Attachment 3B

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June 30, 2009

Mr. Harry Manolopoulos
Project Procurement Specialist
Bechtel Power Corporation
5275 Westview Drive
Frederick, Maryland 21703

Subject: **Structural Fill Dynamic Laboratory Testing Results, Rev. 1**
Calvert Cliffs Nuclear Power Plant Unit 3
Bechtel Job No. 25237
Bechtel Purchase Order No. 25237-103-P0A-CY05-00001
MACTEC Project Number 6234-08-4783

Dear Mr. Manolopoulos:

MACTEC Engineering and Consulting, Inc. (MACTEC) has provided laboratory testing services for the above-referenced project. The testing was done as requested by Bechtel and includes dynamic testing of proposed structural fill materials. The tested materials included Graded Aggregate Base (GAB), Crusher Run Aggregate (CR6), and Coarse Aggregate Underdrain 57 (57), as identified on Attachment 3 of Purchase Order No. 25237-103-POA-CY05-00001.

This laboratory data report consists of the following:

- Attachment 1, consisting of a laboratory test results of grain size distribution tests performed by MACTEC on the CR6, GAB, 57, and CR6 Vulcan Quarry Statistical Average samples,
- Attachment 2, consisting of dynamic laboratory test results from testing performed by the University of Texas at Austin (UT).

Seventeen buckets of each material type were sampled by MACTEC from the Vulcan Quarry in Havre de Grace, Maryland on March 19 and 20, 2009. These samples are identified as Composite(4th Batch) in this report. Dynamic laboratory testing was performed by the University of Texas at Austin (UT) on Composite(4th Batch) for the dynamic properties, including Resonant Column Torsional Shear (RCTS) and Free-Free tests. Each sample was scalped to remove particles larger than ¾-inches in diameter prior to testing.

The test results included in this report are from the samples tested by MACTEC (grain size distribution reports only) and samples tested by UT for dynamic properties. Tables 1 and 2 below outline the dynamic testing program and the location of the dynamic test results:

MACTEC Engineering and Consulting, Inc.
2801 Yorkmont Road, Suite 100 ● Charlotte, NC 28208 ● Phone: 704.357.8600

Table 1: RCTS Testing

Material Description	Approximate Sample Diameter	Approximate Test Sample Remolded Condition	Location of Results in Attachment 2
CR6 Blended	2.8" diameter	95% modified Proctor maximum dry density	Appendix A
		100% modified Proctor maximum dry density	Appendix D
GAB Blended	2.8" diameter	95% modified Proctor maximum dry density	Appendix C
		100% modified Proctor maximum dry density	Appendix G
57 Blended	2.8" diameter	80% relative density	Appendix B
		100% relative density	Appendix H
CR6 Vulcan Quarry Statistical Avg. Sample*	2.8" diameter	95% modified Proctor maximum dry density	Appendix E
		100% modified Proctor maximum dry density	Appendix F

Table 2: Free-Free Testing

Material Description	Approximate Sample Diameter	Approximate Test Sample Remolded Condition	Location of Results in Attachment 2
CR6 Vulcan Quarry Statistical Avg. Sample*	2.8" diameter	95% modified Proctor maximum dry density	Appendix K
	6" diameter	95% modified Proctor maximum dry density	Appendix I
	6" diameter	100% modified Proctor maximum dry density	Appendix J
57 Blended	2.8" diameter	80% relative density	Appendix N
	6" diameter	80% relative density	Appendix L
	6" diameter	100% relative density	Appendix M

*The Vulcan Quarry in Havre de Grace, Maryland has performed over 200 grain size distribution tests on CR6 material produced at their quarry. Based on these tests, Vulcan Quarry has determined an approximate average grain size distribution of the CR6 material. An average CR6 sample was created during this testing program from the sampled CR6 material (Sample Identification Nos. CR6-18, CR6-20, and CR6-24) to approximate the average grain size distribution of the CR6 material as determined by Vulcan Quarry. This material is identified in this report as CR6 Vulcan Quarry Statistical Average sample.

We have enjoyed assisting you on this phase of the project and look forward to continuing to serve as your geotechnical and laboratory testing consultant on the remainder of this project.

Very truly yours,
MACTEC ENGINEERING AND CONSULTING, INC.

Steven E. Kiser
Project Manager

Clay E. Sams
Senior Principal

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ATTACHMENT 1

LABORATORY TEST DATA

PARTICLE SIZE DISTRIBUTION REPORT

- CR6-18, CR6-20 VULCAN QUARRY STATISTICAL AVERAGE SAMPLE
- CR6-24 VULCAN QUARRY STATISTICAL AVERAGE SAMPLE
- GAB SAMPLE
- CR6 SAMPLE
- 57 SAMPLE

CALVERT CLIFFS NUCLEAR POWER PLANT UNIT 3
BECHTEL JOB NO. 25237

MACTEC PROJECT NO. 6234-08-4783

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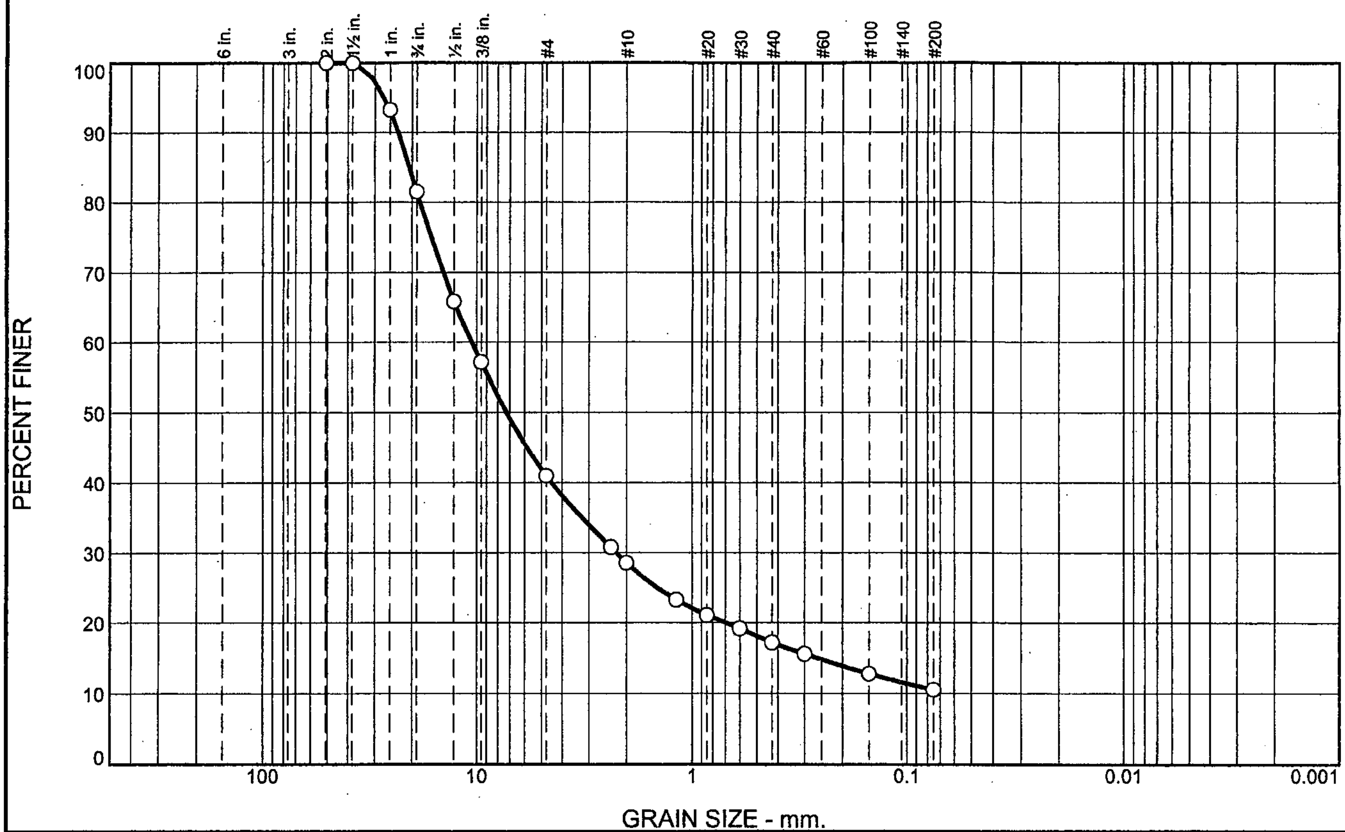
Particle Size Distribution Report ASTM C136



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	18.5	40.5	12.5	11.3	6.7	10.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2in.	100.0		
1.5in	100.0		
1in.	93.2		
3/4in	81.5		
1/2in.	65.9		
3/8in.	57.1		
#4	41.0		
#8	30.8		
#10	28.5		
#16	23.2		
#20	21.0		
#30	19.2		
#40	17.2		
#50	15.6		
#100	12.8		
#200	10.5		

* (no specification provided)

Soil Description

Poorly Graded Gravel with Silt and Sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{85}= 20.6348 D_{60}= 10.5279 D_{50}= 7.2563
D_{30}= 2.2300 D_{15}= 0.2584 D_{10}= NC
C_u= NC C_c= NC

Classification

USCS= GP-GM AASHTO= A-1-a

Remarks

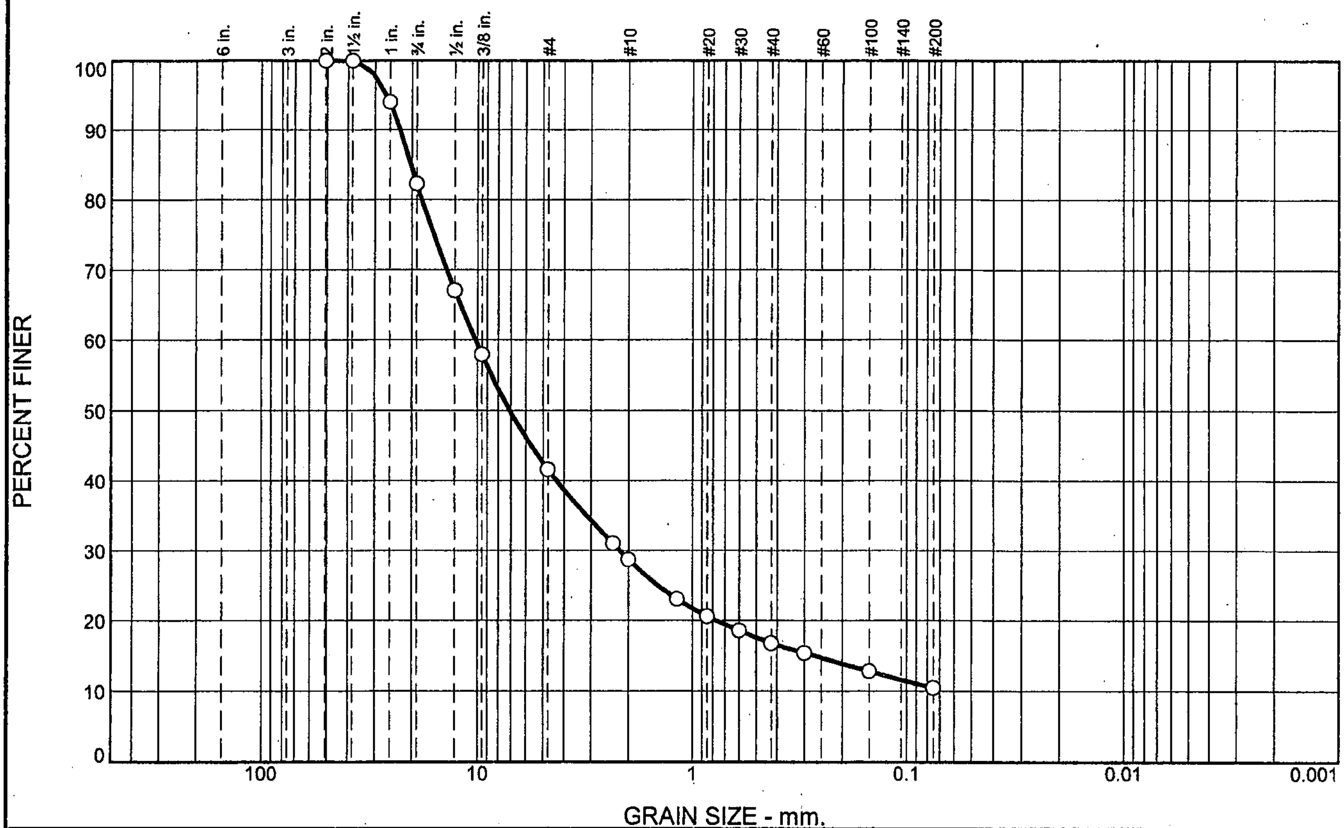
Sample created by sieving out buckets CR6-18 and CR6-20 to individual sieve sizes and then bleding them to match CR6 Vulcan Quarry Statistical Average values. (NC=Not Calculated)

Sample No.: CR6-18, CR6-20 **Source of Sample:** CR6 Vulcan Quarry Statistical Average **Date:** 6-1-09
Location: CR6 Vulcan Quarry Statistical Average **Elev./Depth:** NA

MACTEC Engineering and Consulting, Inc. Charlotte, North Carolina	**Client:** **Project:** Calvert Cliffs **Project No:** 6234-08-4783 **Figure** M 6-25-09

Tested By: D Kopitsky DAK **Checked By:** M Hamlett

Particle Size Distribution Report ASTM C136



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	17.7	40.7	12.9	11.9	6.4	10.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2in.	100.0		
1.5in.	100.0		
1in.	94.0		
3/4in.	82.3		
1/2in.	67.1		
3/8in.	57.9		
#4	41.6		
#8	31.0		
#10	28.7		
#16	23.0		
#20	20.6		
#30	18.6		
#40	16.8		
#50	15.4		
#100	12.8		
#200	10.4		

* (no specification provided)

Soil Description

Poorly Graded Gravel with Silt and Sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{85}= 20.2882 D_{60}= 10.2025 D_{50}= 7.0892
D_{30}= 2.1925 D_{15}= 0.2692 D_{10}= NC
C_u= NC C_c= NC

Classification

USCS= GP-GM AASHTO= A-1-a

Remarks

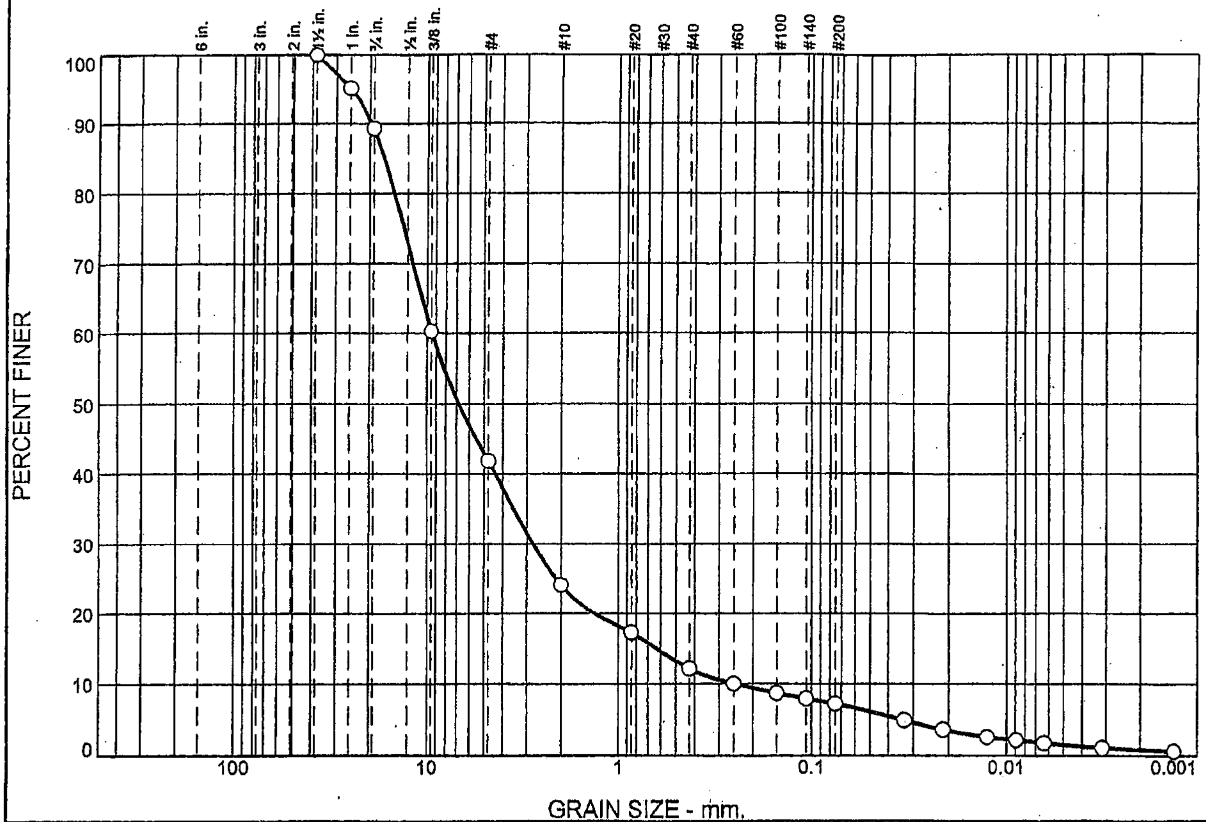
Sample created by sieving out bucket CR6-24 to inividual sieve sizes and then bleding them to match CR6 Vulcan Quarry Statistical Average values. (NC=Not Calculated)

Sample No.: CR6-24 **Source of Sample:** CR6 Vulcan Quarry Statistical Average **Date:** 6-11-09
Location: CR6 Vulcan Quarry Statistical Average **Elev./Depth:** NA

MACTEC Engineering and Consulting, Inc. Charlotte, North Carolina	**Client:** **Project:** Calvert Cliffs **Project No:** 6234-08-4783 **Figure** NA 6-25-09

Tested By: D Kopitsky DAK **Checked By:** D Pryor DWP

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	10.7	47.4	17.9	11.9	4.9	5.8	1.4

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5in.	100.0		
1in.	95.1		
3/4in.	89.3		
3/8in.	60.3		
#4	41.9		
#10	24.0		
#20	17.3		
#40	12.1		
#60	10.0		
#100	8.6		
#140	7.9		
#200	7.2		

* (no specification provided)

Material Description

Poorly Graded Gravel with Silt and Sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{85}= 16.7829 D_{60}= 9.4546 D_{50}= 6.8262
D_{30}= 2.7909 D_{15}= 0.6280 D_{10}= 0.2507
C_u= 37.72 C_c= 3.29

Classification

USCS= GP-GM AASHTO= A-1-a

Remarks

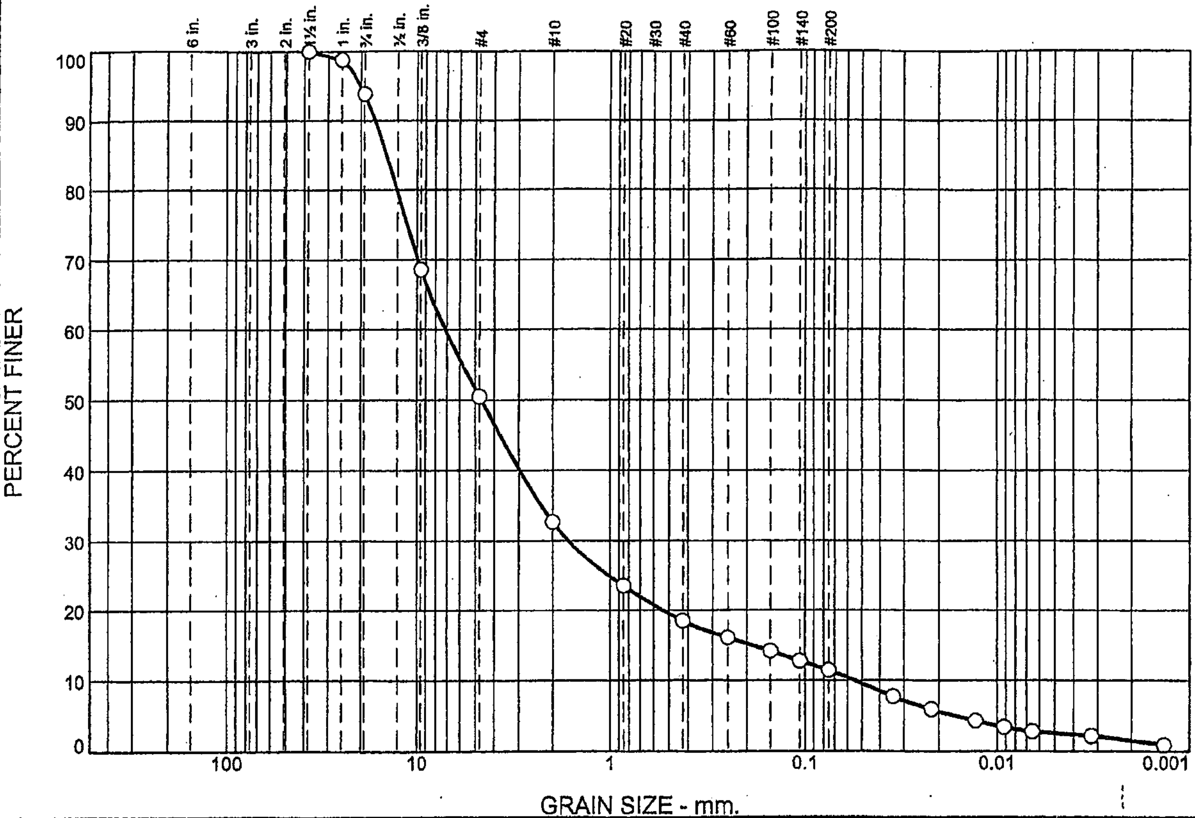
ASTM D422-63 (2007)
ASTM D4318-05

Sample Number: Composite(3rd Batch) **Depth:** Not Indicated
Location: GAB Composite(3rd Batch) **Date:** 1-26-09

MACTEC Engineering and Consulting, Inc.	**Client:** Bechtel Power Corporation
	Project: Calvert Cliffs Nuclear Power Plant Unit 3 COL
Charlotte, North Carolina	**Project No:** 6234084783 **Figure** MW 6-17-09

Tested By: D Kopitsky DMK **Checked By:** D Pryor DWP

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	6.2	43.3	17.8	14.2	7.1	8.9	2.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5in.	100.0		
1in.	98.8		
3/4in.	93.8		
3/8in.	68.6		
#4	50.5		
#10	32.7		
#20	23.5		
#40	18.5		
#60	16.1		
#100	14.1		
#140	12.7		
#200	11.4		

* (no specification provided)

Material Description

Poorly Graded Gravel With Silt and Sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{85}= 14.5538 D_{60}= 7.1532 D_{50}= 4.6443
D_{30}= 1.6553 D_{15}= 0.1889 D_{10}= 0.0547
C_u= 130.77 C_c= 7.00

Classification

USCS= GP-GM AASHTO= A-1-a

Remarks

ASTM D422-63 (2007)
ASTM D4318-05

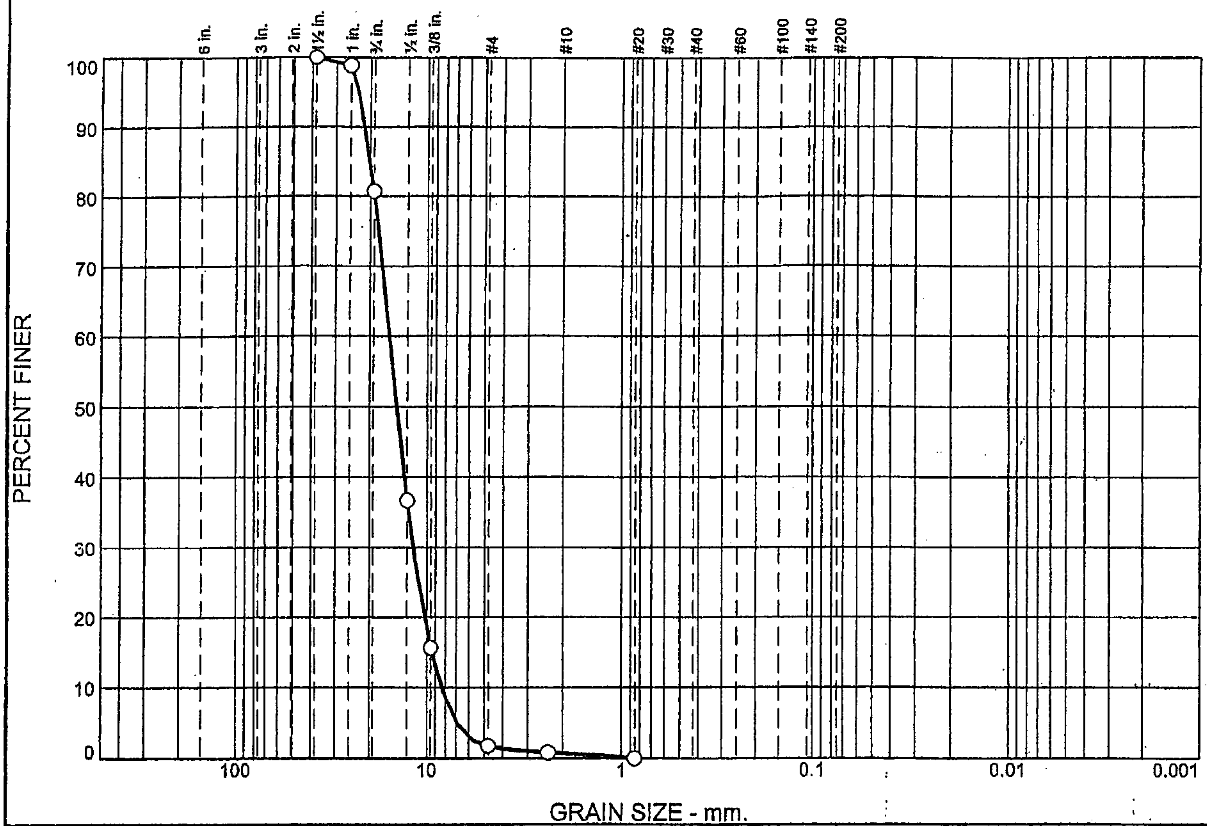
Sample Number: Composite(3rd Batch) **Depth:** Not Indicated
Location: CR6 Composite(3rd Batch) **Date:** 1-26-09

MACTEC Engineering and Consulting, Inc.
Charlotte, North Carolina

Client: Bechtel Power Corporation
Project: Calvert Cliffs Nuclear Power Plant Unit 3 COL
Project No: 6234084783 **Figure** MA 6-17-09

Tested By: D Kopitsky DAK **Checked By:** D Pryor DWP

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	19.3	78.9	1.1	0.7	0.0	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5in.	100.0		
1in.	98.8		
3/4in.	80.7		
1/2in.	36.7		
3/8in.	15.6		
#4	1.8		
#8	0.8		
#20	0.0		

* (no specification provided)

Material Description

Poorly Graded Gravel

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{85}= 19.9917 D_{60}= 15.6996 D_{50}= 14.3909
D_{30}= 11.8025 D_{15}= 9.4167 D_{10}= 8.3777
C_u= 1.87 C_c= 1.06

Classification

USCS= GP AASHTO= A-1-a

Remarks

ASTM D6913-04
ASTM D4318-05

Sample Number: Composite(3rd Batch) **Depth:** Not Indicated
Location: 57 Composite(3rd Batch) **Date:** 1-22-09

MACTEC Engineering and Consulting, Inc. Charlotte, North Carolina	**Client:** Bechtel Power Corporation **Project:** Calvert Cliffs Nuclear Power Plant Unit 3 COL **Project No:** 6234084783 **Figure** MA 6-17-21

Tested By: D Pryor DWP Checked By: D Kopitsky DAK

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ATTACHMENT 2

LABORATORY TEST DATA

RCTS AND FREE-FREE TEST RESULTS OF STRUCTURAL FILL

- APPENDICES A THROUGH H – RCTS TEST RESULTS
- APPENDICES I THROUGH N – FREE-FREE TEST RESULTS

CALVERT CLIFFS COL
BECHTEL JOB NO. 25237

TESTING PERFORMED AT UNIVERSITY OF TEXAS AT AUSTIN

MACTEC PROJECT NO. 6234-08-4783

Data Reviewed and Accepted By:

CLAY E. SAMS
Name

Clay E Sams
Signature

June 29, 2009
Date

MACTEC Engineering and Consulting, Inc.
2801 Yorkmont Road, Suite 100 ● Charlotte, NC 28208 ● Phone: 704.357.8600

APPENDIX A

UT Specimen UTA-67-A (1I)
Sample ID : CR6-17
Type = Scalped, Reconstituted Gravel with Silt and Sand (GP-GM*)

Water Content, w = 6.4 %

G_S = 2.716*

Degree of Saturation = 72.1%

Total Unit Weight, γ_t = 145.4 lb/ft^3

Dry Unit Weight, γ_d = 136.6 lb/ft^3

Target : γ_d = 136.8 lb/ft^3 ± 1 lb/ft^3

w = 6.4% ± 1.0%

*** Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

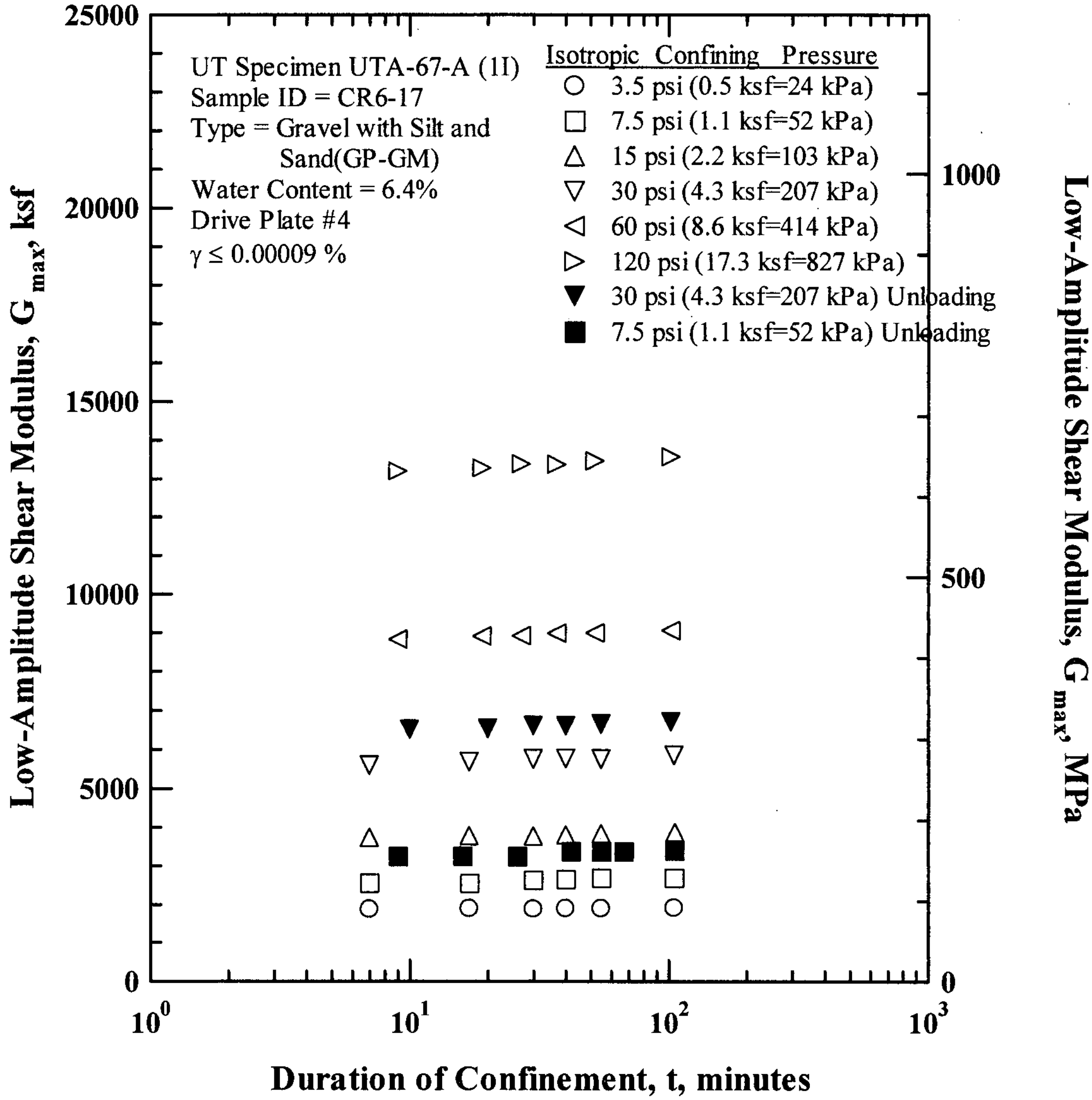


Figure A.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1I)

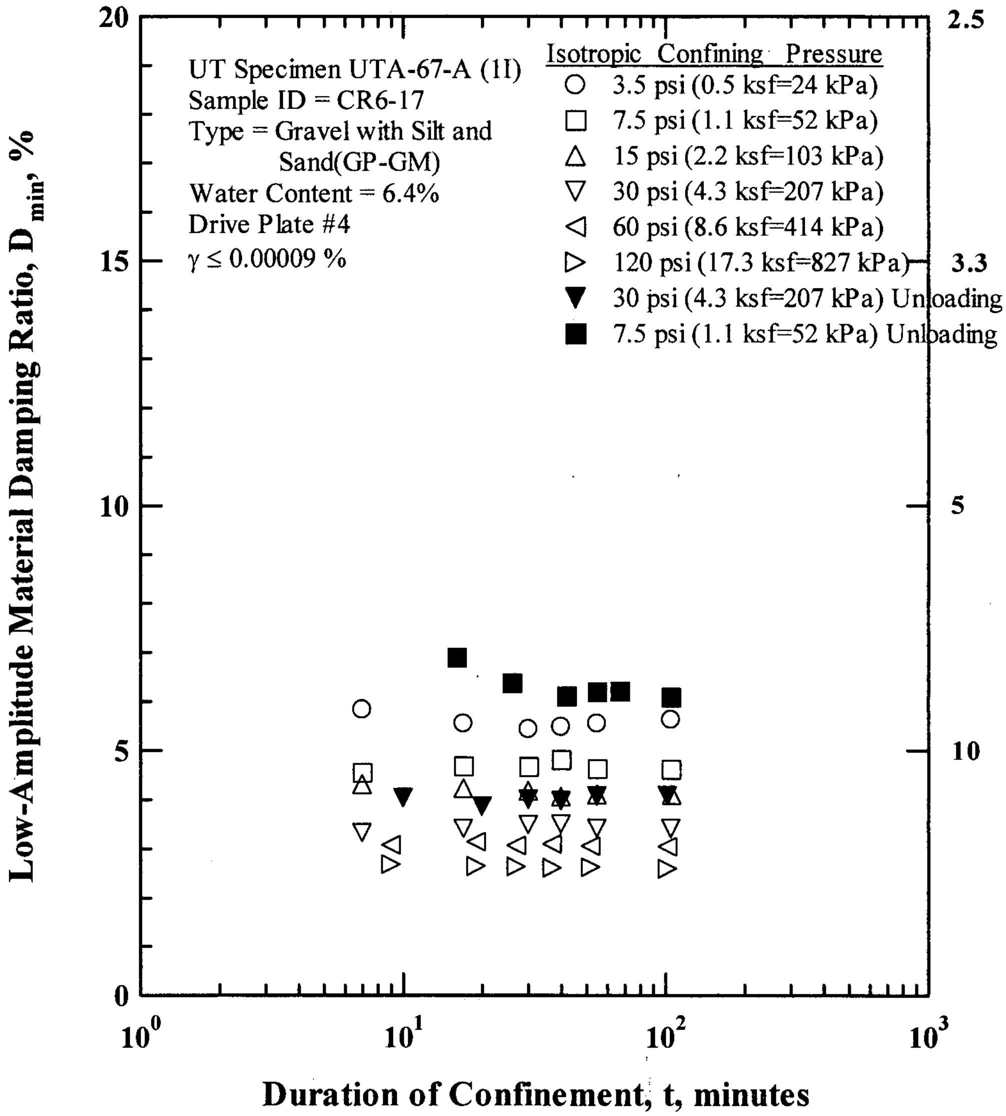


Figure A.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1I)

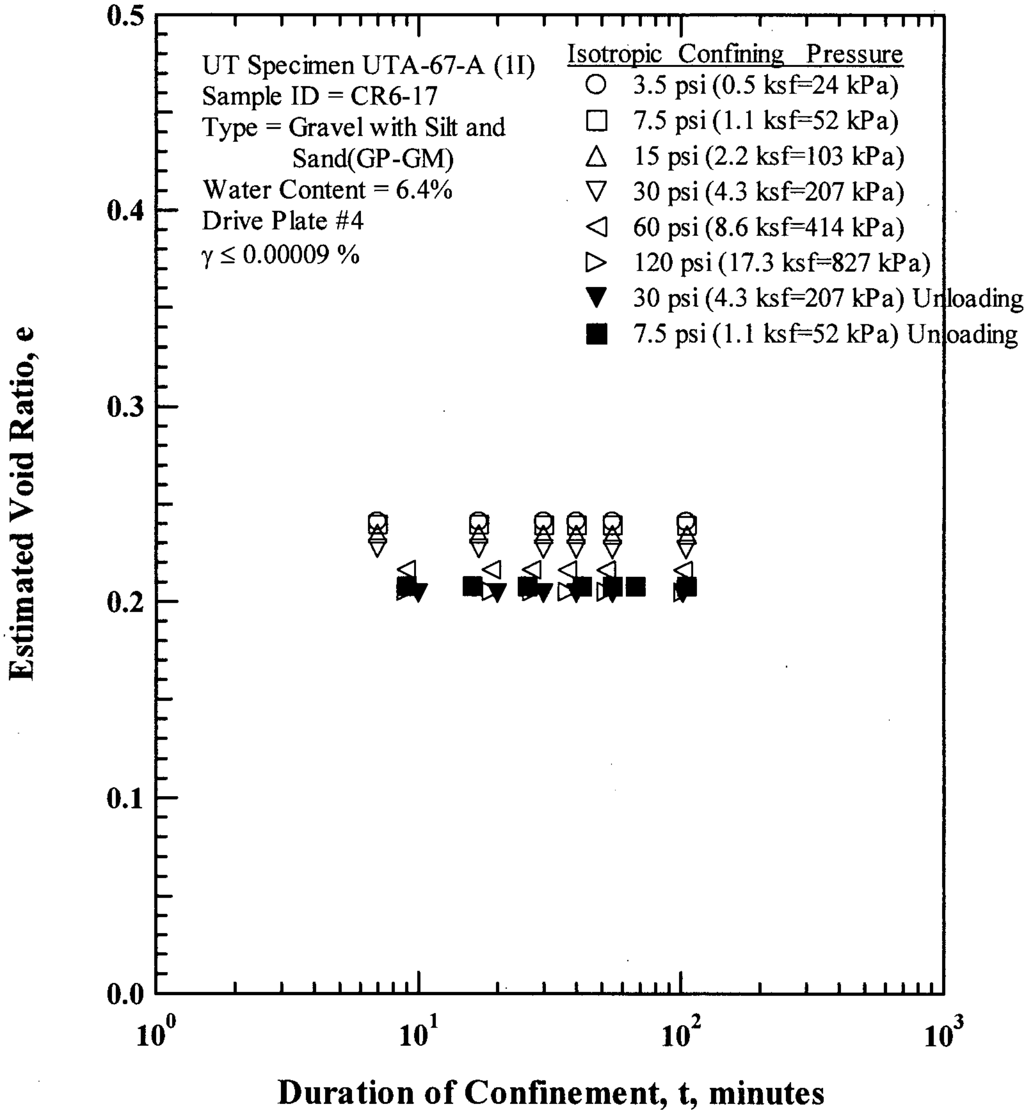


Figure A.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1I)

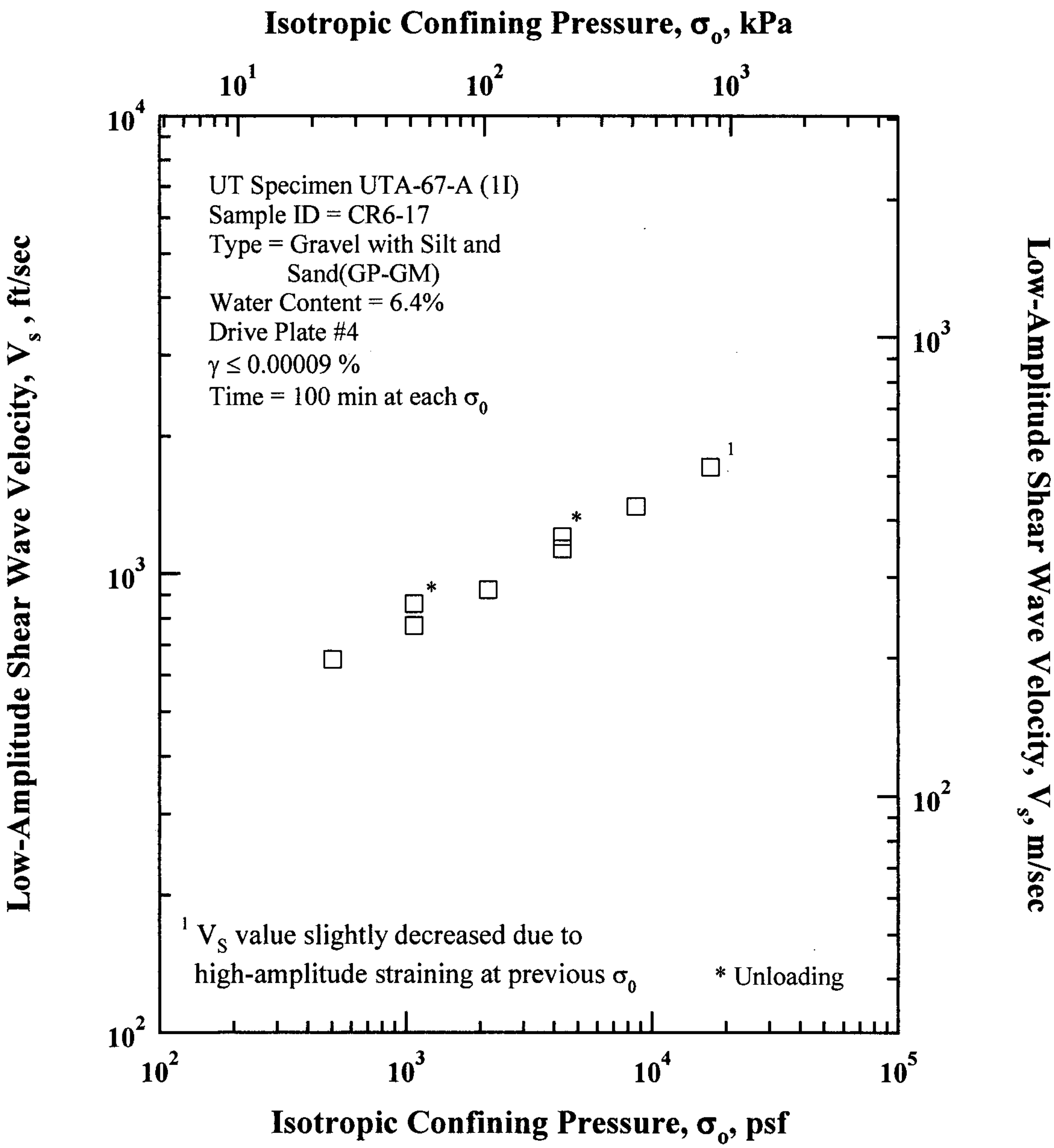


Figure A.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1I)

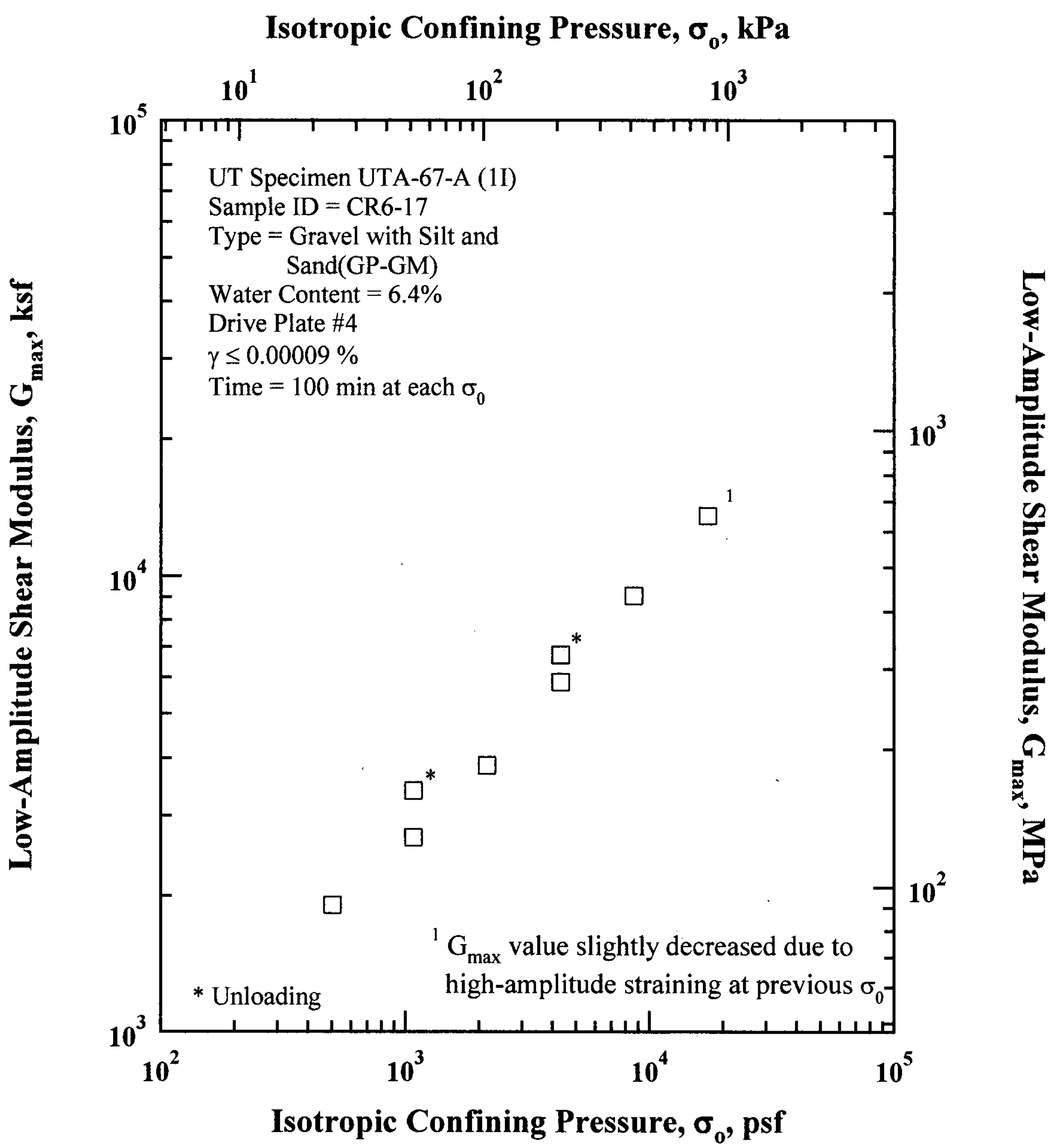


Figure A.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1I)

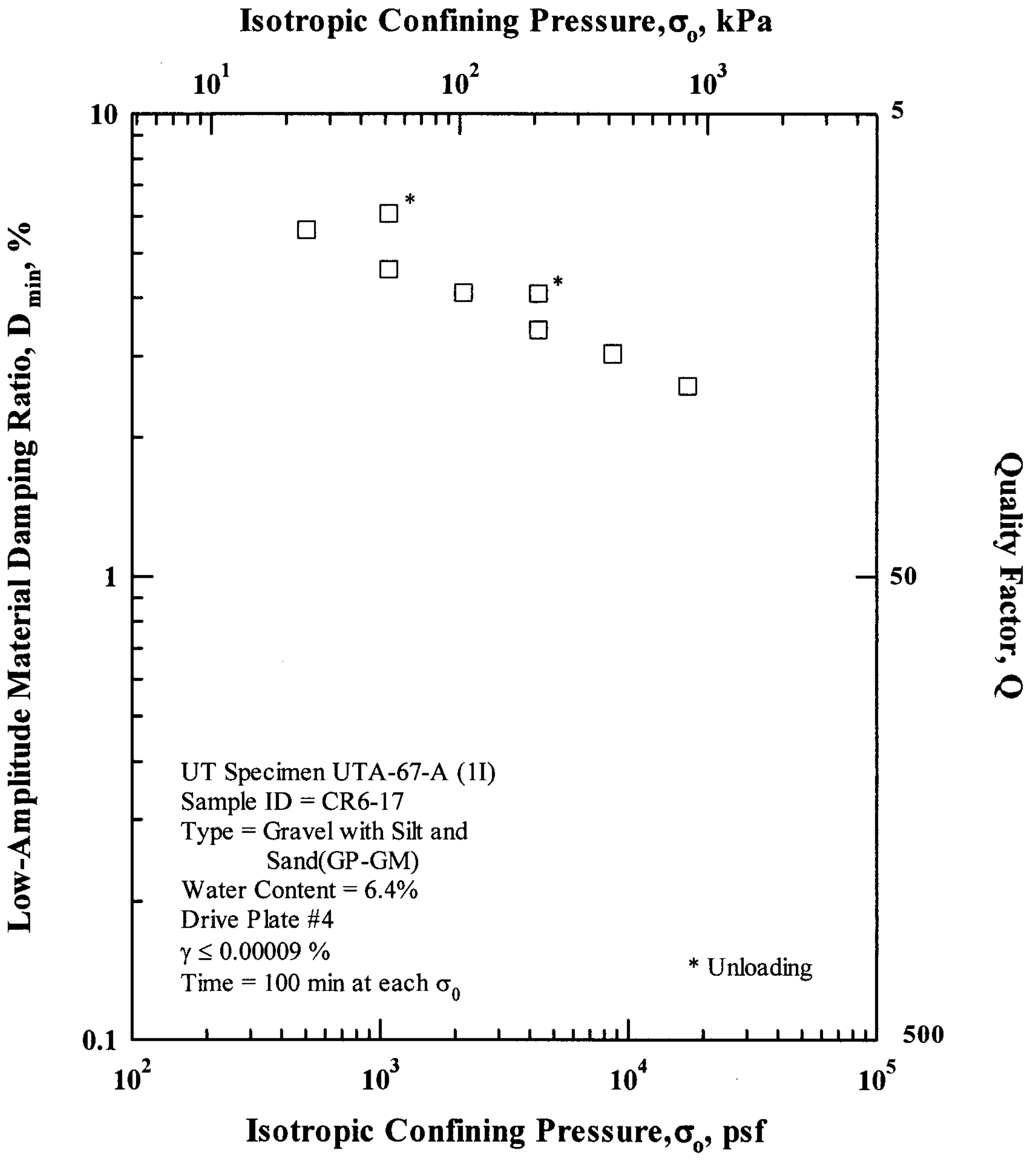


Figure A.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1I)

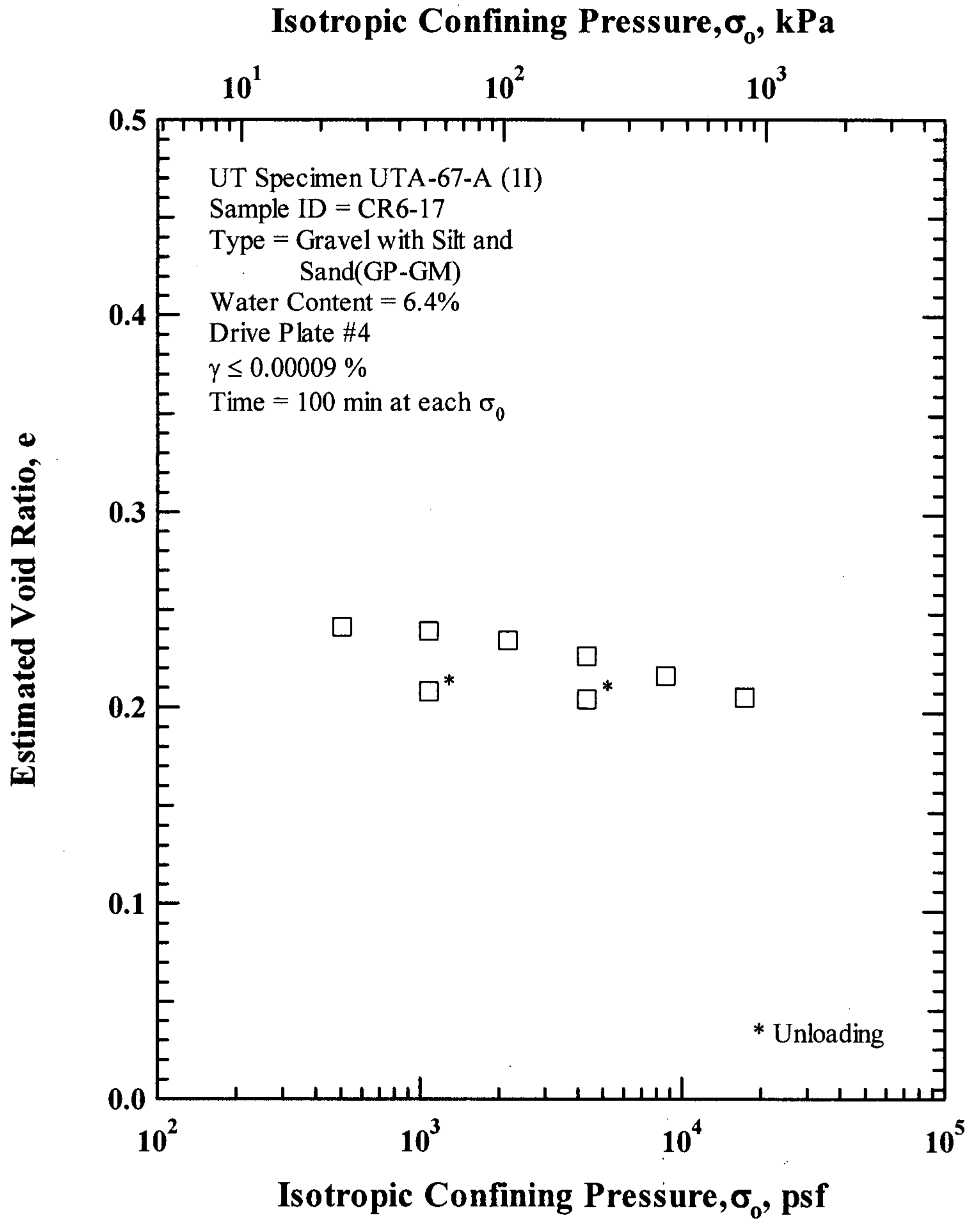


Figure A.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1I)

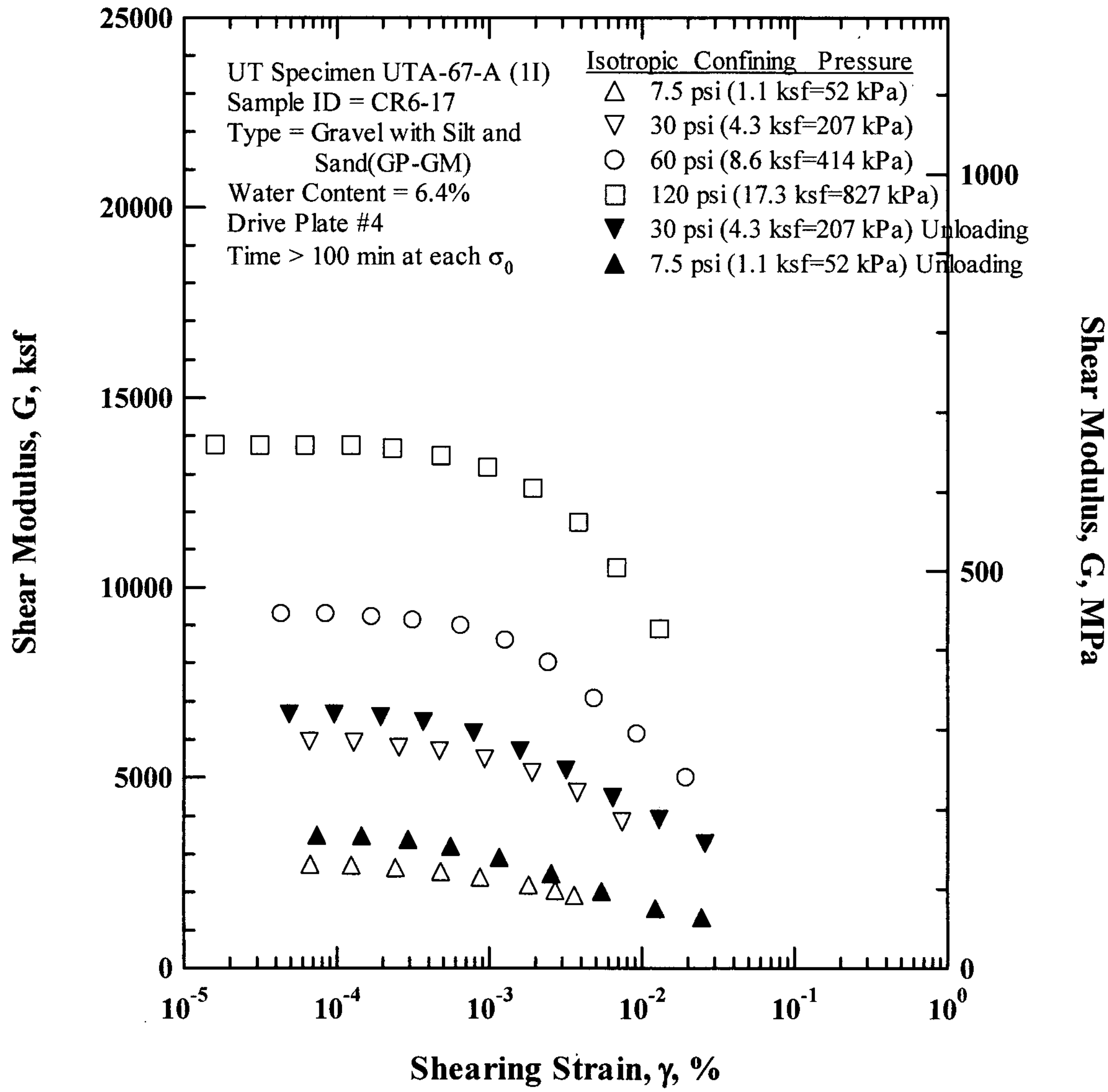


Figure A.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-A (1I)

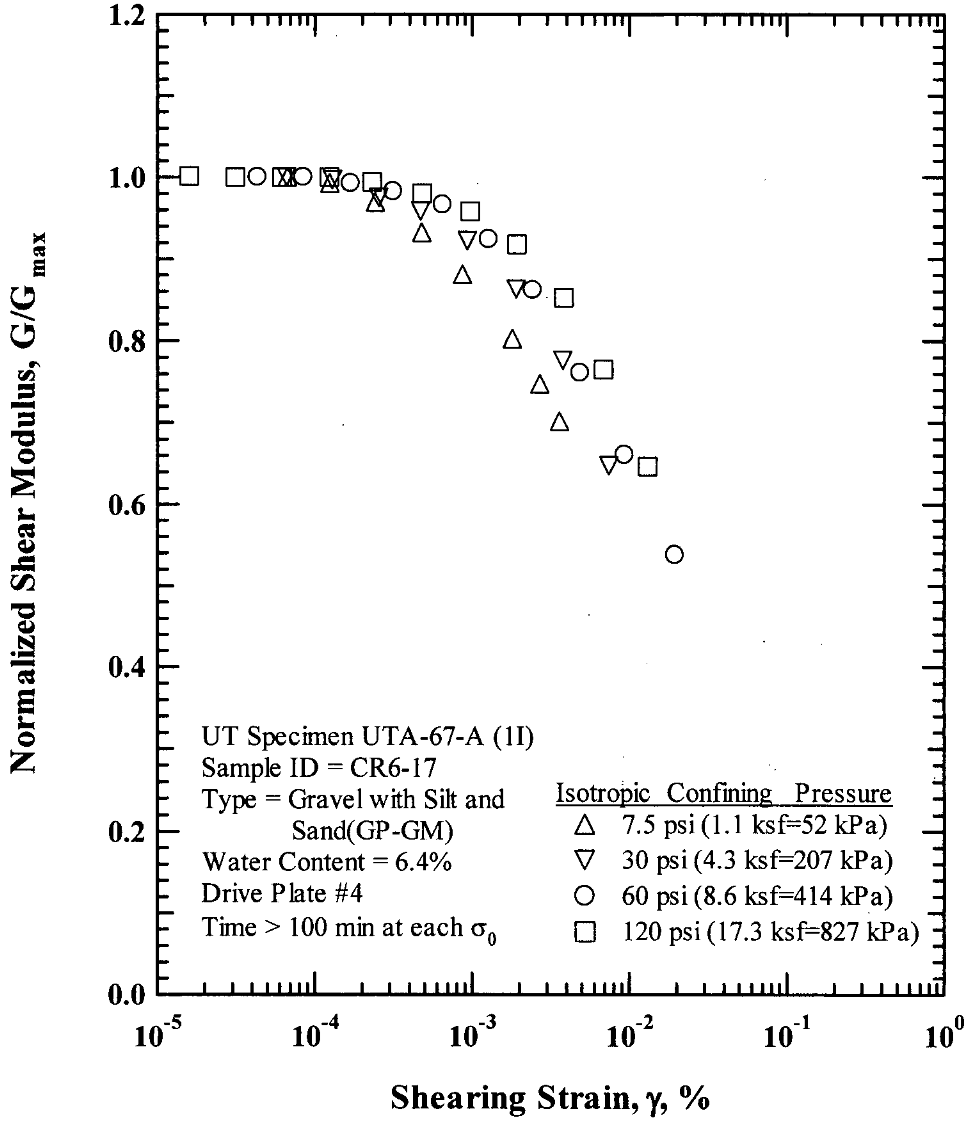


Figure A.9 Variation in Normalized Shear Modulus with Shearing Strain upon Loading at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-A (1I)

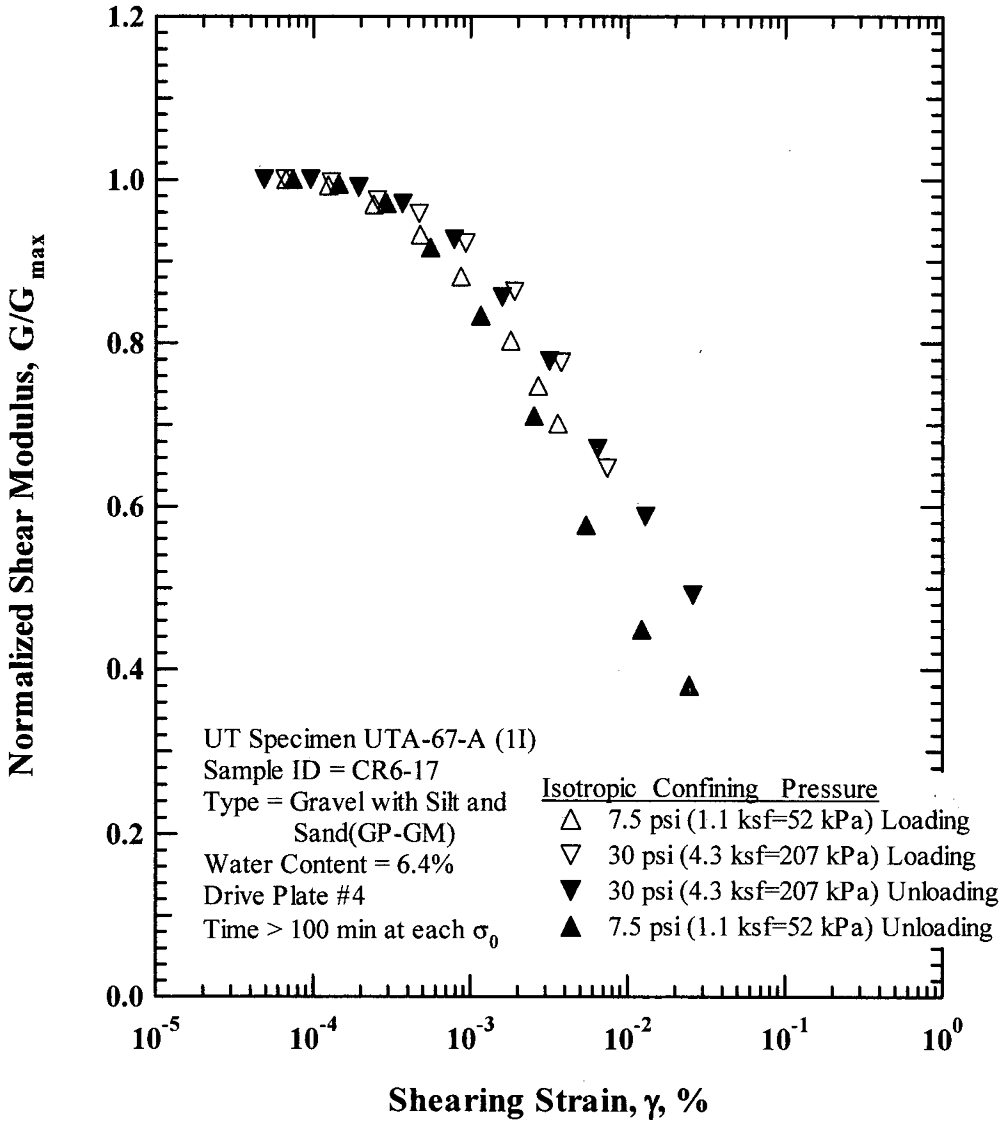


Figure A.10 Comparison of the Variations in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures upon Loading and Unloading from Resonant Column Tests of Specimen UTA-67-A (1I)

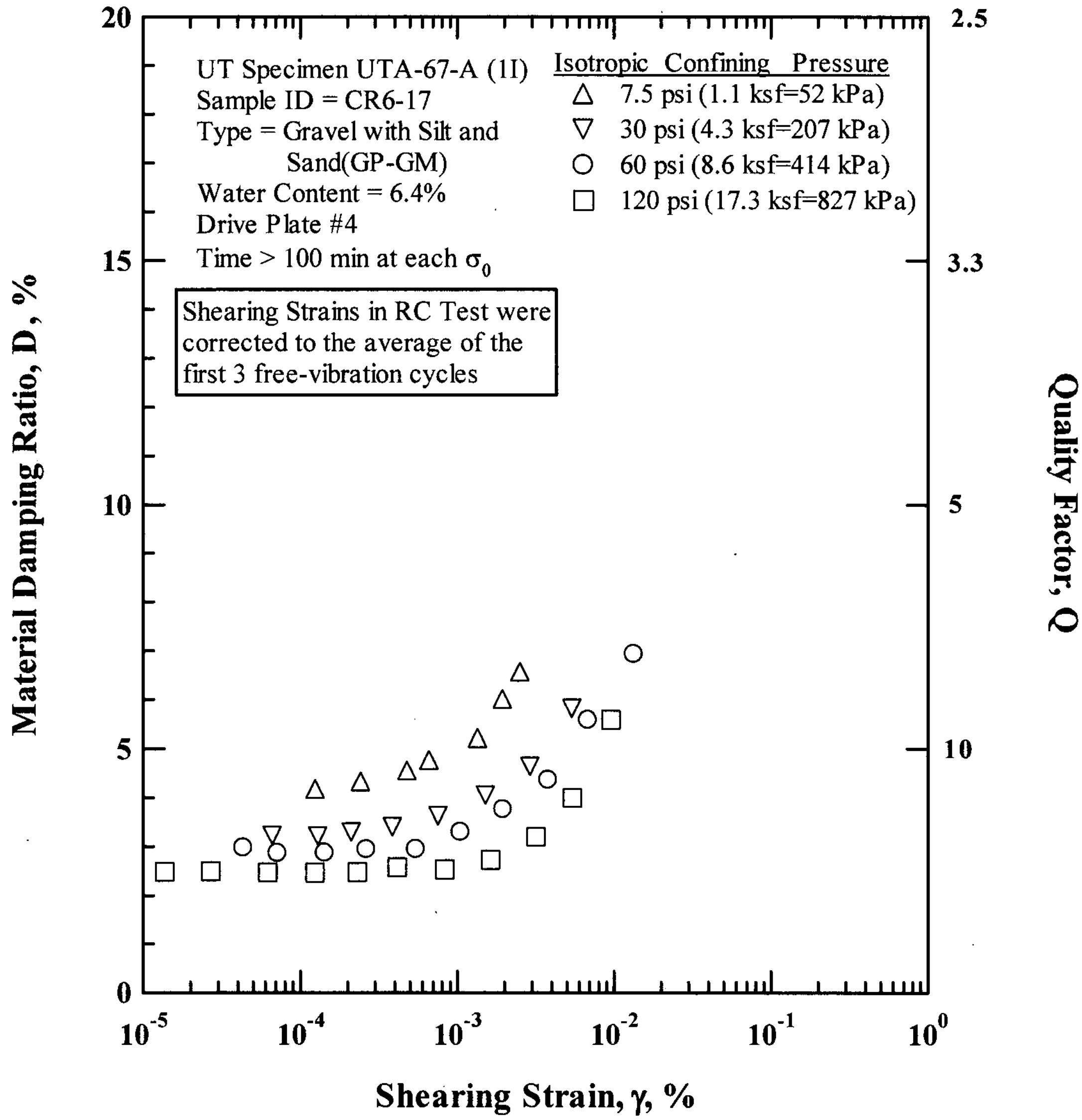


Figure A.11 Variation in Material Damping Ratio with Shearing Strain upon Loading at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-A (1I)

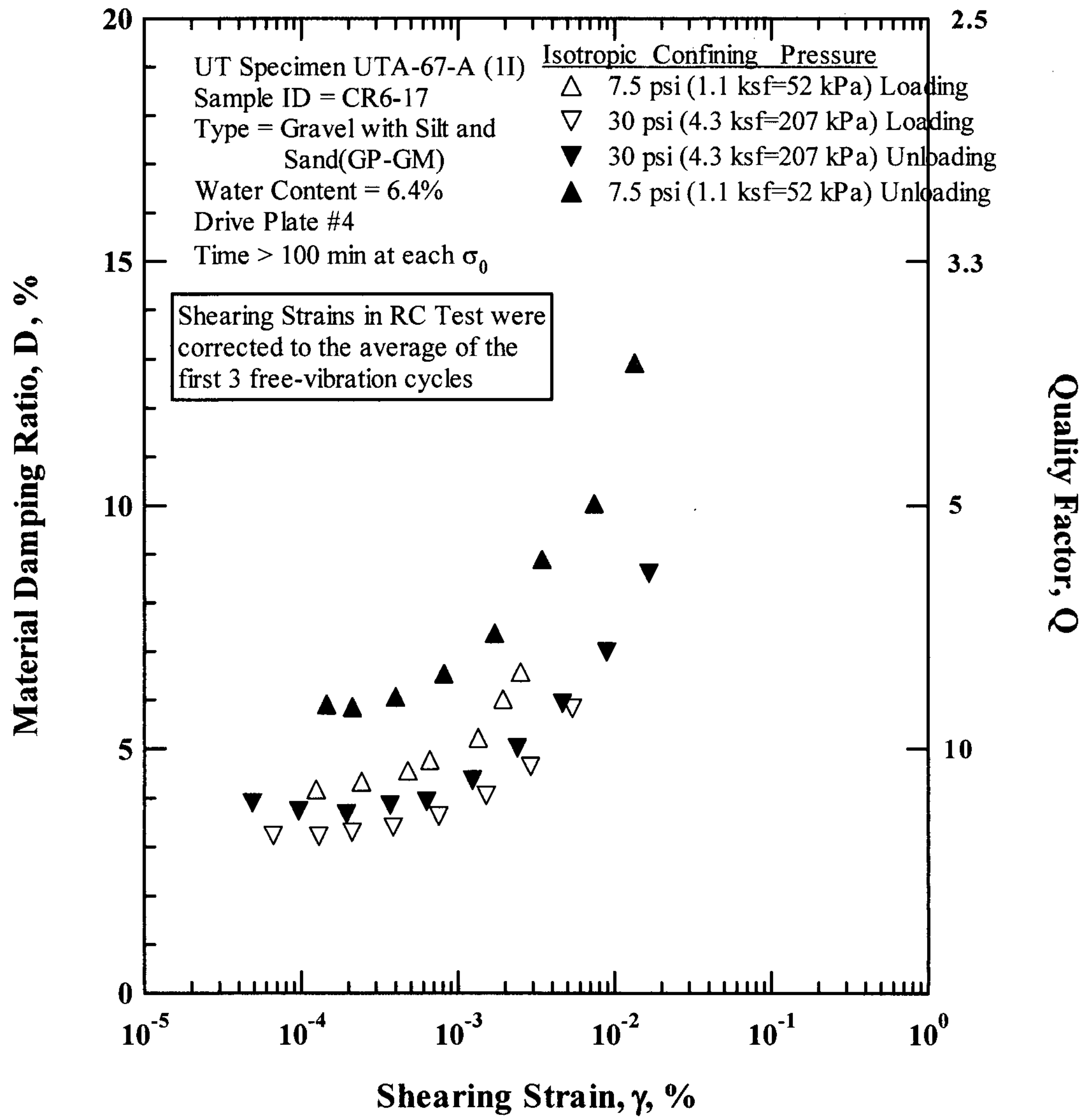


Figure A.12 Comparison of the Variations in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures upon Loading and Unloading from Resonant Column Tests of Specimen UTA-67-A (1I)

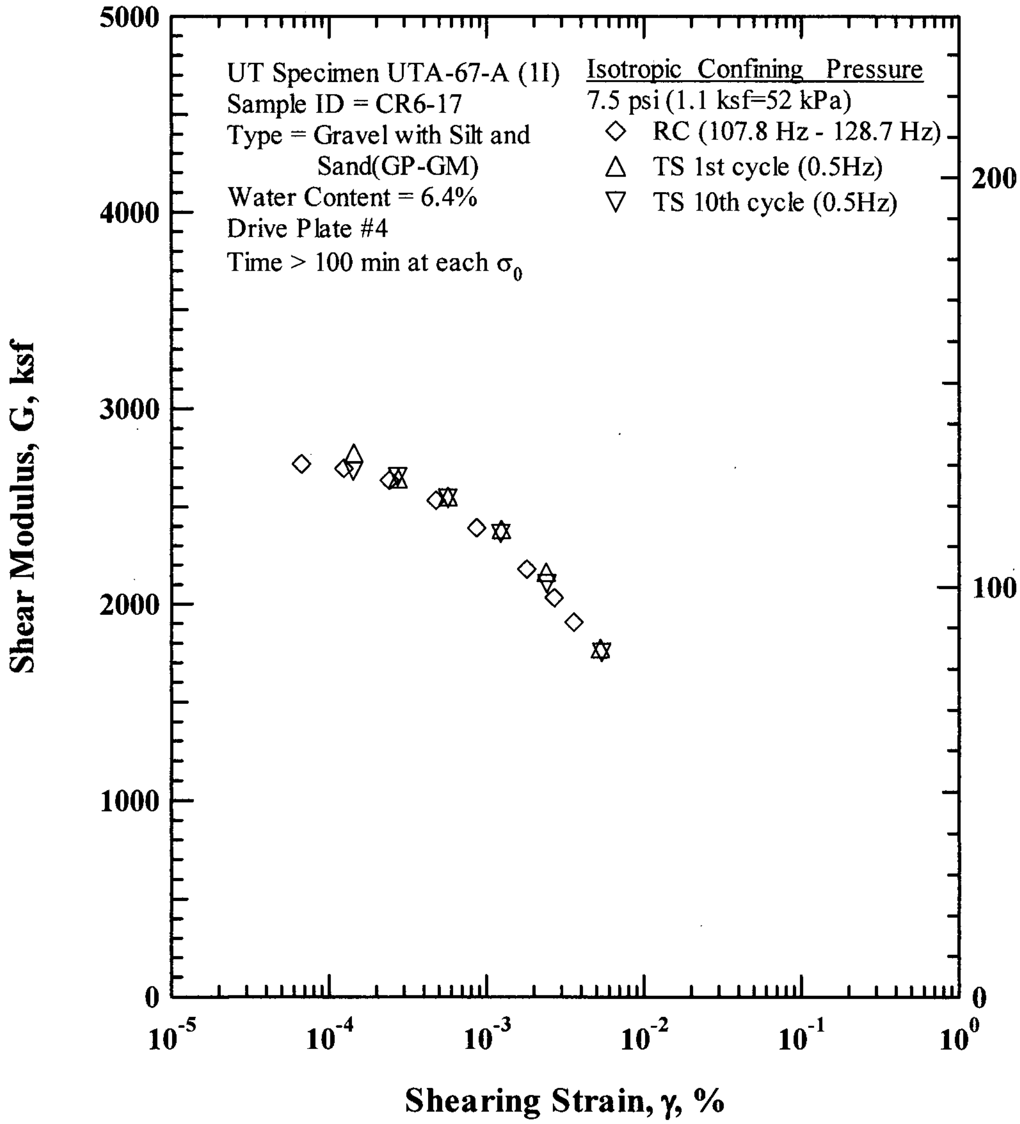


Figure A.13 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

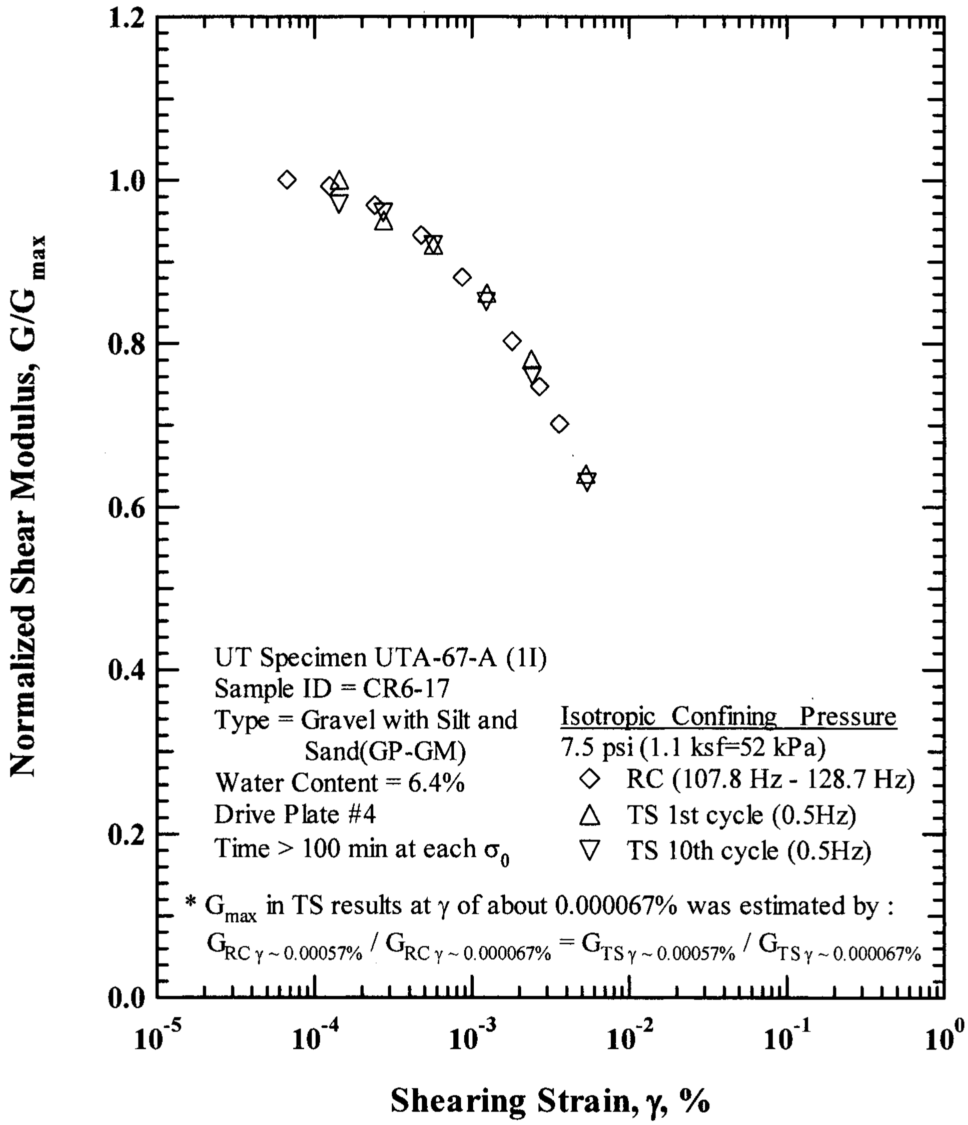


Figure A.14 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

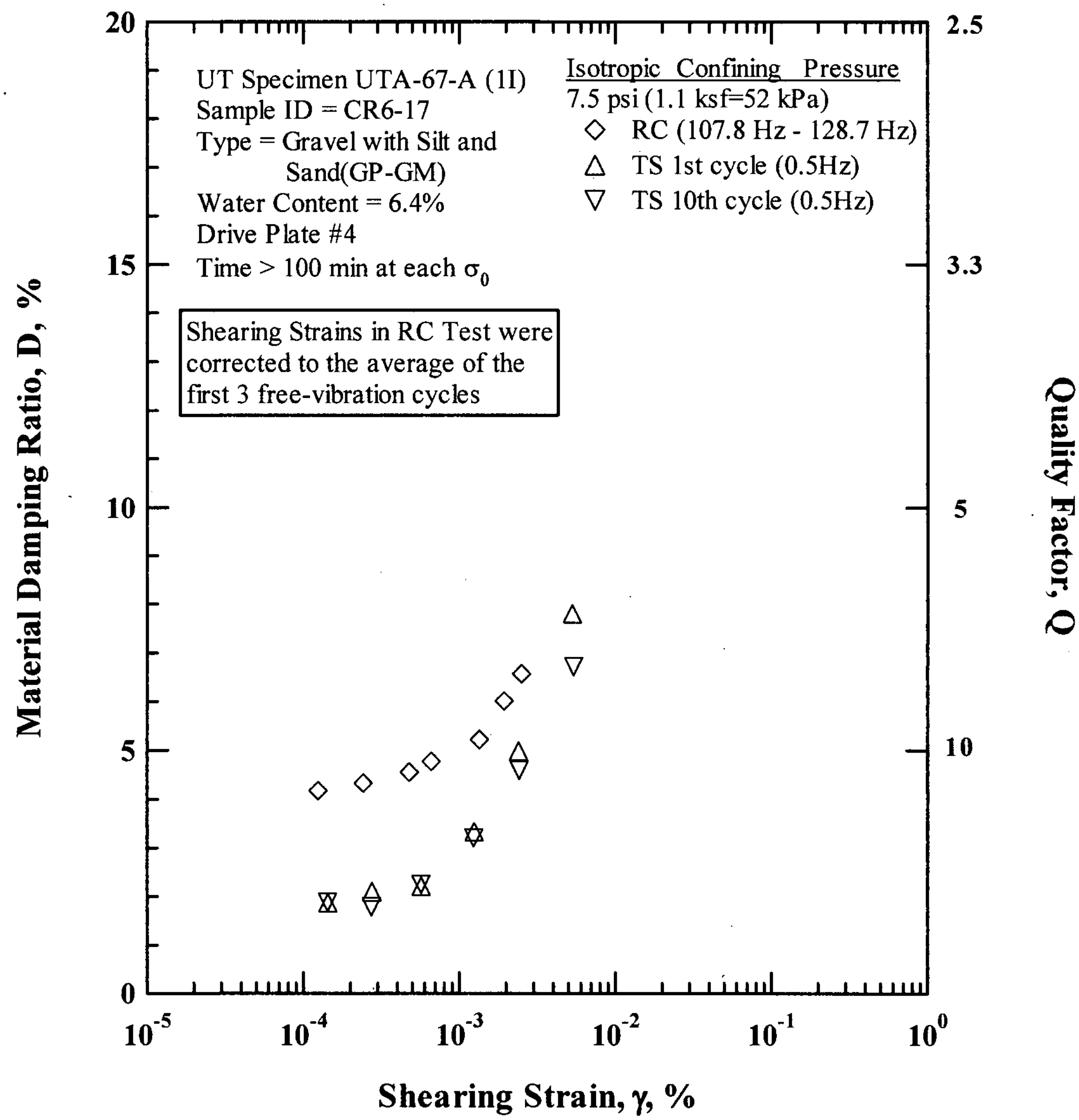


Figure A.15 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

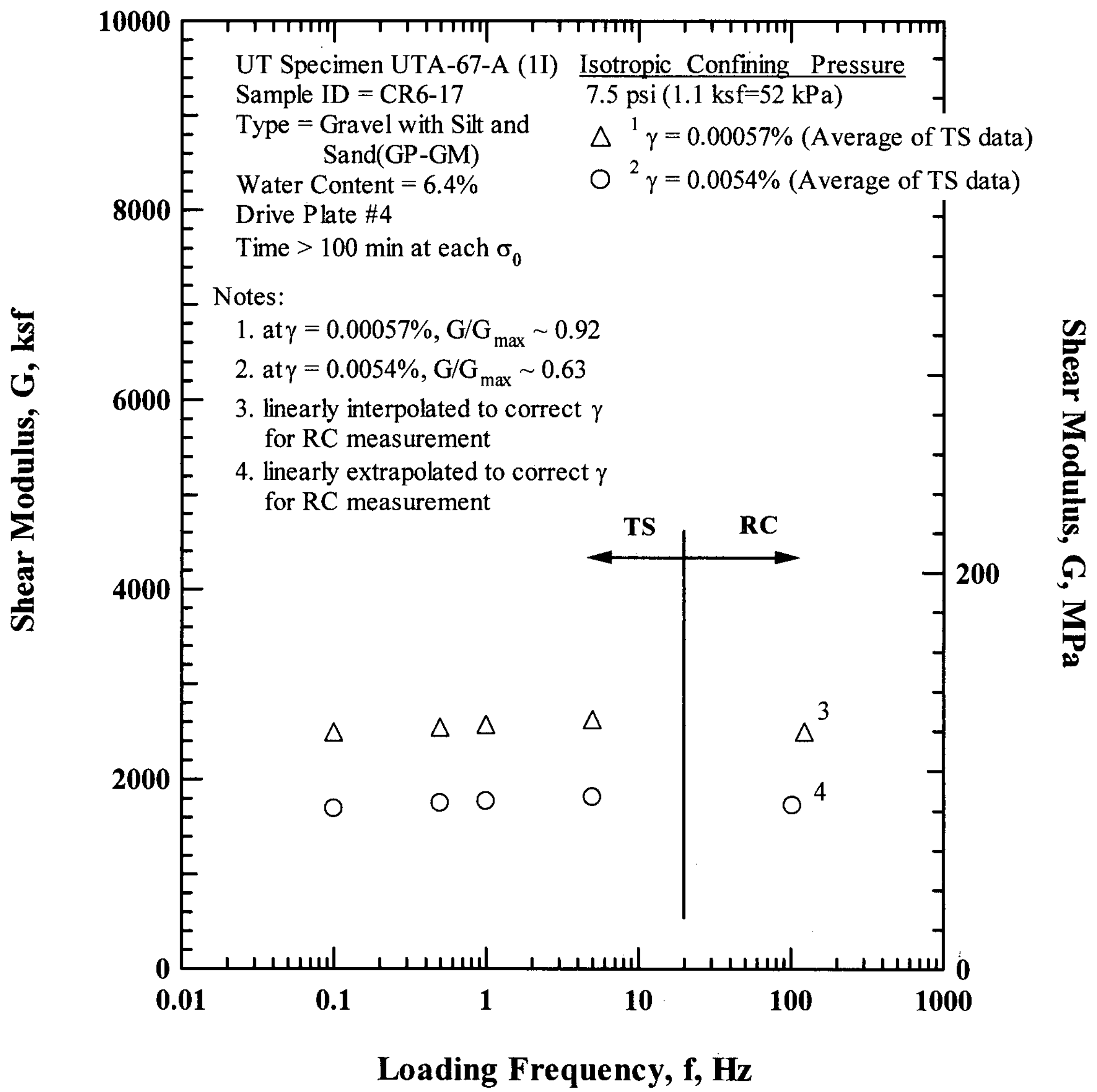


Figure A.16 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

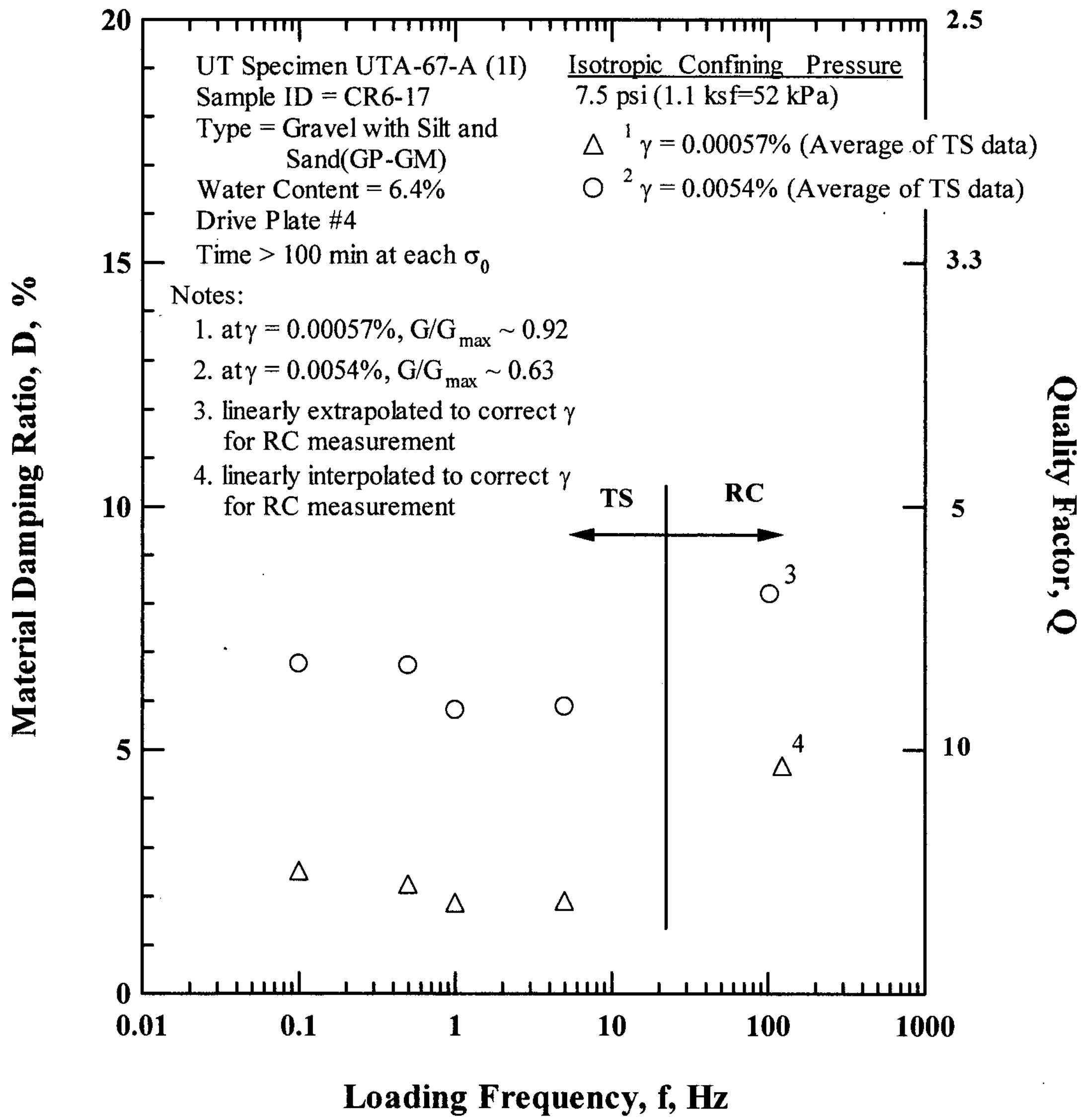


Figure A.17 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

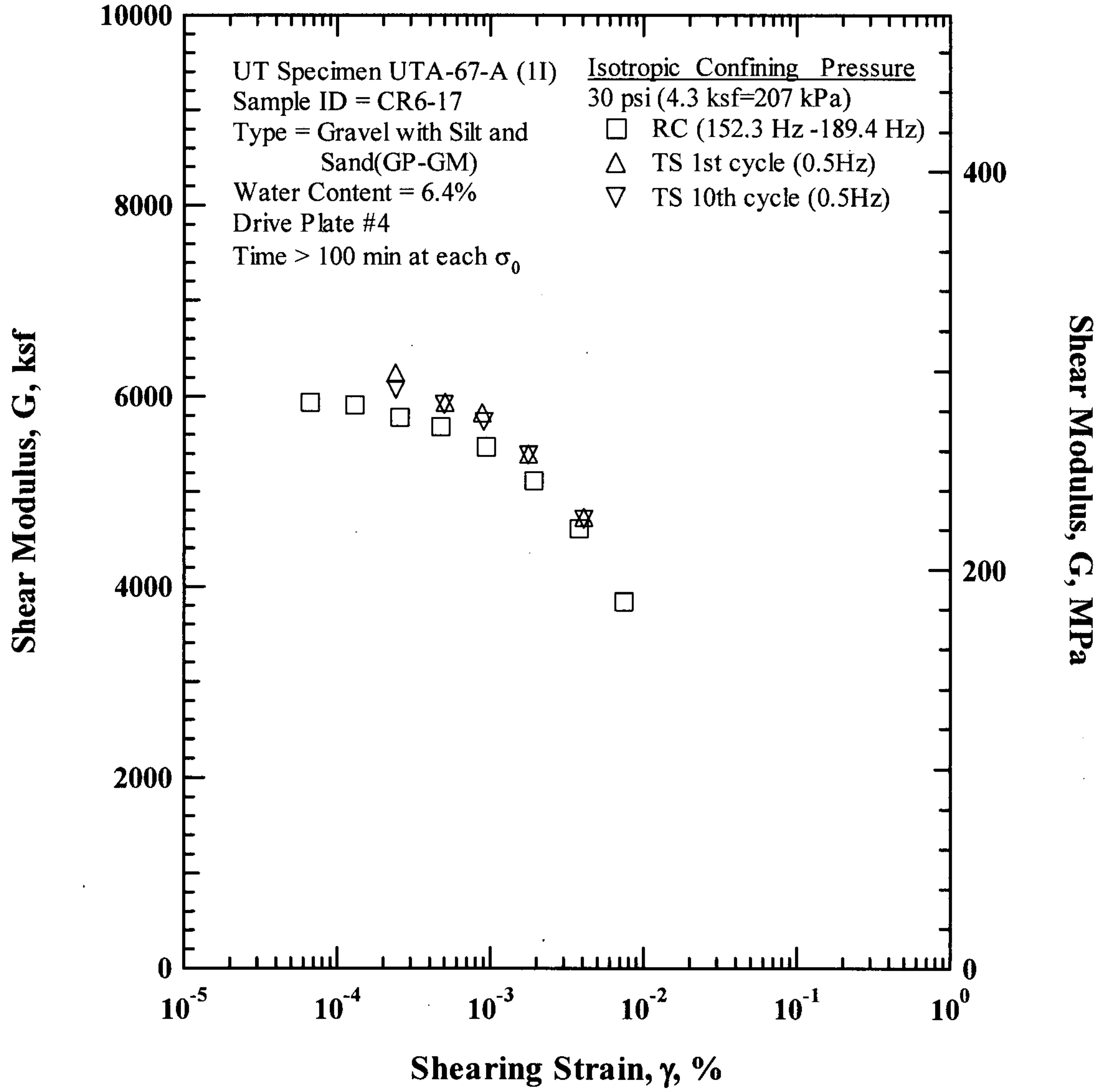


Figure A.18 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

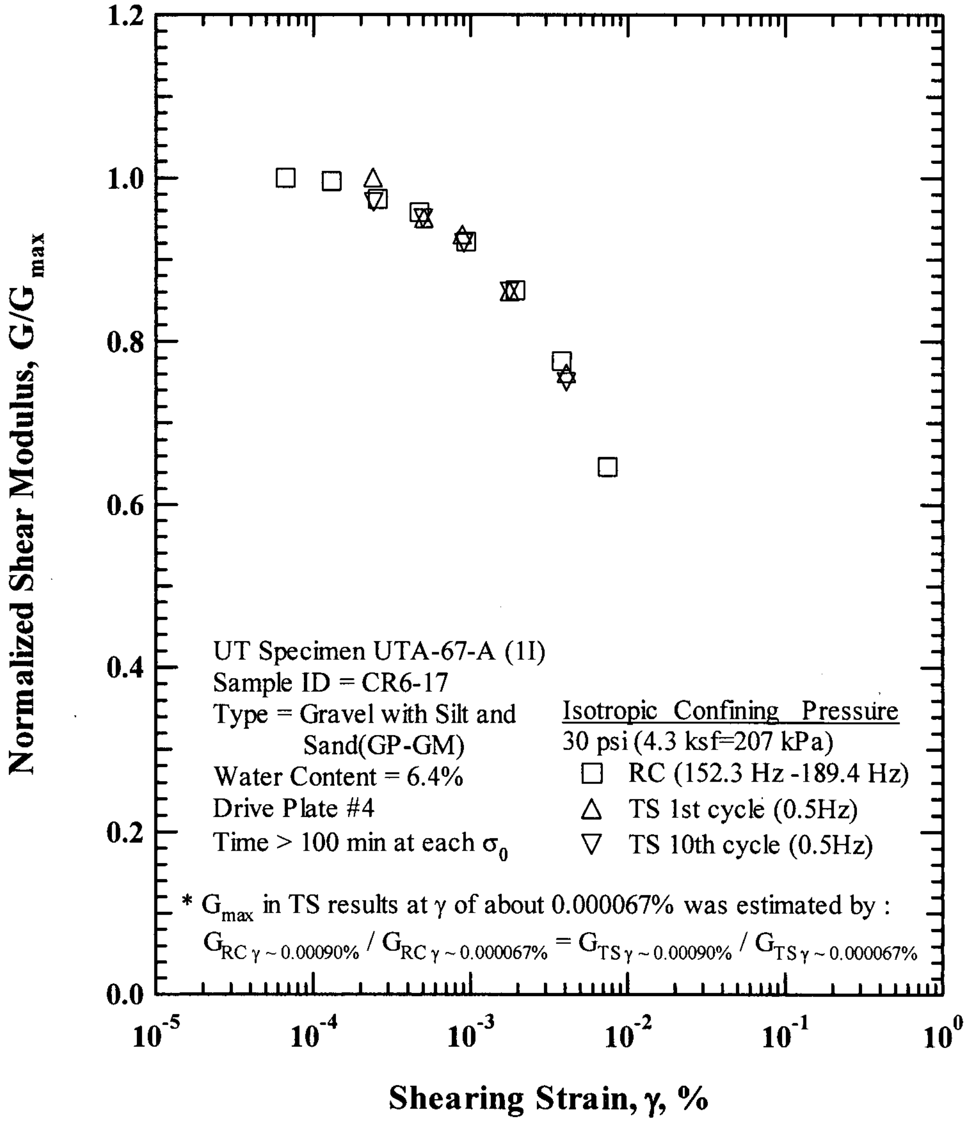


Figure A.19 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

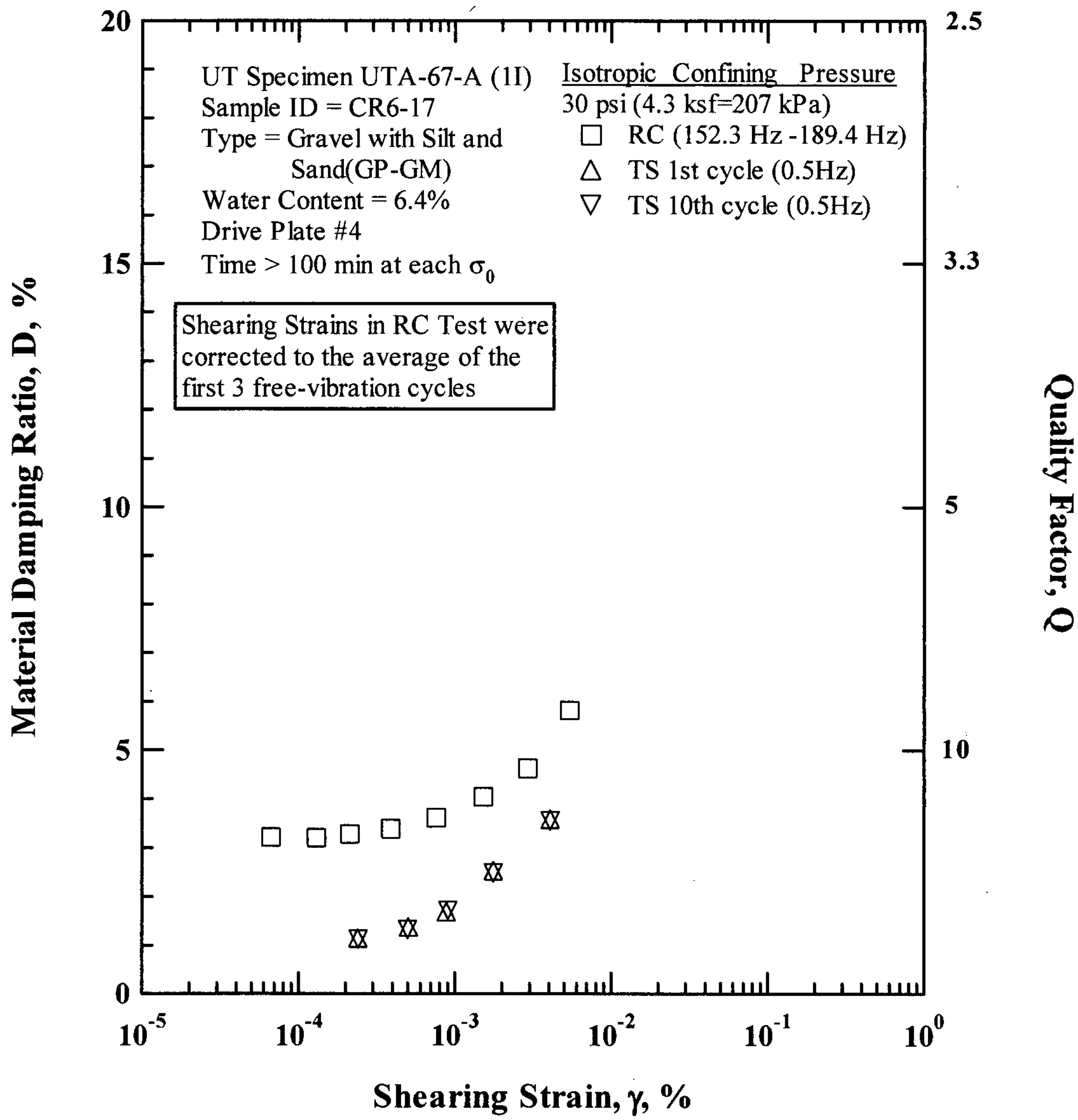


Figure A.20 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

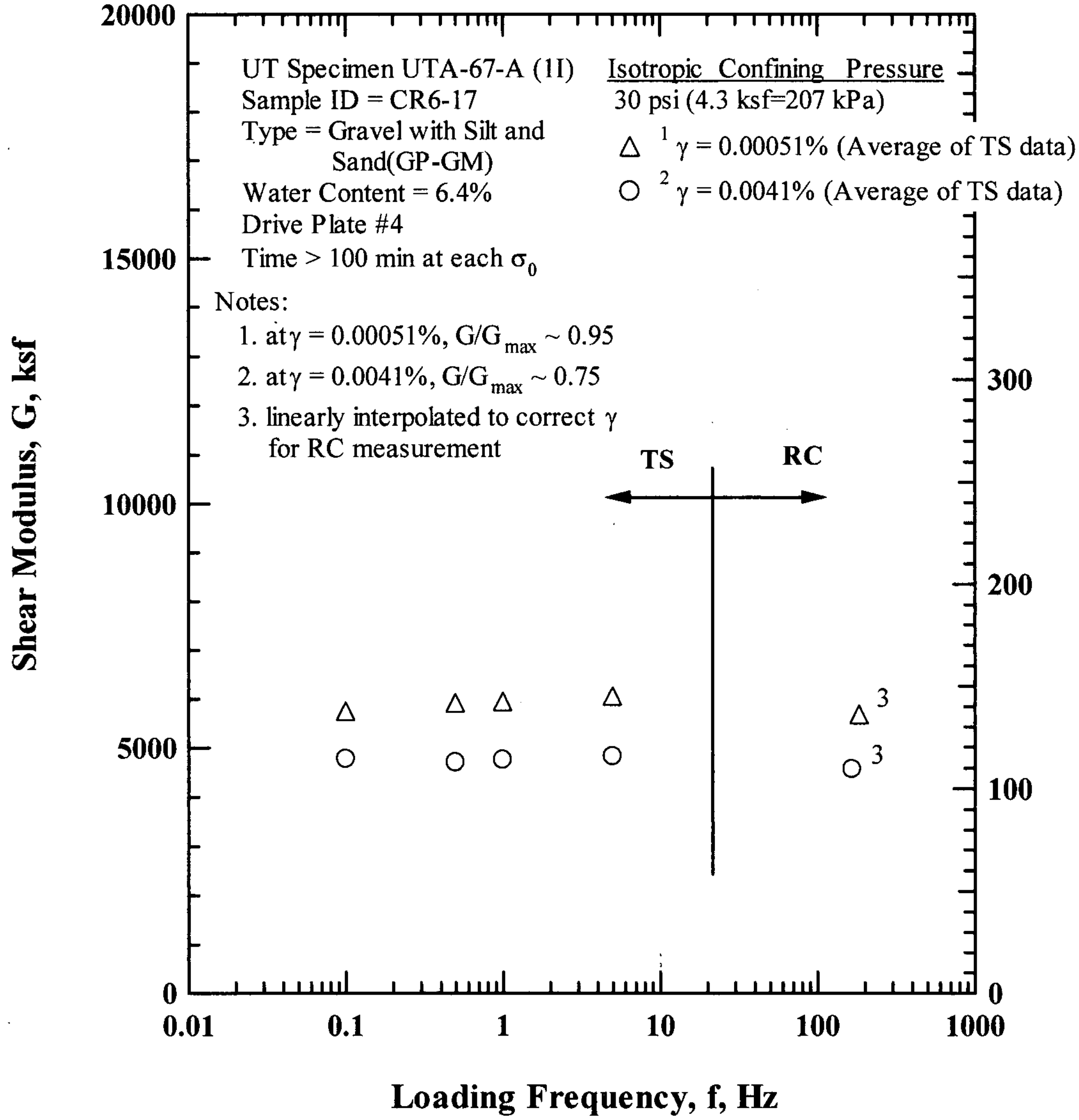


Figure A.21 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

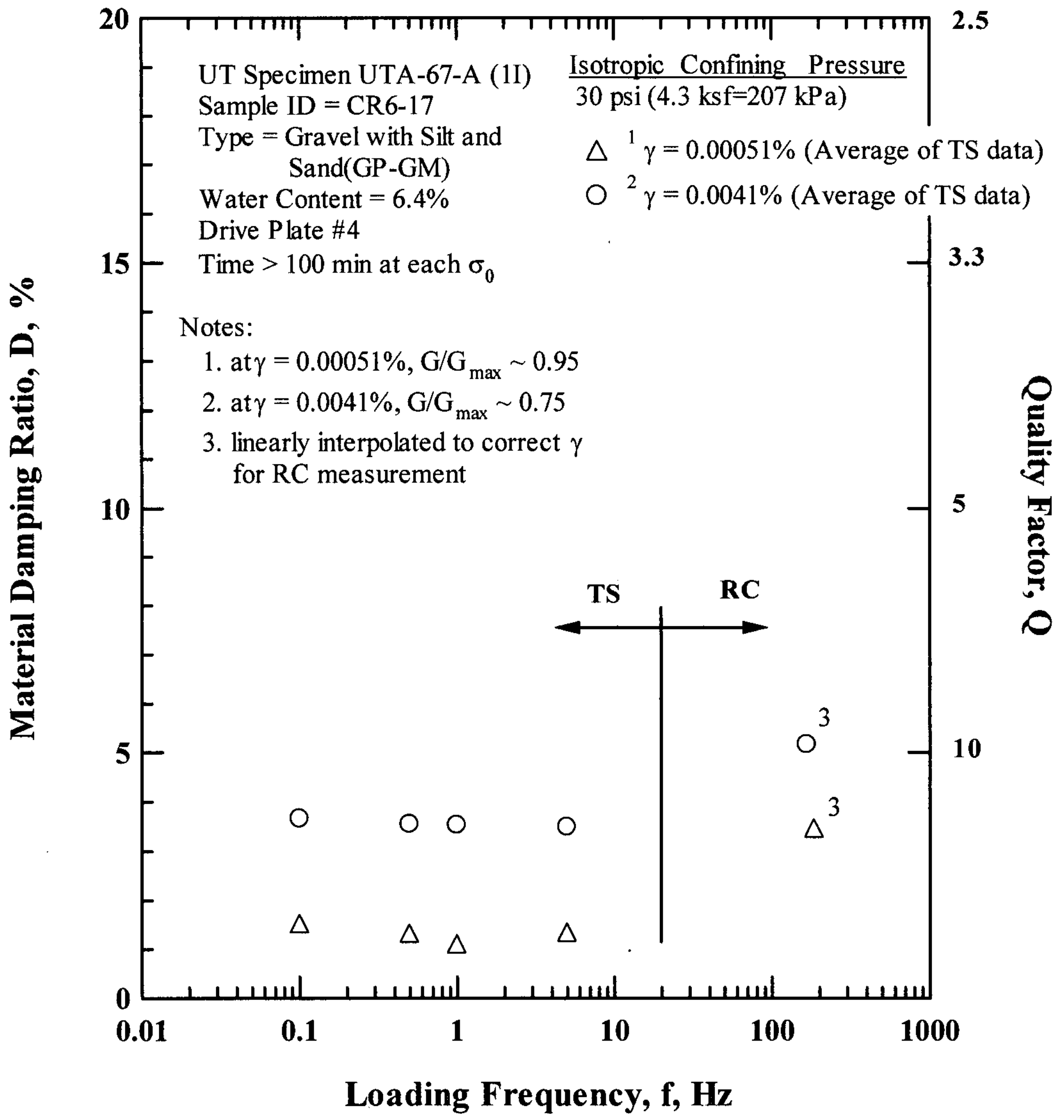


Figure A.22 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

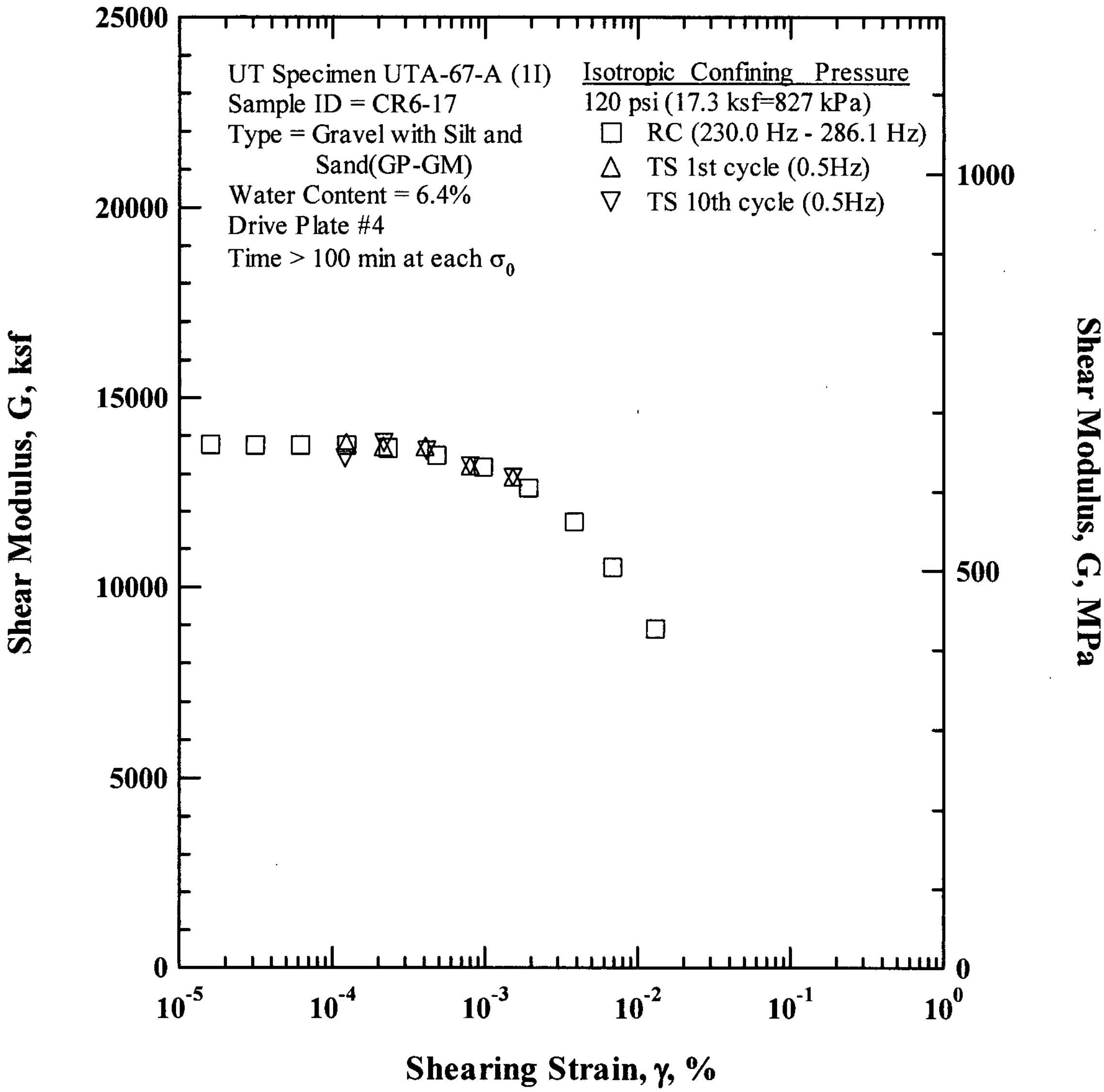


Figure A.23 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

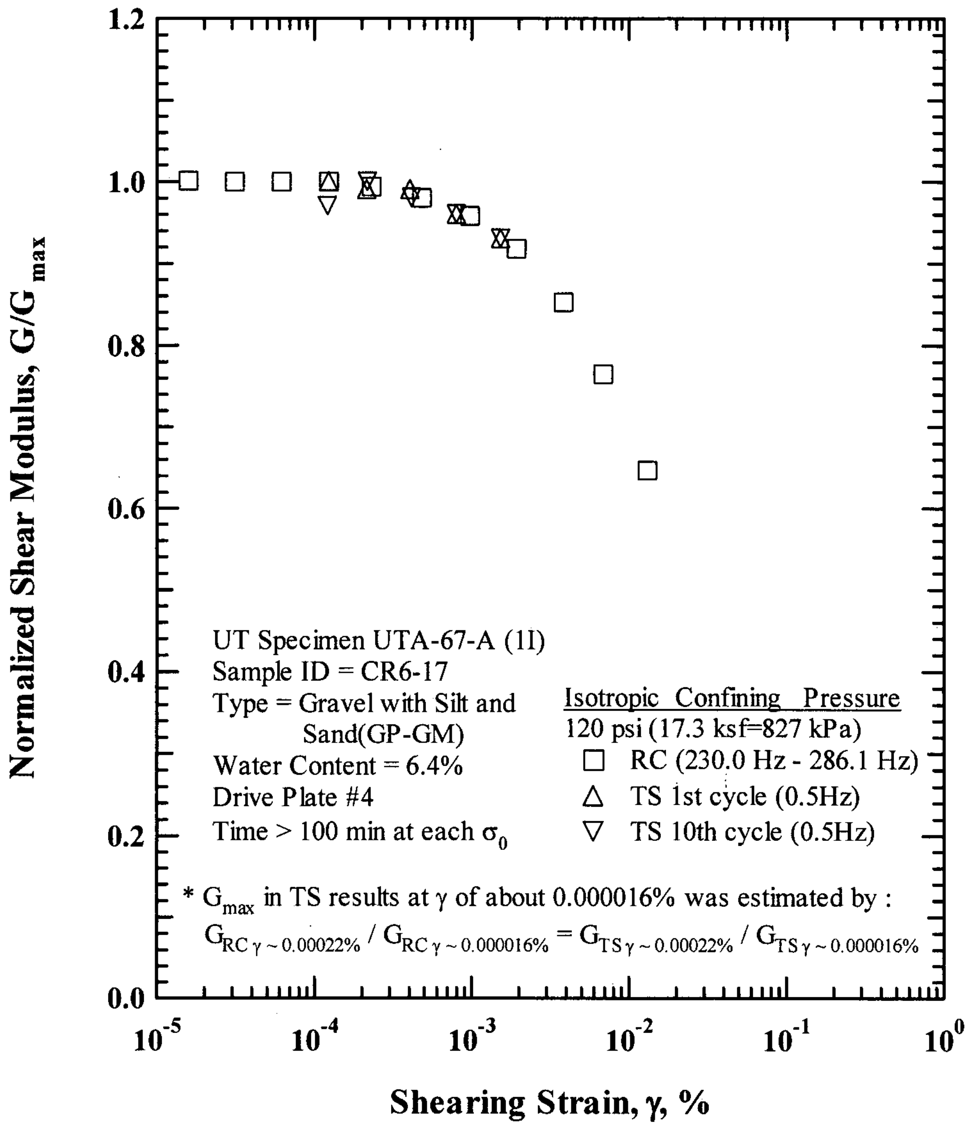


Figure A.24 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

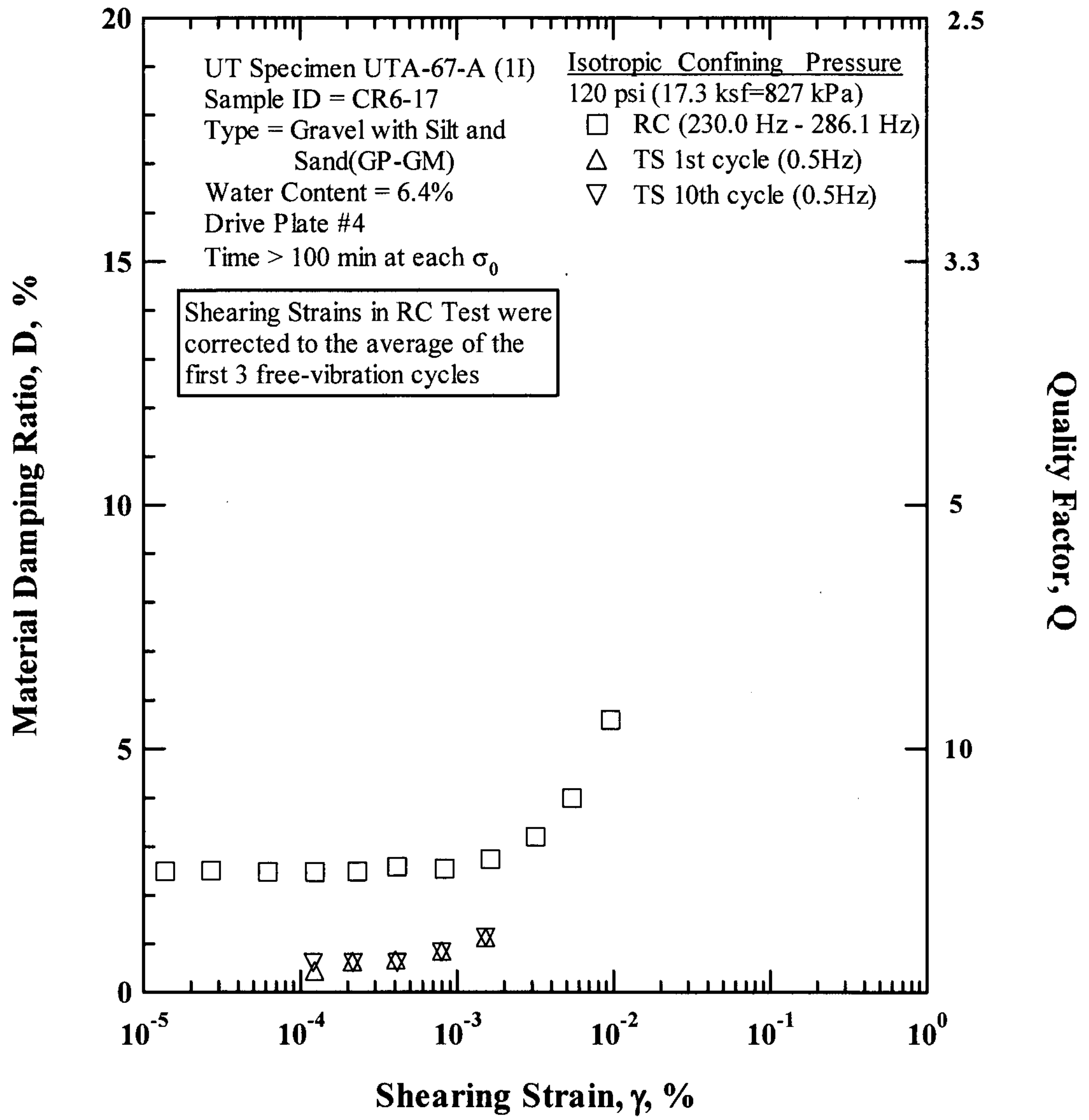


Figure A.25 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

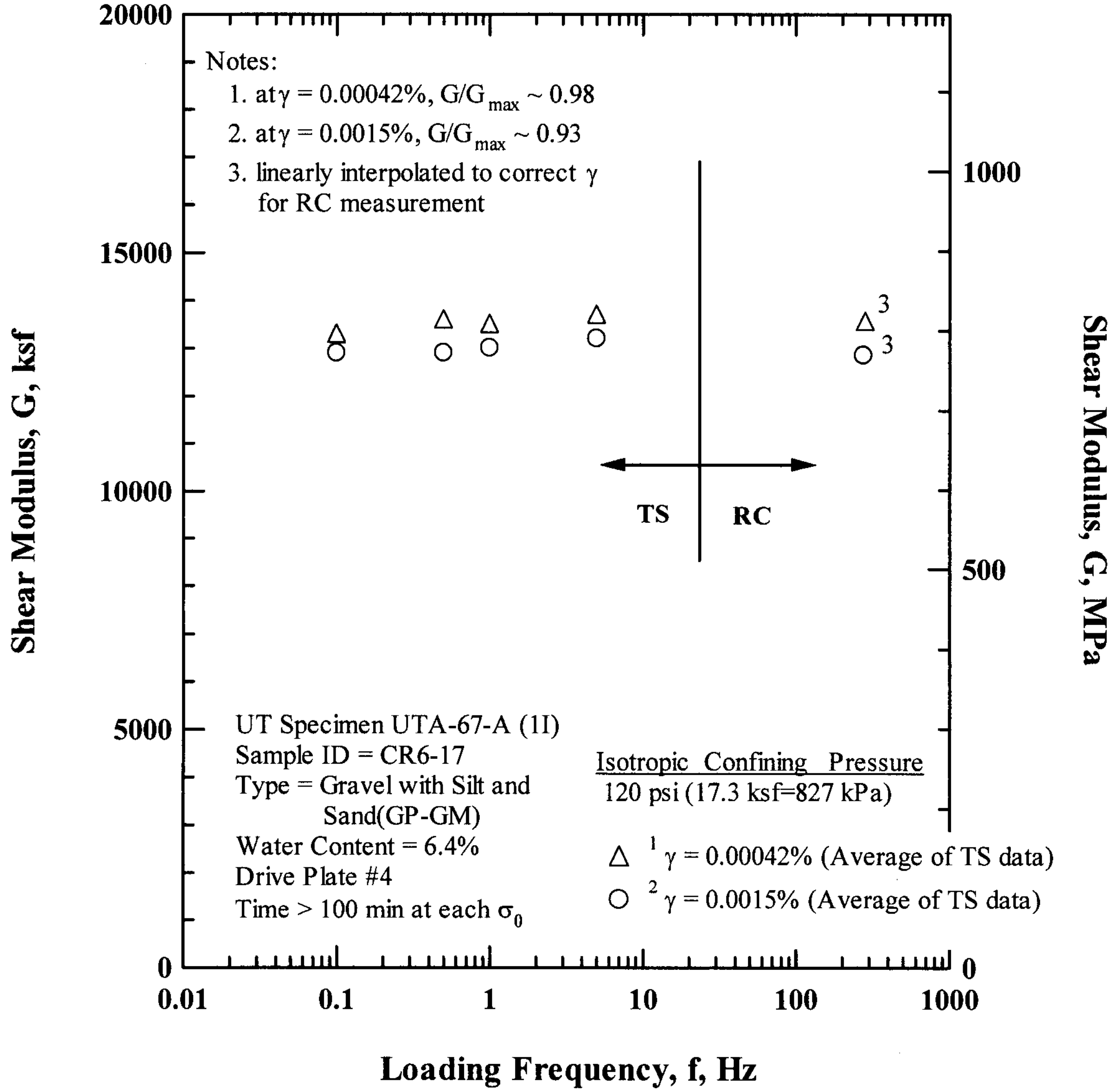


Figure A.26 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

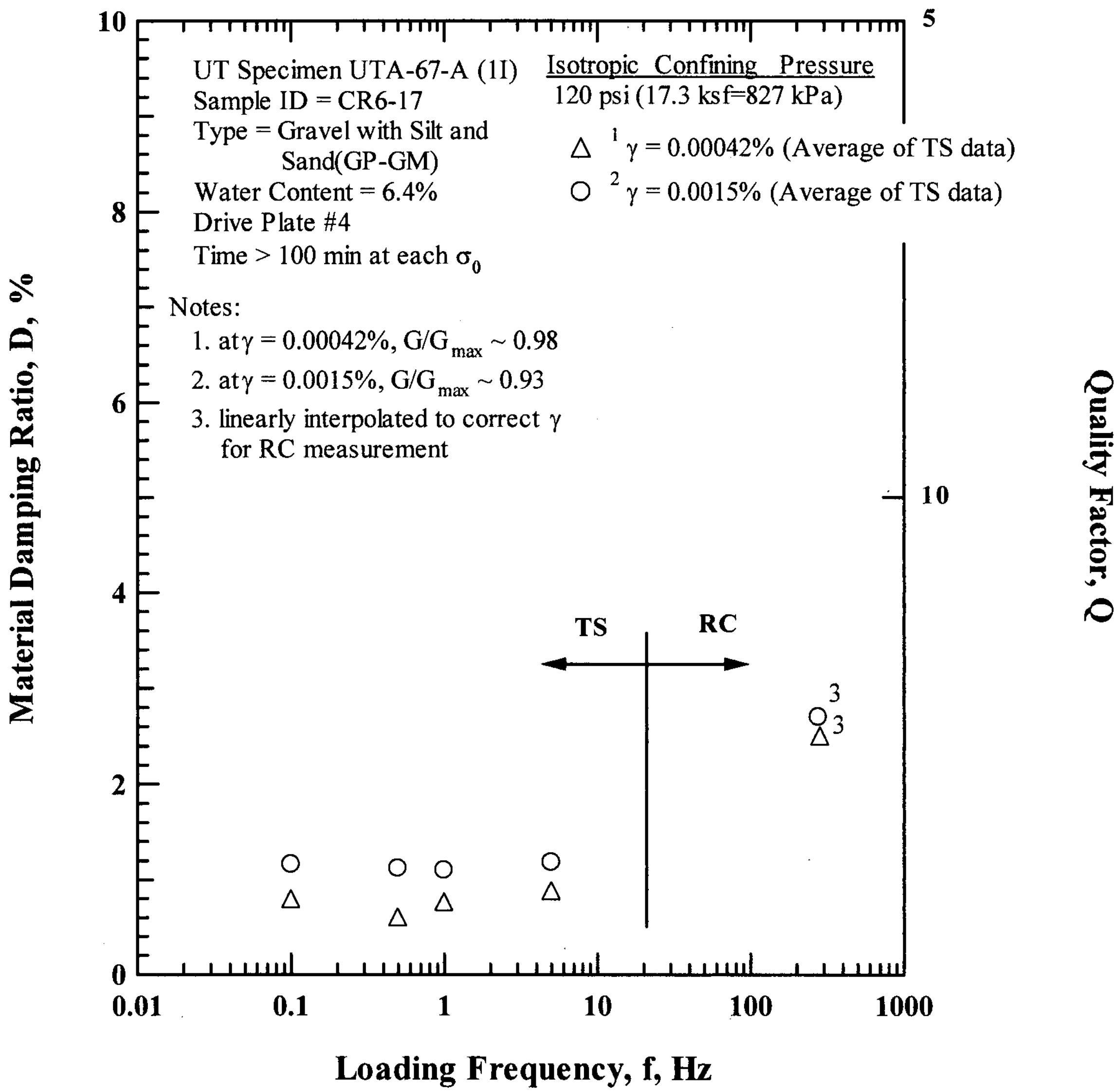


Figure A.27 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1I)

Table A.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-A (1I)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_S	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.5	504	24	1905	91.3	650	5.62	0.24
7.5	1080	52	2680	128.5	770	4.61	0.24
15	2160	103	3851	184.6	922	4.10	0.23
30	4320	207	5846	280.2	1133	3.41	0.23
60	8640	414	9047	433.7	1406	3.03	0.22
120	17280	827	13563	650.2	1715	2.59	0.20
30 (Unloading)	4320	207	6699	321.1	1205	4.08	0.20
7.5 (Unloading)	1080	52	3393	162.6	859	6.08	0.21

Table A.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
6.73E-05	2715	1.00	6.73E-05	-
1.25E-04	2694	0.99	1.25E-04	4.17
2.44E-04	2632	0.97	2.44E-04	4.32
4.81E-04	2529	0.93	4.81E-04	4.55
8.72E-04	2389	0.88	6.66E-04	4.76
1.81E-03	2177	0.80	1.35E-03	5.21
2.71E-03	2029	0.75	1.95E-03	6.00
3.61E-03	1904	0.70	2.53E-03	6.56

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

$^-$ High Noise Level Interfering with Damping Measurement

Table A.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.45E-04	2770	1.00	1.86	1.44E-04	2680	0.97	1.87
2.77E-04	2640	0.95	2.09	2.75E-04	2650	0.96	1.78
5.73E-04	2550	0.92	2.20	5.71E-04	2540	0.92	2.24
1.25E-03	2380	0.86	3.33	1.24E-03	2360	0.85	3.20
2.41E-03	2160	0.78	4.97	2.43E-03	2100	0.76	4.59
5.34E-03	1770	0.64	7.79	5.43E-03	1750	0.63	6.71

Table A.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
6.67E-05	5933	1.00	6.67E-05	3.22
1.30E-04	5909	1.00	1.30E-04	3.21
2.57E-04	5778	0.97	2.12E-04	3.29
4.73E-04	5682	0.96	3.88E-04	3.39
9.36E-04	5470	0.92	7.59E-04	3.62
1.92E-03	5114	0.86	1.52E-03	4.05
3.80E-03	4605	0.78	2.92E-03	4.63
7.47E-03	3839	0.65	5.42E-03	5.81

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table A.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
2.41E-04	6240	1.00	1.14	2.43E-04	6070	0.97	1.12
5.08E-04	5930	0.95	1.37	5.02E-04	5910	0.95	1.32
8.88E-04	5820	0.93	1.68	9.10E-04	5730	0.92	1.71
1.78E-03	5390	0.86	2.52	1.78E-03	5380	0.86	2.48
4.09E-03	4720	0.76	3.58	4.10E-03	4700	0.75	3.55

Table A.6 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 60 psi (8.6 ksf=414 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
4.35E-05	9290	1.00	4.35E-05	2.97
8.49E-05	9289	1.00	7.17E-05	2.86
1.70E-04	9212	0.99	1.43E-04	2.87
3.15E-04	9124	0.98	2.65E-04	2.94
6.51E-04	8977	0.97	5.47E-04	2.95
1.28E-03	8586	0.92	1.05E-03	3.30
2.44E-03	8001	0.86	1.96E-03	3.76
4.89E-03	7072	0.76	3.81E-03	4.37
9.35E-03	6138	0.66	6.85E-03	5.58
1.95E-02	4988	0.54	1.34E-02	6.93

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table A.7 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 120 psi (17.3 ksf = 827 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
1.59E-05	13771	1.00	1.37E-05	2.49
3.13E-05	13757	1.00	2.69E-05	2.50
6.18E-05	13756	1.00	6.18E-05	2.48
1.24E-04	13758	1.00	1.24E-04	2.47
2.31E-04	13676	0.99	2.31E-04	2.49
4.81E-04	13485	0.98	4.13E-04	2.58
9.70E-04	13186	0.96	8.34E-04	2.54
1.92E-03	12629	0.92	1.63E-03	2.73
3.82E-03	11723	0.85	3.17E-03	3.20
6.83E-03	10524	0.76	5.42E-03	4.00
1.31E-02	8898	0.65	9.57E-03	5.59

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table A.8 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 120 psi (17.3 ksf = 827 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.24E-04	13800	1.00	0.42	1.22E-04	13400	0.97	0.60
2.16E-04	13700	0.99	0.61	2.18E-04	13800	1.00	0.60
4.07E-04	13700	0.99	0.65	4.16E-04	13600	0.98	0.60
8.00E-04	13200	0.96	0.83	8.00E-04	13200	0.96	0.81
1.53E-03	12900	0.93	1.11	1.53E-03	12900	0.93	1.12

Table A.9 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa) Unloading

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
4.90E-05	6660	1.00	4.90E-05	3.90
9.68E-05	6660	1.00	9.68E-05	3.74
1.95E-04	6594	0.99	1.95E-04	3.67
3.72E-04	6461	0.97	3.72E-04	3.85
7.94E-04	6170	0.93	6.33E-04	3.92
1.60E-03	5697	0.86	1.24E-03	4.36
3.20E-03	5183	0.78	2.41E-03	5.01
6.49E-03	4472	0.67	4.68E-03	5.92
1.30E-02	3910	0.59	8.96E-03	6.97
2.61E-02	3270	0.49	1.67E-02	8.60

