ENCLOSURE 3

CALCULATION WCG-1-1368

"FREQUENCY DEPENDENT DYNAMIC SHEAR

STRESSES IN THE EARTHFILL BETWEEN

SHEETPILES AT THE INTAKE PUMPING STATION"

TITLE: FREQUENCY DEPENDENT DYNAMIC SHEAR STRESSES IN THE EARTHFILL BETWEEN SHEETPILES AT INTAKE PUMPING STATION

Plant/Unit
WATTS BAR NUCLEAR PLANT/#1

PREPARING ORGANIZATION
NE, EBASCO SERVICES, INC.

KEY NOUNS (Consult RIMS DESCRIPTORS LIST) INTAKE PUMPING STATION, FREQUENCY, SHEAR STRESS, BACKFILL, SEISMIC ANALYSIS, SHAKE

BRANCH/PROJECT IDENTIFIERS
WCG-1-1368

Each time these calculations are issued, preparers must ensure that the original (RO) RIMS accession number is filled in.

Rev	(for RIMS' use)	RIMS accession number
R0	MAY 0 6 1992 (287)	B18 '92 0428 253
R		
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APPLICABLE DESIGN DOCUMENT(S)
WB-DC-20-24

SAR SECTION(S): NR
UNID SYSTEM(S): NR

Revision 0	R1	R2	R3
ECN No. (or Indicate Not Applicable) N/A WSL 4-27-92			
Prepared: W.S. LEE WSLee			
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Date 4/27/92			
USE FORM TVA 10534 IF MORE SPACE REQUIRED — List all pages added by this revision			
List all pages deleted by this revision			
List all pages changed by this revision			

Safety-related? Yes [X] No [ ]

Statement of Problem
DEMONSTRATE THAT THE FREQUENCY DEPENDENT DYNAMIC SHEAR STRESSES IN THE CLASS A BACKFILL DURING A SEISMIC EVENT IS WITHIN THE AVAILABLE SHEAR STRENGTH OF THE BACKFILL

ORIGINAL

Abstract: These calculations contain an unverified assumption(s) that must be verified later. Yes [ ] No [X]

RO. SUPERCEDE PAGES 5 TO 21 OF WCG-1-1369, R2. DETERMINE FREQUENCY DEPENDENT DYNAMIC SHEAR STRESSES DEVELOPED WITHIN THE CLASS A BACKFILL HELD BETWEEN THE SHEET PILES DURING A SEISMIC EVENT BY USING THE "SHAKE" COMPUTER PROGRAM AND DEMONSTRATE THAT THE SHEAR STRESSES ARE WITHIN THE AVAILABLE SHEAR STRENGTH OF THE BACKFILL. THIS CALC MEETS APPLICABLE DESIGN CRITERIA.

WSL 4-27-92

[ ] Microfilm and store calculations in RIMS Service Center
[X] Microfilm and return calculations to: Calc Library
Microfilm and destroy. [ ]
Address: IOB-A BLDG. CEB
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Debbie Kilgore
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TVA **BRANCH PROJECT I.D.** WCG-1-1368

TITLE: FREQUENCY DEPENDENT DYNAMIC SHEAR STRESSES IN THE EARTHFILL BETWEEN SHEETPILES AT INTAKE PUMPING STATION
PREP. BY: W.S. LEE DATE: 4-27-92
CHECKED BY: K. Ramachandra DATE: 4-27-92

REVISION LOG

Revision No.	DESCRIPTION OF REVISION	Date Approved
0	THIS CALCULATION REPLACES PAGES 5 TO 21 OF CALCULATION DOCUMENT 1Y-SA-008, R1, RIMS NO. CEB 82 0604 002, WCG-1-1369 R2	4/27/92

CALCULATION DESIGN VERIFICATION (INDEPENDENT REVIEW) FORM

WCG-1-1368 — BRANCH/PROJECT ID/CALCULATION NO.

