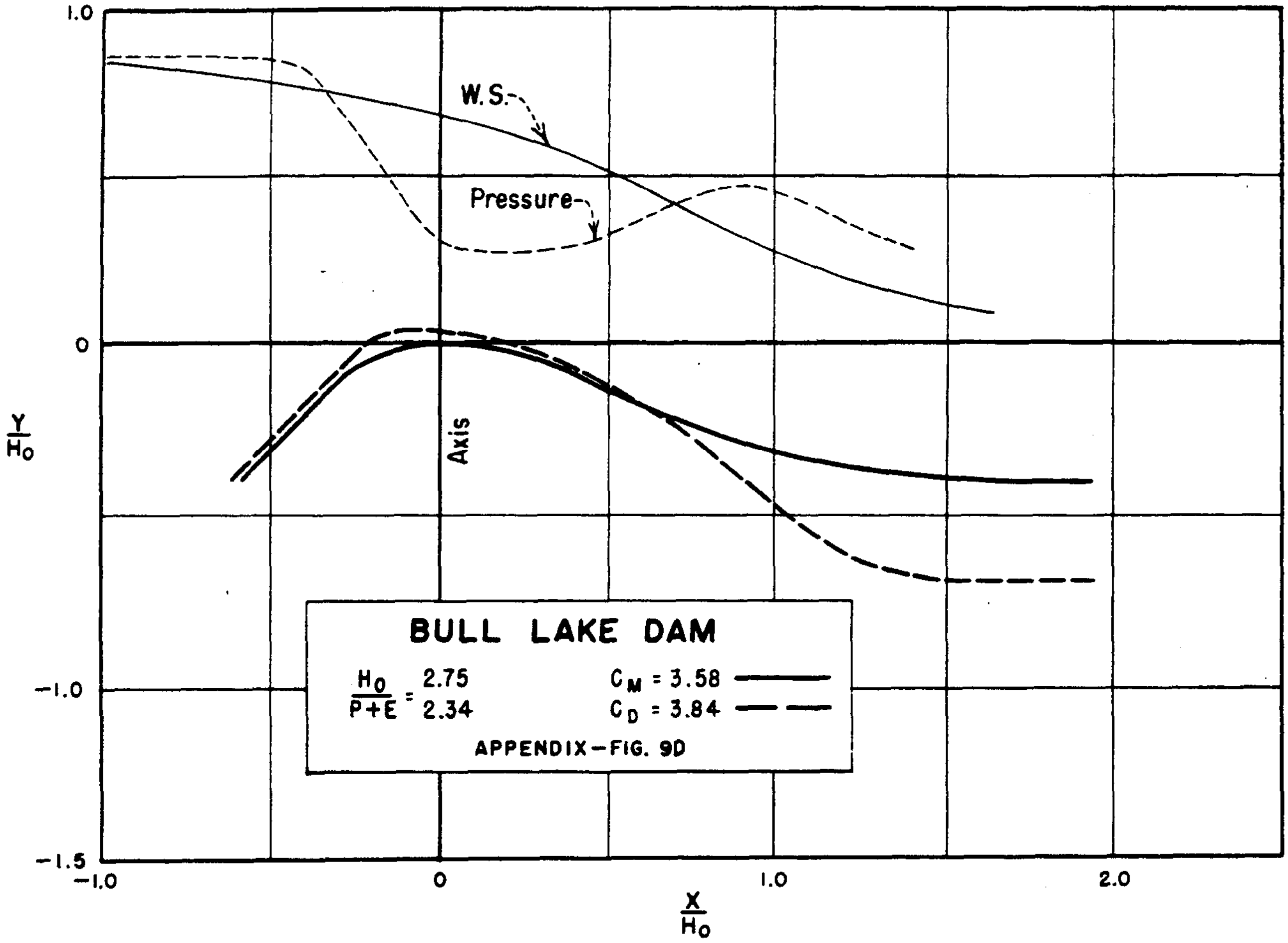


FIGURE 26 - Spillways with overfall suppressed.



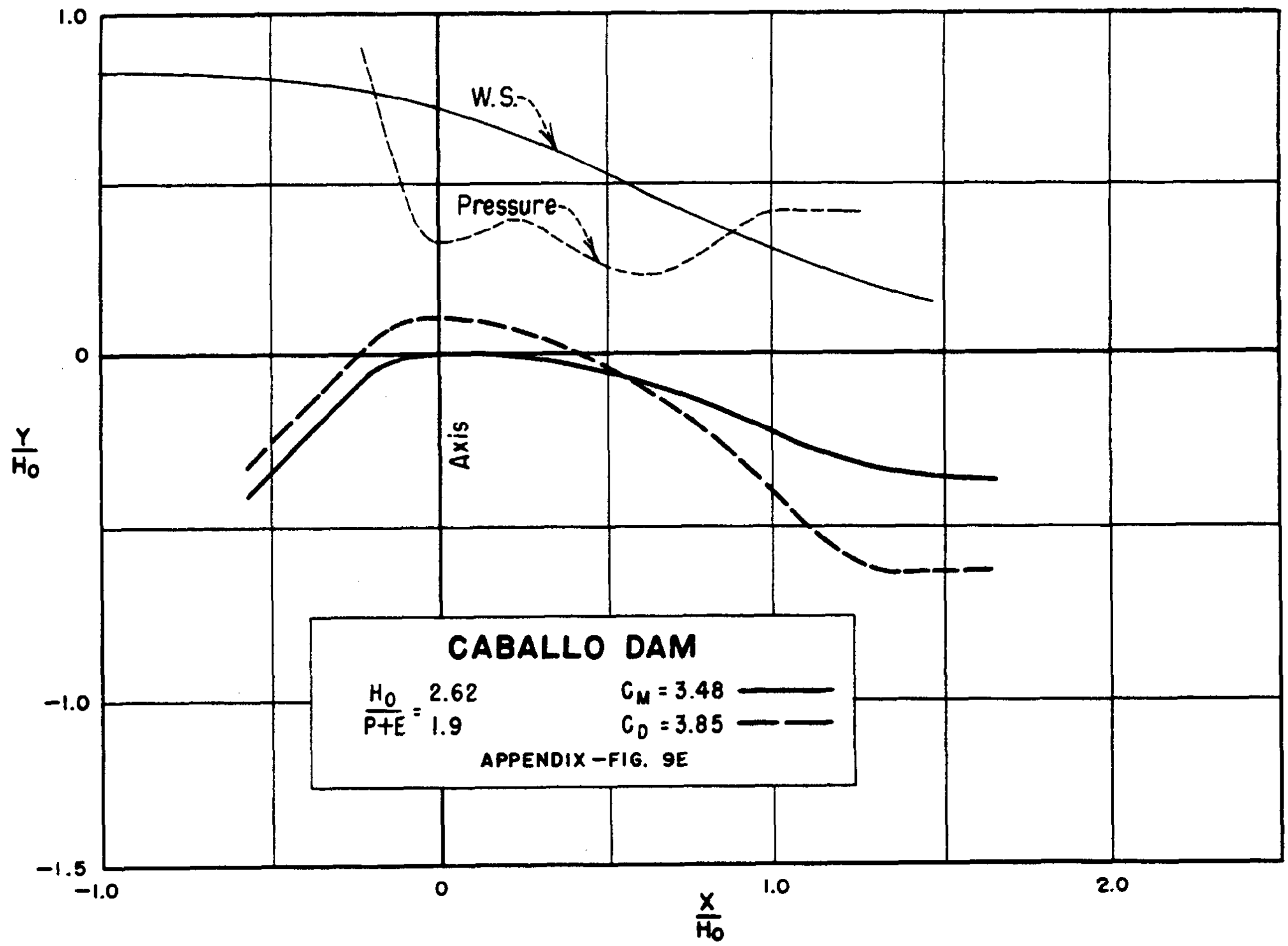
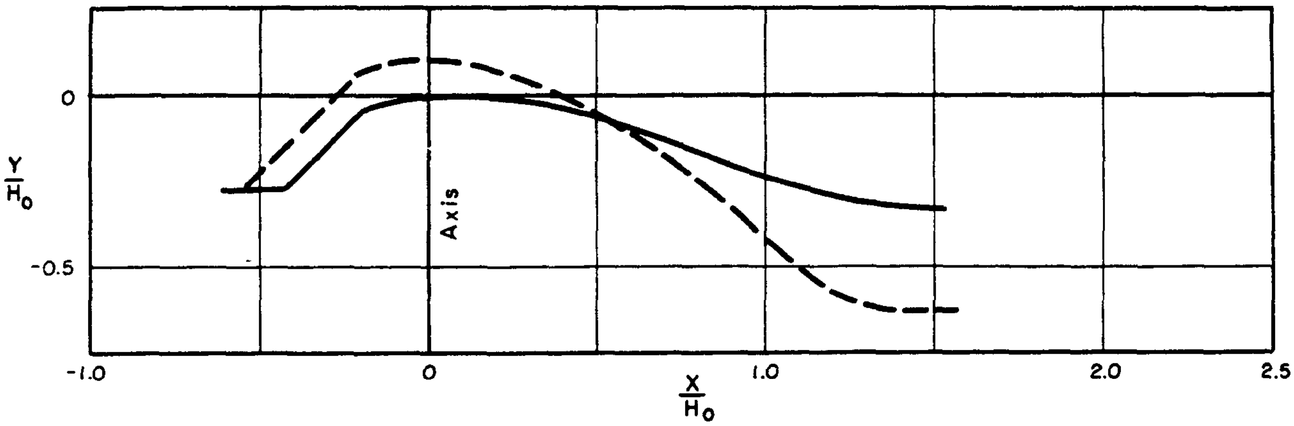


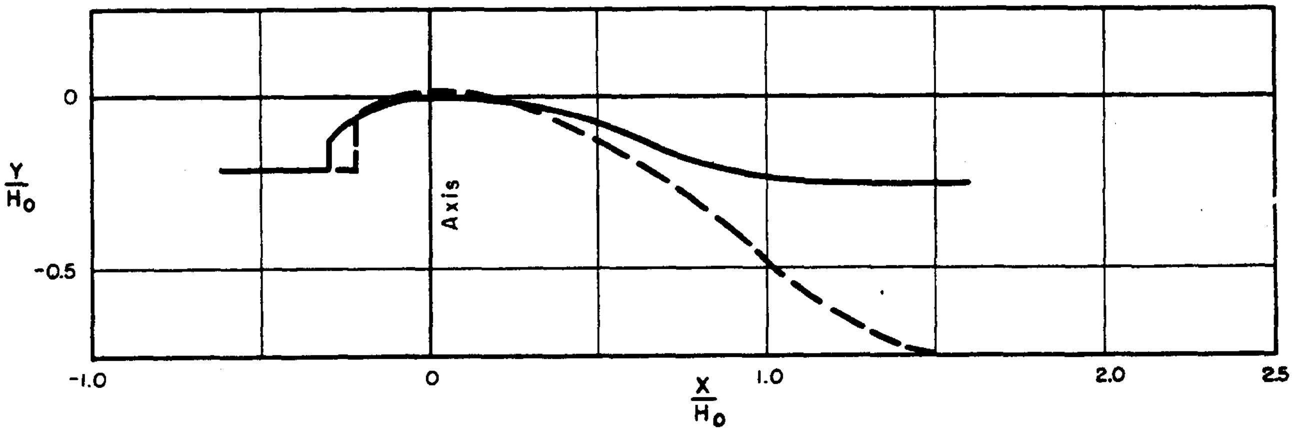
FIGURE 27 - Spillways with overfall suppressed.