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table A.10 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa) Unloading

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
7.47E-05	3482	1.00	7.47E-05	-
1.46E-04	3463	0.99	1.46E-04	5.90
2.94E-04	3377	0.97	2.13E-04	5.84
5.60E-04	3189	0.92	4.01E-04	6.05
1.17E-03	2896	0.83	8.18E-04	6.53
2.56E-03	2472	0.71	1.73E-03	7.36
5.48E-03	2007	0.58	3.46E-03	8.88
1.23E-02	1558	0.45	7.46E-03	10.03
2.48E-02	1325	0.38	1.35E-02	12.92

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

$^-$ High Noise Level Interfering with Damping Measurement

APPENDIX B

UT Specimen UTA-67-B (2E)
Sample ID : 57-8
Type = Scalped, Reconstituted Gravel (GP*)

Water Content, w = 1.0 %
G_S = 2.833*
Degree of Saturation = 3.5 %
Total Unit Weight, γ_t = 98.7 lb/ft^3
Dry Unit Weight, γ_d = 97.8 lb/ft^3
Target : γ_d= 98.6 lb/ft^3 ± 1 lb/ft^3
w= 1.0 % ± 1.0 %

* **Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

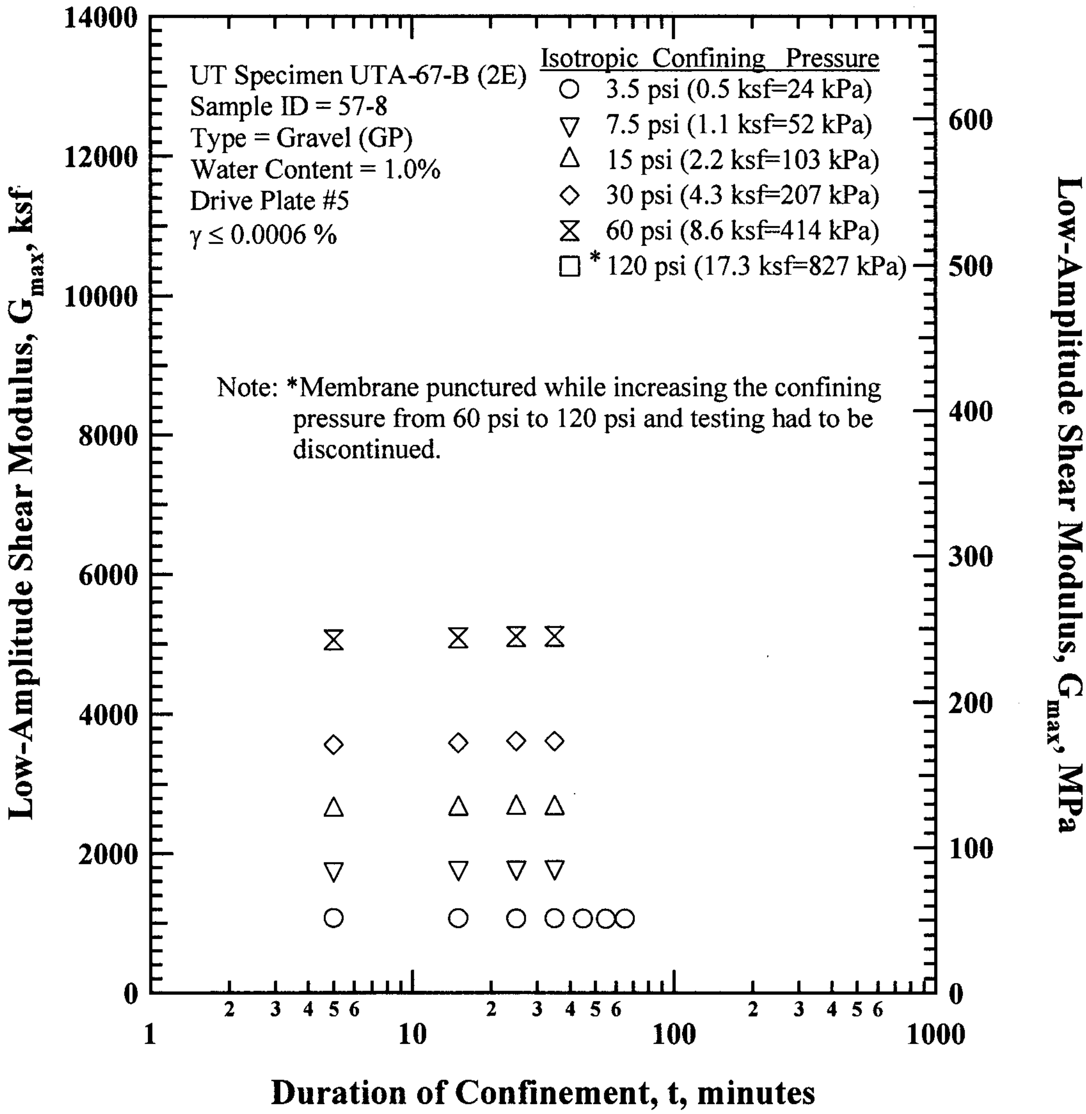


Figure B.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2E)

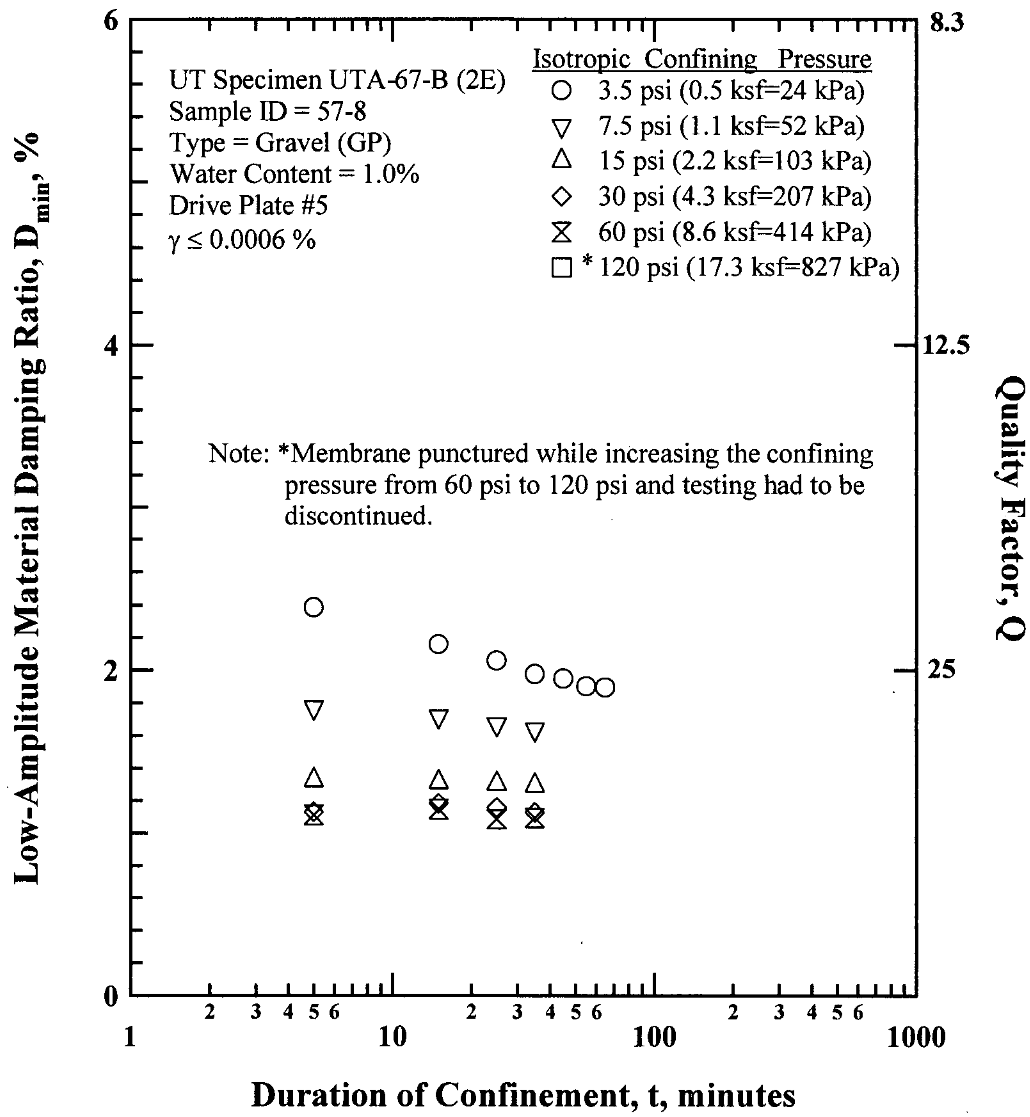


Figure B.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2E)

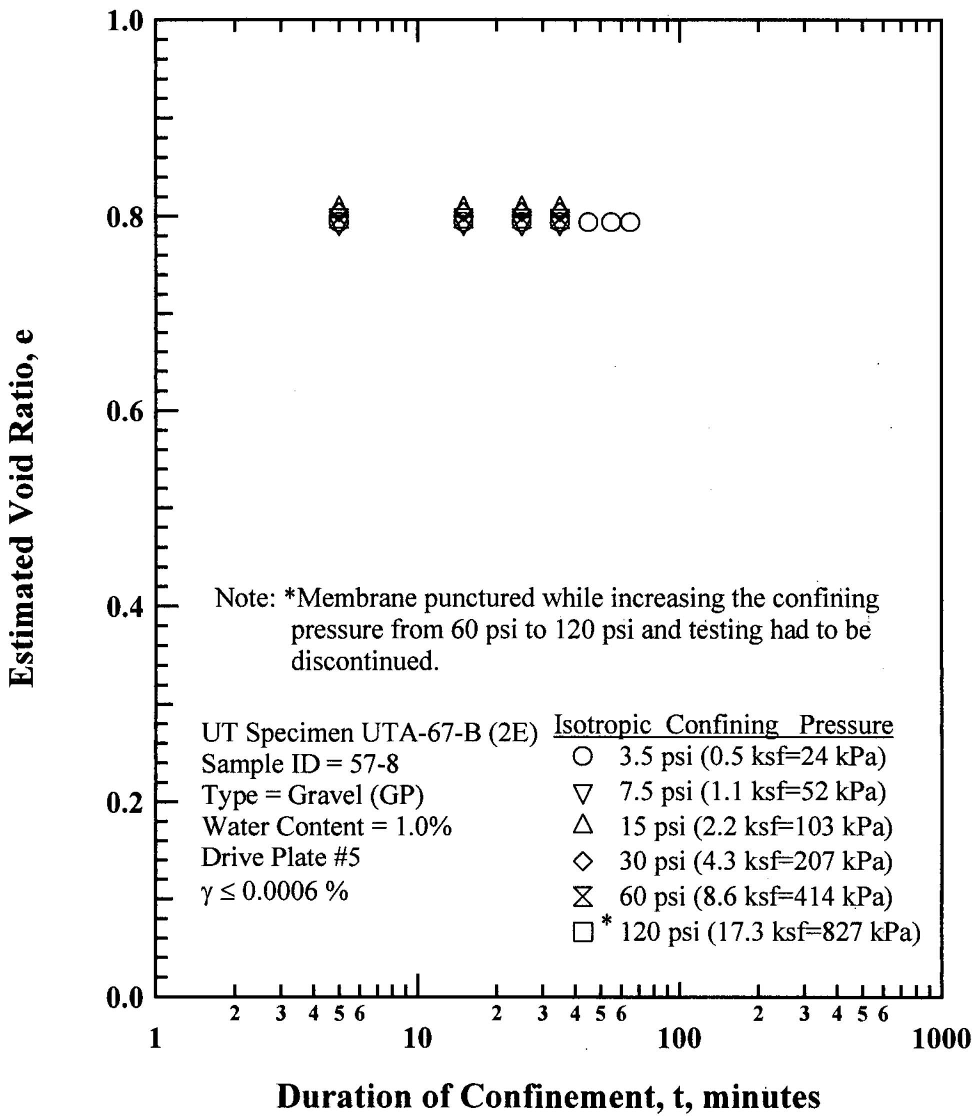


Figure B.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2E)

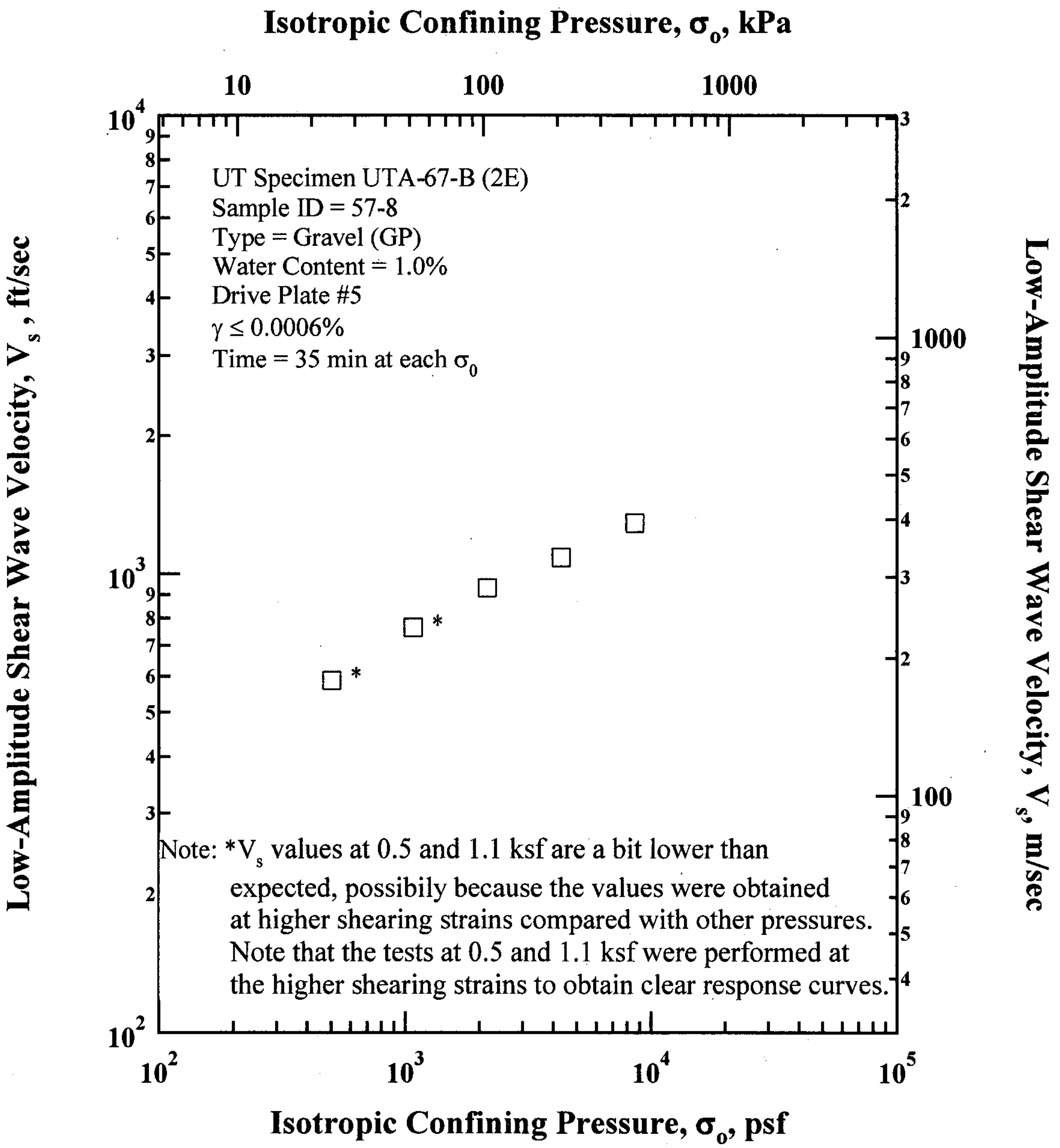


Figure B.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2E)

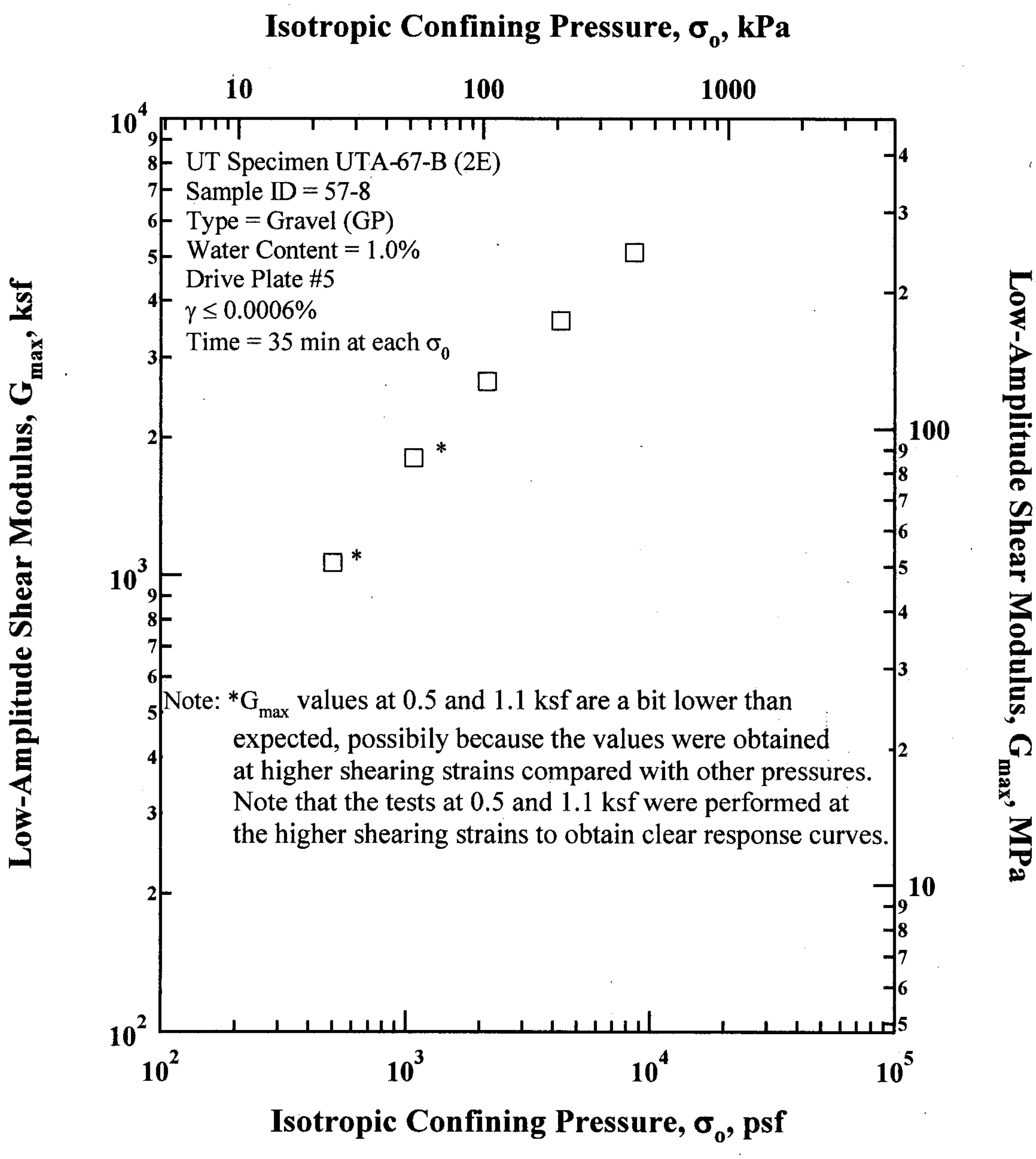


Figure B.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2E)

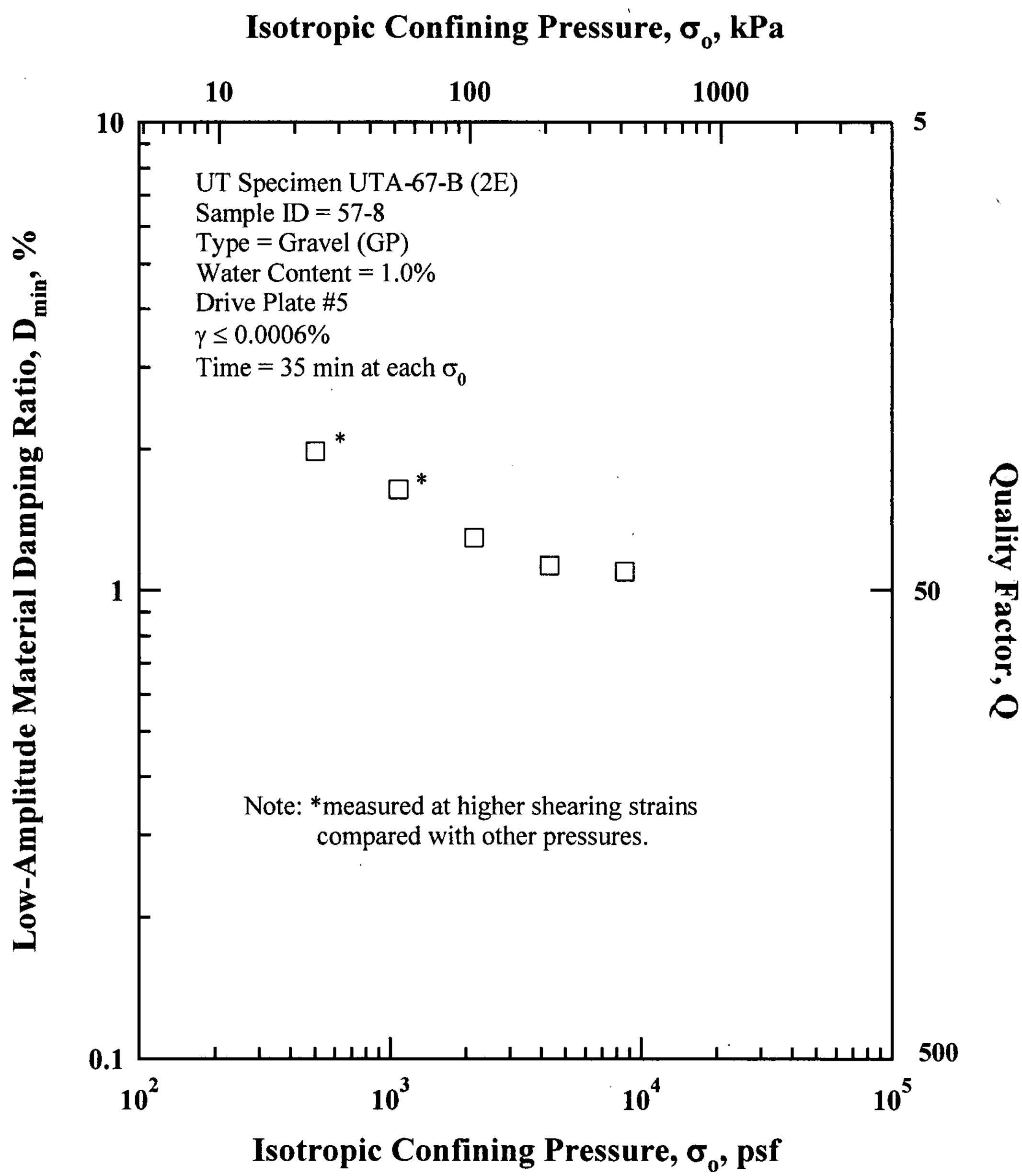


Figure B.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2E)

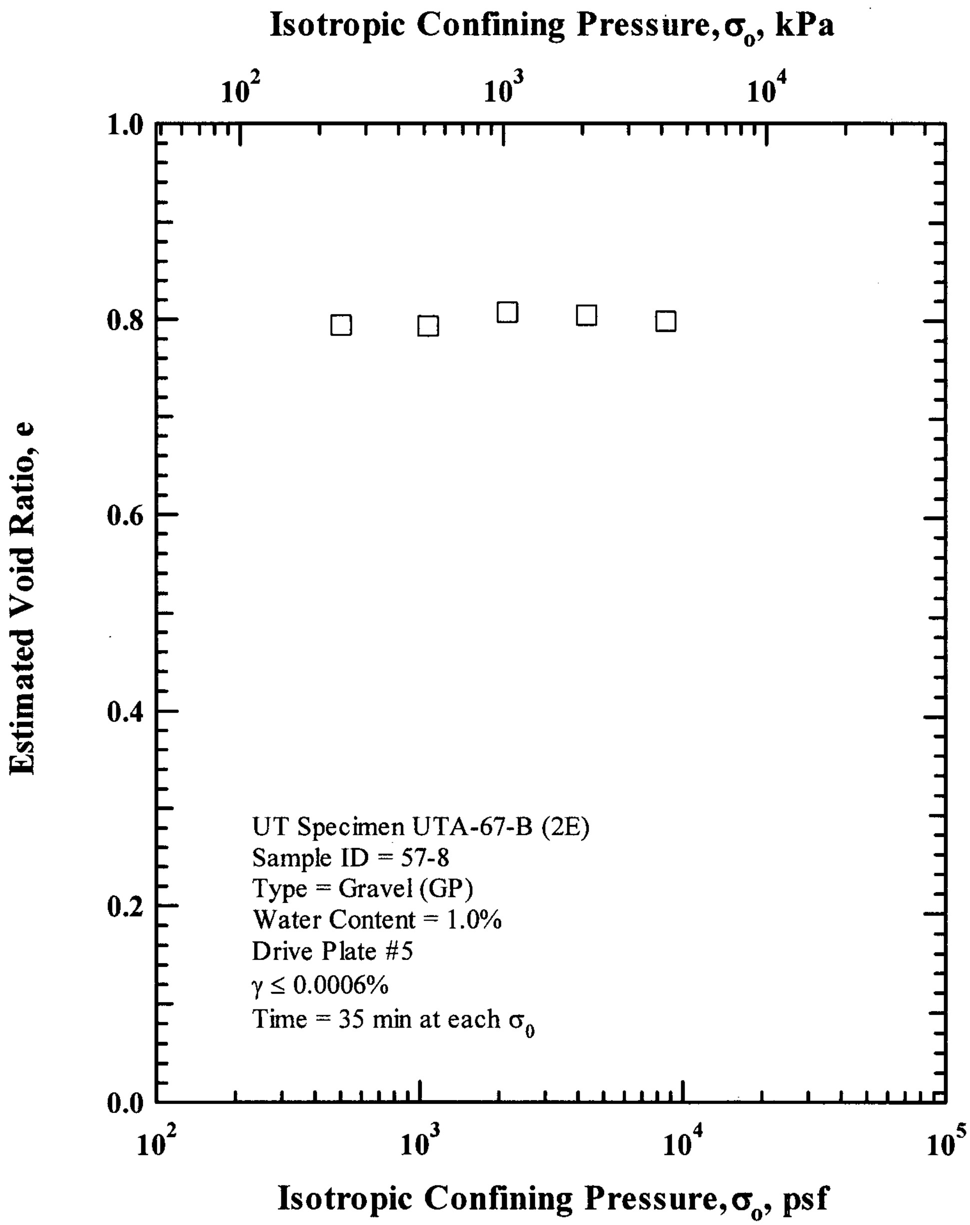


Figure B.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2E)

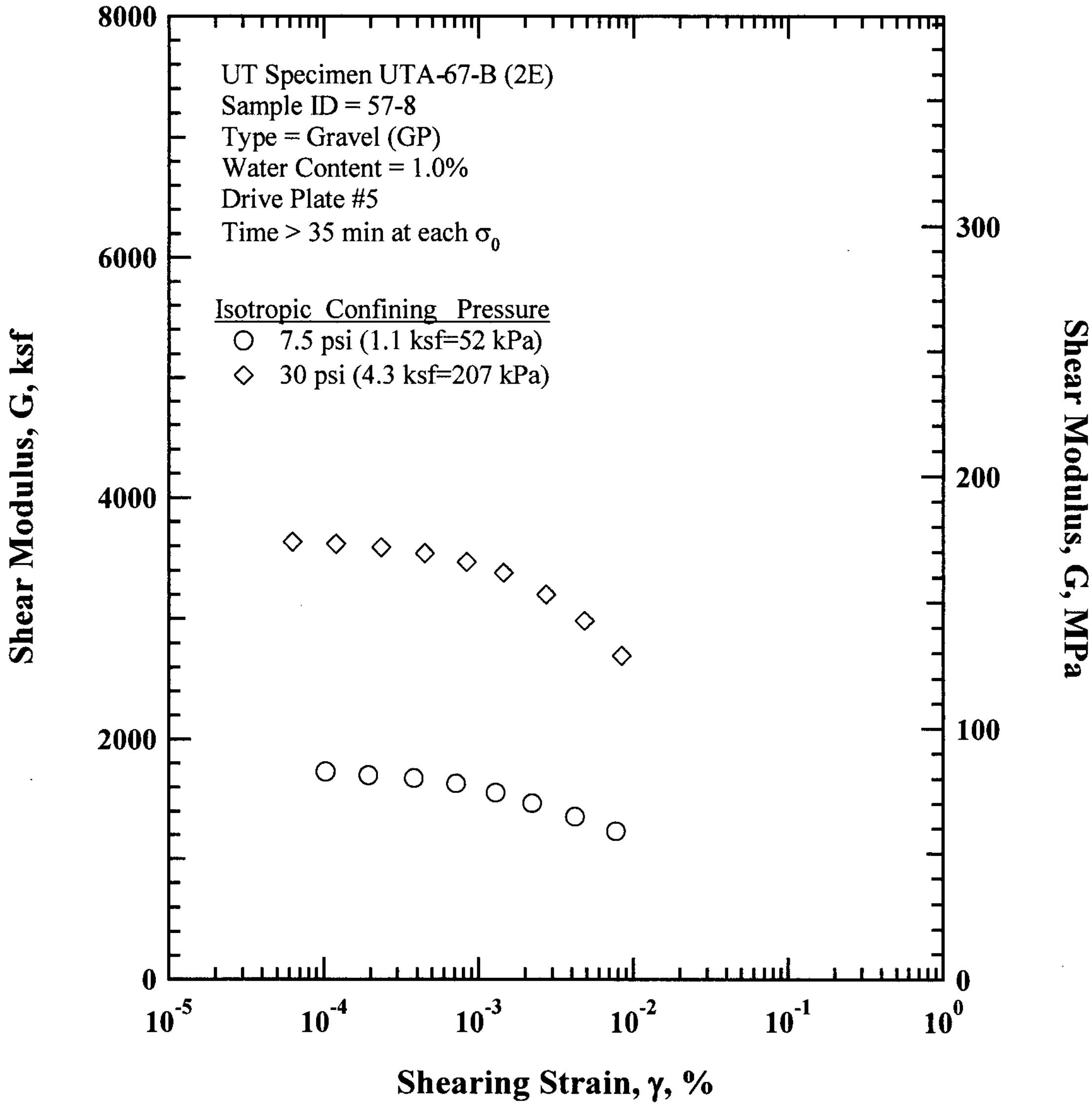


Figure B.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-B (2E)

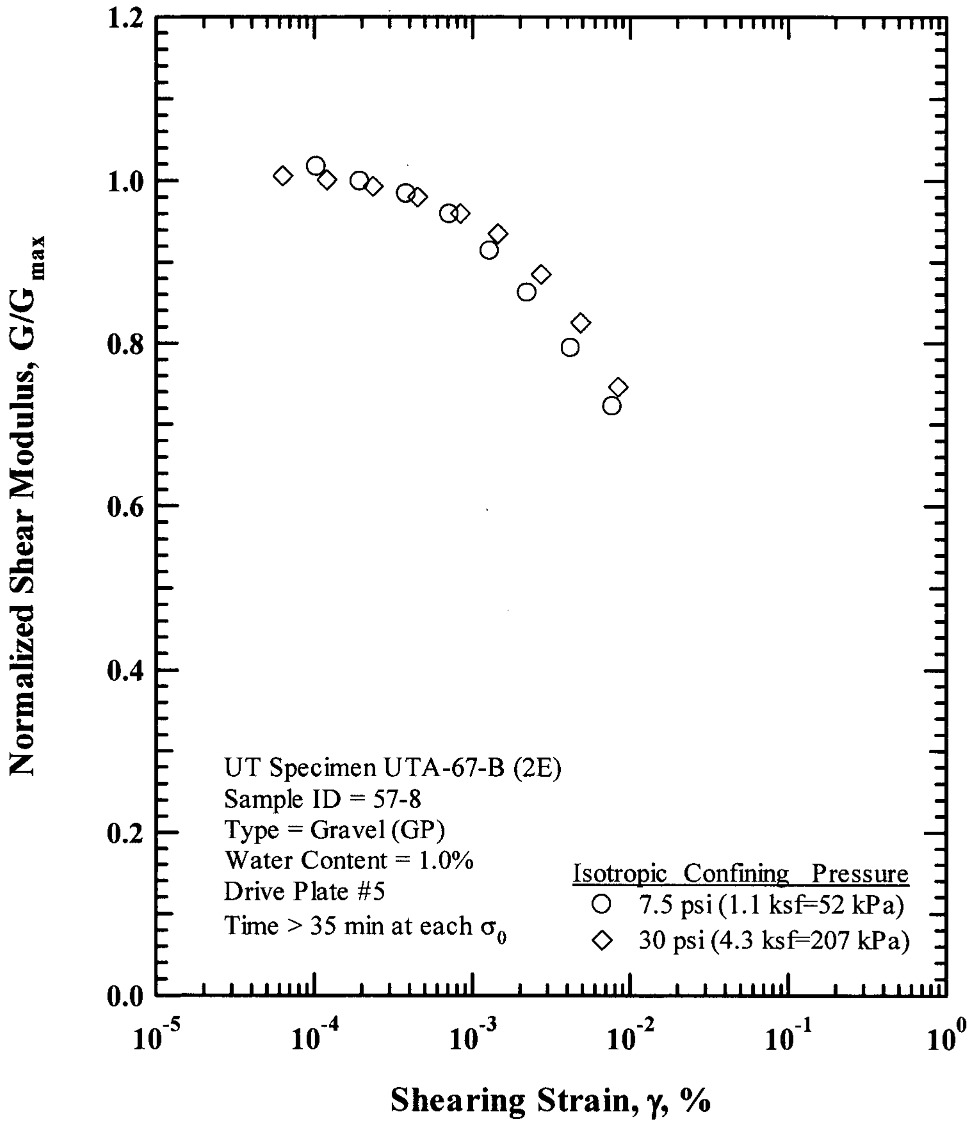


Figure B.9 Variation in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-B (2E)

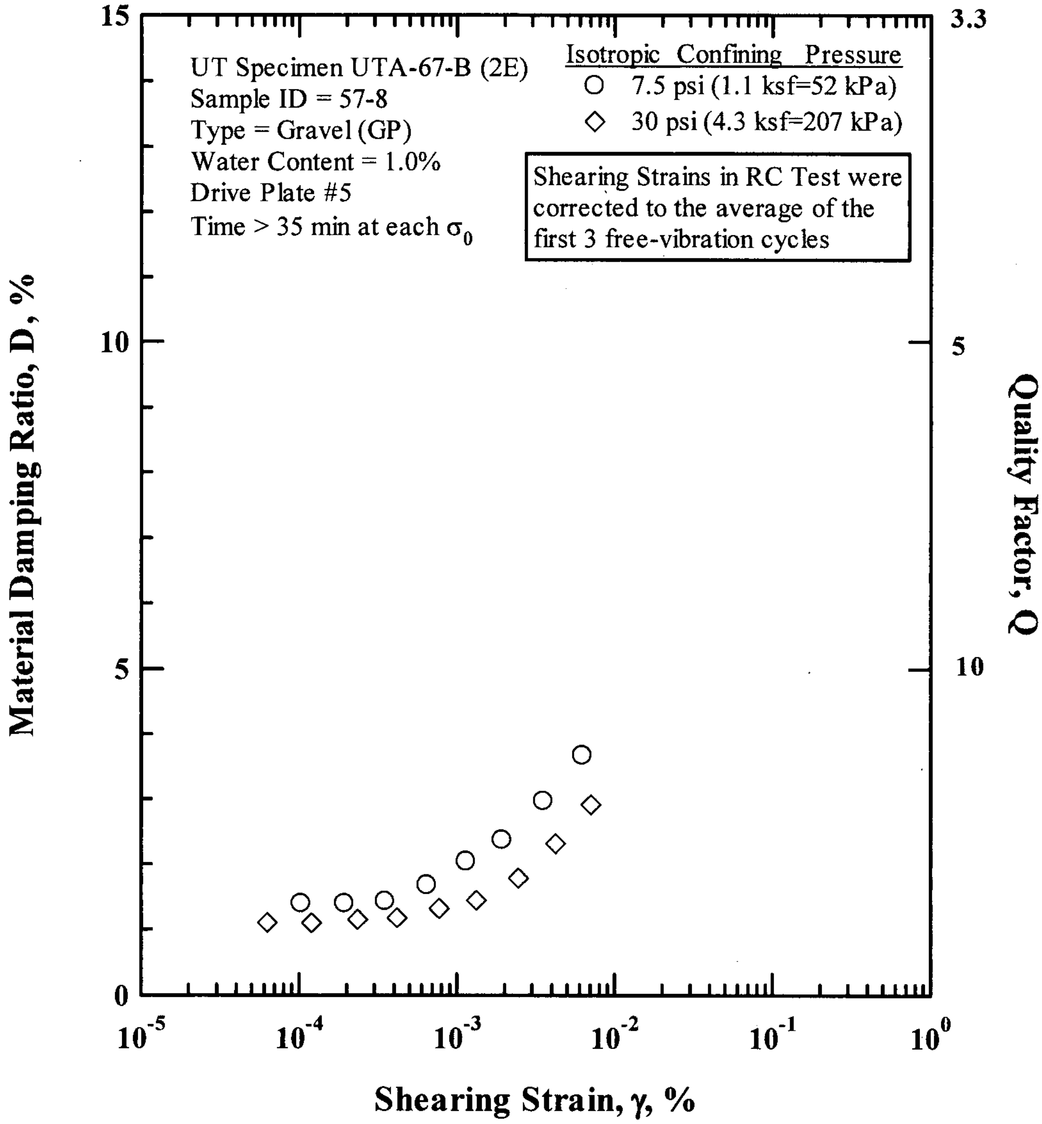


Figure B.10 Variation in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-B (2E)

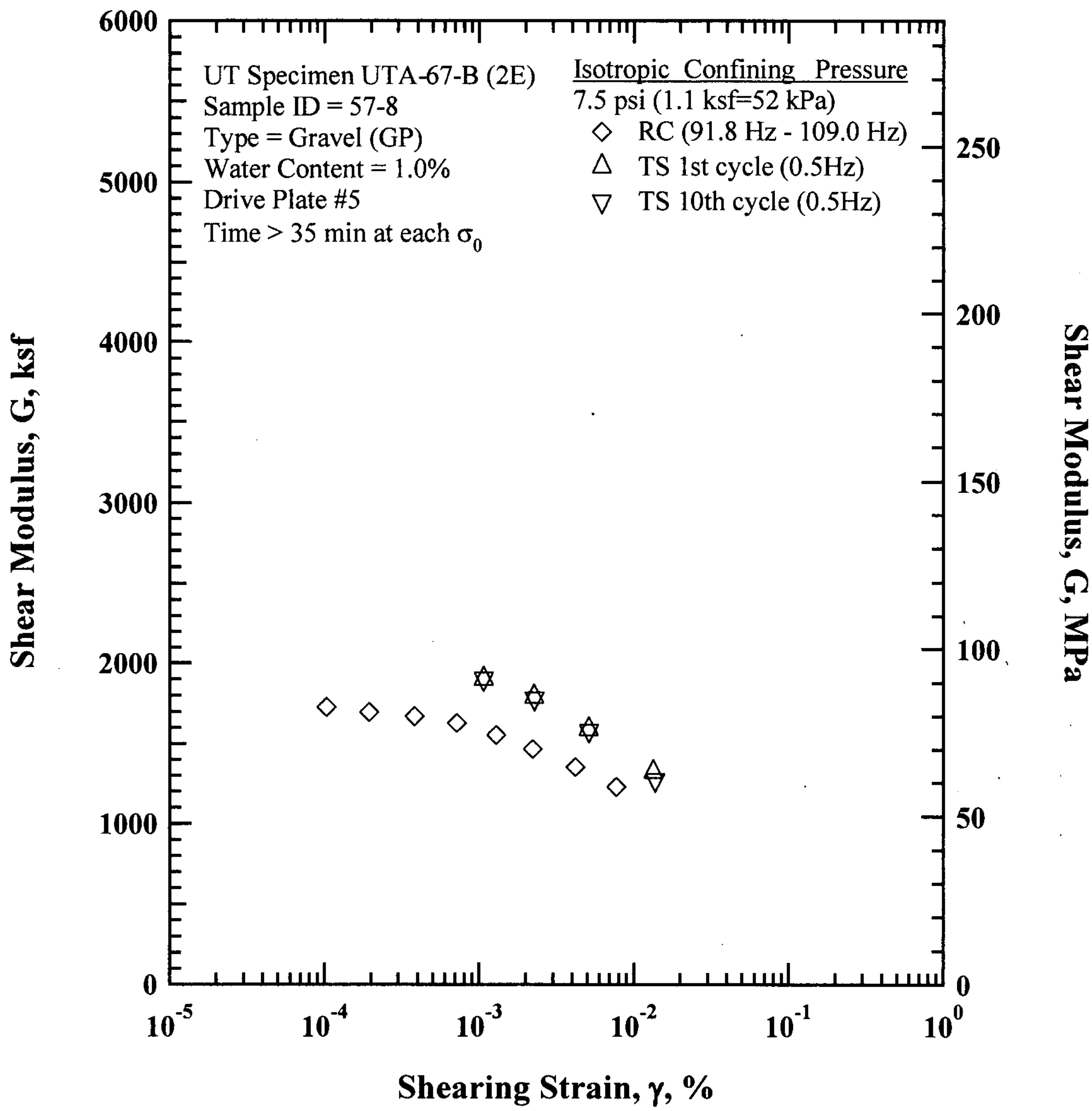


Figure B.11 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

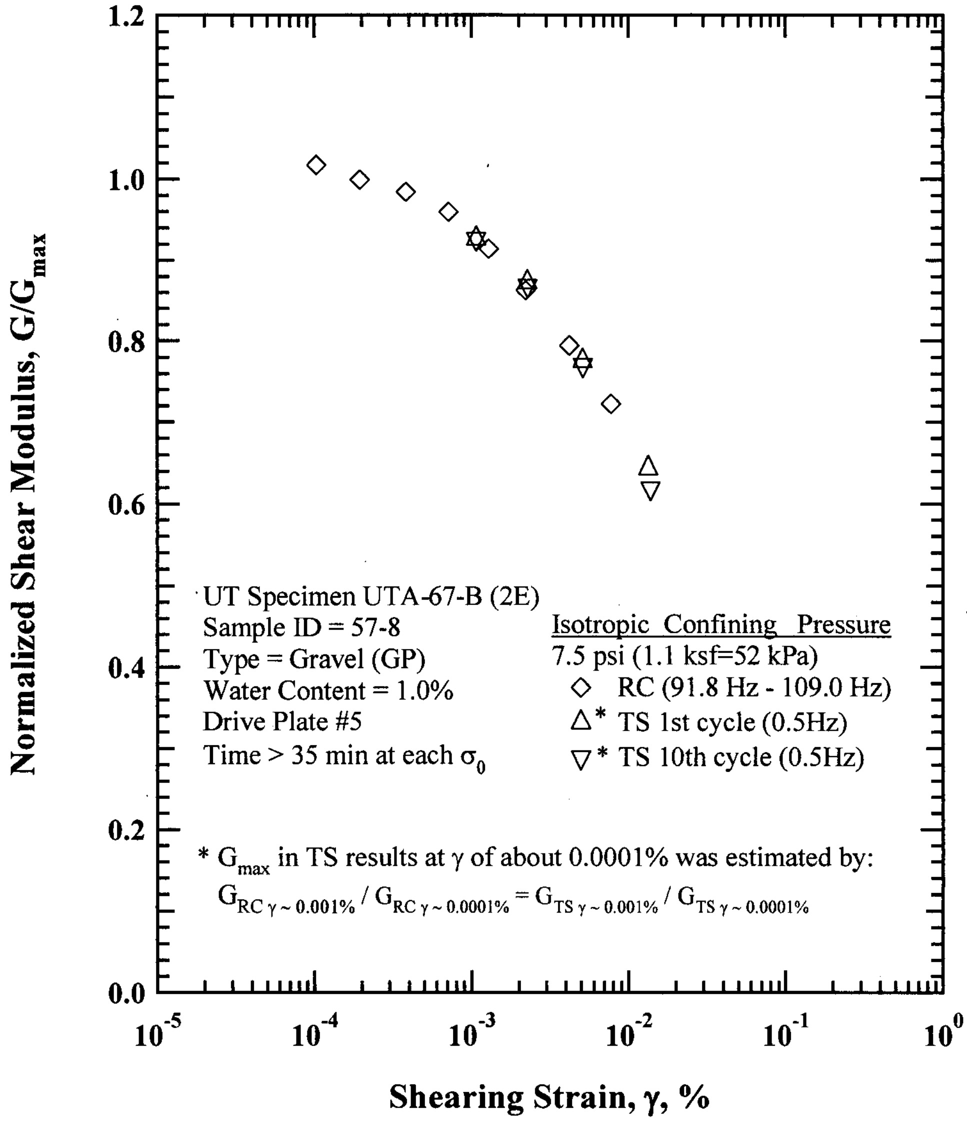


Figure B.12 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

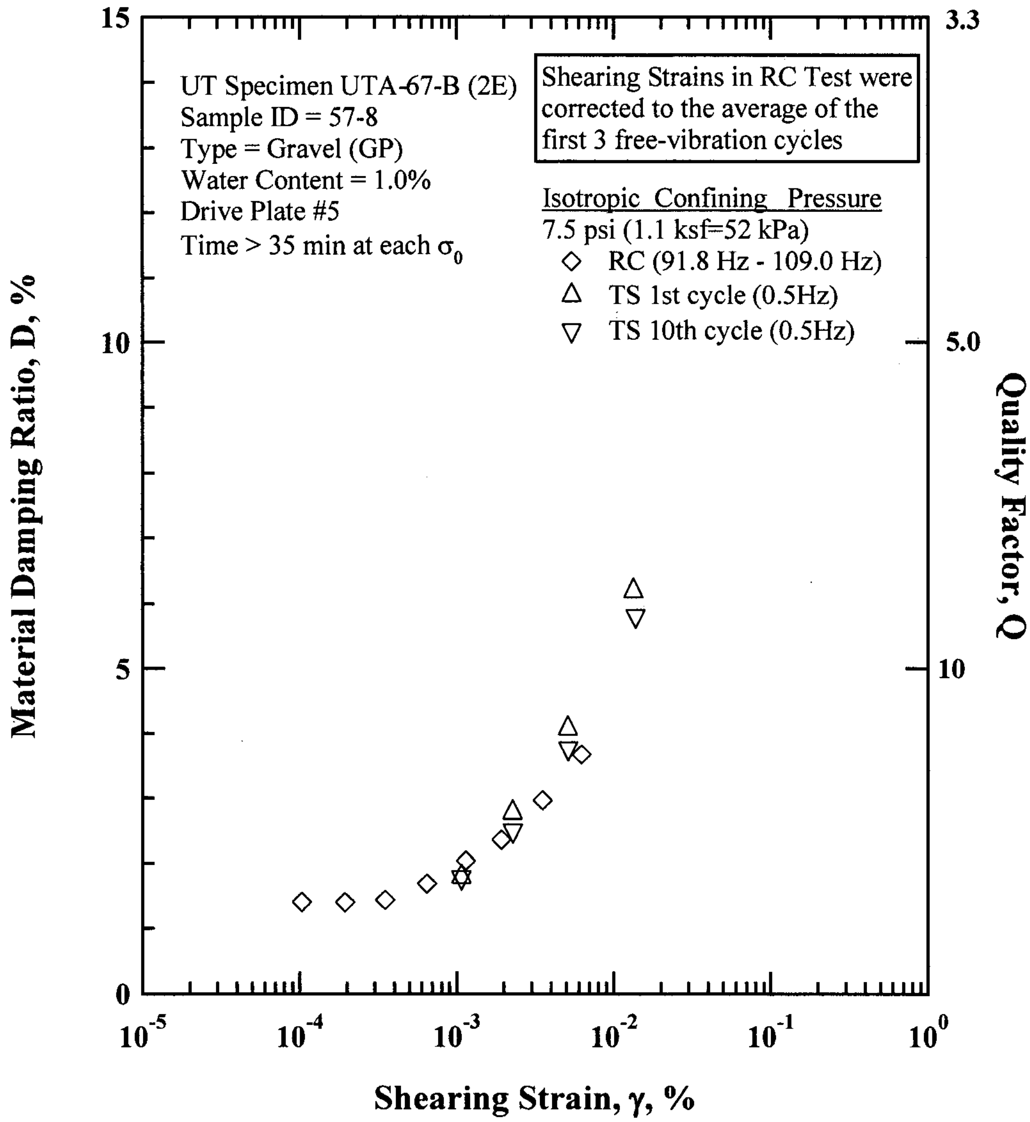


Figure B.13 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

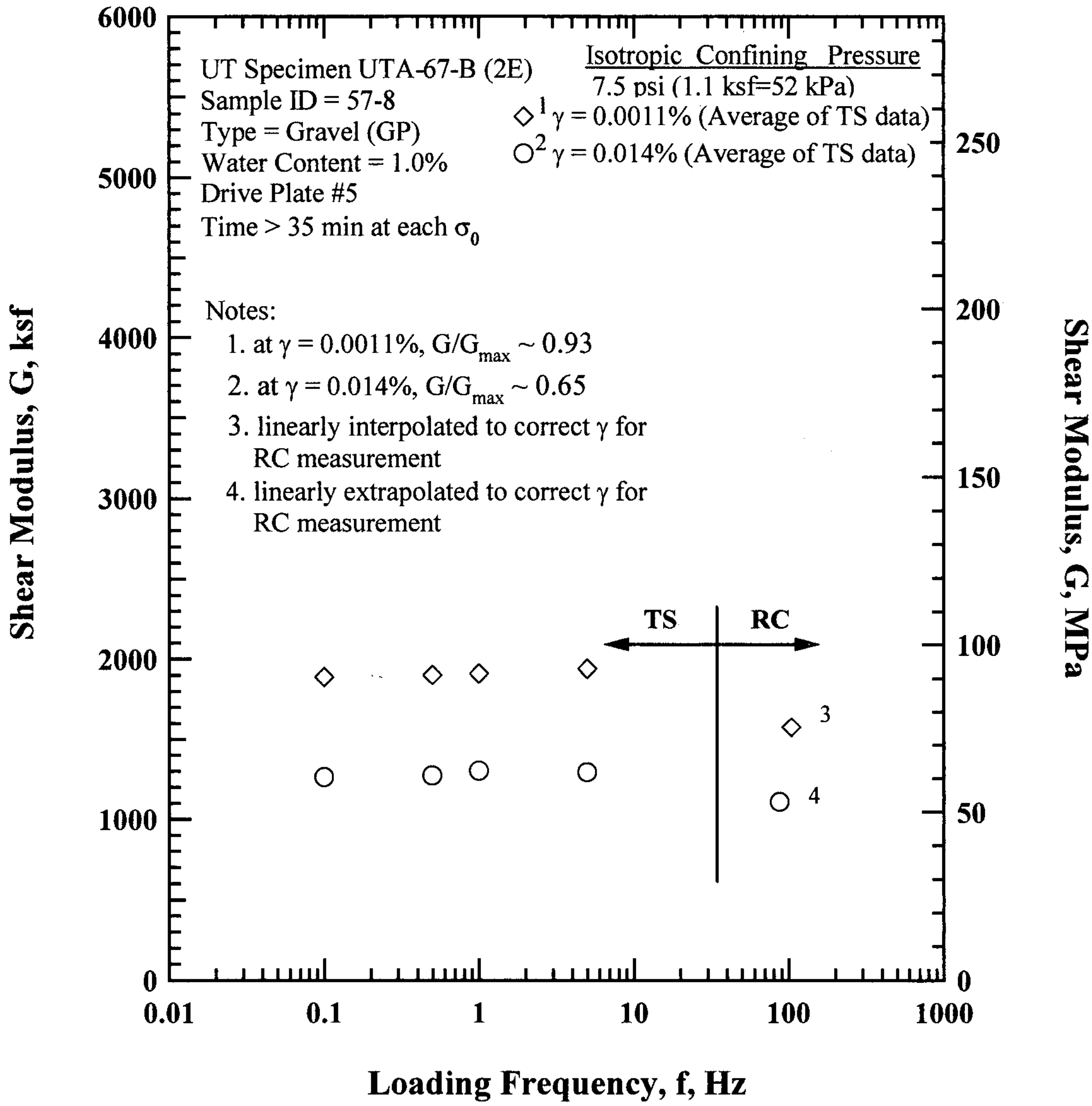


Figure B.14 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

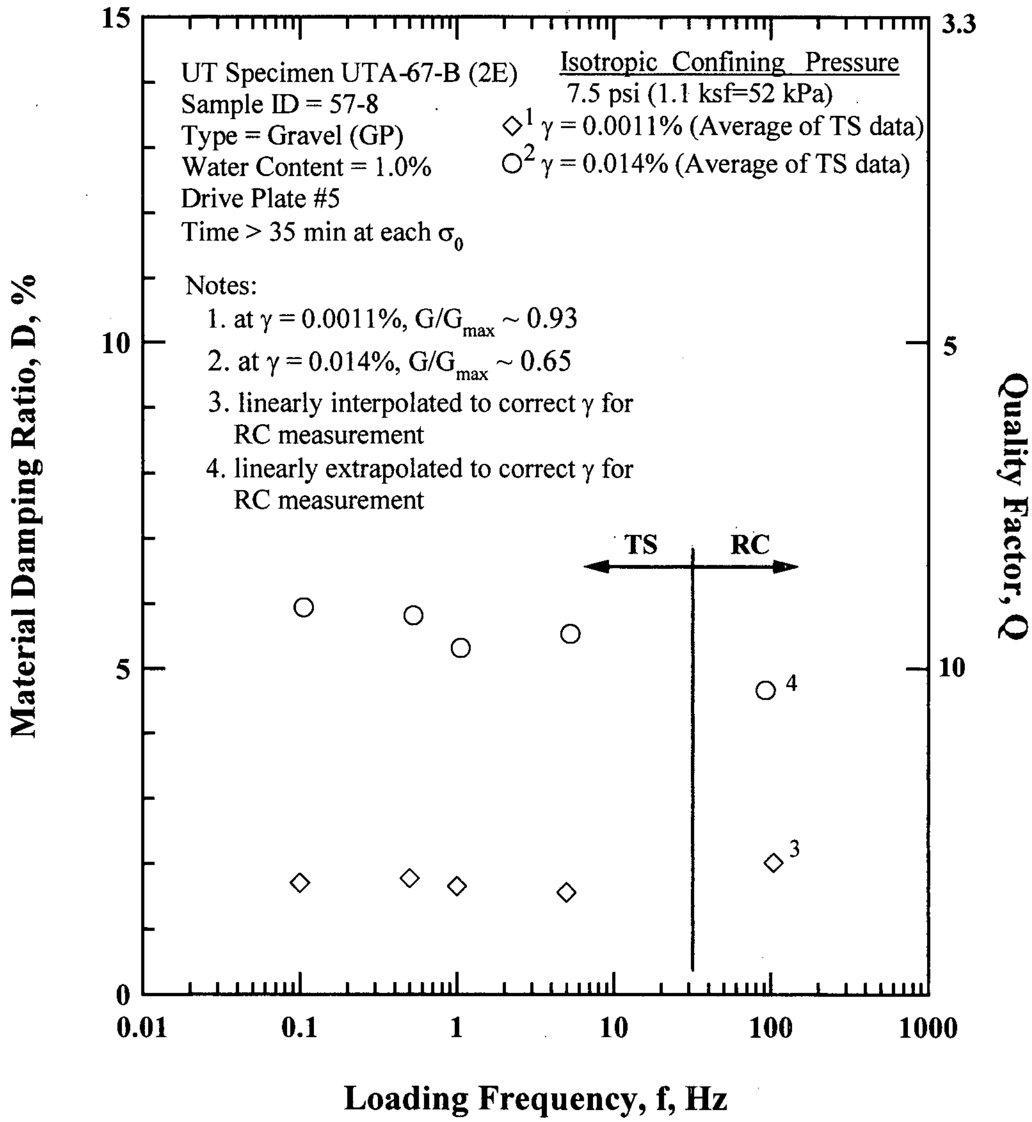


Figure B.15 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

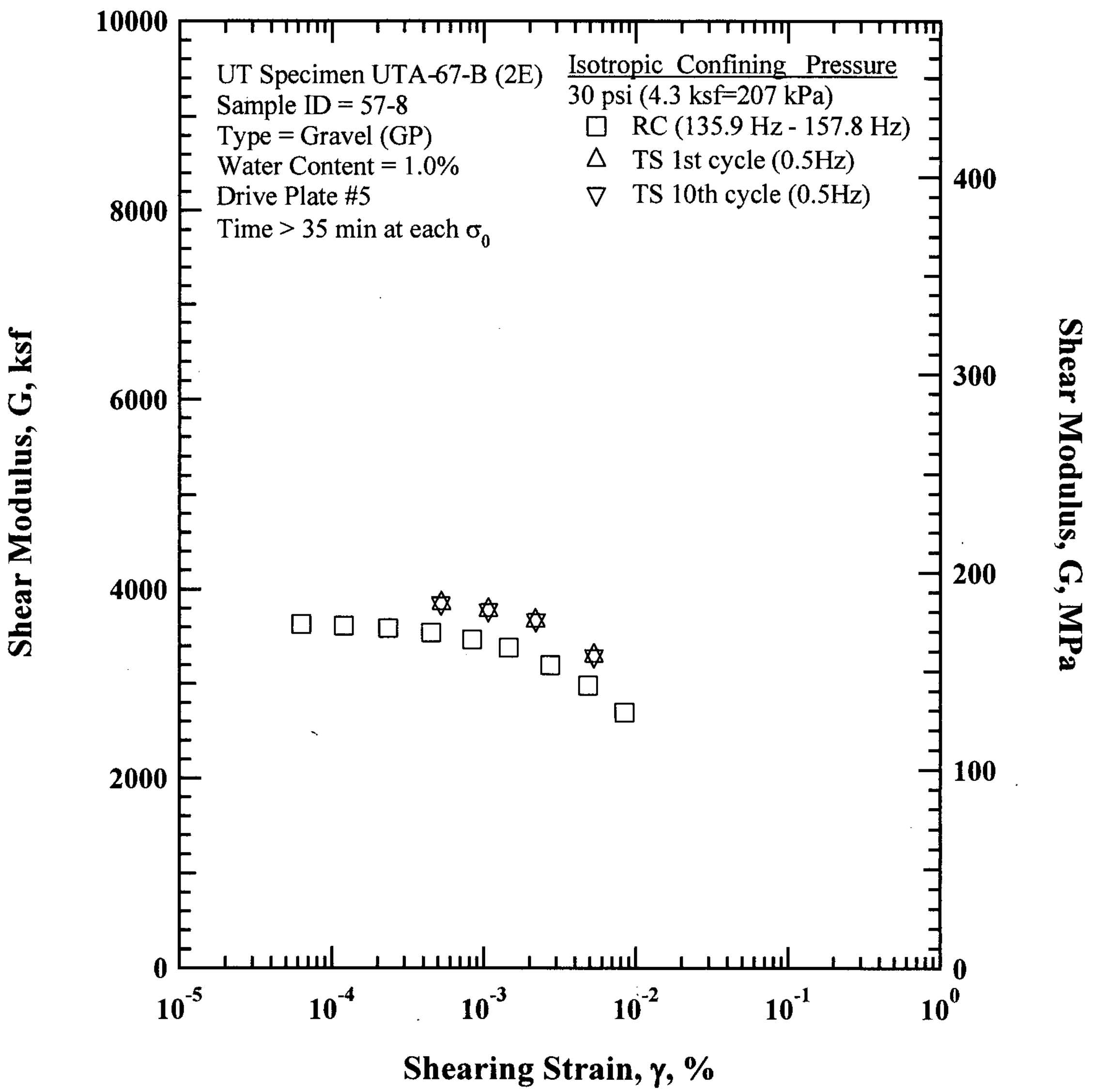


Figure B.16 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

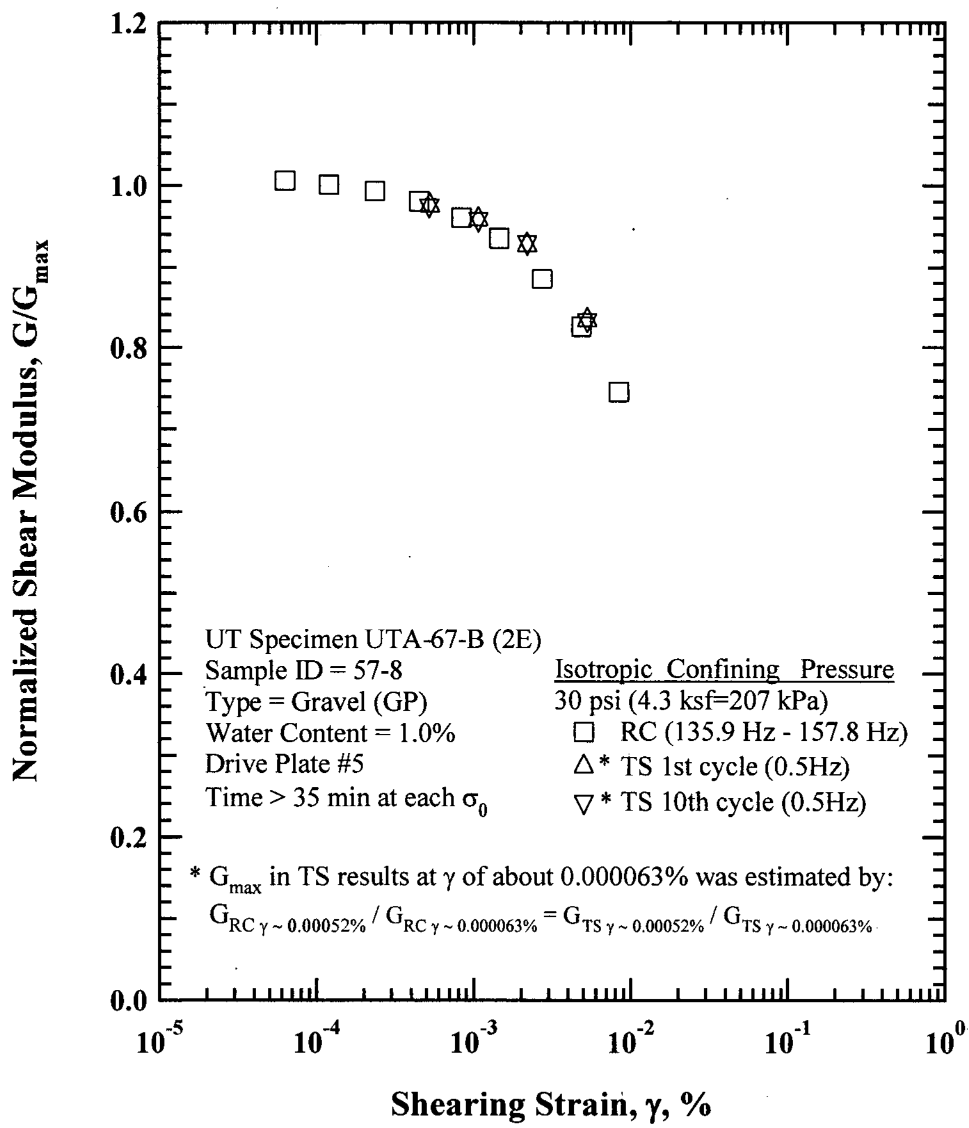


Figure B.17 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

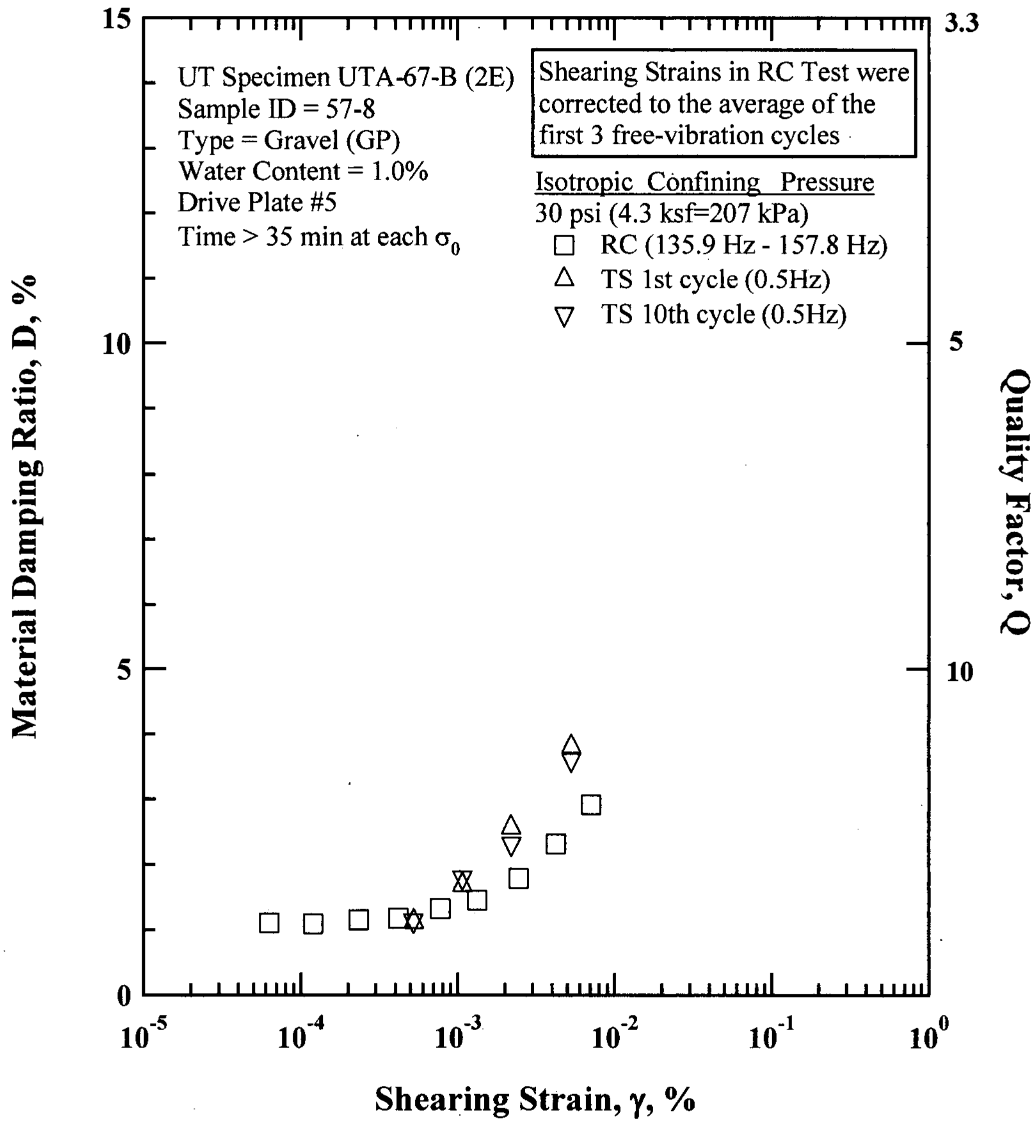


Figure B.18 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

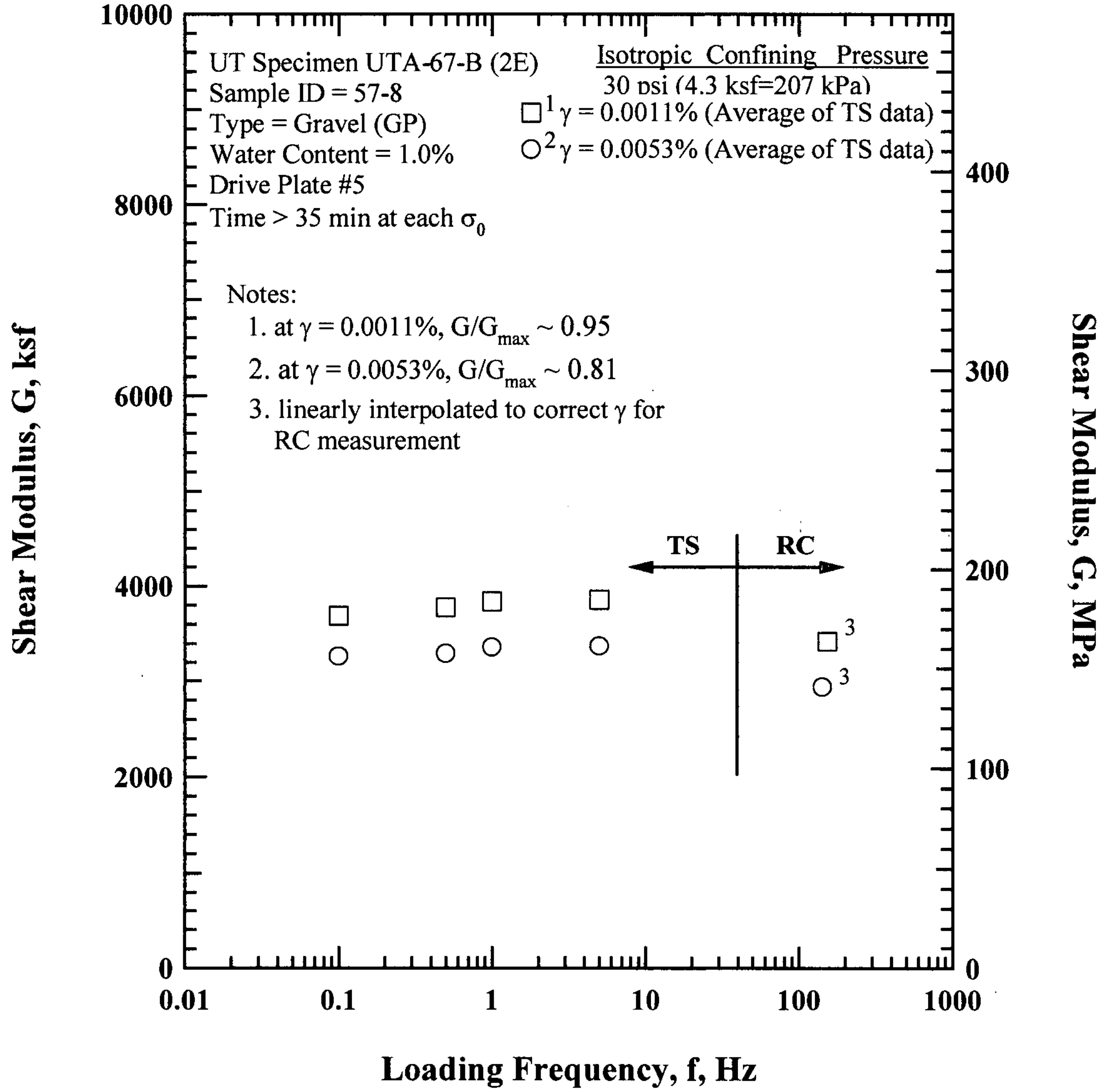


Figure B.19 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

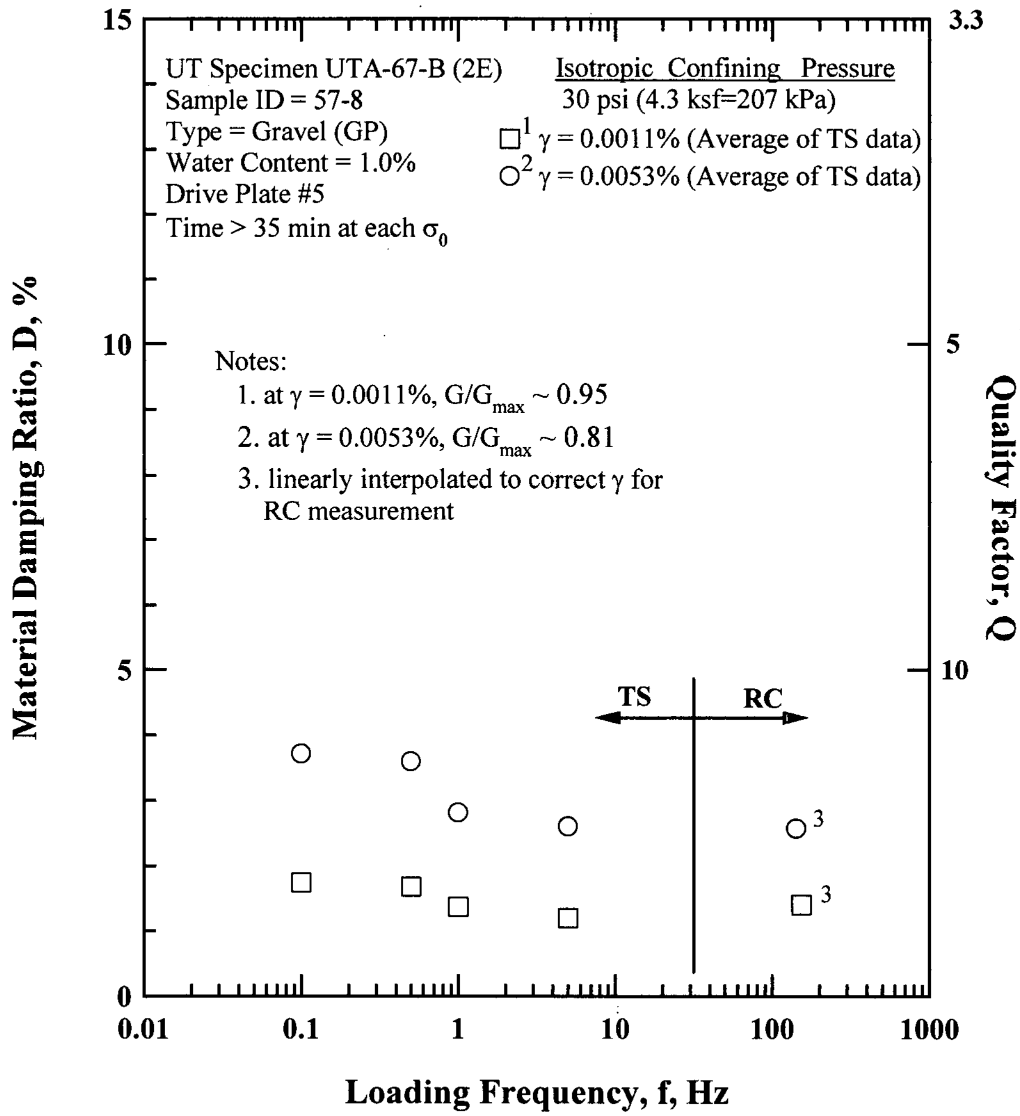


Figure B.20 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2E)

Table B.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-B (2E)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_s	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.5	504	24	1065	51.0	587	1.98	0.79
7.5	1080	52	1801	86.3	763	1.64	0.79
15	2160	104	2654	127.2	930	1.29	0.81
30	4320	207	3613	173.2	1084	1.13	0.80
60	8640	414	5107	244.8	1287	1.09	0.80

Table B.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-B (2E); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
1.03E-04	1728	1.01	1.03E-04	1.40
1.95E-04	1697	0.99	1.95E-04	1.39
3.82E-04	1672	0.98	3.51E-04	1.43
7.16E-04	1629	0.95	6.47E-04	1.68
1.29E-03	1552	0.91	1.14E-03	2.04
2.23E-03	1464	0.85	1.93E-03	2.36
4.21E-03	1349	0.79	3.54E-03	2.96
7.74E-03	1226	0.72	6.26E-03	3.67

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table B.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-B (2E); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.07E-03	1900	0.93	1.78	1.07E-03	1900	0.93	1.77
2.27E-03	1790	0.87	2.77	2.28E-03	1780	0.87	2.50
5.11E-03	1590	0.77	4.07	5.14E-03	1580	0.77	3.76
1.34E-02	1320	0.64	6.19	1.38E-02	1270	0.62	5.81

Table B.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-B (2E); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
6.31E-05	3632	1.00	6.31E-05	1.10
1.20E-04	3614	1.00	1.20E-04	1.09
2.35E-04	3587	0.99	2.35E-04	1.15
4.50E-04	3538	0.98	4.19E-04	1.18
8.39E-04	3467	0.96	7.74E-04	1.32
1.45E-03	3377	0.93	1.33E-03	1.45
2.73E-03	3197	0.88	2.45E-03	1.78
4.86E-03	2981	0.82	4.23E-03	2.31
8.42E-03	2692	0.74	7.09E-03	2.91

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table B.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-B (2E); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
5.26E-04	3850	0.98	1.12	5.21E-04	3850	0.98	1.14
1.07E-03	3780	0.96	1.68	1.07E-03	3780	0.96	1.79
2.19E-03	3660	0.93	2.56	2.20E-03	3670	0.93	2.31
5.30E-03	3290	0.83	3.80	5.30E-03	3290	0.83	3.59

APPENDIX C

UT Specimen UTA-67-C (3E)
Sample ID : GAB-10
Type = Scalped, Reconstituted Gravel with Silt and Sand (GP-GM*)

Water Content, w = 5.8 %

G_S = 2.824*

Degree of Saturation = 61.5 %

Total Unit Weight, γ_t = 147.3 lb/ft^3

Dry Unit Weight, γ_d = 139.2 lb/ft^3

Target : γ_d= 138.6 lb/ft^3 ± 1 lb/ft^3

w= 6.4 % ± 1.0 %

* **Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

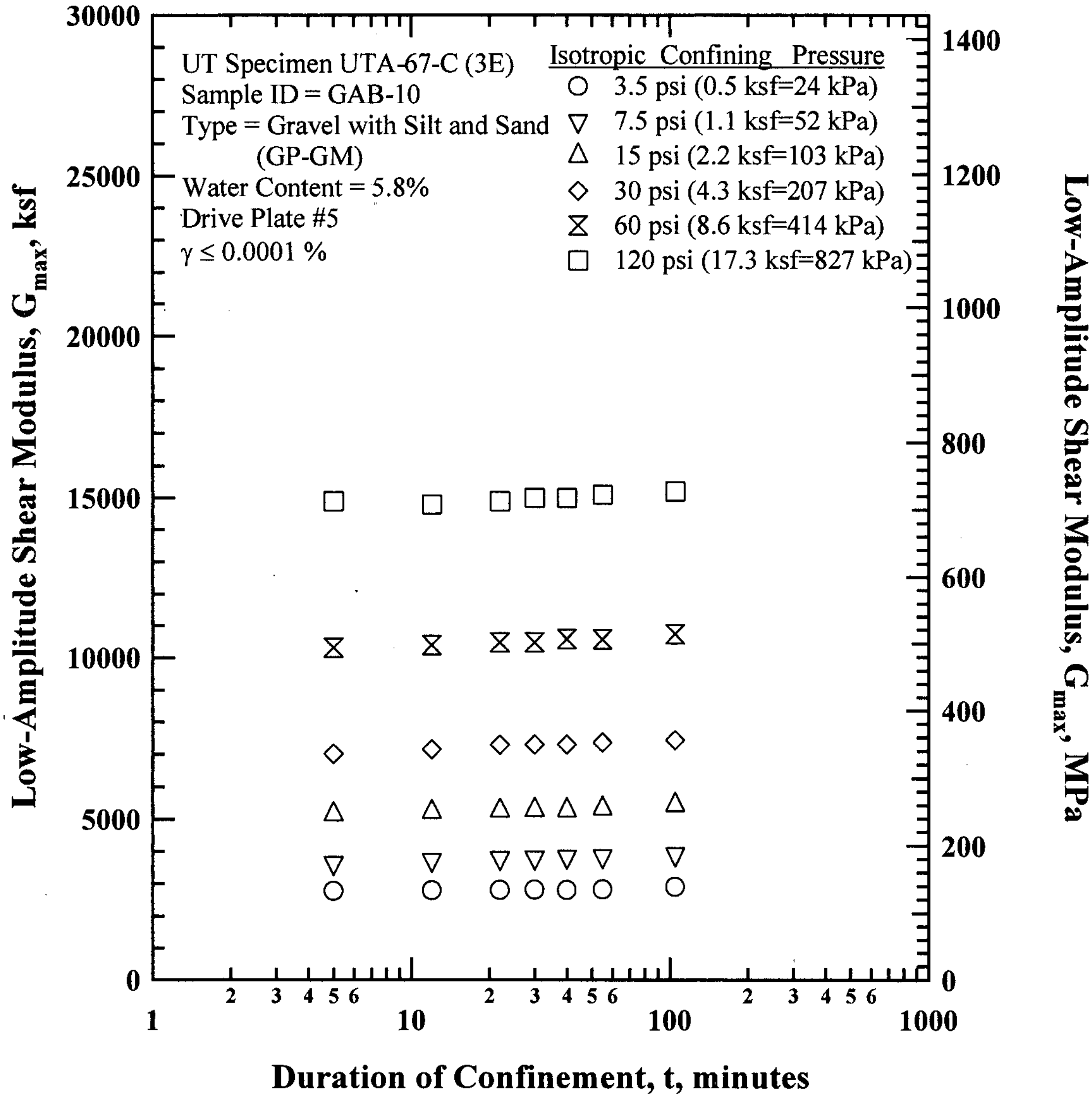


Figure C.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3E)

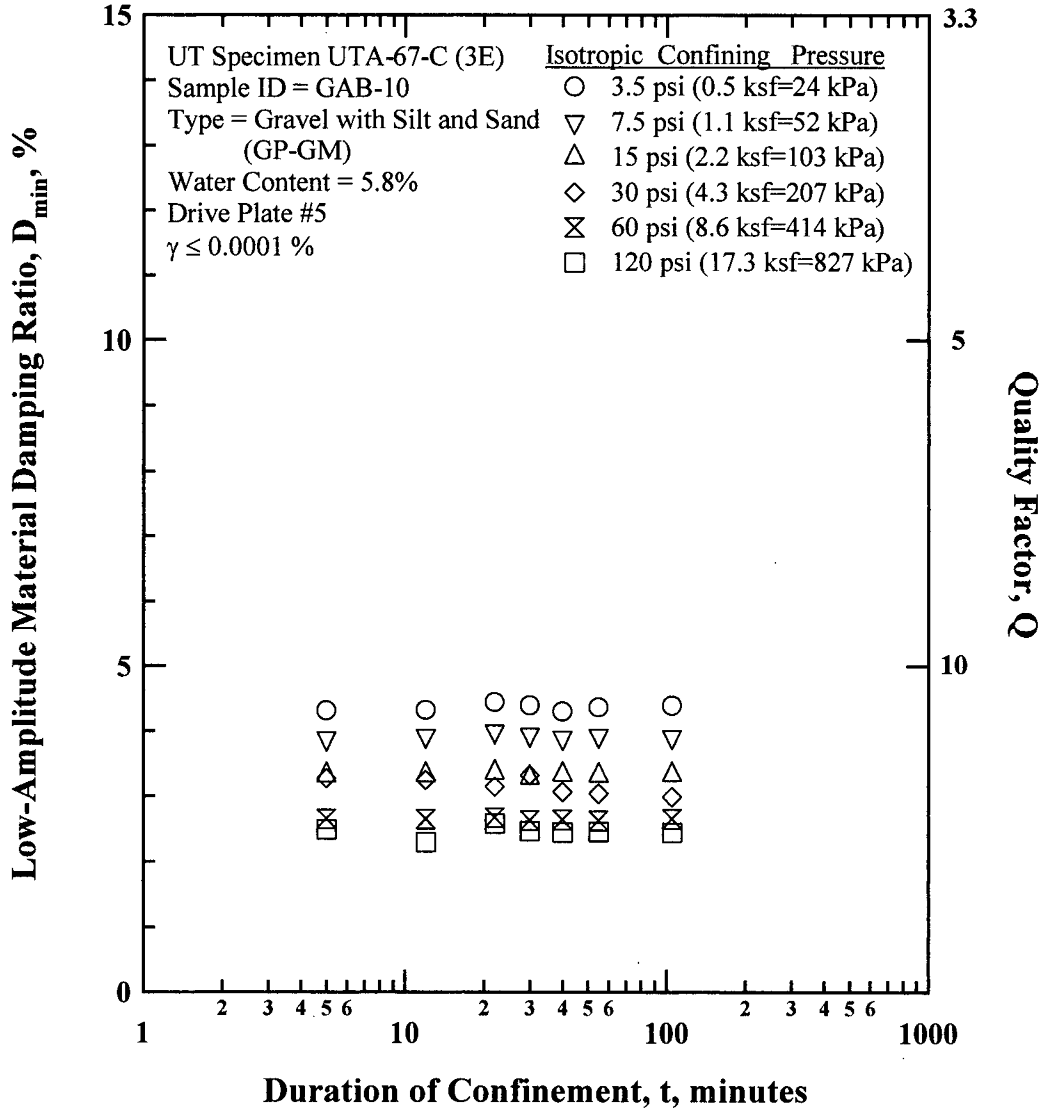


Figure C.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3E)

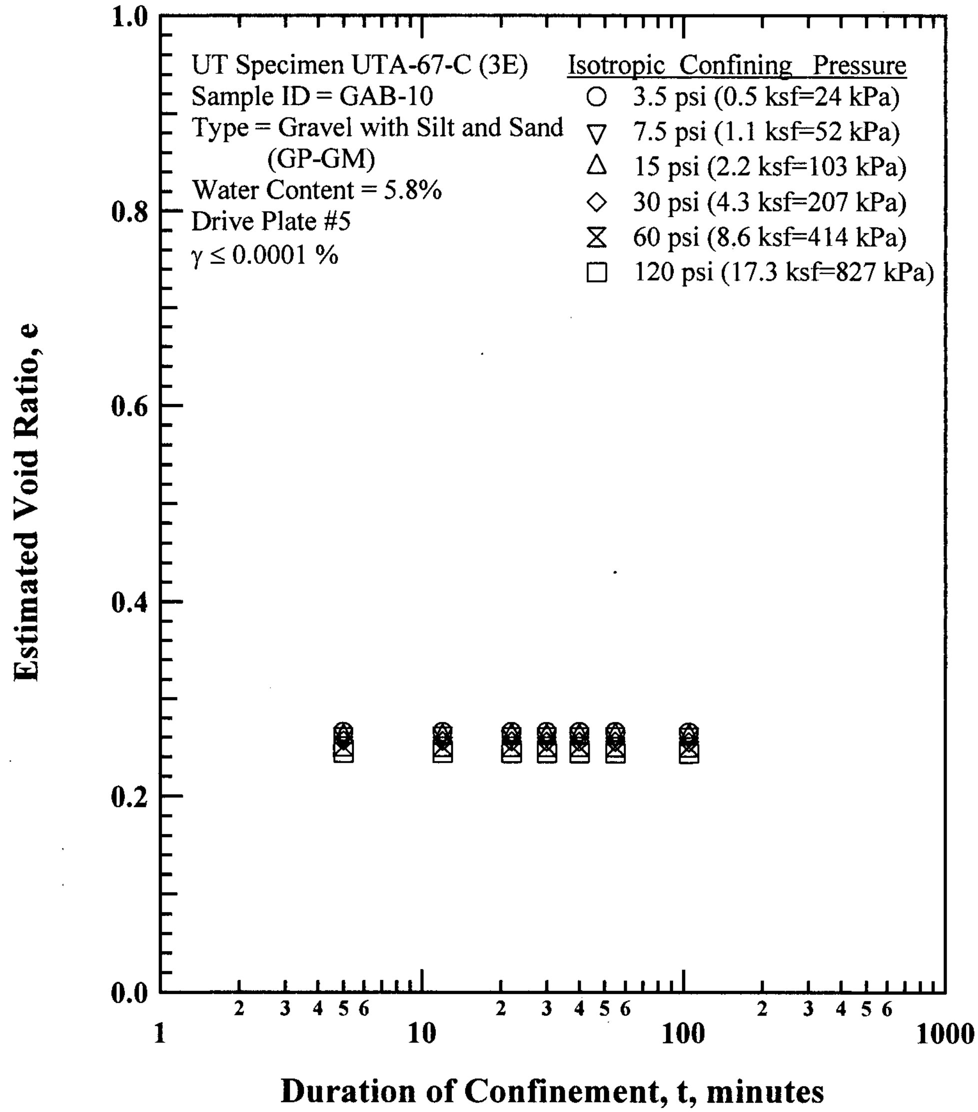


Figure C.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3E)

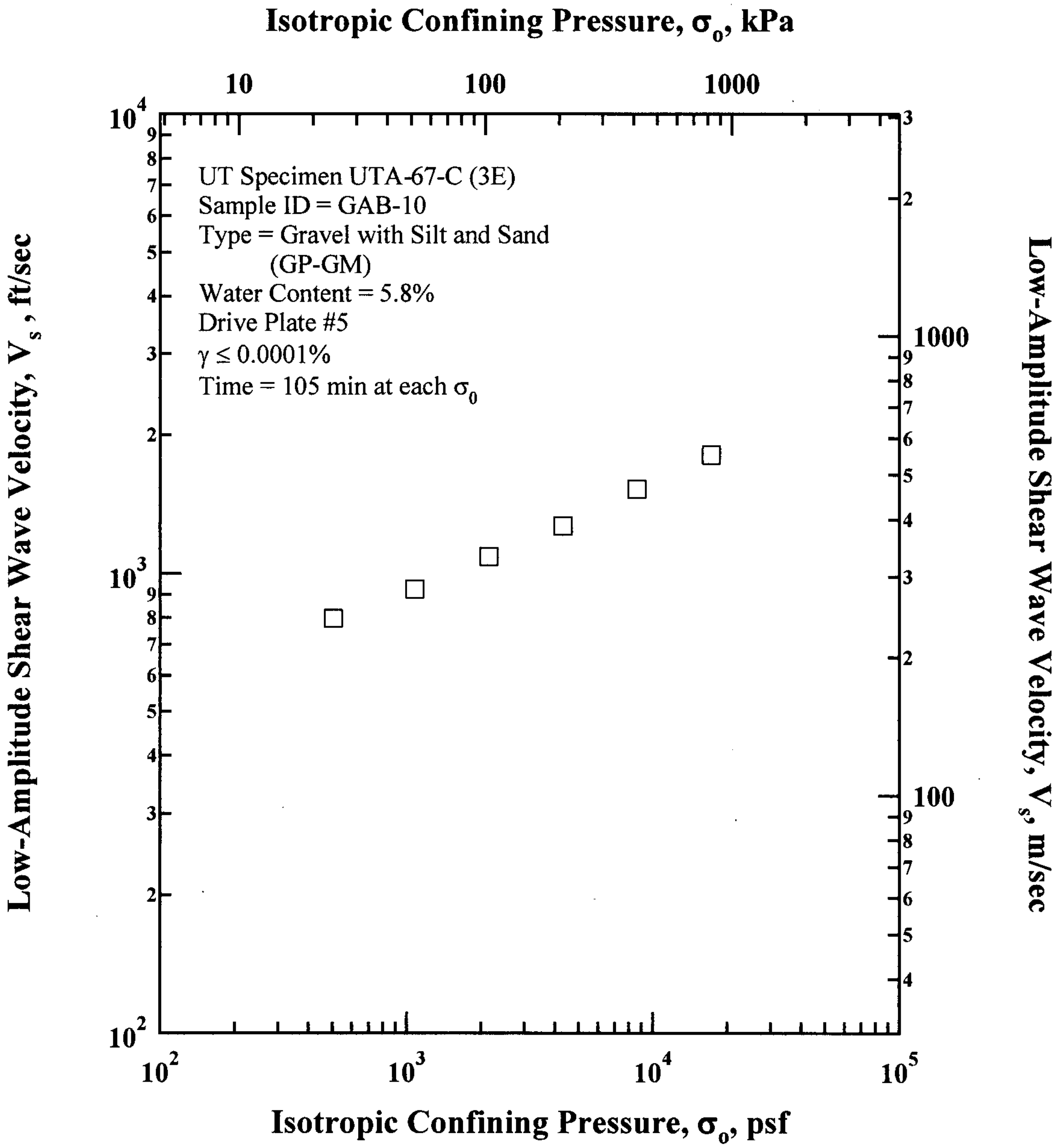


Figure C.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3E)

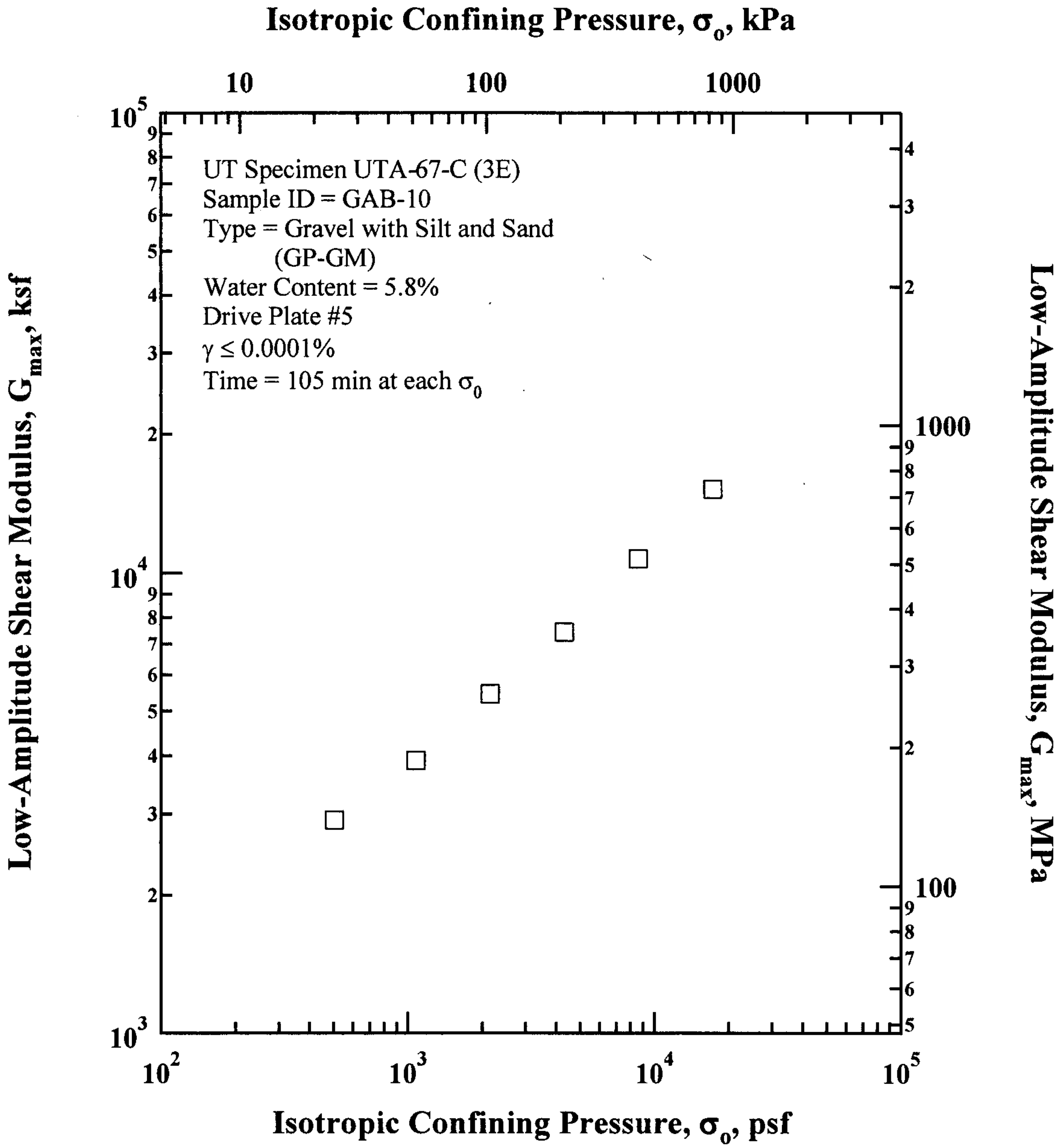


Figure C.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3E)

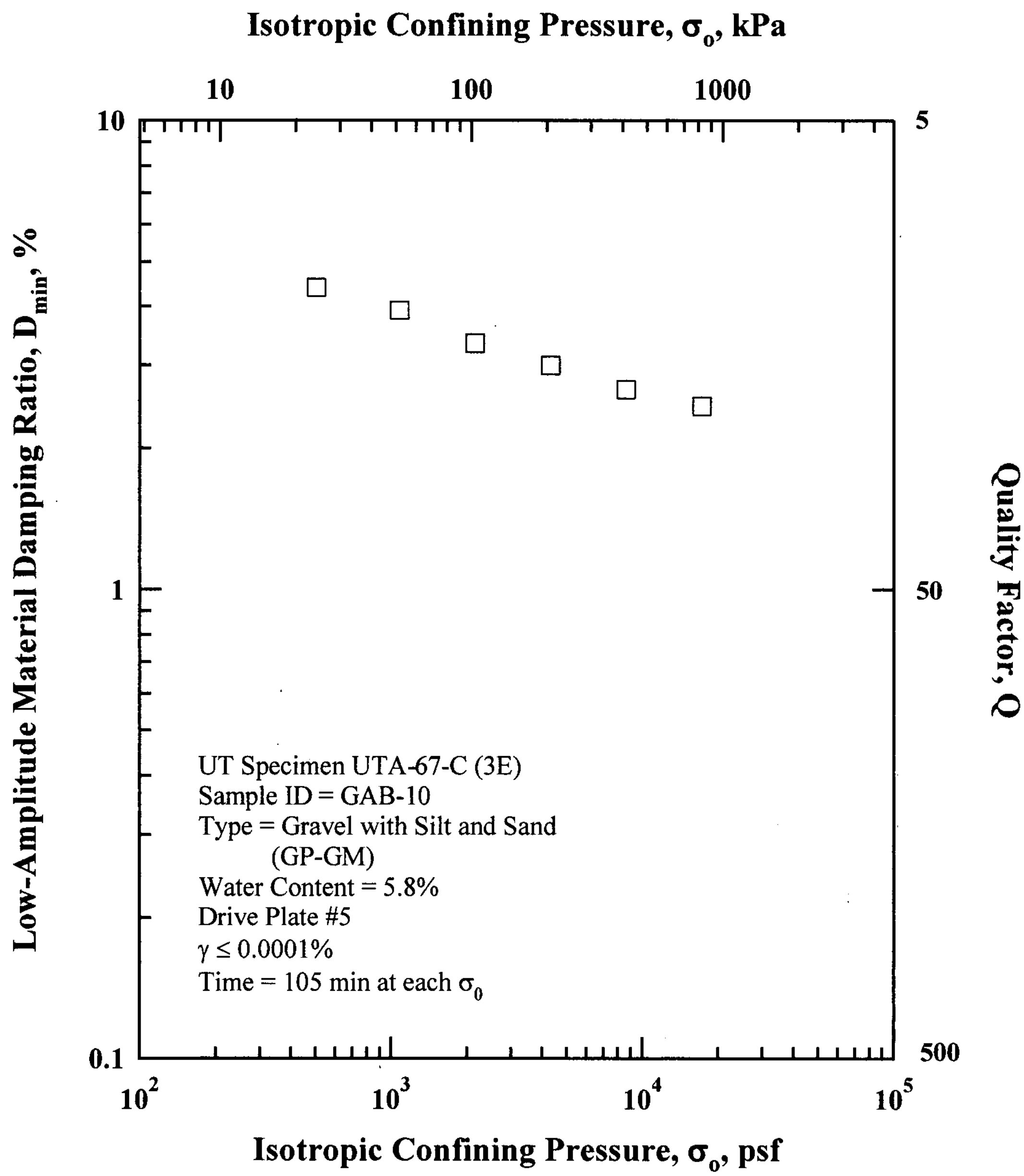


Figure C.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3E)

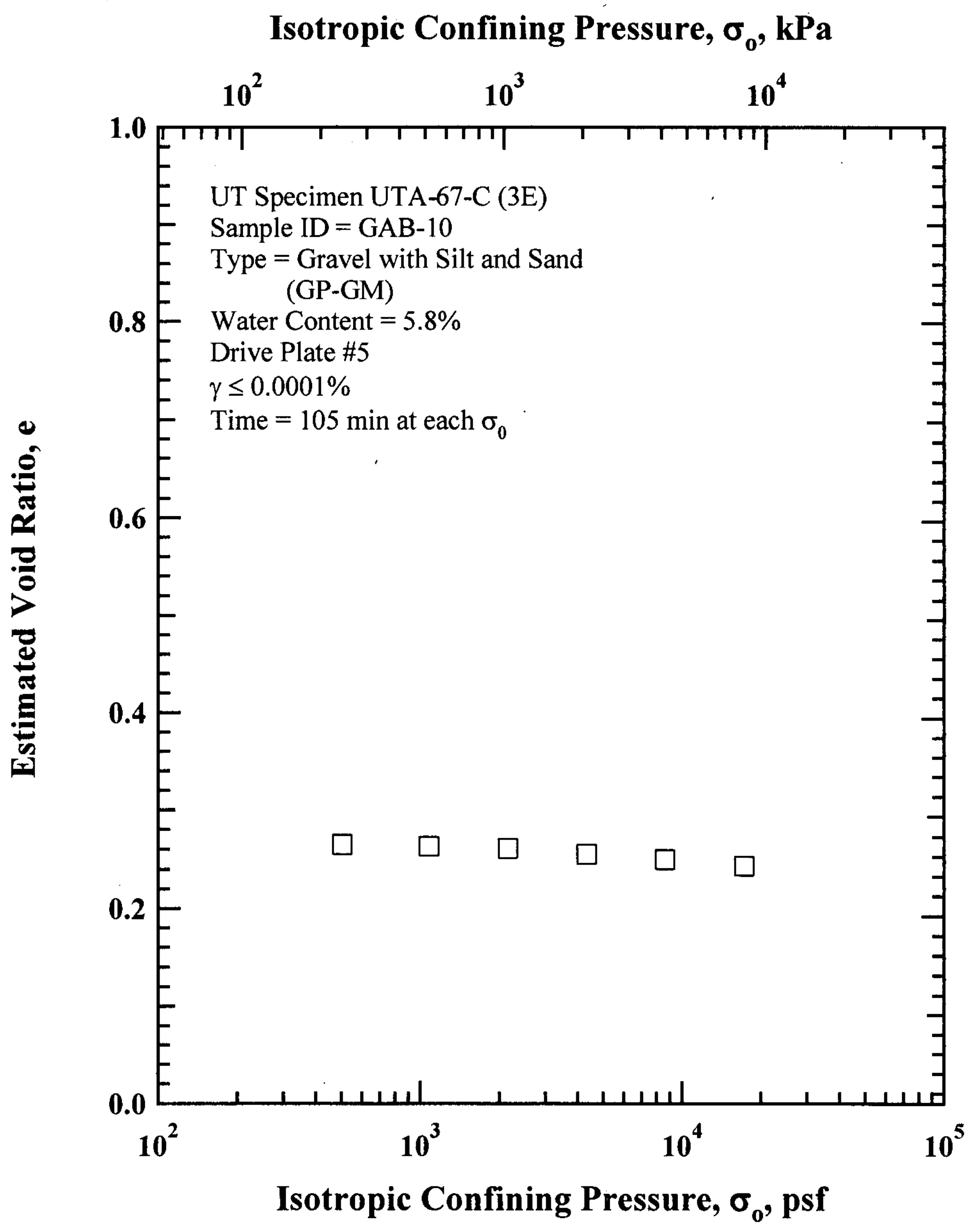


Figure C.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3E)

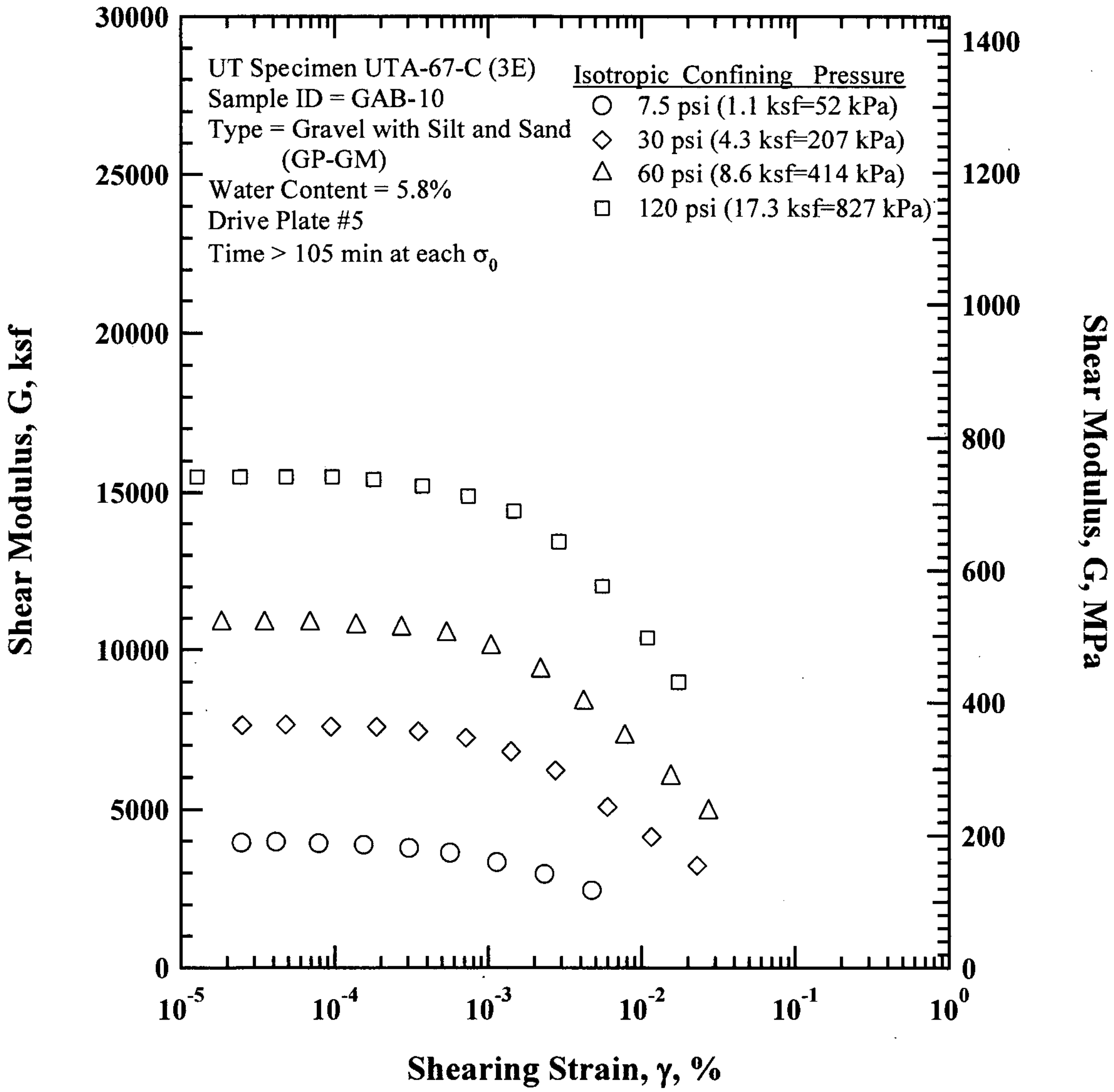


Figure C.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-C (3E)

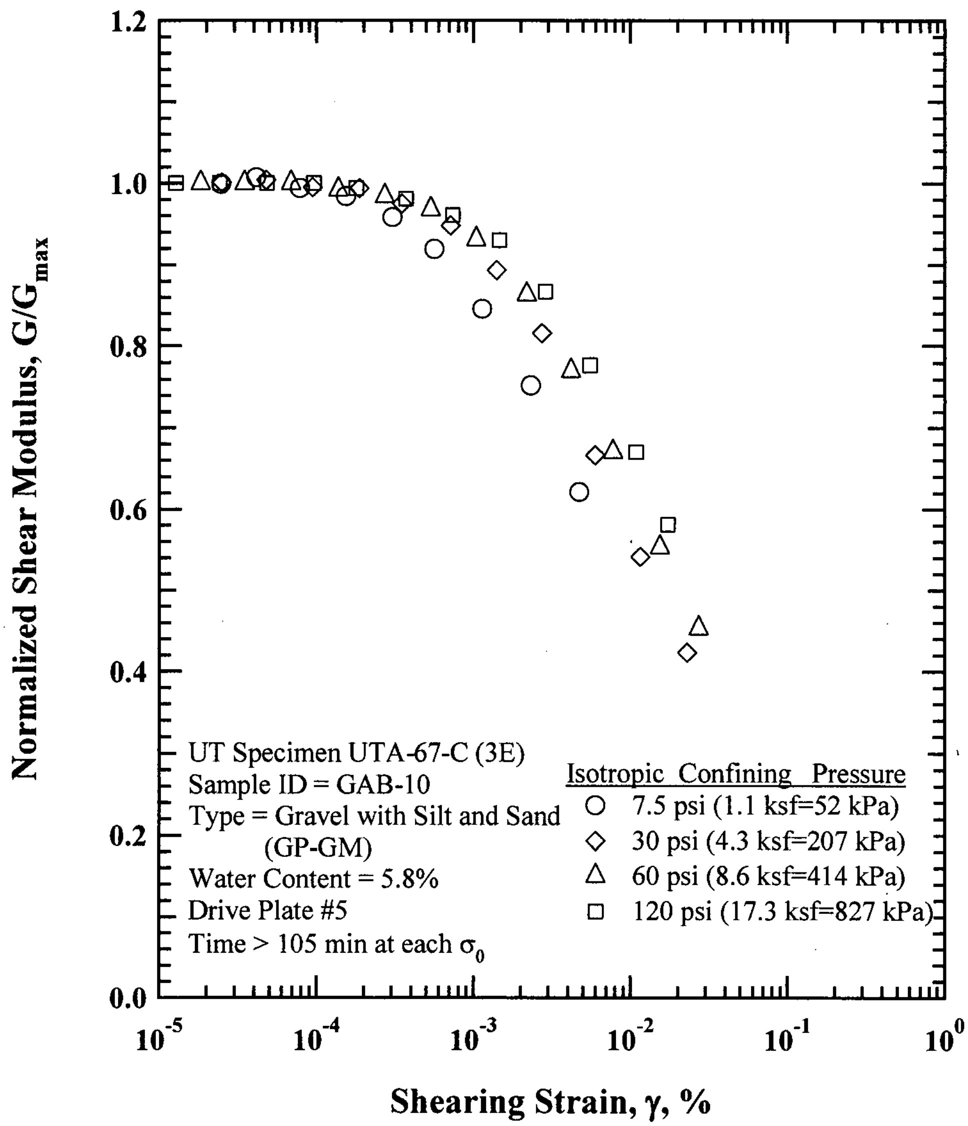


Figure C.9 Variation in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-C (3E)

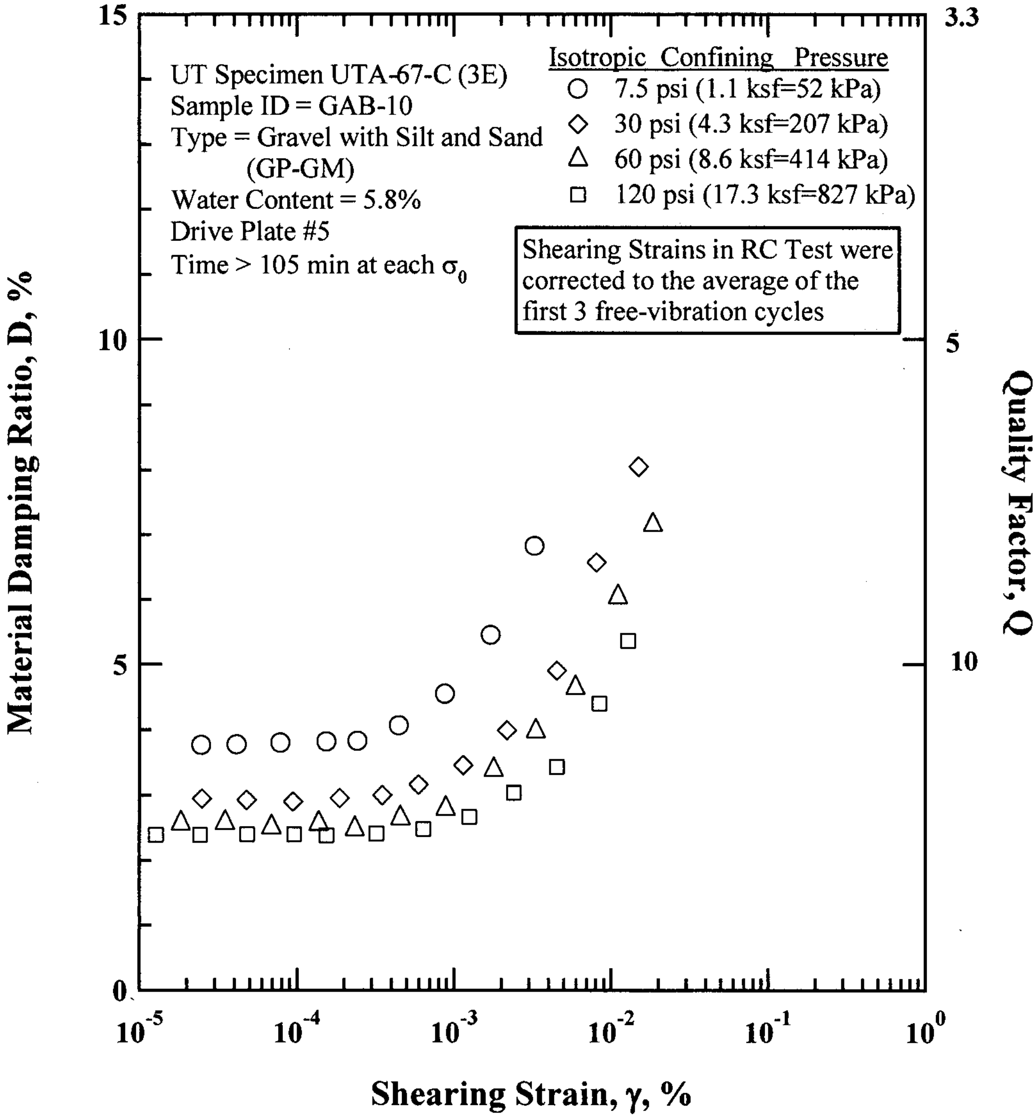


Figure C.10 Variation in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-C (3E)

