Attachment 02.04.03-08K
TVA letter dated February 2, 2010
RAI Response

ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8K: Dam Rating Curve, Fort Patrick Henry

(82 Pages including Cover Sheet)

NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58 090120 003	Calculations (nuclear)	L58 091230 023

Calc Title: Dam Rating Curve, Fort Patrick Henry

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080010	0	1	Entire calc ☒ Selected pages ☐
NEW								

ACTION	NEW ☐ REVISION ☒	DELETE ☐ RENAME ☐	SUPERSEDE ☐ DUPLICATE ☐	CCRIS UPDATE ONLY ☐ (Verifier Approval Signatures Not Required)	No CCRIS Changes ☐ (For calc revision, CCRIS been reviewed and no CCRIS changes required)

UNITS	SYSTEMS	UNIDS
N/A	N/A	N/A

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
*See Below	N/A	E

QUALITY RELATED?	SAFETY RELATED? (If yes, QR = yes)	UNVERIFIED ASSUMPTION	SPECIAL REQUIREMENTS AND/OR LIMITING CONDITIONS?	DESIGN OUTPUT ATTACHMENT?	SAR/TS and/or ISFSI SAR/CoC AFFECTED
Yes ☒ No ☐	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☐ No ☒

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
C. J. Grace	205.298.6074	CEB	Design Review - See Pg 5.1	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Chris Grace [signature]	12/21/2009	Andrew Murr [signature]	12/21/2009
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Andrew Murr [signature]	12/21/2009	K.R. Spates [signature]	12/23/09

STATEMENT OF PROBLEM/ABSTRACT

Headwater rating curves for 20 dams are required as inputs to TVA's SOCH and TRBROUTE models, which perform flood-routing calculations for the Tennessee River and tributaries. The headwater rating curves for each dam provide total dam discharge as a function of headwater elevation. This calculation presents the headwater rating curve for Fort Patrick Henry Dam.

This calculation contains electronic attachments and must be stored in EDMS as an Adobe .pdf file to maintain the ability to retrieve the electronic attachments.

*EDCN 22404A (SQN), EDCN 54018A (WBN), EDCN Later (BFN)

Limiting Condition Note: The headwater rating curve provided in this calculation is limited in application to maximum PMF headwater elevation of 1288 feet (See Section 5.0 in the calculation for the basis of this limiting condition).

MICROFICHE/EFICHE Yes ☐ No ☒ FICHE NUMBER(S)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: LP4D-C
☐ LOAD INTO EDMS AND RETURN CALCULATION TO:

TVAN CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58 090120 003	Calculations (nuclear)	N/A

Calc Title: Dam Rating Curve, Fort Patrick Henry

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC						Entire calc ☐ Selected pages ☐
NEW	CN	NUC	GEN	CEB	CDQ000020080010	N/A	0	

ACTION	NEW ☒ REVISION ☐	DELETE ☐ RENAME ☐	SUPERSEDE ☐ DUPLICATE ☐	CCRIS UPDATE ONLY ☐ (Verifier Approval Signatures Not Required)	No CCRIS Changes ☐ (For calc revision, CCRIS been reviewed and no CCRIS changes required)

UNITS	SYSTEMS	UNIDS
N/A	N/A	N/A

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
N/A	N/A	E

QUALITY RELATED?	SAFETY RELATED? (If yes, QR = yes)	UNVERIFIED ASSUMPTION	SPECIAL REQUIREMENTS AND/OR LIMITING CONDITIONS?	DESIGN OUTPUT ATTACHMENT?	SAR/TS and/or ISFSI SAR/CoC AFFECTED
Yes ☒ No ☐	Yes ☒ No ☐	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
jvpeyton	865-632-3280	CEB	Design Review	☐ Yes ☒ No

PREPARER	DATE	CHECKER SIGNATURE	DATE
J.V. Peyton G.A. Schohl [signatures]	12/3/2008	[signature] JANIE B. MAUTER	12/16/08
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
[signatures] ANDREW C. MUHR Russell B. Williston	12/16/08	[signature] E.R. Spates	1/20/09

STATEMENT OF PROBLEM/ABSTRACT

Headwater rating curves for 20 dams are required as inputs to TVA's SOCH and TRBROUTE models, which perform flood-routing calculations for the Tennessee River and tributaries. The headwater rating curves for each dam provide total dam discharge as a function of headwater elevation. This calculation presents the headwater rating curve for Fort Patrick Henry Dam.

This calculation contains electronic attachments and must be stored in EDMS as an Adobe .pdf file to maintain the ability to retrieve the electronic attachments.

MICROFICHE/EFICHE Yes ☐ No ☒ FICHE NUMBER(S)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: LP4D-C
☐ LOAD INTO EDMS AND RETURN CALCULATION TO:

NPG CALCULATION COVERSHEET/CCRIS UPDATE

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	REV
	CN	NUC	GEN	CEB	CDQ000020080010	1

ALTERNATE CALCULATION IDENTIFICATION

BLDG	ROOM	ELEV	COORD/AZIM	FIRM	Print Report Yes ☐
				BWSC	

CATEGORIES SR/LC

KEY NOUNS (A-add, D-delete)

ACTION (A/D)	KEY NOUN	A/D	KEY NOUN

CROSS-REFERENCES (A-add, C-change, D-delete)

ACTION (A/C/D)	XREF CODE	XREF TYPE	XREF PLANT	XREF BRANCH	XREF NUMBER	XREF REV
A	P	EN	WBN	CEB	54018	
A	P	EN	SQN	CEB	22404	
A	S	CN	GEN	CEB	CDQ000020080053	
D	S	CN	GEN	CEB	CDQ000020080054	

CCRIS ONLY UPDATES:
Following are required only when making keyword/cross reference CCRIS updates and page 1 of form NEDP-2-1 is not included:

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE

PREPARER PHONE NO.	EDMS ACCESSION NO.

NPG CALCULATION RECORD OF REVISION	
CALCULATION IDENTIFIER	CDQ000020080010
Title	Dam Rating Curve, Fort Patrick Henry
Revision No.	**DESCRIPTION OF REVISION**
0	Initial issue Total pages: 67 Attachment 1: 2 pages; Attachment 2: 1 page Appendix A: 5 pages; Attachments A1 thru A3: 1 page each; Attachment A4: 7 pages; Attachment A5: 1 page; Attachment A6: 5 pages; Attachments A7 thru A14: 1 page each.
1	Revised to eliminate Unverified Assumption in Section 3.2; added Reference 2.20 (Page 8); revise CCRIS input information on Page 2 and Revised coversheet. This calculation was also revised to address the following : • PER 203951- The verification of the original calculation was completed by personnel who had not completed the required NEDP-7 Job Performance Record (JPR). A verification JPR is now in place for all personnel engaged in verification tasks. Checking includes only changes made in this revision as the checking of the calculation was not impacted by PER 203951. The verification is inclusive of work completed prior to this revision. • PER 203872- replace NEDP-2 forms on Pages 1 through 6 (excluding Page 1a) with the forms from the NEDP-2 Revision in effect at the time of calculation issuance. • Removed UVA 3.2.1. Replaced with: o Assumption 3.1.2 based on Reference 2.20 and, o Assumption 3.1.3 based on Appendix B. • Added Limiting Condition to calculation in Section 5.0. Significant changes in Revision 1 are noted with a right margin revision bar. Administrative changes and typos are excluded. Pages deleted: none Pages revised: 1, 2, 3, 4, 5, 8, 9 New pages added: 1a (Rev 0 coversheet), 5.1 (NEDP 2-4), B1-B4 Calculation header was revised (Title and Revision) on pages 8-9 Total pages for Revision 1: 73 Attachment 1: 2 pages; Attachment 2: 1 page Appendix A: 5 pages; Attachments A1 thru A3: 1 page each; Attachment A4: 7 pages; Attachment A5: 1 page; Attachment A6: 5 pages; Attachments A7 thru A14: 1 page each. Appendix B: 4 pages

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ000020080010	Revision: 1	

TABLE OF CONTENTS

NPG CALCULATION TABLE OF CONTENTS (CONTINUED)

Calculation Identifier: CDQ000020080010	Revision: 1	

TABLE OF CONTENTS(Continued)

NPG CALCULATION VERIFICATION FORM

Calculation Identifier: CDQ000020080010 Revision: 1

Method of verification used:		Verifier: Andrew Murr Date 12/21/2009
1. Design Review	☒	
2. Alternate Calculation	☐	
3. Qualification Test	☐	

Comments:

This calculation entitled, "Dam Rating Curve, Fort Patrick Henry," was verified by independent design review. The process involved a critical review of the calculation to ensure that it is correct and complete, uses appropriate methodologies, and achieves its intended purpose. The inputs were reviewed and determined to be appropriate inputs for this calculation. The results of the calculation were reviewed and were found to be reasonable and consistent with the inputs provided. Backup files and documents were consulted as necessary to verify data and analysis details found in the calculation.

Detailed comments and editorial suggestions for the changes made in this revision were transmitted to the author and reviewer by email along with a marked up copy of the calculation.

The methodology used to justify the operability of the gates is based solely on the conclusions of the "Watts Bar Dam – Flood and Earthquake Analysis on Radial Spillway Gates." Appendix B uses the same assumptions, methodology, and approach developed in the Watts Bar radial gate analysis to determine the forces on the radial gates in a closed position with the forces on the gates in the maximum open position. This appendix does not assert that a structural analysis has been performed beyond that found in the Watts Bar radial gate calculation.

(Note: The design verification of this calculation revision is for the total calculation, not just the changes made in the revision. This complete re-verification is performed to disposition PER 203951 as described in the Calculation Revision Log on Page 3).

NPG COMPUTER INPUT FILE
STORAGE INFORMATION SHEET

Document CDQ000020080010	Rev. 0	Plant: GEN	

Subject:
Dam Rating Curve, Fort Patrick Henry

☐ Electronic storage of the input files for this calculation is not required. Comments:

There are no electronic input or output files associated with this calculation.

☒ Input files for this calculation have been stored electronically and sufficient identifying information is provided below for each input file. (Any retrieved file requires re-verification of its contents before use.)

These files are electronically attached to the parent ADOBE.pdf calculation file. All files are therefore stored in an unalterable medium and are retrievable through the EDMS number for this calculation.

Attachment 3: Excel file: "Ft.Patrick Henry Dam Rating Curve Turbine Discharge.xls"
Attachment 4: TVA Drawing No. 10W200 R8
Attachment 5: TVA Drawing No. 10W201 R8
Attachment 6: TVA Drawing No. 10N203 R5
Attachment 7: TVA Drawing No. 46N401 R0
Attachment 8: TVA Drawing No. 54N201 R1
Attachment 9: TVA Drawing No. 54N202 R1

Appendix A Attachments:

Attachment A15: Excel file: "Ft Pat Henry Model Data for Headwater Ratings.xls"
Attachment A16: TVA Drawing No. 54N200 R1
Attachment A17: TVA Drawing No. 51N202 R3

☐ Microfiche/eFiche

1.0 Purpose

Headwater rating curves for twenty dams geographically located on the Tennessee River and its tributaries above the existing Bellefonte Nuclear facility are required as inputs to TVA's SOCH and TRBROUTE models, which perform flood-routing calculations. The headwater rating curves for each dam provide total dam discharge as a function of headwater elevation. This calculation determines the headwater rating curve for Fort Patrick Henry Dam with all spillway gates fully open.

TVA developed methods of analysis, procedures, and computer programs for determining design basis flood levels for nuclear plant sites in the 1970's. Determination of maximum flood levels included consideration of the most severe flood conditions that may be reasonably predicted to occur at a site as a result of both severe hydrometerological conditions and seismic activity. This process was followed to meet Nuclear Regulatory Guide 1.59. At that time, there were no computer programs available that would handle unsteady flow and dam failure analysis. As a result of this early work and method development TVA developed a runoff and stream course modeling process for the TVA reservoir system. This process provided a basis for currently licensed plants (Sequoyah Nuclear Plant, Watts Bar Nuclear Plant, and Browns Ferry Nuclear Plant). The Bellefonte Nuclear Plant (BLN) Units 1 & 2 Final Safety Analysis Report (FSAR) was also based on this process.

BLN Unit 3 & 4 Combined Operating License Application (COLA) was submitted using data and analysis that was determined for the original BLN FSAR (Unit 1 and Unit 2) and was documented in a 1998 reassessment. In 1998, the analysis process and documentation was brought under the nuclear quality assurance process for the first time. A quality assurance audit conducted by NRC staff in early 2007 raised several questions related to past work regarding design basis flood level determinations. This calculation supports a portion of the effort to improve the design basis documentation.

Drawing 10W200 (Reference 2.1) provides plan and elevation views of Fort Patrick Henry Dam. For headwaters in the normal operating range, discharge is passed through the turbines or the spillway. The spillway consists of five spillway bays, each with a radial, or tainter, gate to control discharge. If, as during a probable maximum flood (PMF) event, headwater rises above the normal operating range, discharge may pass also over the dam nonoverflow section, the tops of the open spillway gates and the tops of the spillway piers.

2.0 References

2.1 TVA drawing 10W200 R8, "General Plan, Elevation & Sections."
2.2 TVA drawing 10W201 R8, "General Plan, Elevation & Sections."
2.3 TVA drawing 54N200 R1, "Radial Gates Arrangement."
2.4 TVA drawing 54N201 R1, "Radial Gates Structural Details – Sheet 1."
2.5 TVA drawing 54N202 R1, "Radial Gates Structural Details – Sheet 2."
2.6 "Fort Patrick Henry Dam Spillway Discharge Tables," River Operations, Tennessee Valley Authority, March 1999, TVA EDMS accession no. L58081211803.
2.7 "Hydraulic Design Criteria," USACE (U. S. Army Engineer Waterways Experiment Station), Eighteenth Issue, Vicksburg, MS, 1988.
2.8 Handbook of Hydraulics, E. F. Brater and H. W. King, Sixth Ed., McGraw Hill, 1976.
2.9 "Hydraulic Design Criteria," USACE (U.S. Army Engineer Waterways Experiment Station), Eighteenth Issue, Vicksburg, MS, 1988, Hydraulic Design Chart 711 (HDC 711).
2.10 "Hydraulic Model Studies, Fort Patrick Henry Project," TVA Division of Water Control Planning Technical Monograph No. 87, TVA Research Library call no. 999.6278 T2985fo.
2.11 "Rating Curves for Flow over Drum Gates," Joseph N. Bradley, Paper No. 2677, Transactions of the American Society of Civil Engineers, vol. 119, pp. 403-433, 1954.
2.12 Open Channel Flow, Sec. 2.7, F. M. Henderson, Macmillan, New York, 1966.
2.13 Bellefonte Nuclear Plant FSAR, Units 1 and 2, Section 2.4.3.3, page 2.4-16.
2.14 TVA drawing 51N202 R3, "Concrete Blocks 12, 13 & 14 Outline."
2.15 TVA drawing 10N203 R5, "Principal Features of Design."
2.16 TVA drawing 46N401 R0, "Architectural Elevations Sheet 1."
2.17 TVA Fort Patrick Henry Project drawing 47K909 R0, "Powerhouse Generating Unit 1, Operating Characteristics of 33,000 KVA Generating Unit Based on Acceptance Test," Fort Patrick Henry Blue Book, page 23.
2.18 TVA Fort Patrick Henry Project drawing 47K910 R0, "Powerhouse Generating Unit 2, Operating Characteristics of 33,000 KVA Generating Unit Based on Acceptance Test," Fort Patrick Henry Blue Book, page 24.
2.19 Design of Small Dams, US Department of the Interior, Bureau of Reclamation, 2nd Edition 1973, Revised reprint 1977.
2.20 "Basis for Dam Spillway Gate/Outlet Open Configuration for Flood Analyses," Tennessee Valley Authority, May 29, 2009 (EDMS No. L58 090529 800)

3.0 Assumptions & Methodology

The headwater rating curves developed in these calculations will be used in simulations of probable maximum flood events. Consequently, the rating curves have been calculated well above the normal operating range and several feet above the top of the dam.

3.1 Assumptions

3.1.1 Assumption: The tailwater rating curve provided as Attachment 1 accurately predicts the tailwater elevation for the range of discharge required for the headwater rating curve.

Technical Justification: The tailwater rating curve was generated by the TVA Flood Risk group. This tailwater rating curve is used by TVA during actual flood events as input for river management decisions and is the best available source of tailwater elevation data. In addition, the evaluation in Section 6.5 of this calculation demonstrates that the discharge for Fort Patrick Henry dam is not sensitive to the accuracy of the tailwater curve.

3.1.2 Assumption: All spillway gates will be set to the maximum openings specified in the spillway discharge tables.

Technical Justification: For technical justification, see Reference 2.20, "Basis for Dam Spillway Gate/Outlet Open Configuration for Flood Analyses."

3.1.3 Assumption: All spillway gates will remain operable in the closed position and in the maximum opened position as specified in the spillway discharge tables.

Technical Justification: The radial gates will remain operable in the maximum opened position based on the findings of the "Watts Bar Dam – Flood and Earthquake Analysis on Radial Spillway Gates" (Reference B1). Appendix B uses the same assumptions, methodology, and approach as the Watts Bar radial gate analysis to compare forces on the gates in a closed position with forces on the gates in the maximum open position to provide technical justification for the gates to remain operable in the maximum open position during a PMF.

3.2 Unverified Assumptions

None.

3.3 Methodology -- Discharge Equations

Discharges past the dam are computed as either "free" discharge or "orifice" discharge. Free discharge refers to free surface overflow and is computed using a weir-type equation as follows (Reference 2.7 provides weir flow equations for overflow discharges):

$$Q_f = C_f L H_c^{1.5} \tag{1}$$

in which Q_f = free discharge (cfs), C_f = free discharge coefficient ($ft^{0.5}$/sec -- may vary with HW), L = length of overflowing section (ft), H_c = head on crest (ft) = HW - Z_c, HW = headwater elevation (ft), and Z_c = top, or crest, elevation of overflowing section (ft). This equation need not be modified to account for tailwater submergence because the tailwater does not rise high enough to affect the free discharges computed for this headwater rating curve.

Flow over the nonoverflow section, the tops of the open spillway gates, and the tops of the spillway piers is treated as free discharge. Flow over the spillway crest is treated as free discharge for headwater elevations below $H_c = H_{Lmin}$, the head at which the overflowing nappe first touches the bottoms of the open gates (see Attachment A5). H_{Lmin} varies with gate opening, V, defined as the vertical distance between the spillway crest and the bottom of the gate.

For headwater elevations above $H_c = H_{Lmin}$ flow through the spillway gates is treated as orifice discharge. Orifice discharge refers to flow passing through a contracted opening and is computed using an orifice-type equation as follows (Reference 2.7, Hydraulic Design Chart 311-1):

$$Q_g = C_g G_n L \sqrt{2g(H_c - H_{mp})} \tag{2}$$

in which Q_g = orifice discharge (cfs), C_g = orifice discharge coefficient (dimensionless -- varies with gate opening and H_c), G_n = effective gate opening = minimum distance between the gate lip and the crest (ft), g = acceleration of gravity, and H_{mp} = vertical distance between the mid-point of G_n and the crest. This equation is modified, if required, to account for tailwater submergence as follows:

$$Q_{gs} = S_g Q_g \tag{3}$$

in which Q_{gs} = "corrected" orifice discharge (cfs) and S_g = tailwater submergence factor (dimensionless -- varies with d/H_c and gate opening, G_n).

3.4 Methodology -- Spillway Discharge Calculations

The discharge coefficient, C_f, for free discharge over a spillway crest varies with head, H_c (References 2.7 and 2.8 both provide this kind of data). For the Fort Patrick Henry spillway crest, the relationships $H_{Lmin}(V)$ and $C_f(H_c)$are available from model test data (Appendix A). The relationship between orifice discharge coefficient, C_g, and head, H_c, for various gate openings, V (up to V = 25 feet), is also available from the model test data. The crest length, L, and crest elevation, Z_c, are shown on TVA drawings (e.g., References 2.1 and 2.2). The parameters G_n and H_{mp} are determined from geometry (Appendix A).

The physical model used to measure spillway discharge included several bays and the piers between them. Consequently, pier contraction effects are implicitly included in the discharge coefficients derived from the model test data.

Under the assumption that all spillway gates are fully open, the two end bays (first and last) are the only spillway bays subject to end contraction effects. These effects, which may reduce discharge through these two bays by a few percent, are neglected in this calculation. Neglecting this minor effect has negligible impact on the dam rating curve.

3.5 Methodology -- Discharge Coefficients

Values of the discharge coefficient, C_f, for flows over the nonoverflow section, the tops of the open spillway gates, and the tops of the spillway piers, are estimated using Hydraulic Design Chart 711 (Reference 2.9). Length, L, and crest elevation, Z_c, in each case are determined from TVA drawings (all relevant drawings are defined as References).

The upper plot of HDC 711 (Reference 2.9) shows that C_f is about 2.65 for very broad crests ($H_l/B < 0.4$ where $H_l = H_c$ and B = streamwise length of the crest) and gradually increases to 3.1, the maximum value for a "broad-crested" weir, as H_l/B increases to about 1.2. As H_l/B increases above 1.2, C_f continues to increase as the weir transitions from broad-crested to sharp-crested at about $H_l/B = 2.0$. Since the estimation of discharge over the top of various sections of a dam and its embankments is an approximation, small variations in C_f with H_c are not modeled and the effects of end contractions are neglected. A single representative value for C_f within the range of its variation is used for all headwater elevations included in the rating. Neglecting minor variations in C_f values and end contractions has negligible impact on the dam rating curve.

4.0 Design Input

Sec	Input Parameter	Source	Symbol	Value
4.1	**Acceleration of gravity**			
		Common knowledge	g	32.2 ft/sec^2
4.2	**Spillway crest parameters**			
4.2.1	Crest length	Five 35-foot wide bays; Ref. 2.1	L	175 feet
4.2.2	Crest elevation	Attachment A7, page A24	Z_c	1228.0 feet
4.2.3	Free discharge coefficient	Polynomial fit to model data given in Attachment A10 and discussed in Appendix A	$C_f(H_c)$	Equation A3
4.3	**Spillway gate parameters**			
4.3.1	Vertical opening	Discussed in Appendix A	V	31.0 feet
4.3.2	Effective gate opening	Computed in Appendix A	G_n	31.54 feet
4.3.3	Mid-point elevation of opening relative to crest	Computed in Appendix A	H_{mp}	15.375 feet
4.3.4	Headwater elevation at which nappe touches gates	H_{Lmin} estimated in Appendix A and Attachment A9	$H_{Lmin} + Z_c$	1265.49 feet
4.3.5	Orifice discharge coefficient	Extrapolated curve given in Attachment A12 and Table A2 and discussed in Appendix A	$C_g(H_c)$	Interpolate between points in Table A2
4.4	**Spillway gate overflow**			
4.4.1	Overflow discharge coeff.	Calculations in Section 6.0, pages 22 -24	C_o	3.2
4.4.2	Overflow elevation	Computed in Appendix A	Z_o	1277 feet
4.4.3	Overflow length	Same as spillway crest, Ref. 2.1	L_o	175 feet
4.5	**Powerhouse overflow**			
4.5.1	Discharge coefficient	Calculation page 18	C_f	2.65
4.5.2	Overflow elevation	TVA drawing 46N401, Downstream Elevation	Z_c	1285 feet
4.5.3	Overflow length	TVA drawing 46N401, Downstream Elevation	L	151.5 feet
4.6	**Spillway piers overflow**			
4.6.1	Discharge coefficient	Calculation page 18	C_f	2.68
4.6.2	Overflow elevation	TVA drawing 10N203, G-G	Z_c	1272.42 feet
4.6.3	Overflow length	TVA drawing 10N203, Plan	L	39.0 feet
4.7	**Nonoverflow Dam (B=12')**			
4.7.1	Discharge coefficient	Calculation page 17	C_f	3.0
4.7.2	Overflow elevation	TVA drawing 10W201	Z_c	1270.0 feet
4.7.3	Overflow length	Calculation page 16	L	241.5 feet

4.0 **Design Input (Continued)**

Sec	Input Parameter	Source	Symbol	Value
4.8	**Nonoverflow Dam (B=26.25')**			
4.8.1	Discharge coefficient	Calculation page 17	C_f	2.74
4.8.2	Overflow elevation	TVA drawing 10W201, E-E	Z_c	1270.0 feet
4.8.3	Overflow length	Calculation page 16	L	17.5 feet
4.9	**Tailwater Rating Curve**			
	TW vs. total discharge, Q	Attachment 1, page 30, Q=325,290 cfs	TW(Q)	1258 feet

5.0 Special Requirements/Limiting Conditions

Calculations performed in Appendix B demonstrate that the spillway gate PMF hydrostatic loads in the expected fully open position are comparable to the normal spillway gate design loads in the fully closed position. Although a detailed gate analysis could potentially demonstrate the capability of the gate to withstand higher headwater elevations, the applicability of this calculation is limited to headwater elevations no greater than 1288.0 feet, near the maximum expected headwater elevation for the PMF at the Fort Patrick Henry Dam. If PMF headwater elevations at the Fort Patrick Henry Dam exceed 1288.0 feet, a revision of this calculation will be required.

6.0 Calculations

The calculations included in this section are overflow lengths, overflow parameters, configuration of spillway gates for the maximum open position, overflow parameter for the tainter spillway gates and tailwater submergence effect on discharge.

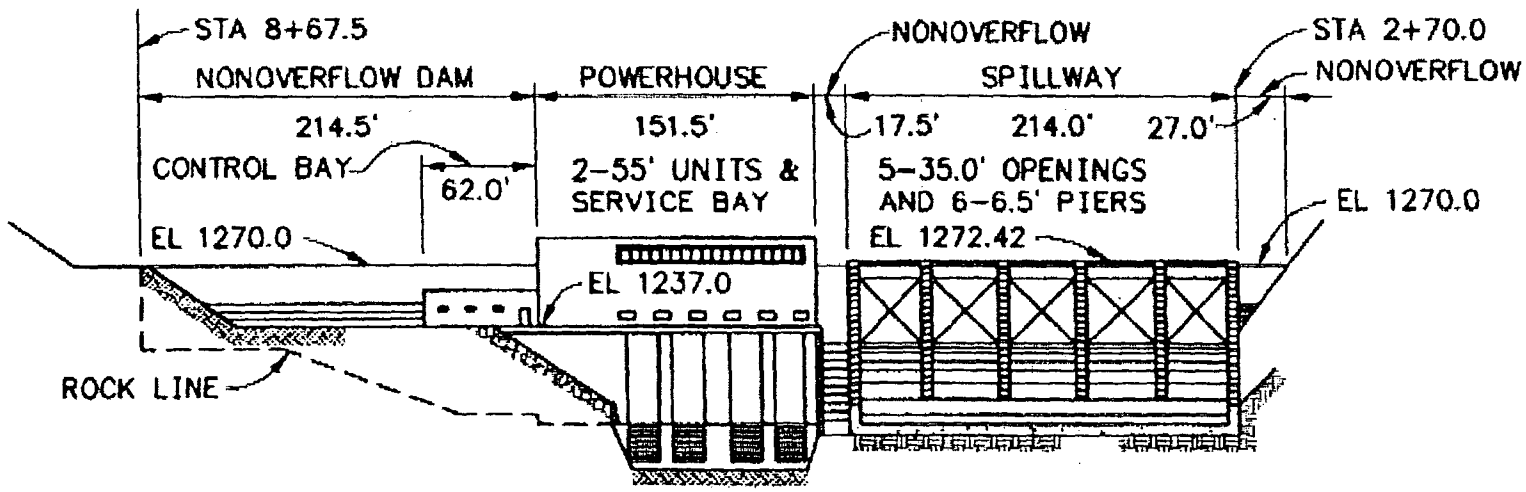
Dam Rating Curve

Computed By: JVPeyton 10-24-08 Checked By: JB Mauter

Fort Patrick Henry Page 16
CDQ000020080010

6.1 Overflow Lengths

Ref: TVA drawing 10W200



DOWNSTREAM ELEVATION

Lengths @ El 1270

L_{over} (Nonoverflow lengths shown above) = 214.5' + 17.5' + 27.0' = 259'

L_{over} (B, Width = 12') = 214.5 + 27.0 = 241.5'

L_{over} (B, Width = 26.5') = 17.5'

Length @ Power House, El 1285 (Top of Coping, Dwg 46N401)

L (Powerhouse, shown above) = 151.5'

SUBJECT Dam Rating Curve PROJECT Fort Patrick Henry

CDQ000020080010

COMPUTED BY JVPeyton DATE 10-24-08 CHECKED BY JBMauter DATE

6.2 Overflow Parameters
Top of Dam, El 1270.0

Ref: Army Corp of Engineers, "Hydraulic Design Criteria," Eighteenth Issue, Hydraulic Design Chart 711.