0 — REVISION

Method of design verification (independent review) used (check method used):

1. Design Review X
2. Alternate Calculation NR
3. Qualification Test NR

Justification (explain below):

Method 1: In the design review method, justify the technical adequacy of the calculation and explain how the adequacy was verified (calculation is similar to another, based on accepted handbook methods, appropriate sensitivity studies included for confidence, etc.).

Method 2: In the alternate calculation method, identify the pages where the alternate calculation has been included in the calculation package and explain why this method is adequate.

Method 3: In the qualification test method, identify the QA documented source(s) where testing adequately demonstrates the adequacy of this calculation and explain.

DESIGN REVIEW IS APPLICABLE TO THIS CALCULATION, SINCE IT IS BASED ON STANDARD ENGINEERING HANDBOOK METHODS.

KR 4-27-92

KRIS RAMACHANDRA K Ramachandra — Design Verifier (Independent Reviewer)

4-27-92 — Date

~~NOTE: THE FOLLOWING SHEET IS 3A~~

KR 4/27/92

EBASCO SERVICES INC.
BRANCH/PROJECT ID WCG-1-1368

SUBJECT	PROJECT	SHEET 4 OF 12
FREQUENCY DEPENDENT DYNAMIC SHEAR STRESSES IN THE EARTHFILL BETWEEN SHEETPILES AT INTAKE PUMPING STATION	WBNP UNIT 1	WATTS BAR NUCLEAR PLANT COMPUTED WSZ DATE 4-23-92 CHECKED KR DATE 4-23-92

TABLE OF CONTENTS

THIS CALCULATION PACKAGE CONTAINS 287 TOTAL PAGES

5.0 PURPOSE

The purpose of this revision is to provide frequency dependent, dynamic shear stresses developed within the Class A backfill held between the sheetpiles during a seismic event and demonstrate that the developed stresses are within the shear strength of the soils.

6.0 APPLICABLE CRITERIA

X 1. Dynamic Earthquake Analysi of Category I Structures and Earth Embankment, WB-DC-20-24 (B26 91 0305 076 R6) dated 3-05-91

7.0 APPLICABLE CODES AND STANDARDS

None.

8.0 ASSUMPTIONS, LITERATURE SEARCHES AND OTHER APPLICABLE BACKGROUND DATA

None

9.0 APPLICABLE REFERENCES (MARKED X)

X 1. Dynamic Analysis of Backfill Contained by Sheetpile Walls at the Intake Pumping Station (CEB 82 0604 002 dated 6-21-1982 R1), WCG-1-1369, R2.

X 2. Seismic Assessment Report, Watts Bar Nuclear Plant, by Bechtel 890714S001 (B26 8906 100) dated 6-29-1989, R1

X 3. Standard Review Plan (SRP) Nos. 3.7.1 Revision 2 and 3.7.2, Revision 2, 1989.

X 4. "SHAKE", Version 1.1 Computer User Manual, Controlled copy issued by TVA.

10.0 APPLICABLE DESIGN INPUT DATA (MARKED X)

X 1. Dynamic Analysis of Backfill Contained by SHeetpile Walls at the Intake Pumping Station (CEB 82 0604 002 dated 6-21-1982, R1), (Soil Profile).

X 2. Seismic Assessment Report, Watts Bar Nuclear Plant, by Bechtel 890714S001 (B26 8906 100) dated 6-29-1989, R1, (Dynamic Properties - shear modulus, damping ratios and strain).

X 3. Two time histories as per design criteria WB-DC-20-24, Set B Criteria provided by TVA in their mainframe.

