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CALCULATION TITLE PAGE

*SEE INSTRUCTIONS ON REVERSE SIDE

▲ 5010.64 (FRONT)

CLIENT & PROJECT	PAGE 1 OF 35 + 17A&B + 28A
PRIVATE FUEL STORAGE, LLC - PRIVATE FUEL STORAGE FACILITY	ATTACH A (1p)

CALCULATION TITLE (Indicative of the Objective):	QA CATEGORY (✓)
DOCUMENT BASES FOR RECOMMENDED VALUES OF DYNAMIC SOIL PROPERTIES AND COEFFICIENT OF SUBGRADE REACTION	☑ I - NUCLEAR SAFETY RELATED ☐ II ☐ III ☐ ____ OTHER

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05996.01	G(B)	01		119

* APPROVALS - SIGNATURE & DATE						
PREPARER(S)/DATE(S)	REVIEWER(S)/DATE(S)	INDEPENDENT REVIEWER(S)/DATE(S)	REV. NO. OR NEW CALC NO.	SUPERSEDES * CALC. NO. OR REV. NO.	CONFIRMATION * REQUIRED (✓) YES	NO
PAUL J. TRUDEAU 1/31/97 [signature]	NURI T. GEORGES 2/7/97 [signature]	NURI T. GEORGES 2/7/97 [signature]	0		✓	
PAUL J. TRUDEAU 5/8/97 [signature]	Alan F Brown 5/8/97 [signature]	Alan F Brown 5/8/97 [signature]	1	0		✓
PAUL J. TRUDEAU 5/30/97 [signature]	Alan F Brown 6/4/97 Alan Brown by NTG via telecon	Alan F Brown 6/4/97 Alan Brown by NTG	2	1		✓

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REASONS FOR REV 2

Add calculation of average values of ranges of Vp and Vs reported by Geosphere Midwest (1997)

REASONS FOR REV 1

Remove "Requires Confirmation" re:

- Geosphere Midwest preliminary results from geophysical surveys
- Strain-compatible properties based on soil amplification analyses
- Cask weights revised from 300 K to 354 K, based on p C3 of Calc 05996.01-G(B)-05 Rev 0.

OBJECTIVE

Document the bases for recommended values of geotechnical parameters required for use in seismic analyses. These include low-strain values of:

shear wave velocity,
compression wave velocity,
Poisson's ratio,
shear modulus,
compression modulus,
elastic modulus,

and strain-compatible values of:

shear modulus,
compression modulus,
Poisson's ratio,
elastic modulus, and
modulus of subgrade reaction.

BACKGROUND

Preliminary estimates of these geotechnical parameters were provided to Holtec International via Letter No. S-V-41, dated 10/16/96. Since then, geotechnical borings, laboratory testing, and seismic refraction and reflection surveys have been performed and Geomatrix Consultants, Inc has prepared Calc 05996.01-G(PO5)-1, which documents the bases for the strain-compatible soil properties. The purpose of this calculation is to review and revise, if necessary, the preliminary estimates of these geotechnical parameters.

METHOD/ASSUMPTIONS

Methods and assumptions are identified below under the discussion of the development of each geotechnical parameter.

SOURCES OF DATA

- Boring logs and laboratory test results are included in PFSF Report No. 05996.01-G(B)-2 Rev 0, "Geotechnical Data Report."
- Seismic survey results, provided by Geosphere, Inc, are included in PFSF Report No. 05996.1-G(PO9)-1 Rev 0, "Seismic Survey of the Private Fuel Storage Facility."
- Soil amplification analyses are performed and strain-compatible soil properties are reported in Calc 05996.01-G(PO5)-1 Rev 0, "Development of Soil and Foundation Parameters in Support of Dynamic Soil-structure Interaction Analyses," prepared by Geomatrix Consultants, Inc, .

DISCUSSION

Generalized Subsurface Profile

The soil profile at the site was investigated by drilling a series of exploratory borings up to 100 ft deep, as well as by performing seismic refraction (S and P-wave) and reflection surveys. Standard Penetration Test (SPT) samples were obtained at 5 ft intervals in these borings. Based on these borings, the generalized soil profile, shown in Figure 1, consists of three layers. The uppermost layer extends to a depth of between 25 and 35 ft and is mainly interlayered silt, silty clay, and clayey silt. The silts are nonplastic, whereas the clayey silts and silty clays are commonly slightly to moderately plastic, with some being highly plastic. SPT N-values are mostly between 8 and 20 blows per ft, indicating "stiff" or "medium dense" materials. Most samples were dry or damp. These materials probably represent deeper water facies of Lake Bonneville.

A distinct change in material occurs at about 25 to 35 ft. SPT N-values commonly exceed 100 blows per ft, and refusal (>100 blows per 6 in.) conditions are often encountered. The upper 25 to 30 ft consists of very dense, dry, fine sand. Thin layers of fine gravel and coarse sand also are evident, indicating a near-shore environment of deposition. A few clayey zones were encountered, but they had no apparent effect on the blow counts.

The two borings that were drilled to a depth of 100 ft (Borings A-1 and D-4) indicate that this layer is underlain by very dense silt, with occassional layers of silty sand and clayey silt. SPT N-values generally indicate refusal (>100 blows per 6 in.) conditions.

The groundwater table was not encountered in the borings, which were completed to 100 ft depth. Seismic refraction results indicate the compression wave (P-wave) velocity changes from an average of 2,780 fps to an average of 5,525 fps at about 100 to 130 ft depth, which may represent the water table.

These borings did not encounter bedrock; however, interpretation of the seismic reflection survey data indicates that the depth to bedrock is between 520 ft and 880 ft below the surface at the site in the vicinity of the Storage Facility.

Geotechnical Laboratory Tests

Geotechnical laboratory tests were performed on undisturbed samples obtained in these borings. These included determination of water content, Atterberg Limits, percent fines, and specific gravity. Unconsolidated-undrained triaxial compression tests and consolidation tests also were performed. See Report No. 05996.01-G(B)-2 Rev 0 for additional details about these tests.

Unconsolidated-undrained triaxial tests were performed on two undisturbed tube samples of the clayey silt, obtained from depths of 10 to 12 ft. Figure 2 presents the results of these tests plotted as maximum shear stress vs normal stress and indicates that the undrained shear strength of this clayey silt is 2.2 to 2.4 ksf. See Report No. 05996.01-G(B)-2 Rev 0 for additional details.

A total of 5 consolidation tests were performed on undisturbed tube samples from Borings C-1 and C-2. The strain vs log stress plots, included as Figures 3A to 3D, indicate that the maximum past pressure of this clayey silt is approximately 3 tsf. These plots also indicate that after exceeding the maximum past pressure, the secondary compression is significant. The large secondary compression may be due to deformation of a weakly cemented structure of the silt.

Strain-Compatible Soil Properties

Soil amplification analyses are performed and strain-compatible soil properties are reported in Calc 05996.01-G(PO5)-1 Rev 0, "Development of Soil and Foundation Parameters in Support of Dynamic Soil-structure Interaction Analyses," prepared by Geomatrix Consultants, Inc, . The results of this calculation are summarized in Attachment A, Transmittal from Chin Man Mok of Geomatrix Consultants, Inc, to Stan Macie, dated March 28, 1997.

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ESTIMATE SHEAR MODULUS OF UPPER LAYER OF CLAYEY SILT, SILT, SILTY CLAY (LOW STRAINS)

NOTE: z VARIES FROM 25' TO 30'.

SOIL PROPERTIES: SPECIFIC GRAVITY = 2.72

CONSOL TEST	e_o	γ_m PCF	γ_d PCF	ω %	S %	z FT	$\bar{\sigma}_{v_{MPP}}$ TSF	PI
C1-U3B	1.62	84.3	64.7	30.3	50.7	10.8	3.6	4.9
C1-U3C	2.04	77.6	55.8	38.9	51.8	11.2	2.8	13.2
C1-U3D	2.28	75.8	51.7	46.7	55.6	11.4	3.0	17.0
C2-U2C	1.62	82.8	64.9	27.6	46.4	10.9	3.0	7.7
C2-U2E	1.95	80.3	57.5	39.7	55.3	11.7	NA	12.7
	AVG: 1.9	80.2						AVG = 11.1

	z FT	× γ_m PCF	$\bar{\sigma}_v$ PSF	$\bar{\sigma}_v$ TSF	$\bar{\sigma}_{v_{MPP}}$ TSF	OCR
C1-U3B	10.8	84.3	910	0.46	3.6	7.9
C1-U3C	11.2	77.6	869	0.44	2.8	6.4
C1-U3D	11.4	75.8	864	0.43	3.0	6.9
C2-U2C	10.9	82.8	903	0.45	3.0	6.6
			AVG = 886			AVG = 7.0

NOTE: z_w ASSUMED TO BE > 120 FT

$$G_{MAX}(PSI) = 1230 \frac{(2.97 - e)^2}{1+e} (OCR)^K \sqrt{\bar{\sigma}_o \,(PSI)}$$

EQ 2
HARDIN & DRNEVICH (1972)

$K = f(PI)$ FOR $7.7 < PI < 17$ $K \simeq 0.1$

$$\therefore\ G_{MAX}(PSI) = 1230 \frac{(2.97 - 1.9)^2}{1 + 1.9} (7.0)^{0.1} \sqrt{\frac{1 + 2(0.5)}{3} \, 886 \frac{\#}{FT^2} \times \frac{1\ FT^2}{144\ IN.^2}}$$

