STONE & WEBSTER ENGINEERING CORPORATION

CALCULATION TITLE PAGE

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5010.64 (FRONT)

CLIENT & PROJECT	PAGE 1 OF ~~8~~ ~~15~~ 17
PRIVATE FUEL STORAGE, LLC - PRIVATE FUEL STORAGE FACILITY	+ 5 PP OF ATTACH'S
CALCULATION TITLE (Indicative of the Objective): DYNAMIC SETTLEMENTS OF THE SOILS UNDERLYING THE SITE	QA CATEGORY (✓) ☒ I - NUCLEAR SAFETY RELATED ☐ II ☐ III ☐ ______ OTHER

CALCULATION IDENTIFICATION NUMBER

J. O. OR W.O. NO.	DIVISION & GROUP	CURRENT CALC. NO.	OPTIONAL TASK CODE	OPTIONAL WORK PACKAGE NO.
05996.01	G(B)	11		

*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 5/20/97 Paul J. Trudeau	THOMAS E. SPONSELLER 5/20/97 Thomas E. Sponseller	THOMAS E. SPONSELLER 5/20/97 Thomas E. Sponseller	0			✓
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RECORD OF CHANGES

Rev No.	Description of Changes	Pages Revised	Pages Added	Pages Replaced
0	Original Issue	N/A	N/A	N/A
1	Respond to NRC RAI No. 1 – Question 2-8			ALL
2	0.53g Design Basis Ground Motion			ALL
3	0.711g Design Basis Ground Motion and incorporate changes to 1996 borings and CTB borings added to SAR Appendix 2A in Sept 1999.			ALL

REASON FOR REV. 1

Rev. 1 was prepared to document the estimated dynamic settlements of the nonplastic silts in the upper layer of soils at the site that were reported in response to Question 2-8 of NRC Request for Additional Information No. 1.

REASON FOR REV. 2

Document the estimated dynamic settlements of the nonplastic silts in the upper layer of soils at the site for the 2,000-yr return period design basis ground motion (0.53g).

REASON FOR REV. 3

1. Document the estimated dynamic settlements of the nonplastic silts in the upper layer of soils at the site for the revised 2,000-yr return period design basis ground motion (0.711g).
2. Updated Table 2 to incorporate the changes that were made to the logs of the borings that were drilled throughout the site in 1996 (Borings A-1 through A-4, B-1 through B-4, C-1 through C-4, D-1 through D-4, E-3, and E-4) based on Atterberg limits tests that were performed in 1998 and 1999 and reported in Attachments 3 and 5 of Appendix 2A of the SAR.
3. Incorporated results of borings that were drilled in the Canister Transfer Building area in 1998.
4. Updated dynamic soil properties (shear modulus and unit weights) of the soils within the upper ~30 ft of the profile to agree with the best-estimate dynamic soil properties presented in Table 7 of Geomatrix (2001).

OBJECTIVE

Estimate the dynamic settlement of the soils underlying the proposed Private Fuel Storage Facility (PFSF) at the Skull Valley, UT site due to shaking caused by the design earthquake.

DATA/ASSUMPTIONS

Figure 1 presents a generalized subsurface profile, which was developed based on the borings that were drilled in late 1996. The locations of these borings are presented on SAR Figure 2.6-2, and the logs of these borings are included in Attachment 1 of Appendix 2A of the SAR. The groundwater table was not encountered in these borings, the deepest of which were drilled to depths of 100 ft. In addition, seismic refraction surveys indicate that the groundwater table is greater than ~100 ft below grade at the site (see p11 of Geosphere Midwest, 1997). Additional borings were drilled in the vicinity of the Canister Transfer Building in 1998. The locations of these borings are presented on SAR Figures 2.6-18 and 19, and the logs of these borings also are included in Attachment 1 of Appendix 2A of the SAR. An observation well was installed in Boring CTB-5, and the depth to the groundwater measured in that well was found to be ~124.5 ft below grade.

The top ~30 ft of the profile consists of silt, silty clay, and clayey silt. As documented in Calculation 05996.02-G(B)-05-2, the median blow count for this material is ~14 blows per ft (based on Borings A-1 through D-4), indicating that it is "stiff", it appears to be weakly cemented, and undrained triaxial tests on the clayey silt indicates that it has a cohesion of greater than 2,000 psf. Similar results were obtained for the borings drilled in the Canister Transfer Building area.

A review of the sample descriptions included in the boring logs indicates that only two samples of nonplastic silt are characterized as "loose". These two samples, Samples S-1 in Borings AR-2 and AR-3, were both obtained at the ground surface along the access road. All other nonplastic silt samples for which density is included in the description are characterized as being dense, very dense, or compact.

The following discussion applies to the SPT samples obtained in the upper layer of silt, silty clay, and clayey silt in the areas of the site proposed for the cask storage pads, the canister transfer building, and the security and health physics building. It excludes the samples obtained at the ground surface, which represent soils that will be excavated and replaced by soil cement during construction of the facilities. The soil cement layer, typically less than 5-ft thick, will not be susceptible to dynamic settlement.

The borings drilled at the site indicate that the upper layer (~30 ft) consists mostly of soils with some plasticity, especially in the pad emplacement area. As discussed below under "Method", plastic soils are not susceptible to dynamic settlements as a result of compaction due to soil grain slip. Only cohesionless soils are susceptible to this form of dynamic settlement. However, to be conservative, this analysis assumes that this form of dynamic settlement applies to those silt samples that are characterized as both nonplastic and slightly plastic. Dynamic settlement due to soil grain slip is assumed to not apply for those soils that are characterized as moderately plastic or highly plastic; therefore, the dynamic settlement analysis excludes all SPT samples classified as MH, CL, or CH, since those specimens are assumed to have sufficient cohesion that dynamic compaction due to soil grain slip will not occur for those soils. The dynamic settlement analysis does include, however, those samples where a portion of the sample was classified as ML along with MH, CL, or CH.

Table 1 identifies all of the soil samples that were obtained in the borings drilled in 1996 and 1998 characterized as silts in the upper ~30-ft thick layer of the profile. It includes all samples with USC symbols of ML, SC, SM, or SP. It indicates which are characterized as nonplastic, slightly plastic, moderately plastic, highly plastic, or a combination of these. Table 1 also lists the depths, N-values, USC symbol, and estimated thickness of nonplastic and slightly plastic silts in the upper layer. The plasticity characterization of most of these samples was determined based on the results of the Atterberg limits tests, which are presented in Tables 1 of Attachments 5 through 8 of Appendix 2A of the SAR.

