APPENDIX D

COMPUTATIONS FOR DESIGN OF SPILLWAY

D-l. Introduction. The following example will illustrate some of the procedures and guidance provided in this manual for the design of a gated elliptical crest spillway. This example will show the following:

a. The development of the spillway and gage sizes.

b. The computation of the spillway discharge rating curve.

c. The development of the spillway crest equations and upper nappe profile.

d. The determination of the gate trunnion location.

e. The determination of hydrostatic pressures that can be expected on the spillway crest surface.

D-2. Computer Programs. The following CORPS system computer programs were used for this example:

a. H1107, Stage-discharge relation for an elliptical crest spillway

b. H1108, Crest and upper nappe profiles for elliptical crest spillway

c. H1109, Pressure distribution for an elliptical crest spillway

The design engineer should periodically check the list of available CORPS programs to determine if additional programs have been added to the system.

D-3. Design Conditions. The following information describes the design criteria and assumptions for this example:

Maximum reservoir elevation	1,500 feet*
Spillway design flood (SDF)	66,200 ft^3/sec
Spillway piers, type 3	12 feet thick
Spillway upstream face slope	1H:lV
Spillway crest tangent to chute at	1H:lV
Spillway crest elevation	1,458 feet
Tainter gate radius	45 feet

Overflow crest to conform to elliptical upstream crest shape with an H_e/H_c ratio of 1.33 and a P/H_d ratio of 0.5.

* All elevations cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

D-4. Computations.

a. The initial step is to determine the size of the spillway bays and the tainter gates.

(1) Spillway bay width

$$Q = CL_e(H_e)^{1.5}$$

$$L_e = L - 2(nK_p + K_a)H_e$$

Pier loss coefficient $K_p = -0.025$ from Plate 3-10

Abutment loss coefficient $K_a = 0.2$ from Plate 3-12

H_e = max pool elevation - crest elevation

$H_e = 1{,}500 - 1{,}458 = 42$ feet

$H_d^e = 42(1.33) = 31.57$ feet

$P = 31.57(0.5) = 15.78$ feet

$L_e = L - 2\,[1(-0.025) + 0.2]\,42$

$L_e = L - 14.8$

Spillway discharge coefficient $C = 3.98$ from Plate 3-3

$66{,}200 = 3.98(L - 14.8)(42)^{1.5}$

$L = 75.9$ feet, use 76.0 feet.

Two spillway bays should be used.

Spillway bay width $W_b = L/2 = 76/2$

$= 38$ feet

(2) Approximate height of spillway tainter gate

H_e (max) = 42 feet

Freeboard = 2 feet

Gate seat location, vertical distance below crest apex = 0.5 feet approximately.

Height of gate = H_e + freeboard + 0.5

$= 42 + 2 + 0.5 = 44.5$ feet

Gate height to width ratio is approximately 1.2, which conforms to the height to width ratios of the gates described in Table 6-l.

b. Computation of the spillway discharge rating curve for uncontrolled flow over an elliptical-shaped spillway crest will be accomplished using CORPS computer program H1107. This computer program utilizes equations 2-l and 2-2 and data from the following plates and design assumptions:

(1) Plate 3-3 or 3-4 for spillway discharge coefficients

(2) Plate 3-6 for pier contraction coefficients, and

(3) Plate 3-11 or 3-12 for abutment contraction coefficients

(4) $H_d = 31.57$

(5) $P = 15.78$

Input and output for H1107 is found at the end of this appendix.

c. The equations that define the shape of the spillway crest curves and the water surface profile over the crest are developed by use of the data provided by CORPS program H1108. Input and output for H1108 is found at the end of this appendix.

(1) **The downstream curve equation**

$$X^n = KH_d^{n-1} Y \qquad \text{(Equation 3-l)}$$

$n = 1.85$

$K = 2.05$ from H1108

$H_d = 31.57$

$$X^{1.85} = 2.05(31.57)^{0.85}Y$$

$$Y = X^{1.85}/35.56$$

(2) The upstream curve equation

$$\frac{X^2}{A^2} + \frac{(Y - B)^2}{B^2} = 1 \qquad \text{(Equation 3-2)}$$

$A = 7.692$, $B = 4.514$ from H1108

$$\frac{X^2}{7.692^2} + \frac{(Y - 4.51)^2}{4.514^2} = 1$$

$$X = (-2.9Y^2 + 26.219Y)^{1/2}$$

d. The gate trunnion is now located using the computed crest coordinate and upper nappe surface data. The trunnion is located to clear the water surface of the maximum uncontrolled discharge (paragraph 6-2a) and to prevent surging of the water surface upstream from the gates with gate-controlled conditions (paragraph 3-7).

