REPORT
Reconciliation of EPRI and RCTS Results
Calvert Cliffs Nuclear Power Plant Unit 3

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1 PURPOSE

The purpose of this report is to 1) present and compare the soil strain-dependent EPRI curves with the site-specific Resonant Column Torsional Shear (RCTS) test results, 2) adopt final shear modulus and damping curves for the project, and 3) evaluate the soil amplification using both the EPRI-based and RCTS-based data.

This work was performed for Constellation Generating Group, LLC, per Purchase Order No. 500117, Rev. 1, dated April 11, 2006.

2 BACKGROUND

As part of the initial development of the soil dynamic properties for the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 project, EPRI shear modulus and damping curves were adopted. Use of EPRI curves was due to the absence of RCTS test results for the site soils at the time. The adopted EPRI curves and the basis for their selection are addressed in Reference 1.

As part of the subsurface investigation, RCTS tests were commissioned for the site soils and the results of these tests are now available. A total of 13 samples were identified for RCTS testing with 7 additional samples placed in reserve as backup, if needed to replace any of the original 13 samples. Thirteen RCTS tests, along with the necessary index tests, were performed. All of the RCTS results were reviewed and were found acceptable by Dr. Kenneth Stokoe of the University of Texas at Austin. The RCTS test results are presented in Reference 2.

Selection and quantity of RCTS tests were based on the site stratigraphy, the thickness of various soil strata, their position with respect to the Category I structures, and sample availability. The locations of RCTS samples, and other relevant information, are shown on a typical site stratigraphic profile in Figure 1. A summary of the RCTS samples and their index properties is shown in Table 1.

3 EPRI CURVES

Since the RCTS test results will be compared with the EPRI curves that were initially adopted, the EPRI curves are presented herein for ease of comparison. Selection of EPRI curves is addressed in Reference 1. The EPRI curves and numerical values are reproduced and shown in this report as Figure 2 and Table 2.

4 RCTS TEST RESULTS

RCTS tests were performed on soils from the upper 400 feet of the site. More than one sample was tested in most of the soil strata. Samples were tested at depths ranging from about 15 to 400 feet below the existing ground surface (the ground surface at the time of the geotechnical investigation). All samples tested were obtained from tube samples, except for one sample (sample identified by the laboratory as “Appendix No. H” in Table 1), which was obtained from reconstituting jar samples. The quantity of samples tested from each stratum, and their locations, are shown in Figure 1, indicating the following number of samples tested from each stratum:

- Stratum I-Terrace Sand: 1 sample
- Stratum IIa-Chesapeake Clay/Silt: 2 samples
- Stratum IIb-Chesapeake Cemented Sand: 3 samples
- Stratum IIc-Chesapeake Clay/Silt: 5 samples
- Stratum III-Nanjemoy Sand: 2 samples

- Soils below Stratum III: 0 (zero) samples, given that the soil borings during the geotechnical investigation did not penetrate these soils

The RCTS test results for individual samples are summarized and presented in Figures 3 through 15, with the corresponding numerical values given in Tables 3 through 15. Other complimentary information is also presented on the respective figures for ready comparison, namely:

- Selected EPRI Curve: shear modulus and damping ratios from the initially adopted EPRI curves
- Randomized EPRI Curve: the randomized minimum and maximum values of shear modulus and damping ratios, as well as the mean values $\pm 1\sigma$ (sigma)
- RCTS Test Results: RCTS results at the mean in-situ stress (σ_o) and at 4 times the mean in-situ stress
- Relationship from RCTS Results: curves representing the G/G_{max} and damping ratios from the RCTS tests for comparison with EPRI and randomized curves

A "key" is shown on each figure, identifying the above information.

The curves fitted to the RCTS data are based on test results at confining stresses representing the in-situ stress for the test sample. In general, the results indicate that the RCTS curves offer higher shear modulus and lower damping ratios than those represented by the initially adopted EPRI curves. This is discussed below in more detail.

5 EVALUATION OF RCTS TEST RESULTS

As noted above, the RCTS test results indicate higher shear modulus ratio and lower damping ratio than the initially adopted EPRI curves. The relative differences in both shear modulus ratio and damping ratio between RCTS and the initially adopted EPRI curves was calculated at different strain levels and are shown in Figure 16. The results indicate from zero to over 200% difference in G/G_{max} values over a shear strain range from 1E-4% to 1%. Similarly, the results indicate about $\pm$60% difference in damping ratio values over a shear strain range from 1E-4% to 1%. These differences in both the G/G_{max} and damping ratios are over extreme strain values (from 1E-4 to 1%), a strain range unlikely to be experienced by the site soils. It should be noted that results of seismic analyses using the initially adopted EPRI curves indicated that the mean (of maximum) strain values were mostly in the 1E-2% range (Reference 3). These strain values, for each soil stratum, are shown on the respective curves for that stratum in Figure 17.

Figure 17 indicates that at a strain level of about 1E-2$\pm$%, the difference between the initially adopted EPRI and the actual RCTS G/G_{max} values is much more limited than the previously noted 200%, actually ranging from about 1 to 11%, or average of about 6% for the noted strain level. This difference is not considered significant, given the natural variation in soils and the expected variation in RCTS test results**.** It is also noted that in the randomization of the G/G_{max} values at a strain level of 1E-2%, the minimum and maximum values (with respect to the mean) are allowed to vary by as much as $\pm$7%, and sometimes by as much as $\pm$8%. The observed average value of 6% noted above is within the acceptable 7-8% range for randomization.

Similarly, from Figure 17, at a strain level of 1E-2$\pm$%, the difference between the initially adopted EPRI and the actual RCTS damping ratio values range from about -50% to +15%, or average of about 33%. Again, this difference is not considered significant, given the natural variation in soils and the expected variation in RCTS test results**.** It is also noted that in the randomization of the damping ratio values at a strain level of 1E-2%, the minimum and maximum values (with respect to the mean)

are allowed to vary from about -50% to +100%, or average of about 75%. The observed average value of 33% noted above is well within the acceptable -50% to +100% range for randomization.

Finally, the results of all 13 RCTS tests are combined, in terms of shear modulus and damping ratios, and are presented in Figure 18. Three distinct groups are noted in the G/G_{max} curves for the site soils. Given the relative similarity in responses among various groups of tests, and particularly in light of small variations at low strain levels (approximately 1E-2%), it is possible to provide an average curve for each of the three distinct groups. A similar approach is followed for the damping curves shown in Figure 18. The average curves for the three distinct groups, for both shear modulus and damping ratios, are presented in Figure 19. The numerical values for these average curves are given in Table 16. These represent the strain-dependent properties for soils in the upper approximately 400 feet at the CCNPP Unit 3 site. For comparison purposes, these curves are shown along with the initially adopted EPRI curves in Figure 20.

6 STRAIN-DEPENDENT PROPERTIES FOR SOILS BELOW 400 FEET

As noted earlier, RCTS tests were performed on soils collected from the upper 400 feet of the site. RCTS tests were not performed on soils below 400 feet, for the boring depths were limited to about 400 feet, and therefore, soils samples were not available for testing. These deeper soils, in descending order, are the Marlboro Clay, Aquia/Brightseat Sand, Patapsco Sand, and the Patuxent/Arundel Clay.

To assess their utilization, EPRI curves initially adopted for these soils were compared with the set of curves derived from the RCTS results for the upper soils, as shown in Figure 21. The results indicate the following relative to the RCTS-based curves

- Marlboro Clay and Patuxent/Arundel Clay Curves: the EPRI curves are identical and fall nearly half-way between the RCTS-based curves for the Stratum I Sand (Curve 3) and Strata II and III soils (Curve 2) in their G/G_{max} relationship and closer to Curve 3 in their damping relationship. Based on the available RCTS results, it is inconceivable for these soils at such great depths (and expected high strength) to behave as “softly” as Stratum I Sand (Curve 3) which is at relatively shallow depths and primarily non-plastic. Therefore, as a minimum, the Marlboro and Patuxent/Arundel clays are expected to behave closer to that represented by Curve 2. On this basis, Curve 2 is a reasonable representation for these soils and is used for the dynamic characterization of Marlboro Clay and Patuxent/Arundel Clay.
- Aquia/Brightseat Sand and Patapsco Sand: the EPRI curves are nearly identical and follow Curve 2 closely in their G/G_{max} and damping relationship. Based on the RCTS results, and given their depths, these soils are expected to behave somewhere in the region represented by Curves 1 and 2, and possibly closer to Curve 1. Given that a number of the RCTS tests on sandy soils banded closely and were represented by Curve 2, the deeper sandy soils of the Aquia/Brightseat and Patapsco are expected to produce relationships that are mimicked by Curve 2, as a minimum. On this basis, Curve 2 is a reasonable representation for these soils and is used for the dynamic characterization of Aquia/Brightseat Sand and Patapsco Sand.

It is important to note that the calculated maximum strains based on the initially adopted EPRI curves for soils below 400 feet are in the 10^{-3}% to 10^{-2}% range for the 1E-4 and 1E-5 rock input motions, respectively, as shown in Figure 22. At these strain levels, the difference between the EPRI-based and RCTS-based curves are minor to insignificant, as evident in Figure 21.

7 CONCLUSIONS

A total of 13 RCTS tests were performed on soils from the CCNPP Unit 3 site. Final shear modulus ratio and damping ratio curves for all the soils at the CCNPP Unit 3 site are summarized in Figure 23, with the numerical values given in Table 17.

A comparison of the RCTS results with the initially adopted EPRI curves indicate that the difference between these curves at a mean strain level of about 1E-2% (the approximate mean strain level calculated in the soils from the initial seismic evaluation based on EPRI curves) is well within ranges considered acceptable for the randomization of these curves. This suggests that a new seismic analysis using the RCTS results would not significantly change the outcome of the initial seismic analysis that was based on the EPRI curves. This is particularly supported by the shape of the RCTS test curves that indicate consistently higher shear modulus and lower damping than the initially adopted EPRI curves, since such stiffer dynamic response should result in strains somewhat lower than (or at least similar to) the initially observed value of 1E-2±%, a level at which the RCTS and EPRI curves converge even closer with practically insignificant differences.

8 CONFIRMATORY ANALYSIS

To assess the above observations, an analysis was performed, comparing the sensitivity in soil amplification for both the EPRI-based and RCTS-based curves. The work consisted of separately running a soil column analysis using the EPRI-based curves (Figure 2) and the RCTS-based curves (Figure 23), without randomization. The shear wave velocity profile and material parameters were per Reference 1. Amplifications, in terms of spectral ratio of response motion to input motion, at outcrop depths of 0 (zero) and 41 feet for both high frequency (HF) and low frequency (LF) 10^{-4} rock input motions, were obtained. The results are documented in Reference 4, and reported herein as Figures 24 and 25.

The results support the observations made earlier. They indicate that the differences in amplification factors are very small, especially at the LF input. At the HF input, small differences are evident; however, the RCTS-based results indicate reduced amplification, which should result in reduced spectral acceleration than from the EPRI-based curves. Accordingly, based on results of this analysis, it is concluded that the EPRI-based and site-specific RCTS-based curves arrive at very similar soil amplification, and therefore, the response motion (GMRS) presented in Reference 3 is sufficient for the CCNPP Unit 3 design.

9 REFERENCES

1. Calvert Cliffs Unit 3, Combined License Application, Rev. 0, Part 2, FSAR, Vol. 4, Section 2.5.4, "Stability of Subsurface Materials and Foundations" NRC Accession No. ML072000175, dated 7/13/2007.
2. Schnabel Engineering North, LLC (2007), Geotechnical Subsurface Investigation Data Report, Addendum No. 3 (RCTS Test Results), Rev. 02, CGG Combined Operating License Application (COLA) Project, Calvert Cliffs Nuclear Power Plant (CCNPP), Calvert County, Maryland.
3. Calvert Cliffs Unit 3, Combined License Application, Rev. 0, Part 2, FSAR, Vol. 3, Section 2.5.2, "Vibratory Ground Motion" NRC Accession No. ML072000172, dated 7/13/2007.
4. Risk Engineering, Inc. (2007), Calvert Cliffs Sensitivity of Site Response to RCTS vs. EPRI Soil Curves, 0620-ACR-038.

Table 1. Summary of RCTS Samples and Index Properties

Appendix No.	Sample	Sample No.	Sample Top Depth (ft)	Sample Bottom Depth (ft)	Sample Type	Index Testing					
						Lab Class	UW (lb/ft^3)	MC (%)	SG	LL	PI
A	B-437	6	13.5	15.5	UD	SP-SM	124.1	7.2	2.66	NP	NP
B	B-301	10	33.5	35.5	UD	CH	117.5	31.1	2.74	59	42
C	B-305	17	39.5	41.5	UD	SC	117.2	34.7	2.71	72	50
D	B-404	14	52	53.6	UD	SP-SM	117.6	27.7	2.66	NP	NP
E	B-401	31	138.5	140.5	UD	CH	104.1	44.1	2.63	80	49
F	B-401	67	348.5	350.5	UD	SM	116.4	35.6	2.78	52	13
G	B-401	48	228.5	229.6	UD	MH	98.2	58.6	2.48	139	51
H	B-301	76	368.5	370	jar	SM	116.4	34.4	2.86	40	4
	B-301	77	378.5	379.5	jar						
	B-301	78	383.5	384.4	jar						
	B-301	79	388.5	390	jar						
	B-301	81	398.5	400	jar						
	B-401	68	358.5	359.4	jar						
	B-401	70	378.5	380	jar						
I	B-306	17	68	70	UD	CH	115.8	30.7	2.73	62	38
J	B-409	15	35	36.1	UD	SP-SM	124.8	23.3	2.66	NP	NP
K	B-404	22	83.5	85.1	UD	SM	115.4	32.2	2.63	53	25
L	B-401	42	198.5	200.3	UD	SM	101.2	48.8	2.52	82	27
M	B-409	39	95	96.6	UD	SM	109.3	33.1	2.64	61	19

Key:

Appendix No.	Sample designation assigned by the laboratory for tracking purposes
UD	Shelby tube sample
Jar	Glass jar sample
Lab Class	Laboratory classification of soils
UW	Total unit weight
MC	Moisture content
SG	Specific gravity
LL	Liquid limit
PI	Plasticity index

Table 2. Summary Shear Modulus and Damping Ratios from Initially Adopted EPRI Curves

Depth 0-25 ft (Terrace Sand)			Depth 25-40 ft (Chesapeake Clay/Silt)			Depth 40-100 ft (Ches. Cemented Sand)			Depth 100-285 ft (Ches. Clay/Silt)			Depth 285-355 ft (Nanjemoy Cemented Clay/Silt)		
Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1	1.4	1.E-04	1	1.5	1.E-04	1	1	1.E-04	1	2	1.E-04	1	1.5
3.E-04	1	1.5	3.E-04	1	1.5	3.E-04	1	1	3.E-04	1	2	3.E-04	1	1.5
1.E-03	0.98	1.8	1.E-03	1	1.6	1.E-03	1	1.2	1.E-03	1	2	1.E-03	1	1.6
3.E-03	0.914	2.8	3.E-03	0.97	2.05	3.E-03	0.97	1.64	3.E-03	0.995	2.13	3.E-03	0.97	2.05
1.E-02	0.75	5	1.E-02	0.878	3.21	1.E-02	0.87	2.8	1.E-02	0.955	2.75	1.E-02	0.878	3.21
3.E-02	0.509	9.3	3.E-02	0.685	5.77	3.E-02	0.68	5.49	3.E-02	0.832	4.38	3.E-02	0.685	5.77
1.E-01	0.27	15.3	1.E-01	0.413	10.64	1.E-01	0.43	10.2	1.E-01	0.59	8	1.E-01	0.413	10.64
3.E-01	0.116	21.9	3.E-01	0.208	16.22	3.E-01	0.22	16.5	3.E-01	0.34	13.16	3.E-01	0.208	16.22
1.E+00	0.04	27	6.E-01	0.115	18.65	1.E+00	0.09	22.9	6.E-01	0.22	16.15	6.E-01	0.115	18.65
3.E+00	0.02	30	1.E+00	0.075	19	3.E+00	0.05	27	1.E+00	0.15	17.56	1.E+00	0.075	19

Depth 355-456 ft (Nanjemoy Sand)			Depth 456-471 ft (Marlboro Clay)			Depth 471-631 ft (Aquia/Brighseat Sand)			Depth 631-1,731 ft (Patapsco Sand)			Depth 1,731-2,531 ft (Patuxent/Arundel Clay)		
Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)	Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1	0.7	1.E-04	1	1.5	1.E-04	1	0.6	1.E-04	1	0.55	1.E-04	1	1.5
3.E-04	1	0.8	3.E-04	1	1.5	3.E-04	1	0.6	3.E-04	1	0.55	3.E-04	1	1.5
1.E-03	1	0.8	1.E-03	1	1.6	1.E-03	1	0.6	1.E-03	1	0.55	1.E-03	1	1.6
3.E-03	0.988	1.12	3.E-03	0.97	2.05	3.E-03	0.99	0.81	3.E-03	1	0.77	3.E-03	0.97	2.05
1.E-02	0.93	1.8	1.E-02	0.878	3.21	1.E-02	0.95	1.2	1.E-02	0.96	1.15	1.E-02	0.878	3.21
3.E-02	0.791	3.53	3.E-02	0.685	5.77	3.E-02	0.852	2.5	3.E-02	0.88	2.1	3.E-02	0.685	5.77
1.E-01	0.57	7.1	1.E-01	0.413	10.64	1.E-01	0.65	5.3	1.E-01	0.71	4.2	1.E-01	0.413	10.64
3.E-01	0.321	12.78	3.E-01	0.208	16.22	3.E-01	0.41	10.27	3.E-01	0.47	8.45	3.E-01	0.208	16.22
1.E+00	0.15	19.3	6.E-01	0.115	18.65	1.E+00	0.2	16.7	1.E+00	0.265	14.5	6.E-01	0.115	18.65
3.E+00	0.09	23	1.E+00	0.075	19	3.E+00	0.1	20.1	3.E+00	0.16	17.4	1.E+00	0.075	19

Table 3. Summary of RCTS Laboratory Test Results (Appendix A Tests)

Test ID: Appendix A Boring: B-437 Sample No.: UD6 Layer: Stratum I - Terrace Sand
Sample Depth = 14.9 ft
USCS Classification = SP-SM
Sample Description: poorly graded **SAND** with silt
Moisture Content = 3.0%
Total Unit Weight = 124.1 pcf
Specific Gravity = 2.66
LL = NP, PL = NP, PI = NP
Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean} = 8.6 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index
NP = Non-Plastic

Isotropic Confining Stress, σ_o = 8.6 psi								
Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
6.00E-05	1.00	1.28	3.38E-04	1.00	1.59	3.26E-04	1.00	1.27
1.42E-04	1.00	1.36	8.87E-04	1.00	1.50	8.83E-04	1.00	1.49
3.49E-04	0.98	1.72	1.81E-03	1.00	1.67	1.82E-03	0.97	1.66
8.14E-04	0.96	2.13	3.54E-03	0.94	2.18	3.57E-03	0.91	1.96
1.91E-03	0.90	2.55	4.76E-03	0.91	2.51	4.78E-03	0.89	2.53
4.48E-03	0.80	3.05	1.07E-02	0.81	3.45	1.07E-02	0.79	3.32
1.05E-02	0.67	4.07	2.69E-02	0.65	7.89	2.60E-02	0.65	6.41
2.56E-02	0.53	5.74	---	---	---	---	---	---
6.21E-02	0.42	7.65	---	---	---	---	---	---
1.47E-01	0.33	10.43	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 34.4 psi								
Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
2.30E-05	1.00	1.04	8.41E-04	0.97	1.20	8.53E-04	0.95	0.87
5.60E-05	1.00	1.03	1.67E-03	0.94	1.13	1.67E-03	0.94	1.00
1.39E-04	0.99	1.21	3.47E-03	0.90	1.16	3.48E-03	0.90	1.22
3.27E-04	0.98	1.38	7.34E-03	0.85	2.00	7.33E-03	0.85	1.86
8.17E-04	0.96	1.78	---	---	---	---	---	---
1.94E-03	0.92	1.99	---	---	---	---	---	---
4.68E-03	0.84	2.33	---	---	---	---	---	---
1.13E-02	0.73	3.05	---	---	---	---	---	---
2.62E-02	0.61	3.87	---	---	---	---	---	---
4.20E-02	0.53	4.35	---	---	---	---	---	---

Table 4. Summary of RCTS Laboratory Test Results (Appendix B Tests)

Test ID: Appendix B
Boring: B-301
Sample No.: UD10
Layer: Stratum IIa - Ches. Clay/Silt

Sample Depth = 35.4 ft
USCS Classification = CH
Sample Description: fat **CLAY** with sand
Moisture Content = 30.1%
Total Unit Weight = 117.5 pcf
Specific Gravity = 2.74
LL = 55, PL = 17, PI = 42