$\bar{\sigma}_o = 4.1$ PSI

$$G_{MAX} = 1195 \frac{\#}{IN.^2} \times \frac{144\ IN.^2}{FT^2} \times \frac{K}{1000\ \#}$$

$G_{MAX} = 172$ KSF THIS SEEMS LOW - CHECK γ_m

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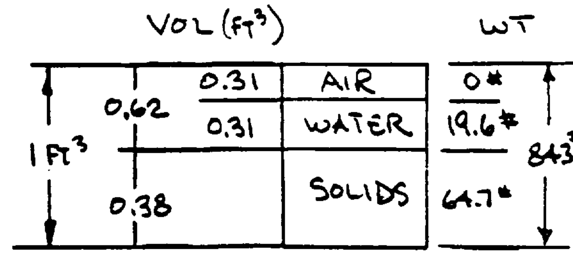
CHECK $\gamma_{SAT'D}$ OF CLAYEY SILT

CONSOL TEST C1-U3B

$e_o = 1.62 = \frac{V_v}{V_s}$

$S = 50.7\% \Rightarrow 0.507 = \frac{V_w}{V_v}$



$\gamma_m = 84.3 \frac{\#}{FT^3} \quad \therefore 1\ FT^3 = 84.3\#$

$w = 30.3\% = \frac{W_w}{W_s} \quad \therefore W_w = 0.303\, W_s$

$W_w + W_s = 84.3\#$

$0.303\, W_s + W_s = 84.3\# \quad \Rightarrow \quad W_s = \frac{84.3\#}{1.303} = 64.7\#$

$\&\ W_w = 0.303\, W_s = 0.303 \times 64.7\# = 19.6\#$

$e_o = 1.62 = \frac{V_v}{V_s} \quad \Rightarrow \quad V_v = 1.62\, V_s$

IN 1 FT³, $V_v + V_s = 1\ FT^3$

$\therefore 1.62 V_s + V_s = 1\ FT^3 \quad \Rightarrow \quad V_s = \frac{1\ FT^3}{2.62} = 0.38\ FT^3$

$\&\ V_v = 1.62\, V_s = 1.62 \times 0.38 = 0.62\ FT^3$

$V_w = \frac{W_w}{\gamma_w} \quad \Rightarrow \quad V_w = \frac{19.6\#}{62.4 \frac{\#}{FT^3}} = 0.31\ FT^3$

$\therefore V_a = 1 - V_w - V_s = 1 - 0.31 - 0.38 = 0.31\ FT^3$

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FOR 100% SATURATION, ALL OF THE VOIDS WOULD BE FILLED WITH WATER. IN THIS CASE, THE 1 FT^3 VOLUME WOULD WEIGH $\underbrace{0.62\ FT^3 \times 62.4\ \frac{\#}{FT^3}}_{W_w} + \underbrace{64.7\ \#}_{W_s}$

OR $W_{SAT'D} = 103.4\ \#$

SINCE THIS IS 1 FT^3, $\gamma_{SAT} = 103.4$ PCF

THIS IS A REASONABLE VALUE FOR γ_{SAT} OF SILT.

∴ THE LOW γ_m VALUES ARE REASONABLE, AND THEY ARE DUE TO THE LOW VALUES OF PERCENT SATURATION.

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ESTIMATE LOW-STRAIN SHEAR MODULUS BASED ON RESULTS OF SEISMIC REFRACTION SURVEY: SEISMIC LINES 1 & 2. GEOSPHERE MIDWEST (1997)

$$G = \rho V_s^2$$

LAYER 1

$V_{s_{AVG}} = 750 \frac{FT}{SEC}$ $\rho = \frac{\gamma_m}{g} = \frac{80\ \#/FT^3}{32.2\ FT/SEC^2}$

AVG = 800 FPS, BUT SEE DISCUSSION ON p. 17A (2)

$$G_{MAX\ LAYER\ 1} = \frac{80\ \frac{\#}{FT^3}}{32.2\ \frac{FT}{SEC^2}} \times \left(750\ \frac{FT}{SEC}\right)^2 \times \frac{K}{1000\ \#} = 1398\ KSF$$

SAY **1400 KSF**

FOR LAYER 2 $V_{s_{AVG}} = 2110 \frac{FT}{SEC}$

NOTE: THIS LAYER IS MOSTLY VERY DENSE, DRY SAND, WITH SOME SILT & SOME GRAVEL.

BASED ON TABLE 3.2 OF LAMBE & WHITMAN (1969),

$87_{MIN} < \gamma_d < 127_{MAX}$ PCF FOR SILTY SAND

$85 < \gamma_d < 138$ " FINE TO COARSE SAND

$89 < \gamma_d < 146$ " SILTY SAND & GRAVEL.

SINCE LAYER IS MOSTLY DRY, FINE SAND,

ASSUME $\gamma_{d_{min}} = 87$ PCF $\gamma_{d_{MAX}} = \frac{127+138}{2} \cong 130$ PCF

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$$D_r = \frac{\gamma_{d\,MAX}}{\gamma_d} \times \frac{\gamma_d - \gamma_{d\,MIN}}{\gamma_{d\,MAX} - \gamma_{d\,MIN}} \times 100\%$$ EQ 3.1 LAMBE & WHITMAN (1969)

ASSUME $D_r = 85\%$ (THE LOWER BOUND OF RANGE OF D_r FOR VERY DENSE SANDS BASED ON FIG 7.5 OF ↑)

$$0.85 = \frac{130}{\gamma_d} \times \frac{\gamma_d - 87}{130 - 87}$$

$$0.85\,\gamma_d\,(43) = 130\,\gamma_d - 11{,}310.$$

$$93.5\,\gamma_d = 11{,}310 \quad \Rightarrow \quad \gamma_d = 121 \text{ PCF}.$$

ASSUME $\gamma_t = 125$ PCF FOR LAYER 2*
(ASSUMES $\omega \sim 4\%$; $\gamma_t = (1+\omega)\,\gamma_d$)

$$\therefore G_{MAX_{LAYER\,2}} = \rho V_s^2 = \frac{125 \frac{\#}{FT^3}}{32.2 \frac{FT}{SEC^2}} \times \left(2110 \frac{FT}{SEC}\right)^2 \times \frac{K}{1000\,\#}$$

$$G_{MAX_{LAYER\,2^*}} = 17{,}283 \text{ KSF} = 120 \text{ KSI}$$

SAY 17,280 KSF

NOTE: THIS SEEMS TO BE VERY HIGH, EVEN FOR DENSE SANDS. CHECK AS f (N-VALUE).

* ALSO APPLIES FOR LAYER 3

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OBJECTIVE:

ESTIMATE LOW-STRAIN SHEAR MODULI BASED ON SPT N-VALUES

METHOD:

OHSAKI & IWASAKI (1973) INDICATES

$$G_{MAX} \simeq 1200\, N^{0.8} \ \frac{t}{m^2}$$

WHERE N = SPT N-VALUE.

CONVERTING TO KSF

$$G_{MAX} = 1200 \frac{t}{m^2} \times \left(\frac{m}{100\,cm} \times \frac{2.54\,cm}{in.} \times \frac{12\,in.}{ft} \right)^2 \times \frac{1{,}000\,Kg}{t} \times \frac{\#}{0.4536\,Kg} \times \frac{k}{1{,}000\,\#} \ N^{0.8}$$

$$G_{MAX}\,(KSF) = 245.78\, N^{0.8}$$

LAYER	N BL/FT	G_{MAX} KSF	γ PCF	$V_s = \sqrt{\frac{G}{\rho}}$ FT/SEC
1	8 TO 20	1297 TO 2700	80	722 TO 1042
2	~ 100	9784	125	1588
3	~ 150*	13,534	130	1831
	~ 200	17,036	130	2054

NOTE: G_{MAX} VALUES CALC'D BASED ON BLOW COUNTS ARE SIMILAR TO G_{MAX} VALUES BASED ON SEISMIC REFRACTION SURVEY FOR LOWER RANGE OF N-VALUES FOR LAYER 1 & A REASONABLE VALUE OF N = 200 FOR LAYERS 2 & 3.

* N-VALUES TYPICALLY >100/3-6 IN., ASSUME N = 150 TO 200 BL/FT

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COMPARISON OF LOW-STRAIN SHEAR MODULI - KSF DETERMINED USING VARIOUS PROCEDURES

BASED ON:		LAYER 1	LAYER 2 & 3	
HARDIN-DRNEVICH EQ.		172	NO LAB TESTS TO INDICATE VOID RATIO; ∴ G_{MAX} NOT CALC'D	
SPT N-VALUES				
OHSAKI & IWASAKI (1973)	N= 8	~1300	N= 100	9,784
	N= 20	2700	N= 200	17,036
SEISMIC REFRACTION:	V_s = 750 FPS	1400 KSF	V_s = 2110 FPS	G_{MAX} = 17,283 KSF

CONCLUSION - LOW-STRAIN SHEAR MODULI

NOTE: G_{MAX} BASED ON V_s DETERMINED IN SEISMIC REFRACTION SURVEY (LINES 1 & 2) ARE CONSIDERED TO BE THE MOST RELIABLE.

∴ G_{MAX} = 1400 KSF FOR LAYER 1

= 17,280 KSF FOR LAYERS 2 & 3

ESTIMATE POISSON'S RATIO (LOW-STRAIN)

NOTE: LAMBE & WHITMAN (1969) (p.232 SECT 15.1) INDICATES "THE POISSON'S RATIO μ TO BE USED IN THE EQUATIONS* CAN BE ESTIMATED WITH SATISFACTORY ACCURACY AS 0.35 FOR SOILS OF LOW SATURATION AND 0.5 FOR FULLY SATURATED SOILS."