$B = 12'$
See A-A & B-B TVA dwg 10W201 and the chart on page 19.

$$\frac{H_1}{B} = \frac{0}{12'} = 0 \Rightarrow C_f \cong 2.65$$

$$\frac{H_1}{B} = \frac{(El\ 1290^{*} - El\ 1270)}{12'} = 1.67 \Rightarrow C_f \cong 3.35$$

$$\text{Use } C_f\ (\text{Average}) = \frac{2.65 + 3.35}{2} = 3.0$$

$B = 26.25$
See E-E TVA dwg 10W201 and the chart on page 19.

$$\frac{H_1}{B} = \frac{0}{26.25'} = 0 \Rightarrow C_f \simeq 2.65$$

$$\frac{H_1}{B} = \frac{(El\ 1290^{*} - El\ 1270)}{26.25'} = 0.76 \Rightarrow C_f \simeq 2.82$$

$$\text{Use } C_f\ (\text{Average}) = \frac{2.65 + 2.82}{2} = 2.74$$

B - streamwise length of weir crest. See Section 3.4, page 11.

* Assumed. Maximum headwater elevation considered in this calculation.

SUBJECT Dam Rating Curve PROJECT Fort Patrick Henry

CDQ000020080010

COMPUTED BY N Peyton DATE 10-24-08 CHECKED BY JB Mauter DATE

6.2 Overflow Parameters (Continued)

Tops of Spillway Piers, El 1272.42

L = 6 piers @ 6.5' wide = 39'

$$\frac{H_1}{B} = \frac{0}{35'} = 0 \Rightarrow C_f \simeq 2.65$$

$$\frac{H_1}{B} = \frac{El\ 1290^{*} - El\ 1272.42'}{35'} = \frac{17.58}{35'} = 0.50 \Rightarrow C_f \simeq 2.70$$

Use $C_f \text{(Average)} = \frac{2.65 + 2.70}{2} = 2.68$

B - streamwise length of weir crest. See Section 3.4, page 11; F-F TVA drawing 10W201 and page 19.

Powerhouse, El 1285.0

L = 151.5'

$$\frac{H_1}{B} = \frac{0}{59.5'} = 0 \Rightarrow C_f \simeq 2.65$$

$$\frac{H_1}{B} = \frac{El\ 1290^{*} - El\ 1285}{59.5'} = 0.08 \simeq 0 \Rightarrow C_f = 2.65$$

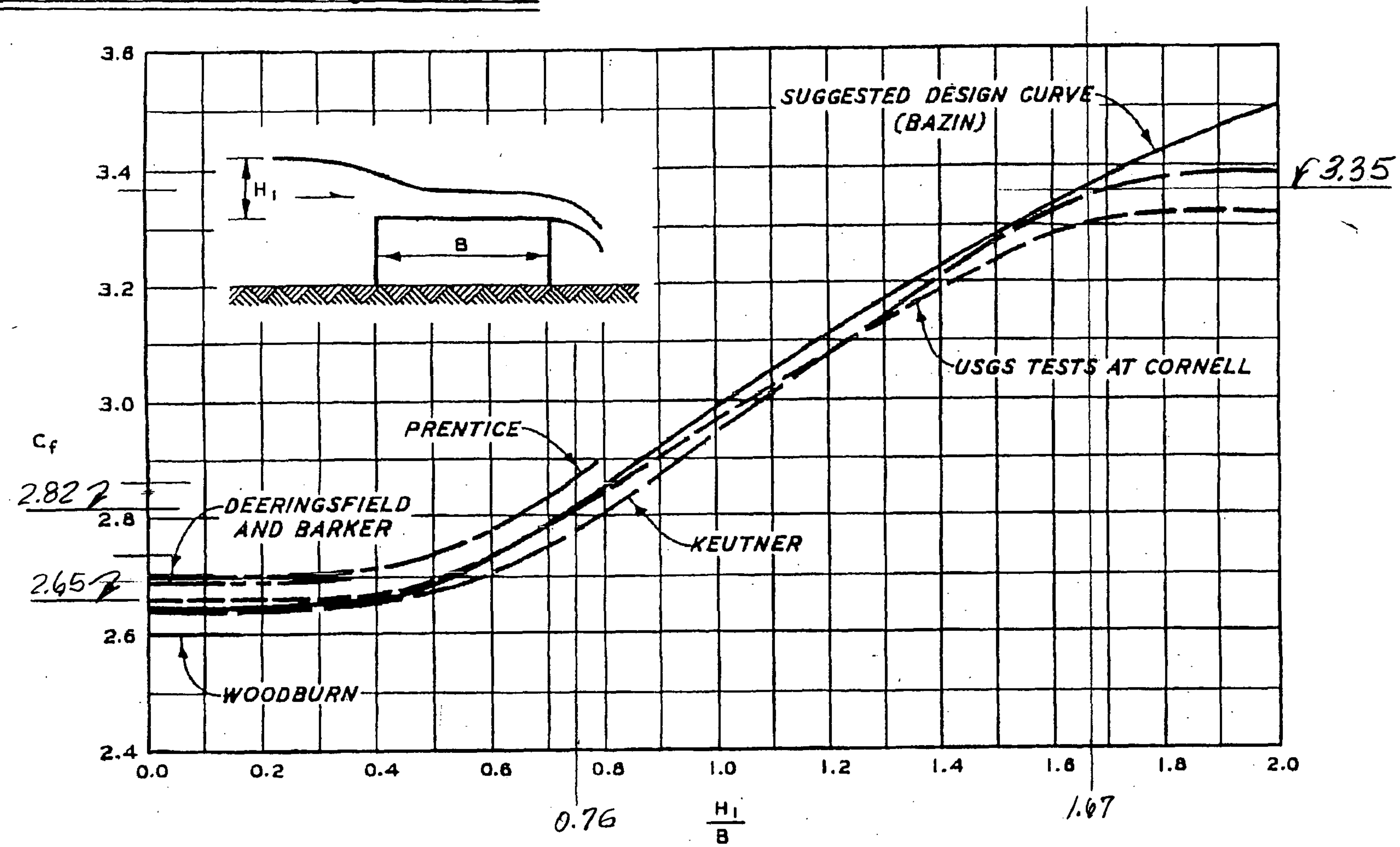
Use C_f = 2.65

B - streamwise length of weir crest. See Section 3.4, page 11; C-C, TVA drawing 10W201 and page 19.

* Assumed. Maximum headwater elevation considered in this calculation.

Dam Rating Curve
Computed By: JV Peyton 10-24-08 Checked By: JB Mauter

6.2 Overflow Parameters (Continued)



a. FREE FLOW

Ref: Army Corp of Engineers, "Hydraulic Design Criteria", 18th Issue, Design Chart 711.

SUBJECT Dam Rating Curve PROJECT Fort Patrick Henry

CDQ000020080010

COMPUTED BY JV Peyton DATE 10-24-08 CHECKED BY JB Mauter DATE

6.3 Configuration of Spillway Gates - Maximum Open

Ref: TVA drawings 54N200 R1 & 54N201 R1

The elevation of the top edge of the gate is determined using AUTOCAD.

The angles calculated below are used to plot the gate in the closed position. The gate is rotated so that the vertical distance from the spillway crest to the bottom edge of the gate is 31', the maximum the gate is opened.

θ_1 (Angle from bottom edge to ℄ lower arms) $= \frac{180 \ell}{\pi r} = \frac{180(3'\text{-}0\frac{1}{8}'')}{\pi(36')} = 4.7912°$

θ_2 (Angle between ℄ lower & upper arms) $= \frac{180 \ell}{\pi r} = \frac{180[(9'\text{-}9\frac{5}{16}'')+(1'\text{-}2'')+(8'\text{-}7'')]}{\pi(36')}$

$= \frac{180(19.5260')}{\pi(36')} = 31.0766°$

θ_3 (Angle from ℄ upper arm to top edge) $= \frac{180 \ell}{\pi r} = \frac{180[(10'\text{-}0\frac{7}{8}'')+(5'\text{-}0\frac{1}{8}'')]}{\pi(36')}$

$= \frac{180(15.0833')}{\pi(36')} = 24.0058°$

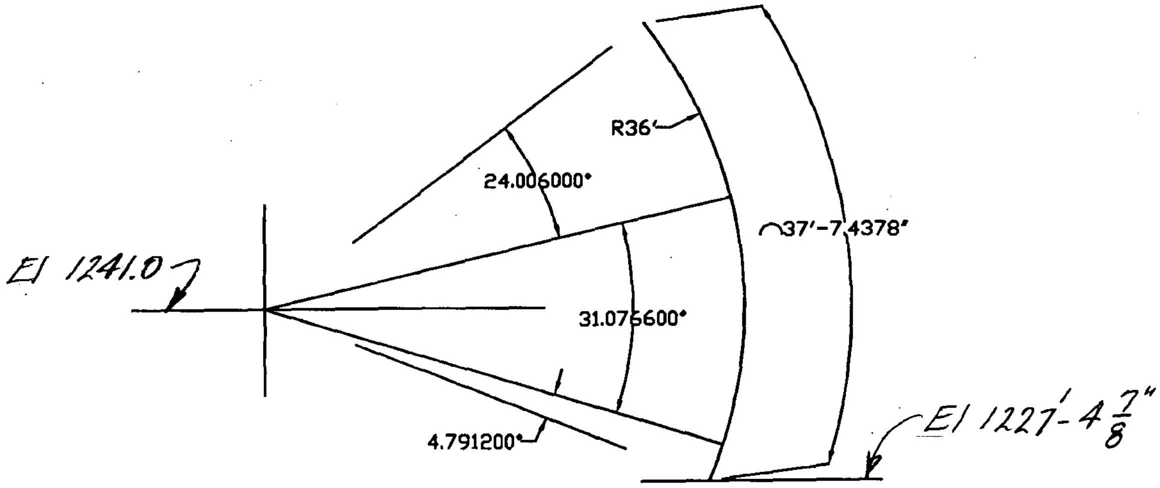
Total arc length of gate skin;

$$\ell = (3'\text{-}0\tfrac{1}{8}'')+(9'\text{-}9\tfrac{5}{16}'')+(1'\text{-}2'')+(8'\text{-}7'')+(10'\text{-}0\tfrac{7}{8}'')+(5'\text{-}0\tfrac{1}{8}'') = 37'\text{-}7\tfrac{7}{16}''$$

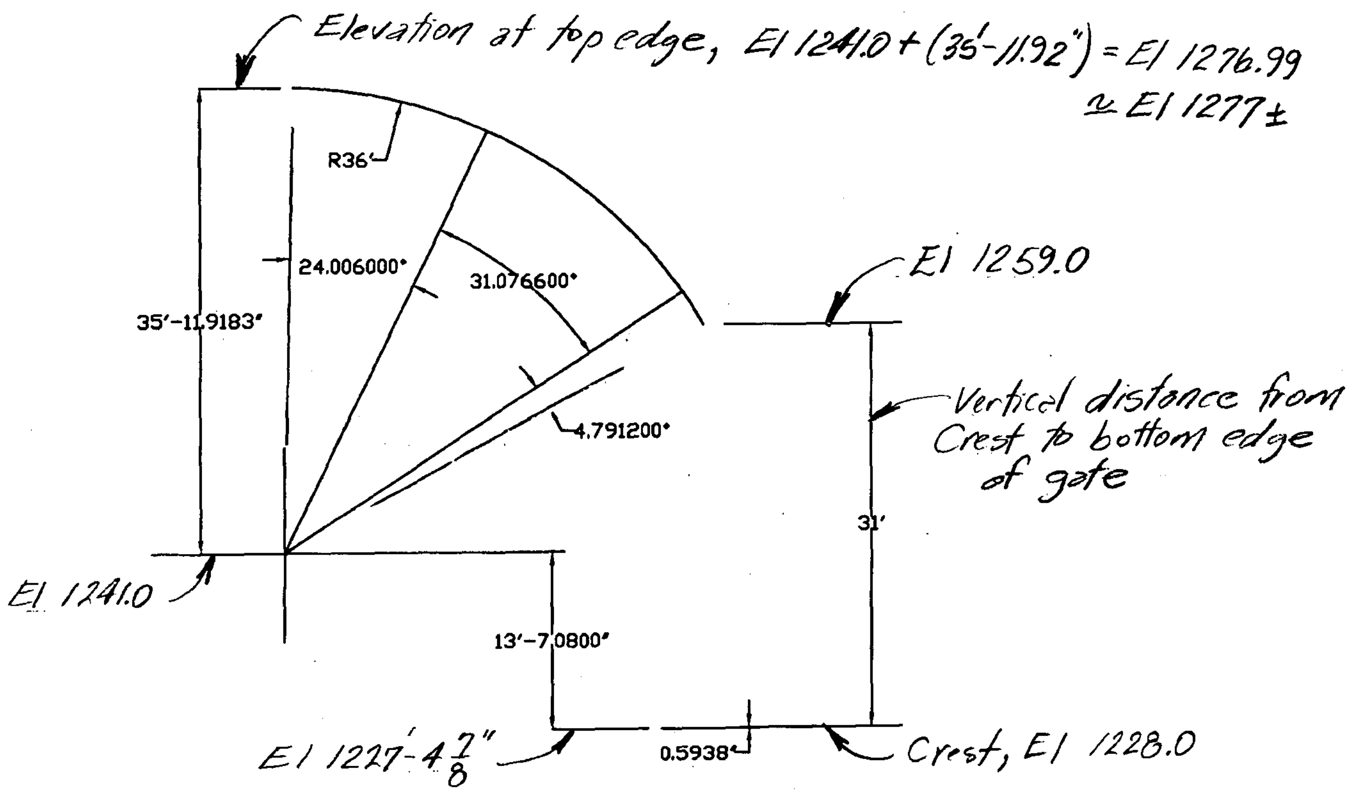
$$\theta = \frac{180\ell}{\pi r} = \frac{180(37'\text{-}7\frac{7}{16}'')}{\pi(36')} = \frac{180(37.6198')}{\pi(36')} = 59.8738°$$

$$\theta = 4.7912° + 31.0766° + 24.0058° = 59.8736°$$

6.3 Configuration of Spillway Gates - Maximum Open (Continued)



Gate Closed



Max Gate Open

SUBJECT Dam Rating Curve PROJECT Fort Patrick Henry

CDQ000020080010

COMPUTED BY JV Peyton DATE 10-30-08 CHECKED BY JB Mauter DATE

6.4 Overflow Parameter For Tainter Spillway Gate

Ref: 1. "Rating Curves for Flow Over Drum Gates," Joseph N. Bradley, Paper No. 2677, Transactions of the American Society of Civil Engineers, Vol. 119, pp. 403-433, 1954.

2. Attachment A6

3. TVA drawing 54N201 R1

* Determing Z_1 from 54N200 R1 A-A yields a slightly different result (Appendix A, page A3):

$Z_1 = El\ 1241.0 - (El\ 1227 - 4\tfrac{7}{8})$

$= 13'-7\tfrac{1}{8}''$

$Z_1 = 13.5937'$

Angle Subtended By Edges of Gate

$$\theta = \sin^{-1}\left(\frac{Z_2}{R}\right) + \sin^{-1}\left(\frac{Z_1}{R}\right)$$

$$Z_1 = (2'-10'') + (9'-7\tfrac{5}{16}'') + (1'-2'') = 13'-7\tfrac{5}{16}'' = 13.6094'^{*}$$

$$Z_2 = (8'-6'') + (9'-4'') + (4'-2'') = 22'-0'' = 22.0000'$$

$$\theta = \sin^{-1}\left(\frac{22.0'}{36.0'}\right) + \sin^{-1}\left(\frac{13.6094'}{36.0'}\right) = 37.6699^\circ + 22.2123^\circ = 59.8821^\circ$$

Angle From Horizontal Line Through Trunnion To Bottom Edge

$$\alpha = \sin^{-1}\left(\frac{Z}{R}\right) = \sin^{-1}\left(\frac{El\ 1259.0 - El\ 1241.0}{36'}\right) = \sin^{-1}\left(\frac{18'}{36'}\right)$$

$$\alpha = 30.0^\circ$$

Angle ϕ

$$y_0 = El\ 1276.99' - El\ 1241.0 = 35.99'$$

$$X_0 = R\cos(\theta - \alpha) = 36'\cos[59.8821^\circ - (-30.0^\circ)] = 0.0741'$$

$$\phi = \tan^{-1}\left(\frac{X_0}{y_0}\right) = \tan^{-1}\left(\frac{0.0741'}{35.99'}\right) = 0.12^\circ \simeq 0.0$$

SUBJECT Dam Rating Curve PROJECT Fort Patrick Henry

CDQ000020080010

COMPUTED BY JV Peyton DATE 10-31-08 CHECKED BY JB Mauter DATE

6.4 Overflow Parameter For Tainter Spillway Gate (Continued)

The overflow parameters for flow depth over the gate, $0 \le H \le 13'$ (El 1290 - El 1277) are taken from Figure 6 of "Rating Curves for Flow Over Drum Gates." See the following page.

Minimum flow; $\frac{H}{r} = 0 \Rightarrow C_g = 3.0 \pm$

Maximum flow; $\frac{H}{r} = \frac{13'}{36'} = 0.36 \Rightarrow 3.59 \pm$

Use $C_g = C_0 = 3.2$

6.4 Overflow Parameter For Tainter Spillway Gate (Continued)

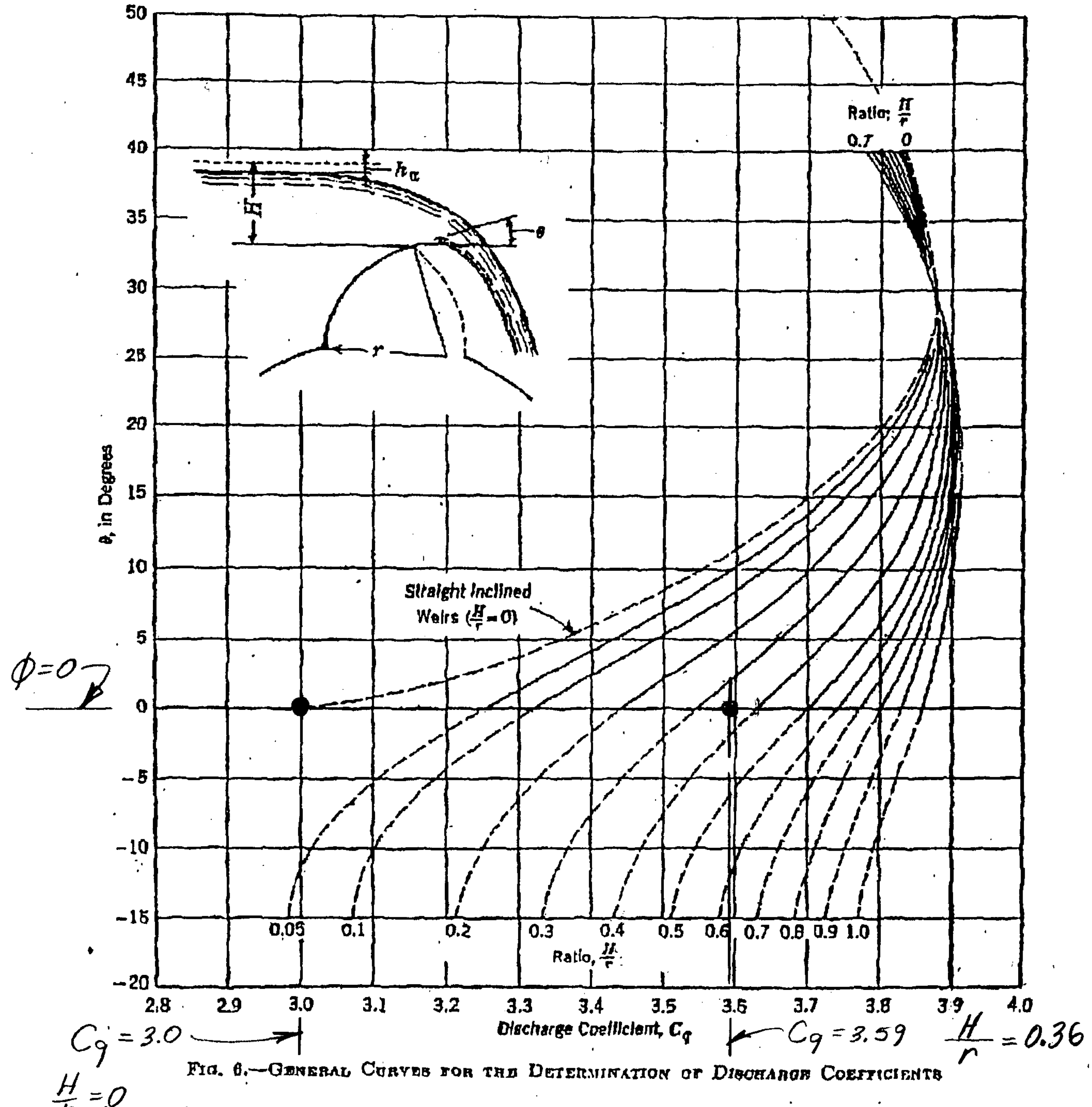


FIG. 6.—GENERAL CURVES FOR THE DETERMINATION OF DISCHARGE COEFFICIENTS

6.5 Tailwater Submergence Effect on Discharge

The effect of the tailwater submergence on the discharge is evaluated using Attachments 1, "Fort Patrick Henry Tailwater Rating," and Attachment 2, "Figure 252, Effects of downstream influences on flow over weir crests." Attachment 2 is from "Design of Small Dams," US Department of the Interior, Bureau of Reclamation, 2nd edition 1973, revised reprint 1977, page 380 (Reference 2.19). "Design of Small Dams" was published to provide safe practices for the design of small dams and is an industry accepted reference.

The maximum headwater elevation considered in this calculation is El 1290. The discharge calculated for headwater El 1290 is 325,290 cfs, Table 7.1 and Figure 7.1. Although the headwater rating curve provided in this calculation extends to the elevations noted, Section 5.0 of this calculation limits the applicability of this curve to the headwater elevation defined in Section 5.0.

From Attachment 1, Fort Patrick Henry Tailwater Rating, the tailwater elevation for the maximum discharge (325,290 cfs) is El 1258. This elevation is lower than the elevation of the top of the nonoverflow sections of the dam (El 1270), the elevation of the tops of the spillway piers (El 1272.42), the elevation of the top of the spillway gates when fully open (El 1277) and the elevation of the top of the powerhouse (El 1285). Therefore discharge over these features is not affected by the tailwater at El 1258.

The vertical distance from the crest to the downstream apron and the depth of flow in the downstream channel, as it relates to the headwater level, are the submergence factors identified in "Design of Small Dams," page 376, which alter the coefficient of discharge. The percent decrease in coefficient of discharge is estimated using Attachment 2 (Figure 252) as follows:

H_e = Headwater elevation minus crest elevation = 1290-1228 = 62'
h_d = Headwater elevation minus tailwater elevation = 1290-1258 = 32'
d = Depth of tailwater above apron = 1258-1182.5 = 75.5.'

The elevation of the apron, 1182.5, is shown by drawing 51N202 R3, Sections A-A & A1-A1 (Attachment A17).

The degree of submergence is:

$(h_d / H_e) = (32' / 62') = 0.52.$

The position of downstream apron is:

$[(h_d + d) / H_e] = [(32' + 75.5') / 62'] = 1.73.$

These ratios, degree of submergence and position of downstream apron, are plotted on Attachment 2. The decrease in coefficient of discharge shown is approximately 0.5 %. This is not a significant reduction and is neglected.

6.6 Turbine Discharge

The turbine generators are assumed to operate until the tailwater reaches Elevation 1237, the elevation of the switchyard and the elevation of the doorways to the powerhouse. References 2.17 and 2.18 provide the turbine discharge based on the gross head for the dam. The gross head is the difference between the headwater elevation and the tailwater elevation. The lowest gross head shown on References 2.17 and 2.18 is 55 feet. The turbine discharge for lower values of gross head is determined by extrapolation. The following table summaries the iterative steps to determine the turbine discharge for a range of headwater values.