MOON LAKE DAM
(FINAL DESIGN)

$\frac{H_0}{P+E} = \frac{4.0}{2.57}$ $C_M = 3.28$ ——— $C_D = 3.80$ – – –

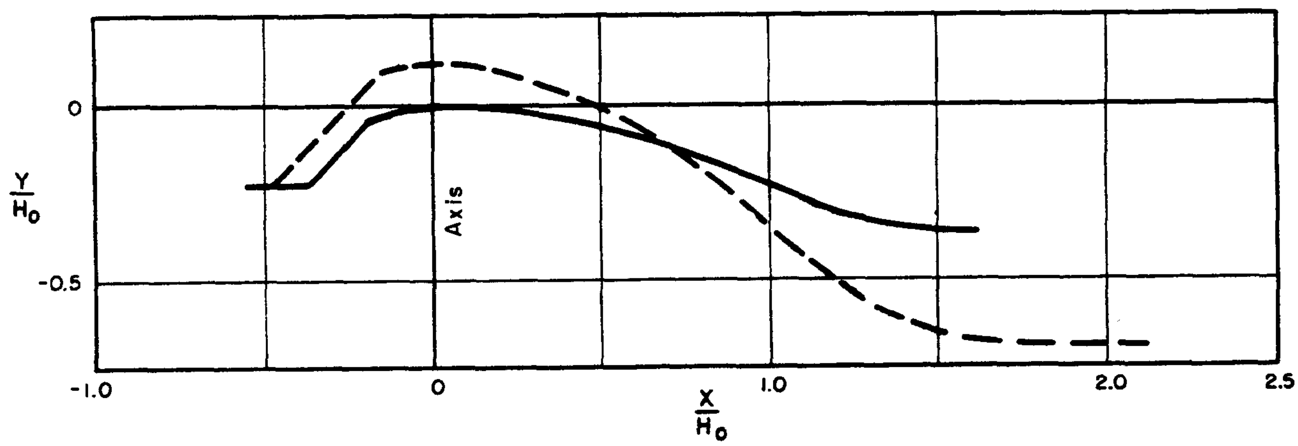
CONTRACTION IN CHUTE D.S.
APPENDIX - FIG. 9F



DEER CREEK DAM

$\frac{H_0}{P+E} = \frac{5.0}{4.22}$ $C_M = 3.46$ ——— $C_D = 3.61$ – – –

CONTRACTION IN CHUTE D.S.
APPENDIX - FIG. 9G



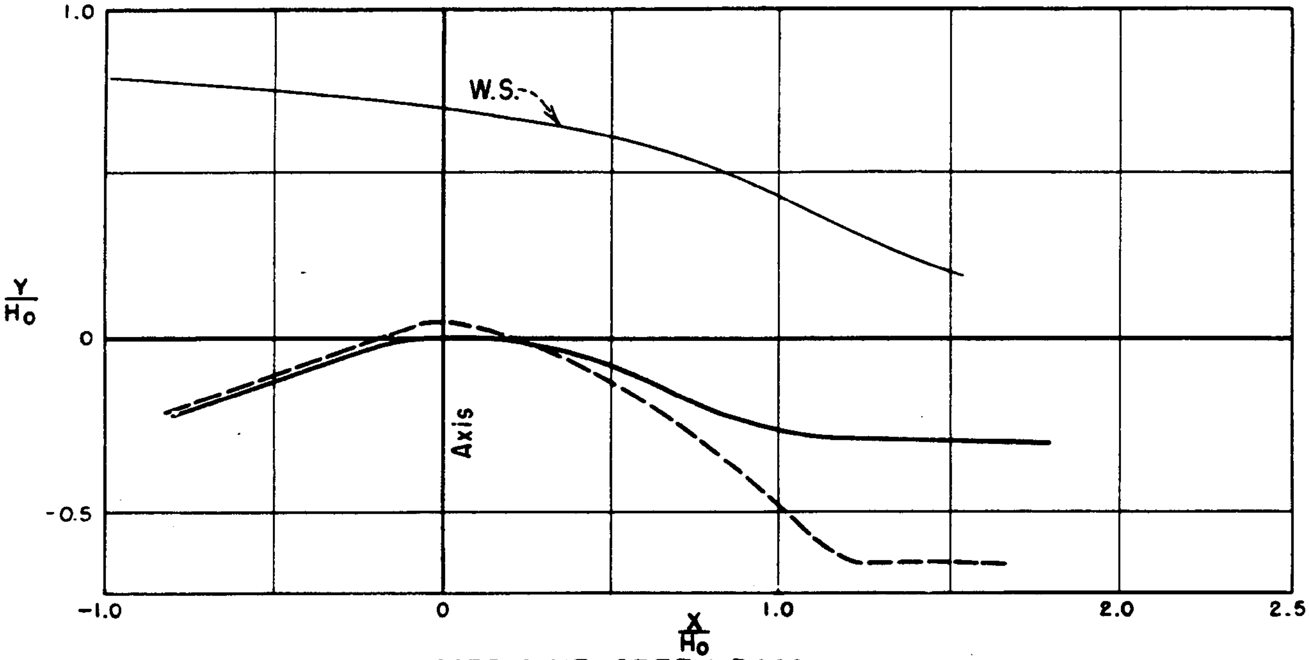
ALAMOGORDO DAM

$\frac{H_0}{P+E} = \frac{5.2}{2.82}$ $C_M = 3.18$ ——— $C_D = 3.79$ – – –

CONTRACTION IN CHUTE D.S.
APPENDIX - FIG. 9H

FIGURE 28 - Spillways with overfall suppressed.

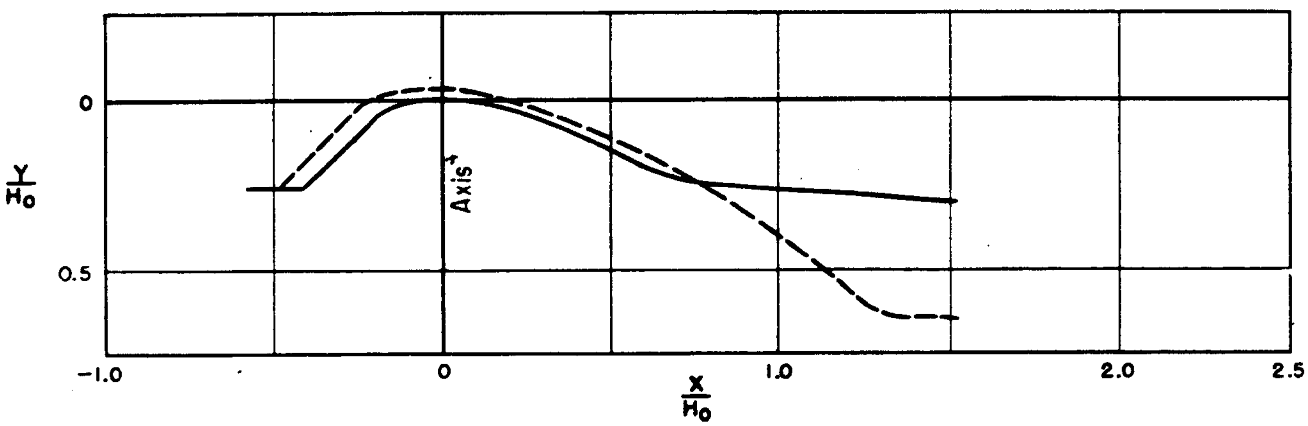
SHEET 8 OF 11



MEDICINE CREEK DAM (LOW CREST)

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

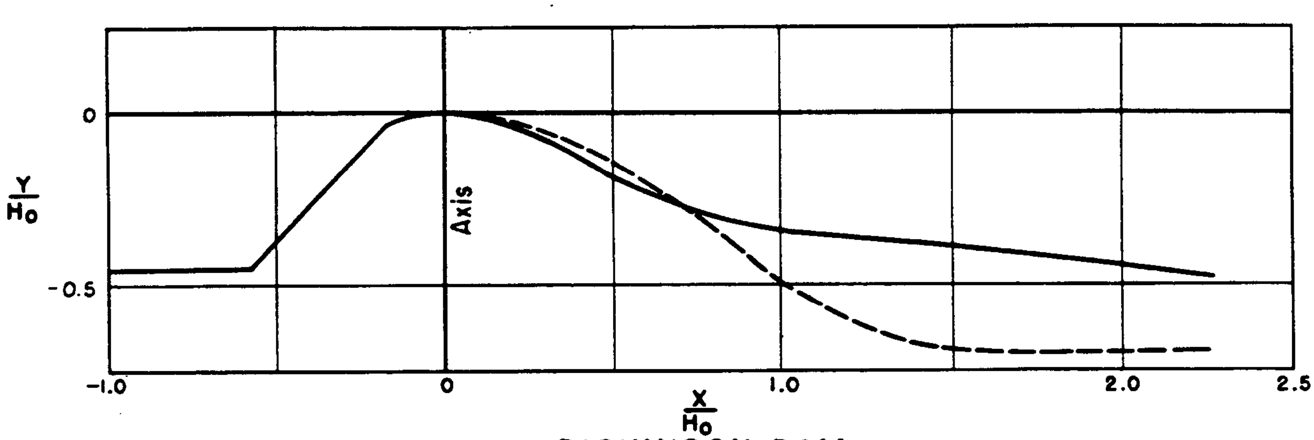
APPENDIX — FIG. 10C



KEYHOLE DAM

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

APPENDIX — FIG. 10D



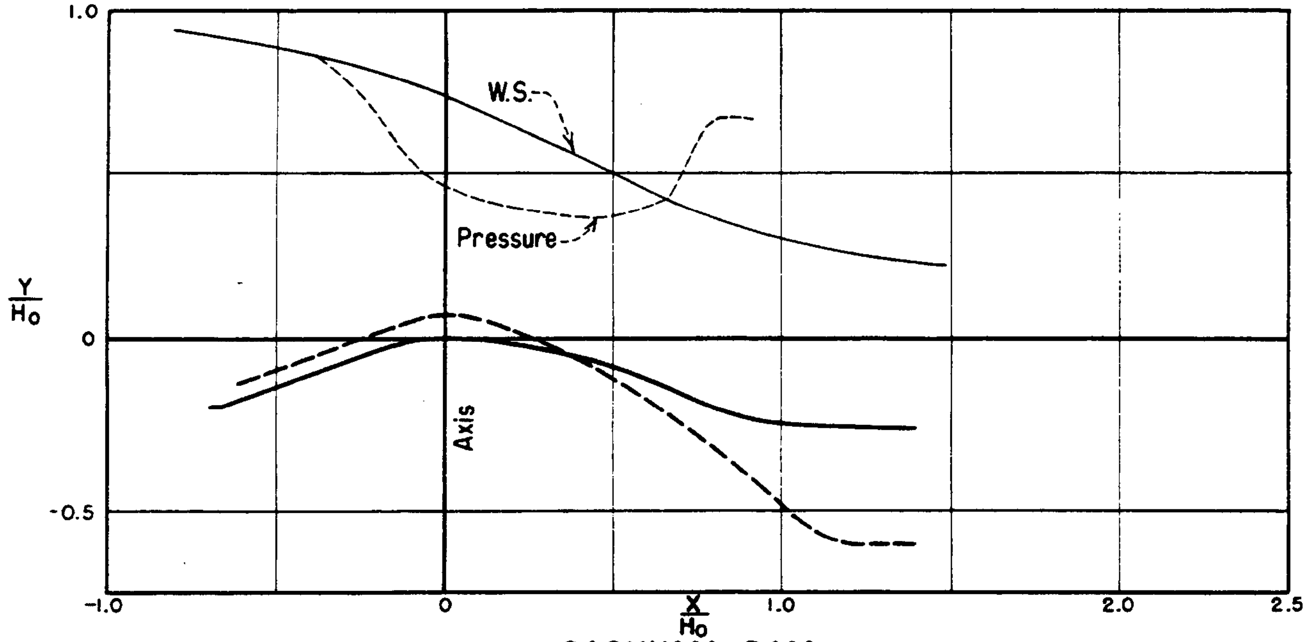
DICKINSON DAM

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

APPENDIX — FIG. 10B

FIGURE 29 - Spillways with overfall suppressed.