GROUNDWATER IS ESTIMATED TO BE AT DEPTH ≥ 120 FT. ABOVE THIS DEPTH, THE SOILS ARE CORRECTLY CHARACTERIZED AS BEING "OF LOW SATURATION"; ∴ ASSUME $\mu = 0.35$.

OHSAKI & IWASAKI (1973) INDICATE

$$\mu = \frac{(V_p/V_s)^2 - 2}{2\left[(V_p/V_s)^2 - 1\right]}$$

LAYER 1 AVG VALUES OF V_p & V_s FROM GEOSPHERE MIDWEST (1997)

$$\therefore \mu_{AVG_1} = \frac{(1280/800)^2 - 2}{2\left[\left(\frac{1280}{800}\right)^2 - 1\right]} = 0.18 \text{ FOR LAYER 1}$$

↑ THIS SEEMS LOW - SEE p 17A

LAYER 2

$$\mu_{AVG_2} = \frac{(2780/2110)^2 - 2}{2\left[(2780/2110)^2 - 1\right]} = -0.18$$

N.G. FOR LAYER 2

* THE EQUATIONS USED FOR EVALUATION OF SPRING CONSTANTS FOR DYNAMICALLY LOADED FOUNDATIONS

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POISSON'S RATIO

LAYER 2 CONT'D BASED ON V_p & V_s MEAS'D BY GEOSPHERE

NOTE: GEOSPHERE REPORTS FOR LAYER 2 BASED ON SEISMIC LINES 1 & 2 (IN THE STORAGE FACILITY AREA):

SEISMIC LINE 1	SEISMIC LINE 2	
$2725 < V_p < 3475$ FPS	$2200 < V_p < 2725$ FPS	±15%
$1750 < V_s < 2600$ FPS	$1675 < V_s < 2425$ FPS	±20%

IF WE ASSUME $V_p = V_{P_{AVG}} + 15\%$, $V_p \doteq 3200$ FPS

" " " $V_s = V_{S_{AVG}} - 20\%$, $V_s \simeq 1690$ FPS

THIS RESULTS IN

$$\mu_{AVG_2} = \frac{(3200/1690)^2 - 2}{2\left[(3200/1690)^2 - 1\right]} = 0.31$$

THIS IS MORE REASONABLE FOR POISSONS RATIO OF LAYER 2.

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POISSON'S RATIO

OHSAKI & IWASAKI (1973) REPORT POISSON'S RATIO OF SANDY SOILS CAN BE ESTIMATED USING

$$* \quad \mu = 0.2 + 0.3\sqrt{1 - \frac{1}{16}\left[(\log_{10} G) - 2\right]^2}$$

FOR $500 < G < 100000 \ T/m^2$

FOR LAYER 1

$$G_{MAX} \simeq 1590 \ \frac{K}{FT^2} \times \left(\frac{1 \ FT}{12 \ IN.} \cdot \frac{IN.}{2.54 \ Cm} \cdot \frac{100 \ cm}{m}\right)^2 \times \frac{1000\#}{K} \times$$

$$\times \frac{0.4536 \ kg}{\#} \times \frac{T}{1000 \ kg} = 7763 \ \frac{T}{m^2}$$

$$\mu = 0.2 + 0.3\sqrt{1 - \frac{1}{16}\left[(\log_{10} 7{,}763) - 2\right]^2}$$

$$\mu = 0.2 + 0.26 = \underline{\underline{0.46}}$$

FOR LAYERS 2 & 3 $\quad G_{MAX} = 17{,}280 \ KSF = 84{,}380 \ \frac{T}{m^2}$

$$\Rightarrow \mu = 0.2 + 0.3\sqrt{1 - \frac{1}{16}\left[(\log_{10}(84{,}380) - 2\right]^2} = 0.2 + 0.20 = \underline{\underline{0.40}}$$

* NOTE: MOST OF THE SAMPLES THAT FORMED THE BASIS OF THIS EQUATION WERE LOCATED BELOW THE GROUNDWATER TABLE, AND THUS, WERE SATURATED. LAYERS 1-3 AT THE SKULL VALLEY SITE ARE NON-SATURATED (~DRY); ∴ THE VALIDITY OF THIS EQUATION FOR THESE SOILS IS QUESTIONABLE.

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POISSON'S RATIO

p 7.1-153 NAVFAC DM 7.01 (1986) $\nu = 0.25$ COHESIONLESS SOILS
$= 0.33$ COHESIVE SOILS

TABLE 3.9 DAS (1995) INDICATES

TYPE OF SOIL	μ
MEDIUM DENSE SAND	0.25 - 0.40
DENSE SAND	0.30 - 0.45
SILTY SAND	0.20 - 0.40
SAND & GRAVEL	0.15 - 0.35

CONCLUSION - POISSON'S RATIO

ASSUME POISSON'S RATIO = 0.35 BASED ON DISCUSSION ON PP 17A & 17B.

ASSUME POISSON'S RATIO = 0.30 FOR LAYERS 2 & 3. CALCULATING μ BASED ON THE PRELIMINARY RESULTS REPORTED BY GEOSHPERE, INC OF COMPRESSIONAL WAVE AND SHEAR WAVE VELOCITIES FOR LAYER 2 (WHICH COMPRISES LAYERS 2 & 3 SHOWN IN FIGURE 1 OF THIS CALC), RESULTS IN A NEGATIVE VALUE OF μ, WHICH IS UNREASONABLE. ∴ RECOMMEND $\mu = 0.3$ BASED ON:

- AVG OF VALUE FOR NONSATURATED SOILS PER LAMBE & WHITMAN ($\mu = 0.35$) AND VALUE FOR COHESIONLESS SOILS RECOMMENDED BY NAVFAC (1986) ($\mu = 0.25$).
- $\mu = 0.3$ IS IN MIDDLE OF RANGE RECOMMENDED BY DAS (1995) FOR SILTY SAND
- HIGHER VALUES OF μ YIELD BULK MODULUS FOR THESE SOILS THAT IS GREATER THAN BULK MODULUS OF WATER, WHICH IS UNREASONABLE.
- CONSISTENT WITH μ CALC'D BASED ON $V_P = V_{P_{AVG}} + 15\%$ & $V_S = V_{S_{AVG}} - 20\%$ (RANGES REPORTED BY GEOSPHERE).

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CALCULATION SHEET

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REVIEW OF POISSONS RATIO FOR LAYER 1.

CALCULATED VALUE OF 0.18, WHICH WAS BASED
ON AVERAGE VALUES OF V_p & V_s REPORTED BY
GEOSPHERE MIDWEST (1997), SEEMS LOW.

BASED ON THE DISCUSSION PRESENTED ABOVE, $\mu = 0.35$
SEEMS TO BE A MORE REASONABLE VALUE.

GEOMATRIX CALC 05996.01-G(POS)-1 REV 0 RECOMMENDS

V_p = 1500 FPS ρ = 81 pcf

V_s = 515 FPS & G = 668 KSF

μ = 0.433 & E = 1915 KSF

BASED ON SHAKE ANALYSES THAT USED

$V_s \simeq 750$ FPS FOR LAYER 1 (705 FPS < V_s < 794 FPS)

AS INPUT.

GEOSPHERE MIDWEST (1997) REPORTS ACCURACY = ±20% FOR LAYER 1 V_s VALUES.

AT LINE 1 725 FPS < V_s < 825 FPS $V_{s_{AVG}}$ = 775 FPS
" " 2 700 " " 950 " 825

$V_{s_{AVG}}$ = 800 FPS

NOTE: THIS IS NOT MUCH DIFFERENT THAN THE VALUE
OF V_s = 750 FPS USED BY GEOMATRIX & IT
IS WITHIN THE RANGE REPORTED BY GEOSPHERE (1997)

∴ RECOMMEND KEEPING V_s = 750 FPS

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POISSON'S RATIO

GEOSPHERE (1997) REPORTS ACCURACY OF ± 20% FOR LAYER 1 V_p VALUES

AT LINE 1	1125 FPS < V_p < 1300 FPS	$V_{P_{AVG}}$ = 1213 FPS
" " 2	1150 < " < 1550 FPS	" = 1350 "

$V_{P_{AVG}}$ = 1281 FPS.

NOTE: IF WE USE V_p = 1550 FPS, WHICH IS AT UPPER RANGE OF VALUES REPORTED BY GEOSPHERE WITHOUT ± 20% & IS CONSISTENT WITH VALUE USED BY GEOMATRIX.

$$\mu = \frac{(V_P/V_S)^2 - 2}{2\left[(V_P/V_S)^2 - 1\right]} = \frac{(1550/750)^2 - 2}{2\left[(1550/750)^2 - 1\right]} = 0.35 .$$

THIS IS MORE REASONABLE FOR POISSONS RATIO OF SILT, SILTY CLAY, CLAYEY SILT THAN 0.18 OBTAINED IF AVERAGE VALUES OF V_p & V_s ARE USED.