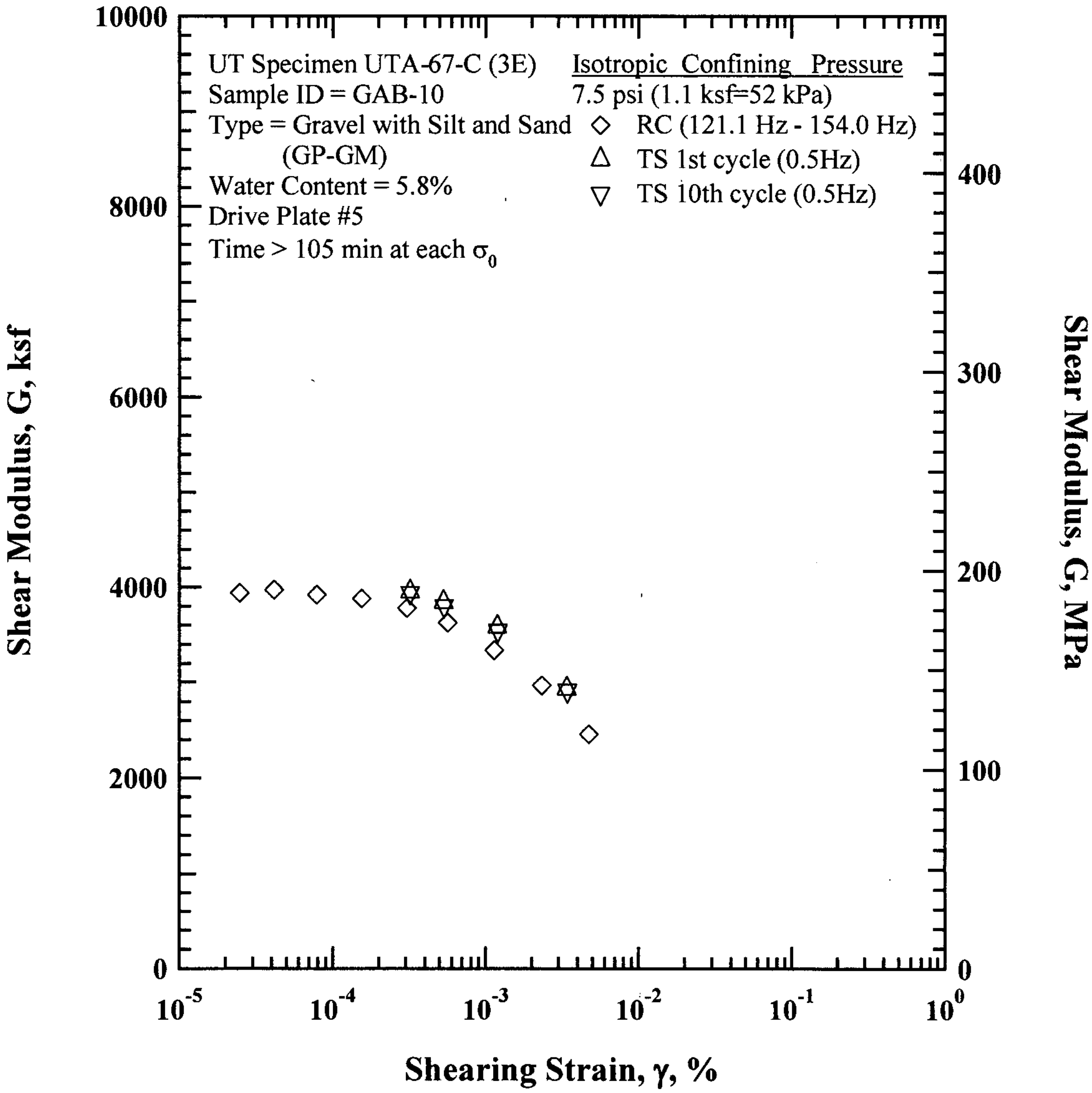


Figure C.11 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

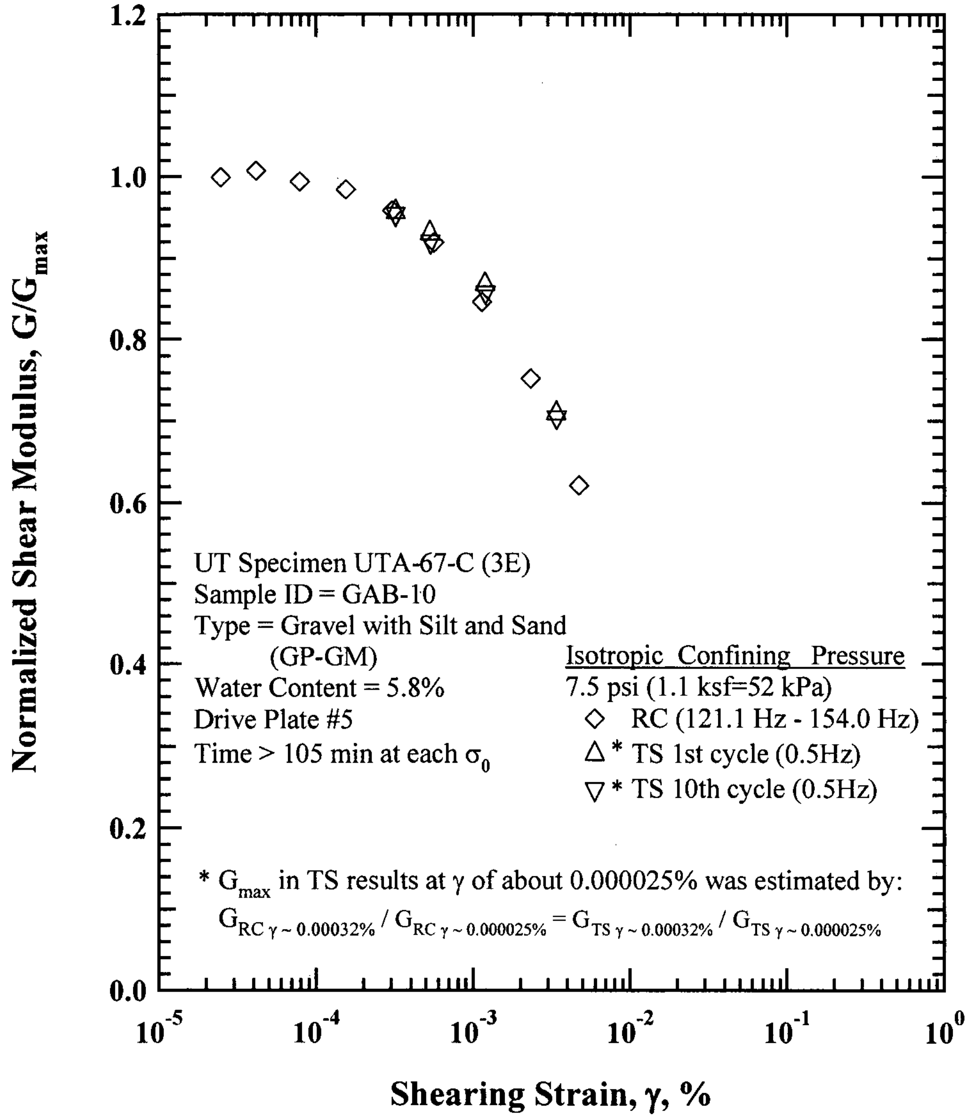


Figure C.12 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

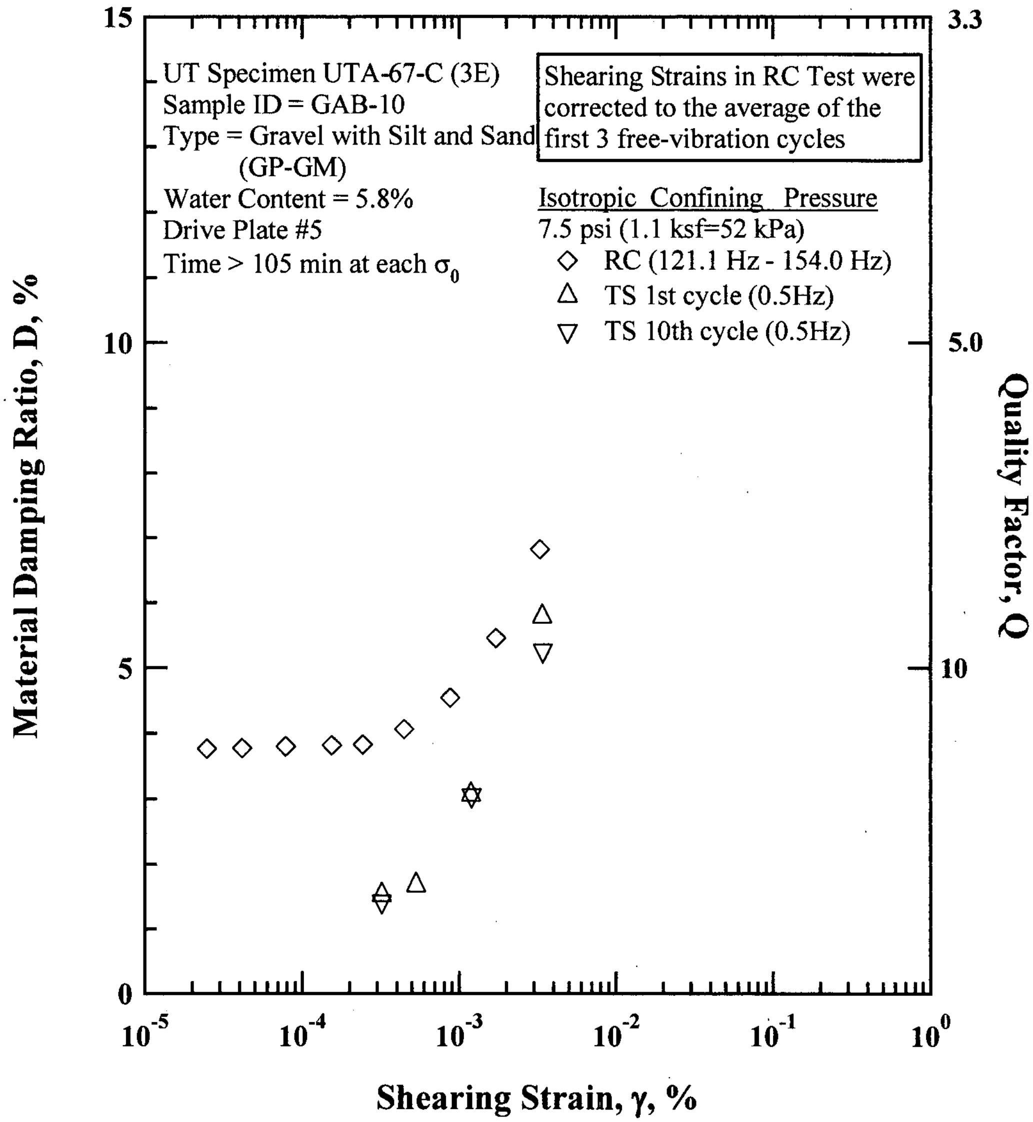


Figure C.13 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

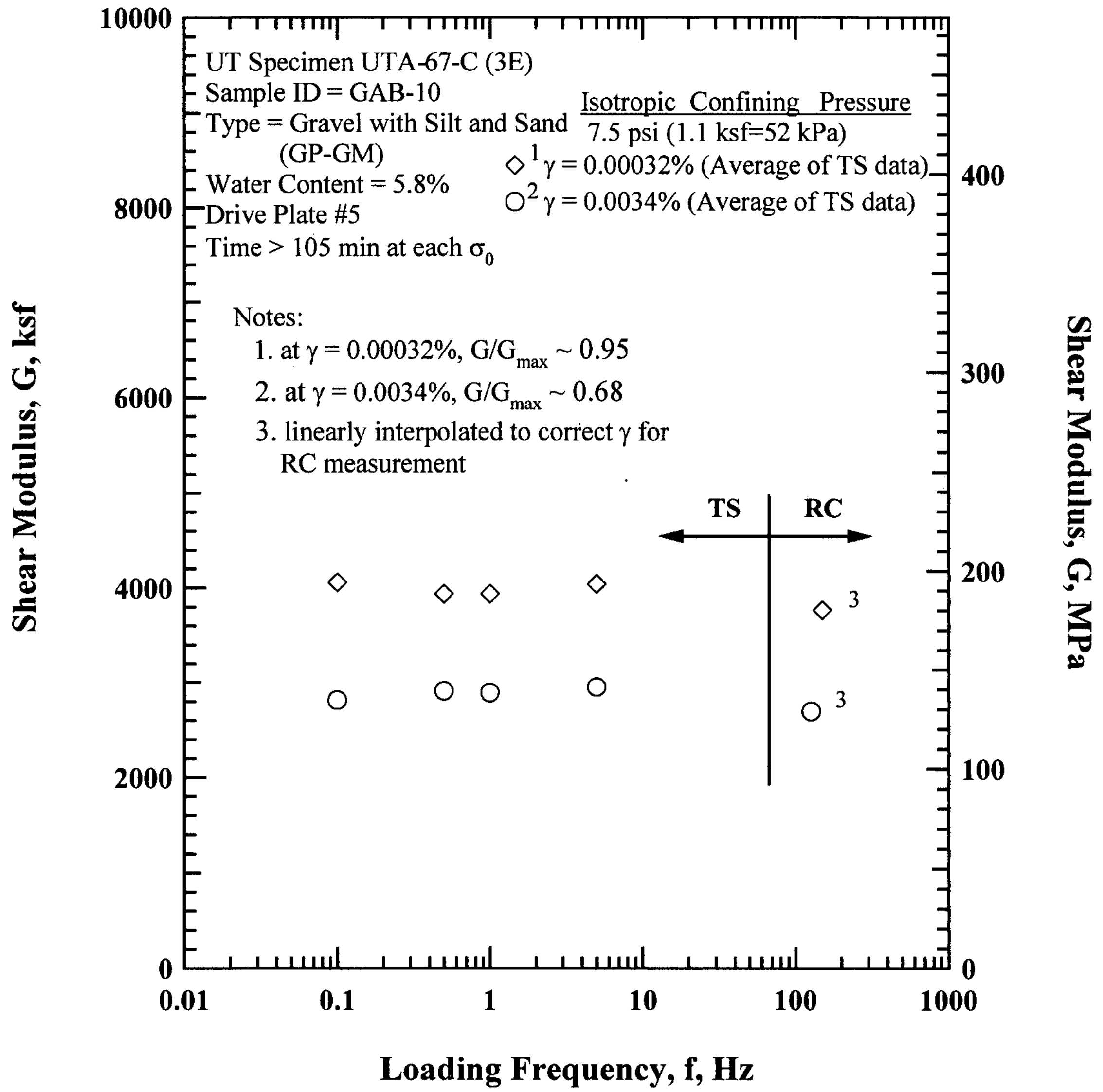


Figure C.14 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

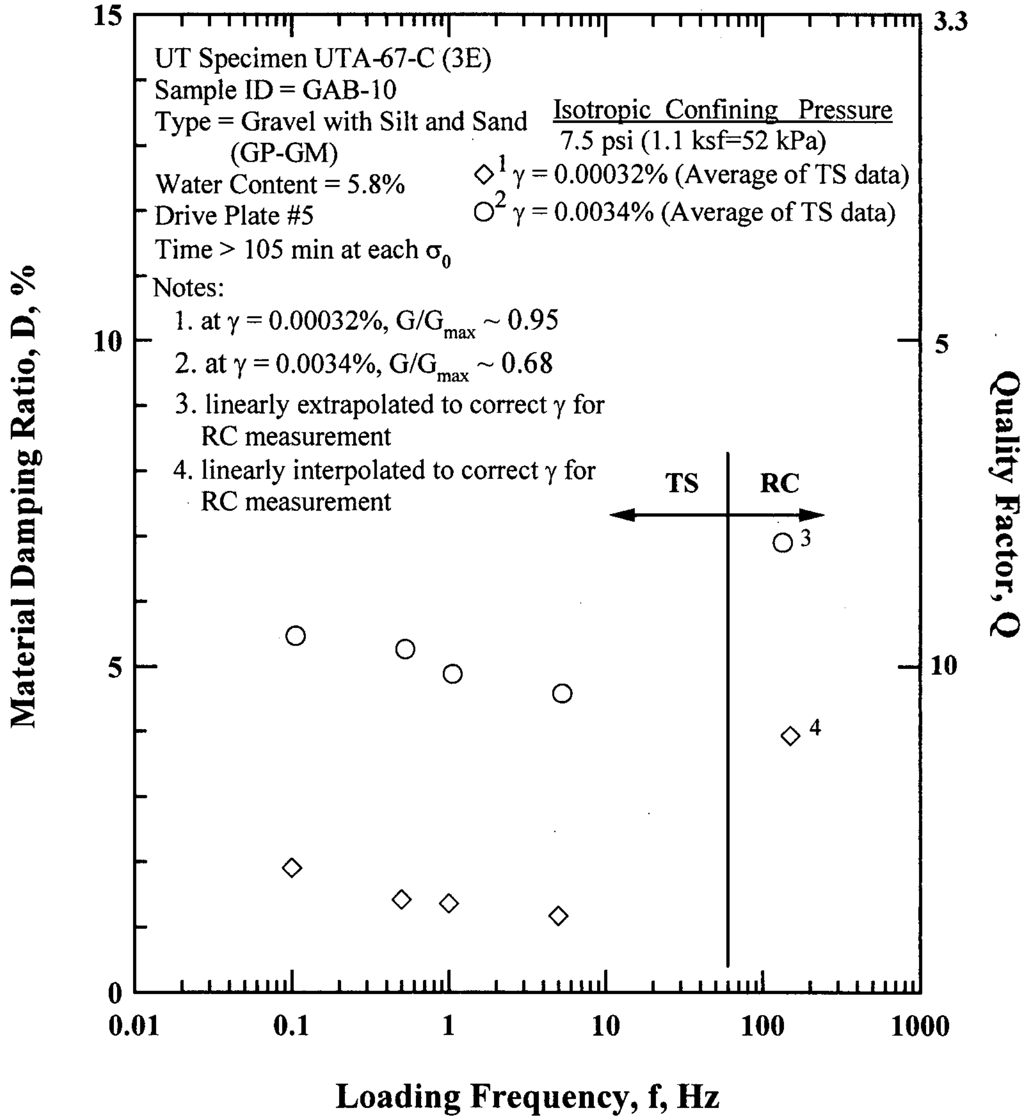


Figure C.15 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

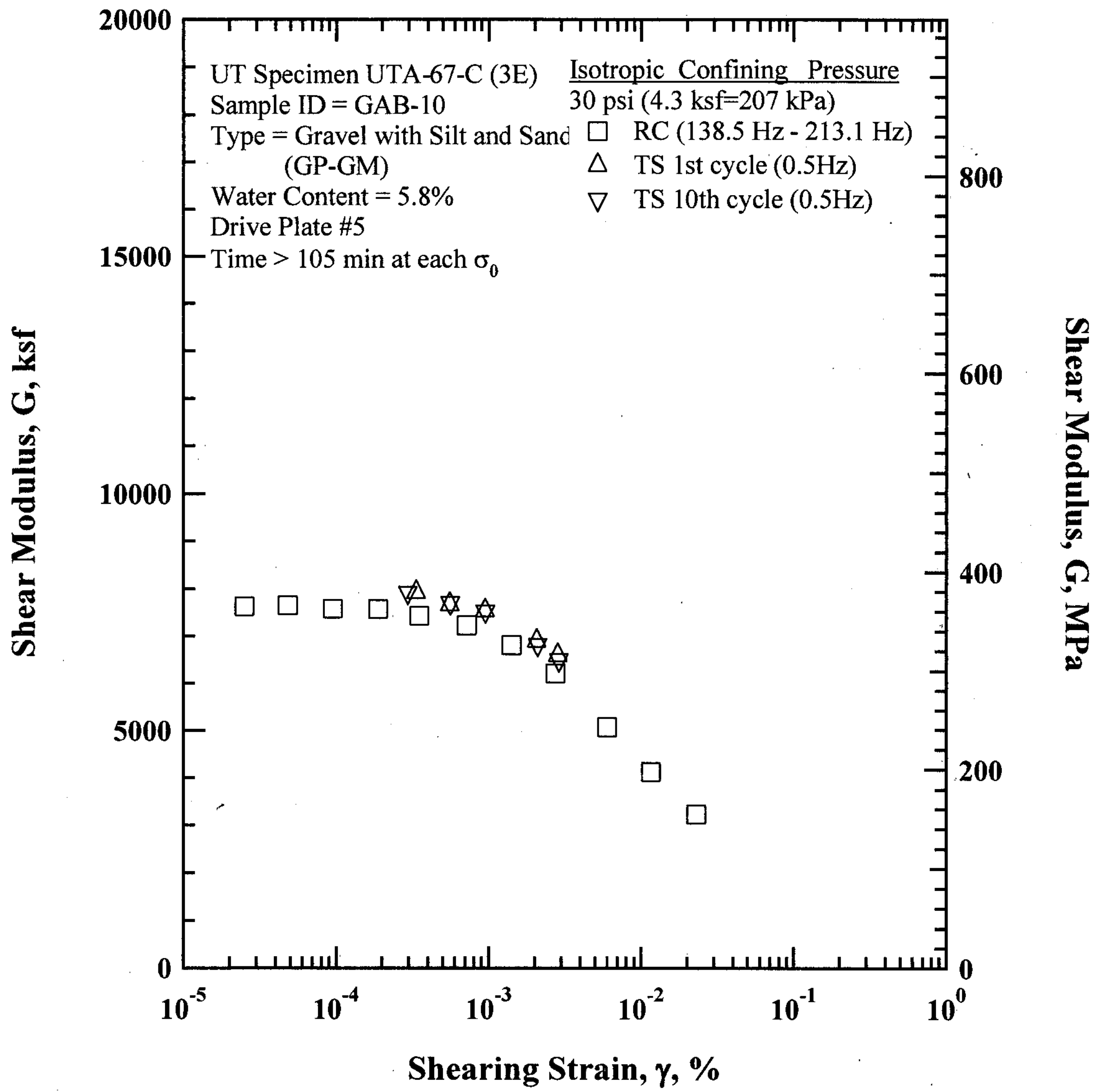


Figure C.16 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

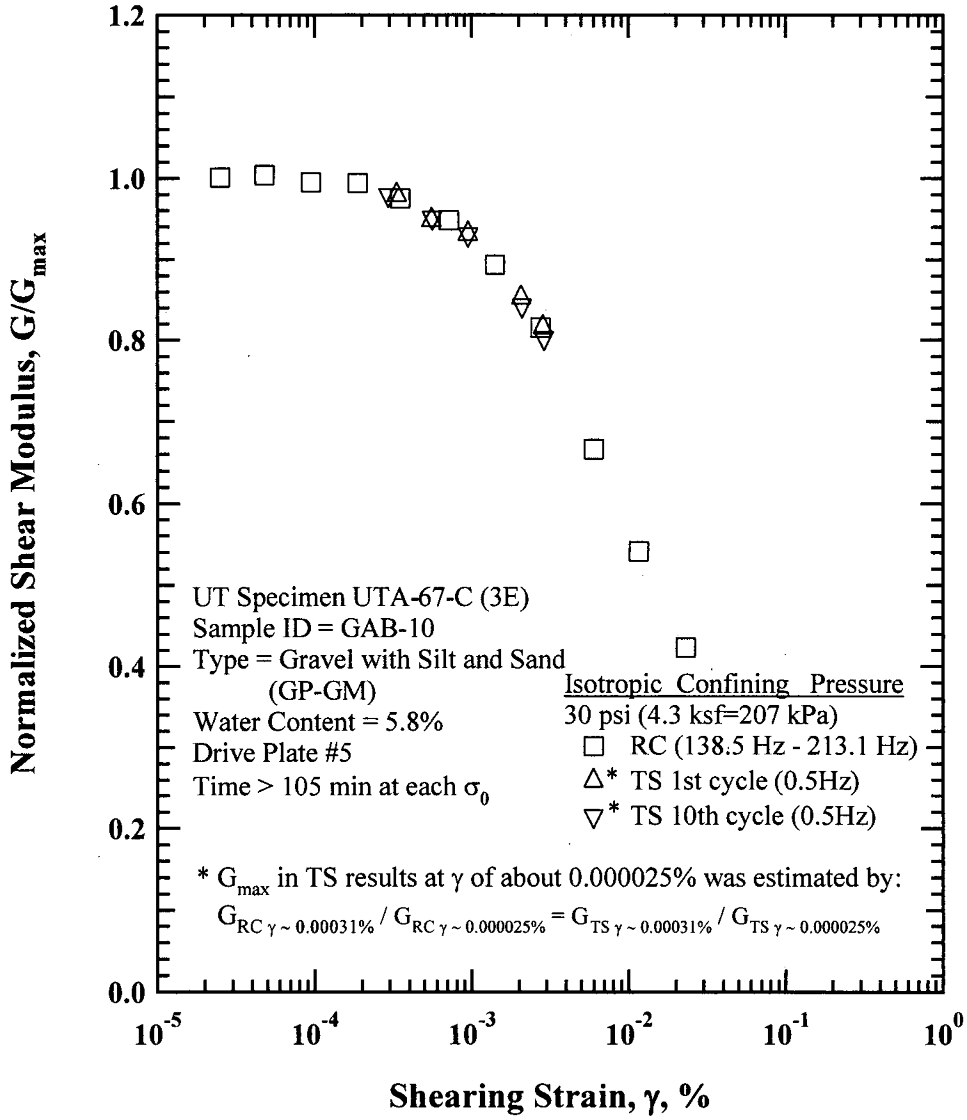


Figure C.17 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

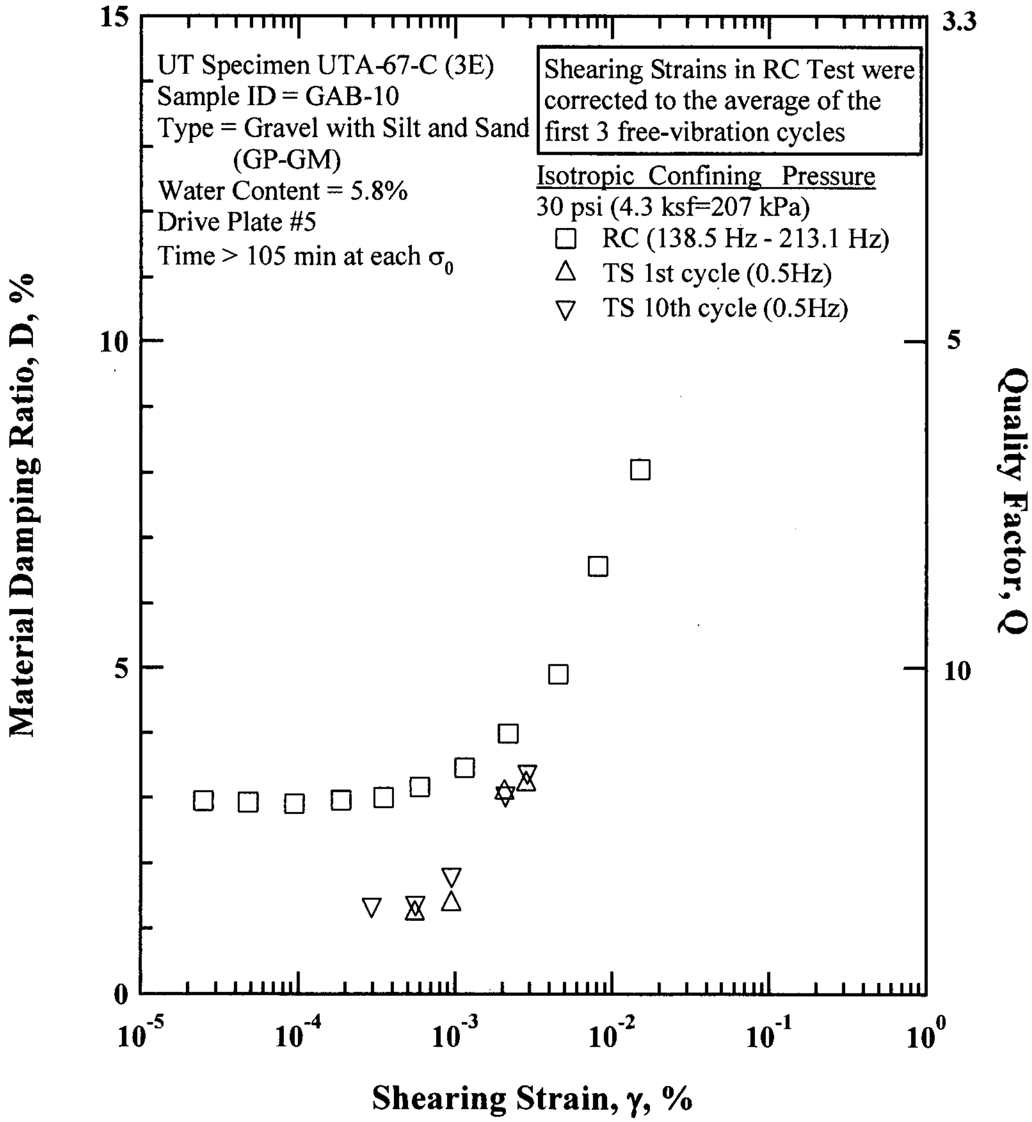


Figure C.18 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

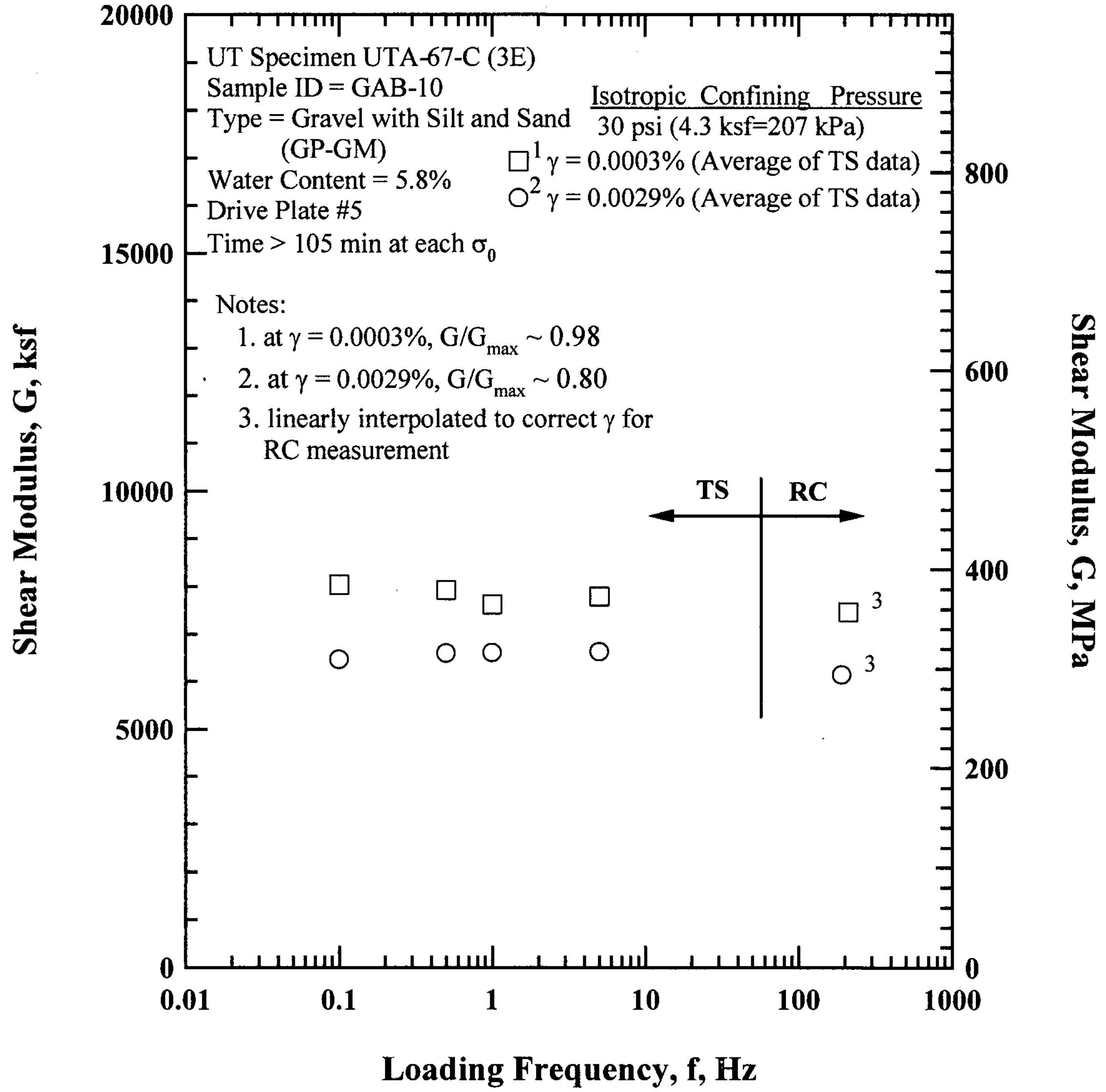


Figure C.19 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

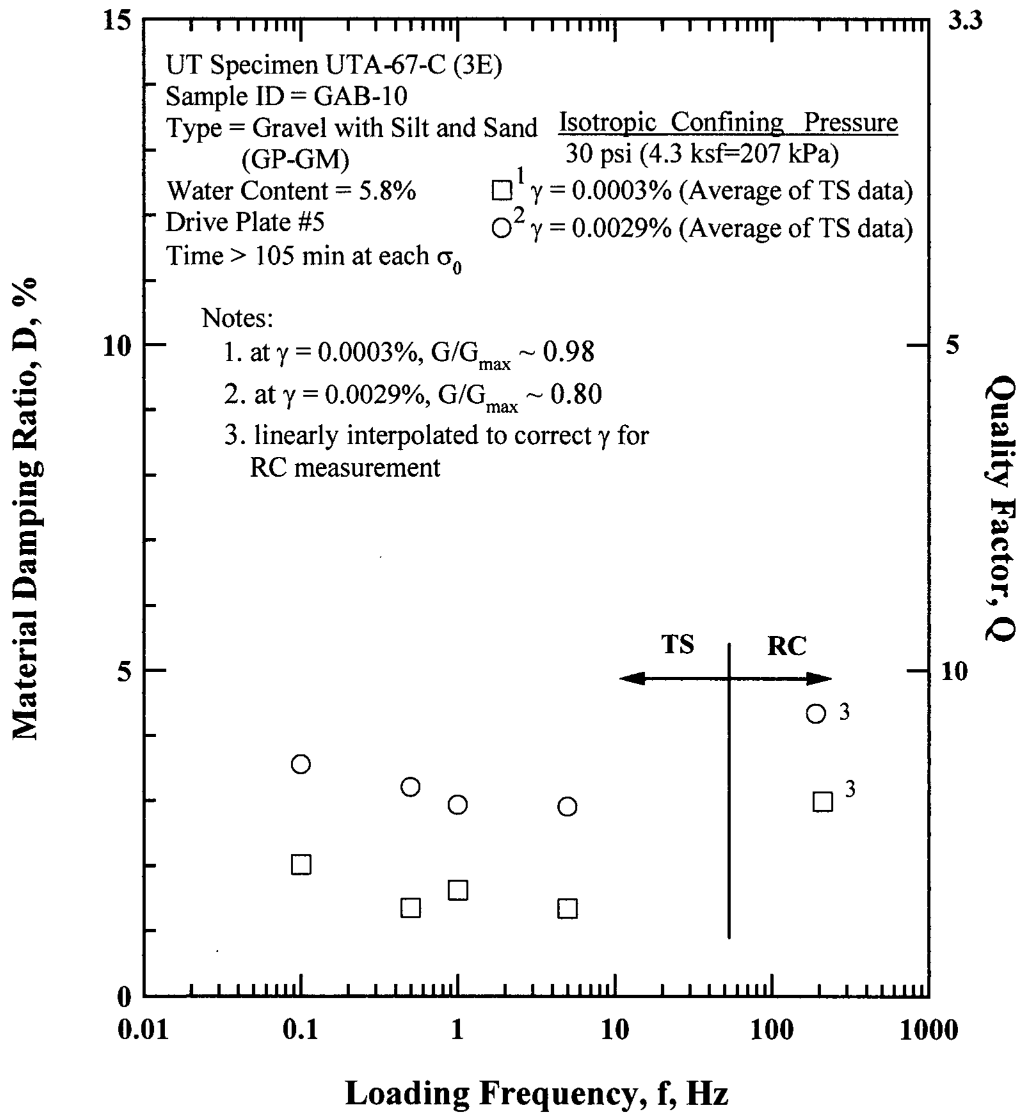


Figure C.20 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

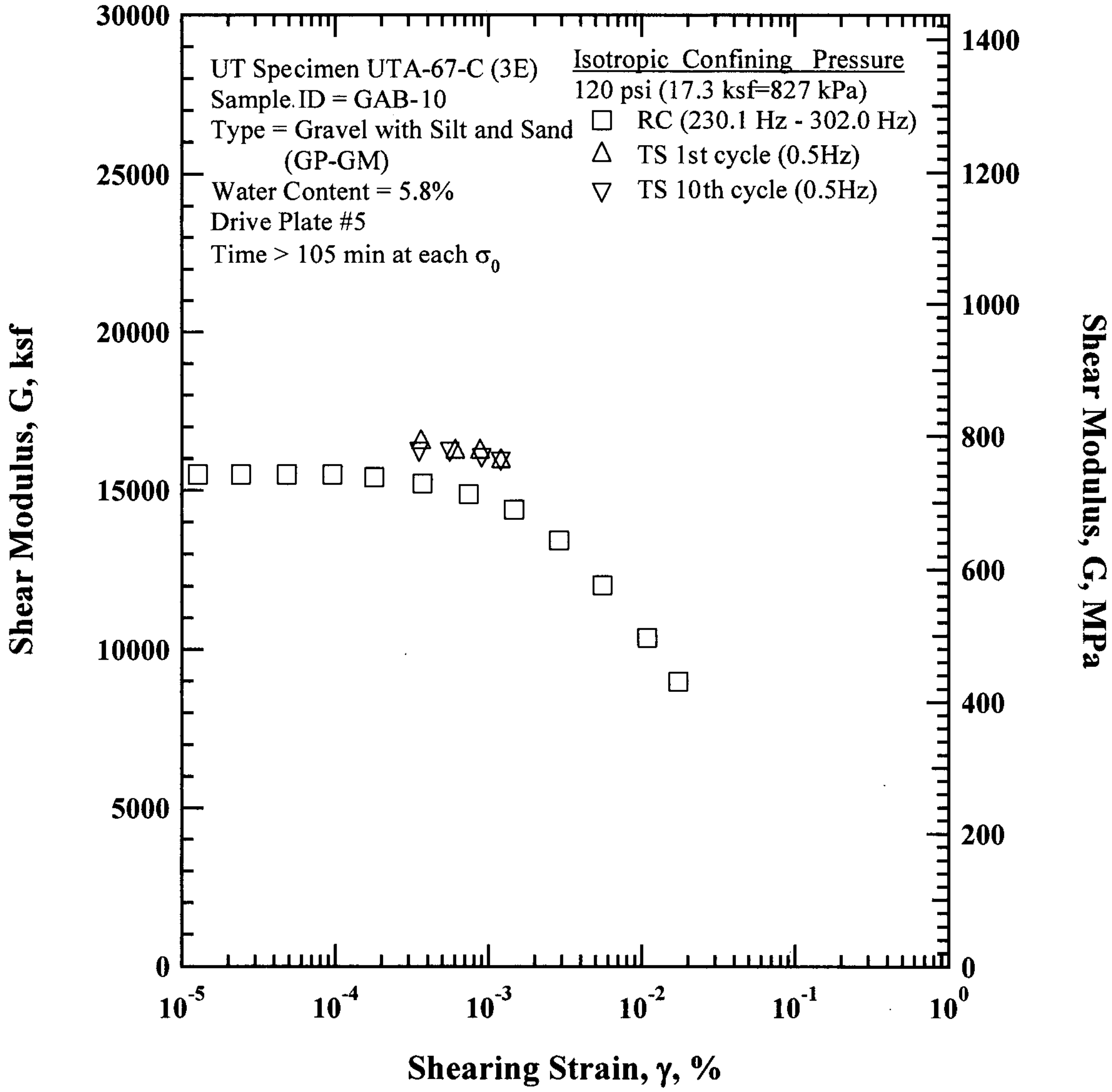


Figure C.21 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

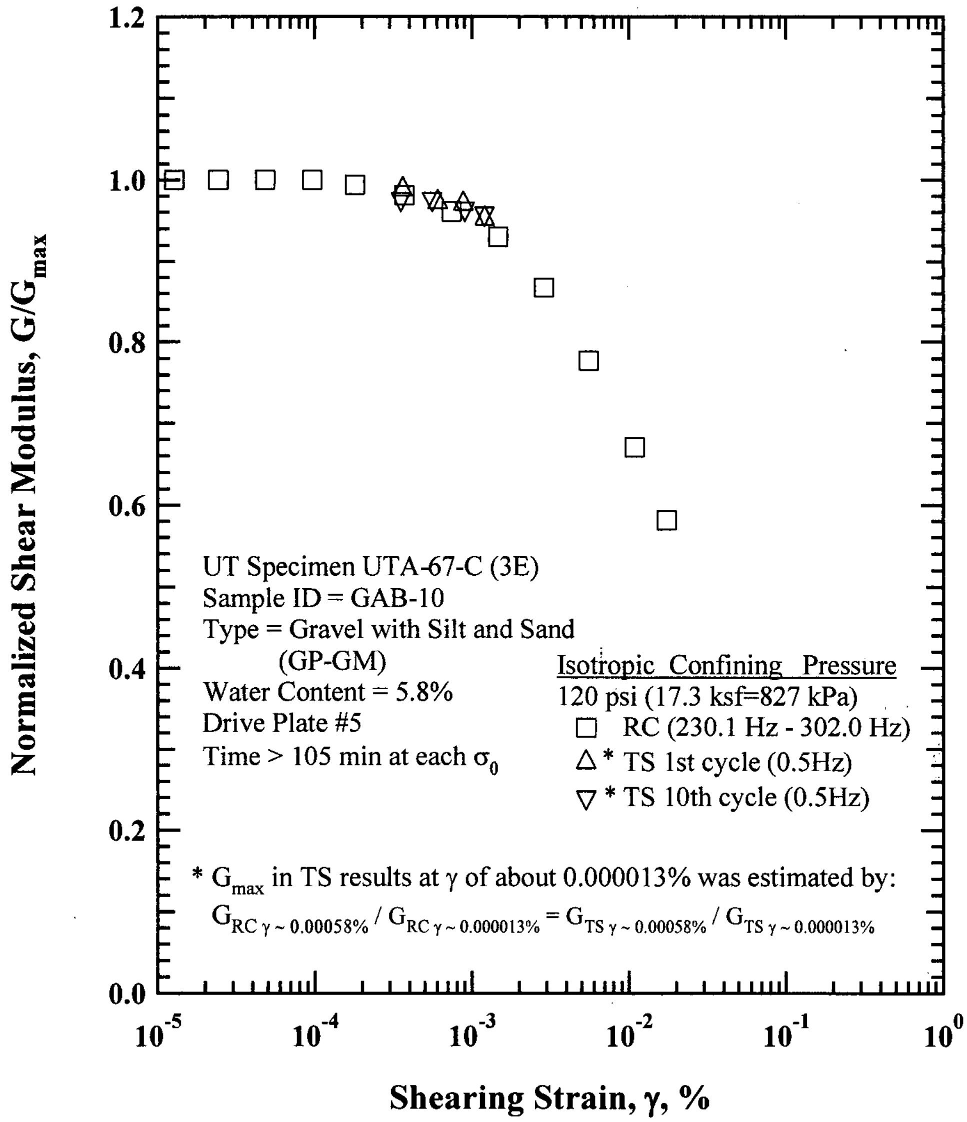


Figure C.22 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

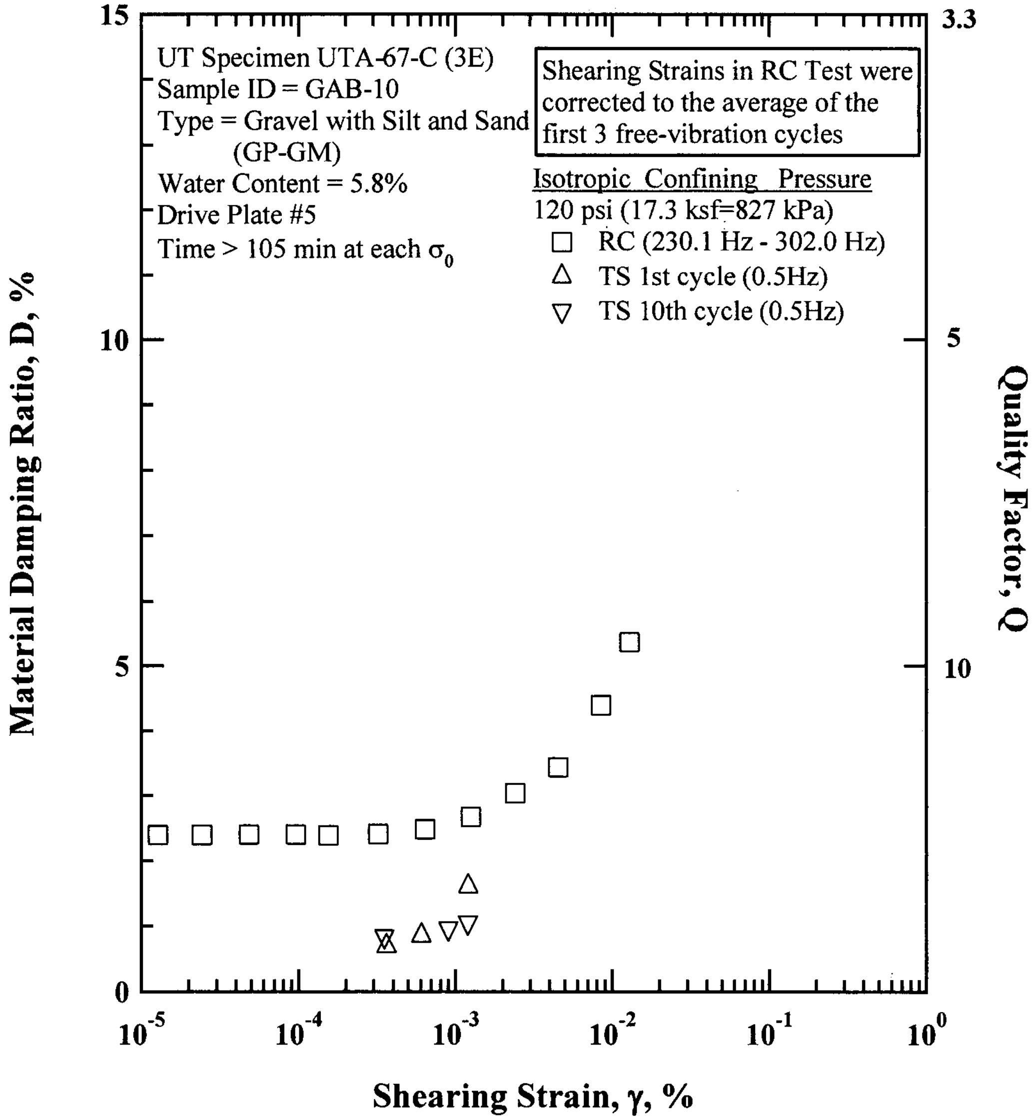


Figure C.23 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

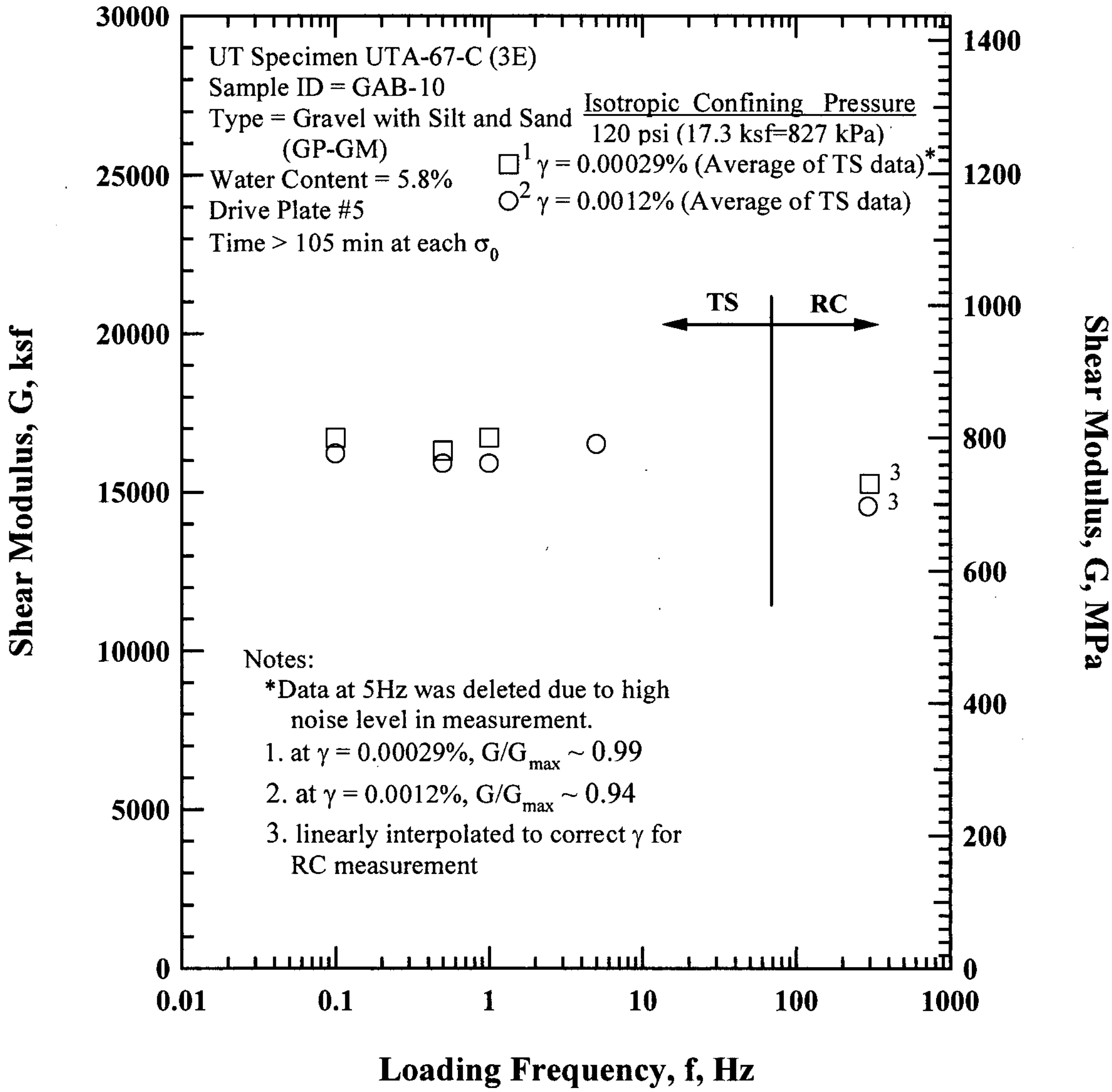


Figure C.24 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

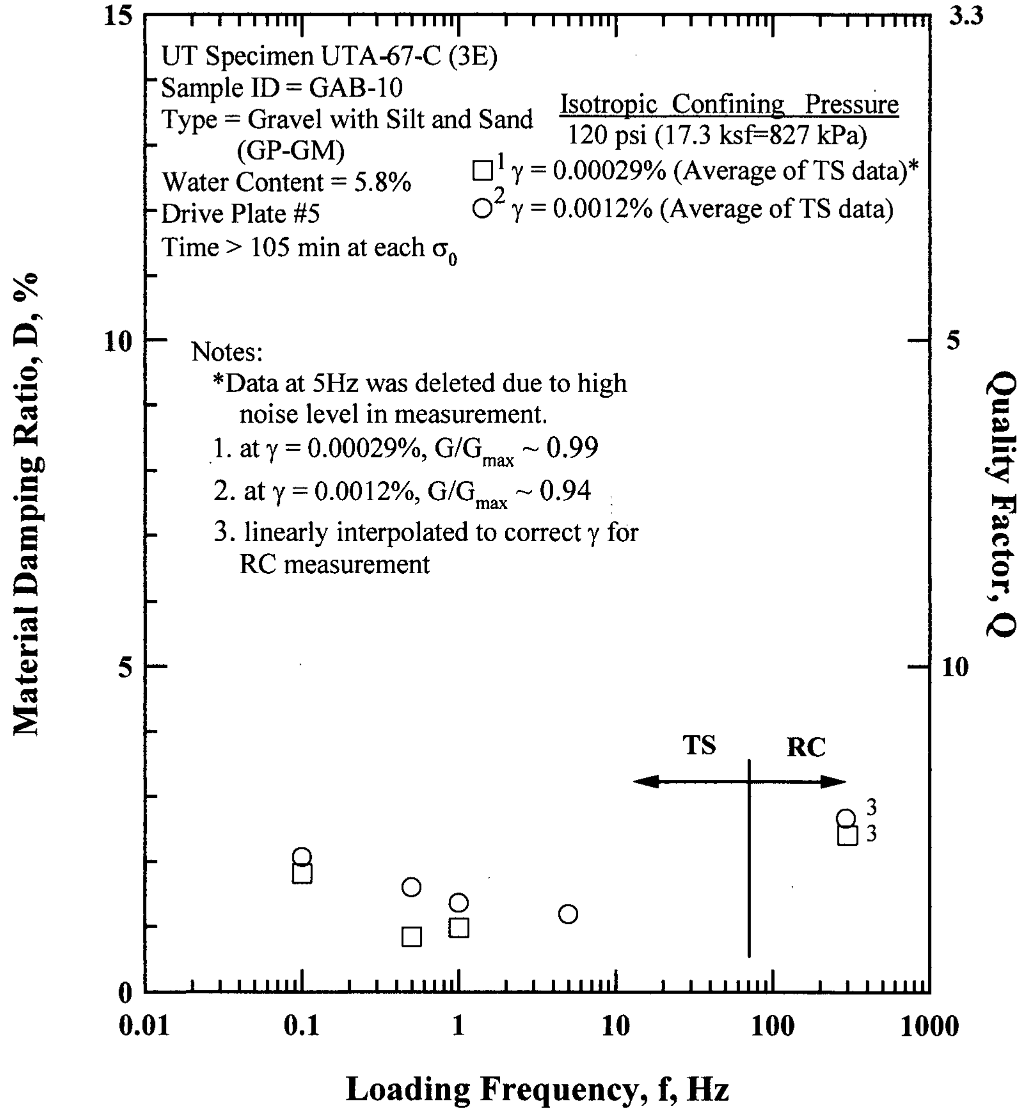


Figure C.25 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3E)

Table C.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-C (3E)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_s	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.5	504	24	2908	139.4	797	4.39	0.27
7.5	1080	52	3904	187.2	923	3.91	0.26
15	2160	104	5444	261.0	1089	3.33	0.26
30	4320	207	7427	356.1	1270	2.99	0.26
60	8640	414	10738	514.8	1525	2.66	0.25
120	17280	828	15196	728.5	1810	2.45	0.24

Table C.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3E); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
2.49E-05	3939	1.00	2.49E-05	3.76
4.17E-05	3972	1.01	4.17E-05	3.77
7.88E-05	3920	0.99	7.88E-05	3.80
1.55E-04	3880	0.98	1.55E-04	3.82
3.06E-04	3778	0.96	2.45E-04	3.82
5.66E-04	3625	0.92	4.48E-04	4.06
1.14E-03	3333	0.85	8.81E-04	4.54
2.33E-03	2965	0.75	1.72E-03	5.45
4.75E-03	2455	0.62	3.28E-03	6.82

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table C.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-C (3E); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
3.21E-04	3950	0.96	1.52	3.22E-04	3940	0.95	1.42
5.31E-04	3840	0.93	1.67	5.35E-04	3800	0.92	-
1.19E-03	3580	0.87	3.06	1.20E-03	3540	0.86	3.05
3.39E-03	2930	0.71	5.78	3.43E-03	2910	0.70	5.26

- High Noise Level Interfering with Damping Measurement

Table C.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3E); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average+ Shearing Strain, %	Material Damping Ratio^x, D, %
2.51E-05	7627	1.00	2.51E-05	2.95
4.82E-05	7647	1.00	4.82E-05	2.92
9.50E-05	7577	0.99	9.50E-05	2.90
1.88E-04	7569	0.99	1.88E-04	2.96
3.51E-04	7428	0.98	3.51E-04	3.00
7.18E-04	7224	0.95	5.97E-04	3.16
1.41E-03	6805	0.89	1.15E-03	3.45
2.74E-03	6211	0.82	2.18E-03	3.99
5.99E-03	5073	0.67	4.54E-03	4.90
1.16E-02	4129	0.54	8.14E-03	6.57
2.31E-02	3234	0.42	1.51E-02	8.05

+ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

x Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table C.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-C (3E); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
3.34E-04	7919	0.98	-	2.95E-04	7920	0.98	1.35
5.56E-04	7670	0.95	1.22	5.60E-04	7690	0.95	1.38
9.48E-04	7530	0.93	1.37	9.50E-04	7520	0.93	1.81
2.07E-03	6890	0.85	3.07	2.10E-03	6810	0.84	3.05
2.85E-03	6590	0.81	3.20	2.89E-03	6490	0.80	3.39

- High Noise Level Interfering with Damping Measurement

Table C.6 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3E); Isotropic Confining Pressure, σ_o =60 psi (8.6 ksf=414 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
1.84E-05	10834	1.00	1.84E-05	2.57
3.51E-05	10825	1.00	3.51E-05	2.57
6.92E-05	10825	1.00	6.92E-05	2.51
1.38E-04	10738	0.99	1.38E-04	2.56
2.72E-04	10656	0.98	2.35E-04	2.48
5.36E-04	10486	0.97	4.58E-04	2.65
1.04E-03	10078	0.93	8.85E-04	2.79
2.19E-03	9343	0.86	1.80E-03	3.38
4.20E-03	8335	0.77	3.34E-03	3.98
7.77E-03	7255	0.67	5.97E-03	4.63
1.55E-02	5988	0.55	1.11E-02	6.03
2.73E-02	4906	0.45	1.86E-02	7.15

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table C.7 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3E); Isotropic Confining Pressure, σ_o =120 psi (17.3 ksf=827 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
1.28E-05	15492	1.00	1.28E-05	2.40
2.43E-05	15492	1.00	2.43E-05	2.39
4.83E-05	15492	1.00	4.83E-05	2.40
9.62E-05	15491	1.00	9.62E-05	2.40
1.79E-04	15404	0.99	1.55E-04	2.39
3.71E-04	15203	0.98	3.21E-04	2.41
7.41E-04	14884	0.96	6.39E-04	2.48
1.47E-03	14402	0.93	1.25E-03	2.67
2.88E-03	13431	0.87	2.41E-03	3.03
5.53E-03	12032	0.78	4.53E-03	3.43
1.09E-02	10375	0.67	8.46E-03	4.40
1.74E-02	8998	0.58	1.29E-02	5.36

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table C.8 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-C (3E); Isotropic Confining Pressure, σ_o =120 psi (17.3 ksf=827 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
3.64E-04	16500	0.99	0.69	3.52E-04	16300	0.98	0.84
6.06E-04	16230	0.97	0.85	5.58E-04	16300	0.98	-
8.83E-04	16200	0.97	-	9.01E-04	16100	0.96	0.96
1.21E-03	15900	0.95	1.60	1.20E-03	16000	0.96	1.05

- High Noise Level Interfering with Damping Measurement

APPENDIX D

UT Specimen UTA-67-A (1M)
Sample ID : CR6-17
Type = Scalped, Reconstituted Gravel with Silt and Sand (GP-GM*)

Water Content, w = 6.1 %

G_S = 2.716*

Degree of Saturation = 85.5%

Total Unit Weight, γ_t = 150.7 lb/ft^3

Dry Unit Weight, γ_d = 142.0 lb/ft^3

Target : γ_d = 144.0 lb/ft^3 ± 2 lb/ft^3

w = 6.4% ± 1.0%

*** Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

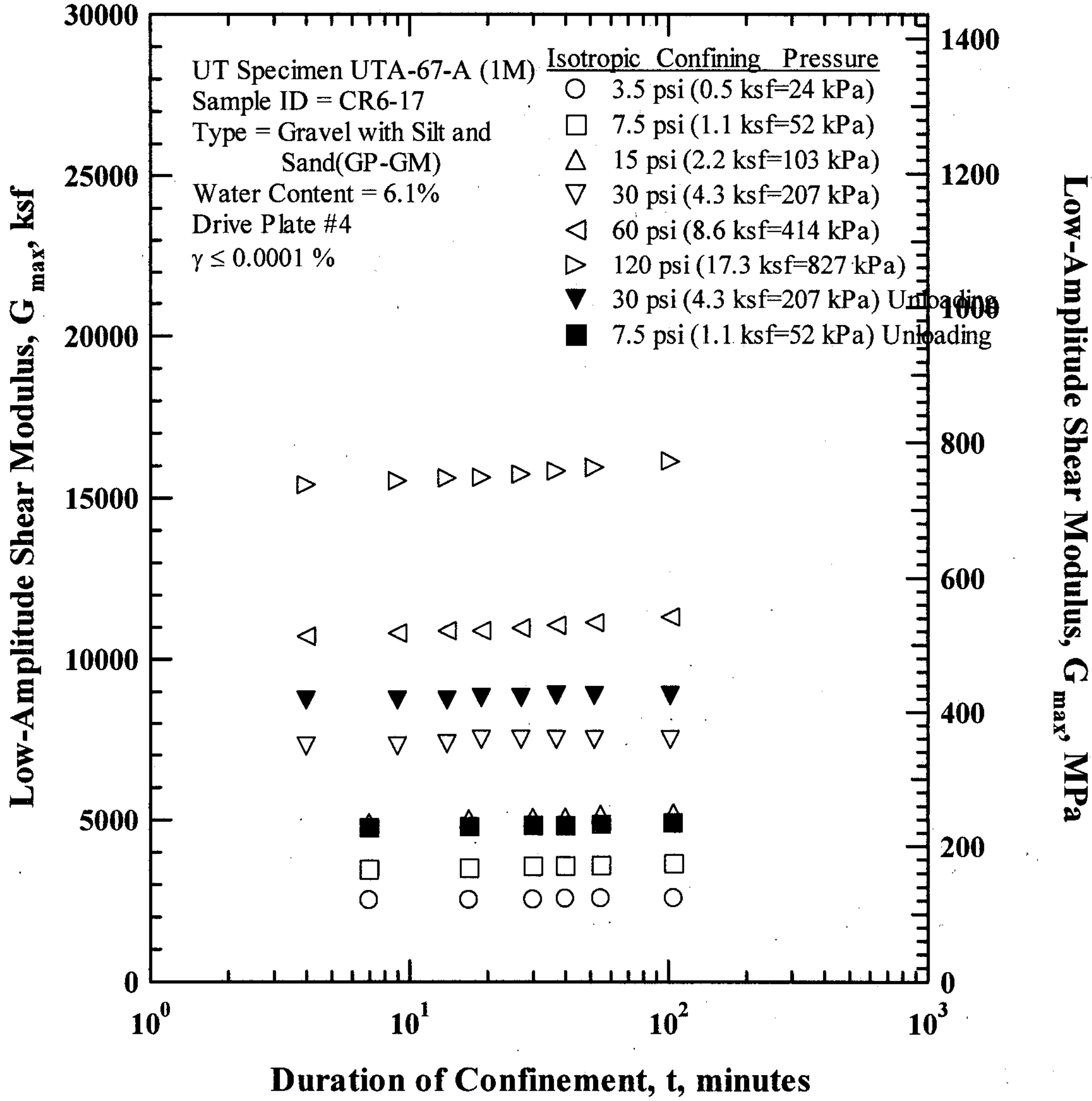


Figure D.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1M)

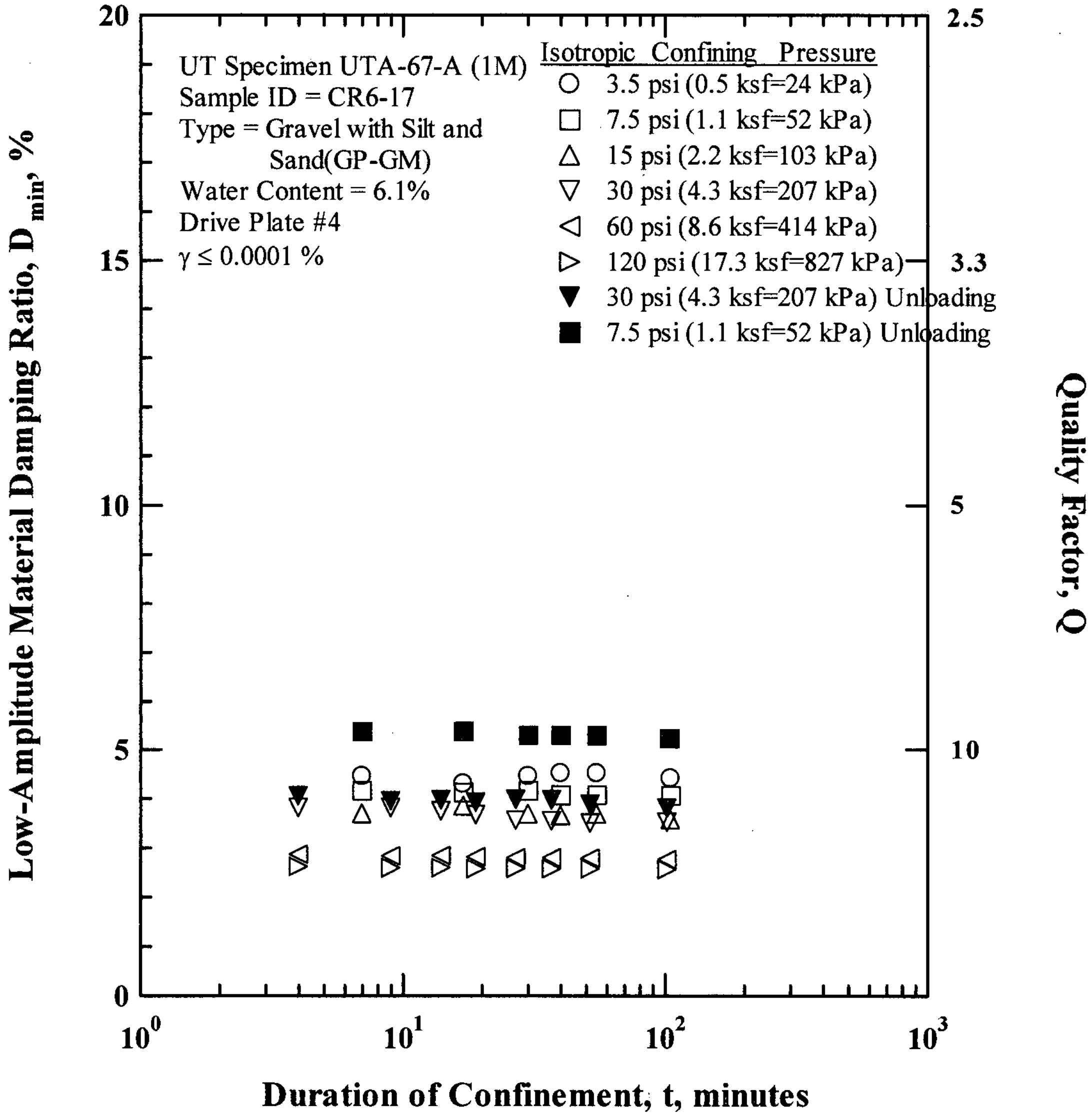


Figure D.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1M)

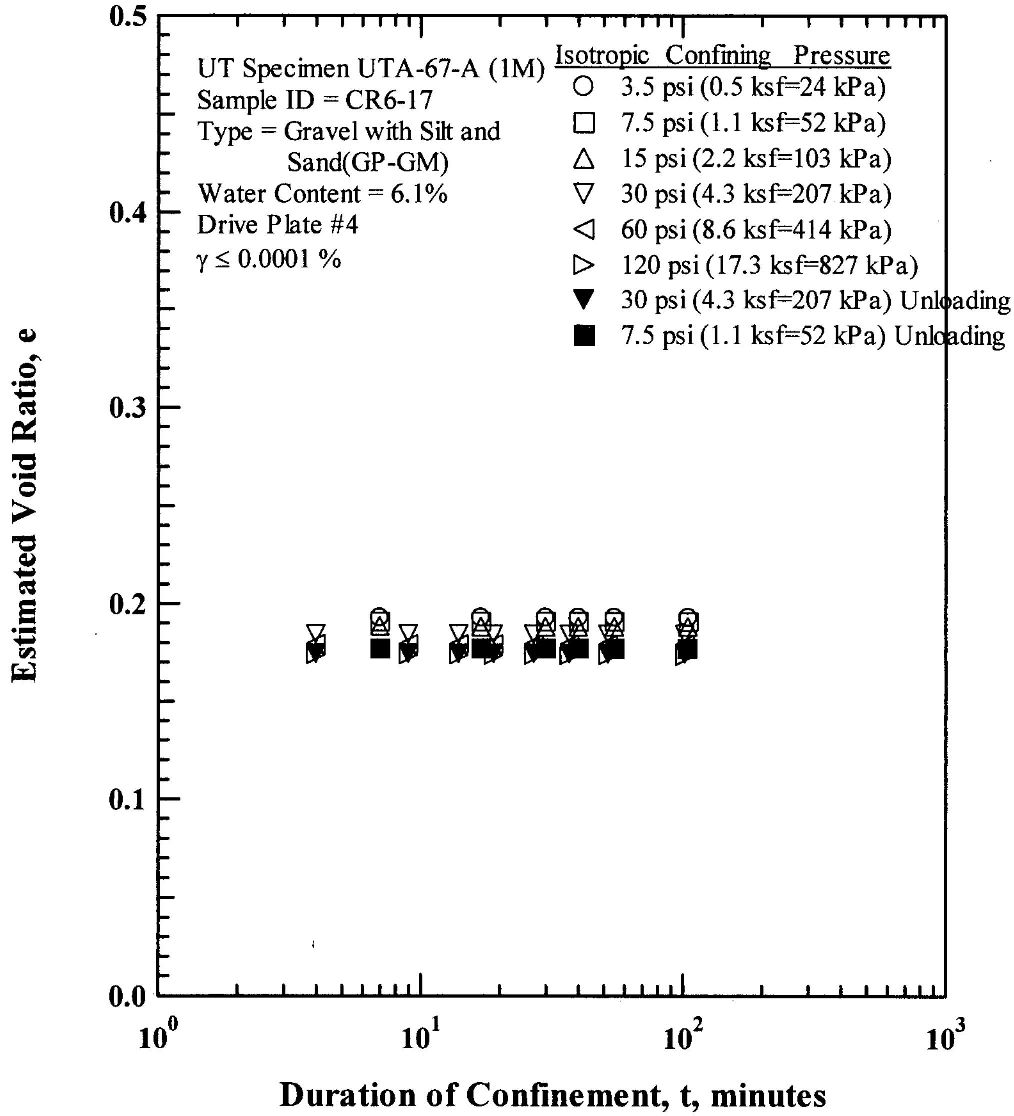


Figure D.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1M)

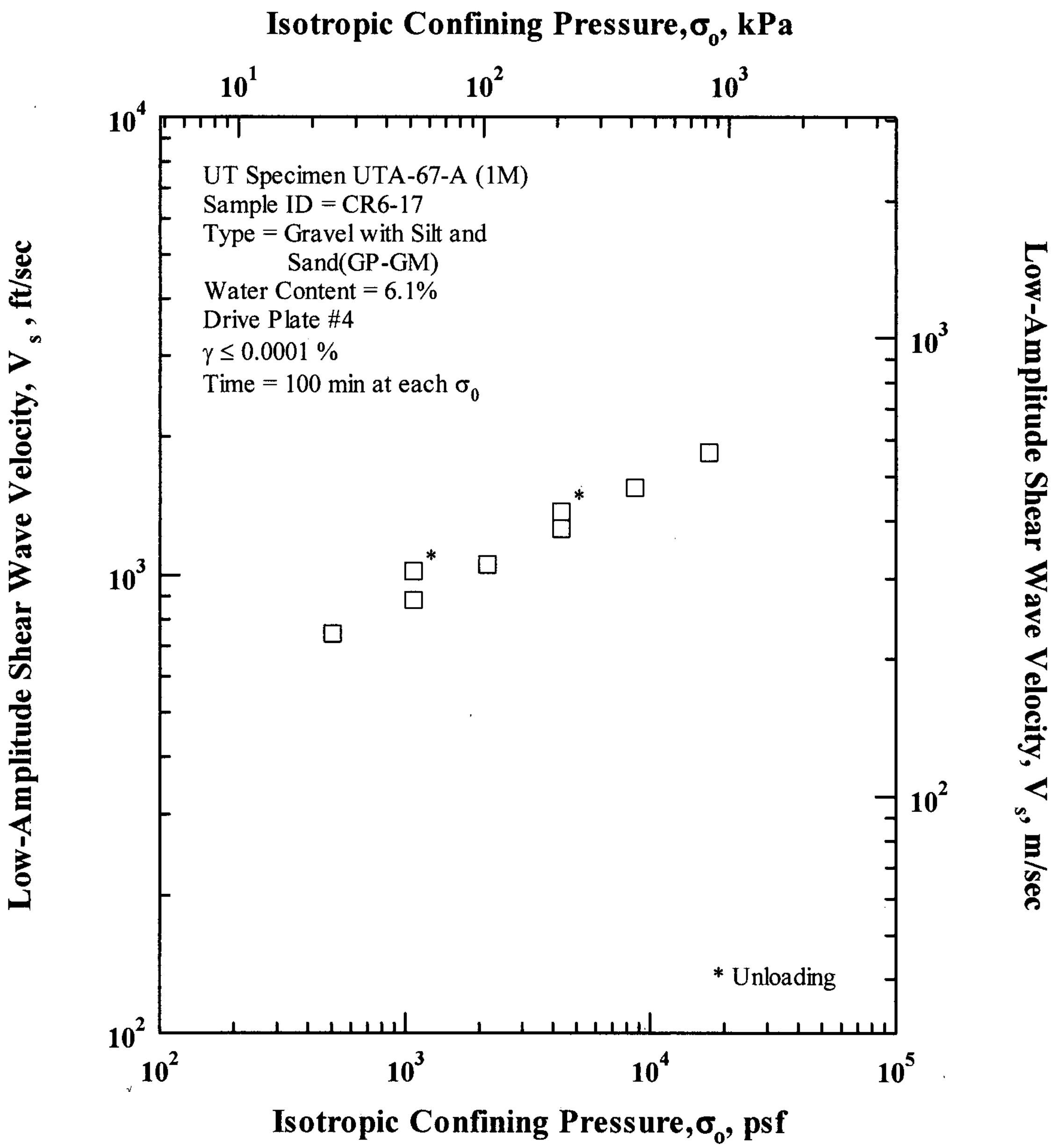


Figure D.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1M)

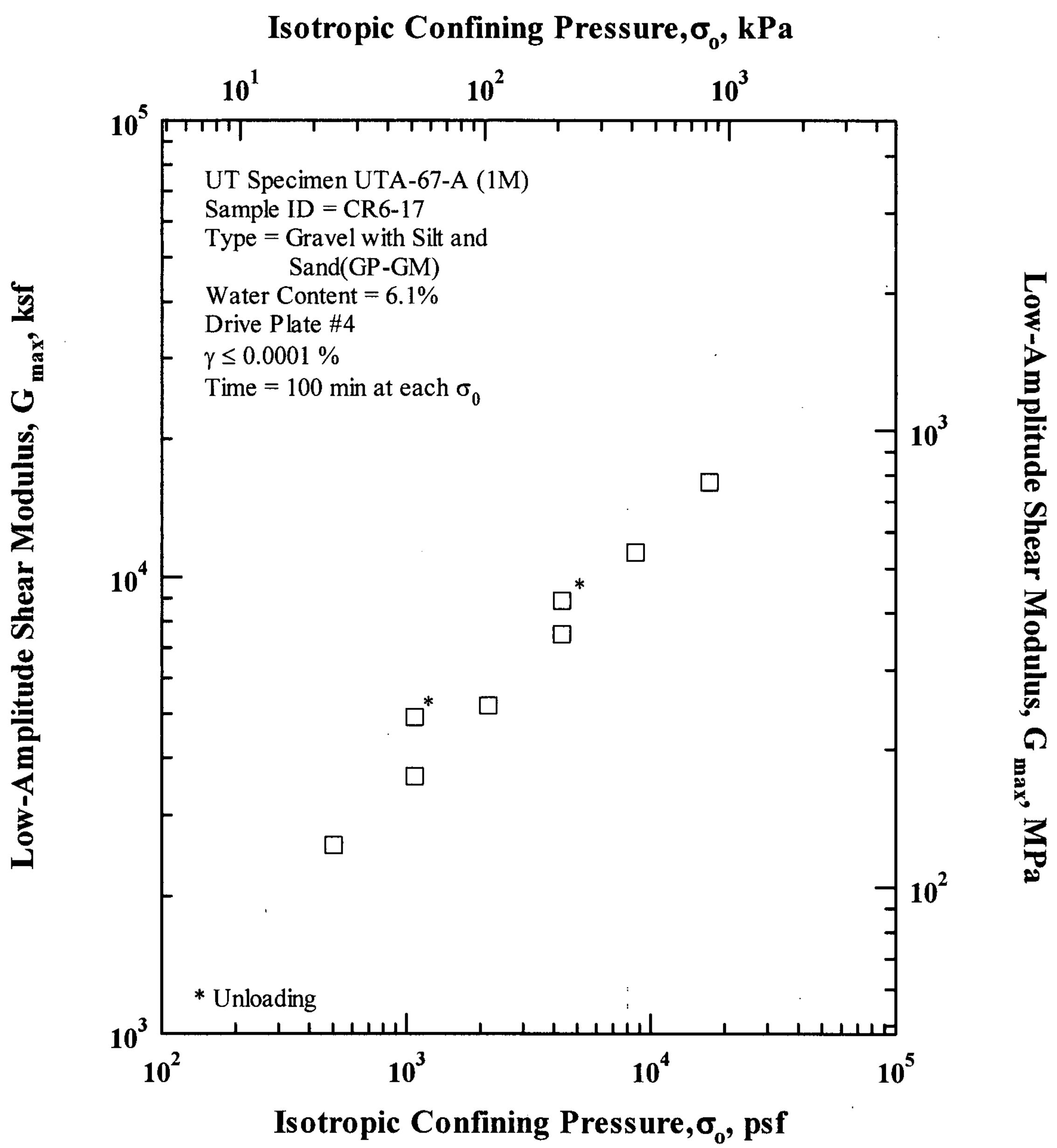


Figure D.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1M)

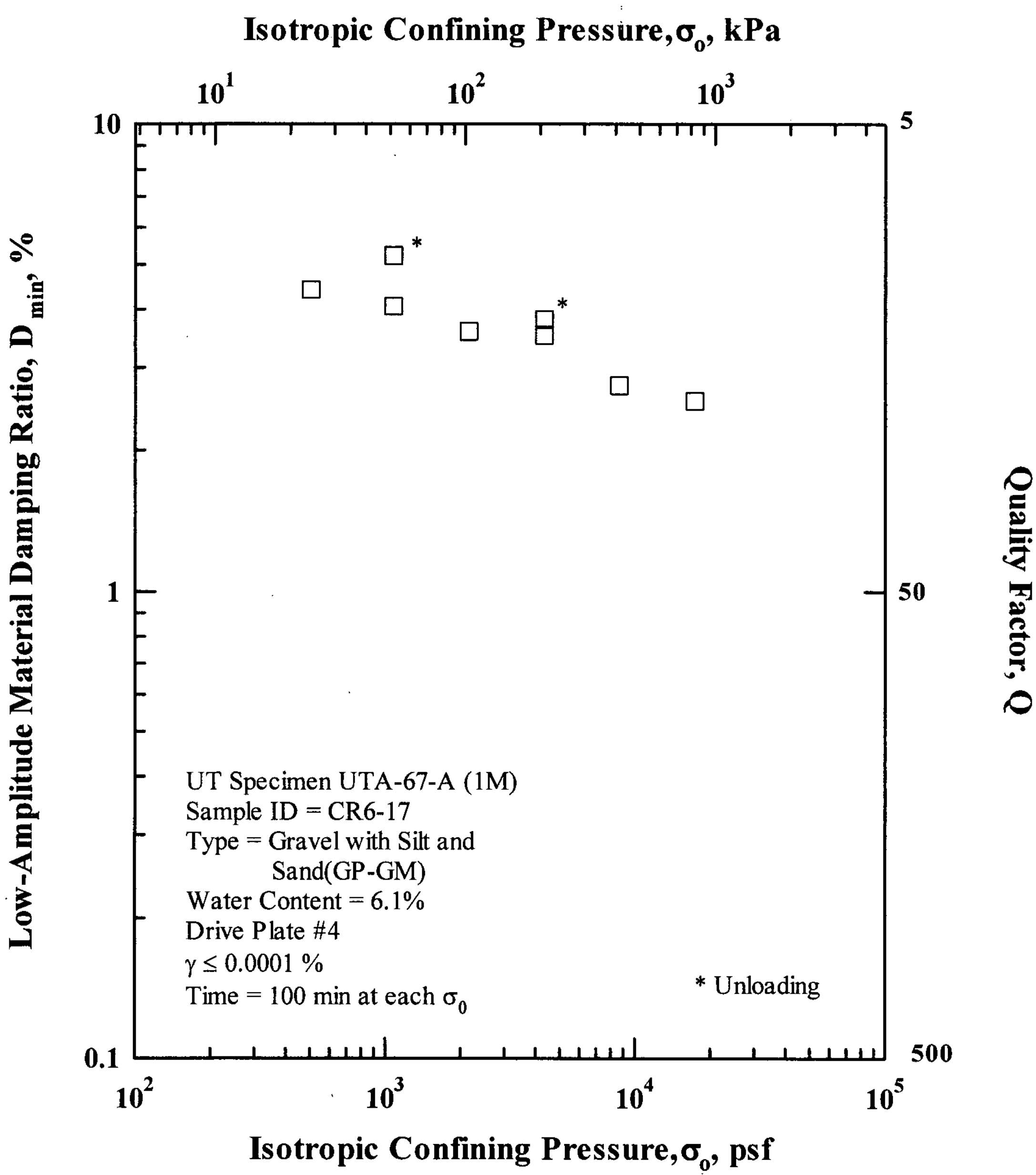


Figure D.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1M)

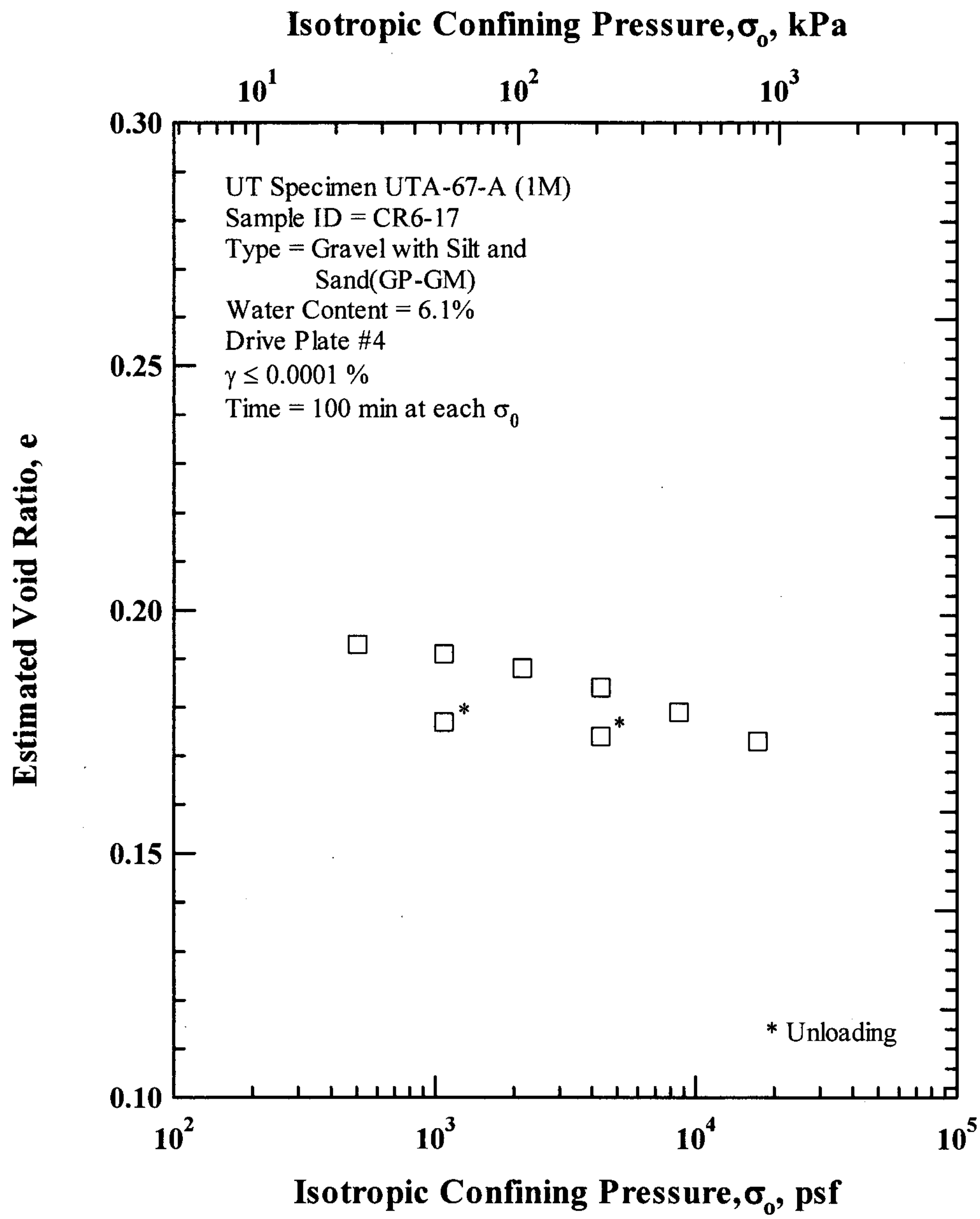


Figure D.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-A (1M)

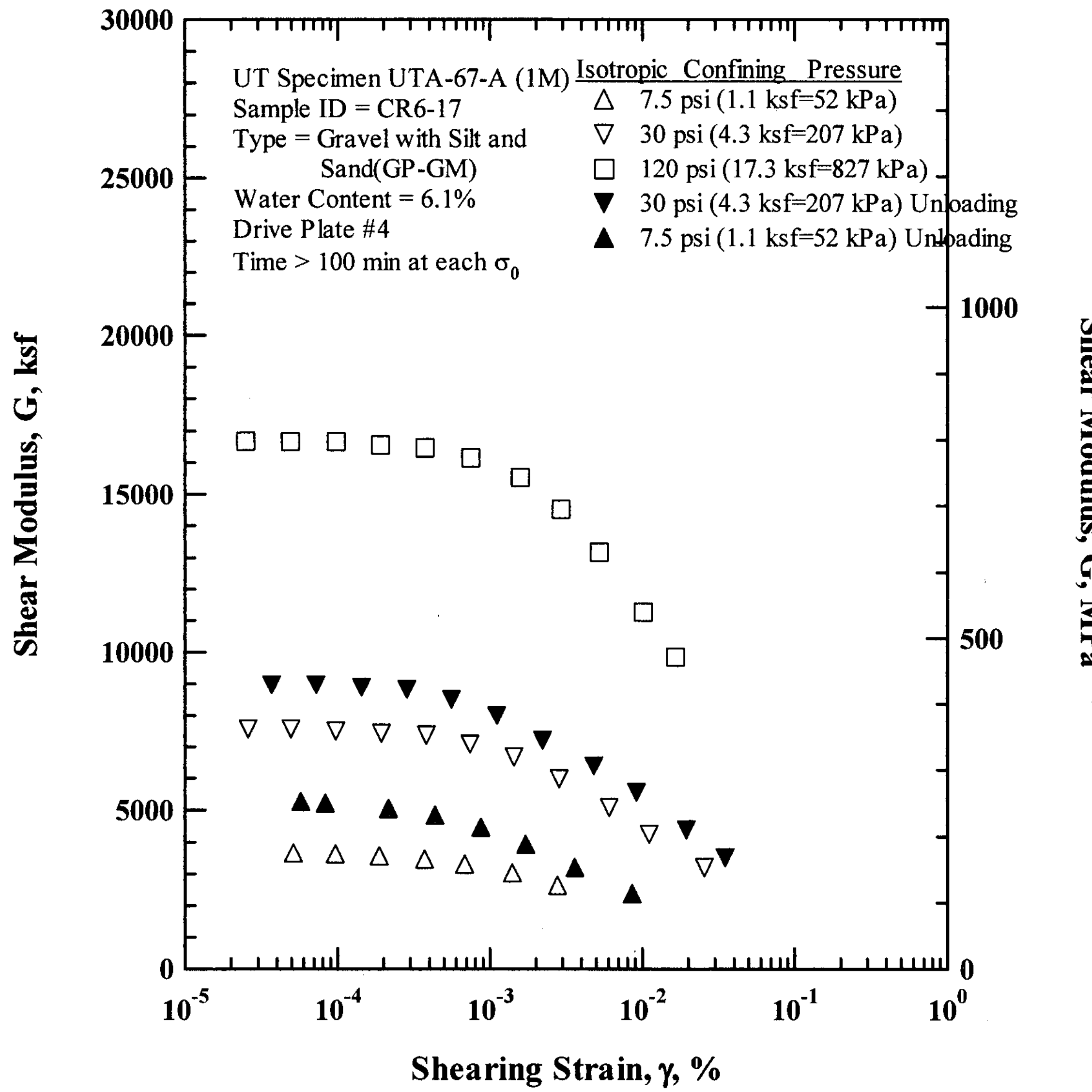


Figure D.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-A (1M)

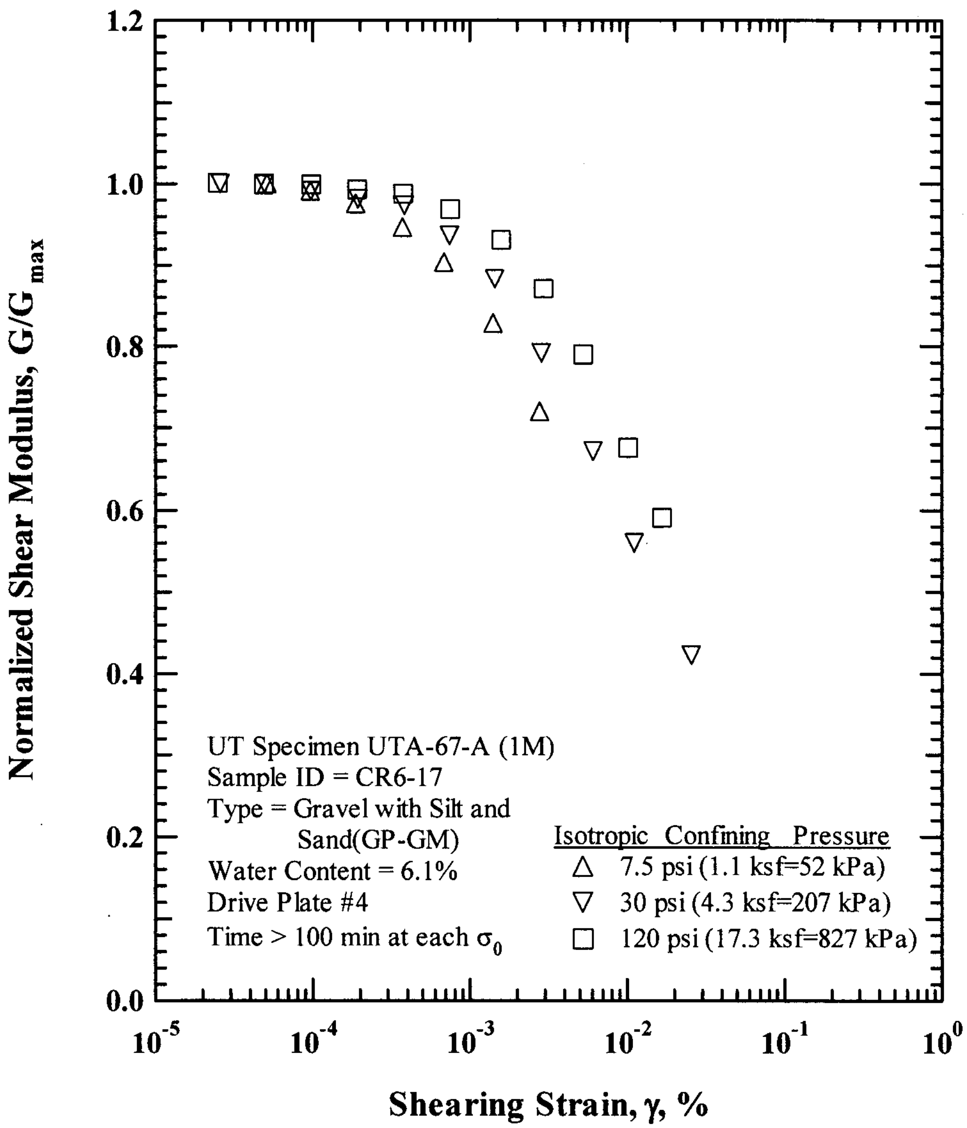


Figure D.9 Variation in Normalized Shear Modulus with Shearing Strain upon Loading at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-A (1M)

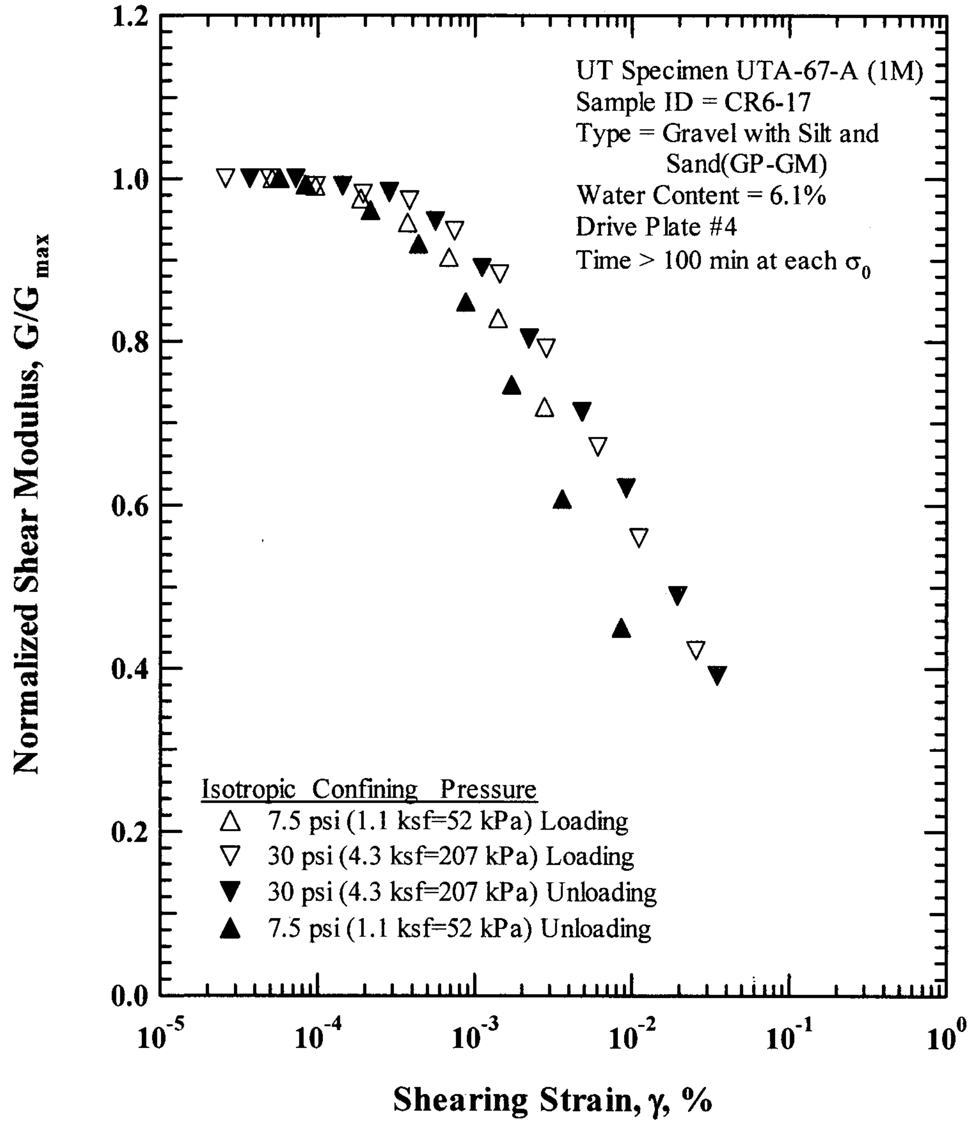


Figure D.10 Comparison of the Variations in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures upon Loading and Unloading from Resonant Column Tests of Specimen UTA-67-A (1M)

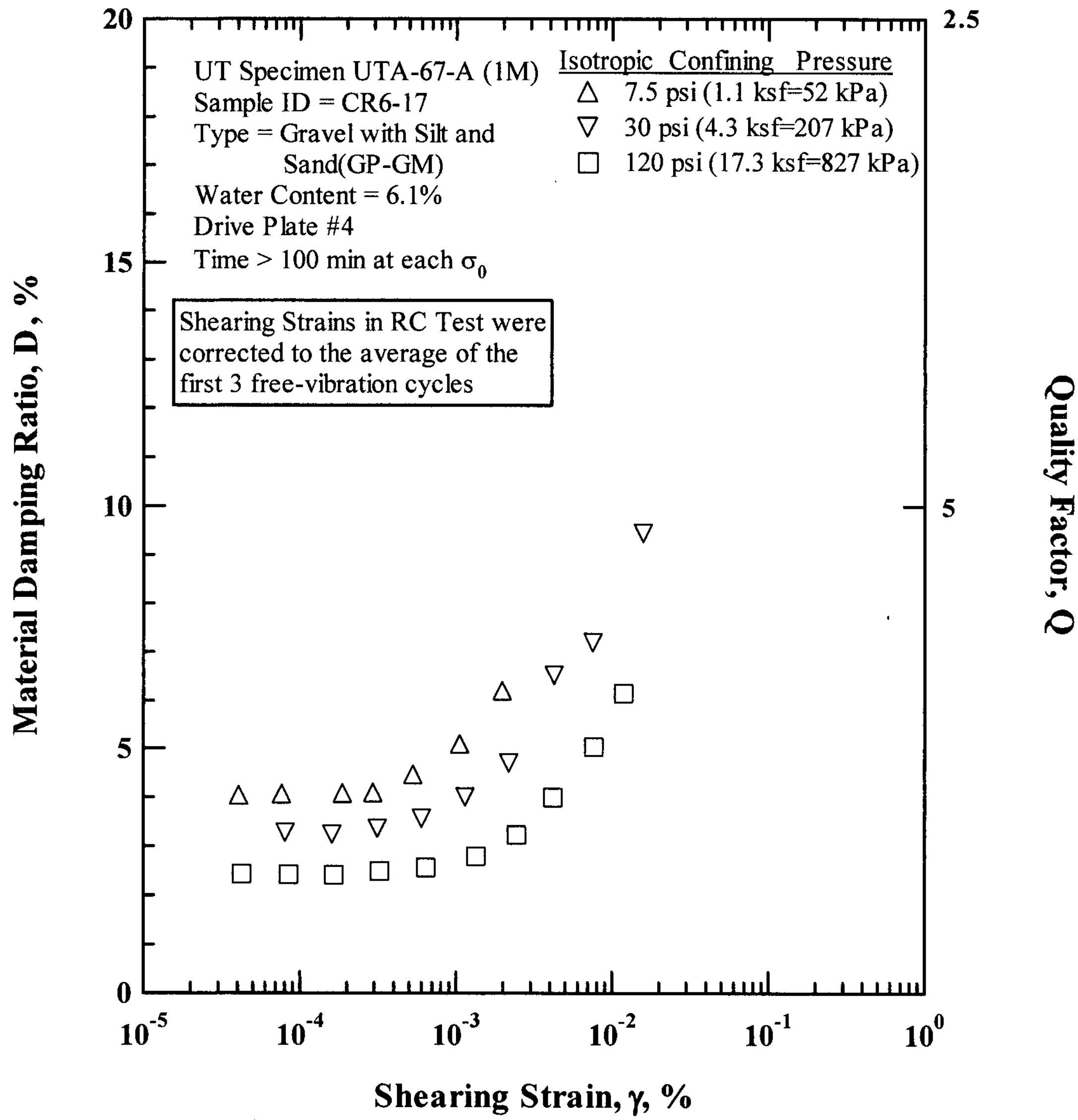


Figure D.11 Variation in Material Damping Ratio with Shearing Strain upon Loading at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-A (1M)

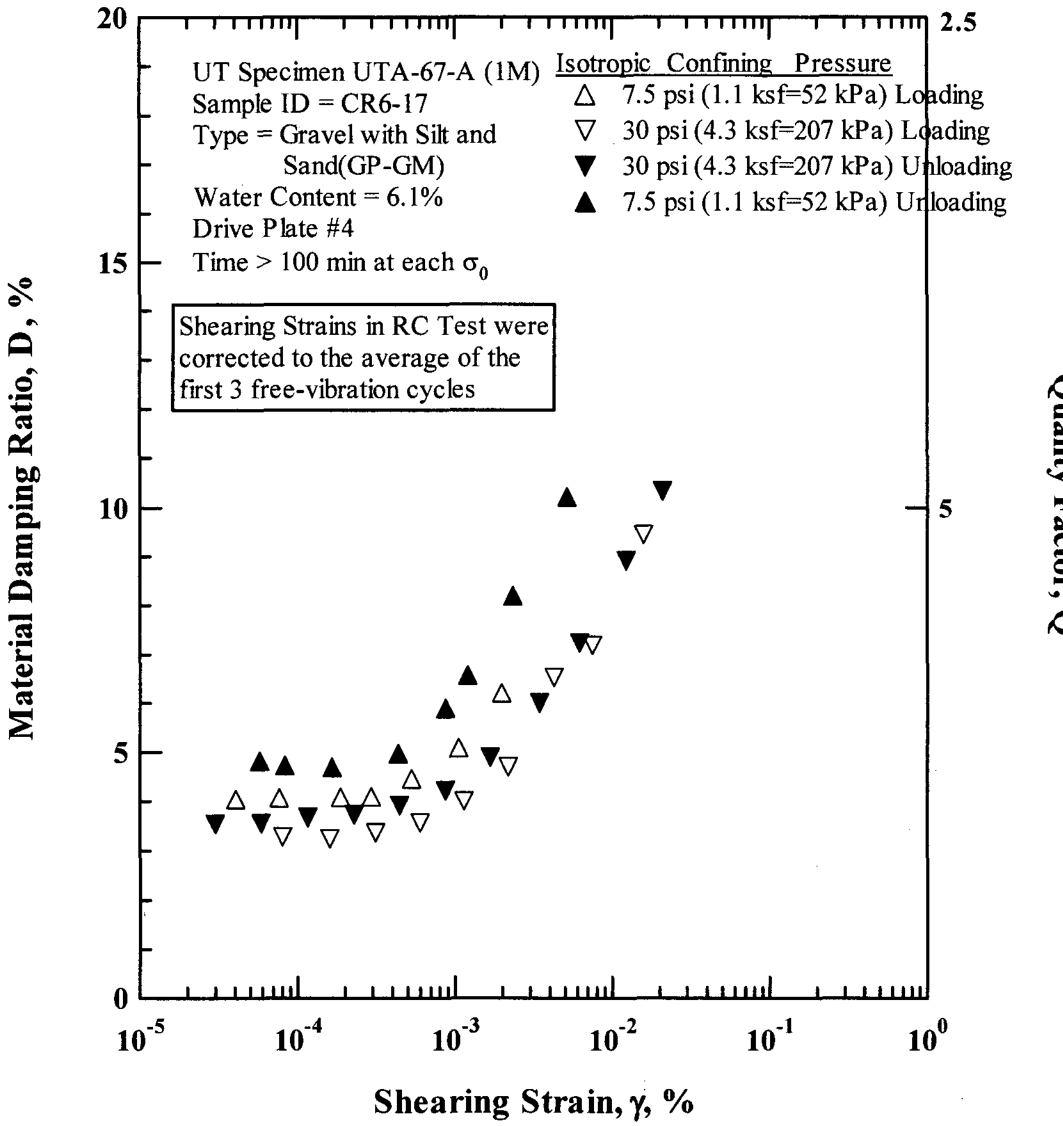


Figure D.12 Comparison of the Variations in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures upon Loading and Unloading from Resonant Column Tests of Specimen UTA-67-A (1M)

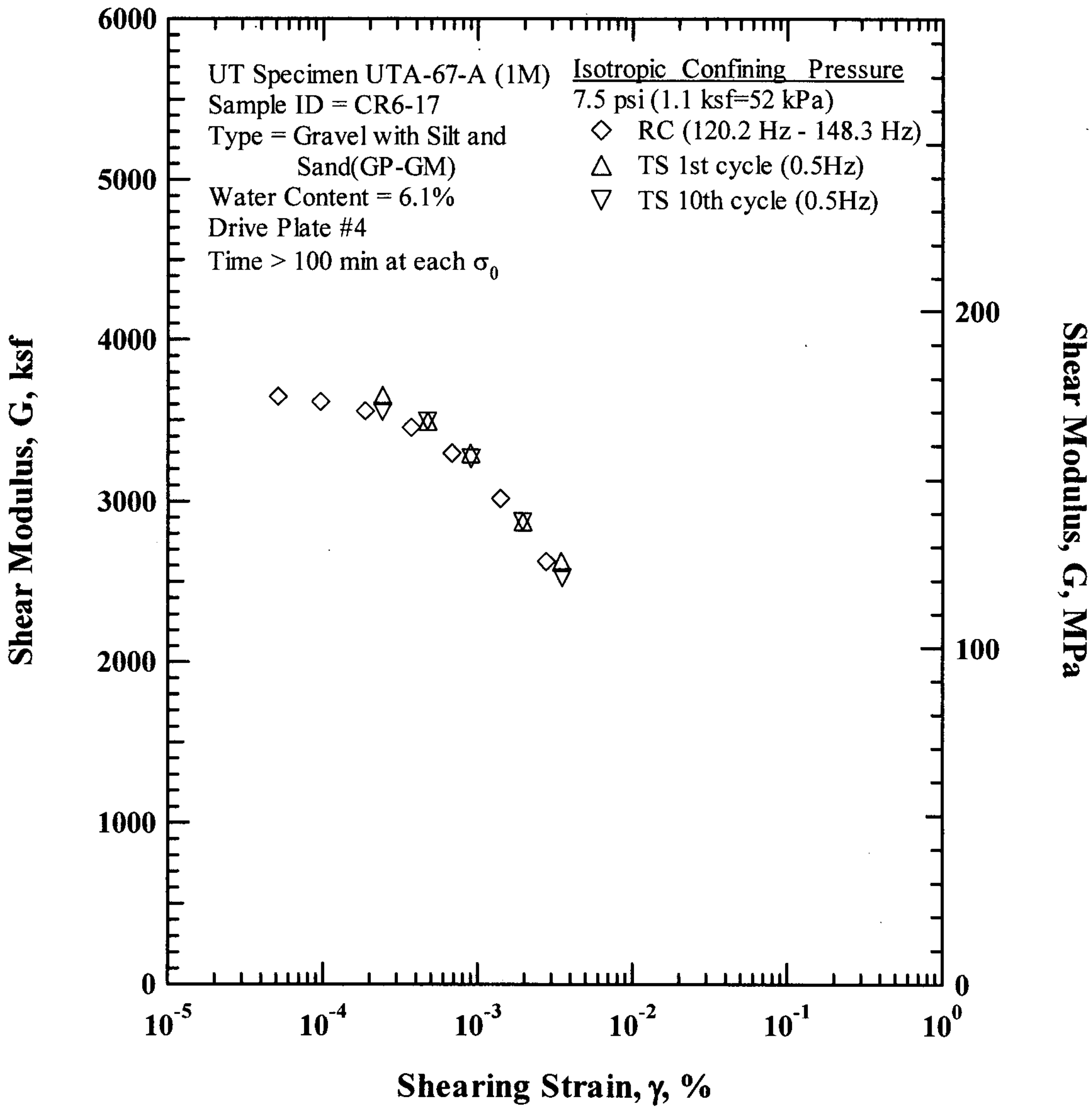


Figure D.13 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

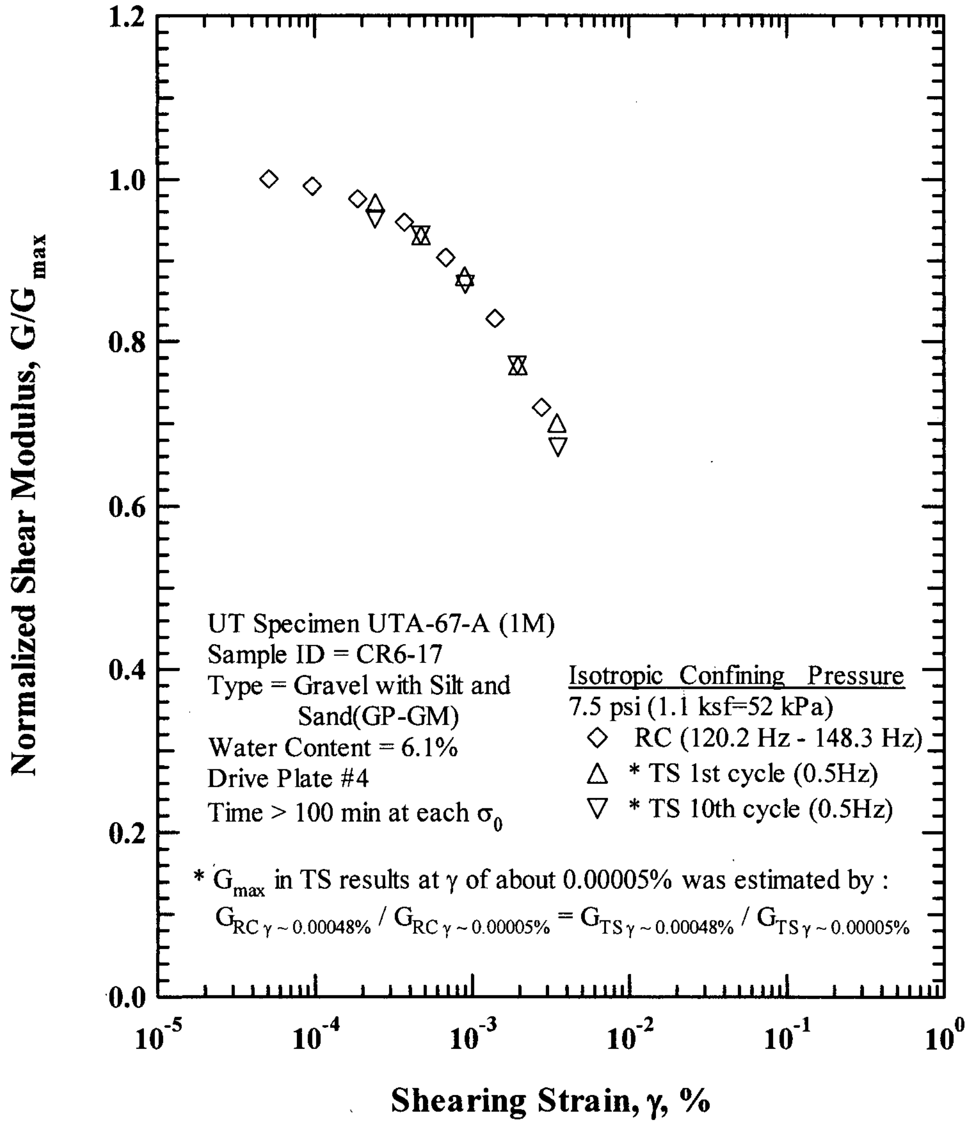


Figure D.14 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

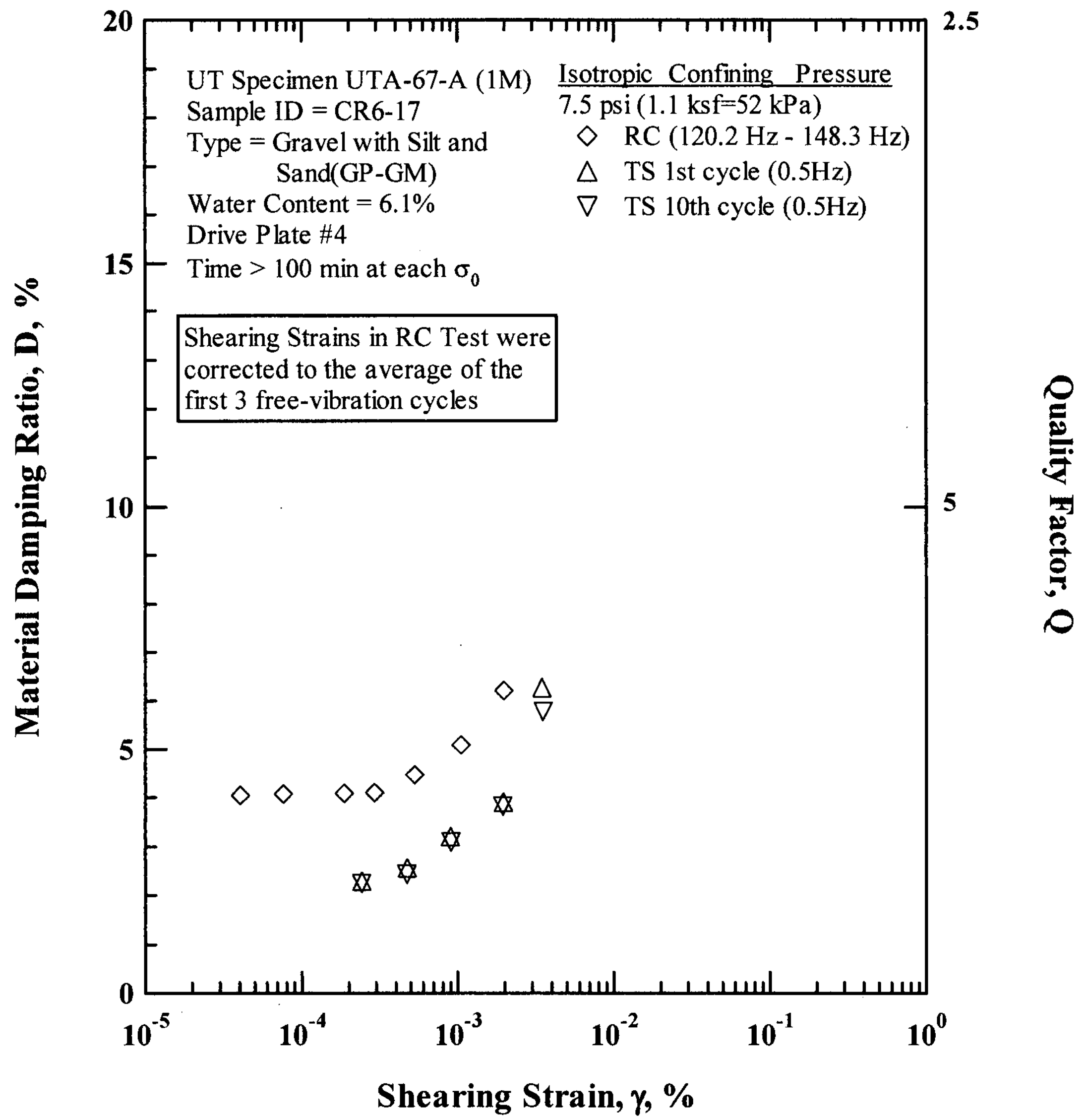


Figure D.15 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

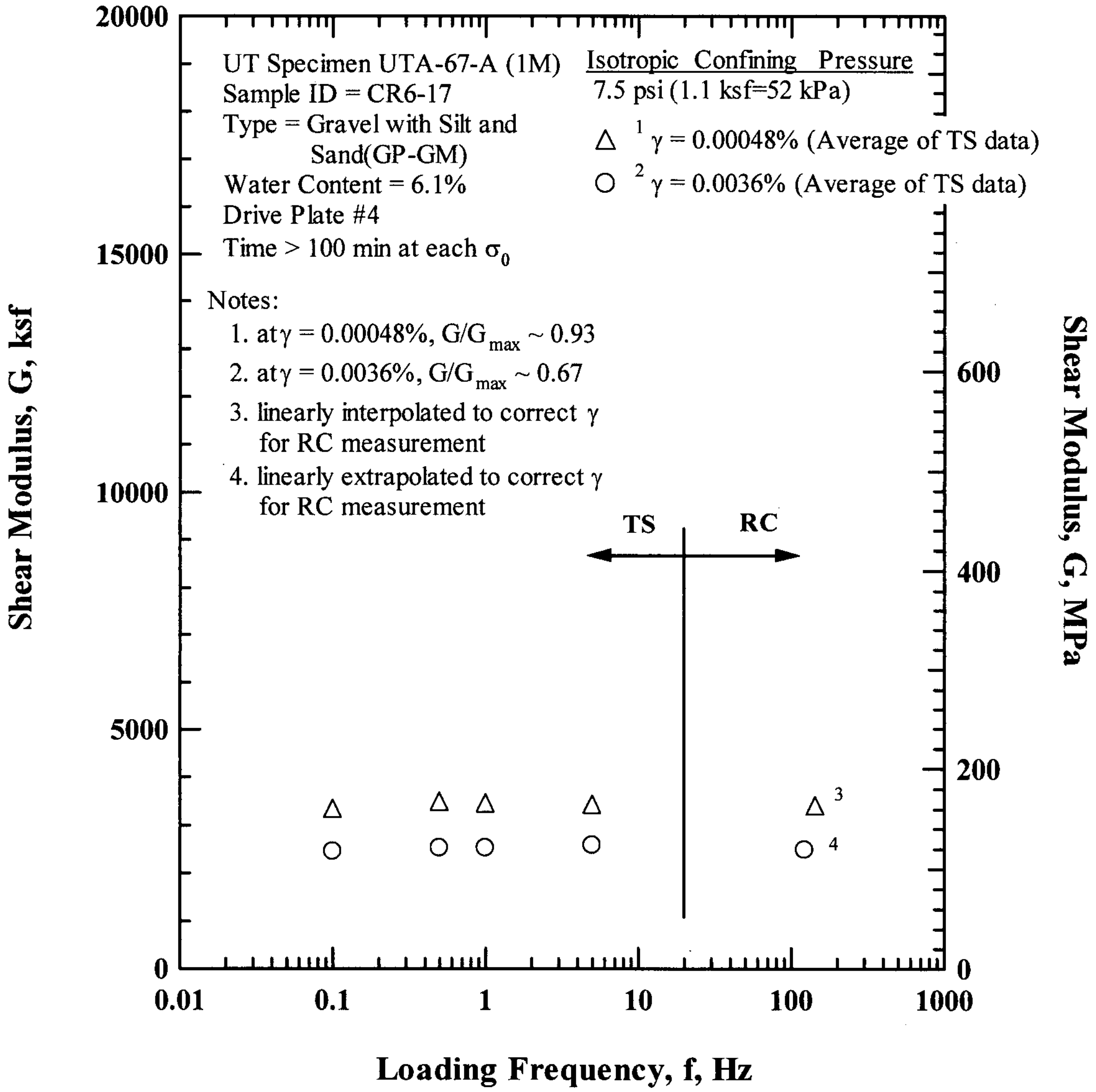


Figure D.16 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

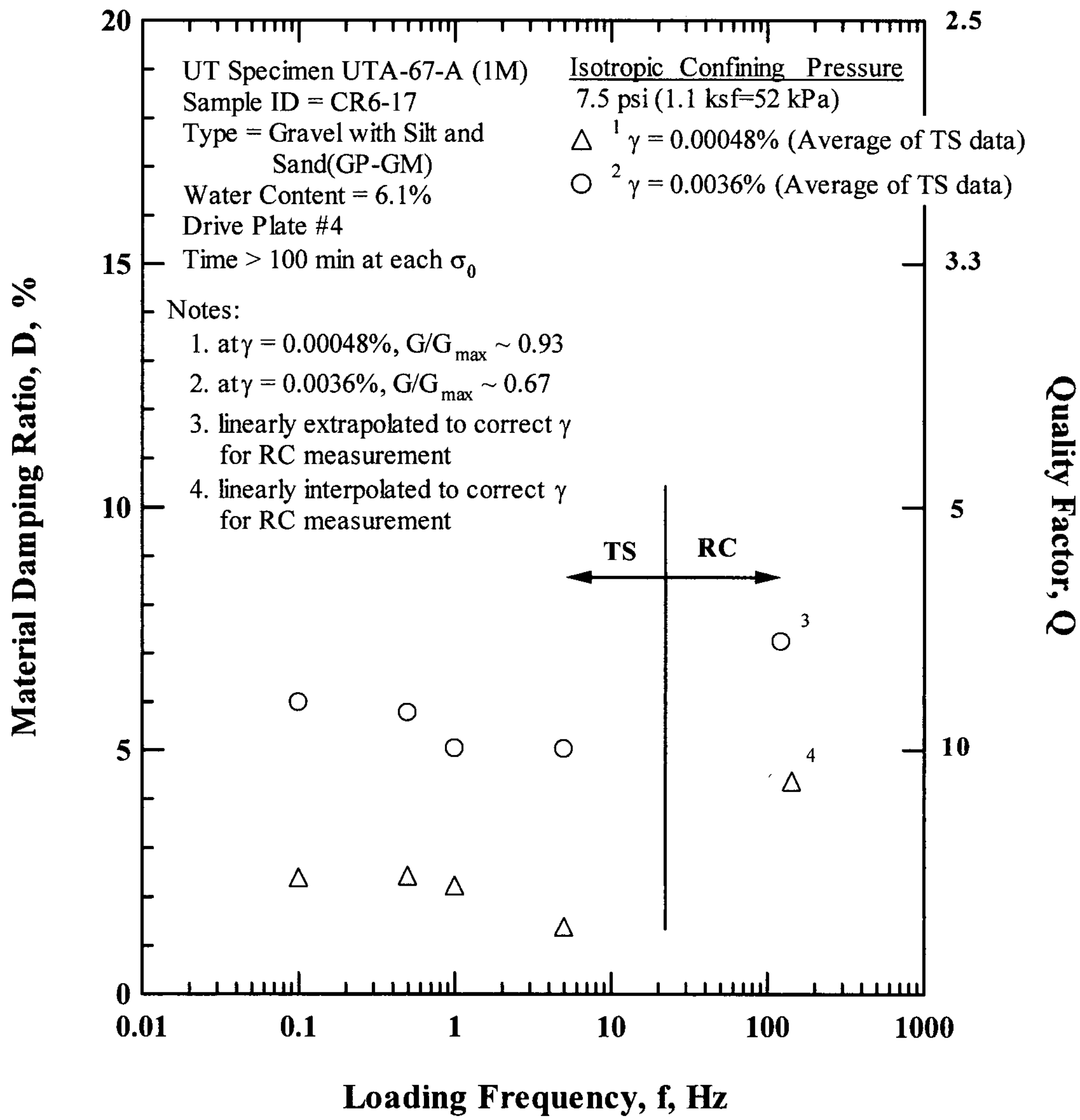


Figure D.17 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

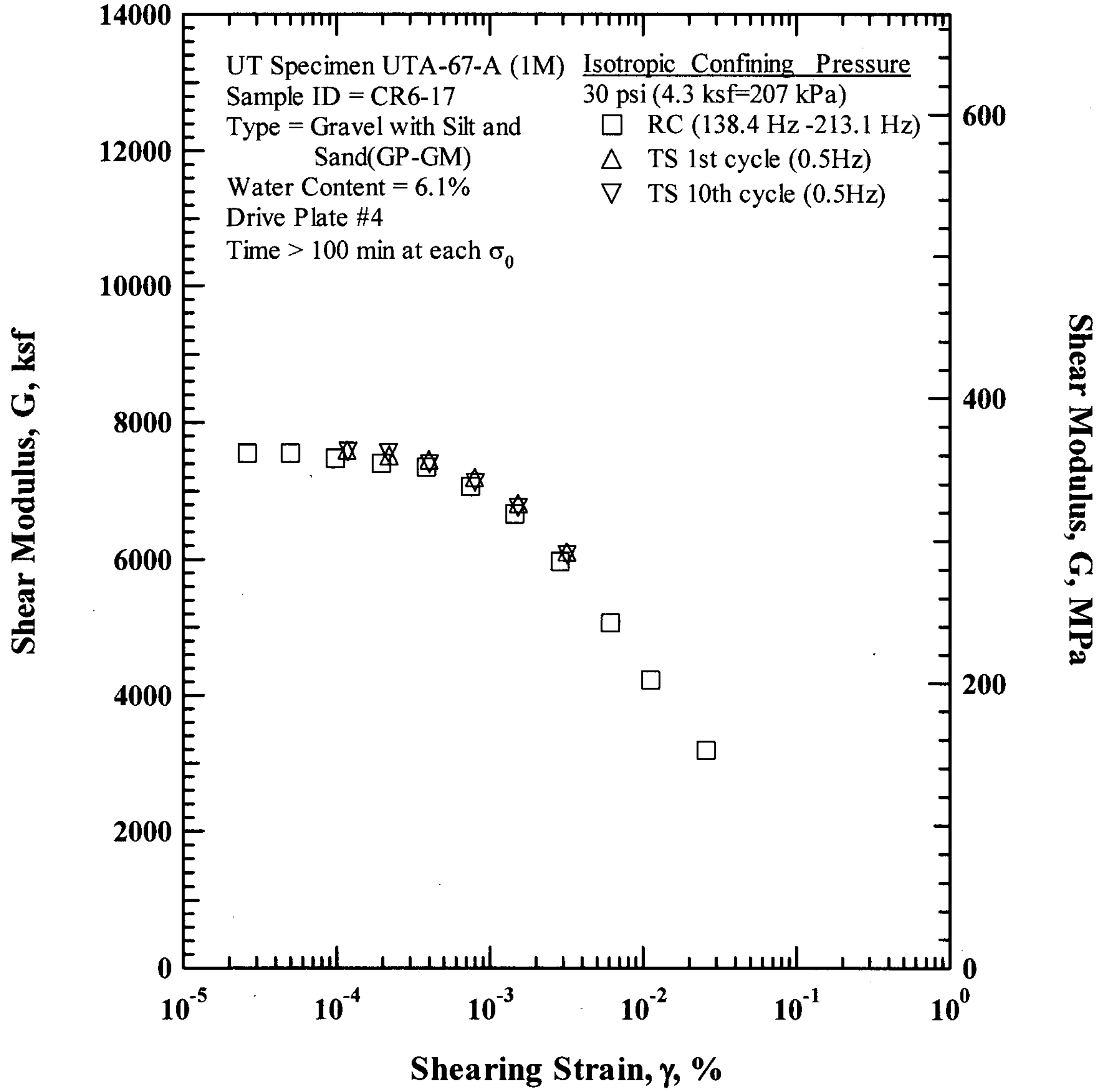


Figure D.18 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

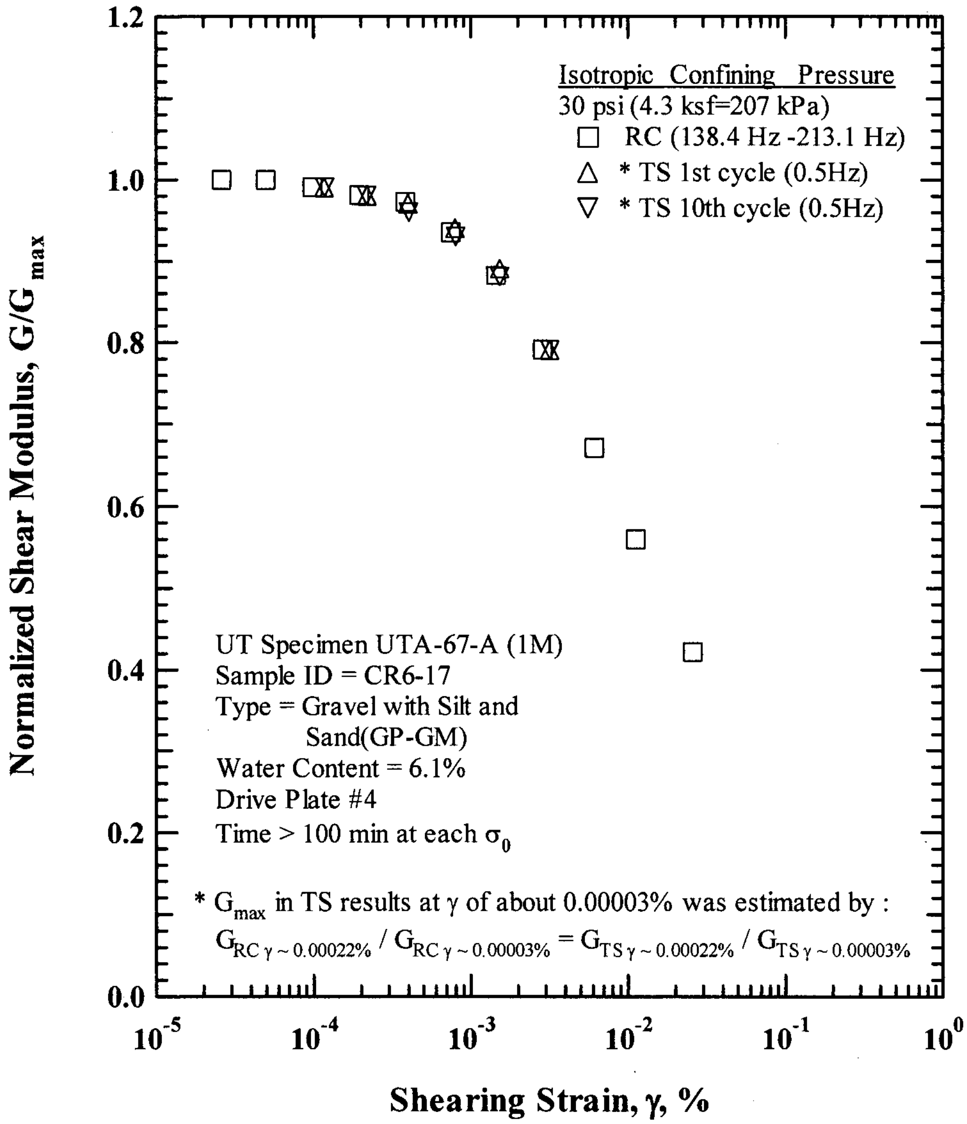


Figure D.19 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

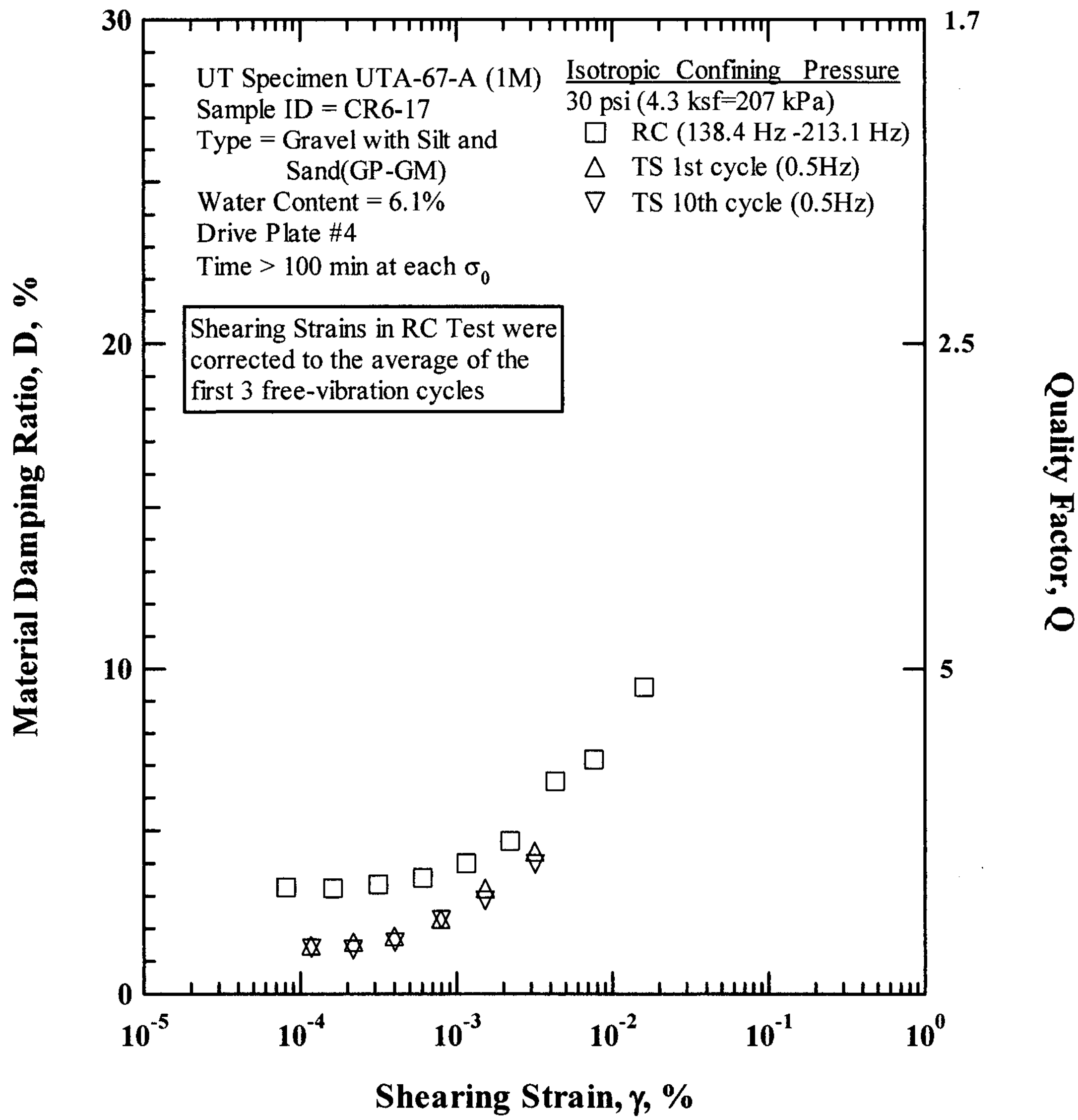


Figure D.20 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

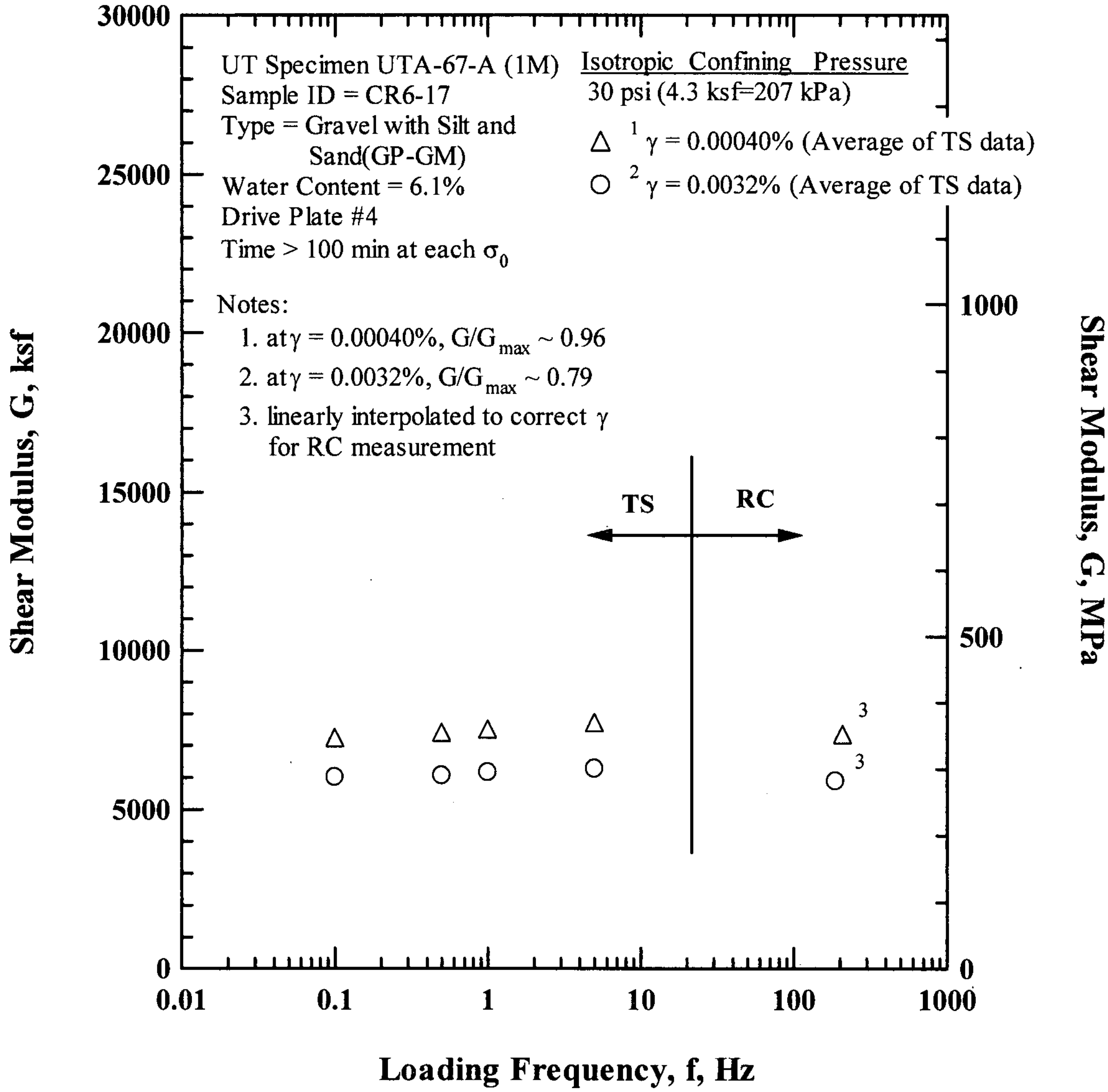


Figure D.21 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

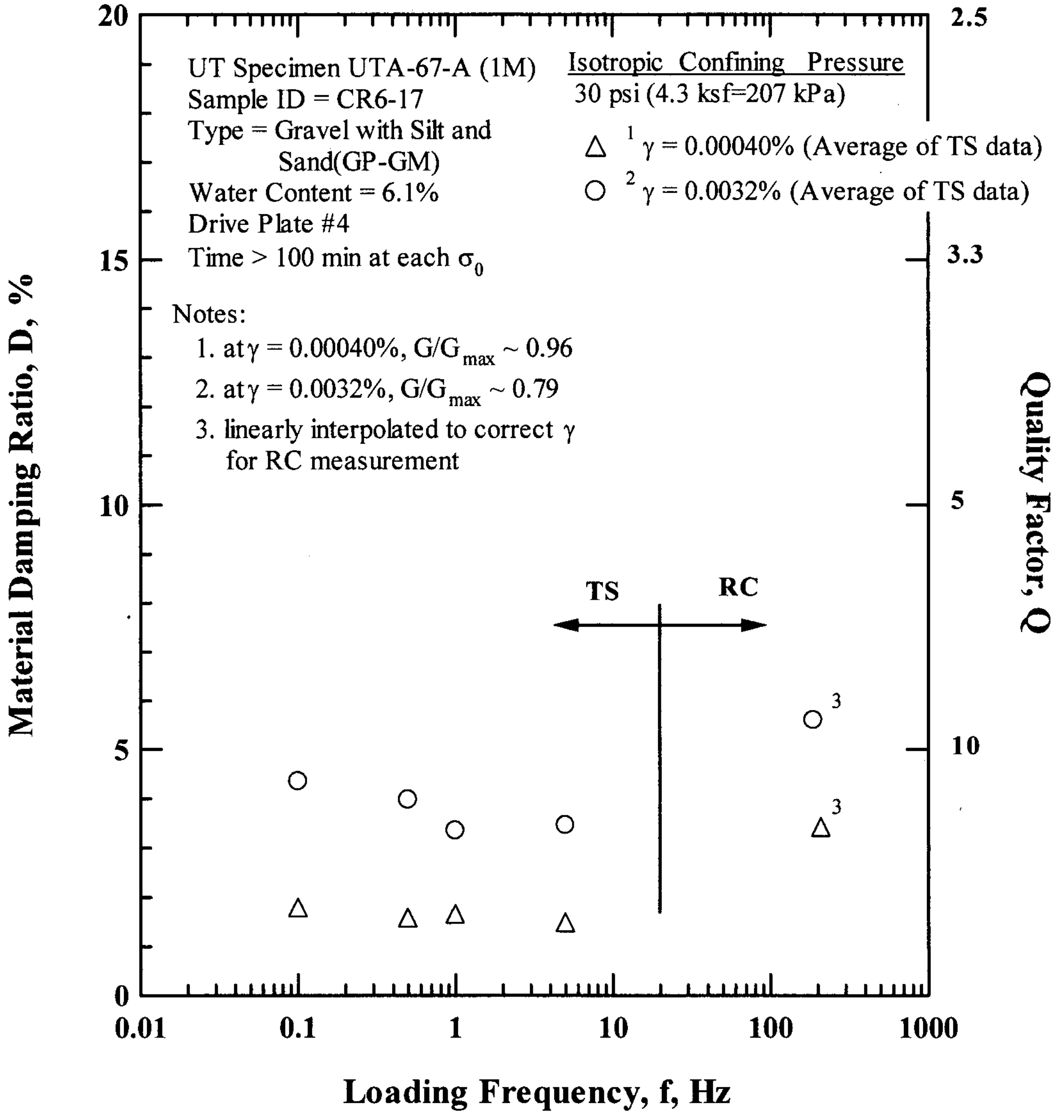


Figure D.22 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

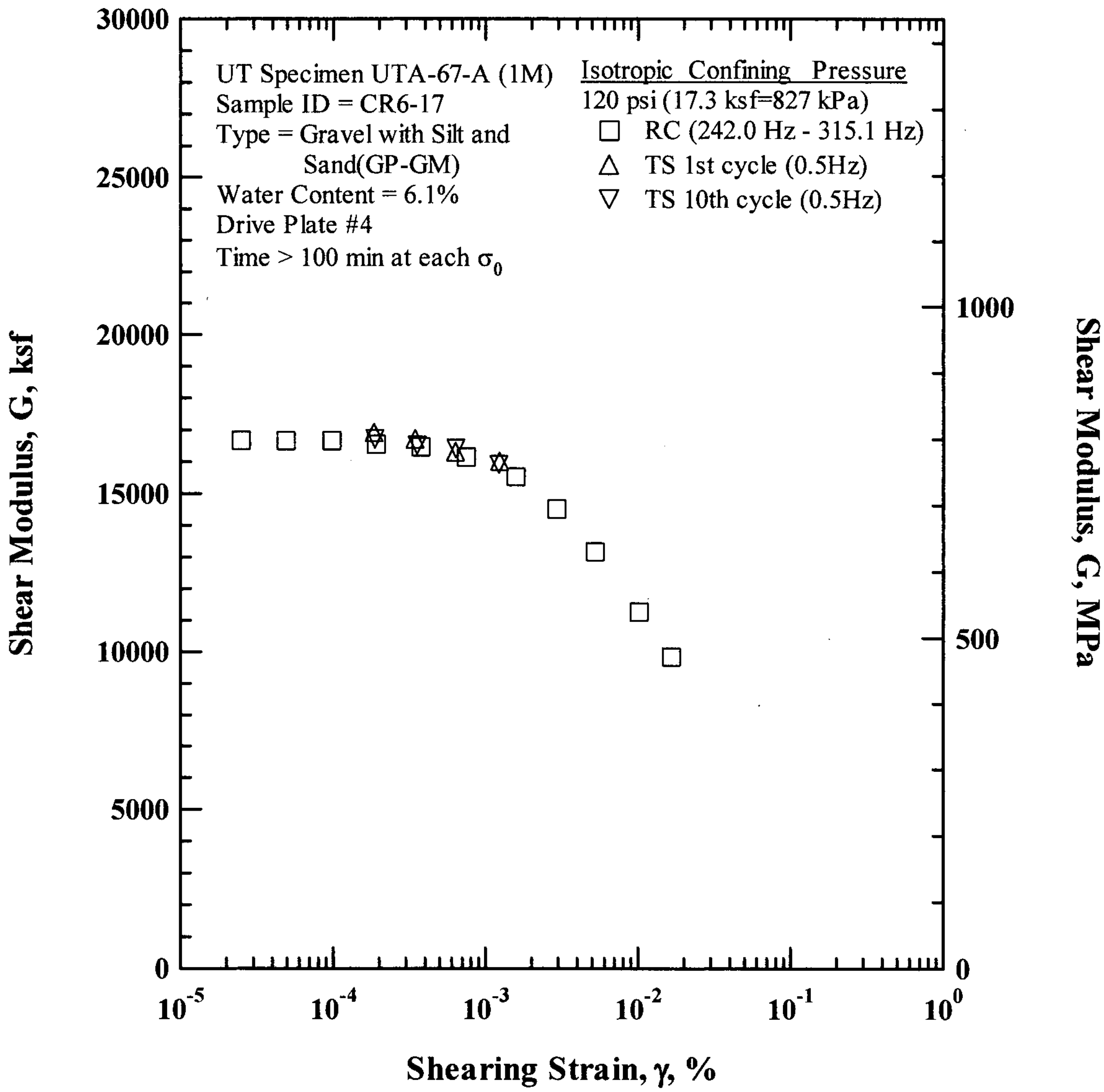


Figure D.23 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

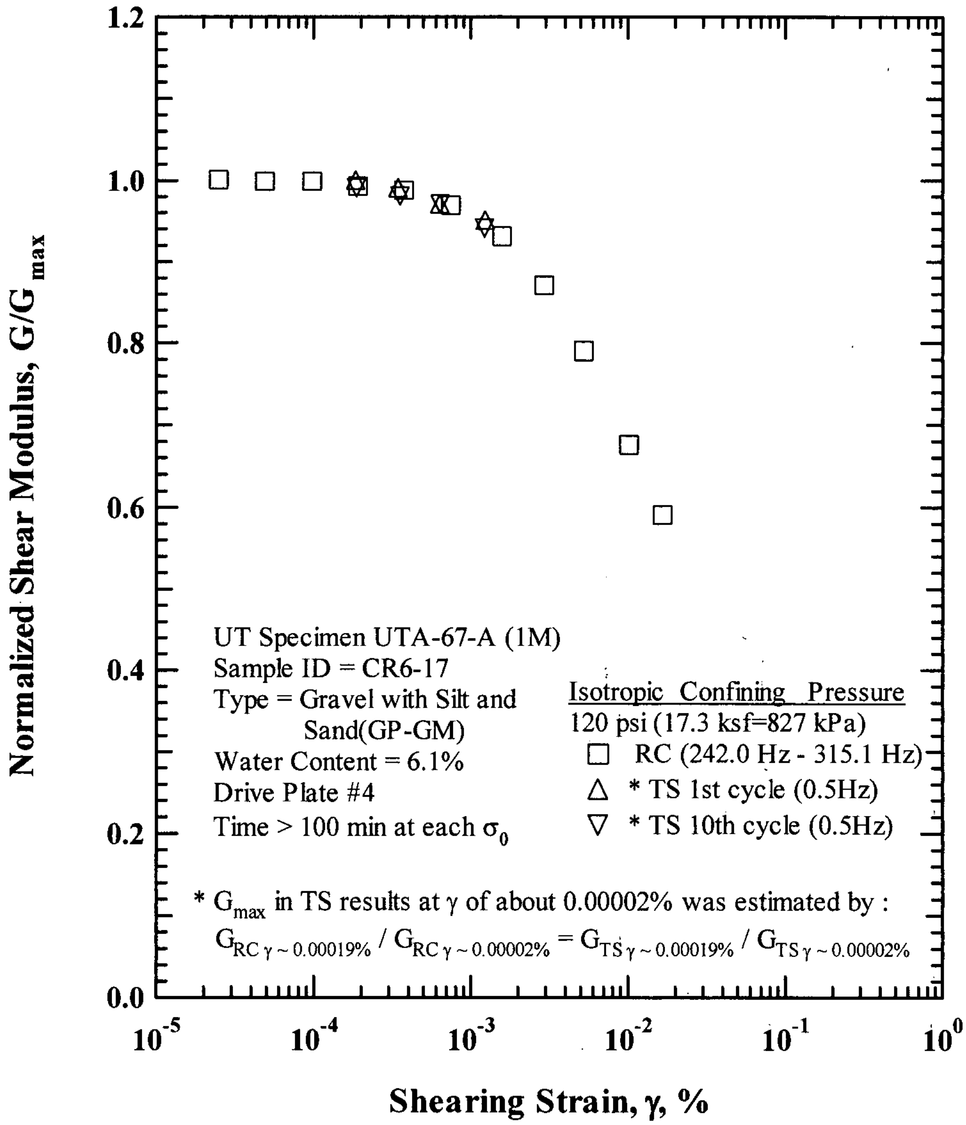


Figure D.24 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

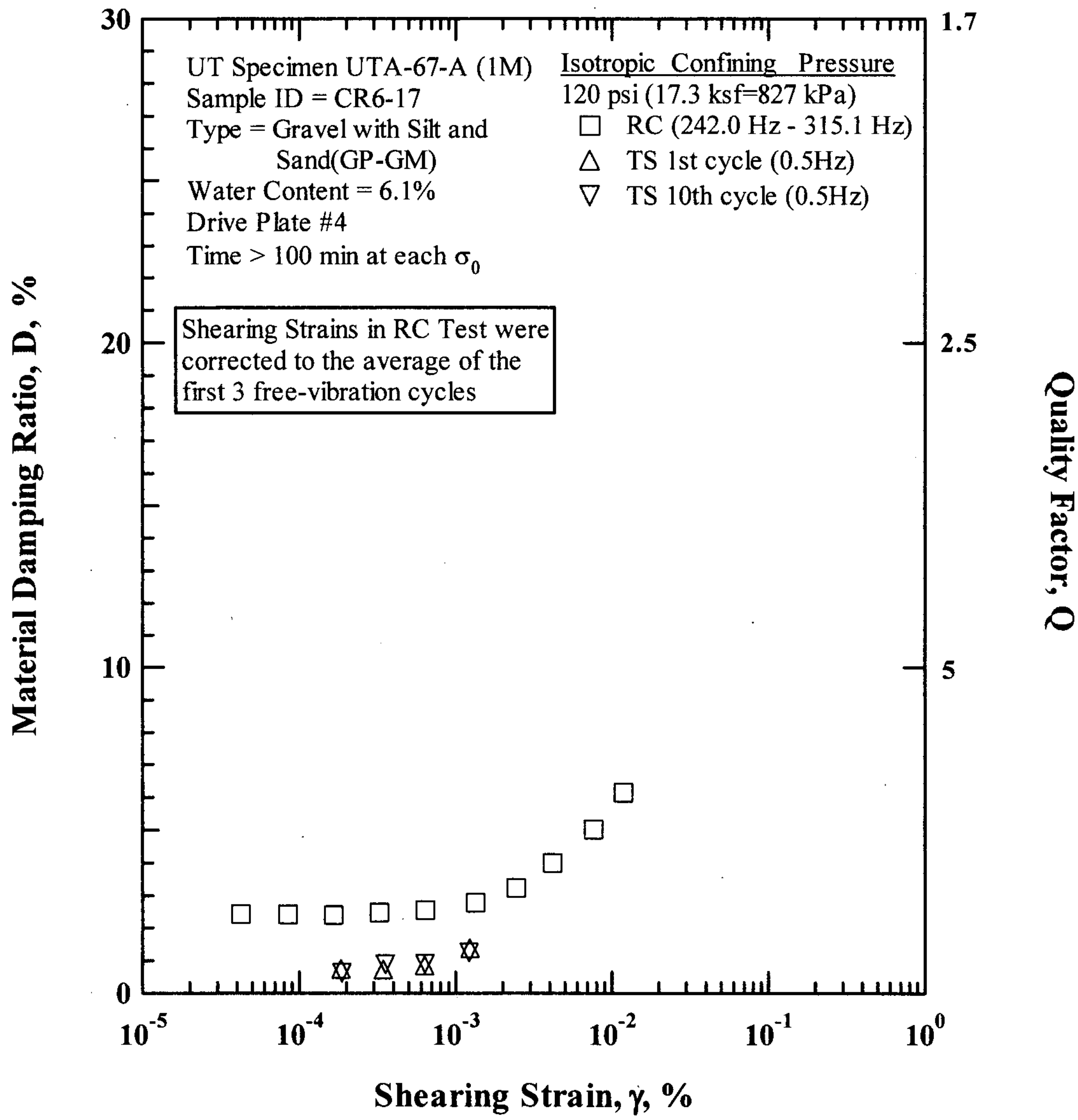


Figure D.25 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

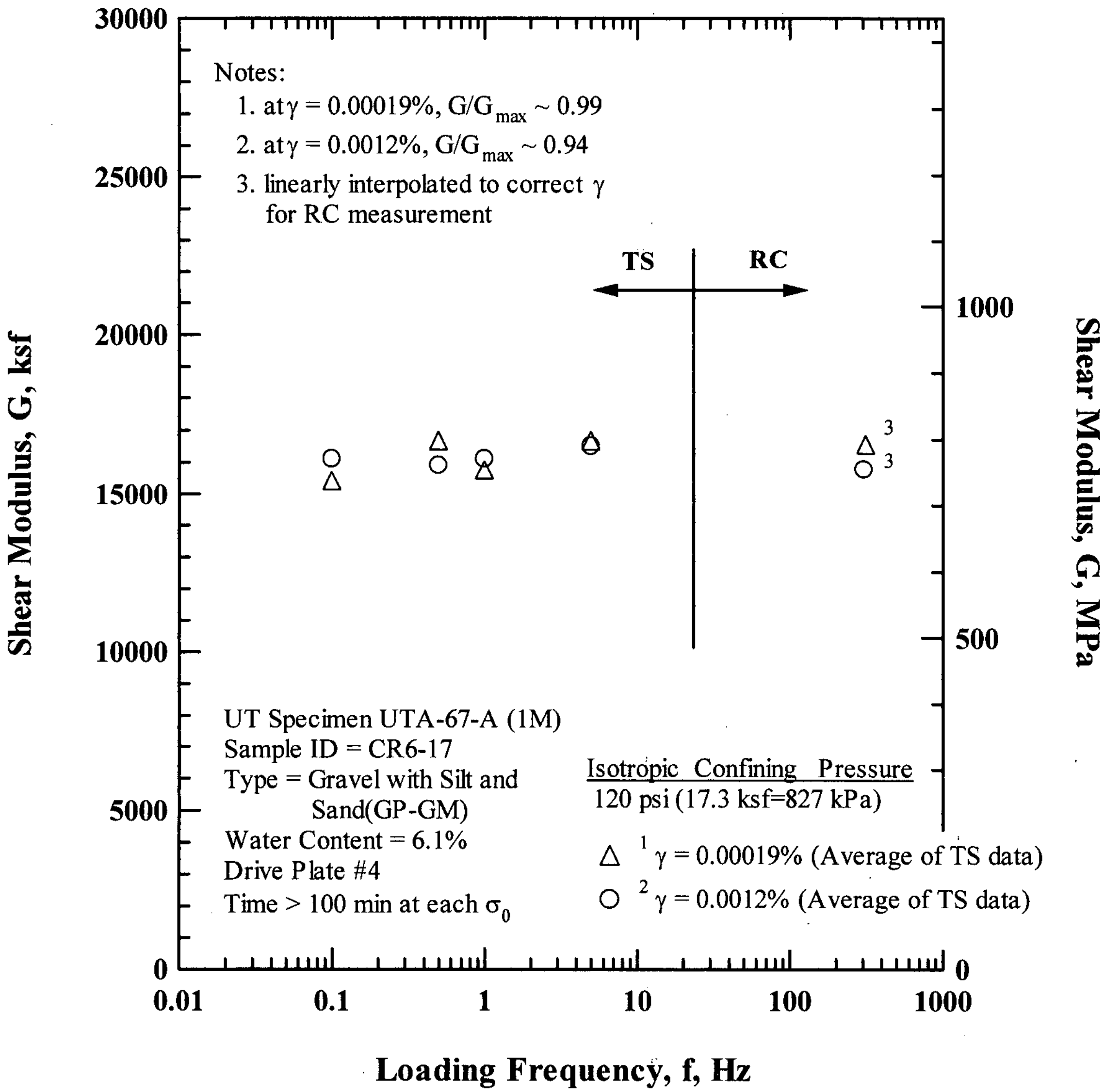


Figure D.26 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

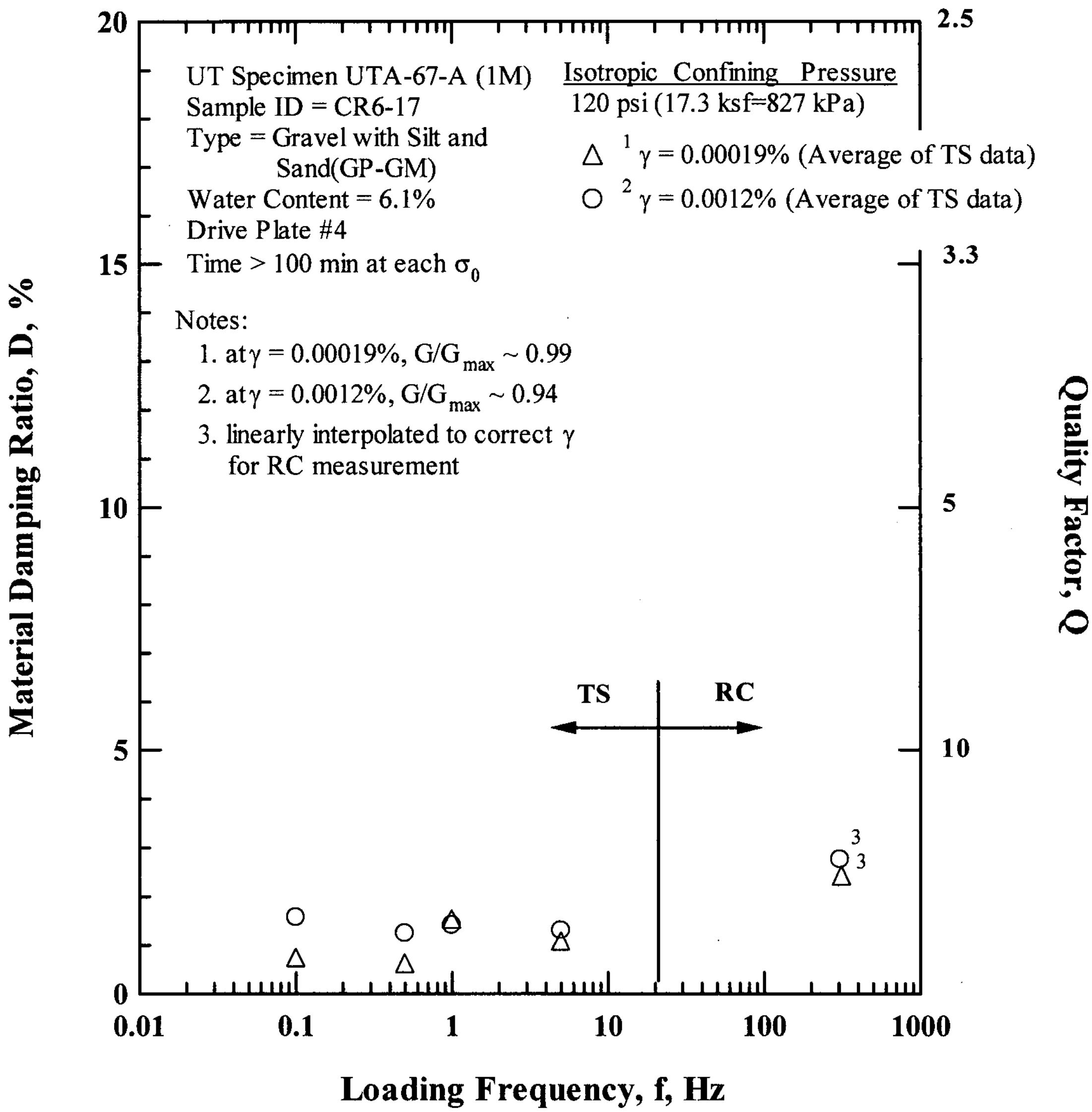


Figure D.27 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-A (1M)