11.0 CALCULATIONS

11.1 Background

The document EN DES CALCULATIONS, MEDS ACCESSION NUMBER CEB 82 0604 002, Revision 1, dated 6-21-1982 titled "seismic analysis of earthfill contained by sheetpile walls at the Intake Pumping Station" (Reference 9.1), presented dynamic shear stresses based on an approximate convolution analysis. This calculation was based on the following assumptions:

a) Rigid body motion
b) Linear distribution of the acceleration in the soil column
c) Inertial force = mass × average acceleration
d) Maximum shear stress = 3/2 × average shear stress
e) Damping = 10% for acceleration amplification estimates
f) Comparison of the calculated shear stress with the available shear strength of the soil column at different depths using the relation:

Allowable shear stress = $c + \sigma \tan \phi$
where
c = cohesion
σ = effective overburden stress
ϕ = Angle of internal friction

The previous study ignored the effect of frequency in the analysis. The shear wave velocity in the bedrock varied from 800 feet per second (fps) to 1400 fps in the parametric study.

The material properties used were:

Cohesion = 1200 psf
Unit weight = 120 pcf
Angle of internal friction = 15°

11.2 Approach

a) Use the TVA validated mainframe program "SHAKE", Version 1.1 (Reference 9.4), developed by the University of California at Berkeley for the frequency dependent convolution analysis. The cutoff frequency in this exercise is 200 Hz.

b) The analyses were performed by using two different horizontal acceleration time histories (Set B) in the bedrock (Reference 10.3). The analyses were performed for the soil column subjected to peak OBE and SSE design criteria given in Paragraph 4.2.2 of the Design Criteria WB-DC-20-24 (Reference 6.1). The peak horizontal accelerations are:

OBE	0.09g
SSE	0.215g

c) The shear moduli of the soil column were varied by +100% and -50% as per the recommendations in Standard Review Plan (SRP) (Reference 9.3). The maximum shear modulus of the Class A Backfill is 4500 ksf as per Table O-5, Page O-18 of the Bechtel Report (Reference 9.2).

d) The graphs of shear modulus/maximum shear modulus and Damping Ratio (%) versus Cyclic Shear Strain (%) for Class A Backfill given in Figure O-4, Page O-20 of the Bechtel Report (Reference 9.2) were used for strain compatible reiterations by the SHAKE program.

e) An effective strain equal to 0.65 times the maximum strain as recommended by the User Manual, SHAKE, Page 24 (Reference 9.4) was used.

f) The soil profile identical to the previous stress calculation (Reference 9.1) was used.

11.3 Analysis

The following analyses were run:

OBE (0.09g peak, horizontal)

Case 1: Time history 1, G_{max} (maximum shear modulus) = 4500 ksf
Case 2: Time history 1, G_{max} = G_{max} of Case 1 + 100%
Case 3: Time history 1, G_{max} = G_{max} of Case 1 - 50%
Case 4: Time history 2, G_{max} = 4500 ksf
Case 5: Time history 2, G_{max} = G_{max} of Case 1 + 100%
Case 6: Time history 2, G_{max} = G_{max} of Case 1 - 50%

SSE (0.215g peak, horizontal)

Case 7: Time history 1, G_{max} = 4500 ksf
Case 8: Time history 1, G_{max} = G_{max} of Case 1 + 100%
Case 9: Time history 1, G_{max} = G_{max} of Case 1 - 50%
Case 10: Time history 2, G_{max} = 4500 ksf
Case 11: Time history 2, G_{max} = G_{max} of Case 1 + 100%
Case 12: Time history 2, G_{max} = G_{max} of Case 1 - 50%

The acceleration time histories have a total of 6000 points each. The validated SHAKE program limits the maximum number of terms used in the Fourier Transform to 4096. The program requires that the number of terms in the

Fourier Transform be higher than the number of acceleration points in the time history. In view of this limitation, the analyses were performed using the first 4000 acceleration points. It may be noted that the maximum acceleration points of the two time histories are well within the first 4000 acceleration points. However, two sensitivity analyses were performed to assess the impact of the number of acceleration points utilized in the analyses. Therefore a total of 14 cases were analyzed to envelope the uncertainties in material properties and software limitations.