∴ FOR LAYER 1, RECOMMEND USING

V_p = 1550 FPS

V_s = 750 FPS $\Rightarrow G = \rho V_s^2 = \frac{0.080 \text{ KCF}}{32.2} \times 750^2 = 1398$ KSF

SAY 1400 KSF

μ = 0.35

ESTIMATE LOW-STRAIN MODULI OF ELASTICITY

$E = 2(1+\mu)G$ FROM EQ 12.4 LAMBE & WHITMAN (1969)

FOR LAYER 1 $\mu = 0.35$ $G = 1400$ KSF

$\therefore E_{MAX_1} = 2(1+0.35)1400 \text{ KSF} = \underline{\underline{3780}} \text{ KSF}$

$= 26.2$ KSI

FOR LAYERS 2 & 3 $\mu = 0.30$ $G = 17{,}280$ KSF

$\therefore E_{MAX_{2\&3}} = 2(1+0.30)17{,}280 \text{ KSF} = \underline{\underline{44{,}936}} \text{ KSF}$

$= 312$ KSI

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ESTIMATE LOW-STRAIN CONSTRAINED MODULI (= COMPRESSION MODULUS)

$$D = \frac{E(1-\mu)}{(1+\mu)(1-2\mu)}$$ EQ 12.8 LAMBE & WHITMAN (1969)

LAYER 1 $\mu = 0.2$ $E = 3816$ KSF

$$\therefore D = \frac{3780 \text{ KSF } (1-0.35)}{(1+0.35)(1-2\times0.35)} = \underline{\underline{6067 \text{ KSF}}}$$ SAY 6070 KSF

42.1 KSI

LAYERS 2 & 3 $\mu = 0.30$ $E = 44{,}936$ KSF

$$\therefore D = \frac{44{,}936 \text{ KSF } (1-0.30)}{(1+0.30)(1-2\times0.30)} = \underline{\underline{60{,}490 \text{ KSF}}}$$

= 420 KSI

BELOW GWT $\mu \simeq 0.5$ $\therefore$ DENOMINATOR $\simeq 0$.

NOTE: LAMBE & WHITMAN (1969) EQ 12.9c $\Rightarrow C_D = \sqrt{\frac{D}{\rho}}$

WHERE C_D = DILATATIONAL VELOCITY, WHICH = V_p

$\therefore$ CALC $D = \rho V_p^2$ WHERE $V_p \simeq 5525$ FPS BELOW GWT BASED ON GEOSPHERE, INC'S SEISMIC REFRACTION LINES 1 & 2

$$\therefore D = \frac{0.125 \text{ K/FT}^3}{32.2 \frac{\text{FT}}{\text{SEC}^2}} \times \left(5525 \frac{\text{FT}}{\text{SEC}}\right)^2 = \underline{118{,}500 \text{ KSF}}$$

= 823 KSI

ESTIMATE LOW-STRAIN BULK MODULI

$$B = \frac{\sigma_o}{\Delta V / V} = \frac{E}{3(1-2\mu)}$$

EQ 12.6 LAMBE & WHITMAN (1969)

LAYER 1

$$B_{MAX_1} = \frac{3780 \text{ KSF}}{3(1-2(0.35))} = \underline{4200 \text{ KSF}}$$

29.2 KSI

LAYER 2 & 3

$$B_{MAX_2} = \frac{44{,}936 \text{ KSF}}{3(1-2(0.30))} = \underline{\underline{37{,}447 \text{ KSF}}}$$

= 260 KSI

BELOW GWT ($Z > 120'$)

FROM SW-AJA (1972) p. 119

For soils located below the water table (saturated), undrained modulus values are required. Undrained saturated specimens in hydrostatic compression exhibit the stress deformation behavior of the pore water, since water is virtually incompressible. As a result of this condition, bulk modulus values approaching that of water (i.e., approximately 320,000 psi) should be used in analyses.

$$\therefore B_{BELOW\ GWT} = 320 \frac{K}{IN.^2} \times \frac{144 \text{ IN.}^2}{FT^2} = \underline{\underline{46{,}080 \text{ KSF}}}$$

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COEFFICIENT OF VERTICAL SUBGRADE REACTION: STORAGE PAD

STORAGE PAD 30' × 64' × 3' PER SWEC DRAWING 0599601-EY-2-E

$$k_s = \frac{p}{y}$$ EQ 1 TERZAGHI (1955)

FOOTING ON CLAY:

$$k_s = k_{s_1} \frac{1}{B}$$ EQ. 7 TERZAGHI (1955)

TABLE 2 OF TERZAGHI (1955) INDICATES

$k_{s_1} = 50 - 100 \frac{T}{FT^3}$ FOR STIFF CLAY $q_u = 1\text{-}2$ TSF

UU TESTS ON UPPER LAYER ⇒ q_u : 2.2 - 2.4 KSF = 1.1 - 1.2 TSF

⇒ FOR CLAY, $k_{s_{15' \times 15'}} = 50 \frac{T}{FT^3} \times \frac{1\ FT}{15\ FT} = 3.33 \frac{T}{FT^3} = 6.67 \frac{K}{FT^3}$

NOTE: $3.33 \frac{T}{FT^3} \times \left(\frac{1\ FT}{12\ IN.}\right)^3 \times \frac{2000\ \#}{T} = 3.86\ \#/IN.^3$

$50 \frac{T}{FT^3}$ " " $= 57.9\ \#/IN.^3$

p 265 DAS (1995) INDICATES $k_{s_1} = 44\text{-}92 \frac{\#}{IN.^3}$ FOR STIFF CLAY.

∴ $k_{s_1} = 50 \frac{T}{FT^3} = 58 \frac{\#}{IN.^3}$ IS WITHIN THE RANGE RECOMMENDED BY DAS.

FOR RECTANGULAR FOOTING, DAS (1995) RECOMMENDS

$$k = \frac{k_{B \times B}\left(1 + 0.5 \frac{B}{L}\right)}{1.5} = \frac{3.33 \frac{T}{FT^3}\left(1 + 0.5 \frac{15'}{64'}\right)}{1.5} = 2.48 \frac{T}{FT^3}$$

$= 5.0\ K/FT^3$

NOTE: $k_{s_{15' \times 64'}} = 0.75\, k_{s_{15' \times 15'}}$ $= 2.87$ PCI

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COEFFICIENT OF SUBGRADE REACTION

FOOTING ON SAND: $k_{1'\times1'} = 6N \ \frac{T}{FT^3}$ EQ 4.49 DAS (1995)

FOR UPPER LAYER $8 < N < 20$ TYPICALLY

FOR $N = 8$ $k_{1'\times1'} = 48\ T/FT^3$

$N = 20$ $k_{1'\times1'} = 160\ T/FT^3$

ASSUMING $N = 10$ $k_{1'\times1'} = 60\ T/FT^3$

TERZAGHI (1955) PROPOSES THE FOLLOWING VALUES OF $k_{s_{1'\times1'}}$ FOR DRY OR MOIST SANDS AS A FUNCTION OF DENSITY: { 40 T/FT3 FOR LOOSE; 130 T/FT3 FOR MEDIUM }

LAYER 1 IS SILT, SILTY CLAY, & CLAYEY SILT; ∴ ASSUME $k_{s_{1'\times1'}}$ IS 60 T/FT3, THE LOWER BOUND FOR MEDIUM DENSE SANDS RECOMMENDED BY TERZAGHI (1955), & COMPARABLE TO $N = 10\ \frac{BL}{FT}$ ACCORDING TO DAS (1995).

$$k_{B'\times B'} = k_s = k_{s_1}\left(\frac{B+1}{2B}\right)^2 \quad \text{EQ 8 TERZAGHI (1955)}$$

$$\therefore k_{15'\times15'} = k_s = 60\ \frac{T}{FT^3}\left(\frac{15+1}{2\times15}\right)^2 = 17.07\ \frac{T}{FT^3} = 34.1\ \frac{K}{FT^3}$$

$$= 19.75\ \frac{\#}{IN.^3}$$

$$k_{15'\times64'} = 0.75\ k_{15'\times15'} = 0.75 \times 34.1\ \frac{K}{FT^3} = \underline{\underline{25.4\ K/FT^3}}$$

COEFFICIENT OF SUBGRADE MODULUS BASED ON VERTICAL SPRING CONSTANT FOR DYNAMICALLY LOADED FOOTING

STATIC CONDITIONS

$$k_{v_s} = \frac{G}{1-\nu}\,\beta_z\sqrt{4cd}$$

TABLE 10-14 RICHART, HALL, & WOODS (1970)

ASSUME $\gamma \simeq 0.3\%$ FOR STATIC CONDITIONS $\therefore G/G_{MAX} \simeq 0.2$

$$G = 0.2 \times G_{MAX} = 0.2 \times 1590 \text{ KSF} = 318 \text{ KSF}$$

$$\nu = 0.2$$

B = DISTANCE BETWEEN ℄'S OF CASKS

$$\beta_z \cong 2^{\pm} \quad \text{FOR} \quad \frac{d}{c} = \frac{B/2}{L/2} = \frac{15/2}{64/2} \simeq 0.25$$

FIG 10-16 RICHART, HALL, & WOODS (1970)

$$\therefore k_{v_s} = \frac{318 \text{ K/FT}^2}{1-0.2} \times 2 \times \sqrt{4\ \frac{64'}{2} \times \frac{15'}{2}}$$

$$k_{v_s} = 24{,}632 \text{ K/FT}$$

$$k_s = \frac{k_{v_s}}{A} = \frac{24{,}632 \text{ K/FT}}{15 \times 64 \text{ FT}^2} = 25.7 \frac{\text{K}}{\text{FT}^3}$$

12.8 T/FT^3

14.9 #/IN.^{3}

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COEF OF SUBGRADE REACTION

SUMMARY OF RESULTS
COEFFICIENT OF SUBGRADE REACTION

METHOD		$k_{15' \times 64'}$ K/FT³	$k_{1' \times 1'}$ T/FT³
TERZAGHI (1955)	CLAY	5.0	50
" "	SAND	25.4	60
VERTICAL SPRING CONSTANT		25.7	N/A

DISCOUNTING CLAY VALUE, AVG ~ 25 K/FT³

DISCUSSION: LAYER 1 IS MOSTLY NONPLASTIC SILT, WHICH, BEING COHESIONLESS, IS EXPECTED TO BEHAVE MORE LIKE SAND THAN CLAY. ∴ DISCOUNT THE k_s CALC'D FOR CLAY. THE AVERAGE OF k_s CALCULATED BY THREE DIFFERENT METHODS FOR A SINGLE 15'x 64' PAD IS ~25 K/FT³. TO ACCOUNT FOR THE PLACEMENT OF PADS ~ END-TO-END, THIS VALUE SHOULD BE REDUCED SLIGHTLY (~20%); ∴

CONCLUSION - COEFFICIENT OF SUBGRADE REACTION FOR THE 15'x 64' STORAGE PAD IS ~ 20 K/FT³.