Table 2 identifies summarizes the total thickness of nonplastic and slightly plastic silts in these borings in the upper layer of the profile. These estimates are based on the Standard Penetration Test (SPT) data presented in Table 1. As shown, the average thickness of nonplastic and slightly plastic silts in these borings is ~7 ft. Borings A-1 through A-4, B-1, B-3, B-4, C-1 through C-4, D-1 through D-3, E-1, E-2, and CTB-2 through CTB-6 have less than or equal to 10 ft of nonplastic or slightly plastic silts. Boring B-2 in the northern edge of the pad emplacement area, west of the centerline running north-south, has ~11 ft of nonplastic to slightly plastic silts. Borings CTB-1, 7, and 8 and Borings D-4 and E-3 encountered 11 to 15 ft of nonplastic to slightly plastic silts in the upper ~30-ft thick layer. Boring E-4, located ~500 ft south and east of the Canister Transfer Building, encountered ~25 ft of nonplastic to slightly plastic silts. Note that these nonplastic silts often include occasional thin layers of clay or plastic silt, which will minimize the potential for dynamically induced settlement. Conservatively assume that the nonplastic silts are ~15-ft thick under the entire site in the analyses that follow. This value represents the upper bound of all of the thickness data for all of the borings, except for Boring E-4, which is located south and east of all of the safety-related structures at the site.

A total of 83 SPT samples of nonplastic to slightly plastic silts (ML, SC, SM, and SP) were obtained in the upper layer in these borings (excluding the surface samples). These are identified in Table 1 and a statistics of the blow count data are presented in Table 3. Of these 83 SPT samples, 28 were nonplastic, 18 were slightly plastic, and 37 exhibited plasticity ranging from moderately plastic to highly plastic.

The N-values for the nonplastic and slightly plastic silts in this layer ranged from 10 blows/ft to 60 blows/ft. The average N-value was 25 blows/ft, and the median was 23 blows/ft. At the center of this layer, the effective vertical stress (σ'_v) at the time of the drilling was ~15 ft x 92 pcf, or 1,380 psf. This median N-value at this σ'_v corresponds to a corrected blow count, N_1, of ~28 blows/ft, based on the relationship between penetration resistance and relative density developed by Gibbs and Holtz (1957) for granular soils. See Figure 1 of the RELDEN User's Manual (SWEC, 1979) – copy of this figure is included as Attachment A.

Assuming that these nonplastic silts are cohesionless, they would behave more like fine sands rather than cohesive soils. In this case, Figure 7.5 of Lambe and Whitman (1969) is used to estimate their relative density based on their penetration test blow counts. A copy of this figure is included as Attachment B. This figure presents the relationship between penetration resistance and relative density developed by Gibbs and Holtz (1957) for granular soils. This is very conservative, since a decrease in mean grain size tends to cause a decrease in SPT N-value for the same relative density, and the nonplastic silts at the site have a much smaller mean grain-size than the sand and fine sand used by Gibbs and Holtz to develop this relationship. Using the 10 psi (1.44 ksf) curve in this figure, or slightly below it, which is the appropriate overburden stress for the mid-depth of this layer, fine sands having the median blow count of the nonplastic silts in this layer would be characterized as "very dense", not "loose".

As indicated on the boring logs in PFSF Report 05996.01-G(B)-2-1 (SWEC, 1997), this material is underlain by very dense, fine sands, which have uncorrected blow counts that commonly exceed 100 blows/ft. The underlying soils, which are below the groundwater table, are greater than 100 ft below grade, and the P-wave velocities (5,100 fps to 5,900 ft/sec), reported by Geosphere Midwest (1997), indicate that these soils too are very dense. SPT N-values, obtained as deep as 226.5 ft below grade in Boring CTB-1, confirm that these materials are very dense to hard silts.

METHOD

Dynamic settlements, as reported in the geotechnical literature, are based on two different mechanisms, depending on whether the soils are above the groundwater table or below the groundwater table. Silver and Seed (1971) developed a technique for estimating dynamic settlements of dry cohesionless sands above the groundwater table. For such soils, the dynamic settlement mechanism is compaction due to soil grain slip, and it is a function of the magnitude of the cyclic shear strain developed due to the earthquake, the applied number of cycles of this shear strain, and the relative density of the granular soils.

Dynamic settlements of the clayey silts and silty clays in the upper layer are not expected to occur at the PFSF site due to shaking caused by the design earthquake because the cohesion and plasticity of these materials precludes their compaction due to grain slip. Dynamic settlements of the underlying very dense fine sand are not expected to occur because of their high relative density. The underlying silts, even though they are submerged, they also are very dense or hard and, thus, are not expected to experience dynamically induced settlements due to shaking caused by the design earthquake. Furthermore, these soils are too far removed from the surface to cause problems if they were to experience dynamic settlement. Therefore, dynamic settlements of the soils underlying the proposed PFSF at Skull Valley, UT will be limited to those associated with dynamic compaction due to grain slip of the nonplastic silts within the upper 30 ft of the profile.

The method used to estimate dynamic settlements of the nonplastic silts are based on those presented in Tokimatsu and Seed (1987). As they indicate, for soils above the groundwater table, dynamic settlements are calculated based on procedures originally developed by Silver and Seed (1971), and the effects of multidirectional shaking are estimated based on studies reported by Pyke, Seed, and Chan (1975). For soils below the groundwater table, dynamic settlements are calculated based on procedures developed by Lee and Albaisa (1974); however, all of the nonplastic silts in the upper 30 ft of the profile are well above the groundwater table.

Figure 13 of Tokimatsu and Seed (1987) presents the relationship between volumetric strain due to compaction, cyclic shear strain, and corrected penetration resistance (N_1) of dry sands for 15 equivalent uniform strain cycles. A copy of this figure is included as Attachment C. The cyclic shear strain is estimated based on the average cyclic shear stress due to shaking caused by the design earthquake and the shear modulus of the soil. Figure 13 is used to estimate the volumetric strain due to compaction for 15 equivalent uniform strain cycles. Table 4 of Tokimatsu and Seed (1987 - copy included as Attachment D) is then used to adjust for differences in the number of representative cycles of applied shear stress due to the design earthquake (~12 for Magnitude 7) and the 15 cycles used in Tokimatsu and Seed's studies. The dynamic settlement is calculated as the volumetric strain multiplied by the thickness of the nonplastic silts in the layer. Multidirectional effects of the earthquake are addressed by multiplying this result by 2, based on studies reported by Pyke, Seed, and Chan (1975).