Table D.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-A (1M)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_S	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.5	504	24	2584	123.9	743	4.41	0.19
7.5	1080	52	3646	174.8	882	4.06	0.19
15	2160	103	5214	250.0	1054	3.58	0.19
30	4320	207	7478	358.5	1261	3.51	0.18
60	8640	414	11303	541.9	1548	2.75	0.18
120	17280	827	16125	773.0	1846	2.55	0.17
30 (Unloading)	4320	207	8875	425.5	1370	3.80	0.17
7.5 (Unloading)	1080	52	4915	235.6	1020	5.23	0.18

Table D.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
5.16E-05	3646	1.00	4.09E-05	4.03
9.74E-05	3613	0.99	7.71E-05	4.06
1.89E-04	3555	0.98	1.89E-04	4.07
3.74E-04	3450	0.95	2.96E-04	4.08
6.87E-04	3291	0.90	5.33E-04	4.45
1.41E-03	3014	0.83	1.06E-03	5.08
2.79E-03	2622	0.72	1.99E-03	6.19

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table D.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
2.45E-04	3650	0.97	2.28	2.44E-04	3550	0.95	2.23
4.77E-04	3490	0.93	2.55	4.74E-04	3490	0.93	2.42
9.04E-04	3290	0.88	3.19	9.12E-04	3260	0.87	3.08
1.97E-03	2870	0.77	3.89	1.96E-03	2870	0.77	3.81
3.49E-03	2620	0.70	6.25	3.54E-03	2520	0.67	5.77

Table D.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
2.61E-05	7551	1.00	2.61E-05	-
4.97E-05	7551	1.00	4.97E-05	-
9.82E-05	7479	0.99	8.11E-05	3.27
1.95E-04	7408	0.98	1.61E-04	3.23
3.84E-04	7349	0.97	3.16E-04	3.36
7.45E-04	7070	0.94	6.06E-04	3.56
1.45E-03	6661	0.88	1.15E-03	4.00
2.86E-03	5974	0.79	2.19E-03	4.69
6.11E-03	5068	0.67	4.28E-03	6.51
1.12E-02	4227	0.56	7.61E-03	7.18
2.57E-02	3189	0.42	1.59E-02	9.43

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

[-] High Noise Level Interfering with Damping Measurement

Table D.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.18E-04	7586	0.99	1.46	1.19E-04	7570	0.99	1.38
2.20E-04	7507	0.98	1.57	2.19E-04	7554	0.98	1.34
4.02E-04	7452	0.97	1.75	4.06E-04	7390	0.96	1.57
7.98E-04	7190	0.94	2.28	8.06E-04	7120	0.93	2.26
1.54E-03	6810	0.89	3.21	1.54E-03	6750	0.88	2.85
3.20E-03	6100	0.79	4.34	3.22E-03	6060	0.79	3.97

Table D.6 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 120 psi (17.3 ksf = 827 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
2.49E-05	16674	1.00	2.49E-05	-
4.89E-05	16657	1.00	4.23E-05	2.44
9.78E-05	16657	1.00	8.46E-05	2.42
1.91E-04	16550	0.99	1.65E-04	2.41
3.76E-04	16462	0.99	3.24E-04	2.49
7.45E-04	16146	0.97	6.40E-04	2.56
1.57E-03	15523	0.93	1.33E-03	2.79
2.94E-03	14511	0.87	2.43E-03	3.23
5.24E-03	13168	0.79	4.16E-03	4.00
1.01E-02	11268	0.68	7.64E-03	5.03
1.66E-02	9843	0.59	1.18E-02	6.15

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

[-] High Noise Level Interfering with Damping Measurement

Table D.7 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 120 psi (17.3 ksf = 827 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.86E-04	16896	1.00	0.72	1.89E-04	16656	0.99	0.61
3.47E-04	16700	0.99	0.71	3.57E-04	16500	0.98	0.87
6.39E-04	16300	0.97	0.83	6.41E-04	16400	0.97	0.89
1.24E-03	16000	0.95	1.37	1.23E-03	15900	0.94	1.24

Table D.8 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa) Unloading

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
3.73E-05	8952	1.00	3.03E-05	3.53
7.28E-05	8952	1.00	5.92E-05	3.55
1.45E-04	8874	0.99	1.17E-04	3.66
2.87E-04	8797	0.98	2.31E-04	3.72
5.62E-04	8490	0.95	4.48E-04	3.91
1.12E-03	7966	0.89	8.77E-04	4.21
2.22E-03	7188	0.80	1.69E-03	4.88
4.83E-03	6385	0.71	3.47E-03	5.99
9.24E-03	5556	0.62	6.27E-03	7.22
1.96E-02	4376	0.49	1.24E-02	8.90
3.51E-02	3497	0.39	2.10E-02	10.32

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table D.9 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-A (1M); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa) Unloading

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
5.79E-05	5254	1.00	5.79E-05	4.80
8.38E-05	5213	0.99	8.38E-05	4.72
2.18E-04	5050	0.96	1.67E-04	4.68
4.39E-04	4831	0.92	4.39E-04	4.96
8.75E-04	4451	0.85	8.75E-04	5.88
1.72E-03	3921	0.75	1.21E-03	6.56
3.62E-03	3187	0.61	2.36E-03	8.18
8.64E-03	2366	0.45	5.18E-03	10.21

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

APPENDIX E

UT Specimen UTA-67-E (5E)
Sample ID : CR6-20
(Vulcan Quarry Statistical Avg. Sample)
Type = Scalped, Reconstituted Gravel with Silt and Sand (GP-GM*)

Water Content, w = 5.5 %

G_S = 2.716*

Degree of Saturation = 59.8 %

Total Unit Weight, γ_t = 143.1 lb/ft^3

Dry Unit Weight, γ_d = 135.6 lb/ft^3

Target : γ_d= 136.4 lb/ft^3 ± 1 lb/ft^3

w= 4.6 % ± 1.0 %

* **Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

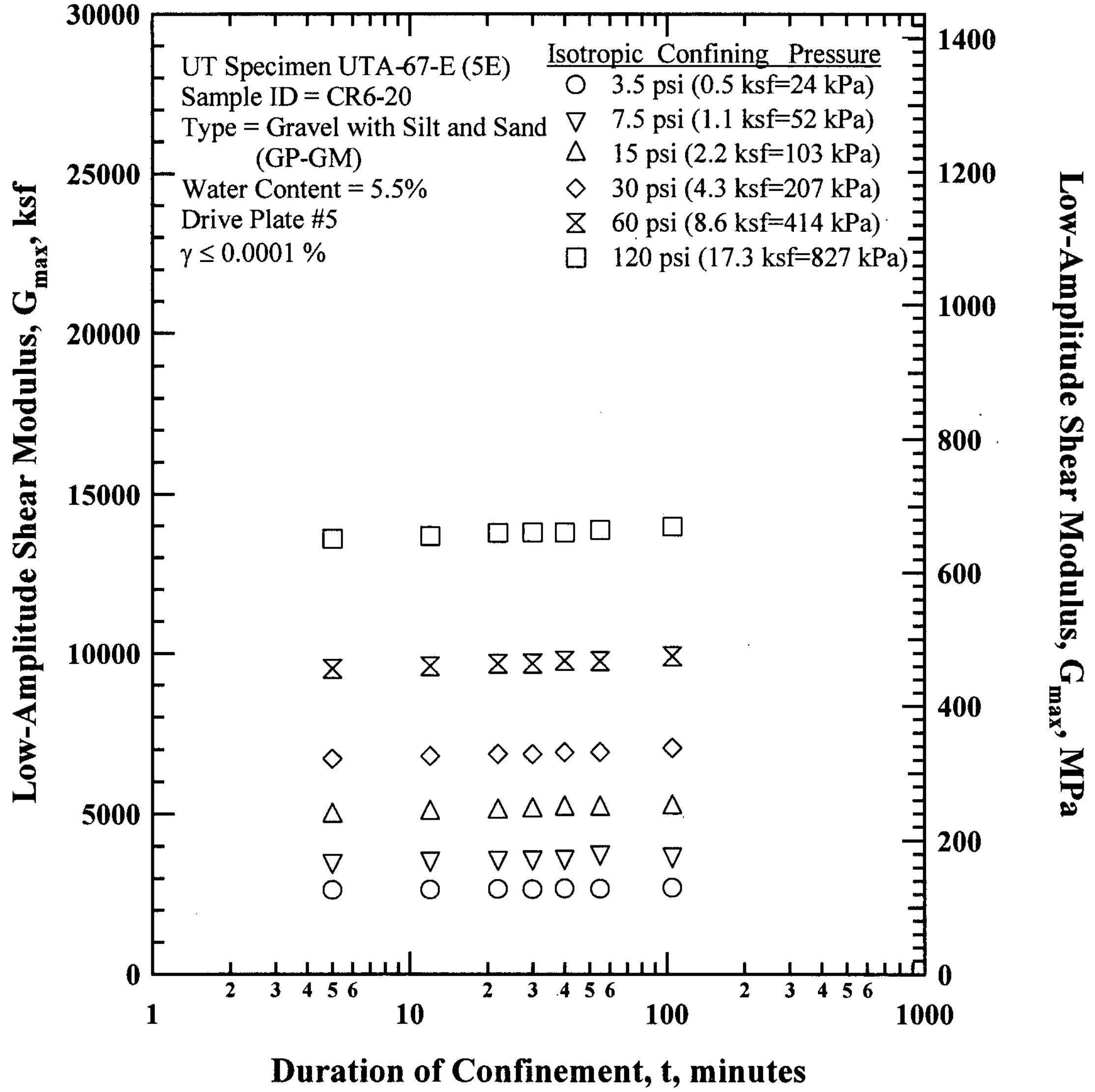


Figure E.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5E)

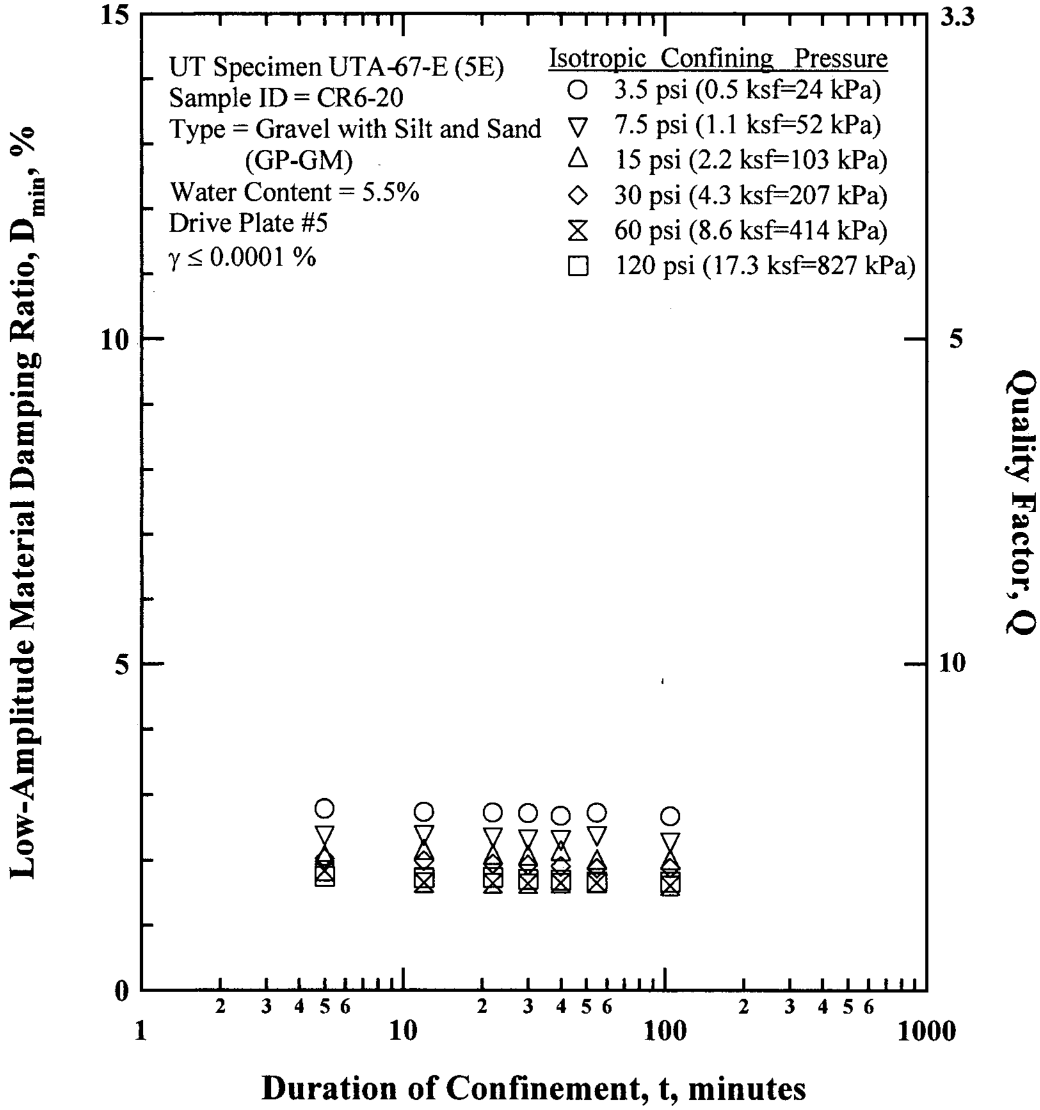


Figure E.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5E)

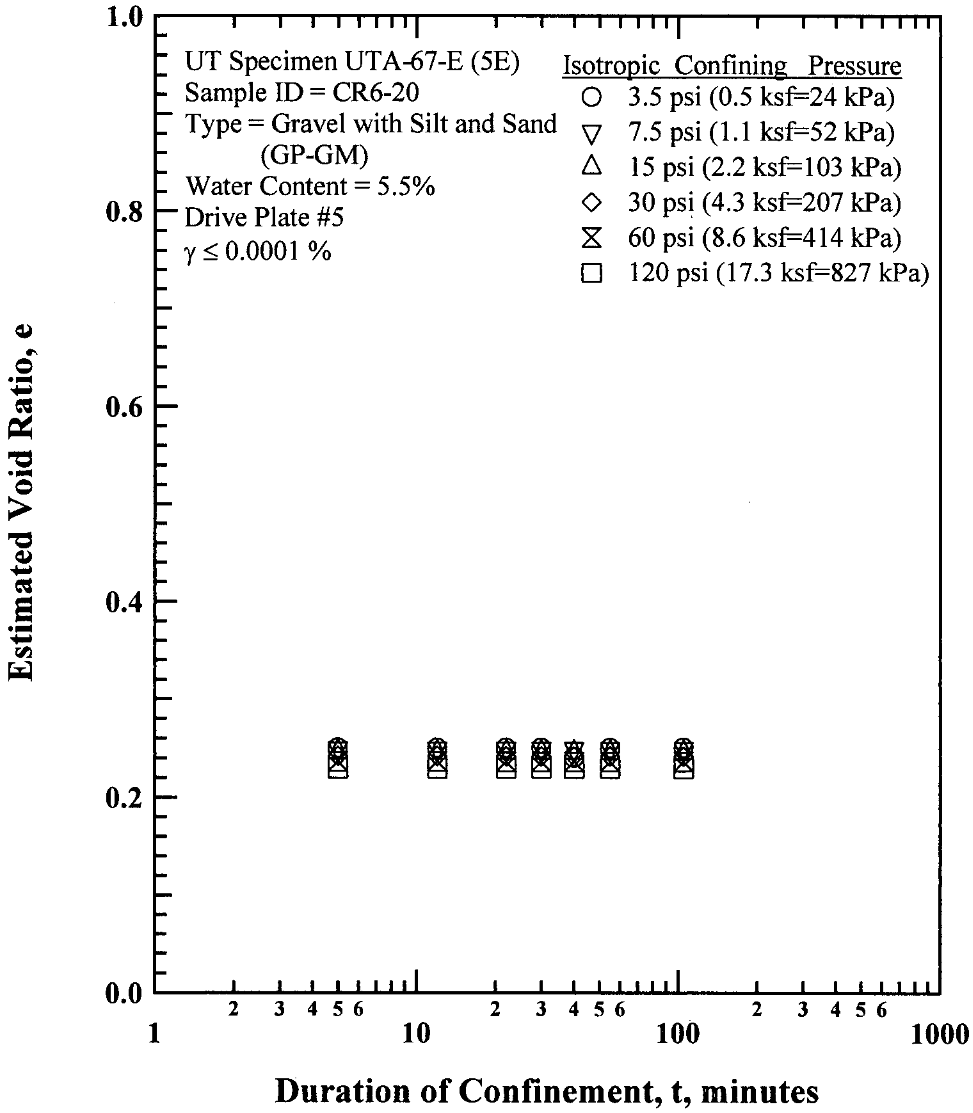


Figure E.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5E)

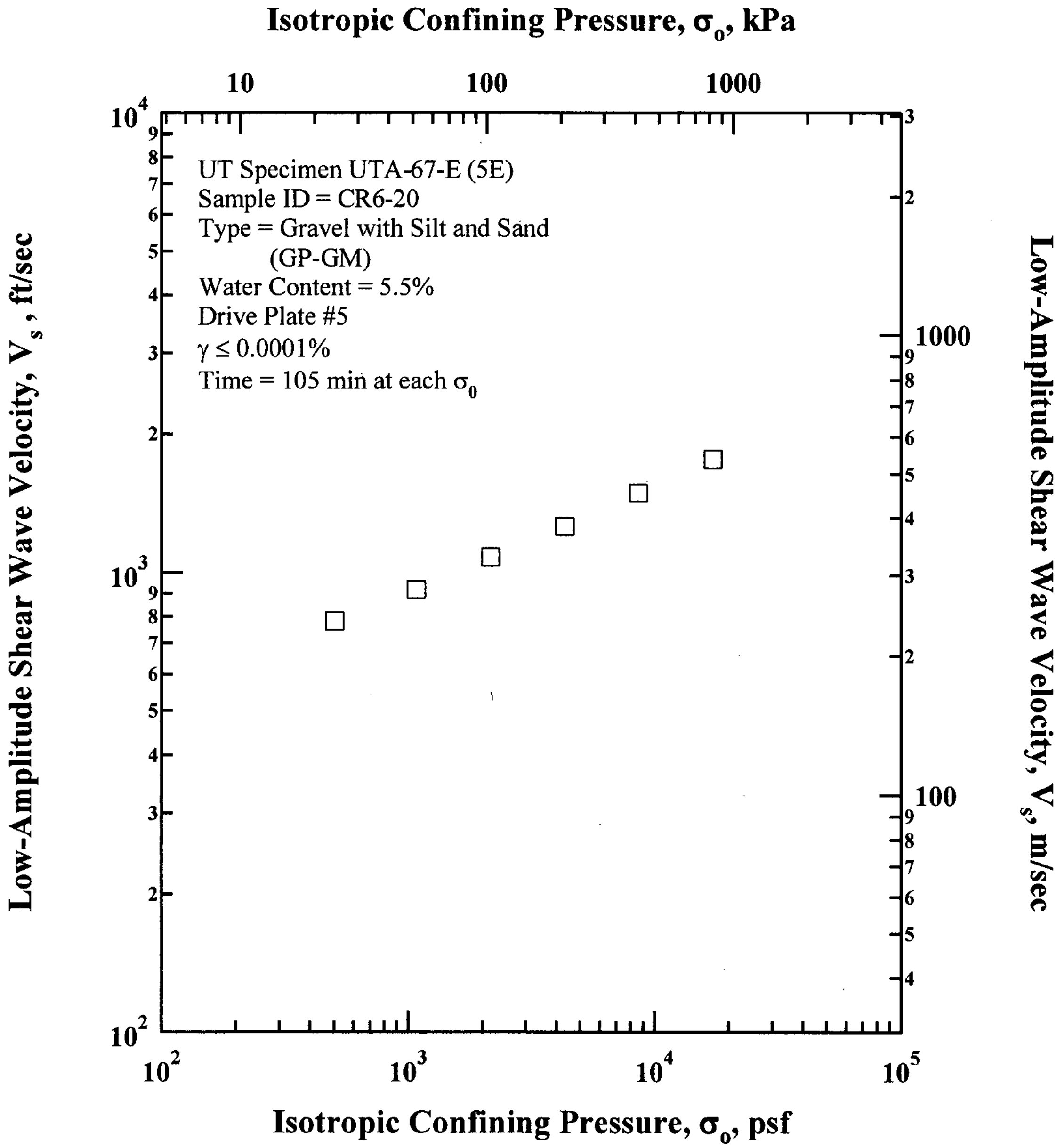


Figure E.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5E)

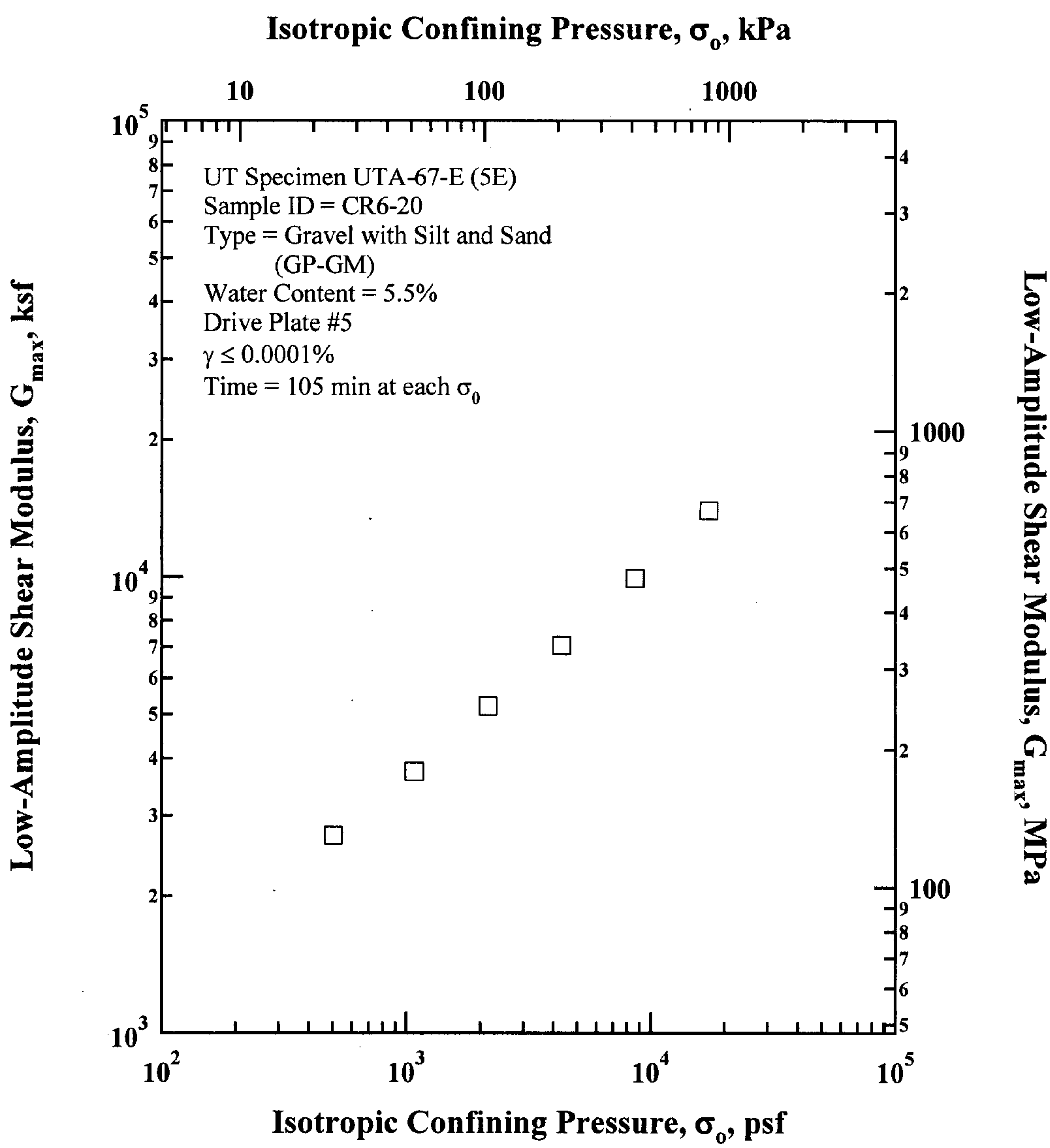


Figure E.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5E)

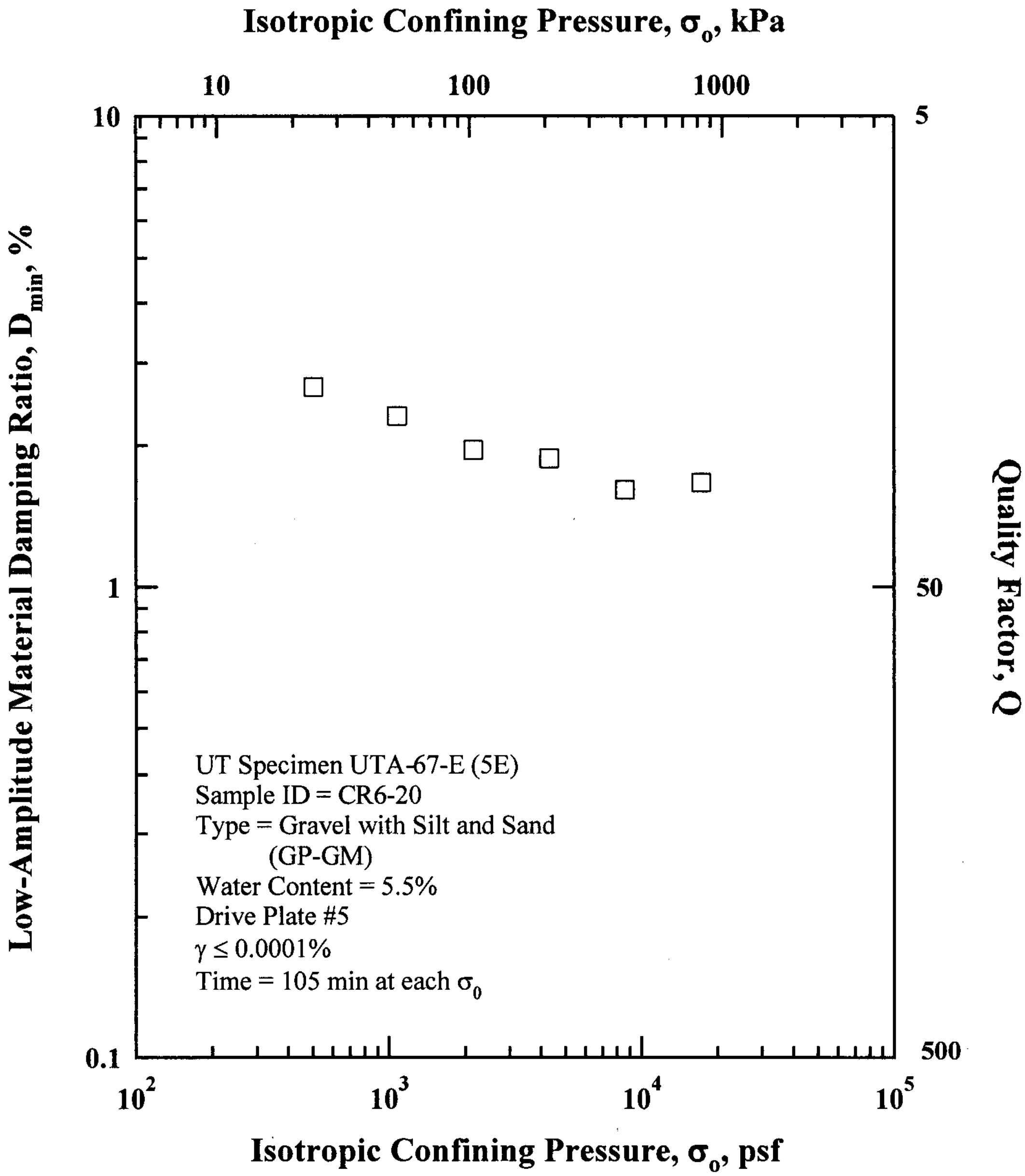


Figure E.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5E)

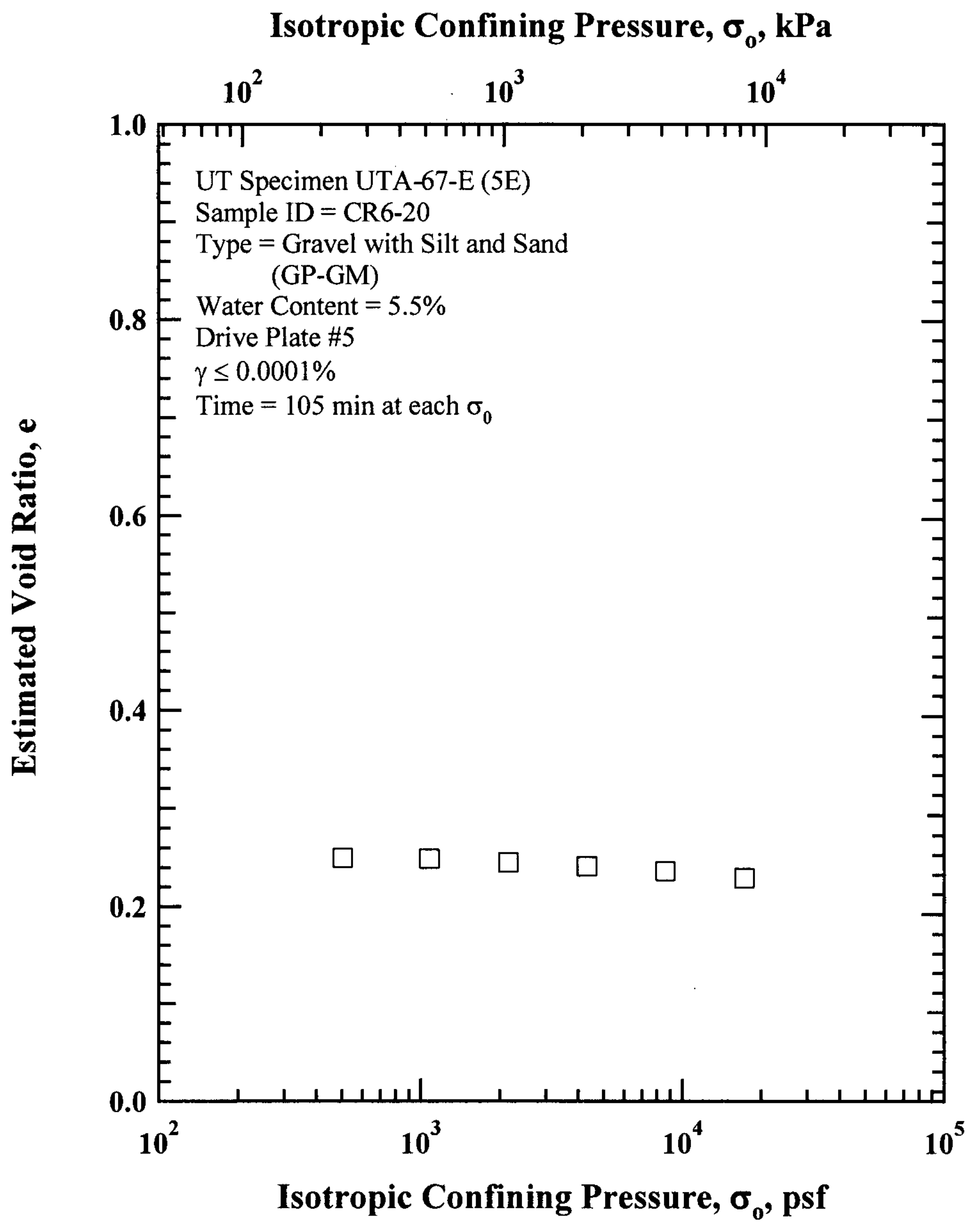


Figure E.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5E)

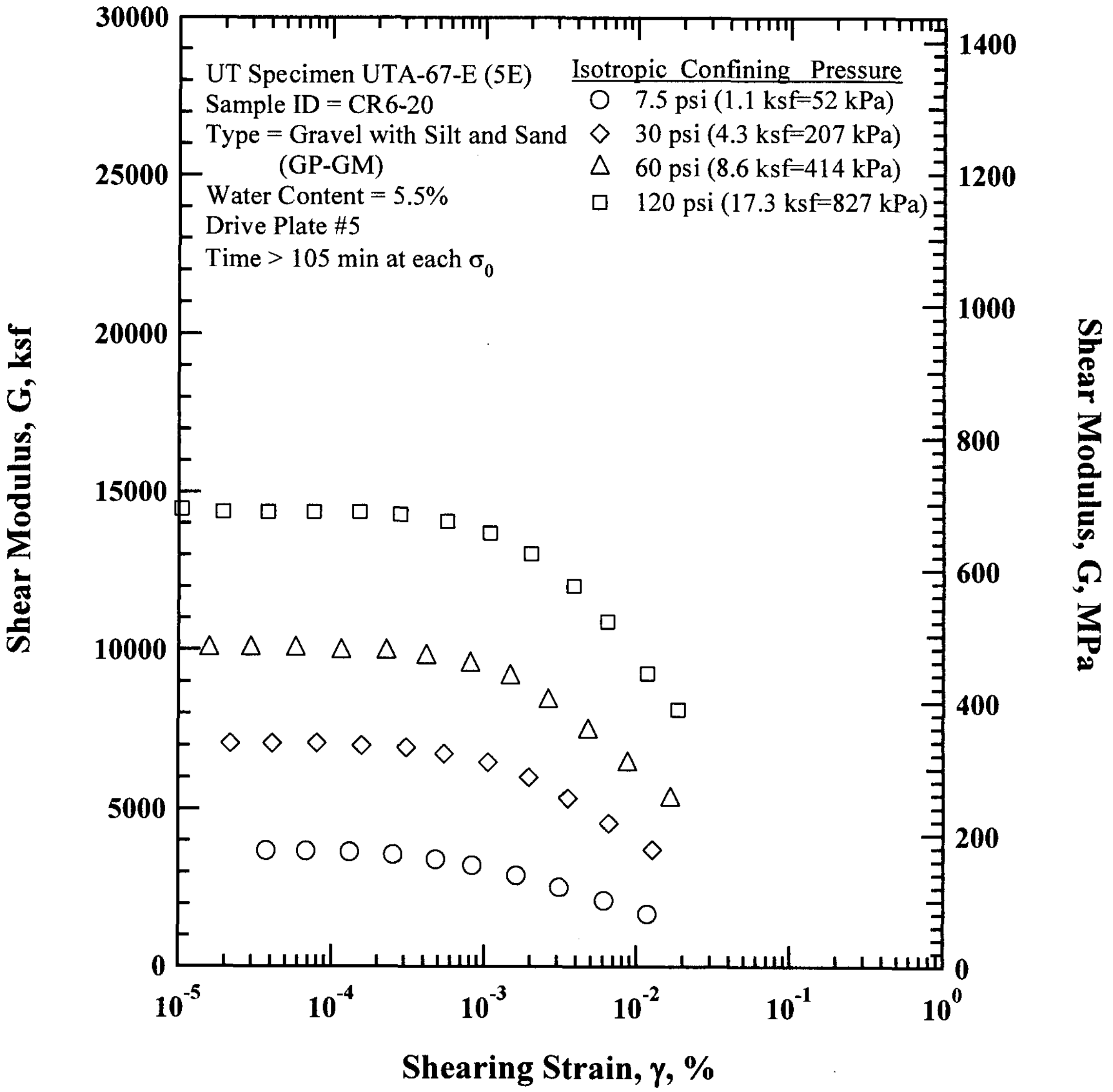


Figure E.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-E (5E)

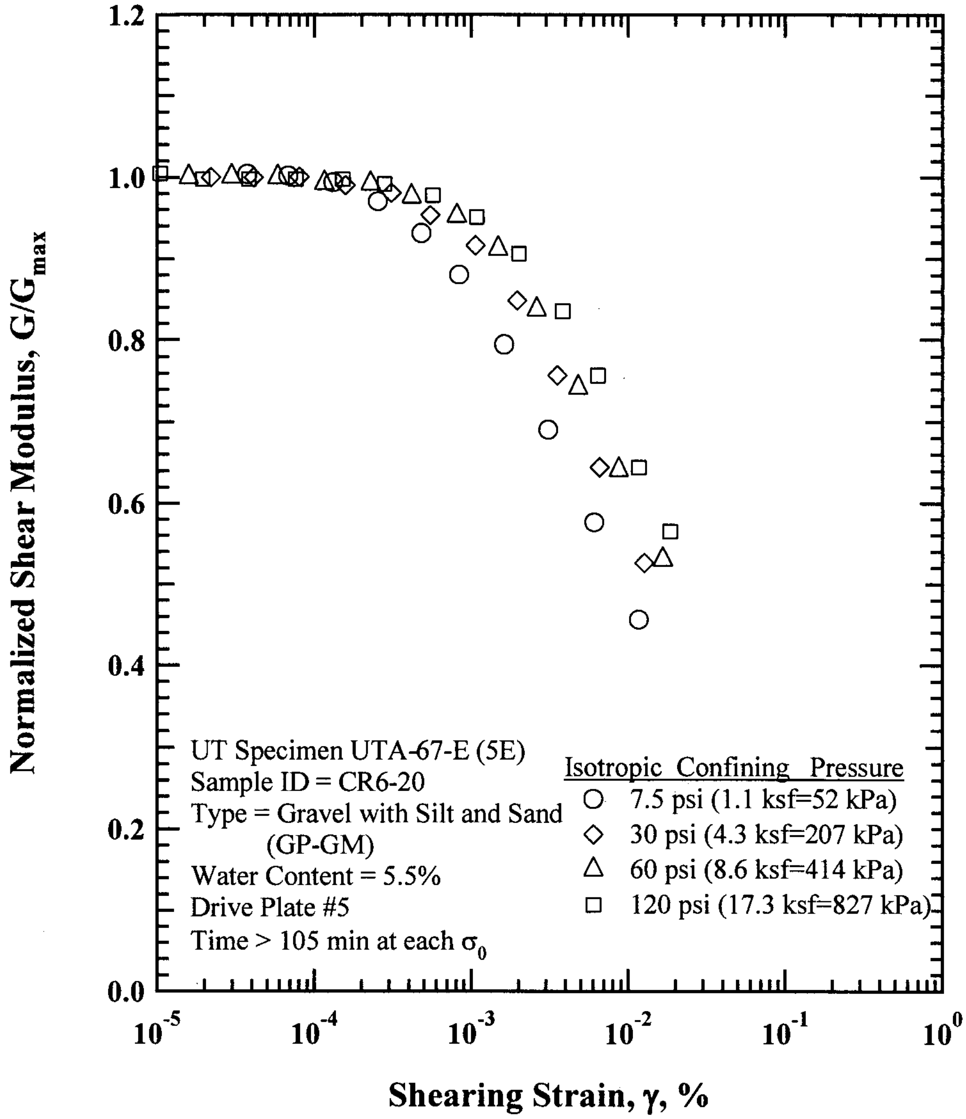


Figure E.9 Variation in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-E (5E)

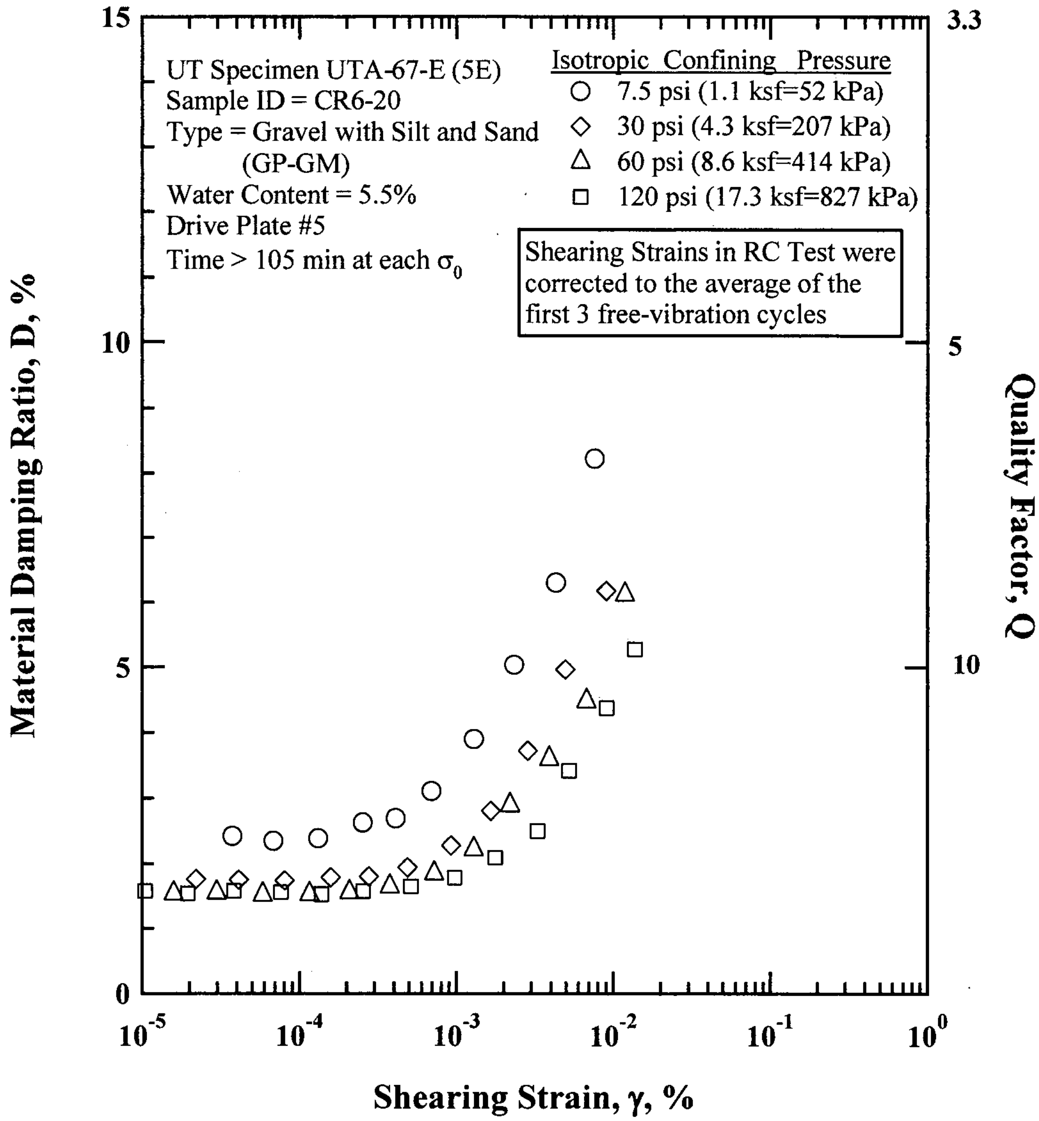


Figure E.10 Variation in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-E (5E)

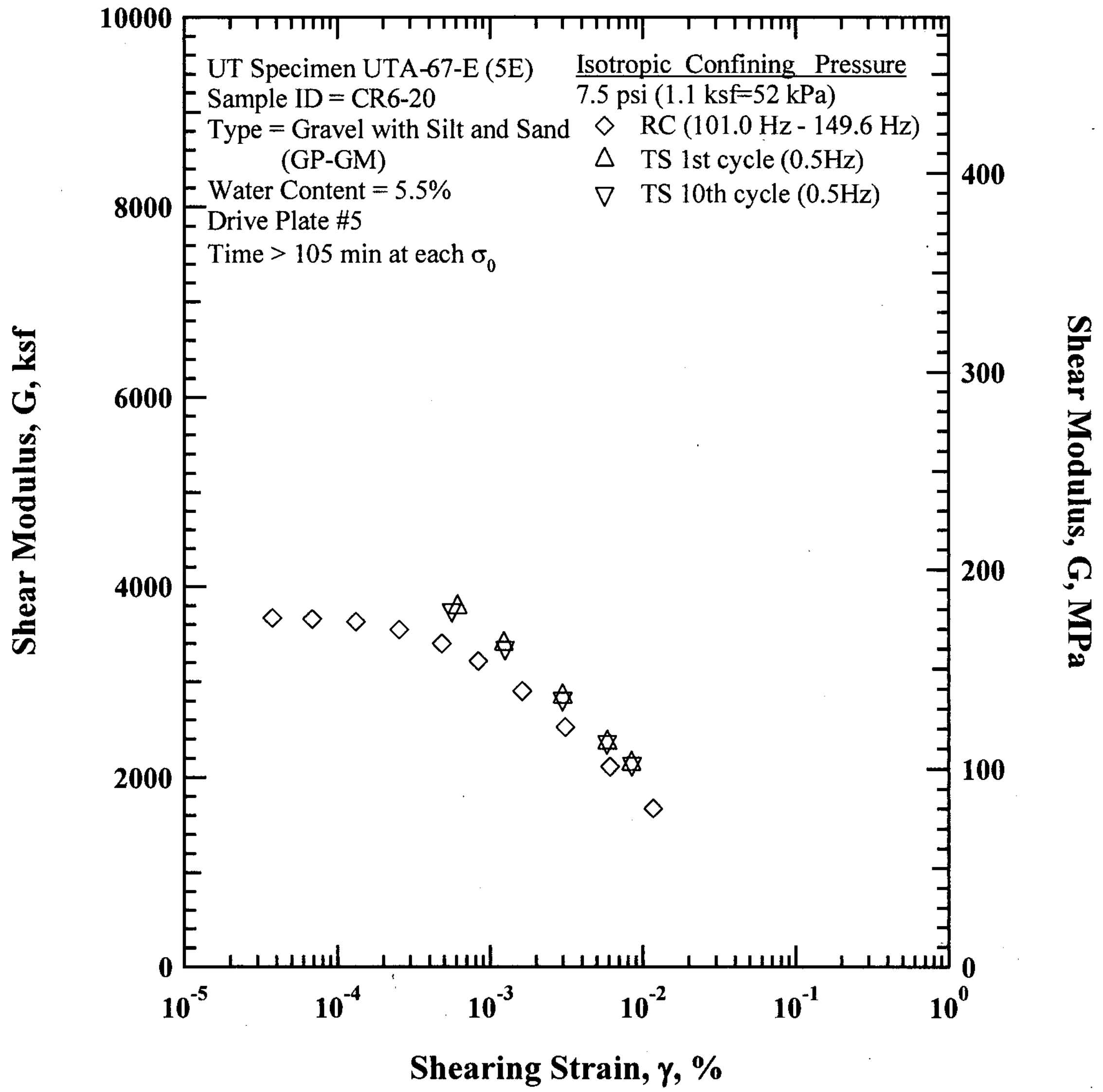


Figure E.11 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

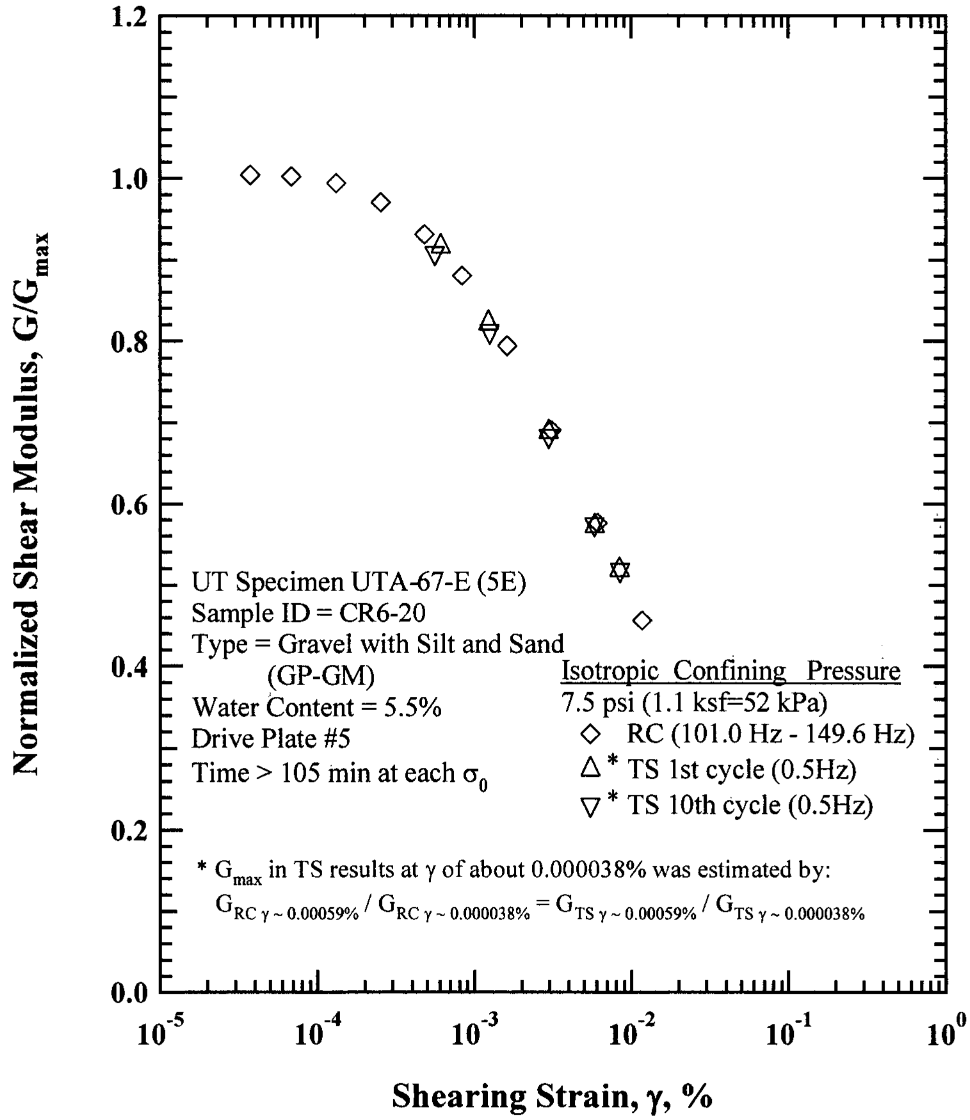


Figure E.12 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

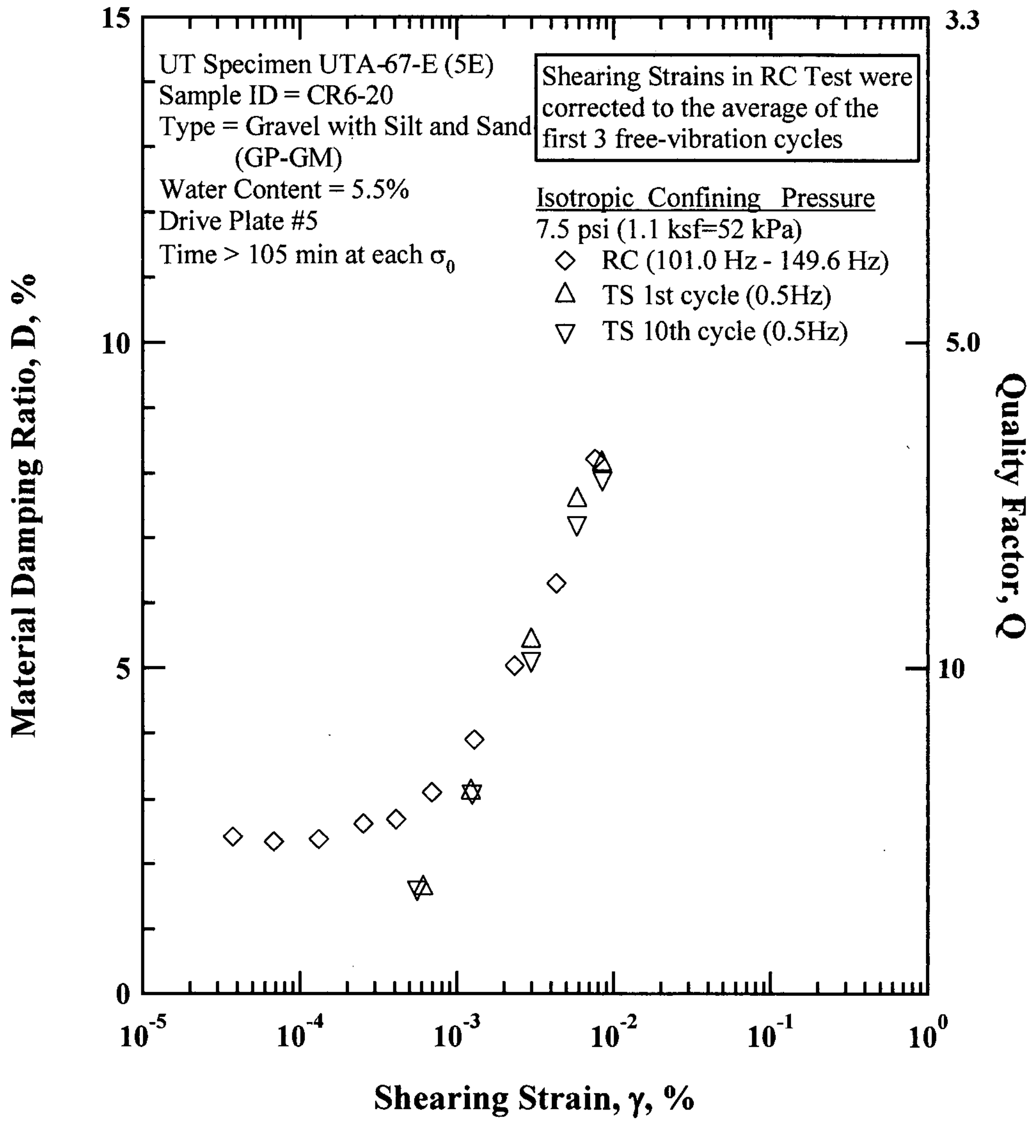


Figure E.13 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

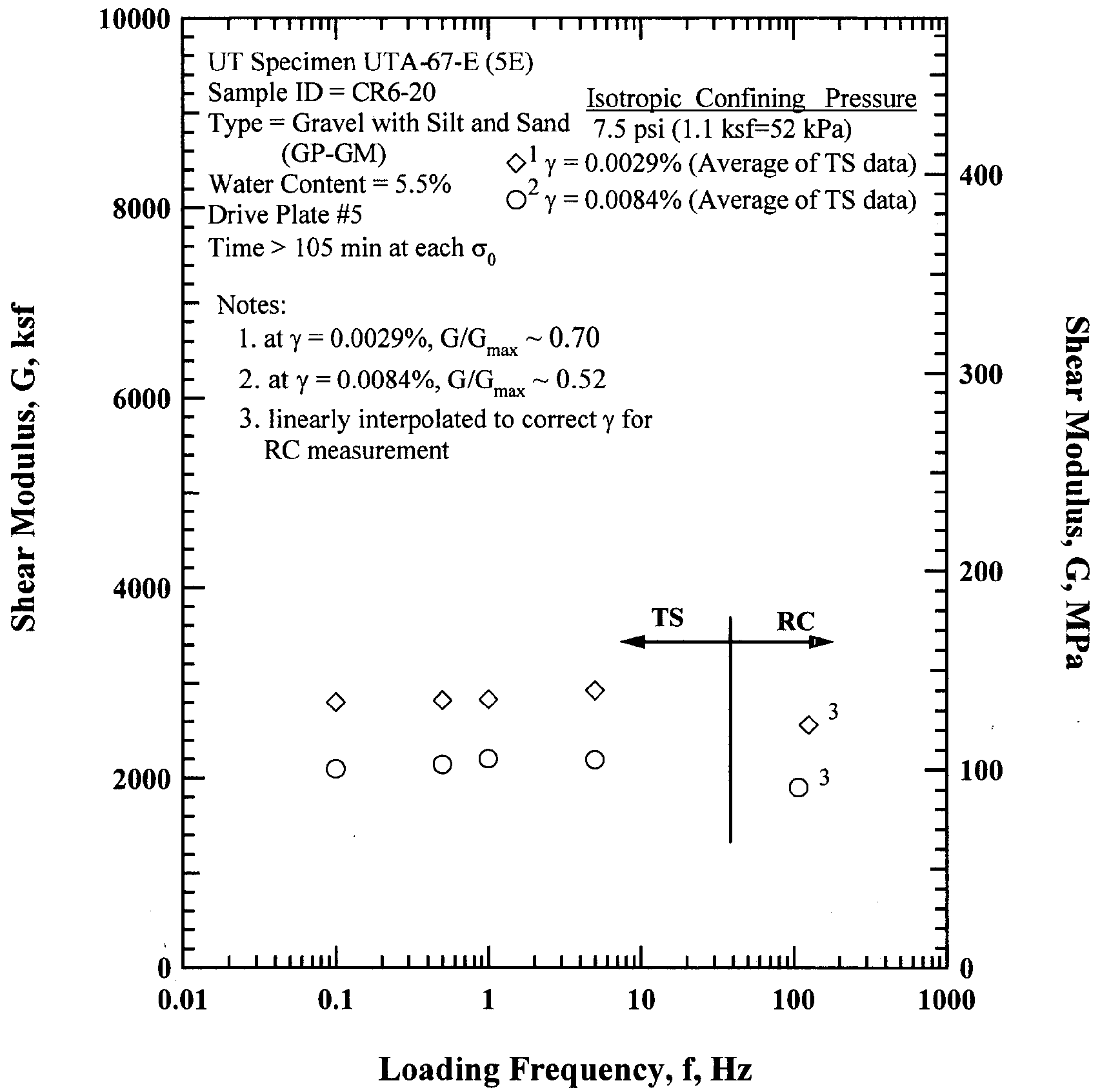


Figure E.14 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

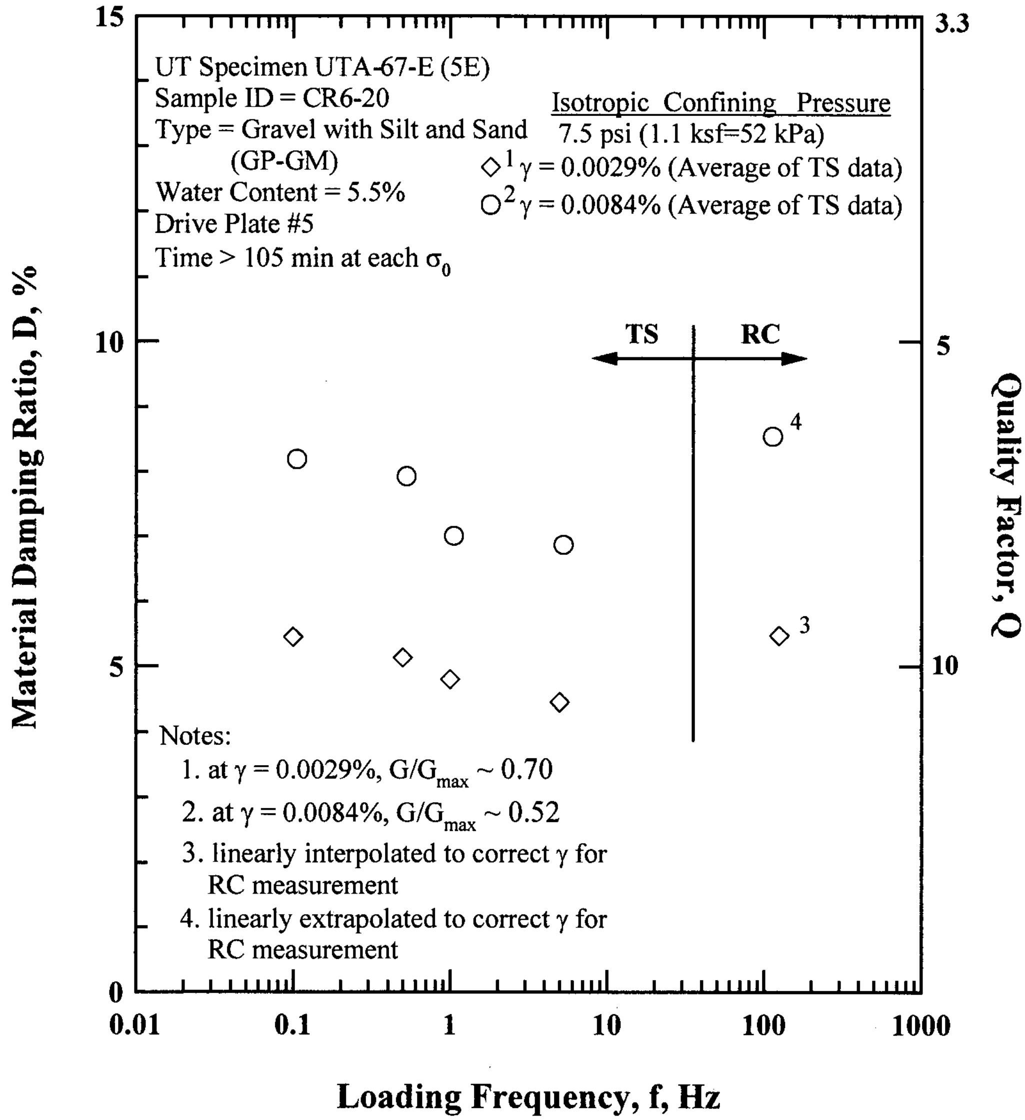


Figure E.15 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

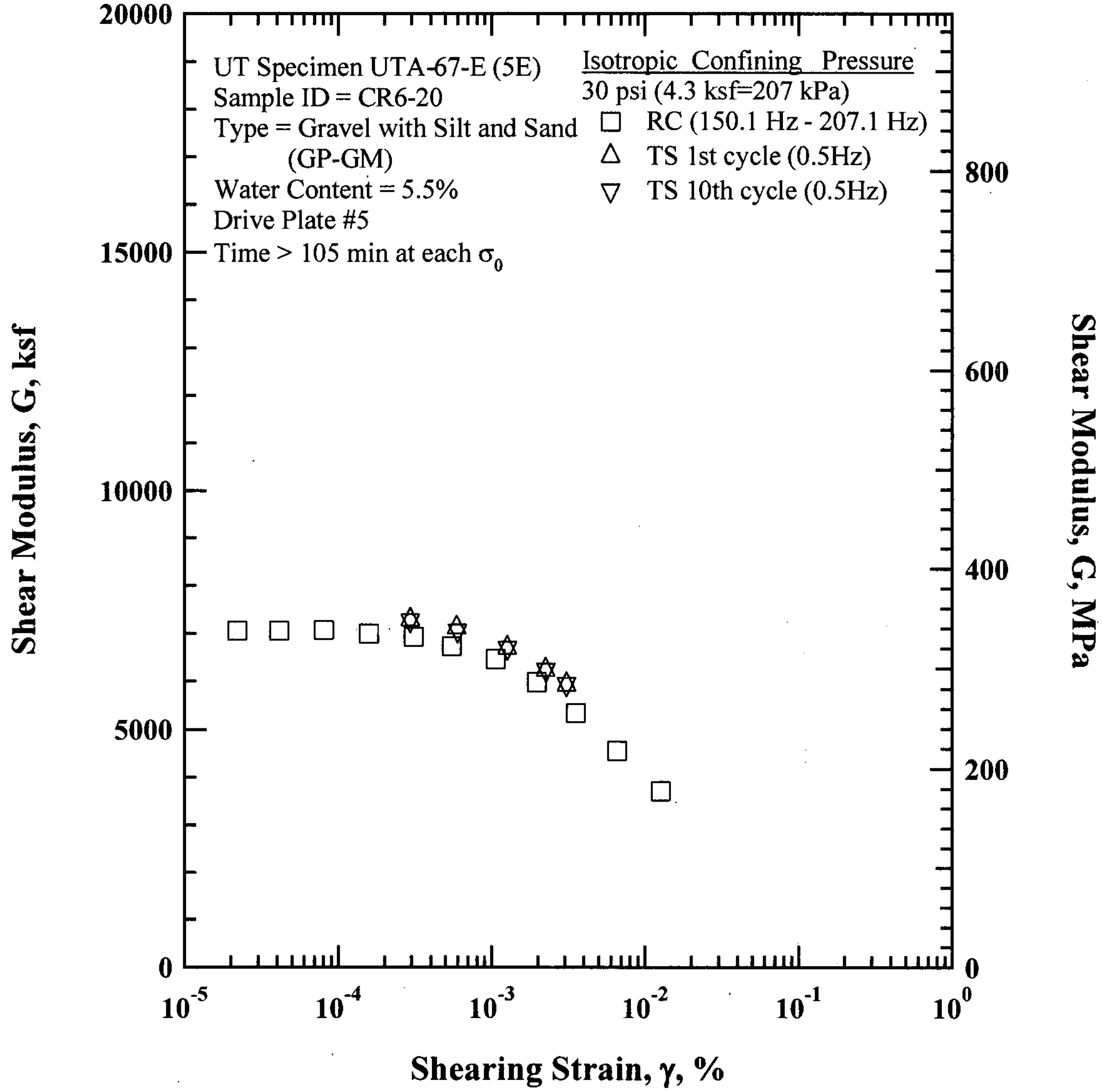


Figure E.16 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

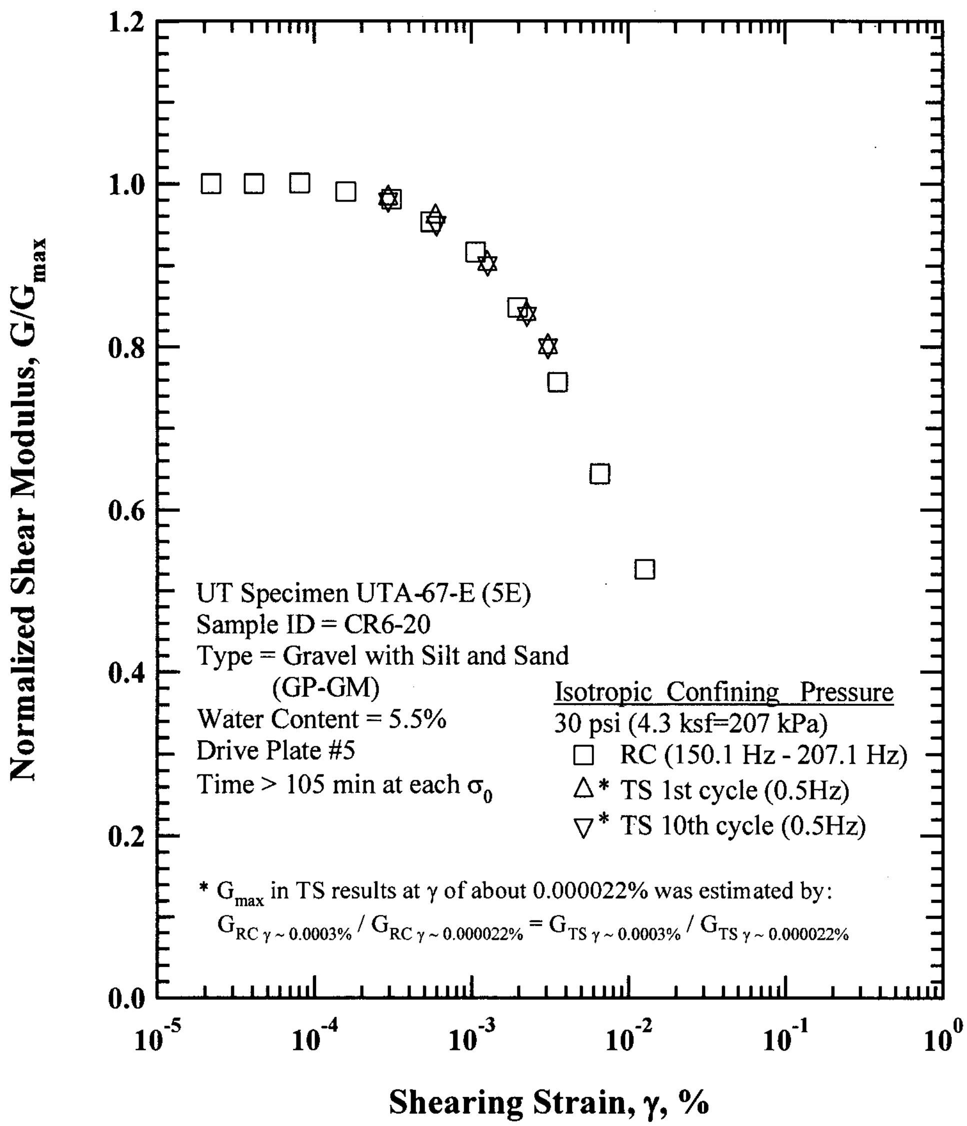


Figure E.17 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

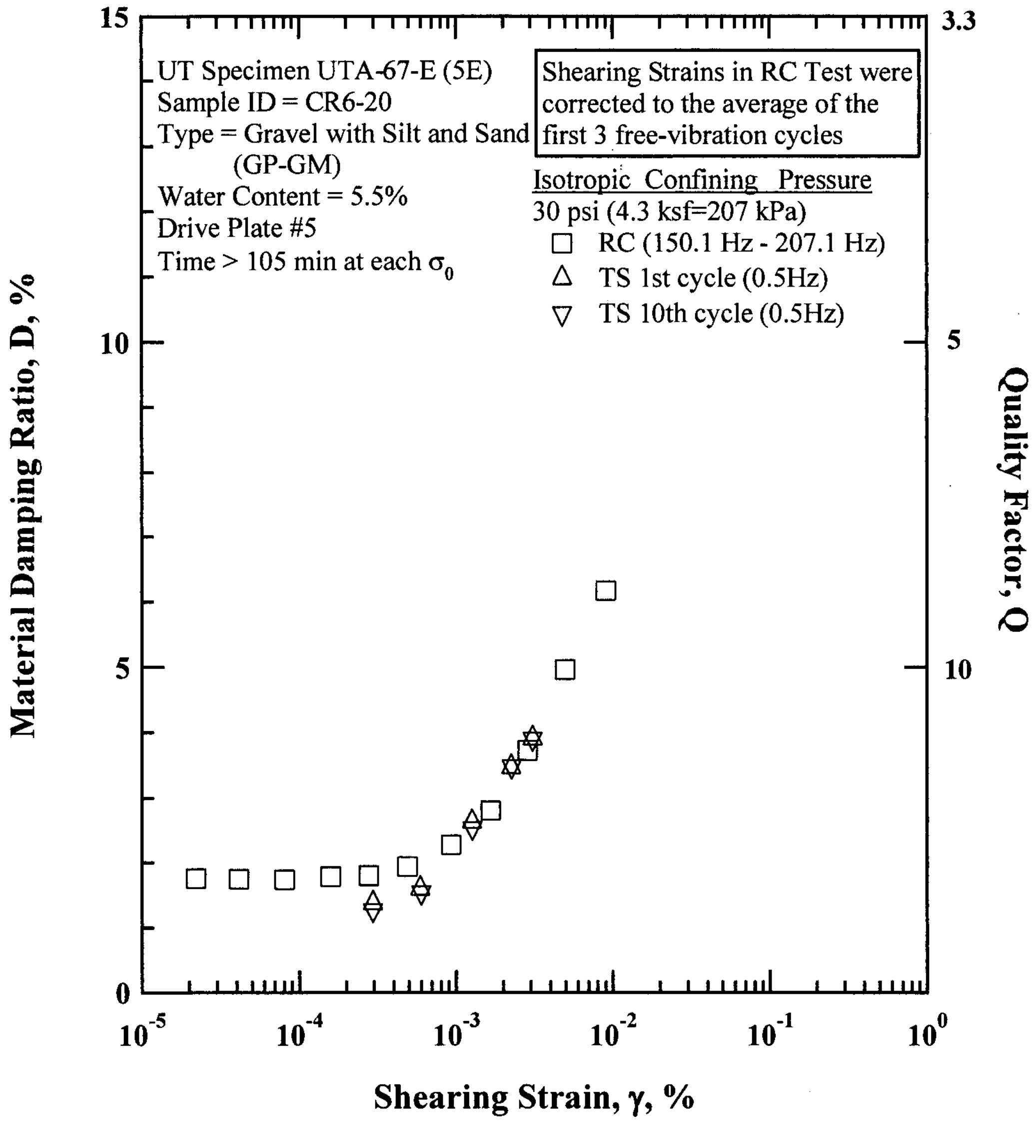


Figure E.18 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

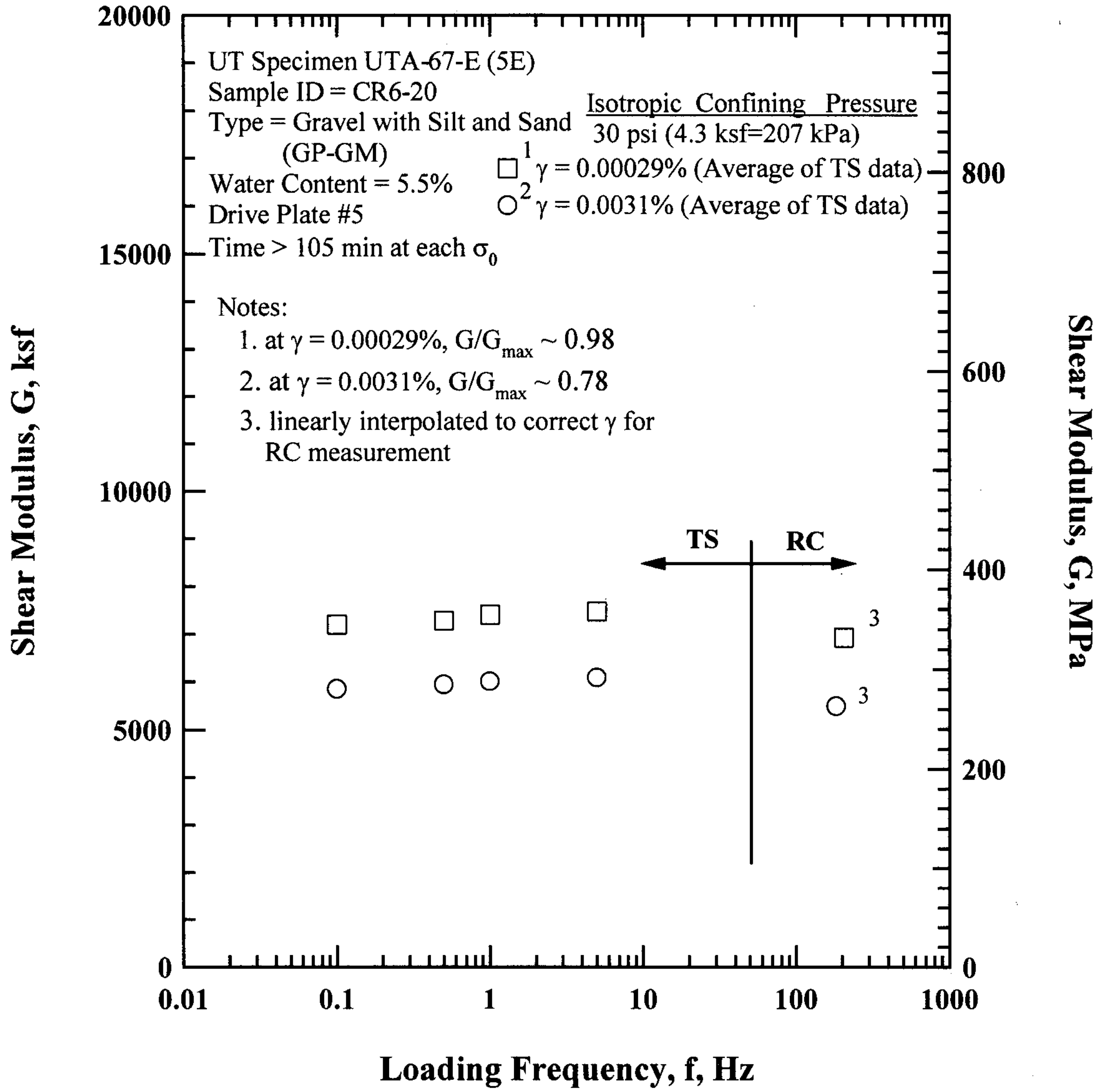


Figure E.19 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

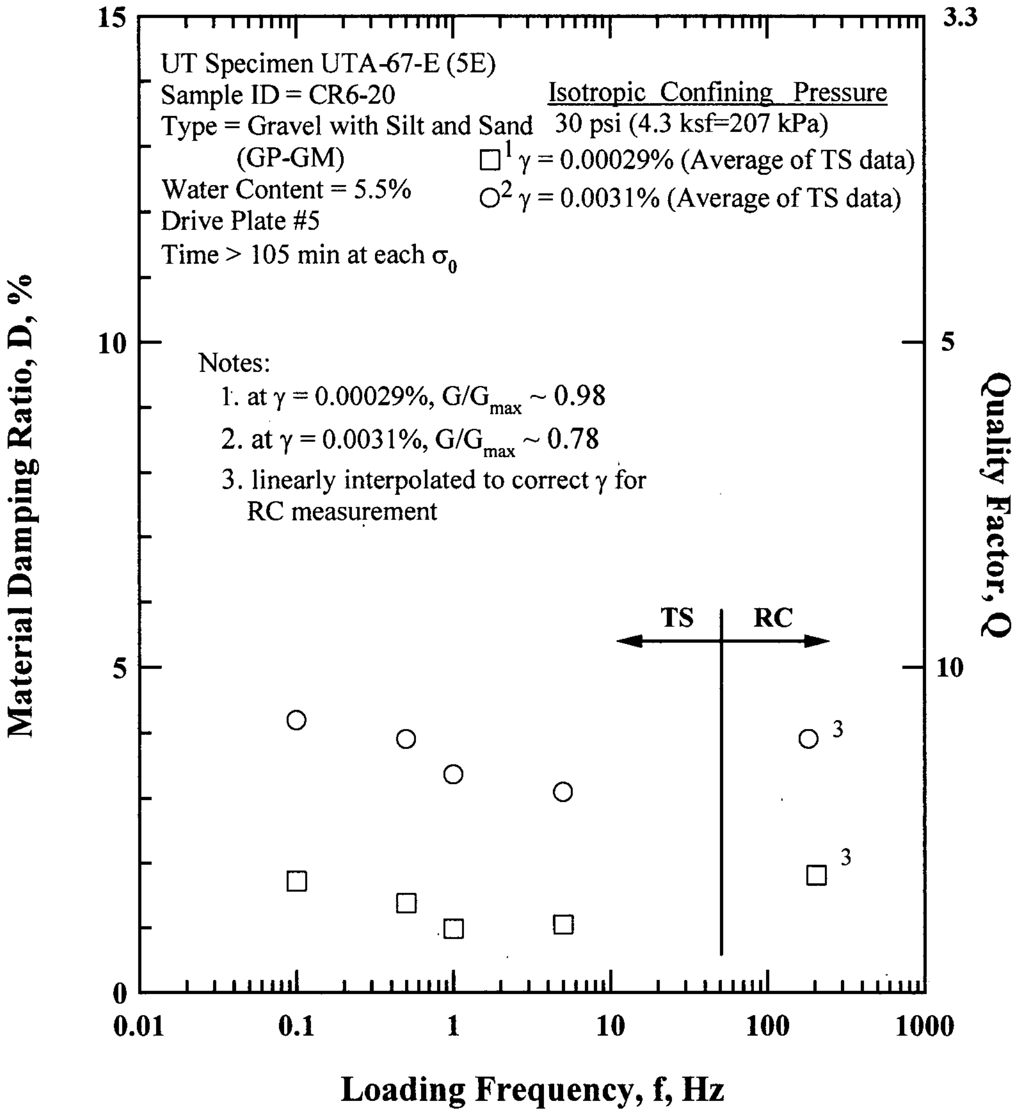


Figure E.20 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

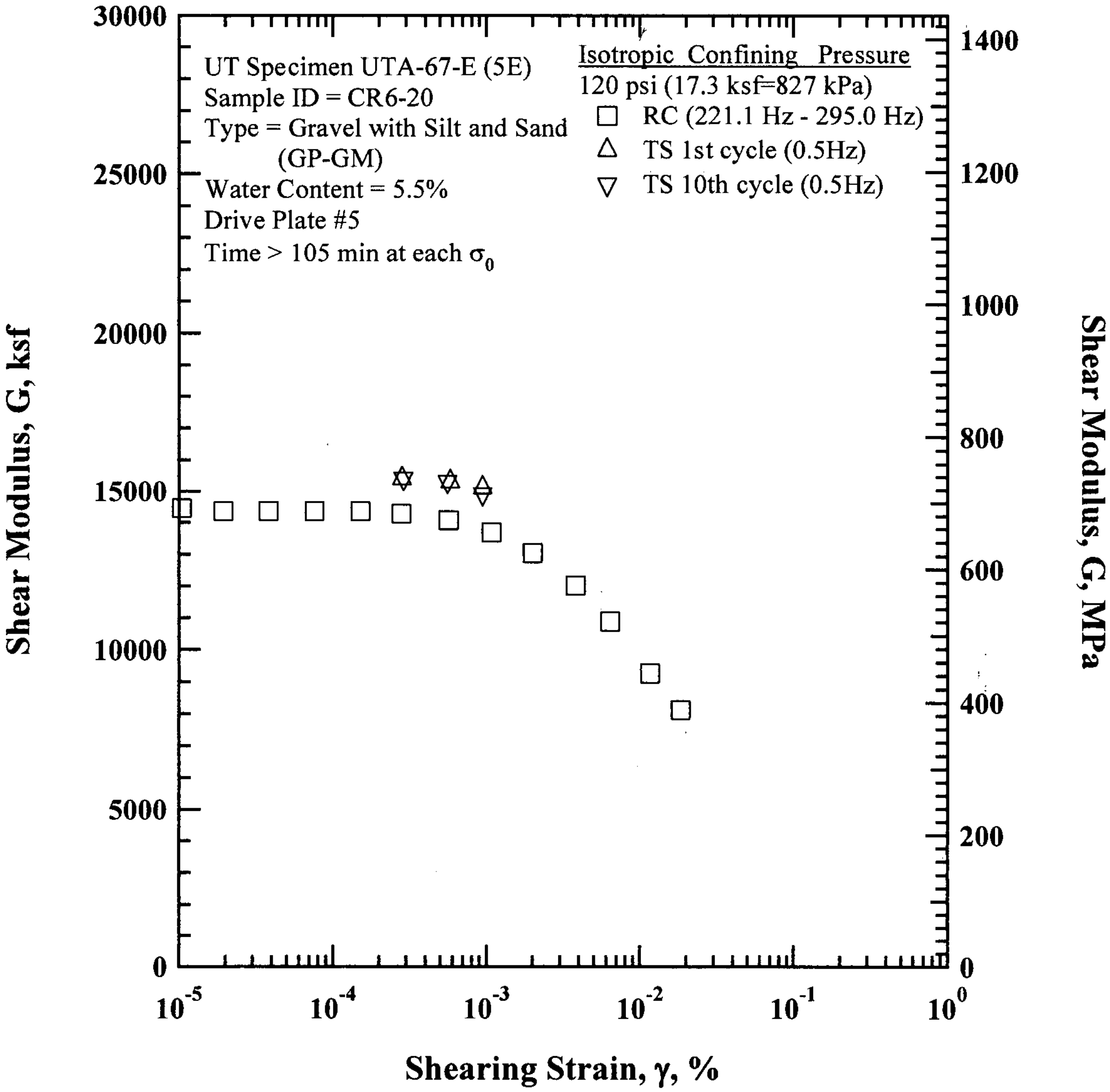


Figure E.21 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

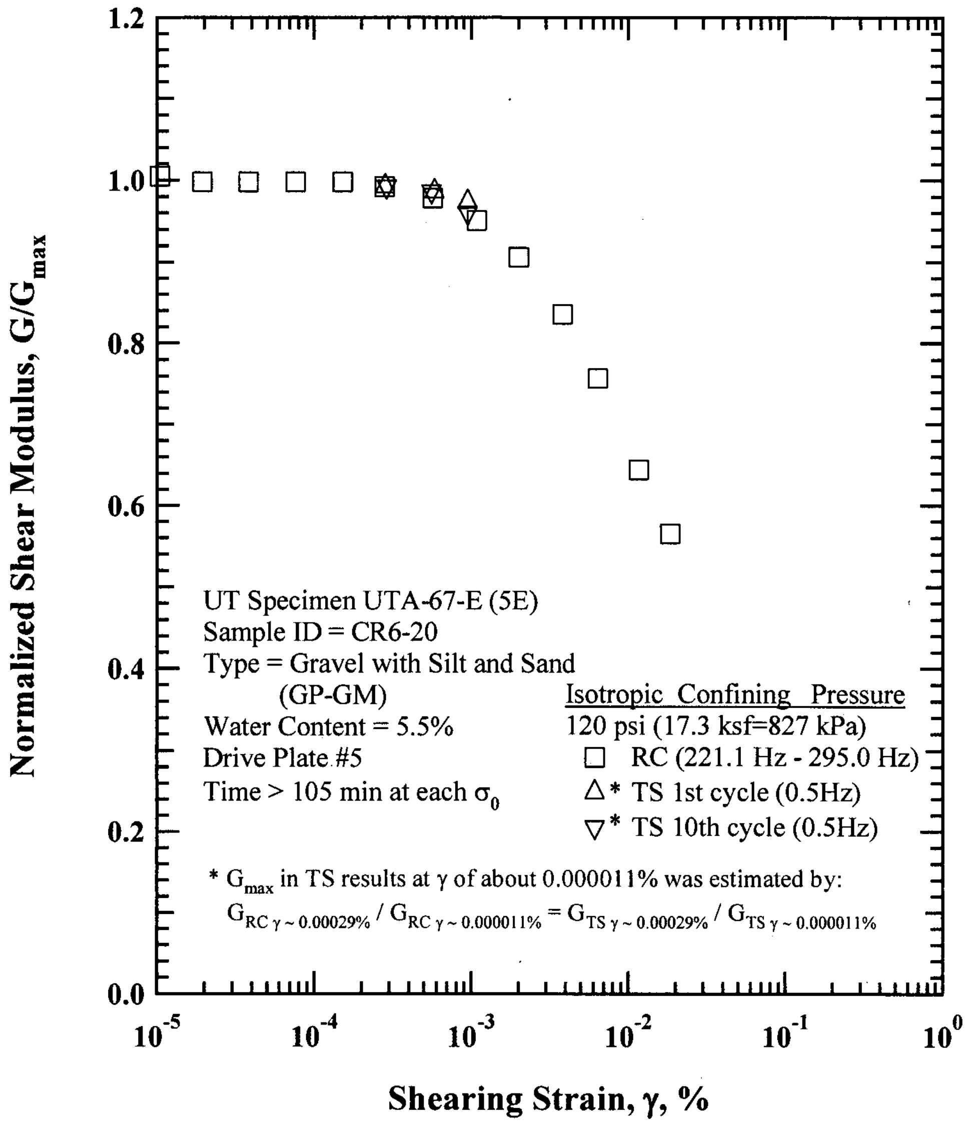


Figure E.22 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

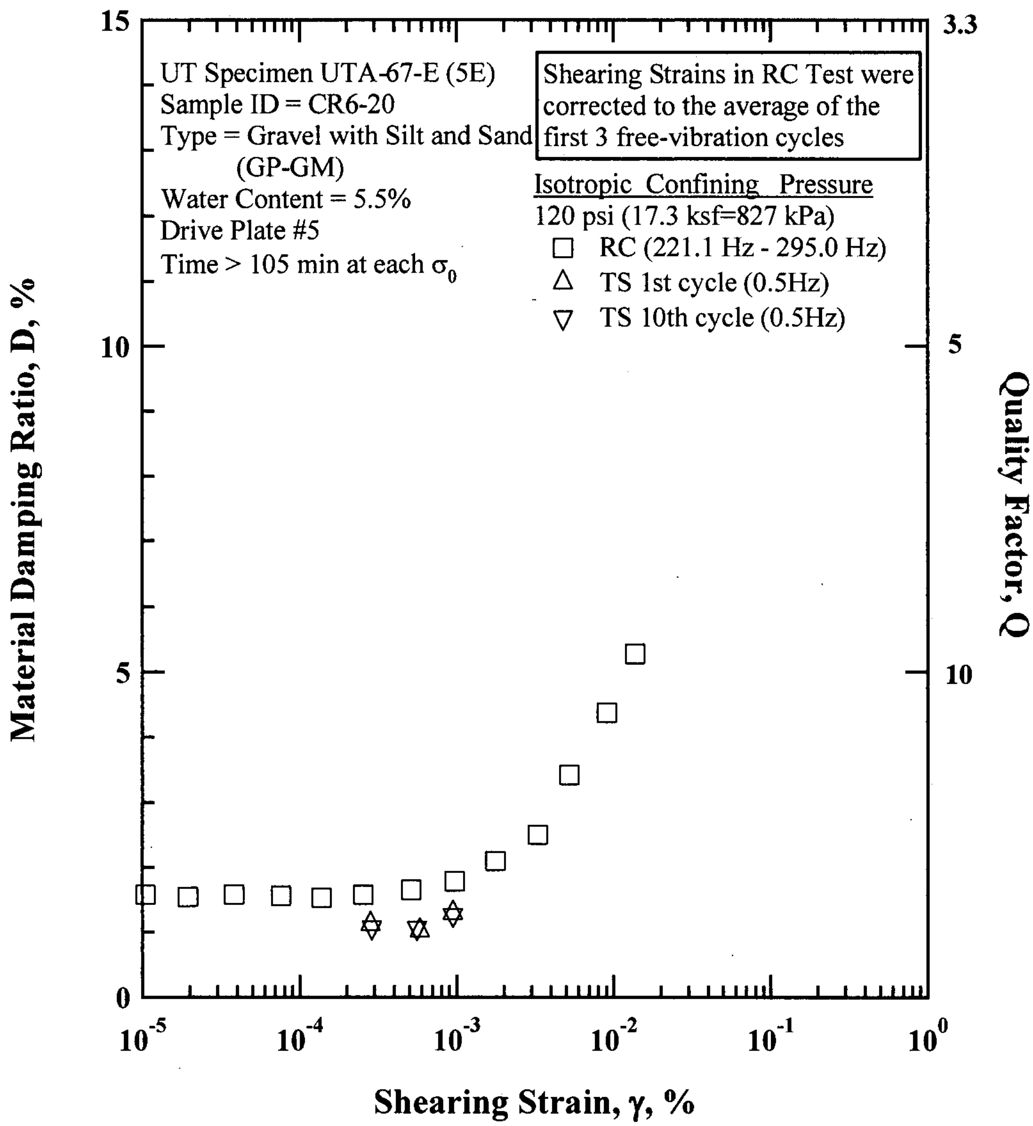


Figure E.23 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

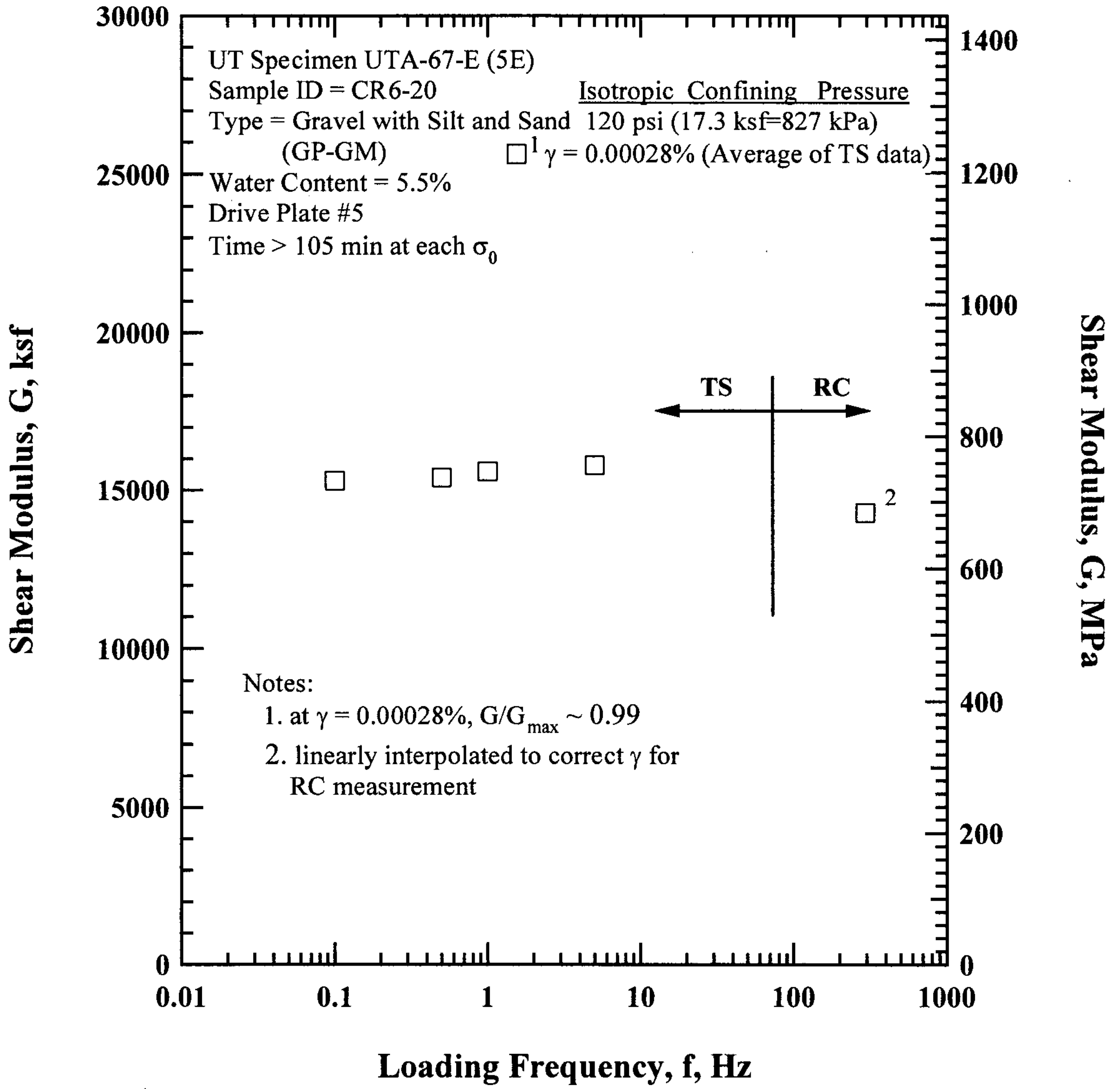


Figure E.24 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

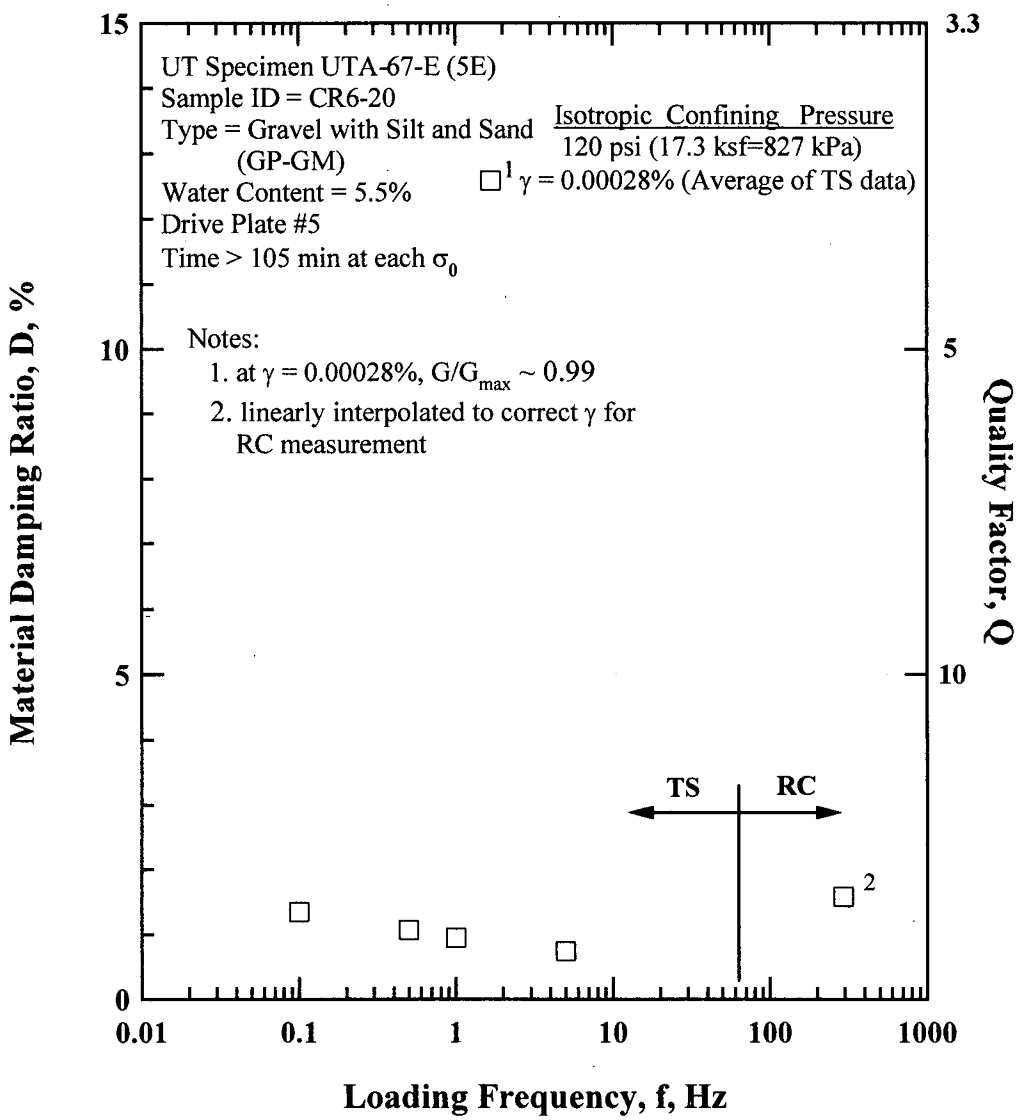


Figure E.25 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5E)

Table E.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-E (5E)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_s	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.5	504	24	2709	129.9	781	2.67	0.25
7.5	1080	52	3741	179.3	917	2.31	0.25
15	2160	104	5196	249.1	1080	1.96	0.25
30	4320	207	7054	338.1	1257	1.88	0.24
60	8640	414	9923	475.7	1488	1.61	0.24
120	17280	828	13984	670.4	1763	1.67	0.23

Table E.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5E); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
3.75E-05	3666	1.00	3.75E-05	2.42
6.84E-05	3656	1.00	6.84E-05	2.35
1.32E-04	3627	0.99	1.32E-04	2.38
2.55E-04	3540	0.97	2.55E-04	2.63
4.83E-04	3397	0.93	4.12E-04	2.69
8.37E-04	3211	0.88	6.97E-04	3.10
1.62E-03	2898	0.79	1.30E-03	3.90
3.11E-03	2519	0.69	2.34E-03	5.04
6.11E-03	2110	0.58	4.33E-03	6.30
1.17E-02	1671	0.46	7.64E-03	8.21

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table E.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-E (5E); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
6.12E-04	3780	0.92	1.62	5.60E-04	3750	0.91	1.63
1.23E-03	3390	0.82	3.10	1.25E-03	3350	0.81	3.11
2.99E-03	2840	0.69	5.41	2.99E-03	2820	0.68	5.13
5.87E-03	2360	0.57	7.58	5.84E-03	2370	0.57	7.22
8.43E-03	2140	0.52	8.14	8.50E-03	2140	0.52	7.92

Table E.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5E); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
2.21E-05	7053	1.00	2.21E-05	1.76
4.13E-05	7054	1.00	4.13E-05	1.75
8.07E-05	7061	1.00	8.07E-05	1.74
1.59E-04	6987	0.99	1.59E-04	1.79
3.10E-04	6919	0.98	2.78E-04	1.80
5.49E-04	6726	0.95	4.89E-04	1.94
1.06E-03	6462	0.92	9.26E-04	2.28
1.96E-03	5984	0.85	1.66E-03	2.80
3.55E-03	5343	0.76	2.86E-03	3.72
6.57E-03	4545	0.64	4.96E-03	4.96
1.27E-02	3710	0.53	9.05E-03	6.17

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table E.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-E (5E); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
2.95E-04	7280	0.98	1.38	2.96E-04	7270	0.98	1.27
5.90E-04	7110	0.96	1.60	5.98E-04	7050	0.95	1.54
1.26E-03	6690	0.90	2.63	1.27E-03	6690	0.90	2.53
2.25E-03	6230	0.84	3.47	2.26E-03	6230	0.84	3.48
3.08E-03	5930	0.80	3.91	3.08E-03	5940	0.80	3.90

Table E.6 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5E); Isotropic Confining Pressure, σ_o =60 psi (8.6 ksf=414 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
1.59E-05	10003	1.00	1.59E-05	1.53
2.97E-05	10014	1.00	2.97E-05	1.55
5.85E-05	10003	1.00	5.85E-05	1.52
1.16E-04	9933	0.99	1.16E-04	1.53
2.29E-04	9923	0.99	2.08E-04	1.56
4.16E-04	9762	0.98	3.77E-04	1.64
8.08E-04	9522	0.95	7.23E-04	1.84
1.48E-03	9130	0.91	1.29E-03	2.22
2.62E-03	8377	0.84	2.21E-03	2.89
4.82E-03	7430	0.74	3.91E-03	3.60
8.74E-03	6417	0.64	6.77E-03	4.48
1.66E-02	5299	0.53	1.19E-02	6.12

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table E.7 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5E); Isotropic Confining Pressure, σ_o =120 psi (17.3 ksf=827 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average+ Shearing Strain, %	Material Damping Ratiox, D, %
1.05E-05	14456	1.00	1.05E-05	1.58
1.95E-05	14357	1.00	1.95E-05	1.54
3.83E-05	14358	1.00	3.83E-05	1.58
7.61E-05	14359	1.00	7.61E-05	1.56
1.52E-04	14357	1.00	1.38E-04	1.53
2.80E-04	14276	0.99	2.54E-04	1.57
5.67E-04	14067	0.98	5.13E-04	1.65
1.08E-03	13684	0.95	9.72E-04	1.78
2.01E-03	13037	0.91	1.77E-03	2.09
3.83E-03	12021	0.84	3.30E-03	2.50
6.40E-03	10887	0.76	5.24E-03	3.42
1.17E-02	9261	0.64	9.09E-03	4.38
1.85E-02	8123	0.56	1.37E-02	5.27

+ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

x Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table E.8 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-E (5E); Isotropic Confining Pressure, σ_o =120 psi (17.3 ksf=827 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
2.83E-04	15400	0.99	1.12	2.89E-04	15400	0.99	1.07
5.82E-04	15300	0.99	1.02	5.58E-04	15300	0.99	1.06
9.47E-04	15100	0.97	1.29	9.46E-04	14900	0.96	1.26

APPENDIX F

UT Specimen UTA-67-E (5I)
Sample ID : CR6-20
(Vulcan Quarry Statistical Avg. Sample)
Type = Scalped, Reconstituted Gravel with Silt and Sand (GP-GM*)

Water Content, w = 4.4 %

G_S = 2.716*

Degree of Saturation = 65.3%

Total Unit Weight, γ_t = 149.6 lb/ft^3

Dry Unit Weight, γ_d = 143.3 lb/ft^3

Target : γ_d = 143.6 lb/ft^3 ± 2 lb/ft^3

w = 4.6% ± 1.0%

*** Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

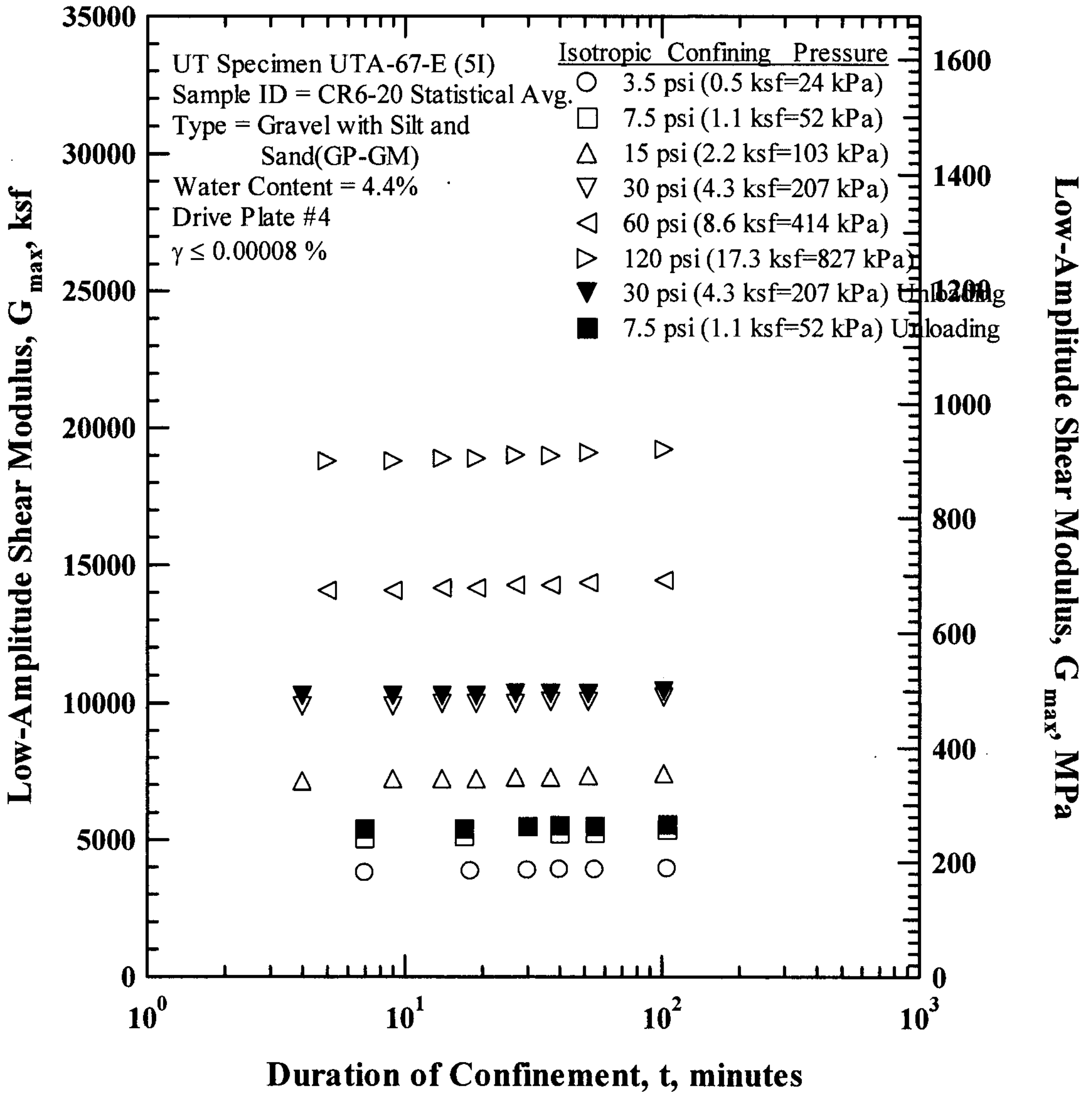


Figure F.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5I)

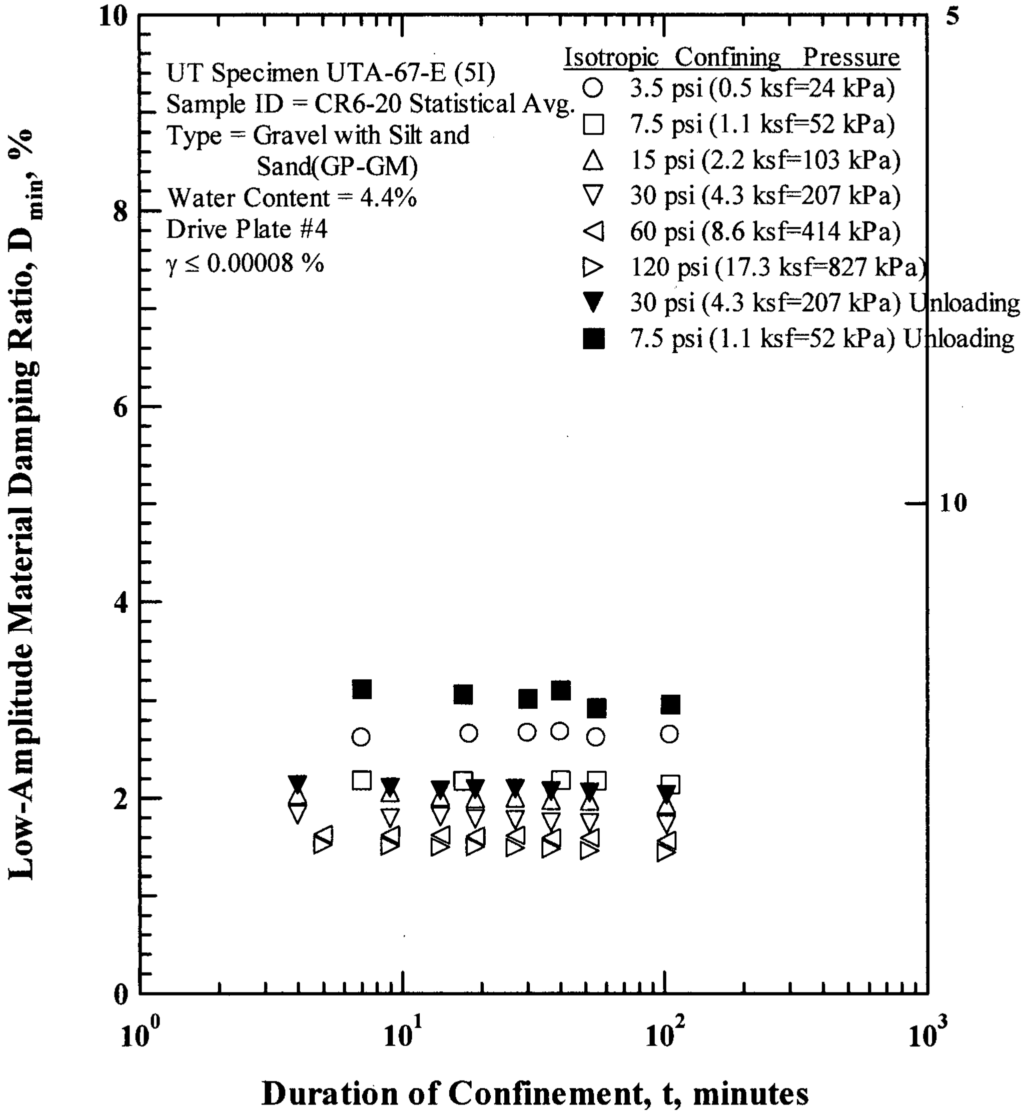


Figure F.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5I)

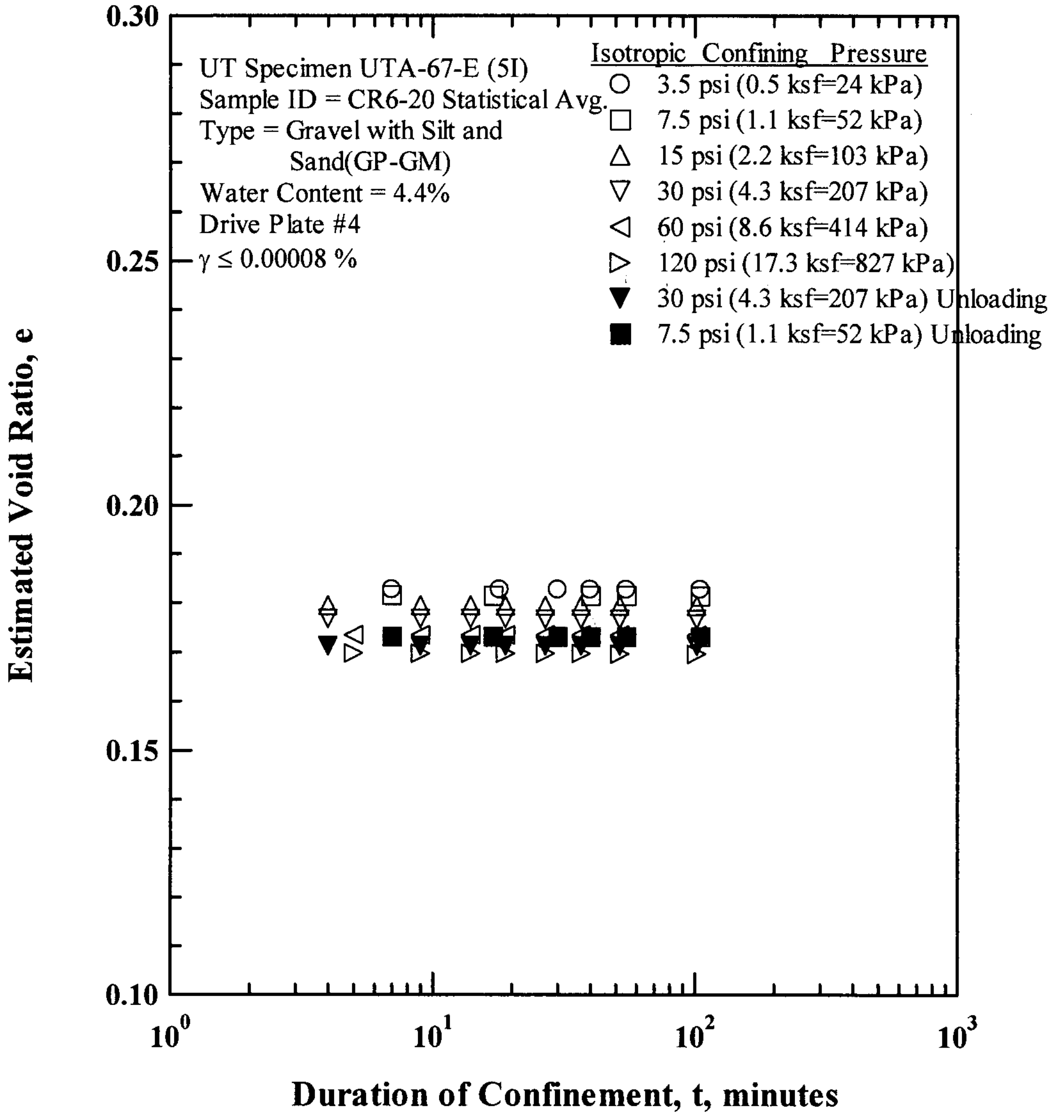


Figure F.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5I)

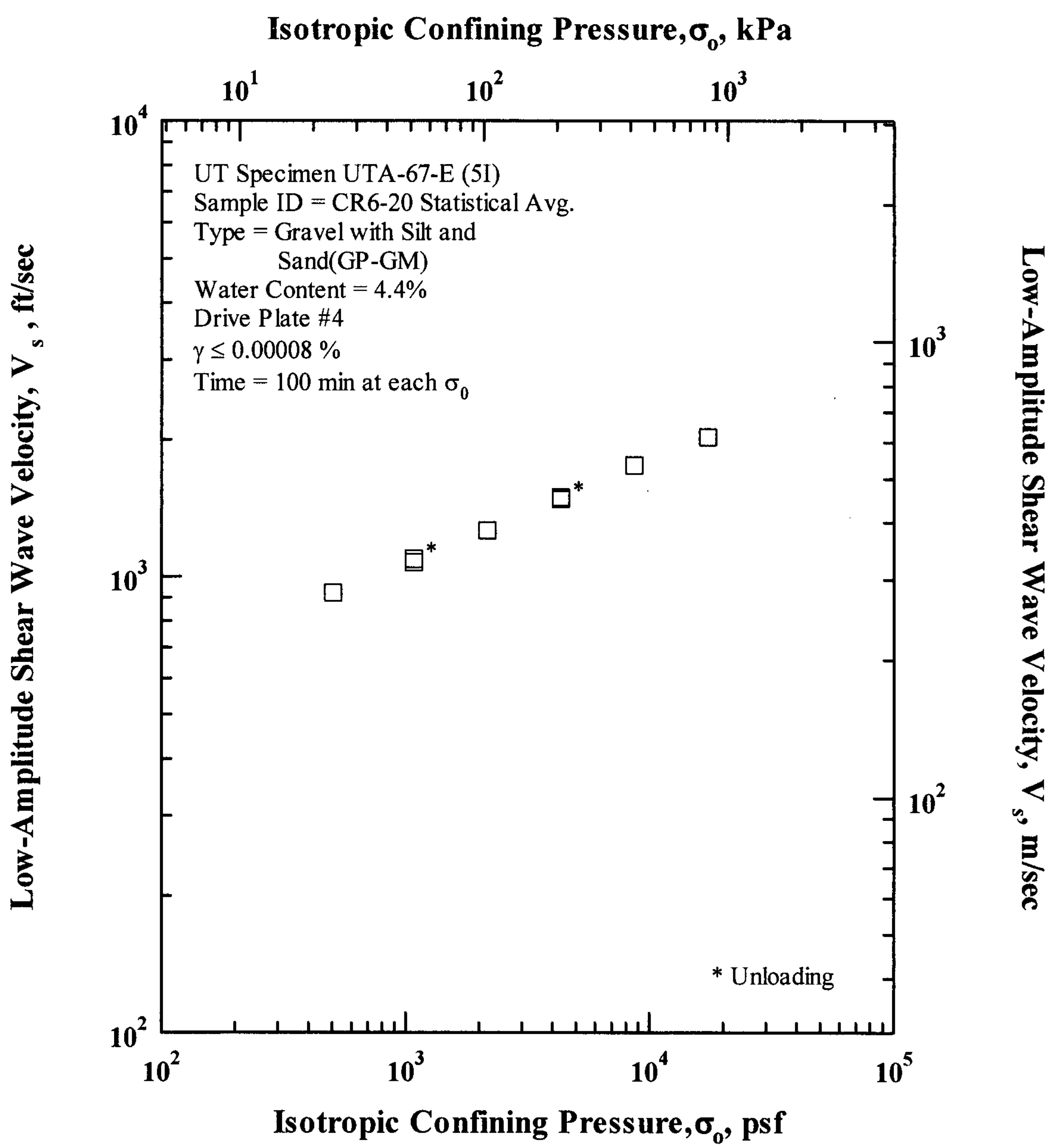


Figure F.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5I)

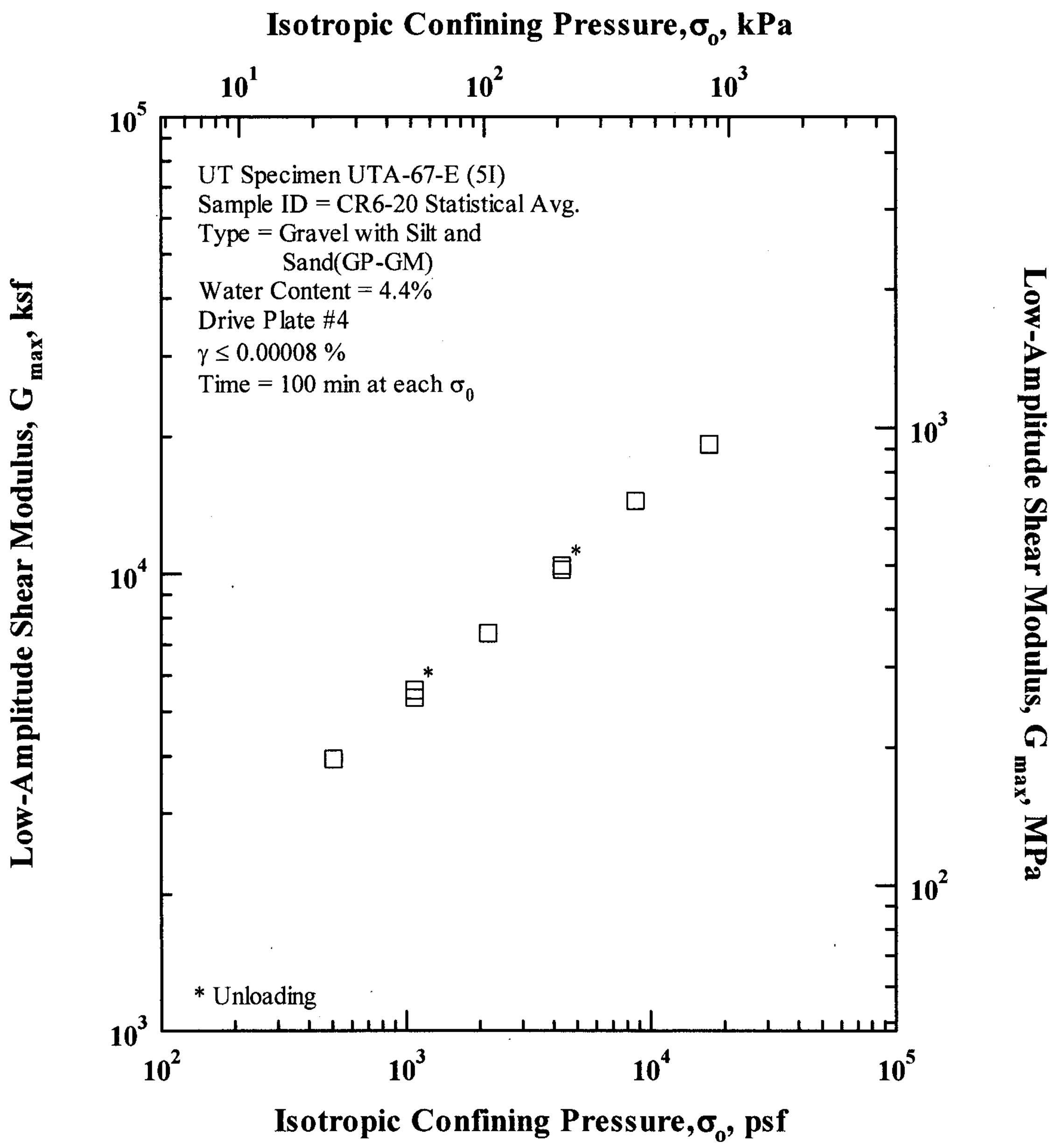


Figure F.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5I)

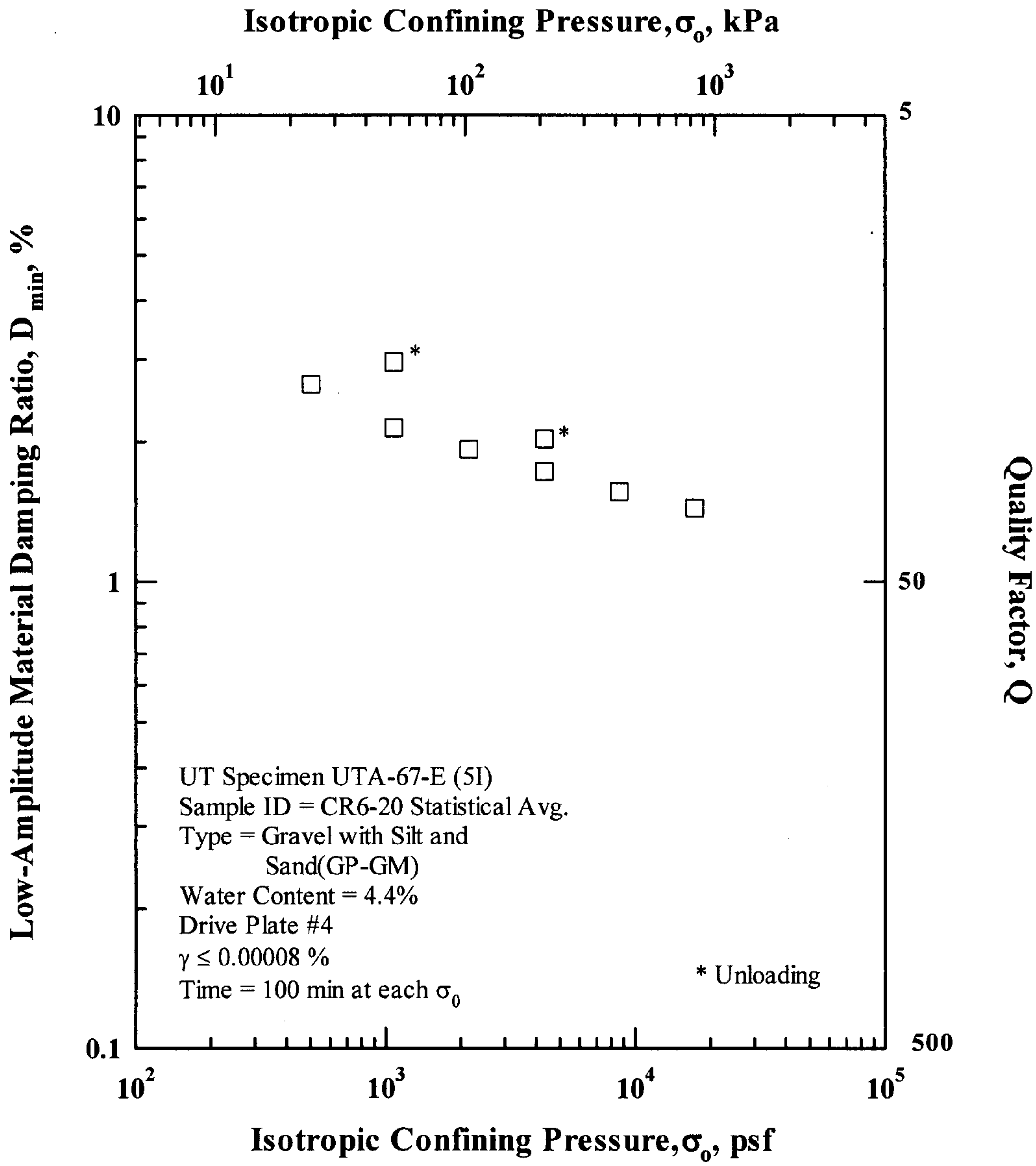


Figure F.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5I)