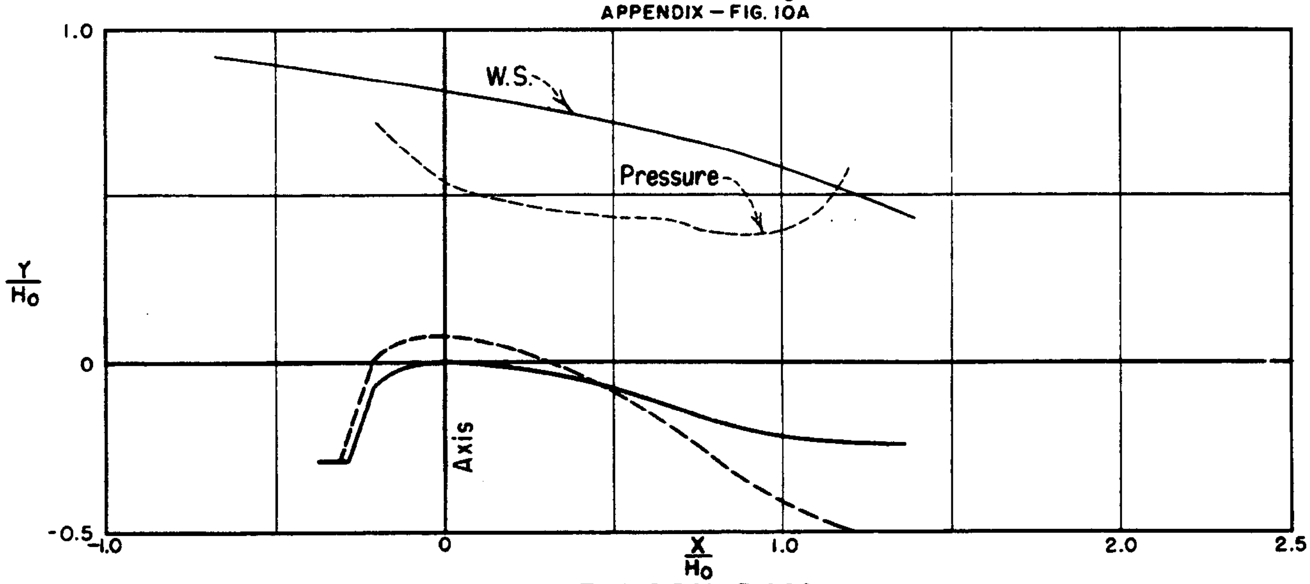
SHEET 9 OF 11



CACHUMA DAM

$\frac{H_O}{P+E} = \frac{5.0}{3.55}$ $C_M = 3.42$ ——— $C_D = 3.76$ — —

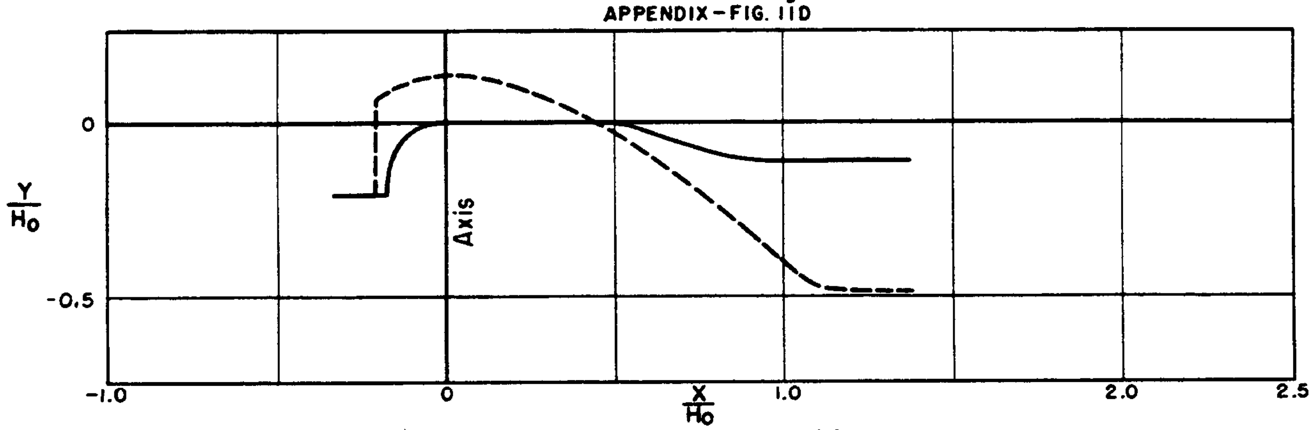
APPENDIX – FIG. 10A



FALCON DAM

$\frac{H_O}{P+E} = \frac{3.44}{2.50}$ $C_M = 3.33$ ——— $C_D = 3.78$ — —

APPENDIX – FIG. 11D



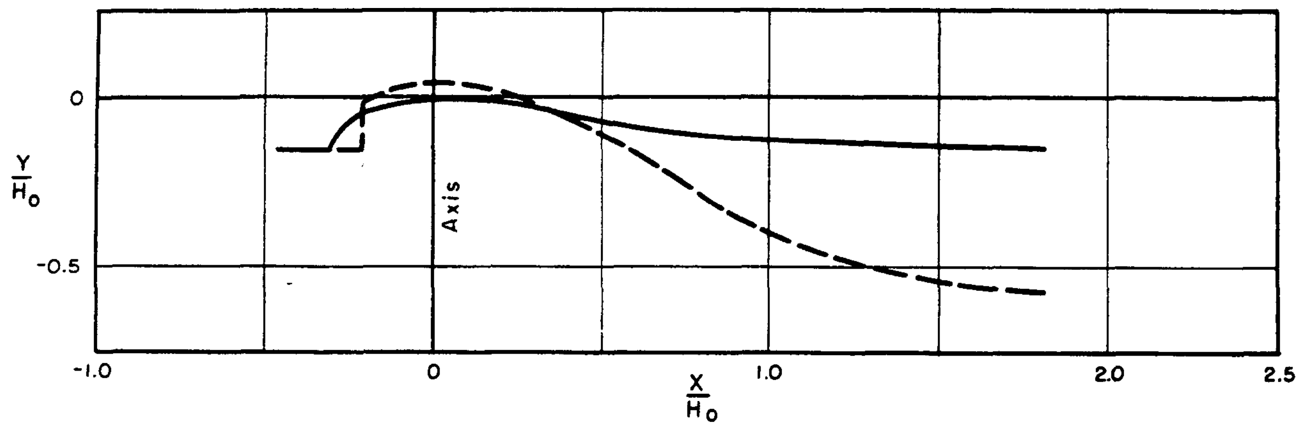
HORSESHOE DAM

$\frac{H_O}{P+E} = \frac{4.75}{2.54}$ $C_M = 3.20$ ——— $C_D = 3.74$ — —

APPENDIX – FIG. 11B

FIGURE 30 - Spillways with overfall suppressed.

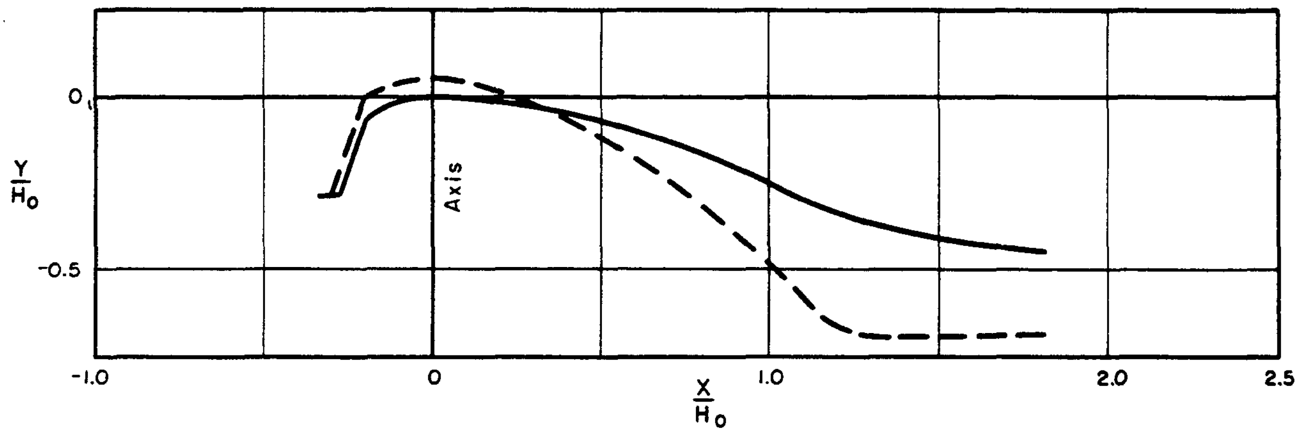
SHEET 10 OF 11



CASCADE DAM

$\frac{H_o}{P+E} = \frac{6.67}{4.75}$ $C_M = 3.38$ ——— $C_D = 3.57$ – – –

APPENDIX - FIG. 11E

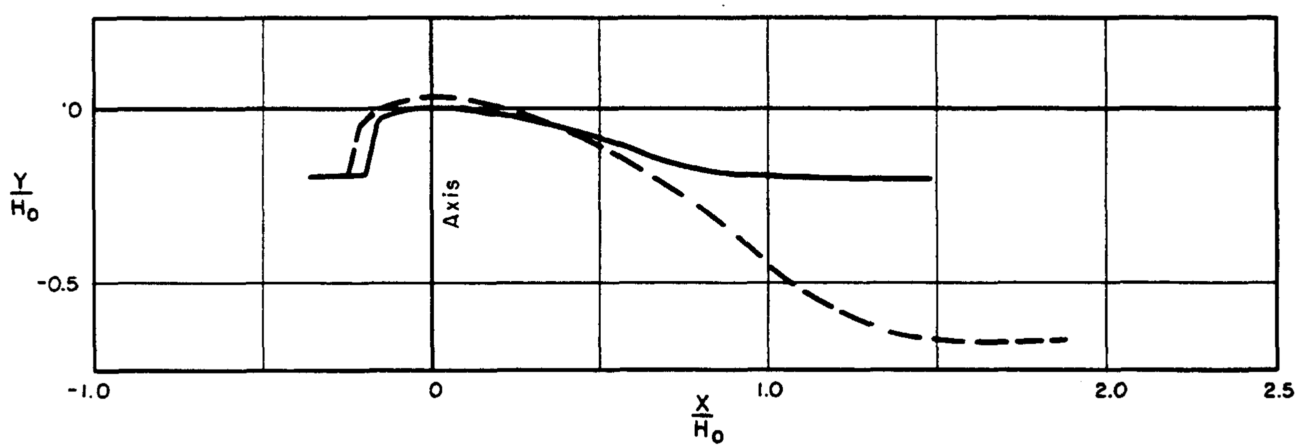


TIBER DAM

(WITHOUT CURTAIN WALL)

$\frac{H_o}{P+E}$ $\frac{3.49}{2.77}$ $C_M = 3.49$ ——— $C_D = 3.77$ – – –

APPENDIX - FIG. 11A



BOYSEN DAM

(FINAL DESIGN)

$\frac{H_o}{P+E} = \frac{5.20}{4.51}$ $C_M = 3.45$ ——— $C_D = 3.57$ – – –

APPENDIX - FIG. 11C

FIGURE 31 - Spillways with overfall suppressed.