HW	Spillway Discharge cfs	Estimated Turbine Discharge cfs	Estimated Total Discharge cfs	TW	Gross Head	Turbine Discharge For 33' Gross Head	Total Discharge cfs
1240	24837	9000	34000	1208	32	8000	32837
1250	65686	9000	75000	1217	33	8000	73686
1260	121847	9000	131000	1227	33	8000	129847
1270	164558	9000	174000	1237	33	8000	172558

The iteration to determine the turbine discharge is as follows:

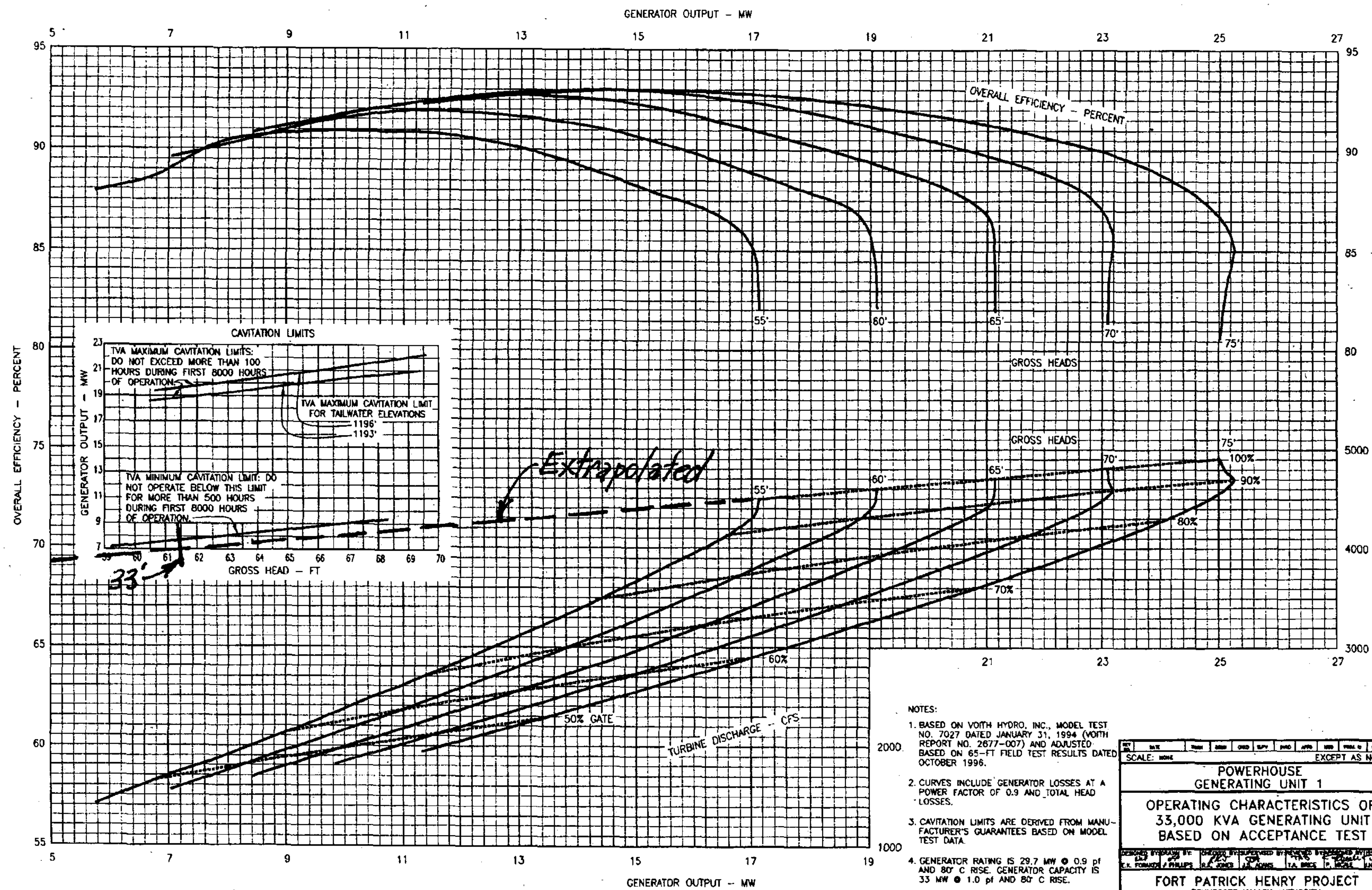
1. The spillway discharge for the headwater elevations 1240, 1250, 1260 and 1270 are taken from Table 7.1, page 27.
2. The tailwater elevations for headwater elevations 1240, 1250, 1260 and 1270 are determined from Attachment 1-1, the tailwater rating curve, for the Estimated Total Discharge.
3. The gross head (HW-TW) for the headwater elevations 1240, 1250, 1260 and 1270 are calculated. A gross head of 33' is used to estimate the turbine discharge for all the elevations.
4. The turbine discharge for 33' gross head is taken from drawings 47K909 R0 and 47K910 R0, references 2.17 and 2.18.
5. Finally, the total discharge is the sum of the spillway discharge and the turbine discharge for 33' gross head.

The gross head of 33' for all headwater elevations and the rounding of the turbine discharge don't significantly affect the result since the turbine discharge is a small percentage of the total discharge expected.

The turbine discharge continues until the tailwater reaches elevation 1237, the elevation at which the switchyard and powerhouse are flooded. Once stopped, the turbines are not expected to be restarted immediately when the tailwater drops below elevation 1237. Due to flooding of the powerhouse and switchyard the turbines may not operate for several days. To consider both rising and falling headwater, Table 7.1 lists the total discharge for the dam including turbine discharge and the total discharge for the dam without turbine discharge. Figure 7.1 is the rating curve including turbine discharge and Figure 7.2 is the rating curve without turbine discharge included.

Calculation No. CDQ0000200810

Prepared: JVPeyton 12-2-08 Checked: JBMauter



NOTES:

1. BASED ON VOITH HYDRO, INC., MODEL TEST NO. 7027 DATED JANUARY 31, 1994 (VOITH REPORT NO. 2677-007) AND ADJUSTED BASED ON 65-FT FIELD TEST RESULTS DATED OCTOBER 1996.
2. CURVES INCLUDE GENERATOR LOSSES AT A POWER FACTOR OF 0.9 AND TOTAL HEAD LOSSES.
3. CAVITATION LIMITS ARE DERIVED FROM MANUFACTURER'S GUARANTEES BASED ON MODEL TEST DATA.
4. GENERATOR RATING IS 29.7 MW @ 0.9 pf AND 80° C RISE. GENERATOR CAPACITY IS 33 MW @ 1.0 pf AND 80° C RISE.
5. THIS DRAWING SUPERSEDES DRAWING NOS. 47K904 AND 47K905.

SCALE: NONE EXCEPT AS NOTED

POWERHOUSE
GENERATING UNIT 1

OPERATING CHARACTERISTICS OF 33,000 KVA GENERATING UNIT BASED ON ACCEPTANCE TEST

DESIGNED BY: E.K. FORAKER; DRAWN BY: PHILLIPS; CHECKED BY: R.K. JONES; SUPERVISED BY: J.E. ADAMS; REVIEWED BY: T.A. BRICE; APPROVED BY: P. MCALE; ISSUED BY: J.K. COLSON

FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
FOSSIL AND HYDRO ENGINEERING

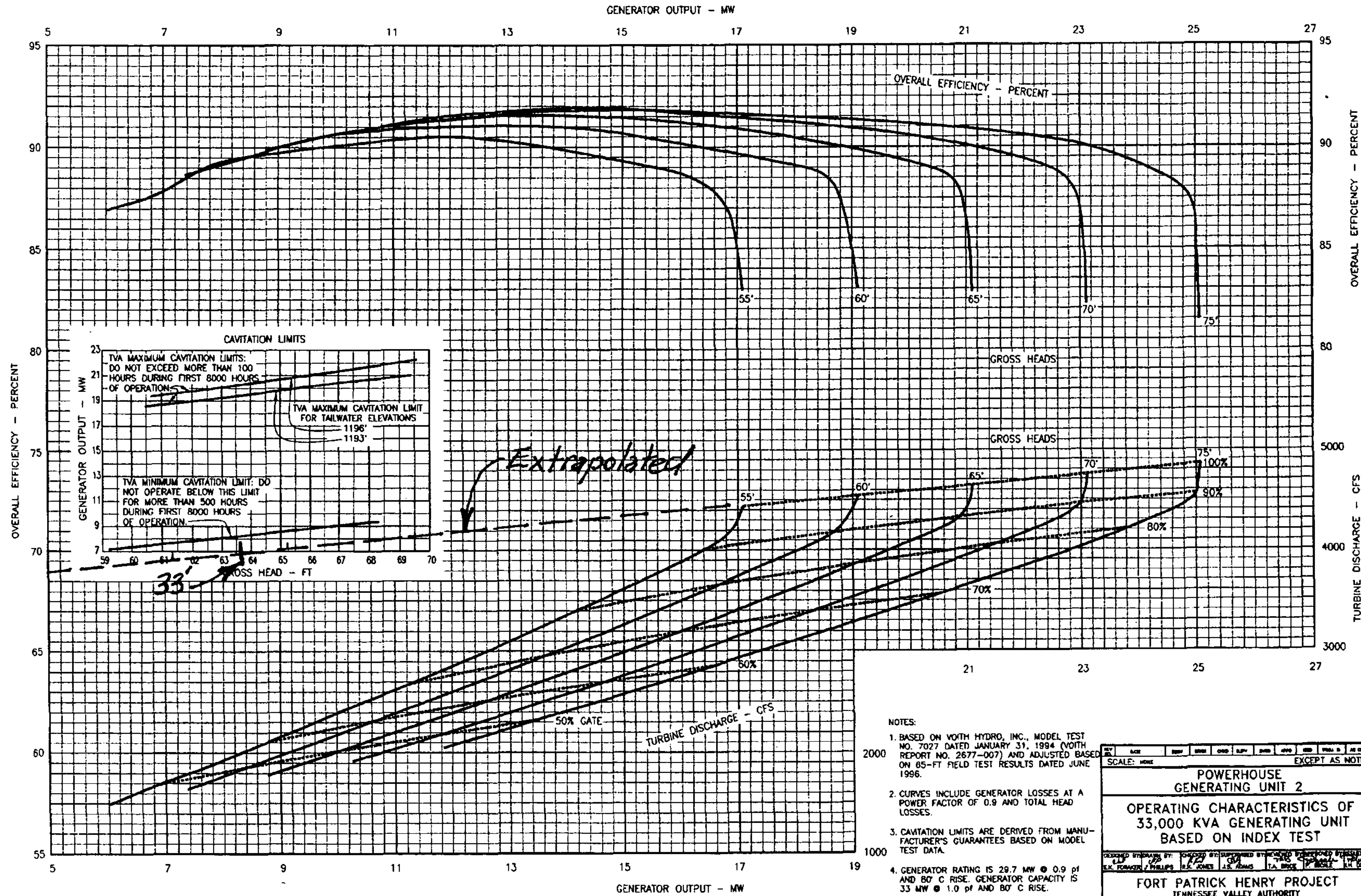
AUTOCAD R12 | DATE 12-20-?? | 32 | M | 47K909 | R0

ISSUED BY:

CAD SYSTEM DRAWING DO NOT ALTER MANUALLY

DRAWING PLOT FACTOR: 1=1
INSERTED DRAWING: X=1,Y=1.13

32 M 47K910



NOTES:

1. BASED ON VOITH HYDRO, INC., MODEL TEST NO. 7027 DATED JANUARY 31, 1994 (VOITH REPORT NO. 2677-007) AND ADJUSTED BASED ON 65-FT FIELD TEST RESULTS DATED JUNE 1996.
2. CURVES INCLUDE GENERATOR LOSSES AT A POWER FACTOR OF 0.9 AND TOTAL HEAD LOSSES.
3. CAVITATION LIMITS ARE DERIVED FROM MANUFACTURER'S GUARANTEES BASED ON MODEL TEST DATA.
4. GENERATOR RATING IS 29.7 MW @ 0.9 pf AND 80° C RISE. GENERATOR CAPACITY IS 33 MW @ 1.0 pf AND 80° C RISE.
5. THIS DRAWING SUPERSEDES DRAWING NOS. 47K904 & 47K905.

SCALE: NONE EXCEPT AS NOTED

POWERHOUSE
GENERATING UNIT 2

OPERATING CHARACTERISTICS OF 33,000 KVA GENERATING UNIT BASED ON INDEX TEST

FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
FOSSIL AND HYDRO ENGINEERING

AUTOCAD R12 | 32 | M | 47K910 | R0

CAD SYSTEM DRAWING
DO NOT ALTER MANUALLY

7.0 Results/Conclusions

The headwater rating results are tabulated as total discharge in cubic feet per second (cfs) vs. headwater elevation in feet in Table 7.1. The headwater rating curve is plotted in Figure 7.1 and Figure 7.2.

As discussed in Section 5.0, the dam (headwater) rating curves provided in Figures 7.1 and 7.2 and tabulated in Table 7.1 are limited in applicability to headwater elevations no greater than 1288.0 feet.

Table 7.1

Dam Rating Curve

For 0 ≤ Hc ≤ 37.49: $C_f = 2.8+0.08548Hc-0.003963Hc^2+0.0001039Hc^3-0.0000009857Hc^4$

For 38 ≤ Hc ≤ 62: C_g is given by Attachments A11 and A12.

g = 32.2 ft/s²

Spillway Parameters

L = 175 feet

Z_c = 1228 feet

G_n = 31.540 feet

H_{mp} = 15.375 feet

Overtopping Flows

	Spillway Gate	P-house	Nonover B=12	Nonover B=26.25	Pier
C_f =	3.20	2.65	3.00	2.74	2.68
Z_c =	1277	1285	1270	1270	1272.42
L =	175.0	151.5	241.5	17.5	39.0

HW feet	Total Discharge, Q: Including Turbine Discharge 1000 cfs	Total Discharge, Q: Without Turbine Discharge 1000 cfs	feet H_c	Spillway C_f | C_g	Spillway cfs Q_f | Q_g	Spillway Gate	P-house	Nonover B=12	Nonover B=26.25	Pier	Turbine Discharge
1228	**8.00**	**0.00**	0	2.800	0						8000
1230	**9.46**	**1.46**	2	2.956	1463						8000
1232	**12.32**	**4.32**	4	3.085	4319						8000
1234	**16.21**	**8.21**	6	3.191	8208						8000
1236	**20.99**	**12.99**	8	3.279	12986						8000
1238	**26.55**	**18.55**	10	3.353	18553						8000
1240	**32.84**	**24.84**	12	3.414	24837						8000
1242	**39.78**	**31.78**	14	3.467	31783						8000
1244	**47.36**	**39.36**	16	3.514	39357						8000
1246	**55.54**	**47.54**	18	3.557	47536						8000
1248	**64.31**	**56.31**	20	3.598	56311						8000
1250	**73.69**	**65.69**	22	3.637	65686						8000
1252	**83.67**	**75.67**	24	3.678	75668						8000
1254	**94.27**	**86.27**	26	3.718	86268						8000
1256	**105.50**	**97.50**	28	3.760	97498						8000
1257	**111.35**	**103.35**	29	3.782	103350						8000
1258	**117.36**	**109.36**	30	3.803	109361						8000
1260	**129.85**	**121.85**	32	3.846	121847						8000
1262	**142.93**	**134.93**	34	3.889	134931						8000
1264	**156.56**	**148.56**	36	3.930	148560						8000
1265	**163.56**	**155.56**	37	3.950	155556						8000
1265.49	**167.02**	**159.02**	37.49	3.959	159022						8000
1266	**167.92**	**159.92**	38	0.759	159916						8000
1267	**169.31**	**161.31**	39	0.749	161312						8000
1268	**170.55**	**162.55**	40	0.740	162546						8000
1269	**171.63**	**163.63**	41	0.730	163626						8000
1270	**172.56**	**164.56**	42	0.720	164558			0	0		8000
1271	**168.08**	**168.08**	43	0.719	167310			725	48		
1272	**172.18**	**172.18**	44	0.717	169995			2049	136	0	
1273	**176.68**	**176.68**	45	0.716	172618			3765	249	46	
1274	**181.57**	**181.57**	46	0.715	175180			5796	384	208	
1275	**186.75**	**186.75**	47	0.713	177685			8100	536	433	
1276	**192.20**	**192.20**	48	0.712	180135			10648	705	708	
1277	**198.41**	**198.41**	49	0.713	183080	0		13418	888	1024	
1278	**205.41**	**205.41**	50	0.714	185991	560		16394	1085	1378	
1279	**213.07**	**213.07**	51	0.714	188869	1584		19562	1295	1764	
1280	**221.23**	**221.23**	52	0.715	191716	2910		22911	1516	2181	
1281	**229.82**	**229.82**	53	0.716	194533	4480		26432	1749	2627	
1282	**238.79**	**238.79**	54	0.717	197322	6261		30117	1993	3099	
1283	**248.12**	**248.12**	55	0.718	200083	8230		33959	2248	3597	
1284	**257.77**	**257.77**	56	0.718	202818	10371		37952	2512	4119	
1285	**267.74**	**267.74**	57	0.719	205527	12671	0	42090	2786	4664	
1286	**278.40**	**278.40**	58	0.720	208213	15120	401	46368	3069	5231	
1287	**289.45**	**289.45**	59	0.720	210641	17709	1136	50782	3361	5819	
1288	**300.98**	**300.98**	60	0.720	213042	20430	2086	55328	3662	6428	
1289	**312.94**	**312.94**	61	0.720	215415	23279	3212	60002	3971	7056	
1290	**325.29**	**325.29**	62	0.720	217763	26248	4489	64801	4289	7704	

Figure 7.1
Fort Patrick Henry Rating Curve Including Turbine Discharge

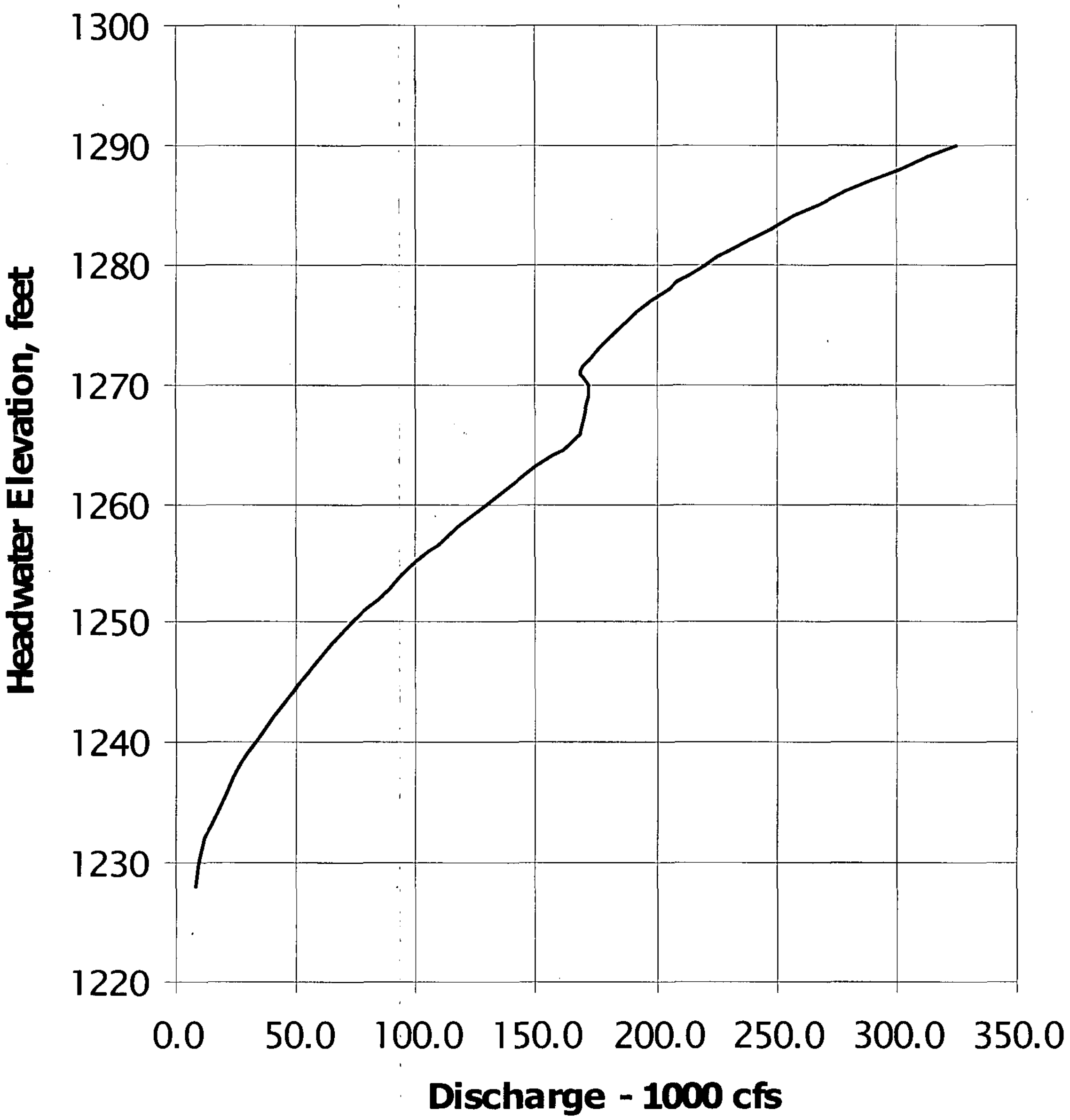
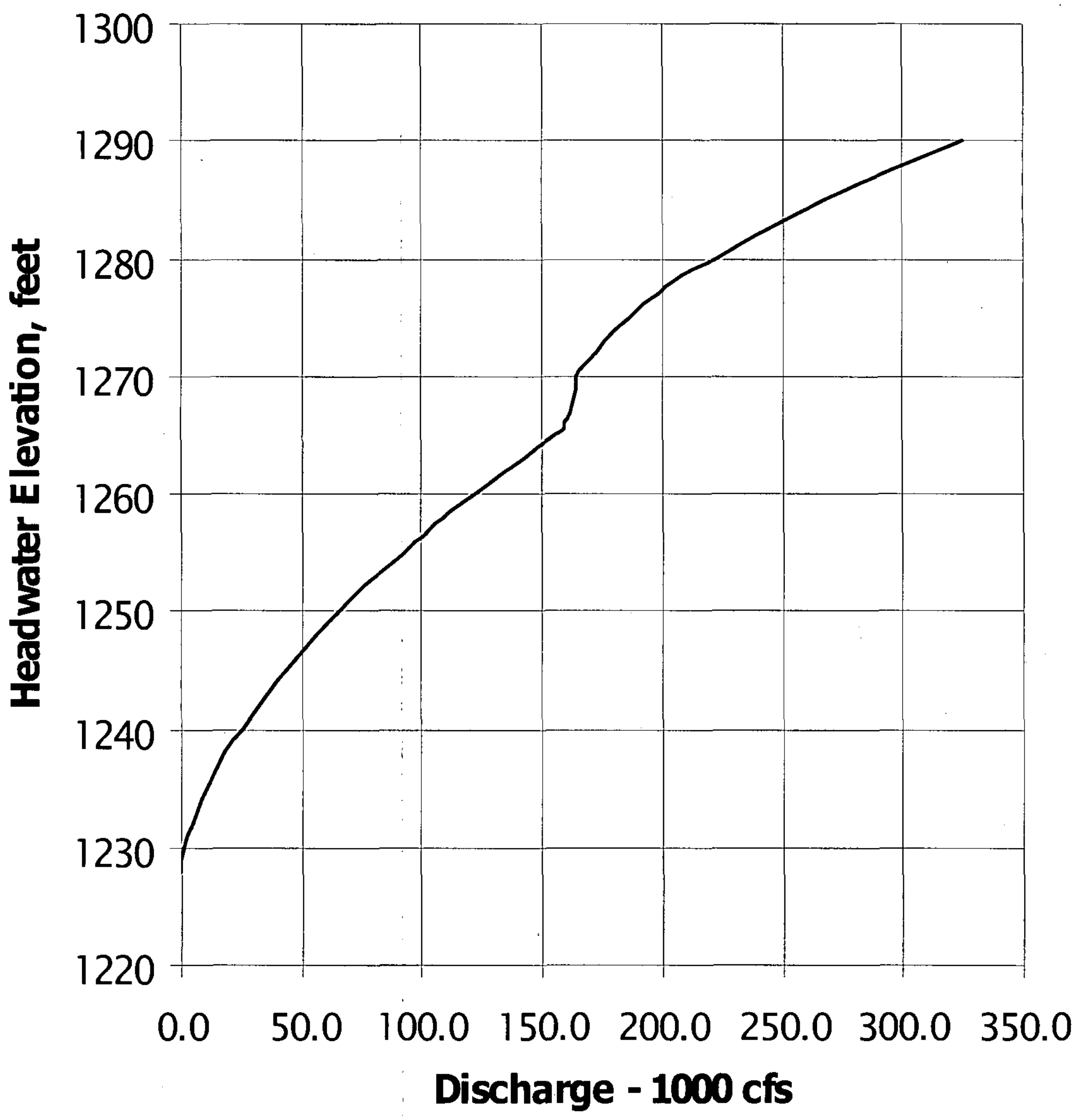


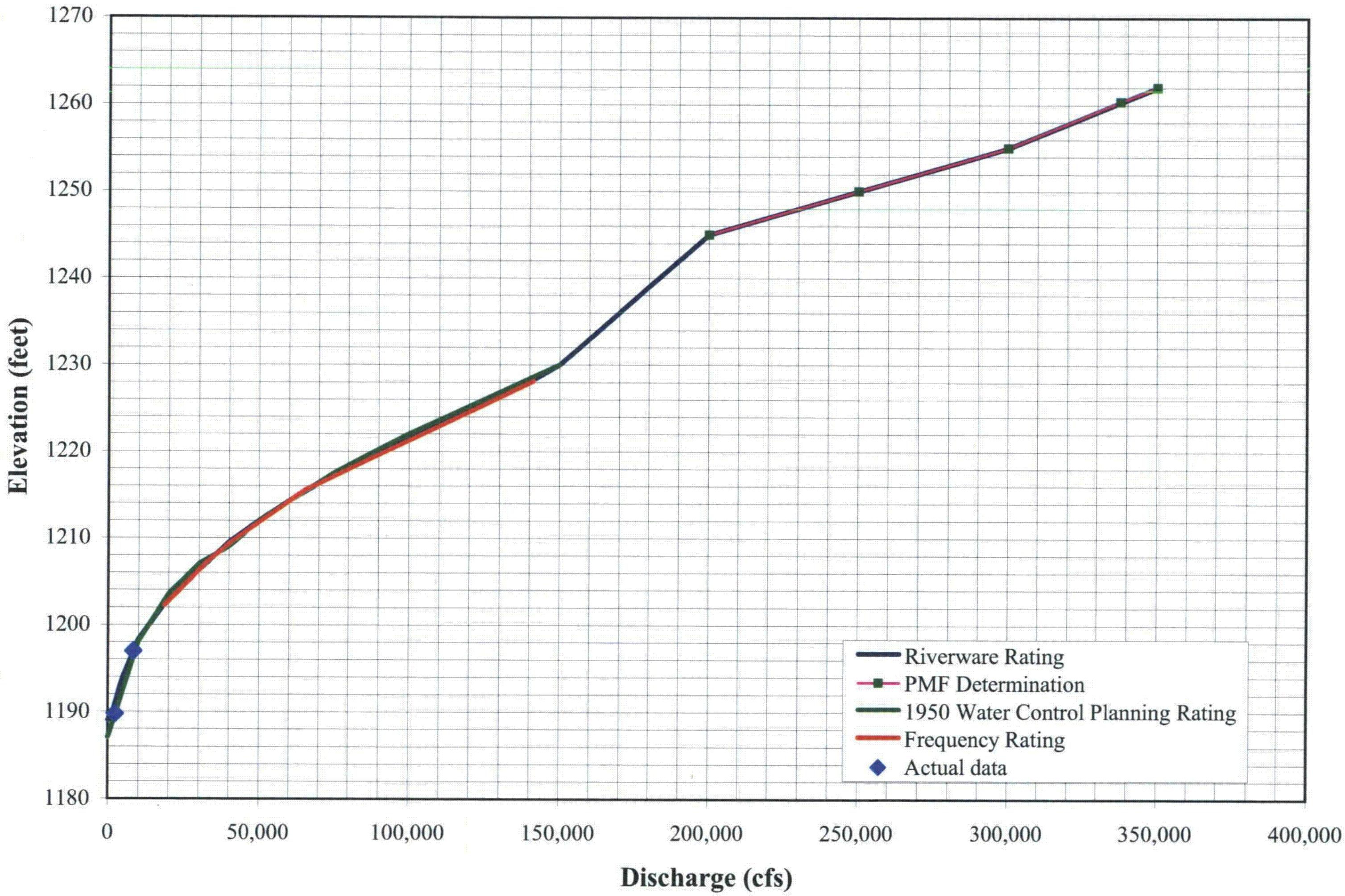
Figure 7.2
Fort Patrick Henry Rating Curve Without Turbine Discharge