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CONCLUSIONS

Table 1 presents the average P-wave and S-wave velocities reported by Geosphere Midwest (in PFSF Report 0599601-G(PO9)-1 Rev 0), as well as low-strain values of various moduli, which were computed based on these data.

Attachment A presents a summary of the strain-compatible soil parameters, which were developed by Geomatrix Consultants, Inc, in PFSF Calc 05996.01-G(PO5)-1, Rev 0.

The coefficient of vertical subgrade reaction is:

$$k_{s_{1'x1'}} = 60\ t/ft^3 = 120\ K/FT^3$$

$$k_{s_{15'x64'}} = 20\ k/ft^3$$

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TABLE 1

SUMMARY OF GEOTECHNICAL PARAMETERS REQUIRED FOR DYNAMIC ANALYSES
Private Fuel Storage Facility - Skull Valley, Utah

Vicinity of Storage Facility Geotechnical Parameter		Layer 1 z < 30'	Layer 2 30' < z < 60'	Layer 3 60' < z < 120'	Layer 4 z > 120'
Low-strain values of:					
Shear wave velocity	ft/sec	750 *	2,110		
Compressional wave velocity	ft/sec	1,550	2,780		5,525
Poisson's ratio		0.35	0.3		~0.5
Shear modulus	ksf	1,400	17,280		
Elastic modulus	ksf	3,780	44,940		
Constrained modulus	ksf	6,070	60,490		118,500
Bulk modulus	ksf	4,200	37,450		46,080
Moist unit weight	pcf	80	125	125	130

(Layer 2 and Layer 3 share the single values shown for the low-strain parameters.)

2

Geosphere Midwest (1997) reported that compressional wave velocities along Seismic Line 3 were significantly higher than the average values recorded along Seismic Lines 1 and 2 and the depths to the bottoms of these layers were greater along Seismic Line 3. Seismic Line 3 is in the vicinity of the Operations & Maintenance Buildings and the western end of the Access Road. The following table presents average values of P-wave velocities based on ranges of values reported by Geosphere Midwest (1997) for Seismic Line 3: 2

Vicinity of Op's & Maintenance Bldg Geotechnical Parameter		Layer 1 z < 50'	Layer 2 & 3 50' < z < 130'	Layer 4 z > 130'
Low-strain values of:				
Compressional wave velocity	ft/sec	1610	2850	5650

* SEE DISCUSSION ON p 17A 2

TABLE 2

PFSF Storage Facility

Seismic Velocities from Geosphere Midwest Report, February 1997

Average Values Based on Ranges Reported by Geosphere

GEOTECHNICAL PARAMETER		Layer 1 z < 30'	Layer 2 30' < z < 60'	Layer 3 60' < z < 120'	Layer 4 z > 120'
Line 1 V_p	Maximum	1300	3475	5900	
	Minimum	1125	2725	5200	
	Average	1213	3100	5550	
Line 2 V_p	Maximum	1550	2725	5900	
	Minimum	1150	2200	5100	
	Average	1350	2463	5500	
Lines 1&2 V_p	**Average**	**1281**	**2781**	**5525**	
Line 1 V_s	Maximum	825	2600		
	Minimum	725	1750		
	Average	775	2175		
Line 2 V_s	Maximum	950	2425		
	Minimum	700	1675		
	Average	825	2050		
Lines 1&2 V_s	**Average**	**800**	**2113**		

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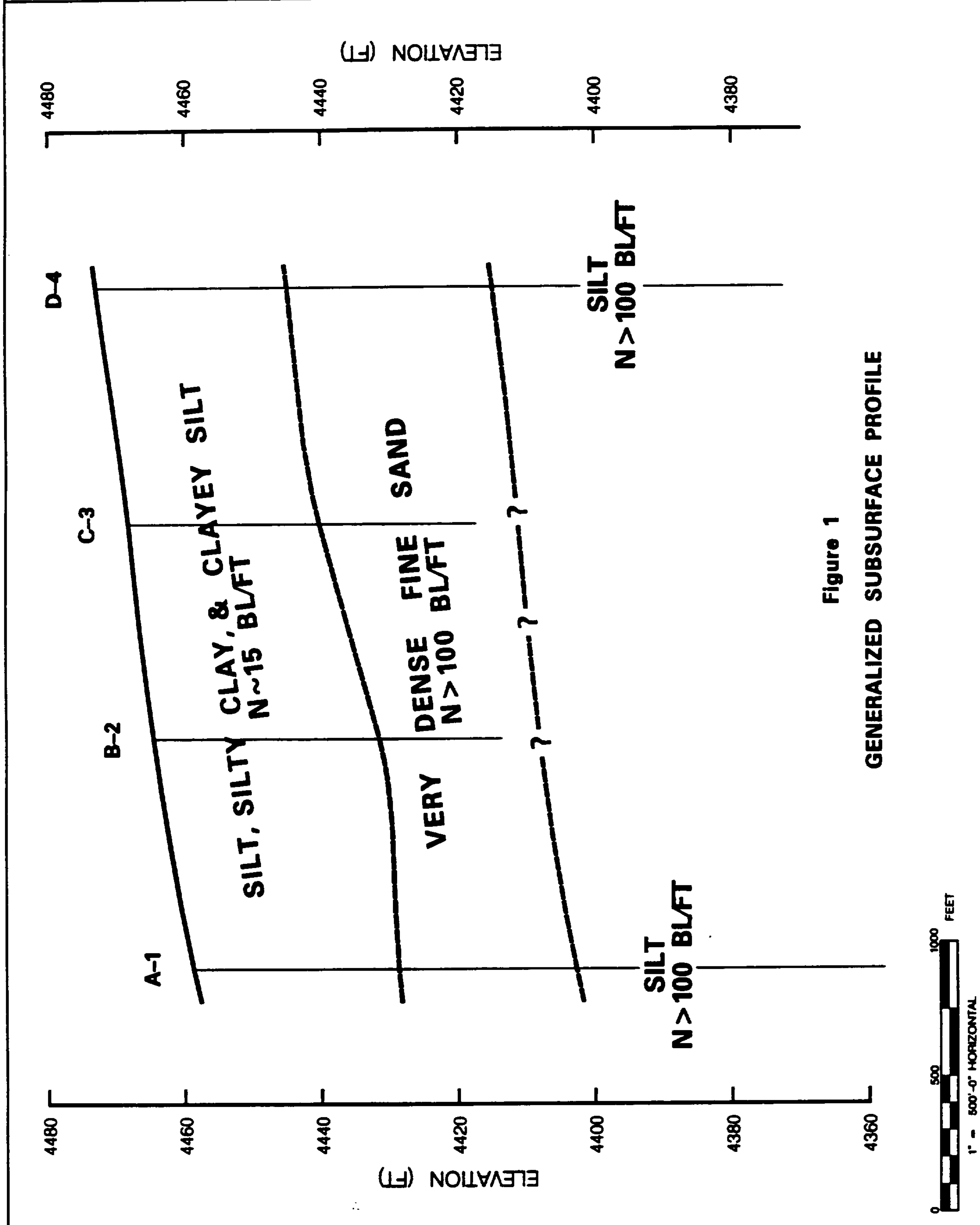