ANALYSES

The average cyclic shear stress developed in the field due to earthquake shaking is calculated as:

$\tau_{avg} = 0.65 \bullet a_{max} \bullet \sigma_v \bullet r_d/g$

where: a_{max} = 0.711 g for the design earthquake

σ_v = $\gamma_{total} \bullet z$ above the groundwater table, = 15' x 92 pcf.

γ_{total} ~ 92 pcf for the upper 30', based on Table 7 of Geomatrix Calc 05996.02-G(PO18)-2, Rev. 1.

z = depth below grade, = 15' for mid-depth of upper 30 ft layer.

r_d = 0.95 for z = 15' (stress reduction factor, which varies from 1.0 at z=0 to 0.9 at z=30')

Thus, τ_{avg} = 0.65 • 0.711g • 15 ft x 92 pcf • 0.95/g = 606 psf

An iterative technique is used to determine the cyclic strain in the field due to the earthquake, γ_{field}. For an assumed value of the cyclic strain, G is calculated as $G_{max} \bullet G / G_{max}$, where G / G_{max} for the nonplastic silt is estimated using the curve for PI=0 presented in Figure 6 of Vucetic and Dobry (1991). A copy of this figure is included as Attachment E.

G_{max} equals 2,027 ksf, based on best-estimate value shown in Table 7 of Geomatrix Calc G(PO18)-2-1, "Dynamic Soil Properties for Spring-Dashpot-Mass Model.

The following table presents the results of these iterations.

Determination of Cyclic Shear Strain Due to the Design Earthquake

Iteration No.	$\gamma_{assumed}$ x10^{-4} in./in.	G / G_{max}	G ksf	γ_{field} x10^{-4} in./in.	$\Delta\gamma$ %
1	10	0.250	507	12.0	16
2	**15**	**0.200**	**405**	**14.9**	**0**

The cyclic strain in the field, γ_{field}, is calculated as τ_{avg} / G. Note, it is equal to the assumed cyclic strain for Iteration No. 2; therefore, additional iterations are not required, and γ_{field} is 14.9 x 10^{-4} in./in., or 0.149%.

The volumetric strain due to compaction from 15 cycles is estimated as a function of this cyclic shear strain and N_1 of ~28 blows/ft based on Figure 13 of Tokimatsu & Seed (1987). This results in a volumetric strain, $\varepsilon_{c,N=15}$, of 0.093%.

The design earthquake is magnitude 7 (SAR Section 2.6.2.3). Table 4 of Tokimatsu & Seed (1987) indicates this corresponds to ~12 cycles of loading and that volumetric strain ratio, $\varepsilon_{c.N=12} / \varepsilon_{c.N=15}$, should be ~0.9. Therefore, the volumetric strain corresponding to the design earthquake is $\varepsilon_{c.N=12}$, which is 0.9 x 0.093%, or 0.084%.

$$\varepsilon_c = \frac{\Delta\rho_{dyn}}{\Delta H}$$

where $\Delta\rho_{dyn}$ is the dynamic settlement of the layer, and ΔH is the thickness of the layer.

The thickness of the nonplastic silts in the upper layer is conservatively estimated to be 15 ft, based on the discussion presented above. Therefore, for unidirectional shaking,

$$\Delta\rho_{dyn,1} = \Delta H \times \varepsilon_{c,N=12} = 15 \text{ ft} \times 12 \text{ in./ft} \times 0.084\% / 100\% = 0.15 \text{ inches.}$$

The dynamic settlement is multiplied by 2 to account for multidirectional shaking due to the earthquake, as recommended by Pyke, Seed, and Chan (1975). This results in an estimated dynamic settlement of the nonplastic silts in the upper layer of 0.30 inches.

DISCUSSION OF RESULTS

As indicated in SWEC (1998), a considerable amount of calcium carbonate is present in these soils, as evidenced by a vigorous reaction upon application of hydrochloric acid to these soils. Therefore, these soils are believed to be cemented, the result of carbonate cement bonding of the silt and clay-size particles, imparting cohesion to these soils.

The nonplastic silts in the upper 30-ft thick layer of the subsurface profile, as evidenced by the SPT data, are not loose. The dense nature of these soils, which is most likely the result of carbonate cement bonding of the silt particles, minimizes the potential for dynamically induced settlements due to the design earthquake. Ignoring the beneficial effect that cementing of these particles would have toward minimizing dynamically induced settlements, the total dynamic settlement is conservatively estimated to be less than ½ of an inch.

This estimated dynamic settlement was determined based on the thickness of nonplastic silts in areas where the nonplastic silts are thickest, not on an average or median thickness. In addition, it ignores the fact that these nonplastic silts are stratified with layers of clay and clayey silt, which will minimize the potential for dynamically induced settlements. Thus, this estimated dynamic settlement is very conservative.

Dynamic settlements will be much less than this over most of the cask storage pad area, since most of the soils in this area are not nonplastic. Rather, these soils are sufficiently stiff and cohesive that they will not experience dynamic compaction due to the shaking caused by the design earthquake.

CONCLUSIONS

Dynamic settlements of the clayey silts and silty clays in the upper 30-ft thick layer of the subsurface profile at the PFSF site are not expected to occur due to the design earthquake because the cohesion and plasticity of these materials precludes their compaction due to grain slip as a result of shaking due to the design earthquake. Dynamic settlements of the underlying very dense fine sand are not expected to occur because of their high relative density. The underlying silts, which are below the groundwater table, also are very dense or hard and, thus, are not expected to experience dynamically induced settlements due to shaking caused by the design earthquake. Furthermore, these soils are too far removed from the surface to cause problems if they were to experience dynamic settlement. Therefore, dynamic settlements of the soils underlying the proposed PFSF at Skull Valley, UT will be limited to those associated with dynamic compaction due to grain slip of the nonplastic silts within the upper 30 ft of the profile.

The total dynamic settlement of these nonplastic silts is estimated to be less than ½ of an inch, even when conservatively assuming that they are not cemented, ignoring the fact that they are stratified with occasional layers of clay and clayey silt, which will minimize the potential for dynamically induced settlements, and that they are calculated using the maximum thickness of nonplastic silts within the upper layer, not an average or median thickness. Dynamic settlements of this magnitude are not expected to adversely affect the performance of the facilities.