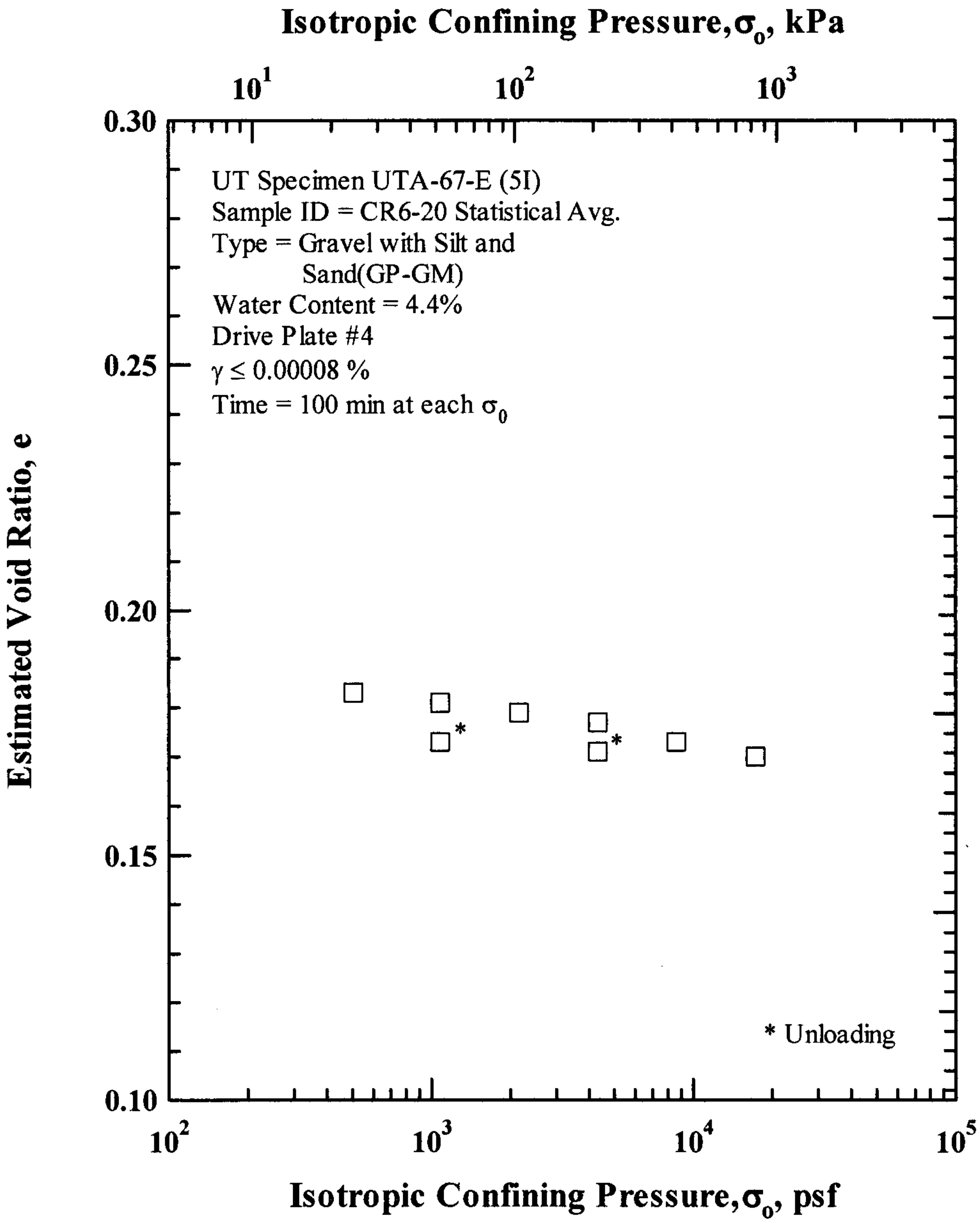


Figure F.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-E (5I)

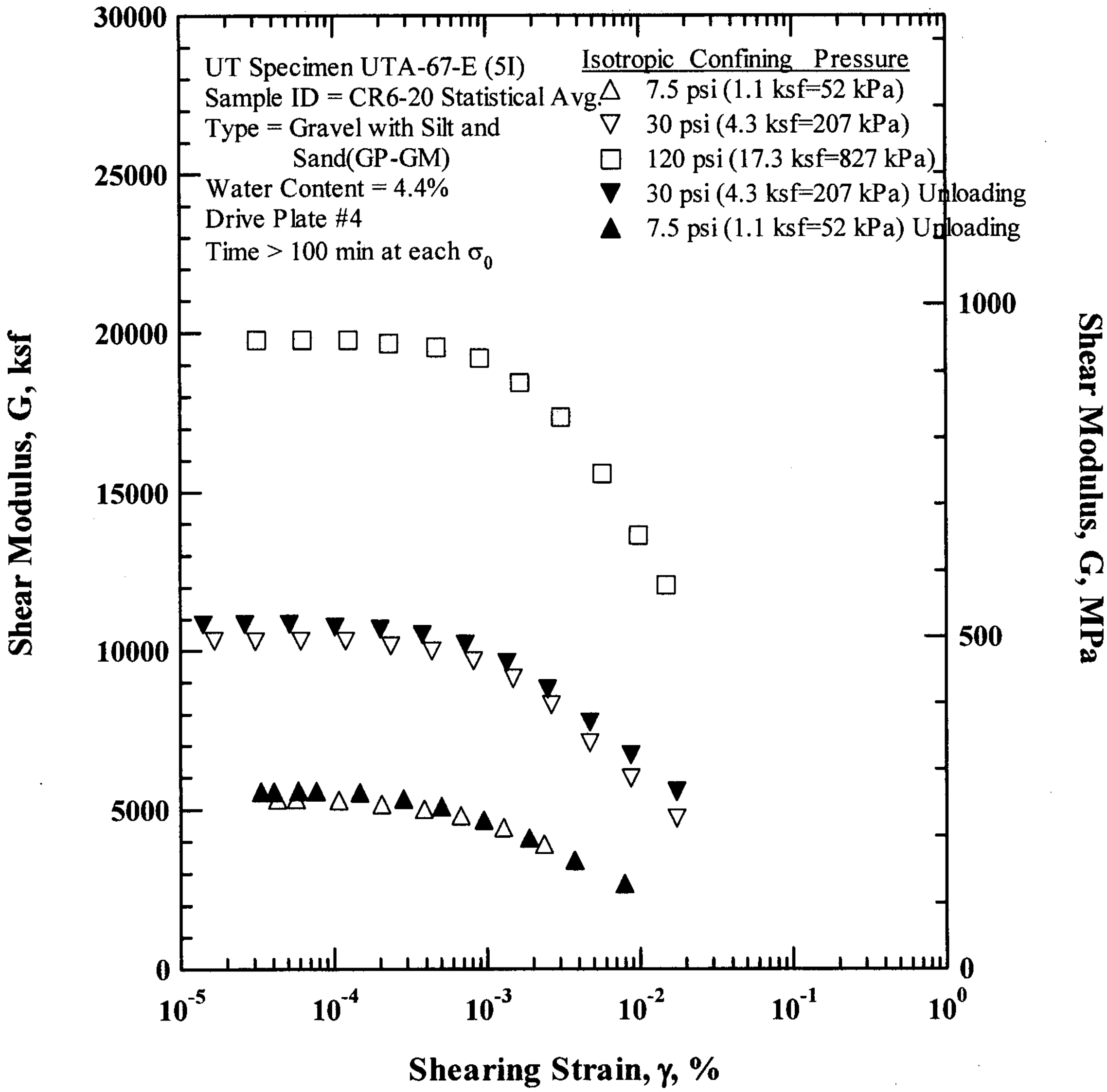


Figure F.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-E (5I)

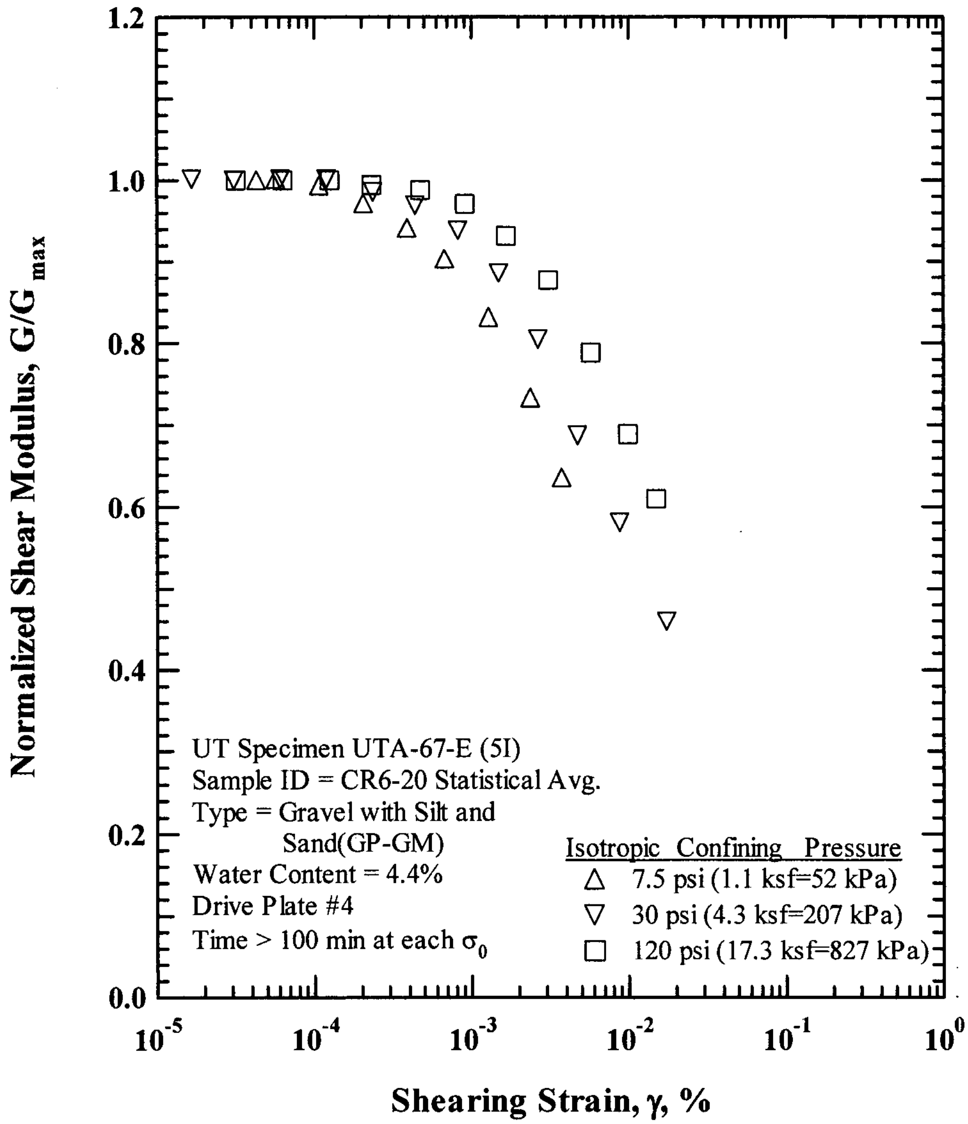


Figure F.9 Variation in Normalized Shear Modulus with Shearing Strain upon Loading at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-E (5I)

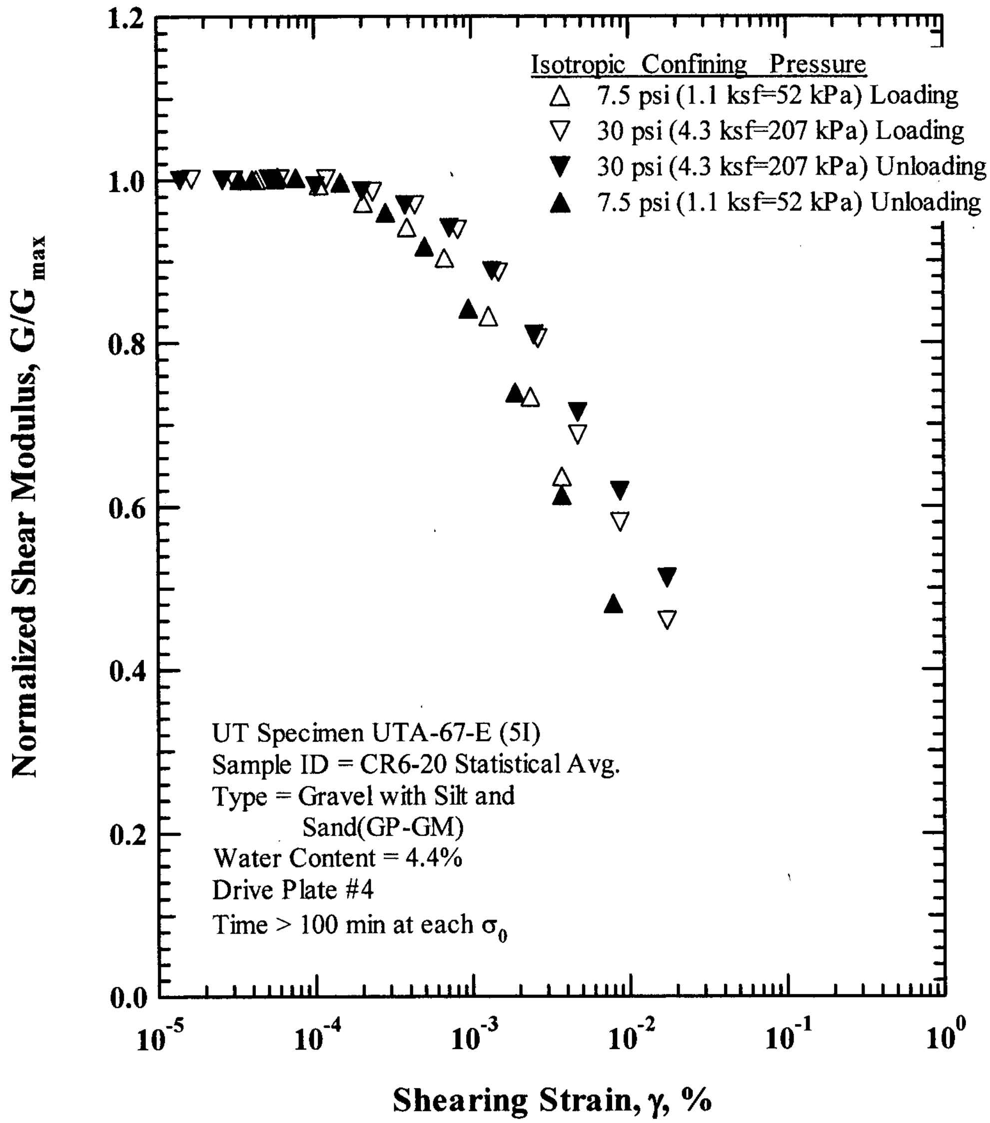


Figure F.10 Comparison of the Variations in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures upon Loading and Unloading from Resonant Column Tests of Specimen UTA-67-E (5I)

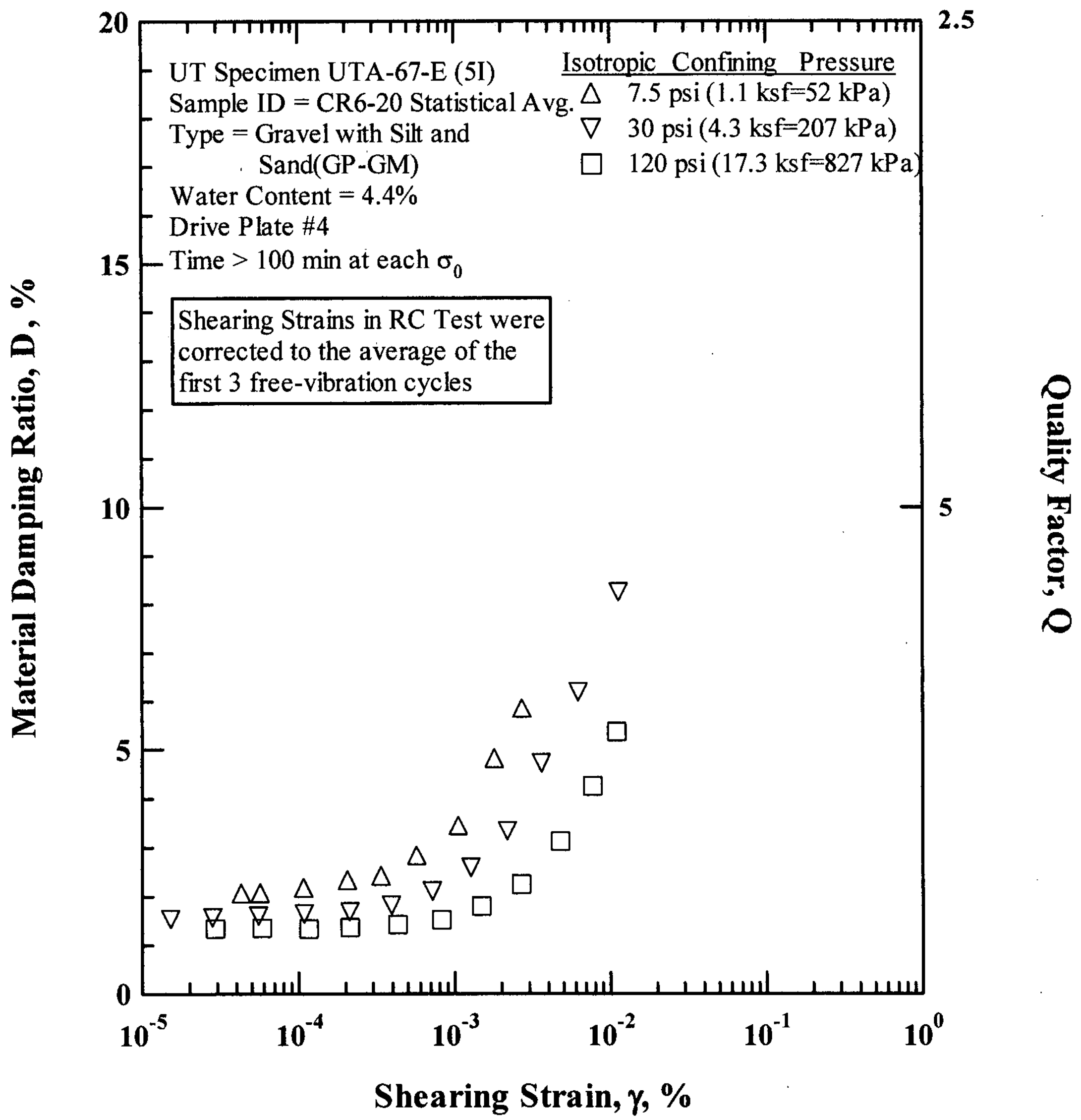


Figure F.11 Variation in Material Damping Ratio with Shearing Strain upon Loading at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-E (5I)

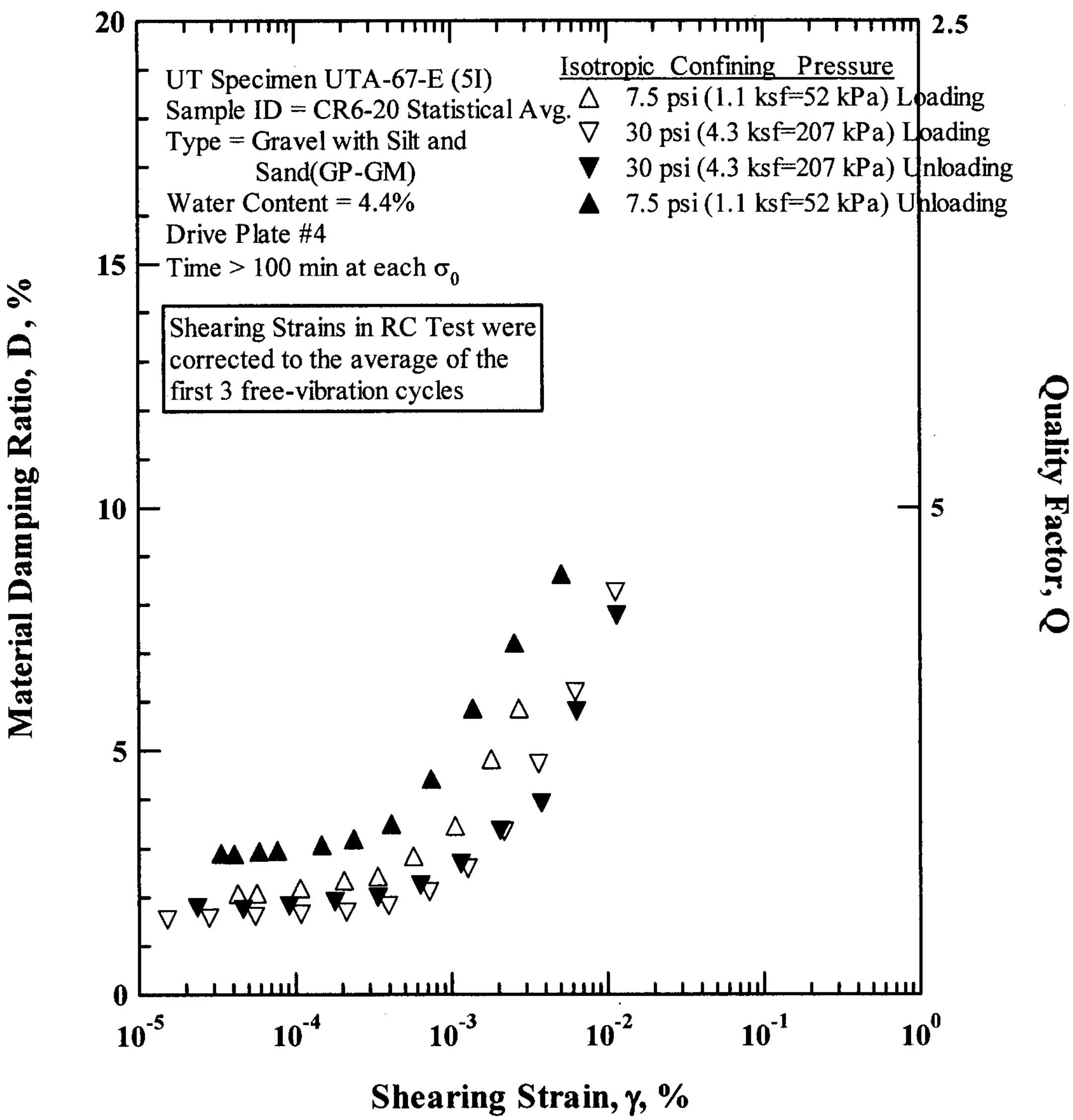


Figure F.12 Comparison of the Variations in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures upon Loading and Unloading from Resonant Column Tests of Specimen UTA-67-E (5I)

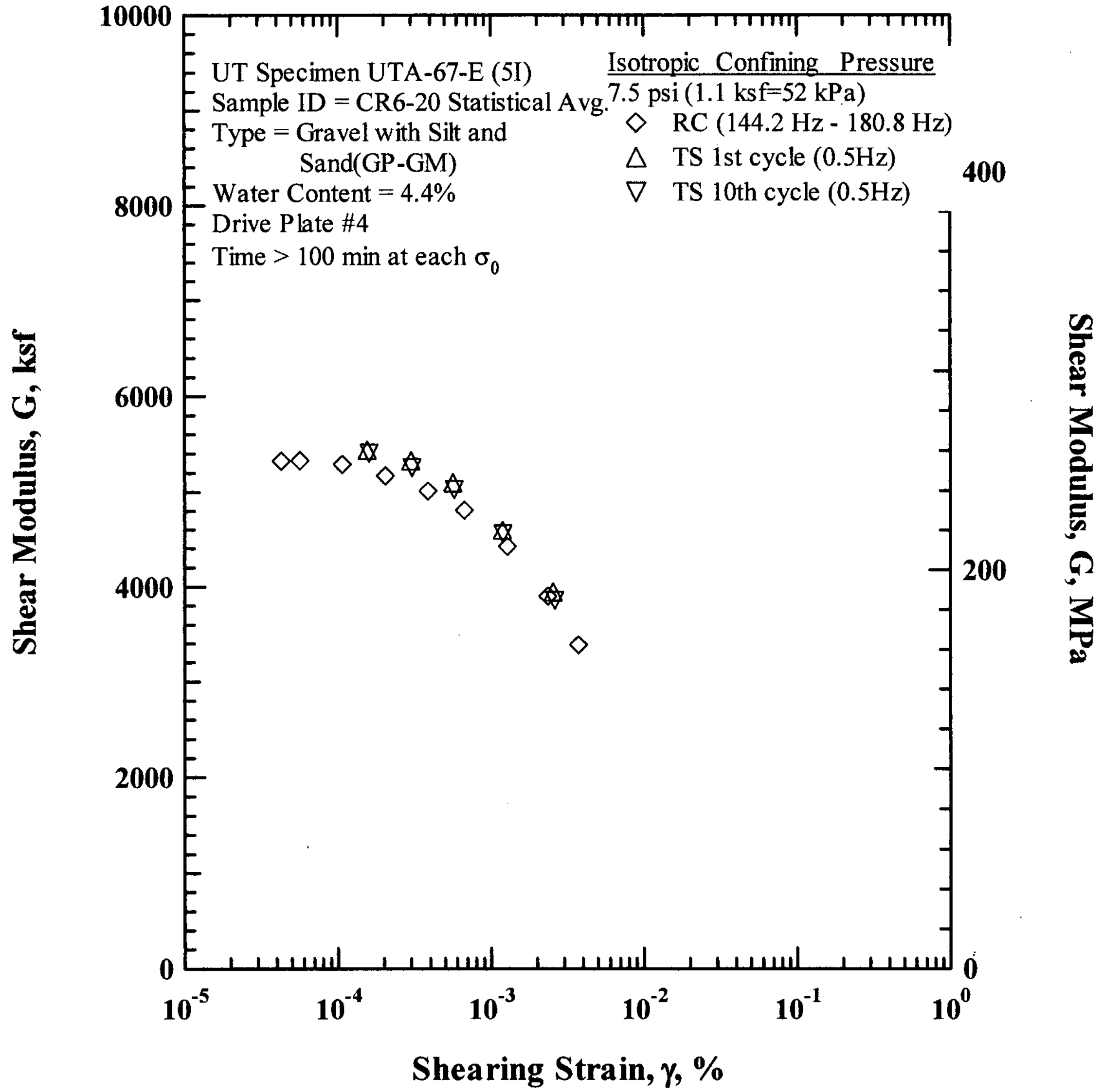


Figure F.13 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

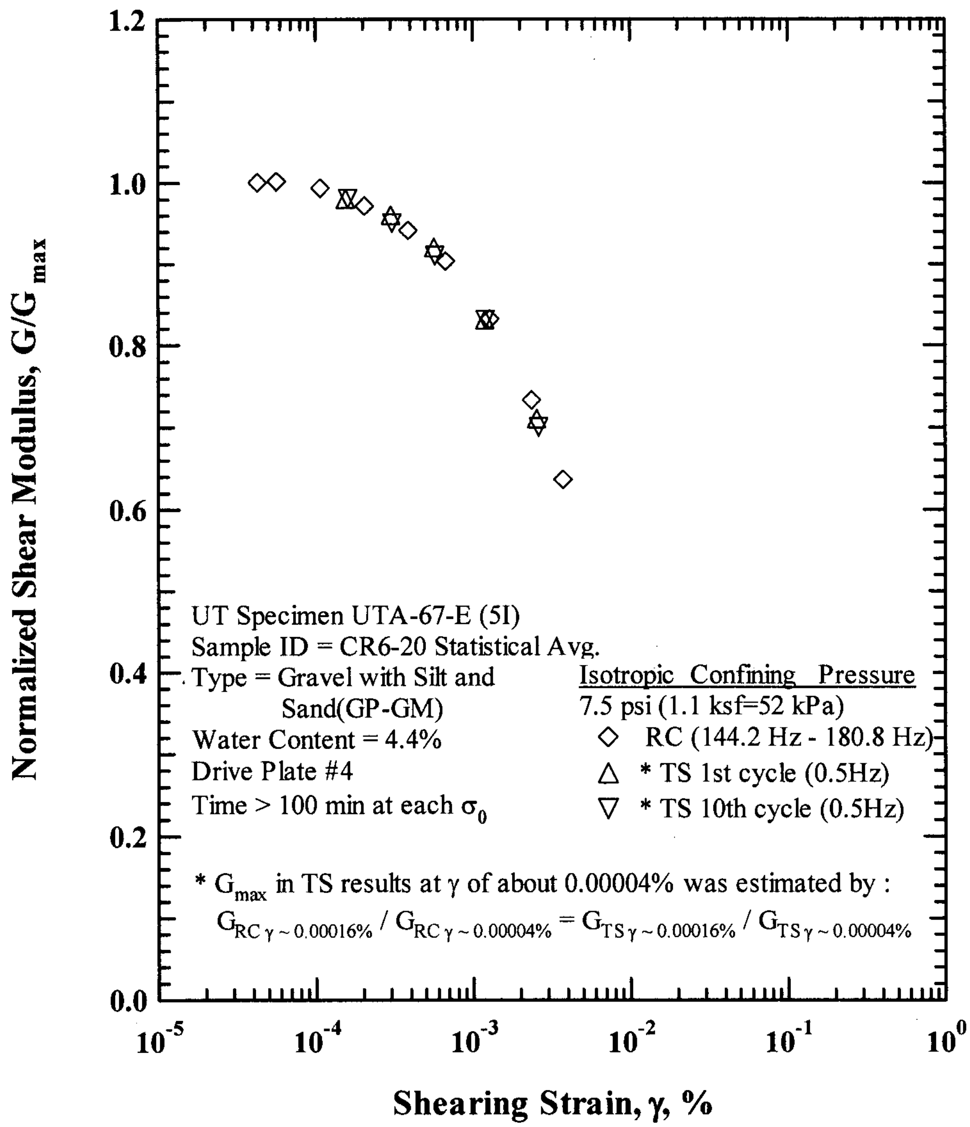


Figure F.14 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

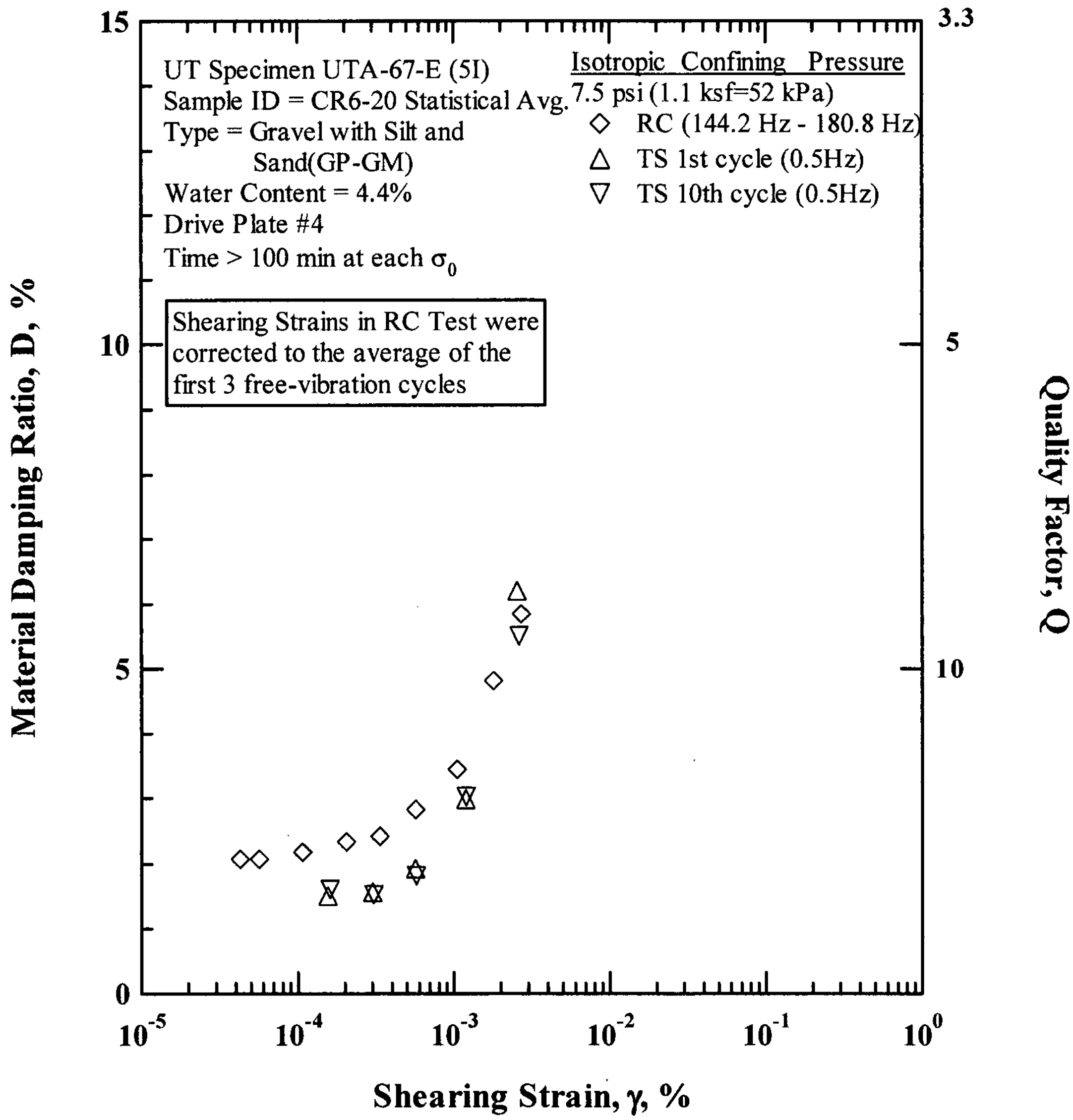


Figure F.15 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

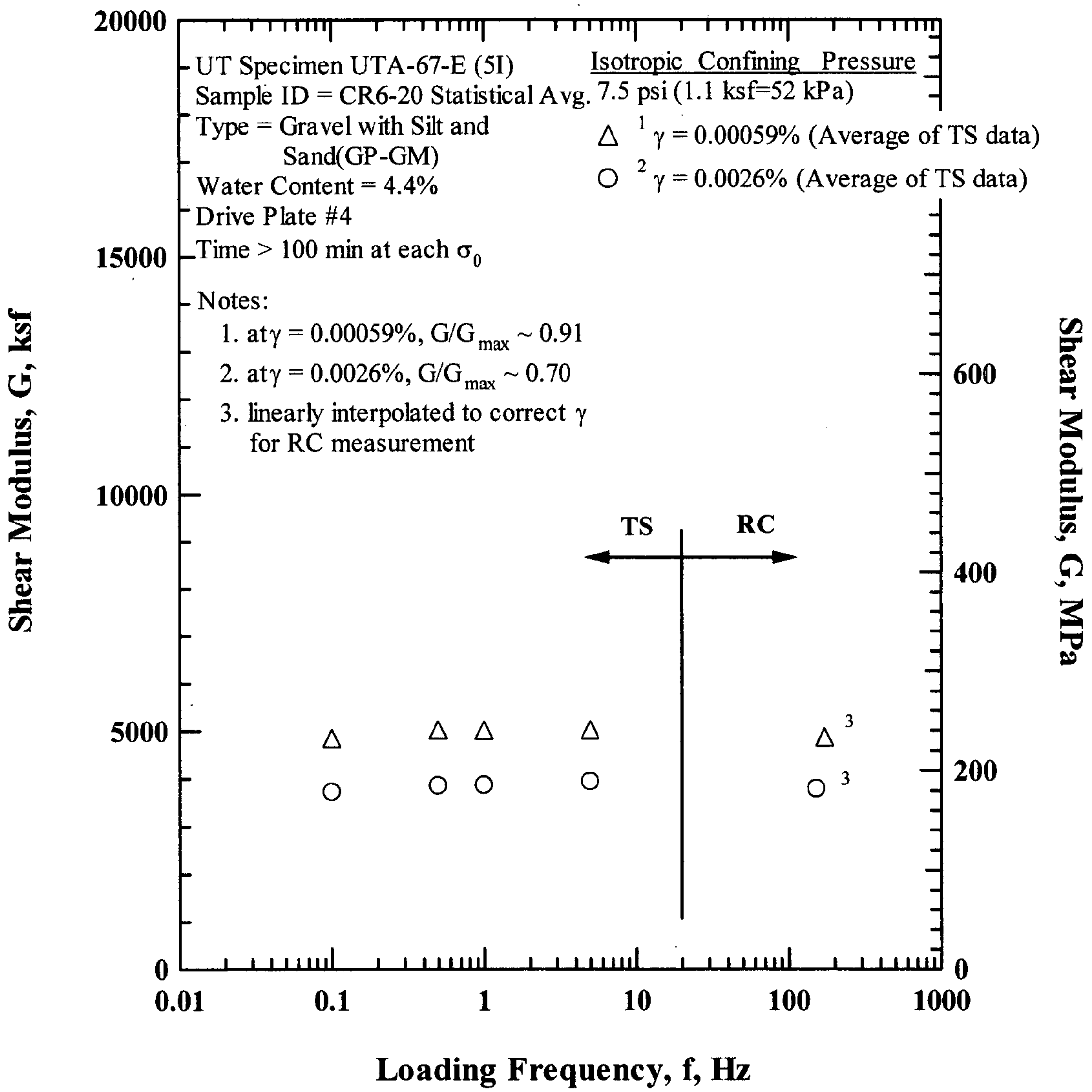


Figure F.16 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

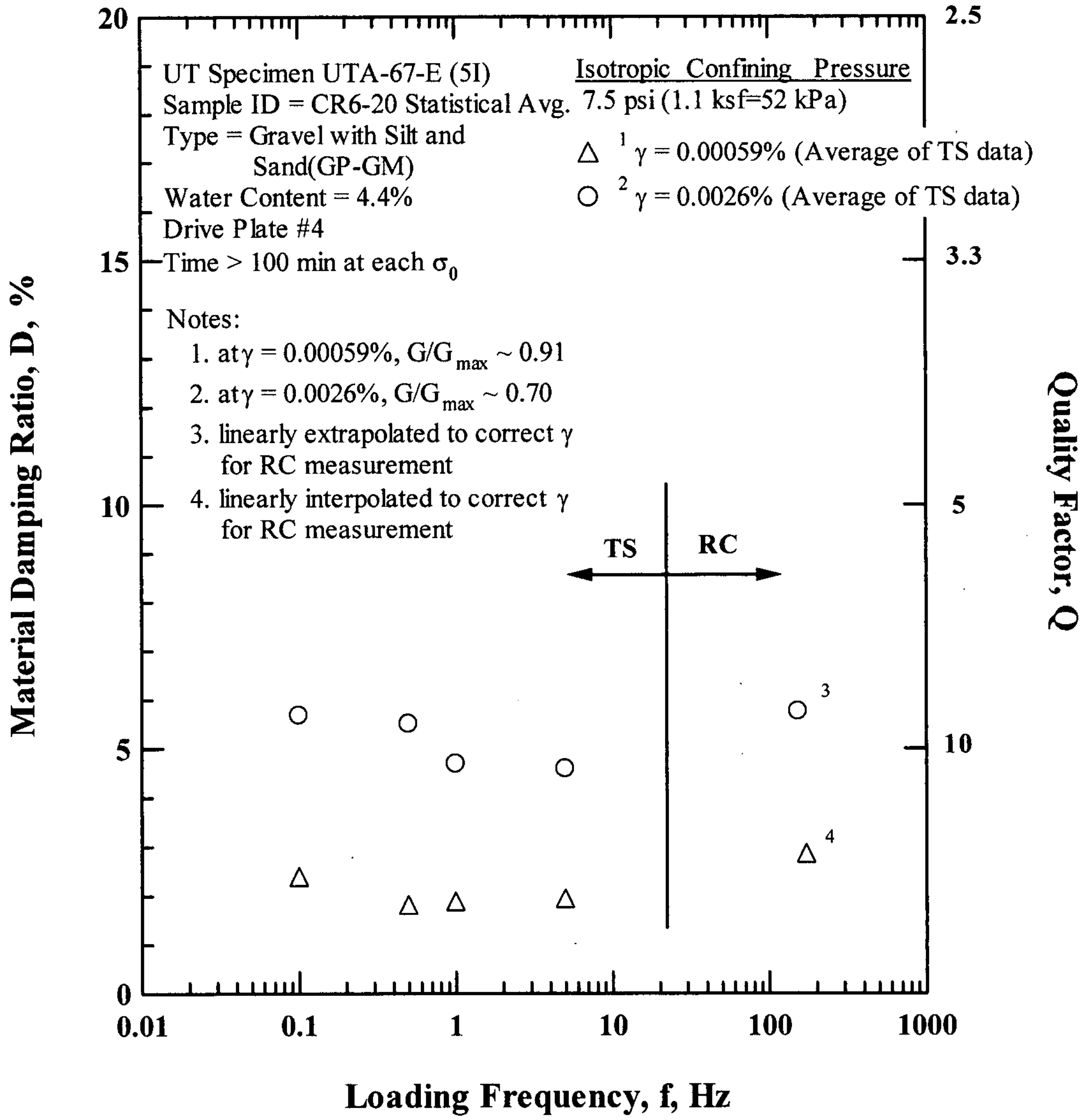


Figure F.17 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Loading Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

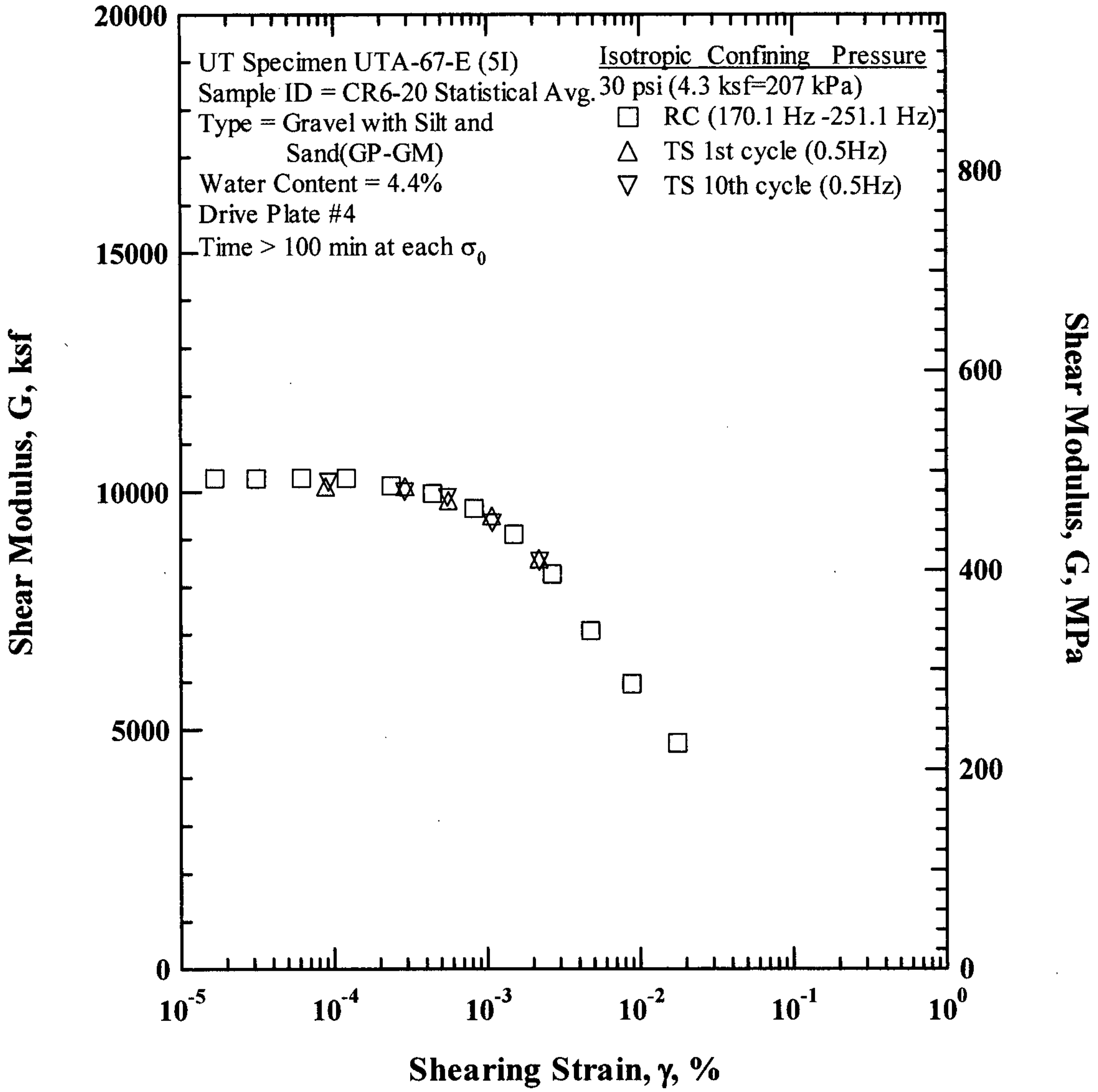


Figure F.18 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

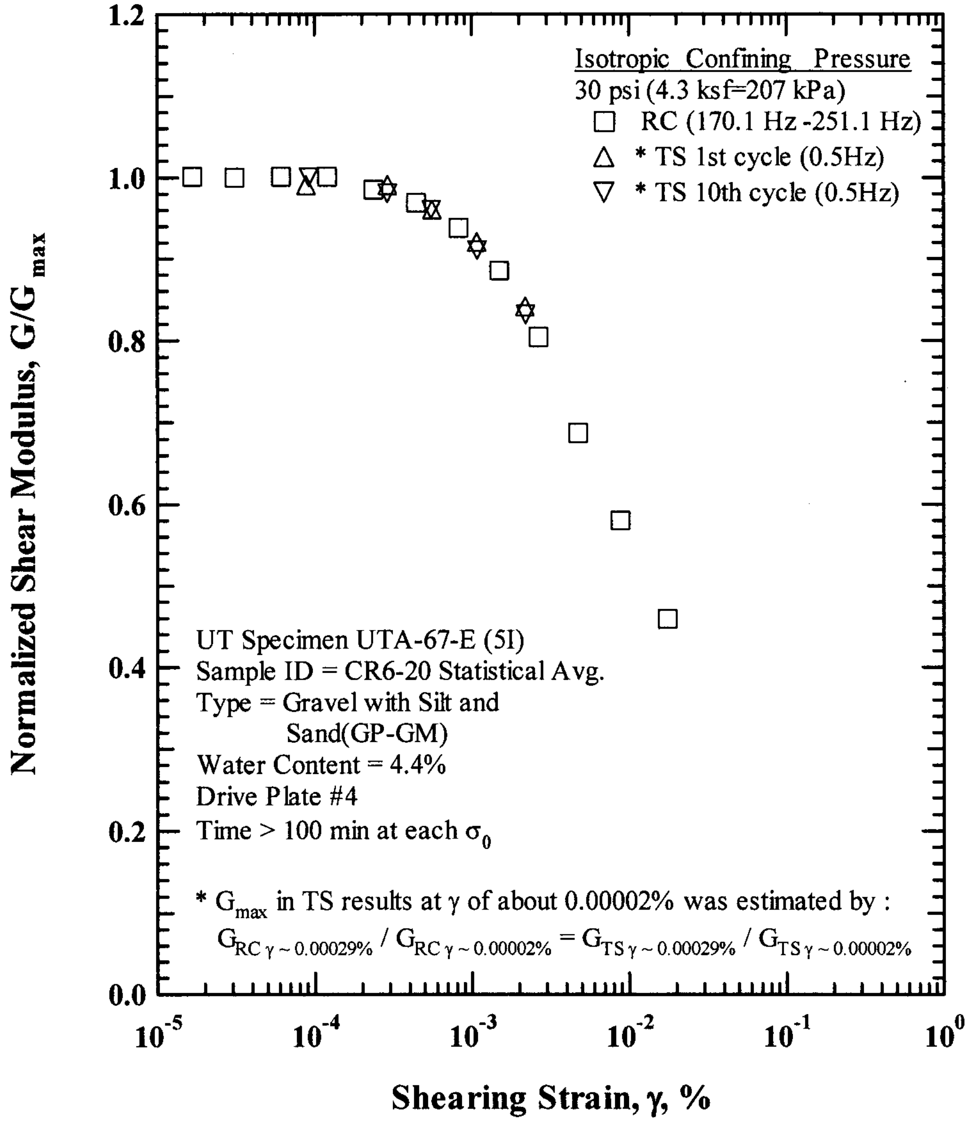


Figure F.19 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

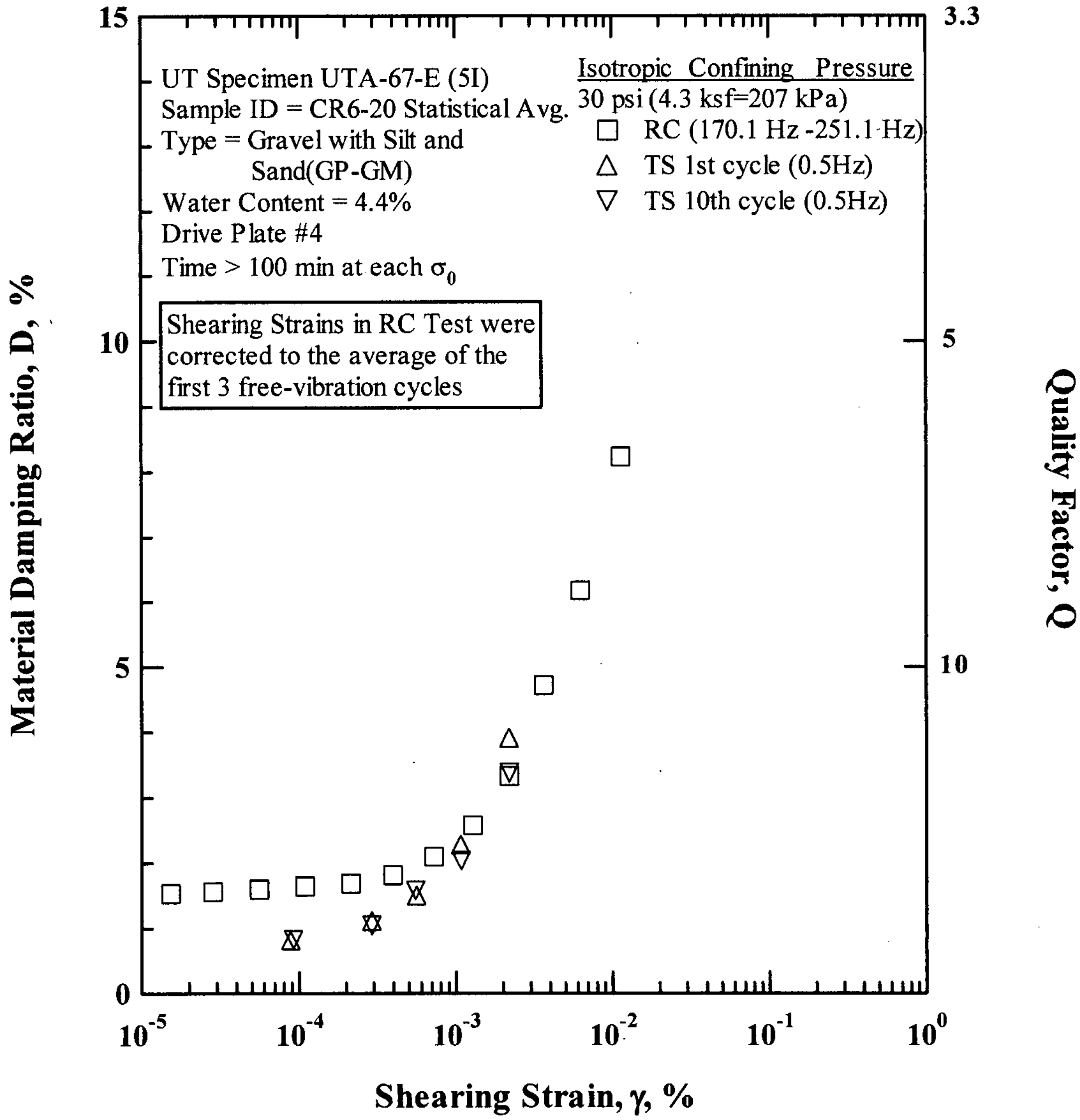


Figure F.20 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

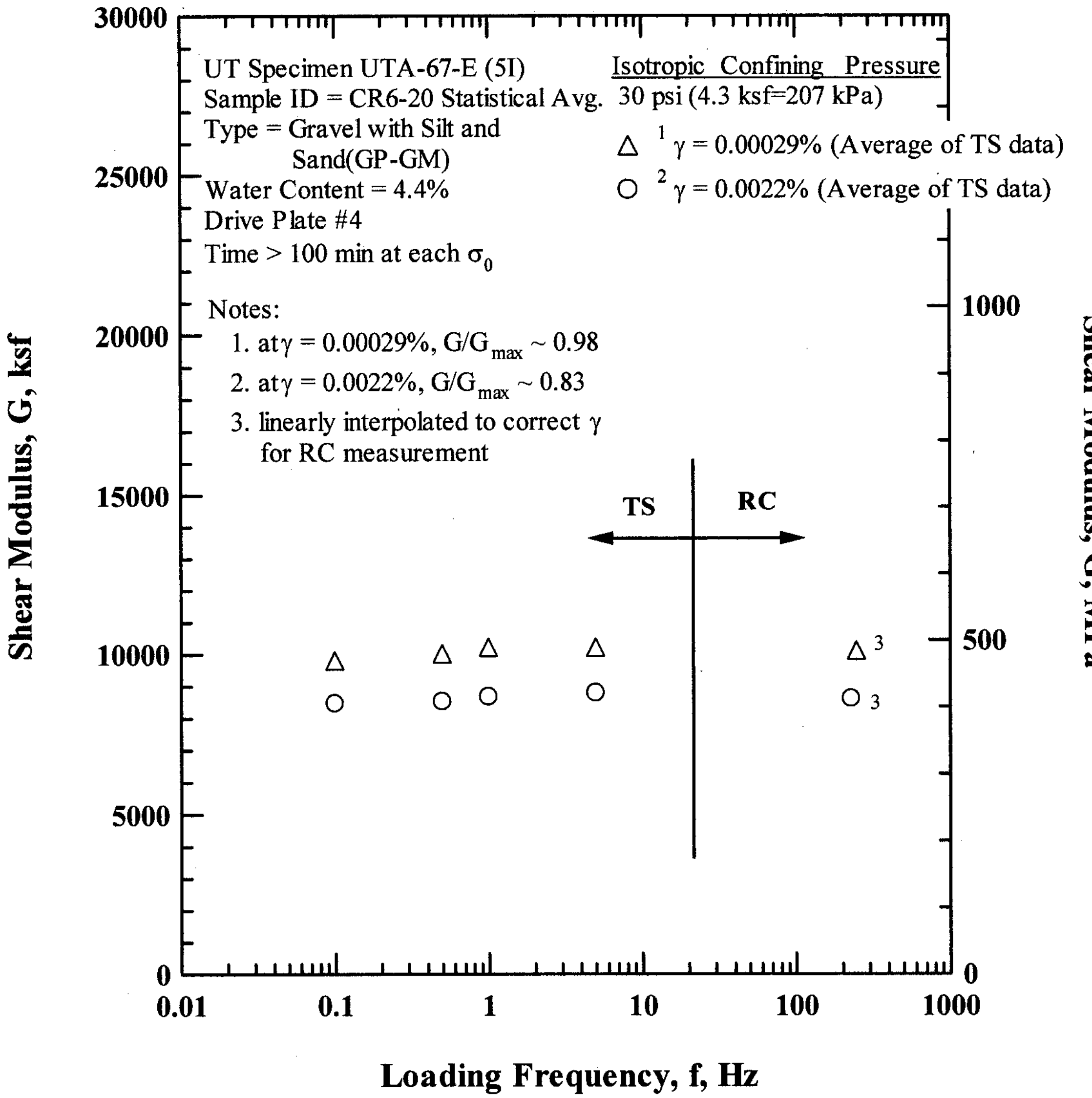


Figure F.21 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

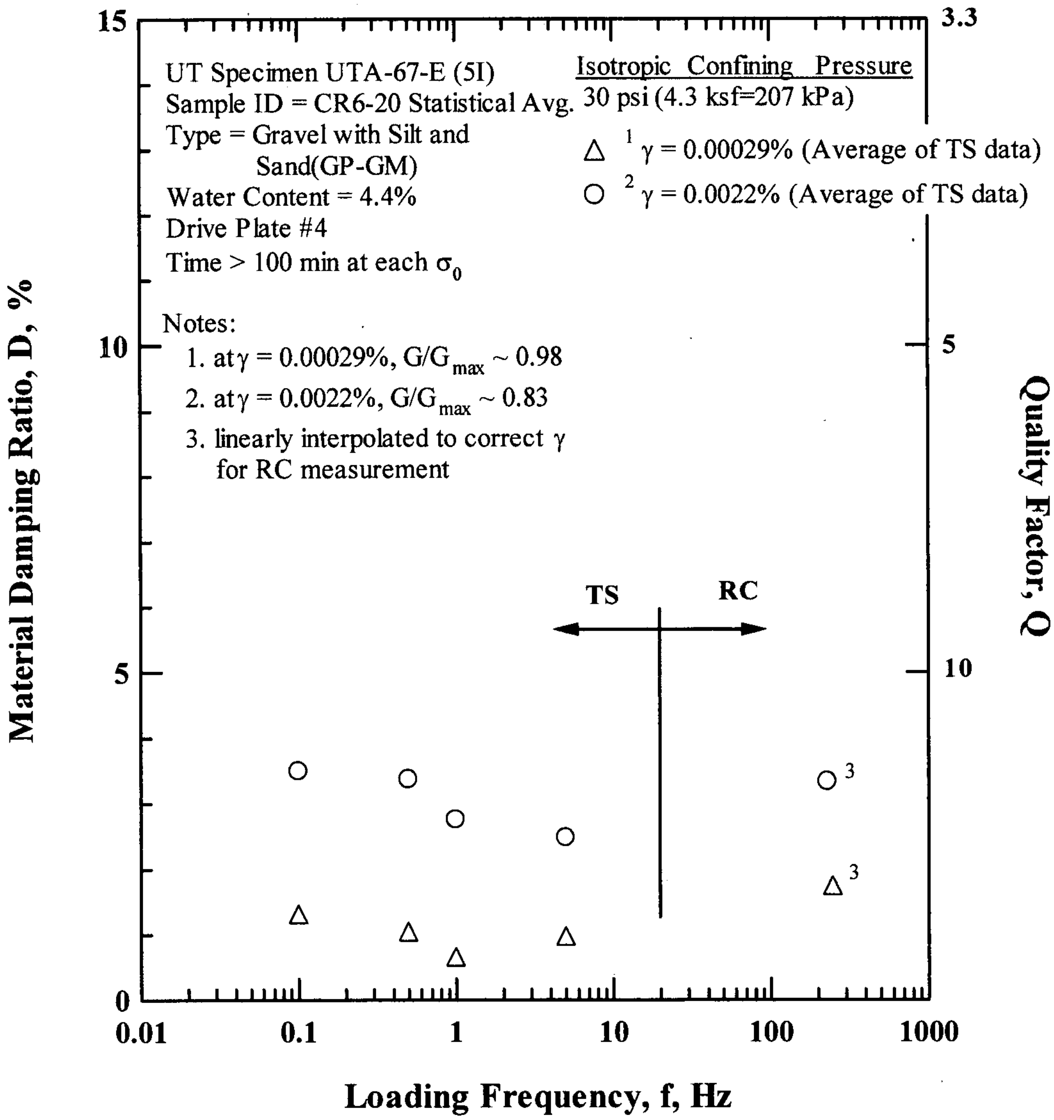


Figure F.22 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Loading Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

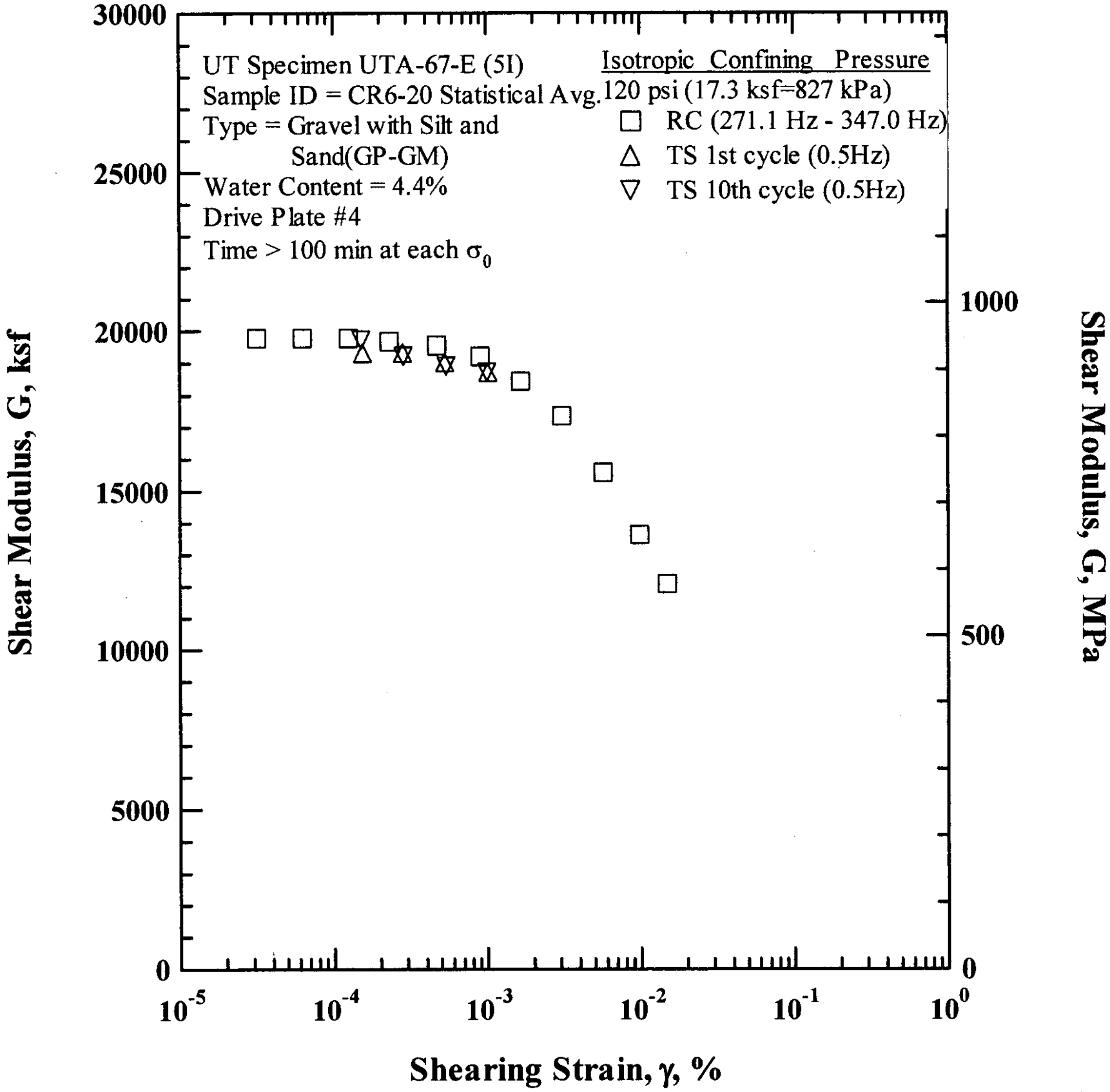


Figure F.23 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

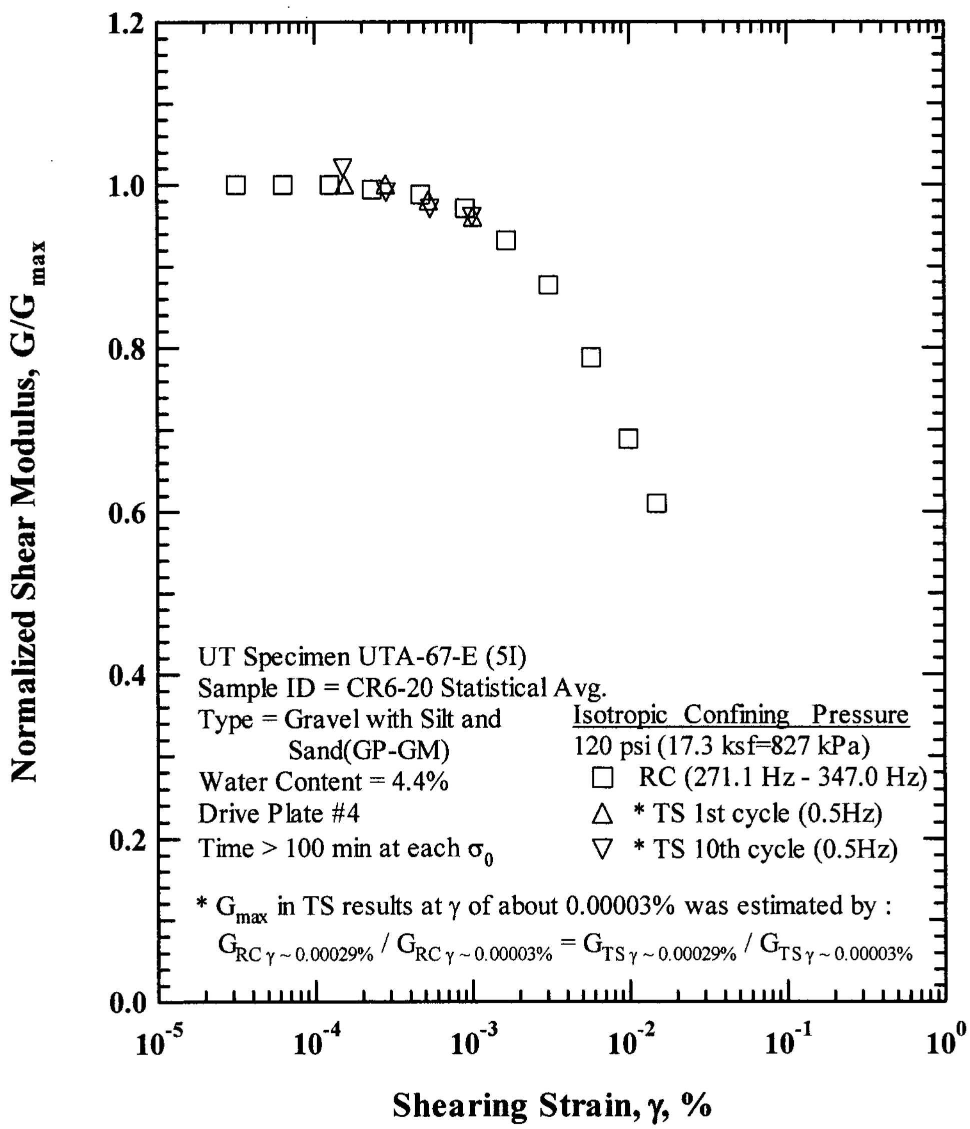


Figure F.24 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

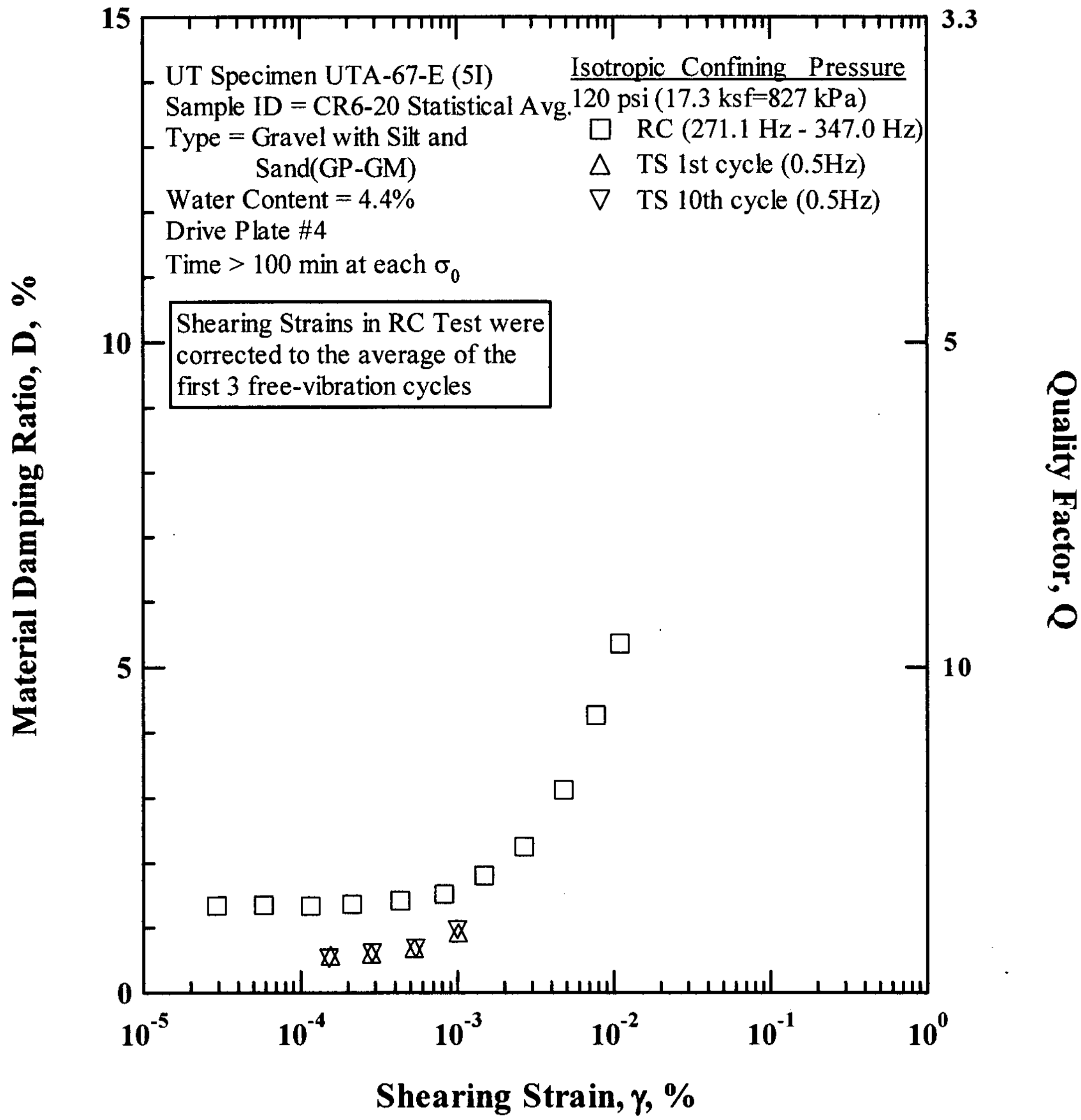


Figure F.25 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

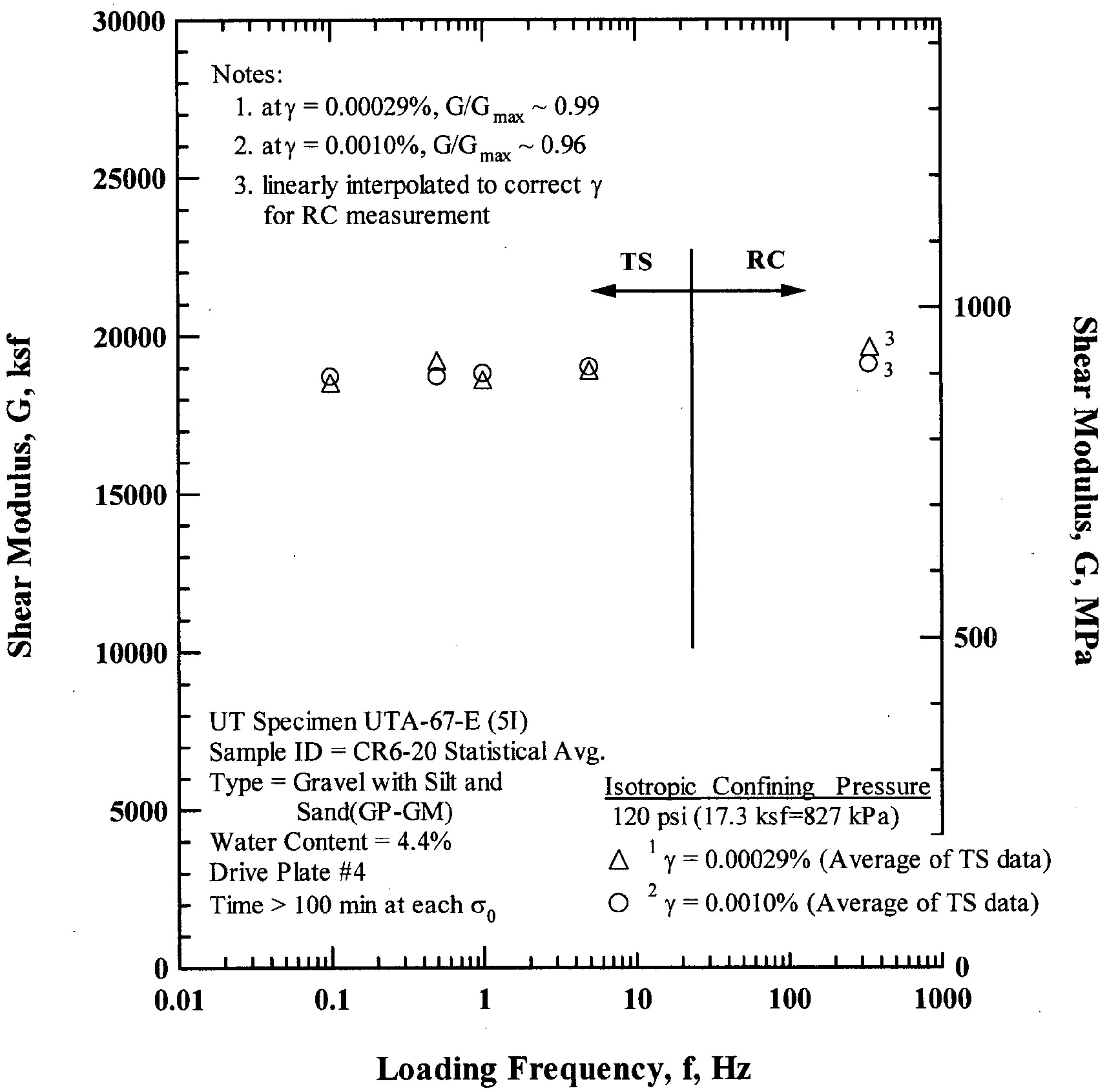


Figure F.26 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

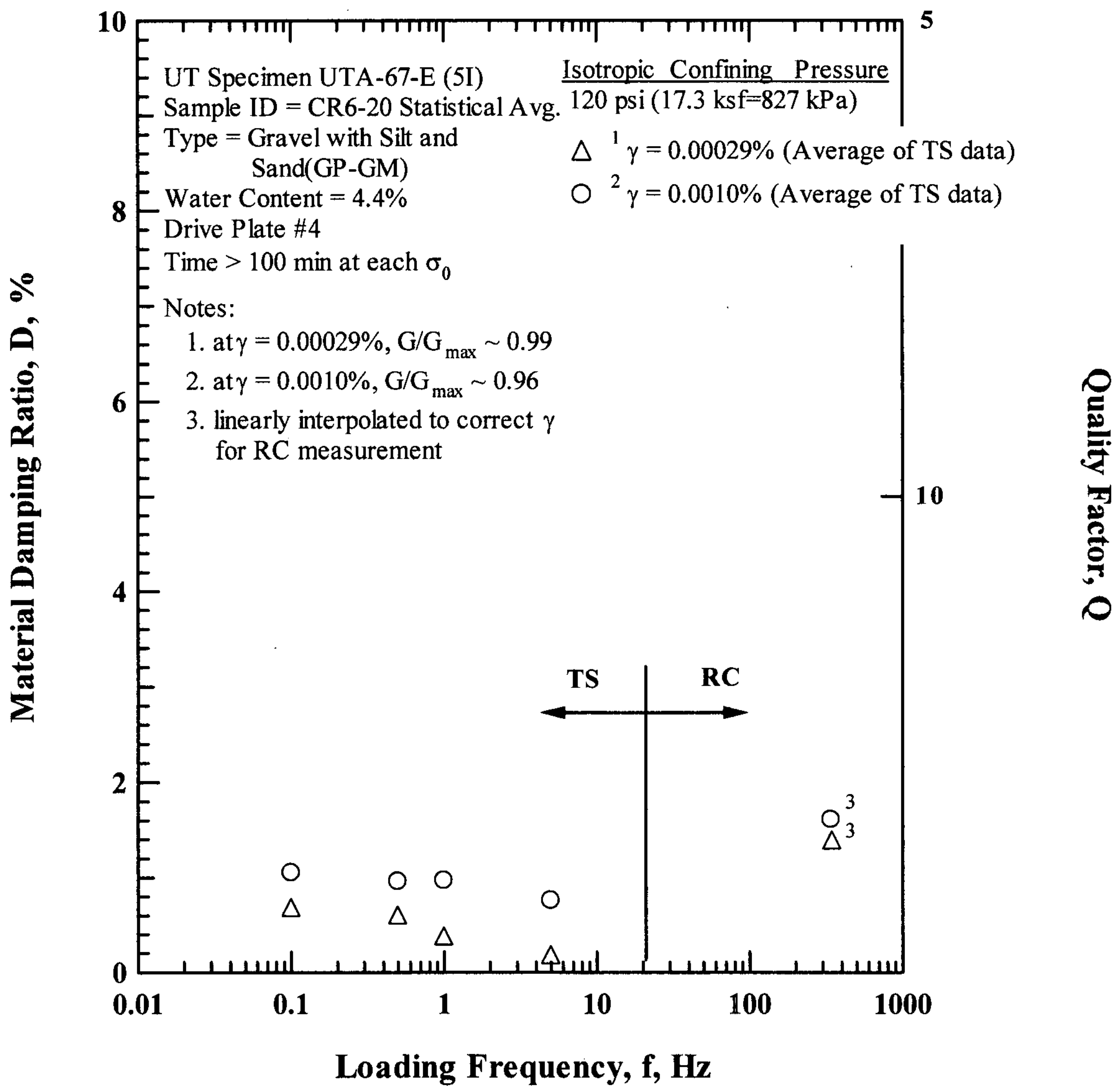


Figure F.27 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-E (5I)

Table F.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-E (5I)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_S	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.5	504	24	3941	188.9	921	2.65	0.18
7.5	1080	52	5355	256.7	1073	2.14	0.18
15	2160	103	7399	354.7	1260	1.93	0.18
30	4320	207	10206	489.3	1479	1.73	0.18
60	8640	414	14436	692.1	1757	1.56	0.17
120	17280	827	19211	921.0	2025	1.44	0.17
30 (Unloading)	4320	207	10414	499.2	1492	2.03	0.17
7.5 (Unloading)	1080	52	5568	266.9	1091	2.96	0.17

Table F.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
4.31E-05	5317	1.00	4.31E-05	2.06
5.70E-05	5321	1.00	5.70E-05	2.07
1.08E-04	5282	0.99	1.08E-04	2.17
2.06E-04	5165	0.97	2.06E-04	2.33
3.91E-04	5004	0.94	3.38E-04	2.42
6.77E-04	4801	0.90	5.73E-04	2.82
1.29E-03	4417	0.83	1.06E-03	3.44
2.38E-03	3896	0.73	1.81E-03	4.81
3.77E-03	3382	0.64	2.73E-03	5.84

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table F.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.57E-04	5430	0.98	1.50	1.62E-04	5400	0.98	1.60
3.03E-04	5320	0.96	1.56	3.08E-04	5250	0.95	1.52
5.69E-04	5090	0.92	1.92	5.79E-04	5020	0.91	1.81
1.20E-03	4590	0.83	2.98	1.21E-03	4550	0.83	3.02
2.56E-03	3940	0.71	6.20	2.63E-03	3850	0.70	5.50

Table F.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average+ Shearing Strain, %	Material Damping Ratio^x, D, %
1.68E-05	10293	1.00	1.53E-05	1.54
3.12E-05	10284	1.00	2.83E-05	1.57
6.15E-05	10292	1.00	5.58E-05	1.60
1.21E-04	10292	1.00	1.09E-04	1.65
2.37E-04	10128	0.98	2.14E-04	1.69
4.42E-04	9966	0.97	3.96E-04	1.82
8.23E-04	9646	0.94	7.25E-04	2.10
1.50E-03	9097	0.88	1.28E-03	2.58
2.66E-03	8270	0.80	2.19E-03	3.33
4.75E-03	7068	0.69	3.64E-03	4.71
8.82E-03	5960	0.58	6.28E-03	6.18
1.75E-02	4722	0.46	1.14E-02	8.24

+ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

x Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table F.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
8.91E-05	10100	0.99	0.81	9.29E-05	10200	1.00	0.82
2.94E-04	10100	0.99	1.11	2.93E-04	10000	0.98	1.04
5.64E-04	9800	0.96	1.50	5.56E-04	9870	0.96	1.58
1.08E-03	9470	0.92	2.27	1.09E-03	9330	0.91	2.03
2.20E-03	8570	0.84	3.90	2.22E-03	8520	0.83	3.37

Table F.6 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 120 psi (17.3 ksf = 827 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average+ Shearing Strain, %	Material Damping Ratio^x, D, %
3.17E-05	19774	1.00	2.92E-05	1.34
6.30E-05	19775	1.00	5.80E-05	1.36
1.26E-04	19774	1.00	1.16E-04	1.34
2.31E-04	19660	0.99	2.13E-04	1.37
4.72E-04	19547	0.99	4.33E-04	1.43
9.03E-04	19208	0.97	8.23E-04	1.52
1.66E-03	18430	0.93	1.48E-03	1.81
3.06E-03	17346	0.88	2.68E-03	2.25
5.73E-03	15580	0.79	4.77E-03	3.13
9.84E-03	13624	0.69	7.71E-03	4.26
1.49E-02	12065	0.61	1.10E-02	5.36

+ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

x Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table F.7 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 120 psi (17.3 ksf = 827 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.56E-04	19300	1.00	0.56	1.53E-04	19700	1.02	0.52
2.85E-04	19300	1.00	0.59	2.88E-04	19200	0.99	0.60
5.35E-04	19000	0.98	0.68	5.47E-04	18900	0.97	0.67
1.02E-03	18700	0.96	0.91	1.01E-03	18700	0.96	0.96

Table F.8 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa) Unloading

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
1.42E-05	10823	1.00	1.30E-05	-
2.65E-05	10825	1.00	2.38E-05	1.78
5.18E-05	10835	1.00	4.66E-05	1.75
1.03E-04	10739	0.99	9.19E-05	1.82
2.02E-04	10667	0.99	1.80E-04	1.90
3.82E-04	10490	0.97	3.39E-04	1.99
7.27E-04	10171	0.94	6.36E-04	2.24
1.36E-03	9597	0.89	1.16E-03	2.68
2.51E-03	8754	0.81	2.06E-03	3.35
4.75E-03	7724	0.71	3.79E-03	3.90
8.80E-03	6687	0.62	6.38E-03	5.79
1.75E-02	5544	0.51	1.16E-02	7.76

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

$^-$ High Noise Level Interfering with Damping Measurement

Table F.9 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-E (5I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa) Unloading

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
3.37E-05	5548	1.00	3.37E-05	2.88
4.09E-05	5549	1.00	4.09E-05	2.87
5.91E-05	5565	1.00	5.91E-05	2.93
7.73E-05	5560	1.00	7.73E-05	2.95
1.49E-04	5524	1.00	1.49E-04	3.06
2.87E-04	5321	0.96	2.38E-04	3.18
5.07E-04	5086	0.92	4.14E-04	3.48
9.59E-04	4662	0.84	7.45E-04	4.41
1.90E-03	4096	0.74	1.38E-03	5.84
3.76E-03	3399	0.61	2.56E-03	7.19
7.97E-03	2664	0.48	5.10E-03	8.60

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

APPENDIX G

UT Specimen UTA-67-C (3I)
Sample ID : GAB-10
Type = Scalped, Reconstituted Gravel with Silt and Sand (GP-GM*)

Water Content, w = 6.2 %

G_S = 2.824*

Degree of Saturation = 87.2 %

Total Unit Weight, γ_t = 155.9 lb/ft^3

Dry Unit Weight, γ_d = 146.8 lb/ft^3

Target : γ_d= 145.9 lb/ft^3 ± 2 lb/ft^3

w= 6.4 % ± 1.0 %

* **Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

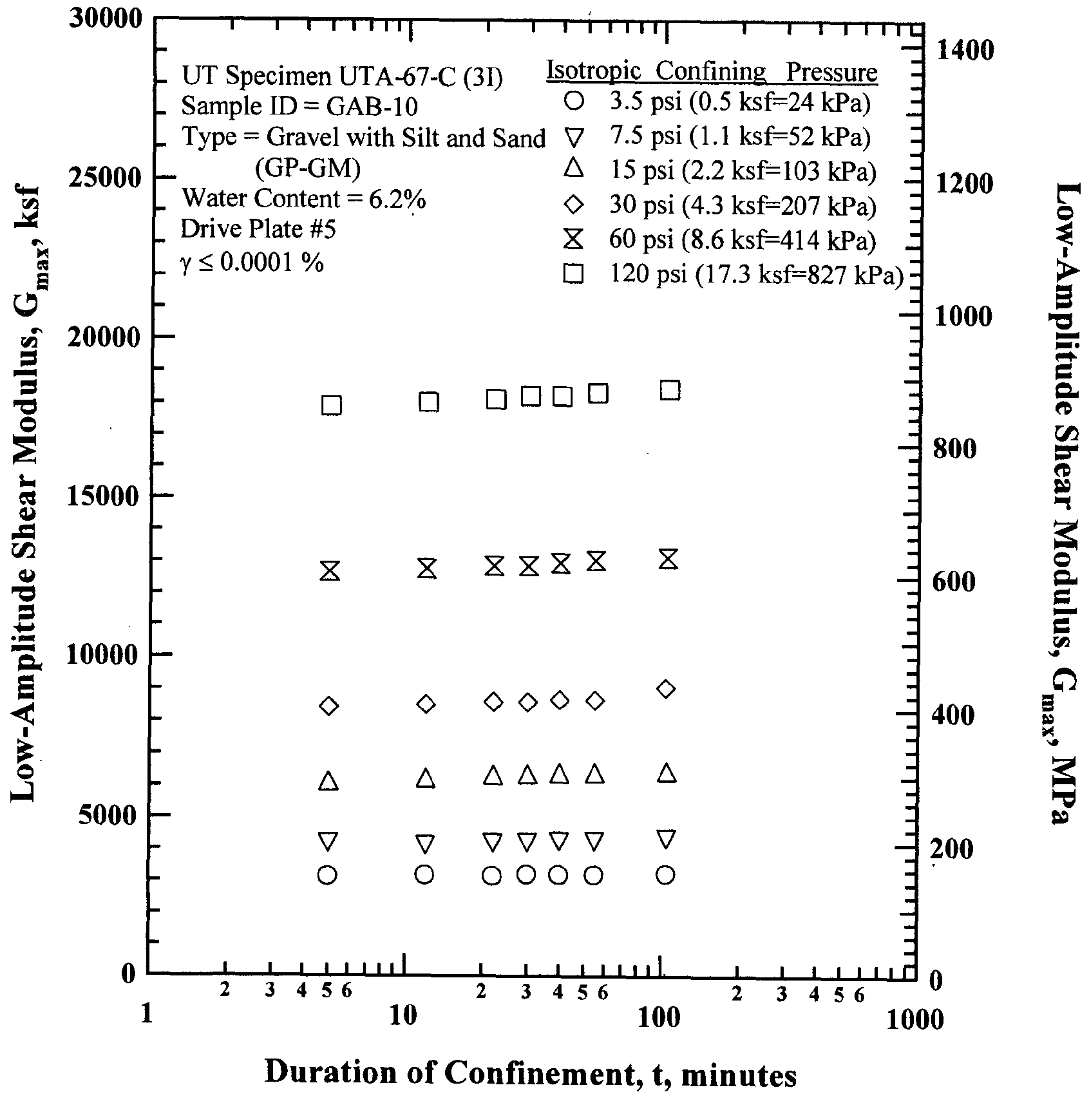


Figure G.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3I)

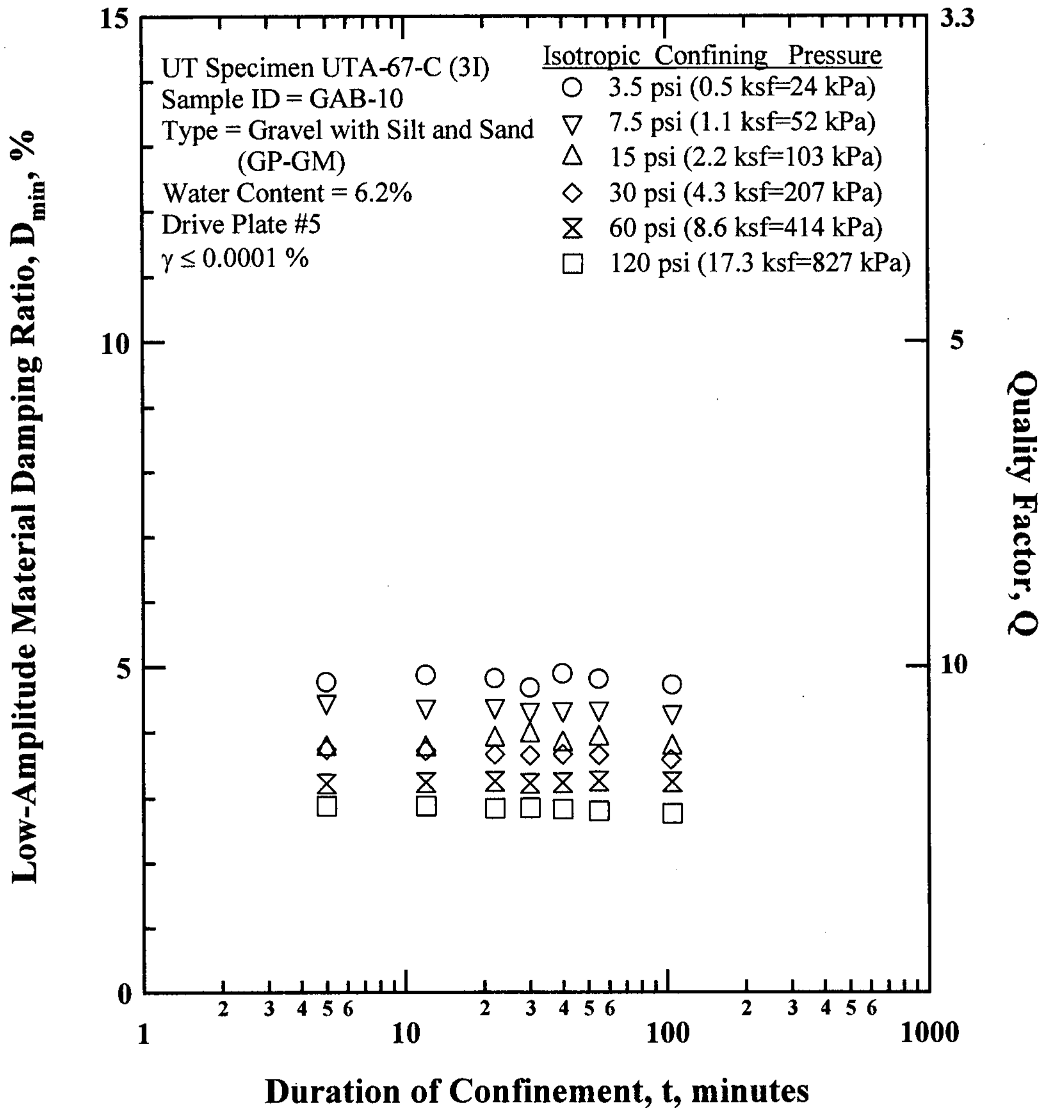


Figure G.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3I)

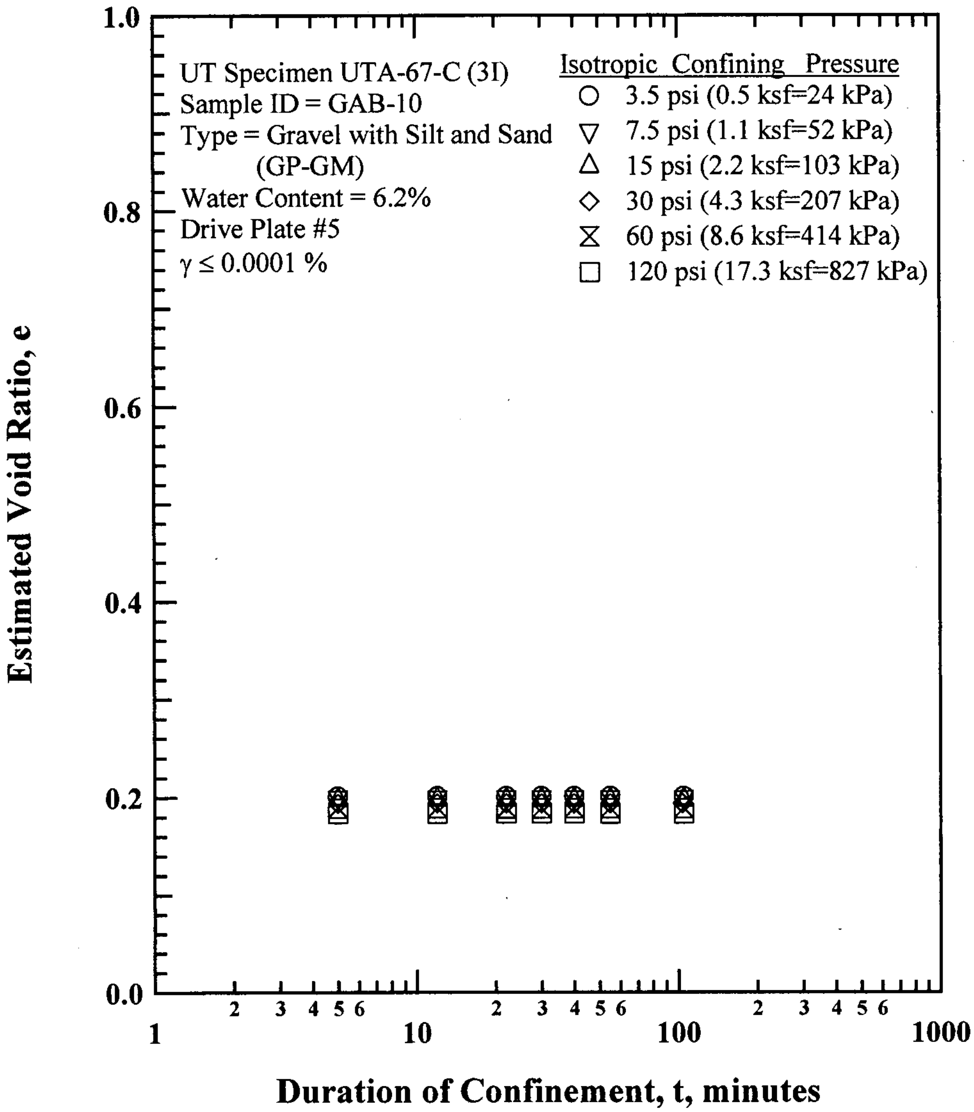


Figure G.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3I)

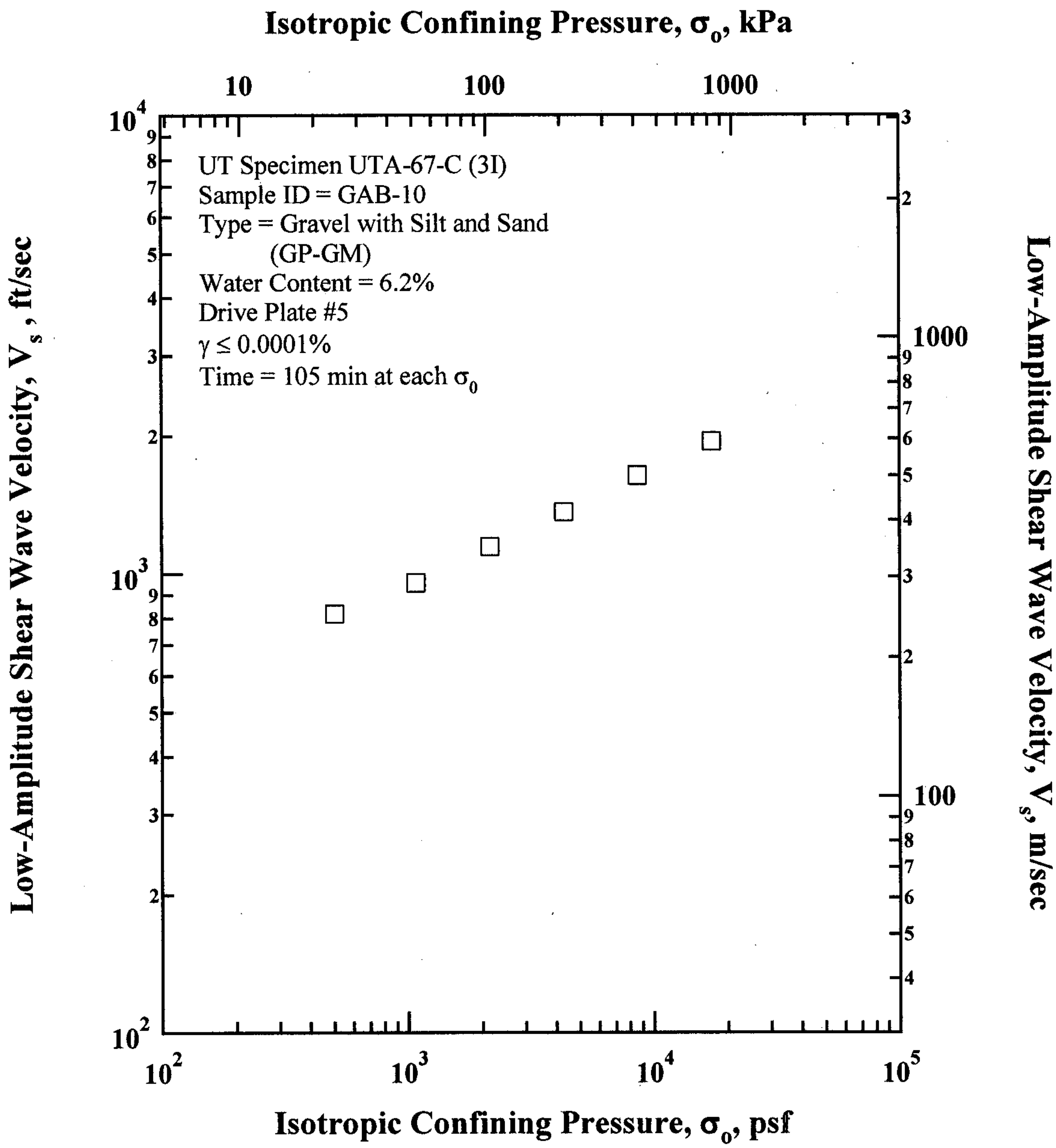


Figure G.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3I)

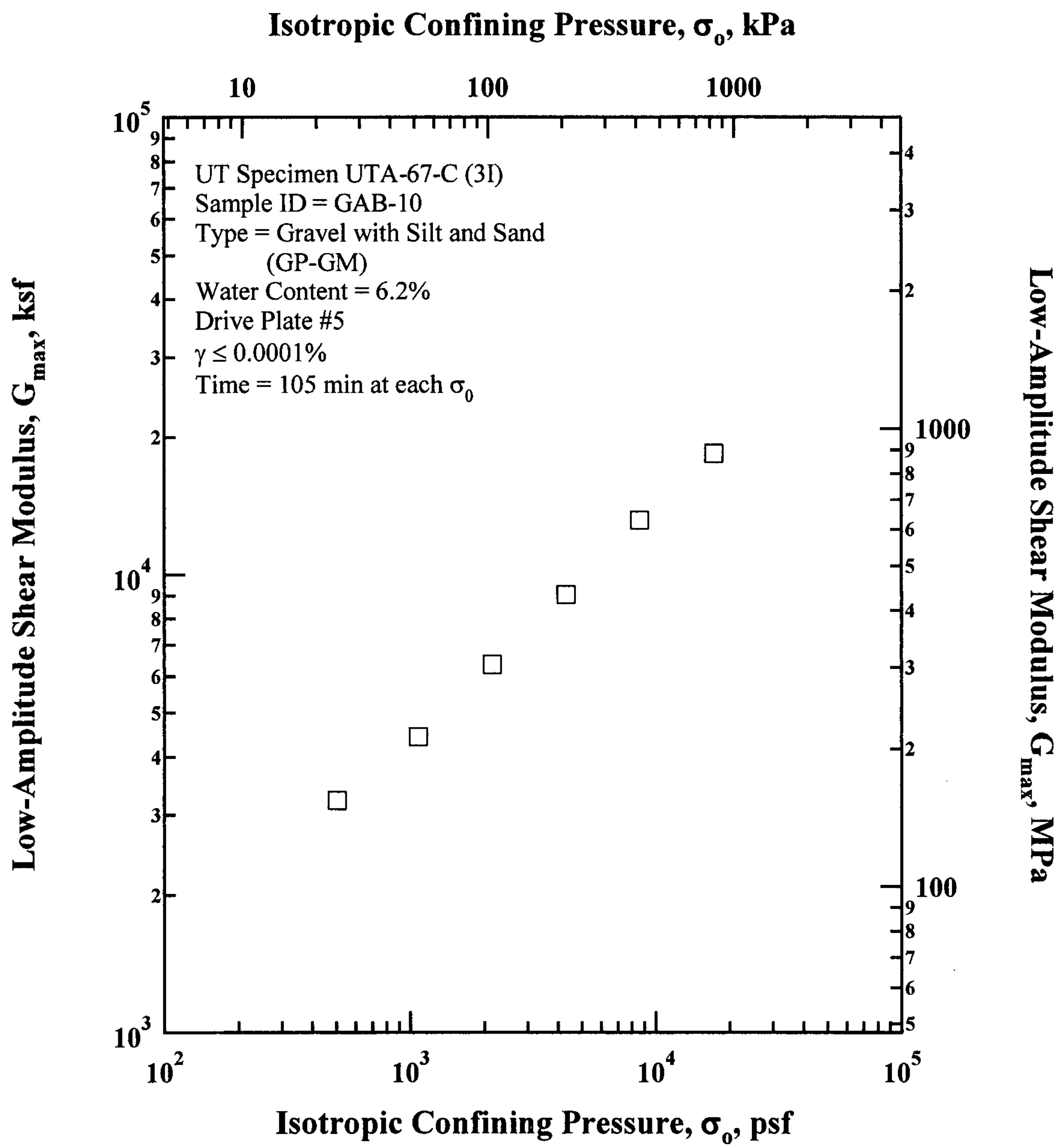


Figure G.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3I)

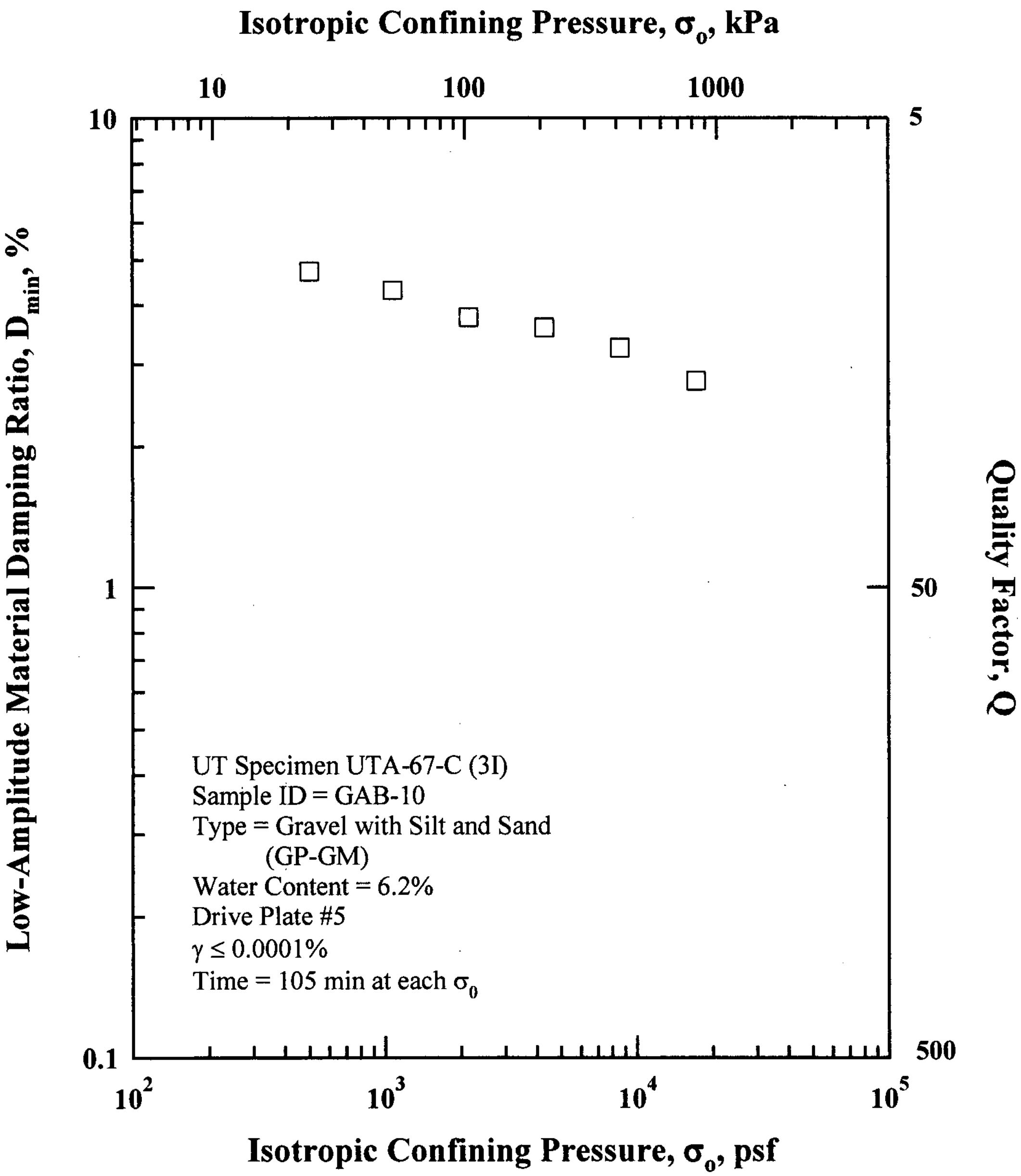


Figure G.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3I)

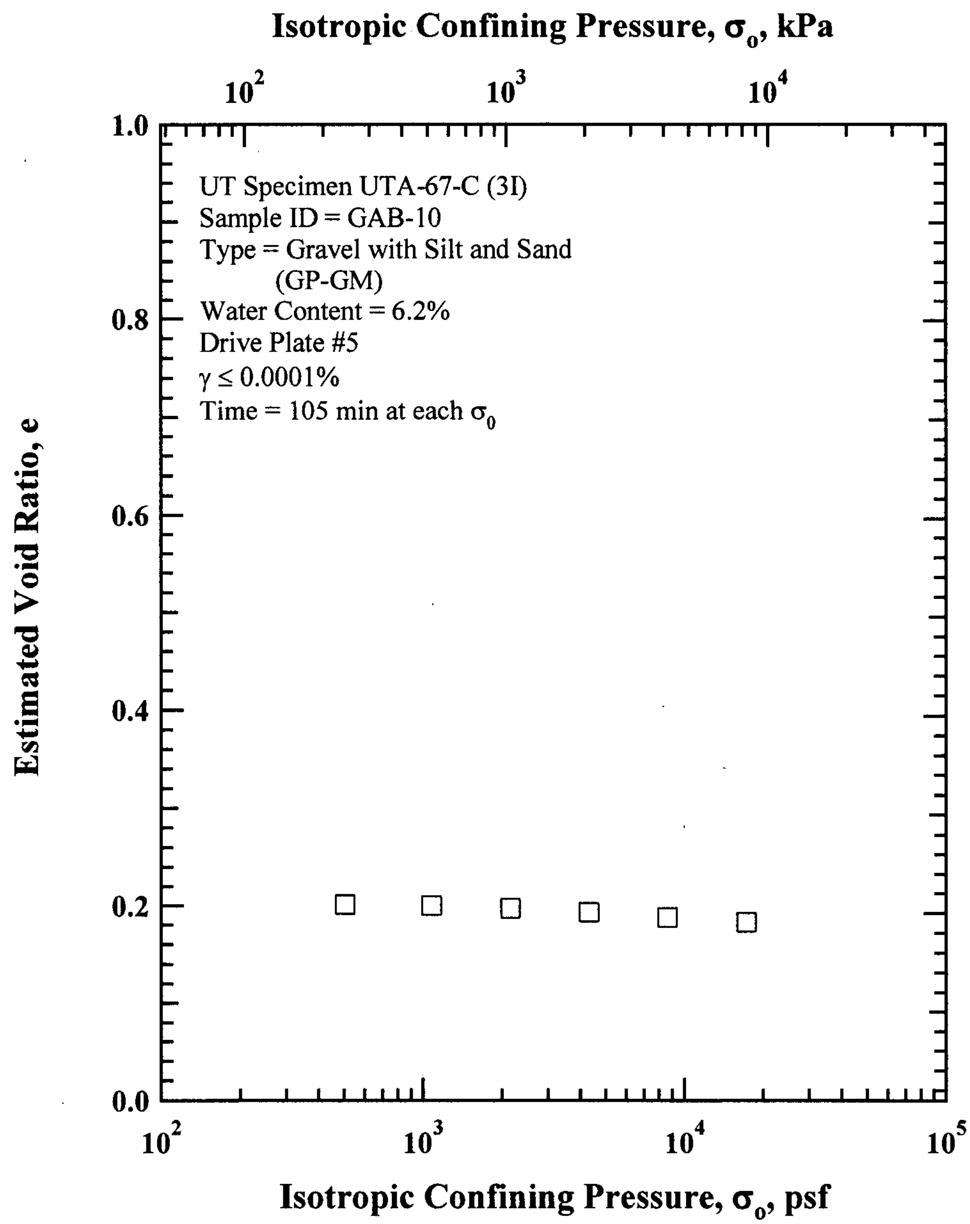


Figure G.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-C (3I)

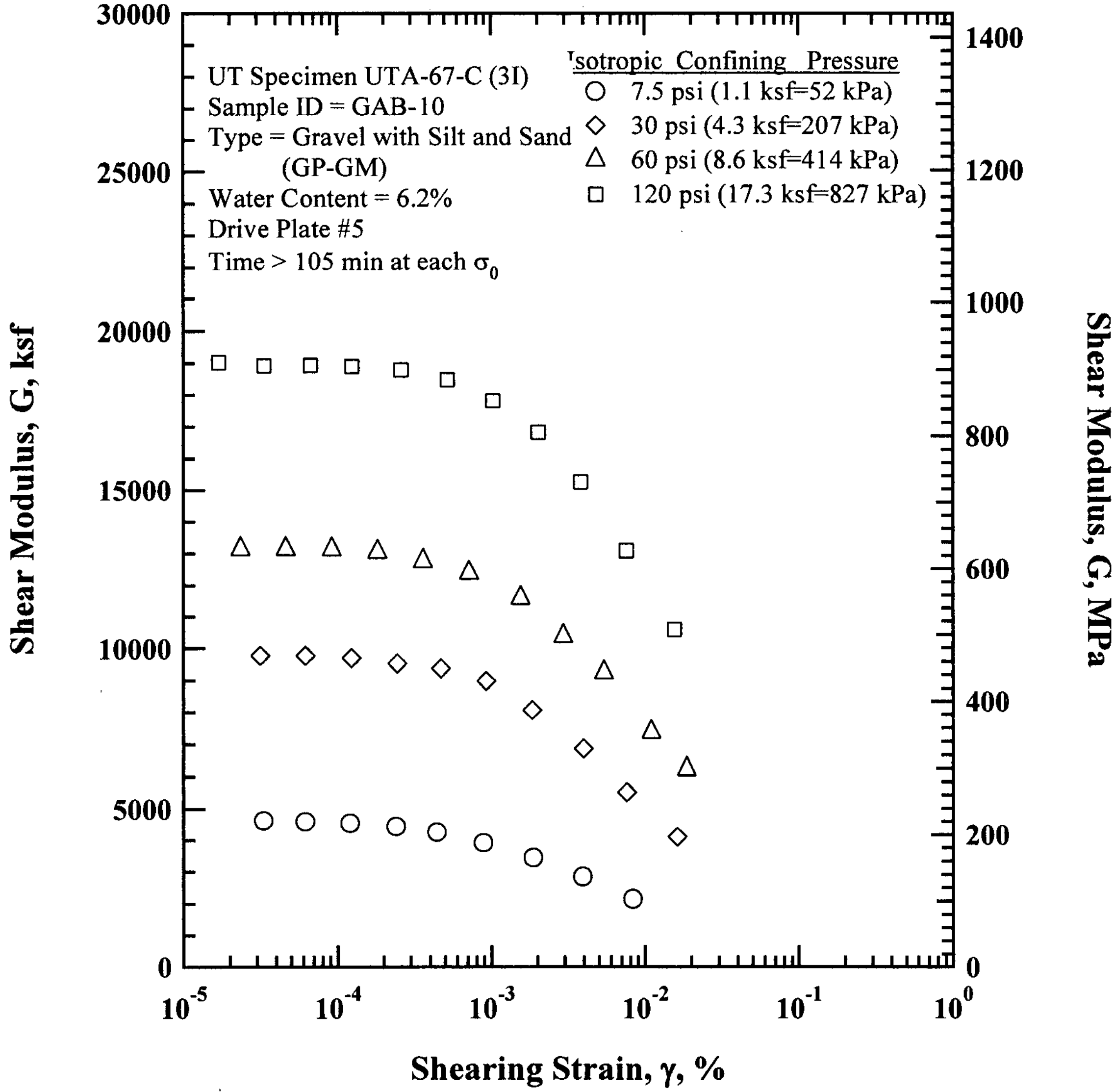


Figure G.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-C (3I)

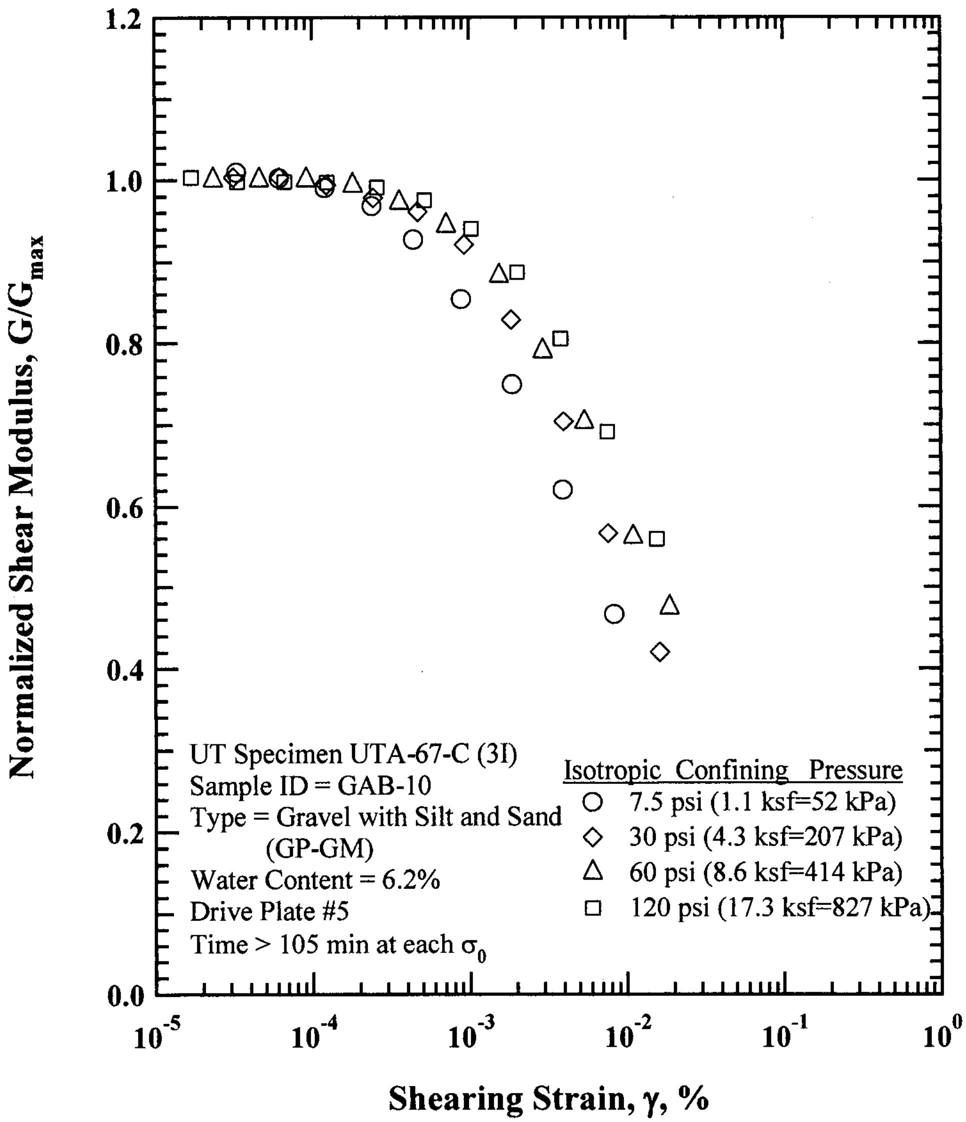


Figure G.9 Variation in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-C (3I)

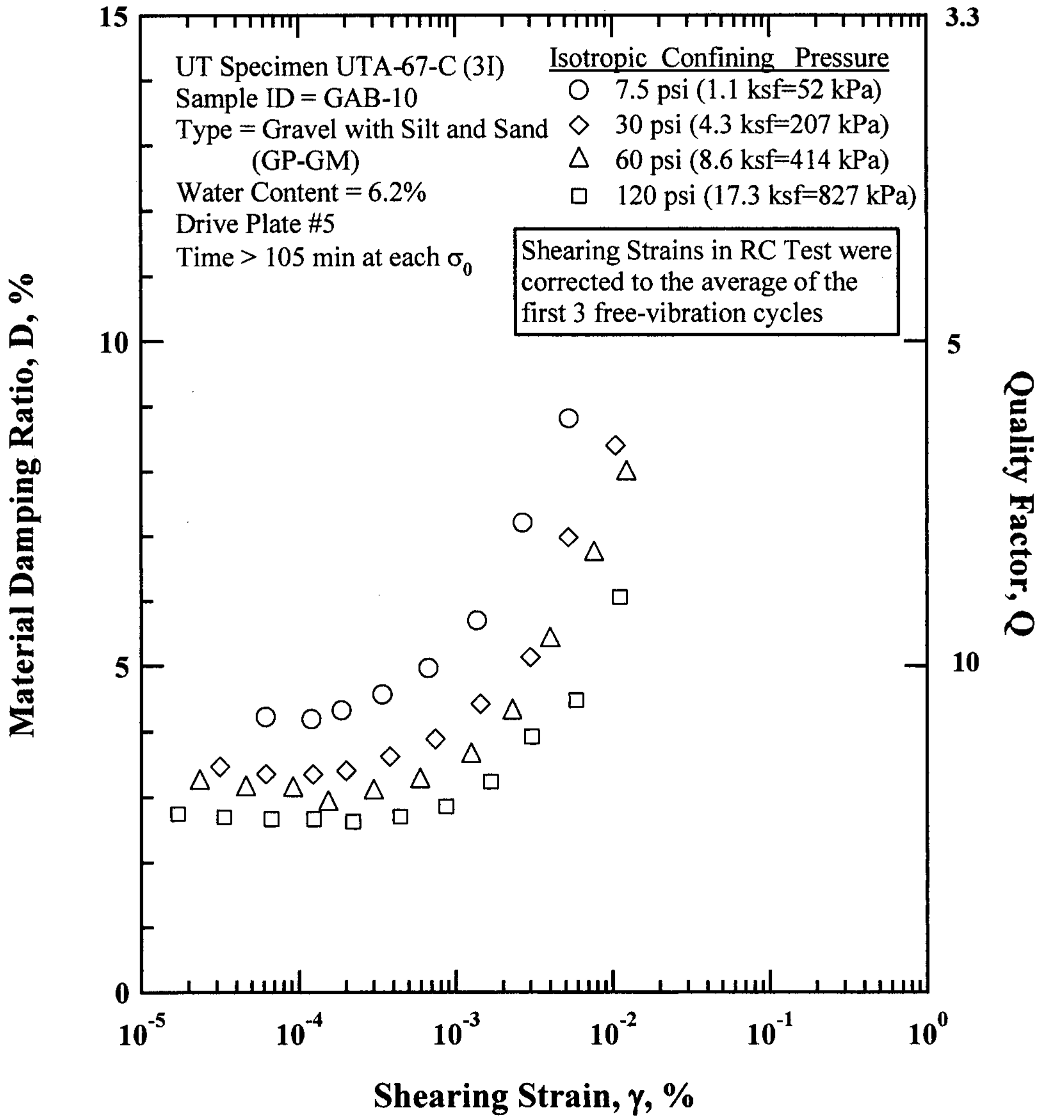


Figure G.10 Variation in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-C (3I)