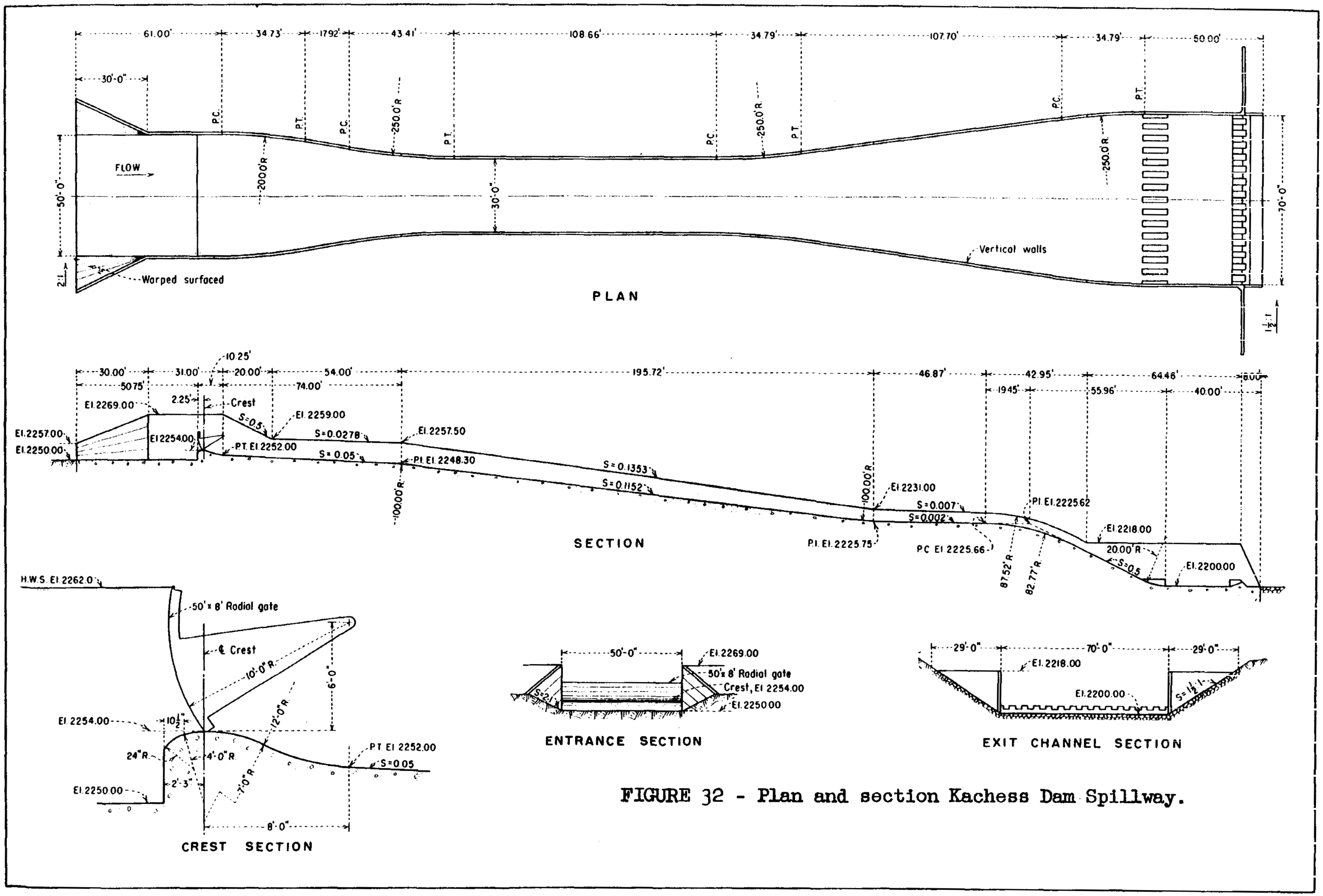
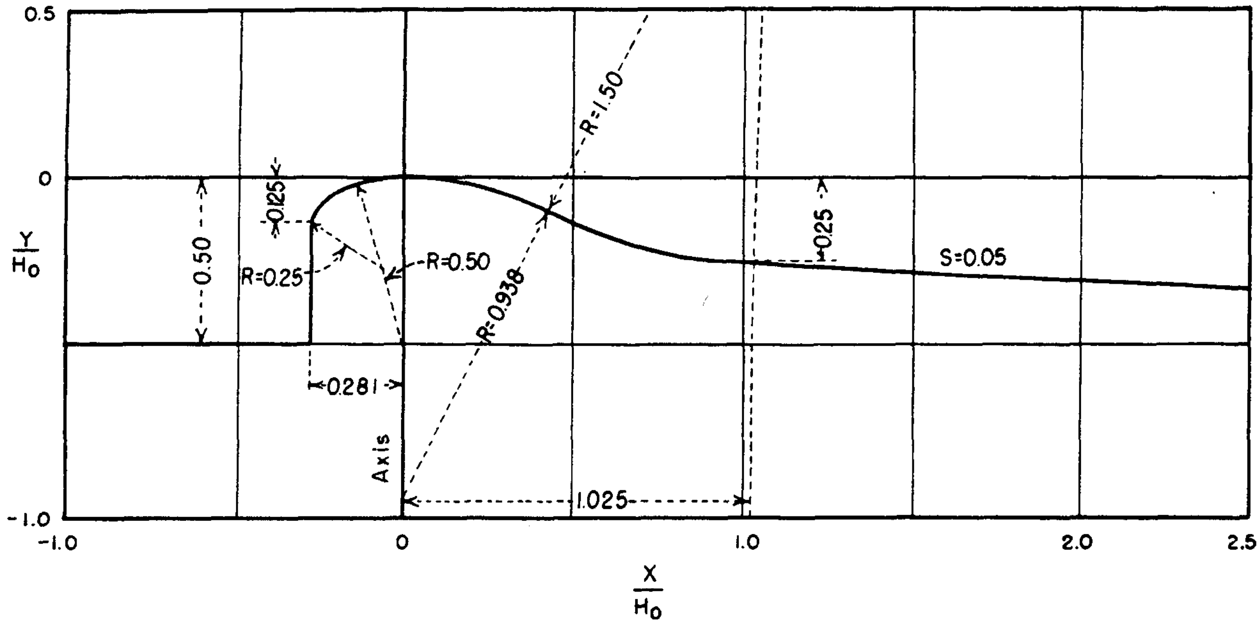
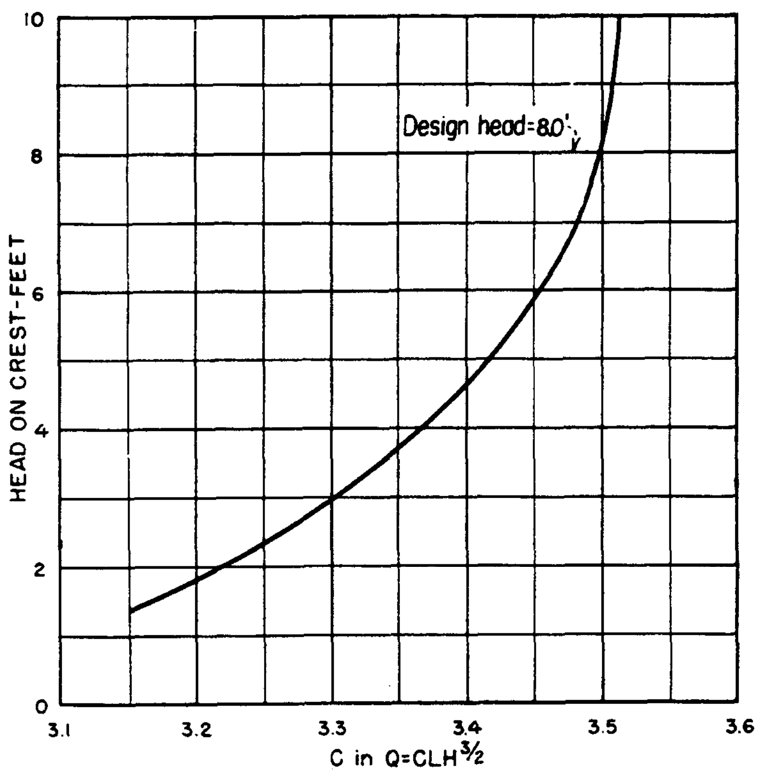


FIGURE 32 - Plan and section Kachess Dam Spillway.

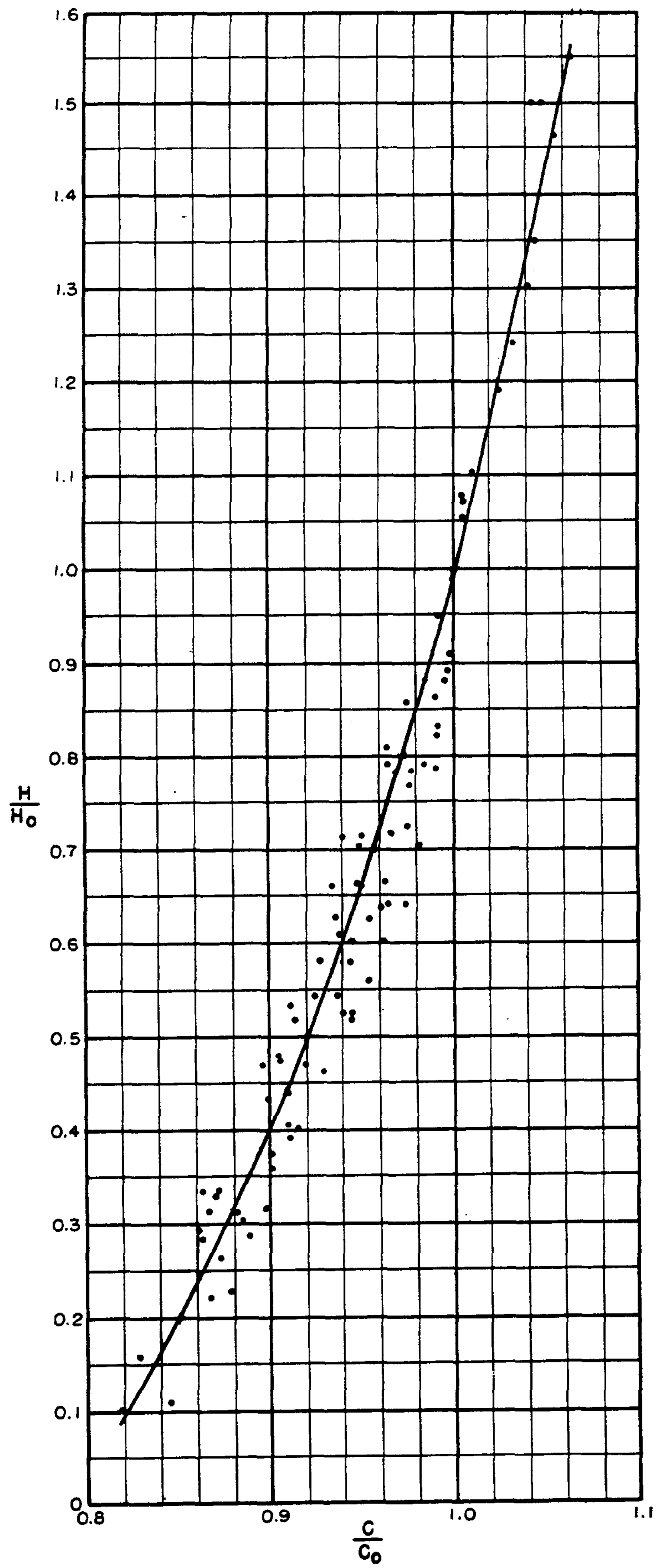


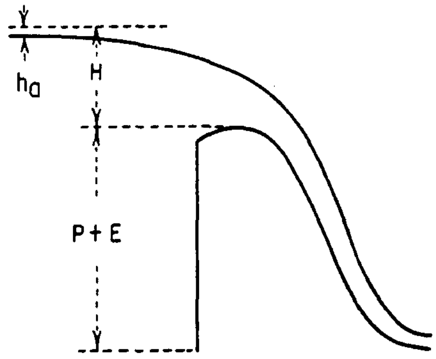
A- PROFILE OF GATE SECTION



B- HEAD- COEFFICIENT CURVE

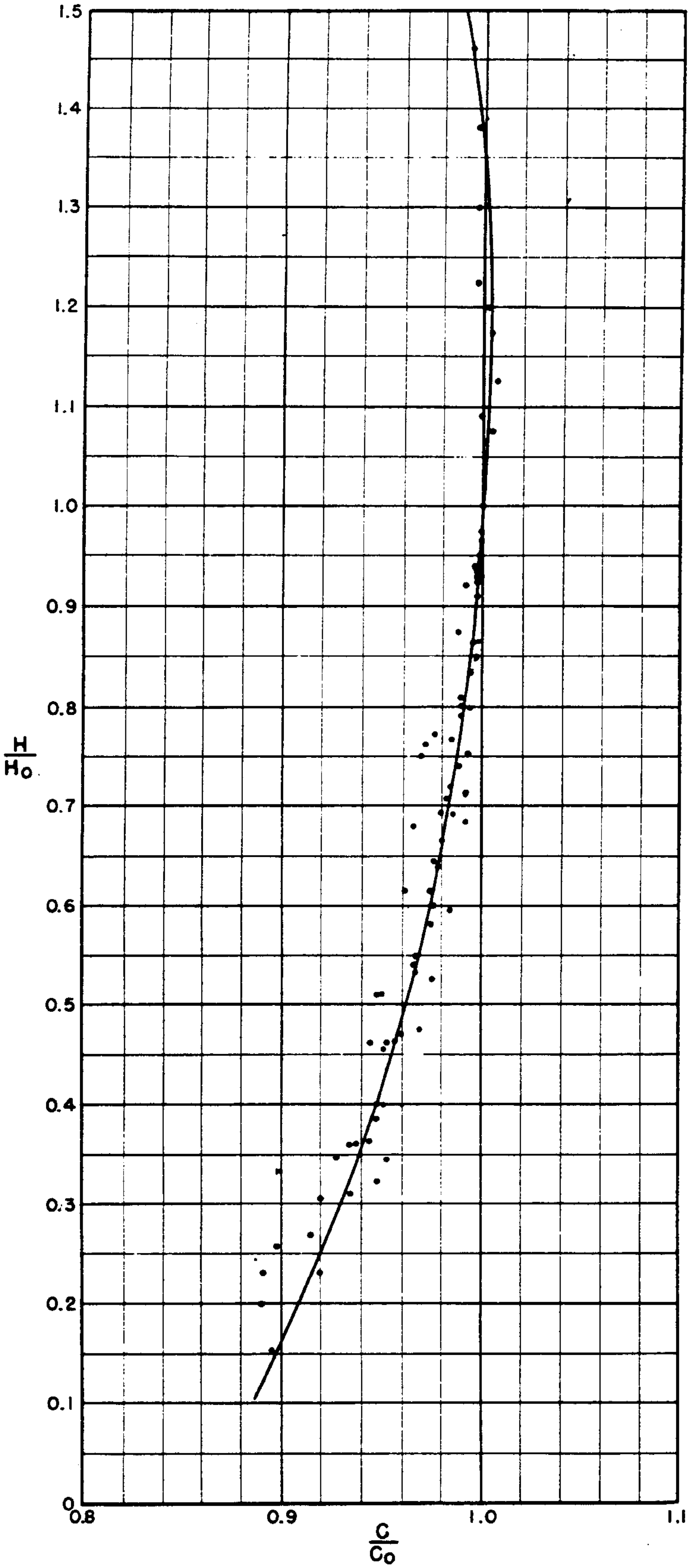
FIGURE 33 - Kachess Dam Spillway (Examples 2 and 4).