Figure 1

GENERALIZED SUBSURFACE PROFILE

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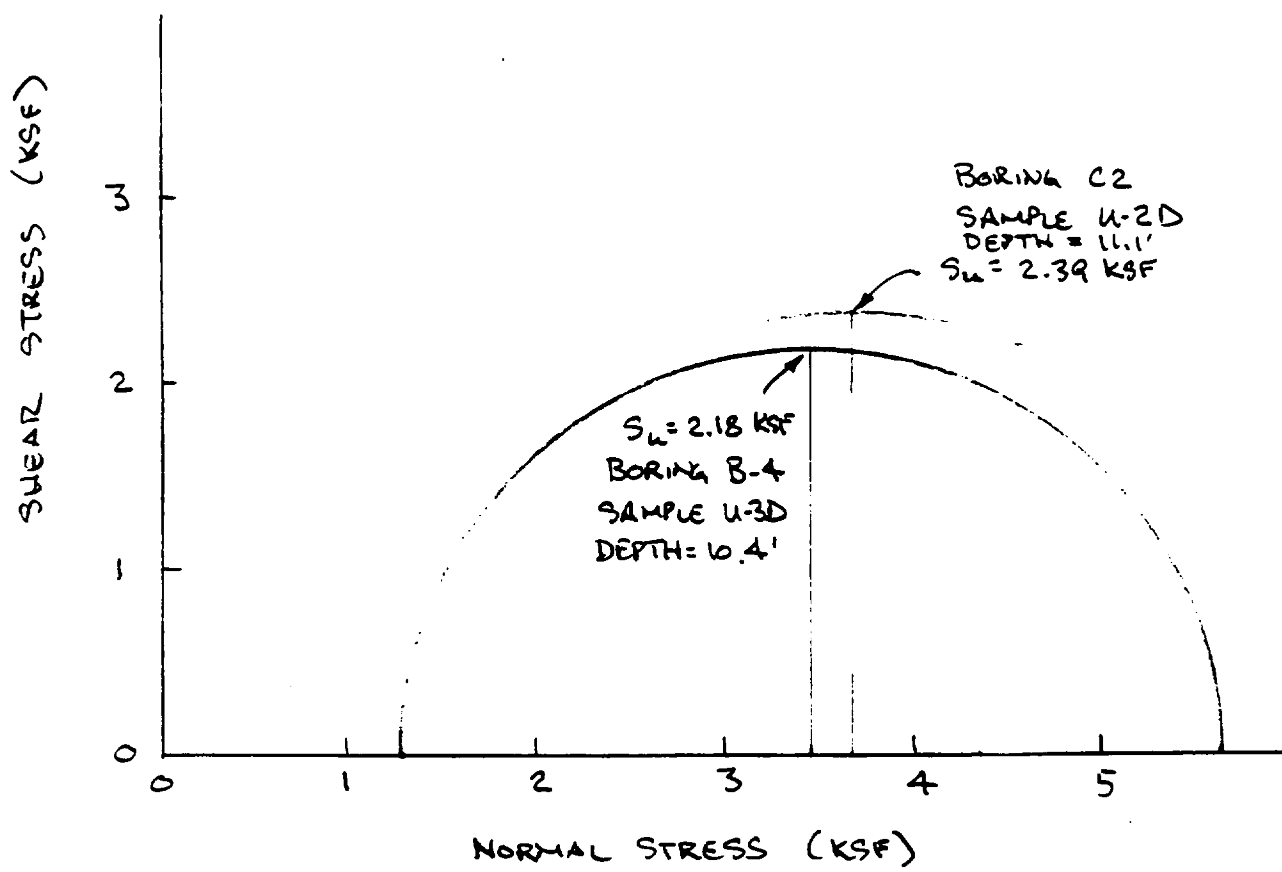
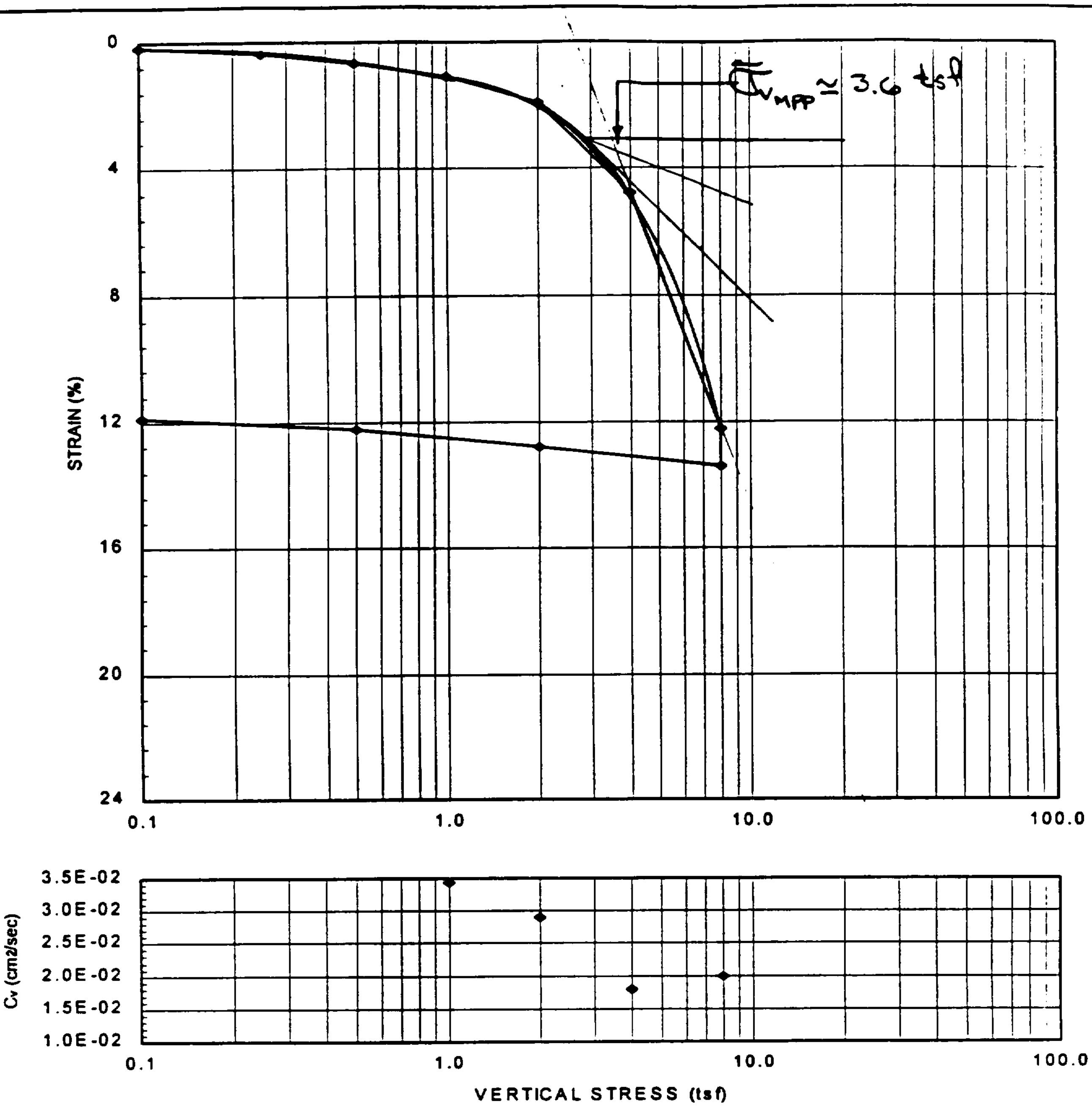
FIGURE 2

RESULTS OF UNCONSOLIDATED - UNDRAINED TRIAXIAL TESTS ON CLAYEY SILT





SAMPLE INFORMATION:

BORING:	C-1	DATE:	1/9/97
SAMPLE:	U-3B	TESTED BY:	ACS
DEPTH:	10.8 ft	CHECKED:	PJT
DESCRIPTION:	Clayey SILT		

SPECIMEN INFORMATION:

	INITIAL	FINAL	SPECIFIC GRAVITY:
WATER CONTENT:	30.3 %	28.7 %	2.72 (est)
DRY UNIT WEIGHT:	64.7 pcf	73.4 pcf	
VOID RATIO:	1.625	1.315	
SATURATION:	50.7 %	59.3 %	

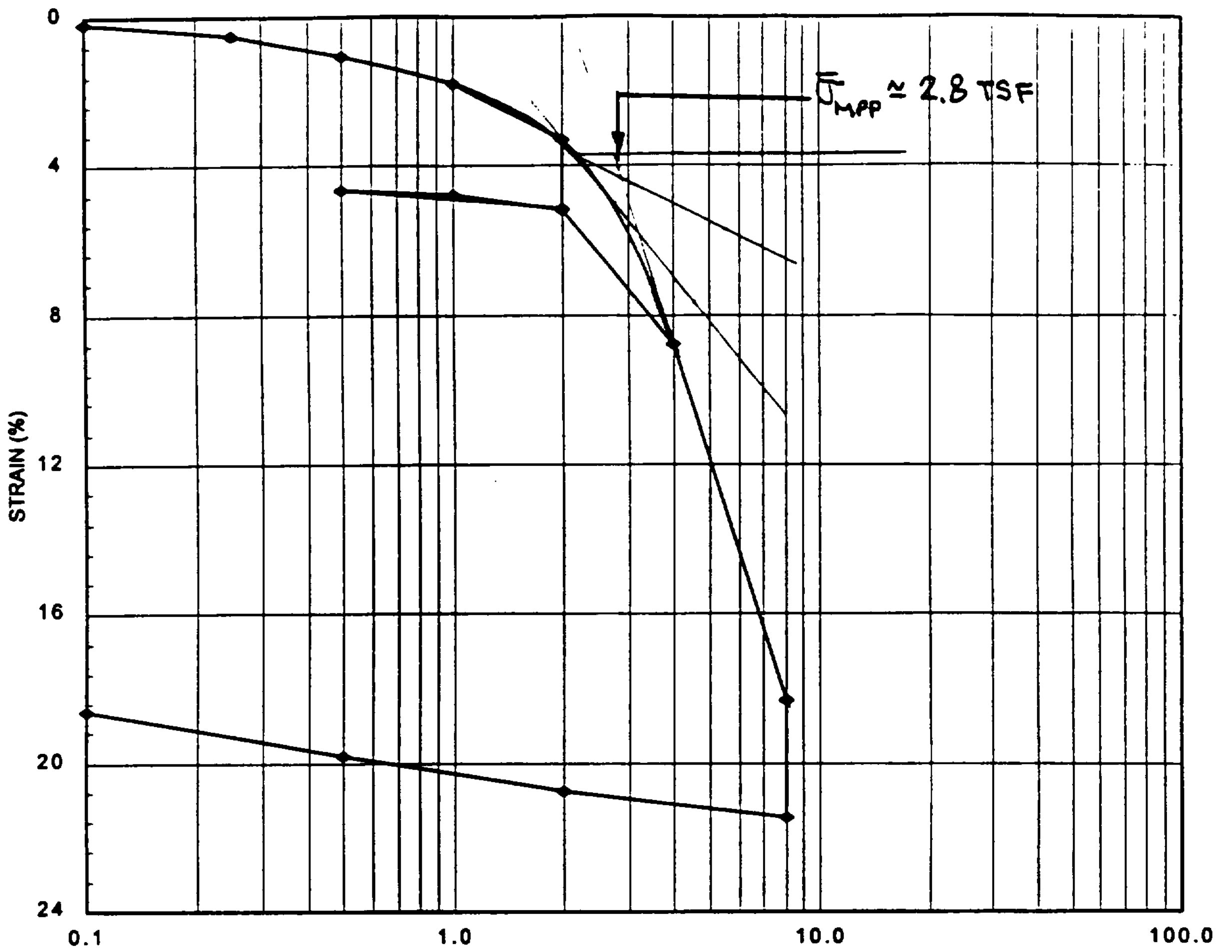
NOTE: Sample was not inundated and porous stones were dry