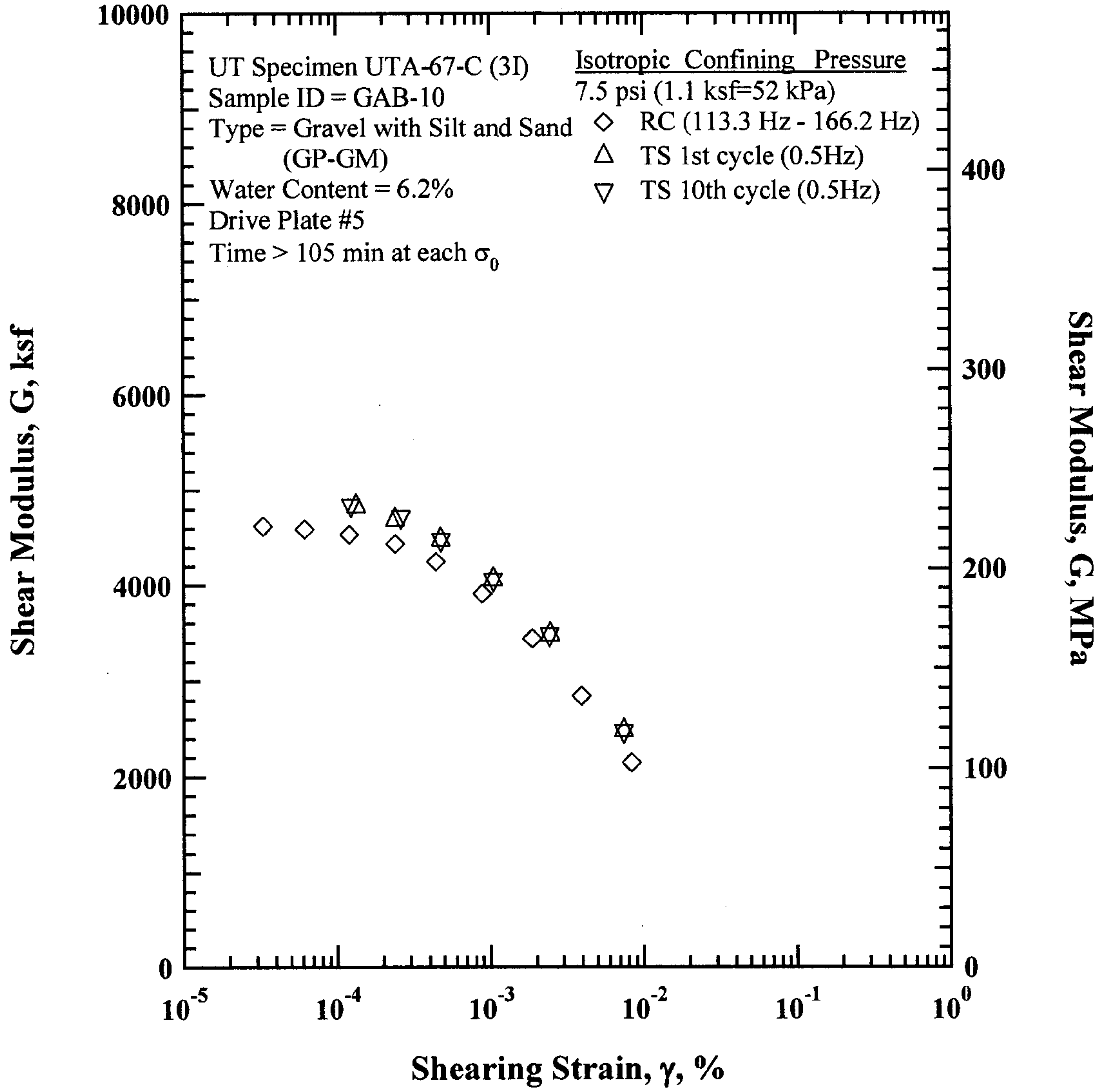


Figure G.11 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

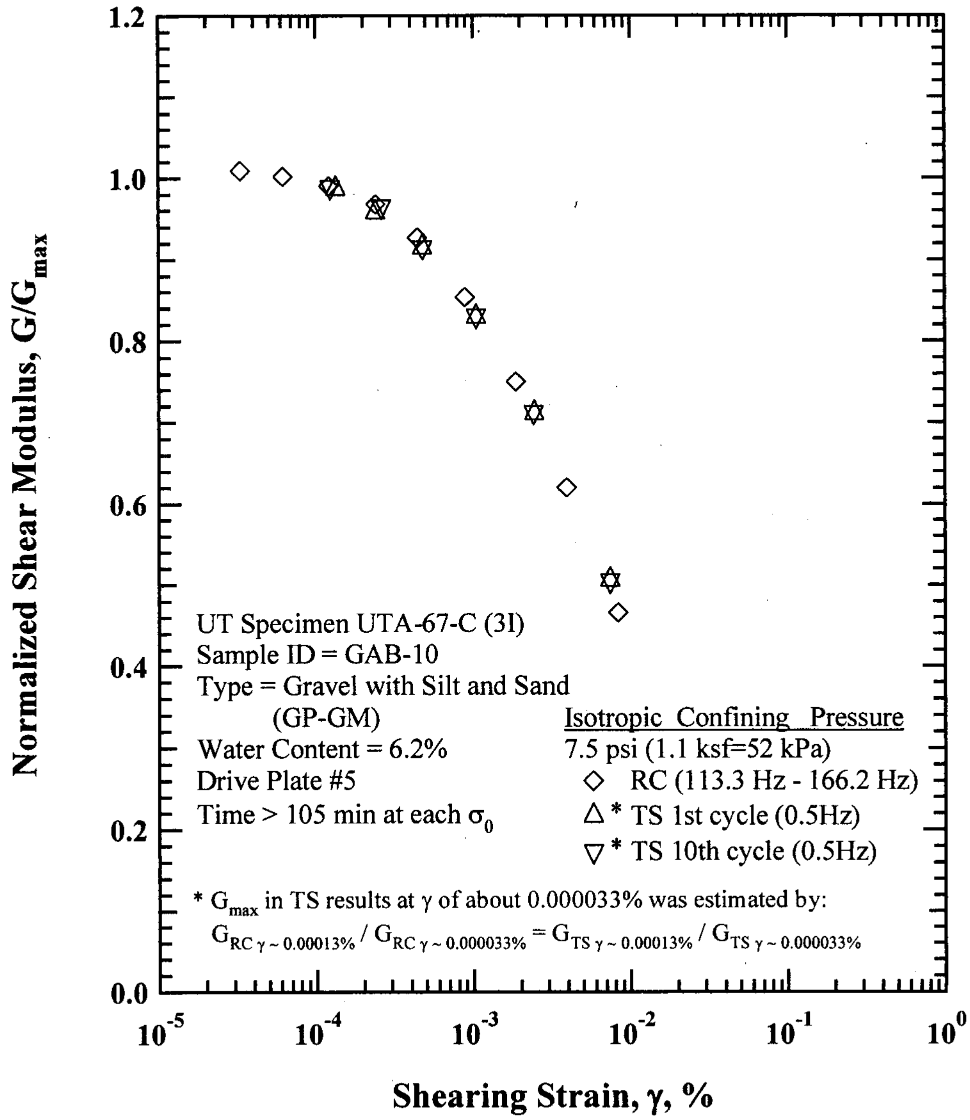


Figure G.12 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

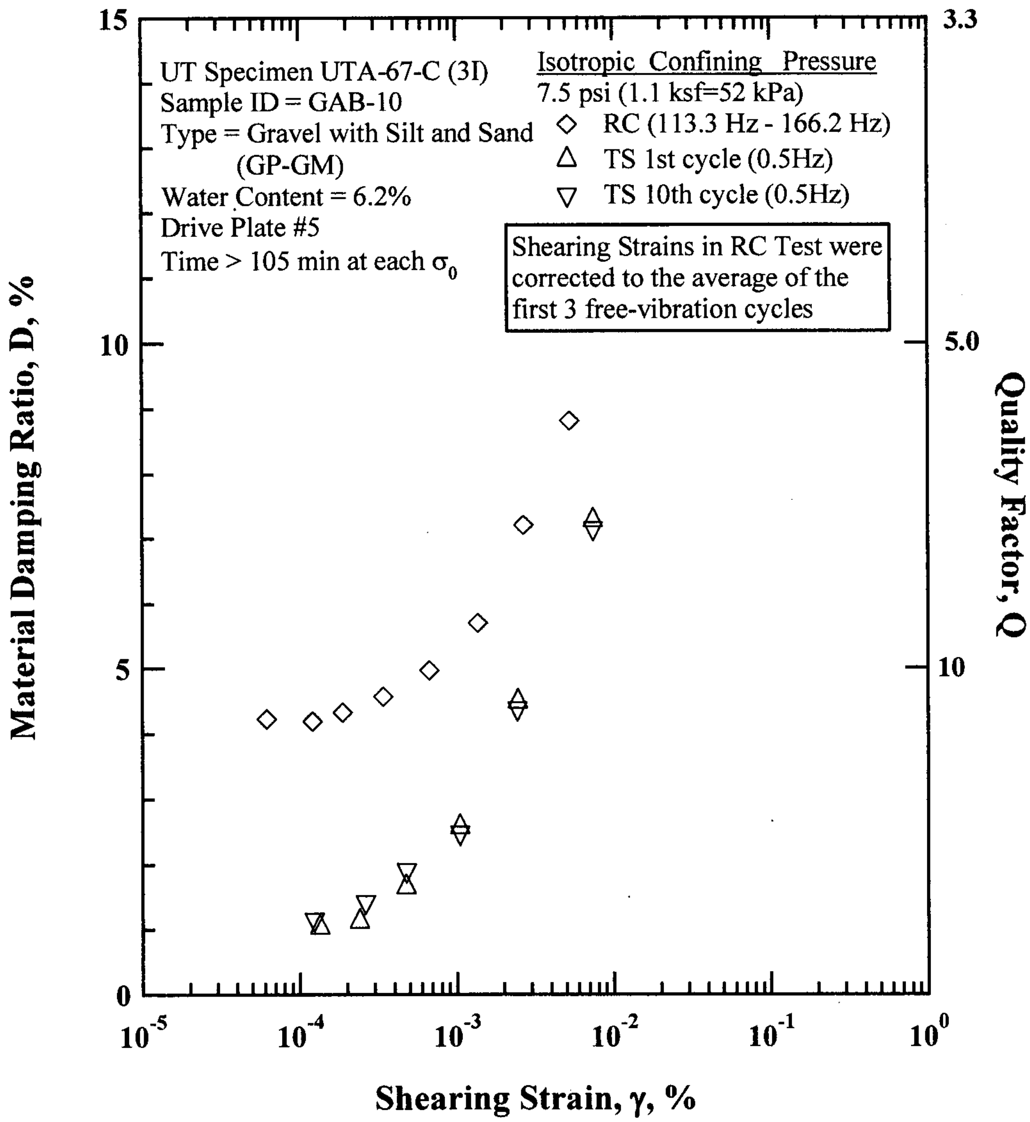


Figure G.13 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

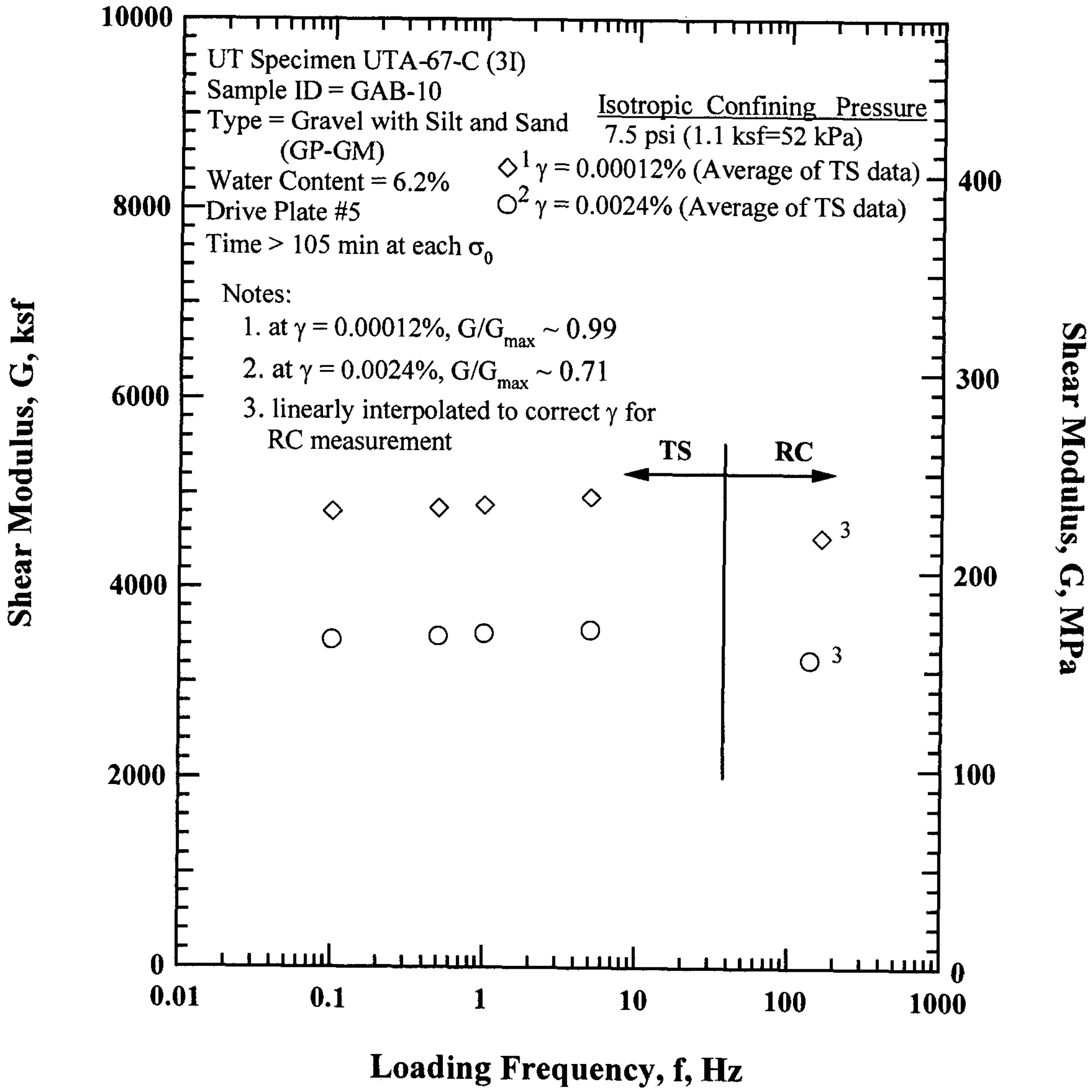


Figure G.14 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

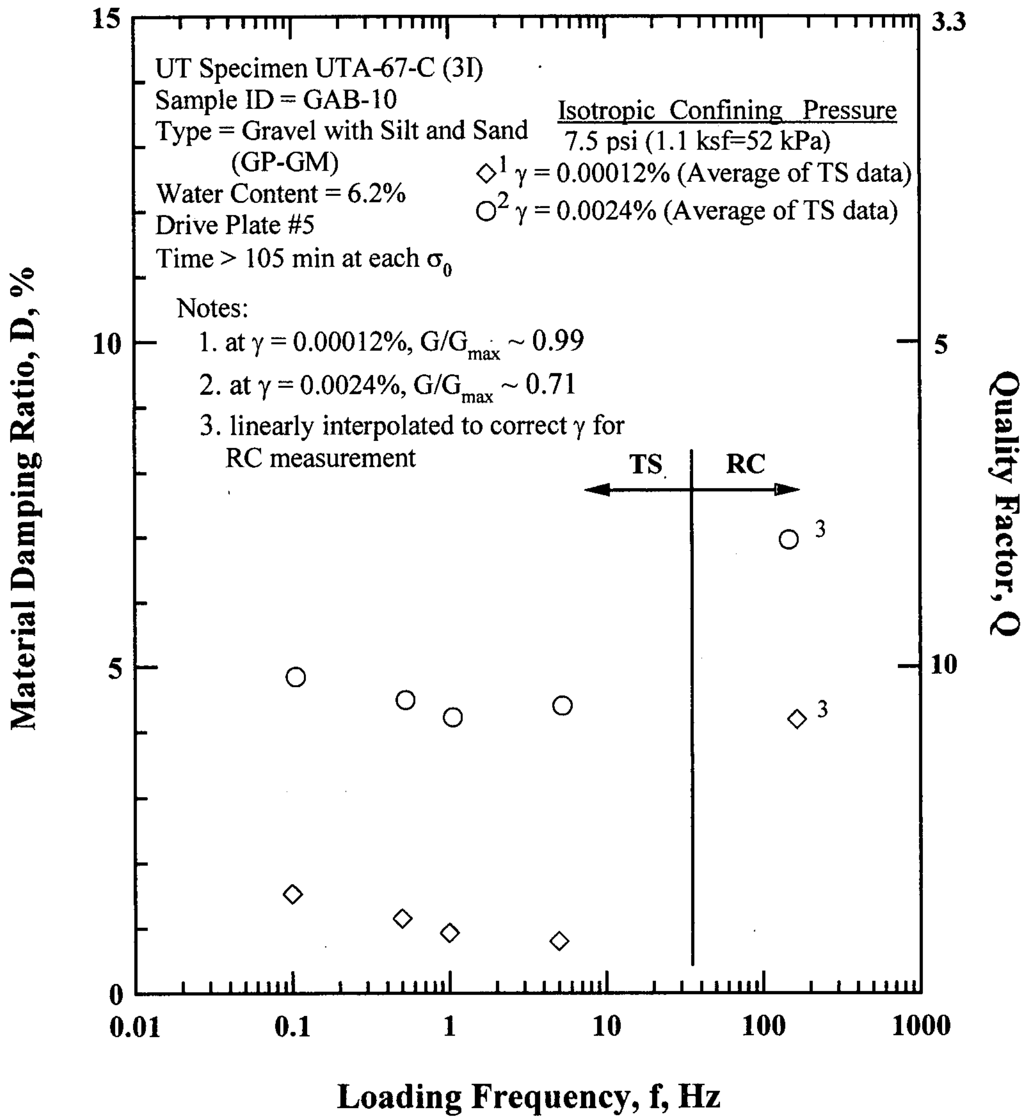


Figure G.15 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

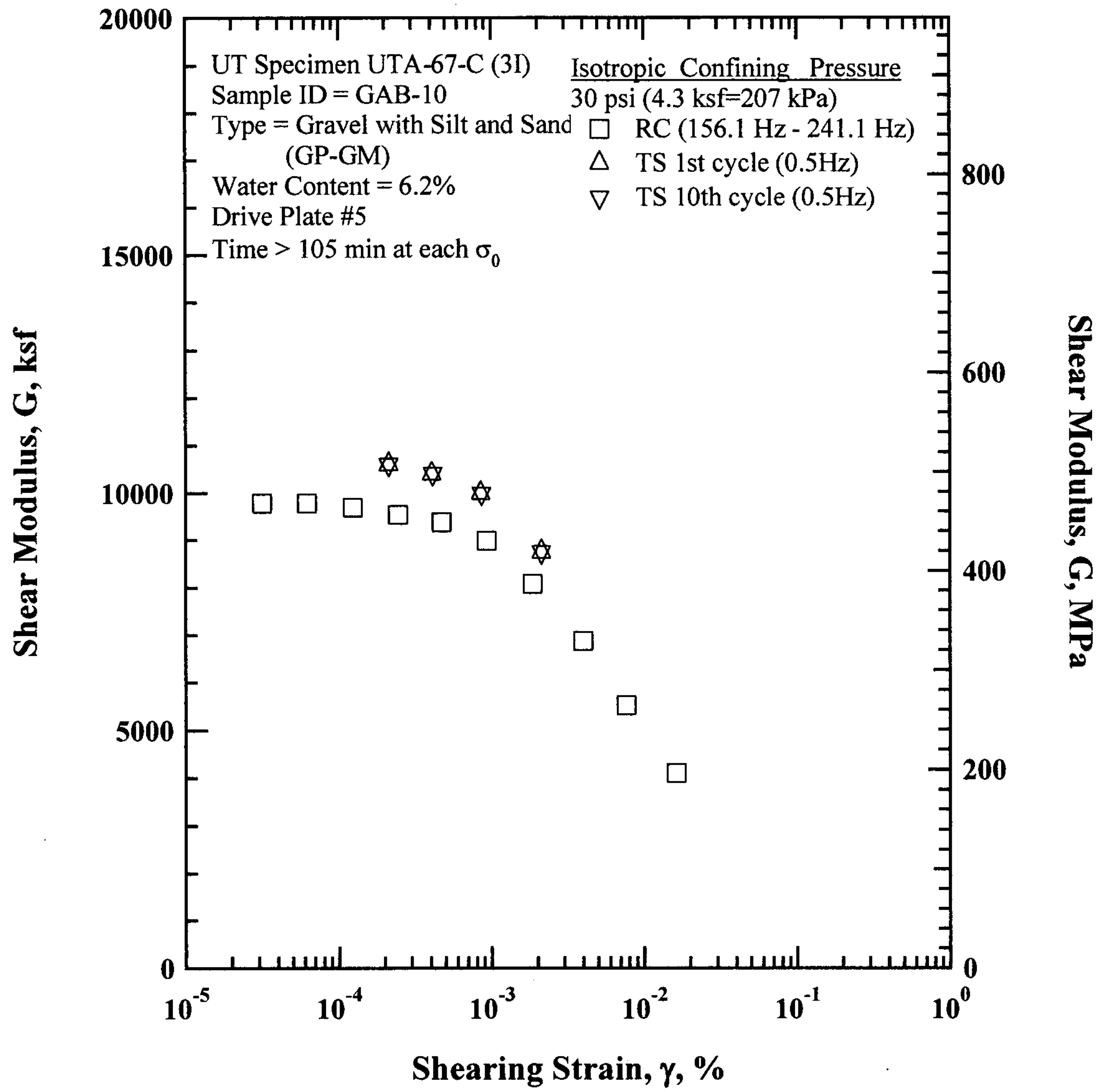


Figure G.16 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

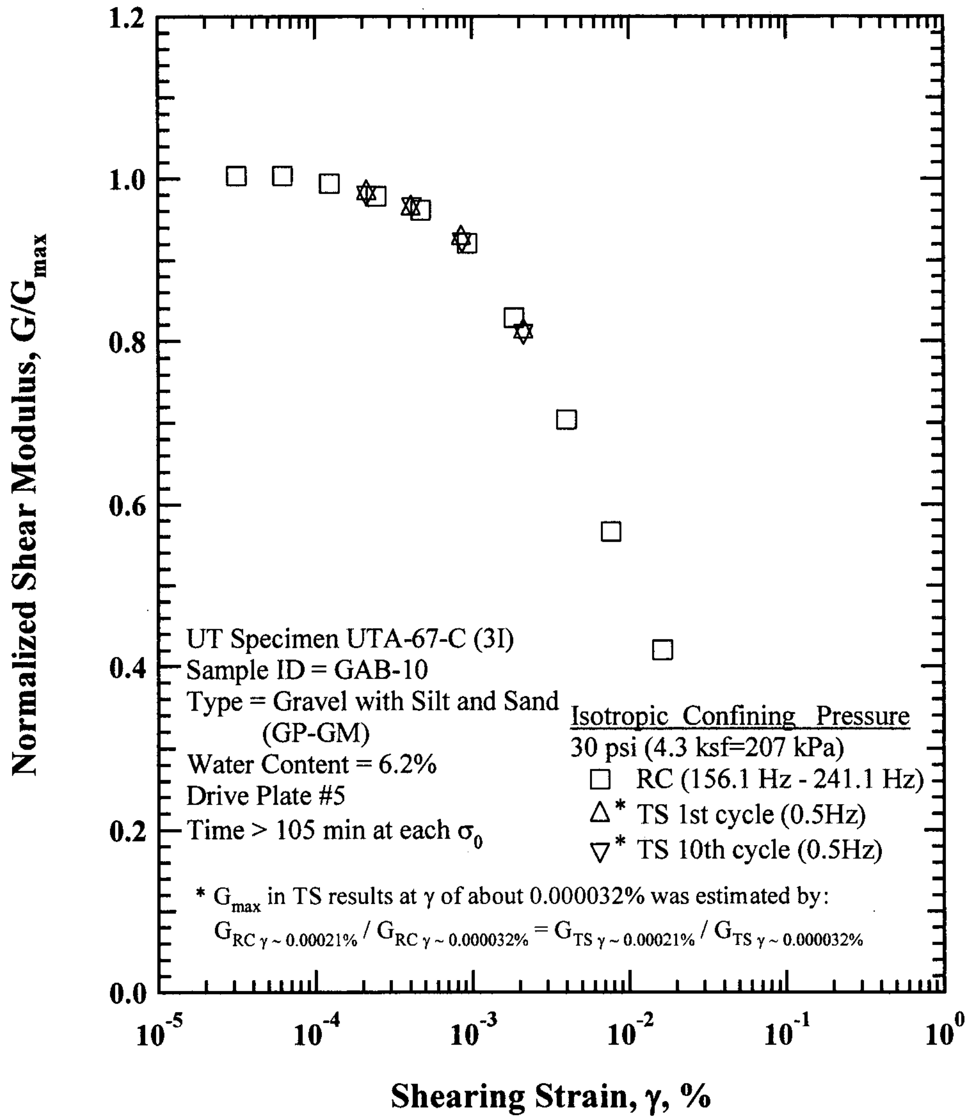


Figure G.17 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

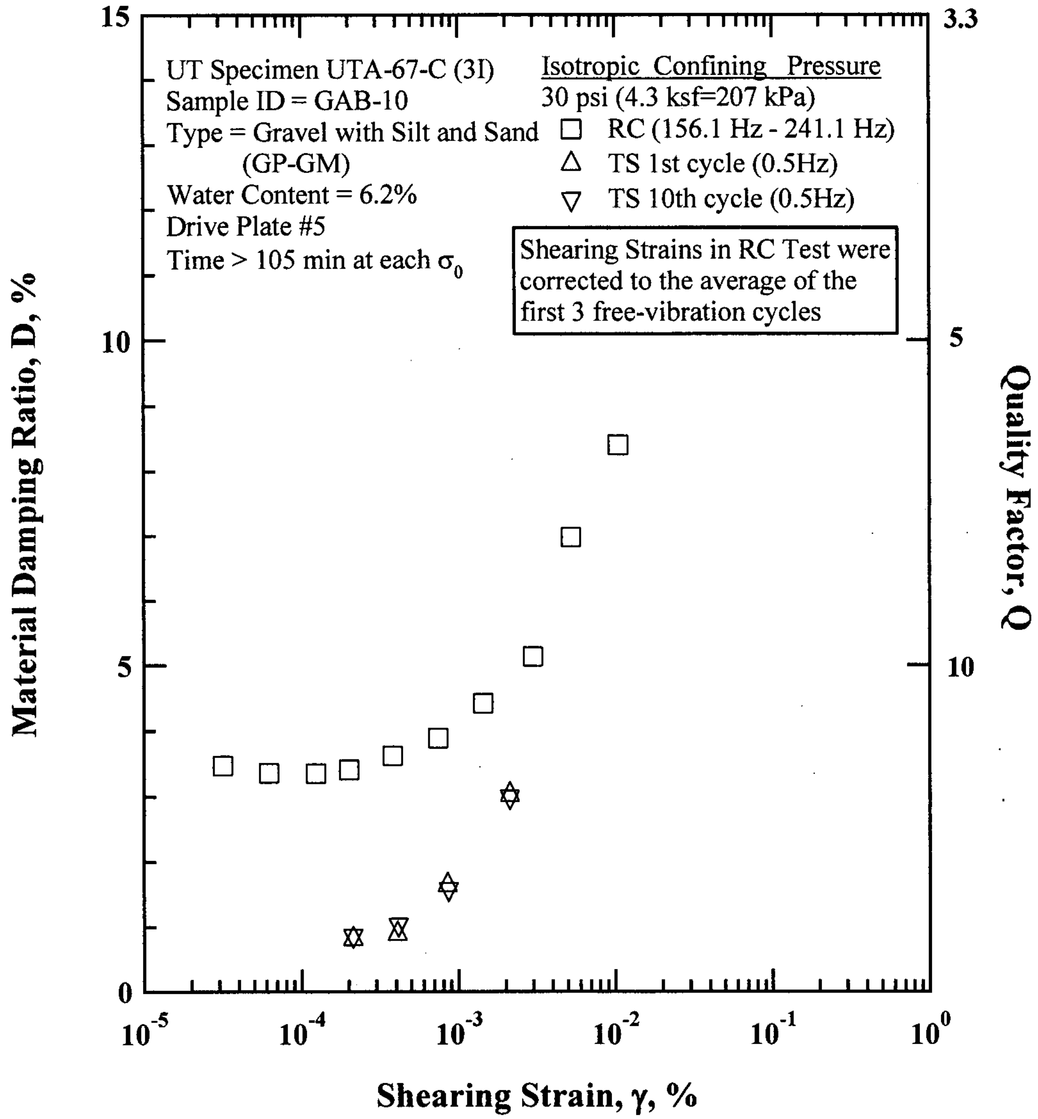


Figure G.18 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

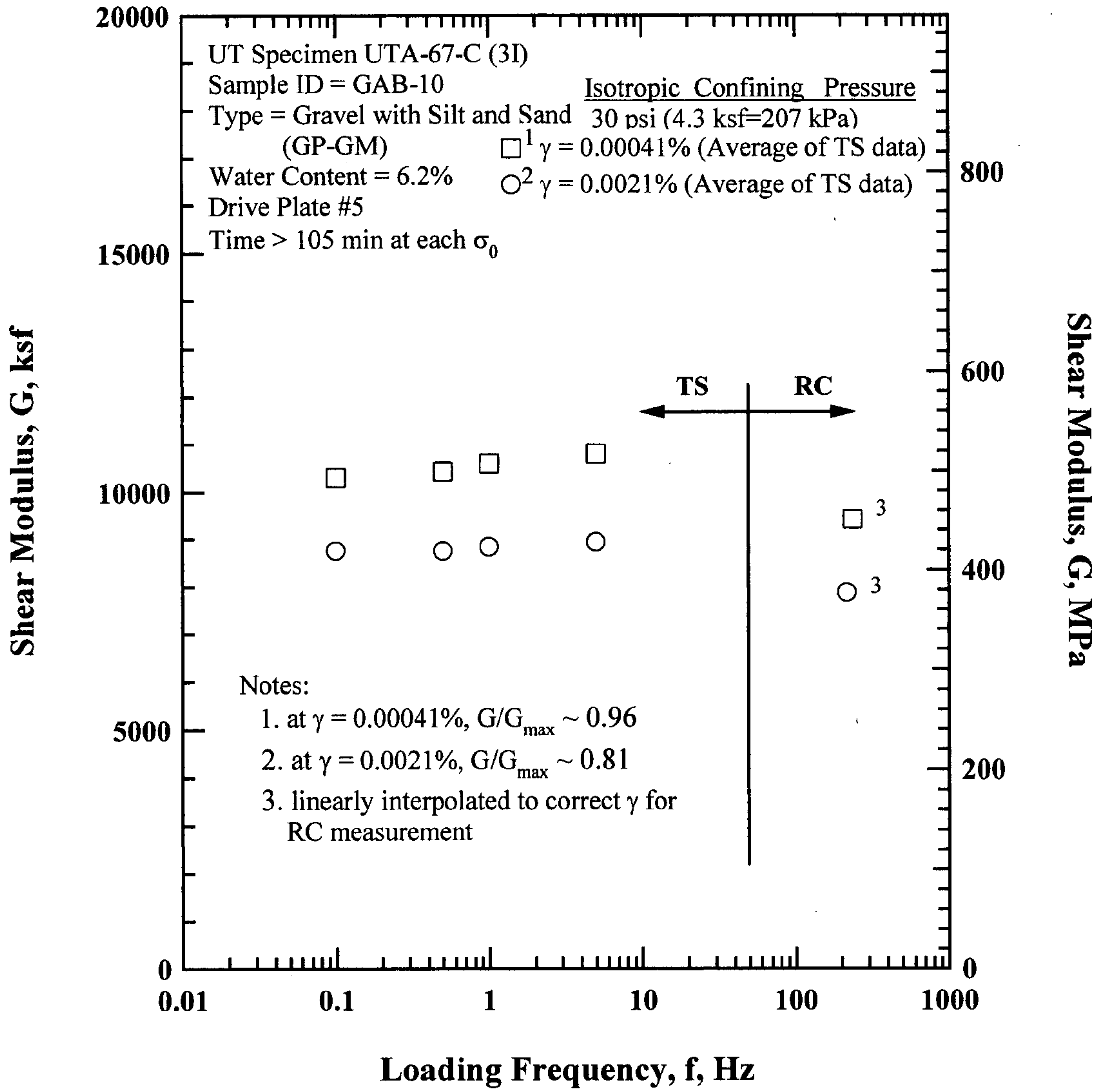


Figure G.19 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

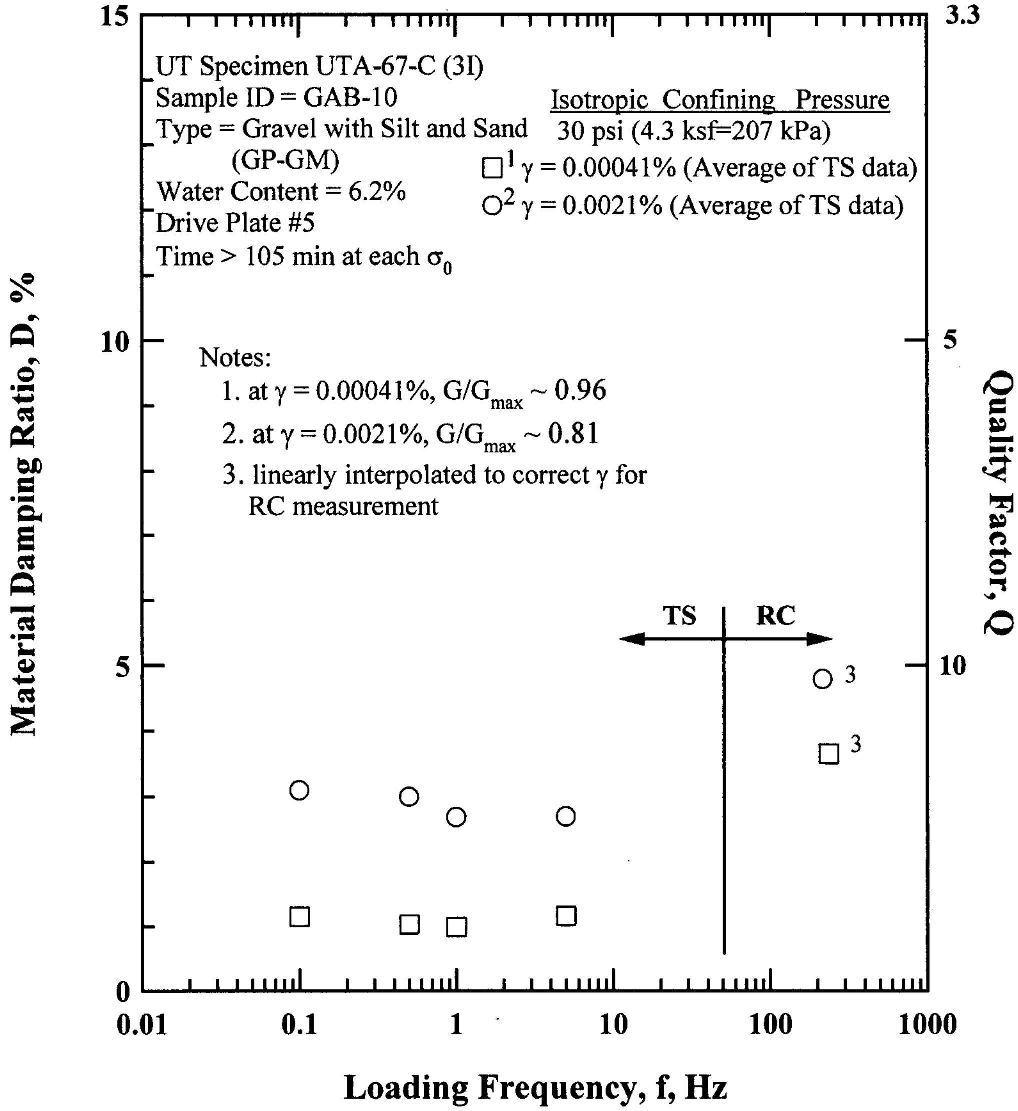


Figure G.20 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

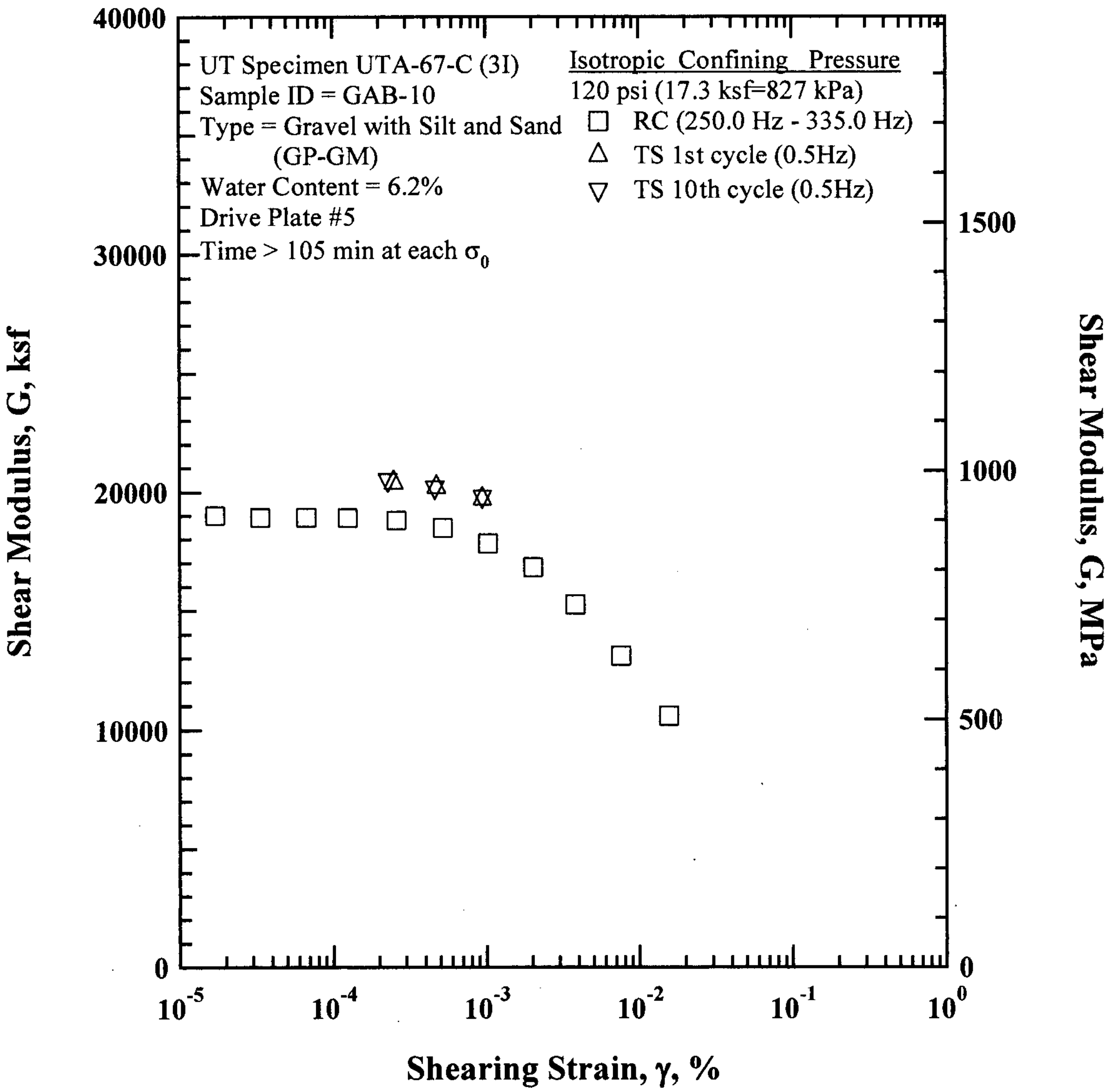


Figure G.21 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

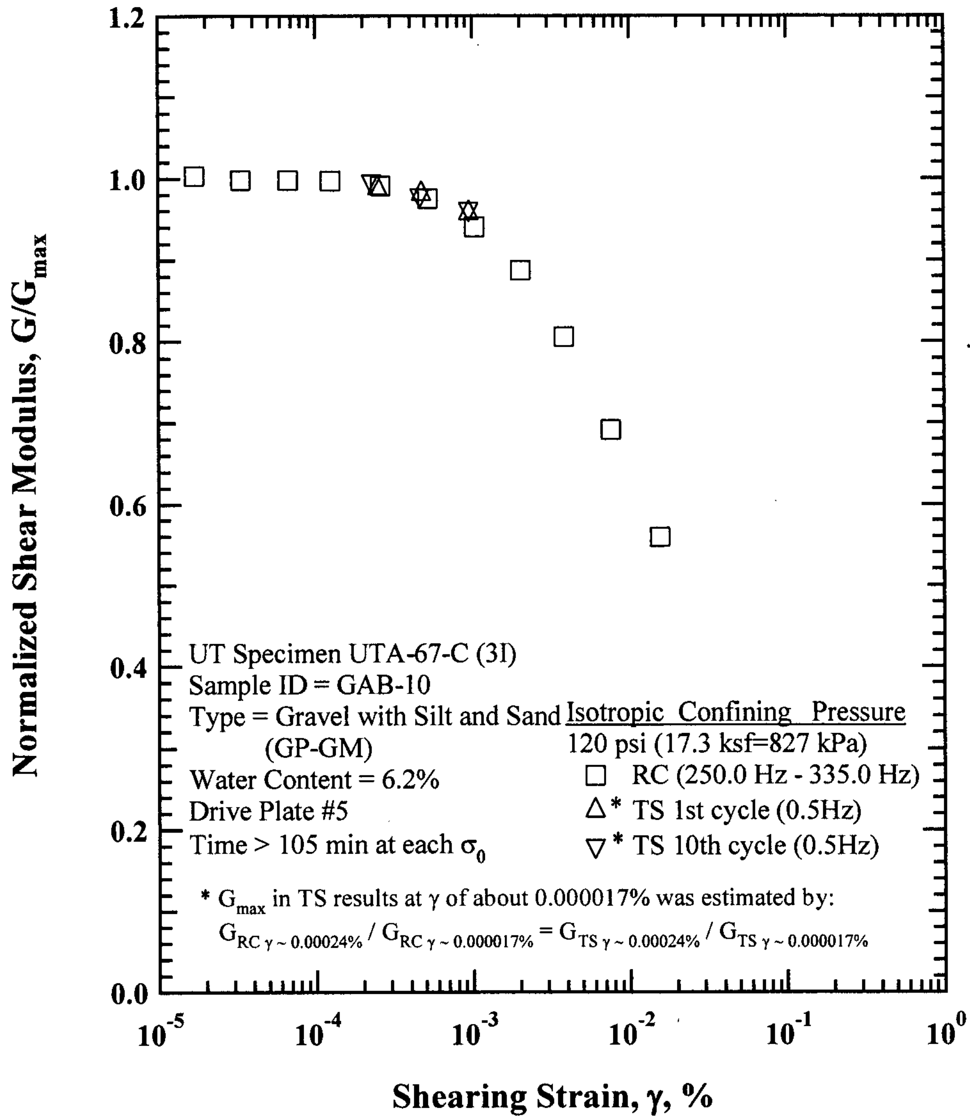


Figure G.22 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

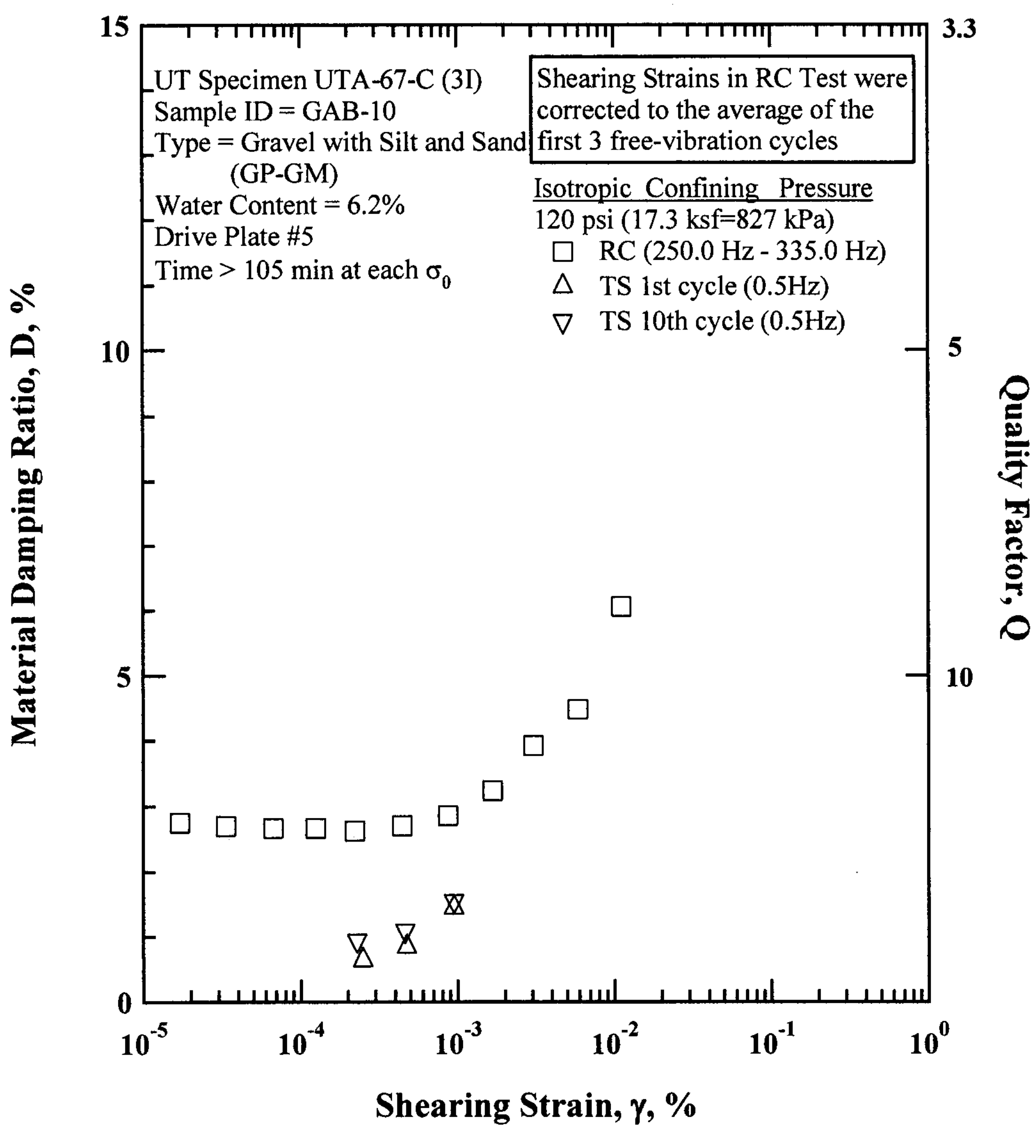


Figure G.23 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

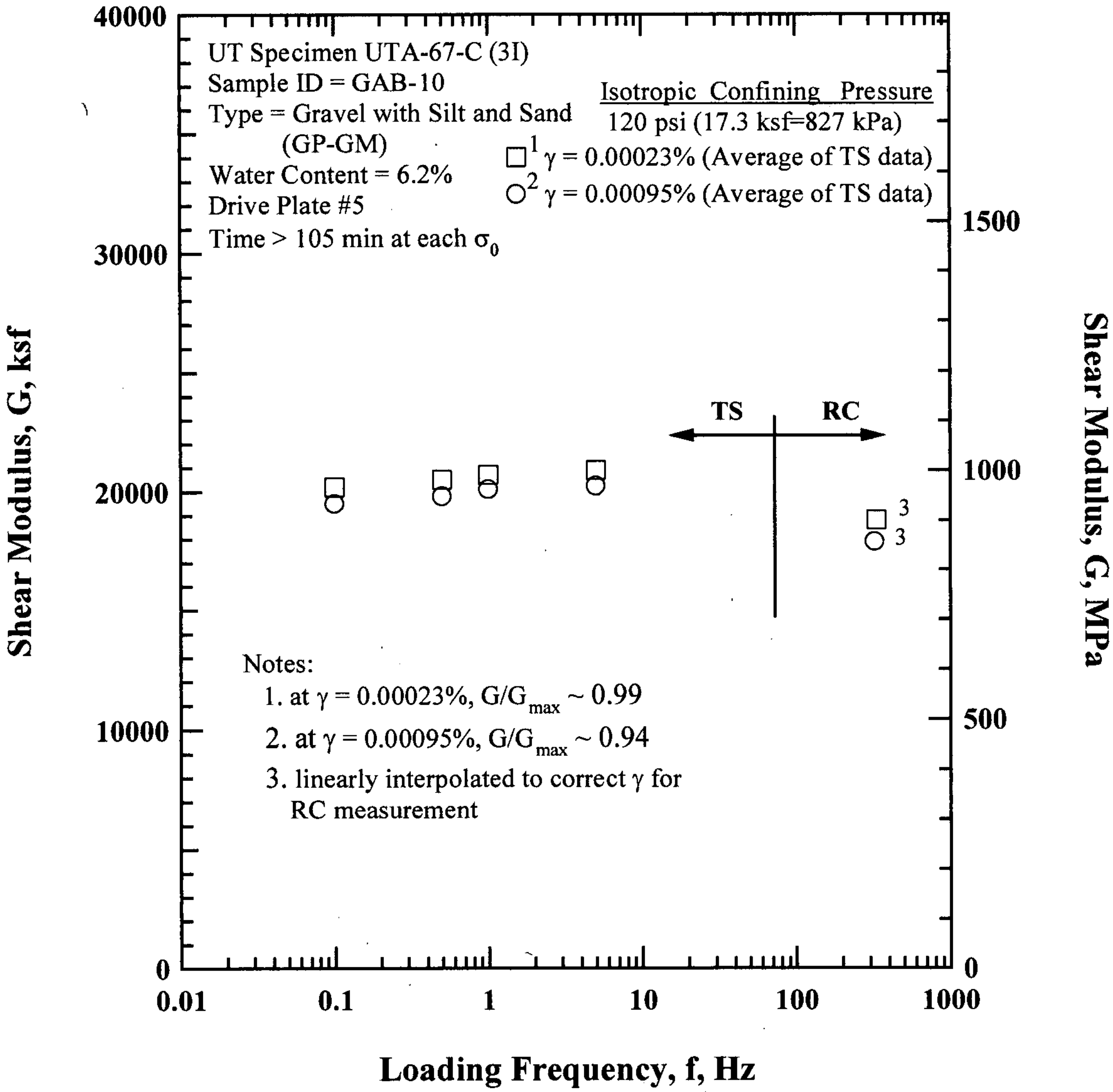


Figure G.24 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 30 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

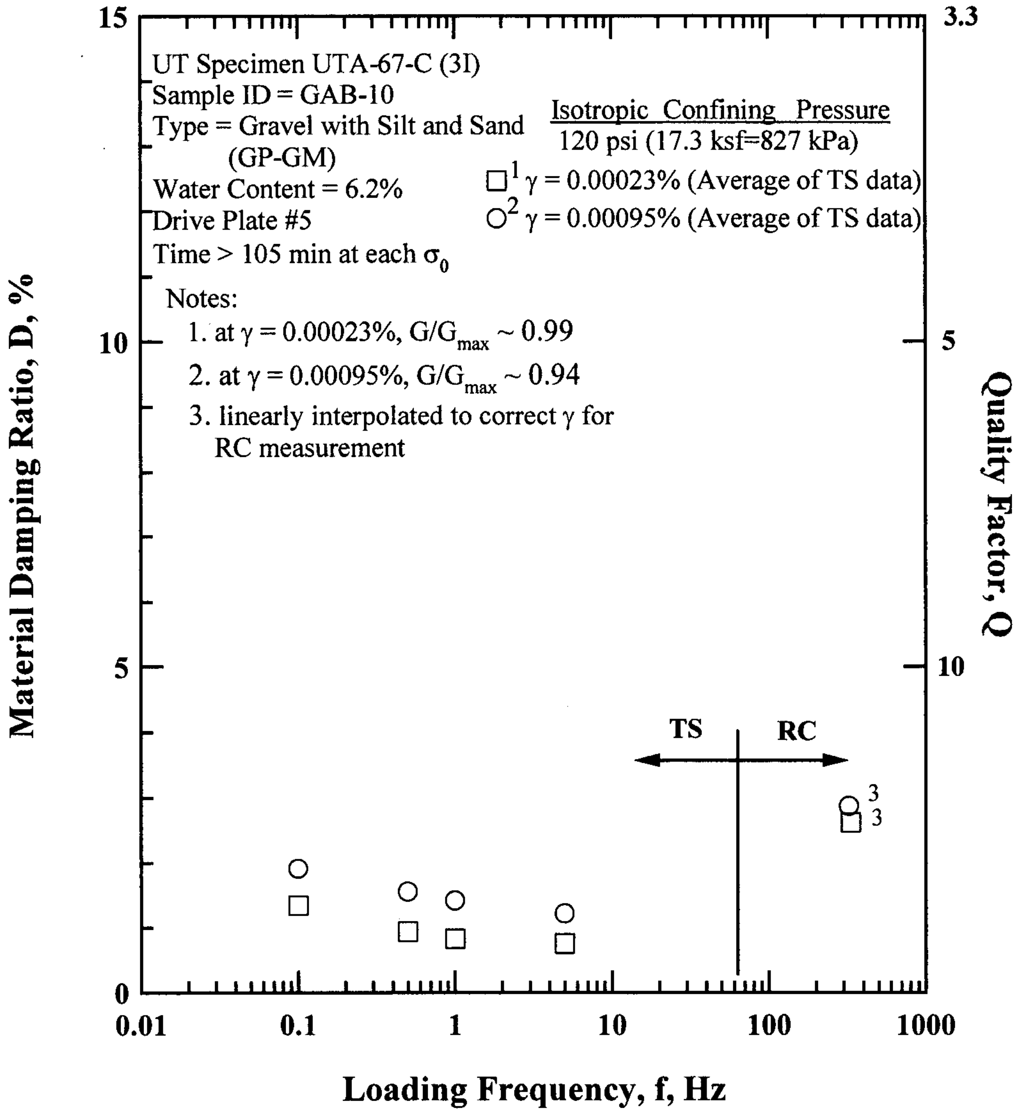


Figure G.25 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure 120 psi (17.3 ksf=827 kPa) from Combined RCTS Tests of Specimen UTA-67-C (3I)

Table G.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-C (3I)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_s	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.5	504	24	3230	154.9	817	4.72	0.20
7.5	1080	52	4429	212.3	956	4.30	0.20
15	2160	104	6354	304.6	1144	3.76	0.20
30	4320	207	9046	433.7	1364	3.58	0.19
60	8640	414	13135	629.7	1641	3.24	0.19
120	17280	828	18453	884.6	1943	2.76	0.18

Table G.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3I); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average$^+$ Shearing Strain, %	Material Damping Ratio^x, D, %
3.32E-05	4622	1.01	3.32E-05	-
6.19E-05	4589	1.00	6.19E-05	4.22
1.21E-04	4534	0.99	1.21E-04	4.19
2.41E-04	4435	0.97	1.88E-04	4.32
4.43E-04	4247	0.93	3.42E-04	4.57
8.89E-04	3907	0.85	6.72E-04	4.96
1.88E-03	3437	0.75	1.37E-03	5.70
3.95E-03	2842	0.62	2.68E-03	7.21
8.37E-03	2148	0.47	5.31E-03	8.81

$^+$ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

^{x} Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

$^-$ High Noise Level Interfering with Damping Measurement

Table G.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-C (3I); Isotropic Confining Pressure, σ_o =7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.34E-04	4830	0.99	1.03	1.24E-04	4840	0.99	1.15
2.40E-04	4690	0.96	1.12	2.62E-04	4720	0.96	1.42
4.76E-04	4480	0.92	1.65	4.78E-04	4480	0.92	1.91
1.05E-03	4057	0.83	2.57	1.05E-03	4062	0.83	2.48
2.46E-03	3480	0.71	4.49	2.44E-03	3482	0.71	4.38
7.43E-03	2475	0.51	7.28	7.44E-03	2472	0.51	7.15

Table G.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3I); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
3.16E-05	9776	1.00	3.16E-05	3.47
6.21E-05	9776	1.00	6.21E-05	3.35
1.24E-04	9694	0.99	1.24E-04	3.35
2.46E-04	9533	0.98	2.01E-04	3.40
4.71E-04	9373	0.96	3.82E-04	3.62
9.29E-04	8981	0.92	7.42E-04	3.89
1.86E-03	8073	0.83	1.44E-03	4.42
4.00E-03	6868	0.70	3.00E-03	5.13
7.64E-03	5515	0.57	5.24E-03	6.98
1.63E-02	4098	0.42	1.05E-02	8.39

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table G.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-C (3I); Isotropic Confining Pressure, σ_o =30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
2.13E-04	10590	0.98	0.81	2.13E-04	10590	0.98	0.86
4.08E-04	10390	0.96	0.89	4.14E-04	10440	0.97	1.03
8.53E-04	9994	0.93	1.64	8.65E-04	9977	0.93	1.58
2.13E-03	8749	0.81	3.02	2.13E-03	8742	0.81	2.99

Table G.6 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3I); Isotropic Confining Pressure, σ_o =60 psi (8.6 ksf=414 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average+ Shearing Strain, %	Material Damping Ratio^x, D, %
2.35E-05	13136	1.00	2.35E-05	3.23
4.62E-05	13137	1.00	4.62E-05	3.13
9.21E-05	13135	1.00	9.21E-05	3.12
1.83E-04	13044	0.99	1.54E-04	2.90
3.60E-04	12762	0.97	3.00E-04	3.07
7.18E-04	12394	0.94	5.94E-04	3.24
1.55E-03	11584	0.88	1.26E-03	3.63
2.94E-03	10379	0.79	2.30E-03	4.29
5.43E-03	9240	0.70	4.02E-03	5.39
1.10E-02	7371	0.56	7.66E-03	6.71
1.87E-02	6223	0.47	1.23E-02	7.96

+ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

x Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table G.7 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-C (3I); Isotropic Confining Pressure, σ_o =120 psi (17.3 ksf=827 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average+ Shearing Strain, %	Material Damping Ratio^x, D, %
1.70E-05	19012	1.00	1.70E-05	2.75
3.35E-05	18916	1.00	3.35E-05	2.70
6.71E-05	18919	1.00	6.71E-05	2.66
1.25E-04	18900	1.00	1.25E-04	2.66
2.60E-04	18785	0.99	2.22E-04	2.63
5.20E-04	18467	0.97	4.43E-04	2.70
1.03E-03	17806	0.94	8.69E-04	2.85
2.02E-03	16812	0.89	1.67E-03	3.24
3.83E-03	15249	0.80	3.05E-03	3.92
7.59E-03	13096	0.69	5.88E-03	4.48
1.56E-02	10592	0.56	1.12E-02	6.06

+ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

x Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table G.8 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-C (3I); Isotropic Confining Pressure, σ_o =120 psi (17.3 ksf=827 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
2.50E-04	20350	0.99	0.64	2.29E-04	20500	1.00	0.94
4.74E-04	20200	0.98	0.84	4.63E-04	20160	0.98	1.09
9.48E-04	19700	0.96	1.45	9.49E-04	19800	0.96	1.55

APPENDIX H

UT Specimen UTA-67-B (2I)
Sample ID : 57-8
Type = Scalped, Reconstituted Gravel (GP*)

Water Content, w = 0.8 %

G_S = 2.833*

Degree of Saturation = 3.2%

Total Unit Weight, γ_t = 104.7 lb/ft^3

Dry Unit Weight, γ_d = 103.9 lb/ft^3

Target : γ_d = 102.1 lb/ft^3 ± 2 lb/ft^3

w = 1.0% ± 1.0%

*** Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

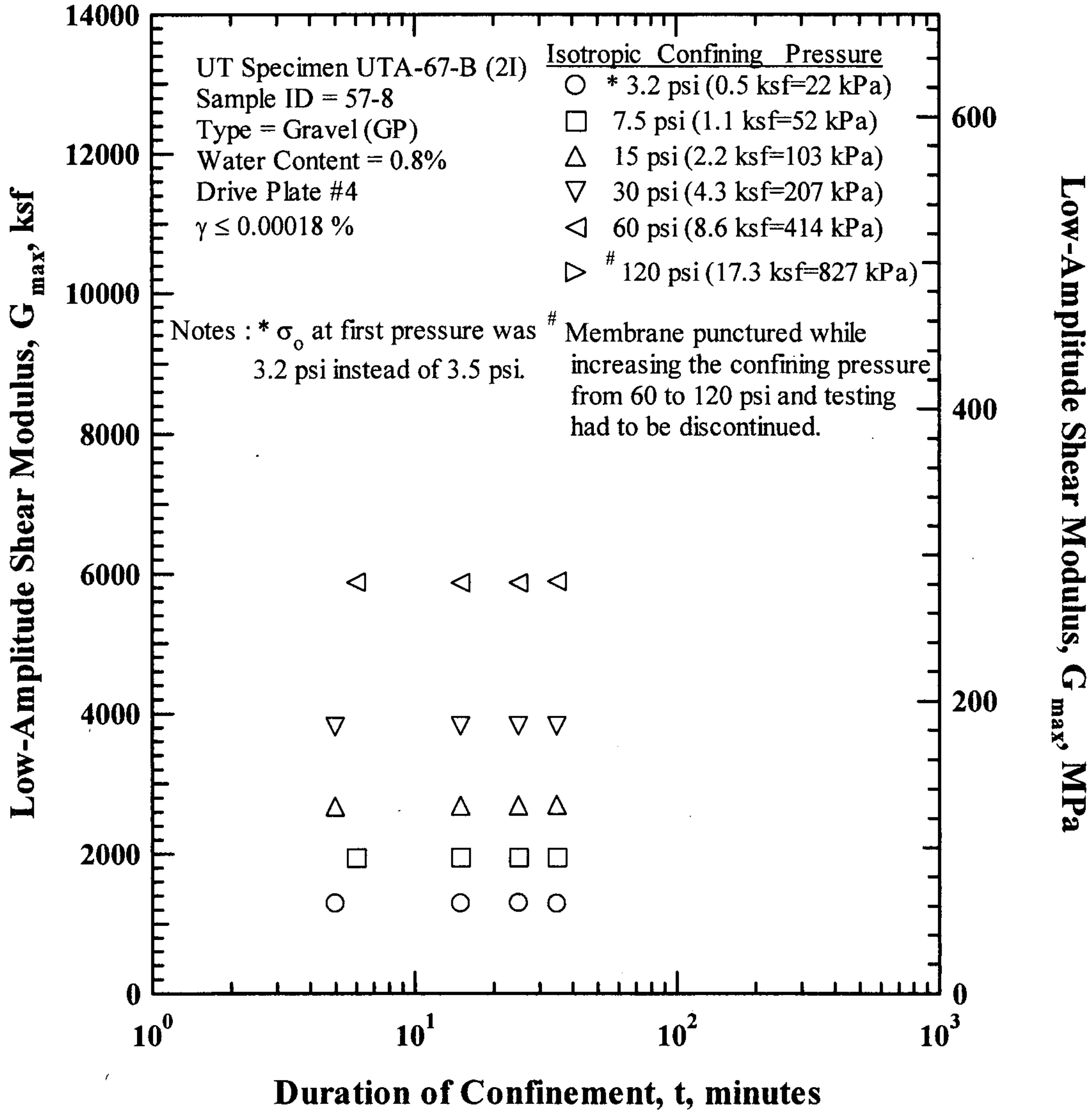


Figure H.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2I)

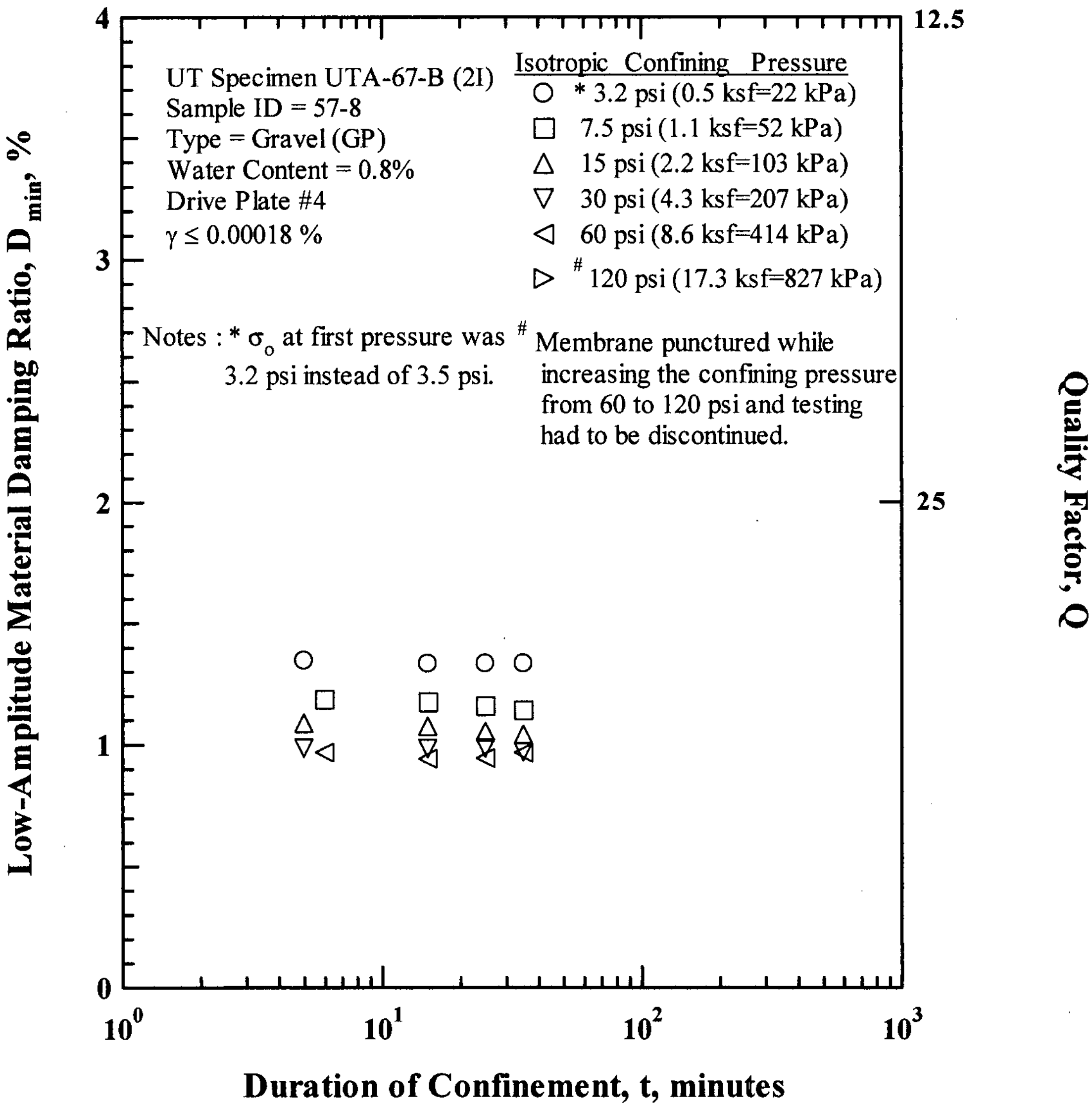


Figure H.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2I)

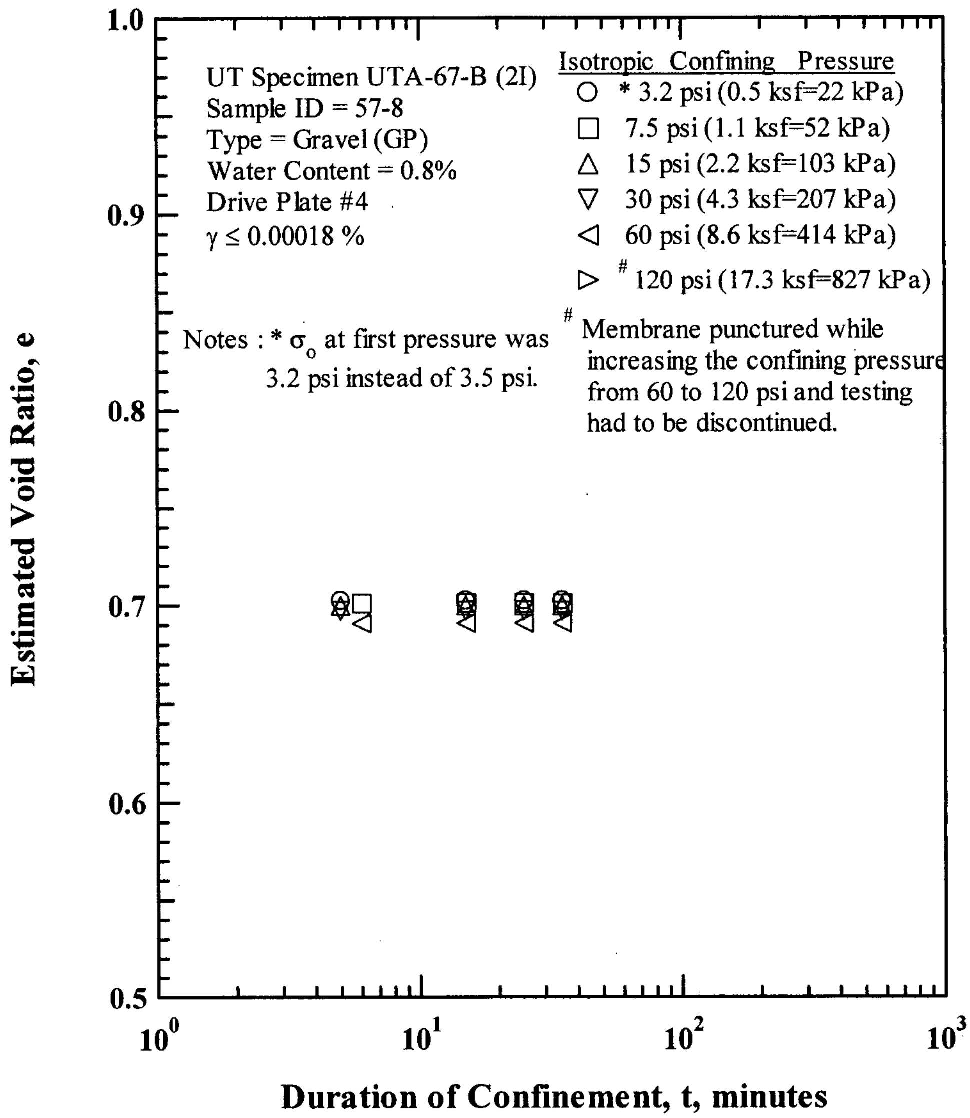


Figure H.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2I)

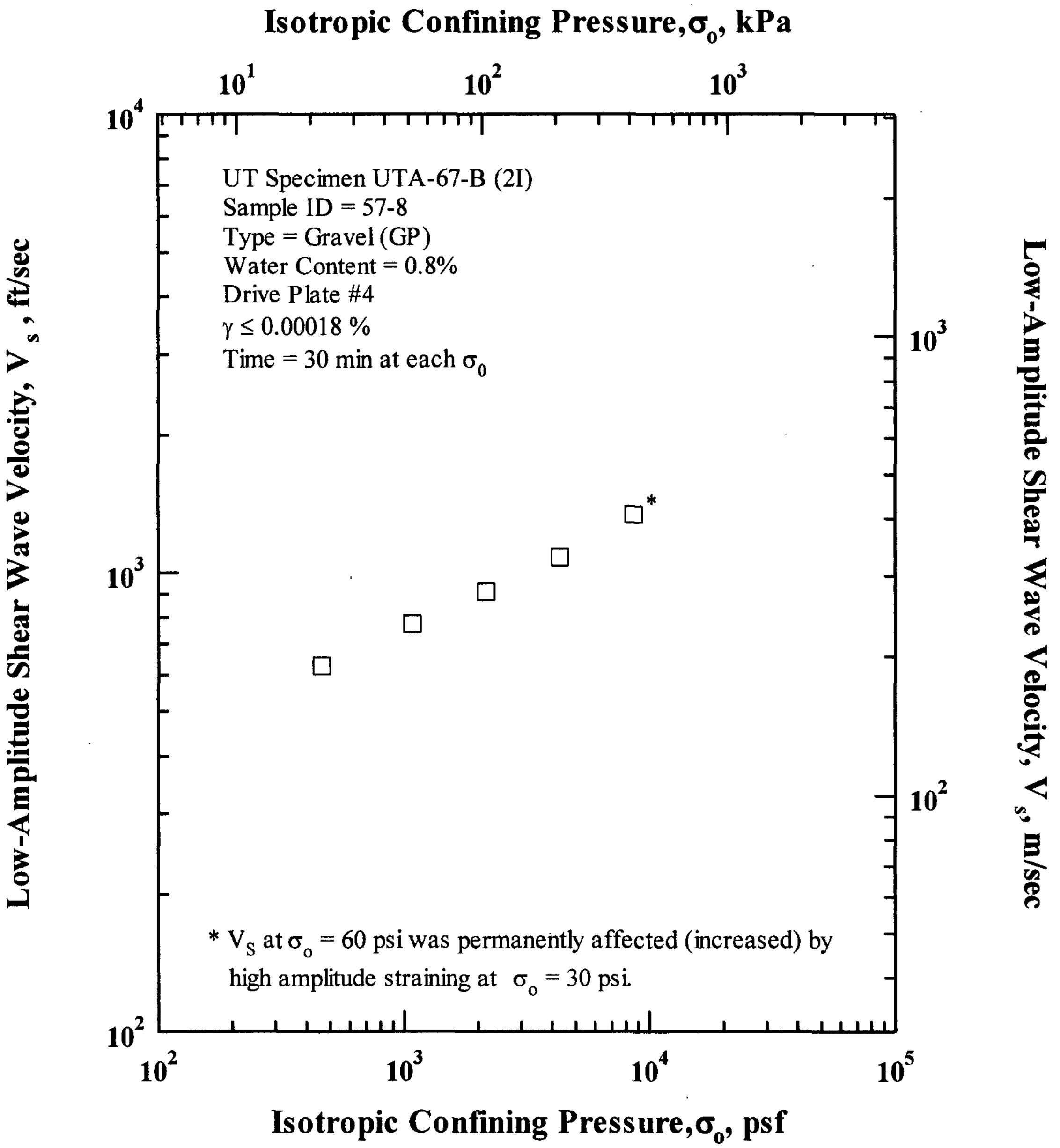


Figure H.4 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2I)

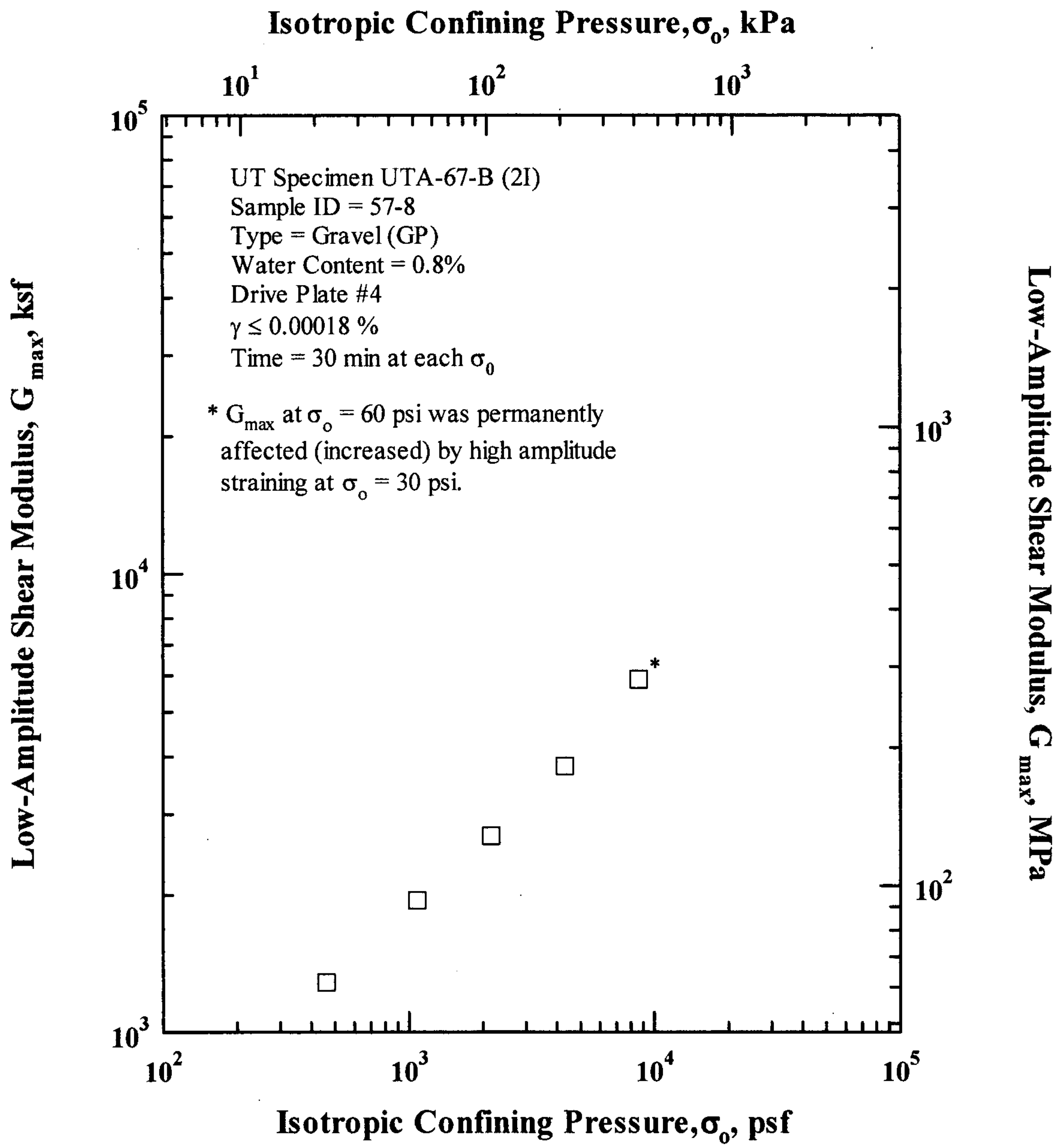


Figure H.5 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2I)

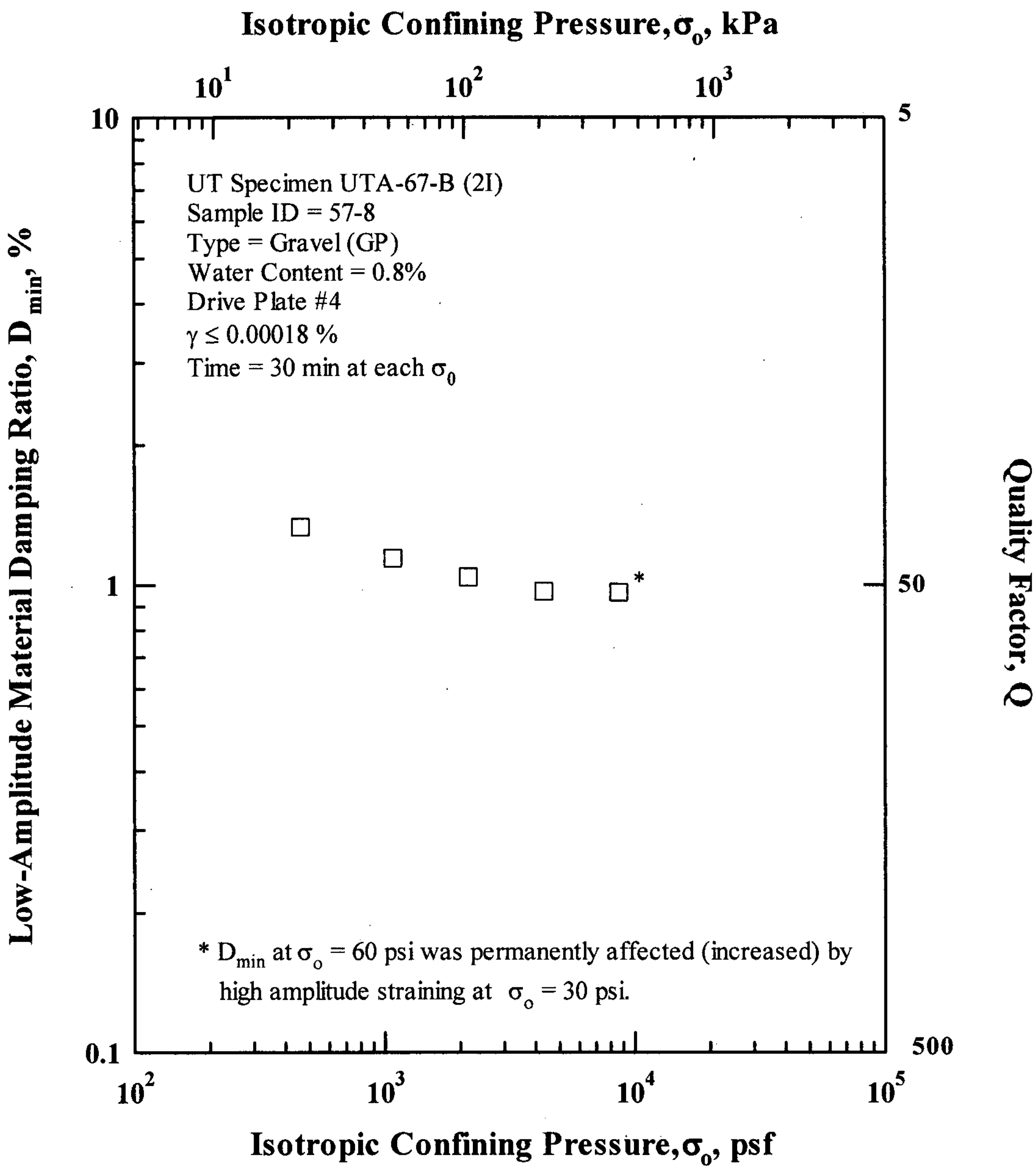


Figure H.6 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2I)

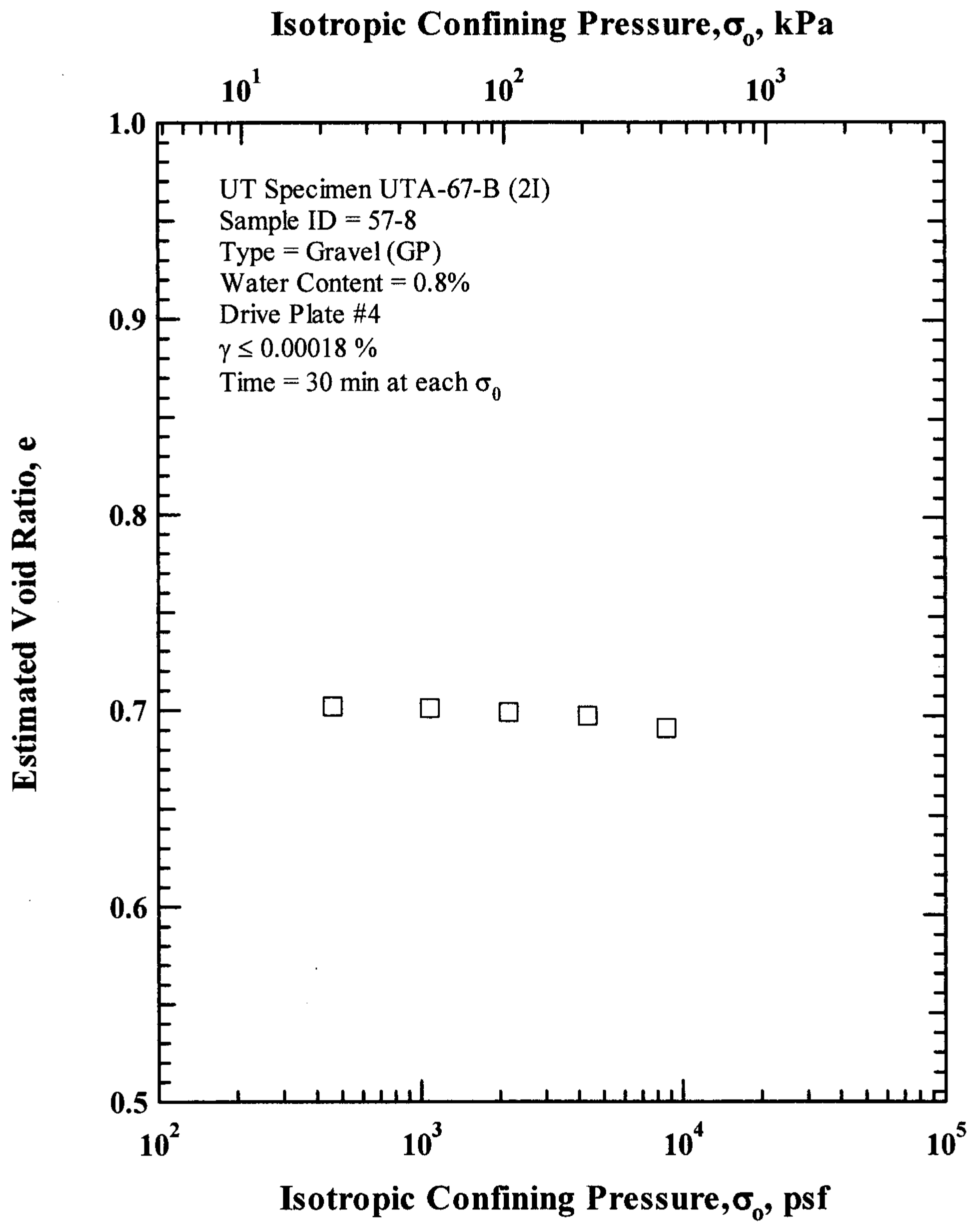


Figure H.7 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen UTA-67-B (2I)

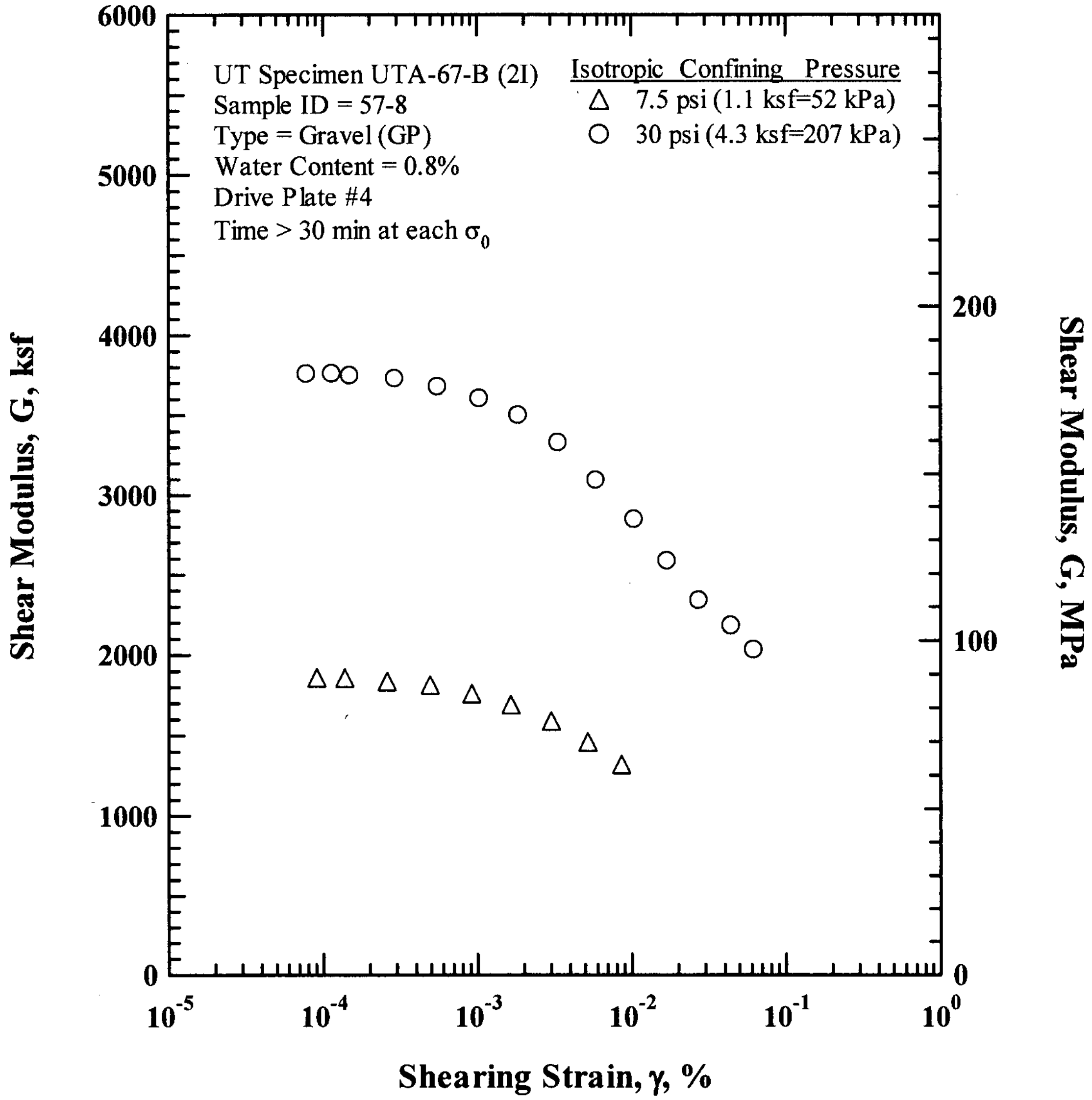


Figure H.8 Variation in Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-B (2I)

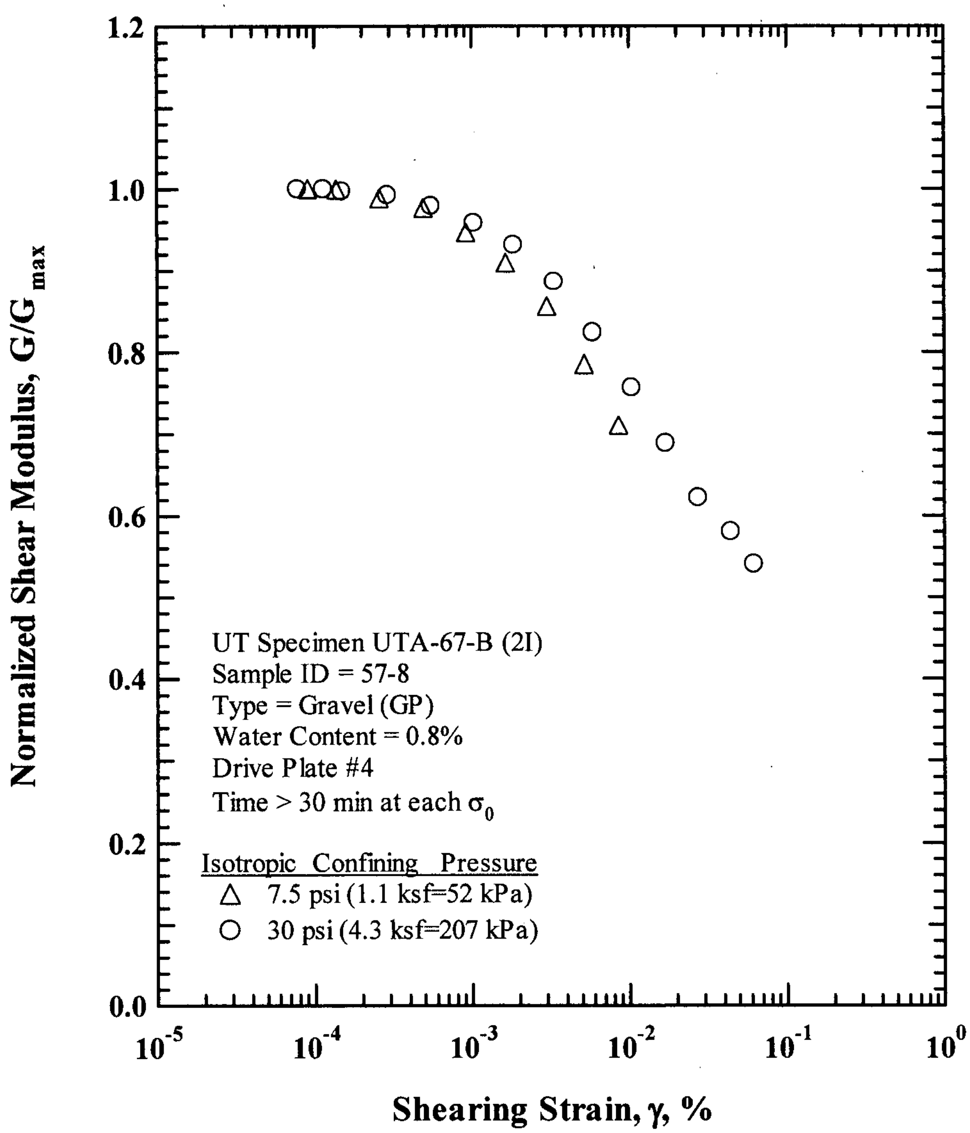


Figure H.9 Variation in Normalized Shear Modulus with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-B (2I)

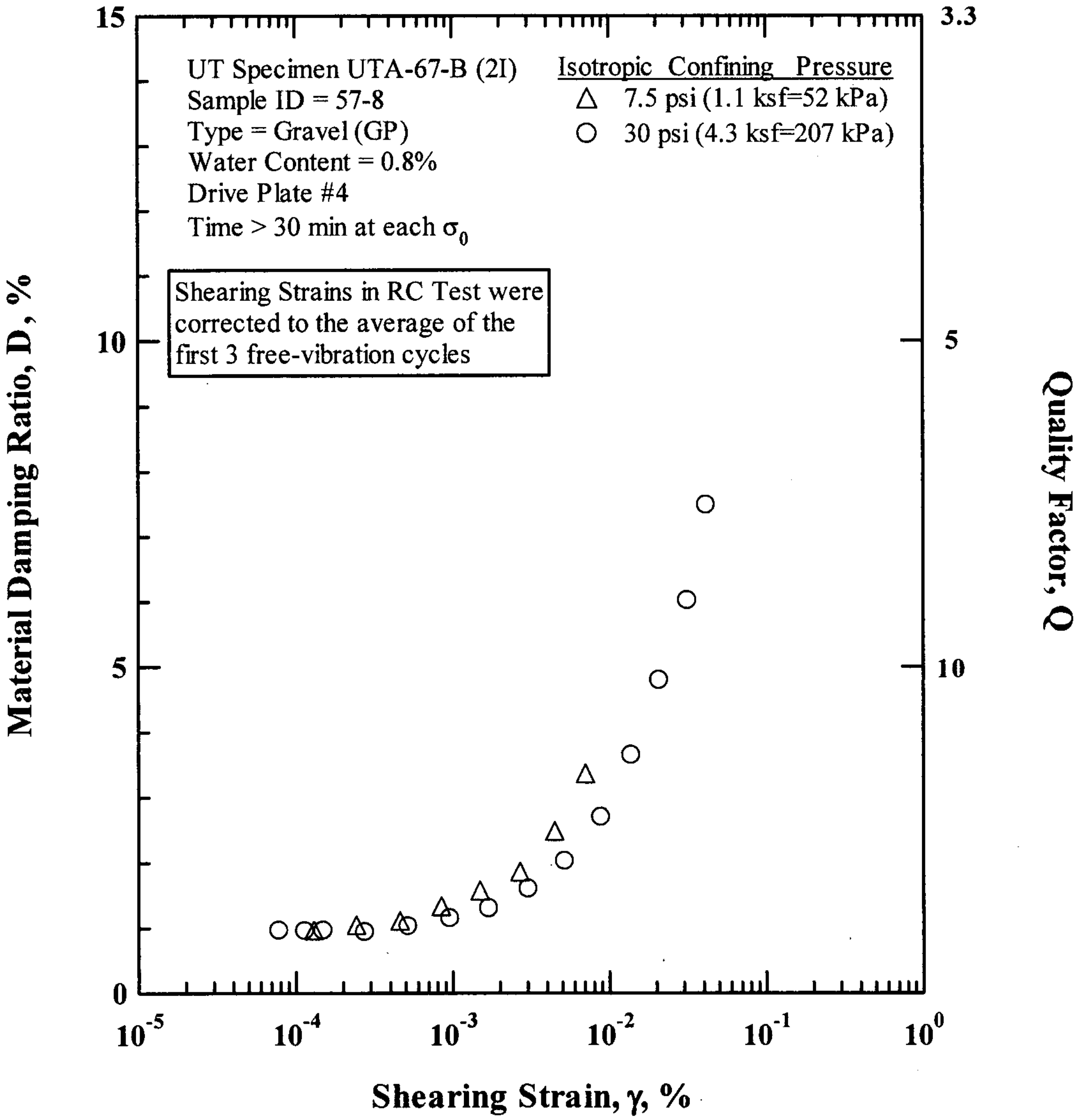


Figure H.10 Variation in Material Damping Ratio with Shearing Strain at Different Isotropic Confining Pressures from Resonant Column Tests of Specimen UTA-67-B (2I)

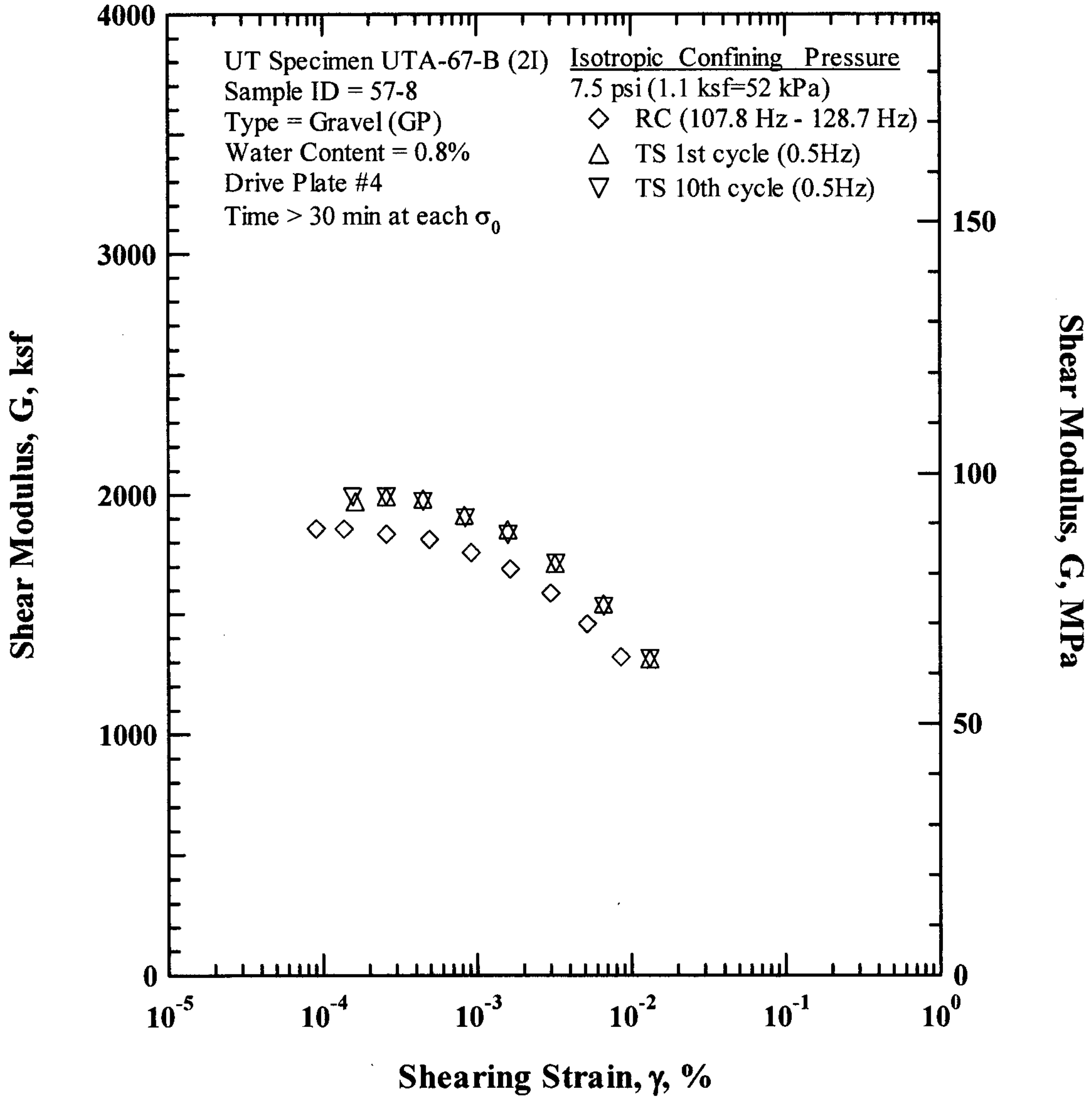


Figure H.11 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

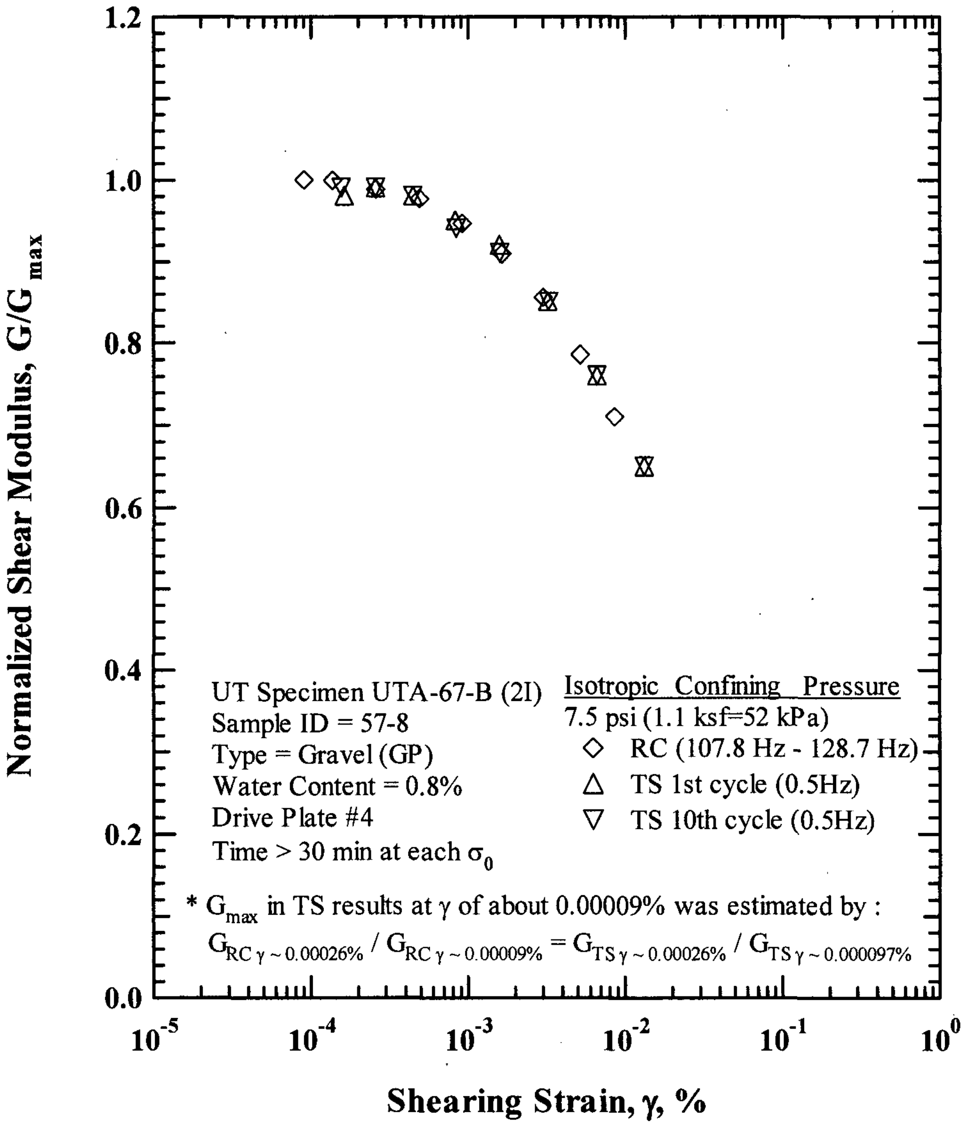


Figure H.12 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

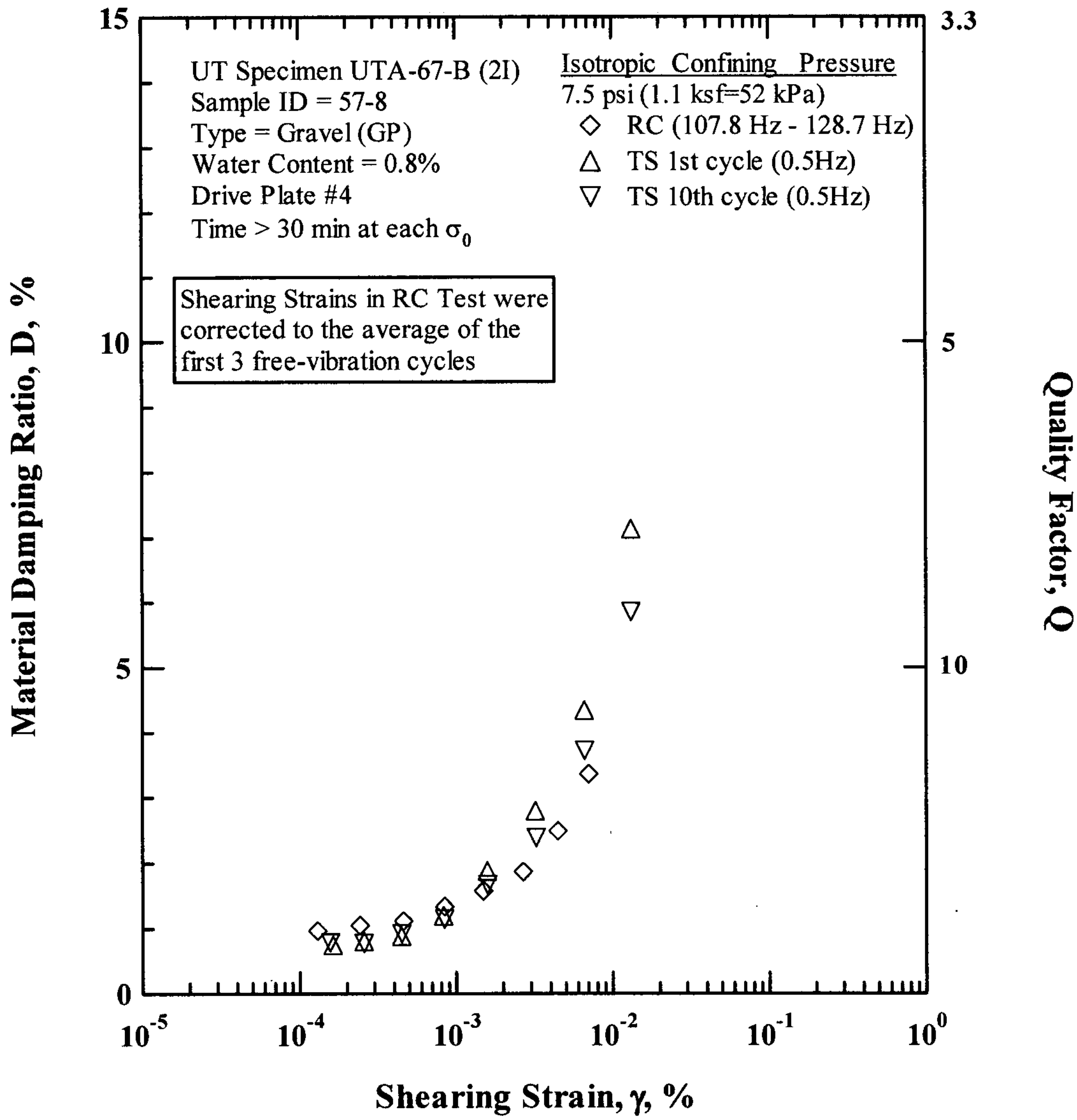


Figure H.13 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

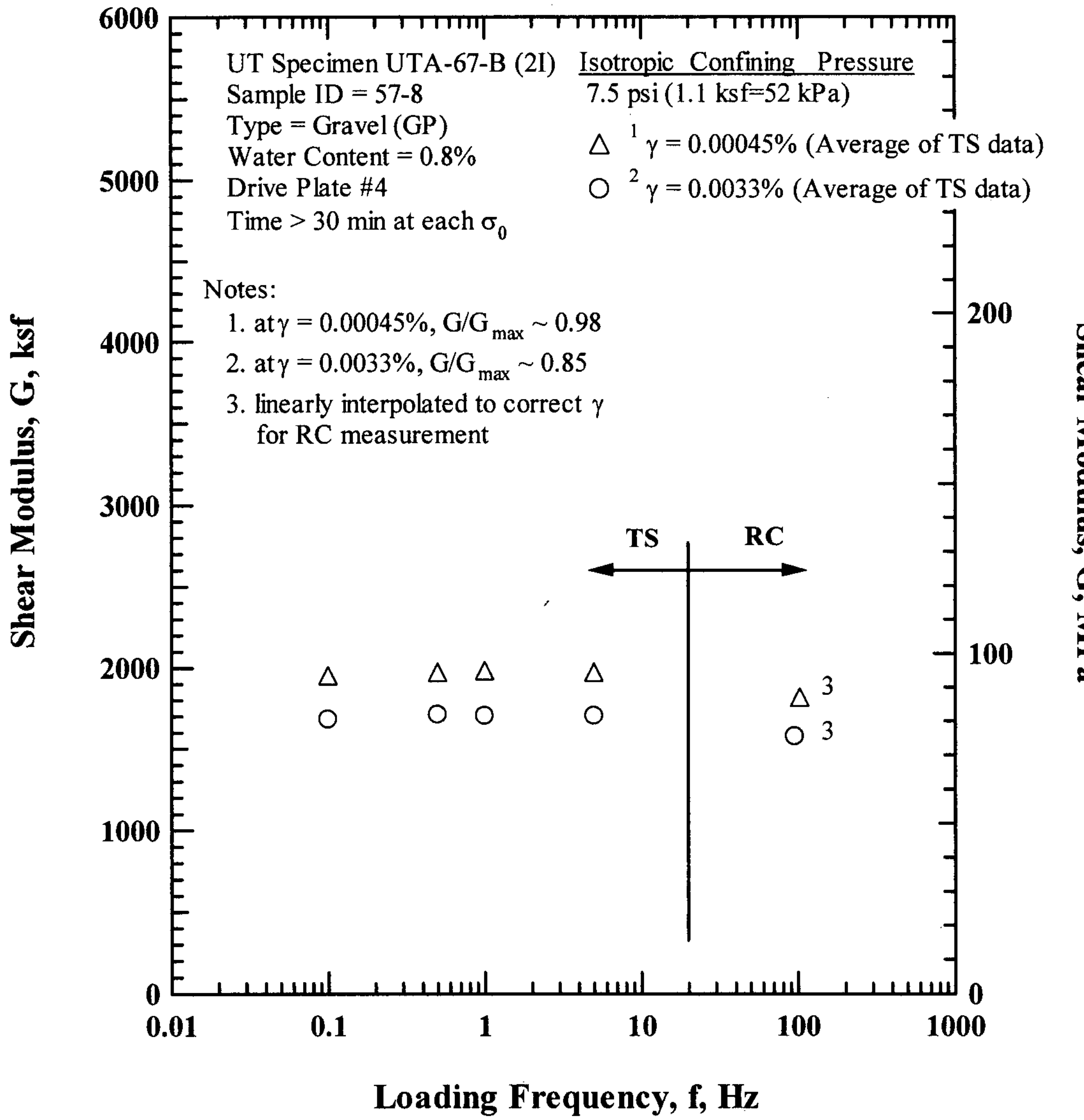


Figure H.14 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

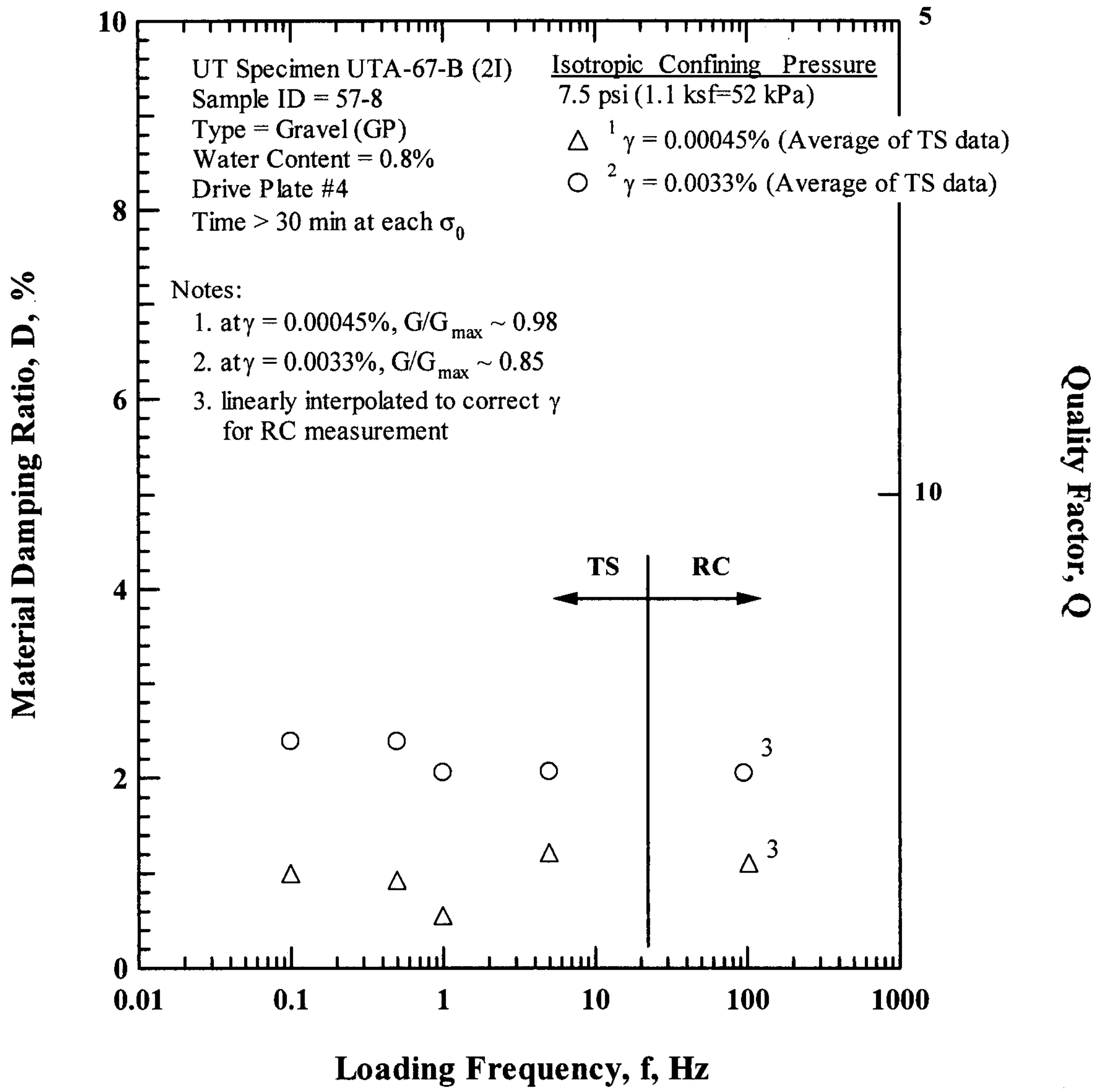


Figure H.15 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure of 7.5 psi (1.1 ksf=52 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

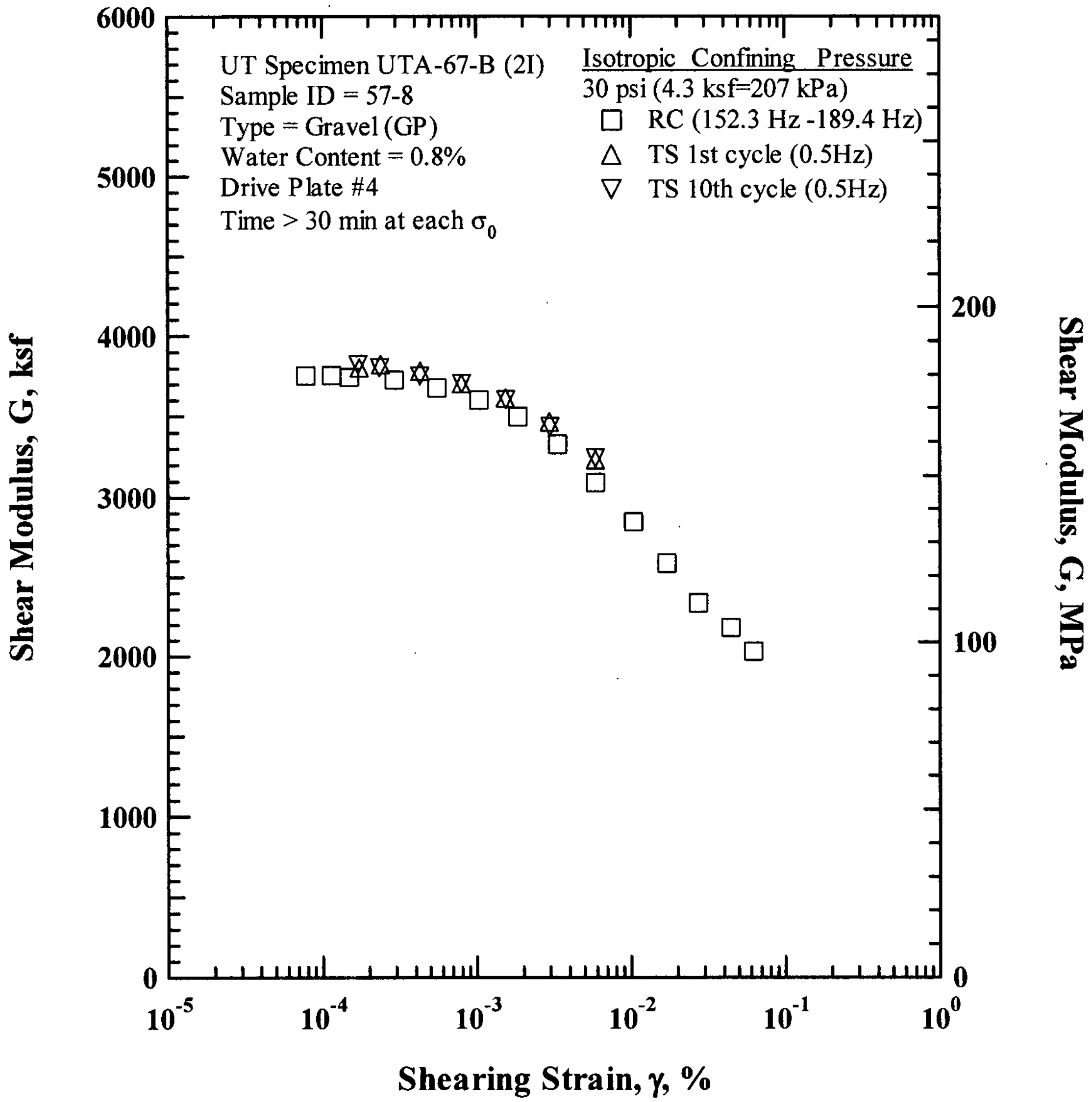


Figure H.16 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

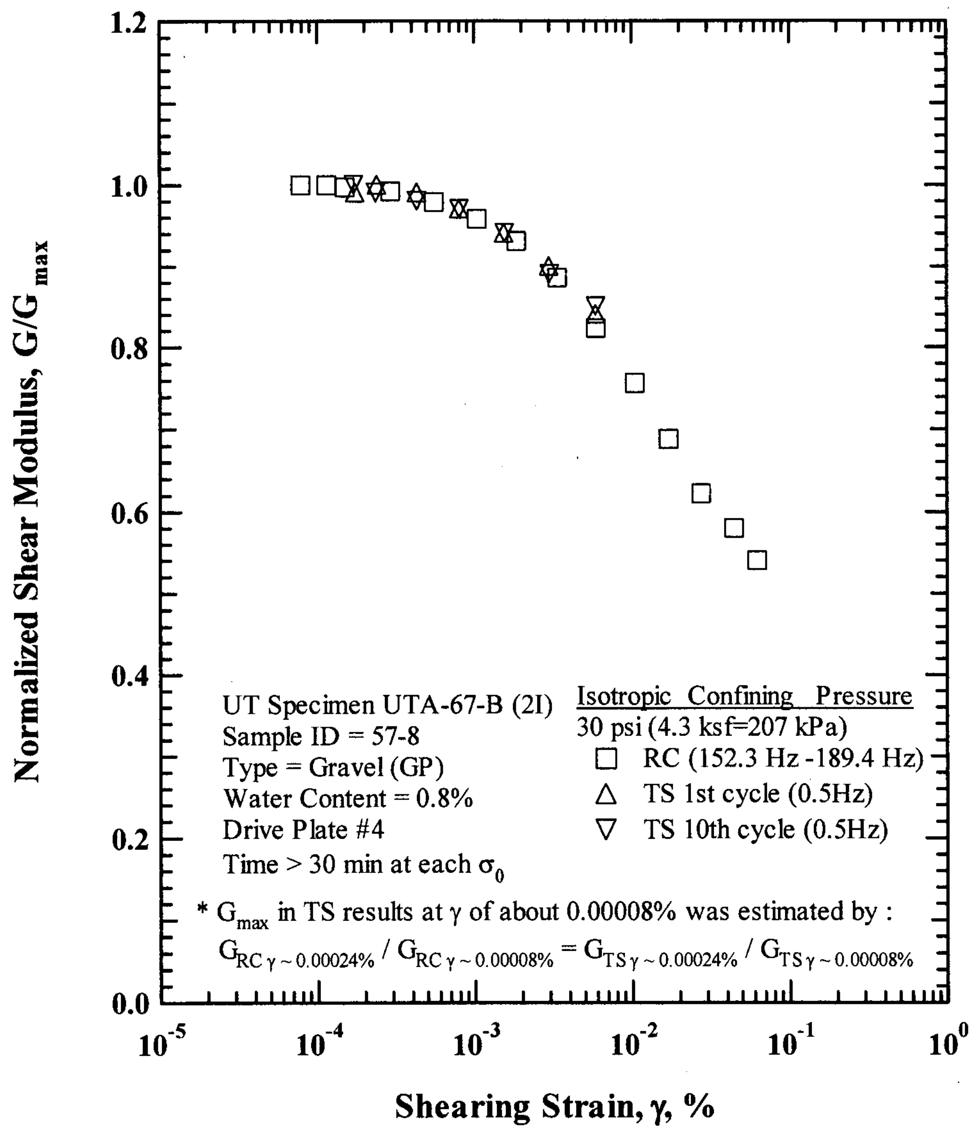


Figure H.17 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

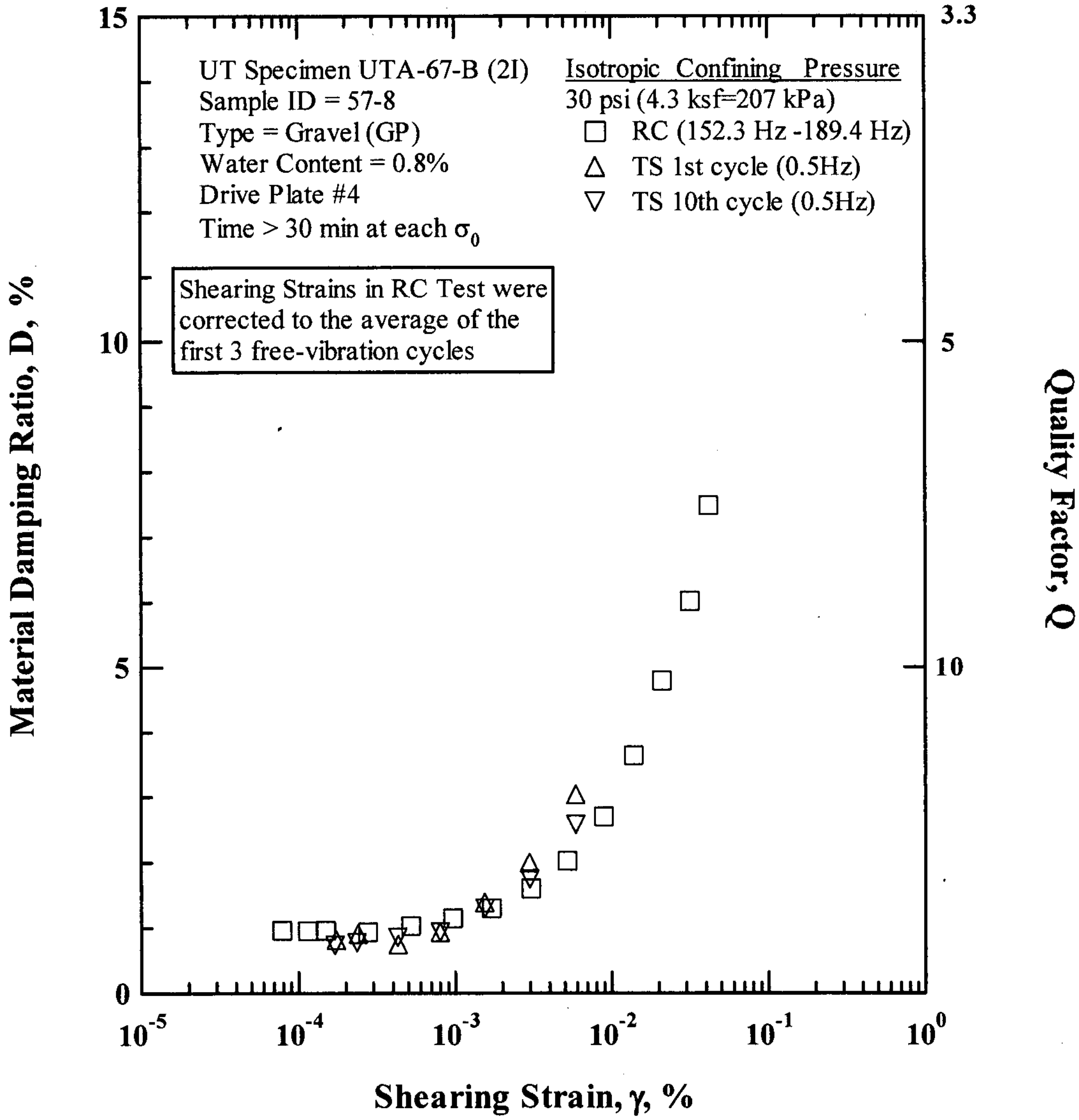


Figure H.18 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

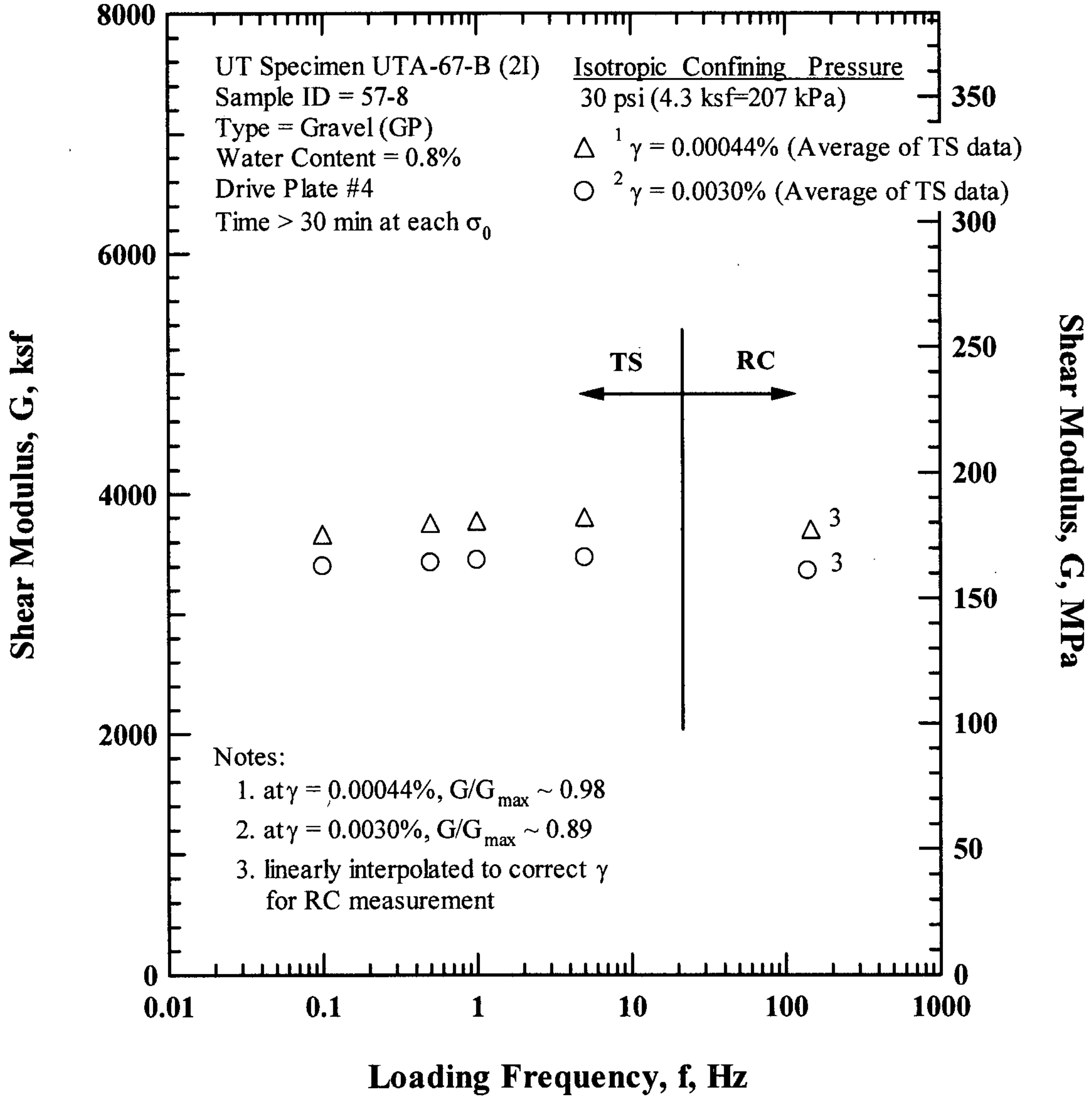


Figure H.19 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

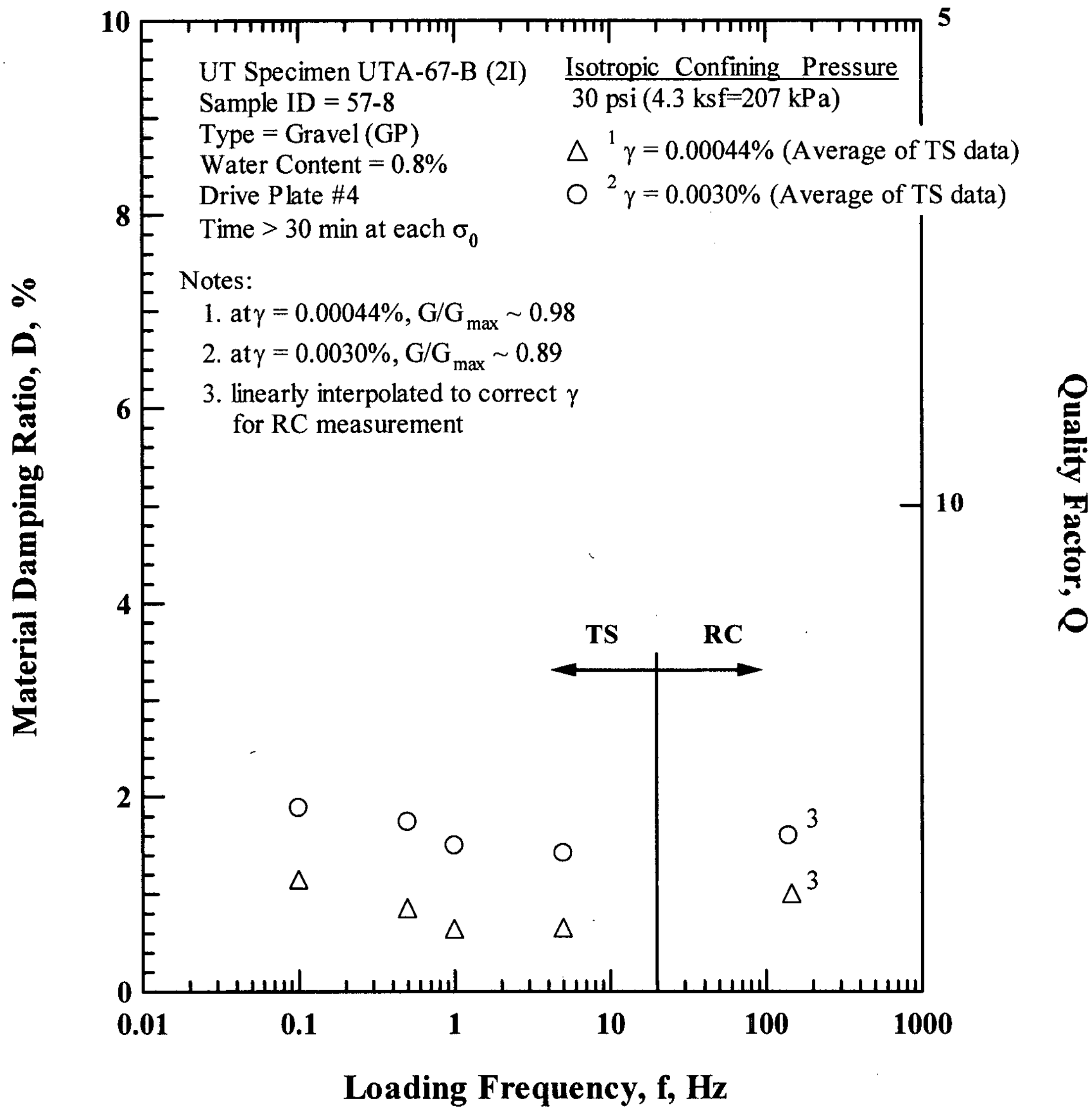


Figure H.20 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure of 30 psi (4.3 ksf=207 kPa) from Combined RCTS Tests of Specimen UTA-67-B (2I)

Table H.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio and Estimated Void Ratio with Isotropic Confining Pressure from RC Tests of Specimen UTA-67-B (2I)

Isotropic Confining Pressure, σ_o			Low-Amplitude Shear Modulus, G_{max}		Low-Amplitude Shear Wave Velocity, V_S	Low-Amplitude Material Damping Ratio, D_{min}	Estimated Void Ratio,e
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	
3.2	460.8	22	1284	61.5	628	1.33	0.70
7.5	1080	52	1944	93.2	773	1.14	0.70
15	2160	103	2692	129.0	909	1.04	0.70
30	4320	207	3812	182.8	1081	0.97	0.70
60	8640	414	5881	281.9	1340	0.97	0.69

Table H.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-B (2I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average[+] Shearing Strain, %	Material Damping Ratio[x], D, %
9.16E-05	1855	1.00	9.16E-05	-
1.39E-04	1854	1.00	1.31E-04	0.96
2.61E-04	1832	0.99	2.45E-04	1.05
4.96E-04	1811	0.98	4.63E-04	1.11
9.22E-04	1755	0.95	8.50E-04	1.33
1.65E-03	1687	0.91	1.50E-03	1.57
3.02E-03	1586	0.85	2.70E-03	1.86
5.23E-03	1456	0.79	4.51E-03	2.48
8.62E-03	1318	0.71	7.09E-03	3.35

[+] Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

[x] Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

[-] High Noise Level Interfering with Damping Measurement

Table H.3 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-B (2I); Isotropic Confining Pressure, σ_o = 7.5 psi (1.1 ksf=52 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.64E-04	1966	0.98	0.74	1.58E-04	1989	0.99	0.78
2.59E-04	1990	0.99	0.80	2.59E-04	1990	0.99	0.77
4.49E-04	1980	0.98	0.88	4.50E-04	1970	0.98	0.92
8.33E-04	1910	0.95	1.19	8.43E-04	1900	0.94	1.14
1.59E-03	1850	0.92	1.87	1.60E-03	1830	0.91	1.66
3.23E-03	1710	0.85	2.79	3.26E-03	1710	0.85	2.38
6.65E-03	1540	0.76	4.33	6.69E-03	1530	0.76	3.71
1.33E-02	1310	0.65	7.13	1.33E-02	1310	0.65	5.85

Table H.4 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from RC Tests of Specimen UTA-67-B (2I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average+ Shearing Strain, %	Material Damping Ratio^x, D, %
7.85E-05	3756	1.00	7.85E-05	0.96
1.15E-04	3757	1.00	1.15E-04	0.96
1.50E-04	3746	1.00	1.50E-04	0.96
2.93E-04	3726	0.99	2.76E-04	0.94
5.55E-04	3676	0.98	5.21E-04	1.03
1.03E-03	3601	0.96	9.64E-04	1.15
1.85E-03	3497	0.93	1.71E-03	1.30
3.36E-03	3328	0.89	3.04E-03	1.60
5.90E-03	3092	0.82	5.22E-03	2.02
1.04E-02	2843	0.76	8.90E-03	2.70
1.71E-02	2584	0.69	1.38E-02	3.64
2.74E-02	2337	0.62	2.09E-02	4.79
4.42E-02	2180	0.58	3.17E-02	6.02
6.21E-02	2029	0.54	4.17E-02	7.49

+ Average Shearing Strain from the First Three Cycles of the Free Vibration Decay Curve

x Average Damping Ratio from the First Three Cycles of the Free Vibration Decay Curve

Table H.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen UTA-67-B (2I); Isotropic Confining Pressure, σ_o = 30 psi (4.3 ksf=207 kPa)

First Cycle				Tenth Cycle			
Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
1.75E-04	3800	0.99	0.81	1.72E-04	3820	1.00	0.73
2.41E-04	3820	1.00	0.90	2.37E-04	3800	0.99	0.77
4.33E-04	3780	0.99	0.74	4.32E-04	3750	0.98	0.85
8.04E-04	3700	0.97	0.93	8.06E-04	3700	0.97	0.93
1.55E-03	3610	0.94	1.38	1.56E-03	3600	0.94	1.29
2.99E-03	3460	0.90	1.99	3.01E-03	3430	0.89	1.74
5.94E-03	3230	0.84	3.03	5.94E-03	3240	0.85	2.57

APPENDIX I
(Free-Free Tests)

UT Specimen UTA-67-D (4I)
Sample ID : CR6-18
(Vulcan Quarry Statistical Avg. Sample)
Type = Scalped, Blended Gravel with Silt and Sand (GP-GM*)
Uniformity Coefficient, $C_u > 100$
Specimen Diameter = 6.01 inch

Water Content, w = 4.79 %

$G_S = 2.716^*$

Degree of Saturation = 52.3 %

Total Unit Weight, $\gamma_t = 142.2$ lb/ft^3

Dry Unit Weight, $\gamma_d = 135.7$ lb/ft^3

Target : $\gamma_d = 136.4$ lb/ft^3 ± 1 lb/ft^3

w= 4.6 % ± 1.0 %

*** Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

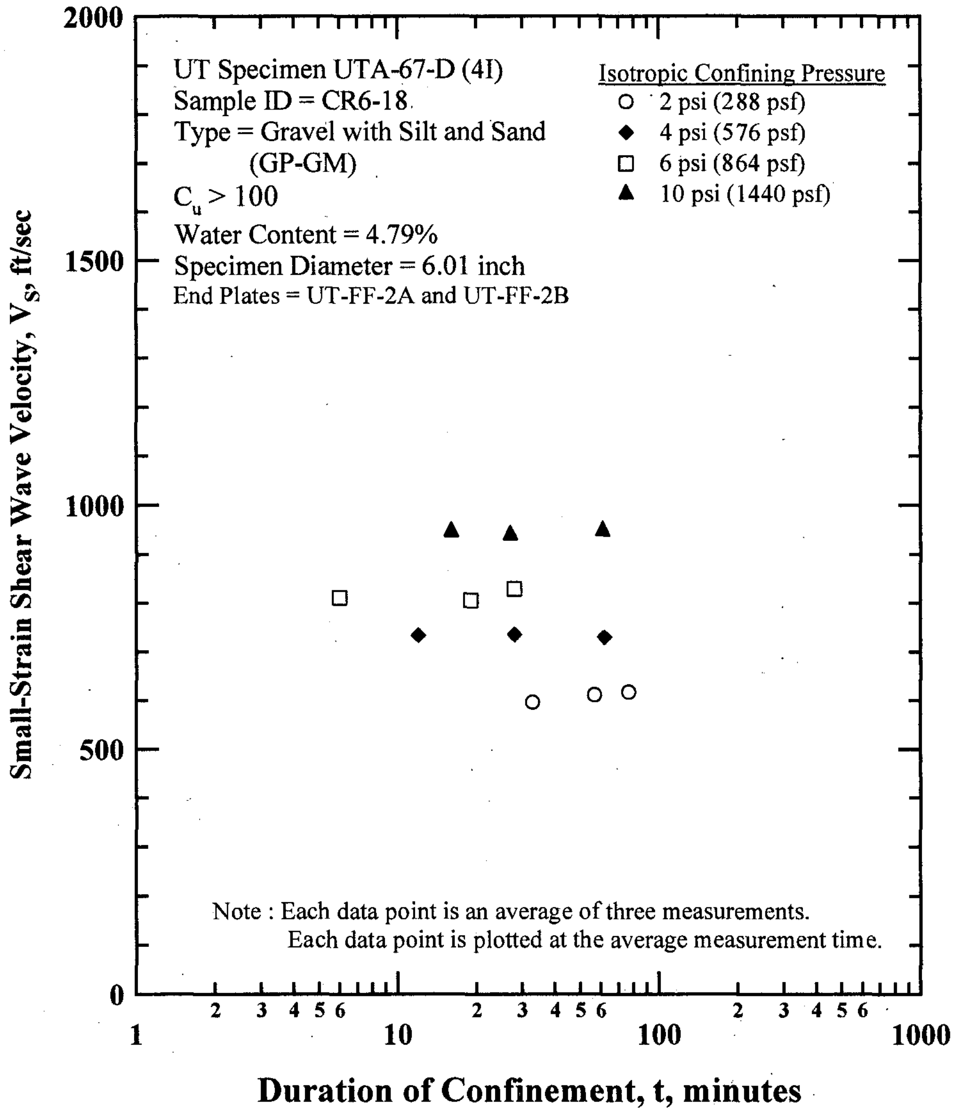


Figure I.1 Variation in Small-Strain Shear Wave Velocities (V_S) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

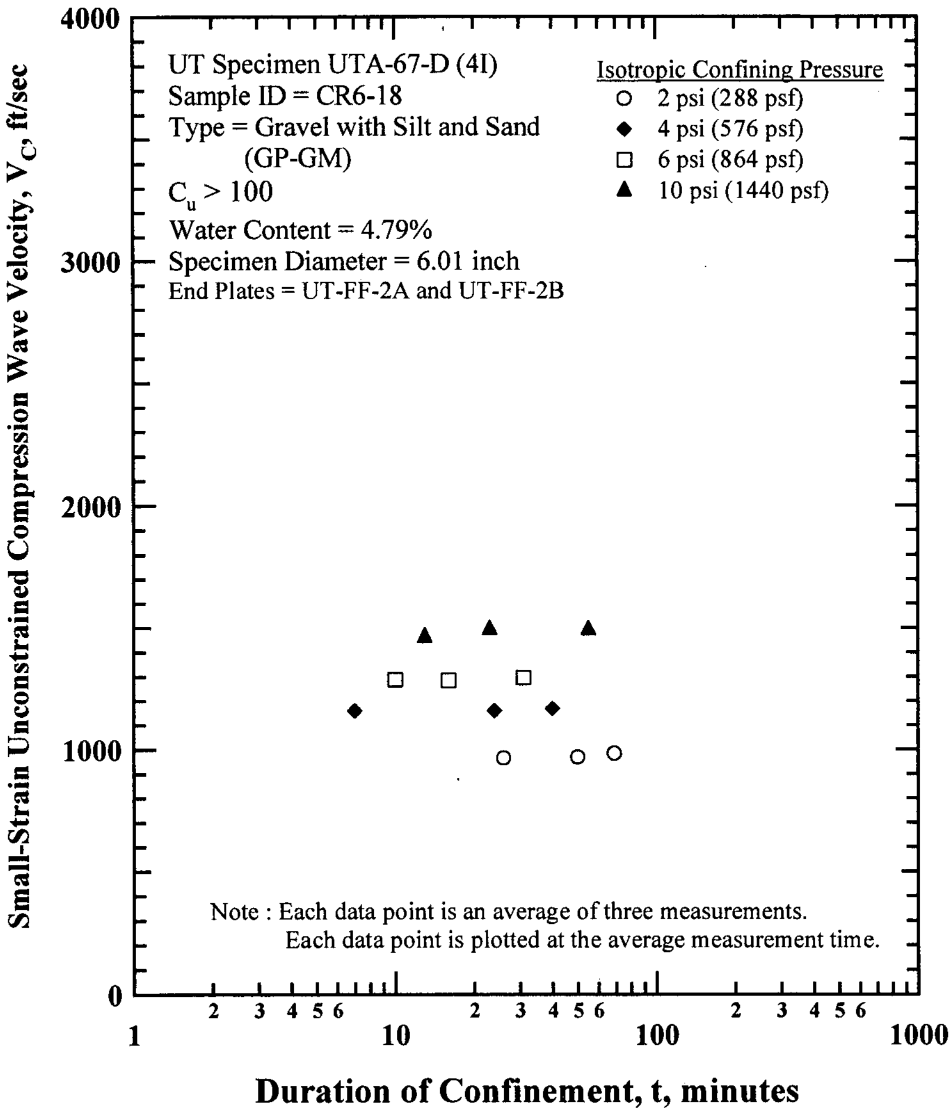


Figure I.2 Variation in Small-Strain Unconstrained Compression Wave Velocities (V_C) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

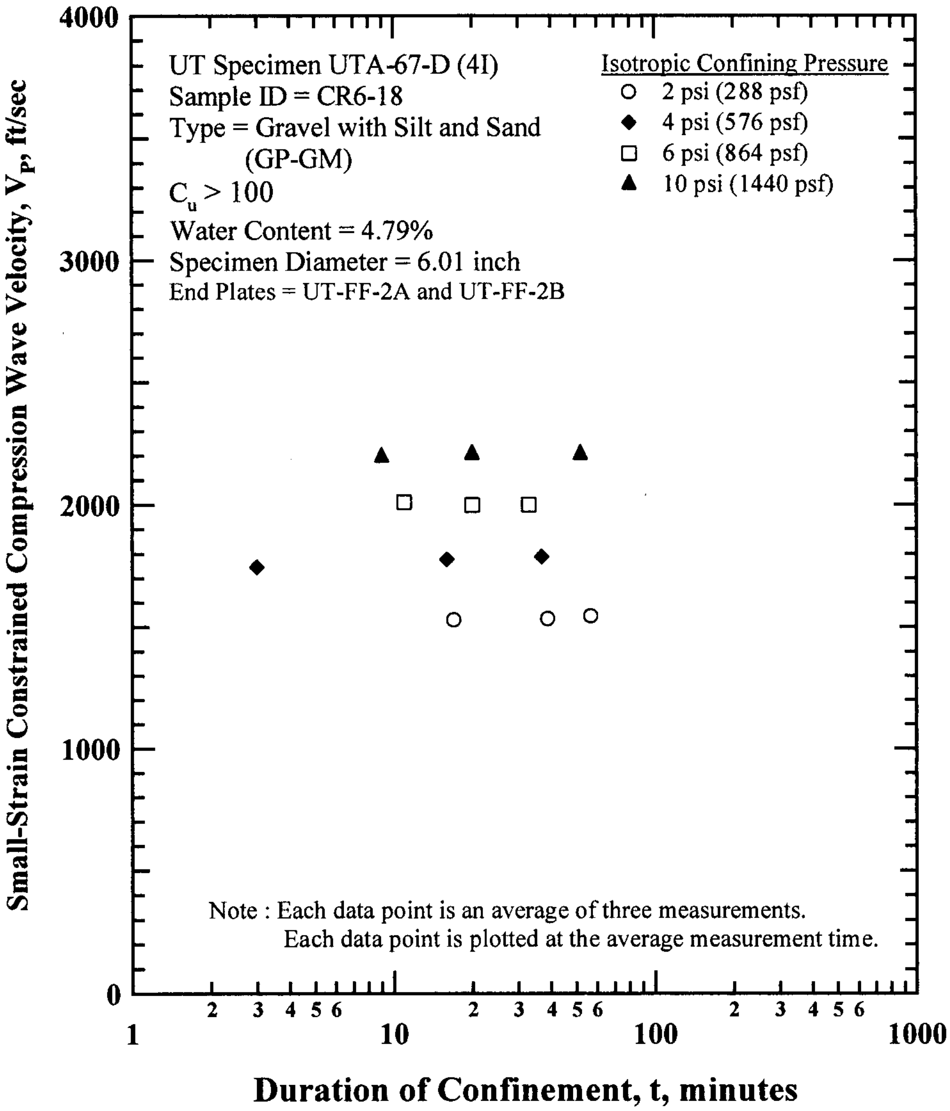


Figure I.3 Variation in Small-Strain Constrained Compression Wave Velocities (V_P) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