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean} = 12 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 12 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
9.80E-05	1.00	1.87	3.09E-04	1.00	1.90	3.13E-04	1.00	1.69
2.01E-04	1.00	1.86	6.03E-04	1.00	1.94	6.05E-04	1.00	2.14
4.96E-04	1.00	1.98	9.31E-04	1.00	2.09	9.60E-04	1.00	2.23
1.33E-03	0.99	2.17	1.89E-03	1.00	2.46	1.89E-03	1.00	2.34
3.18E-03	0.99	2.48	3.88E-03	0.99	2.93	3.92E-03	0.99	2.75
7.88E-03	0.95	3.11	9.62E-03	0.87	3.61	9.60E-03	0.88	3.48
1.85E-02	0.86	3.90	2.18E-02	0.77	4.92	2.23E-02	0.76	5.07
4.53E-02	0.71	5.86	6.48E-02	0.55	8.05	6.67E-02	0.55	8.00
1.20E-01	0.53	8.96	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 48.1 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.30E-04	1.00	1.24	3.03E-04	1.00	1.58	3.16E-04	1.00	1.70
2.19E-04	1.00	1.24	8.75E-04	1.00	1.13	8.78E-04	1.00	1.47
3.95E-04	1.00	1.24	1.74E-03	1.00	1.48	1.75E-03	1.00	1.18
7.64E-04	1.00	1.24	3.54E-03	1.00	1.69	3.54E-03	1.00	1.91
1.50E-03	1.00	1.41	9.67E-03	0.92	2.69	9.65E-03	0.93	2.61
2.91E-03	0.99	1.56	2.14E-02	0.83	3.63	2.17E-02	0.83	3.67
5.67E-03	0.98	2.05	5.55E-02	0.64	6.04	5.72E-02	0.63	6.16
2.14E-02	0.93	2.87	---	---	---	---	---	---
3.97E-02	0.85	3.49	---	---	---	---	---	---
7.56E-02	0.74	4.18	---	---	---	---	---	---
1.58E-01	0.60	5.65	---	---	---	---	---	---
3.79E-01	0.46	7.73	---	---	---	---	---	---
8.81E-01	0.33	10.75	---	---	---	---	---	---

Table 5. Summary of RCTS Laboratory Test Results (Appendix I Tests)

Test ID: Appendix I
Boring: B-306
Sample No.: UD17
Layer: Stratum IIa - Ches. Clay/Silt

Sample Depth = 69.3 ft
USCS Classification = CH
Sample Description: fat **CLAY,** trace sand
Moisture Content = 31.2%
Total Unit Weight = 115.8 pcf
Specific Gravity = 2.73
LL = 62, PL = 24, PI = 38

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean}= 23.6 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 23.6 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
2.35E-04	1.00	1.63	5.75E-04	1.00	1.03	5.73E-04	1.00	1.11
4.26E-04	1.00	1.61	9.77E-04	1.00	1.03	9.91E-04	1.00	1.11
8.80E-04	1.00	1.62	1.98E-03	1.00	1.17	1.97E-03	1.00	1.29
1.79E-03	1.00	1.62	4.02E-03	1.00	1.63	4.05E-03	1.00	1.60
3.53E-03	1.00	1.63	---	---	---	---	---	---
6.81E-03	0.98	1.68	---	---	---	---	---	---
1.27E-02	0.96	1.80	---	---	---	---	---	---
2.31E-02	0.91	1.95	---	---	---	---	---	---
4.19E-02	0.83	2.06	---	---	---	---	---	---
7.93E-02	0.71	2.66	---	---	---	---	---	---
1.69E-01	0.56	4.01	---	---	---	---	---	---
2.78E-01	0.49	6.48	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 94.3 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.40E-04	1.00	1.28	1.00E-03	1.00	1.25	1.00E-03	1.00	1.00
2.73E-04	1.00	1.27	1.98E-03	1.00	1.08	2.01E-03	1.00	1.14
5.56E-04	1.00	1.29	4.02E-03	1.00	1.16	4.01E-03	1.00	1.13
1.11E-03	1.00	1.29	1.00E-02	0.95	1.66	9.98E-03	0.96	1.70
2.21E-03	1.00	1.29	---	---	---	---	---	---
4.40E-03	1.00	1.29	---	---	---	---	---	---
8.58E-03	1.00	1.33	---	---	---	---	---	---
1.63E-02	0.98	1.41	---	---	---	---	---	---
2.91E-02	0.94	1.53	---	---	---	---	---	---
5.04E-02	0.88	1.80	---	---	---	---	---	---
9.03E-02	0.78	2.59	---	---	---	---	---	---
1.75E-01	0.65	3.40	---	---	---	---	---	---
3.87E-01	0.50	5.18	---	---	---	---	---	---

Table 6. Summary of RCTS Laboratory Test Results (Appendix C Tests)

Test ID: Appendix C
Boring: B-305
Sample No.: UD17
Layer: Stratum IIb - Ches. Cem. Sand

Sample Depth = 41 ft
USCS Classification = SC
Sample Description: clayey **SAND** with shells
Moisture Content = 44.9%
Total Unit Weight = 117.2 pcf
Specific Gravity = 2.71
LL = 72, PL = 22, PI = 50

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean}= 20.7 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 20.7 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
2.73E-04	1.00	1.59	5.00E-04	1.00	1.51	4.98E-04	1.00	1.35
5.73E-04	1.00	1.59	9.81E-04	1.00	1.34	1.00E-03	1.00	1.29
1.15E-03	1.00	1.59	1.99E-03	1.00	1.61	2.00E-03	1.00	1.41
2.31E-03	1.00	1.64	4.09E-03	0.97	1.53	4.08E-03	0.98	1.55
8.85E-03	0.98	1.74	9.66E-03	0.88	2.26	9.63E-03	0.89	2.26
1.67E-02	0.94	1.86	2.14E-02	0.79	3.60	2.18E-02	0.79	3.72
3.07E-02	0.88	2.01	5.52E-02	0.62	5.65	5.68E-02	0.60	5.67
5.65E-02	0.80	2.41	---	---	---	---	---	---
1.10E-01	0.69	3.35	---	---	---	---	---	---
2.41E-01	0.54	4.95	---	---	---	---	---	---
6.32E-01	0.38	8.54	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 82.8 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
6.65E-04	1.00	0.78	Test results discarded.			Test results discarded.		
1.29E-03	1.00	0.77	---	---	---	---	---	---
2.44E-03	1.00	0.88	---	---	---	---	---	---
4.90E-03	0.99	0.89	---	---	---	---	---	---
9.52E-03	0.98	0.93	---	---	---	---	---	---
1.78E-02	0.95	1.15	---	---	---	---	---	---
3.19E-02	0.90	1.44	---	---	---	---	---	---
5.75E-02	0.82	1.91	---	---	---	---	---	---
1.05E-01	0.72	2.68	---	---	---	---	---	---
2.17E-01	0.57	3.93	---	---	---	---	---	---
5.90E-01	0.38	6.15	---	---	---	---	---	---

Table 7. Summary of RCTS Laboratory Test Results (Appendix J Tests)

Test ID: Appendix J
Boring: B-409
Sample No.: UD15
Layer: Stratum IIb - Ches. Cem. Sand

Sample Depth = 36.1 ft
USCS Classification = SP-SM
Sample Description: poorly graded **SAND** with silt
Moisture Content = 21.5%
Total Unit Weight = 124.8 pcf
Specific Gravity = 2.66
LL = NP, PL = NP, PI = NP

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean}= 11.8 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index
NP = Non-Plastic

Isotropic Confining Stress, σ_o = 11.8 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.33E-04	1.00	0.40	5.89E-04	1.00	0.41	5.81E-04	1.00	0.55
2.67E-04	1.00	0.40	1.01E-03	1.00	0.42	1.01E-03	1.00	0.28
5.23E-04	1.00	0.46	2.05E-03	1.00	0.68	2.07E-03	0.99	0.74
1.05E-03	1.00	0.56	4.27E-03	0.96	1.01	4.31E-03	0.95	0.95
1.93E-03	0.98	0.63	1.02E-02	0.86	1.97	1.02E-02	0.86	2.09
3.50E-03	0.96	0.90	2.20E-02	0.80	3.08	2.21E-02	0.79	3.07
6.25E-03	0.93	1.19	3.52E-02	0.75	4.21	3.51E-02	0.75	4.26
1.06E-02	0.89	1.67	---	---	---	---	---	---
1.75E-02	0.83	2.16	---	---	---	---	---	---
2.86E-02	0.76	2.76	---	---	---	---	---	---
4.77E-02	0.68	3.60	---	---	---	---	---	---
8.01E-02	0.60	5.22	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 47.2 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
6.40E-05	1.00	0.37	5.76E-04	1.00	0.33	5.80E-04	1.00	0.40
1.28E-04	1.00	0.40	1.01E-03	1.00	0.27	1.03E-03	1.00	0.28
2.53E-04	1.00	0.40	2.07E-03	0.98	0.26	2.07E-03	0.99	0.51
4.97E-04	1.00	0.47	4.23E-03	0.96	0.89	4.26E-03	0.96	0.93
1.01E-03	1.00	0.49	1.01E-02	0.92	1.29	1.01E-02	0.93	1.30
1.92E-03	0.99	0.57	1.55E-02	0.90	1.61	1.55E-02	0.91	1.64
3.50E-03	0.97	0.71	---	---	---	---	---	---
6.17E-03	0.95	1.01	---	---	---	---	---	---
1.10E-02	0.92	1.32	---	---	---	---	---	---
1.76E-02	0.89	1.69	---	---	---	---	---	---
2.86E-02	0.84	1.99	---	---	---	---	---	---
4.54E-02	0.78	2.44	---	---	---	---	---	---
7.25E-02	0.69	3.28	---	---	---	---	---	---
9.65E-02	0.64	4.46	---	---	---	---	---	---
1.17E-01	0.61	5.28	---	---	---	---	---	---

Table 8. Summary of RCTS Laboratory Test Results (Appendix D Tests)

Test ID: Appendix D
Boring: B-404
Sample No.: UD14
Layer: Stratum IIb - Ches. Cem. Sand

Sample Depth = 53.2 ft
USCS Classification = SP-SM
Sample Description: poorly graded **SAND** with silt
Moisture Content = 28.3%
Total Unit Weight = 117.6 pcf
Specific Gravity = 2.66
LL = NP, PL = NP, PI = NP

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean} = 21.9 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index
NP = Non-Plastic

Isotropic Confining Stress, σ_o = 21.9 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
3.41E-04	1.00	0.93	3.32E-04	1.00	1.05	2.94E-04	1.00	0.97
6.94E-04	1.00	0.94	5.81E-04	1.00	1.28	6.02E-04	1.00	0.79
1.37E-03	1.00	0.96	1.01E-03	1.00	0.77	1.04E-03	1.00	0.67
2.63E-03	1.00	0.93	1.98E-03	1.00	1.07	2.05E-03	1.00	1.15
4.94E-03	0.97	1.04	4.10E-03	1.00	1.59	4.10E-03	1.00	1.48
9.13E-03	0.94	1.26	9.55E-03	0.92	2.23	9.58E-03	0.93	2.28
1.67E-02	0.89	1.72	2.04E-02	0.86	3.52	2.05E-02	0.86	3.53
3.06E-02	0.83	2.39	5.09E-02	0.69	6.25	5.10E-02	0.70	6.06
5.61E-02	0.76	3.09	---	---	---	---	---	---
9.74E-02	0.67	4.35	---	---	---	---	---	---
1.73E-01	0.56	5.28	---	---	---	---	---	---
3.48E-01	0.44	6.48	---	---	---	---	---	---
5.34E-01	0.38	7.68	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 87.6 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
2.57E-04	1.00	0.74	9.36E-04	1.00	0.79	9.44E-04	1.01	0.57
5.10E-04	1.00	0.66	1.93E-03	1.00	0.90	1.89E-03	1.01	0.89
1.05E-03	1.00	0.78	3.80E-03	1.00	0.77	3.84E-03	0.99	0.69
3.91E-03	0.98	0.71	9.97E-03	0.95	1.25	9.92E-03	0.96	1.39
7.29E-03	0.96	0.81	2.08E-02	0.92	1.95	2.08E-02	0.91	1.89
1.33E-02	0.93	0.89	3.88E-02	0.86	3.10	3.88E-02	0.86	2.95
2.35E-02	0.90	1.17	---	---	---	---	---	---
4.13E-02	0.84	1.72	---	---	---	---	---	---
7.11E-02	0.76	2.32	---	---	---	---	---	---
1.21E-01	0.67	2.90	---	---	---	---	---	---
2.11E-01	0.57	3.65	---	---	---	---	---	---
3.67E-01	0.48	4.84	---	---	---	---	---	---

Table 9. Summary of RCTS Laboratory Test Results (Appendix K Tests)

Test ID: Appendix K
Boring: B-404
Sample No.: UD22
Layer: Stratum IIc - Ches. Clay/Silt (sandy portion)

Sample Depth = 84 ft
USCS Classification = SM
Sample Description: Silty **SAND**
Moisture Content = 32.2%
Total Unit Weight = 115.4 pcf
Specific Gravity = 2.63
LL = 53, PL = 28, PI = 25

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean} = 30.3 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index
NP = Non-Plastic

Isotropic Confining Stress, σ_o = 30.3 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
2.78E-04	1.00	1.27	3.37E-04	1.00	0.63	3.27E-04	1.00	0.79
5.04E-04	1.00	1.29	6.51E-04	1.00	0.72	6.49E-04	1.00	0.74
9.88E-04	1.00	1.28	1.03E-03	1.00	0.85	1.02E-03	1.00	0.80
1.94E-03	1.00	1.31	2.07E-03	1.00	1.00	2.07E-03	1.00	0.93
3.71E-03	0.99	1.41	4.29E-03	0.97	1.34	4.31E-03	0.95	1.45
7.17E-03	0.96	1.61	1.03E-02	0.87	2.28	1.03E-02	0.86	2.26
1.36E-02	0.91	1.94	2.29E-02	0.78	3.30	2.32E-02	0.77	3.35
2.51E-02	0.85	2.43	5.38E-02	0.67	4.56	5.43E-02	0.66	4.55
4.66E-02	0.77	3.20	---	---	---	---	---	---
9.07E-02	0.67	4.47	---	---	---	---	---	---
1.82E-01	0.57	5.38	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 121.1 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.14E-04	1.00	0.99	3.60E-04	1.00	0.52	3.67E-04	1.00	0.67
2.28E-04	1.00	0.99	7.24E-04	1.00	0.62	7.19E-04	1.00	0.60
4.52E-04	1.00	0.99	1.02E-03	1.00	0.63	1.02E-03	1.00	0.69
9.31E-04	1.00	0.99	2.00E-03	1.00	0.74	2.02E-03	1.00	0.68
1.86E-03	1.00	0.98	4.06E-03	1.00	1.06	4.05E-03	1.00	1.06
3.64E-03	0.99	1.03	1.03E-02	0.94	1.65	1.03E-02	0.95	1.65
6.95E-03	0.97	1.22	2.19E-02	0.89	1.94	2.21E-02	0.89	2.14
1.28E-02	0.95	1.32	4.25E-02	0.82	3.18	4.26E-02	0.82	3.11
2.32E-02	0.90	1.62	---	---	---	---	---	---
4.14E-02	0.84	1.92	---	---	---	---	---	---
7.51E-02	0.77	2.64	---	---	---	---	---	---
1.39E-01	0.67	3.56	---	---	---	---	---	---
2.61E-01	0.57	5.24	---	---	---	---	---	---

Table 10. Summary of RCTS Laboratory Test Results (Appendix M Tests)

Test ID: Appendix M Boring: B-409 Sample No.: UD39 Layer: Stratum IIc - Ches. Clay/Silt (sandy portion)	Isotropic Confining Stress, σ_o = 28 psi								
	Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
Sample Depth = 96.1 ft	3.20E-04	1.00	1.19	--	--	--	1.77E-04	1.00	0.65
USCS Classification = SM	6.58E-04	1.00	1.19	--	--	--	3.39E-04	1.00	0.38
Sample Description: Silty **SAND**	1.30E-03	1.00	1.19	--	--	--	6.40E-04	1.00	0.48
Moisture Content = 33.1%	2.55E-03	1.00	1.18	--	--	--	1.02E-03	1.00	0.79
Total Unit Weight = 109.3 pcf	4.90E-03	1.00	1.23	--	--	--	2.06E-03	1.00	0.97
Specific Gravity = 2.64	9.32E-03	0.96	1.31	--	--	--	4.24E-03	1.00	1.13
LL = 61, PL = 42, PI = 19	1.72E-02	0.93	1.53	--	--	--	1.02E-02	0.95	2.01
	3.15E-02	0.87	2.11	---	---	---	---	---	---
Estimated In-Situ K_0 = 0.5	5.79E-02	0.79	2.68	---	---	---	---	---	---
Estimated In-Situ σ'_{mean}= 28 psi	1.09E-01	0.69	3.78	---	---	---	---	---	---

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index
NP = Non-Plastic

Isotropic Confining Stress, σ_o = 119.1 psi								
Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.59E-04	1.00	1.00	3.56E-04	1.00	0.53	3.69E-04	1.00	0.48
3.09E-04	1.00	1.04	7.33E-04	1.00	0.62	7.19E-04	1.00	0.68
6.30E-04	1.00	1.04	1.01E-03	1.00	0.60	1.02E-03	1.00	0.66
1.25E-03	1.00	1.08	2.02E-03	1.00	0.66	2.03E-03	1.00	0.66
2.47E-03	1.00	1.09	4.11E-03	0.98	0.85	4.10E-03	0.99	0.88
4.81E-03	0.99	1.09	8.42E-03	0.96	1.15	8.44E-03	0.96	1.12
9.15E-03	0.97	1.14	---	---	---	---	---	---
1.69E-02	0.95	1.19	---	---	---	---	---	---
3.06E-02	0.90	1.34	---	---	---	---	---	---
5.48E-02	0.84	1.85	---	---	---	---	---	---
9.97E-02	0.76	2.57	---	---	---	---	---	---
1.85E-01	0.67	3.72	---	---	---	---	---	---
3.50E-01	0.57	5.61	---	---	---	---	---	---
4.95E-01	0.52	6.55	---	---	---	---	---	---

Table 11. Summary of RCTS Laboratory Test Results (Appendix E Tests)

Test ID: Appendix E
Boring: B-401
Sample No.: UD31
Layer: Stratum IIc - Ches. Clay/Silt
Sample Depth = 140 ft
USCS Classification = CH
Sample Description: sandy fat **CLAY**
Moisture Content = 41.1%
Total Unit Weight = 104.1 pcf
Specific Gravity = 2.63
LL = 80, PL = 31, PI = 49
Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean}= 46.6 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 46.6 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
3.93E-04	1.00	1.24	5.40E-04	0.98	0.71	5.77E-04	1.00	0.80
6.95E-04	1.00	1.21	1.09E-03	0.99	1.05	1.12E-03	1.00	0.97
1.23E-03	1.00	1.27	2.14E-03	1.00	1.01	2.14E-03	1.00	0.89
2.15E-03	1.00	1.31	4.33E-03	0.99	1.04	4.37E-03	1.00	0.88
4.16E-03	1.00	1.35	---	---	---	---	---	---
9.87E-03	1.00	1.64	---	---	---	---	---	---
2.04E-02	0.98	1.91	---	---	---	---	---	---
3.91E-02	0.91	2.31	---	---	---	---	---	---
7.42E-02	0.82	2.99	---	---	---	---	---	---
1.54E-01	0.70	4.32	---	---	---	---	---	---
3.07E-01	0.58	5.67	---	---	---	---	---	---
4.91E-01	0.50	7.02	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 186.3 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
5.11E-04	1.00	1.17	3.38E-03	0.99	1.23	3.35E-03	1.00	1.30
1.06E-03	1.00	1.18	6.72E-03	1.00	1.26	6.74E-03	0.99	1.58
2.12E-03	1.00	1.16	1.01E-02	1.00	1.55	1.01E-02	1.00	1.62
4.21E-03	1.00	1.16	2.16E-02	0.95	1.89	2.17E-02	0.95	1.83
8.30E-03	0.99	1.36	---	---	---	---	---	---
1.59E-02	0.97	1.55	---	---	---	---	---	---
2.90E-02	0.94	1.82	---	---	---	---	---	---
5.14E-02	0.89	2.25	---	---	---	---	---	---
9.11E-02	0.82	2.79	---	---	---	---	---	---
1.69E-01	0.73	3.43	---	---	---	---	---	---
3.45E-01	0.60	5.02	---	---	---	---	---	---
6.57E-01	0.49	6.25	---	---	---	---	---	---

Table 12. Summary of RCTS Laboratory Test Results (Appendix L Tests)

Test ID: Appendix L
Boring: B-401
Sample No.: UD42
Layer: Stratum IIc - Ches. Clay/Silt

Sample Depth = 200.3 ft
USCS Classification = SM
Sample Description: silty SAND
Moisture Content = 48.8%
Total Unit Weight = 101.2 pcf
Specific Gravity = 2.52
LL = 82, PL = 55, PI = 27

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean} = 62.5 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 62.5 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
2.56E-04	1.00	0.89	7.34E-04	1.00	0.77	7.31E-04	1.00	0.69
5.08E-04	1.00	0.89	1.03E-03	1.00	0.84	1.04E-03	1.00	0.80
1.09E-03	1.00	0.89	2.08E-03	1.00	0.84	2.08E-03	1.00	0.80
2.13E-03	1.00	0.89	4.19E-03	1.00	0.81	4.19E-03	1.00	0.85
4.16E-03	1.00	0.91	1.04E-02	1.00	1.09	1.03E-02	1.00	1.27
8.12E-03	0.99	0.93	---	---	---	---	---	---
1.53E-02	0.98	1.08	---	---	---	---	---	---
2.79E-02	0.94	1.15	---	---	---	---	---	---
5.01E-02	0.89	1.35	---	---	---	---	---	---
9.01E-02	0.81	1.86	---	---	---	---	---	---
1.66E-01	0.72	2.80	---	---	---	---	---	---
3.22E-01	0.61	3.97	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 250 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.11E-04	1.00	0.78	3.67E-04	1.00	0.61	3.70E-04	1.00	0.54
2.25E-04	1.00	0.75	7.19E-04	1.00	0.64	7.20E-04	1.00	0.75
4.48E-04	1.00	0.76	1.03E-03	1.00	0.80	1.04E-03	1.00	0.78
9.23E-04	1.00	0.75	2.06E-03	1.00	0.77	2.06E-03	1.00	0.75
1.84E-03	1.00	0.74	4.16E-03	1.00	0.77	4.13E-03	1.00	0.68
3.63E-03	1.00	0.74	---	---	---	---	---	---
7.11E-03	0.99	0.79	---	---	---	---	---	---
1.36E-02	0.98	0.83	---	---	---	---	---	---
2.50E-02	0.96	0.91	---	---	---	---	---	---
4.82E-02	0.91	1.17	---	---	---	---	---	---
8.54E-02	0.85	1.54	---	---	---	---	---	---
1.52E-01	0.77	2.22	---	---	---	---	---	---
2.90E-01	0.66	3.50	---	---	---	---	---	---
4.21E-01	0.59	4.44	---	---	---	---	---	---

