Tennessee Valley Authority, Post Office Box 2000, Spring City, Tennessee 37381

John H. Garrity
Vice President, Watts Bar Nuclear Plant

AUG 22 1991

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Gentlemen:

In the Matter of the Application of	)	Docket Nos. 50-390
Tennessee Valley Authority	)	50-391

WATTS BAR NUCLEAR PLANT (WBN) UNITS 1 AND 2 - RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION (RAI) ON FINAL SAFETY ANALYSIS REPORT (FSAR) SECTION 2.5, AMENDMENTS 54-63 (TAC 77061 AND 77548)

Reference: Letter from NRC to TVA, Watts Bar Nuclear Plant - Request for Additional Information on FSAR Section 2.5, Amendment 54-63 (TAC 77061 and 77548), July 9, 1991

By the referenced letter, NRC requested additional information on Watts Bar FSAR Section 2.5, Amendments 54-63.

Enclosed find the TVA responses to these Geotechnical issues. No new commitments are contained in this submittal. Referenced calculations and documentation are available on site for NRC review. No FSAR text changes are considered necessary.

If any additional questions exist relative to the enclosed, please contact P. L. Pace at (615)-365-1824.

Very truly yours,

TENNESSEE VALLEY AUTHORITY

John H. Garrity

John H. Garrity

Enclosure
cc: See page 2

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PDR ADOCK 05000390
K PDR

U.S. Nuclear Regulatory Commission

AUG 22 1991

cc (Enclosure):

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ENCLOSURE

WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

NRC Question 1:

What is the basis for the assumptions made in FSAR Section 2.5.4.2.2.6.1 (Amendment 63) concerning the proportions of different rock types (and the modulus value of rock type 3), in the four settlement calculations made for comparison of building settlements?

TVA Response 1:

Settlement calculations were made to establish bounding limits and average conditions for comparison to the settlement calculations made for the six core holes tested with the pressuremeter.

Calculations which used 100% of a single rock type were developed to determine the sensitivity of the calculated settlement to rock type. The percentages of each rock type for the calculation considering a combination of rock types were developed from the average of holes 20, 29, 39, 41, 43 and 52 for the upper 50 feet and from the average of holes 20 and 39 for below 50 feet as indicated in Section 2.5.4.2.2.6.3.

As shown by FSAR Figure 2.5-211, the moduli assumed for rock types 1 and 2 are a lower bound of the moduli determined from the rock core data.

The modulus of 1×10^6 psi for rock type 3, limestone, is based on the following:

a. This value is near the upper range of reliability of readings from the Menard Pressuremeter due to flexibility of the instrument.
b. The modulus value is in the lower (conservative) range of values found in technical literature.
c. The modulus value is significantly lower than the modulus for concrete with a comparable unit weight.

Amendment 63 corrected typographical errors in Section 2.5.4.2.2.6.1. The information contained in this section is essentially unchanged since being submitted prior to Amendment 54. The acceptance of this information is documented in Section 2.5 of the NRC Safety Evaluation Report related to the operation of Watts Bar Nuclear Plant, Units 1 and 2, June 1982 and Section 2.5 of Supplement No. 3 to the report, January 1985.

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WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
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NRC Question 2:

The lower half of page 2.5-102 and the full page of 2.5-103 of the FSAR are left blank without any notation; however, Amendment 59 is marked at the margins of these blank pages. Confirm that these blank spaces were left intentionally blank.

TVA Response 2:

The lower half of page 2.5-102 and the full page of 2.5-103 were intentionally left blank. Since the information on these pages was deleted by Amendment 59, a revision bar and the amendment number were placed in the right margin to denote the change. By maintaining page 2.5-103 as a blank page when the deletion was made the following pages were not affected.

ENCLOSURE

WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

NRC Question 3:

In Section 2.5.4.2.2.9.2 (Amendment 63), it is stated that all rock supported Category I structures were designed for total settlement of 1 to 2 inches and differential settlement of 1 inch. Provide the basis for this value of the differential settlement. Also state, and justify, the amounts of differential settlements for which Category I buried pipes entering the structures from the soil or rock were designed.

TVA Response 3:

The basis for the 1 inch differential settlement is TVA Report No. 9-2004, "Engineering Analysis of Rock Foundation," March 2, 1971, which is documented in calculation WCG-1-489 (B26891222100).

The revisions made to FSAR Section 2.5.4.2.2.9.2 by Amendments 54 through 63 were minor wording clarifications that did not change the technical content of the section. NRC staff acceptance of TVA's evaluation of the effects of differential settlement on safety-related components located at the interfaces of rock-supported structures is documented in Section 2.5.4.3 of the NRC Safety Evaluation Report related to the operation of Watts Bar Nuclear Plant, Units 1 and 2, June 1982 and in Section 2.5.4.3 of Supplement No. 3 to the report dated January 1985.

The ERCW and HPFP piping are the only safety related buried piping systems. These pipes were evaluated for the maximum building interface differential settlement of 4.8 inches. The evaluation is documented in TVA Calculation WCG-1-867, "Buried ERCW and HPFP Piping/Settlement Evaluation" (B18910429253). The potential settlements were determined using the strain criteria shown by FSAR Table 2.5-65 which was previously accepted by the NRC staff. The potential settlements along the length of the ERCW pipe are shown on Figures 2.5-571 through 2.5-575 and are documented by TVA Calculation WCG-1-868, "Evaluation of Potential Settlement," Revision 1 (B18910503269).