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Table 1

N-Values of Nonplastic and Slightly Plastic Silts (USC = ML, SC, SM, and SP) in Upper 25 to 30-ft Layer at PFSF Borings Drilled Throughout the Site Area in 1996 and Under the Canister Transfer Building in 1998

Boring ID	Sample	Depth (ft)		Rec. (in.)	Blowsper 6 in.	SPT N	USC	Plasticity	Δh of NP or SP Silts	Total Thick-ness of NP & SP Silts
A-1	S 3	10.00	11.50	13.0	6-9-13	22	ML	SP	5	
A-1	S 4	15.00	16.50	15.0	7-9-10	19	ML	MP		
A-1	S 6	**25.00**	**26.50**	12.0	7-15-21	36	ML	**NP**	**5**	**10**
A-2	U 2	5.00	7.00	25.0	PUSH		ML	MP		
A-2	S 3	10.00	11.50	14.0	5-5-6	11	ML	SP	5	
A-2	S 4	15.00	16.50	13.0	7-7-7	14	ML	MP		
A-2	S 5	20.00	21.50	14.0	5-6-11	17	ML	MP		
A-2	S 6	25.00	26.50	15.0	5-6-10	16	ML	MP		5
A-3	S 4	15.00	16.50	13.0	6-7-8	15	ML	MP		
A-3	S 5	20.00	21.50	13.0	6-8-12	20	ML	MP		
A-3	S 6	25.00	26.50	16.0	8-12-18	30	ML	SP	5	
A-3	S 7	**30.00**	**31.50**	14.0	12-14-20	34	ML	**NP**	**5**	**10**
A-4	S 3	**10.00**	**11.50**	12.0	6-6-7	13	ML	**NP**	**5**	**5**
B-1	S 3	10.00	11.50	13.0	7-7-8	15	ML	MP		
B-1	S 4	15.00	16.50	16.0	6-10-10	20	ML	MP		
B-1	S 5	20.00	21.50	16.0	4-5-7	12	ML-MH	MP-HP		0
B-2	U 1	8.00	10.00	25.0	PUSH		ML	SP-MP	3	
B-2	S 3	10.00	11.50	12.0	4-6-7	13	ML	SP-MP	3	
B-2	S 4	**15.00**	**16.50**	14.0	3-7-9	16	ML	**NP**	**5**	**11**
B-3	S 2	15.00	16.50	14.0	5-8-10	18	ML	SP	5	
B-3	S 5	**30.00**	**31.50**	16.0	8-12-16	28	ML	**NP**	**5**	**10**
B-4	U 3B	**11.00**	**12.00**	0.0			ML	**NP**	**3**	
B-4	S 4	15.00	16.50	12.0	8-7-8	15	ML	MP		
B-4	S 5	20.00	21.50	13.0	5-10-11	21	ML	MP		
B-4	S 6	25.00	26.50	14.0	6-10-11	21	ML	MP		
B-4	S 7	**30.00**	**31.50**	14.0	9-14-20	34	ML	**NP**	**2.5**	**5.5**
C-1	U 3	10.00	12.00	24.0	PUSH		ML-MH	MP-HP		
C-1	S 4	15.00	16.50	15.0	8-8-8	16	ML	MP		
C-1	S 5	20.00	21.50	18.0	4-4-4	$\boxed{8}$	ML	MP		0
C-2	U 2	10.00	12.00	25.0	PUSH		ML	MP		

Table 1

N-Values of Nonplastic and Slightly Plastic Silts (USC = ML, SC, SM, and SP) in Upper 25 to 30-ft Layer at PFSF Borings Drilled Throughout the Site Area in 1996 and Under the Canister Transfer Building in 1998

Boring ID	Sample	Depth (ft)		Rec. (in.)	Blowsper 6 in.	SPT N	USC	Plasticity	Δh of NP or SP Silts	Total Thick-ness of NP & SP Silts
C-2	S 3	20.00	21.50	18.0	4-5-6	11	ML	MP		
C-2	S 4	25.00	26.50	14.0	7-14-20	34	ML	MP/NP	2	28.5
C-3	S 3	10.00	11.50	14.0	3-3-5	8	ML	MP		0
C-4	S 3	10.00	11.50	15.0	3-4-7	11	ML	SP	5	
C-4	S 4	15.00	16.50	12.0	6-6-8	14	ML	MP		
C-4	S 7	30.00	31.50	13.0	8-10-11	21	SM	NP	3	8
D-1	S 4	15.00	16.50	16.0	4-6-7	13	ML	MP		0
D-2	S 2	5.00	6.50	15.0	3-3-3	6	ML	MP		
D-2	S 4	15.00	16.50	16.0	5-7-8	15	ML	MP		
D-2	S 5	20.00	21.50	15.0	6-9-9	18	ML	MP		0
D-3	S 2	5.00	6.50	11.0	1-5-9	14	ML	MP		
D-3	S 3	10.00	11.50	15.0	3-4-7	11	ML	MP/NP	3	
D-3	S 4	15.00	16.50	18.0	4-4-5	9	ML	MP		
D-3	S 5	20.00	21.50	18.0	4-5-6	11	ML	MP		
D-3	S 6	25.00	26.50	16.0	8-14-25	39	ML	NP	5	8
D-4	S 3	10.00	11.50	8.0	5-10-14	24	ML/SM	SP/NP	5	
D-4	S 4	15.00	16.50	12.0	10-12-10	22	ML	NP/MP	2.5	
D-4	S 6	25.00	26.50	14.0	6-7-9	16	CL-ML	SP	5	12.5
E-1	S 4	15.00	16.50	18.0	6-7-8	15	ML	MP		
E-1	S 5	20.00	21.50	18.0	4-4-7	11	ML-MH	MP-HP		0
E-2	U 1	5.00	7.00	26.0	PUSH		ML	SP-MP	3.5	
E-2	S 3	15.00	17.00	2.0	9-7-9-12	16	ML	SP-MP	5	
E-2	S 5	25.00	27.00	20.0	8-12-18-	30	ML-MH	MP-HP		8.5
E-3	S 4	15.00	16.50	16.0	7-10-12	22	ML	NP	5	
E-3	S 5	20.00	21.50	16.0	4-7-8	15	ML-CL	SP	5	
E-3	S 6	25.00	26.50	15.0	5-6-12	18	ML	NP	5	15
E-4	S 2	5.00	6.50	13.0	9-10-16	26	SM	NP	5	
E-4	S 3	10.00	11.50	12.0	13-25-27	52	SM	NP	5	
E-4	S 4	15.00	16.50	12.0	8-20-20	40	ML	NP	5	
E-4	S 5	20.00	21.50	17.0	6-6-10	16	ML	SP	5	

Table 1

N-Values of Nonplastic and Slightly Plastic Silts (USC = ML, SC, SM, and SP) in Upper 25 to 30-ft Layer at PFSF Borings Drilled Throughout the Site Area in 1996 and Under the Canister Transfer Building in 1998