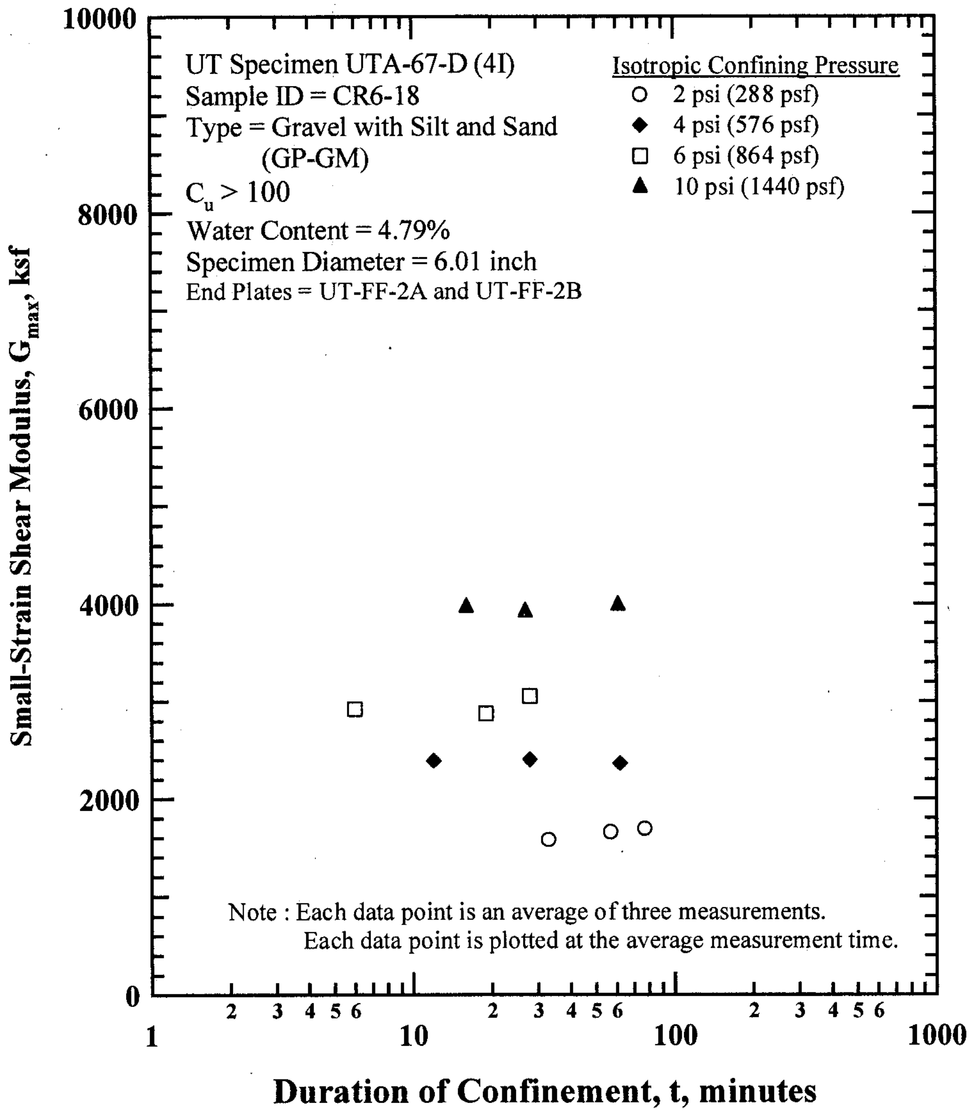


Figure I.4 Variation in Small-Strain Shear Modulus (G_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

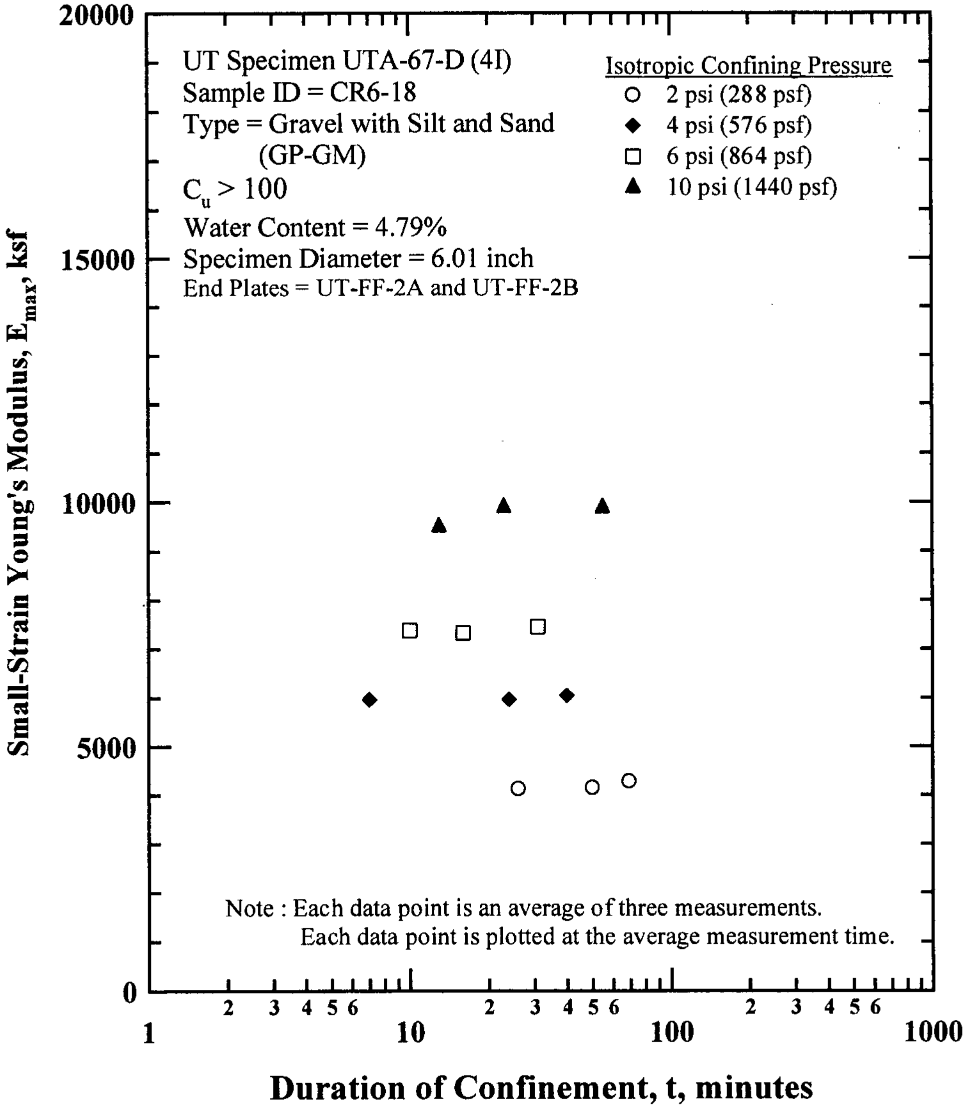


Figure I.5 Variation in Small-Strain Young's Modulus (E_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

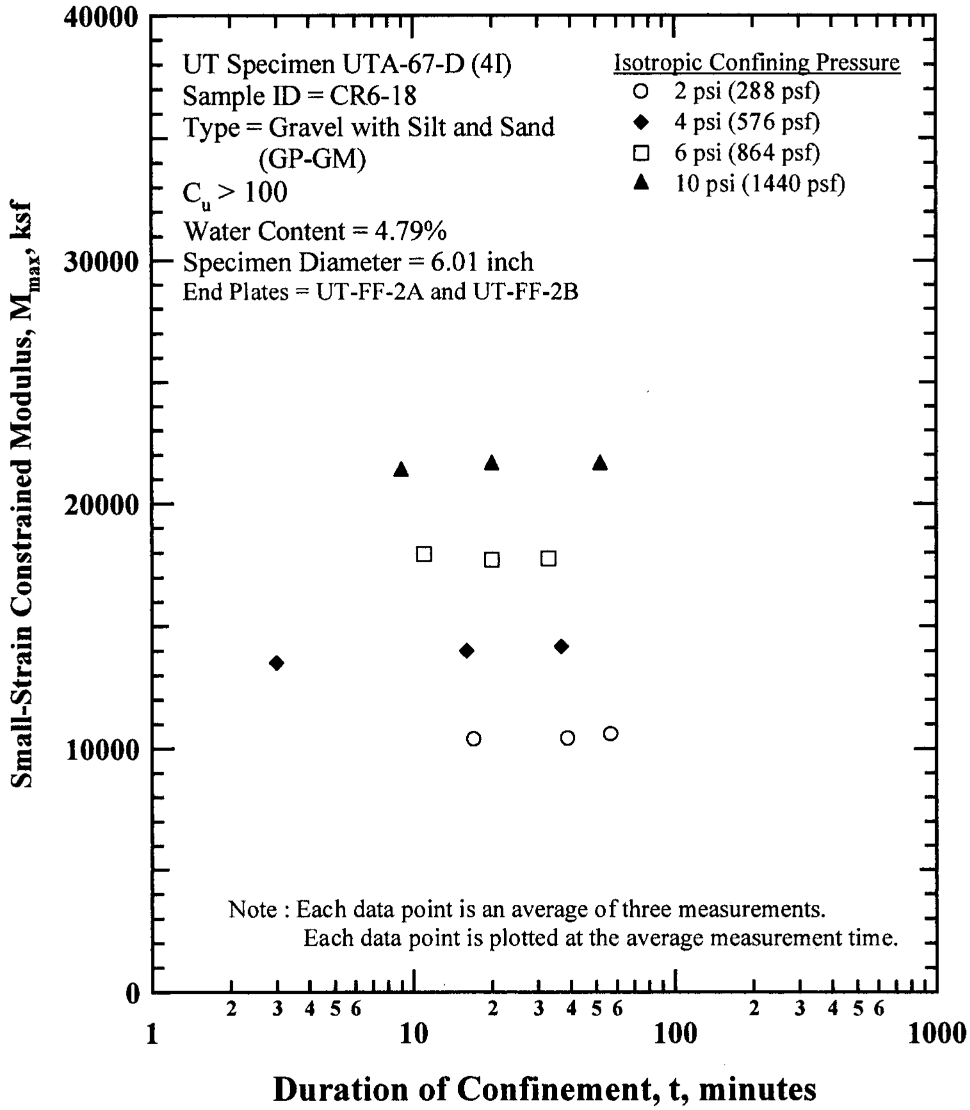


Figure I.6 Variation in Small-Strain Constrained Modulus (M_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

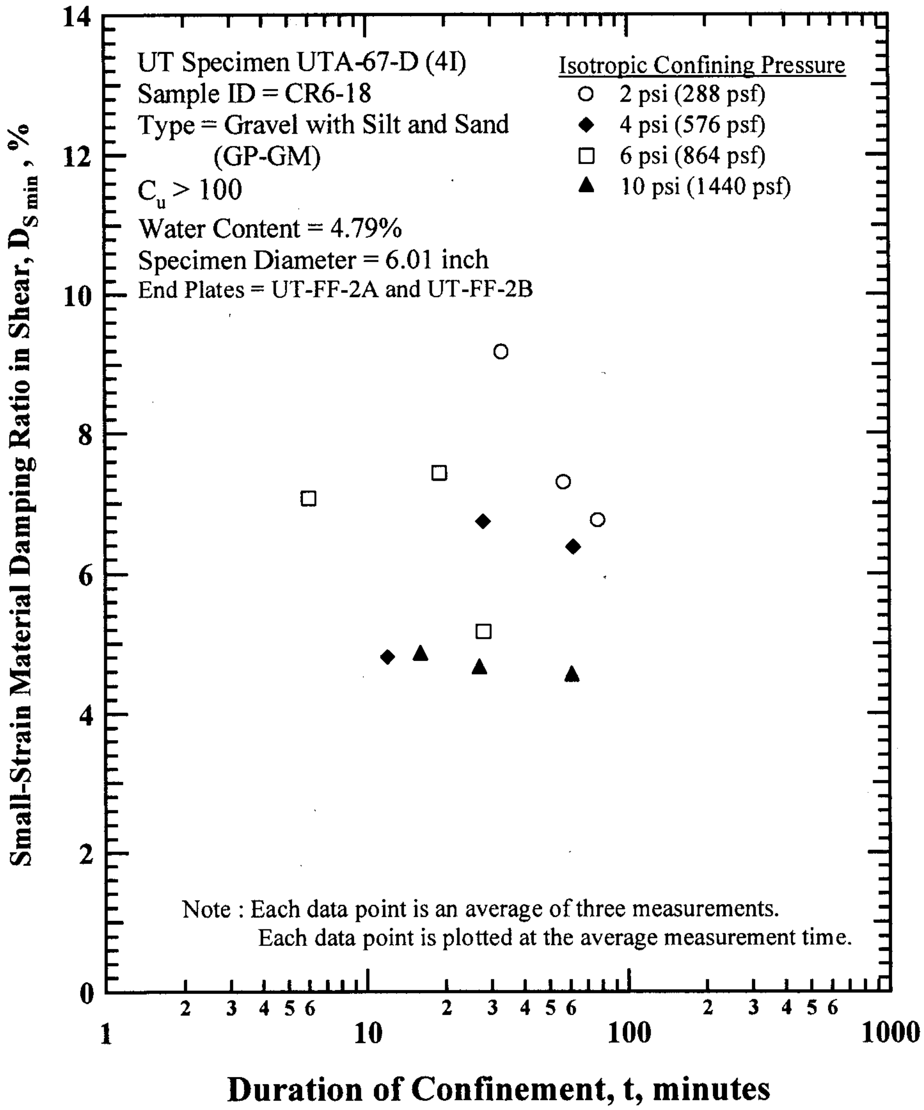


Figure I.7 Variation in Small-Strain Material Damping Ratio in Shear ($D_{S\ min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

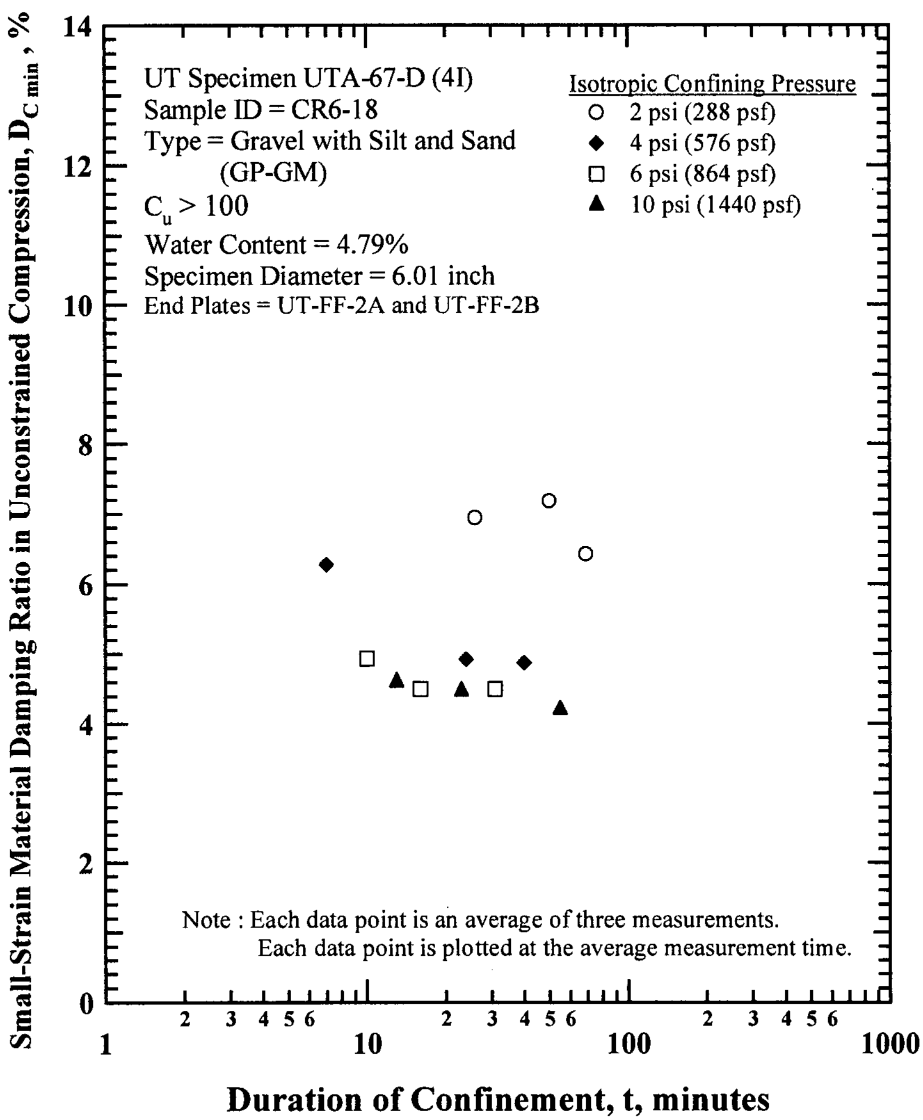
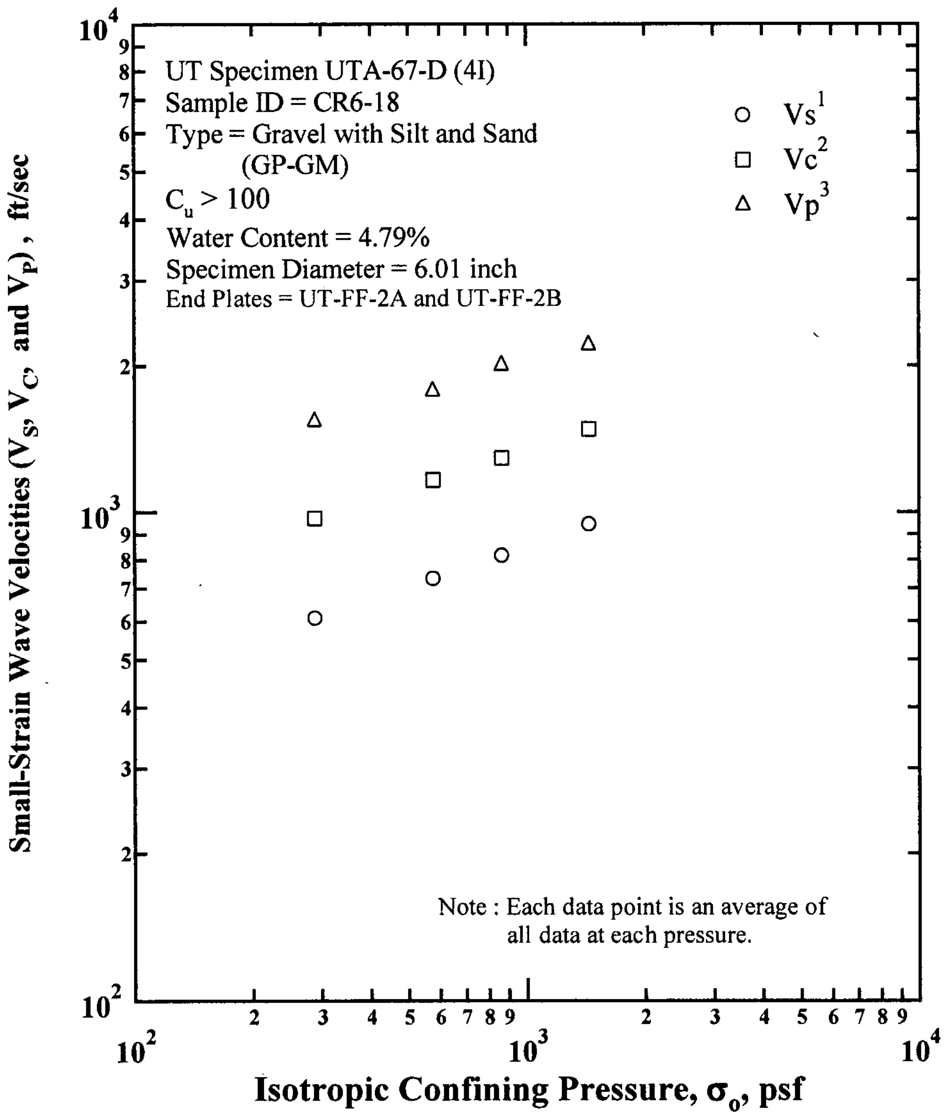
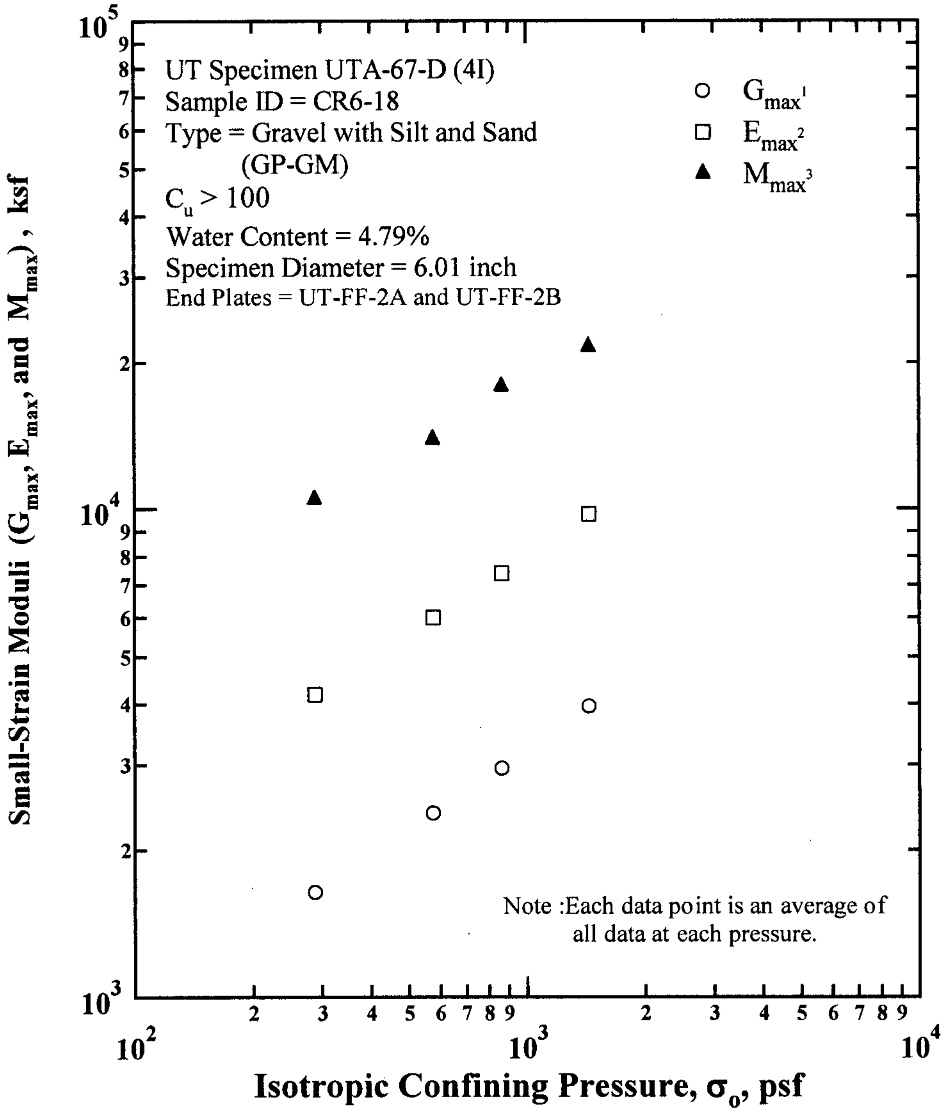


Figure I.8 Variation in Small-Strain Material Damping Ratio in Unconstrained Compression ($D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)



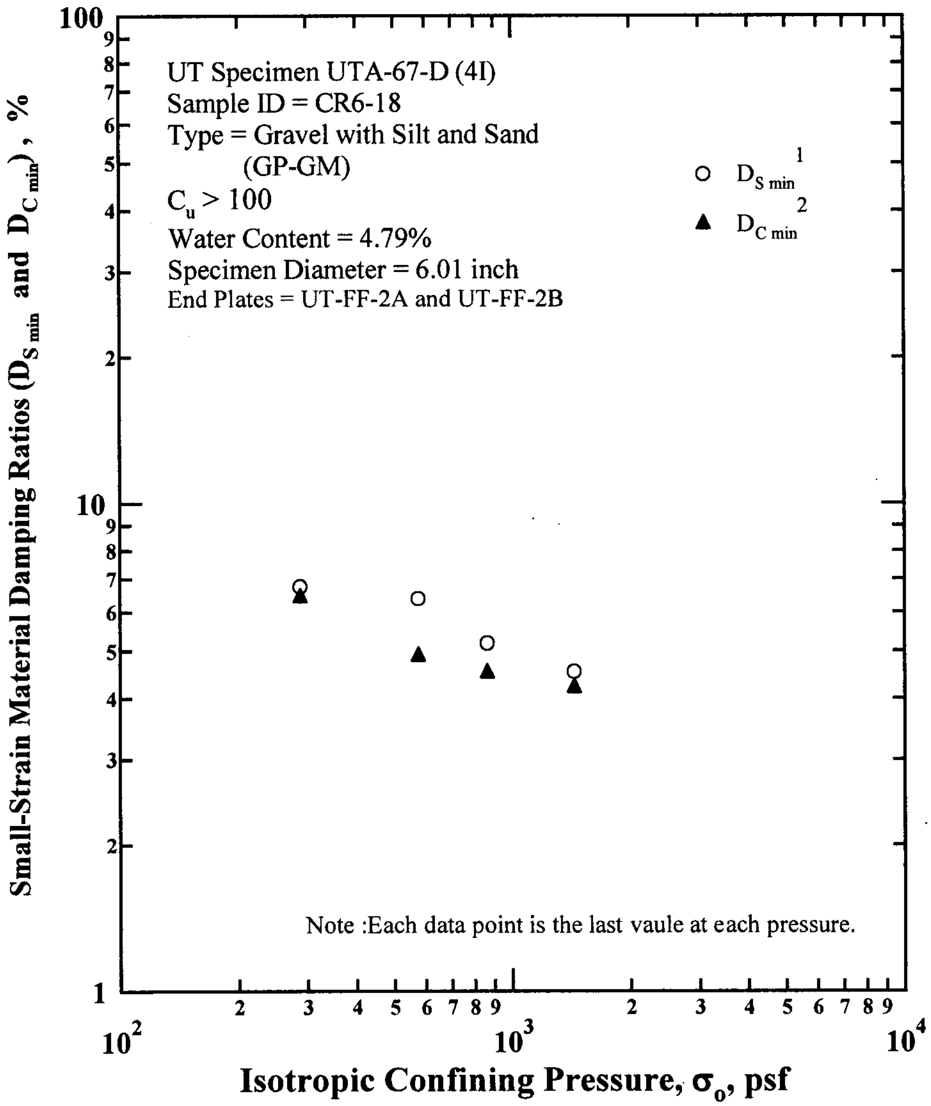
Notes : 1. V_S=Small-Strain Shear Wave Velocity
2. V_C=Small-Strain Unconstrained Compression Wave Velocity
3. V_P=Small-Strain Constrained Compression Wave Velocity

Figure I.9 Variation in Small-Strain Wave Velocities (V_S, V_C, and V_P) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)



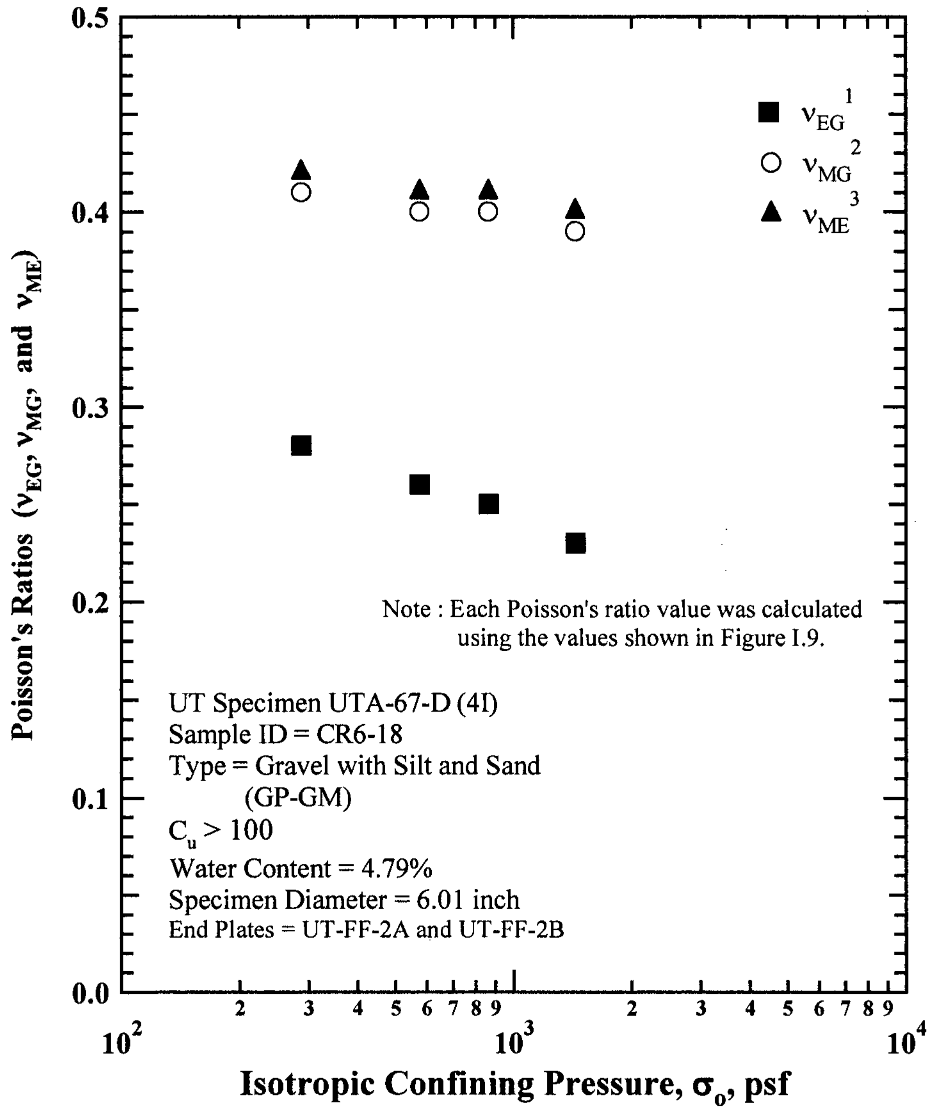
Notes :1. G_{max}=Small-Strain Shear Modulus
2. E_{max}=Small-Strain Young's Modulus
2. M_{max}=Small-Strain Constrained Modulus

Figure I.10 Variation in Small-Strained Moduli (G_{max}, E_{max}, and M_{max}) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)



Notes :1.$D_{S\,min}$ = Small-Strain Material Damping Ratio in Shear
2.$D_{C\,min}$ = Small-Strain Material Damping Ratio in Unconstrained Compression

Figure I.11 Variation in Small-Strained Material Damping Ratios ($D_{S\,min}$ and $D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-D (4I)



Notes : 1. ν_{EG}=Poisson's Ratios from the Relationship between V_C and V_S
2. ν_{MG}=Poisson's Ratios from the Relationship between V_P and V_S
3. ν_{ME}=Poisson's Ratios from the Relationship between V_P and V_C

Figure I.12 Variation in Poisson's Ratios (ν_{EG}, ν_{MG}, and ν_{ME}) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-D (4I)

Table I.1 Variations in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Shear Modulus, G_{max}*		Small-Strain Shear Wave Velocity, V_S*	Small-Strain Material Damping Ratio in Shear, $D_{S\,min}$*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	33	1575	75.5	596	9.17
2	288	14	57	1655	79.4	611	7.30
2	288	14	77	1690	81.0	617	6.75
4	576	28	12	2386	114.4	733	4.80
4	576	28	28	2401	115.1	735	6.73
4	576	28	62	2360	113.1	729	6.37
6	864	41	6	2920	140.0	811	7.07
6	864	41	19	2874	137.8	805	7.43
6	864	41	28	3053	146.4	829	5.17
10	1440	69	16	3961	189.9	945	4.83
10	1440	69	27	3915	187.7	939	4.63
10	1440	69	61	3981	190.9	947	4.53

Note : * Average of three measurements

Table I.2 Variation in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Small-Strain Shear Modulus, G_{max}*		Small-Strain Shear Wave Velocity, V_S*	Small-Strain Material Damping Ratio in Shear, $D_{S\,min}$**
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	1640	79	608	6.75
4	576	28	2383	114	733	6.37
6	864	41	2949	141	815	5.17
10	1440	69	3952	189	944	4.53

Notes : * Average of all data at each pressure
** The last value at each pressure

Table I.3 Variations in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Young's Modulus, E_{max}^{*}		Small-Strain Unconstrained Compression Wave Velocity, V_C^{*}	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}^{*}$
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	26	4125	197.7	964	6.94
2	288	14	50	4154	199.1	967	7.18
2	288	14	69	4283	205.3	982	6.42
4	576	28	7	5966	286.0	1159	6.27
4	576	28	24	5966	286.0	1159	4.92
4	576	28	40	6048	290.0	1167	4.87
6	864	41	10	7369	353.3	1288	4.93
6	864	41	16	7324	351.1	1284	4.50
6	864	41	31	7452	357.2	1296	4.50
10	1440	69	13	9481	454.5	1461	4.60
10	1440	69	23	9879	473.6	1492	4.47
10	1440	69	55	9868	473.1	1491	4.20

Note : * Average of three measurements

Table I.4 Variation in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Small-Strain Young's Modulus, E_{max}^{*}		Small-Strain Unconstrained Compression Wave Velocity, V_C^{*}	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}^{**}$
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	4187	201	971	6.42
4	576	28	5993	287	1162	4.87
6	864	41	7382	354	1289	4.50
10	1440	69	9743	467	1481	4.20

Notes : * Average of all data at each pressure
** The last value at each pressure

Table I.5 Variations in Small-Strain ConstrainedCompression Wave Velocity and Small-Strain ConstrainedModulus with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)
2	288	14	17	10372	497.2	1528
2	288	14	39	10414	499.3	1532
2	288	14	57	10586	507.5	1544
4	576	28	3	13512	647.8	1745
4	576	28	16	13994	670.9	1775
4	576	28	37	14162	678.9	1786
6	864	41	11	17939	860.0	2010
6	864	41	20	17702	848.6	1997
6	864	41	33	17749	850.9	1999
10	1440	69	9	21325	1022.3	2192
10	1440	69	20	21575	1034.3	2204
10	1440	69	52	21575	1034.3	2204

Note : * Average of three measurements

Table I.6 Variation in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)
2	288	14	10458	501	1535
4	576	28	13890	666	1769
6	864	41	17797	853	2002
10	1440	69	21492	1030	2200

Note : * Average of all data at each pressure

Table I.7 Variation in Poisson's Ratios with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Poisson's Ratio		
(psi)	(psf)	(kPa)	ν_{EG}[1]	ν_{MG}[2]	ν_{ME}[3]
2	288	14	0.28	0.41	0.42
4	576	28	0.26	0.40	0.41
6	864	41	0.25	0.40	0.41
10	1440	69	0.23	0.39	0.40

Notes : 1. Poisson's ratio from the relationship between V_C and V_S tabulated in Tables I.4 and I.2, respectively.

2. Poisson's ratio from the relationship between V_P and V_S tabulated in Tables I.6 and I.2, respectively.

3. Poisson's ratio from the relationship between V_P and V_C tabulated in Tables I.6 and I.4, respectively.

APPENDIX J
(Free-Free Tests)

UT Specimen UTA-67-G (7E)
Sample ID : CR6-24
(Vulcan Quarry Statistical Avg. Sample)
Type = Scalped, Blended Gravel with Silt and Sand (GP-GM*)
Uniformity Coefficient, $C_u > 100$
Specimen Diameter = 6.04 inch

Water Content, w = 4.94 %
$G_S = 2.716^*$
Degree of Saturation = 69.8 %
Total Unit Weight, $\gamma_t = 149.2\ lb/ft^3$
Dry Unit Weight, $\gamma_d = 142.2\ lb/ft^3$
Target : $\gamma_d = 143.6\ lb/ft^3 \pm 2\ lb/ft^3$
w= 4.6 % ± 1.0 %

* Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.

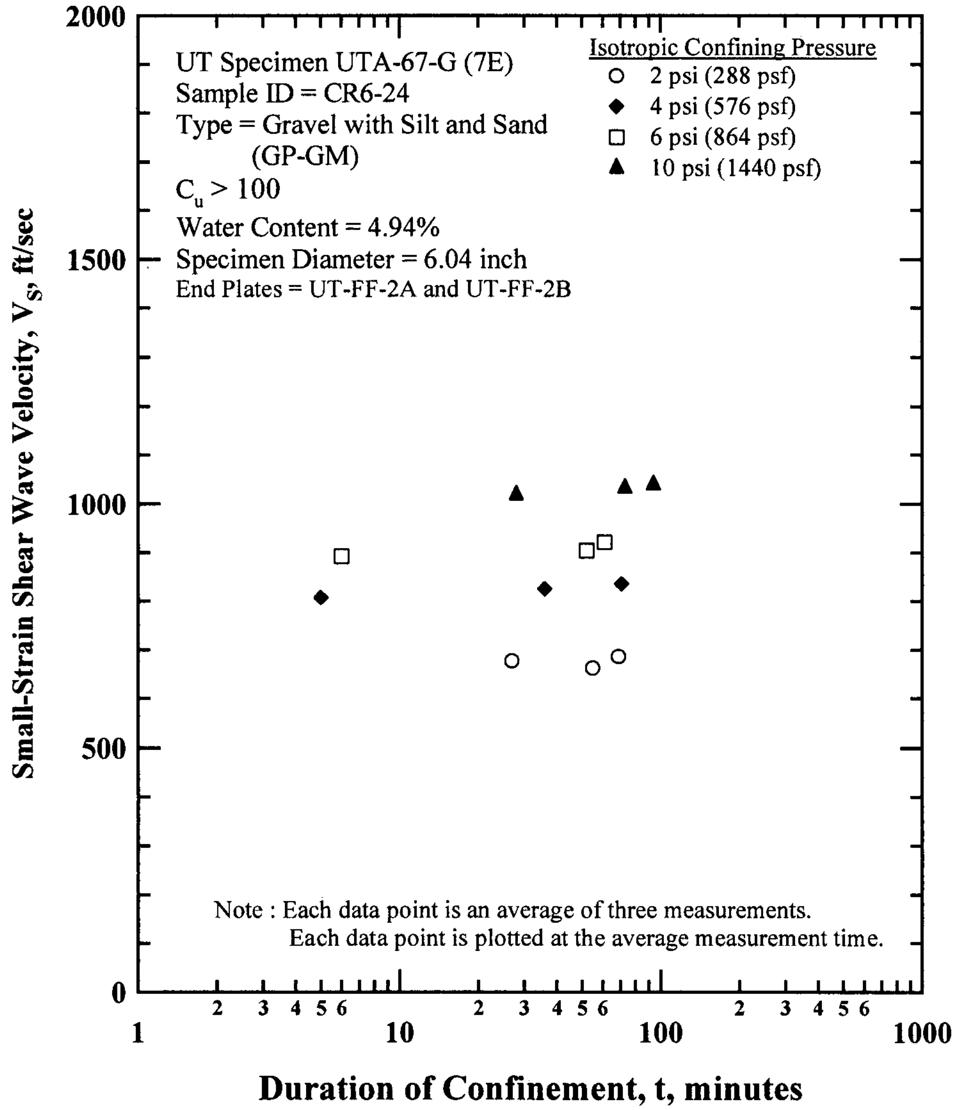


Figure J.1 Variation in Small-Strain Shear Wave Velocities (V_S) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

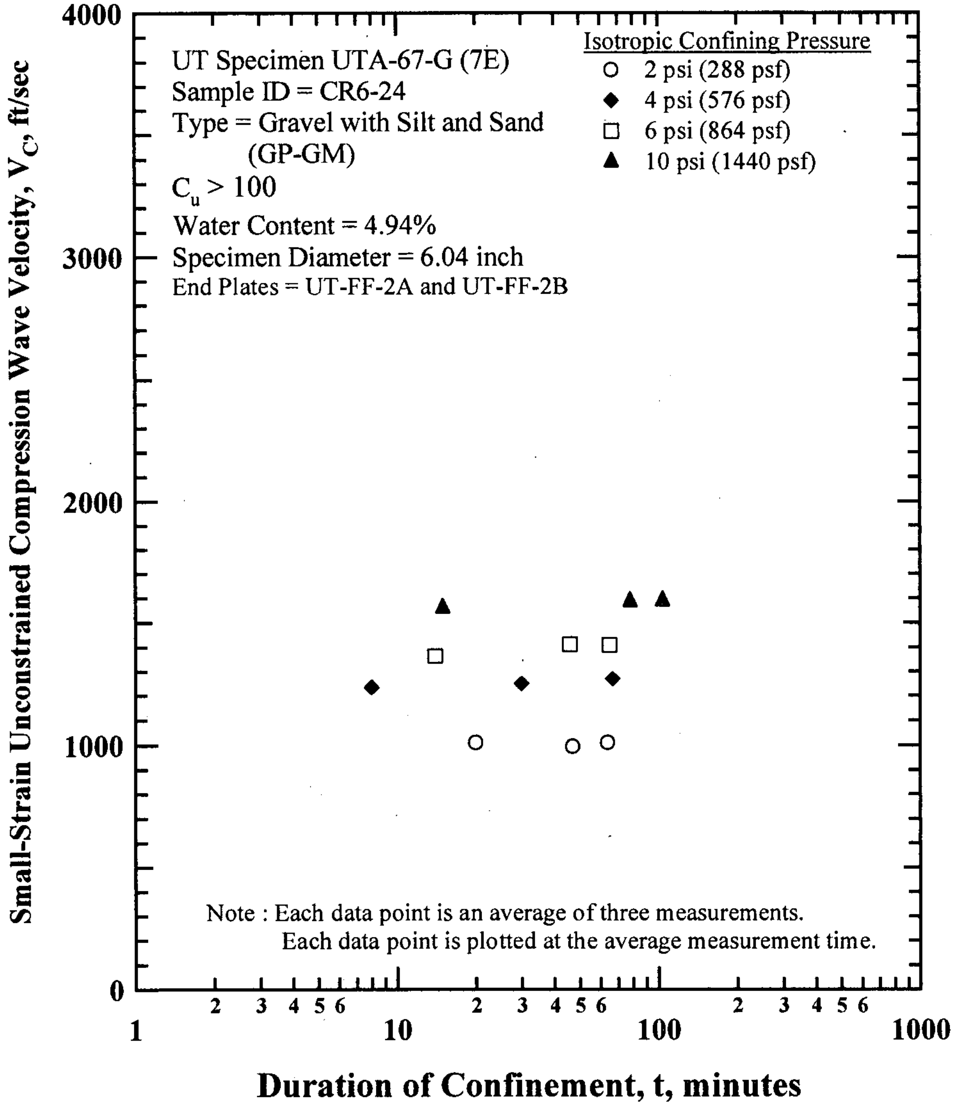


Figure J.2 Variation in Small-Strain Unconstrained Compression Wave Velocities (V_C) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

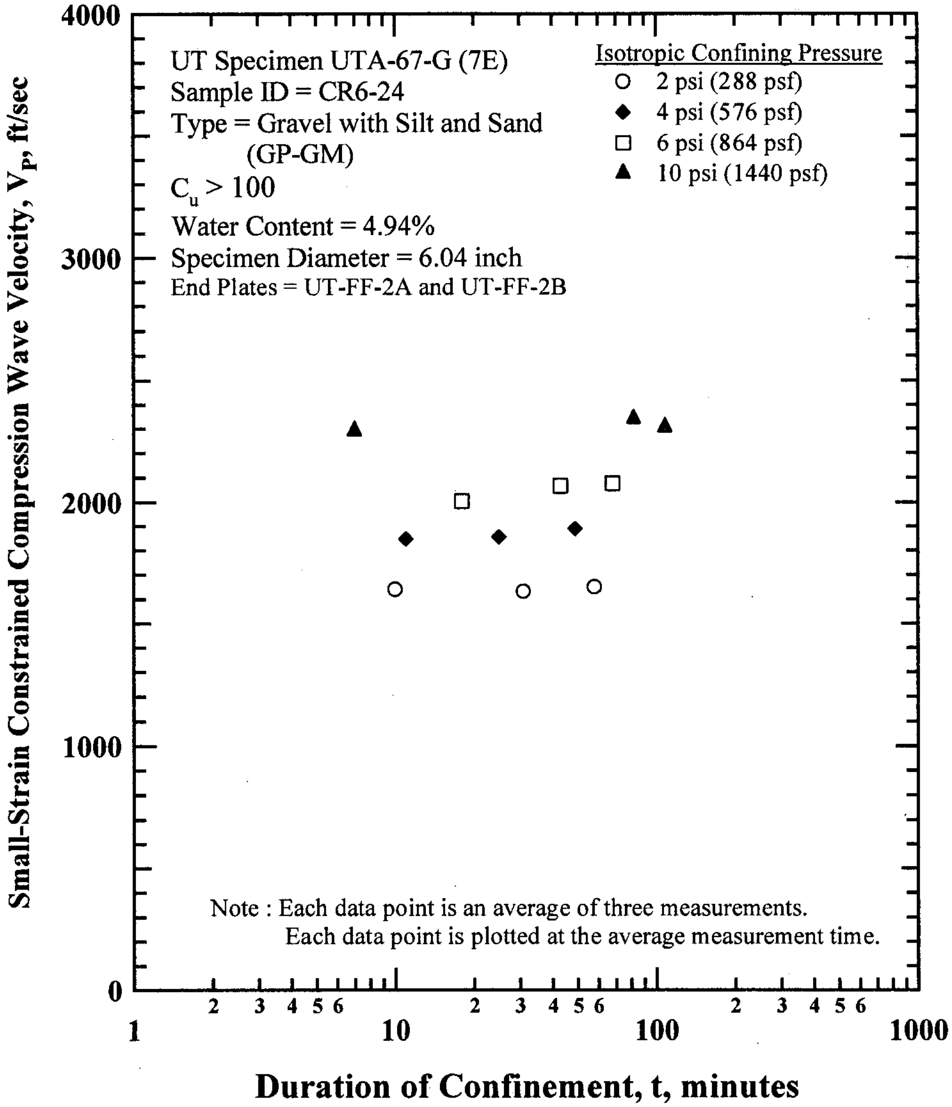


Figure J.3 Variation in Small-Strain Constrained Compression Wave Velocities (V_P) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

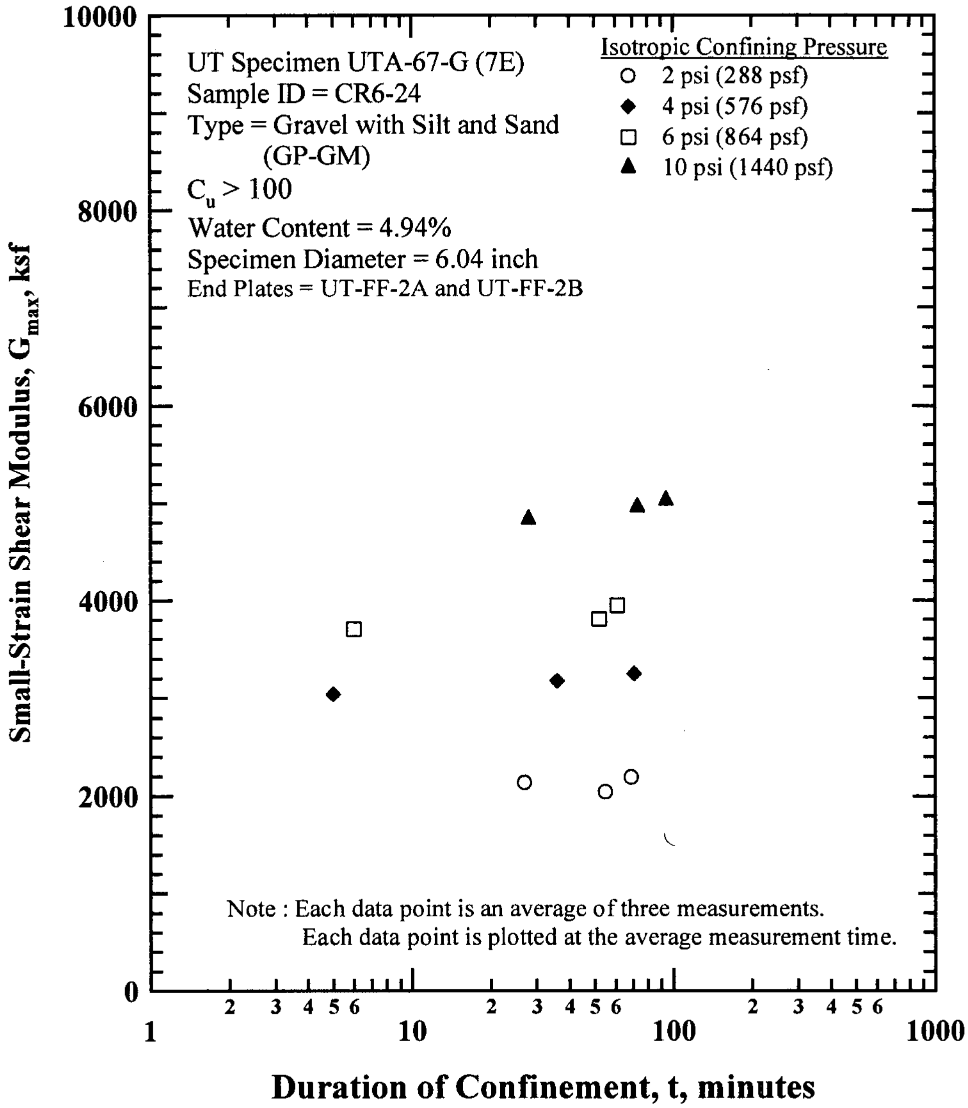


Figure J.4 Variation in Small-Strain Shear Modulus (G_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

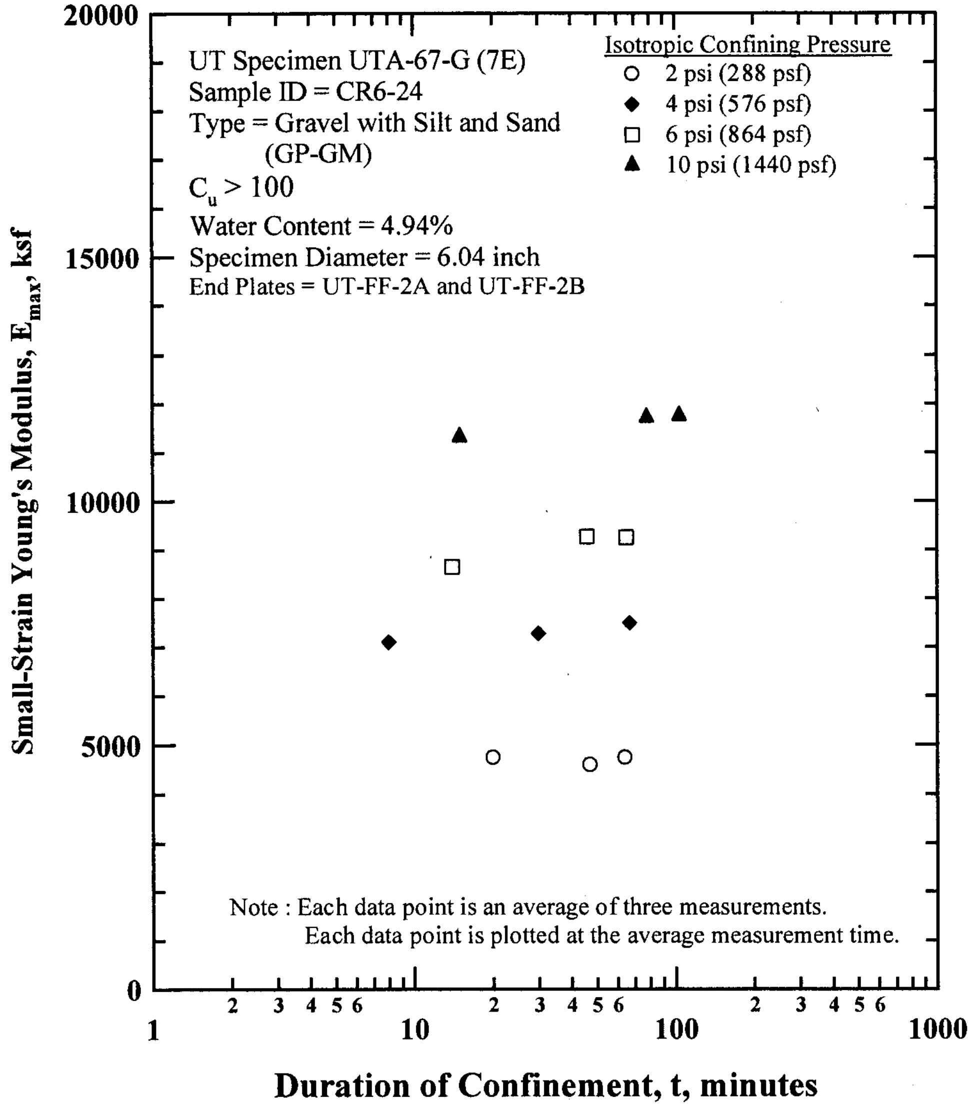


Figure J.5 Variation in Small-Strain Young's Modulus (E_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

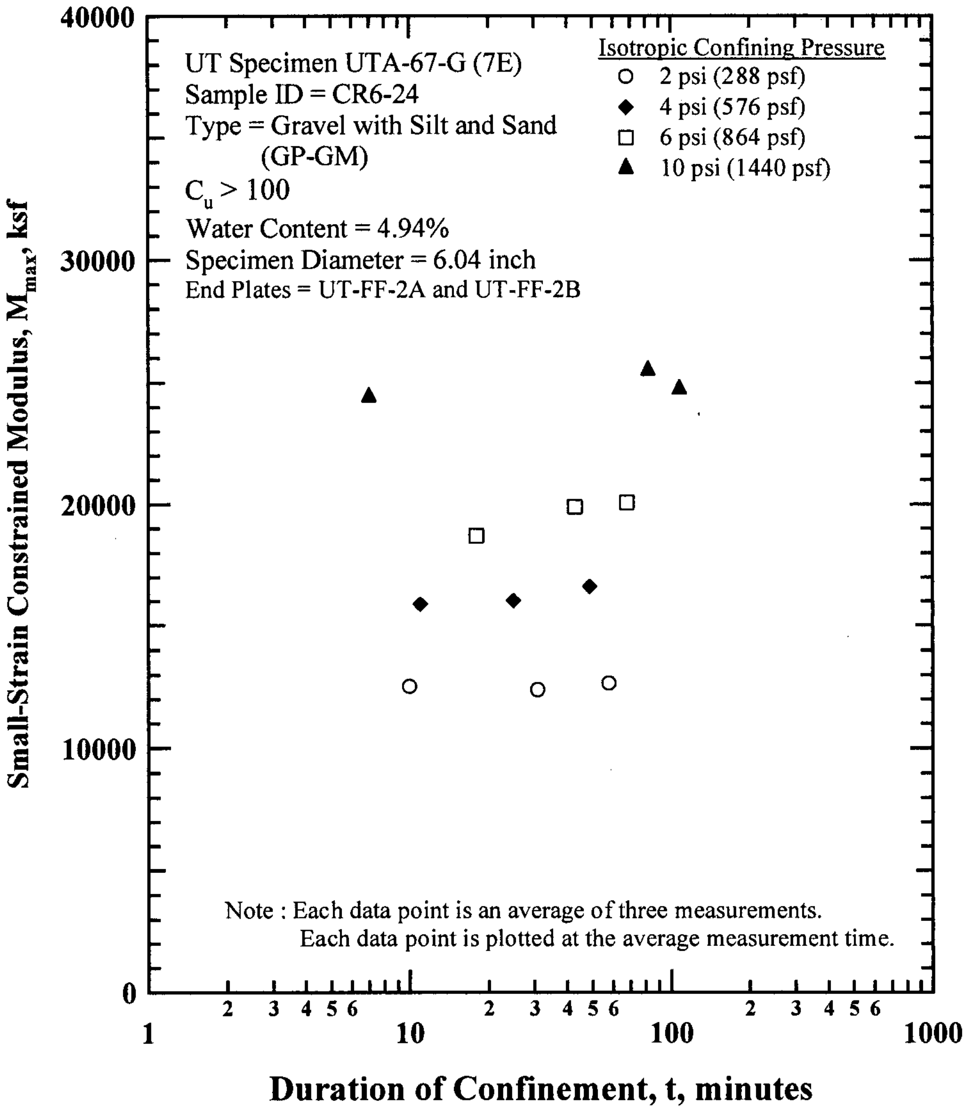


Figure J.6 Variation in Small-Strain Constrained Modulus (M_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

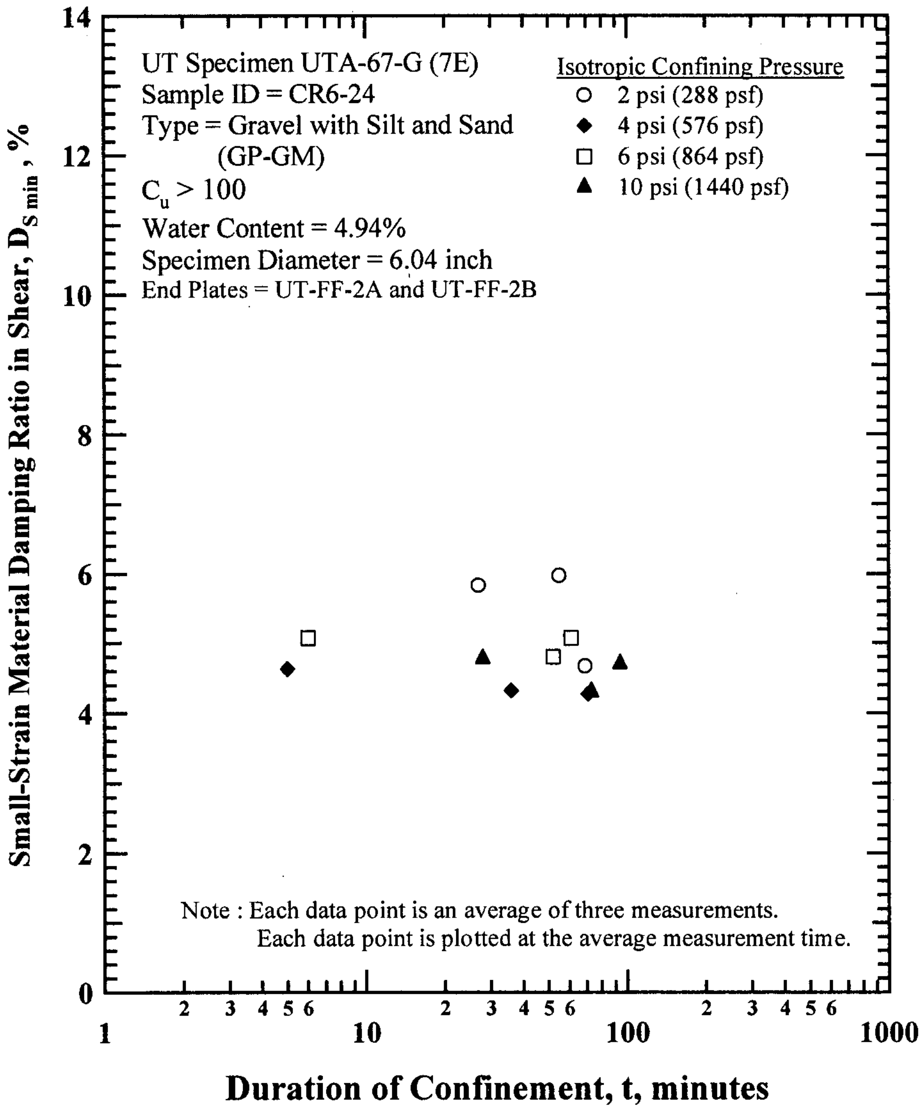


Figure J.7 Variation in Small-Strain Material Damping Ratio in Shear ($D_{S\ min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

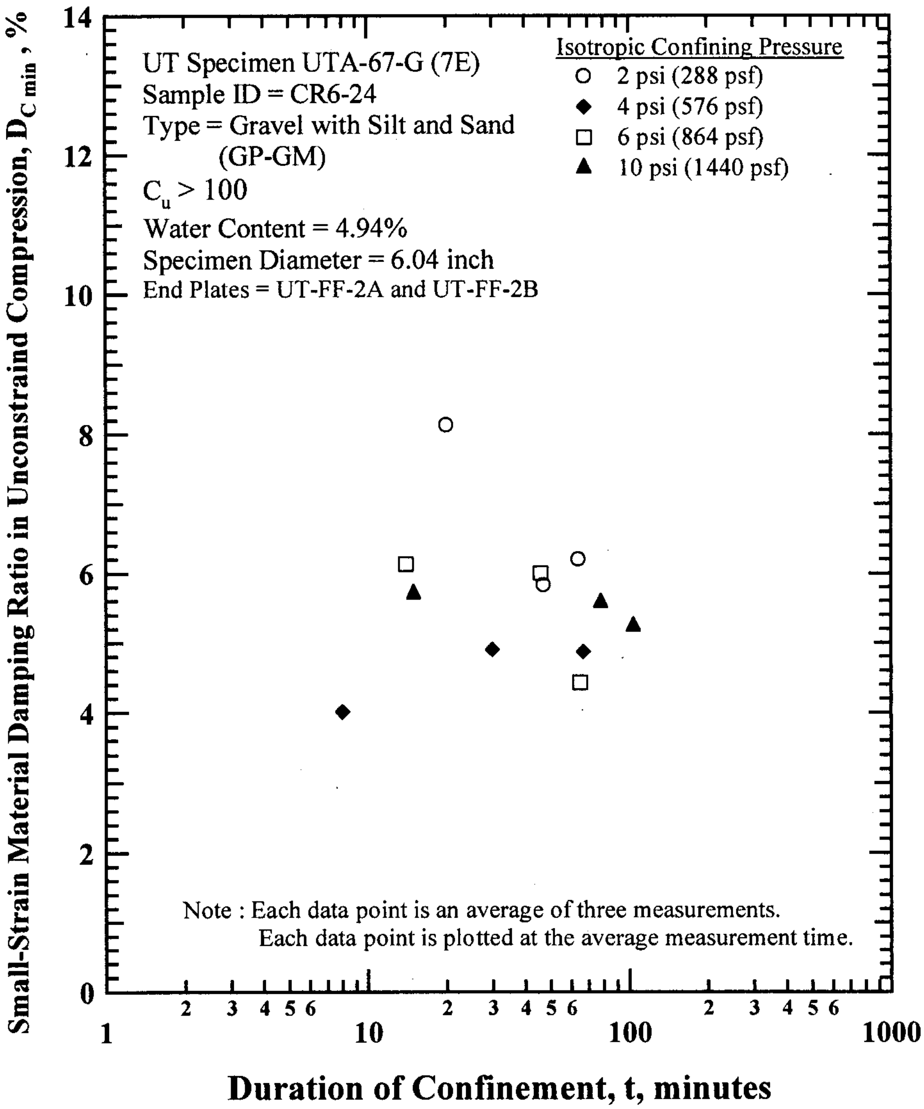
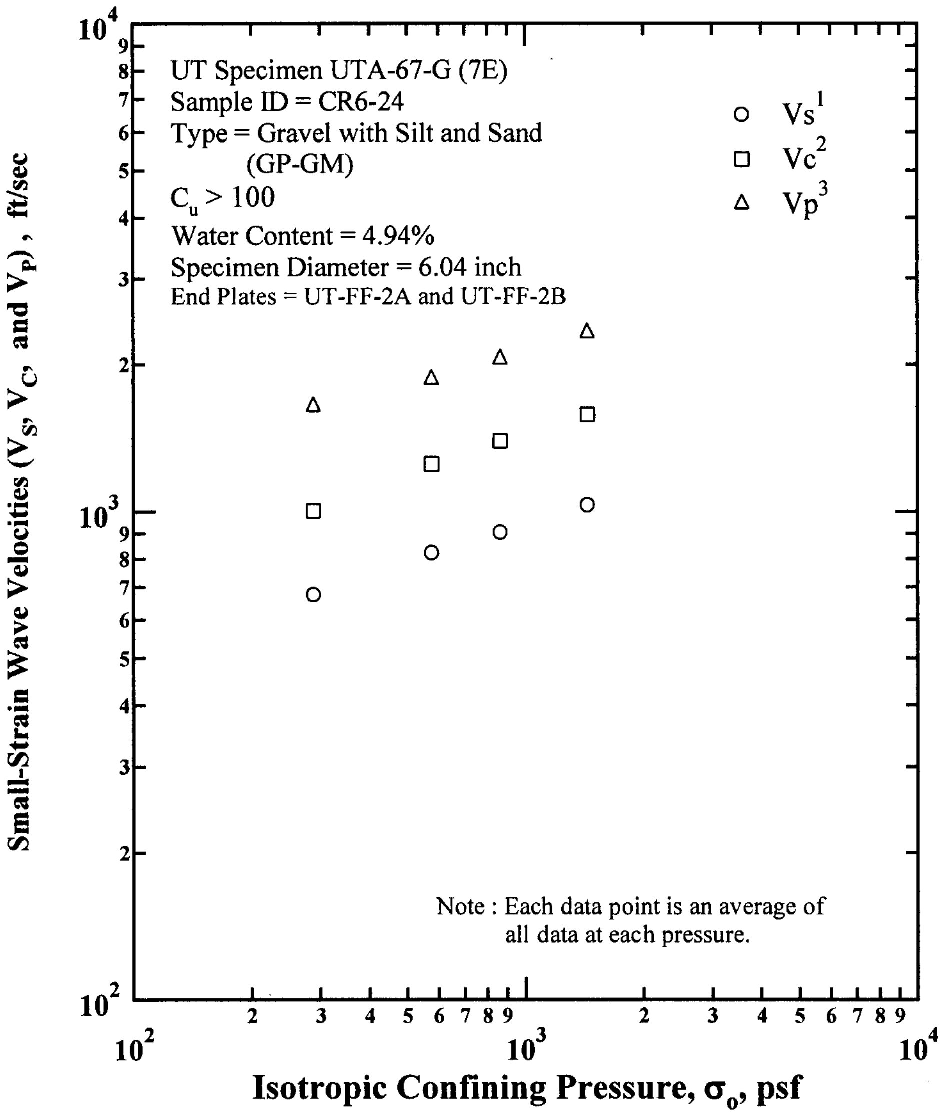
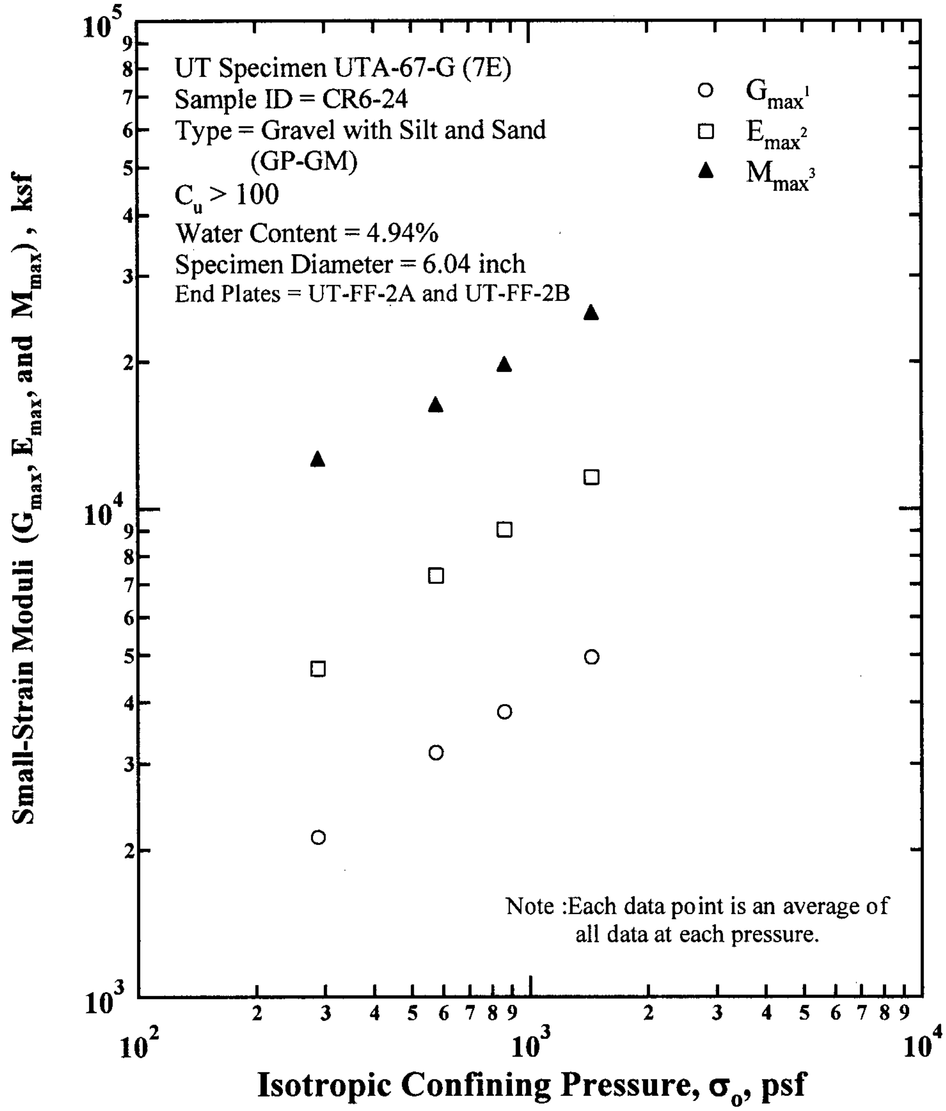


Figure J.8 Variation in Small-Strain Material Damping Ratio in Unconstrained Compression ($D_{C\ min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)



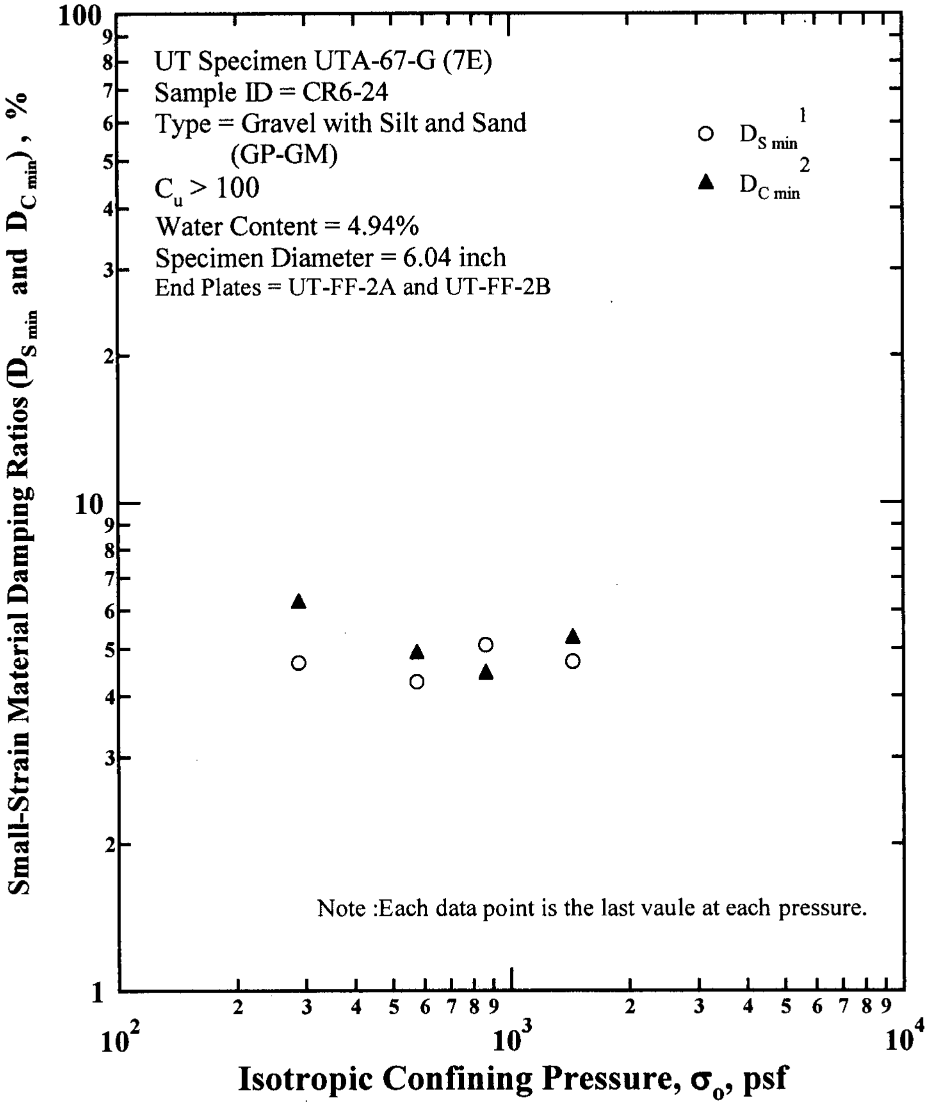
Notes :1. V_S=Small-Strain Shear Wave Velocity
2. V_C=Small-Strain Unconstrained Compression Wave Velocity
3. V_P=Small-Strain Constrained Compression Wave Velocity

Figure J.9 Variation in Small-Strain Wave Velocities (V_S, V_C, and V_P) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)



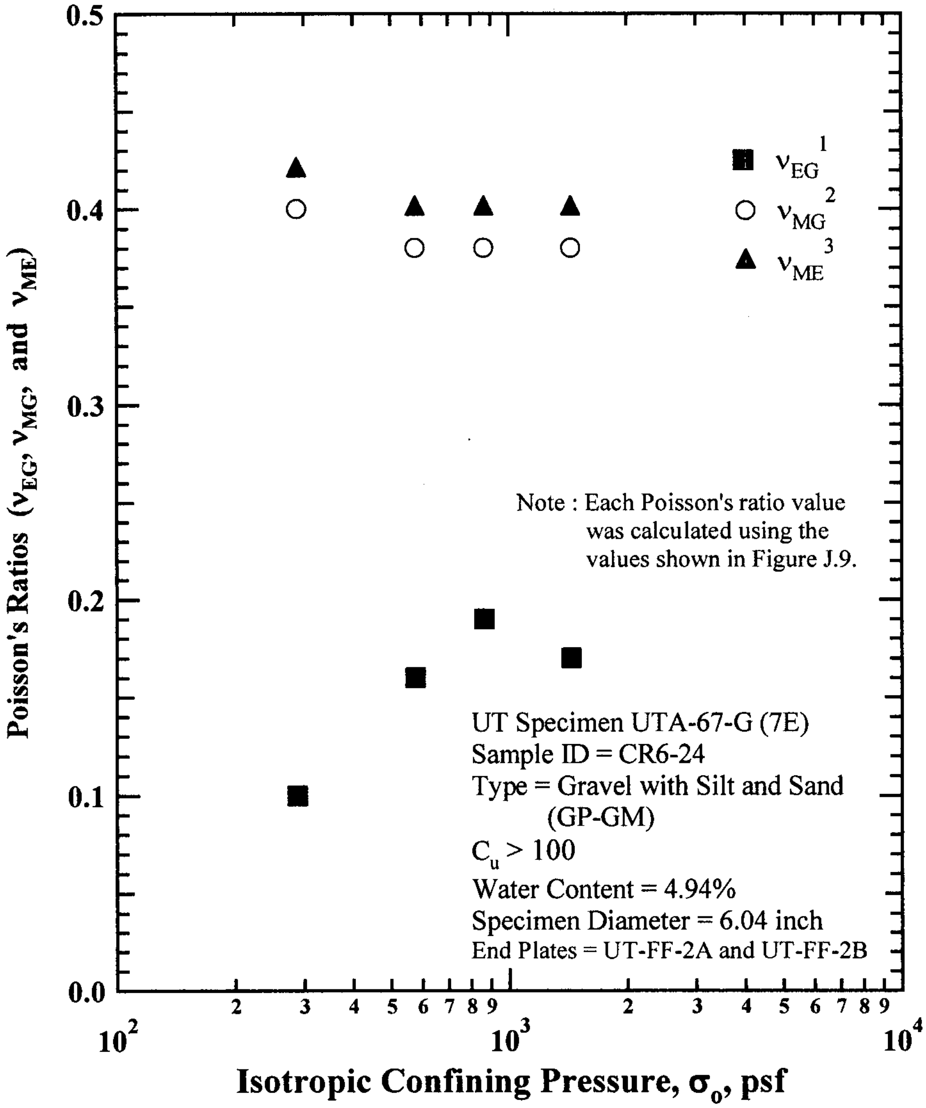
Notes :1. G_{max}=Small-Strain Shear Modulus
2. E_{max}=Small-Strain Young's Modulus
2. M_{max}=Small-Strain Constrained Modulus

Figure J.10 Variation in Small-Strained Moduli (G_{max}, E_{max}, and M_{max}) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)



Notes :1. $D_{S\,min}$ = Small-Strain Material Damping Ratio in Shear
2. $D_{C\,min}$ = Small-Strain Material Damping Ratio in Unconstrained Compression

Figure J.11 Variation in Small-Strained Material Damping Ratios ($D_{S\,min}$ and $D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-G (7E)



Notes :1. ν_{EG}=Poisson's Ratios from the Relationship between V_C and V_S

2. ν_{MG}=Poisson's Ratios from the Relationship between V_P and V_S

3. ν_{ME}=Poisson's Ratios from the Relationship between V_P and V_C

Figure J.12 Variation in Poisson's Ratios (ν_{EG}, ν_{MG}, and ν_{ME}) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-G (7E)

Table J.1 Variations in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-G (7E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Shear Modulus, G_{max}^*		Small-Strain Shear Wave Velocity, V_S^*	Small-Strain Material Damping Ratio in Shear, $D_{S\ min}^*$
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	27	2135	102.3	677	5.83
2	288	14	55	2041	97.9	662	5.97
2	288	14	69	2190	105.0	686	4.67
4	576	28	5	3034	145.4	807	4.63
4	576	28	36	3171	152.0	825	4.32
4	576	28	71	3244	155.5	835	4.27
6	864	41	6	3701	177.4	892	5.07
6	864	41	52	3806	182.5	904	4.80
6	864	41	61	3947	189.2	921	5.07
10	1440	69	28	4829	231.5	1018	4.77
10	1440	69	73	4957	237.6	1032	4.30
10	1440	69	94	5026	240.9	1039	4.70

Note : * Average of three measurements

Table J.2 Variation in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

Isotropic Confining Pressure, σ_o			Small-Strain Shear Modulus, G_{max}^*		Small-Strain Shear Wave Velocity, V_S^*	Small-Strain Material Damping Ratio in Shear, $D_{S\ min}^{**}$
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	2122	102	675	4.67
4	576	28	3150	151	822	4.27
6	864	41	3818	183	905	5.07
10	1440	69	4937	237	1030	4.70

Notes : * Average of all data at each pressure
** The last value at each pressure

Table J.3 Variations in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-G (7E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Young's Modulus, E_{max} *		Small-Strain Unconstrained Compression Wave Velocity, V_C *	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$ *
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	20	4736	227.0	1009	8.13
2	288	14	47	4588	220.0	993	5.83
2	288	14	64	4736	227.0	1009	6.20
4	576	28	8	7092	340.0	1234	4.01
4	576	28	30	7266	348.3	1249	4.90
4	576	28	67	7488	359.0	1268	4.87
6	864	41	14	8652	414.8	1363	6.13
6	864	41	46	9265	444.2	1411	6.00
6	864	41	65	9245	443.2	1409	4.43
10	1440	69	15	11312	542.3	1559	5.70
10	1440	69	78	11706	561.2	1586	5.57
10	1440	69	104	11741	562.9	1588	5.23

Note : * Average of three measurements

Table J.4 Variation in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

Isotropic Confining Pressure, σ_o			Small-Strain Young's Modulus, E_{max} *		Small-Strain Unconstrained Compression Wave Velocity, V_C *	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$ **
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	4687	225	1003	6.20
4	576	28	7282	349	1251	4.87
6	864	41	9054	434	1394	4.43
10	1440	69	11586	555	1578	5.23

Notes : * Average of all data at each pressure
** The last value at each pressure

Table J.5 Variations in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-G (7E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)
2	288	14	10	12525	600.4	1640
2	288	14	31	12390	594.0	1631
2	288	14	58	12660	606.9	1649
4	576	28	11	15862	760.4	1846
4	576	28	25	16018	767.9	1855
4	576	28	49	16606	796.1	1889
6	864	41	18	18696	896.3	2004
6	864	41	43	19892	953.6	2067
6	864	41	68	20057	961.5	2076
10	1440	69	7	24410	1170.2	2290
10	1440	69	82	25474	1221.2	2339
10	1440	69	108	24709	1184.6	2304

Note : * Average of three measurements

Table J.6 Variation in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

Isotropic Confining Pressure, σ_o			Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)
2	288	14	12525	600	1640
4	576	28	16162	775	1863
6	864	41	19548	937	2049
10	1440	69	24864	1192	2311

Note : * Average of all data at each pressure

Table J.7 Variation in Poisson's Ratios with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-G (7E)

Isotropic Confining Pressure, σ_o			Poisson's Ratio		
(psi)	(psf)	(kPa)	ν_{EG}[1]	ν_{MG}[2]	ν_{ME}[3]
2	288	14	0.08	0.40	0.42
4	576	28	0.15	0.38	0.40
6	864	41	0.17	0.38	0.40
10	1440	69	0.17	0.37	0.40

Notes : 1. Poisson's ratio from the relationship between V_C and V_S tabulated in Tables J.4 and J.2, respectively.

2. Poisson's ratio from the relationship between V_P and V_S tabulated in Tables J.6 and J.2, respectively.

3. Poisson's ratio from the relationship between V_P and V_C tabulated in Tables J.6 and J.4, respectively.

APPENDIX K

(Free-Free Tests)

UT Specimen UTA-67-D (4E)
Sample ID : CR6-18
(Vulcan Quarry Statistical Avg. Sample)
Type = Scalped, Blended Gravel with Silt and Sand (GP-GM*)
Uniformity Coefficient, $C_u > 100$
Specimen Diameter = 2.80 inch

Water Content, w = 4.39 %
$G_S = 2.716$*
Degree of Saturation = 50.1 %
Total Unit Weight, $\gamma_t = 142.7$ lb/ft^3
Dry Unit Weight, $\gamma_d = 136.9$ lb/ft^3
Target : $\gamma_d = 136.4$ lb/ft$^3 \pm 1$ lb/ft^3
w= 4.6 % ± 1.0 %

* **Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

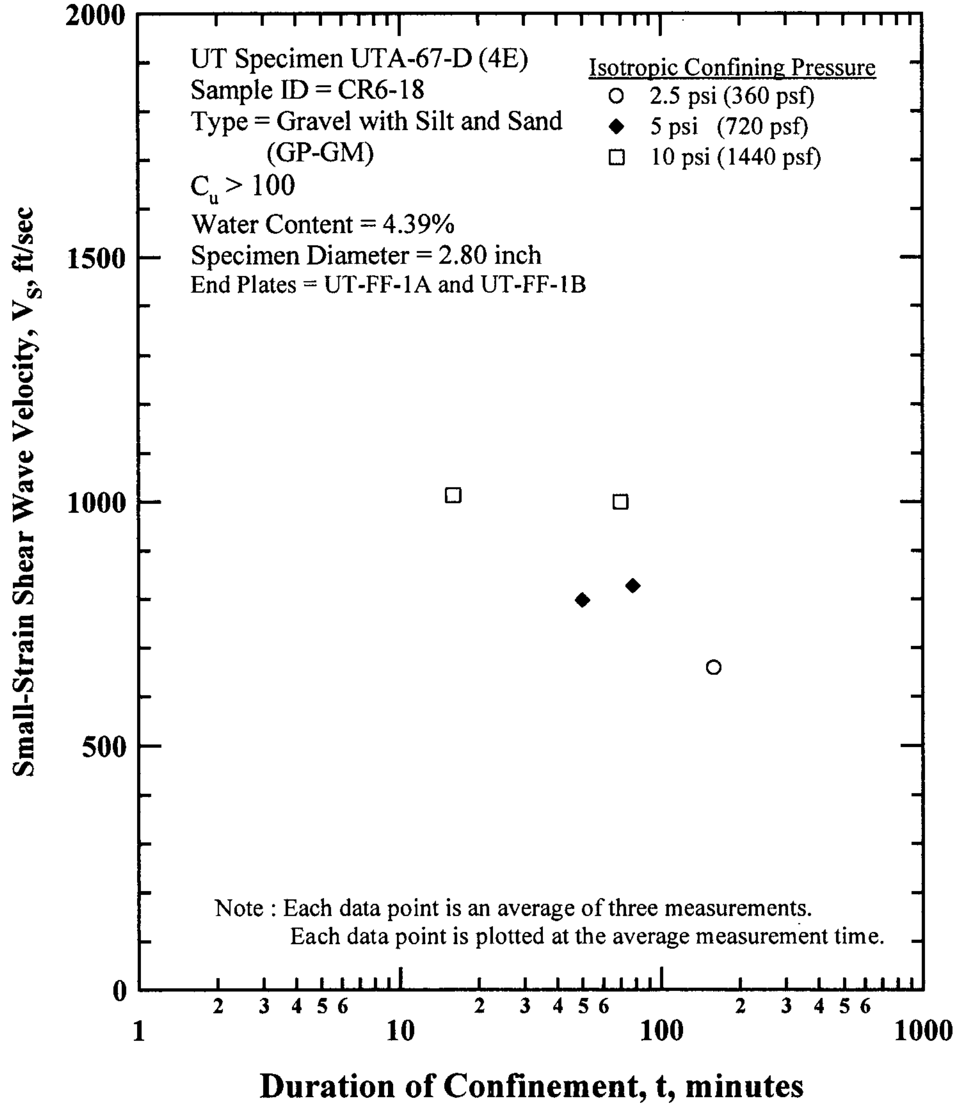


Figure K.1 Variation in Small-Strain Shear Wave Velocities (V_S) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)

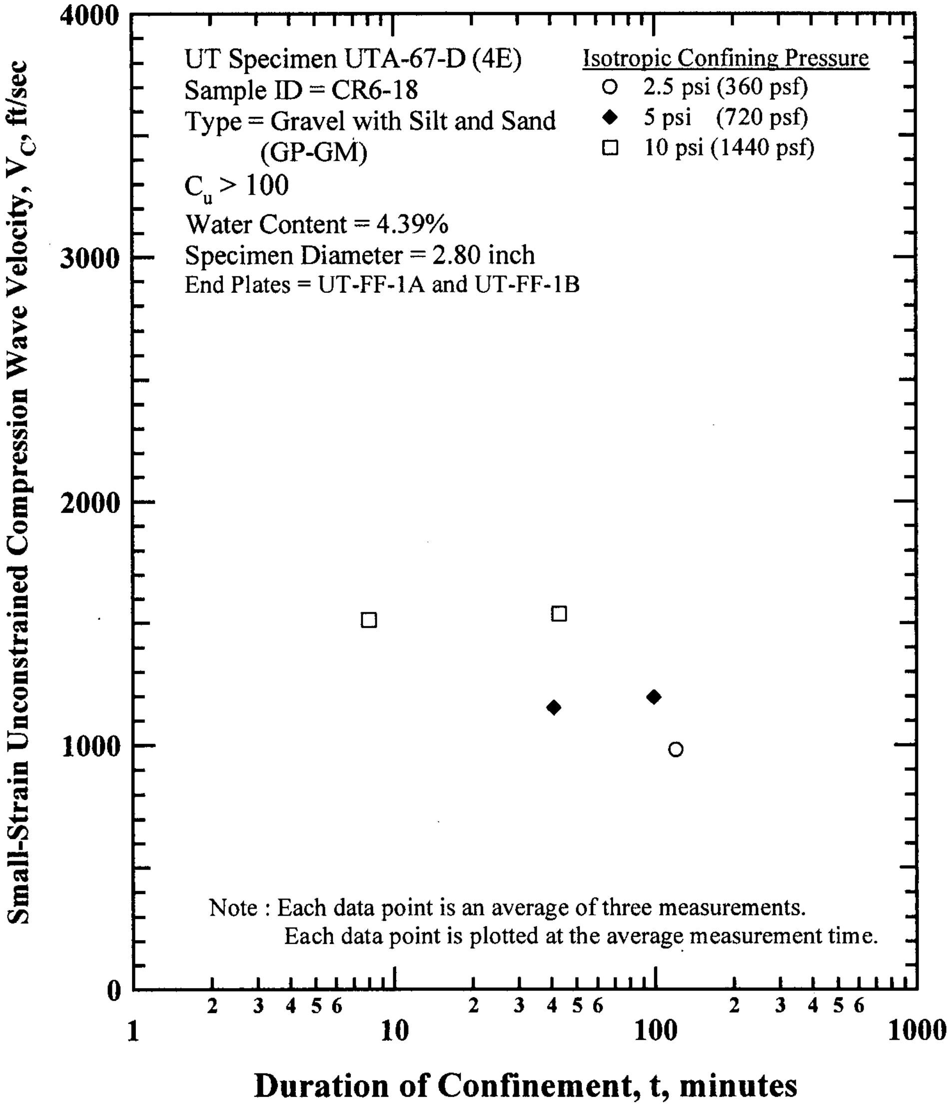


Figure K.2 Variation in Small-Strain Unconstrained Compression Wave Velocities (V_C) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)

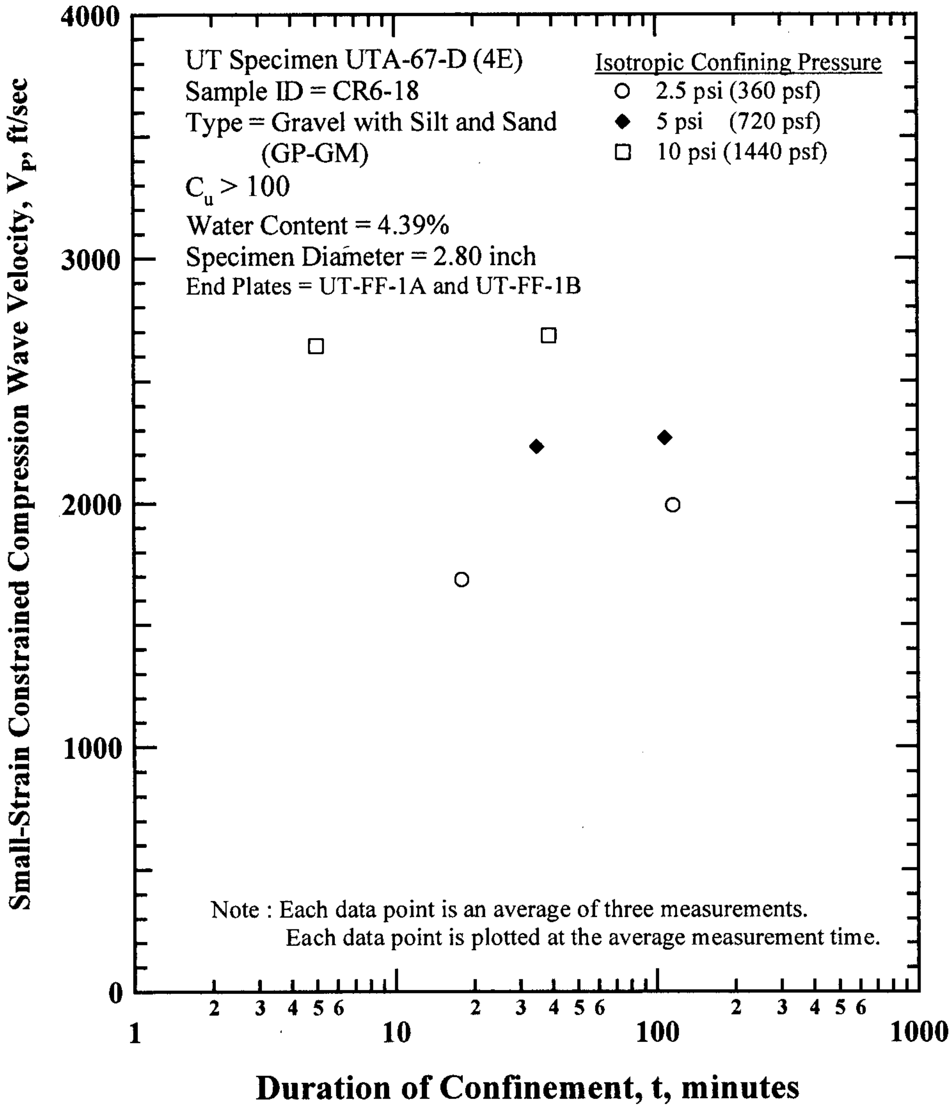


Figure K.3 Variation in Small-Strain Constrained Compression Wave Velocities (V_P) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)

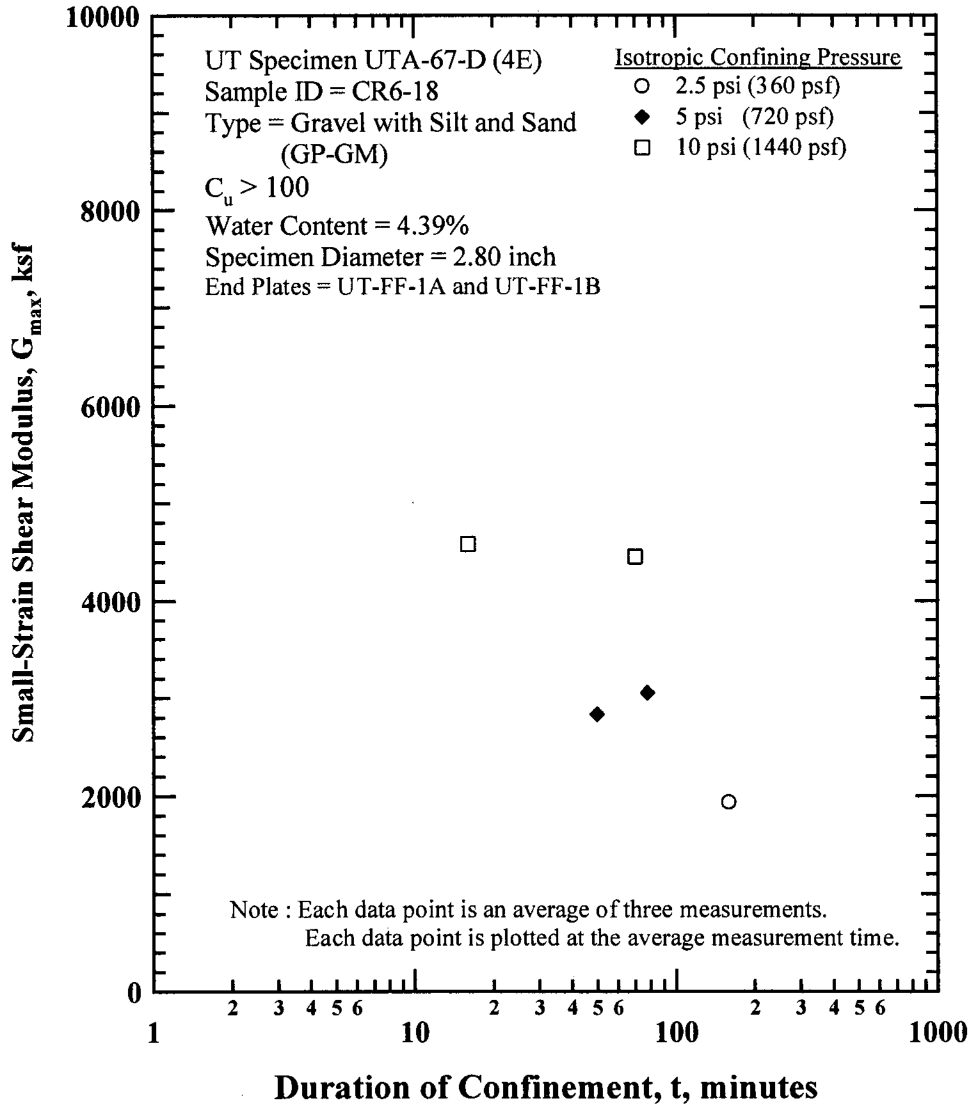


Figure K.4 Variation in Small-Strain Shear Modulus (G_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)

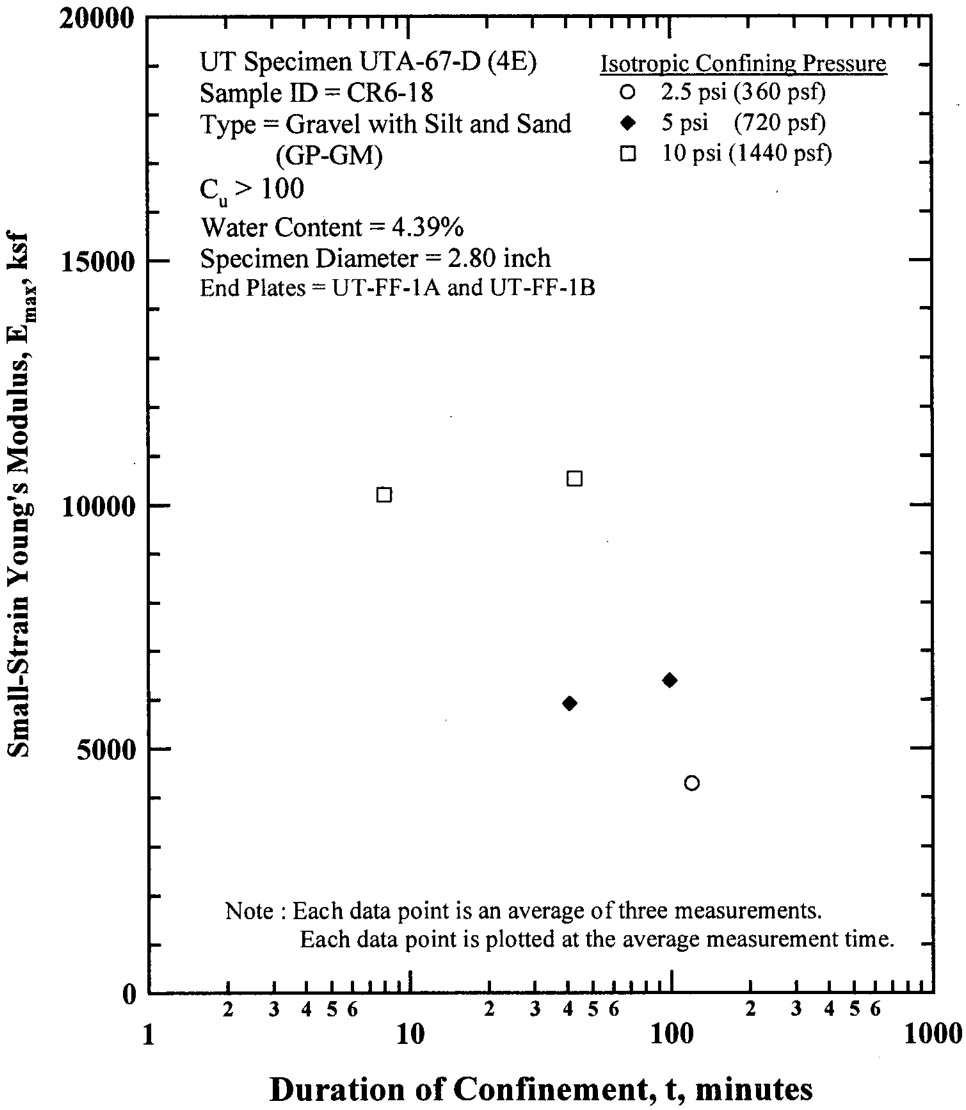


Figure K.5 Variation in Small-Strain Young's Modulus (E_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)

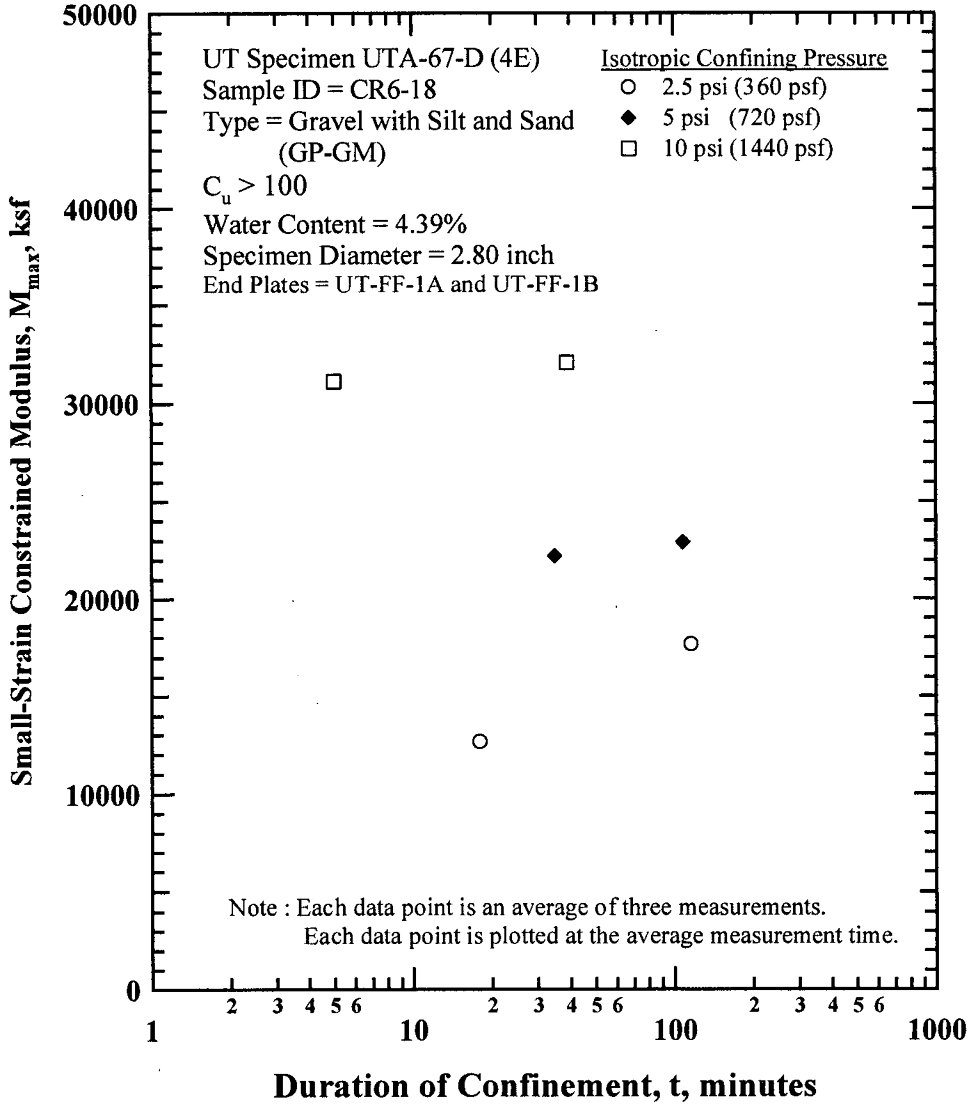


Figure K.6 Variation in Small-Strain Constrained Modulus (M_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)

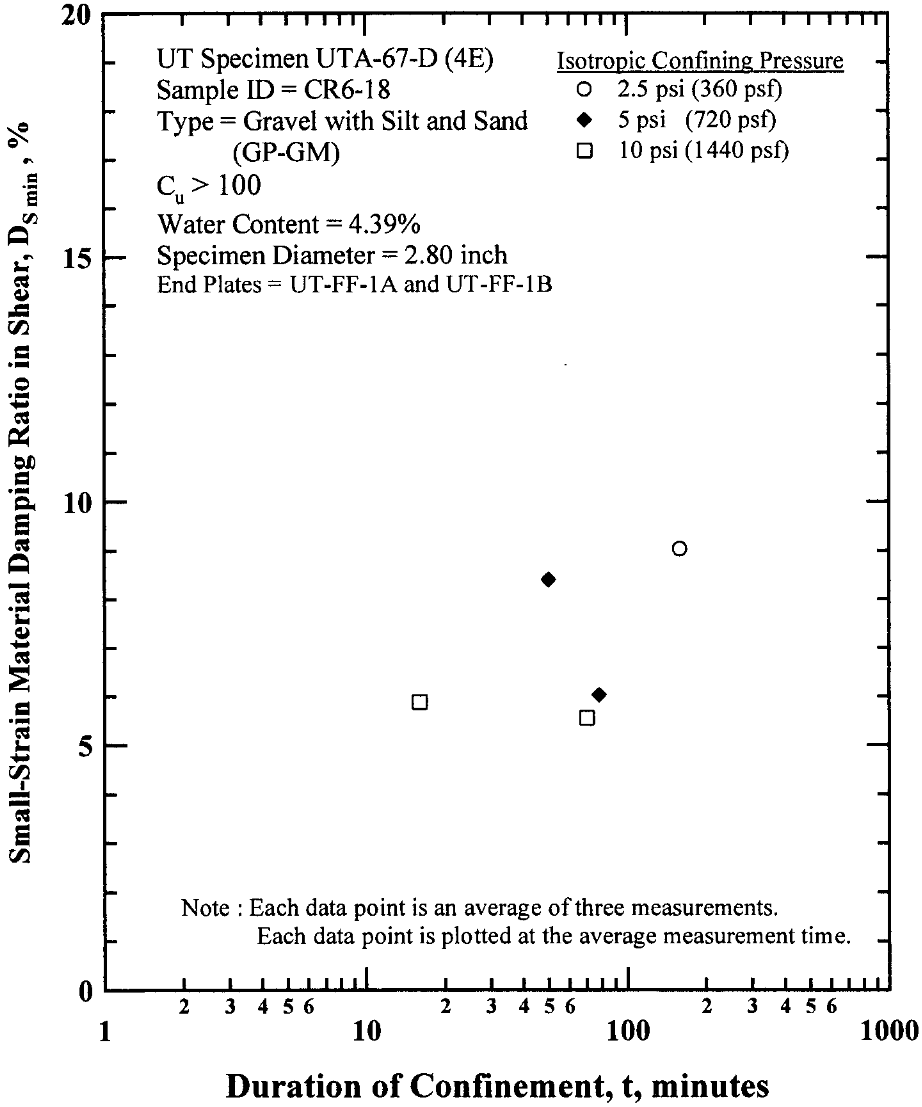


Figure K.7 Variation in Small-Strain Material Damping Ratio in Shear ($D_{S\,min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)

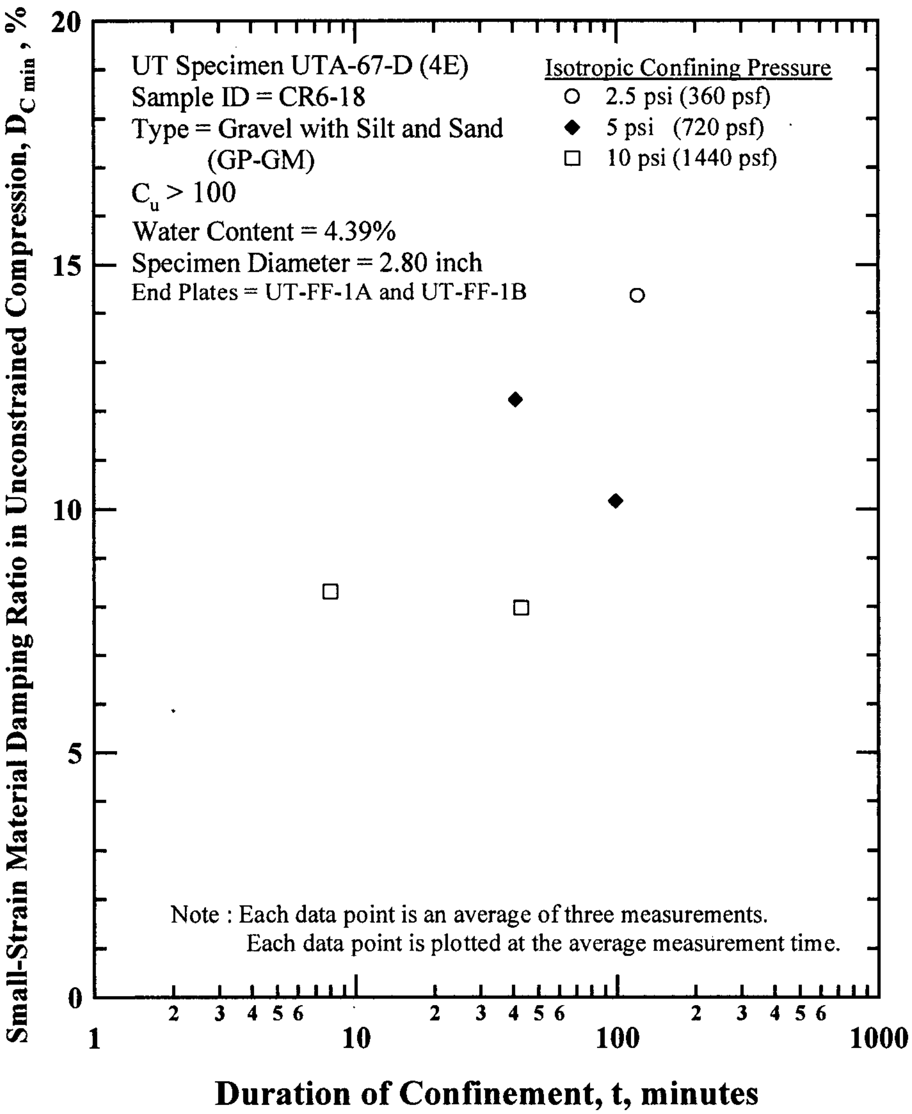
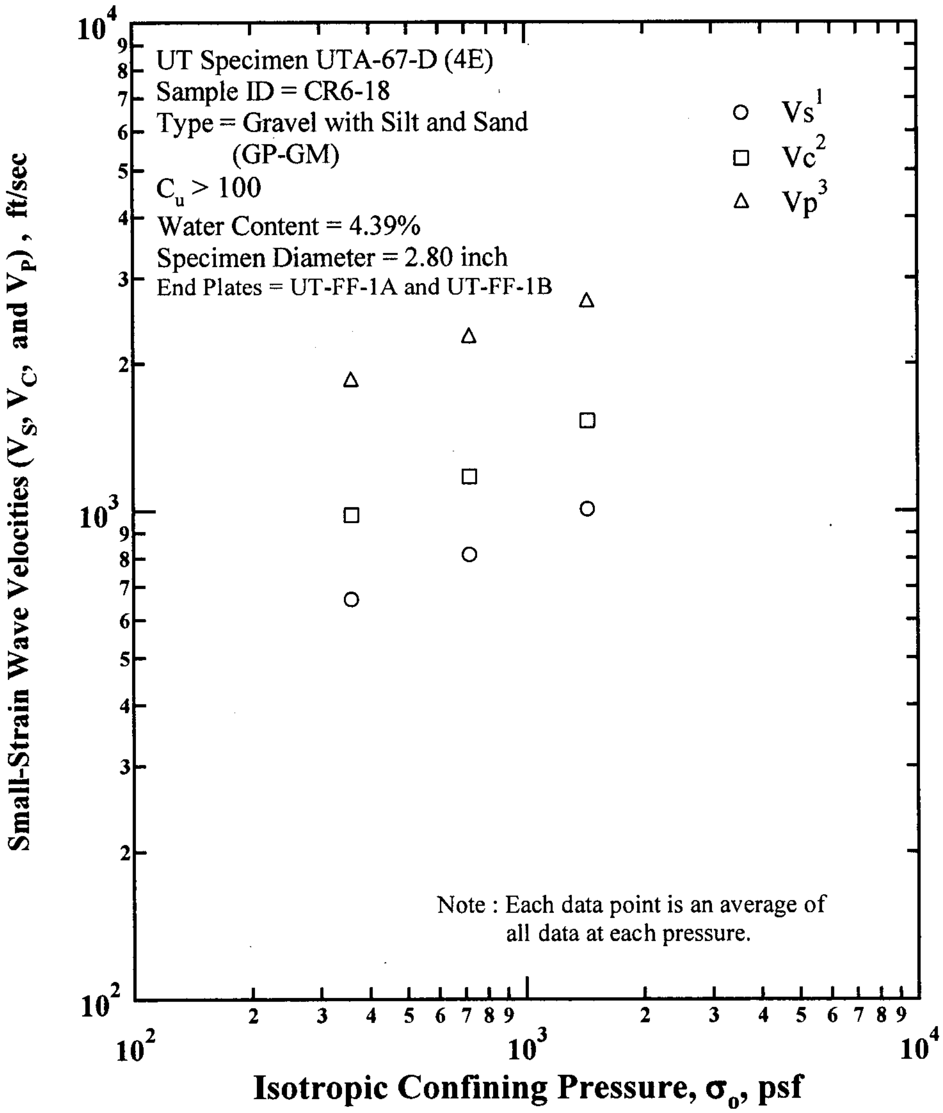
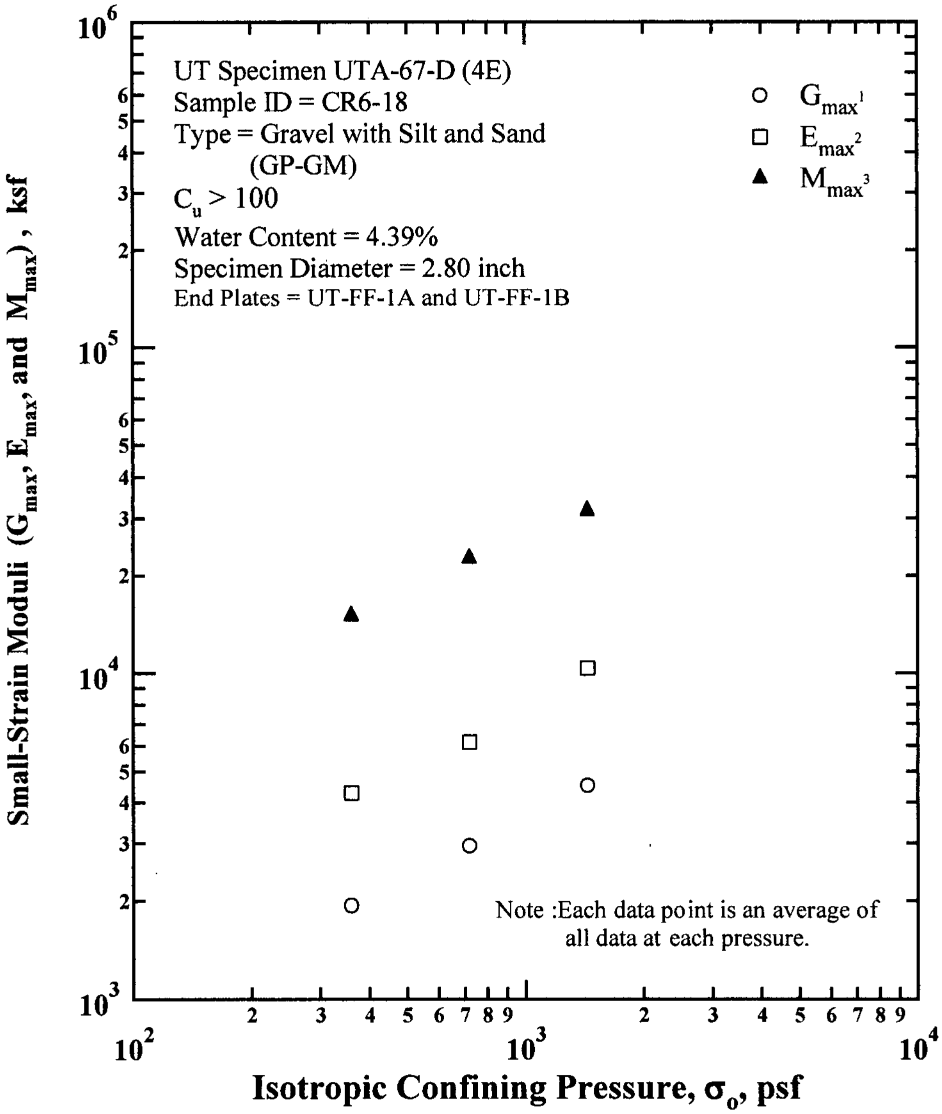


Figure K.8 Variation in Small-Strain Material Damping Ratio in Unconstrained Compression ($D_{C\ min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)



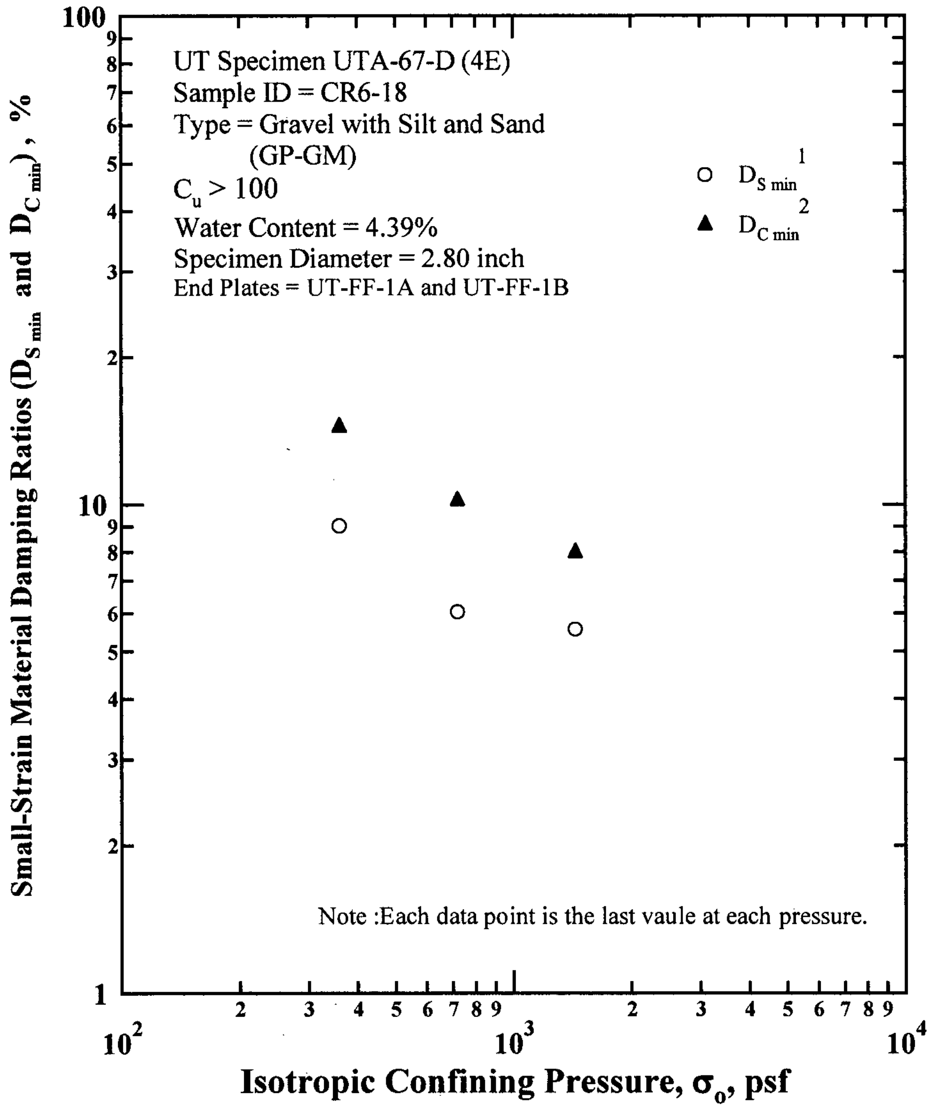
Notes :1. V_S=Small-Strain Shear Wave Velocity
2. V_C=Small-Strain Unconstrained Compression Wave Velocity
3. V_P=Small-Strain Constrained Compression Wave Velocity

Figure K.9 Variation in Small-Strain Wave Velocities (V_S, V_C, and V_P) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)



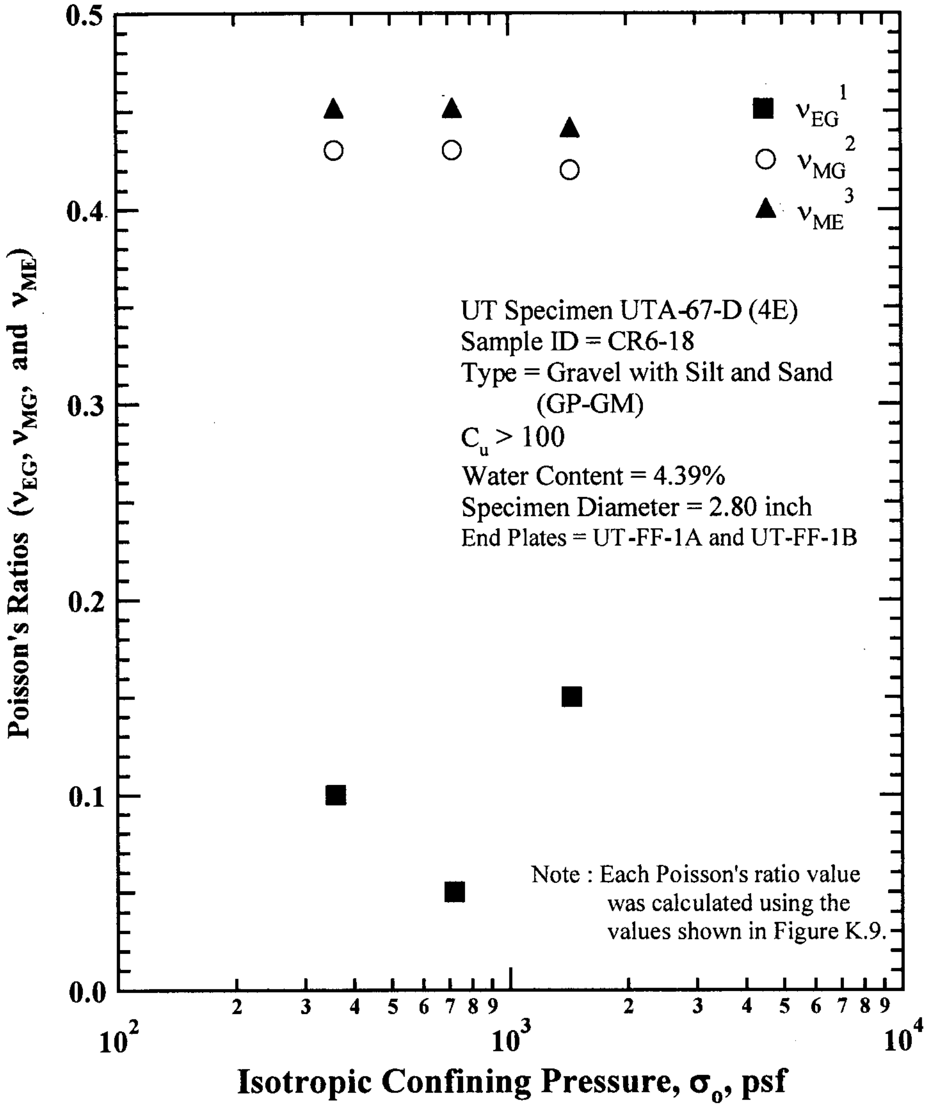
Notes :1.G_{max}=Small-Strain Shear Modulus
2. E_{max}=Small-Strain Young's Modulus
2. M_{max}=Small-Strain Constrained Modulus

Figure K.10 Variation in Small-Strained Moduli (G_{max}, E_{max} , and M_{max}) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4E)



Notes :1.$D_{S\ min}$ = Small-Strain Material Damping Ratio in Shear
2.$D_{C\ min}$ = Small-Strain Material Damping Ratio in Unconstrained Compression

Figure K.11 Variation in Small-Strained Material Damping Ratios ($D_{S\ min}$ and $D_{C\ min}$) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-D (4E)



Notes :1. ν_{EG}=Poisson's Ratios from the Relationship between V_C and V_S

2. ν_{MG}=Poisson's Ratios from the Relationship between V_P and V_S

3. ν_{ME}=Poisson's Ratios from the Relationship between V_P and V_C

Figure K.12 Variation in Poisson's Ratios (ν_{EG}, ν_{MG}, and ν_{ME}) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-D (4E)

Table K..1 Variations in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Shear Modulus, G_{max} *		Small-Strain Shear Wave Velocity, V_S *	Small-Strain Material Damping Ratio in Shear, $D_{S\ min}$ *
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2.5	360	17	159	1937	92.9	659	9.03
5	720	34	50	2832	135.7	797	8.40
5	720	34	78	3050	146.2	827	6.03
10	1440	69	16	4577	219.4	1013	5.87
10	1440	69	70	4450	213.3	999	5.55

Note : * Average of three measurements

Table K.2 Variation in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Small-Strain Shear Modulus, G_{max} *		Small-Strain Shear Wave Velocity, V_S *	Small-Strain Material Damping Ratio in Shear, $D_{S\ min}$ **
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2.5	360	17	1937	93	659	9.03
5	720	34	2941	141	812	6.03
10	1440	69	4514	216	1006	5.55

Notes : * Average of all data at each pressure
** The last value at each pressure

Table K.3 Variations in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Young's Modulus, E_{max} *		Small-Strain Unconstrained Compression Wave Velocity, V_C *	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$ *
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2.5	360	17	120	4274	204.9	979	14.35
5	720	34	41	5915	283.6	1152	12.22
5	720	34	99	6383	306.0	1196	10.16
10	1440	69	8	10207	489.3	1513	8.31
10	1440	69	43	10536	505.1	1537	7.97

Note : * Average of three measurements

Table K.4 Variation in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Small-Strain Young's Modulus, E_{max} *		Small-Strain Unconstrained Compression Wave Velocity, V_C *	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$ **
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2.5	360	17	4274	205	979	14.35
5	720	34	6149	295	1174	10.16
10	1440	69	10371	497	1525	7.97

Notes : * Average of all data at each pressure
** The last value at each pressure

Table K.5 Variations in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)
2.5	360	17	18	12651	606.5	1684
2.5	360	17	116	17661	846.7	1990
5	720	34	35	22186	1063.6	2231
5	720	34	108	22907	1098.2	2267
10	1440	69	5	31124	1492.1	2642
10	1440	69	39	32081	1538.0	2682

Note : * Average of three measurements

Table K.6 Variation in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)
2.5	360	17	15156	727	1837
5	720	34	22547	1081	2249
10	1440	69	31602	1515	2662

Note : * Average of all data at each pressure

Table K.7 Variation in Poisson's Ratios with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-D (4I)

Isotropic Confining Pressure, σ_o			Poisson's Ratio		
(psi)	(psf)	(kPa)	ν_{EG} [1]	ν_{MG} [2]	ν_{ME} [3]
2.5	360	17	0.10	0.43	0.45
5	720	34	0.05	0.43	0.45
10	1440	69	0.15	0.42	0.44

Notes : 1. Poisson's ratio from the relationship between V_C and V_S tabulated in Tables K.4 and K.2, respectively.