ENCLOSURE

WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

NRC Question 4:

a. Justify the appropriateness of the values of the dynamic soil properties summarized in Tables 2.5-17a through 2.5-17d and used in the soil-structure interaction analysis (FSAR Section 2.5.4.4.2.4, Amendment 63).

b. Also provide the sources and the bases for acceptance of the curves showing the shear modulus and damping variations with strain (FSAR Figures 2.5-233A through 2.5-233K, Amendment 63).

TVA Response 4:

The tables and figures summarizing the dynamic soil properties, and showing the shear modulus and damping variations with strain were submitted as part of Enclosure 4 of TVA's letter from M. Ray to the NRC, "Watts Bar Nuclear Plant (WBN) - Revision to Corrective Action Plan (CAP) for Seismic Analysis," June 29, 1989. Justification of the values and the basis of acceptance is contained in Attachment 0-1 of Enclosure 4.

NRC acceptance of the use of these properties in the soil-structure interaction analyses of the Category I structures founded on soils is documented in Section 3.3 of NRC Inspection Report No. 50-390/89-21 and 50-391/89-21, May 10, 1990.

ENCLOSURE

WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

NRC Question 5:

Provide a copy of a sample calculation of liquefaction potential evaluation for the material located about 17.5 ft below the surface discussed in FSAR Section 2.5.4.8, page 2.5-128 (Amendment 63); justify the various assumptions made (including the appropriateness of material properties used) in the analysis.

TVA Response 5:

Details of the methodologies used in the calculations of liquefaction potential are contained in reference 167 of FSAR Section 2.5.4.8, "TVA Watts Bar Nuclear Plant - Liquefaction Evaluation of the ERCW Pipeline Route," Revision 1, March 17, 1982 (CEB820317026).

The revisions made to FSAR Section 2.5.4.8 by Amendments 54 through 63 were typographical clarifications that did not change the technical content of the section. NRC staff acceptance of TVA's evaluation of liquefaction potential at Watts Bar is detailed in Section 2.5.4.4 of the NRC Safety Evaluation Report related to the operation of Watts Bar Nuclear Plant, Units 1 and 2, June 1982, and Section 2.5.4.4 of Supplement No. 3 to the report dated January 1985.

ENCLOSURE

WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

NRC Question 6:

It is stated in FSAR Section 2.5.5.2.3 (Amendment 59) that no stability analysis has been performed for station 6+78 of trench A because the soil profile was not identified above the top of the shale. TVA states that this is not considered critical since 17 of the 18 cross-sections of trench A were analyzed and found to be adequate. Provide, for the staff review, the stability analysis calculations for the station 5+78 of trench A and the station 2+50 of trench B for which the factors of safety against slope failure are 1.03 and 1.00 respectively.

TVA Response 6:

Stability analyses related to the underground barriers are documented in Calculation WCG-1-737, "Analysis of As-Built Conditions for Remedial Treatment for Liquefaction Potential for ERCW Pipeline" (B26910401151). The stability analysis for station 5+78 of Trench A is shown on pages 69a to 78. The stability analysis for station 2+50 of Trench B is shown on pages 164a to 174. These pages are attached. FSAR Figure 2.5-583 contains the criteria, material properties and methodology used in the analyses.

ENCLOSURE

WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Response References:

1. TVA Report No. 9-2004, "Engineering Analysis of Rock Foundation," March 2, 1971, documented in TVA Calculation WCG-1-489, "Watts Bar Nuclear Plant Engineering Analysis of Rock Foundation" (B26891222100).

2. TVA Calculation WCG-1-867, "Buried ERCW and HPFP Piping/Settlement Evaluation," Revision 0 (B18910429253).

3. TVA Calculation WCG-1-868, "Evaluation of Potential Settlement," Revision 1 (B18910503269).

4. TVA letter from M. J. Ray to the NRC dated June 19, 1989, "Watts Bar Nuclear Plant (WBN) - Revision to Corrective Action Plan (CAP) for Seismic Analysis."

5. NRC letter from B. D. Liaw to O. D. Kingsley, Jr. dated May 10, 1990, "NRC Inspection Report Nos. 50-390/89-21 and 50-391/89-21."

6. TVA Report No. CEB 82-6, "Liquefaction Evaluation of the ERCW Pipeline Route," Revision 1 (CEB820317026).

7. NRC Safety Evaluation Report related to the operation of Watts Bar Nuclear Plant, Units 1 and 2, Supplement No. 3, January 1985.

8. TVA Calculation WCG-1-737, Analysis of As-Built Conditions for Remedial Treatment for Liquefaction Potential for ERCW Pipeline," Revision 1 (B26910401151).

9. NRC Safety Evaluation Report related to the operation of Watts Bar Nuclear Plant, Units 1 and 2, June 1982.

ATTACHMENT

WATTS BAR NUCLEAR PLANT
NRC REVIEW OF FSAR SECTION 2.5, AMENDMENT 54-63
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

TVA 10697 (DNE-8-86) ORIGINAL DNE CALCULATIONS

QA Record

TITLE Analysis of As-built Conditions for Remedial Treatment for Liquefaction Potential for ERCW Pipeline	PLANT/UNIT WBN/1&2
PREPARING ORGANIZATION WBEP	KEY NOUNS (Consult RIMS DESCRIPTORS LIST) N3, soil, stability, liquefaction, ERCW, piping
BRANCH/PROJECT IDENTIFIERS WCG-1-737 MCL-D11	Each time these calculations are issued, preparers must ensure that the original (RO) RIMS accession number is filled in.
APPLICABLE DESIGN DOCUMENT(S) WB-DC-20-24	
SAR SECTION(S) 2.5.4 & 2.5.5 / UNID SYSTEM(S) NA	

Rev	(for RIMS' use)	RIMS accession number
R0		CEB840816 018
R 1	9 1053 0C0019 (344)	B26 '91 0401 151
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Revision 0	R1	R2	R3
ECN No. (or indicate Not Applicable)	~~DCN M08818~~ DCN A03583 DCN P02439		
Prepared	HRSchickel		
Checked	Syed B Ahmed 3-8-91		
Reviewed	MHPerry		
Approved	MHPerry for JGA		
Date	4/1/91		
List all pages added by this revision.	see revision log		
List all pages deleted by this revision.			
List all pages changed by this revision.			

