Paul C. Rizzo Associates, Inc.
ENGINEERS / CONSULTANTS / CM

Paul C. Rizzo Associates, Inc
500 Penn Center Blvd. Suite 100, Pittsburgh, PA 15235
www.rizzoassoc.com

Boring R-7-1

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396976.23 ft **E. 875797.30 ft**

GROUND SURFACE ELEVATION: 0.22 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-320.0							SM	
-321.0	321.0	ST-16	72%			320.95-450.5 ft Silty sand, 80% sand, fine to medium, subrounded; 20% fines, low plasticity, medium toughness; pale olive (10Y 6/2) with dusky yellow green (5GY 5/2), moist, weak HCl reaction, dense consistency, weak cementation, [Peace River Formation] interbedded with sandy lean clay, 90% fines, medium plasticity, low toughness; 10% sand, fine; 0% gravel; dusky yellow green (5GY 5/2), dry, strong HCl reaction, soft consistency, weak cementation, Exist as lenses up to 0.3ft in thickness. Some lenses contain no sand. [Peace River Formation]	SP-SM	
-322.0	322.0	S-22	50/3 N1(50/3) 100%					
-323.0	323.0							
-324.0	324.0							
-325.0	325.0							
-326.0	326.0							
-327.0	327.0							
-328.0	328.0							
-329.0	329.0	ST-17	92%				SP-SM	
-330.0	330.0	S-23	50/5 N1(50/5) 100%				sm	
-331.0	331.0							
-332.0	332.0							
-333.0	333.0							
-334.0	334.0							
-335.0	335.0							
-336.0	336.0							
-337.0	337.0							
-338.0	338.0	ST-18	85%				SP	
-339.0	339.0	S-24	50/4 N1(50/4) 100%					

DATE STARTED: 8/20/13
DATE FINISHED: 9/6/13
FIELD GEOLOGIST: Jason Lee
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
DRILLER: Eddie Palmer

NOTES:

DRILL RIG: DR-16
HAMMER ID:

Boring R-7-1

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396976.23 ft E. 875797.30 ft

GROUND SURFACE ELEVATION: 0.22 ft

DESCRIPTION

320.95-450.5 ft Silty sand, 80% sand, fine to medium, subrounded; 20% fines, low plasticity, medium toughness; pale olive (10Y 6/2) with dusky yellow green (5GY 5/2), moist, weak HCl reaction, dense consistency, weak cementation, [Peace River Formation]

interbedded with sandy lean clay, 90% fines, medium plasticity, low toughness; 10% sand, fine; 0% gravel; dusky yellow green (5GY 5/2), dry, strong HCl reaction, soft consistency, weak cementation, Exist as lenses up to 0.3ft in thickness. Some lenses contain no sand. [Peace River Formation]

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	USCS SYMBOL	REMARKS
-340.0							
-341.0	341.0						
-342.0	342.0						
-343.0	343.0						
-344.0	344.0						
-345.0	345.0						
-346.0	346.0	ST-19	75%			SP-SM	
-347.0	347.0	S-25	49-50/4 N1(50/4) 100%				
-348.0	348.0						
-349.0	349.0						
-350.0	350.0					sm	
-351.0	351.0						
-352.0	352.0						
-353.0	353.0						
-354.0	354.0						
-355.0	355.0	ST-20	80%			SP-SM	
-356.0	356.0	S-26	50/4 N1(50/4) 100%				
-357.0	357.0						
-358.0	358.0						
-359.0	359.0						

DATE STARTED: 8/20/13
DATE FINISHED: 9/6/13
FIELD GEOLOGIST: Jason Lee
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling

NOTES:

APPROVED BY: EOT

DRILLER: Eddie Palmer

DRILL RIG: DR-16

HAMMER ID:

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Boring R-7-1

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PROJECT NO.: 13-5054

COORDINATES

N. 396976.23 ft **E. 875797.30 ft**

GROUND SURFACE ELEVATION: 0.22 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-360.0						320.95-450.5 ft Silty sand, 80% sand, fine to medium, subrounded; 20% fines, low plasticity, medium toughness; pale olive (10Y 6/2) with dusky yellow green (5GY 5/2), moist, weak HCl reaction, dense consistency, weak cementation, [Peace River Formation] interbedded with sandy lean clay, 90% fines, medium plasticity, low toughness; 10% sand, fine; 0% gravel; dusky yellow green (5GY 5/2), dry, strong HCl reaction, soft consistency, weak cementation, Exist as lenses up to 0.3ft in thickness. Some lenses contain no sand. [Peace River Formation]		
-361.0	361.0							
-362.0	362.0							
-363.0	363.0							
-364.0	364.0	ST-21	64%					
-365.0	365.0	S-27	50/3 N1(50/3) 100%					
-366.0	366.0							
-367.0	367.0							
-368.0	368.0							
-369.0	369.0							
-370.0	370.0						sm	
-371.0	371.0							
-372.0	372.0							
-373.0	373.0	ST-22	68%				SP-SM	
-374.0	374.0	S-28	50/4 N1(50/4) 100%					
-375.0	375.0							
-376.0	376.0							
-377.0	377.0							
-378.0	378.0							
-379.0	379.0							