Boring ID	Sample	Depth (ft)		Rec. (in.)	Blowsper 6 in.	SPT N	USC	Plasticity	Δh of NP or SP Silts	Total Thick-ness of NP & SP Silts
E-4	S 6	25.00	26.50	16.0	7-10-14	24	ML	NP	5	25
CTB-1	S 4	9.00	11.00	24.0	5-5-5-7	10	SM	SP	1	
CTB-1	U 5A	11.00	13.00	11.0	PUSH		SC	MP		
CTB-1	U 5B	11.65	11.65	0.0			SM	NP	2	
CTB-1	S 6	15.00	17.00	12.0	10-14-10-	24	ML	SP	4	
CTB-1	S 8	25.00	27.00	15.0	10-10-14-	24	ML	SP	4	11
CTB-2	S 2	5.00	7.00	16.0	6-6-7-9	13	ML	MP		
CTB-2	S 5	11.00	13.00	3.0	5-7-9-11	16	ML	SP	3	
CTB-2	S 7	20.00	22.00	18.0	6-8-10-10	18	ML	MP		
CTB-2	S 8	25.00	27.00	17.0	6-8-12-12	20	ML	MP		3
CTB-3	S 5	11.00	13.00	19.0	6-10-12-	22	ML	MP		
CTB-3	S 6	15.00	17.00	17.0	8-9-9-10	18	SM/ML	SP/MP	2	
CTB-3	S 7	20.00	22.00	19.0	7-10-10-	20	SM	SP	2	4
CTB-4	S 2	2.00	4.00	13.0	3-1-4-5	5	ML	MP		
CTB-4	S 6	10.00	12.00	13.0	5-8-8-8	16	ML	MP		
CTB-4	U 7	12.00	13.50	16.0	PUSH		ML/SP	SP/NP	2	
CTB-4	S 8	14.00	16.00	15.0	8-12-12-	24	ML/SM	SP/NP	2	
CTB-4	U 9	16.00	17.50	19.0	PUSH		ML/SM	NP	2	
CTB-4	U 11	20.00	21.50	20.0	PUSH		ML	MP		
CTB-4	U 13	24.00	25.50	19.5	PUSH		ML	MP		
CTB-4	U 15	28.00	29.50	16.0	PUSH		ML/SM	NP	2	8
CTB-5(OW)	S 2	2.00	4.00	2.0	10-10-11-	21	ML/SM	MP		
CTB-5(OW)	U 6	10.00	12.00	19.0	PUSH		ML	NP	2	
CTB-5(OW)	S 7	12.00	14.00	17.0	9-12-12-	24	SM	NP	2	
CTB-5(OW)	U 8	14.00	16.00	20.0	PUSH		SM	NP	2	
CTB-5(OW)	S 9	16.00	18.00	8.0	12-14-18-	32	ML	NP	2	
CTB-5(OW)	U 10	18.00	20.00	22.0	PUSH		ML	MP		
CTB-5(OW)	U 12	22.00	24.00	26.0	PUSH		ML	MP-HP		6
CTB-6	S 4	10.00	12.00	20.0	3-3-4-5	7	CH/ML	HP/MP		
CTB-6	S 5	15.00	17.00	14.0	10-20-20-	40	ML/SM	MP/NP	2.5	
CTB-6	S 6	20.00	22.00	19.0	7-10-10-	20	ML	MP		

Table 1

N-Values of Nonplastic and Slightly Plastic Silts (USC = ML, SC, SM, and SP) in Upper 25 to 30-ft Layer at PFSF Borings Drilled Throughout the Site Area in 1996 and Under the Canister Transfer Building in 1998

Boring ID	Sample	Depth (ft)		Rec. (in.)	Blowsper 6 in.	SPT N	USC	Plasticity	Δh of NP or SP Silts	Total Thick-ness of NP & SP Silts
CTB-6	S 7	25.00	27.00	24.0	3-5-7-8	12	ML	MP		2.5
CTB-7	U 3	7.00	9.00	19.0	PUSH		SP	NP	2.5	
CTB-7	S 4	10.00	12.00	12.0	16-25-35-	60	SM	NP	4	
CTB-7	S 5	15.00	17.00	12.0	18-18-10-	28	ML	NP/MP	2	
CTB-7	S 7	25.00	27.00	18.0	10-10-12-	22	ML	SP	5	13.5
CTB-8	S 3	7.00	9.00	19.0	5-9-7-8	16	ML	SP	2	
CTB-8	S 4	9.00	11.00	13.0	18-12-18-	30	SM	NP	2	
CTB-8	S 5	11.00	13.00	12.0	20-20-30-	50	SM	NP	3	
CTB-8	S 6	15.00	17.00	9.0	18-20-18-	38	SM	NP	5	
CTB-8	S 7	20.00	22.00	20.0	6-8-10-12	18	SM/MH	NP/HP	1.5	13.5

NOTES: This sheet only addresses Layer 1 silts with USC = ML, SC, SM and SP, excluding AR borings and Borings 1 & 2.

Layer 1 CL, CH, and MH samples are excluded.

	indicates NP samples.
5	indicates N < 10.

Table 2

Approximate Thickness of Nonplastic Silts in PFSF Borings Drilled Throughout the Site Area in 1996 and Under the Canister Transfer Building in 1998

Boring ID	Thickness of NP & SP Soils Including Surface Samples (ft)	Thickness of NP & SP Surface Samples (ft)	Thickness of NP & SP Soils Excluding Surface Samples (ft)
A-1	12.5	2.5	10.0
A-2	7.5	2.5	5.0
A-3	12.5	2.5	10.0
A-4	7.5	2.5	5.0
B-1	2.5	2.5	0.0
B-3	12.5	2.5	10.0
B-4	8.0	2.5	5.5
C-1	2.5	2.5	0.0
C-2	4.5	2.5	2.0
C-3	0		0.0
C-4	10.5	2.5	8.0
D-1	2.5	2.5	0.0
D-2	2.5	2.5	0.0
D-3	8.0		8.0
E-1	0.0		0.0
E-2	11.0	2.5	8.5
CTB-2	3.0		3.0
CTB-3	4.0		4.0
CTB-4	8.0		8.0
CTB-5(OW)	8.0		8.0
CTB-6	2.5		2.5
B-2	13.5	2.5	11.0
CTB-1	11.0		11.0
CTB-7	13.5		13.5
CTB-8	13.5		13.5
D-4	15.0	2.5	12.5
E-3	17.5	2.5	15.0
E-4	27.5	2.5	25.0
Average	***8.6***	***1.5***	***7.1***

Table 3

Summary of N-Values of Nonplastic and Slightly Plastic Silts (USC = ML, SC, SM, and SP) in Upper 25 to 30-ft Layer at PFSF, But Excluding Samples from 0 to 1.5 ft

28 NP samples 18 SP samples		**37 MP & HP samples**		**83 Total # of ML, SC, SM, and SP samples**	
Minimum	10	Minimum	5	Minimum	5
Average	25	Average	15	Average	21
Median	**23**	Median	15	Median	18
Maximum	60	Maximum	30	Maximum	60
N < 10	0	N < 10	6	N < 10	6

Note: Based on SPT data from Borings A-1 through E-4 and CTB Borings.