Use form TVA 10534 if more space required.

see next sheet

Safety-related? Yes ☒ No ☐

Statement of Problem

To analyze the as-built conditions for the underground barrier to verify the design of the remedial treatment.

Abstract

These calculations contain an unverified assumption(s) that must be verified later. Yes ☐ No ☒

R1 To revise the as-built analysis for Trench B to reflect the changes due to reconstruction of the cooling tower blowdown line across the underground barrier, and due to installation of a clay liner on the east end of the yard pond. The reevaluation showed the construction changes would result in insignificant changes in the analysis results. The minimum factors-of-safety are still greater than 1.0 for each section of Trench B.

59B2

☐ Microfilm and store calculations in RIMS Service Center.

☒ Microfilm and return calculations to: Calculation Center

Microfilm and destroy. ☐

Address: QAC 1C WBN

cc: RIMS, SL 26 C-K

This Page Revised By Rev. 1

COMPUTED _____ DATE _____
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SHEET

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Approach 1
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CTBL & Yard Pond Changes 5b
Underground Barrier Trench A Stability Analysis 5f
Summary 6
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Station 1+28 . . . . . 14a
Station 1+78 . . . . . 20a
Station 2+28 . . . . . 26a
Station 2+78 . . . . . 32a
Station 3+28 . . . . . 38a
Station 3+78 . . . . . 44a
Station 4+28 . . . . . 50a
Station 4+78 . . . . . 56a
Station 5+28 . . . . . 62a
Station 5+78 . . . . . 69a
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Station 5+00 . . . . . .204a
Station 5+50 . . . . . .210a
Station 6+00 . . . . . .216a
Block Sample Evaluation 222a

Appendix A - As-Built Cross-Sections Trench A A0-A18
Appendix B - As-Built Cross-Sections Trench B B0-B12-A
Appendix C - Construction Progress Photographs C0-65

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UNDERGROUND BARRIER
TRENCH A