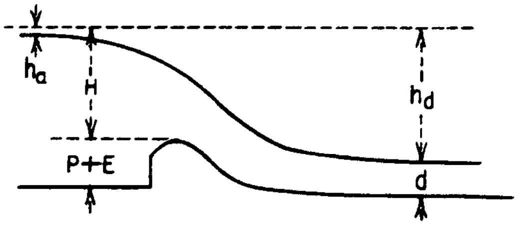




$\frac{H_o}{P+E}$	SPILLWAY
0.07	Shasta
.08	Friant
.09	Grand Coulee
.09	Bhakra
.09	Hoover S2-C3
.13	Norris
.14	Hiwassee
.22	Dos Bocas
.23	Capilano
.24	Madden
.26	Canyon Ferry
.27	Wilson
.31	Marshall Ford (Prelim)
.31	Marshall Ford (Final)
.37	Imperial
.42	Wheeler
.45	Angostura
.65	Moon Lake
.65	Davis (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).

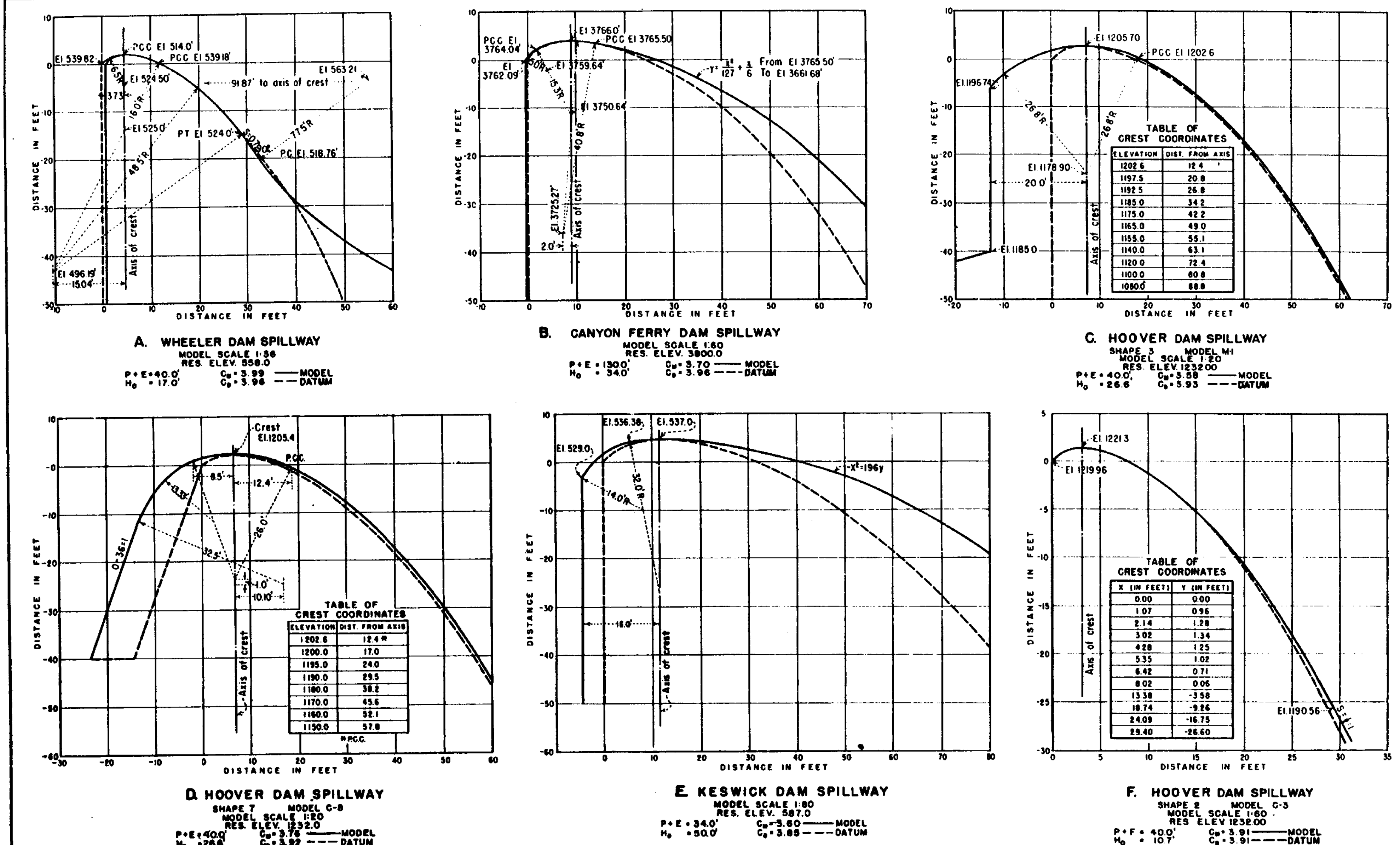




$\frac{H_o}{P+E}$	SPILLWAY	$\frac{h_d+d \text{ (Actual)}}{h_d+d \text{ (Experimental)}}$
17	Rye Patch	0.71
8	Alcova	.71
5.2	Boysen (Final)	.72
5.5	Green Mountain	.75
3.1	Scofield	.76
3.6	Bartlett	.76
4.8	Anderson Ranch	.76
5.0	Cachuma	.78
3.4	Falcon	.79
2.8	Unity	.79
2.8	Dickinson	.80
4.5	Medicine Creek (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



C. TABLE OF CREST COORDINATES

ELEVATION	DIST. FROM AXIS
1202.6	12.4
1197.5	20.8
1192.5	26.8
1185.0	34.2
1175.0	42.2
1165.0	49.0
1155.0	55.1
1140.0	63.1
1120.0	72.4
1100.0	80.8
1080.0	88.8

D. TABLE OF CREST COORDINATES

ELEVATION	DIST. FROM AXIS
1202.6	12.4*
1200.0	17.0
1195.0	24.0
1190.0	29.5
1180.0	38.2
1170.0	45.6
1160.0	52.1
1150.0	57.8

*P.C.C.

F. TABLE OF CREST COORDINATES

X (IN FEET)	Y (IN FEET)
0.00	0.00
1.07	0.96
2.14	1.28
3.02	1.34
4.28	1.25
5.35	1.02
6.42	0.71
8.02	0.06
13.38	-3.58
18.74	-9.26
24.09	-16.75
29.40	-26.60

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

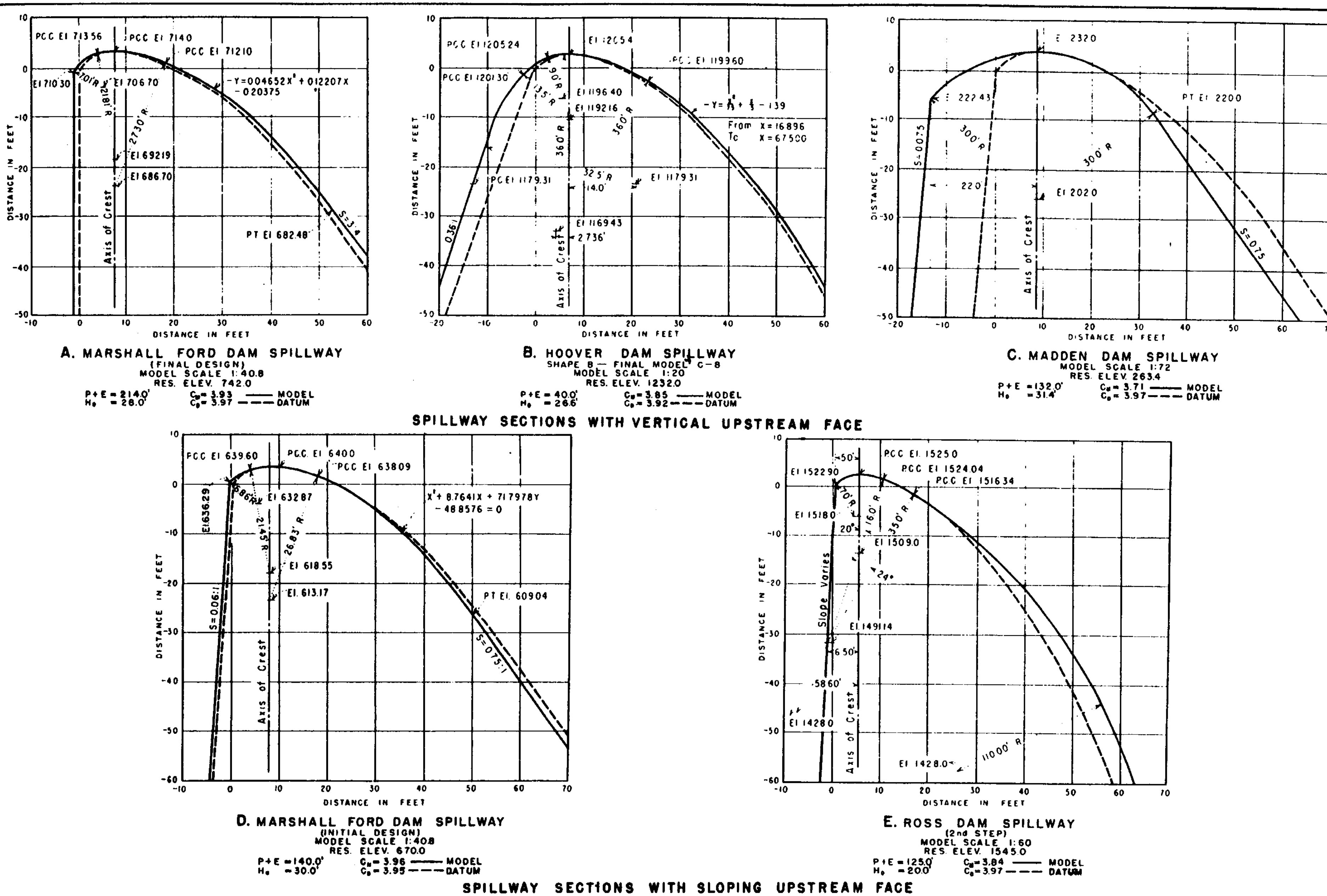


FIGURE 2 - Comparison of discharge coefficients
Model coefficient versus datum coefficient
for spillway sections with vertical and
sloping upstream faces