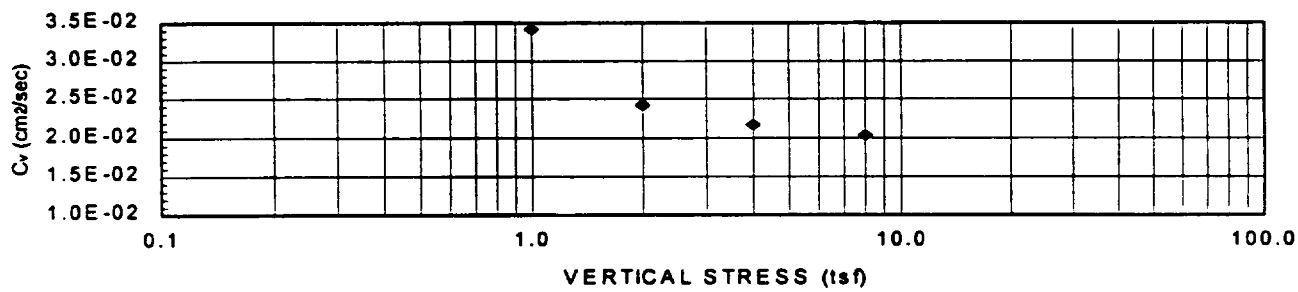
PRIVATE FUEL STORAGE FACILITY
SKULL VALLEY
PRIVATE FUEL STORAGE, LLC

FIGURE 3A
CALC 05996.01-G(B)-01-1 P 31

STONE & WEBSTER ENGINEERING CORP.
BOSTON, MASSACHUSETTS

CONSOLIDATION TEST RESULTS
BORING C-1, SAMPLE U-3B





SAMPLE INFORMATION:

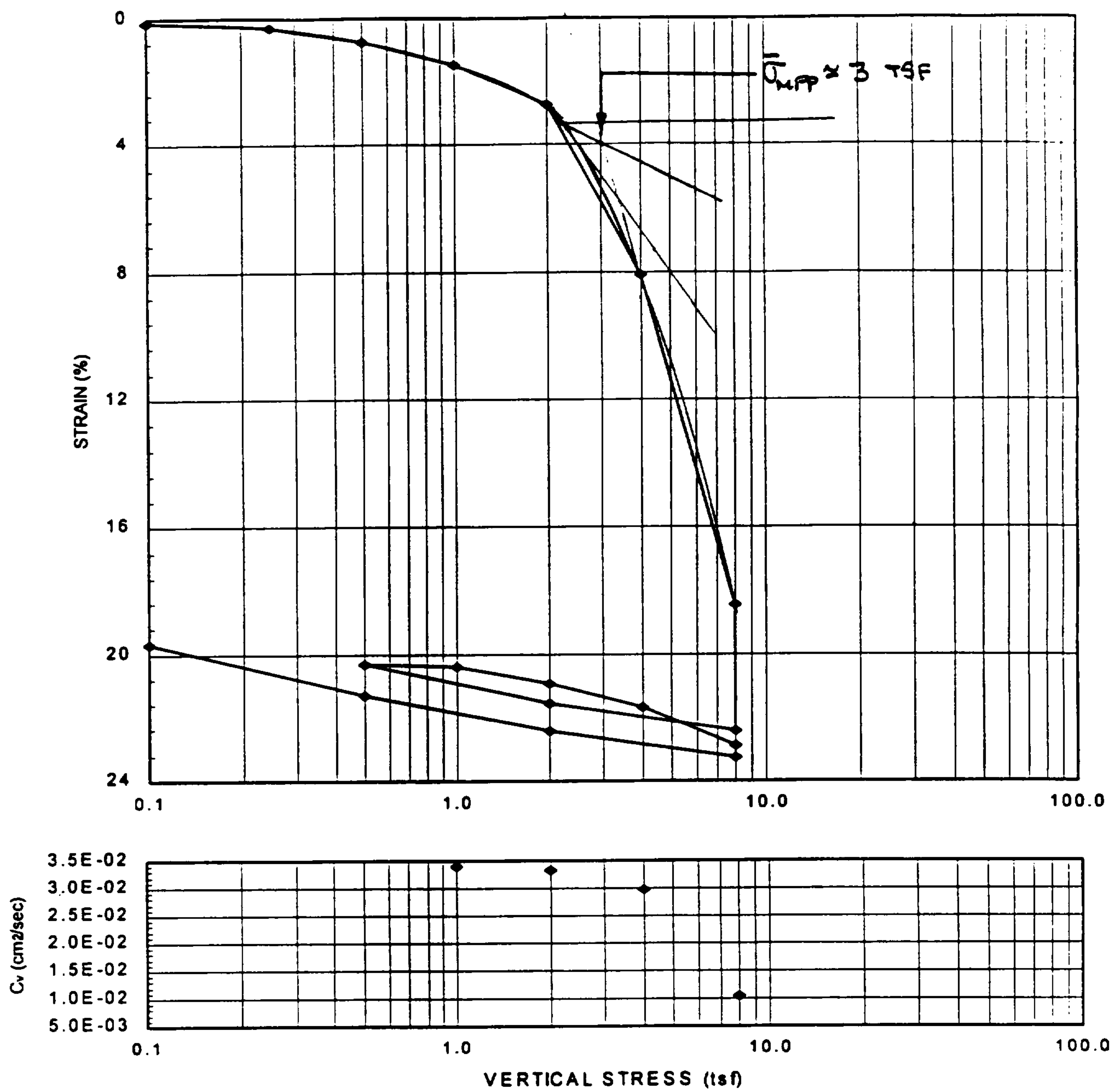
BORING:	C-1	DATE:	12/20/96
SAMPLE:	U-3C	TESTED BY:	ACS
DEPTH:	11.2 ft	CHECKED:	PJT
DESCRIPTION:	Clayey SILT		

SPECIMEN INFORMATION:

	INITIAL	FINAL	SPECIFIC GRAVITY:
WATER CONTENT:	38.9 %	51.9 %	2.72
DRY UNIT WEIGHT:	55.8 pcf	68.4 pcf	
VOID RATIO:	2.041	1.484	
SATURATION:	51.8 %	95.2 %	

NOTE: Sample was not inundated and porous stones were moist

PRIVATE FUEL STORAGE FACILITY SKULL VALLEY PRIVATE FUEL STORAGE, LLC	FIGURE 3B CALC 05996.01-G(B)-01-1 p 32
STONE & WEBSTER ENGINEERING CORP. BOSTON, MASSACHUSETTS	CONSOLIDATION TEST RESULTS BORING C-1, SAMPLE U-3C



SAMPLE INFORMATION:

BORING:	C-1	DATE:	12/12/96
SAMPLE:	U-3D	TESTED BY:	ACS
DEPTH:	11.4 ft	CHECKED:	PJT
DESCRIPTION:	Clayey SILT		

SPECIMEN INFORMATION:	INITIAL	FINAL	SPECIFIC GRAVITY:
WATER CONTENT:	46.7 %	62.4 %	2.72
DRY UNIT WEIGHT:	51.7 pcf	64.1 pcf	
VOID RATIO:	2.285	1.649	
SATURATION:	55.6 %	103.0 %	