Attachments

Attachment 1-1

Fort Patrick Henry Tailwater Rating



Source: TVA River Operations
Flood Risk Section

Attachment 1-2

Fort Patrick Henry Tailwater Rating

Q*1000	Q	Elevation
0	0	1189
0.8	800	1189
4	4,000	1193
5	5,000	1194
10	10,000	1198.25
20	20,000	1203
30	30,000	1206.25
40	40,000	1209.5
50	50,000	1212
60	60,000	1214.25
70	70,000	1216.25
80	80,000	1218.2
90	90,000	1220
100	100,000	1221.8
110	110,000	1223.4
120	120,000	1225
130	130,000	1226.5
140	140,000	1228
150	150,000	1230
200	200,000	1245
250	250,000	1250
300	300,000	1255
350	350,000	1262

Water Control Planning 1950

Dicharge	Elevation
0	1187
10,000	1198
20,000	1203.5
30,000	1207
40,000	1209
50,000	1212
75,000	1217.5
100,000	1222
125,000	1226
150,000	1230

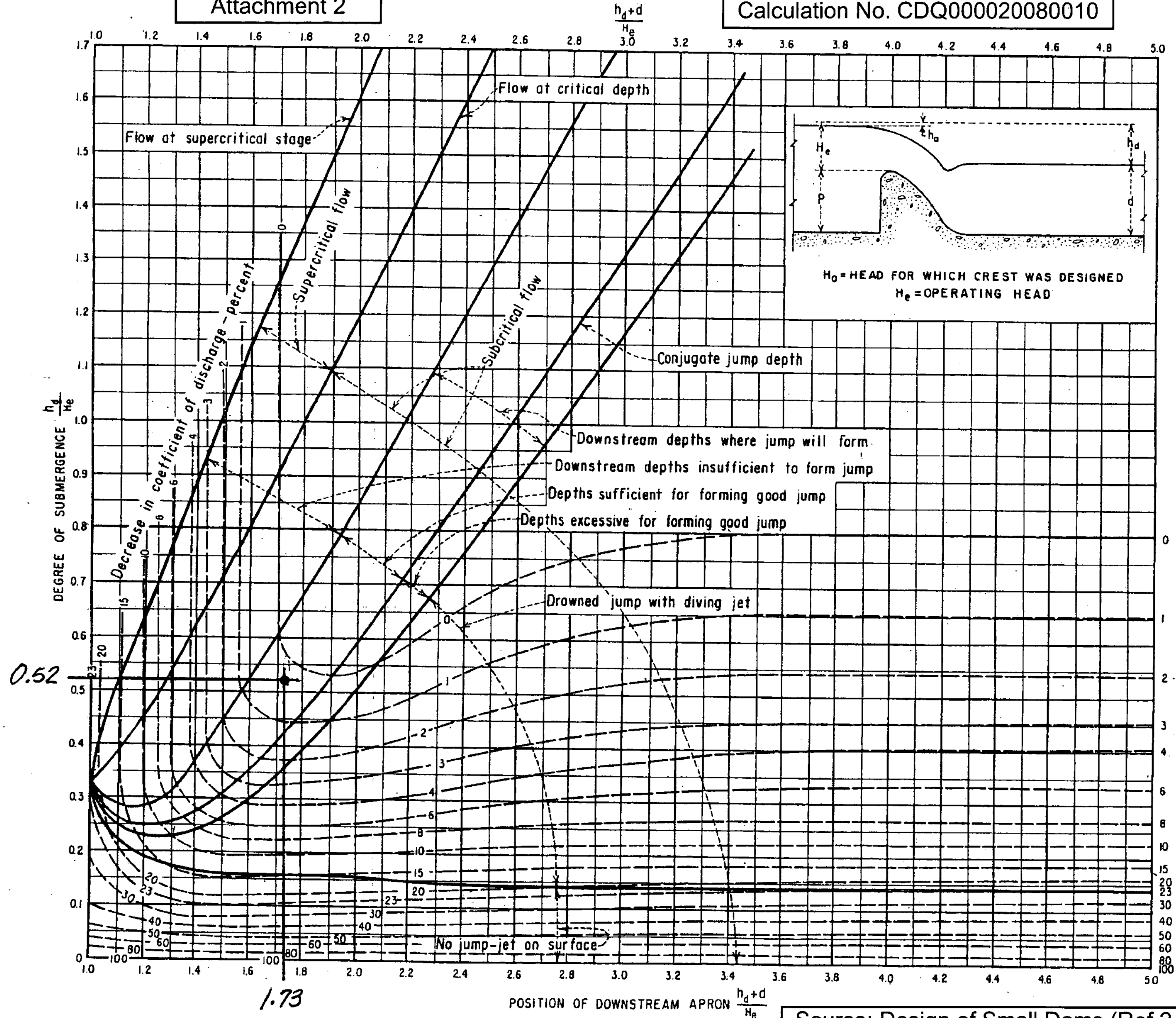
Frequency Floods

Dicharge	Elevation	Freq
18,600	1202.20	10
33,000	1207.30	50
41,000	1209.60	100
65,500	1215.50	500
141,400	1228.1	MPF
200,000	1245	
250,000	1250	
300,000	1255	
337,800	1260.36	**PMF**
350,000	1262	

Actual data

2400	1189.7
8400	1196.9

Source: TVA River Operations
Flood Risk Section



Source: Design of Small Dams (Ref 2.19), page 380

Figure 252. **Effects of downstream influences on flow over weir crests. 288-D-2412.**

Appendix A

Appendix A: Spillway Discharge Coefficients and Submergence Factors for Fort Patrick Henry Dam from 1:15 and 1:112.5 Scale Model Test Data

TVA has model test data describing the relationships between discharge, headwater, tailwater, and gate opening for most of its spillways. These data, which are the basis for the spillway discharge tables developed for each dam, are used in the headwater rating curve calculations. Use of reference book discharge coefficients for standard crests would result in inferior results because TVA's spillway crests are not standard.

Fort Patrick Henry Dam has five spillway bays, each controlled by a radial (tainter) gate as illustrated in Attachment A1. For headwater rating curve calculations the gates are assumed to be open to their maximum open position as specified in the Spillway Gate Arrangements table in Reference A1 and included as Attachment A2. As shown in this table, the maximum opening corresponds to reading "31" on the gate position indicators for the spillway. As referred to in Attachment A3 (from Reference A2), the indicating dials for the spillway gates at Fort Patrick Henry were specially fabricated to indicate actual vertical opening in feet. Thus, the vertical distance, V, between the bottom lip of a raised spillway gate and the spillway crest is 31 feet for gate position indicator reading "31."

Reference A3 is a comprehensive report on the hydraulic model studies conducted for Fort Patrick Henry Dam. Attachment A4 is a copy of Chapter 8, "Spillway Operations" from that report. Test data from a 1:112.5 scale model were taken to establish the free discharge rating for the spillway crest. Test data from a 1:15 scale model were taken to establish the orifice discharge rating parameters for different gate openings. Data were collected for twelve different gate openings varying from V = 0.5 feet to V = 25 feet. Data were not collected for gate openings as large as V = 31 feet, however, because under normal operating conditions the overflowing nappe will never touch the bottom of a gate open this far. But under the PMF conditions considered for the headwater rating curves the nappe will touch the gate in this position. Consequently, the data for gate openings V = 25, 21, 17, 13, and 10 feet are used here to estimate orifice flow discharge characteristics for V = 31 feet.

A.1 References

A1. "Fort Patrick Henry Dam Spillway Discharge Tables," River Operations, Tennessee Valley Authority, March, 1999, EDMS Accession No. L58081211803.

A2. TVA Files, binder "Fort Patrick Henry, Spillway Rating, Model Scales - 1:112.5 & 1:50.

A3. "Fort Patrick Henry Project Hydraulic Model Studies, Tennessee Valley Authority, Technical Monograph No. 87, Knoxville, Tennessee, 1960, TVA Research Library call no. 999.6278 T2985fo.

A4. "Hydraulic Design Criteria," USACE (U. S. Army Engineer Waterways Experiment Station), Eighteenth issue, Vicksburg, MS, 1988

A5. TVA drawing no: 54N200, R1 (Attachment A7 and Electronic Attachment A16)

A6. TVA drawing no: 51N202, R3 (Attachments A8 and Electronic Attachment A17)

A.2 Discharge Equations

Attachment A5 is a definition sketch for flow over the Fort Patrick Henry Dam spillway. Free discharge occurs for headwater elevations below the elevation at which the overflowing nappe first touches the bottom lip of the gate, or $H_c \le H_{Lmin}$, and is computed using a weir equation (e.g., Reference A4, Sheet 711):

$$Q_f = C_f L H_c^{1.5} \qquad \text{(A1)}$$

in which Q_f = free discharge (cfs), C_f = free discharge coefficient ($ft^{0.5}/s$ -- varies with H_c), L = length of overflowing section (ft), H_c = head on crest (ft) = HW - Z_c, HW = headwater elevation (ft), and Z_c = top, or crest, elevation of overflowing section (ft).

For headwater elevations above the elevation at which the nappe touches the gate lip, or $H_c > H_{Lmin}$, orifice flow occurs and is computed from (e.g., Reference A4)

$$Q_g = C_g G_n L \sqrt{2g(H_c - H_{mp})} \qquad \text{(A2)}$$

in which Q_g = orifice discharge (cfs), C_g = orifice discharge coefficient (dimensionless -- varies with gate opening and H_c), G_n = effective gate opening = minimum distance between the gate lip and the crest (ft), g = acceleration of gravity (32.2 ft/s^2 -- common knowledge, Reference A4, sheet. 000-1 for example), and H_{mp} = vertical distance between the mid-point of G_n and the crest.

A.3 Model Test Data

The 1:112.5 scale and 1:15 scale Fort Patrick Henry model test data (Reference A3) are used to determine

- $C_f(H_c)$
- H_{Lmin} and $C_g(H_c)$ for V = 31 ft.

The model test data, scaled to prototype values, for both orifice and free discharge are plotted in Attachment A4-4 and tabulated in Attachment A4-5. These data are used below to estimate H_{Lmin} and $C_g(H_c)$ for V = 31 feet and to establish a curve fit for $C_f(H_c)$.

A.4 Geometry

Parameters G_n, H_{mp}, Z_o (gate overflow elevation), and β (angle plotted against discharge coefficient in Reference A4) are computed from crest and gate geometry as described in Attachment A6. Table A1 gives the values of these parameters for V = 10, 13, 17, 21, 25, and 31 feet.

Table A1: Geometrical Parameters for Relevant Gate Openings

V, feet	G_n, feet	H_{mp}, feet	Z_o, feet	β, deg.
10	10.139	4.951	1270.53	80.1
13	13.118	6.462	1272.14	85.4
17	17.123	8.464	1273.95	91.9
21	21.165	10.456	1275.38	97.9
25	25.255	12.436	1276.38	103.7
31	31.540	15.375	1277.00	112.2

As an example, the procedure for computing the geometrical parameters for V = 31 feet is given here. From Attachment A7 (Reference A5),

- R = 36 feet
- Z_c = 1228 feet
- Z_{tr} = 1241 feet
- z_1 = 1241 - 1227.406 = 13.594 feet
- z_2 =1263 - 1241 = 22.0 feet

where the parameters are defined in Attachment A6-2. Referring to Attachment A6:

Angle θ: $\theta = \sin^{-1}\left(\frac{22}{36}\right) + \sin^{-1}\left(\frac{13.594}{36}\right) = 59.856°$

Angle α: $\alpha = \tan^{-1}\left(\frac{1241-1228-31}{\sqrt{36^2-(1241-1228-31)^2}}\right) = -30.0°$

Overflow elevation Z_o: $Z_o = 1241 + 36\sin[59.856-(-30)] = 1277.00$ feet

Gate lip y-coordinate: $y_\ell = 1241-1228-31 = -18.0$ feet

Gate lip x-coordinate: $x_\ell = \sqrt{36^2-(-18)^2} = 31.177$ feet

From Attachment A8 (Reference A6), the equation for the spillway crest segment downstream from the valve seat is:

$$y_s^* = f(x_s^*) = 0.592 + \frac{x_s^*-5.333}{5} + \frac{(x_s^*-5.333)^2}{133} \quad \text{for } x_s^* \geq 5.333$$

in which $y_s^* = y_s - 13$ and $x_s^* = 38.75 - x_s$. In terms of y_s and x_s:

$$y_s = f(x_s) = 13.592 - \frac{x_s-33.417}{5} + \frac{(x_s-33.417)^2}{133} \quad \text{for} \quad x_s \leq 33.417 \text{ feet}$$

and

$$\frac{dy_s}{dx_s} = -0.70251 + \frac{x_s}{66.5}$$

To get effective gate opening, G_n, solve the following equation for x_{sn}:

$$x_{sn} - 31.177 + \left[13.592 - \frac{x_s-33.417}{5} + \frac{(x_s-33.417)^2}{133} - (-18)\right]\left[-0.70251 + \frac{x_{sn}}{66.5}\right] = 0$$

Solution:

- x_{sn} = 36.129 feet (by iteration), but crest equation was valid only for x_s <= 33.417 feet.

From Attachment A8 (Reference A6), the equation for the spillway crest segment between the crest and the valve seat is:

$$y_s^* = f(x_s^*) = \frac{(x_s^*)^{1.8}}{34.378} \quad \text{for } 0 \leq x_s^* \leq 5.333$$

In terms of y_s and x_s:

$$y_s = f(x_s) = 13 + \frac{(38.75 - x_s)^{1.8}}{34.378} \quad \text{for } 33.417 \le x_s \le 38.75$$

and

$$\frac{dy_s}{dx_s} = -\frac{1.8(38.75 - x_s)^{0.8}}{34.378}$$

The equation for x_{sn} is now:

$$x_{sn} - 31.177 + \left[13 + \frac{(38.75 - x_{sn})^{1.8}}{34.378} - (-18)\right]\left[-\frac{1.8(38.75 - x_{sn})^{0.8}}{34.378}\right] = 0$$

Solution:

- x_{sn} = 35.440 feet (by iteration), which is in the valid range for the crest equation used.
- $y_{sn} = 13+(38.75 - 35.44)^{1.8}/34.378 = 13.251$
- $G_n = \sqrt{(35.440 - 31.177)^2 + (13.251 - (-18))^2} = 31.540$ feet

and

- $H_{mp} = 31-[13.251 - (-18)]/2 = 15.375$ feet
- $\beta = \frac{\pi}{2} - \tan^{-1}\left(\frac{-18}{31.177}\right) - \tan^{-1}\left(\frac{35.44 - 31.177}{13.251 - (-18)}\right) = 90 - (-30.0) - 7.77 = 112.2°$

A.5 Determination of $H_{Lmin}(V)$

Values for H_{Lmin} are not listed in Attachment A4-5 but are indicated graphically in Attachment A4-4, as the points at which the curves for different gate openings meet the free discharge curve (gates raised above water surface). Values scaled from this plot for gate openings 25, 21, 17, 13, 10, 8, and 6.5 feet are indicated on the plot. Attachment A9 lists these values and fits a straight line to the data (spreadsheet included as Electronic Attachment A15). A value of H_{Lmin} for V = 31 feet is established by using the straight-line fit to extrapolate the data. The following is used for the headwater rating curve calculations:

H_{Lmin} = 37.49 feet for V = 31 feet.

A.6 Determination of $C_f(H_c)$

Attachment A10 shows the 1:112.5 scale model test data for free discharge from Attachment A4-5 and a polynomial curve fit to the data:

$$C_f = 2.8 + 0.08548H_c - 0.003963H_c^2 + 1.039\text{x}10^{-4}H_c^3 - 9.875\text{x}10^{-7}H_c^4 \qquad \text{(A3)}$$

Equation A3 is used to compute $C_f(H_c)$ for the headwater rating curve calculations. Values of C_f are needed up to $H_c = H_{Lmin}$, or 37.5 feet, which is a few feet higher than the data range. The plot in Attachment A10 shows that Equation A3 can be used to estimate C_f for H_c values slightly above the data range.

A.7 Determination of $C_g(H_c)$ for V = 31 feet

Attachment A11 shows the calculations and results for extrapolating $C_g(H_c)$ for V = 31 feet from the model data for other gate openings. The first column in Attachment A11 indicates the data for which $H_c = H_{Lmin}$, at which H_c is just high enough to touch the bottom of the gate. The discharge indicated for V = 31 feet at $H_c = H_{Lmin}$ is the free discharge computed using $C_f(H_c)$ from equation A3. The first three numerical columns list the model data (scaled to prototype dimensions) for V = 10, 13, 17, 21, and 25 feet as listed in Attachment A4-5. The rows that do not include values of discharge, Q, were added to extrapolate the data. The next two columns after the model data list prototype geometrical parameters. The last numerical column lists the C_g values computed from the data. Values that were "estimated" for extrapolation purposes are labeled as such to the right of the C_g column.

Attachment A12 shows C_g plotted against H_c for all gate openings. All curves include extrapolated segments to H_c = 60 feet. The extrapolations were guided by plotting the C_g values estimated for H_c=60 feet against angle β on Hydraulic Design Chart 311-1 from Reference A4. This chart, which shows U.S. Army Corps of Engineers data for tainter gates on standard crests, is included as Attachment A13 with the Fort Patrick Henry data added. The value of X/H_d for Fort Patrick Henry is 0.15 (X = 5.333 feet, Attachment A7, and H_d = 35, Attachment A14). Presumably because TVA's spillway crests are not standard, TVA data always lie to the left of the suggested design curves on this chart.

The estimated curve for V = 31 feet starts with the value for $H_c = H_{Lmin}$ and runs approximately parallel to the curve for V = 25 feet. Given the absence of data, this extrapolated line segment fit for $C_g(H_c)$ at V = 31 feet is used for the headwater rating calculations. Table A2 lists the points describing the extrapolated relationship.

Table A2: Points Defining Extrapolated Curve for $C_g(H_c)$ at V = 31 feet.

H_c, feet	C_g
37.5	0.764
42	0.720
48	0.712
58	0.720
60	0.720

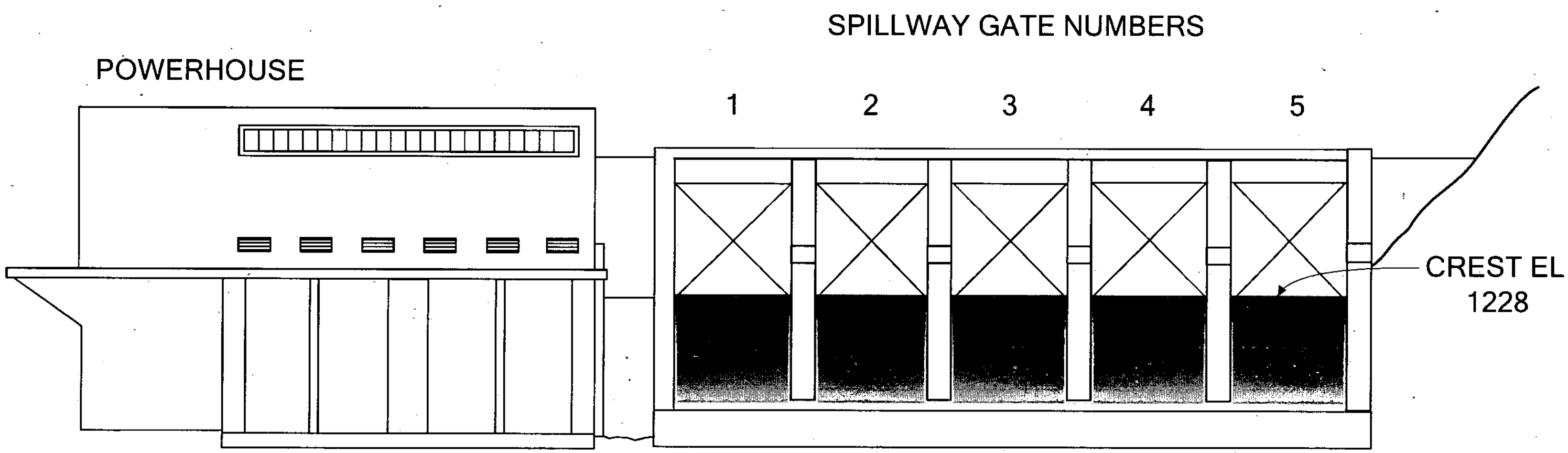
Appendix A
Attachments

Attachment A1

Source: Reference A1

FORT PATRICK HENRY DAM

LOCATION OF SPILLWAY GATES



DOWNSTREAM ELEVATION

FORT PATRICK HENRY DAM

SPILLWAY GATE ARRANGEMENTS

Arrange-ment Number	Gate Number				
	1	2	3	4	5
1	-	-	-	C	-
2	-	C	-	C	-
3	-	C	-	C	C
4	C	C	-	C	C
5	C	C	C	C	C
6	C	C	C	0.5	C
7	C	0.5	C	0.5	C
8	C	0.5	C	0.5	0.5
9	0.5	0.5	C	0.5	0.5
10	0.5	0.5	0.5	0.5	0.5
11	0.5	0.5	0.5	1	0.5
12	0.5	1	0.5	1	0.5
13	0.5	1	0.5	1	1
14	1	1	0.5	1	1
15	1	1	1	1	1
16	1	1	1	1.5	1
17	1	1.5	1	1.5	1
18	1	1.5	1	1.5	1.5
19	1.5	1.5	1	1.5	1.5
20	1.5	1.5	1.5	1.5	1.5
21	1.5	1.5	1.5	2	1.5
22	1.5	2	1.5	2	1.5
23	1.5	2	1.5	2	2
24	2	2	1.5	2	2
25	2	2	2	2	2
26	2	2	2	3	2
27	2	3	2	3	2
28	2	3	2	3	3
29	3	3	2	3	3
30	3	3	3	3	3

Arrange-ment Number	Gate Number				
	1	2	3	4	5
31	3	3	3	4	3
32	3	4	3	4	3
33	3	4	3	4	4
34	4	4	3	4	4
35	4	4	4	4	4
36	4	4	4	5	4
37	4	5	4	5	4
38	4	5	4	5	5
39	5	5	4	5	5
40	5	5	5	5	5
41	5	5	5	6.5	5
42	5	6.5	5	6.5	5
43	5	6.5	5	6.5	6.5
44	6.5	6.5	5	6.5	6.5
45	6.5	6.5	6.5	6.5	6.5
46	6.5	6.5	6.5	8	6.5
47	6.5	8	6.5	8	6.5
48	6.5	8	6.5	8	8
49	8	8	6.5	8	8
50	8	8	8	8	8
51	8	8	8	10	8
52	8	10	8	10	8
53	8	10	8	10	10
54	10	10	8	10	10
55	10	10	10	10	10
56	10	10	10	13	10
57	10	13	10	13	10
58	10	13	10	13	13
59	13	13	10	13	13
60	13	13	13	13	13

Arrange-ment Number	Gate Number				
	1	2	3	4	5
61	13	13	13	17	13
62	13	17	13	17	13
63	13	17	13	17	17
64	17	17	13	17	17
65	17	17	17	17	17
66	17	17	17	21	17
67	17	21	17	21	17
68	17	21	17	21	21
69	21	21	17	21	21
70	21	21	21	21	21
71	21	21	21	25	21
72	21	25	21	25	21
73	21	25	21	25	25
74	25	25	21	25	25
75	25	25	25	25	25
76	25	25	25	31	25
77	25	31	25	31	25
78	25	31	25	31	31
79	31	31	25	31	31
80	31	31	31	31	31

GATE OPENINGS

Figures in columns under each gate number refer to gate opening indicator reading
dash (-) indicates closed gate
C indicates gate raised to crest elevation

February 10, 1954

Albert S. Fry

Rex A. Elder

RATING CURVES AND GATE OPERATING INSTRUCTIONS - BOONE AND FORT PATRICK HENRY DAM SPILLWAYS (ASF 1282 AND 1303)

To provide a means of operating the Boone and Fort Patrick Henry spillway gates in the interim period before spillway discharge tables are prepared and issued, we recommend the following.

1. The rating curves and spillway operating schedule prepared for the Boone model studies report should be issued to the operating personnel at that dam. The spillway operating schedule is detailed enough that the operating personnel can determine the proper gate settings when used in conjunction with the rating table. The gates at this dam have individual gate hoists and each hoist is equipped with an indicating dial which we have arranged to have marked with every foot and one-half foot of gate opening.

2. The gate operation sequence schedule table—Fort Patrick Henry Dam—which accompanies this memorandum should be issued. This schedule will, when issued in conjunction with the spillway rating curves that have already been issued, allow the setting of discharges up to a total spillway flow of 65,000 cfs. These gates are equipped with gate operating equipment and indicators similar to those at Boone. They also have been calibrated to indicate every foot and one-half foot of gate opening.

The tests on the Henry model, while they are still not complete, indicate that the estimated curves for various small discharges as shown on the rating curves that have been issued for Fort Henry are reasonably accurate. Small flow releases, if necessary, can therefore be made with reasonable assurance.

Rex A. Elder

RAE:ab

CHAPTER 8

SPILLWAY OPERATION

LIMITATIONS UPON GATE OPERATION

The model studies to develop the design of the spillway apron, described in Chapter 3, were generally made with all the gates opened the same amount. Since it would not be practical to arrange the prototype gate controls to make the openings always equal, it was advisable to determine a gate-opening sequence which would combine good hydraulic performance with a practicable operation schedule. In order to achieve these results, it was found imperative that a limit for gate-opening inequality be established which would prevent improper or detrimental spillway operation.

1:50 Scale Model

Model studies in the flume showed that the gate operation restrictions enumerated in the Summary in Chapter 3 under "General Operating Tests of Selected Design" would result in satisfactory spillway operation without significant erosion. The amounts of erosion for different gate openings are shown in Table 15.

1:112.5 Scale Model

A comprehensive study of gate operation was made on the 1:112.5 scale model to determine the best gate-operating sequence. Photographs of confetti flow patterns were made to aid in this determination and for use as a reference when there might be future need to prepare gate-operating sequences to meet special needs. Appendix C contains a table showing the gate arrangements for which pictures were taken.

Gate Operating Schedule

The gate operating schedule was developed upon the basis of the erosion observed in the 1:50 scale model and the flow patterns observed in the 1:112.5 scale model. The order for opening the gates is 4, 2, 5, 1, 3.

The maximum opening for each gate is 1 foot until all gates have reached this opening, after which the gates shall be opened in the same order to a maximum opening of 3 feet. From a uniform 3-foot opening the gates shall then be opened successively to 5 feet, and thereafter in 5-foot increments in accordance with the same operating pattern to maintain balanced operation with a maximum difference of 5 feet in the settings of any two gates. Smaller increments in gate opening may be used, provided that the same opening sequence is maintained.

Trash Removal

No trash gate was provided. It was determined by visual inspection of the model approach flows that Gate 3 should be used for trash removal. When it is desirable to remove trash, Gate 3 should be raised above the surface and kept open only long enough to rid the surface of the trash.

SPILLWAY DISCHARGE RATING

The spillway discharge rating was determined from tests conducted on the 1:15 and 1:112.5 scale models with check tests on the 1:50 scale model. The 1:112.5 and 1:50 scale models were designed and used primarily for development of the apron design and were not specifically designed as rating models. They were therefore used only to establish the free-discharge curve for the condition of all gates raised above the water surface. The 1:15 scale model, consisting of a single spillway bay, was used to determine accurate ratings for partial gate openings. A detailed description of all three models is given in Chapter 2.