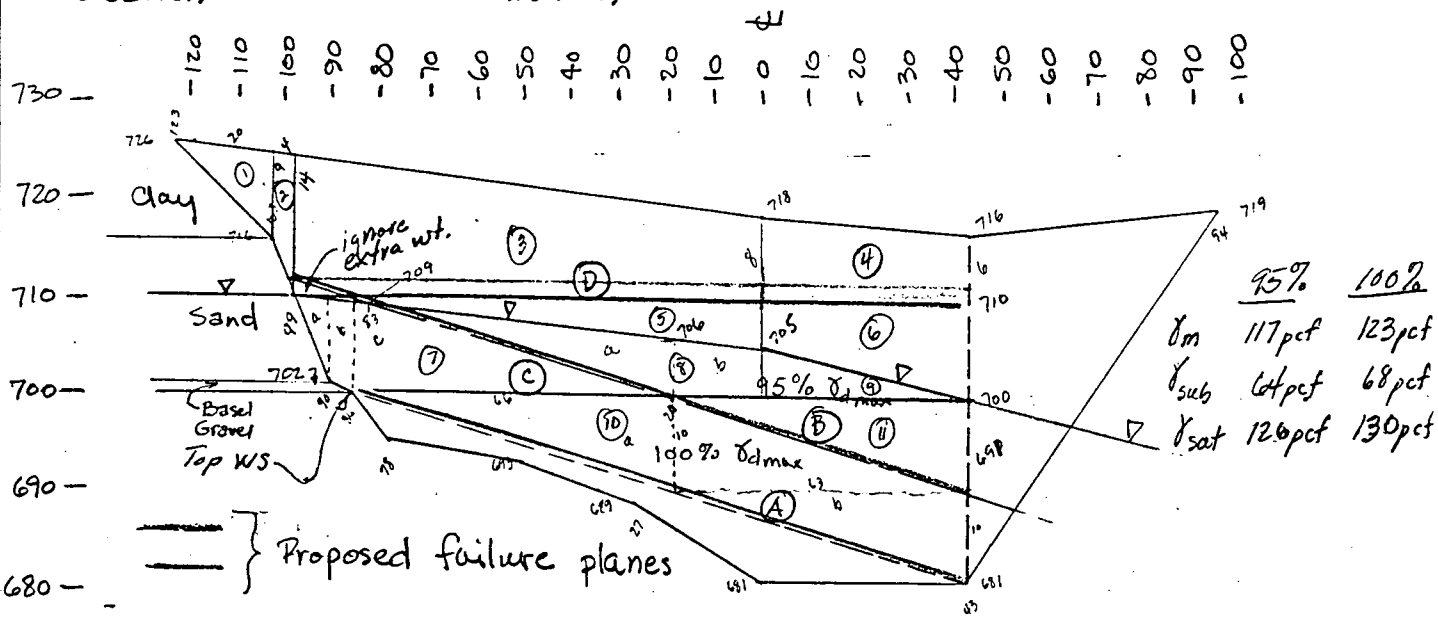
STABILILTY ANALYSIS
STATION 5+78

WBN
Remedial Treatment

COMPUTED HRT DATE 1-18-84
CHECKED JMA DATE 1-20-84

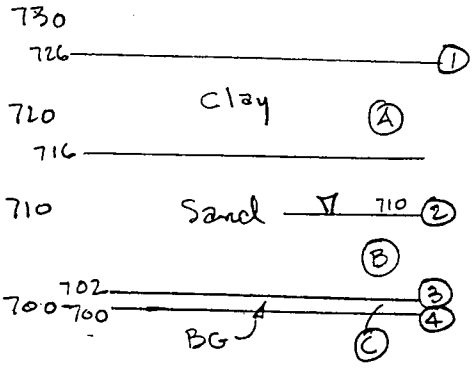
Check of as-built configuration

Section 5+78 – Trench A



Calculate the earth pressure –

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi}$$



$\gamma_m = 120$ pcf $\phi = 28°$ $c = 0.4$ tsf $K_a = 0.36$

$\gamma_m = 120$ pcf $\phi = 28°$ $c = 0.4$ tsf $K_a = 0.36$

$\gamma_{sub} = 58$ pcf $\phi = 0$ $c = 0$ $K_a = 1.0$

$\gamma_{sub} = 68$ pcf $\phi = 30°$ $c = 0$ $K_a = 0.33$

Assume the slope above the trench will be ignored - earlier study showed this to have neglible effect on the trench stability.

Zone A

$$E_{a_a} = \frac{K_a}{2}\left(\gamma_m h^2\right) - 2ch\sqrt{K_a} + \frac{2c^2}{\gamma_m}$$

$$E_{a_a} = \frac{0.36}{2}\left(120(16)^2\right) - 2(800)16\sqrt{.36} + \frac{2(800)^2}{120}$$

$$E_{a_a} = 5530 - 15360 + 10667 = \underline{836 \text{ p/f}}$$

Sta 5+78 – Trench A

Zone B

$p_t = 16(120) = 1920$ psf

$p_b = 1920 + 8(58) = 2384$ psf

$E_{a_b} = 1.0\left(\frac{1920+2384}{2}\right)8 + \frac{1}{2}(62.4)8^2 =$

$E_{a_b} = 17216 + 1997 = 19213$ p/f

Zone C

$p_t = 2384$ psf

$p_b = 2384 + 2(68) = 2520$ psf

$E_{a_c} = 0.33\left(\frac{2384+2520}{2}\right)2 + \left(\frac{8+10}{2}\right)^{ft}(62.4)^{psf}2^{ft} =$

$E_{a_c} = 1618 + 1123 = 2752$ p/f

Total Earth Pressure

Zone	E_a
A	836 p/f
B	19213 p/f
C	2752 p/f
	$\Sigma = 22{,}801$ p/f $= E_a$

Total Dynamic Earth Pressure $0.3(22{,}801) = 6840$ p/f

Total Dynamic Earth Pressure above WT

$E_D = 0.3(836) = 251$ p/f

SHEET 72 OF

WBN
Remedial Treatment

COMPUTED HRT DATE 1-18-84
CHECKED JMA DATE 1-20-84

Section 5+78 - Trench A

Determination of barrier weight for section

Area 1 approx $\frac{1}{2}(9')(20')\,117^{pcf} = 10530\ p/ft$

Area 2 approx $4'\left(\frac{9+14}{2}\right)117 = 5382\ p/f$

Area 3 approx $\left[8(99) + \frac{1}{2}(6)99)\right]117 = 127413\ p/f$

Area 4 $\left[(6)(43) + \frac{1}{2}(2)(43)\right]117 = 35217\ p/f$

Area 5 $\frac{1}{2}(99)(5)(117) = 28958\ p/f$

Area 6 $\left[(5)(43) + \frac{5}{2}(43)\right]117 = 37732\ p/f$

Area 7 (approx) $\left[\overset{a}{\frac{9}{2}(8)} + \overset{b}{\left(\frac{8+10}{2}\right)(4)} + \frac{10}{2}(66)\right]\gamma_{sat}\ 130 = 52260\ p/f$

$\left(\quad '' \quad\right)\gamma_{sub}\ 68 = 27336\ p/f$

Area 8 $\left[\overset{a}{\frac{1}{2}((9)(66) - (3)(66))} + \overset{b}{\frac{(6+5)}{2}(20)}\right]\gamma_{sat}\ 126 = 38808\ p/f$

$\left(\quad '' \quad\right)\gamma_{sub}\ 64 = 19712\ p/f$

Area 9 $\left(\frac{1}{2}\right)(5)(43)\ \gamma_{sat}\ 126 = 13545\ p/f$

$\left(\quad '' \quad\right)\gamma_{sub}\ 64 = 6880\ p/f$

Area 10 $\left[\overset{a}{\frac{1}{2}(10)(66)} + \overset{b}{(10)(63)}\right]\gamma_{sat}\ 130 = 124800\ p/f$

$\left(\quad '' \quad\right)\gamma_{sub}\ 68 = 65280\ p/f$

TVA 11030 (WM-7-75)

SHEET 73 OF

WBN
Remedial Treatment

COMPUTED HRT DATE 1-18-84
CHECKED JMA DATE 1-20-80

Section 5+78 · Trench A

Area 11 $\frac{1}{2}(63)(9)\ \gamma_{sat}\ 126 = 35721$ p/f

(") $\gamma_{sub}\ 64 = 18144$ p/f

Failure Plane	W_t (p/f)	N_{eff} (p/f)	Areas	Length
A	510366	382584	1 – 11	130' (A)
B	333306	289968	1-6, 8, 9, 11	144' (A)
C	349845	299160	1-9	129' CC/CE
D	178542	178542	1-4	142' A