Table 13. Summary of RCTS Laboratory Test Results (Appendix G Tests)

Test ID: Appendix G
Boring: B-401
Sample No.: UD48
Layer: Stratum IIc - Ches. Clay/Silt

Sample Depth = 229 ft
USCS Classification = MH
Sample Description: elastic **SILT** with sand
Moisture Content = 65.2%
Total Unit Weight = 98.2 pcf
Specific Gravity = 2.48
LL = 139, PL = 88, PI = 51

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean} = 70.3 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 70.3 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.88E-04	1.00	0.98	1.03E-03	1.00	0.74	1.00E-03	1.00	0.66
3.83E-04	1.00	0.98	2.02E-03	1.00	0.67	2.04E-03	1.00	0.65
8.18E-04	1.00	0.95	4.11E-03	1.00	0.66	4.09E-03	1.00	0.65
1.62E-03	1.00	0.92	1.06E-02	0.96	1.04	1.07E-02	0.95	1.02
3.22E-03	1.00	0.92	2.25E-02	0.91	1.73	2.27E-02	0.90	1.52
6.24E-03	1.00	0.94	5.01E-02	0.82	2.70	5.05E-02	0.81	2.66
1.20E-02	0.98	0.96	---	---	---	---	---	---
2.19E-02	0.96	1.12	---	---	---	---	---	---
3.86E-02	0.92	1.31	---	---	---	---	---	---
6.82E-02	0.86	1.73	---	---	---	---	---	---
1.24E-01	0.77	2.32	---	---	---	---	---	---
2.34E-01	0.67	3.22	---	---	---	---	---	---
4.69E-01	0.55	5.08	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 281.3 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.31E-04	1.00	0.83	---	---	---	9.41E-04	1.00	0.62
2.63E-04	1.00	0.83	---	---	---	1.85E-03	1.00	0.79
5.21E-04	1.00	0.83	3.72E-03	1.00	0.66	3.76E-03	1.00	0.71
1.08E-03	1.00	0.83	1.02E-02	0.99	0.97	1.02E-02	0.99	1.03
2.15E-03	1.00	0.80	2.09E-02	0.96	1.22	2.10E-02	0.97	1.20
4.26E-03	1.00	0.81	4.14E-02	0.92	1.77	4.14E-02	0.93	1.76
8.33E-03	0.99	0.82	---	---	---	---	---	---
1.59E-02	0.99	0.82	---	---	---	---	---	---
2.94E-02	0.97	0.96	---	---	---	---	---	---
5.27E-02	0.92	1.10	---	---	---	---	---	---
9.31E-02	0.86	1.41	---	---	---	---	---	---
1.67E-01	0.78	2.03	---	---	---	---	---	---
3.15E-01	0.68	3.09	---	---	---	---	---	---
6.23E-01	0.55	4.70	---	---	---	---	---	---

Table 14. Summary of RCTS Laboratory Test Results (Appendix F Tests)

Test ID: Appendix F
Boring: B-401
Sample No.: UD67
Layer: Stratum III - Nanjemoy Sand
Sample Depth = 349 ft
USCS Classification =SM
Sample Description: silty **SAND**
Moisture Content = 53.6%
Total Unit Weight = 116.4 pcf
Specific Gravity = 2.78
LL = 52, PL = 39, PI = 13
Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean}= 113.9 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 113.9 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
4.00E-05	1.00	2.98	6.31E-04	1.00	0.79	6.36E-04	1.00	0.98
8.00E-05	1.00	3.01	1.07E-03	1.00	0.52	1.06E-03	1.00	1.00
1.58E-04	1.00	3.07	2.15E-03	1.00	0.82	2.13E-03	1.00	0.72
3.15E-04	1.00	3.11	4.34E-03	0.99	1.20	4.34E-03	0.98	0.75
6.52E-04	1.00	3.27	1.05E-02	0.93	1.83	1.04E-02	0.94	1.80
1.31E-03	0.99	3.38	2.22E-02	0.88	2.49	2.24E-02	0.87	2.50
2.59E-03	0.99	3.60	3.92E-02	0.81	3.31	3.91E-02	0.81	3.24
5.09E-03	0.97	3.81	---	---	---	---	---	---
9.84E-03	0.94	4.03	---	---	---	---	---	---
1.87E-02	0.89	4.55	---	---	---	---	---	---
3.59E-02	0.81	5.01	---	---	---	---	---	---
7.02E-02	0.71	5.99	---	---	---	---	---	---
1.42E-01	0.60	7.70	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 455.6 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
Measurements for 455.6 psi tests were likely adversely affected by high straining during tests at 113.9 psi, therefore, discarded.								
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Table 15. Summary of RCTS Laboratory Test Results (Appendix H Tests)

Test ID: Appendix H
Borings: B-301 & B-401
Sample No.: Composite
Layer: Stratum III - Nanjemoy Sand

Sample Depth = 359-385 ft
USCS Classification = SM
Sample Description: silty **SAND**
Moisture Content = 19.2%
Total Unit Weight = 116.4 pcf
Specific Gravity = 2.86
LL = 40, PL = 36, PI = 4

Estimated In-Situ K_0 = 0.5
Estimated In-Situ σ'_{mean}= 120.4 psi

LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

Isotropic Confining Stress, σ_o = 120.4 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
1.08E-04	1.00	2.78	4.95E-04	1.00	1.42	4.97E-04	0.99	1.16
2.15E-04	1.00	2.78	9.93E-04	1.00	1.37	9.72E-04	1.00	0.94
4.28E-04	1.00	2.88	1.98E-03	1.00	1.11	1.95E-03	0.99	1.05
8.78E-04	1.00	2.94	3.99E-03	0.99	1.59	4.03E-03	0.96	1.69
1.75E-03	0.99	2.96	1.01E-02	0.93	2.16	1.01E-02	0.91	2.04
3.45E-03	0.97	3.33	2.17E-02	0.87	3.03	2.19E-02	0.84	2.99
6.70E-03	0.94	3.96	---	---	---	---	---	---
1.17E-02	0.89	4.47	---	---	---	---	---	---
2.51E-02	0.78	5.74	---	---	---	---	---	---
5.10E-02	0.65	6.86	---	---	---	---	---	---
1.04E-01	0.55	8.19	---	---	---	---	---	---

Isotropic Confining Stress, σ_o = 455.0 psi

Resonant Column			Torsional Shear (1st Cycle)			Torsional Shear (10th Cycle)		
Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)	Peak Shear Strain (%)	Shear Modulus (G/G_{max})	Damping Ratio (%)
Measurements for 455.0 psi tests were likely adversely affected by high straining during tests at 120.4 psi, therefore, discarded.								
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Table 16. Summary Average Shear Modulus and Damping Ratios Values from RCTS Results

Stratum I-Terrace Sand (Depth 0-25 ft)		
Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1	1.4
3.E-04	1	1.5
1.E-03	0.98	1.8
3.E-03	0.915	2.3
1.E-02	0.76	3.8
3.E-02	0.56	6.5
1.E-01	0.34	10.5
3.E-01	0.2	14.8
1.E+00	0.1	

Stratum IIc-Chesapeake Clay/Silt (Depth 135-285 ft)		
Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1.0	1.1
3.E-04	1.0	1.1
1.E-03	1.0	1.1
3.E-03	1.0	1.13
1.E-02	0.99	1.2
3.E-02	0.94	1.5
1.E-01	0.80	2.4
3.E-01	0.63	4.1
6.E-01	0.50	5.8
1.E+00	0.40	7.4

Strata IIa, IIb, and III (Chesapeake & Nanjemoy Soils)		
Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1.0	1.3
3.E-04	1.0	1.3
1.E-03	1.0	1.4
3.E-03	0.99	1.6
1.E-02	0.94	2.2
3.E-02	0.82	3.2
1.E-01	0.62	5.4
3.E-01	0.42	8.4
6.E-01	0.31	10.6
1.E+00	0.25	12.6

Table 17. Final Shear Modulus and Damping Ratios for the CCNPP Unit 3 Soils

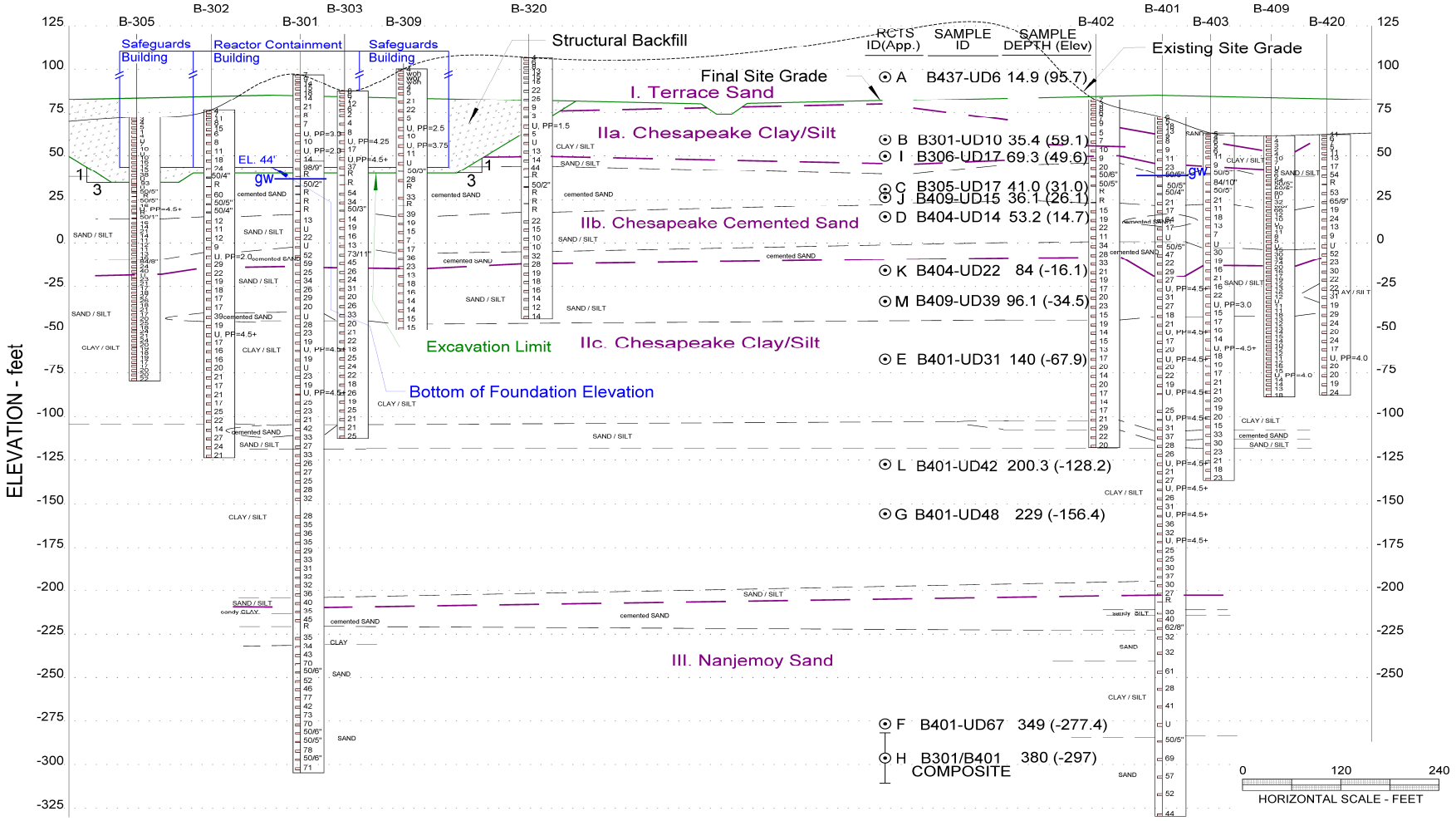
Stratum I-Terrace Sand (Depth 0-25 ft, El. +85 to +60 ft)		
Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1	1.4
3.E-04	1	1.5
1.E-03	0.98	1.8
3.E-03	0.915	2.3
1.E-02	0.76	3.8
3.E-02	0.56	6.5
1.E-01	0.34	10.5
3.E-01	0.2	14.8
1.E+00	0.1	

Stratum IIc-Chesapeake Clay/Silt (Depth 135-285 ft, El. -50 to -200 ft)		
Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1.0	1.1
3.E-04	1.0	1.1
1.E-03	1.0	1.1
3.E-03	1.0	1.13
1.E-02	0.99	1.2
3.E-02	0.94	1.5
1.E-01	0.80	2.4
3.E-01	0.63	4.1
6.E-01	0.50	5.8
1.E+00	0.40	7.4

All Other Natural Soils		
Cyclic Shear Strain (%)	G/G_{max}	D (%)
1.E-04	1.0	1.3
3.E-04	1.0	1.3
1.E-03	1.0	1.4
3.E-03	0.99	1.6
1.E-02	0.94	2.2
3.E-02	0.82	3.2
1.E-01	0.62	5.4
3.E-01	0.42	8.4
6.E-01	0.31	10.6
1.E+00	0.25	12.6

Note: Depth=0 ft (El. 85 ft) is finished grade.

Figure 1. RCTS Test Locations

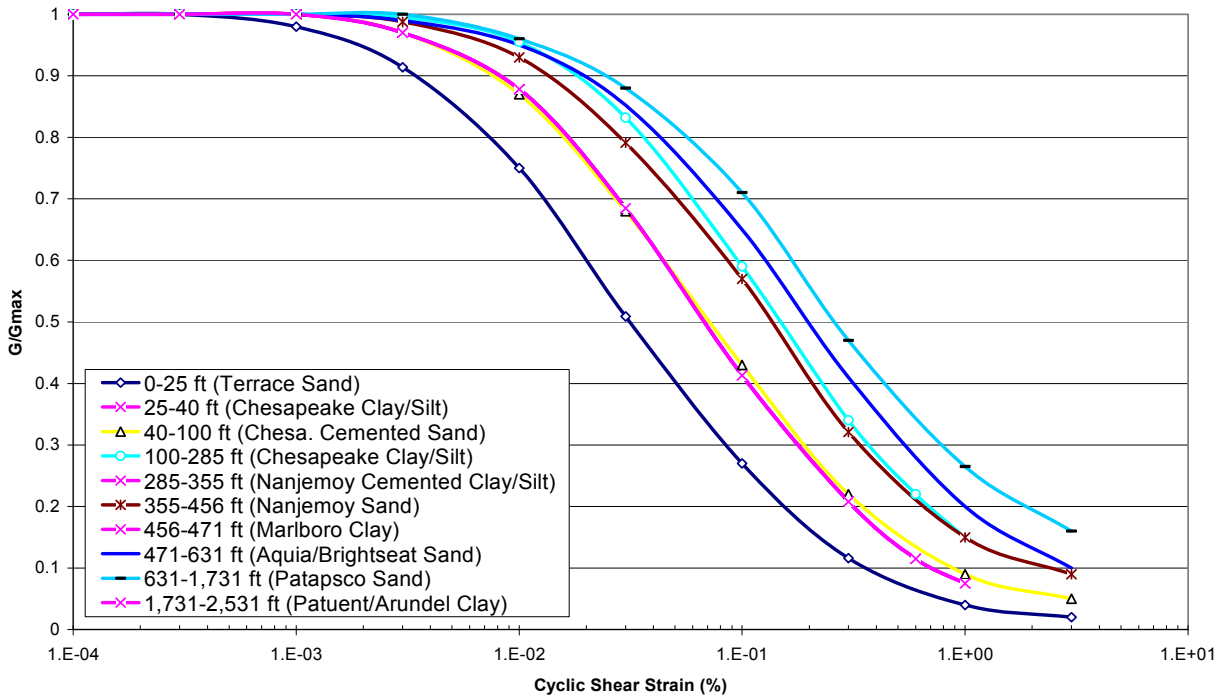


LEGEND:

⊙ RCTS SAMPLE

FIGURE 1:
RCTS TEST LOCATIONS
CCNPP UNIT 3

Figure 2. Shear Modulus and Damping Ratios from Initially Adopted EPRI Curves



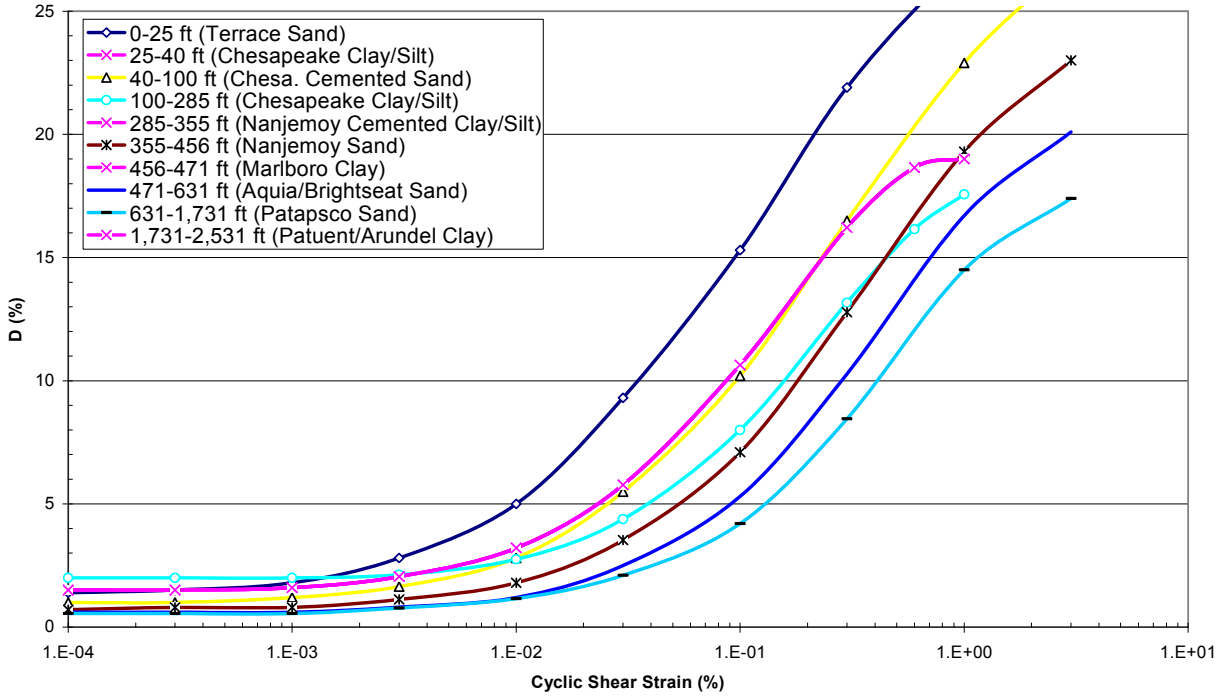
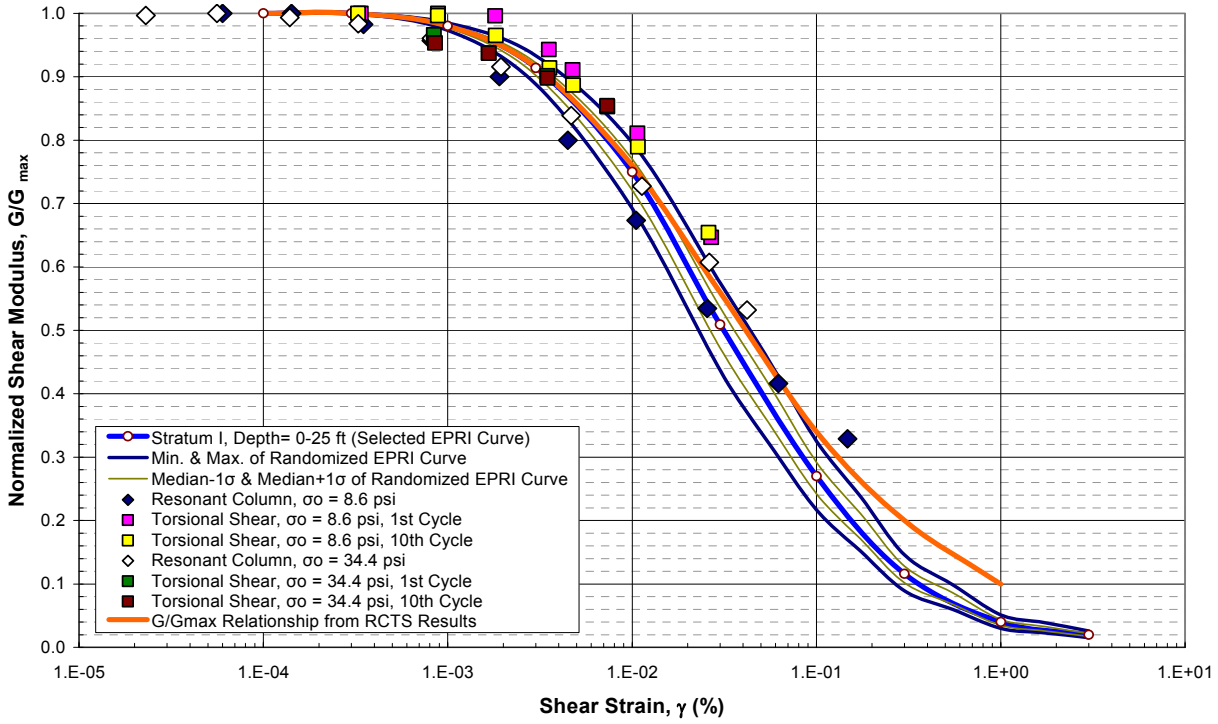


Figure 3. RCTS Test Results: Stratum I-Terrace Sand (Appendix A Tests)