SHEET 2 of 6

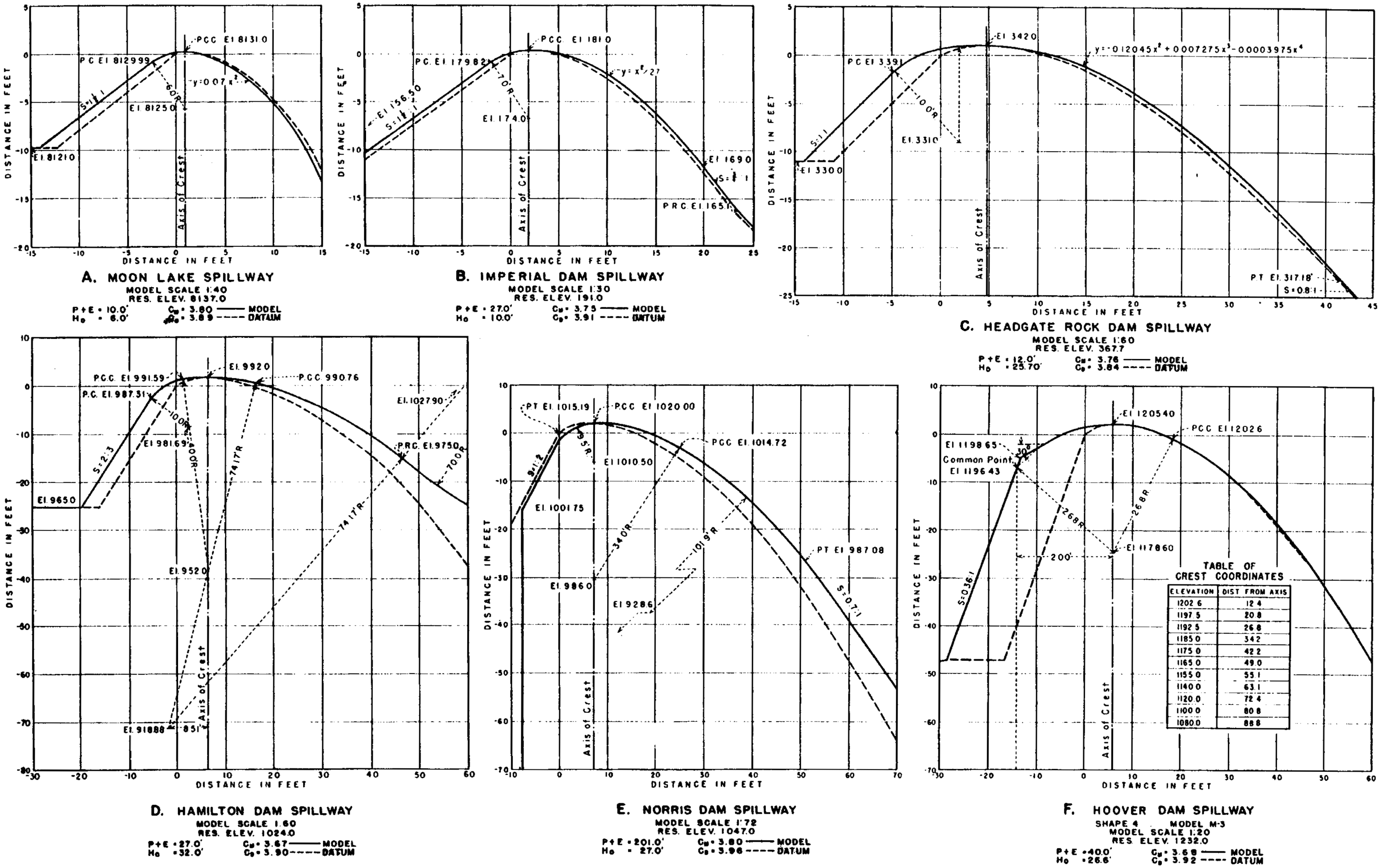


TABLE OF CREST COORDINATES

ELEVATION	DIST. FROM AXIS
1202.6	12.4
1197.5	20.8
1192.5	26.8
1185.0	34.2
1175.0	42.2
1165.0	49.0
1155.0	55.1
1140.0	63.1
1120.0	72.4
1100.0	80.8
1080.0	88.8

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

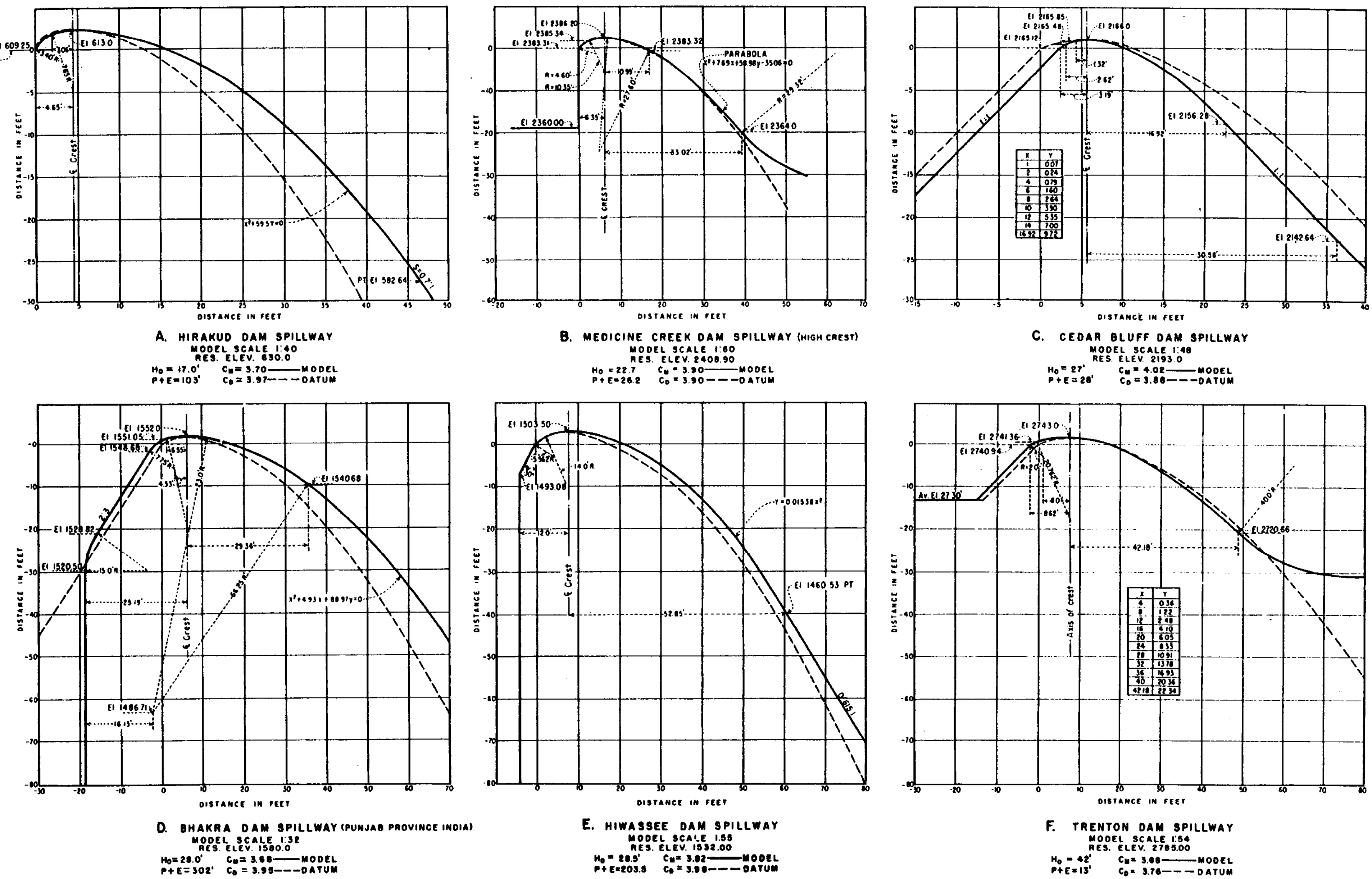


FIGURE 4 - Comparison of discharge coefficients
Model coefficient versus datum coefficient
Miscellaneous spillway shapes

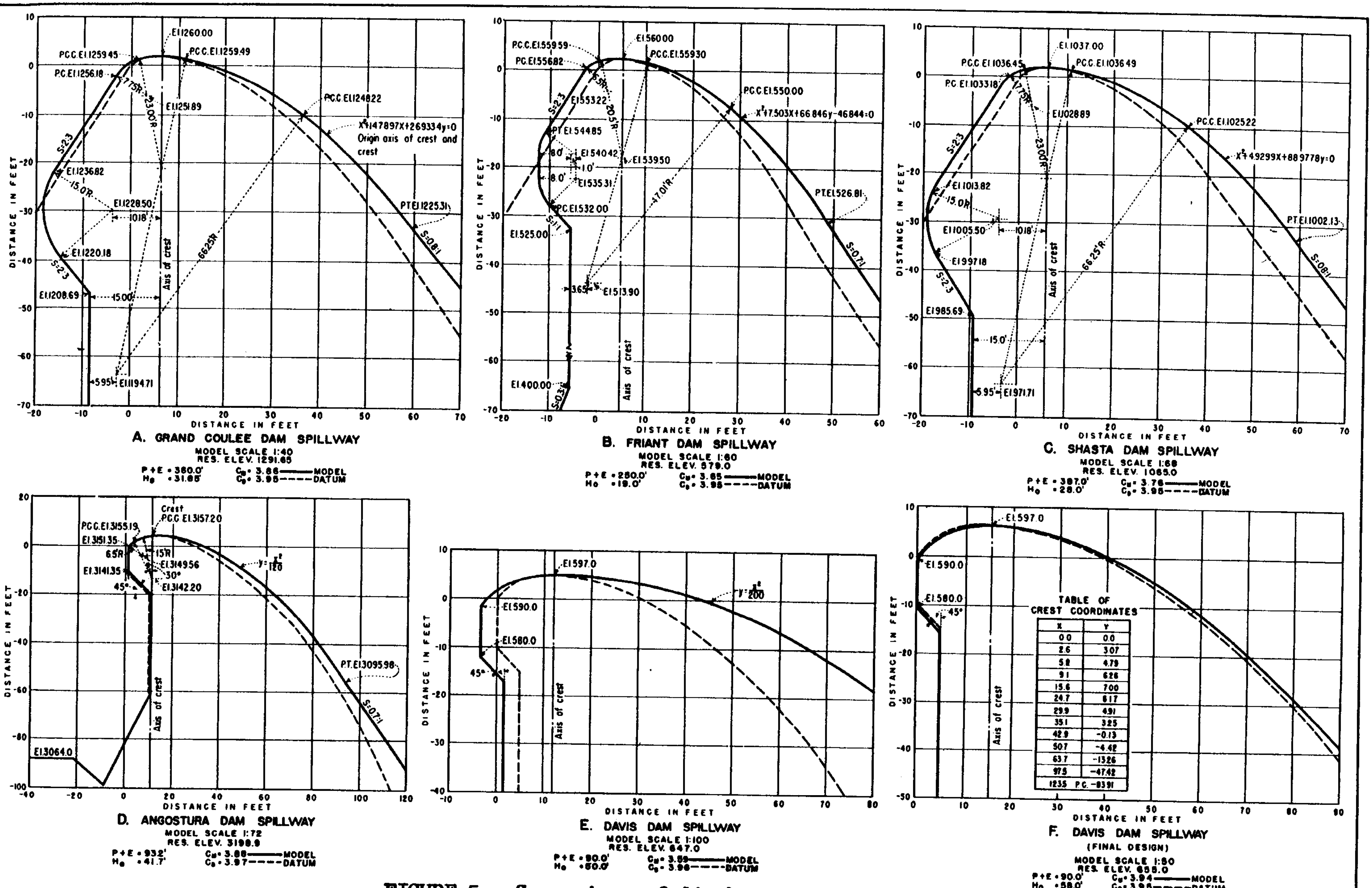


FIGURE 5 - Comparison of discharge coefficients
Model coefficient versus datum coefficient
for spillway with irregular upstream faces