Methods of Measurement

Enough tests were made to define accurately the free-discharge curve and the curve for each gate-opening position tested. Each test was made under conditions of constant and stabilized discharge. The discharge in the 1:112.5 and 1:50 scale models was measured by reading the differential pressure across a previously calibrated diaphragm orifice in the supply line. The 1:15 scale model discharge was measured by means of the diaphragm orifices or a calibrated sharp-crested weir located near the upstream end of the test flume. Headwater elevations on all models were measured with hook gages, reading to 0.001 foot, at the locations shown on Plates 3, 4, and 6.

1:15 Scale Model Tests

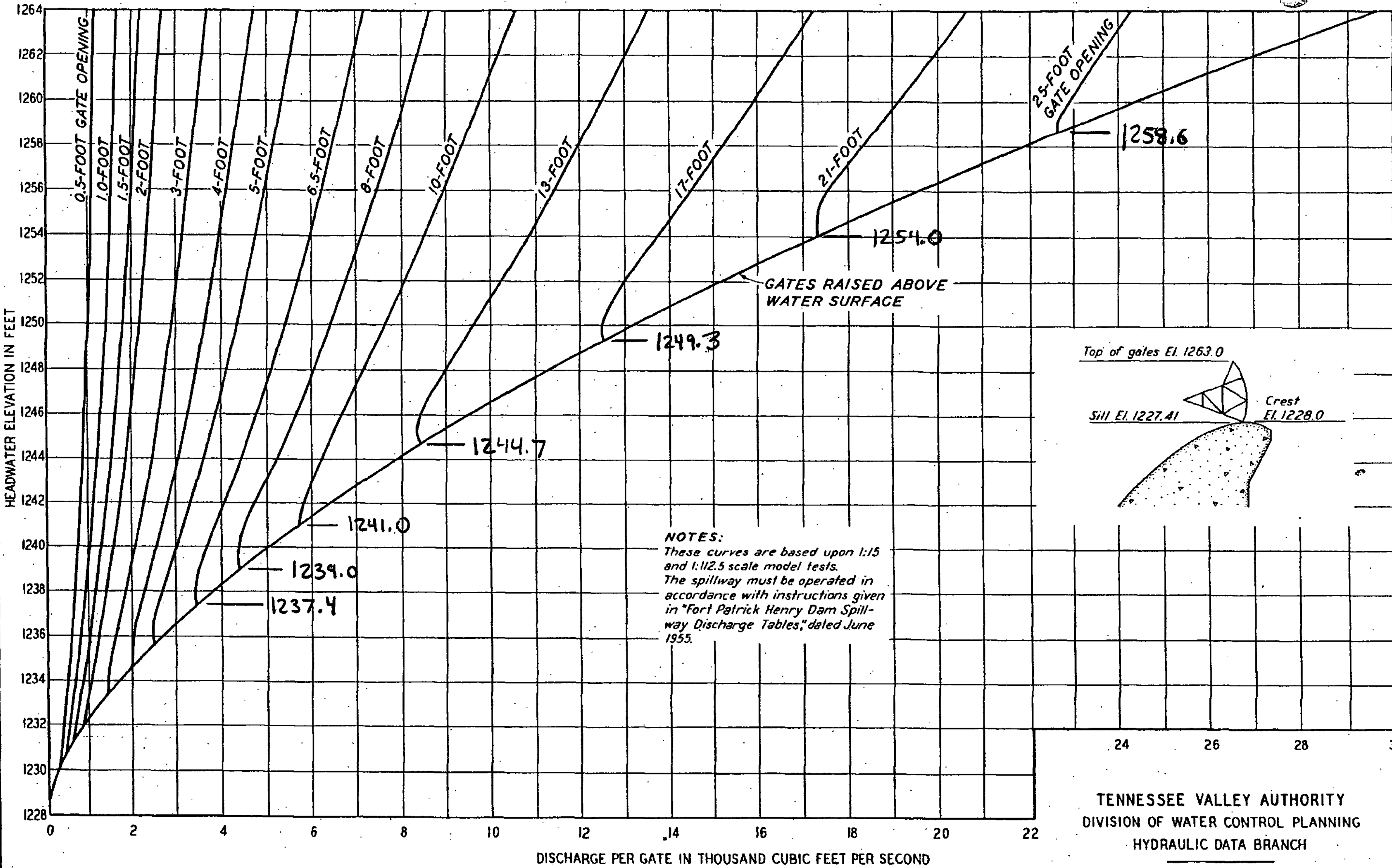
Discharges under partially opened gates were determined from the 1:15 scale model tests in which equal opening of adjacent gates was simulated in the model. This was accomplished by installing vertical walls, upstream from the piers, with their inner faces on the centerlines of the piers confining the single bay of the model. The walls had the same effect upon the flow as mirrors in the same positions would have upon the visual concept of the model, and the resulting contraction effect was equal to that produced by opening the adjacent gates. The spillway end contraction effect, produced by having the adjacent gates closed, was neglected because it has been found to be practically negligible at partial gate openings.

1:112.5 Scale Model Tests

Discharges unregulated by any gates were determined from tests on the 1:112.5 scale model, which simulated the entire spillway, the powerhouse, and a reach of the channel both upstream and downstream from the dam. These tests included the end contraction effects, which may appreciably affect the discharge when the gates are raised above the water surface. It was evident from the tests that the bend in the river immediately upstream from the spillway caused the flow to pile up on the left side of Bays 1, 2, 3, and 4 and on the right side of Bay 5 as shown in Figure 14 with a subsequent effect upon the discharge rating.

Rating Curves

Plate 36 shows the rating curves developed from all the model test data. These curves cover the complete operating range of the spillway. The gate discharge data were obtained at gate openings of 0.5, 1, 2, 3, 5, 6.5, 8, 10, 13, 17, 21, and 25 feet. The curves for other openings were obtained by



NOTES:
These curves are based upon 1:15 and 1:112.5 scale model tests.
The spillway must be operated in accordance with instructions given in "Fort Patrick Henry Dam Spillway Discharge Tables," dated June 1955.

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
HYDRAULIC DATA BRANCH

FORT PATRICK HENRY PROJECT
HYDRAULIC MODEL STUDIES
SPILLWAY RATING CURVE

PLATE 36

Attachment A4-4
Source: Reference A3

Page A14
Calculation No: CDQ000020080010

SPILLWAY RATING CURVE

TABLE 29

SUMMARY OF SPILLWAY RATING TEST DATA

Test No.	Model Scale	Gate Opening (feet)*	Headwater Elevation (feet)	Discharge per Bay (cfs)
1	1:15	0.5	1234.57	501
2			1237.38	602
3			1240.87	706
4			1245.58	829
5			1258.78	1095
6			1261.78	1150
7	1:15	1.0	1230.64	447
8			1231.02	456
9			1231.64	500
10			1233.16	601
11			1235.16	725
12			1238.76	898
13	1:15	1.0	1242.46	1049
14			1246.72	1201
15			1250.44	1322
16			1253.23	1398
17			1258.78	1547
18			1262.90	1644
19	1:15	2.0	1232.17	863
20			1232.06	885
21			1234.06	1001
22			1237.52	1307
23			1241.66	1602
24	1:15	2.0	1247.21	1932
25			1250.60	2100
26			1253.92	2255
27			1258.04	2439
28			1263.44	2656
29	1:15	3.0	1234.36	1352
30			1233.40	1375
31			1235.50	1491
32			1236.34	1596
33			1238.24	1809
34	1:15	3.0	1244.65	2401
35			1249.18	2750
36			1253.71	3060
37			1261.21	3520
38			1265.95	3775
39	1:15	5.0	1236.55	2414
40			1237.44	2523
41			1237.58	2546
42			1238.90	2769
43			1239.16	2803
44	1:15	5.0	1241.80	3217
45			1245.04	3675
46			1250.00	4265
47			1253.44	4645
48			1256.76	4981
49	1:15	6.5	1239.54	3517
50			1246.64	4831
51			1252.02	5661
52			1257.96	6450
53	1:15	8.0	1245.22	5437
54			1250.11	6438
55			1255.08	7311
56			1263.80	8613
57	1:15	10.0	1242.07	5774
58			1243.06	5950
59			1246.54	6816
60			1251.52	7989

Test No.	Model Scale	Gate Opening (feet)*	Headwater Elevation (feet)	Discharge per Bay (cfs)
61	1:15	10.0	1256.92	9229
62			1259.82	9763
63			1260.99	9986
64	1:15	13.0	1245.28	8320
65			1245.48	8349
66			1246.26	8476
67			1247.46	8844
68	1:15	13.0	1249.39	9454
69			1254.64	11030
70			1258.86	12190
71			1264.27	13550
72	1:15	17.0	1250.14	12470
73			1251.49	12820
74			1252.05	12990
75			1252.83	13270
76	1:15	17.0	1257.72	15060
77			1260.39	15970
78			1263.96	17160
79	1:15	21.0	1255.22	17360
80			1255.51	17380
81			1255.82	17450
82			1256.14	17520
83			1257.61	18050
84	1:15	21.0	1257.61	18150
85			1258.22	18340
86			1260.34	19240
87			1264.16	20630
88	1:15	25.0	1261.26	23300
89			1261.78	23490
90			1262.59	23750
91	1:15	25.0	1262.89	23880
92			1263.49	24090
93			1263.99	24260
94	1:15	Gates	1230.64	447
95		raised	1232.06	885
96			1233.25	1320
97		above	1233.40	1375
98	1:15	water	1235.88	2562
99			1237.71	3590
100		surface	1236.57	2940
101			1235.32	2290
1A	1:112.5	Gates	1233.10	1330
2A		raised	1234.61	1974
3A			1235.61	2384
4A		above	1236.01	2574
5A			1236.61	2904
6A	1:112.5	water	1236.81	3004
7A		surface	1239.83	4840
8A			1244.17	7994
9A			1241.14	5716
10A	1:112.5	Gates	1248.82	11990
11A		raised	1252.98	16140
12A			1255.62	19100
13A		above	1258.98	22950
14A	1:112.5	water	1247.05	10310
15A		surface	1260.41	24890
16A			1262.34	27330
17A			1264.07	29570

Not used

Free Discharge Data

*Gate opening is measured above the spillway crest elevation.

interpolation. The model data from which the curves were prepared are given in Table 29. The data for the 1:15 and 1:50 scale model tests have been corrected for velocity of approach.

The discharge curves for partial gate openings in the immediate vicinity of the intersection with the free-discharge curve are based upon the 1:15 scale model tests under a condition of rising headwater. The intersection point must be considered as an approximation since it varies both with a rising or falling headwater condition and with approach flow conditions.

Published Spillway Discharge Tables

Spillway discharge tables for use in the actual operation of the dam have been prepared by the Hydraulic Data Branch of the TVA from the rating curves on Plate 36, and were issued in June 1955. They incorporate a series of gate arrangements which comply with the requirements for order and magnitude of successive gate openings as described earlier in this chapter under "Gate Operating Schedule." The allowable 1-foot, 2-foot, and 5-foot increments successively specified therein were determined to be too great for proper flexibility of operation, and the tables were computed for smaller gate opening increments.

The published Spillway Discharge Tables provide discharge values at 0.1-foot intervals of headwater elevation for each of 80 gate arrangements. The arrangements consist of opening each gate successively in the order 4, 2, 5, 1, 3 to each of the 16 positions listed in Table 30. Table 30 is an abridgment of the published tables and shows the discharges at 1-foot intervals of headwater elevation for the 16 arrangements at which all gates are opened uniformly.

ed

ity

TABLE 30

SPILLWAY DISCHARGE IN CUBIC FEET PER SECOND

WITH ALL GATES EQUALLY OPEN

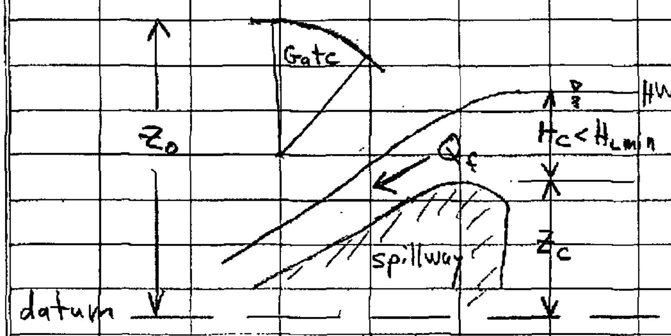
Gate Opening	Headwater Elevation in Feet								
	1256	1257	1258	1259	1260	1261	1262	1263	1264
Crest	2940	3000	3040	3090	3140	3180	3220	3260	*
0.5	5160	5240	5330	5420	5500	5580	5660	5740	*
1	7360	7480	7620	7740	7860	7980	8100	8210	8320
1.5	9580	9760	9920	10100	10260	10420	10580	10730	10880
2	11790	12000	12220	12420	12640	12840	13030	13220	13420
3	16040	16360	16660	16960	17260	17540	17820	18100	18360
4	20360	20750	21160	21560	21940	22300	22680	23040	23400
5	24660	25160	25650	26120	26600	27050	27500	27960	28390
6.5	31060	31720	32320	32930	33520	34180	34720	35320	35920
8	37300	38100	38880	39640	40390	41110	41820	42520	43220
10	44850	45880	46900	47940	48920	49960	50880	51920	52850
13	57100	58460	59780	61120	62400	63730	64940	66220	67440
17	72280	74060	75810	77570	79260	80980	82600	84300	85910
21	87480	89380	91380	93360	95340	97320	99240	101100	102900
25	97560	103400	109300	113200	114500	116100	117800	119600	121300
31	#	#	#	115500	121700	128200	134700	141500	148400

*Gates must be raised to prevent overtopping.
#Gates are above water surface at previous setting.

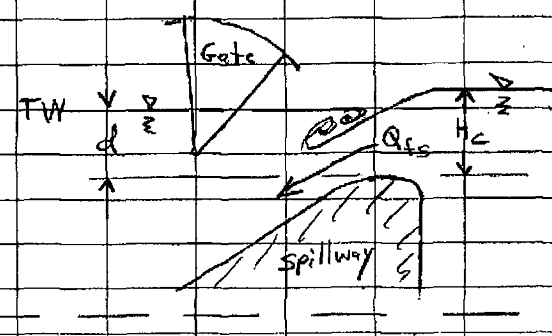
Definition Sketch for Spillway Discharge COMPUTED GAS DATE 8/12/2008

CHECKED ____ DATE ____

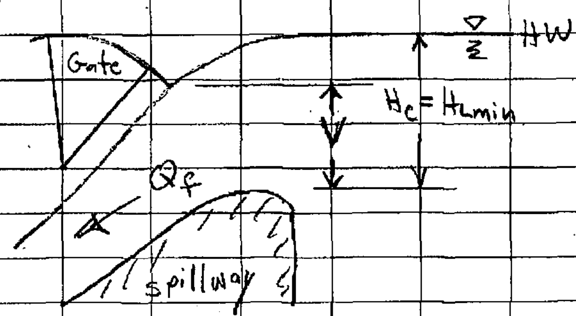
Free Discharge - No Tailwater effect



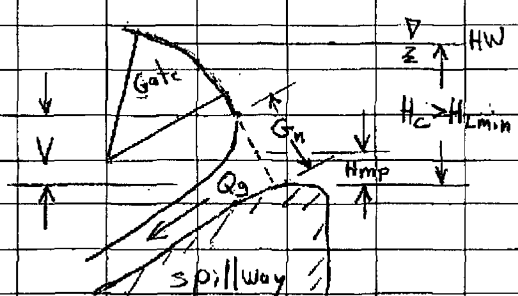
Free Discharge affected by Tailwater



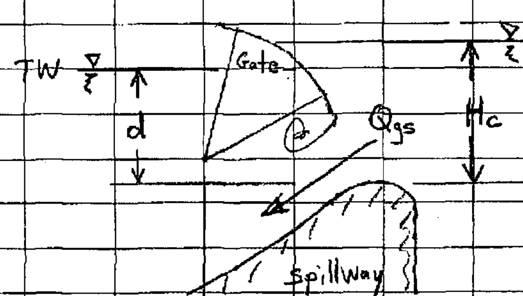
Nappe Touches Gate



Orifice Discharge - No Tailwater Effect



Orifice Discharge affected by Tailwater

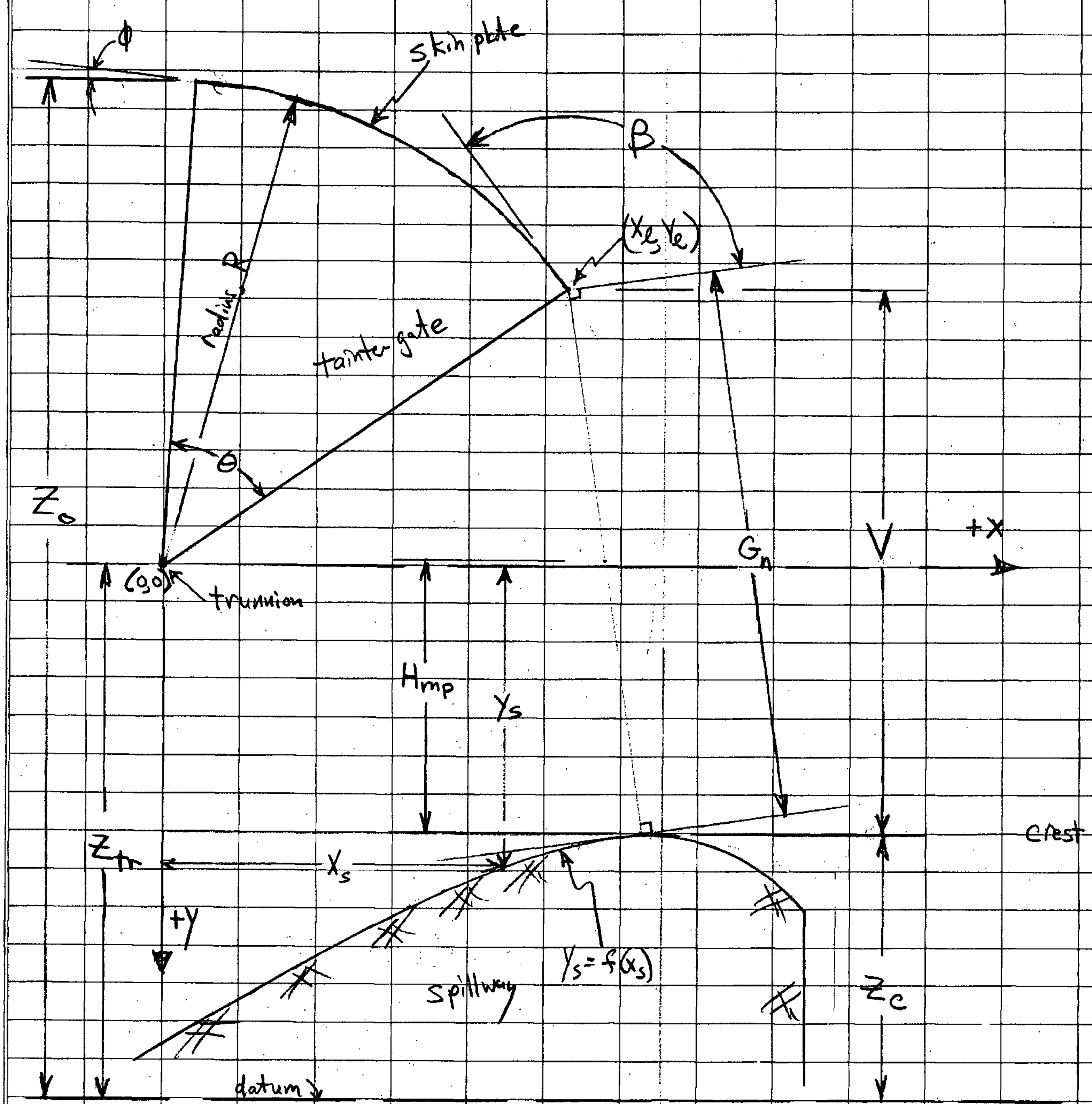


Spillway Discharge Calculations
Geometry for Flow Under an Open Tainter Gate

COMPUTED CAS DATE 8/11/2008

CHECKED ______ DATE ______

Definition Sketch



Spillway Gate Geometry

COMPUTED GAS DATE 8/11/2008
CHECKED ____ DATE ____

Variables

V = vertical distance between the bottom of the open gate and the crest

Z_c = crest elevation

Z_{tr} = trunnion elevation

Z_o = overflow elevation

R = radius of the tainter gate

G_n = minimum distance between the gate lip and the crest

H_{mp} = vertical distance between the mid-point of G_n and the crest

β = angle formed by the tangent to the gate lip and the tangent to the crest curve at the nearest point of the crest curve

θ = angle of the sector of a circle formed by two lines connecting the trunnion axis to the bottom and top of the radial gate.

X, Y = coordinates relative to trunnion axis (Y positive downward)

~~X_s, Y_s = coordinates of spillway surface defined by $Y_s = f(X_s)$~~

X_ℓ, Y_ℓ = coordinates of the gate lip relative to trunnion axis

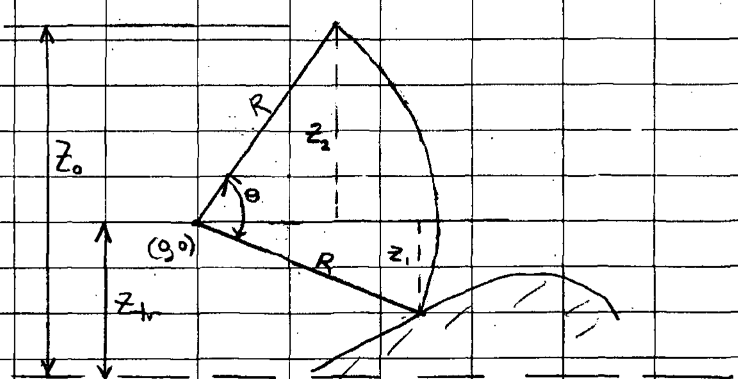
notes: { Y positive downward for all coordinates; all coordinates relative to trunnion axis }

Φ = angle formed by the tangent to the gate top and horizontal

Angle, θ

$$\theta = \sin^{-1}\left(\frac{Z_2}{R}\right) + \sin^{-1}\left(\frac{Z_1}{R}\right)$$

Z_1 & Z_2 are determined from drawings



Closed Gate

Spillway Gate Geometry

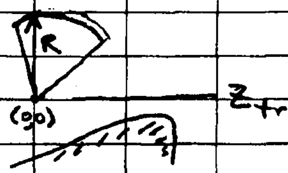
COMPUTED GAS DATE 8/11/2008

CHECKED ____ DATE ____

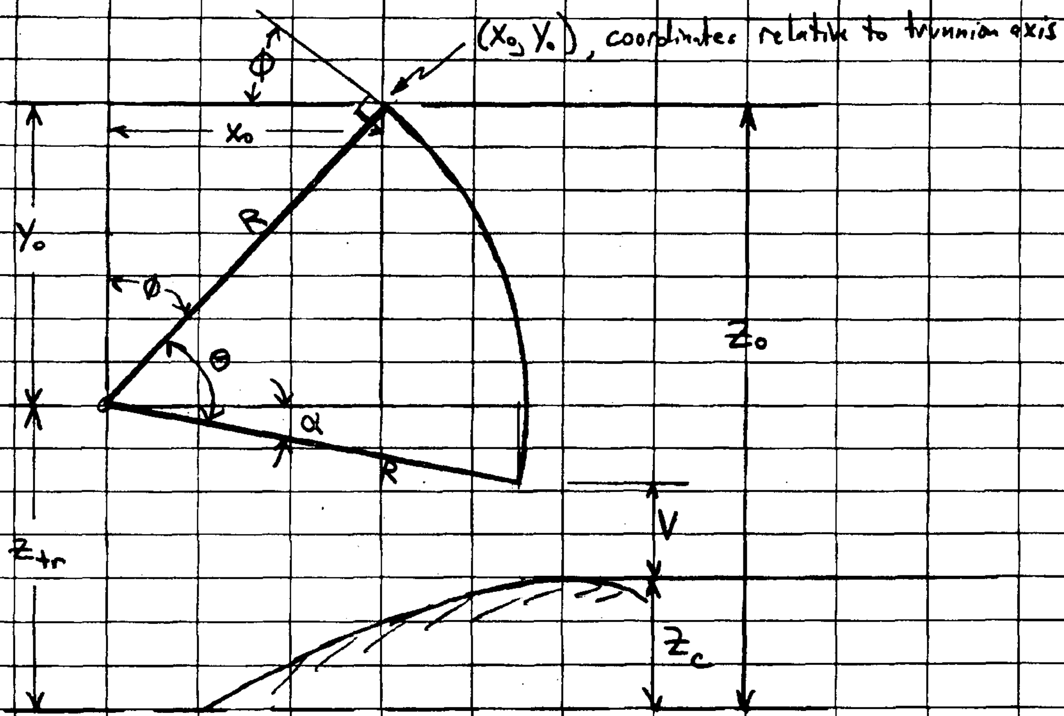
Overflow Elevation, Z_o and Angle, Φ

For a gate opened so far that its upper edge is downstream of the trunnion:

$$Z_o = Z_{tr} + R$$



For a gate opened less:



$$\alpha = \tan^{-1}\left(\frac{Z_{tr} - (Z_{cr} + V)}{\sqrt{R^2 - (Z_{tr} - Z_{cr} - V)^2}}\right)$$

V given

$$\boxed{Z_o = Z_{tr} + R\sin(\theta - \alpha)}$$

and $\boxed{\Phi = \tan^{-1}\left(\frac{X_o}{Y_o}\right)}$ with $\begin{cases} Y_o = Z_o - Z_{tr} \\ X_o = R\cos(\theta - \alpha) \end{cases}$

Spillway Gate Geometry

COMPUTED GAS DATE 8/11/2008

CHECKED ____ DATE ____

Gate Opening, G_n

Gate lip coordinates:

$$\begin{cases} Y_\ell = Z_{tr} - Z_{cr} - Y \\ X_\ell = \sqrt{R^2 - Y_\ell^2} \end{cases}$$

Distance between gate lip and any point on spillway surface is

$$\ell = \sqrt{(X_s - X_\ell)^2 + (Y_s - Y_\ell)^2} \equiv \sqrt{(X_s - X_\ell)^2 + [f(X_s) - Y_\ell]^2}$$

G_n is the minimum distance. ℓ is minimum when $\frac{d\ell}{dX_s} = 0$

$$\frac{d\ell}{dX_s} = \frac{1}{2}\left\{(X_{sn} - X_\ell)^2 + [f(X_{sn}) - Y_\ell]^2\right\}^{-1/2} \cdot \left\{2(X_{sn} - X_\ell) + 2[f(X_{sn}) - Y_\ell]\frac{df(X_{sn})}{dX_s}\right\} = 0$$

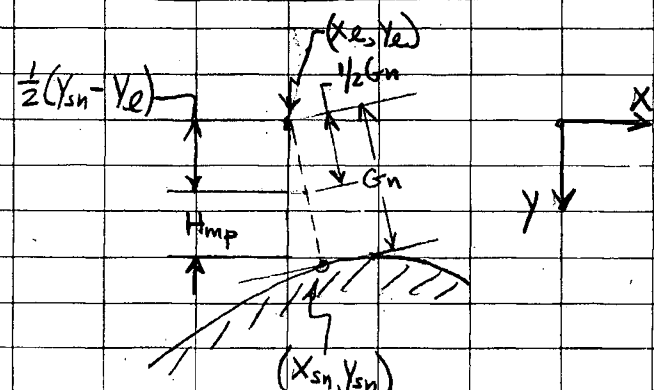
$$\Rightarrow 0 = \frac{(X_{sn} - X_\ell) + [f(X_{sn}) - Y_\ell]\frac{df(X_{sn})}{dX_s}}{\ell_{minimum}}$$

where $X_{sn} = X_s$ for minimum ℓ, $\ell_{minimum} \equiv G_n$.