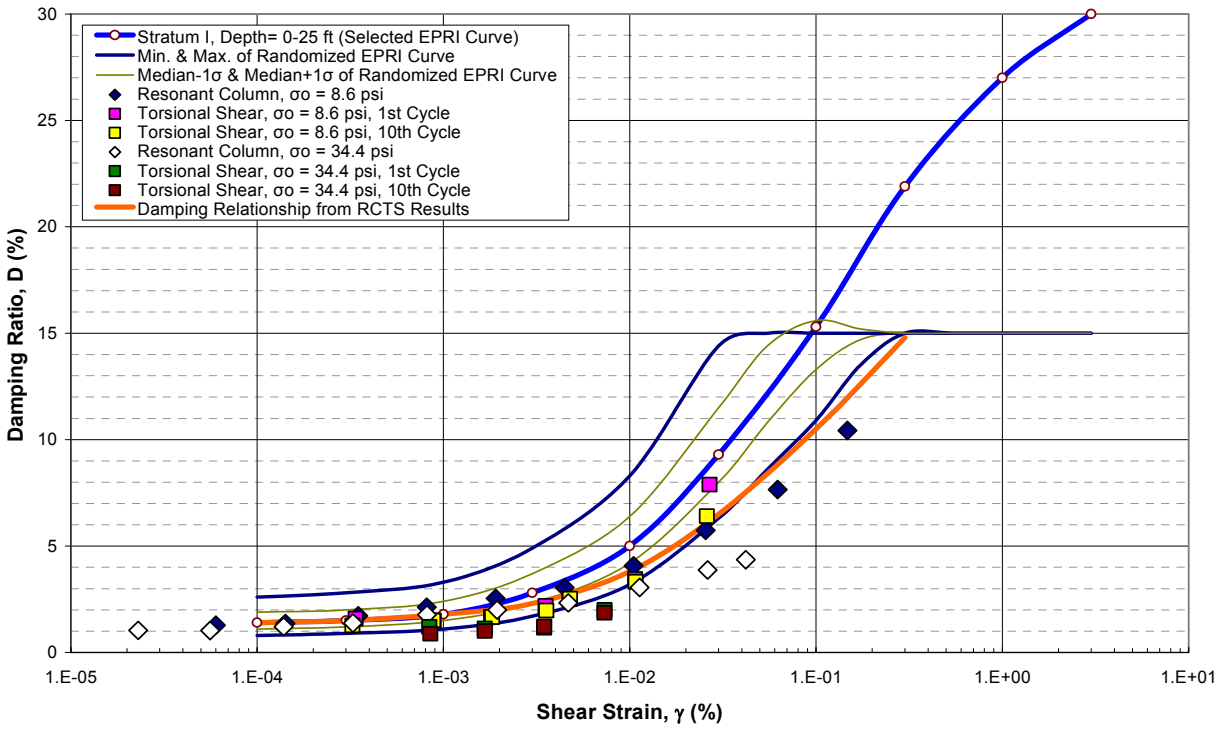
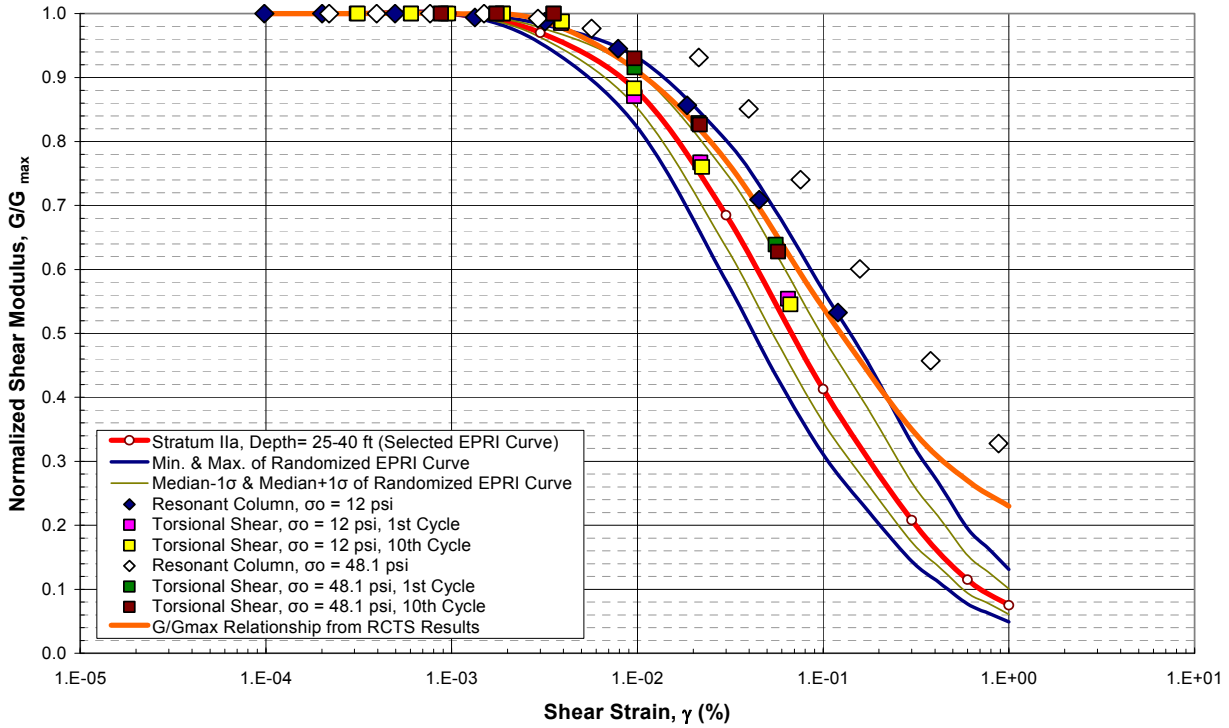


Figure 4. RCTS Test Results: Stratum IIa-Chesapeake Clay/Silt (Appendix B Tests)



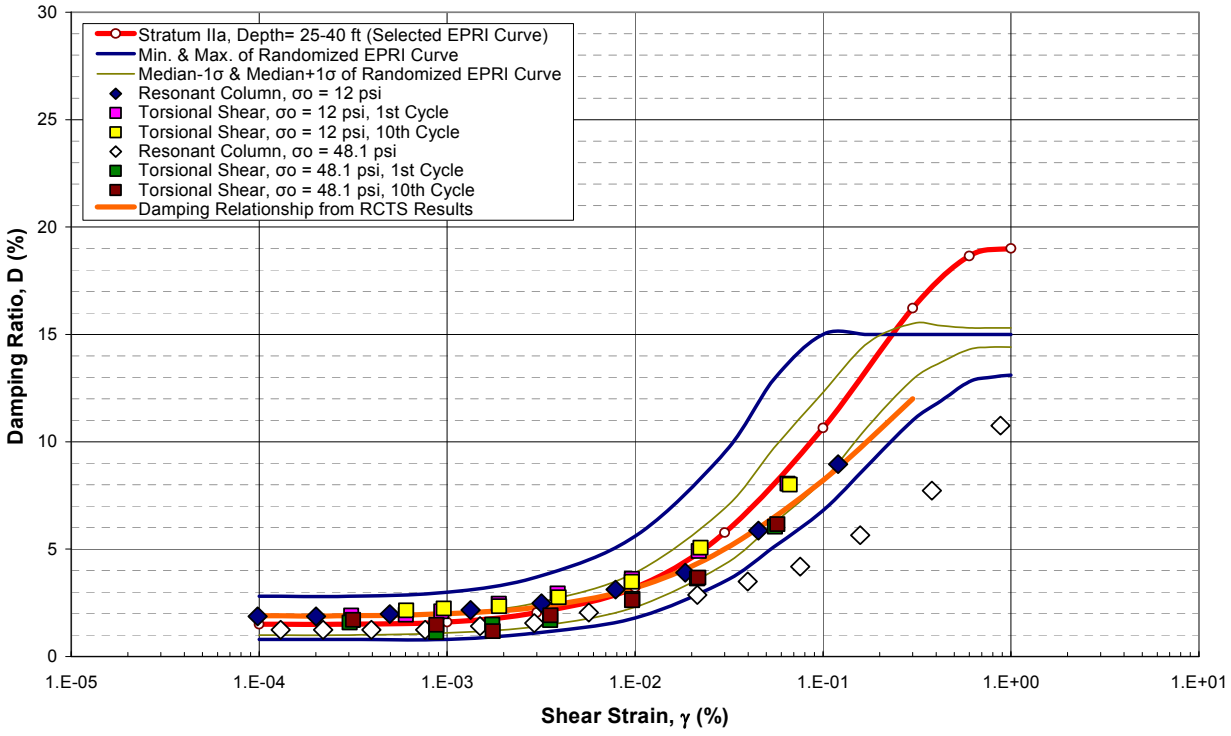
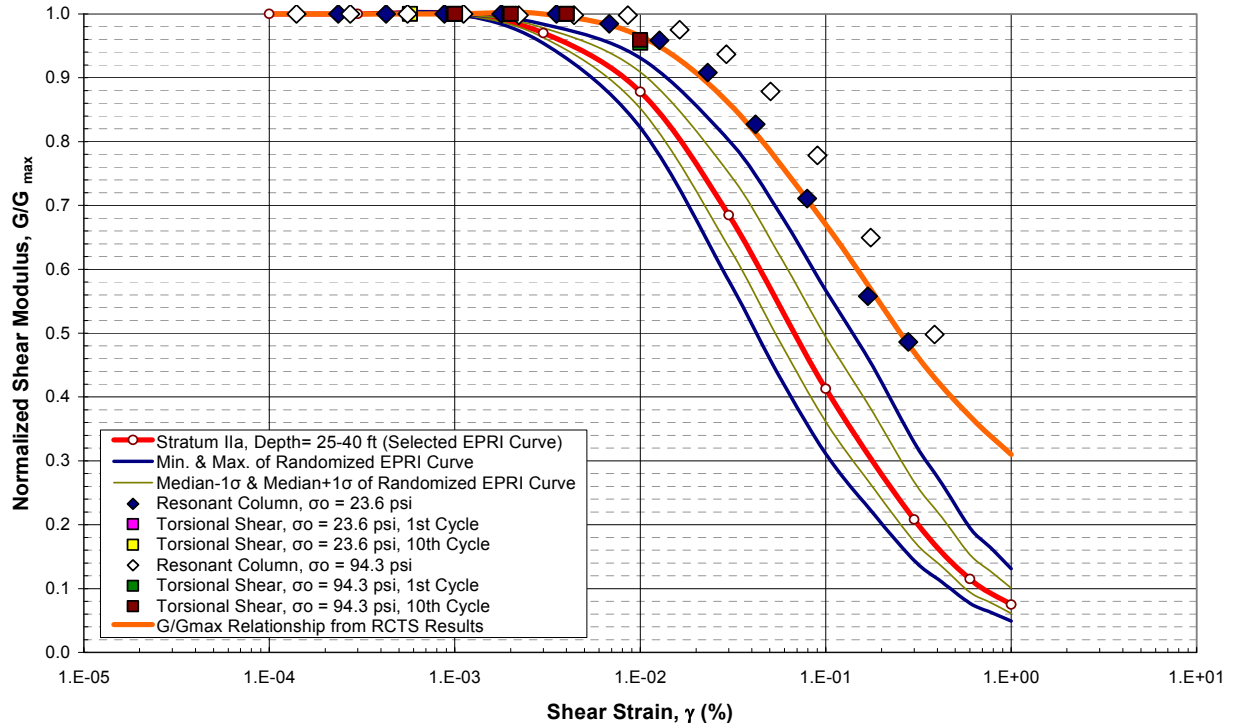


Figure 5. RCTS Test Results: Stratum IIa-Chesapeake Clay/Silt (Appendix I Tests)



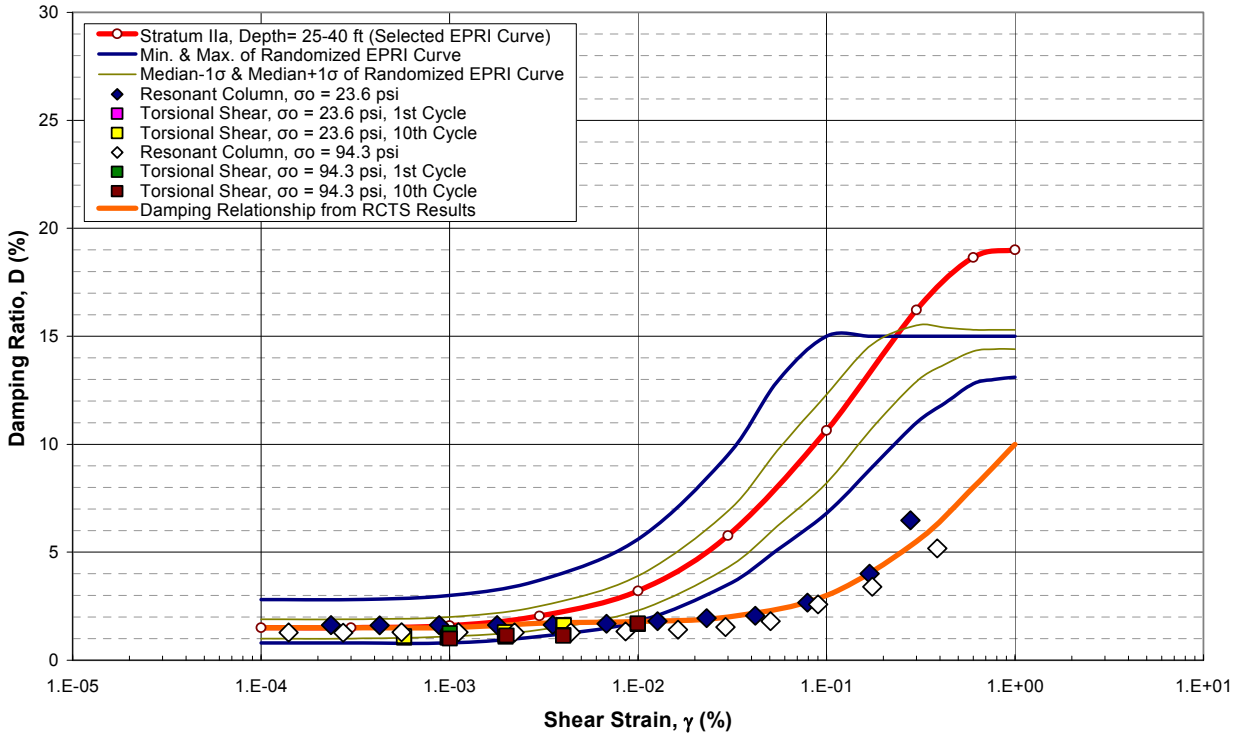


Figure 6. RCTS Test Results: Stratum IIb-Chesapeake Cemented Sand (Appendix C Tests)

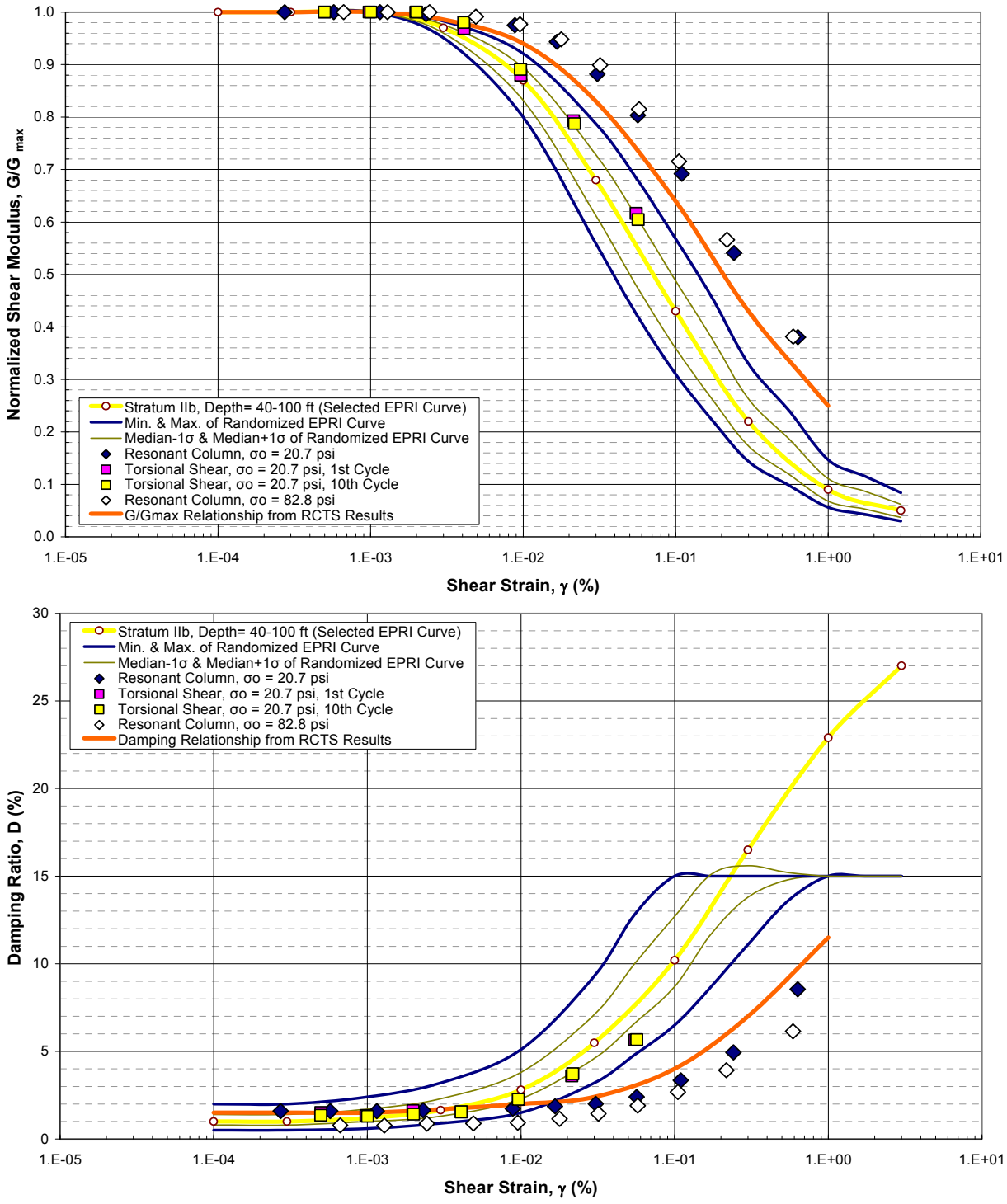
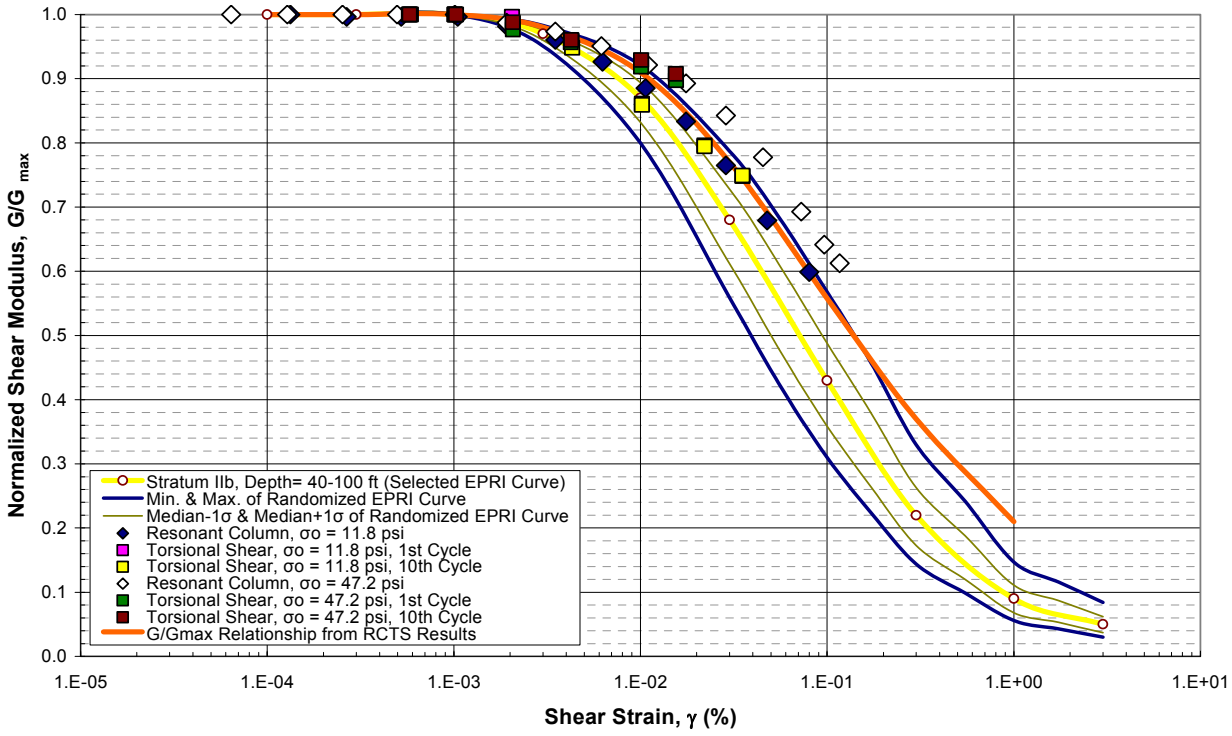


Figure 7. RCTS Test Results: Stratum IIb-Chesapeake Cemented Sand (Appendix J Tests)