(1) Use gate radius r = 45 feet

(2) Gate radius to gate height ratio = 1.01, which conforms to data presented in Table 6-l.

(3) Determine gate seat location from downstream curve equation:

$$Y = X^{1.85}/35.56$$

$$Y = 0.5 \text{ foot (assumed, paragraph D-4a(2))}$$

$$X = 4.95 \text{ feet}$$

(4) Determine trunnion location:

(a) Vertical location: Optimum location for structural purposes is one-third vertical damming height above gate seat.

Maximum damming height = 1,500 - 1,457.5 = 42.5 feet
Optimum trunnion elevation = 1,457.5 + 42.5/3 = 1,471.7 feet
Set trunnion elevation = 1,472 feet

(b) Horizontal location: The trunnion is located at the center of a circle having a radius r of 45 feet. Therefore, the locus of points describing the circle (gate face) can be described by:

$$(X - h)^2 + (Y - v)^2 = r^2$$

with the origin of coordinates located at the crest axis where

X and Y = points on the gate face
h = horizontal distance from the crest axis to the trunnion
v = vertical distance of the trunnion above the crest

Therefore:

X = horizontal distance from axis to gate seat = 4.95 feet
Y - vertical distance from crest to gate seat = -0.5 foot
V = trunnion elevation - crest elevation = 1,472 - 1,458 = 14 feet

$$(4.95 - h)^2 + (-0.5 - 14)^2 = 45$$

$$h^2 - 9.9h - 1,790.25 = 0$$

$$h = 47.55 \text{ feet downstream from crest axis}$$

(c) Check upper nappe profile from CORPS program H1108 to determine if the trunnion is located above the flow profile.

The profile data for the upper nappe alongside the pier (output H1108) shows that the water surface will be 7.6 feet above the spillway crest (water surface elevation = 1,458 + 7.6 = 1,465.6) at a horizontal distance downstream from the crest axis of 44.2 feet.

Since the trunnion is located at elevation 1,472 at a horizontal distance of 47.55 feet downstream from the crest axis, it is obvious that the trunnion is located well above the flow profile.

(d) Check pool surging criteria (paragraph 3-7). Pier nose to be located at the point where the upstream crest becomes tangent with the dam face.

P_L = distance from upstreammost face of tainter gate to pier nose

P_L = Crest axis to trunnion center-line distance + crest axis to upstream crest tangent point distance (from CORPS Program H1108) - gate radius

P_L = 47.55 + 6.63 - 45.0 = 9.18 feet

H_c = Maximum head on crest where the gate controls the discharge

H_c = 0.625(1,500 - 1,458) = 26.25 feet

Use guideline (a), paragraph 3-7, because $P/H_d < 1$

$$P_L/W_b = 9.18/38 = 0.24$$

Therefore, $W_b \geq 1.1H_c$ is required to control surging

$W_b/H_c = 38/26.25 = 1.45 > 1.1$

Pool surging should not occur.

e. The spillway crest shape developed for this example is now checked to determine the pressure regime that would exist on the crest surface during the design flood. The CORPS program H1109 is used for this purpose. The input and output for H1109 is found at the end of this appendix. A review of the output from H1109 shows that for an H_e/H_d ratio of 1.33, minimum crest pressure is -10.7 feet of water, which should be sufficient to preclude cavitation damage.

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**********************************
*  CORPS PROGRAM  #  H1107      *
*  MICRO VERSION  # 84/10/23    *
**********************************


***** CORPS PROGRAM H1107 *****
H1107 WILL PRODUCE A RATING CURVE FOR AN ELLIPTICAL
SPILLWAY CREST DESIGN.
INPUTS ARE:FACE SLOPE CODE,APPROACH DEPTH,DESICN HEAD,
CREST ELEVATION,ABUTMENT CONTRACTION COEF.,NUMBER AND CONT.
COEF. OF PIERS, AND NUMBER AND ELEVATIONS TO BE USED FOR
CALCULATING THE CURVE.
---------------------------------------
H1107 GRAPHICS WILL FIT A SPLINE TO THE POINT INPUT.
TO INSURE AN ACCURATE REPRESENTATION OF THE RATING CURVE
MAKE SURE POINTS ARE EVENLY SPACED OVER THE RANGE NEEDED.
---------------------------------------