Failure Plane A $\qquad c = 0.25$ tsf $\quad \phi = 14°$

$E_a = 22801$ p/f

$E_{aD} = 6840$ p/f

$F_w = 510366\ (0.3) = 153110$ p/f

$F_r = \overset{L}{130}\ (\overset{c}{500}) + \overset{N_{eff}}{382584} \tan 14° = 160389$ p/f

$FS = \dfrac{160389}{22801 + 6840 + 153110} = 0.88 < 1$ Not Good

182751

TVA 11030 (WM-7-75)

WBN

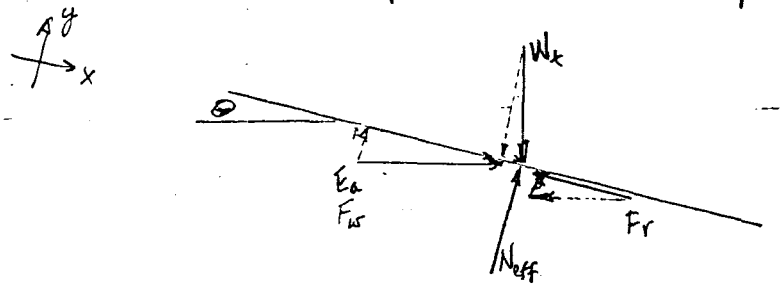
Remedial Treatment

COMPUTED HRT DATE 1-18-84

CHECKED JMH DATE 1-20-84

Section 5+78 Trench A

To consider slope of failure plane A



$\theta = \frac{19}{129} = 8.4°$

$E_a = 29641$ p/f

$F_w = 153110$ p/f

$F_r = 160389$ p/f

$W_t = 510366$ p/f

$E_{a_x} = E_a \cos\theta = 29325$

$E_{a_y} = E_a \sin\theta =$

$F_{w_x} = F_w \cos\theta = 151467$

$F_{w_y} = F_w \sin\theta =$

$F_{r_x} = F_r \cos\theta = 158668$

$F_{r_y} = F_r \sin\theta =$

$W_{t_x} = W_t \sin\theta = 74556$

$$F_s = \frac{F_{r_x}}{E_{a_x} + F_{w_x} + W_{t_x}} = \frac{158668}{29325 + 151467 + 74556} = 0.62 < 1$$

255348

w/o acceleration

$FS = 1.63$

Sta 5+78 Trench A

Failure Plane B $\quad c = 0.1\ tsf \quad \phi = 15°$

$$E_a = \overset{E_a}{836} + \overset{E_{ap}}{251} = 1087\ plf$$

$$F_w = 333{,}306\,(0.3) = 99992\ plf$$

$$F_r = 144\,(200) + 289{,}968 \tan 15° = 106497$$

$$FS = \frac{106497}{1087 + 99992} = 1.05 > 1 \text{ okay}$$

To consider slope of failure plane

$$\tan^{-1}\theta = \frac{19}{142} = 7.62°$$

$E_a = 1087\ plf$
$F_w = 99992\ plf$
$F_r = 106497\ plf$
$W_t = 333{,}306\ plf$

$$E_{ax} = E_a \cos\theta = 1077\ plf$$

$$F_{wx} = F_w \cos\theta = 99109\ plf$$

$$F_{rx} = F_r \cos\theta = 105556\ plf$$

$$W_{tx} = W_t \sin\theta = 44203\ plf$$

$$FS = \frac{105556}{1077 + 99109 + 44203} = 0.73 < 1 \text{ No Good}$$

w/o acceleration
$FS = 2.34$

WBN

Remedial Treatment

COMPUTED HRT DATE 1-19-84

CHECKED JMA DATE 1-20-84

Sta 5+78 Trench A

Failure Plane C

$E_a = 22801 + \overset{E_{ap}}{6840} = 29641$ plf

$F_w = 349{,}845\,(0.3) = 104954$ plf

lower of 14° & 15°

$F_r = 66(500) + 63(200) + 299160 \tan 14° = 120189$ plf

$$FS = \frac{120189}{29641 + 104954} = 0.89 < 1 \quad \text{No Good}$$

Failure Plane D

$E_a = 1087$ plf

$F_w = 178542\,(0.3) = 53563$ plf

$F_r = 142(200) + 178542 \tan 15° = 76240$ plf

$$FS = \frac{76240}{1087 + 53563} = 1.40 > 1 \quad \text{okay}$$

TVA 11030 (WM-7-75)

Det. passive pressure

720 716

710 705 spoil ① h_2 $\gamma_m = 110$ $\phi = 24°$ $\bar{c} = 0$

700 ② 700 $\gamma_m = 120$ $\phi = 28°$ $c = 0.4$ tsf

690 691 "B" Clay ③ h_1 $\gamma_{sat} = 123$ $\phi = 14°$ $c = 0.2$ tsf

680 681 "A" Sand ④ $\gamma_m = 119$, $\gamma_{sat} = 115$ $\phi = 10°$ $c = 0.1$ tsf

Failure Plane A

Det avg γ_m, ϕ, c

zone	h	γ_m	$h\gamma_m$	ϕ	$h\phi$	c	hc
1	11	110	1210	24	264	0	0
2	5	120	600	28	140	800	4000
3	9	120	1080	14	126	400	3600
4	10	119	1190	10	100	200	2000
	35		4080		630		9600

$$\gamma_m = \frac{4080}{35} = 117 \text{ pcf} \qquad \bar{\phi} = \frac{630}{35} = 18° \qquad \bar{c} = \frac{9600}{35} = 274 \text{ psf}$$

$$k_p = 1.89$$

$$E_p = \frac{1.89}{2}\left(117(16^2) + 2(117)16(19) + 55(19)\right) + 2(274)35\sqrt{1.89} + \frac{62.4}{2}(19)^2$$

$$E_p = 114291 + 26368 + 11263 = 151922 \text{ p/f}$$

$$E_{px} = E_p \cos\theta = 150292 \text{ p/f} \times 0.7 = 105205 \text{ p/f}$$

$$FS = \frac{F_{rx} + E_{px}}{E_{ax} + F_{wx} + W_{tx}} = 1.03 > 1 \text{ okay}$$