12.0 SUMMARY

Table 12-1 summarizes the maximum dynamic shear stresses for the OBE conditions (6 cases). Table 12-2 summarizes the maximum dynamic shear stresses for the SSE conditions (6 cases). Table 12-3 summarizes the impact of different number of acceleration points used on the calculated dynamic shear stresses.

Table 12-1 (OBE Case) shows that the maximum dynamic shear stress is 345 psf with time history 1 and G_{max} = -50% of the original G_{max} value of 4500 ksf. The corresponding iterated strain compatible damping ratio is 6.2%. The available undrained shear strength for the Class A backfill is 2100 psf according to Reference 9.2. This gives a factor of safety of 6.1.

Table 12-2 (SSE Case) shows that the maximum dynamic shear stress is 785 psf with time history 2 and G_{max} = 4500 ksf. The corresponding iterated strain compatible damping ratio is 6.5%. With the available undrained shear strength of 2100 ksf, the factor of safety is found to be 2.7. The maximum shear stress using time history 1 is 784 psf with G_{max} = -50% of the original G_{max} value of 4500 ksf. The corresponding iterated strain compatible damping ratio is 9% and the factor of safety is also 2.7.

Table 12-3 shows that by reducing the acceleration points from 4000 to 3520, the maximum deviation in shear stresses from those calculated with 4000 acceleration points is only 0.12%.

EBASCO SERVICES INC.
BRANCH/PROJECT ID WCG-1-1368

SUBJECT	PROJECT	SHEET 9 OF 12
FREQUENCY DEPENDENT DYNAMIC SHEAR STRESSES IN THE EARTHFILL BETWEEN SHEETPILES AT INTAKE PUMPING STATION	WBNP UNIT 1	WATTS BAR NUCLEAR PLANT COMPUTED WJK DATE 4-23-92 CHECKED KCL DATE 4-23-92

TABLE 12-1 MAXIMUM STRESS SUMMARY

OBE CASE

Peak top-of-rock acceleration is 0.09 g (horizontal). Maximum shear moduli is given as 4500 ksf. Maximum shear stresses in the Class A backfill at different depths were calculated with different time history curves and various percentages of the original maximum shear moduli. The undrained shear strength of the fill is given at 2100 psf.

DEPTH (ft)	MAXIMUM SHEAR STRESS AT VARIOUS % OF MAXIMUM SHEAR MODULUS					
	WITH TIME HISTORY CURVE 1			WITH TIME HISTORY CURVE 2		
	-50% (psf)	0% (psf)	+100% (psf)	-50% (psf)	0% (psf)	+100% (psf)
1.6	27.42	23.13	17.11	28.05	21.85	17.44
4.7	79.18	66.94	52.25	79.47	63.73	53.37
7.8	125.16	107.97	85.13	125.14	103.02	87.27
10.9	167.16	145.28	116.56	167.49	137.78	119.85
14.0	205.30	178.99	143.28	203.67	168.18	148.14
17.1	242.05	210.04	166.71	233.02	198.43	173.19
20.2	274.52	239.31	193.36	257.23	226.67	195.50
23.3	302.87	267.21	221.34	276.38	251.95	216.69
26.4	326.93	292.73	248.09	290.19	275.34	237.68
29.5	345.39	313.05	273.38	296.14	296.92	256.42

The minimum factor of safety of 6.08 occured at a depth of 29.5 with G_{max} = 2250 psf with time history curve 1.

TABLE 12-2 MAXIMUM STRESS SUMMARY

SSE CASE

Peak top-of-rock acceleration is 0.125 g (horizontal). Maximum shear moduli (G_{max}) is given as 4500 ksf. Maximum shear stresses in the Class A backfill at different depths were calculated with different time history curves and various percentages of the original maximum shear moduli. The undrained shear strength of the fill is given at 2100 psf.