Solve: $X_{sn} - X_\ell + [f(X_{sn}) - Y_\ell]\frac{df(X_{sn})}{dX_s} = 0$ for X_{sn}

Then: $Y_{sn} = f(X_{sn})$ and $\boxed{G_n = \sqrt{(X_{sn} - X_\ell)^2 + (Y_{sn} - Y_\ell)^2}}$

Mid-Point Head, H_{mp}



$$H_{mp} = Z_{tr} - Z_c - Y_\ell - \frac{1}{2}(Y_{sn} - Y_\ell)$$

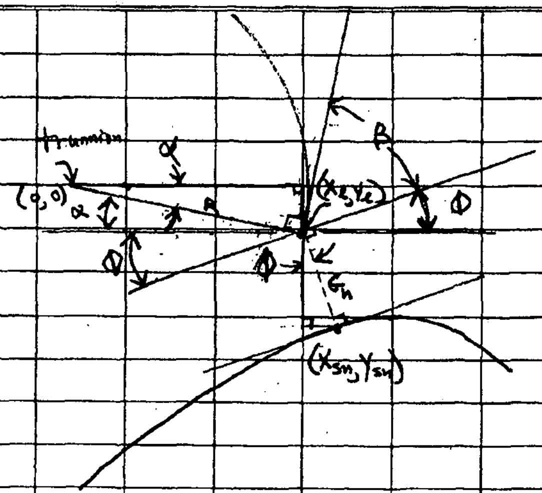
$$\Rightarrow \boxed{H_{mp} = V - \frac{1}{2}(Y_{sn} - Y_\ell)}$$

Spillway Gate Geometry

COMPUTED GAS DATE

CHECKED DATE

Angle, B



$$\beta + \frac{\pi}{2} + \alpha + \Phi = \pi$$

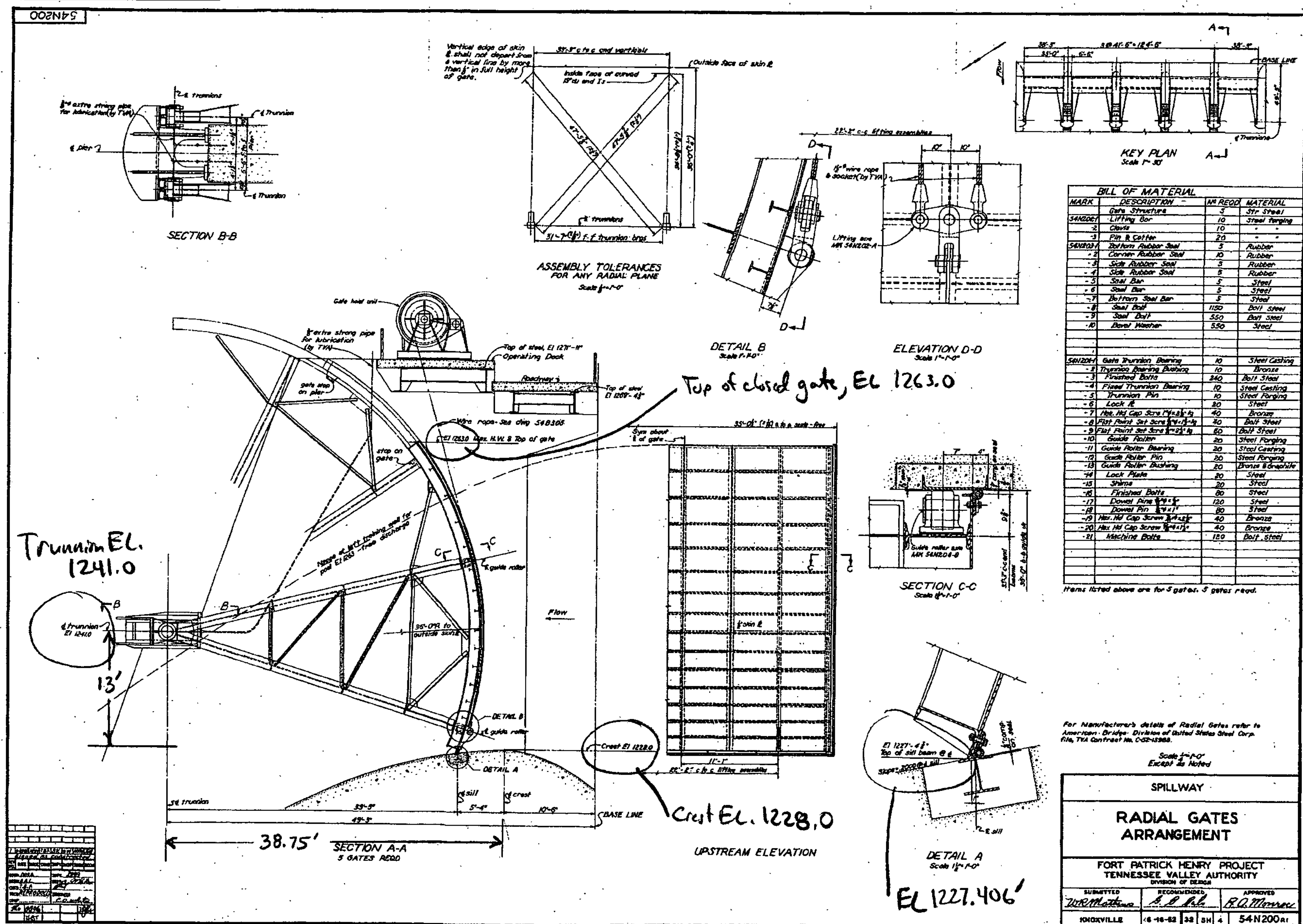
$$\beta + \Phi = \frac{\pi}{2} - \alpha$$

$$\beta = \frac{\pi}{2} - \alpha - \Phi$$

$$\alpha = \tan^{-1}\left(\frac{Y_e}{X_e}\right)$$

$$\Phi = \tan^{-1}\left(\frac{X_{sn} - X_e}{Y_{sn} - Y_e}\right)$$

$$\beta = \frac{\pi}{2} - \tan^{-1}\left(\frac{Y_e}{X_e}\right) - \tan^{-1}\left(\frac{X_{sn} - X_e}{Y_{sn} - Y_e}\right)$$

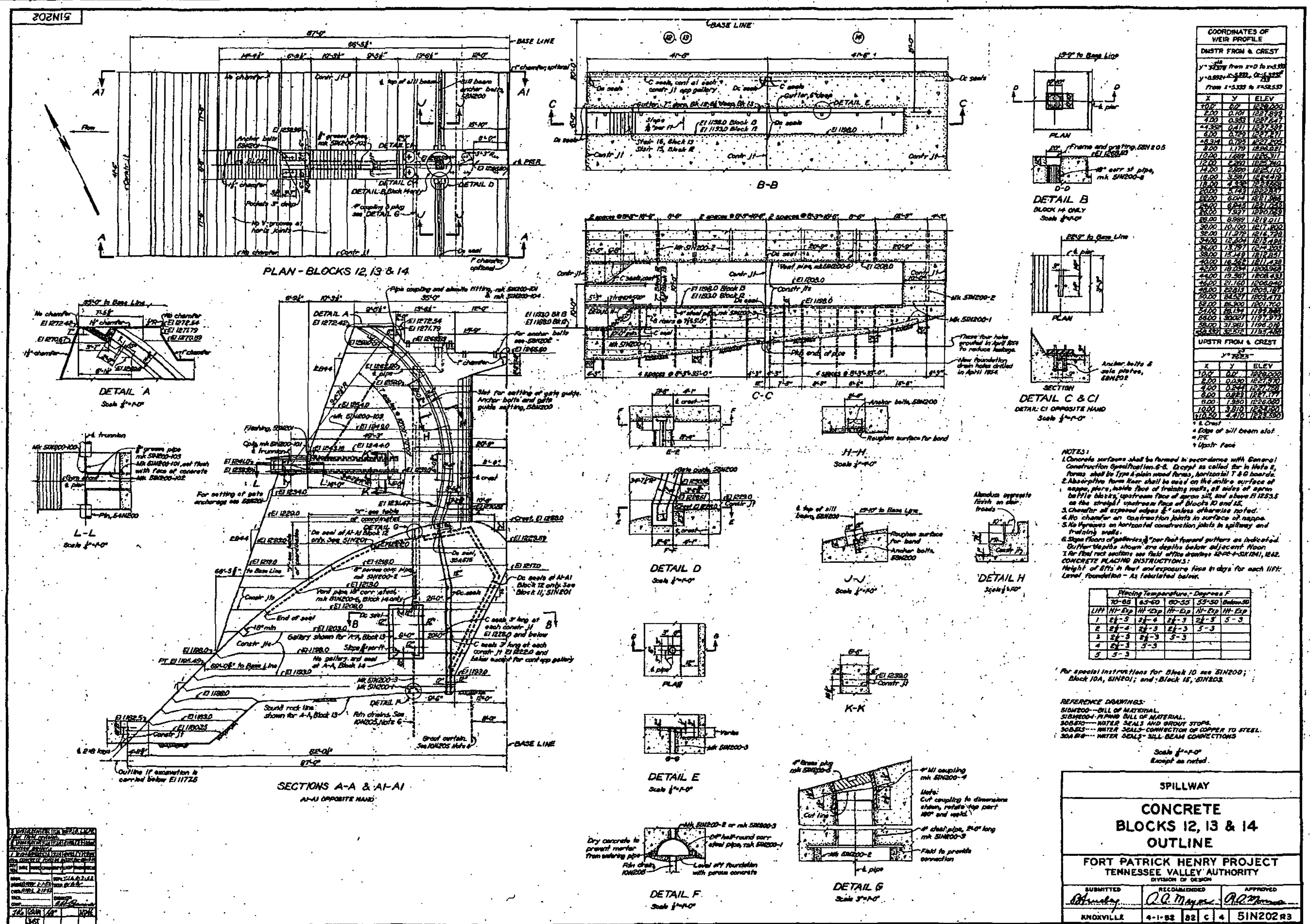


BILL OF MATERIAL

MARK	DESCRIPTION	Nº REQD	MATERIAL
	Gate Structure	5	Str Steel
54N206-1	Lifting Bar	10	Steel forging
-2	Clevis	10	" "
-3	Pin & Cotter	20	" "
54N203-1	Bottom Rubber Seal	5	Rubber
-2	Corner Rubber Seal	10	Rubber
-3	Side Rubber Seal	5	Rubber
-4	Side Rubber Seal	5	Rubber
-5	Seal Bar	5	Steel
-6	Seal Bar	5	Steel
-7	Bottom Seal Bar	5	Steel
-8	Seal Bolt	1150	Bolt Steel
-9	Seal Bolt	550	Bolt Steel
-10	Bevel Washer	550	Steel
54N204-1	Gate Trunnion Bearing	10	Steel Casting
-2	Trunnion Bearing Bushing	10	Bronze
-3	Finished Bolts	240	Bolt Steel
-4	Fixed Trunnion Bearing	10	Steel Casting
-5	Trunnion Pin	10	Steel Forging
-6	Lock Plate	20	Steel
-7	Hex. Hd Cap Scre 1"⌀ x 8½" lg	40	Bronze
-8	Flat Point Set Scre ¾"⌀ x 1½" lg	40	Bolt Steel
-9	Flat Point Set Scre ¾"⌀ x 2½" lg	60	Bolt Steel
-10	Guide Roller	20	Steel Forging
-11	Guide Roller Bearing	20	Steel Casting
-12	Guide Roller Pin	20	Steel Forging
-13	Guide Roller Bushing	20	Bronze & Graphite
-14	Lock Plate	20	Steel
-15	Shims	20	Steel
-16	Finished Bolts	80	Steel
-17	Dowel Pins ¾"⌀ x ½"	120	Steel
-18	Dowel Pin ¾"⌀ x 1"	80	Steel
-19	Hex. Hd Cap Screw ¾"⌀ x 2½"	40	Bronze
-20	Hex Hd Cap Screw ⅝"⌀ x 1½"	40	Bronze
-21	Machine Bolts	120	Bolt Steel

Items listed above are for 5 gates. 5 gates reqd.

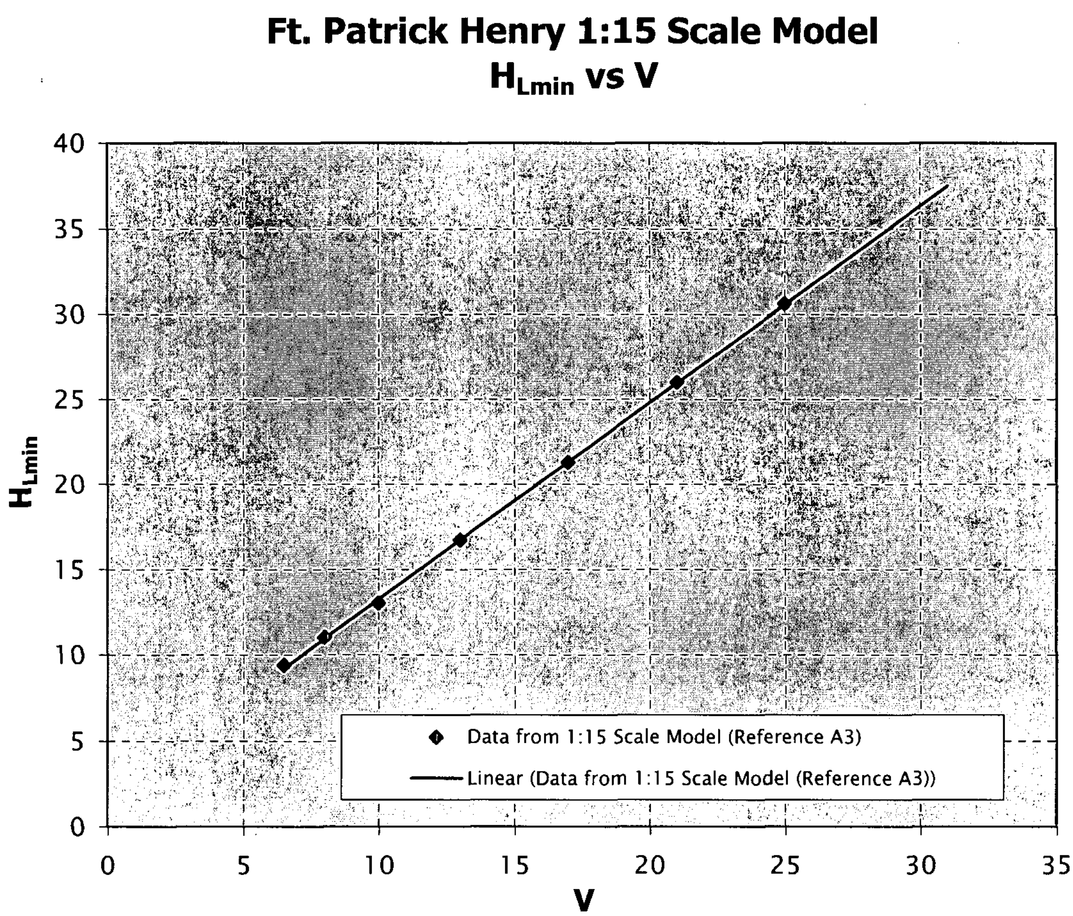
Attachment A8
Source: Reference A6



Ft. Patrick Henry Project
Tainter Gates Partially Opened
Data from 1:15 scale model (Reference A3)
EQUIVALENT PROTOTYPE

Crest EL = 1228 feet

V	HW (data)	H_{Lmin} (data)	H_{Lmin} (fit)	
feet	feet	feet	feet	
6.50	1237.4	9.4	9.22	
8.00	1239.0	11	10.95	
10.00	1241.0	13	13.26	
13.00	1244.7	16.7	16.72	
17.00	1249.3	21.3	21.34	
21.00	1254.0	26	25.95	
25.00	1258.6	30.6	30.57	
31.00			37.49	extrapolated using linear fit on 1:15 scale Model [



Ft Pat Henry Model Data for Headwater Ratings.xls Free Discharge

Fort Patrick Henry
Tainter Gates Raised Above the Water Surface
Data from 1:112.5 scale model (Reference A3)
(equivalent prototype)

Definition: $C_f = Q/(L*H_c^{1.5})$

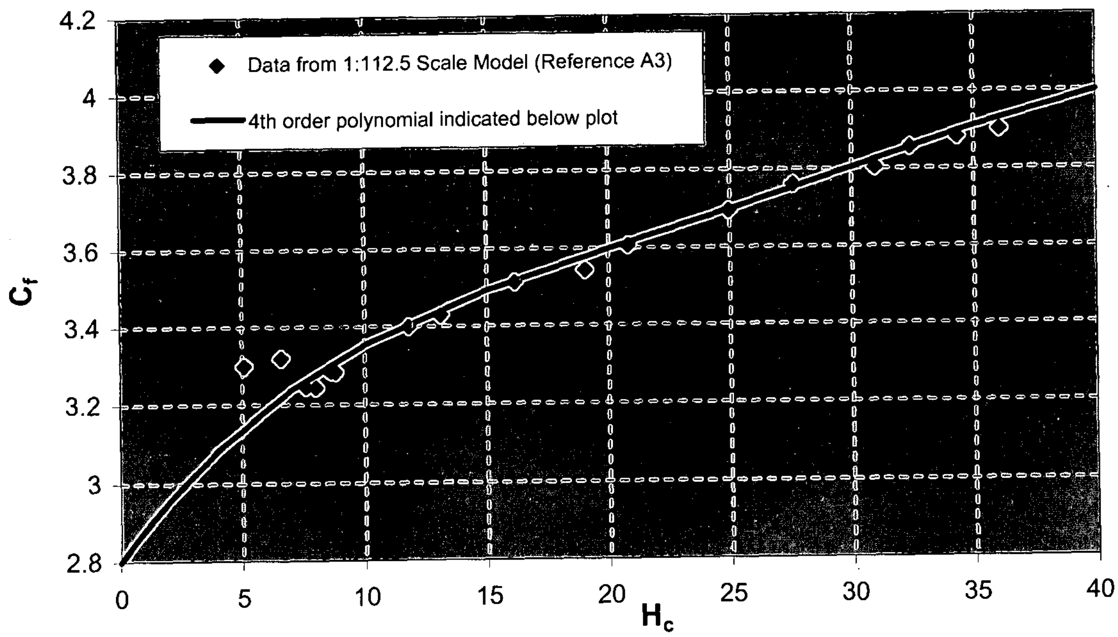
L (one bay) = 35 feet
Crest, Z_c = 1228 feet

HW EL. ft	H_c ft.	Q (per bay) cfs	C_f
1233.1	5.1	1330	3.30
1234.61	6.61	1974	3.32
1235.61	7.61	2384	3.24
1236.01	8.01	2574	3.24
1236.61	8.61	2904	3.28
1236.81	8.81	3004	3.28
1239.83	11.83	4840	3.40
1244.17	16.17	7994	3.51
1241.14	13.14	5,716	3.43
1248.82	20.82	11,990	3.61
1252.98	24.98	16,140	3.69
1255.62	27.62	19,100	3.76
1258.98	30.98	22,950	3.80
1247.05	19.05	10,310	3.54
1260.41	32.41	24,890	3.85
1262.34	34.34	27,330	3.88
1264.07	36.07	29,570	3.90

4th-order curve fit (see plot)

H_c ft.	C_f
0	2.800
0.5	2.842
1	2.882
2	2.956
4	3.085
7	3.237
10	3.353
15	3.491
20	3.598
25	3.698
30	3.803
35	3.910
40	4.000

Free Discharge Coefficient, $C_f(H_c)$
Fort Patrick Henry

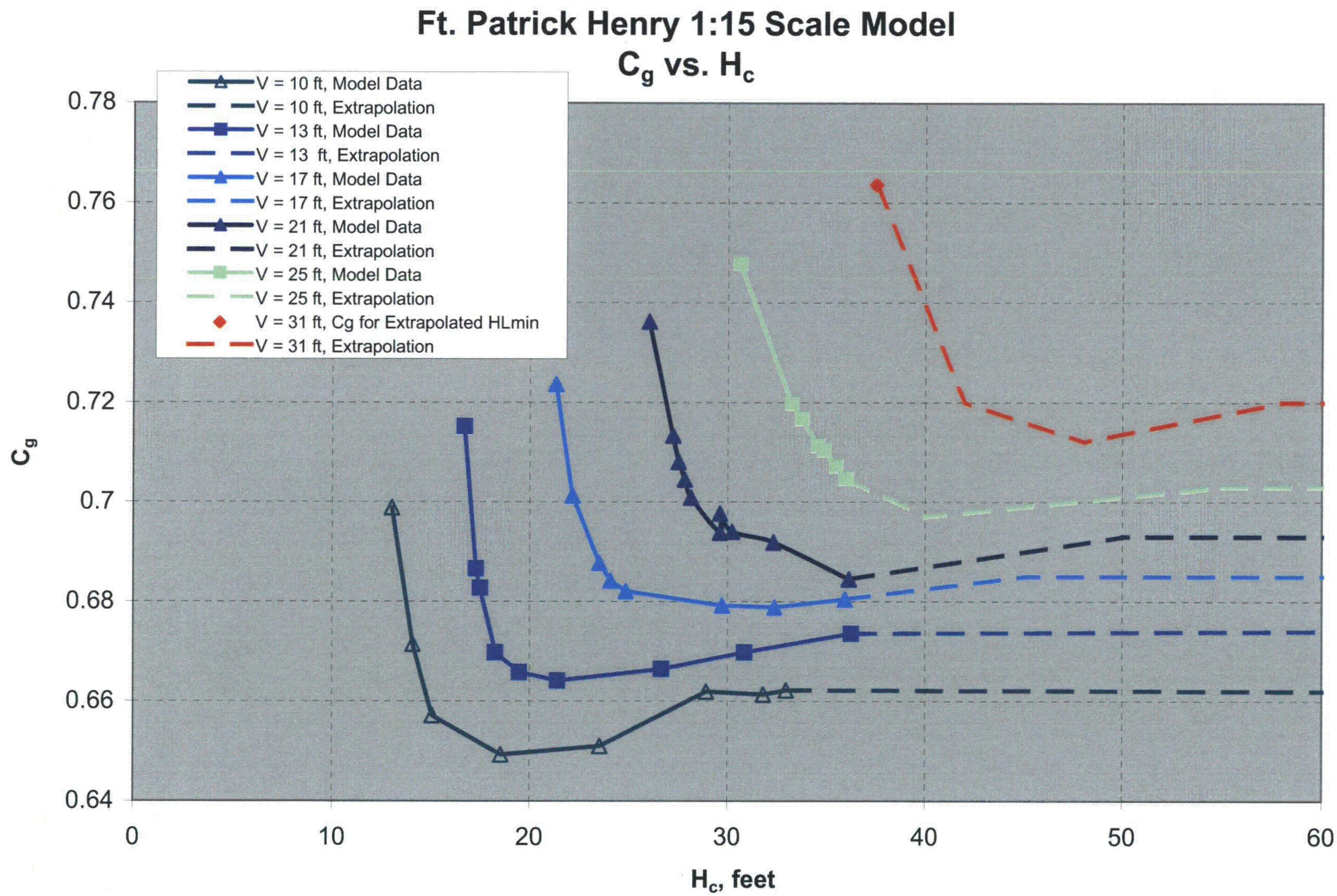


Fort Patrick Henry Project, Tainter Gates Partially Opened
Data from 1:15 scale model as published in Reference A3

Definition: $C_g = Q / \{G_n*L*sqrt[2*g*(H_c-H_{mp})]\}$
H_c = HW - Z_c
g = 32.2 ft/s2
Z_c = 1228 ft
L = 35 ft

	Model Test Data In Prototype Dimensions				Geometry		
	V	HW	H_c	Q	G_n	H_{mp}	C_g
	ft	ft	ft	cfs	ft	ft	
H_c=H_{Lmin}	10.00		13	5646	10.139	4.951	0.699
	10.00	1242.07	14.07	5774	10.139	4.951	0.671
	10.00	1243.06	15.06	5950	10.139	4.951	0.657
	10.00	1246.54	18.54	6816	10.139	4.951	0.649
	10.00	1251.52	23.52	7989	10.139	4.951	0.651
	10.00	1256.92	28.92	9229	10.139	4.951	0.662
	10.00	1259.82	31.82	9763	10.139	4.951	0.661
	10.00	1260.99	32.99	9986	10.139	4.951	0.662
	10.00		60				0.662 *
H_c=H_{Lmin}	13.00		16.7	8430	13.118	6.462	0.715
	13.00	1245.28	17.28	8320	13.118	6.462	0.687
	13.00	1245.48	17.48	8349	13.118	6.462	0.683
	13.00	1246.26	18.26	8476	13.118	6.462	0.670
	13.00	1247.46	19.46	8844	13.118	6.462	0.666
	13.00	1249.39	21.39	9454	13.118	6.462	0.664
	13.00	1254.64	26.64	11030	13.118	6.462	0.666
	13.00	1258.86	30.86	12190	13.118	6.462	0.670
	13.00	1264.27	36.27	13550	13.118	6.462	0.674
	13.00		60				0.674 *
H_c=H_{Lmin}	17.00		21.3	12467	17.123	8.464	0.724
	17.00	1250.14	22.14	12470	17.123	8.464	0.701
	17.00	1251.49	23.49	12820	17.123	8.464	0.688
	17.00	1252.05	24.05	12990	17.123	8.464	0.684
	17.00	1252.83	24.83	13270	17.123	8.464	0.682
	17.00	1257.72	29.72	15060	17.123	8.464	0.679
	17.00	1260.39	32.39	15970	17.123	8.464	0.679
	17.00	1263.96	35.96	17160	17.123	8.464	0.680
	17.00		45				0.685 *
	17.00		60				0.685 *
H_c=H_{Lmin}	21.00		26	17254	21.165	10.456	0.736
	21.00	1255.22	27.22	17360	21.165	10.456	0.713
	21.00	1255.51	27.51	17380	21.165	10.456	0.708
	21.00	1255.82	27.82	17450	21.165	10.456	0.704
	21.00	1256.14	28.14	17520	21.165	10.456	0.701
	21.00	1257.61	29.61	18050	21.165	10.456	0.694
	21.00	1257.61	29.61	18150	21.165	10.456	0.698
	21.00	1258.22	30.22	18340	21.165	10.456	0.694
	21.00	1260.34	32.34	19240	21.165	10.456	0.692
	21.00	1264.16	36.16	20630	21.165	10.456	0.684
	21.00		50				0.693 *
	21.00		60				0.693 *
H_c=H_{Lmin}	25.00		30.6	22608	25.255	12.436	0.748
	25.00	1261.26	33.26	23300	25.255	12.436	0.720
	25.00	1261.78	33.78	23490	25.255	12.436	0.717
	25.00	1262.59	34.59	23750	25.255	12.436	0.711
	25.00	1262.89	34.89	23880	25.255	12.436	0.710
	25.00	1263.49	35.49	24090	25.255	12.436	0.707
	25.00	1263.99	35.99	24260	25.255	12.436	0.705
	25.00		40				0.697 *
	25.00		55				0.703 *
	25.00		60				0.703 *
H_c=H_{Lmin}	31.00		37.5	31819	31.540	15.375	0.764
	31.00		42				0.720 *
	31.00		48				0.712 *
	31.00		58				0.720
	31.00		60				0.720 *