$F_{rx} = N_{eff}(\cos\theta)\tan\phi + cL$ rather than $F_{rx} = (N_{eff}\tan\phi + cL)\cos\theta$

$= 382584(\cos 8.4°)\tan 14° + 500(130)$

$F_{rx} = 159366$ $F_{ry} = 158668$

minor difference

WBN

Remedial Treatment

Trench A

Sta 5+78

COMPUTED HRT DATE 1-31-84

CHECKED [illegible] DATE 2-13-84

Failure Plane B

Det avg γ_m, ϕ, c

Zone	h	γ_m	$h\gamma_m$	ϕ	$h\phi$	c	hc
1	11	110	1210	24	264	0	0
2	5	120	600	28	140	800	4000
3	9	120	1080	14	126	400	3600
	25		2890		530		7600

$\bar{\gamma}_m = \frac{2890}{25} = 116 pcf$ $\bar{\phi} = \frac{530}{25} = 21^\circ$ $\bar{c} = \frac{7600}{25} = 304 psf$

$K_p = 2.12$

$$E_p = \frac{2.12}{2}\left(116(16)^2 + 2(116)(16)9 + 54(9)\right) + 2(304)25\sqrt{2.12} + \frac{62.4}{2}(9)^2$$

$$E_p = 67405 + 22132 + 2527 = 92064 \ p/f$$

$$E_{px} = E_p \cos\theta = 91082 \ p/f \times 0.7 = 63757 \ p/f$$

$$FS = \frac{F_{rx} + E_{px}}{E_{ax} + F_{wx} + W_{tx}} = 1.17 > 1 \text{ okay}$$

COMPUTED _____ DATE _____
CHECKED _____ DATE _____

THIS SHEET ADDED BY REV. 1

FOR INFORMATION ONLY
NO CHECKING REQUIRED

UNDERGROUND BARRIER
TRENCH B

STABILILTY ANALYSIS
STATION 2+50

SHEET 165 OF

WBN

Remedial Treatment

Trench B

Cross Sectional Area

COMPUTED HBT DATE 7-14-84

CHECKED [illegible] DATE 7-23-84

Station 2+50 Correction factor 1.0229

See App B for X-section

Area #	Measured Area (in^2) Trial 1	Trial 2	Trial 3	Avg Area	Corr Area* in^2	Mat'l
1 R	11.87	11.93		11.90	11.63	95%
L	.49	.51		.50	.49	
2 R	.34	.33		.34	.33	1032
L	—	—		—	—	
3 R	10.07	10.22	10.12	10.14	9.91	95% sat
L	8.59	8.63	8.49	8.57	8.38	
4 R	2.03	2.03		2.03	1.98	100% Sat
L	2.76	2.61	2.66	2.68	2.62	
5 R	17.02	17.06		17.04	16.66	5a = 5.15, 5b = 11.51, 1032 sat
L	3.41	3.49		3.45	3.37	
6 R	9.12	9.08		9.10	8.90	1075 sat
L	1.33	1.39		1.36	1.33	
7 R	1.48	1.44		1.46	1.43	100% sat
L	.15	.15		.15	.15	
All R	~~52.14~~	52.04	52.00	52.02	50.86 (50.84)	.04%
L	16.08	16.14		16.11	15.75 (16.34)	3.7%

* Avg Area / Corr factor

1 □" = 100 □"

TVA 11030 (WM-7-75)

SHEET 166 OF

WBN
Remedial Treatment

Trench B

COMPUTED HRT DATE 7/17/84
CHECKED [illegible] DATE 7-25-84

Station 2+50

Potential Failure Plane	Desc	Elevation IPS side	Elevation down side	Mat'l	Length
A	T/WS to T/WS	677	671	A1*	107 ✓
B	1075/1032 interface	685	682	1075/1032	114 ✓
C	1032 & A/A1 interface	695	695	1032 & A	131 → 79 (A), 52 (1032)

* ignore small distance through 1075

Determination of barrier weight

Area #	100² Area	Area x 100 □'	Unit Wt	Weight
1	11.63	1163	117	136071 ✓
2	.33	33	135	4455 ✓
3	9.91	991	126	124866 ✓
			64	63424 ✓
4	1.98	198	130	25740 ✓
			68	13464 ✓
5	16.66	1666	143	238238 ✓
			81	134946 ✓
6	8.90	890	143	127270 ✓
			81	72090 ✓
7	1.43	143	130	18590 ✓
			68	9724
5a	5.15	515	143	73645
			81	41715

TVA 11030 (WM-7-75)

WBN
Remedial Treatment

Trench B

COMPUTED HHT DATE 7/18/84
CHECKED [illegible] DATE 7-24-84

Station 2+50

Weight acting on failure plane

Failure Plane	Areas	W_E	N_{eff}
A	1-7	675230 ✓	434174 ✓
B	1-5	529370 ✓	352360 ✓
C	1-3, 5a	339037 ✓	245,665 ✓