DO YOU WANT GRAPHICS? (Y OR N)
N
INPUT H1107

AA-ENTER UPSTREAM FACE SLOPE CODE:
l=lV:lH OR FLATTER,   2=ALL OTHERS
1
AB-ENTER THE APPROACH CHANNEL ELEVATION (FT-NGVD) (PELE)
1442.22
AC-ENTER THE DESIGN HEAD IN FT. ABOVE CREST AXIS(HD)
31.57
AD-ENTER THE NET SPILLWAY LENGTH IN FT.tW)
  (GROSS LENGTH-SUM OF PIER WIDTHS)
76
AE-ENTER THE SPILLWAY CREST ELEVATION IN FT,NGVD.(ELEV)
1458.
AF-ENTER ABUTMENT CONTRACTION COEFFICIENT
SUGGEST: O.l-CONCRETE OR 0.2-EARTH EMBANKMENT,BOTH WITH SYMMETRIC FLOW
INCREASE FOR FLOW ANGULARITY. SEE HDC 111-3/l AND 111-3/2.(ABUT)
0.2
AC&ENTER THE NUMBER OF PIERS.(PIERNO)

AH-ENTER THE PIER CONTRACTION COEFFICIENT
SEE HDC CHARTS 111-5,111-6, AND 111-22 FOR GUIDANCE
-.020
AI-ENTER THE NUMBER OF HEAD ELEVS TO BE USED. NOT TO EXCEED 100. (NOHE)
8
AJ-ENTER THE DESIRED HEAD ELEVS IN FT,NGVD, SEPARATED BY COMMAS.(HE)
NOT TO EXCEED THE ABOVE NUMBER.
INSURE HEAD ON CREST IS LESS THAN TWICE DESIGN HEAD FOR
ALL VALUES CHOSEN. (DUE TO EXTRAPOLATION LIMITS.)

1500,1495,1490,1485,1480,1475,1470,1466
AK-INPUT PROJECT NAME
EXAMPLE 1
HARDCOPY IF DESIRED - THEN RETURN
```

OUTPUT FOR:EXAMPLE 1

SPILLWAY CREST ELEV = 1458.00 FT.
SPILLWAY DESIGN HEAD = 31.57 FT.
SPILLWAY UPSTREAM FACE SLOPE = 1
SPILLWAY APPROACH DEPTH = 15.8 FT.
ABUTMENT CONTRACTION COEFFFICIENT = .200
NET SPILLWAY LENGTH = 76.00 FT.
NUMBER OF CREST PIERS = 1
PIER CONTRACTION COEFFICIENT = -.020
SPILLWAY BAY WIDTH = 38.00 FT.
NUMBER HEAD ELEVS SELECTED = 8.
HEAD ELEVS SELECTED (SEE BELOW).

HEAD (FT,NGVD)	HEAD (FT)	DISCHARGE PER BAY(CFS)	DISCHARGE TOTAL(CFS)
1500.00	42.00	33093.	66186.
1495.00	37.00	27912.	55825.
1490.00	32.00	22764.	45529 .
1485.00	27.00	17780.	35560.
1480.00	22.00	13094.	26188.
1475.00	17.00	8845.	17689.
1470.00.	12.00	5178.	10355.
1465.00	7.00	2259.	4517.

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**********************************
*  CORPS PROGRAM  #  H1108       *
*  MICRO VERSION  # 84/10/14     *
**********************************
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H1108 WILL DESIGN AN ELLIPTICAL UPSTREAM QUADRANT SPILLWAY AND PROVIDE BOTH UP- AND DOWNSTREAM CREST COORDINATES. THE REQUIRED INPUT IS: AVG. APPROACH DEPTH (AB), DESIGN HEAD (AC) UP- AND DOWNSTREAM FACE SLOPES (AD AND AE), X INCREMENT (AF), WHETHER OR NOT PIERS ARB PRESENT (AG), AND THE ACTUAL HEAD ON THE CREST (AH).

H1108 WILL ALSO PROVIDE COORDINATES FOR THE UPPER NAPPE SURFACE OF SPILLWAYS DESIGNED USING THE ELLIPTICAL UPSTREAM QUADRANT DESIGN PROCEDURE.
EXPERIMENTAL VALUES WERE DETERMINED AT P/HD=0.26,0.5, AND 1.0 AND H/HD VALUES OF 0.5,l.0 AND 1.5. NO 1.5 VALUE IS AVAILABLE FOR P/HD LESS THAN 0.6,

H1108 WILL INTERPOLATE AND EXTRAPOLATE LINEARLY FOR OTHER VALUES OF P/HD AND HE/HD

LIMITS ARE: 0.2<P/HD AND 0.25<HE/HD<2.0
EXCEPT WHEN P/HD<O.S HE/HD MUST BE LESS THAN 1.34
AND WHEN HE/HD>l.O P/HD MUST BE GREATER THAN 0.33