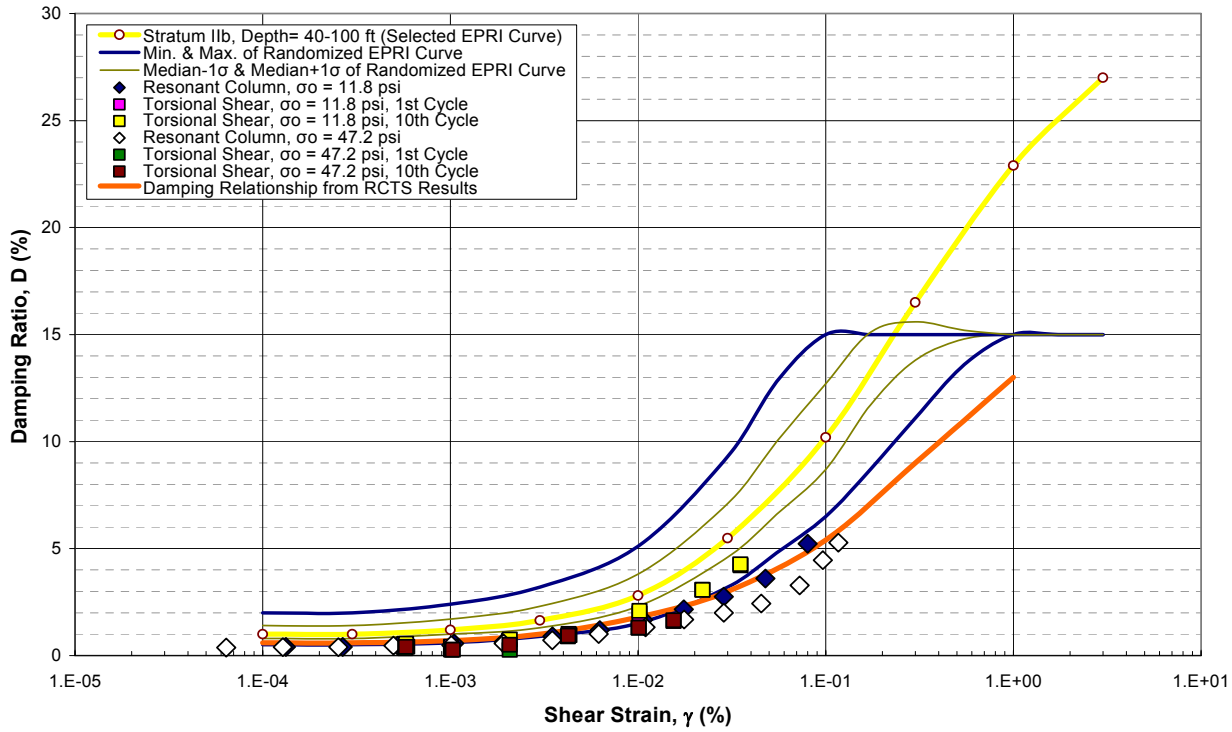
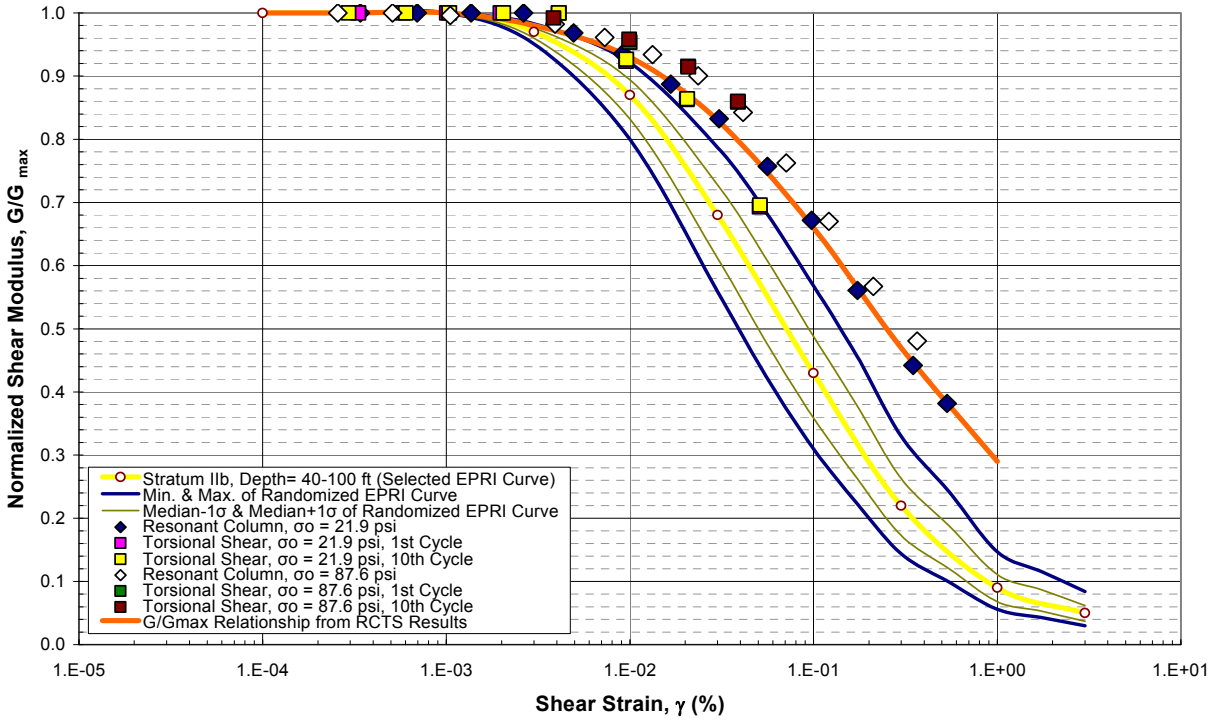


Figure 8. RCTS Test Results: Stratum IIb-Chesapeake Cemented Sand (Appendix D Tests)



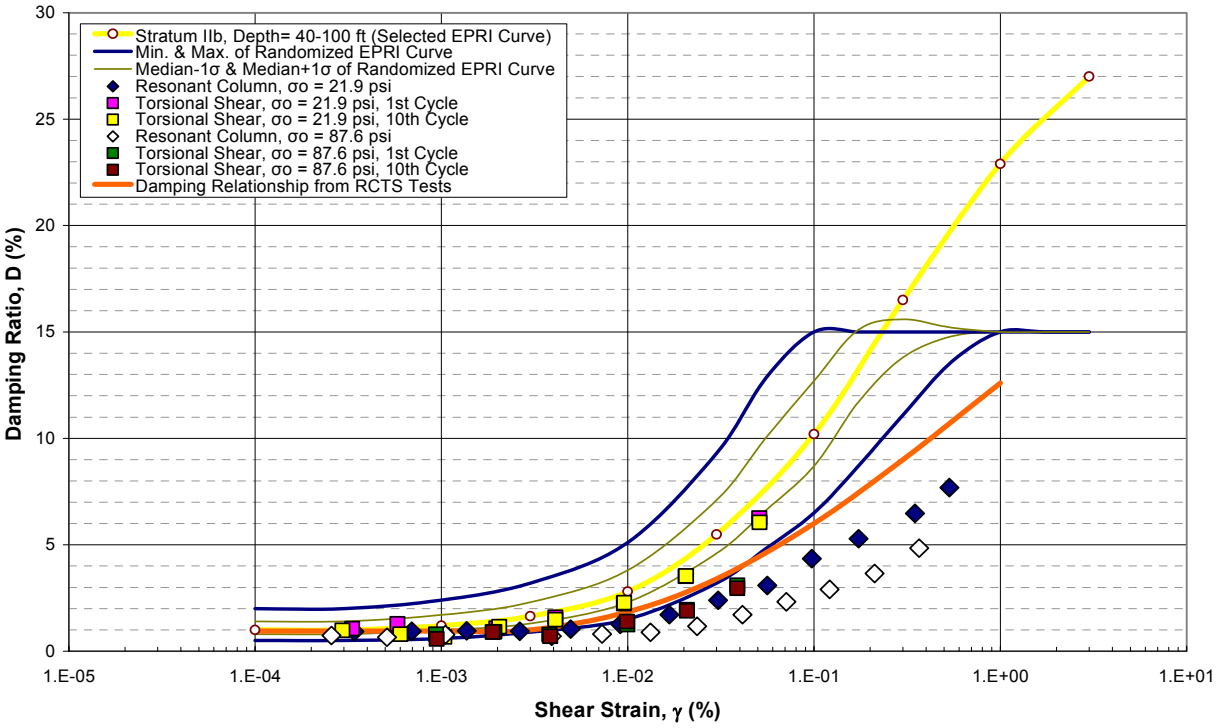
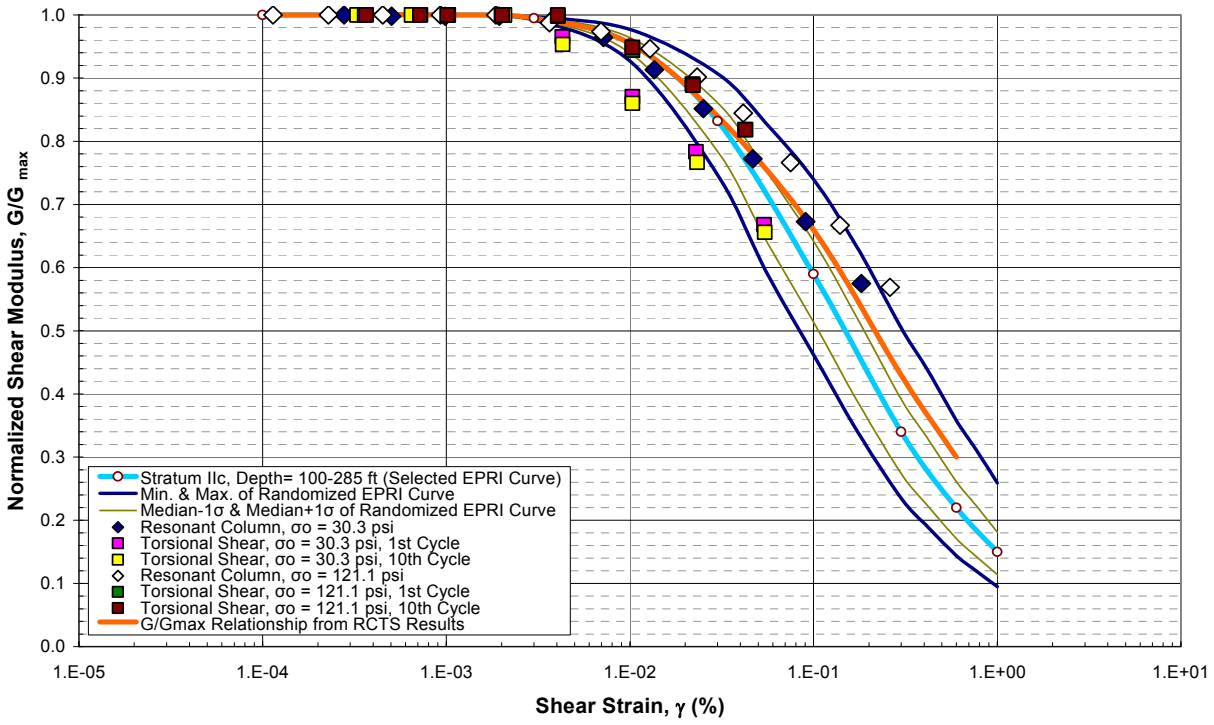


Figure 9. RCTS Test Results: Stratum IIc-Chesapeake Clay/Silt (Appendix K Tests)



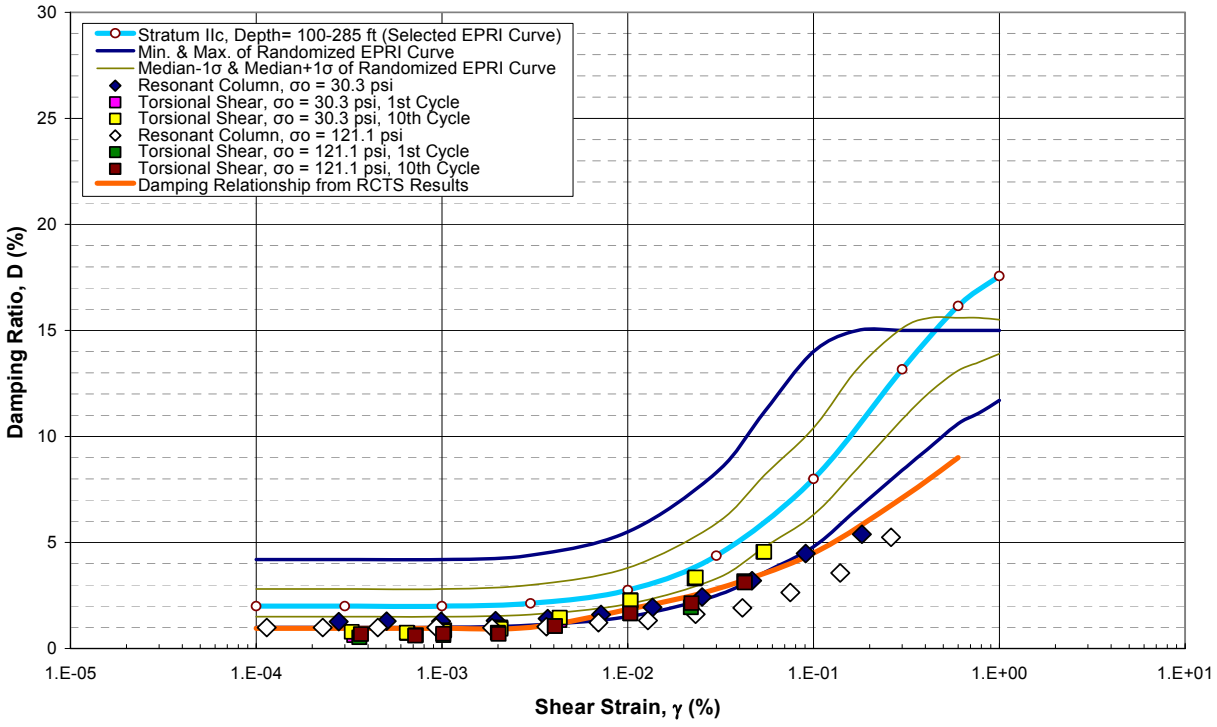
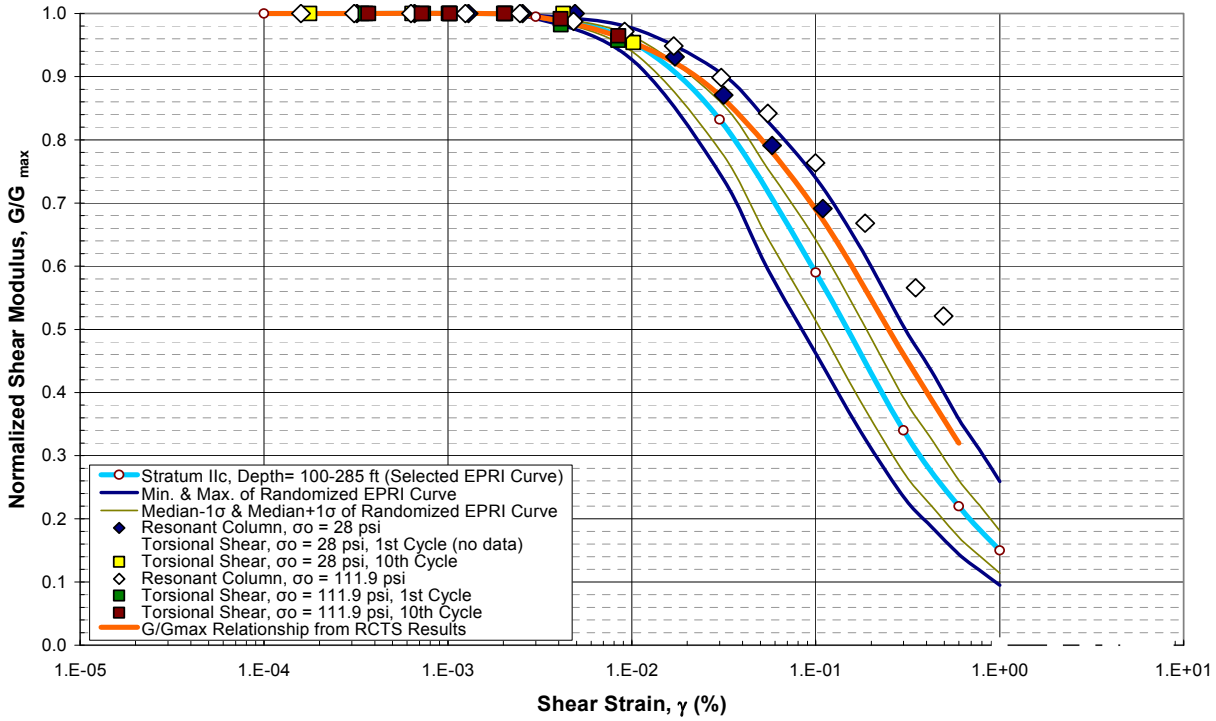


Figure 10. RCTS Test Results: Stratum IIc-Chesapeake Clay/Silt (Appendix M Tests)



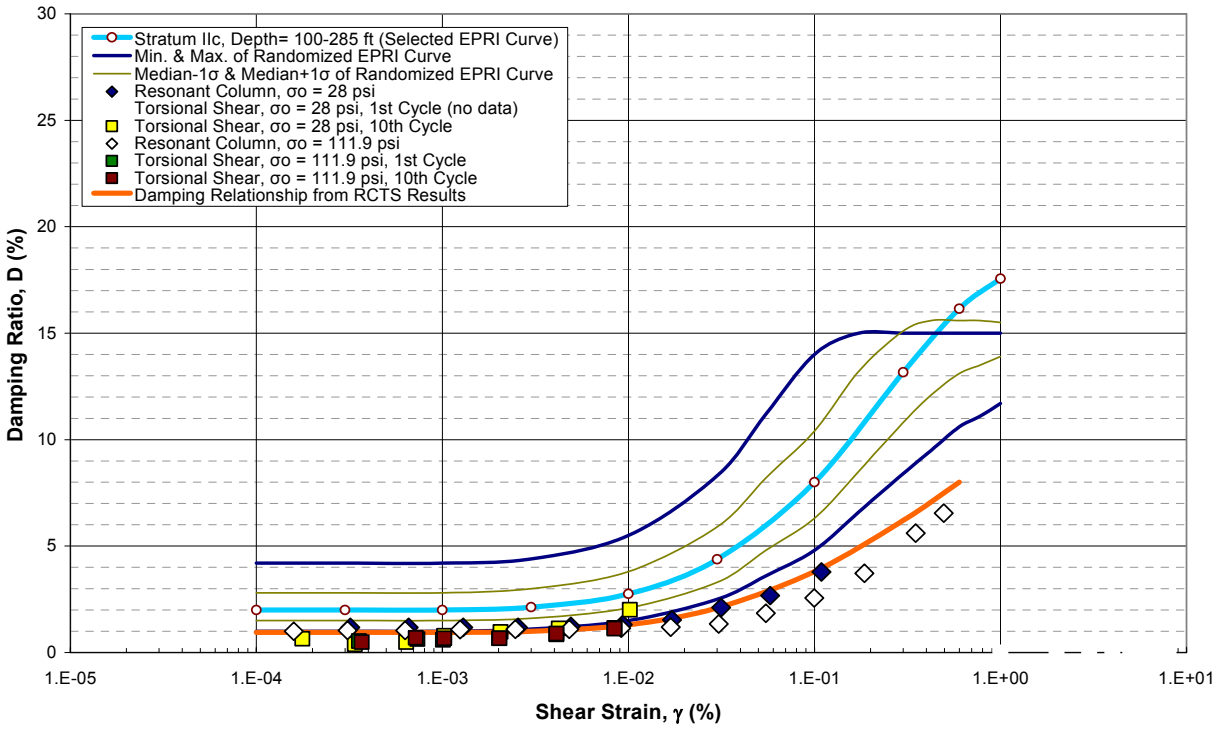


Figure 11. RCTS Test Results: Stratum IIc-Chesapeake Clay/Silt (Appendix E Tests)

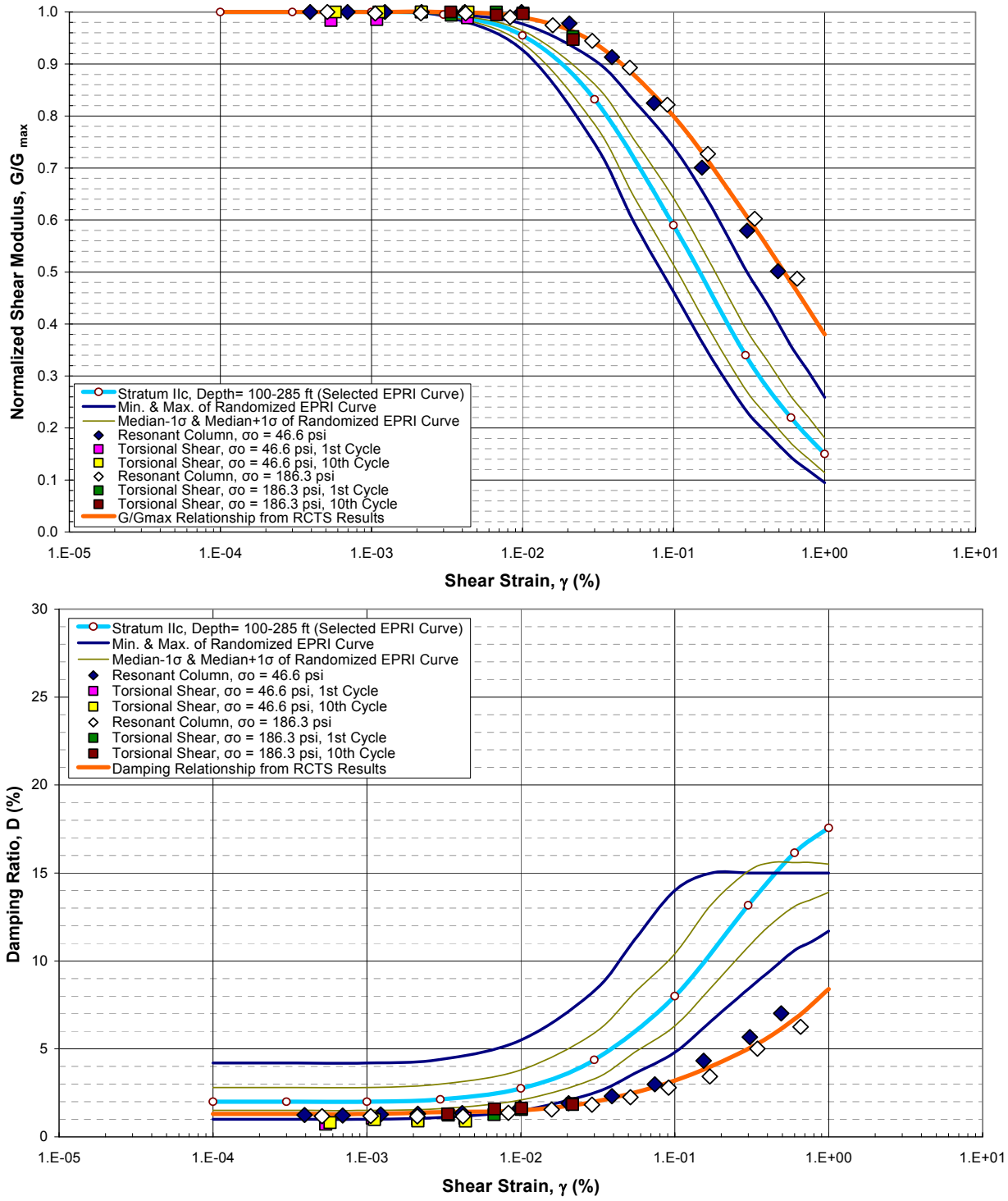


Figure 12. RCTS Test Results: Stratum IIc-Chesapeake Clay/Silt (Appendix L Tests)