WBN

Remedial Treatment

Trench B

Sta 2+50

COMPUTED HRT DATE 7-20-84

CHECKED PMH DATE 7-26-84

Det. earth pressure

720 –

714

710 – ▽ 705 ① $\gamma_m = 120$ $c = 0.4$ $\phi = 28°$

700 – Clay ② $\gamma_{sat} = 123$ $c = 0.2$ $\phi = 14°$

695 – Ⓒ

690 – ③

681.5 685 – Ⓑ ④

680 – 677.5 Sand ⑤ $\gamma_{sat} = 120$ $c = 0$ $\phi = 0$ $k_a = 1.0$

WS Ⓐ

670 –

Det avg γ, ϕ, c for clay

Zone	h	γ_m	$h\gamma_m$	ϕ	$h\phi$	c	hc
1	9	120	1080	28	252	800	7200
2	10	123	1230	14	140	400	4000
3	10	123	1230	14	140	400	4000
4	3.5	123	430	14	49	400	1400
	32.5						

Σ_{1-2}	19	2310	392	11200
Σ_{1-3}	29	3540	532	15200
Σ_{1-4}	32.5	3970	581	16600

$\bar{\gamma}_{m_{1-2}} = \frac{2310}{19} \approx 122$ pcf $\quad \bar{\phi} = \frac{392}{19} \approx 21°$ $\quad \bar{c} = \frac{11200}{19} \approx 590$ psf

$\bar{\gamma}_{m_{1-3}} = \frac{3540}{29} \approx 122$ pcf $\quad \bar{\phi} = \frac{532}{29} \approx 18°$ $\quad \bar{c} = \frac{15200}{29} \approx 520$ psf

$\bar{\gamma}_{m_{1-4}} = \frac{3970}{32.5} \approx 122$ pcf $\quad \bar{\phi} = \frac{581}{32.5} \approx 18°$ $\quad \bar{c} = \frac{16600}{32.5} \approx 510$ psf

$K_{a_{1-2}} = \frac{1 - \sin 21°}{1 + \sin 21°} = 0.47$ $\quad K_a = \frac{1 - \sin 18}{1 + \sin 18} = 0.53$

WBN
Remedial Treatment

Trench B
Sta 2+50

COMPUTED HRT DATE 7-20-84
CHECKED [illegible] DATE 7-26-84

Zone 1-2 $h_1=10'$ $h_2=9'$ $h=19'$

$$E_a = \frac{0.47}{2}\left(122(9)^2 + 2(122)9(10) + 60(10)^2\right) - 2(590)19\sqrt{.47} + \frac{2(590)^2}{122} + \frac{62.4(10)^2}{2}$$

$$E_{a_{1-2}} = (8893 - 15370 + 5706) + \overset{<0 \therefore \text{ use } 0}{3120} = \underline{3120 \text{ plf}}$$

Zone 1-3 $h_1=11'$ $h_2=9'$ $h=20'$

$$E_a = \frac{0.53}{2}\left(122(9)^2 + 2(122)9(20) + 60(20)^2\right) - 2(520)29\sqrt{.53} + \frac{2(520)^2}{122} + \frac{62.4(20)^2}{2}$$

$$E_{a_{1-3}} = 20618 - 21957 + 4433 + 12480 = \underline{15574 \text{ plf}}$$

Zone 1-4 $h_1=23.5'$ $h_2=9'$ $h=32.5'$

$$E_a = \frac{0.53}{2}\left(122(9)^2 + 2(122)9(23.5) + 60(23.5)^2\right) - 2(510)32.5\sqrt{.53} + \frac{2(510)^2}{122} + \frac{62.4(23.5)^2}{2}$$

$$E_{a_{1-4}} = 25075 - 24134 + 4264 + 17230 = \underline{22435 \text{ plf}}$$

Zone 5

$$p_t = 9(120) + 23.5(61) = 2514 \text{ psf}$$

$$p_b = 2514 + 4(58) = 2746 \text{ psf}$$

$$E_{a_5} = 1.0\left(\frac{2514+2746}{2}\right)4 + \left(\frac{23.5+27.5}{2}\right)62.4(4)$$

$$E_{a_5} = 10518 + 6365 = \underline{16883 \text{ plf}}$$

Failure Plane	Effective Zones	E_a	E_d	$\overline{E_a}$
A	1-5	39318	11795	51113
B	1-3	15574	4672	20246
C	1-2	3120	936	4056

1413N

Remedial Treatment

Trench B

Sta 2+50

COMPUTED HRT DATE 7-24-84

CHECKED JMM DATE 8-6-84

Det Passive Pressure

* assumed no sand indicated

710 - 709

▽ 706 ①

$\gamma_m = 120$ $\phi = 28°$ $c = 0.4$

700 - ②

Clay 695 - ⓒ

$\gamma_{sat} = 123$ $\phi = 14°$ $c = 0.2$

690 - ③

681* 682 - Ⓑ ④

680 -

Sand ⑤

$\gamma_{sat} = 124$ $\phi = 10°$ $c = 0.1$

671 Ⓐ

670 -

Det avg γ, ϕ, c

zone	h	γ	$h\gamma$	ϕ	$h\phi$	c	hc
1	3	120	360	28	84	800	2400
2	11	123	1353	14	154	400	4400
3	13	123	1599	14	182	400	5200
4	1	123	123	14	14	400	400
5	10	124	1240	10	100	200	2000
Σ_{1-2}	14		1713		238		6800
Σ_{1-3}	27		3312		420		12000
Σ_{1-5}	38		4675		534		14400

$\bar{\gamma}_{1-2} = \frac{1713}{14} \approx 122$ $\bar{\phi}_{1-2} = \frac{238}{14} \approx 17°$ $\bar{c} = \frac{6800}{14} \approx 490$ $K_p = 1.83$

$\bar{\gamma}_{1-3} = \frac{3312}{27} \approx 123$ $\bar{\phi}_{1-3} = \frac{420}{27} \approx 16°$ $\bar{c} = \frac{12000}{27} \approx 440$ $K_p = 1.76$