2. Poisson's ratio from the relationship between V_P and V_S tabulated in Tables K.6 and K.2, respectively.

3. Poisson's ratio from the relationship between V_P and V_C tabulated in Tables K.6 and K.4, respectively.

APPENDIX L
(Free-Free Tests)

UT Specimen UTA-67-F (6I)
Sample ID : 57-9
Type = Scalped, Blended Gravel (GP)
Uniformity Coefficient, C_u = 1.9
Specimen Diameter = 6.01 inch

Water Content, w = 0.87 %
G_S = 2.833*
Degree of Saturation = 3.1 %
Total Unit Weight, γ_t = 98.8 lb/ft^3
Dry Unit Weight, γ_d = 98.0 lb/ft^3
Target : γ_d= 98.6 lb/ft^3 ± 1 lb/ft^3
w= 1.0 % ± 1.0 %

* **Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

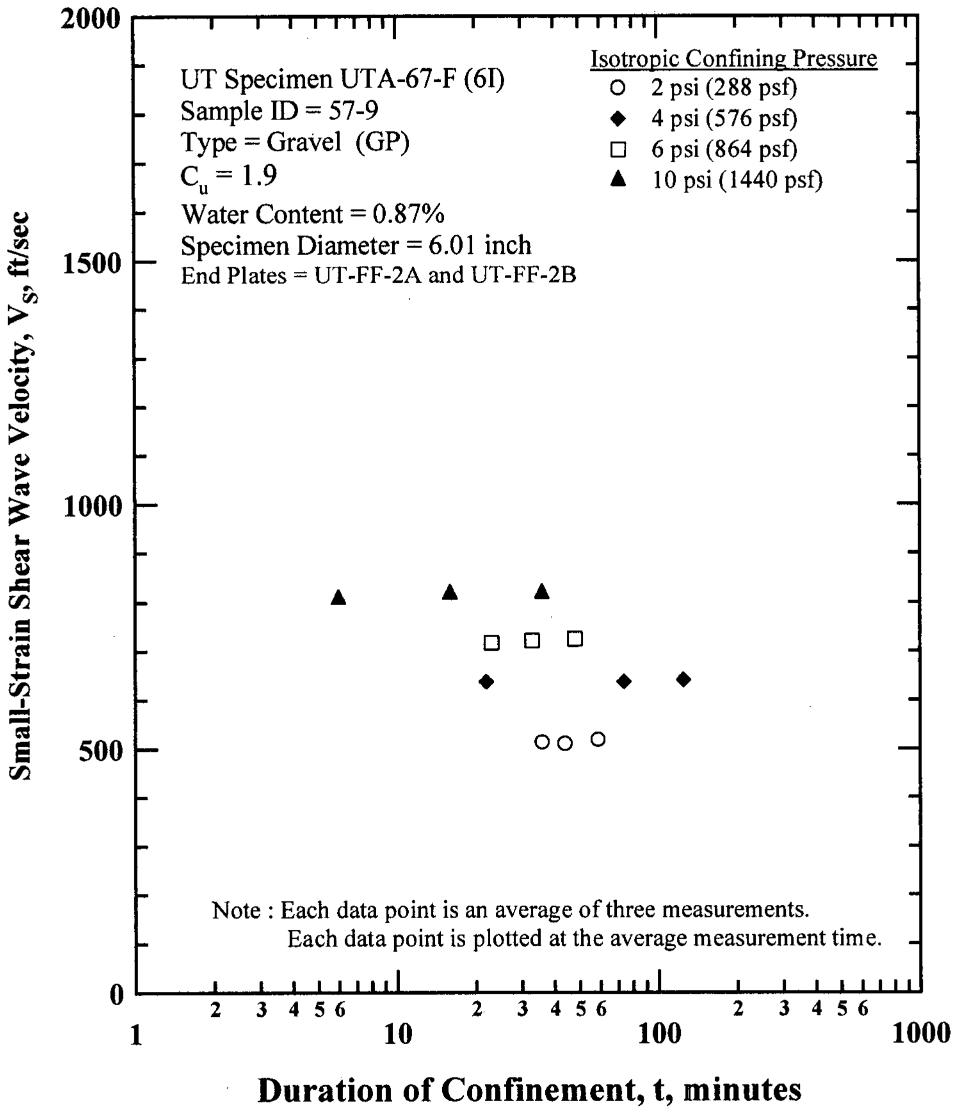


Figure L.1 Variation in Small-Strain Shear Wave Velocities (V_S) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

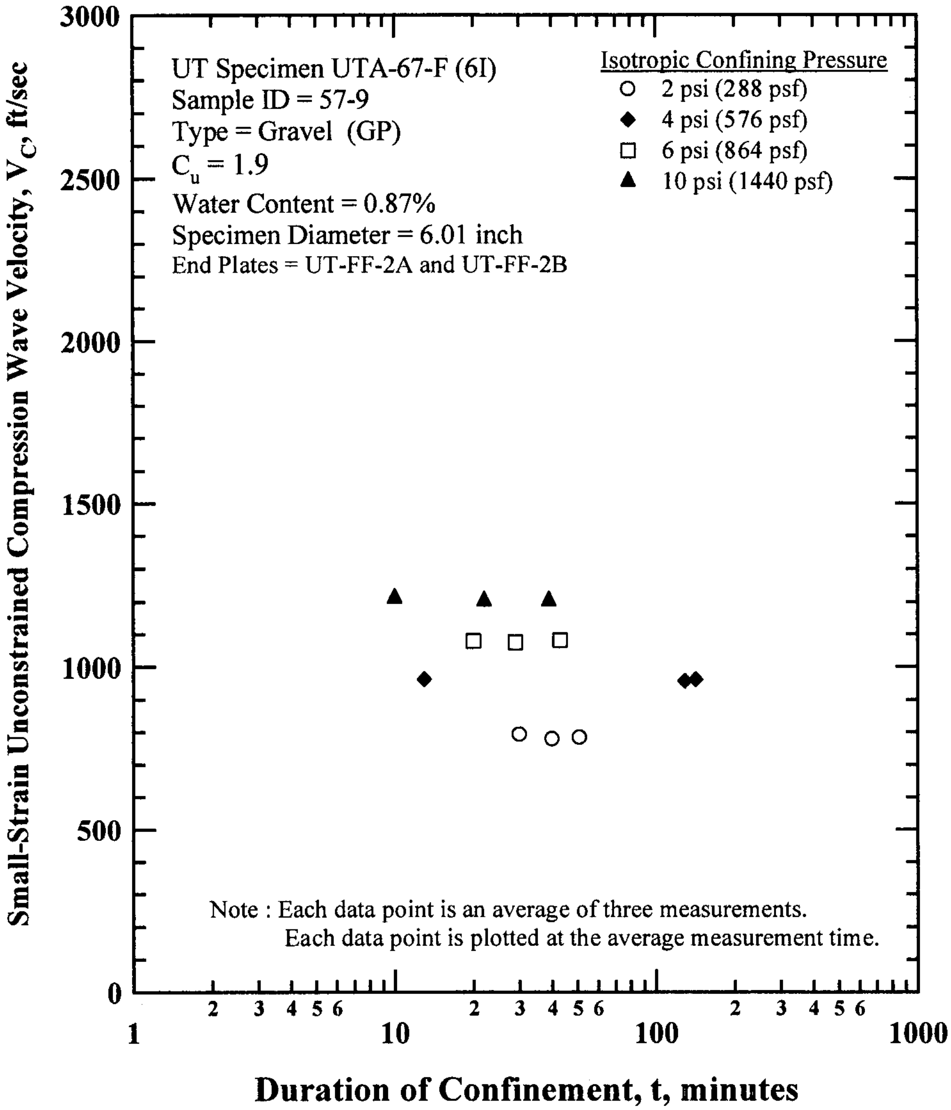


Figure L.2 Variation in Small-Strain Unconstrained Compression Wave Velocities (V_C) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

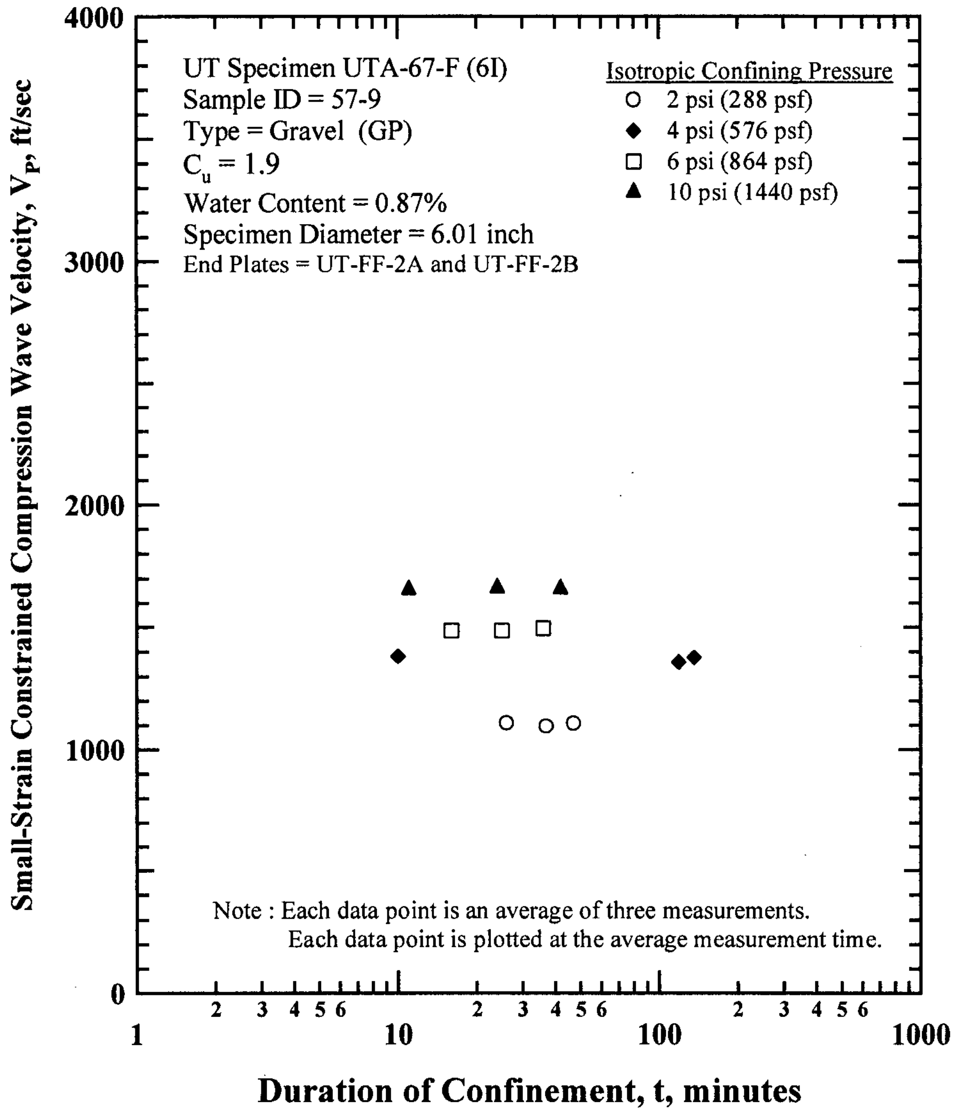


Figure L.3 Variation in Small-Strain Constrained Compression Wave Velocities (V_P) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

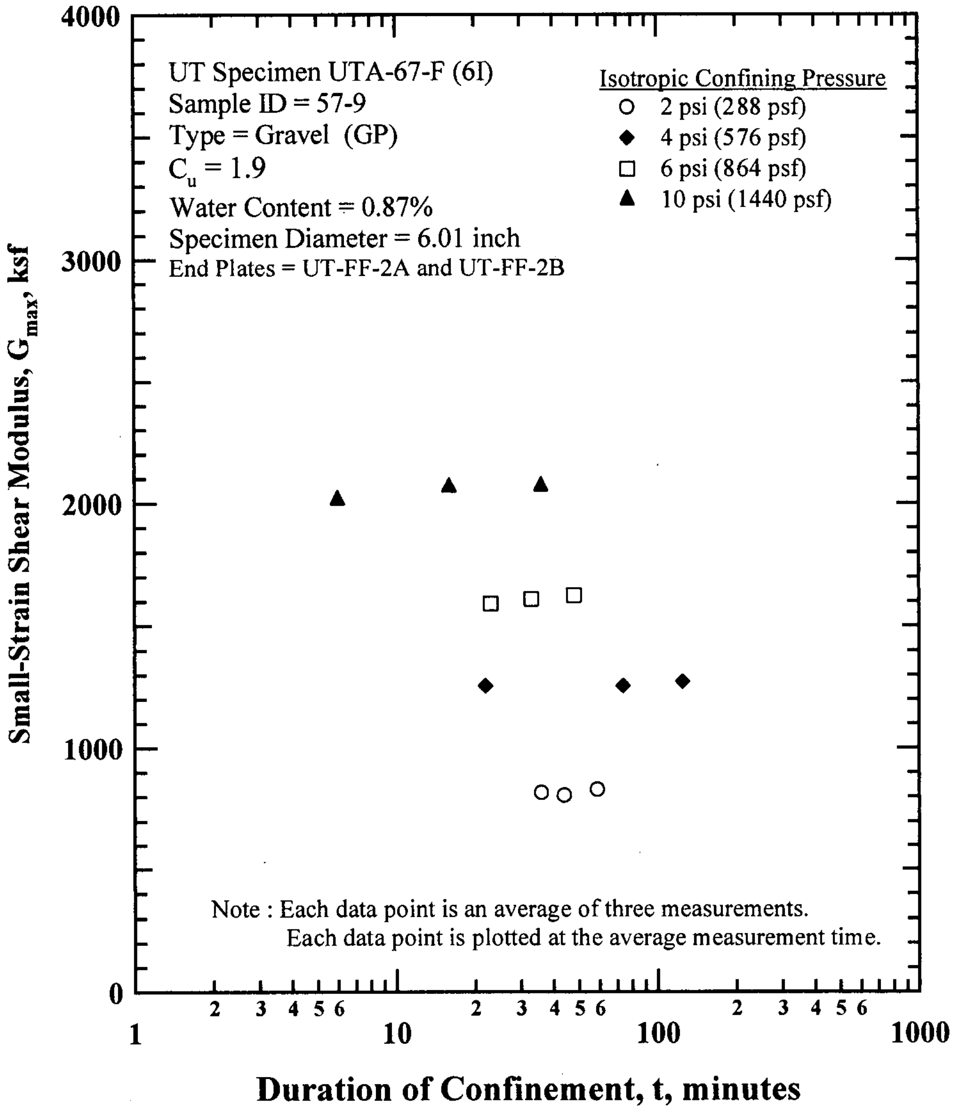


Figure L.4 Variation in Small-Strain Shear Modulus (G_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

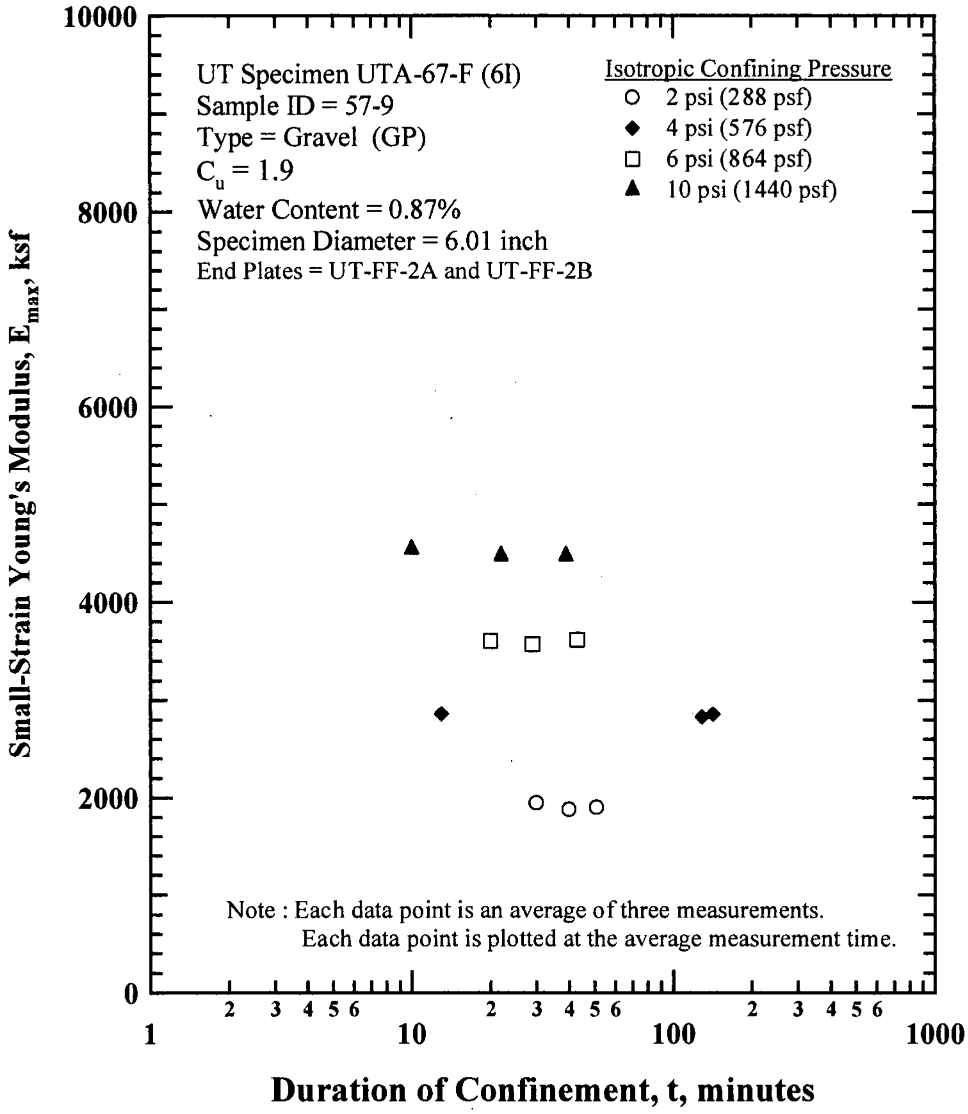


Figure L.5 Variation in Small-Strain Young's Modulus (E_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

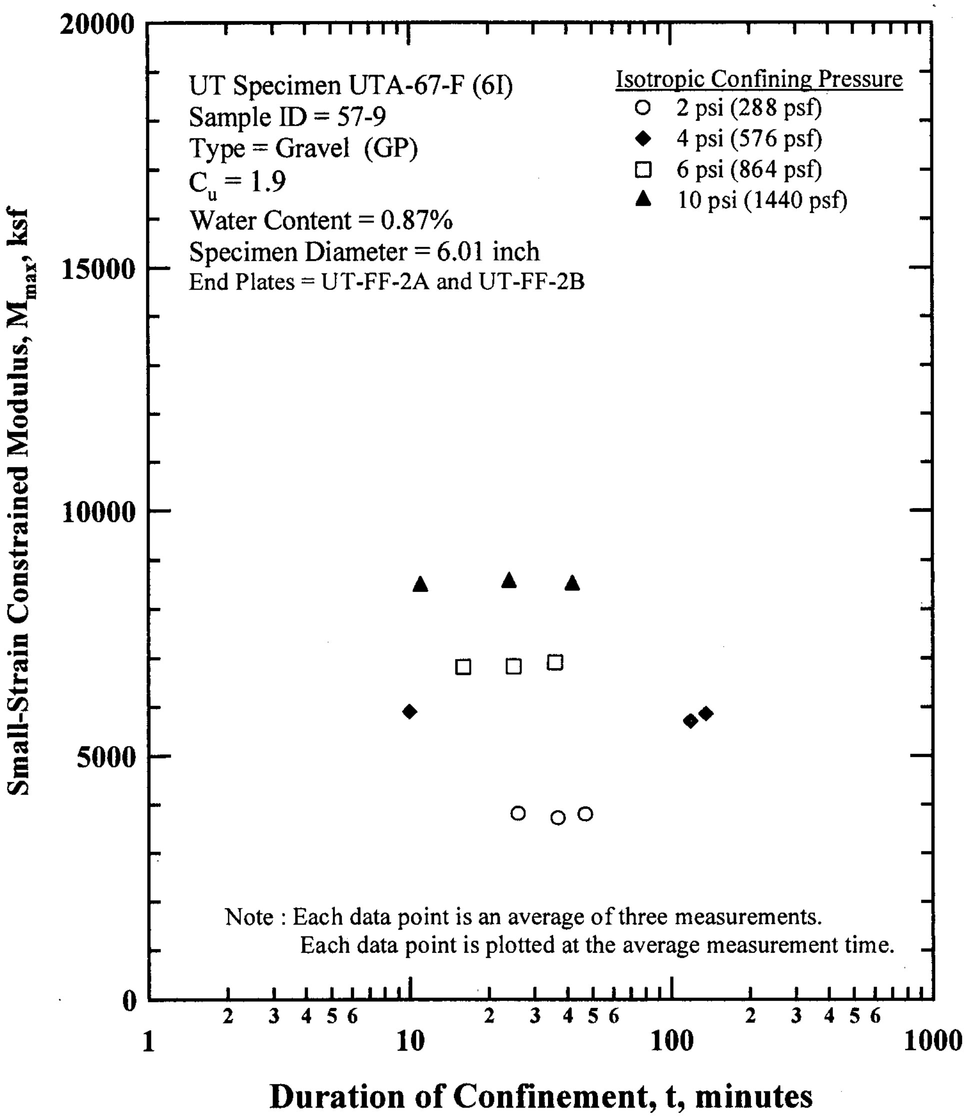


Figure L.6 Variation in Small-Strain Constrained Modulus (M_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

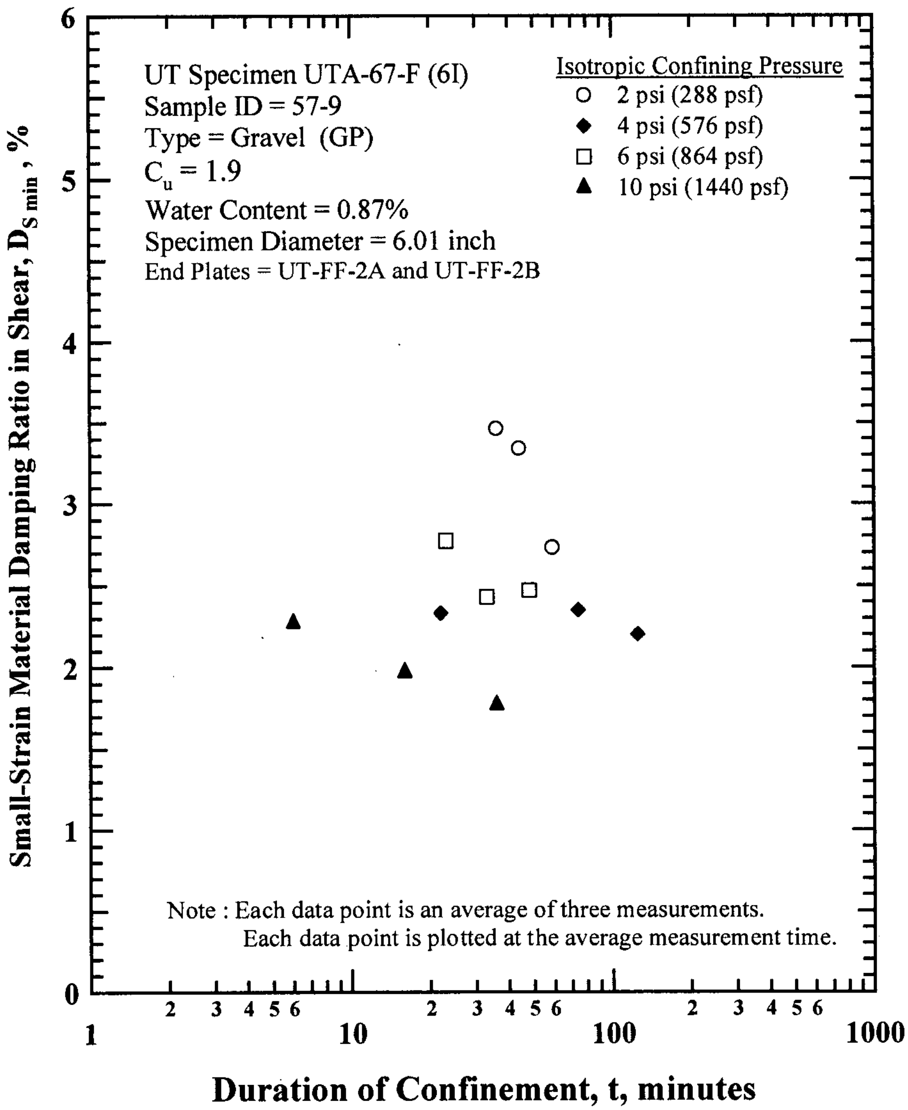


Figure L.7 Variation in Small-Strain Material Damping Ratio in Torsion ($D_{S\,min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

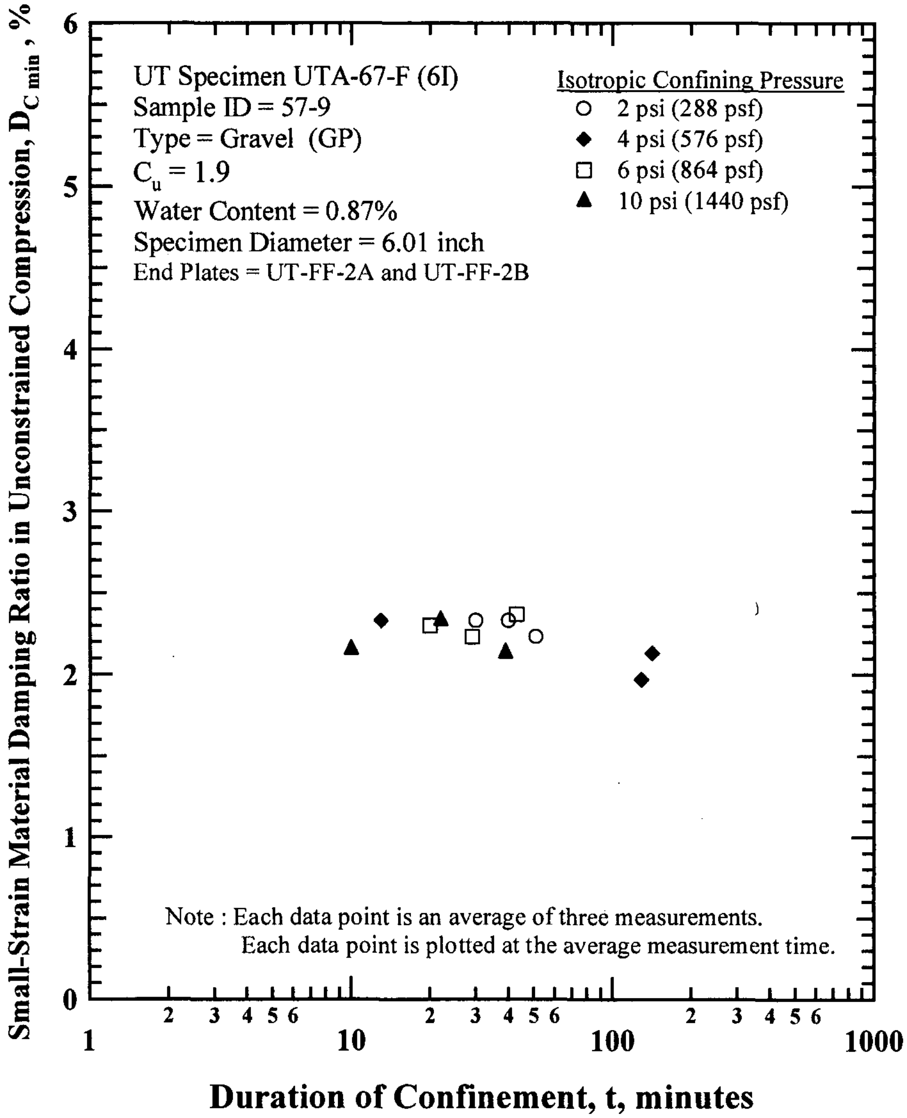
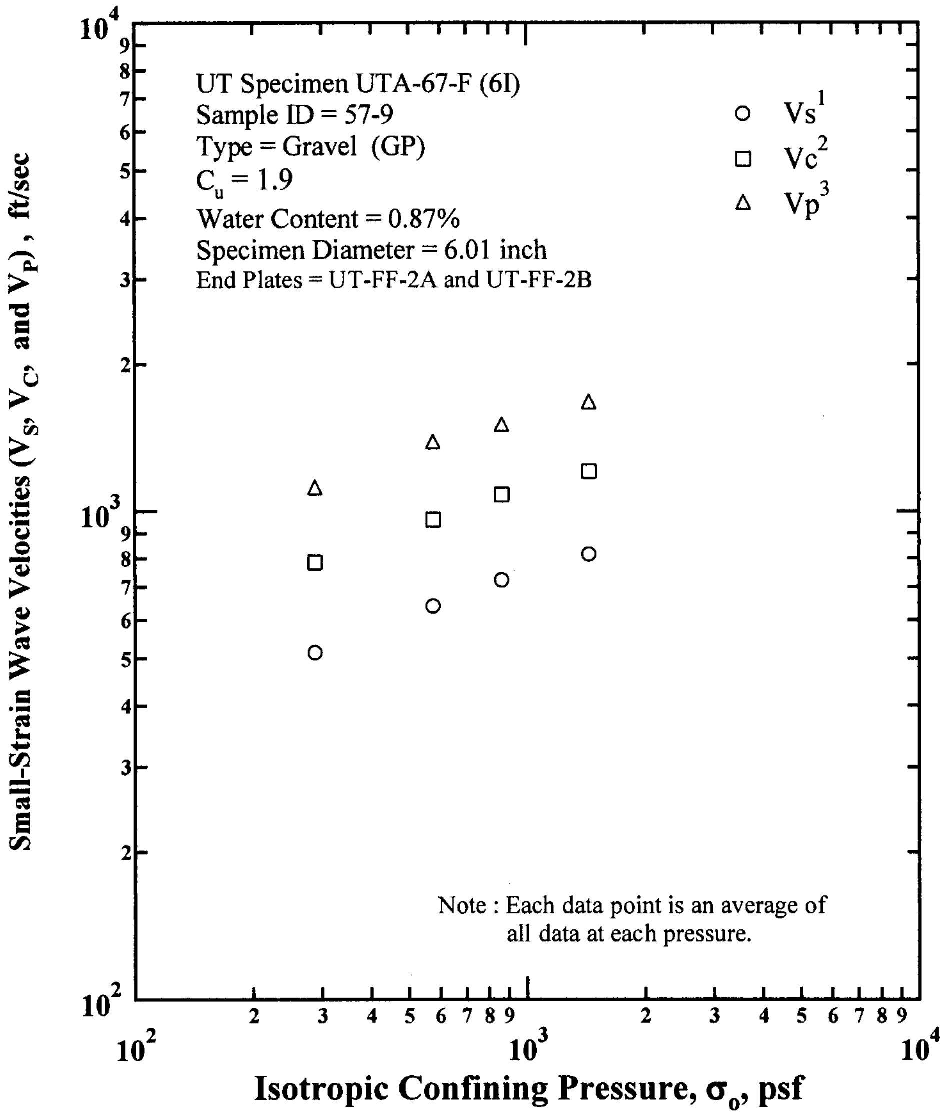
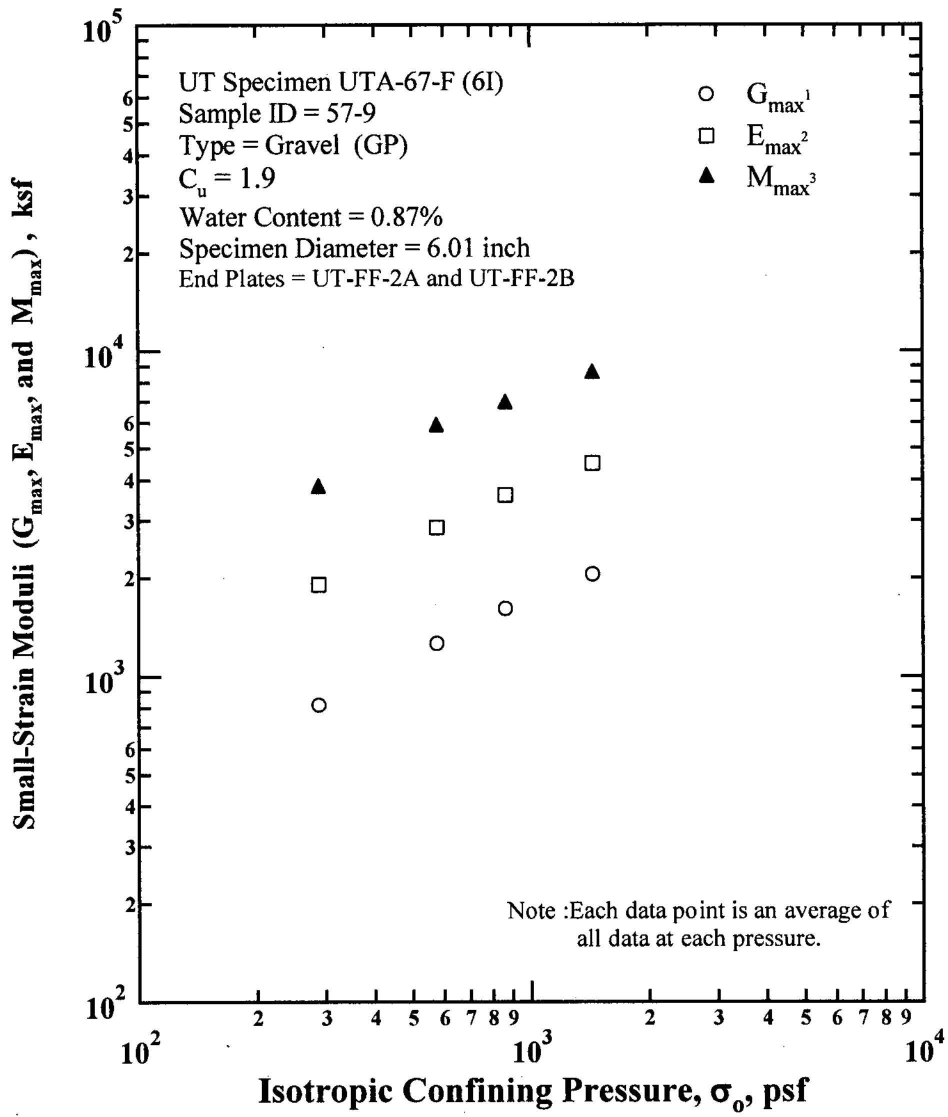


Figure L.8 Variation in Small-Strain Material Damping Ratio in Compression ($D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)



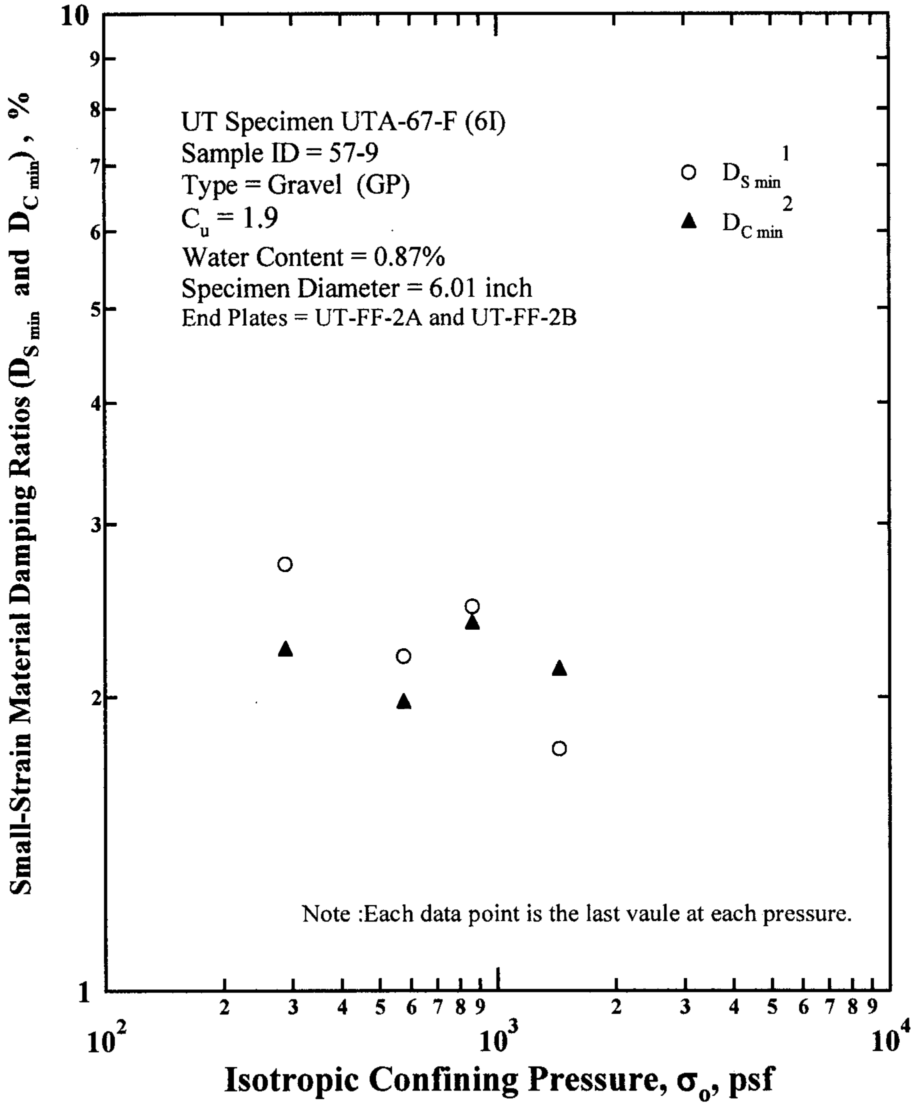
Notes : 1. V_S=Small-Strain Shear Wave Velocity
2. V_C=Small-Strain Unconstrained Compression Wave Velocity
3. V_P=Small-Strain Constrained Compression Wave Velocity

Figure L.9 Variation in Small-Strain Wave Velocities (V_S, V_C, and V_P) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)



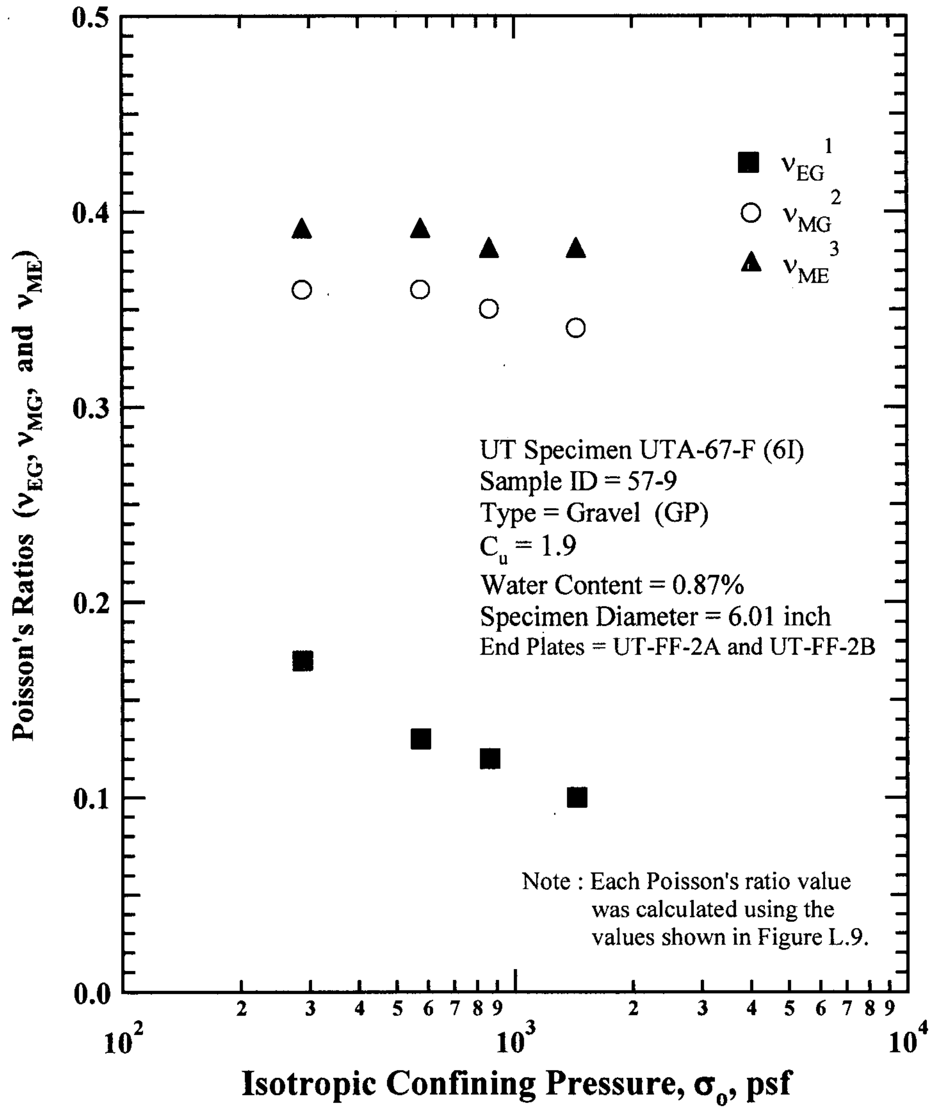
Notes :1.G_{max}=Small-Strain Shear Modulus
2. E_{max}=Small-Strain Young's Modulus
2. M_{max}=Small-Strain Constrained Modulus

Figure L.10 Variation in Small-Strained Moduli (G_{max}, E_{max}, and M_{max}) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)



Notes :1.$D_{S\,min}$ = Small-Strain Material Damping Ratio in Shear
2.$D_{C\,min}$ = Small-Strain Material Damping Ratio in Unconstrained Compression

Figure L.11 Variation in Small-Strained Material Damping Ratios ($D_{S\,min}$ and $D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-F (6I)



Notes :1.ν_{EG}=Poisson's Ratios from the Relationship between V_C and V_S
2.ν_{MG}=Poisson's Ratios from the Relationship between V_P and V_S
3.ν_{ME}=Poisson's Ratios from the Relationship between V_P and V_C

Figure L.12 Variation in Poisson's Ratios (ν_{EG}, ν_{MG}, and ν_{ME}) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-F (6I)

Table L.1 Variations in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-F (6I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Shear Modulus, G_{max} *		Small-Strain Shear Wave Velocity, V_S *	Small-Strain Material Damping Ratio in Shear, $D_{S\,min}$ *
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	36	815	39.1	513	3.46
2	288	14	44	804	38.5	510	3.34
2	288	14	59	828	39.7	518	2.73
4	576	28	22	1255	60.2	637	2.33
4	576	28	74	1255	60.2	637	2.35
4	576	28	125	1272	61.0	641	2.20
6	864	41	23	1590	76.2	717	2.77
6	864	41	33	1609	77.2	721	2.43
6	864	41	48	1625	77.9	725	2.47
10	1440	69	2	2012	96.5	807	2.27
10	1440	69	13	2064	98.9	817	1.97
10	1440	69	33	2068	99.1	818	1.77

Note : * Average of three measurements

Table L.2 Variation in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

Isotropic Confining Pressure, σ_o			Small-Strain Shear Modulus, G_{max} *		Small-Strain Shear Wave Velocity, V_S *	Small-Strain Material Damping Ratio in Shear, $D_{S\,min}$ **
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	816	39	514	2.73
4	576	28	1260	60	638	2.20
6	864	41	1608	77	721	2.47
10	1440	69	2048	98	814	1.77

Notes : * Average of all data at each pressure
** The last value at each pressure

Table L.3 Variations in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-F (6I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Young's Modulus, E_{max}*		Small-Strain Unconstrained Compression Wave Velocity, V_C*	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	30	1945	93.3	793	2.33
2	288	14	40	1879	90.1	779	2.33
2	288	14	51	1899	91.1	784	2.23
4	576	28	13	2860	137.1	962	2.33
4	576	28	142	2855	136.9	961	2.13
4	576	28	129	2830	135.7	957	1.97
6	864	41	20	3600	172.6	1079	2.30
6	864	41	29	3566	170.9	1074	2.23
6	864	41	43	3611	173.1	1081	2.37
10	1440	69	10	4533	217.3	1211	2.15
10	1440	69	22	4469	214.2	1202	2.33
10	1440	69	39	4469	214.2	1202	2.13

Note : * Average of three measurements

Table L.4 Variation in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

Isotropic Confining Pressure, σ_o			Small-Strain Young's Modulus, E_{max}*		Small-Strain Unconstrained Compression Wave Velocity, V_C*	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$**
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	1908	91	785	2.23
4	576	28	2848	137	960	1.97
6	864	41	3592	172	1078	2.37
10	1440	69	4490	215	1205	2.13

Notes : * Average of all data at each pressure
** The last value at each pressure

Table L.5 Variations in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-F (6I)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)
2	288	14	26	3804	182.4	1109
2	288	14	37	3714	178.1	1096
2	288	14	47	3795	181.9	1108
4	576	28	10	5898	282.8	1381
4	576	28	119	5698	273.1	1357
4	576	28	136	5855	280.7	1376
6	864	41	16	6819	326.9	1485
6	864	41	25	6827	327.3	1486
6	864	41	36	6907	331.1	1495
10	1440	69	11	8461	405.6	1654
10	1440	69	24	8536	409.2	1661
10	1440	69	42	8489	407.0	1657

Note : * Average of three measurements

Table L.6 Variation in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

Isotropic Confining Pressure, σ_o			Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)
2	288	14	3771	181	1104
4	576	28	5817	279	1371
6	864	41	6851	328	1488
10	1440	69	8495	407	1657

Note : * Average of all data at each pressure

Table L.7 Variation in Poisson's Ratios with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6I)

Isotropic Confining Pressure, σ_o			Poisson's Ratio		
(psi)	(psf)	(kPa)	ν_{EG} [1]	ν_{MG} [2]	ν_{ME} [3]
2	288	14	0.17	0.36	0.39
4	576	28	0.13	0.36	0.39
6	864	41	0.12	0.35	0.38
10	1440	69	0.10	0.34	0.38

Notes : 1. Poisson's ratio from the relationship between V_C and V_S tabulated in Tables L.4 and L.2, respectively.
2. Poisson's ratio from the relationship between V_P and V_S tabulated in Tables L.6 and L.2, respectively.
3. Poisson's ratio from the relationship between V_P and V_C tabulated in Tables L.6 and L.4, respectively.

APPENDIX M

(Free-Free Tests)

UT Specimen UTA-67-H (8E)
Sample ID : 57-18
Type = Scalped, Blended Gravel (GP)
Uniformity Coefficient, C_u = 1.9
Specimen Diameter = 6.01 inch

Water Content, w = 1.06 %
G_S = 2.833*
Degree of Saturation = 4.1 %
Total Unit Weight, γ_t = 103.3 lb/ft^3
Dry Unit Weight, γ_d = 102.2 lb/ft^3
Target : γ_d= 102.1 lb/ft^3 ± 2 lb/ft^3
w= 1.0 % ± 1.0 %

*** Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

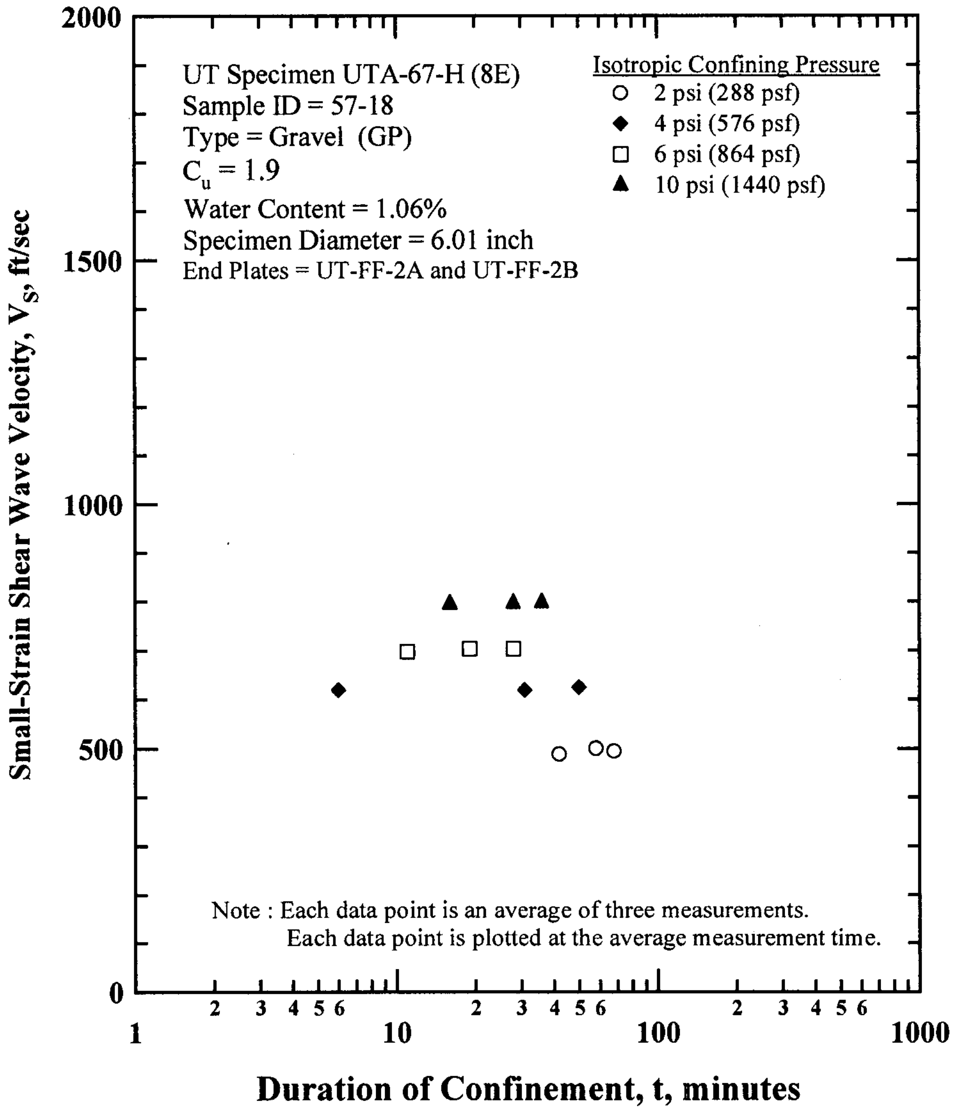


Figure M.1 Variation in Small-Strain Shear Wave Velocities (V_S) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

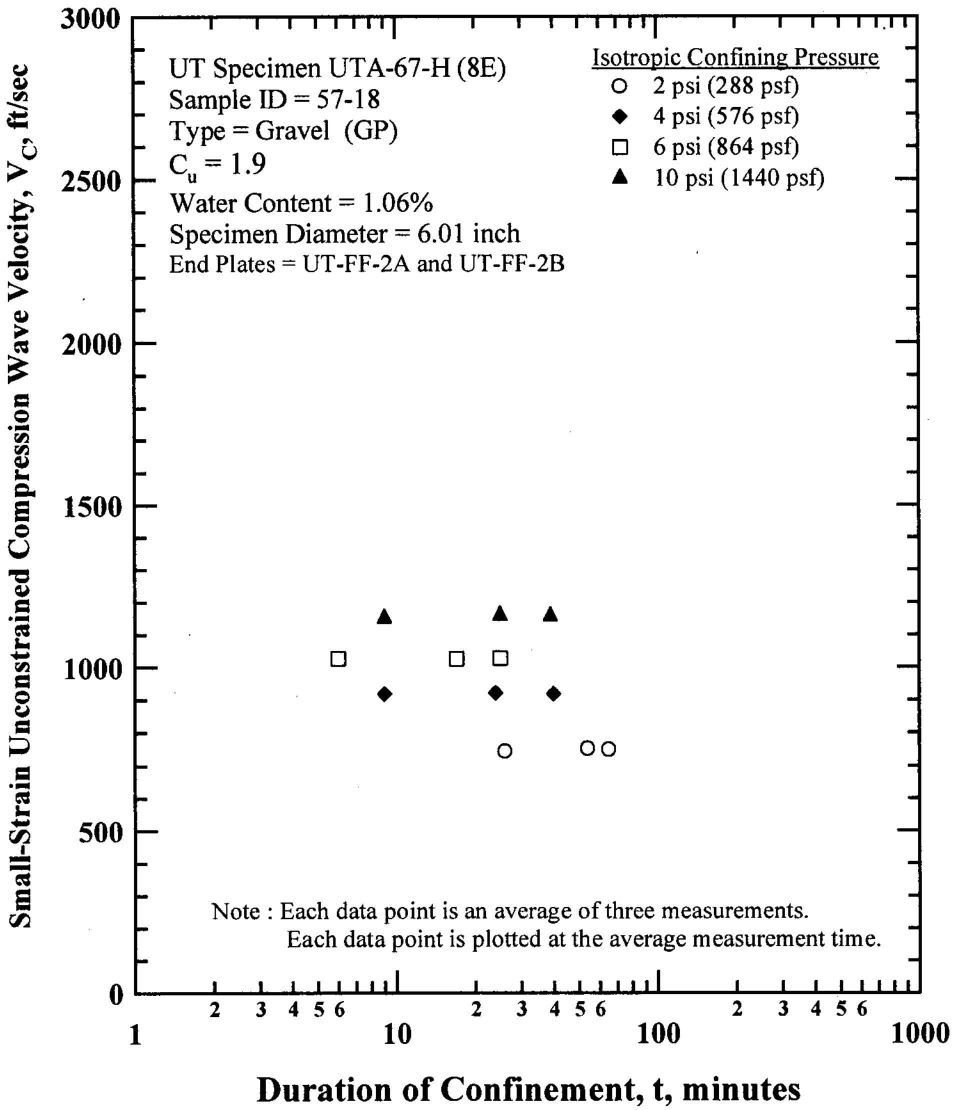


Figure M.2 Variation in Small-Strain Unconstrained Compression Wave Velocities (V_C) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

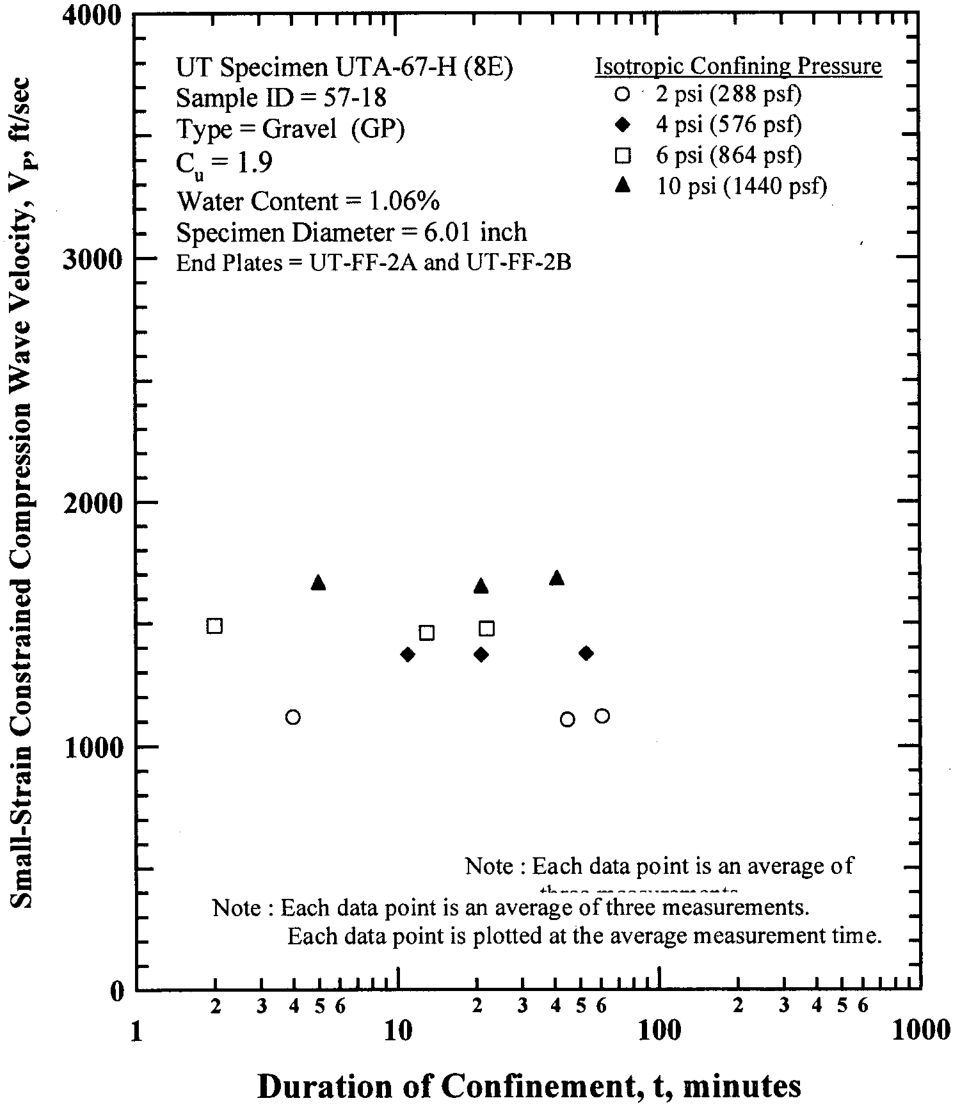


Figure M.3 Variation in Small-Strain Constrained Compression Wave Velocities (V_P) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

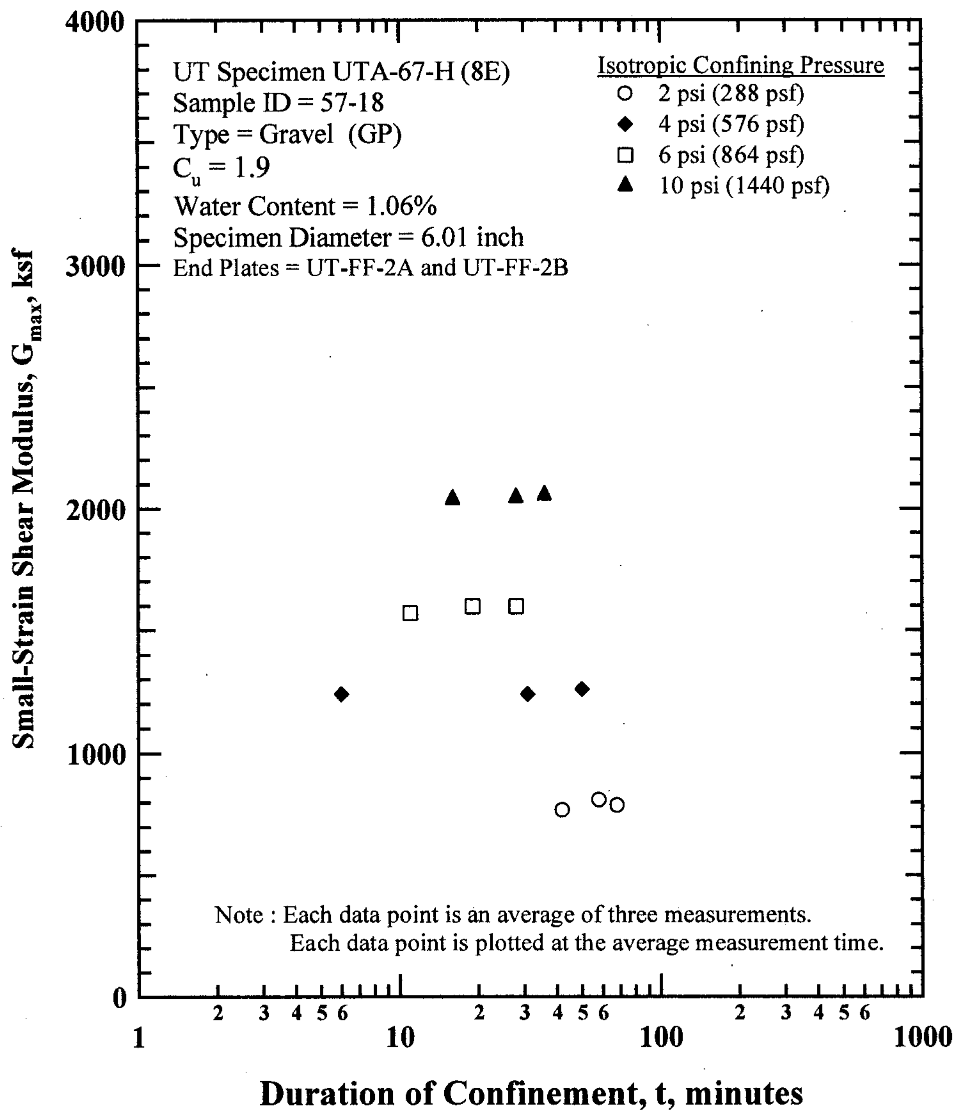


Figure M.4 Variation in Small-Strain Shear Modulus (G_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

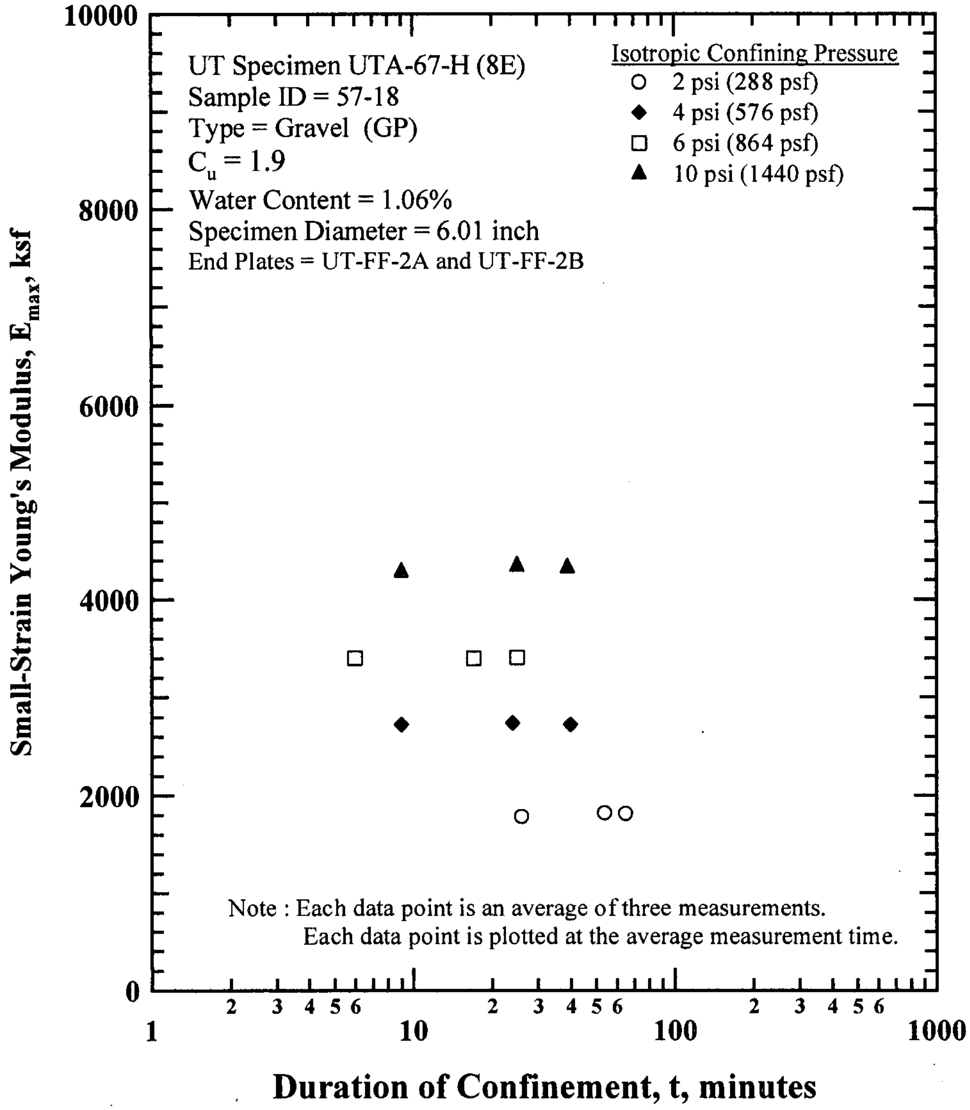


Figure M.5 Variation in Small-Strain Young's Modulus (E_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

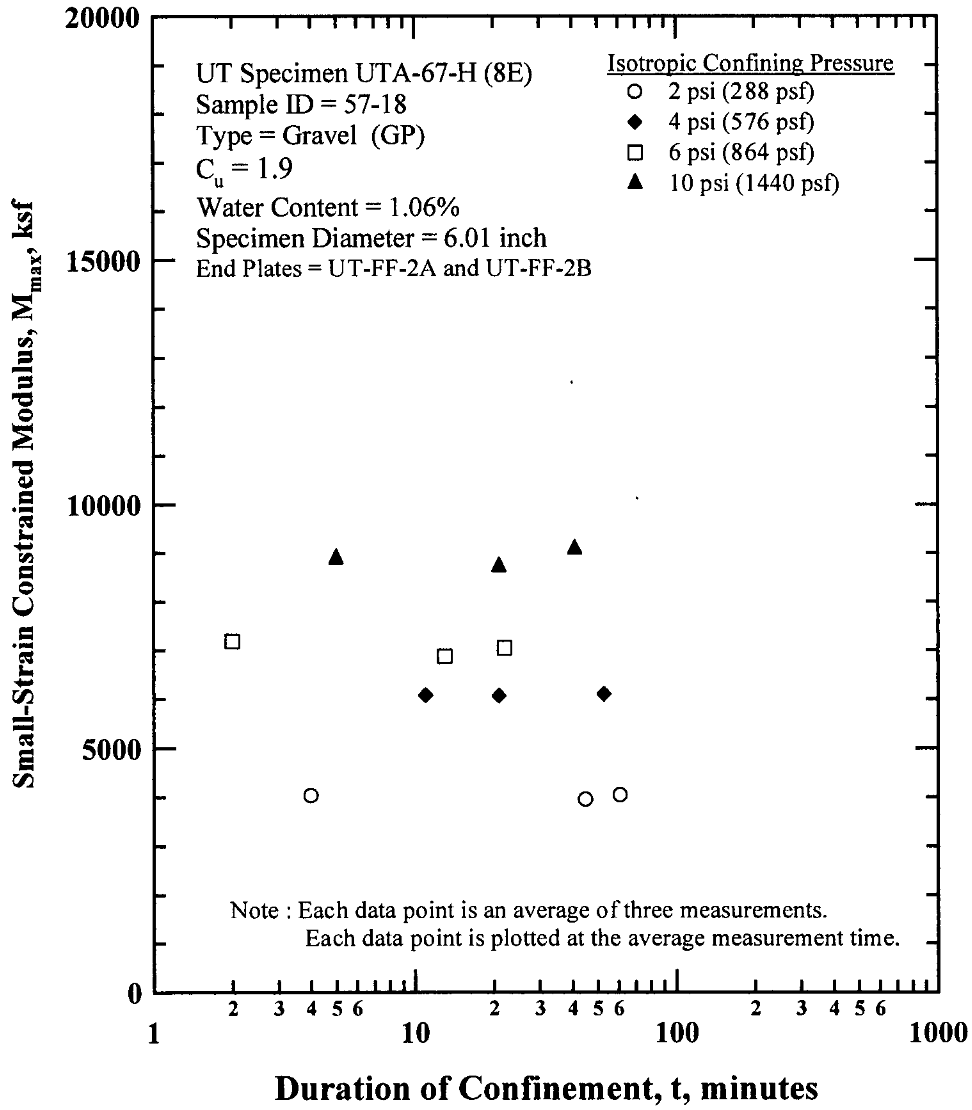


Figure M.6 Variation in Small-Strain Constrained Modulus (M_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

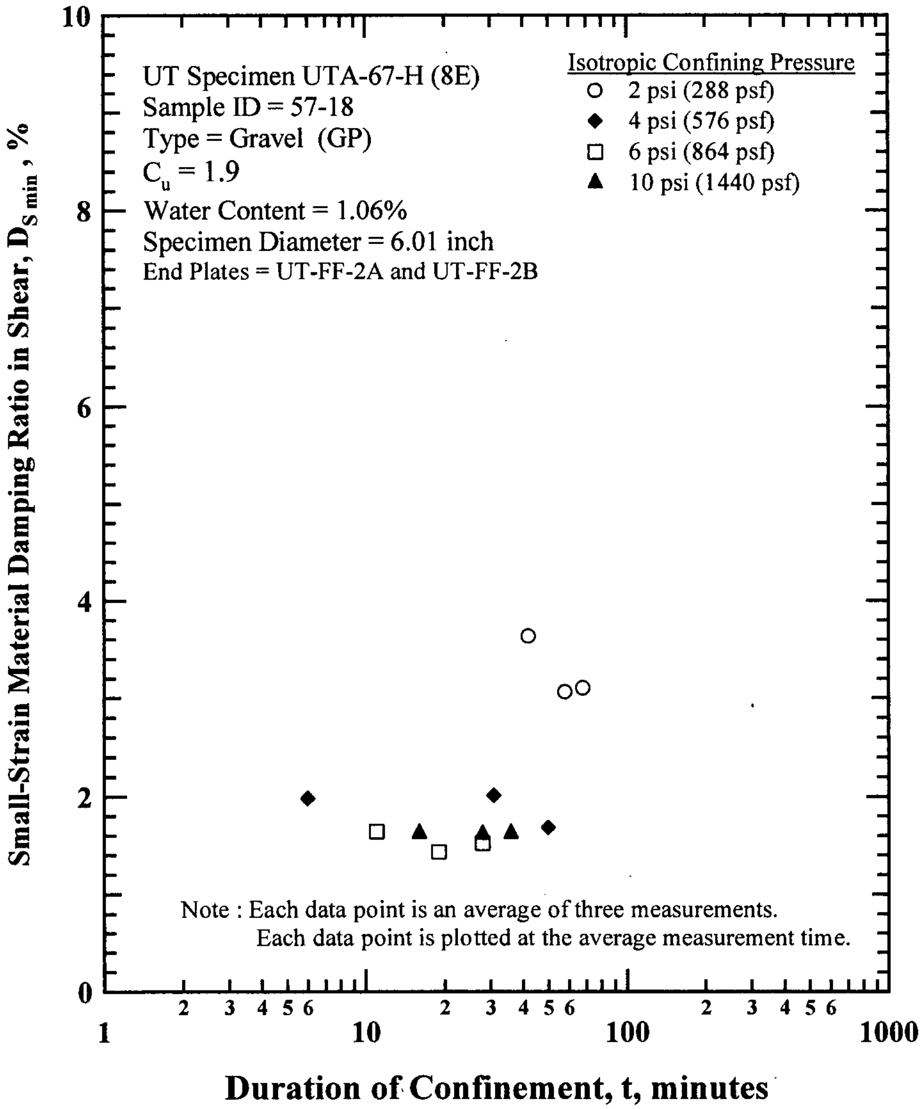


Figure M.7 Variation in Small-Strain Material Damping Ratio in Shear ($D_{S\ min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

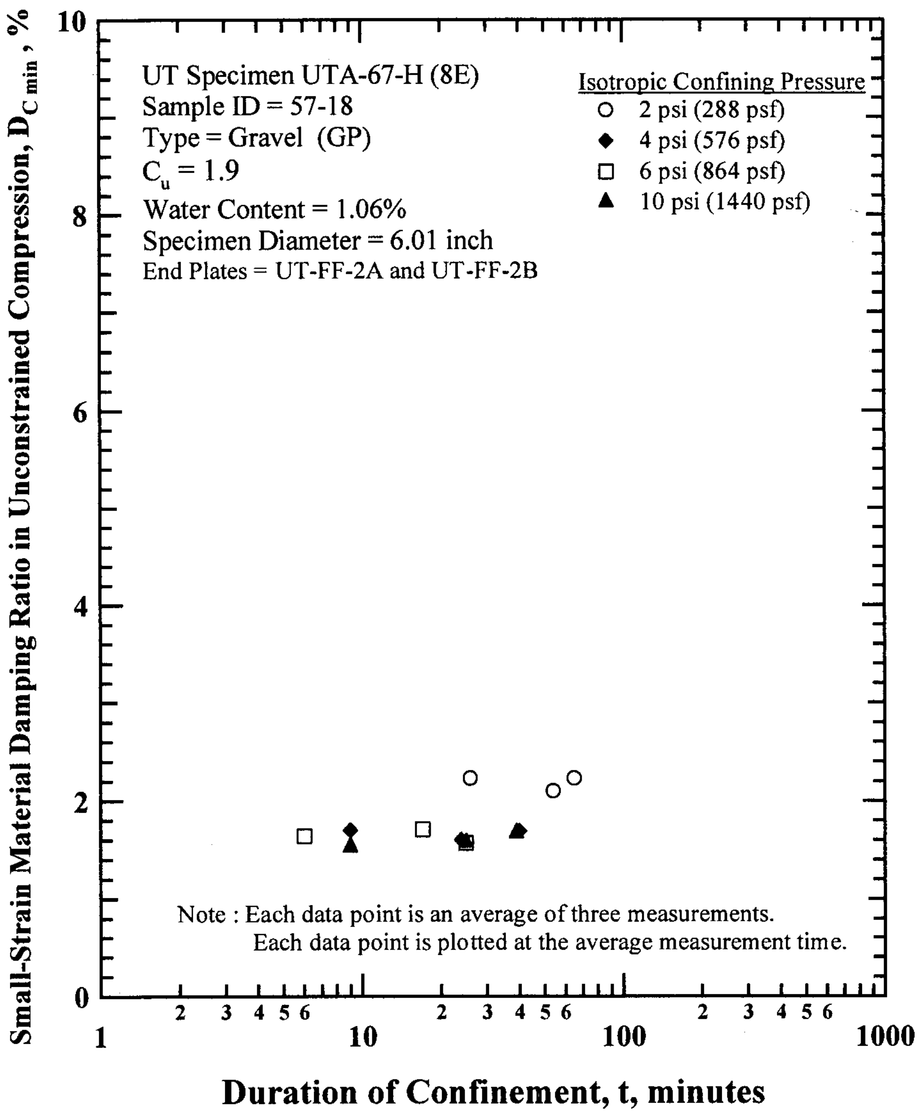
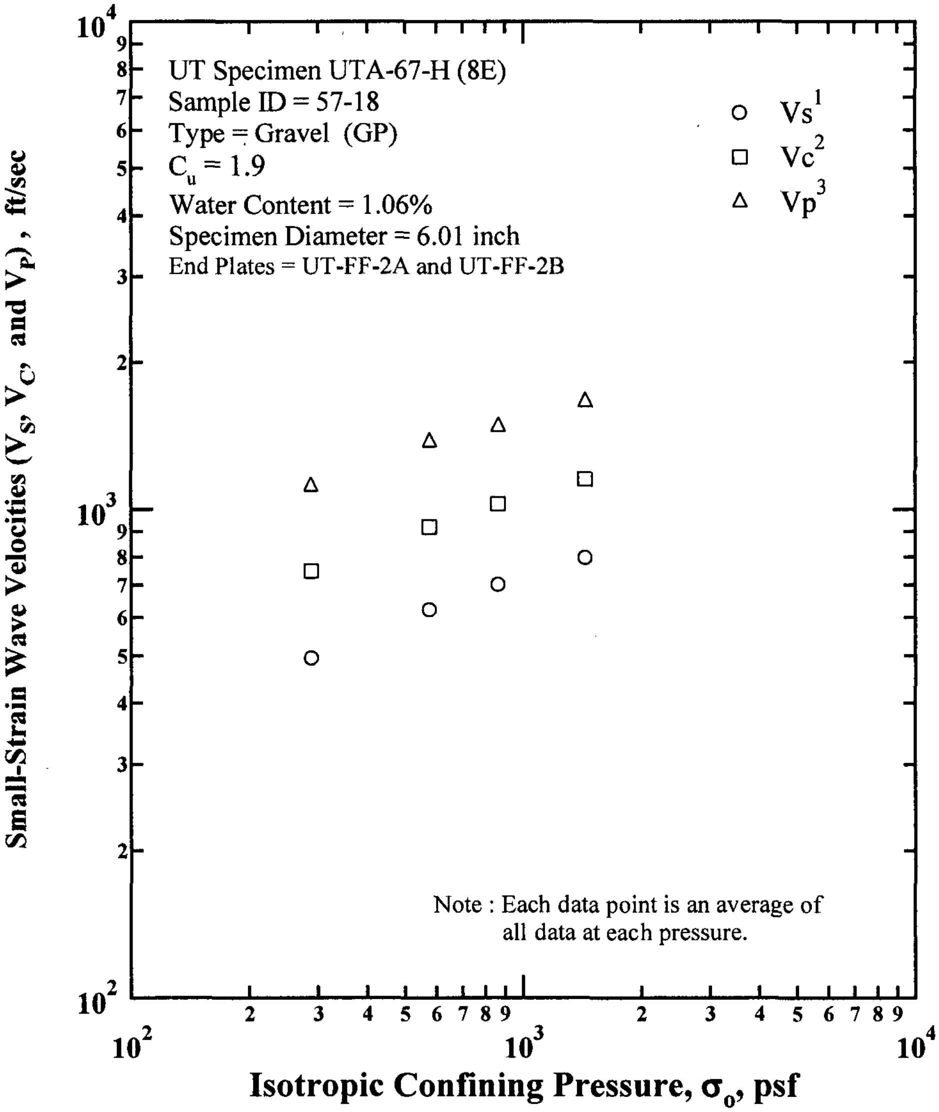
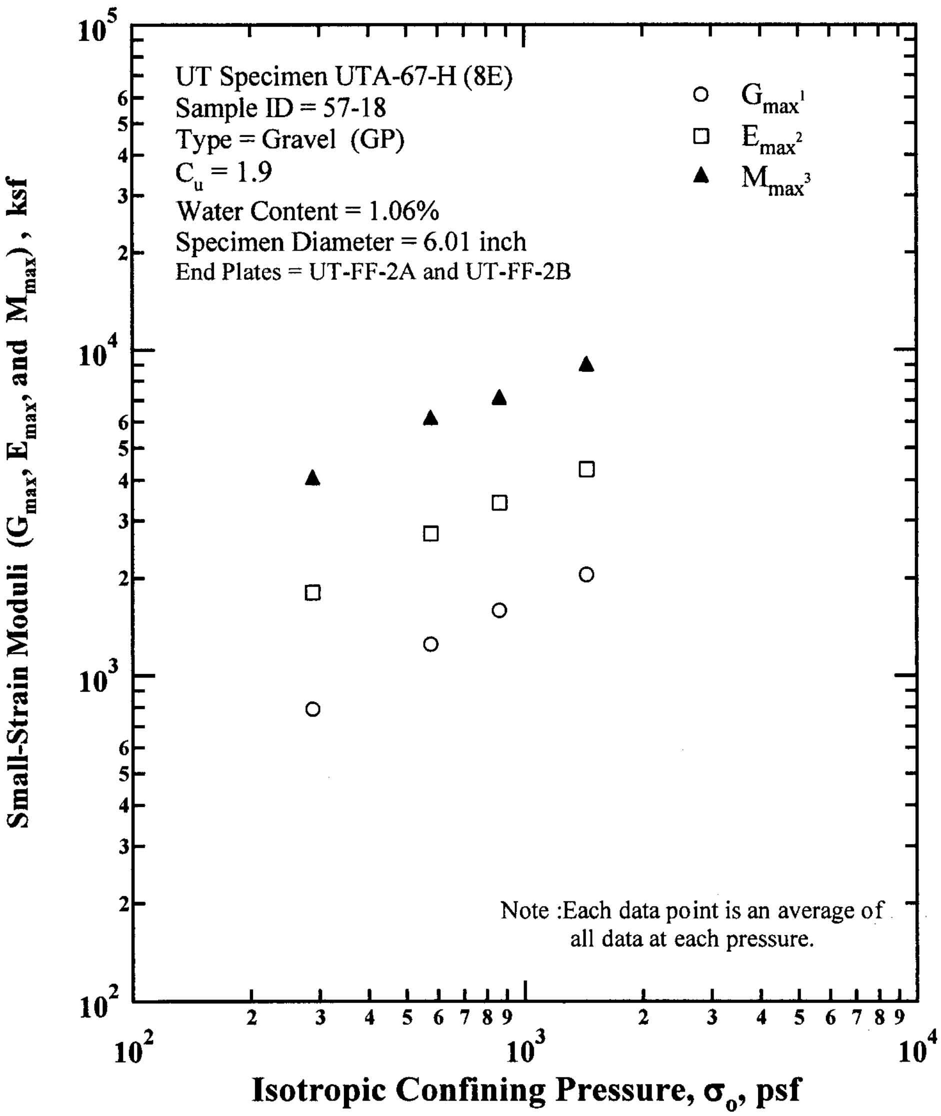


Figure M.8 Variation in Small-Strain Material Damping Ratio in Unconstrained Compression ($D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)



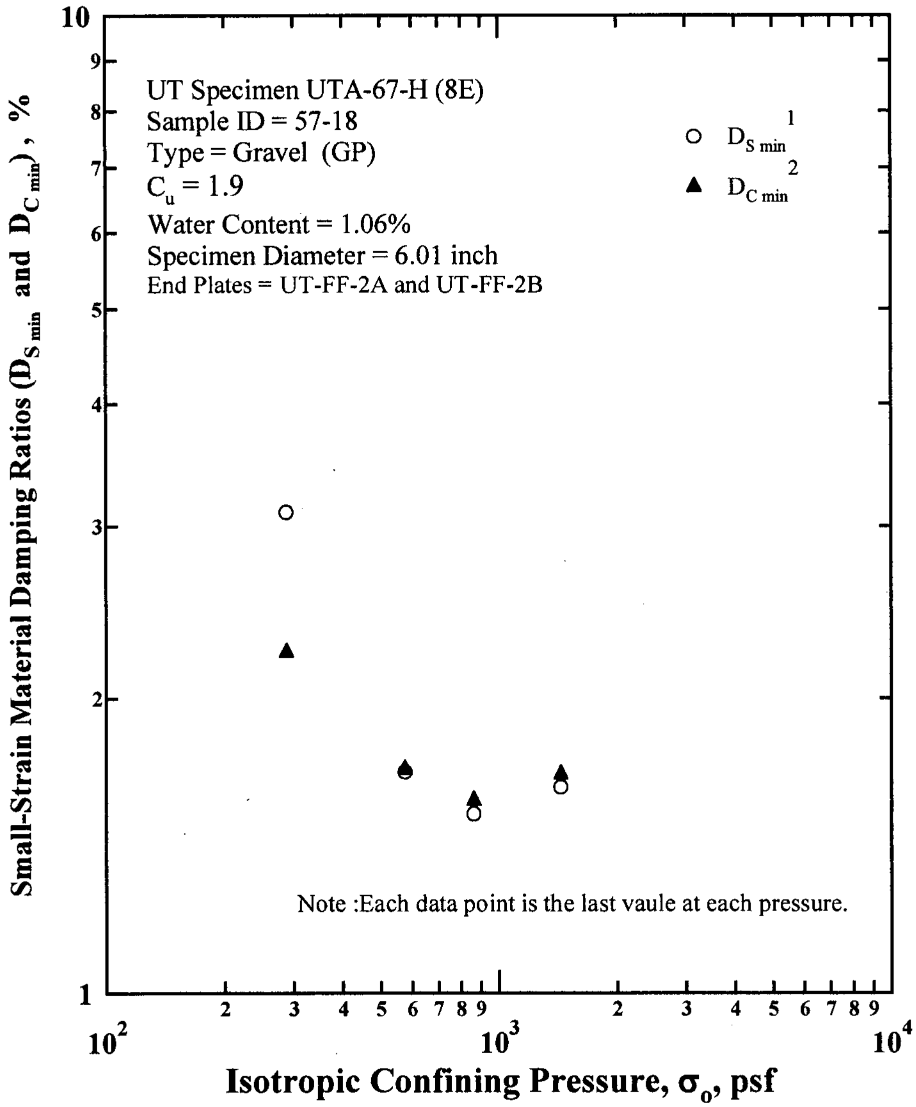
Notes :1.V_S=Small-Strain Shear Wave Velocity
2.V_C=Small-Strain Unconstrained Compression Wave Velocity
3.V_P=Small-Strain Constrained Compression Wave Velocity

Figure M.9 Variation in Small-Strain Wave Velocities (V_S, V_C, and V_P) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)



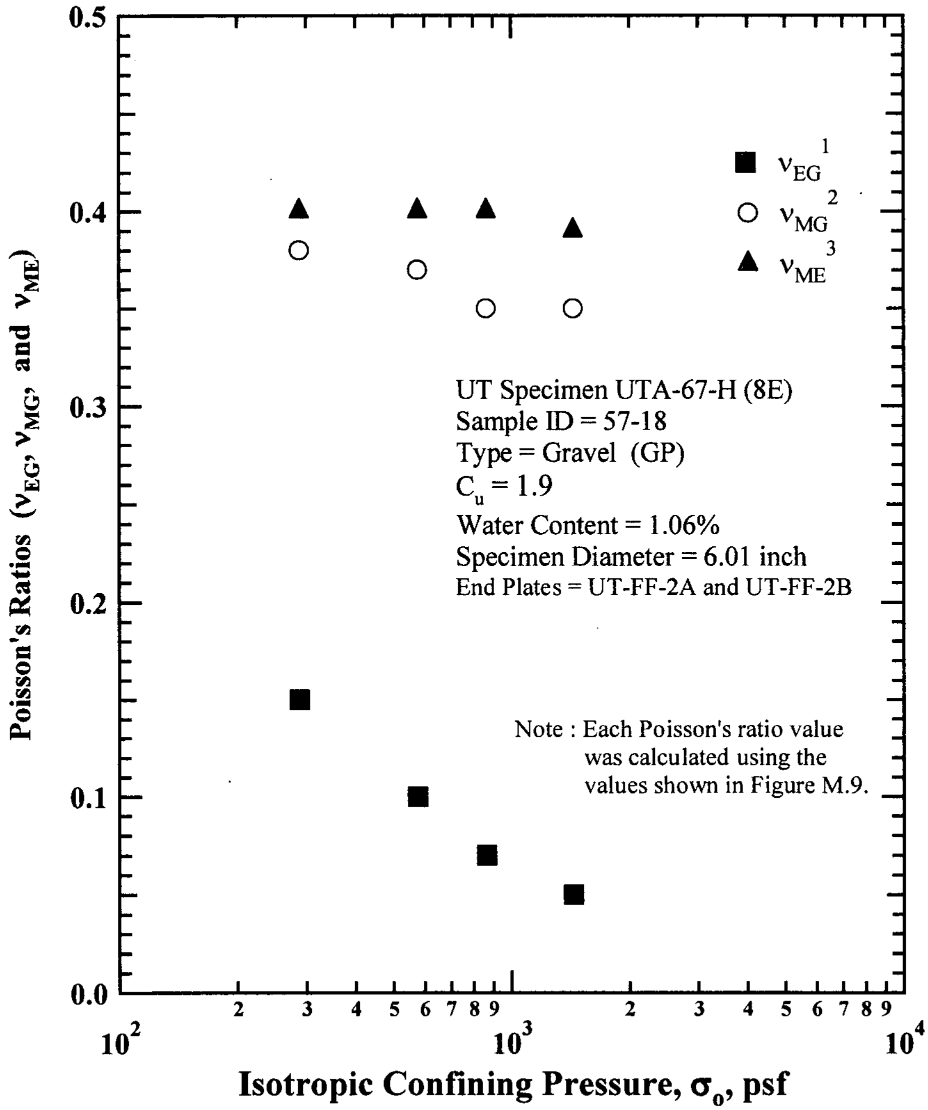
Notes : 1. G_{max}=Small-Strain Shear Modulus
2. E_{max}=Small-Strain Young's Modulus
2. M_{max}=Small-Strain Constrained Modulus

Figure M.10 Variation in Small-Strained Moduli (G_{max}, E_{max}, and M_{max}) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)



Notes :1.$D_{S\ min}$ = Small-Strain Material Damping Ratio in Shear
2.$D_{C\ min}$ = Small-Strain Material Damping Ratio in Unconstrained Compression

Figure M.11 Variation in Small-Strained Material Damping Ratios ($D_{S\ min}$ and $D_{C\ min}$) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-H (8E)



Notes : 1. ν_{EG}=Poisson's Ratios from the Relationship between V_C and V_S
2. ν_{MG}=Poisson's Ratios from the Relationship between V_P and V_S
3. ν_{ME}=Poisson's Ratios from the Relationship between V_P and V_C

Figure M.12 Variation in Poisson's Ratios (ν_{EG}, ν_{MG}, and ν_{ME}) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-H (8E)

Table M.1 Variations in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-H (8E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Shear Modulus, G_{max} *		Small-Strain Shear Wave Velocity, V_S *	Small-Strain Material Damping Ratio in Shear, $D_{S\ min}$ *
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	42	768	36.8	488	3.63
2	288	14	58	809	38.8	500	3.06
2	288	14	68	787	37.7	494	3.10
4	576	28	6	1239	59.4	619	1.98
4	576	28	31	1239	59.4	619	2.01
4	576	28	50	1259	60.4	624	1.68
6	864	41	11	1569	75.2	697	1.64
6	864	41	19	1596	76.5	703	1.43
6	864	41	28	1596	76.5	703	1.52
10	1440	69	16	2037	97.6	794	1.62
10	1440	69	28	2045	98.0	796	1.61
10	1440	69	36	2054	98.5	797	1.62

Note : * Average of three measurements

Table M.2 Variation in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

Isotropic Confining Pressure, σ_o			Small-Strain Shear Modulus, G_{max} *		Small-Strain Shear Wave Velocity, V_S *	Small-Strain Material Damping Ratio in Shear, $D_{S\ min}$ **
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	788	38	494	3.10
4	576	28	1246	60	621	1.68
6	864	41	1587	76	701	1.52
10	1440	69	2045	98	796	1.62

Notes : * Average of all data at each pressure
** The last value at each pressure

Table M.3 Variations in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-H (8E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Young's Modulus, E_{max}*		Small-Strain Unconstrained Compression Wave Velocity, V_C*	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	26	1784	85.5	743	2.23
2	288	14	54	1821	87.3	751	2.10
2	288	14	65	1813	86.9	749	2.23
4	576	28	9	2725	130.6	918	1.70
4	576	28	24	2740	131.4	921	1.60
4	576	28	40	2725	130.6	918	1.69
6	864	41	6	3400	163.0	1026	1.64
6	864	41	17	3395	162.7	1025	1.71
6	864	41	25	3406	163.3	1027	1.57
10	1440	69	9	4275	205.0	1150	1.53
10	1440	69	25	4338	208.0	1159	1.57
10	1440	69	39	4319	207.1	1156	1.67

Note : * Average of three measurements

Table M.4 Variation in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

Isotropic Confining Pressure, σ_o			Small-Strain Young's Modulus, E_{max}*		Small-Strain Unconstrained Compression Wave Velocity, V_C*	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$**
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	1806	87	748	2.23
4	576	28	2730	131	919	1.69
6	864	41	3400	163	1026	1.57
10	1440	69	4311	207	1155	1.67

Notes : * Average of all data at each pressure
** The last value at each pressure

Table M.5 Variations in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-H (8E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)
2	288	14	4	4028	193.1	1117
2	288	14	45	3949	189.3	1106
2	288	14	61	4043	193.8	1119
4	576	28	11	6074	291.2	1371
4	576	28	21	6063	290.6	1370
4	576	28	53	6104	292.6	1375
6	864	41	2	7184	344.4	1491
6	864	41	13	6875	329.6	1459
6	864	41	22	7046	337.8	1477
10	1440	69	5	8878	425.6	1658
10	1440	69	21	8709	417.5	1642
10	1440	69	41	9068	434.7	1675

Note : * Average of three measurements

Table M.6 Variation in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

Isotropic Confining Pressure, σ_o			Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)
2	288	14	4007	192	1114
4	576	28	6080	291	1372
6	864	41	7035	337	1476
10	1440	69	8885	426	1658

Notes : * Average of all data at each pressure

Table M.7 Variation in Poisson's Ratio with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-H (8E)

Isotropic Confining Pressure, σ_o			Poisson's Ratio		
(psi)	(psf)	(kPa)	ν_{EG} [1]	ν_{MG} [2]	ν_{ME} [3]
2	288	14	0.15	0.38	0.40
4	576	28	0.10	0.37	0.40
6	864	41	0.07	0.35	0.40
10	1440	69	0.05	0.35	0.39

Notes : 1. Poisson's ratio from the relationship between V_C and V_S tabulated in Tables M.2 and M.4, respectively.

2. Poisson's ratio from the relationship between V_S and V_P tabulated in Tables M.2 and M.6, respectively.

3. Poisson's ratio from the relationship between V_C and V_P tabulated in Tables M.4 and M.6, respectively.

APPENDIX N
(Free-Free Tests)

UT Specimen UTA-67-F (6E)
Sample ID : 57-9
Type = Scalped, Blended Gravel (GP)
Uniformity Coefficient, C_u = 1.9
Specimen Diameter = 2.76 inch

Water Content, w = 1.24 %
G_S = 2.833*
Degree of Saturation = 4.4 %
Total Unit Weight, γ_t = 99.3 lb/ft^3
Dry Unit Weight, γ_d = 98.1 lb/ft^3
Target : γ_d= 98.6 lb/ft^3 ± 1 lb/ft^3
w= 1.0 % ± 1.0 %

* **Specific gravity and classification provided by MACTEC Engineering and Consulting, Inc.**

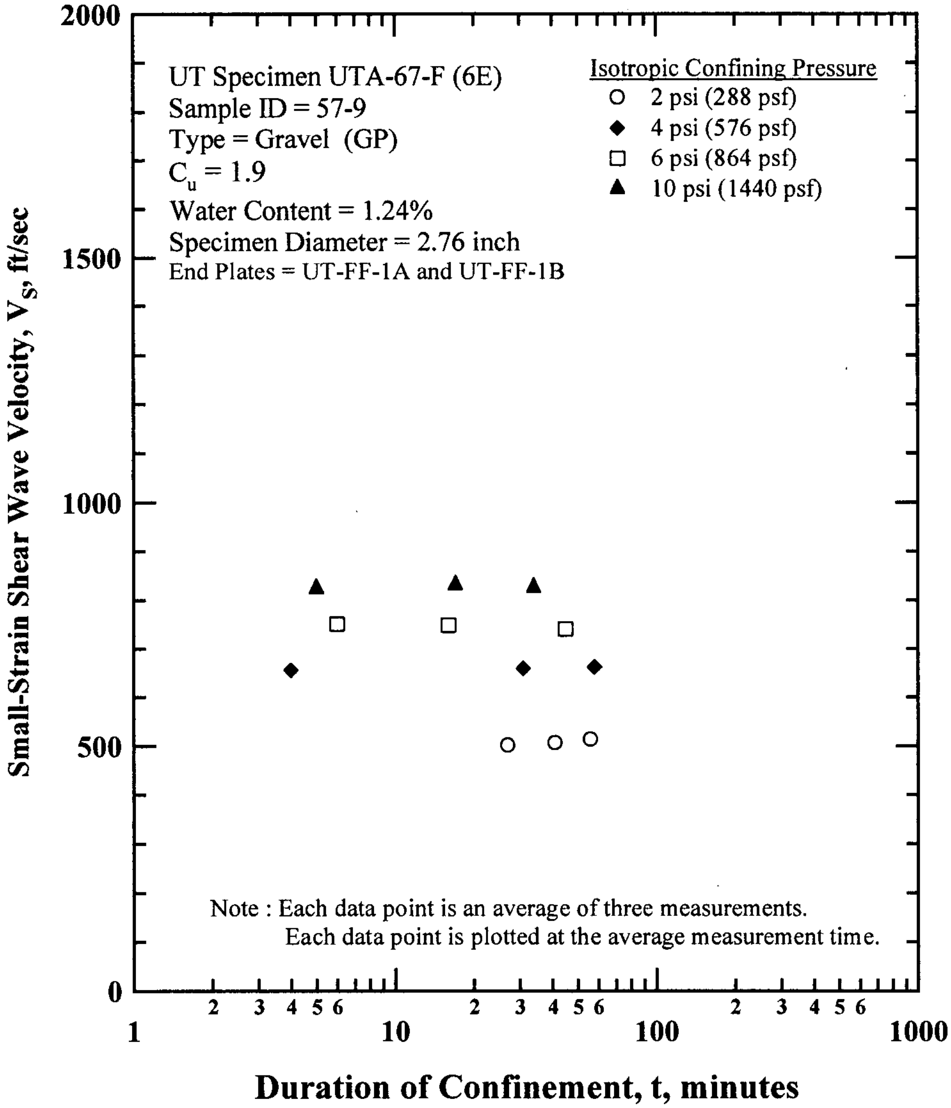


Figure N.1 Variation in Small-Strain Shear Wave Velocities (V_S) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

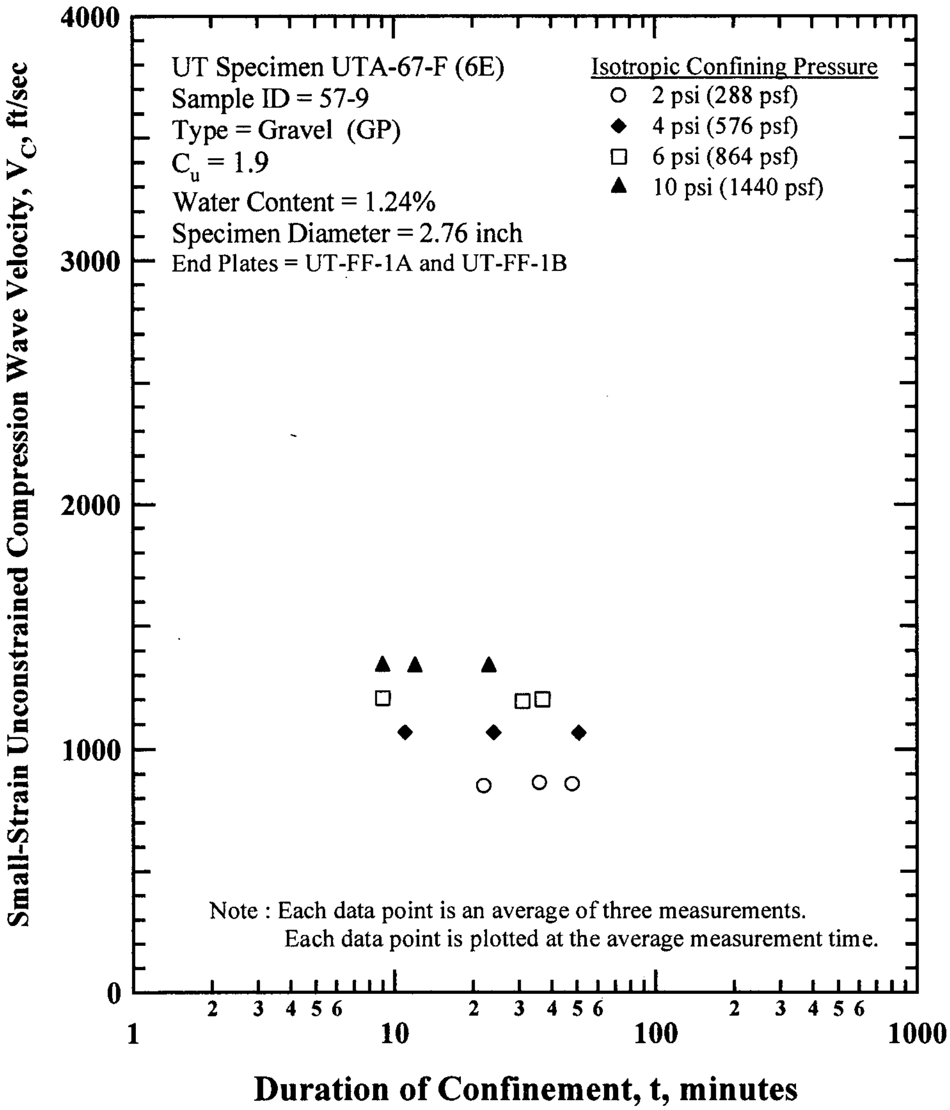


Figure N.2 Variation in Small-Strain Unconstrained Compression Wave Velocities (V_C) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

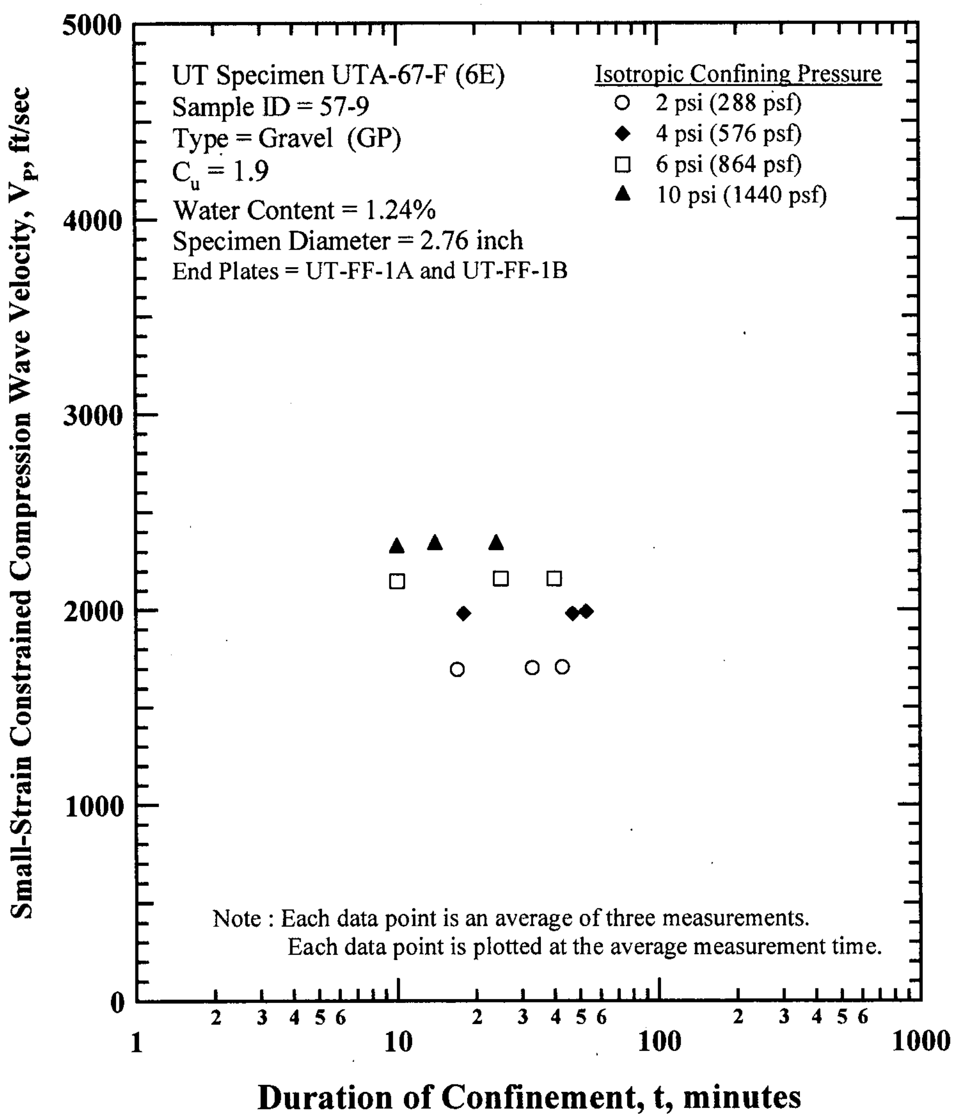


Figure N.3 Variation in Small-Strain Constrained Compression Wave Velocities (V_P) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

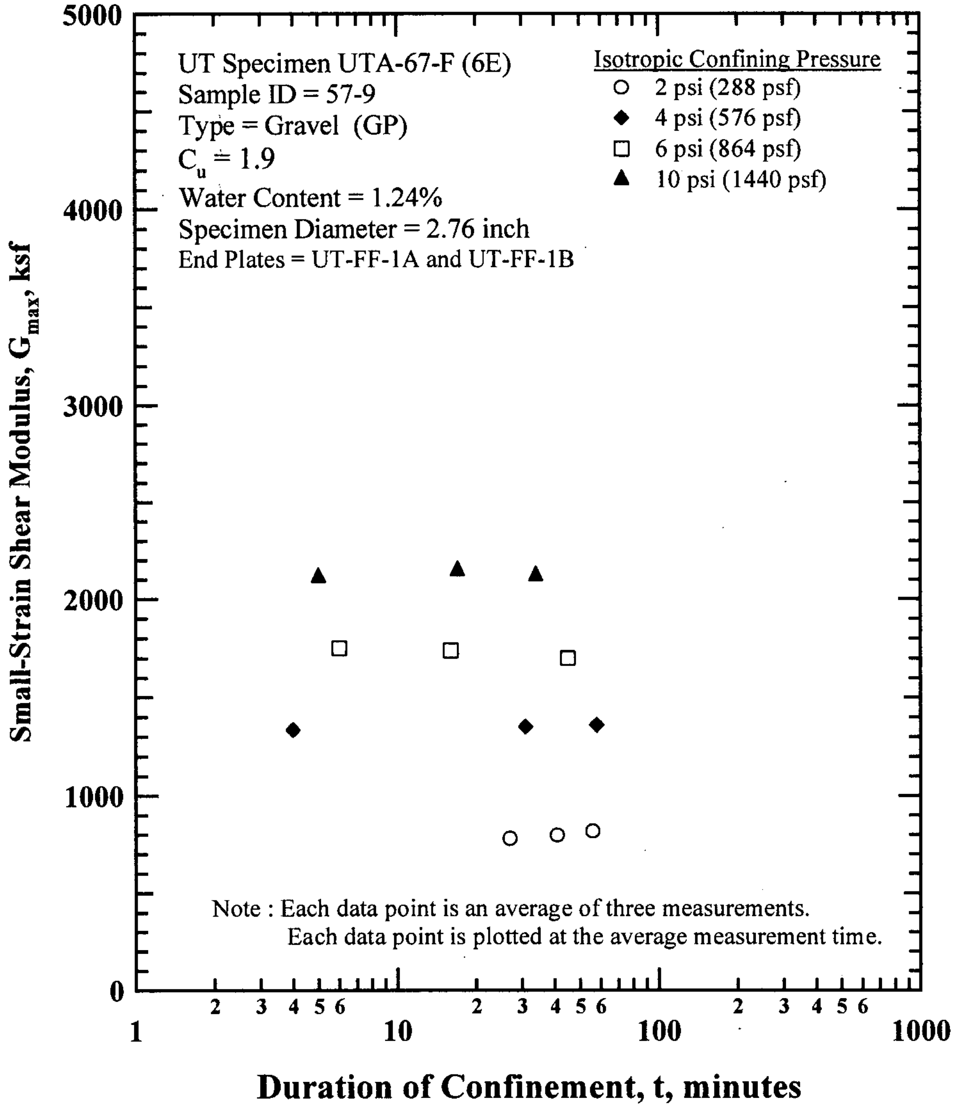


Figure N.4 Variation in Small-Strain Shear Modulus (G_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

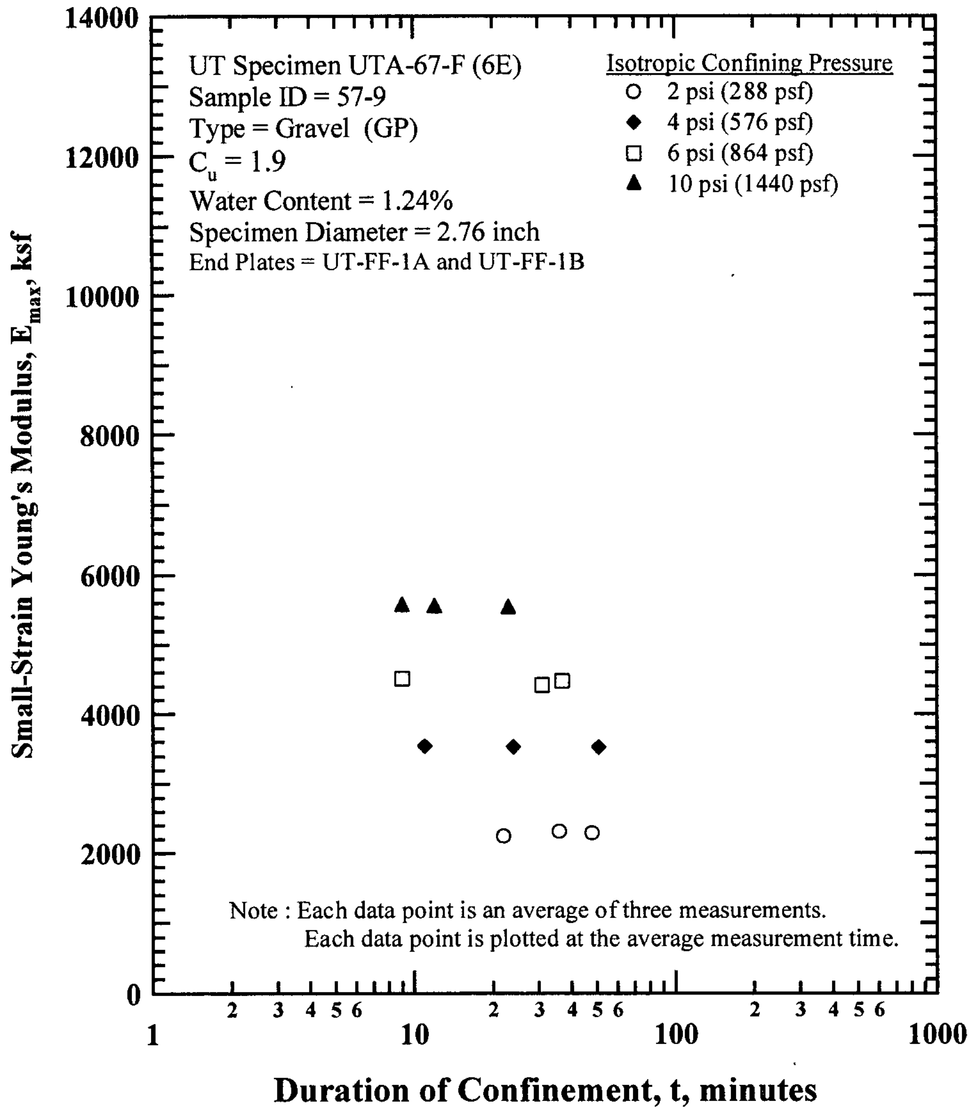


Figure N.5 Variation in Small-Strain Young's Modulus (E_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

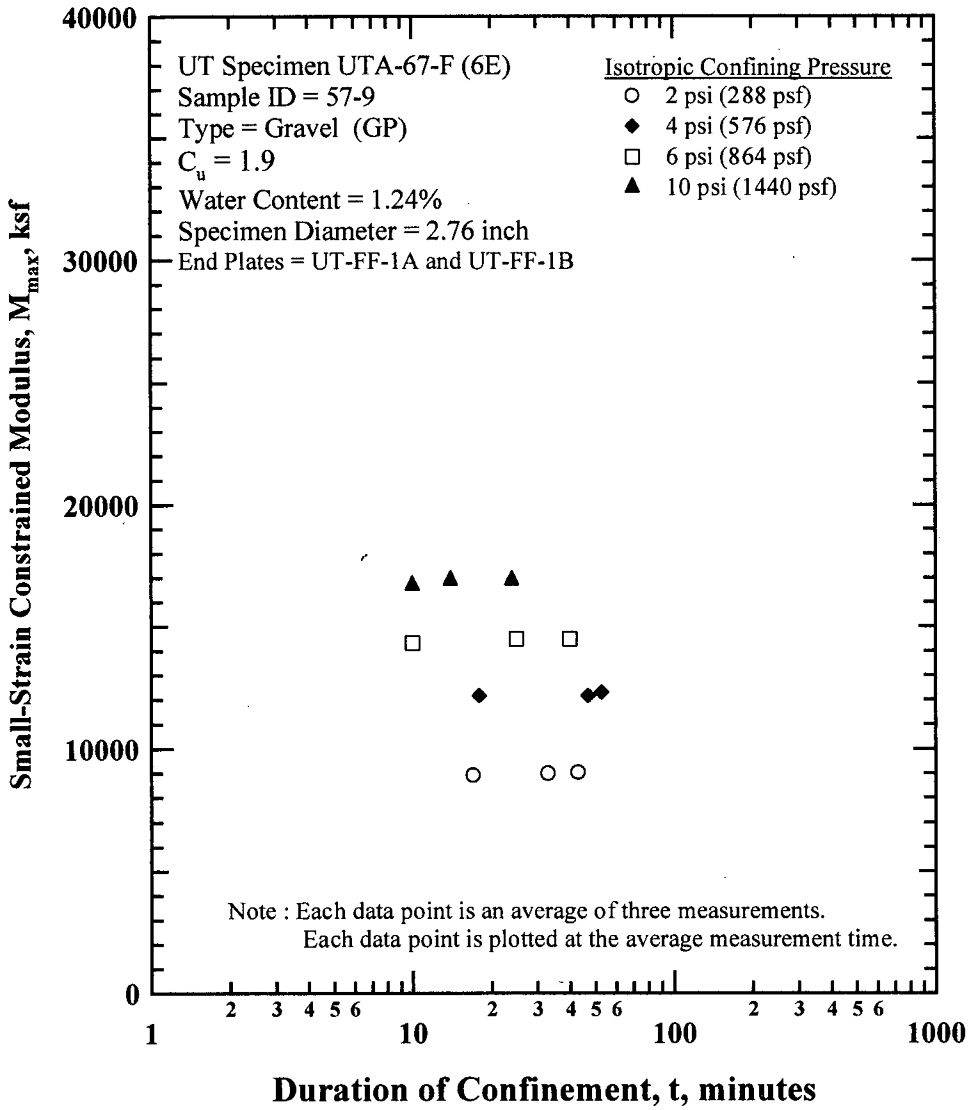


Figure N.6 Variation in Small-Strain Constrained Modulus (M_{max}) with Magnitude and Duration of Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

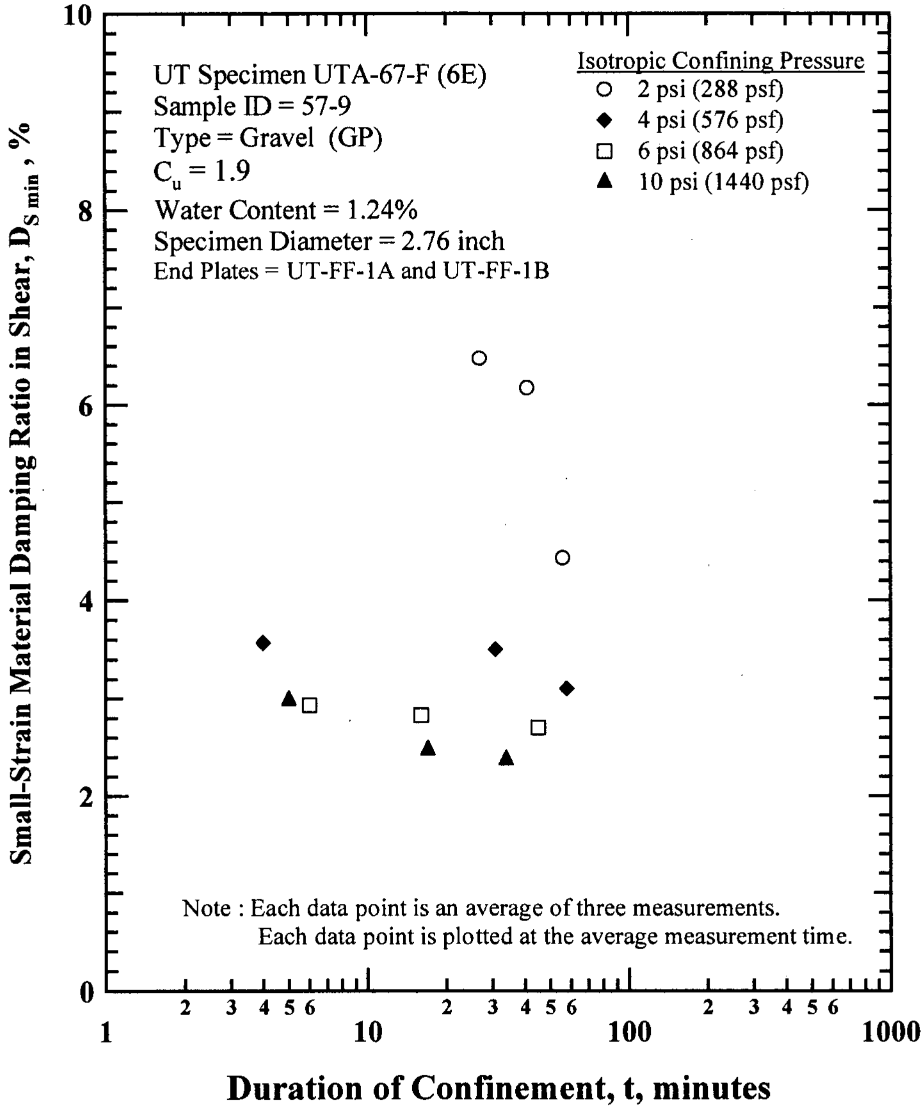


Figure N.7 Variation in Small-Strain Material Damping Ratio in Shear ($D_{S\ min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

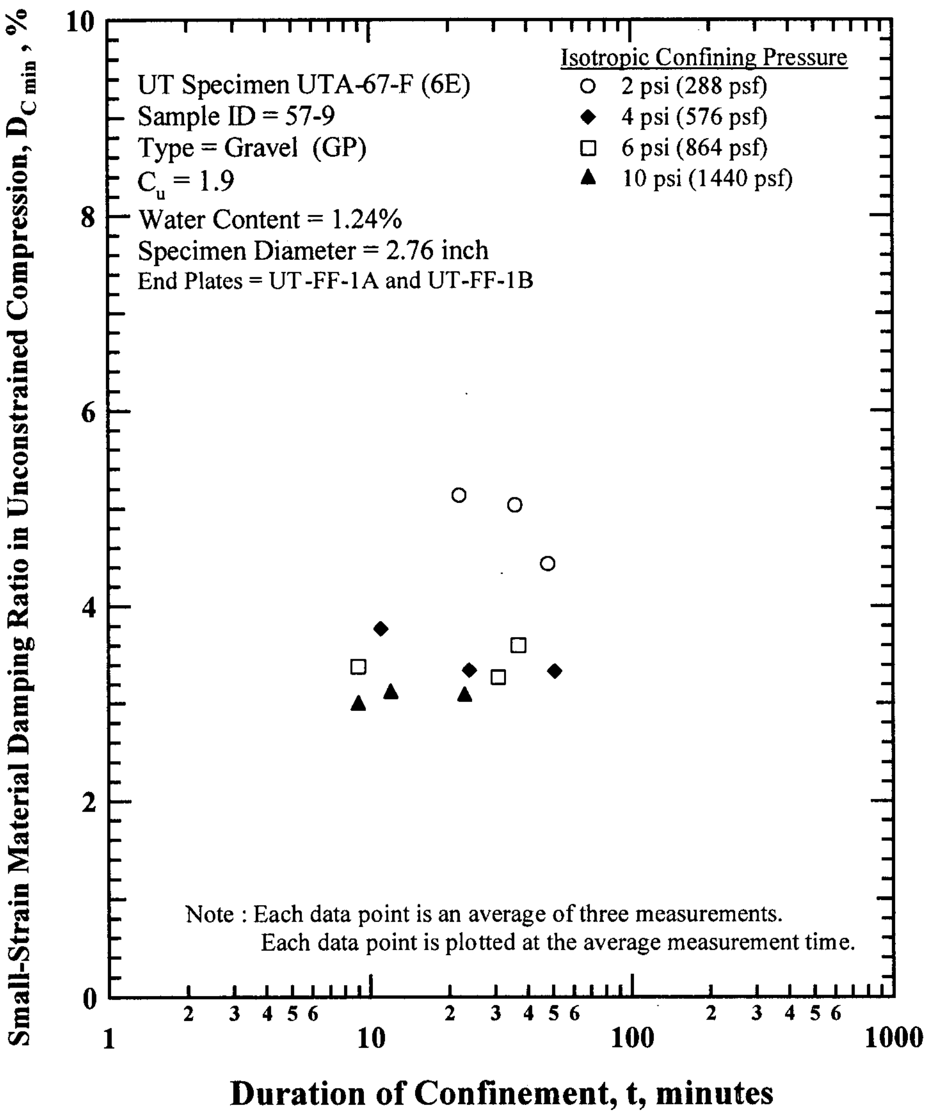
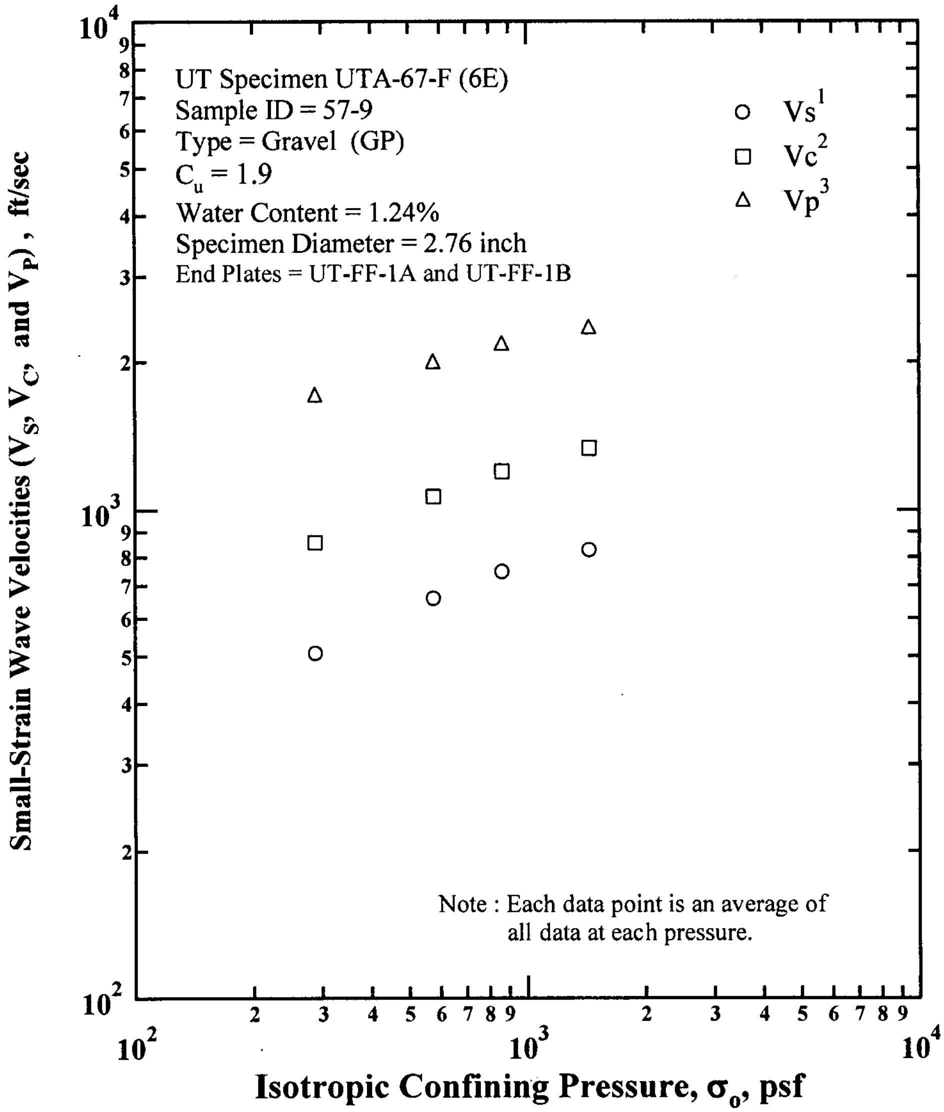
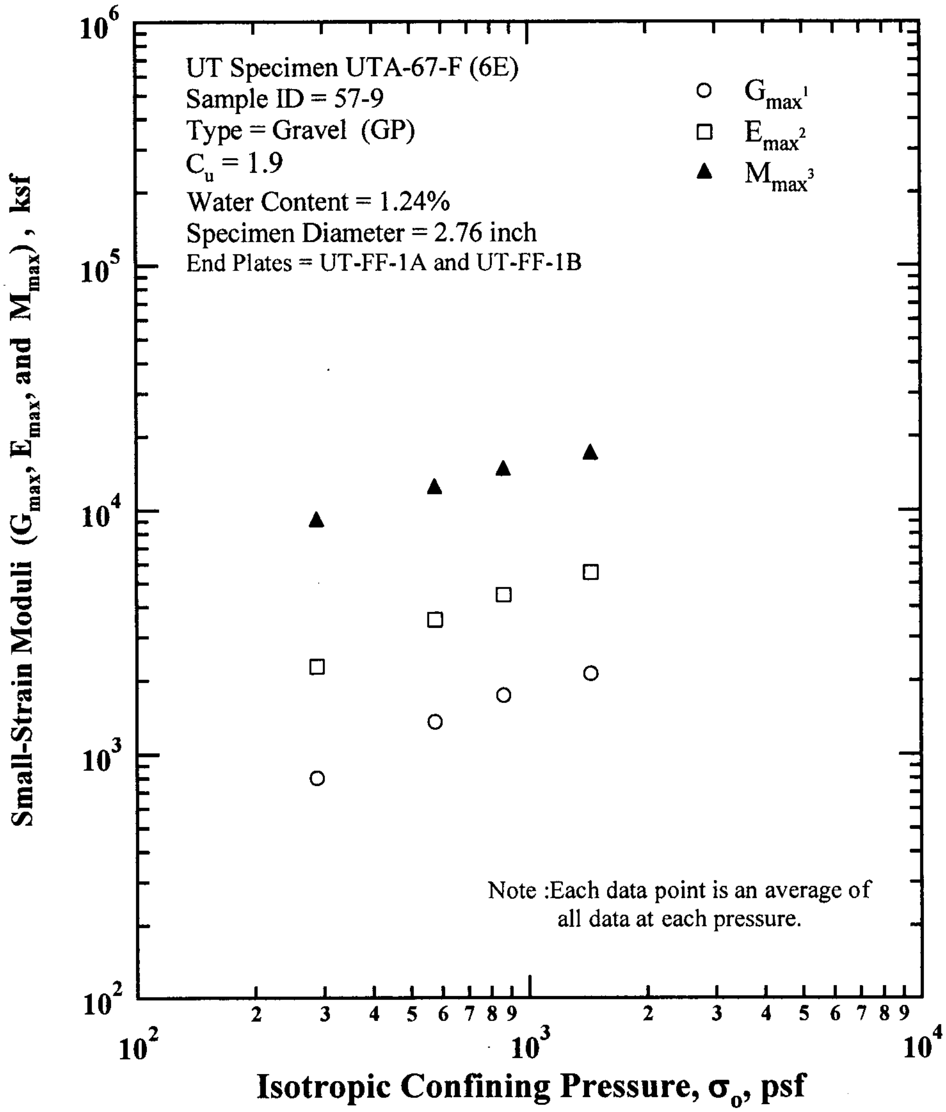


Figure N.8 Variation in Small-Strain Material Damping Ratio in Unconstrained Compression ($D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)



Notes : 1. V_S=Small-Strain Shear Wave Velocity
2. V_C=Small-Strain Unconstrained Compression Wave Velocity
3. V_P=Small-Strain Constrained Compression Wave Velocity

Figure N.9 Variation in Small-Strain Wave Velocities (V_S, V_C, and V_P) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

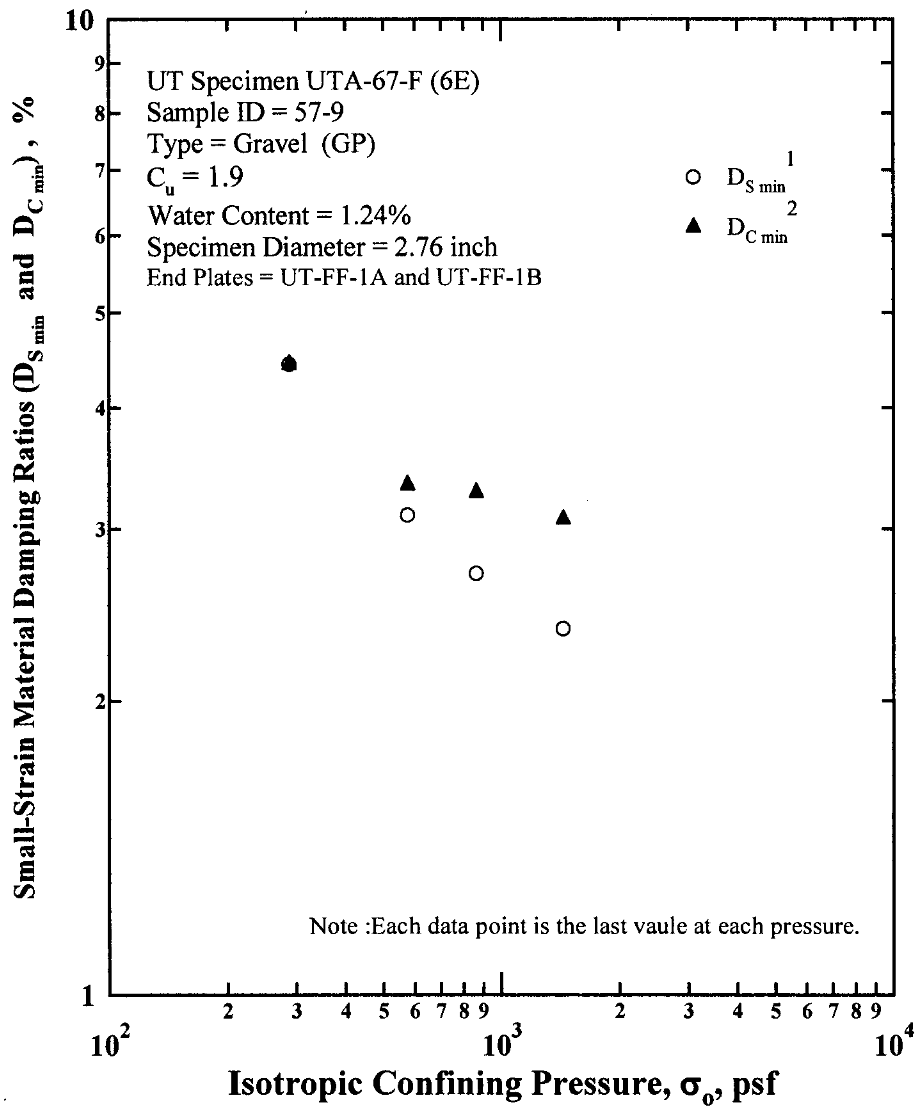


Notes :1.G_{max}=Small-Strain Shear Modulus

2. E_{max}=Small-Strain Young's Modulus

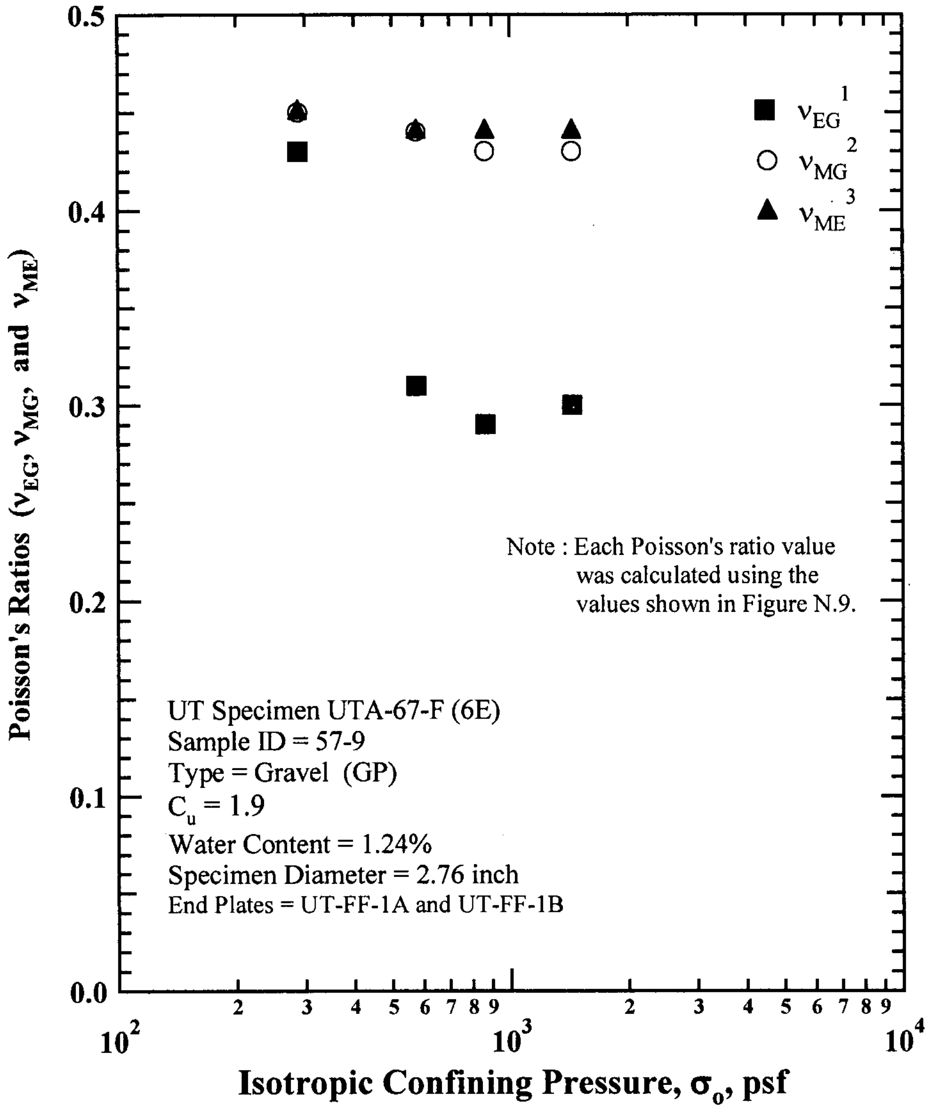
2. M_{max}=Small-Strain Constrained Modulus

Figure N.10 Variation in Small-Strained Moduli (G_{max}, E_{max}, and M_{max}) with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)



Notes :1.$D_{S\,min}$ = Small-Strain Material Damping Ratio in Shear
2.$D_{C\,min}$ = Small-Strain Material Damping Ratio in Unconstrained Compression

Figure N.11 Variation in Small-Strained Material Damping Ratios ($D_{S\,min}$ and $D_{C\,min}$) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-F (6E)



Notes :1. ν_{EG}=Poisson's Ratio from the Relationship between V_C and V_S
2. ν_{MG}=Poisson's Ratio from the Relationship between V_P and V_S
3. ν_{ME}=Poisson's Ratio from the Relationship between V_P and V_C

Figure N.12 Variation in Poisson's Ratios (ν_{EG}, ν_{MG}, and ν_{ME}) with Isotropic Confining Pressure from Free-Free Resonant Column Tests of Specimen UTA-67-F (6E)

Table N.1 Variations in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-F (6E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Shear Modulus, G_{max}*		Small-Strain Shear Wave Velocity, V_S*	Small-Strain Material Damping Ratio in Shear, $D_{S\,min}$*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	27	779	37.4	501	6.47
2	288	14	41	796	38.2	506	6.17
2	288	14	56	818	39.2	513	4.43
4	576	28	4	1334	64.0	656	3.57
4	576	28	31	1349	64.7	659	3.50
4	576	28	58	1359	65.1	662	3.10
6	864	41	6	1751	83.9	751	2.93
6	864	41	16	1738	83.3	748	2.83
6	864	41	45	1700	81.5	740	2.70
10	1440	69	5	2110	101.2	824	2.98
10	1440	69	17	2143	102.7	831	2.47
10	1440	69	34	2117	101.5	826	2.37

Note : * Average of three measurements

Table N.2 Variation in Small-Strain Shear Wave Velocity, Small-Strain Shear Modulus and Small-Strain Material Damping Ratio in Shear with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

Isotropic Confining Pressure, σ_o			Small-Strain Shear Modulus, G_{max}*		Small-Strain Shear Wave Velocity, V_S*	Small-Strain Material Damping Ratio in Shear, $D_{S\,min}$**
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	798	38	507	4.43
4	576	28	1347	65	659	3.10
6	864	41	1730	83	746	2.70
10	1440	69	2123	102	827	2.37

Notes : * Average of all data at each pressure
** The last value at each pressure

Table N.3 Variations in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstrained Compression with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-F (6E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Young's Modulus, E_{max}*		Small-Strain Unconstrained Compression Wave Velocity, V_C*	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)	(%)
2	288	14	22	2238	107.3	849	5.13
2	288	14	36	2308	110.7	862	5.03
2	288	14	48	2286	109.6	858	4.43
4	576	28	11	3538	169.6	1067	3.77
4	576	28	24	3529	169.2	1066	3.34
4	576	28	51	3523	168.9	1065	3.33
6	864	41	9	4507	216.1	1205	3.38
6	864	41	37	4473	214.4	1200	3.60
6	864	41	31	4416	211.7	1193	3.27
10	1440	69	9	5545	265.8	1336	2.98
10	1440	69	12	5526	264.9	1334	3.10
10	1440	69	23	5514	264.4	1333	3.07

Note : * Average of three measurements

Table N.4 Variation in Small-Strain Unconstrained Compression Wave Velocity, Small-Strain Young's Modulus and Small-Strain Material Damping Ratio in Unconstraind Compression with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

Isotropic Confining Pressure, σ_o			Small-Strain Young's Modulus, E_{max}*		Small-Strain Unconstrained Compression Wave Velocity, V_C*	Small-Strain Material Damping Ratio in Unconstrained Compression, $D_{C\ min}$**
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)
2	288	14	2278	109	856	4.43
4	576	28	3530	169	1066	3.33
6	864	41	4465	214	1199	3.27
10	1440	69	5528	265	1334	3.07

Notes : * Average of all data at each pressure
** The last value at each pressure

Table N.5 Variations in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure and Duration of Confinement from Free-Free Testing of Specimen UTA-67-F (6E)

Isotropic Confining Pressure, σ_o			Duration of Confinement	Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(minutes)	(ksf)	(MPa)	(fps)
2	288	14	17	8904	426.8	1693
2	288	14	33	8987	430.8	1701
2	288	14	43	9029	432.8	1705
4	576	28	18	12151	582.5	1978
4	576	28	47	12151	582.5	1978
4	576	28	53	12283	588.9	1989
6	864	41	10	14314	686.2	2147
6	864	41	25	14485	694.4	2160
6	864	41	40	14485	694.4	2160
10	1440	69	10	16682	799.7	2318
10	1440	69	14	16894	809.9	2333
10	1440	69	24	16894	809.9	2333

Note : * Average of three measurements

Table N.6 Variation in Small-Strain Constrained Compression Wave Velocity and Small-Strain Constrained Modulus with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

Isotropic Confining Pressure, σ_o			Small-Strain Constrained Modulus, M_{max}^*		Small-Strain Constrained Compression Wave Velocity, V_P^*
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)
2	288	14	8973	430	1700
4	576	28	12195	585	1982
6	864	41	14428	692	2156
10	1440	69	16823	807	2328

Note : * Average of all data at each pressure

Table N.7 Variation in Poisson's Ratios with Isotropic Confining Pressure from Free-Free Testing of Specimen UTA-67-F (6E)

Isotropic Confining Pressure, σ_o			Poisson's Ratio		
(psi)	(psf)	(kPa)	ν_{EG} [1]	ν_{MG} [2]	ν_{ME} [3]
2	288	14	0.43	0.45	0.45
4	576	28	0.31	0.44	0.44
6	864	41	0.29	0.43	0.44
10	1440	69	0.30	0.43	0.44

Notes : 1. Poisson's ratio from the relationship between V_C and V_S tabulated in Tables N.4 and N.2, respectively.

2. Poisson's ratio from the relationship between V_P and V_S tabulated in Tables N.6 and N.2, respectively.

3. Poisson's ratio from the relationship between V_P and V_C tabulated in Tables N.6 and N.4, respectively.