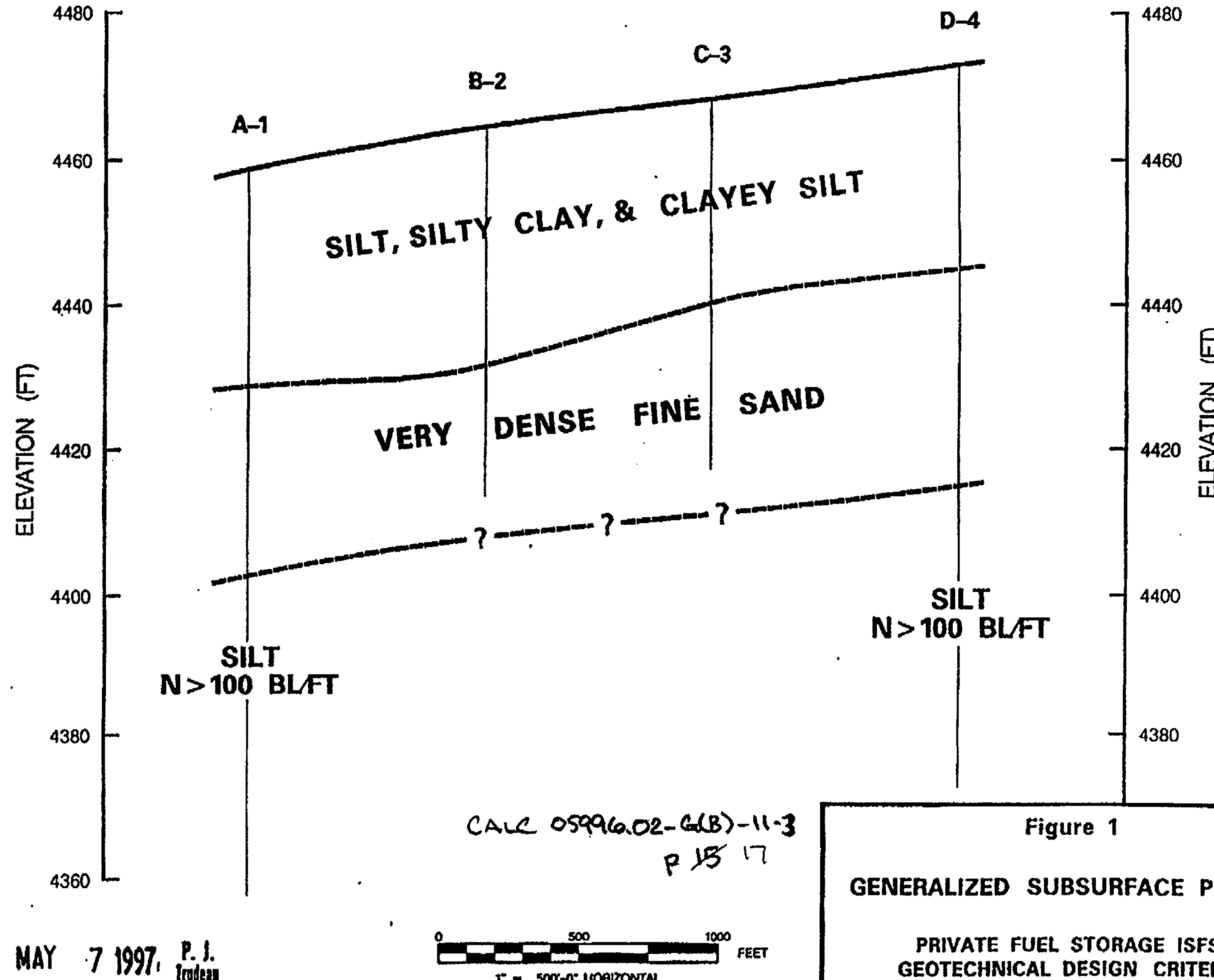

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Figure 1

GENERALIZED SUBSURFACE PROFILE

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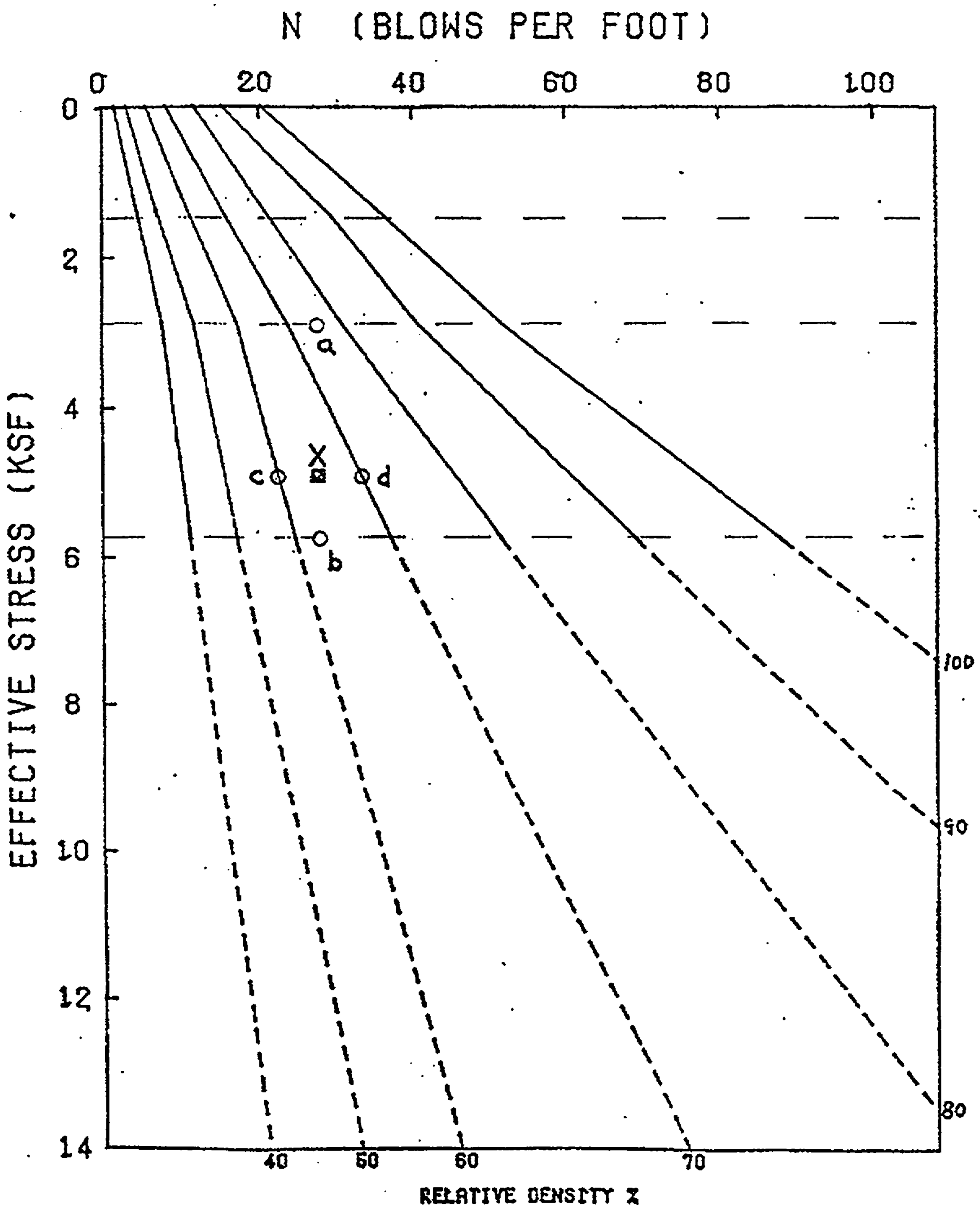