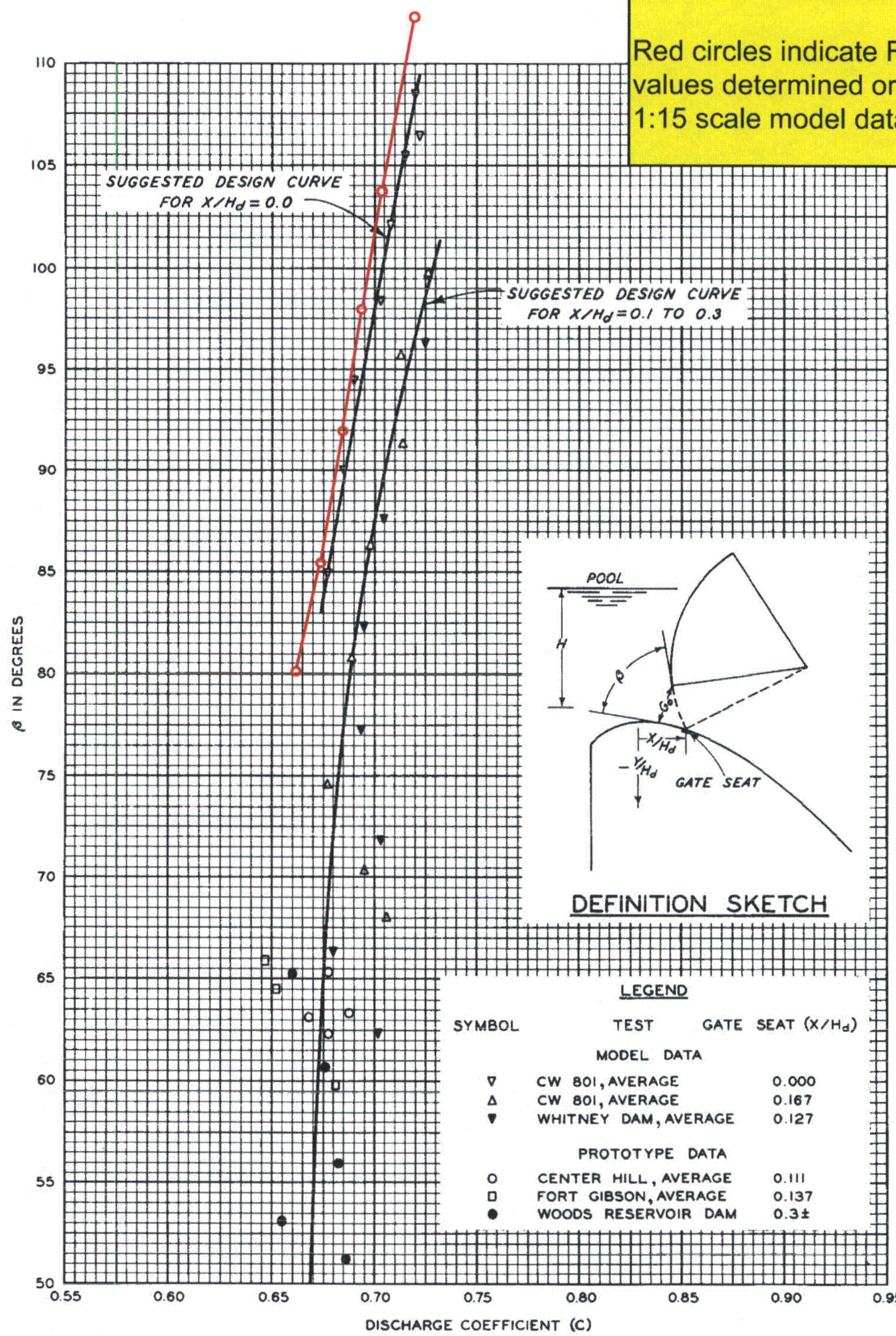
* Value of Cg is estimated; no model data, so no value for Q; geometrical parameters not needed


Ft. Patrick Henry 1:15 Scale Model
Cg vs. Hc
V = 10 ft, Model Data
V = 10 ft, Extrapolation
V = 13 ft, Model Data
V = 13 ft, Extrapolation
V = 17 ft, Model Data
V = 17 ft, Extrapolation
V = 21 ft, Model Data
V = 21 ft, Extrapolation
V = 25 ft, Model Data
V = 25 ft, Extrapolation
V = 31 ft, Cg for Extrapolated HLmin
V = 31 ft, Extrapolation
Cg
0.78
0.76
0.74
0.72
0.7
0.68
0.66
0.64
0
10
20
30
40
50
60
Hc, feet

Calculation No: CDQ000020080010

Page A30
Attachment A13
Source: Reference A4

Red circles indicate Fort Patrick Henry values determined or estimated from 1:15 scale model data



FORMULA

$Q = CG_oB\sqrt{2gH}$

WHERE:

G_o = NET GATE OPENING
B = GATE WIDTH
H = HEAD TO CENTER OF GATE OPENING

TAINTER GATES ON SPILLWAY CRESTS

DISCHARGE COEFFICIENTS

HYDRAULIC DESIGN CHART 311-1

WES 3-56

Tennessee Valley Authority

Tainter Gate Ratings

Basic Model and Prototype Data

	MODEL					PROTOTYPE		
Project	Model Scale	No. of Spill-way Bays	Crest Length L	Approach Width W	Up-stream Depth P	Crest Elev.	Design Head H_o	Pier Nose Radius R
Apalachia	1:28.72	6	6.684	8.00	3.38	1257.0	23.0	3.00
Boone	1:50	5	3.480	(1)	(1)	1350.0	35.0	12.75(2) 11.25(3) 3.50(4)
Ft. Patrick Henry	1:15	1	2.333(5)	2.77(5)	2.29	1228.0	35.0	3.25
Hales Bar	1:34.76	6	6.908(6) 6.905(7)	7.94	0.921	616.0	18.0	3.00
Hiwassee	1:55	7	4.050	8.00	6.35	1503.5		3.00
Watts Bar	1:35	6	6.866	8.00	1.5	713.0	23.5	3.25
Wheeler	1:34.35	6	6.984	7.97	1.253	541.3	16.5	2.50

(1) Variable because approach was reproduced in model.

(2) Right end pier.

(3) Left end pier.

(4) Intermediate piers.

(5) Except as noted on data tabulations.

(6) Gates partially opened.

(7) Gates raised above water surface.

Appendix B

Appendix B: Hydrostatic Loads on the Spillway Tainter Gates

The hydrostatic loads on the spillway tainter gates for Fort Patrick Henry Dam can be found in the following calculations.

B1 References

B1. "Watts Bar Dam – Flood and Earthquake Analysis on Radial Spillway Gates, pages 76-100" Tennessee Valley Authority, HEPE3WBHSQN-WBNBLNBFN.

B2. Calculations

Reference B1 evaluates the structural capacity of the radial spillway gates at Watts Bar Dam. This reference was used as a basis for evaluating the margin between the forces on the closed gates (FR_{closed}) when the headwater elevation is at the top of the gate (1263 feet) and when the gates are completely open (FR_{open}) and the headwater elevation is at 1288 feet at Fort Patrick Henry Dam. The margin is defined as the ration of FR_{open} to FR_{closed}. The calculation of these forces and the results of this comparison are shown in Figure B1.

Comparison of forces when gates are closed and HW is at 1263 feet (top of gate) vs. when gates are fully open and HW at an elevation of 1288 feet.				
	Attribute	Symbol	Value	
	top elev	Zo	1263	
	trun elev	Ztr	1241	
	sill elev	Zsill	1227.41	
	radius	R	36	
	length	L	35	
	angle up	α2	37.67	
	angle lwr	α	22.18	
	angle tot	θ	59.85	
	area of lower slice	Aslice1	676.88	
	proj area	AProjected	1245.65	
	Desgn LdH	FRx	1383179.73	
	Result elv	Z1	1239.27	
	Result ang deg		2.75	
	Result ang rad		0.05	
	Result Dsgn	Horiz	1381587.84	
	Area slice upper	Aslice2	426.04	
	Area triangle	Atriangle	313.45	
	project vert	x1	7.50	
	vert weight water	FRy	114685.91	
	Resultant load - Gates Closed	FR_{closed}	**1387926.15**	
	vert open fm calc	calc App A	31.54	
	max hw	calc	1288.00	
	lwr lip elev	Z2	1258.95	
	bot angle	α3	29.91	
	top elev	Zo	1277.00	
	project area for h ld	AProjected	631.74	
	Flood LdH	FRx	789401.75	
	Height over gate	y1	11.00	
	Height ratio to orig		1.70	
	project vert	x2	31.05	
	Flood LdV1		746039.69	
	Flood ILdV2		357525.12	
	Total Flood LdV	FRy	1103564.81	
	Resultant load - Gates Fully Open	FR_{open}	**1356838.39**	
	Margin	FR_{open}/FR_{closed}	**0.98**	

Figure B1: Ft. Patrick Henry Spillway Gate Margin Evaluation

TVA

Calculation No. CDQ000020080010	Rev: 1	Plant: GEN	Page: B4
Subject: Dam Rating Curve, Fort Patrick Henry	Prepared C.Grace		
	Checked A. Murr		

BWSC | BARGE WAGGONER SUMNER & CANNON, INC.

Project: Hydro Static Force on Gate
Description: Diagram
Project No. ______ Sheet No. ______ of ______
Designer: ______ Date: ______
Checker: ______ Date: ______

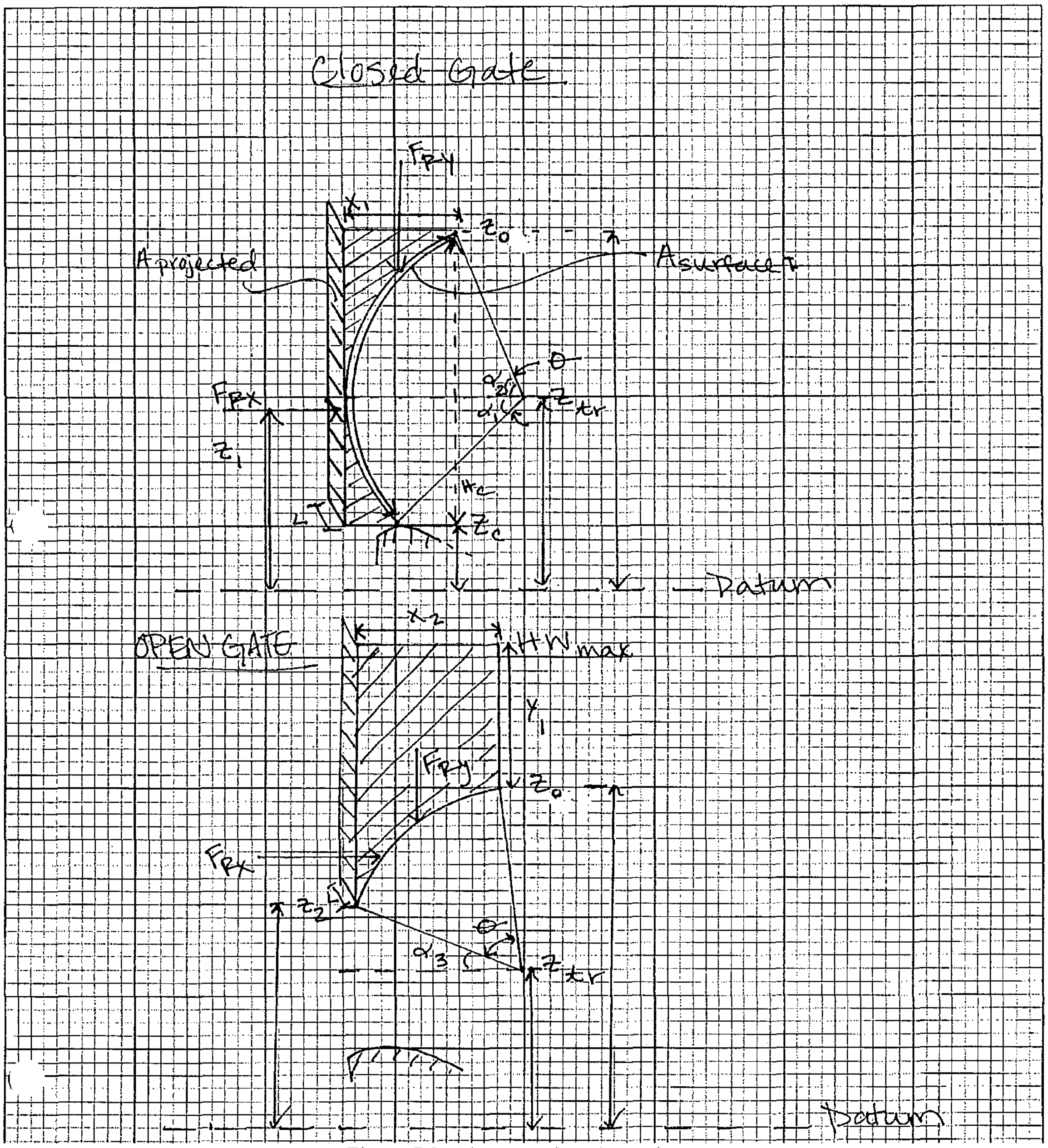
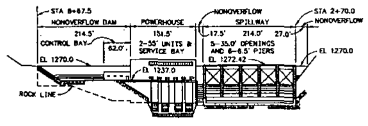
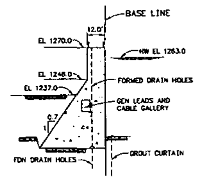


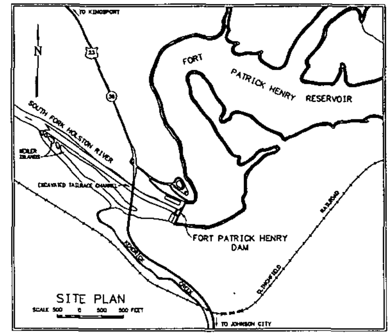
Figure B2: Diagram of Hydrostatic Forces



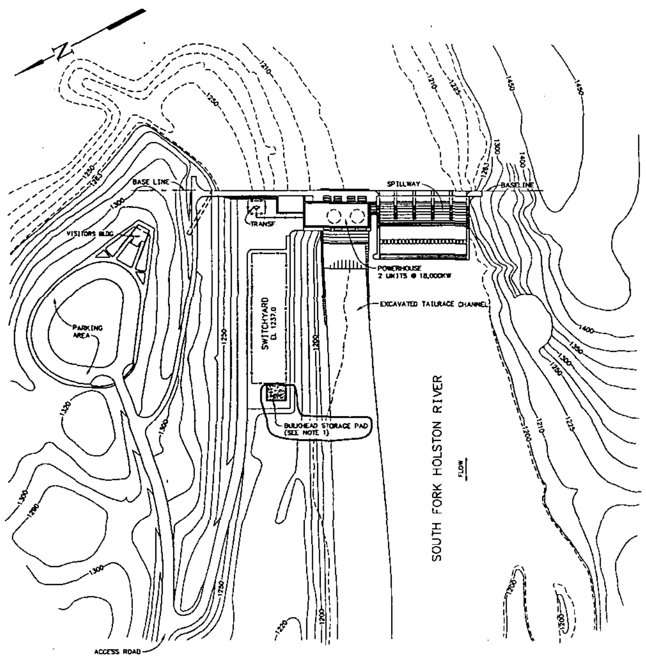
DOWNSTREAM ELEVATION



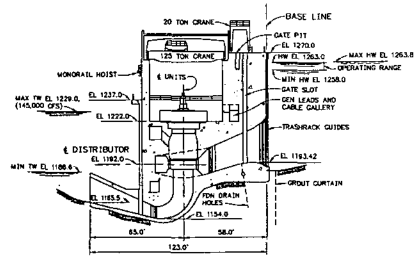
SECTION–NONOVERFLOW DAM



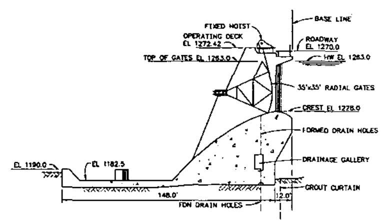
SITE PLAN



PLAN



SECTION–POWERHOUSE



SECTION–SPILLWAY

SCALE 100 0 100 200 FEET
PLAN & DOWNSTREAM ELEVATION

SCALE 30 0 30 60 FEET
SECTIONS

NOTES
1. FOR BULKHEAD STORAGE PAD DETAILS, SEE SHEET 71W220.

R 8 | 2-17-?? | KSR | KGK | KSR | RAJ | RWT | RWT | MAC
ELECTRONICALLY RESTORED, ADDED CONCRETE PAD AND NOTE 1 PER DCN# FPH-03-1

SCALE: 100'=1'-0" EXCEPT AS NOTED

MAIN DAM WORKS

GENERAL PLAN
ELEVATION & SECTIONS

DRAWN BY	CHECKED BY	SUPERVISED BY	REVIEWED BY	APPROVED BY
B.W.W.	W.D.S.	O.H.R.	A.A.M.	R.A.M.

FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
RIVER SYSTEMS OPERATIONS

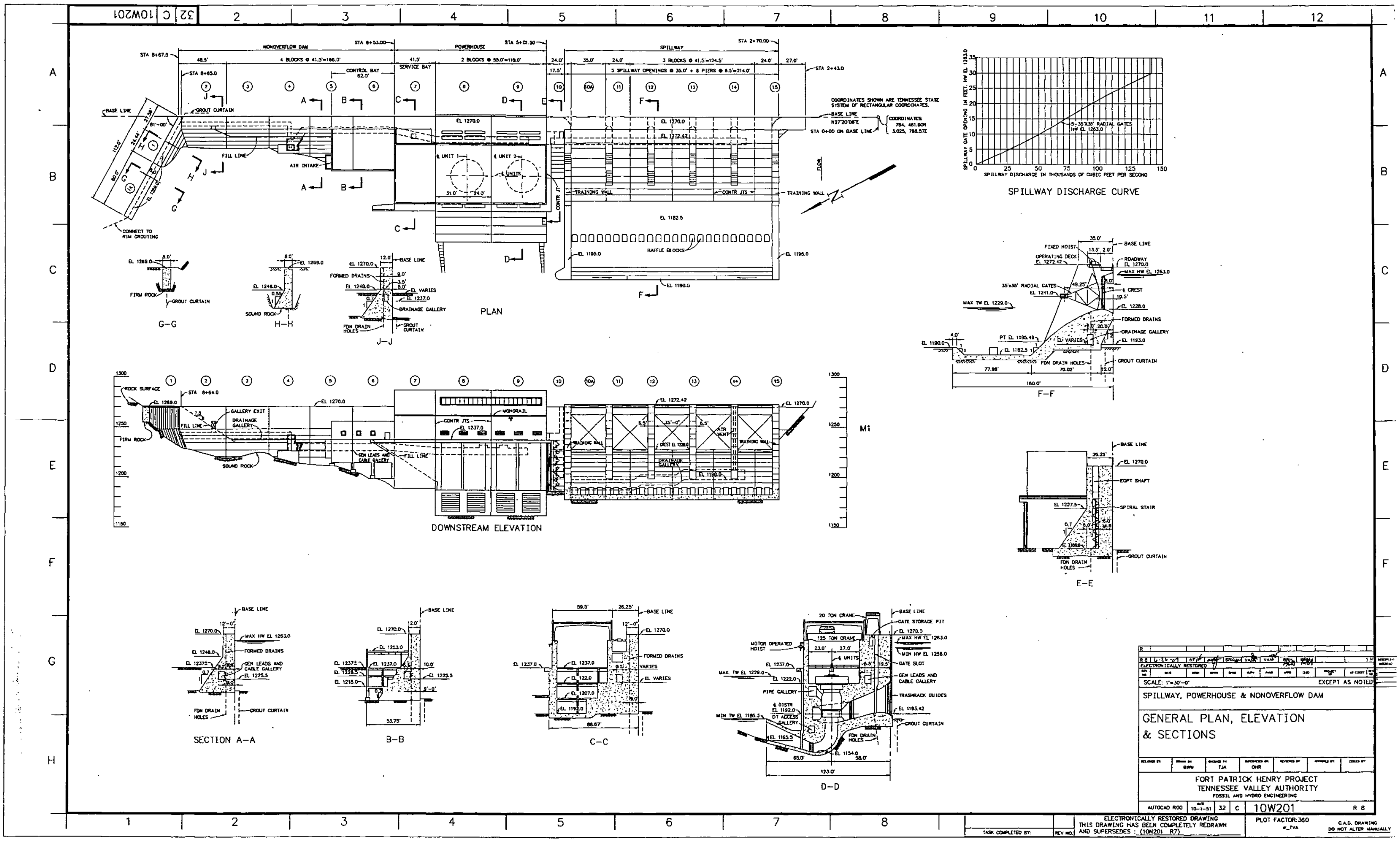
AUTOCAD 2002 | 7-13-51 | 32 | C | 10W200 | R 8

ELECTRONICALLY RESTORED DRAWING
THIS DRAWING HAS BEEN COMPLETELY REDRAWN AND SUPERSEDES :(10N200 R7)

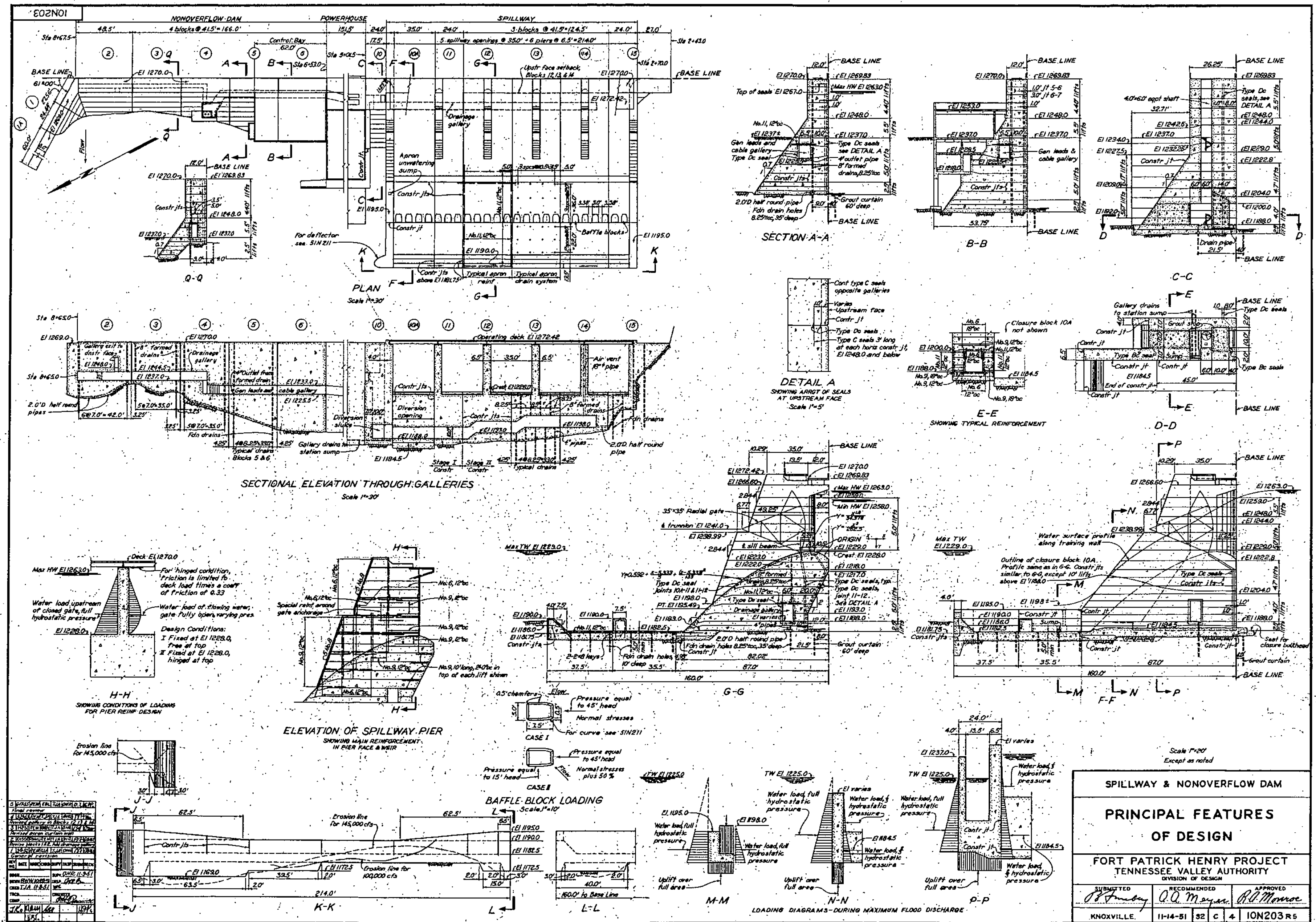
PLOT FACTOR:1200
W_TVA

C.A.D. DRAWING
DO NOT ALTER MANUALLY

TASK COMPLETED BY: | REV NO.