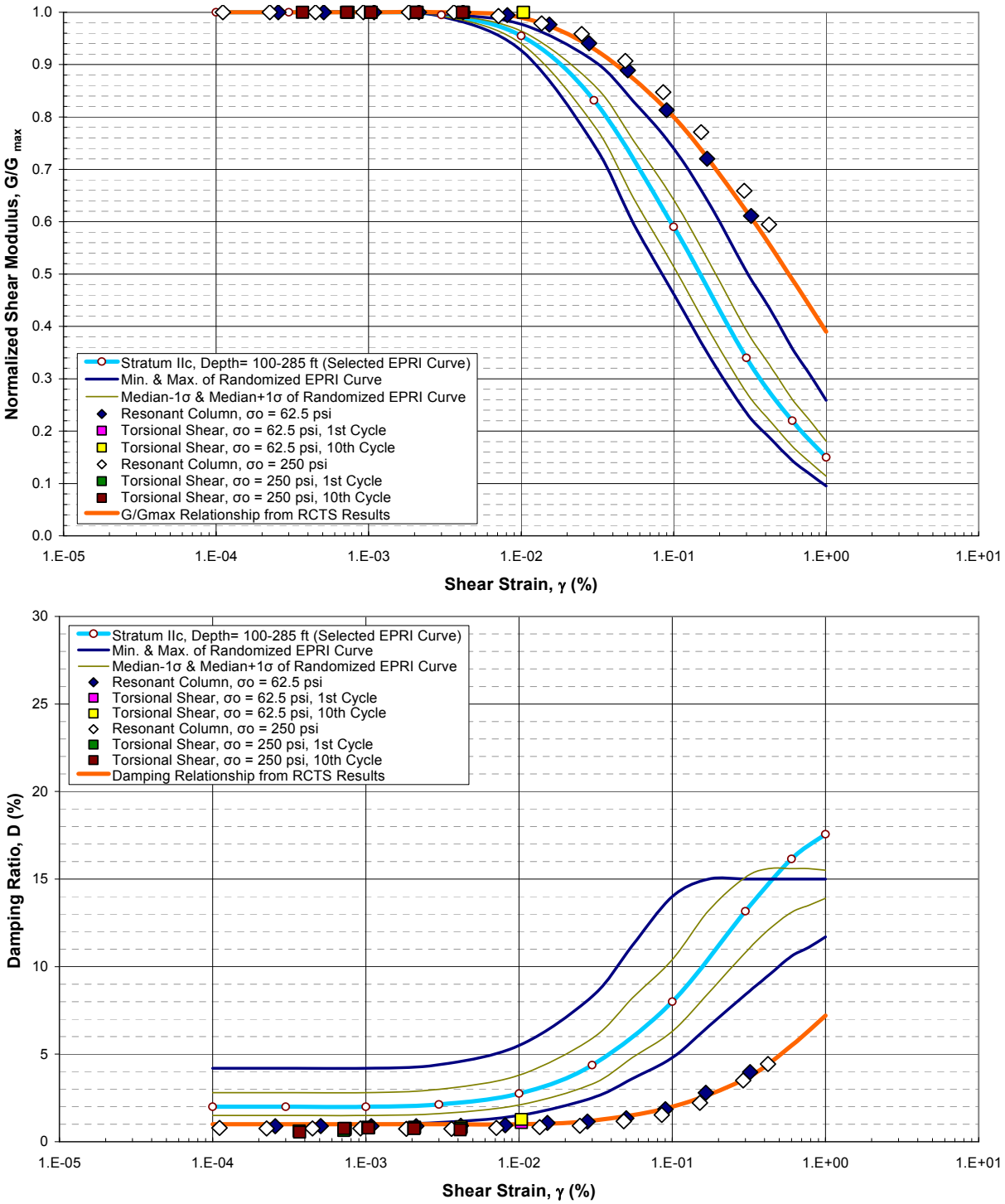
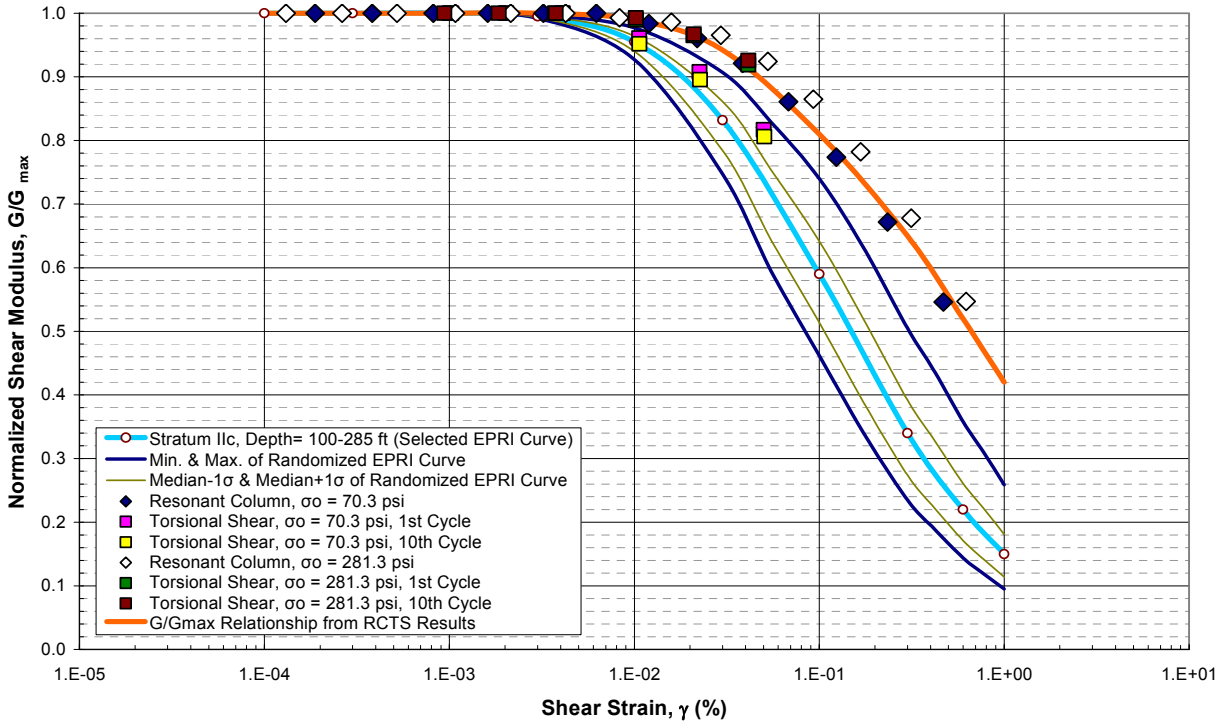


Figure 13. RCTS Test Results: Stratum IIc-Chesapeake Clay/Silt (Appendix G Tests)



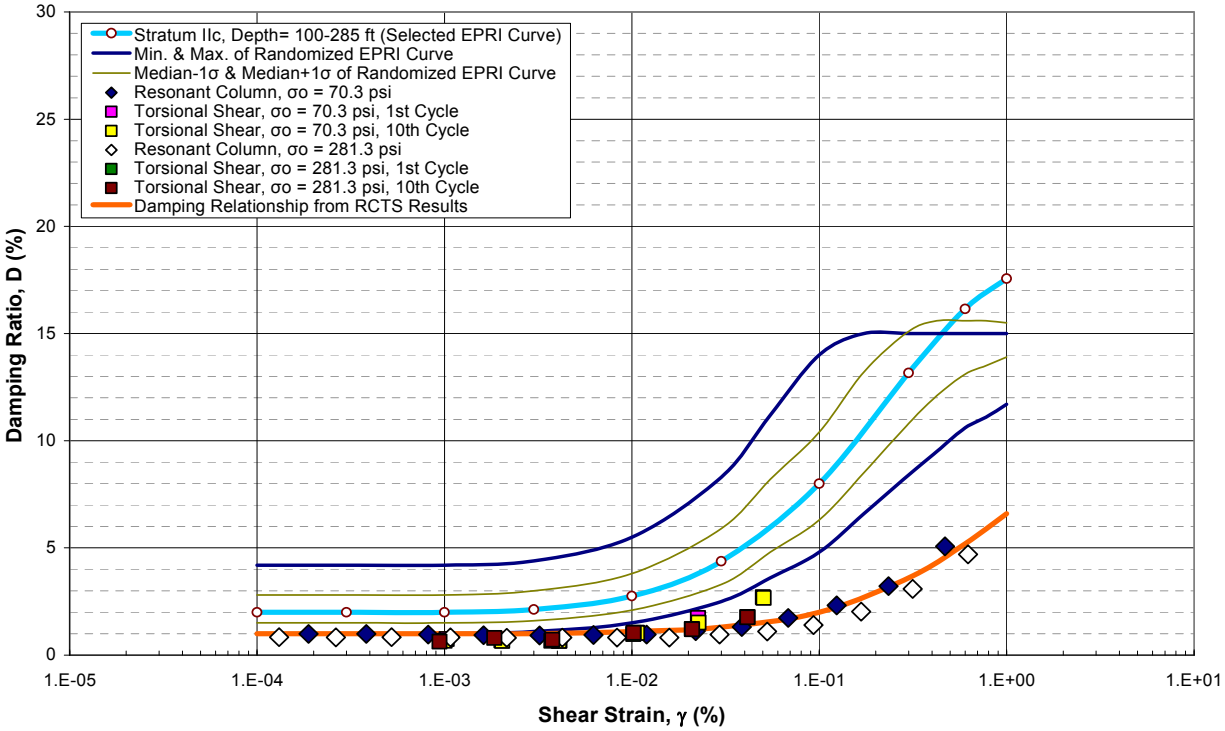
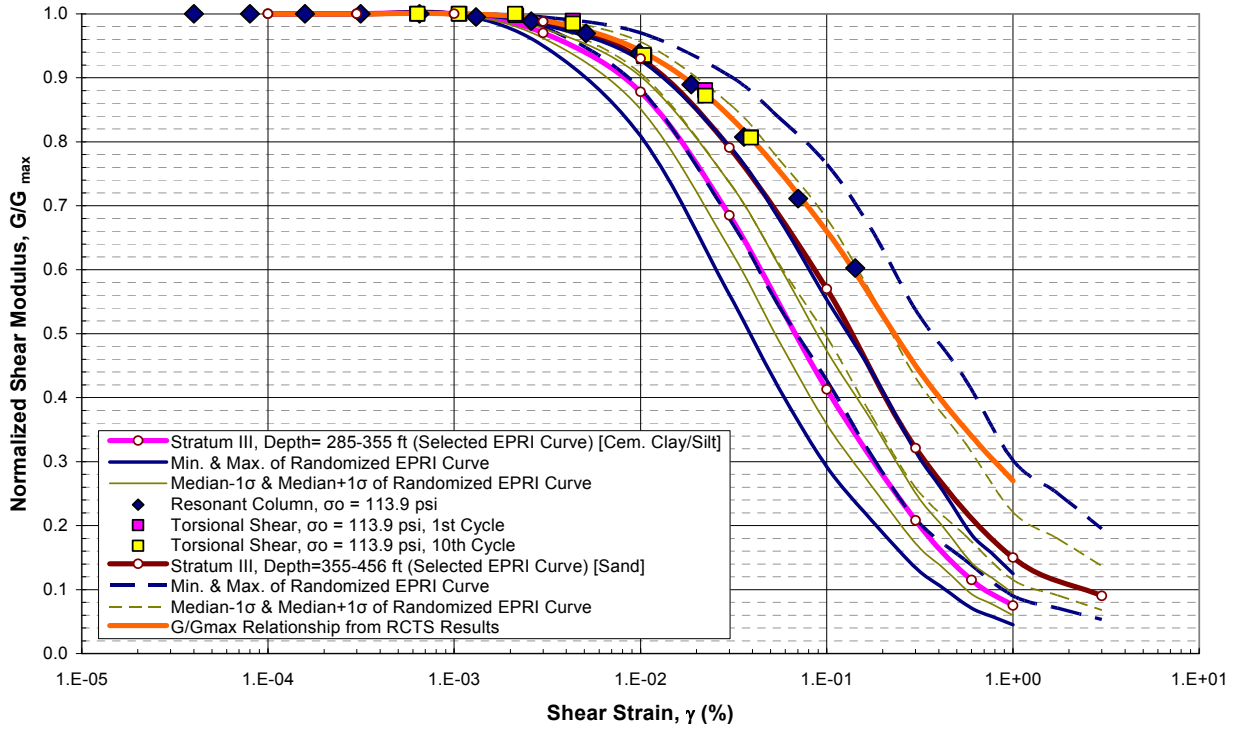


Figure 14. RCTS Test Results: Stratum III-Nanjemoy Sand (Appendix F Tests)



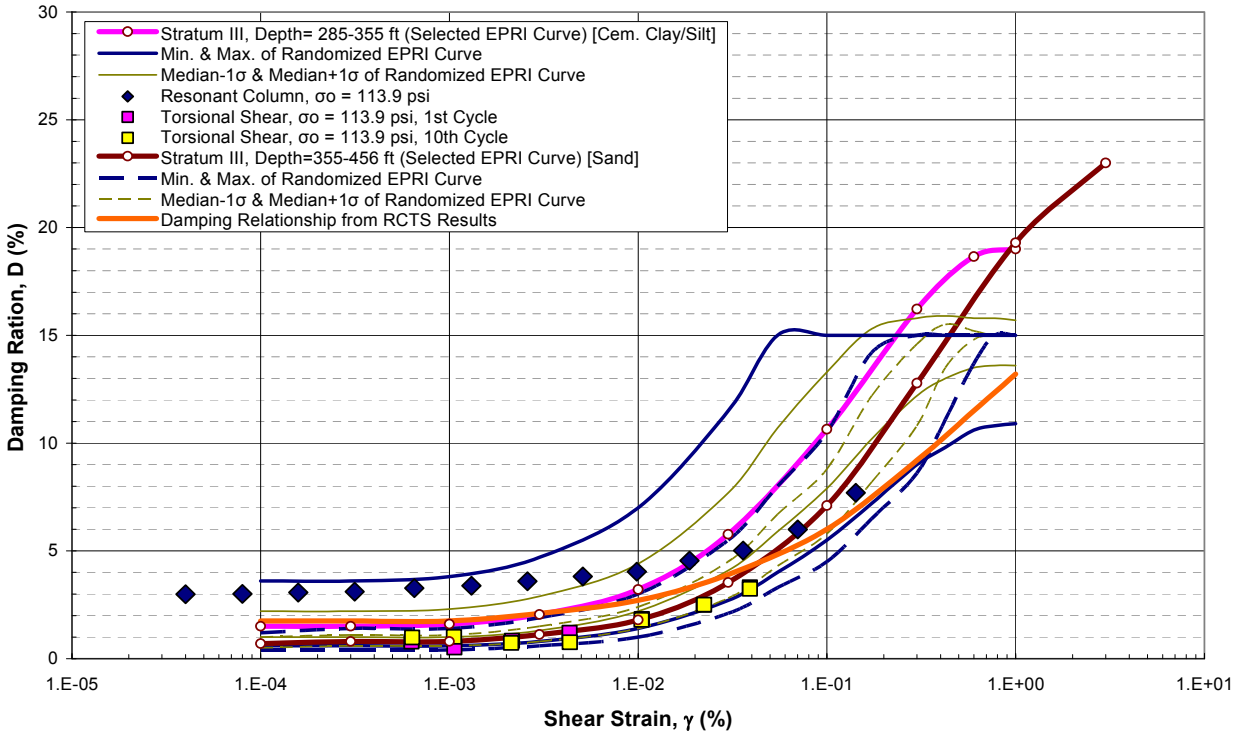
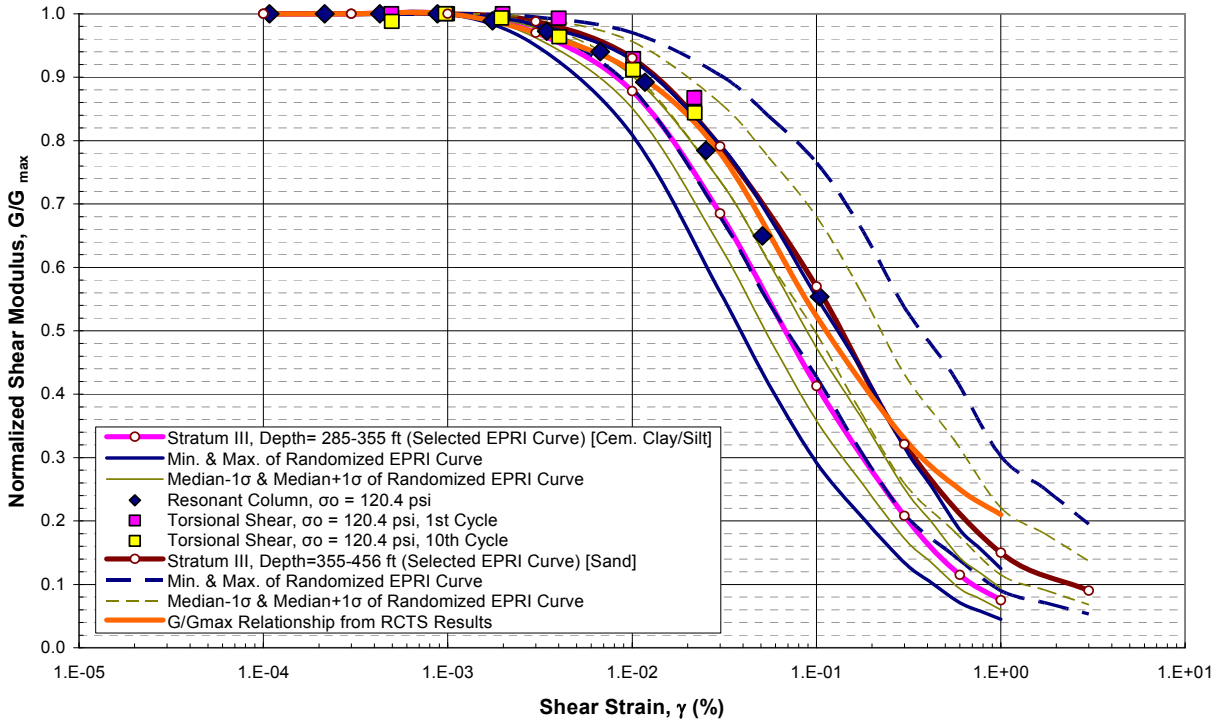


Figure 15. RCTS Test Results: Stratum III-Nanjemoy Sand (Appendix H Tests)