$\bar{\gamma}_{1-5} = \frac{4675}{38} \approx 123$ $\bar{\phi}_{1-5} = \frac{534}{38} \approx 14°$ $\bar{c} = \frac{14400}{38} \approx 380$ $K_p = 1.64$

SHEET 171 OF

WBN
Remedial Treatment

Trench B
Sta 2+50

COMPUTED HRT DATE 7-24-84
CHECKED JMA DATE 8-6-84

1-2

$$E_p = \frac{1.83}{2}\left(122(3)^2 + 2(122)3(11) + 60(11)^2\right) + 2(490)14\sqrt{1.83} + \frac{62.4(11)^2}{2}$$

$$E_{p_{1-2}} = 15015 + 18560 + 3775 = \underline{37350 \text{ plf}} \checkmark$$

1-3

$$E_p = \frac{1.76}{2}\left(123(3)^2 + 2(123)3(24) + 60(24)^2\right) + 2(440)27\sqrt{1.76} + \frac{62.4(24)^2}{2}$$

$$E_{p_{1-3}} = 46966 + 31521 + 17971 = \underline{96458 \text{ plf}} \checkmark$$

1-5

$$E_p = \frac{1.64}{2}\left(123(3)^2 + 2(123)3(35) + 60(35)^2\right) + 2(380)38\sqrt{1.64} + \frac{62.4(35)^2}{2}$$

$$E_{p_{1-5}} = 82358 + 36984 + 38220 = \underline{157563 \text{ plf}} \checkmark$$

Failure Plane	Zones Effective	E_p	E_{pd}	$\overline{E_p}$
A	1-5	157563	47269	110294 ✓
B	1-3	96458	28937	67521 ✓
C	1-2	37350	11205	26145 ✓

SHEET 172
WISN
Remedial Treatment
COMPUTED HRT DATE 7/24/84
CHECKED JMH DATE 8-6-84

Trench B
Sta 2+50

Stability check

	Failure Planes A	B	C		Ref. sheet
W_t plf	675230	529370	339037		167
N_{eff} plf	434174	352360	245665		167
Mat'l	A1	1075	1032 & A		166
ϕ	14°	40°	40°	15°	5a
c (tsf)	0.35	0	0.5	0.1	5a
Length (L)	107'	114'	52'	79'	166
Slope					
Active side	El 677.5	El 685	El 695		168
Passive side	El 671	El 682	El 695		170
E_a plf	39318	15574	3120		169
$\bar{E}_a$ (active+dyn) plf	51113	20246	4056		169
E_p plf	157563	96458	37350		171
$\bar{E}_p$ (passive-dyn) plf	110294	67521	26145		171

if elevation on passive side is higher than active side consider $\theta = 0°$

WBN

Remedial Treatment

Trench B
Sta 2+50

COMPUTED HRT DATE 7-26-84
CHECKED JMH DATE 8-6-84

during EQ | post EQ

Failure Plane A $\theta = \tan^{-1} \frac{677.5-671}{107} = 3.48°$

$F_{rx} = 434174 \tan 14° \cos\theta + 700(107) = 182952$ plf ✓ | $F_{rx} = 182952$ plf

$E_{px} = 110294 \cos\theta = 110091$ plf ✓ | $E_{ax} = 39318 \cos\theta = 39246$ plf

$F_{wx} = 675230 (0.3) \cos\theta = 202196$ plf ✓ | $W_{tx} = 40943$ plf

$E_{ax} = 51113 \cos\theta = 51019$ plf ✓ | $FS = \frac{182952}{39246 + 40943} = 2.28$

$W_{tx} = 675230 \sin\theta \approx 40943$ plf ✓

$FS = \frac{\overset{271394}{182952} + \overset{67521}{110091}}{202196 + 51019 + 40943} = 1.00$ ✓ (1.15)

Failure Plane B $\theta = \tan^{-1} \frac{685-682}{114} = 1.51°$

$F_{rx} = 352360 \tan 40° \cos\theta = 295563$ plf ✓ | $F_{rx} = 295563$ plf

$E_{px} = 67521 \cos\theta = 67498$ plf ✓ | $E_{ax} = 15574 \cos\theta = 15569$ plf

$F_{wx} = 529370 (0.3) \cos\theta \approx 158801$ (158756) | $W_{tx} = 13926$ plf

$E_{ax} = 20246 \cos\theta = 20239$ plf | $FS = \frac{295563}{15569 + 13926} = 10.02$

$W_{tx} = 529370 \sin\theta \approx 13926$ plf (13950)

$FS = \frac{295563 + 67498}{158801 + 20239 + 13926} = 1.88$ ✓

WBN
Remedial Treatment

Trench B
Sta 2+50

COMPUTED HRT DATE 7-26-84
CHECKED JMH DATE 8-6-84

Failure Plane C $\theta = 0°$

proportion N_{eff} to each mat'l based on length

$1032 = 52'$
$A = 79'$
$131'$

$100 \times \frac{52}{131} = 40\%$ for 1032

$F_{rx} = .4(245665)\tan 40° + .6(245665)\tan 15° + 1000(52) + 200(79)$
$F_{rx} = 82455\ p/f + 39495 + 52000 + 15800$
$F_{rx} = 189750\ p/f$

$F_{rx} = 189750\ p/f$

$E_{px} = 26145\ p/f$

$E_{ax} = 15574\ p/f$

$F_{wx} = .3(339037) = 101711$

$FS = \frac{189750}{15574} = 12.18$

$E_{ax} = 4056\ p/f$

$W_{tx} = 0$

$FS = \frac{189750 + 26145}{101711 + 4056} = 2.04$

TVA 11030 (WM-7-75)