```
DO YOU WANT GRAPHICS? (Y OR N)
N
WANT GRID OR TIC AXES? (G OR T)
T
AA-INPUT THE NAME OF THE SPILLWAY DESIGN
EXAMPLE
AB-INPUT AVG. CHANNEL APPROACH DEPTH-P (FT)
 (DIFFERENCE BETWEEN CREST ELEV. AND APPROACH CHANNEL ELEV.)
15.78
AC-INPUT DESIGN HEAD-HD (FT)
31.57
AD-INPUT THE UPSTREAM FACE SLOPE (V,H) (l,0=VERT)
1,1
AE-INPUT THE DOWNSTREAM FACE SLOPE (V,H)
1,1
AF-INPUT THE X (HORIZONTAL) INCREMENT-XINC (FT)
2
AG-DOES THE SPILLWAY HAVE PIERS? (Y OR N)
Y
AH-ACTUAL HEAD ON CREST-HE(FT)
42
HARDCOPY IF DESIRED-THEN RETURN
```

OUTPUT FOR:EXAMPLE

FOR CREST COORDINATES: +X TO THE RIGHT AND +Y DOWNWARD

APPROACH DEPTH (FT)= 15.78
DESIGN HEAD (FT)= 31.57
UPSTREAM FACE SLOPE= 1.00V: l.00H
DOWNSTREAM FACE SLOPE= l.00V: l.00H
A AND B IN ELLIPSE EQUATION= 7.692 4.514
K IN D.S. EQN= 2.060

COORDINATES OF UPSTREAM TANGENT POINT (X,Y)= -6.63, 2.23

COORDINATES FOR DOWNSTREAM TANGENT POINT (X,Y)= 35.61, 19.25

UPSTREAM COORDINATES

X	Y
. 000	.000
-2.000	155
-4.000	:658
-6.000	1.689
-6.636	2.229
-8.000	3.595
-10.000	5.595
-12.000	7.596
-14.000	9.595
-16.000	11.595
-18.000	13.595
-20.000	15.595
-20.186	15.780

DOWNSTREAM COORDINATBS

X	Y
.000	.000
2.000	.094
4.000	.337
6.000	.714
8.000	1.215
10.000	1.836
12.000	2.573
14.000	3.422
16.000	4.381
18.000	5.447
20.000	6.620
22.000	7.896
24.000	9.275
26.000	10.756
28.000	12.336
30.000	14.016
32.000	15.793
34.000	17.668
35.615	19.251

```
UPPER  NAPPE  OUTPUT

DESIGN  HEAD  (FT)=     31.570
ACTUAL  HEAD  (FT)=    42.000
APPROACH  DEPTH  (FT)=     15.780
P/HD=       .4998
HE/HI)=   1.330


THE  ORIGIN  OF  THE  WATER-SURFACE  ELEVATION  COORDINATES  IS  LOCATED
AT THE CREST WITH +X TO THE RIGHT AND +Y UPWARD.