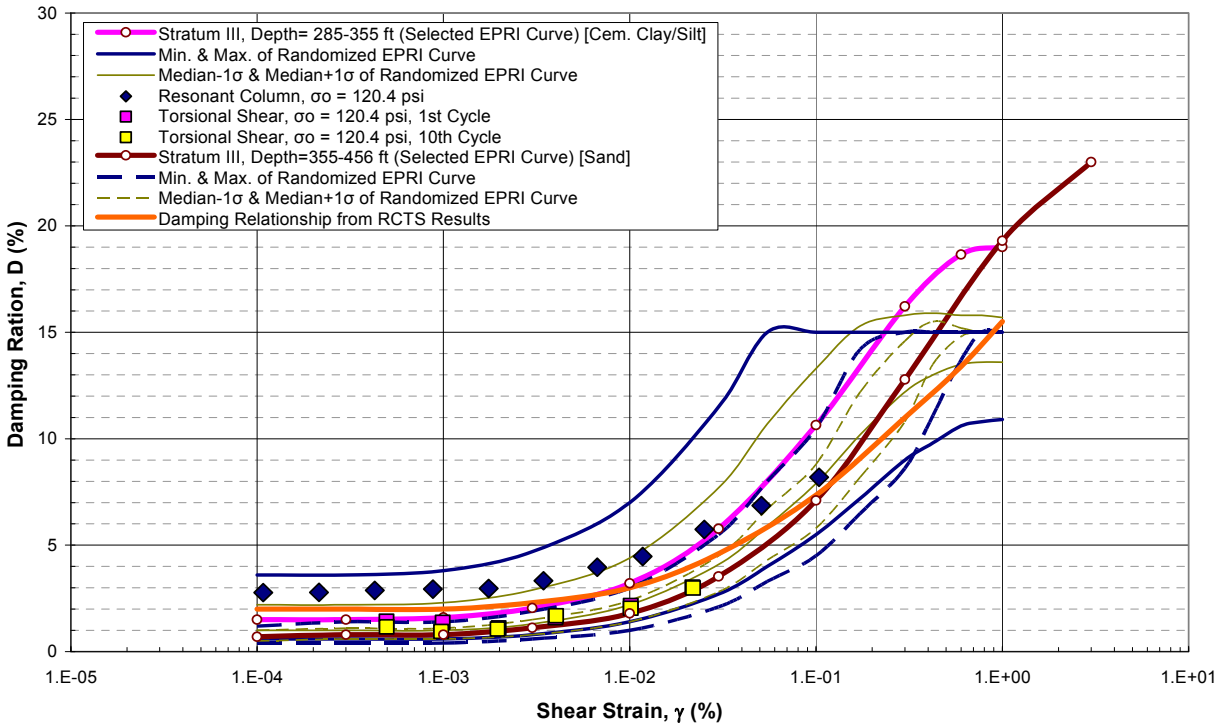
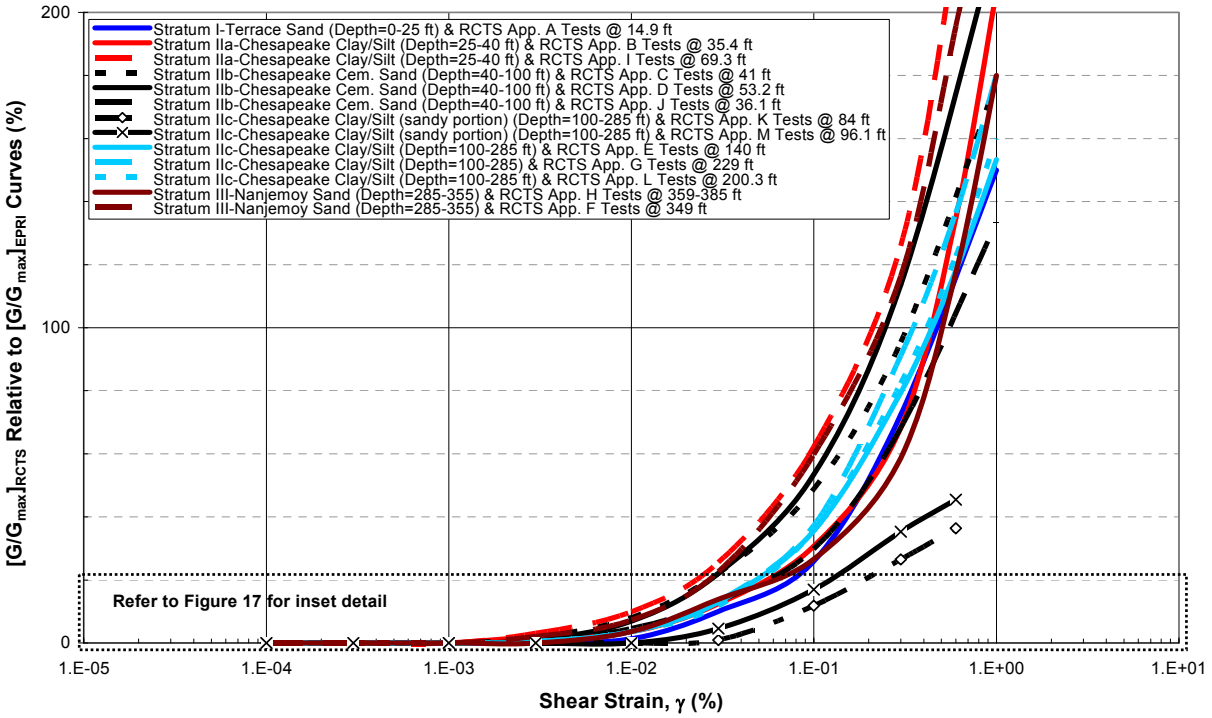


Figure 16. Difference Between RCTS and EPRI Curves: G/G_{max} and Damping



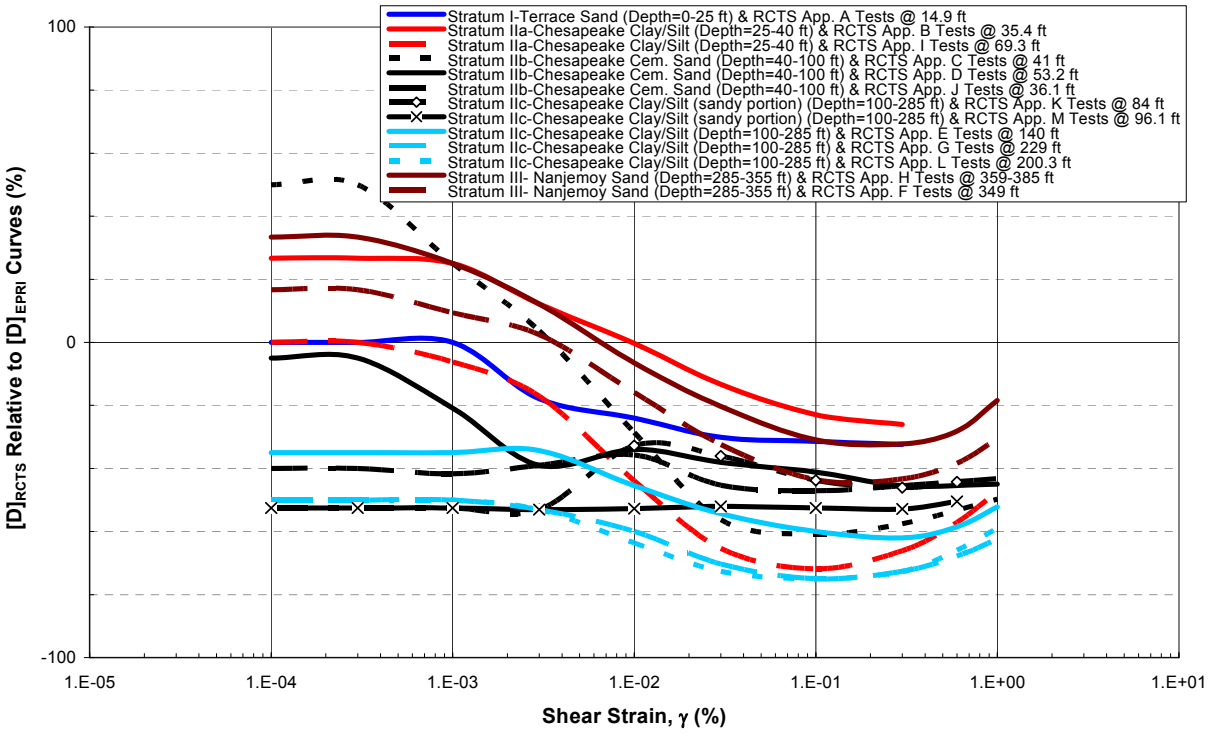
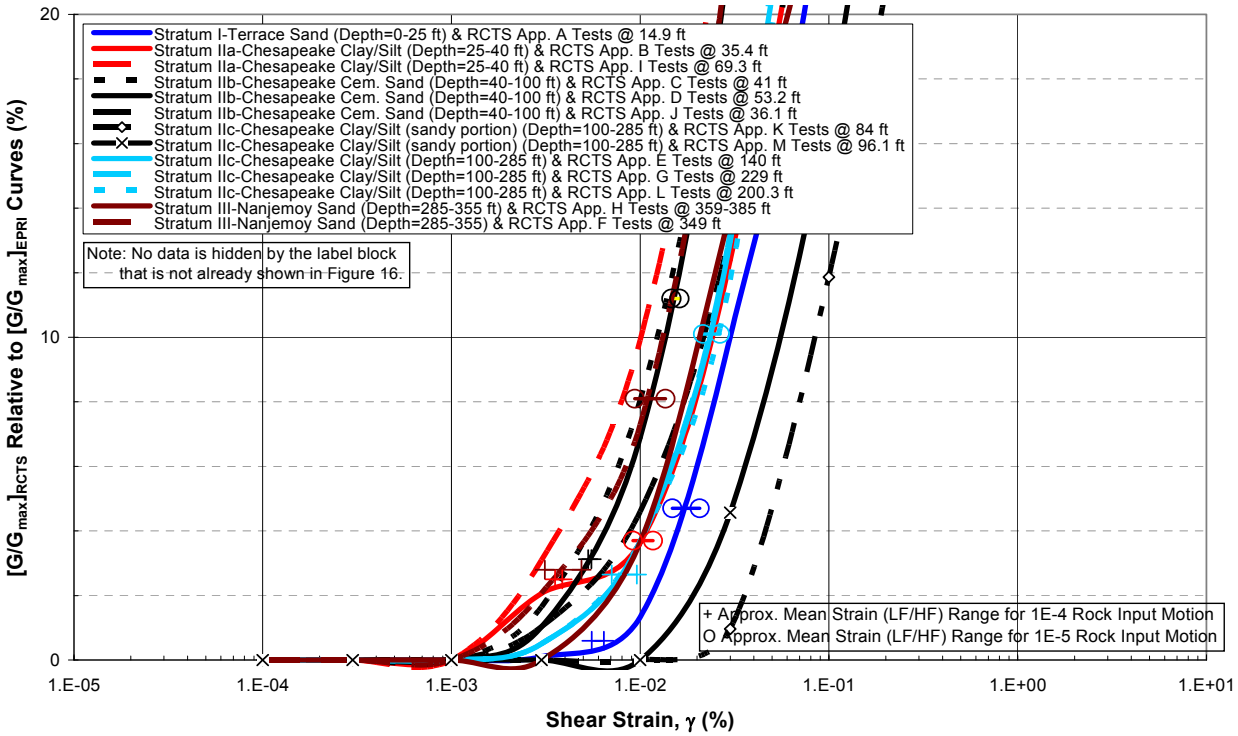


Figure 17. Difference Between RCTS and EPRI Curves: G/G_{max} and Damping at 1E-2±% Strain



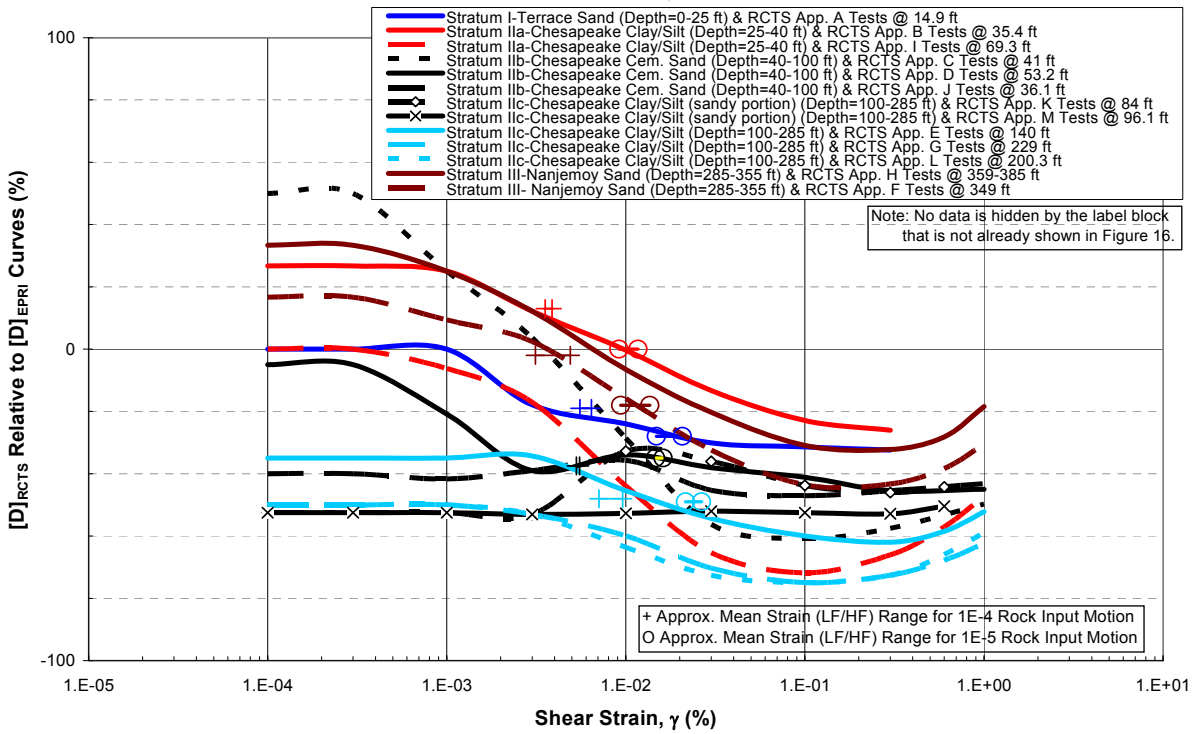


Figure 18. Combined RCTS Test Results

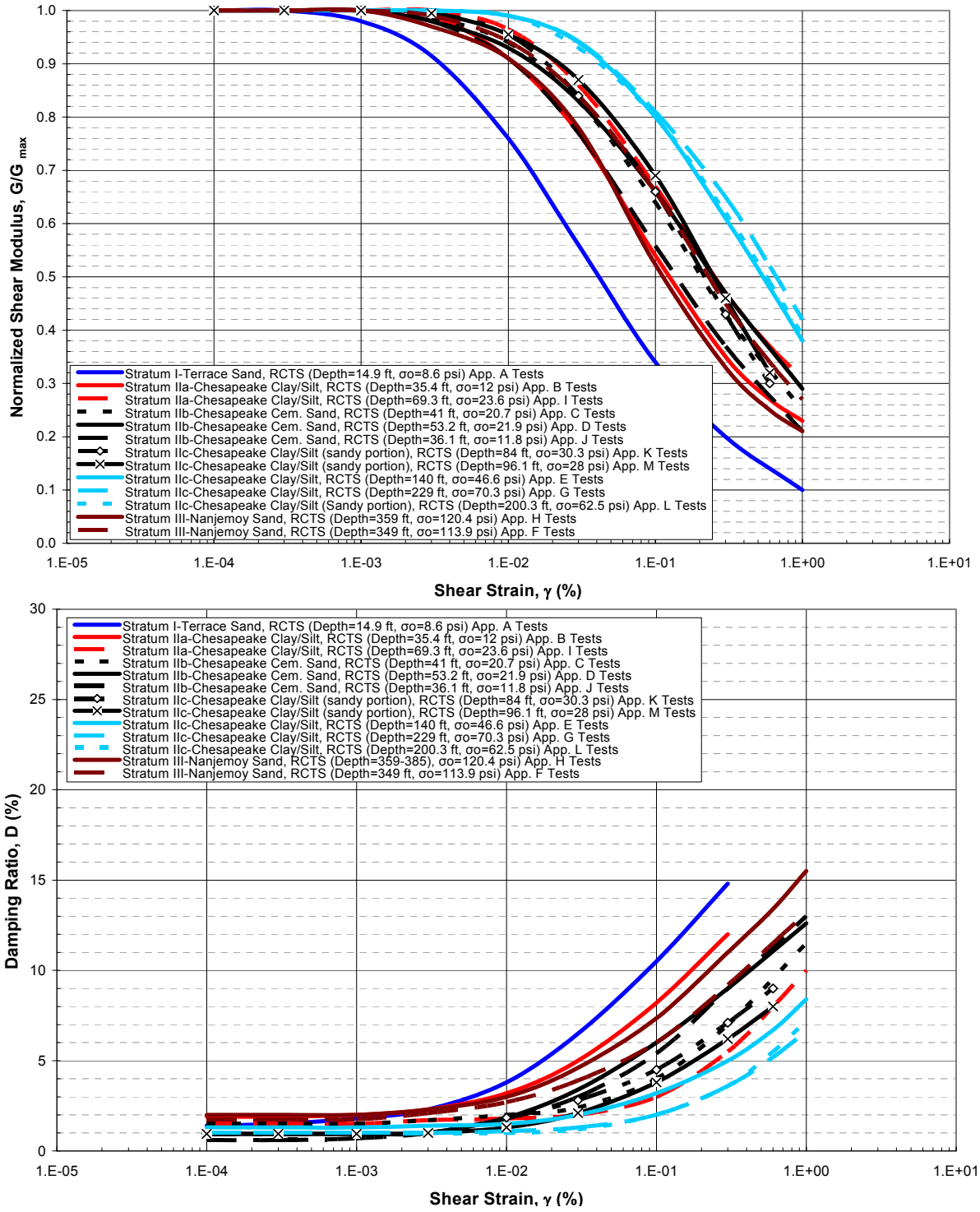
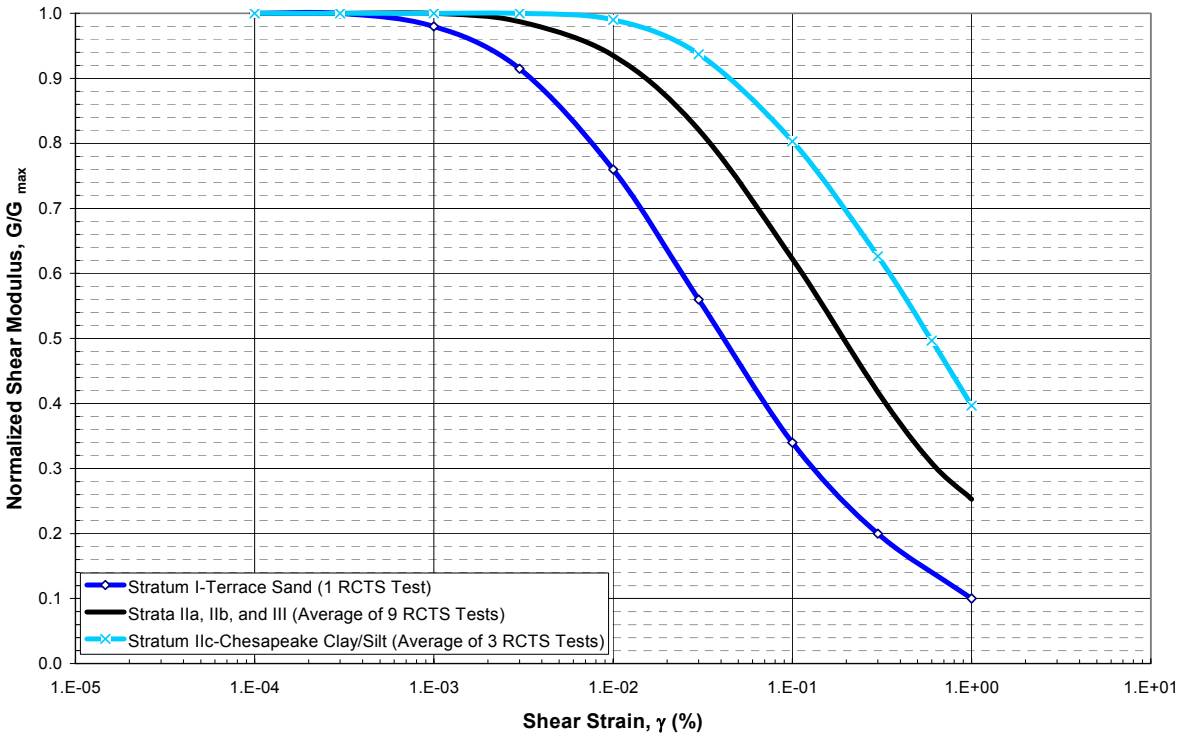