ATTACHMENT A TO
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FIGURE 1

Attachment B

Figure 7.5 from Lambe and Whitman (1969).

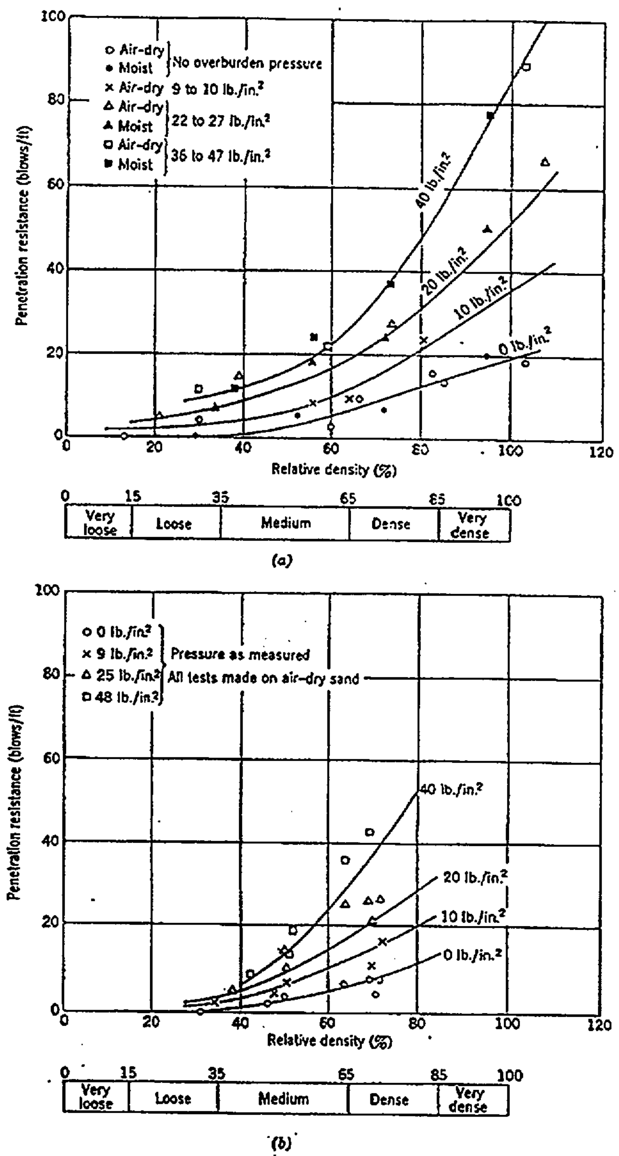

Fig. 7.5 Results of standard penetration tests. (*a*) Coarse sand. (*b*) Fine sand. (From Gibbs and Holtz, 1957.)

STONE & WEBSTER, INC.

CALCULATION SHEET

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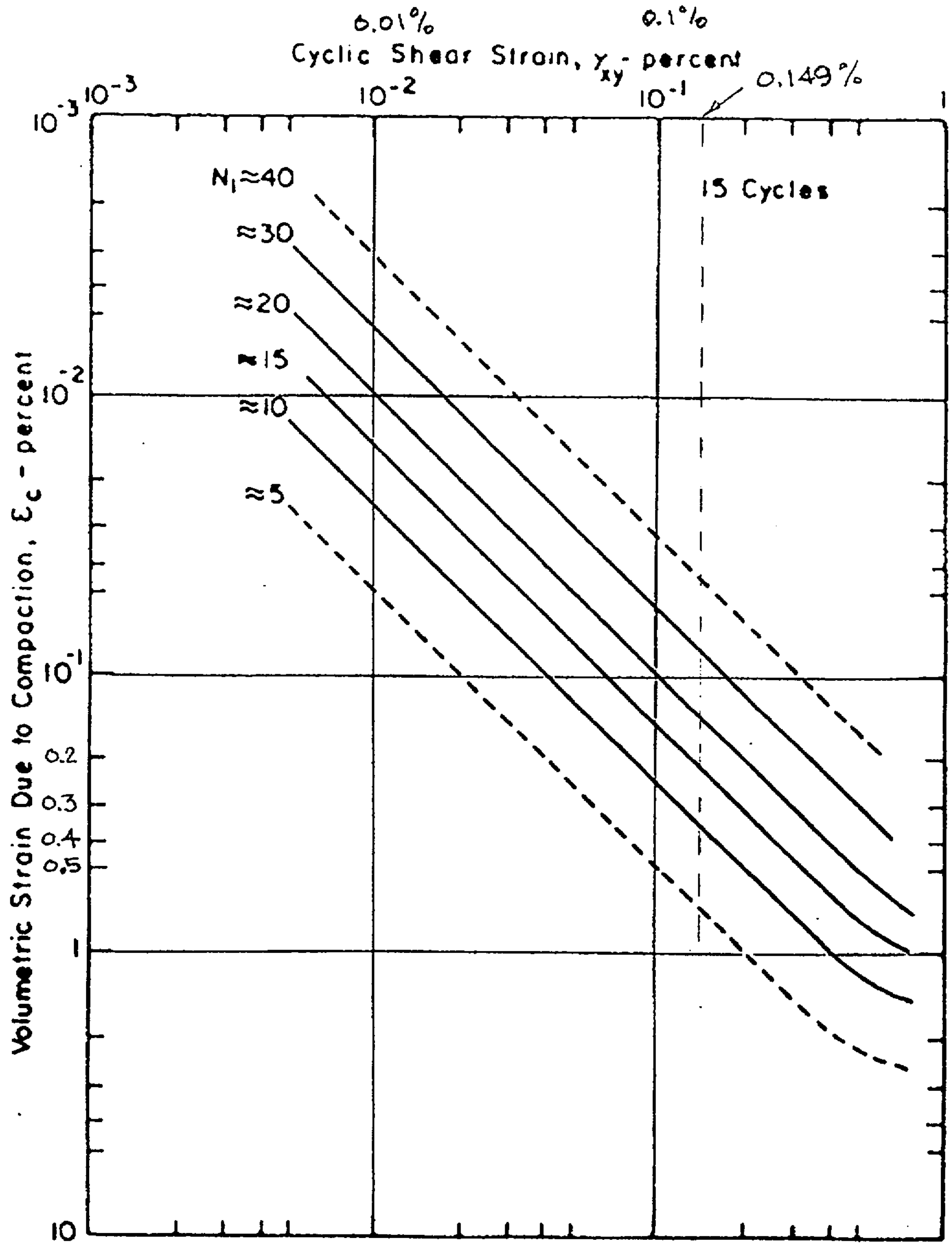
Attachment C