 UPPER  NAPPE  ELEVATIONS  WITH  PIERS(FT)

         BAY C.L.    ALONG  PIERS
  X          Y           Y
 -31.57   33.478      35.732
 -25.26   33.214      35.437
 -18.94   32.604      34.964
 -12.63   31.761      34.312
  -6.31   30.564      33.501
    .00   28.840      32.353
   6.31   26.808      30.721
  12.63   24.030      28.583
  18.94   20.871      25.942
  25.26   16.659      22.761
  31.57   11.533      18.920
  37.88    5.627      14.275
  44.20    -.890       7.612
ENTER  END  OR  RERUN
END
stop  -  Program  terminated.
```

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**********************************
*  CORPS PROGRAM  #  H1109       *
*  MICRO VERSION  # 84/10/23     *
**********************************


           ****** CORPS H1109 ******
H1109 WILL CALCULATE PRESSURES ON CRESTS DESIGNED USING THE ELLIPTICAL
CREST SPILLWAY DESIGN PROCEDURE. PRESSURE DISTRIBUTIONS WERE MEASURED
OVER A RANGE OF X/HD FROM -0.22 TO 1.0, P/HD FROM 0.25 TO 3.4, HE/HD
FROM 0.5 TO l.5, AND FOR VERTICAL AND 1:l UPSTREAM FACE SLOPES.
NO 1:1 VALUES ARE AVAILABLE FOR P/HD OF 3.4.

DUE TO THE IRREGULAR NATURE OF PRESSURE VARIATION WITH P/HD AND HE/HD
H1109 WILL NOT INTERPOLATE FOR INTERMEDIATE VALUES.  INTERMEDIATE
VALUES CAN BE ESTIMATED BY RUNNING H1109 SEVERAL TIMES FOR
THE VALUES DESIRED AND THEN EITHER VISUALLY OR MATHEMATICALLY
INTERPOLATING.
-------------------------------------------------------------------


DO YOU WANT GRAPHICS? (Y OR N)
N


INPUT Hll09
AA-ENTER DESIGN HEAD,FT.
31.57
AB-P/HD  RATIO:0.25,0.5,1.0,OR  3.4
0.5
AC-DOES THE SPILLWAY HAVE PIERS? (Y OR N)
Y
AD-WANT VERTICAL OR 1:1 UPSTREAM FACE SLOPE (l=VERT,2=l:l)?
2
AF-ENTER NAME OF DESIGN PROBLEM
EXAMPLE

HARDCOPY IF DESIRED - THEN RETURN
```

EM lll0-2-1603
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OUTPUT FOR: EXAMPLE

DESIGN HEAD (FT)= 31.570
APPROACH DEPTH (FT)= 15.785
P/HD= .5000

********** 1:1 UPSTREAM FACE **********

THE ORIGIN OF THE CREST PRESSURE COORDINATES IS LOCATED
AT THE CREST WITH +X TO THE RIGHT AND +Y UPWARD.

CREST PRESSURES-CENTER LINE-(FT)

X	H/HD=0.50	H/HD=l.00	H/HD=1.17	H/HD=1.33	H/HD=1.50
-6.95	15.78	18.31	15.78	20.84	20.84
-6.31	14.62	16.73	14.52	18.94	15.78
-5.68	13.89	15.78	13.89	17.99	11.68
-4.74	11.05	12.63	9.79	7.58	3.16
-3.16	9.16	8.52	6.31	3.16	2.21
-1.58	8.84	5.68	3.16	-.32	-6.00
.00	8.52	7.89	4.74	. 32	-4.74
3.16	7.58	6.31	3.16	000	-5.37
6.31	6.63	5.37	2.21	-.63	-6.31
9.47	6.31	5.37	2.53	.oo	-6.31
15.78	5.05	4.10	2.53	-.32	-4.74
22.10	3.79	2.84	1.26	-1.26	-5.05
31.57	3.47	2.84	1.58	-.32	-3.16

CREST PRESSURES-ALONG PIER-(FT)

X	H/HD=0.50	H/HD=l.00	H/HD=1.17	H/HD=1.33	H/HD=l.50
-6.95	17.05	28.41	25.26	24.31	23.68
-6.31	16.10	24.94	22.10	20.84	22.10
-5.68	14.84	22.10	18.94	17.36	18.94
-4.74	12.63	16.42	15.78	12.63	12.63
-3.16	9.47	6.63	3.16	-.95	-6.31
-1.58	6.95	.95	-5.05	-10.73	-19.89
.00	6.31	.95	-3.47	-9.47	-17.99
3.16	6.00	2.84	-1.26	-6.31	-13.26
6.31	5.37	3.47	.32	-4.42	-10.10
9.47	5.05	4.10	1.89	-2.21	-7.26
15.78	4.10	4.10	2.84	00	-4.42
22.10	3.16	3.16	1.58	-:32	-3.47
31.57	2.84	2.21	1.26	-.63	-2.21

ENTER END OR RERUN
END
stop - Program terminated.