Figure 19. Average Shear Modulus and Damping Ratio Curves from RCTS Test Results



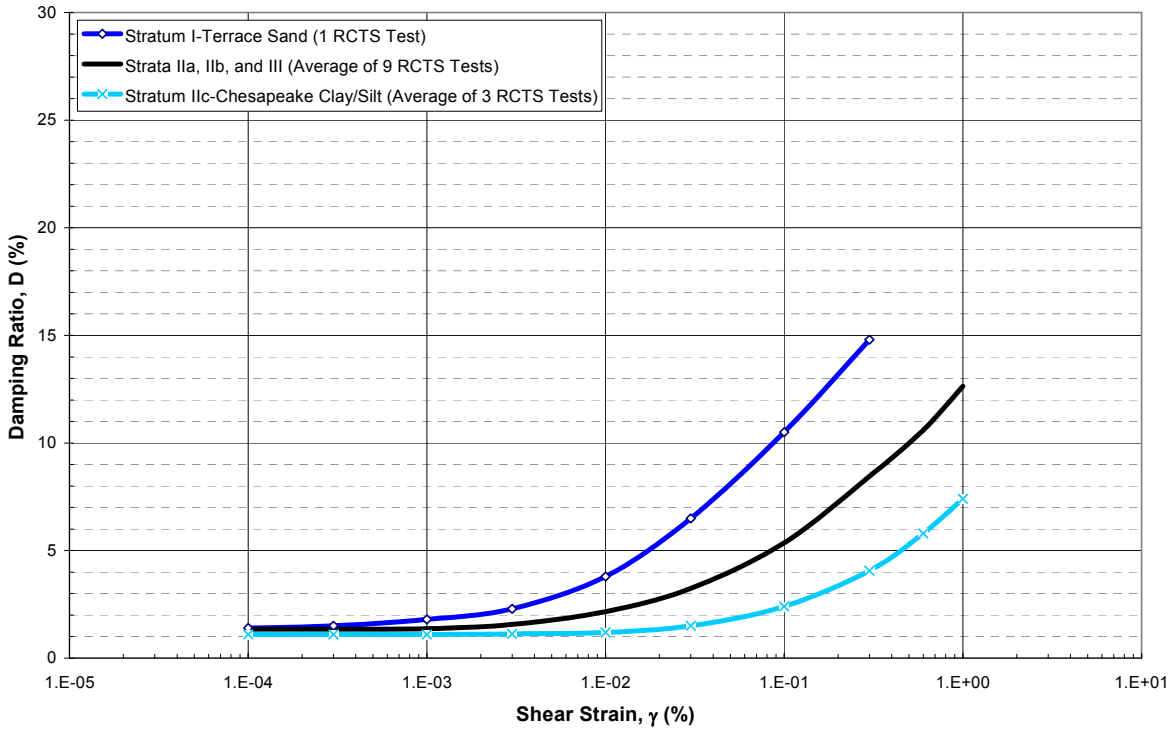
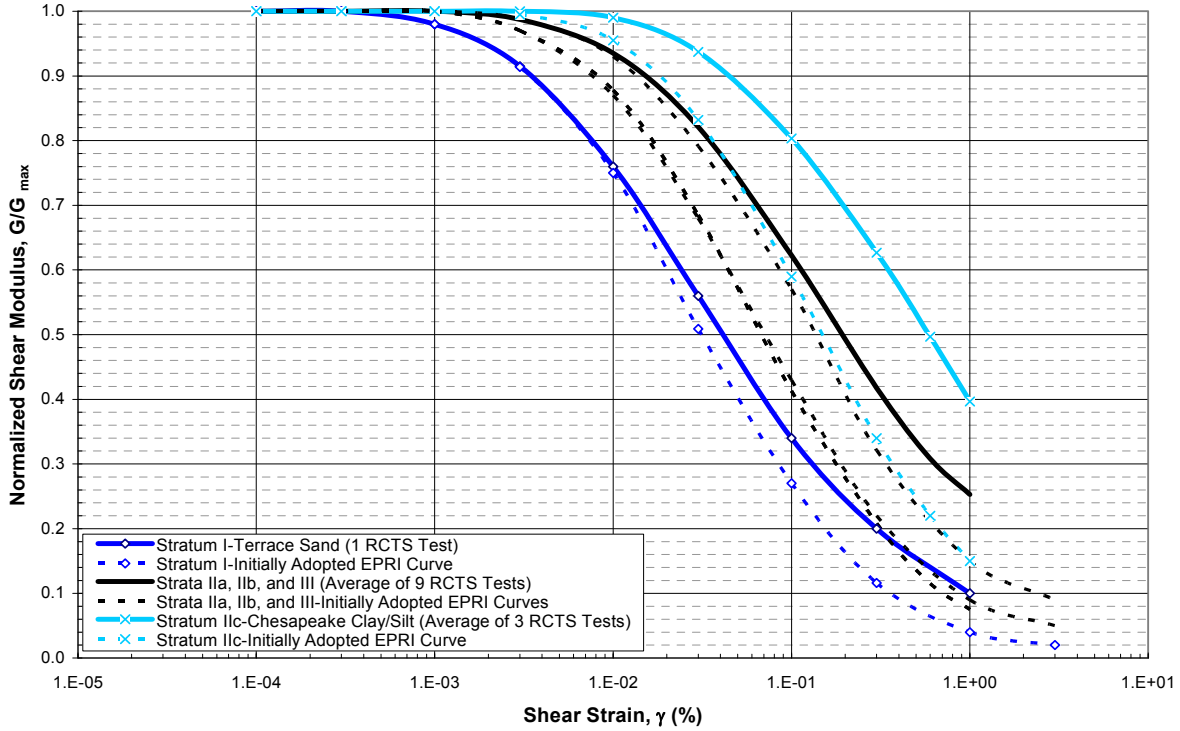


Figure 20. Comparison of Average RCTS Test Results and Initially Adopted EPRI Curves



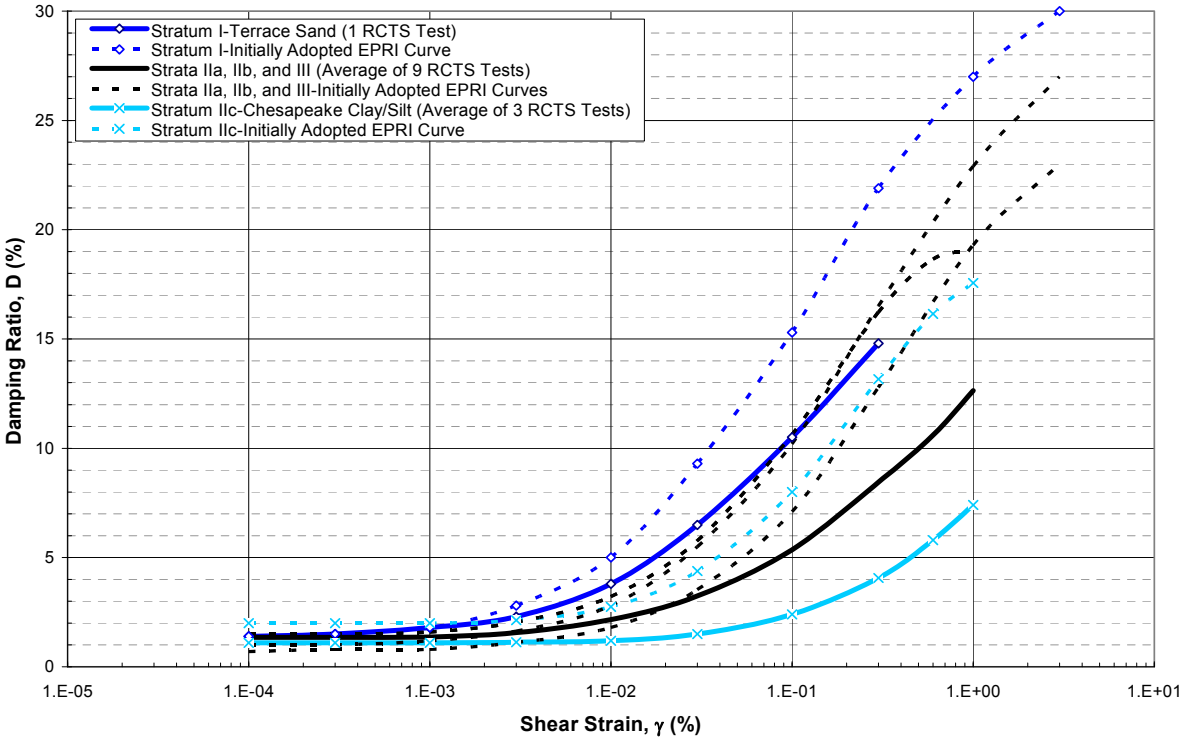


Figure 21. Selection of Shear Modulus and Damping Ratios for Soils Deeper than 400 Feet

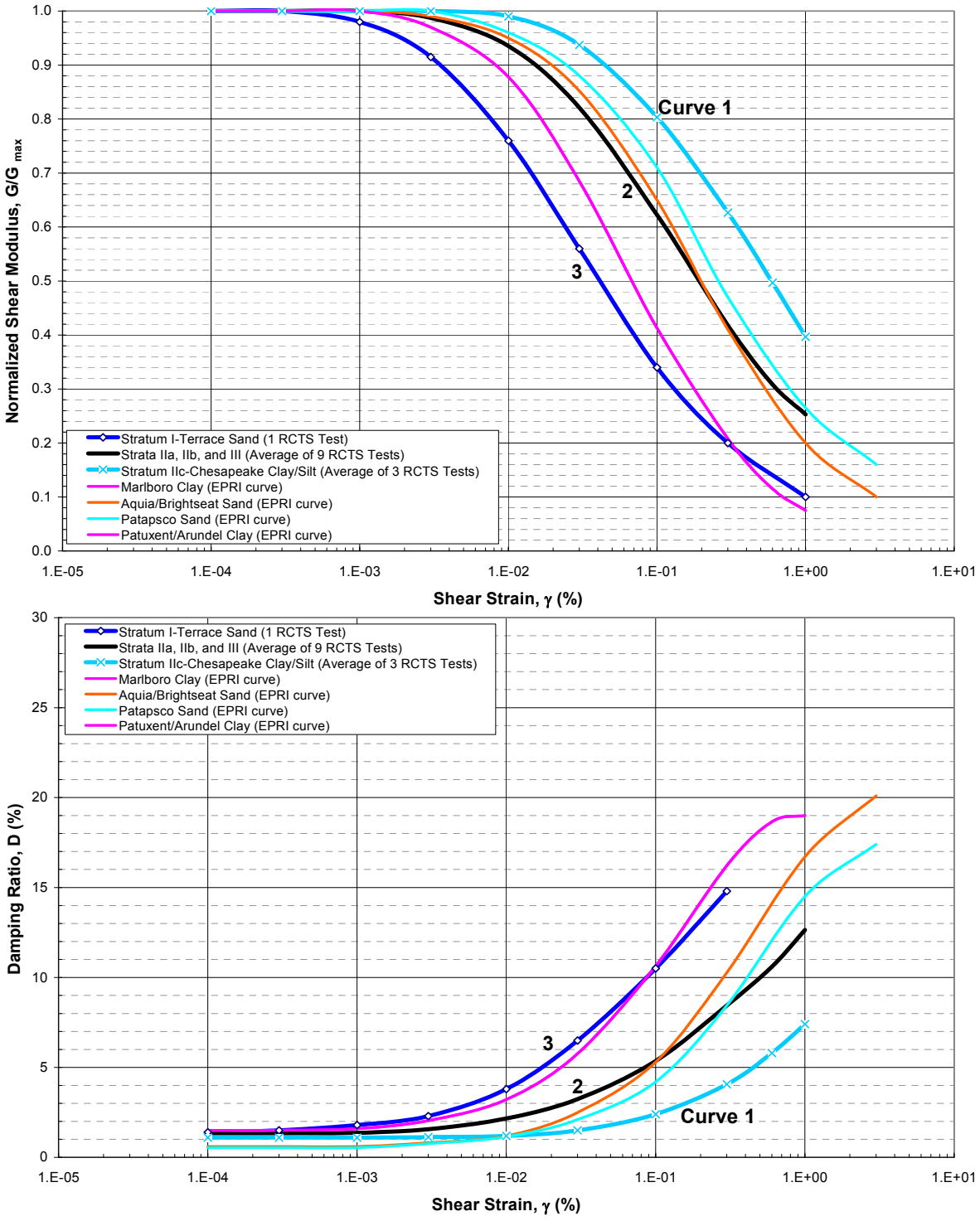
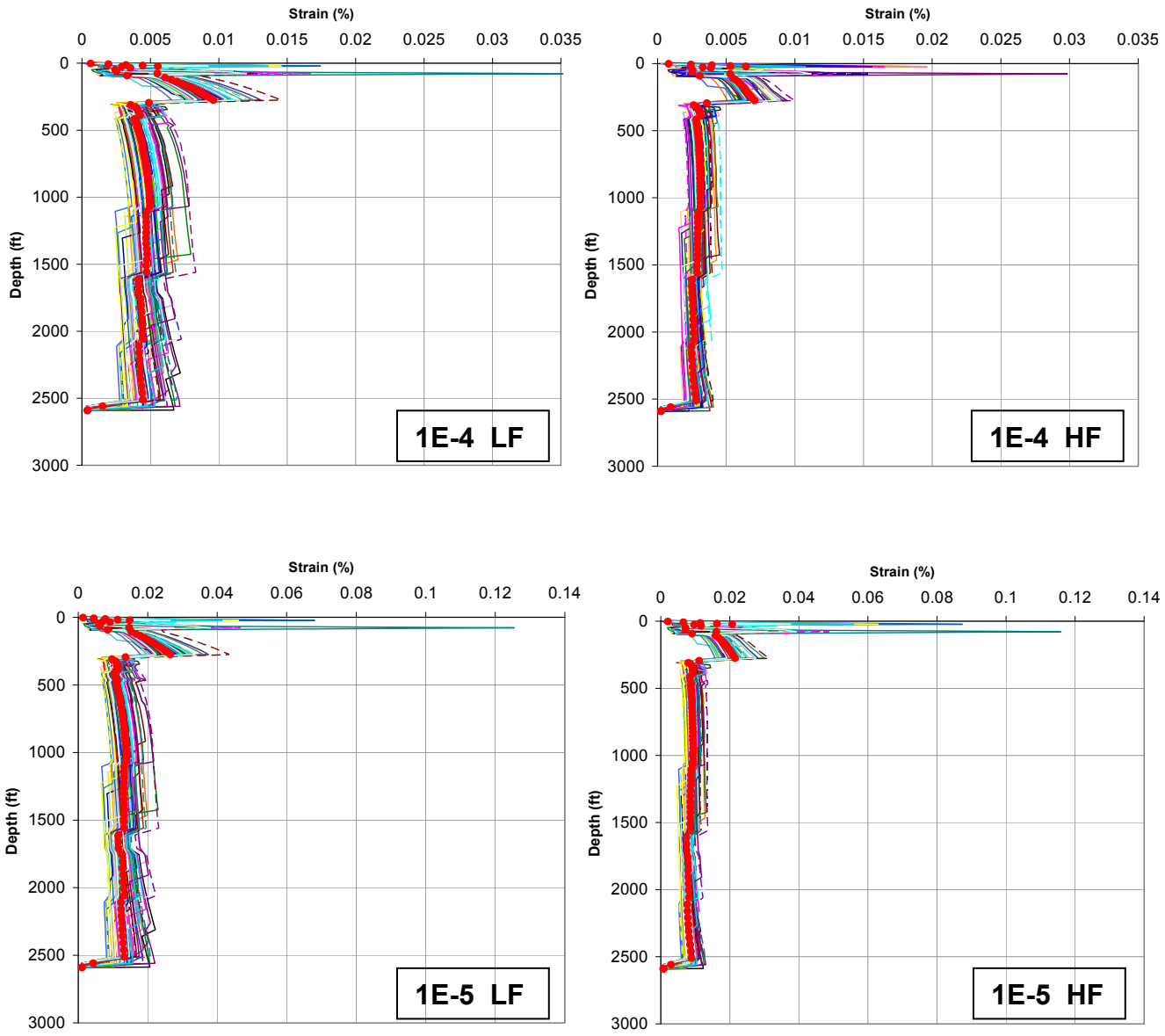


Figure 22. Calculated Maximum Strains Based on Initially Adopted EPRI Curves



Note: Strains shown are maximum, not effective, values.

Figure 23. Final Shear Modulus and Damping Ratios for the CCNPP Unit 3 Soils

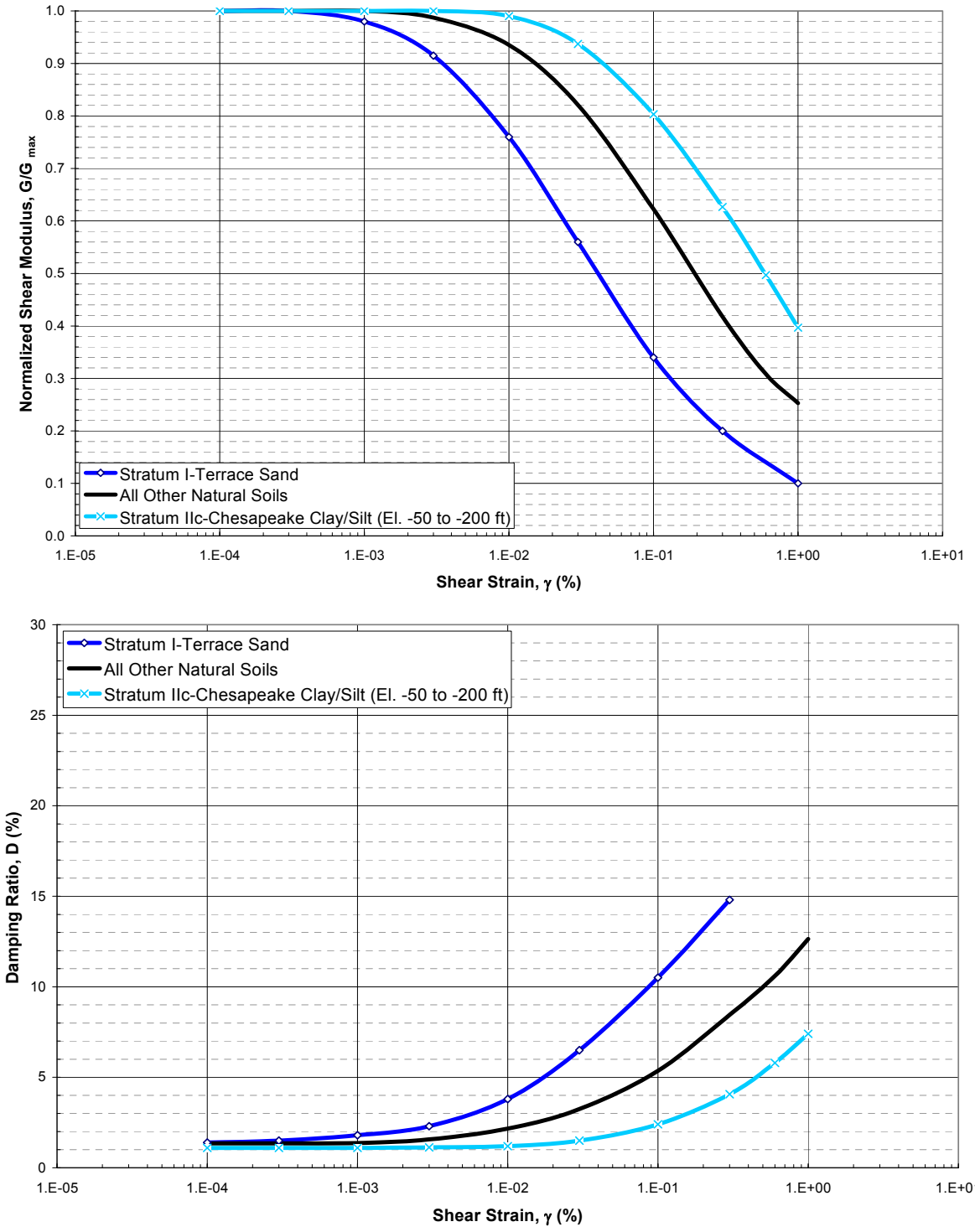


Figure 24. Comparison of Amplification Factors at 1E-4 LF for the CCNPP Unit 3 Soils

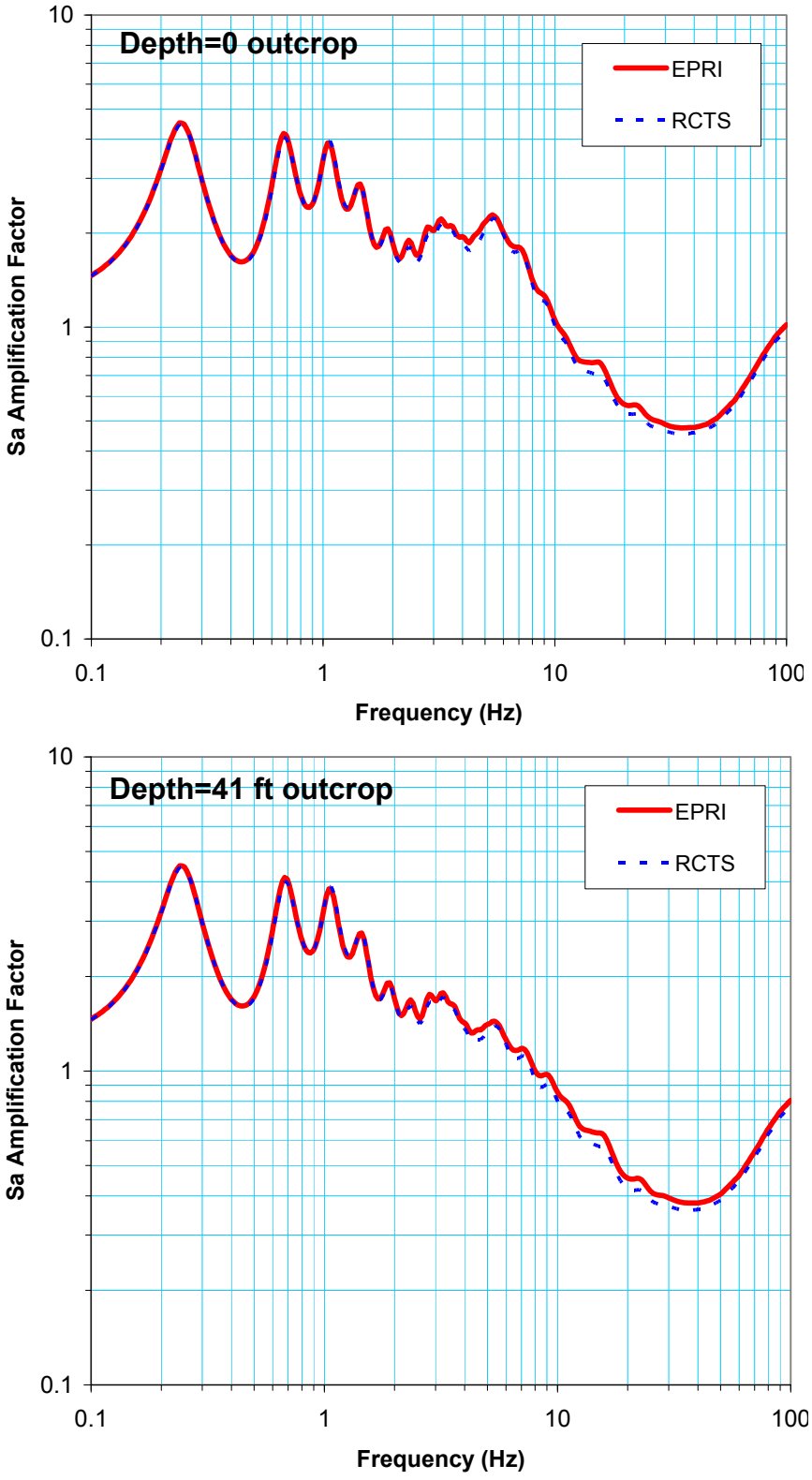


Figure 25. Comparison of Amplification Factors at 1E-4 HF for the CCNPP Unit 3 Soils