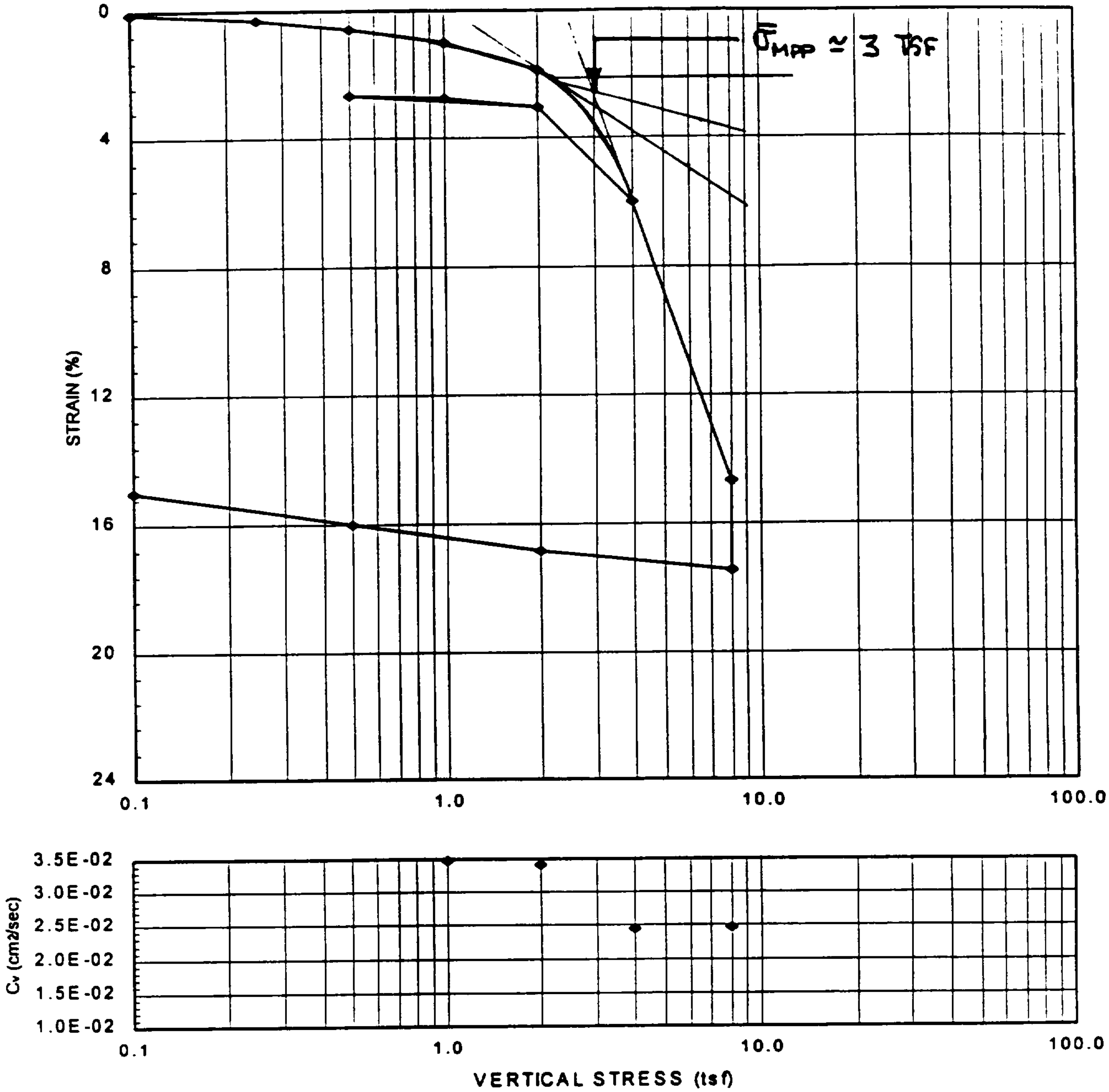
NOTE: Sample was inundated when the applied pressure was 0.5 tsf.

PRIVATE FUEL STORAGE FACILITY
SKULL VALLEY
PRIVATE FUEL STORAGE, LLC

FIGURE 3C
CALC 05996.01-G(B)-01-1 p 33

STONE & WEBSTER ENGINEERING CORP.
BOSTON, MASSACHUSETTS

CONSOLIDATION TEST RESULTS
BORING C-1, SAMPLE U-3D



SAMPLE INFORMATION:

BORING:	C-2	DATE:	12/17/96
SAMPLE:	U-2C	TESTED BY:	ACS
DEPTH:	10.9 ft	CHECKED:	PJT
DESCRIPTION:	Clayey SILT		

SPECIMEN INFORMATION:

	INITIAL	FINAL
WATER CONTENT:	27.6 %	44.2 %
DRY UNIT WEIGHT:	64.9 pcf	76.2 pcf
VOID RATIO:	1.615	1.230
SATURATION:	46.4 %	97.7 %

SPECIFIC GRAVITY: 2.72 (est)

NOTE: Sample was inundated when the applied pressure was 0.5 tsf.

PRIVATE FUEL STORAGE FACILITY
SKULL VALLEY
PRIVATE FUEL STORAGE, LLC

FIGURE 3D
CALC 05996.01-G(B)-01-1 p34

STONE & WEBSTER ENGINEERING CORP.
BOSTON, MASSACHUSETTS

CONSOLIDATION TEST RESULTS
BORING C-2, SAMPLE U-2C

NOTED MAY 8 1997, P. J. Irudaan

STONE & WEBSTER ENGINEERING CORPORATION

CALCULATION SHEET

CALCULATION IDENTIFICATION NUMBER				PAGE 35
J.O. OR W.O. NO.	DIVISION & GROUP	CALCULATION NO.	OPTIONAL TASK CODE	
05996.01	G(B)	01 - 1		

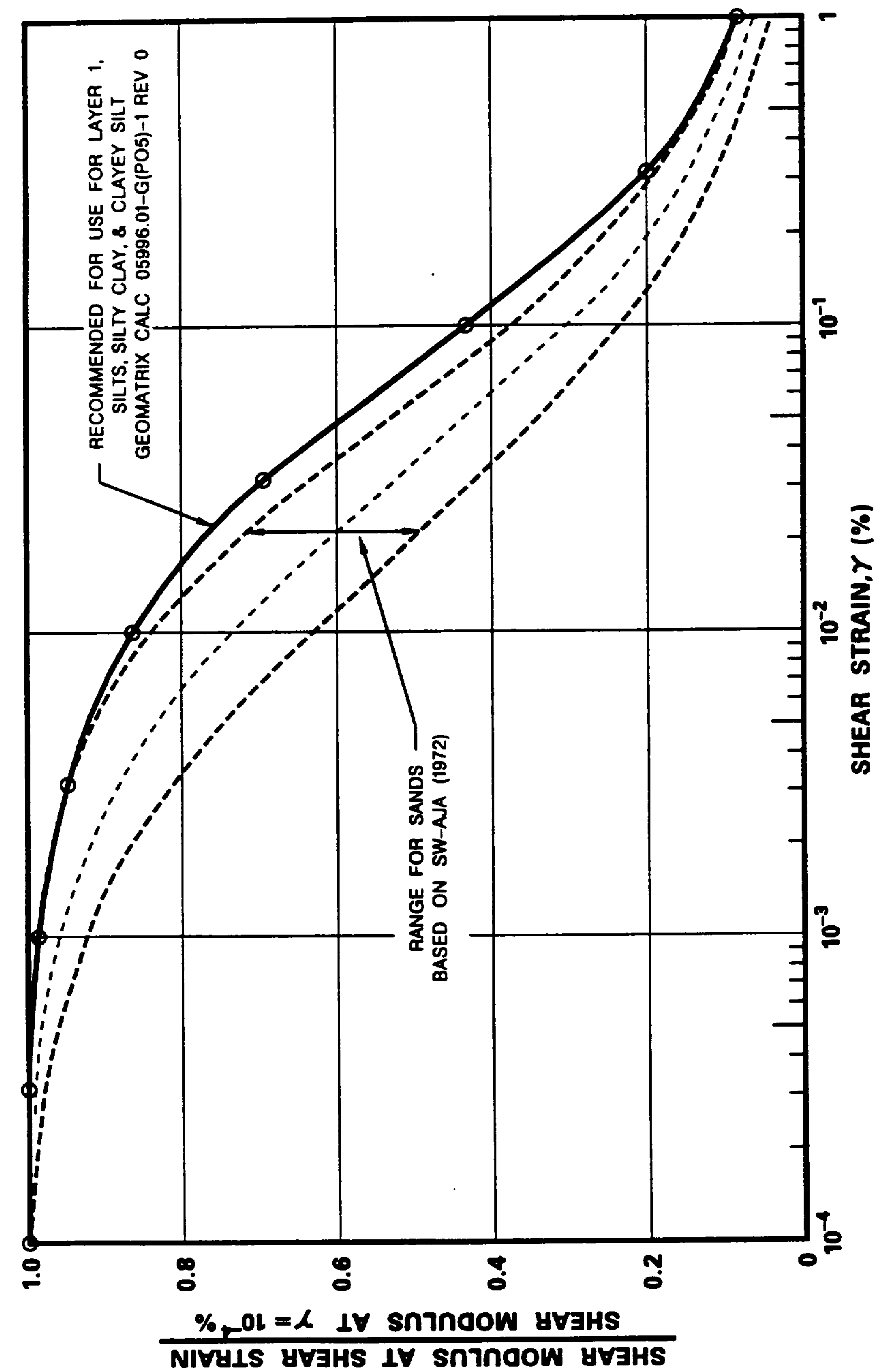


Figure 4

VARIATION OF SHEAR MODULUS WITH SHEAR STRAIN

ATTACHMENT A TO CALC 05996.01-G(B)-01-1 p. A1/1

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TRANSMITTAL

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(1 Page(s) including this page)

DATE: March 28, 1997

NOTED S. M. MACIE MAR 28 '97

Copy – N. Georges
K. Xu
S. Smith
JBG2

TO: Stan Macie
Stone and Webster Engineering Corporation
Denver Operations Center
7677 East Berry Avenue
Englewood, CO 80111-2137
Phone: (303) 741-7305
Fax: (303) 741-7806

FROM: Chin Man Mok

SUBJECT: Soil Parameters for SSI studies
Skull Valley Private Fuel Storage Facility, Project No. 3801

The soil parameters on page 2/11 of Section 1.5 are correct. In summary, these parameters for an equivalent homogeneous isotropic soil medium are:

shear modulus	=	G	=	668	ksf
Young's modulus	=	E	=	1915	ksf
unit weight	=	ρ	=	81	pcf
Poisson's ratio	=	μ	=	0.433	
shear-wave velocity	=	V_s	=	515	fps
compressional-wave velocity	=	V_p	=	1500	fps
shear-wave damping	=	b_s	=	11	%
compressional-wave velocity	=	b_p	=	10	%

Please call us if you have any questions regarding these dynamic soil parameters, or if you need additional information.

NOTED MAR 31 1997 P. J. Trikouros