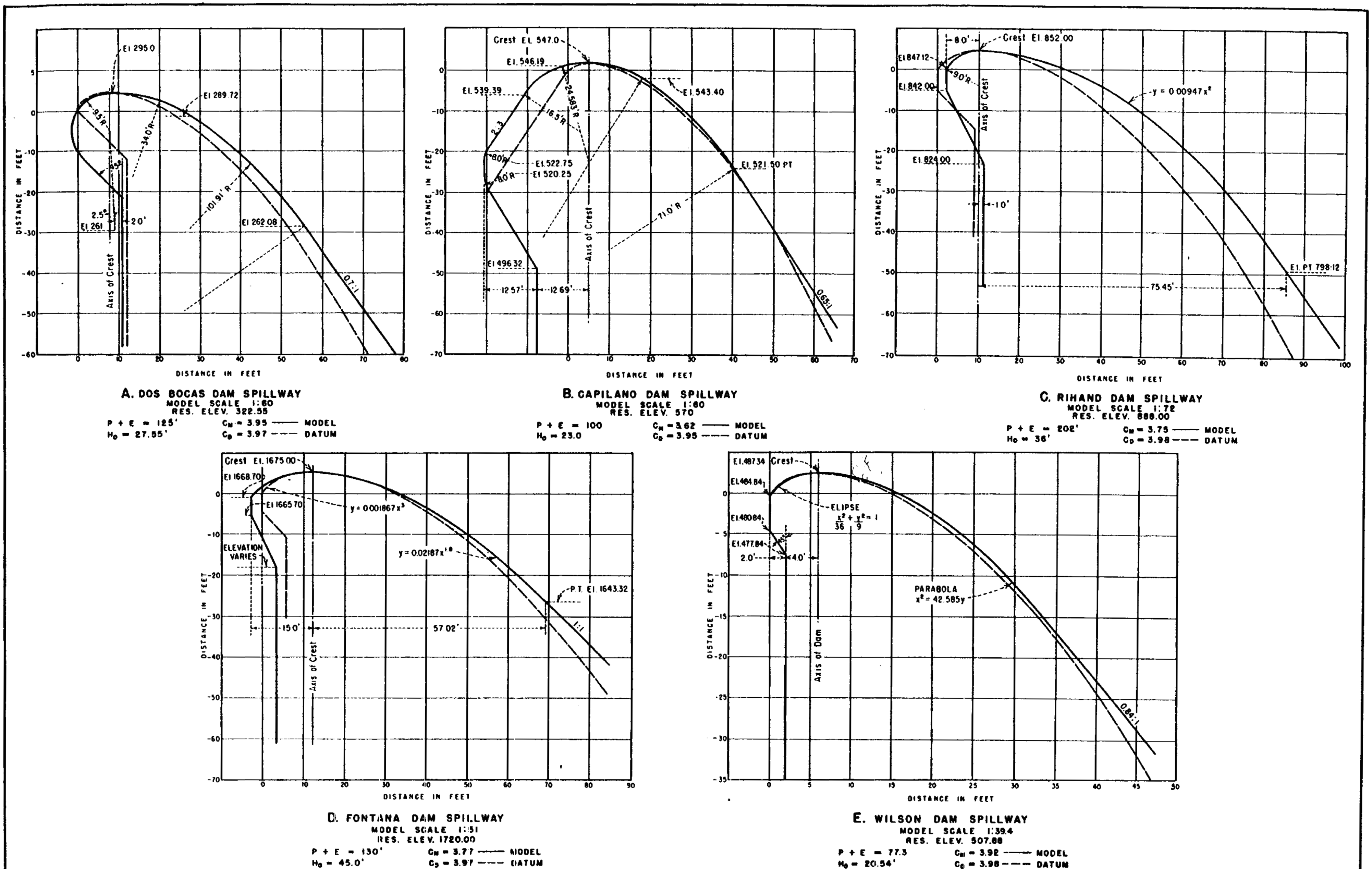


FIGURE 6 - Comparison of discharge coefficients
Model coefficient versus datum coefficient
for spillways with offset in upstream face

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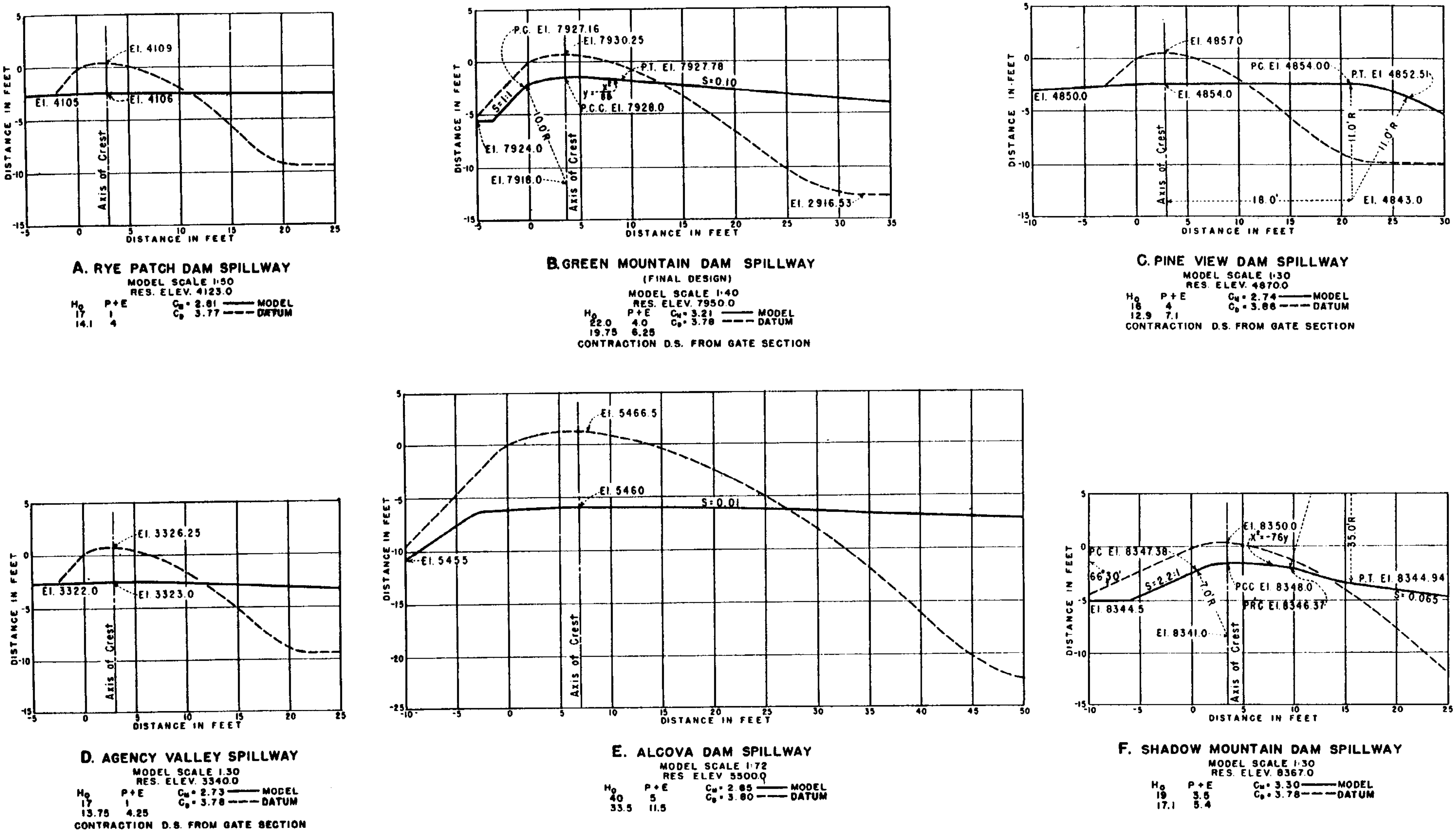
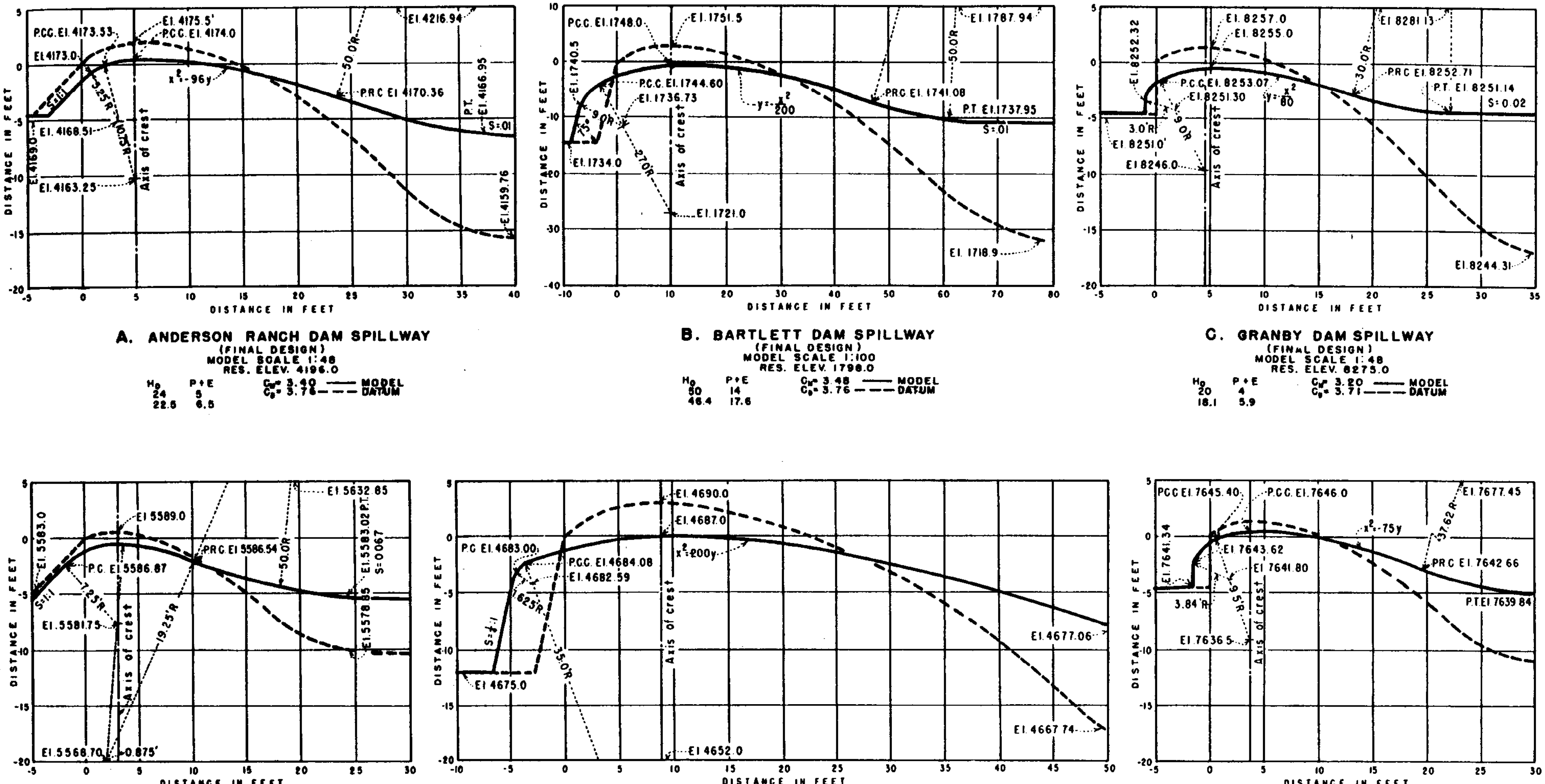


FIGURE 7 - Comparison of discharge coefficients
Model coefficient versus datum coefficient
for earth dam spillway sections with
shallow approach depth

SHEET 1 of 5



A. ANDERSON RANCH DAM SPILLWAY
(FINAL DESIGN)
MODEL SCALE 1:48
RES. ELEV. 4196.0

H_o	P+E	
24	5	C_M = 3.40 —— MODEL
22.5	6.5	C_D = 3.76 – – – DATUM

B. BARTLETT DAM SPILLWAY
(FINAL DESIGN)
MODEL SCALE 1:100
RES. ELEV. 1798.0

H_o	P+E	
50	14	C_M = 3.48 —— MODEL
46.4	17.6	C_D = 3.76 – – – DATUM

C. GRANBY DAM SPILLWAY
(FINAL DESIGN)
MODEL SCALE 1:48
RES. ELEV. 8275.0

H_o	P+E	
20	4	C_M = 3.20 —— MODEL
18.1	5.9	C_D = 3.71 – – – DATUM

D. BOCA DAM SPILLWAY
(FINAL DESIGN)
MODEL SCALE 1:48
RES. ELEV. 5603.40

H_o	P+E	
19.4	5	C_M = 3.50 —— MODEL
14.6	5.8	C_D = 3.61 – – – DATUM

E. BOYSEN DAM SPILLWAY
(PRELIMINARY DESIGN)
MODEL SCALE 1:60
RES. ELEV. 4731.5

H_o	P+E	
44.6	12	C_M = 3.37 —— MODEL
41.4	15.1	C_D = 3.76 – – – DATUM

F. VALLECITO DAM SPILLWAY
(FINAL DESIGN)
MODEL SCALE 1:60
RES. ELEV. 7665.0

H_o	P+E	
19	5	C_M = 3.42 —— MODEL
18	6	C_D = 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**