NONOVERFLOW DAM
POWERHOUSE
SPILLWAY
PLAN
SPILLWAY DISCHARGE CURVE
SPILLWAY GATE OPENING IN FEET, HW EL 1263.0
SPILLWAY DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND
5-35'X35' RADIAL GATES HW EL 1263.0
COORDINATES SHOWN ARE TENNESSEE STATE SYSTEM OF RECTANGULAR COORDINATES.
G-G
H-H
J-J
F-F
DOWNSTREAM ELEVATION
E-E
SECTION A-A
B-B
C-C
D-D
R 8 ELECTRONICALLY RESTORED
SCALE: 1"=30'-0" EXCEPT AS NOTED
SPILLWAY, POWERHOUSE & NONOVERFLOW DAM
GENERAL PLAN, ELEVATION
& SECTIONS
BWW TJA OHR
FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
FOSSIL AND HYDRO ENGINEERING
AUTOCAD R00 10-1-51 32 C 10W201 R 8
ELECTRONICALLY RESTORED DRAWING
THIS DRAWING HAS BEEN COMPLETELY REDRAWN
AND SUPERSEDES : (10N201 R7)
PLOT FACTOR:360
W_TVA
C.A.D. DRAWING
DO NOT ALTER MANUALLY



SPILLWAY & NONOVERFLOW DAM

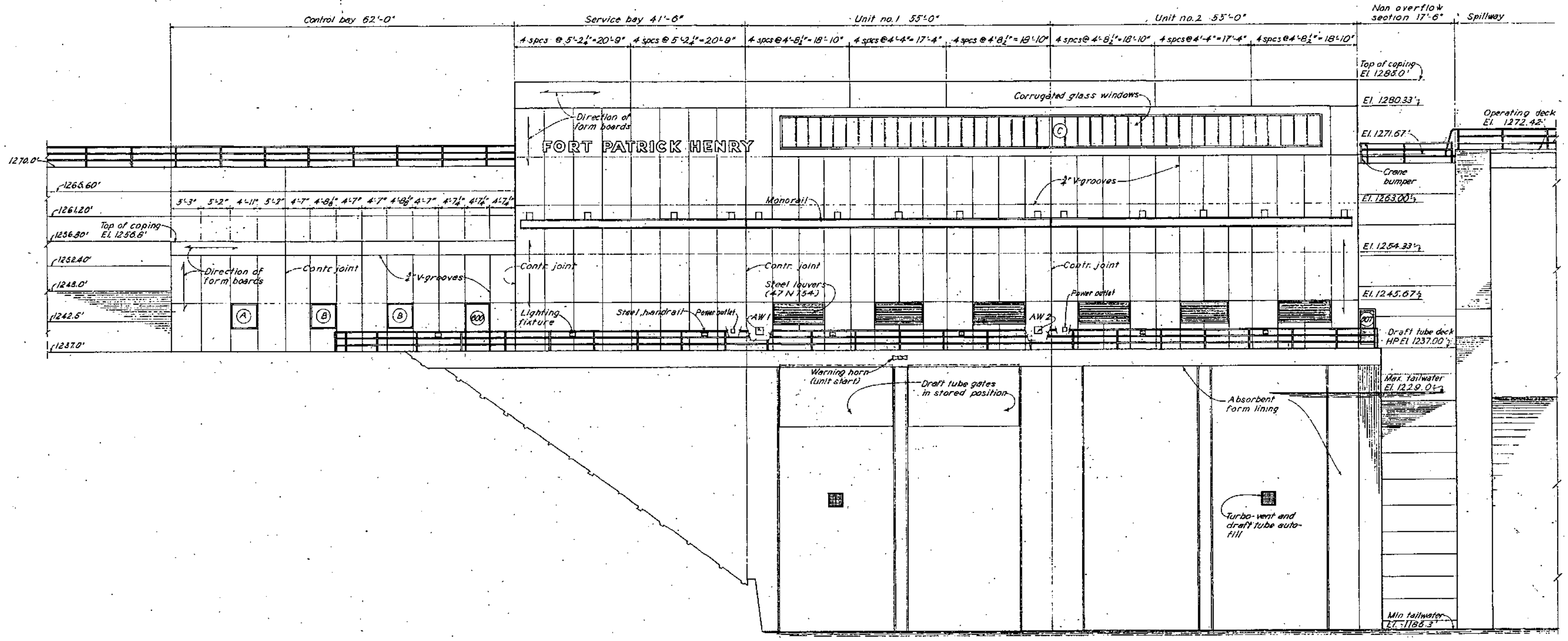
PRINCIPAL FEATURES OF DESIGN

FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF DESIGN

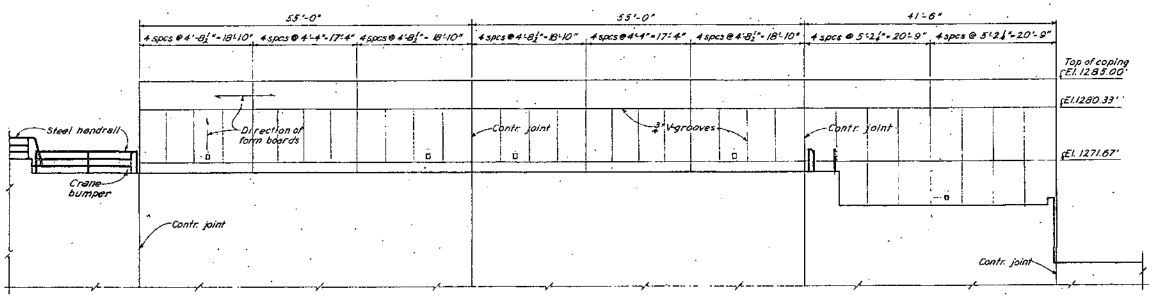
SUBMITTED	RECOMMENDED	APPROVED
P.J. Jumbey	O.Q. Meyer	R.A. Monroe

KNOXVILLE. 11-14-51 | 32 | C | 4 | 10N203 R5

46N401



DOWNSTREAM ELEVATION



UPSTREAM ELEVATION

NOTES:
Exterior and interior concrete finishes to be as follows:
1. Type A plain wood forms, Construction Specification G-8.
a. Horizontal T&G boards - non-overflow blocks of dam, non-over flow side and downstream face of training walls, all interior concrete wall surfaces.
b. T&G boards in directions indicated on exterior elevations.
2. Absorbent form lining boards in a vertical direction without horizontal joints between lifts. For location see civil drawings.

Scale: 1/8" = 1'-0"

POWERHOUSE

ARCHITECTURAL ELEVATIONS SHEET 1

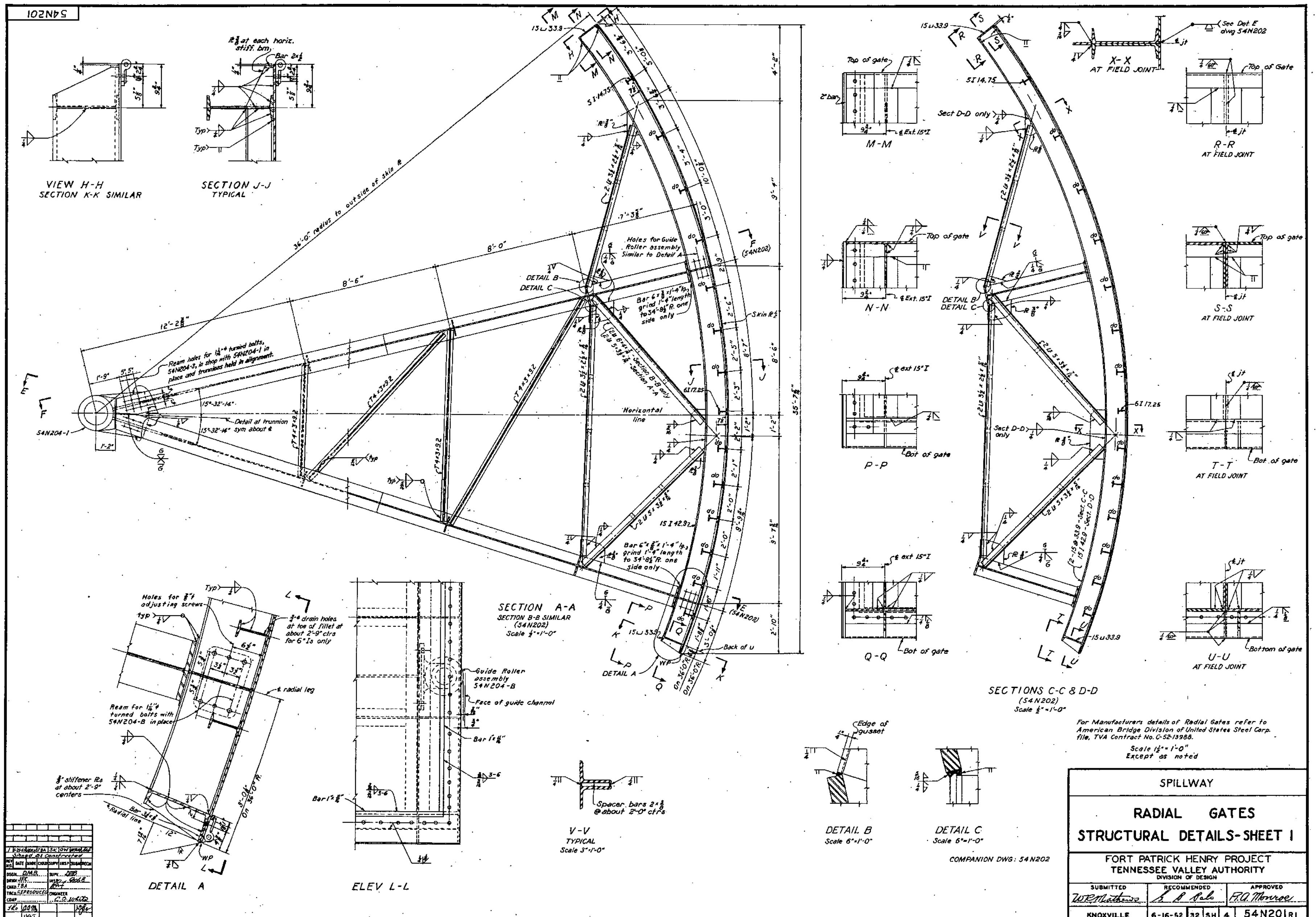
FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF DESIGN

SUBMITTED	RECOMMENDED	APPROVED
H.H. Ostrander	Henry B. Cone	R.A. Monroe

KNOXVILLE | 11-20-52 | 32 | A | 4 | 46 N 401 R0

RECORD DRAWING AS CONSTRUCTED

As constructed 1-13-55



SPILLWAY

RADIAL GATES

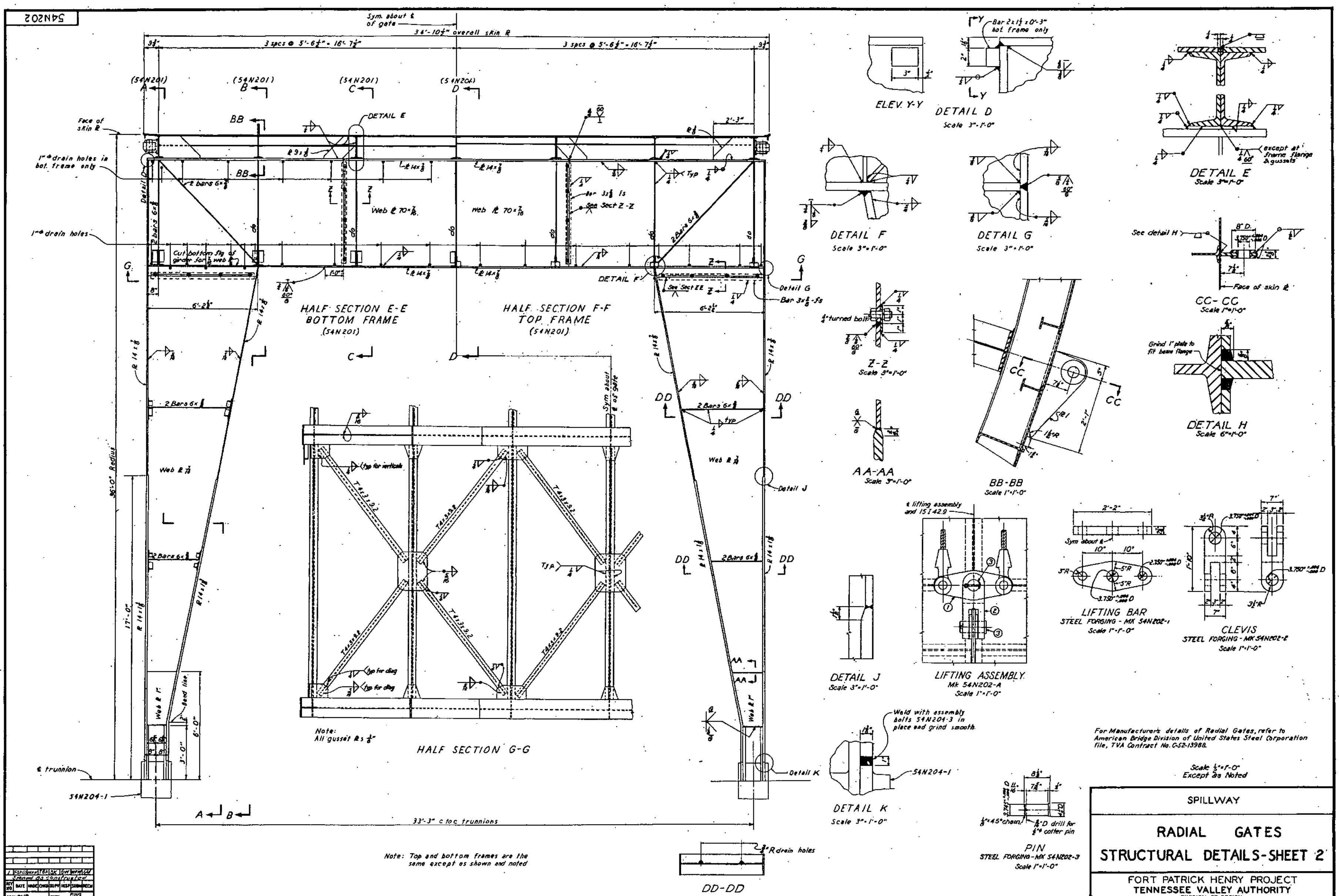
STRUCTURAL DETAILS-SHEET 1

FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF DESIGN

SUBMITTED	RECOMMENDED	APPROVED
W.R. Mathews	S. R. Dale	R.A. Monroe

KNOXVILLE	6-16-52	32	SH	4	54N201 R1

RECORD DRAWING AS CONSTRUCTED



For Manufacturer's details of Radial Gates, refer to American Bridge Division of United States Steel Corporation file, TVA Contract No. C-52-13988.

Scale ½"=1'-0"
Except as Noted

COMPANION DWG: 54N201

SPILLWAY

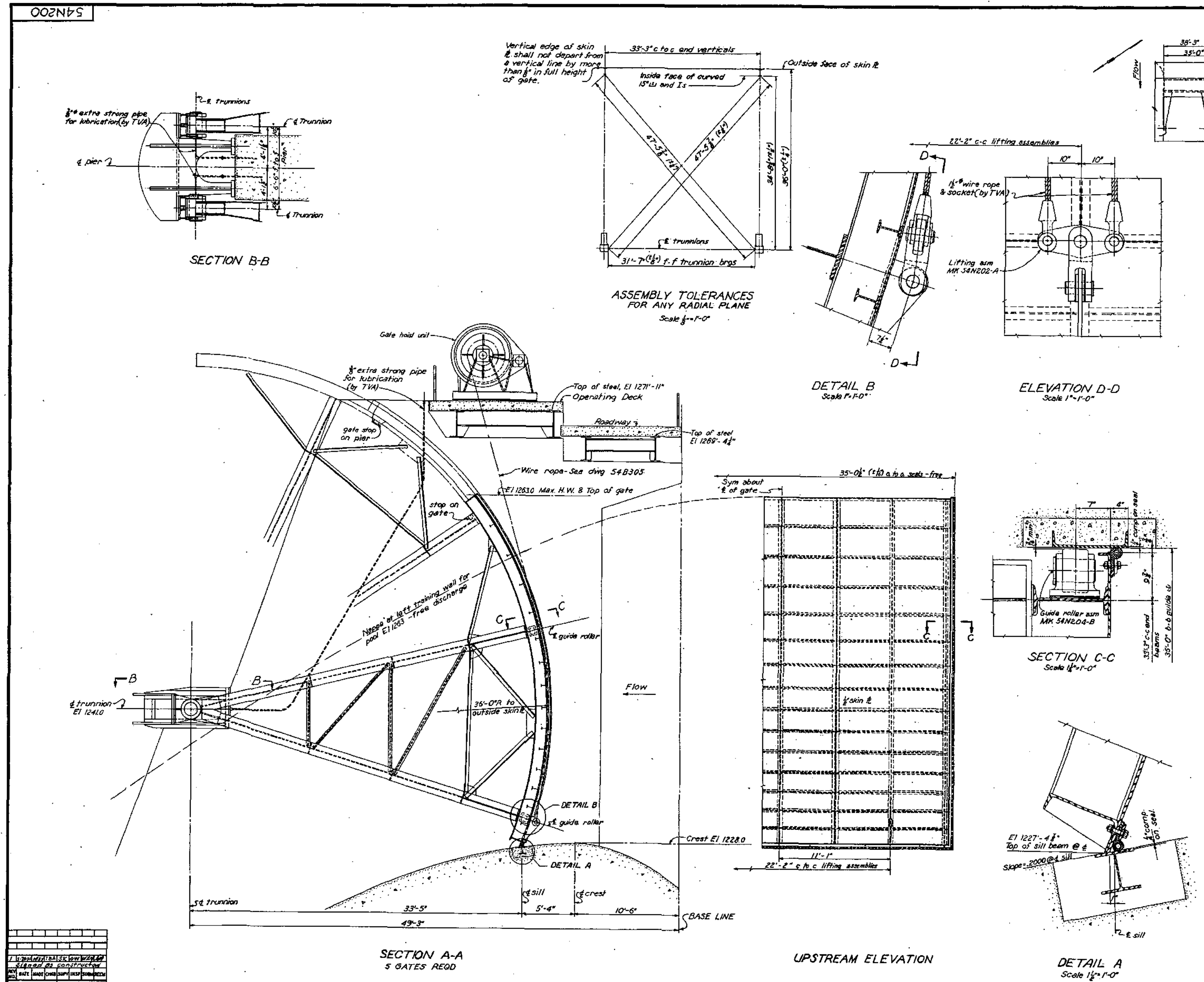
RADIAL GATES
STRUCTURAL DETAILS - SHEET 2

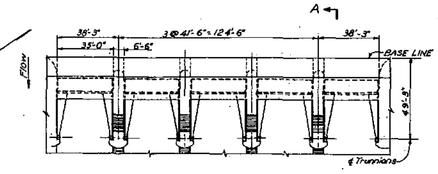
FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF DESIGN

SUBMITTED	RECOMMENDED	APPROVED
W.R. Mathews		R.A. Monroe

KNOXVILLE	6-16-52	32	SH	4	54N202 R1

RECORD DRAWING AS CONSTRUCTED





KEY PLAN
Scale 1"=30'

MARK	DESCRIPTION	Nº REQD	MATERIAL
	Gate Structure	5	Str Steel
54N202-1	Lifting Bar	10	Steel forging
-2	Clevis	10	" "
-3	Pin & Cotter	20	" "
54N203-1	Bottom Rubber Seal	5	Rubber
-2	Corner Rubber Seal	10	Rubber
-3	Side Rubber Seal	5	Rubber
-4	Side Rubber Seal	5	Rubber
-5	Seal Bar	5	Steel
-6	Seal Bar	5	Steel
-7	Bottom Seal Bar	5	Steel
-8	Seal Bolt	1150	Bolt Steel
-9	Seal Bolt	550	Bolt Steel
-10	Bevel Washer	550	Steel
54N204-1	Gate Trunnion Bearing	10	Steel Casting
-2	Trunnion Bearing Bushing	10	Bronze
-3	Finished Bolts	240	Bolt Steel
-4	Fixed Trunnion Bearing	10	Steel Casting
-5	Trunnion Pin	10	Steel Forging
-6	Lock ℞	20	Steel
-7	Hex. Hd Cap Scrs 1"ϕ×2½" lg	40	Bronze
-8	Flat Point Set Scrs ⅝"ϕ×1¾" lg	40	Bolt Steel
-9	Flat Point Set Scrs ⅝"×2¼" lg	60	Bolt Steel
-10	Guide Roller	20	Steel Forging
-11	Guide Roller Bearing	20	Steel Casting
-12	Guide Roller Pin	20	Steel Forging
-13	Guide Roller Bushing	20	Bronze & Graphite
-14	Lock Plate	20	Steel
-15	Shims	20	Steel
-16	Finished Bolts	80	Steel
-17	Dowel Pins ⅝"ϕ×⅝"	120	Steel
-18	Dowel Pin ¼"ϕ×1"	80	Steel
-19	Hex. Hd Cap Screw ⅞"ϕ×2½"	40	Bronze
-20	Hex. Hd Cap Screw ⅝"ϕ×1½"	40	Bronze
-21	Machine Bolts	120	Bolt Steel

Items listed above are for 5 gates. 5 gates reqd.

For Manufacturer's details of Radial Gates refer to American Bridge Division of United States Steel Corp. file, TVA Contract No. C-52-13988.

Scale 1/4"=1'-0"
Except as Noted

SPILLWAY

RADIAL GATES ARRANGEMENT

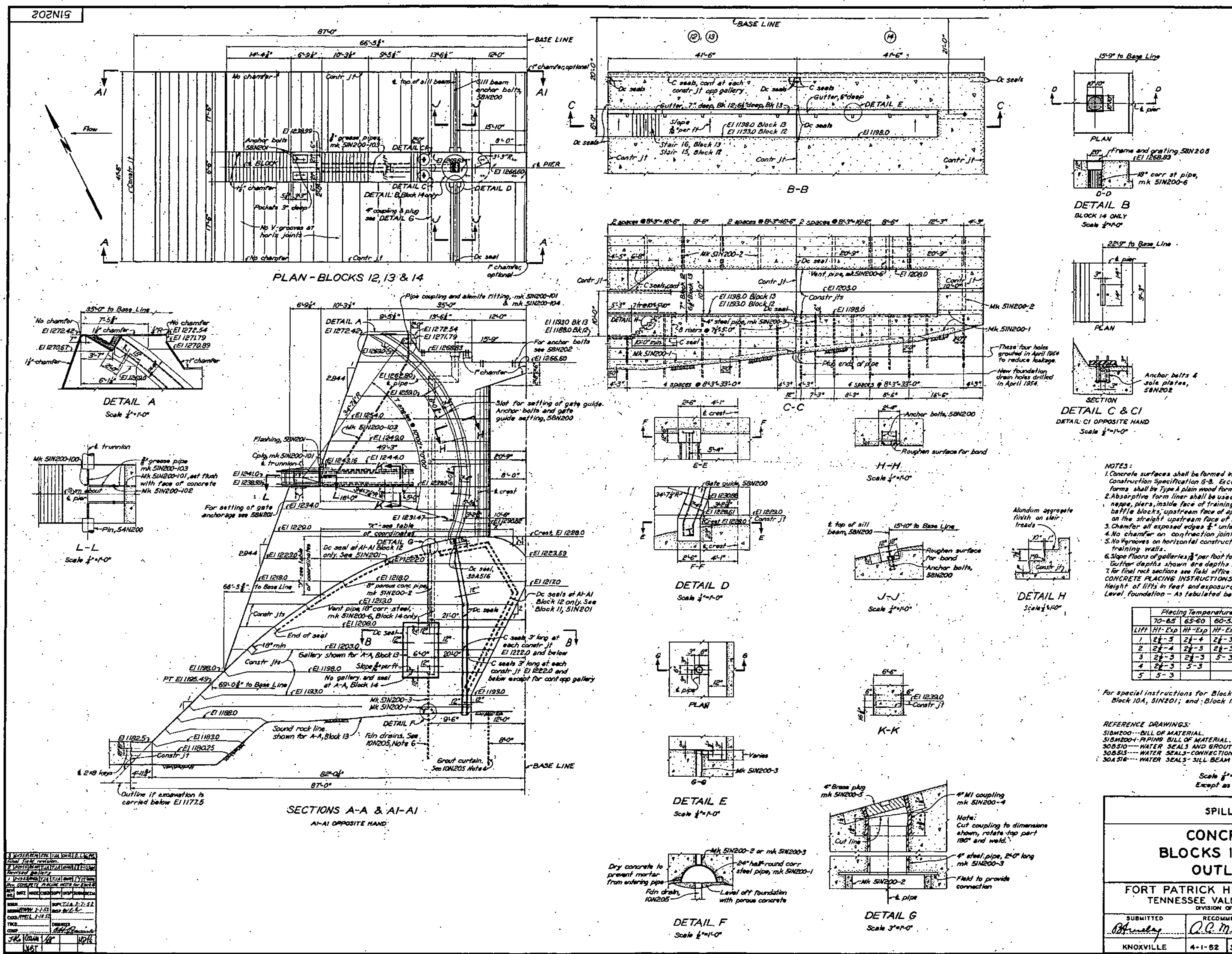
FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF DESIGN

SUBMITTED	RECOMMENDED	APPROVED
W. R. Mathews	E. B. Dale	R. A. Monroe

KNOXVILLE | 6-16-52 | 32 | SH 4 | 54N200 R1

RECORD DRAWING AS CONSTRUCTED 1-3-55

Signed as constructed



COORDINATES OF WEIR PROFILE		
DNSTR FROM ℄ CREST		
$y = \frac{x^{1.8}}{34.378}$ from x=0 to x=5.333; $y = 0.592 + \frac{x-5.333}{3} + \frac{(x-5.333)^2}{133}$ from x=5.333 to x=58.533		
X	Y	ELEV
†0.0'	0.0'	1228.000
2.00	0.101	1227.899
4.00	0.353	1227.647
▲4.352	0.411	1227.589
6.00	0.729	1227.271
▲6.314	0.795	1227.205
8.00	1.179	1226.821
10.00	1.689	1226.311
12.00	2.260	1225.740
14.00	2.890	1225.110
16.00	3.581	1224.419
18.00	4.332	1223.668
20.00	5.143	1222.857
22.00	6.014	1221.986
24.00	6.945	1221.055
26.00	7.937	1220.063
28.00	8.989	1219.011
30.00	10.100	1217.900
32.00	11.272	1216.728
34.00	12.504	1215.496
36.00	13.797	1214.203
38.00	15.149	1212.851
40.00	16.562	1211.438
42.00	18.034	1209.966
44.00	19.567	1208.433
46.00	21.160	1206.840
48.00	22.813	1205.187
50.00	24.527	1203.473
52.00	26.300	1201.700
54.00	28.134	1199.866
56.00	30.027	1197.973
58.00	31.981	1196.019
*58.533	32.512	1195.488
UPSTR FROM ℄ CREST		
$y = \frac{x^3}{262.5}$		
X	Y	ELEV
†0.0'	0.0'	1228.000
2.00	0.030	1227.970
4.00	0.244	1227.756
6.00	0.823	1227.177
8.00	1.950	1226.050
10.00	3.810	1224.190
‡10.50	4.410	1223.590

† ℄ Crest
▲ Edge of sill beam slot
* P.T.
‡ Upstr face

NOTES:

1. Concrete surfaces shall be formed in accordance with General Construction Specification G-8. Except as called for in Note 2, forms shall by Type A plain wood forms, horizontal T & G boards.
2. Absorptive form liner shall be used on the entire surface of nappe, piers, inside face of training walls, all sides of apron baffle blocks, upstream face of apron sill, and above El 1253.5 on the straight upstream face of Blocks 10 and 15.
3. Chamfer all exposed edges ¾" unless otherwise noted.
4. No chamfer on contraction joints in surface of nappe.
5. No V-grooves on horizontal construction joints in spillway and training walls.
6. Slope floors of galleries ⅛" per foot toward gutters as indicated. Gutter depths shown are depths below adjacent floor.
7. For final rock sections see field office drawings 32-PC-4-51K1241, 1242.

CONCRETE PLACING INSTRUCTIONS:

Height of lifts in feet and exposure time in days for each lift: Level foundation – As tabulated below.

	Placing Temperature – Degrees F				
	70-65	65-60	60-55	55-50	Below 50
Lift	Ht-Exp	Ht-Exp	Ht-Exp	Ht-Exp	Ht-Exp
1	2½-5	2½-4	2½-3	2½-3	5-3
2	2½-4	2½-3	2½-3	5-3	
3	2½-3	2½-3	5-3		
4	2½-3	5-3			
5	5-3				

For special instructions for Block 10 see 51N200; Block 10A, 51N201; and Block 15, 51N203.

REFERENCE DRAWINGS:

51BM200---BILL OF MATERIAL.
51BM200-1-PIPING BILL OF MATERIAL.
30B510---WATER SEALS AND GROUT STOPS.
30B515---WATER SEALS-CONNECTION OF COPPER TO STEEL.
30A516---WATER SEALS-SILL BEAM CONNECTIONS

Scale ⅛"=1'-0"
Except as noted.

SPILLWAY

CONCRETE BLOCKS 12, 13 & 14 OUTLINE

FORT PATRICK HENRY PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF DESIGN

SUBMITTED	RECOMMENDED	APPROVED
[signature]	A. C. Meyer	A. A. Monroe

KNOXVILLE | 4-1-52 | 32 | C | 4 | 51N202 R3

RECORD DRAWING AS CONSTRUCTED [signature] 1-9-65