DEPTH (ft)	MAXIMUM SHEAR STRESS AT VARIOUS % OF MAXIMUM SHEAR MODULUS					
	WITH TIME HISTORY CURVE 1			WITH TIME HISTORY CURVE 2		
	-50% (psf)	0% (psf)	+100% (psf)	-50% (psf)	0% (psf)	+100% (psf)
1.6	60.84	60.82	44.01	57.78	61.96	45.07
4.7	179.82	174.67	129.64	167.13	181.50	133.12
7.8	291.85	276.68	206.17	265.46	290.95	212.34
10.9	397.40	367.09	273.74	353.77	388.16	283.51
14.0	501.06	446.2	333.75	428.01	472.97	349.58
17.1	588.63	514.77	390.75	485.11	547.17	406.73
20.2	661.04	574.61	456.14	530.28	614.92	458.66
23.3	717.15	627.55	519.02	592.18	679.38	509.92
26.4	756.91	674.34	579.30	652.17	737.50	560.88
29.5	783.33	712.17	635.97	695.81	784.91	605.96

The minimum factor of safety of 2.68 occured at a depth of 29.5 with G_{max} = 4500 psf with time history curve 2.

EBASCO SERVICES INC.
BRANCH/PROJECT ID WCG-1-1368

SUBJECT:
FREQUENCY DEPENDENT DYNAMIC SHEAR
SHEAR STRESSES IN THE EARTHFILL BETWEEN
SHEETPILES AT INTAKE PUMPING STATION

PROJECT:
WBNP UNIT 1

WATTS BAR NUCLEAR PLANT
COMPUTED WSX DATE 4-23-92
CHECKED KR DATE 4-23-92

TABLE 12-3 PARAMETRIC STUDY: VARIOUS NUMBER OF ACCELERATION POINTS

DIFFERENCES BETWEEN MAXIMUM SHEAR STRESSES BASED ON VARIOUS NUMBER OF ACCELERATION POINTS WITH MAXIMUM SHEAR MODULI AT 4500 KSF, 4096 FOURIER TERMS AND TIME HISTORY CURVE 1

DEPTH (ft)	*ORIGINAL MAXIMUM SHEAR STRESS (psf)	3760 ACCELERATION POINTS		3520 ACCELERATION POINTS	
		MAXIMUM SHEAR STRESS (psf)	DEVIATION FROM ORIGINAL	MAXIMUM SHEAR STRESS (psf)	DEVIATION FROM ORIGINAL
1.6	60.82	60.76	-0.10%	60.76	-0.10%
4.7	174.67	174.5	-0.10%	174.51	-0.09%
7.8	276.68	276.39	-0.10%	276.41	-0.10%
10.9	367.09	366.73	-0.10%	366.75	-0.09%
14	446.2	445.75	-0.10%	445.77	-0.10%
17.1	514.77	514.22	-0.11%	514.25	-0.10%
20.2	574.61	573.97	-0.11%	574.01	-0.10%
23.3	627.55	626.83	-0.11%	626.87	-0.11%
26.4	674.34	673.54	-0.12%	673.58	-0.11%
29.5	712.17	711.27	-0.13%	711.32	-0.12%

* ORIGINAL MAXIMUM SHEAR STRESSES ARE OBTAINED BASED ON 4000 ACCELERATION POINTS

SUBJECT
FREQUENCY DEPENDENT DYNAMIC SHEAR STRESSES IN THE EARTHFILL BETWEEN SHEETPILES AT INTAKE PUMPING STATION

PROJECT
WBNP UNIT 1

WATTS BAR NUCLEAR PLANT
COMPUTED WSX DATE 4-23-92
CHECKED ICR DATE 4-23-92

13.0 CONCLUSIONS

The induced dynamic stresses in the Class A backfill within the sheetpiles during a seismic event are well within the available shear strength of the backfill. The resulting factors of safety are satisfactory and the damping ratios are within the acceptable limits.