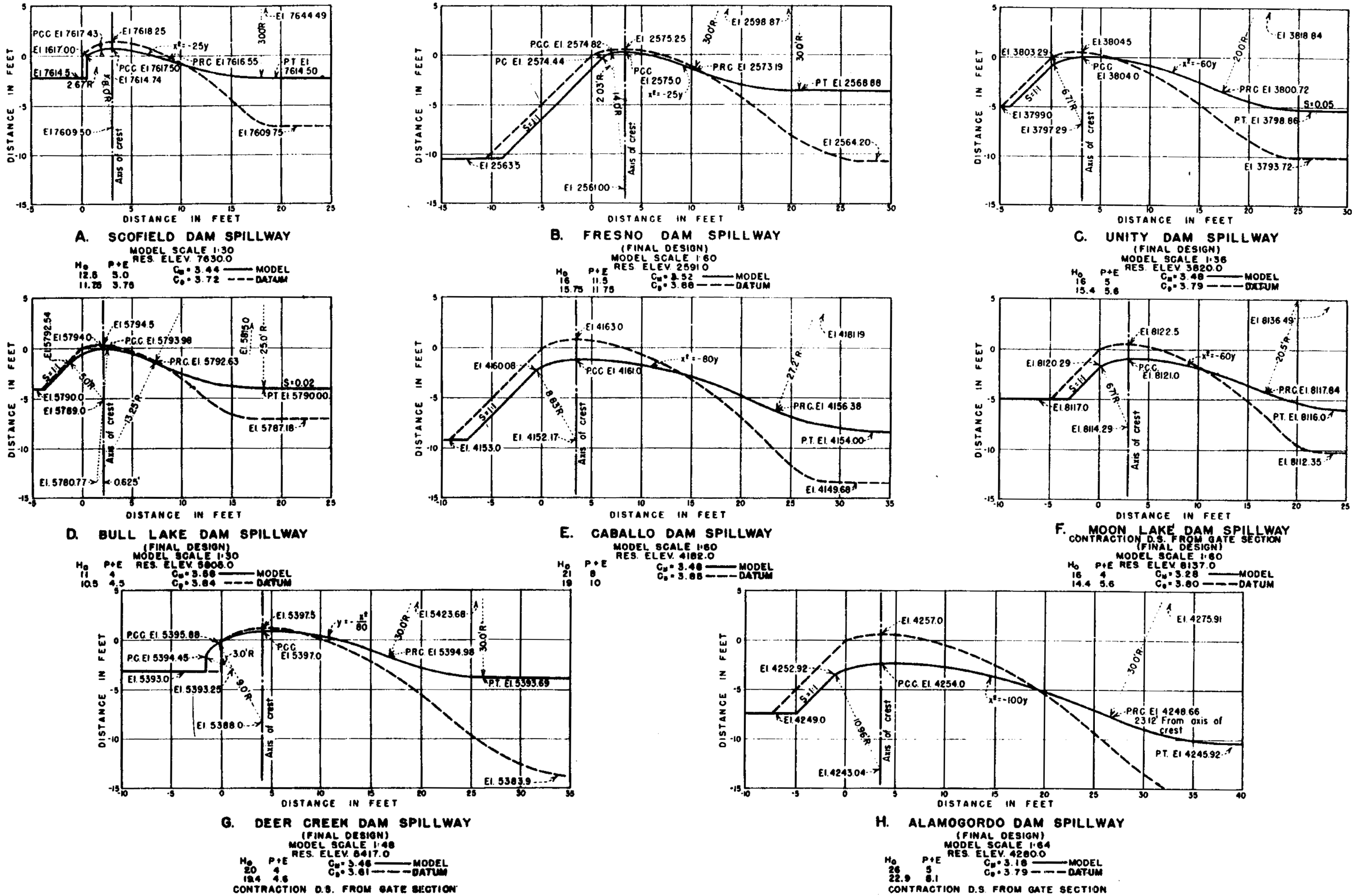
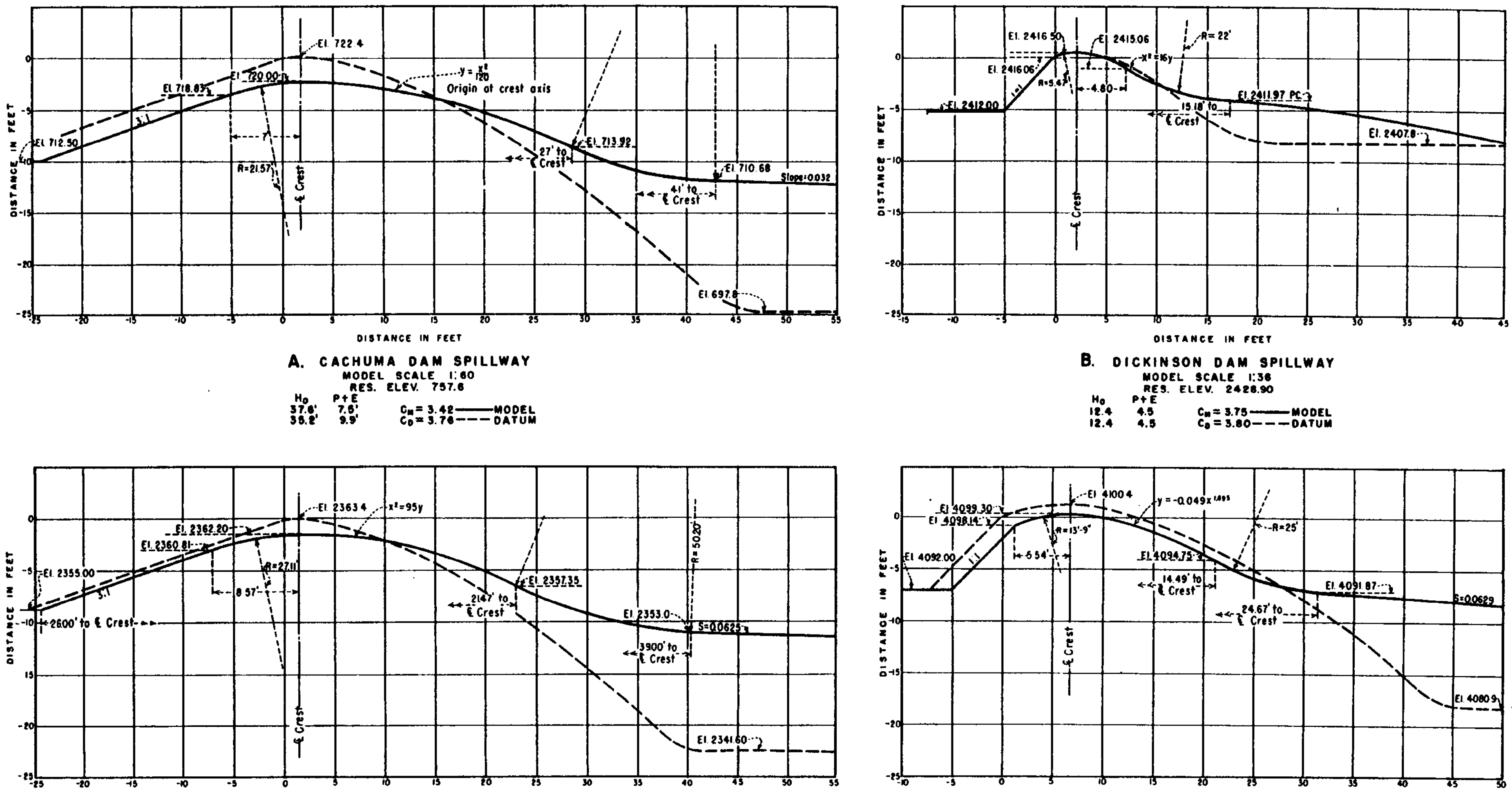


FIGURE 9 - Comparison of discharge coefficients
Model coefficient versus datum coefficient
for earth dam spillway sections with
shallow approach depth



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

H_o	P+E	
37.8'	7.5'	C_M = 3.42 ——— MODEL
35.2'	9.9'	C_D = 3.76 – – – DATUM

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

H_o	P+E	
12.4	4.5	C_M = 3.75 ——— MODEL
12.4	4.5	C_D = 3.80 – – – DATUM

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

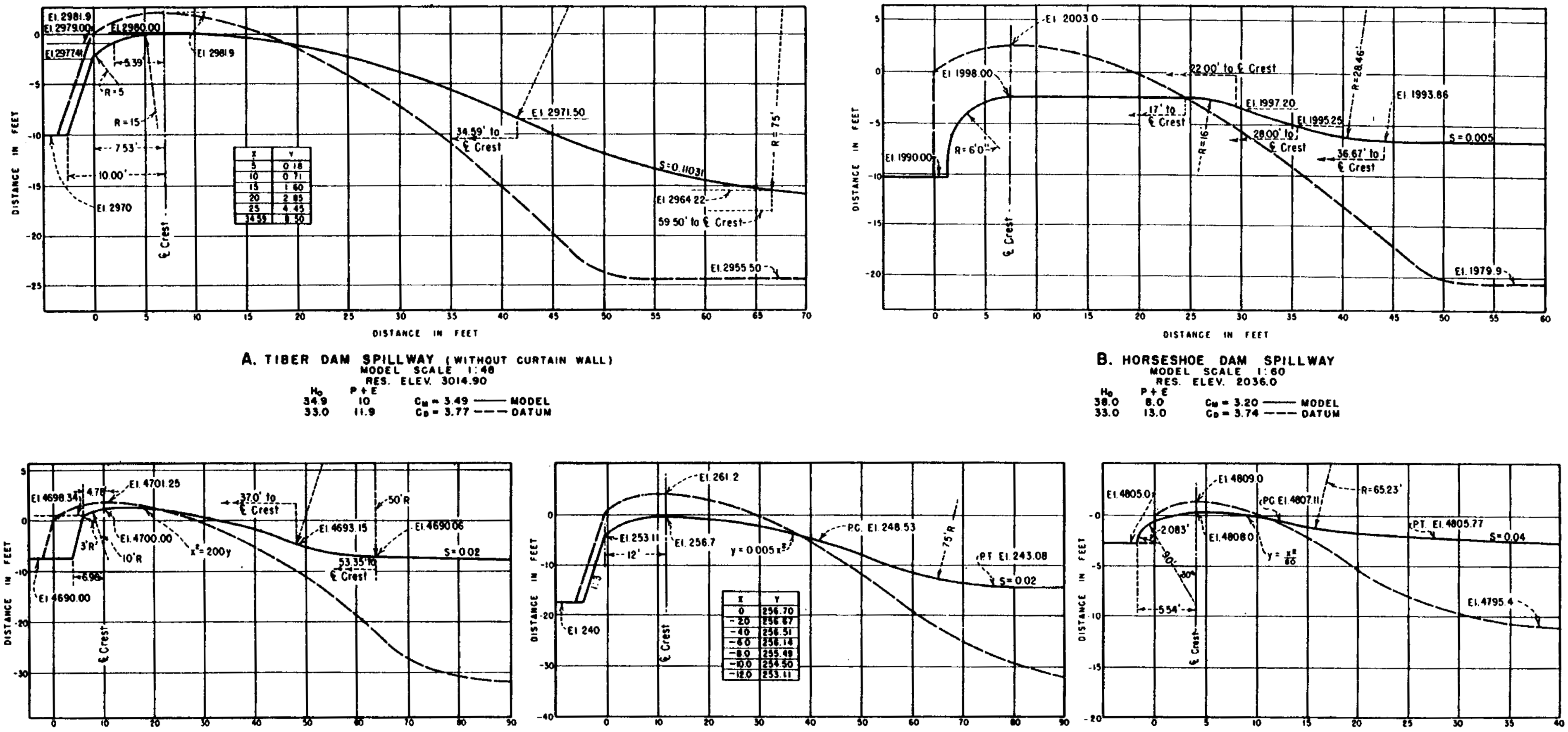
H_o	P+E	
32.6	7.2	C_M = 3.64 ——— MODEL
31.4	8.4	C_D = 3.73 – – – DATUM

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

H_o	P+E	
28.9	7.3	C_M = 3.56 ——— MODEL
27.6	8.4	C_D = 3.73 – – – DATUM

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

SHEET 4 of 5



A. TIBER DAM SPILLWAY (WITHOUT CURTAIN WALL)
MODEL SCALE 1:48
RES. ELEV. 3014.90

H_o	P + E		
34.9	10	C_M = 3.49	—— MODEL
33.0	11.9	C_D = 3.77	– – – DATUM

B. HORSESHOE DAM SPILLWAY
MODEL SCALE 1:60
RES. ELEV. 2036.0

H_o	P + E		
38.0	8.0	C_M = 3.20	—— MODEL
33.0	13.0	C_D = 3.74	– – – DATUM

C. BOYSEN DAM SPILLWAY
MODEL SCALE 1:48
RES. ELEV. 4752.0

H_o	P + E		
52.0	10.0	C_M = 3.45	—— MODEL
50.75	11.25	C_D = 3.57	– – – DATUM

D. FALCON DAM SPILLWAY
MODEL SCALE 1:130
RES. ELEV. 314.2

H_o	P + E		
57.5	16.7	C_M = 3.33	—— MODEL
53.0	21.2	C_D = 3.78	– – – DATUM

E. CASCADE DAM SPILLWAY
MODEL SCALE 1:30
RES. ELEV. 4828.0

H_o	P + E		
20	3.0	C_M = 3.38	—— MODEL
19	4.0	C_D = 3.57	– – – DATUM

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