Figure 13 – Relationship between Volumetric Strain, Shear Strain, and Penetration Resistance for Dry Sands, from Tokimatsu and Seed (1987)



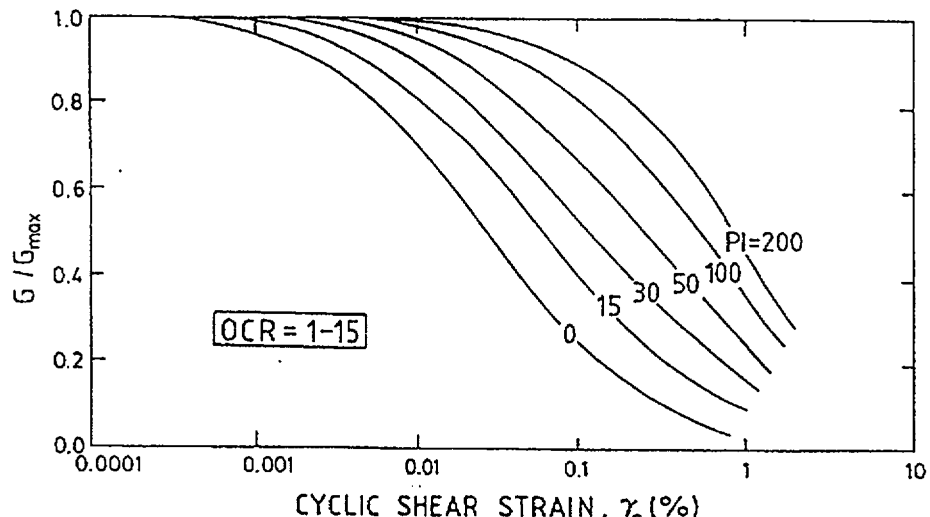
Attachment D

Table 4 – Influence of Earthquake Magnitude on Volumetric Strain Ratio for Dry Sands from Tokimatsu and Seed (1987)

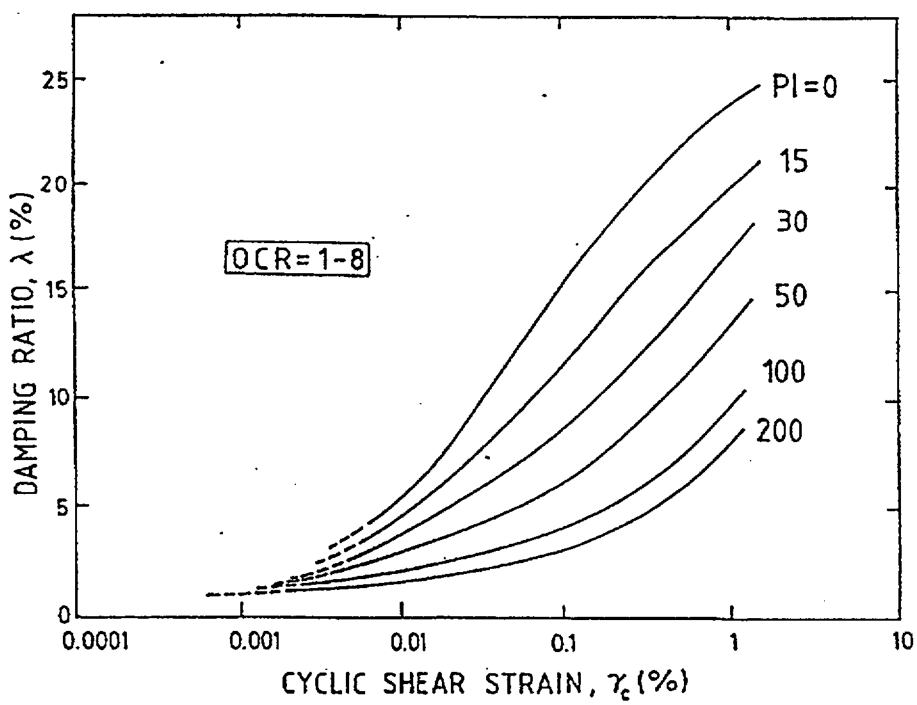
Earthquake magnitude (1)	Number of representative cycles at 0.65 τ_{max} (2)	Volumetric strain ratio, $\epsilon_{C,N}/\epsilon_{C,N=15}$ (3)
8-1/2	26	1.25
7-1/2	15	1.0
6-3/4	10	0.85
6	5	0.6
5-1/4	2–3	0.4

Attachment E

Figure 6 – Relations between G/G_{max} versus γ_c and λ versus γ_c Curves and Soil Plasticity for Normally and Overconsolidated Soils, from Vucetic and Dobry (1991)



(a)



(b)