DATE STARTED: 8/20/13
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FIELD GEOLOGIST: Jason Lee
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APPROVED BY: EOT

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DRILLING CO. Huss Drilling
DRILLER: Eddie Palmer

NOTES:

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Boring R-7-1

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396976.23 ft **E. 875797.30 ft**

GROUND SURFACE ELEVATION: 0.22 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-380.0						320.95-450.5 ft Silty sand, 80% sand, fine to medium, subrounded; 20% fines, low plasticity, medium toughness; pale olive (10Y 6/2) with dusky yellow green (5GY 5/2), moist, weak HCl reaction, dense consistency, weak cementation, [Peace River Formation] interbedded with sandy lean clay, 90% fines, medium plasticity, low toughness; 10% sand, fine; 0% gravel; dusky yellow green (5GY 5/2), dry, strong HCl reaction, soft consistency, weak cementation, Exist as lenses up to 0.3ft in thickness. Some lenses contain no sand. [Peace River Formation]		
	381.0							
-381.0								
	382.0							
-382.0								
	383.0							
-383.0								
	384.0							
-384.0		S-29	50/5 N1(50/5) 100%					
	385.0							
-385.0								
	386.0							
-386.0								
	387.0							
-387.0								
	388.0							
-388.0								
	389.0							
-389.0								
	390.0						sm	
-390.0								
	391.0							
-391.0		ST-23	76%				SM	
	392.0							
-392.0								
		S-30	50/4 N1(50/4) 86%					
	393.0							
-393.0								
	394.0							
-394.0								
	395.0							
-395.0								
	396.0							
-396.0								
	397.0							
-397.0								
	398.0							
-398.0								
	399.0							
-399.0								

DATE STARTED: 8/20/13
DATE FINISHED: 9/6/13
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CHECKED BY: Rolando Benitez
DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
NOTES:
APPROVED BY: EOT
DRILLER: Eddie Palmer
DRILL RIG: DR-16
HAMMER ID:

Boring R-7-1

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396976.23 ft E. 875797.30 ft
GROUND SURFACE ELEVATION: 0.22 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-400.0						320.95-450.5 ft Silty sand, 80% sand, fine to medium, subrounded; 20% fines, low plasticity, medium toughness; pale olive (10Y 6/2) with dusky yellow green (5GY 5/2), moist, weak HCl reaction, dense consistency, weak cementation, [Peace River Formation] interbedded with sandy lean clay, 90% fines, medium plasticity, low toughness; 10% sand, fine; 0% gravel; dusky yellow green (5GY 5/2), dry, strong HCl reaction, soft consistency, weak cementation, Exist as lenses up to 0.3ft in thickness. Some lenses contain no sand. [Peace River Formation]		
	401.0							
-401.0								
	402.0							
-402.0		S-31	39-50/3 N1(50/3) 80%					
	403.0							
-403.0								
	404.0							
-404.0								
	405.0							
-405.0								
	406.0							
-406.0								
	407.0							
-407.0								
	408.0							
-408.0								
	409.0							
-409.0								
	410.0	ST-24	76%				sm	
-410.0								
	411.0	S-32	50/5 N1(50/5) 88%					
-411.0								
	412.0							
-412.0								
	413.0							
-413.0								
	414.0							
-414.0								
	415.0							
-415.0								
	416.0							
-416.0								
	417.0							
-417.0								
	418.0							
-418.0								
	419.0							
-419.0								

DATE STARTED: 8/20/13
DATE FINISHED: 9/6/13
FIELD GEOLOGIST: Jason Lee
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
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NOTES:

DRILL RIG: DR-16
HAMMER ID:

Boring R-7-1

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PROJECT NO.: 13-5054

COORDINATES
N. 396976.23 ft E. 875797.30 ft
GROUND SURFACE ELEVATION: 0.22 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-420.0		S-33	50/5 N1(50/5) 100%			320.95-450.5 ft Silty sand, 80% sand, fine to medium, subrounded; 20% fines, low plasticity, medium toughness; pale olive (10Y 6/2) with dusky yellow green (5GY 5/2), moist, weak HCl reaction, dense consistency, weak cementation, [Peace River Formation] interbedded with sandy lean clay, 90% fines, medium plasticity, low toughness; 10% sand, fine; 0% gravel; dusky yellow green (5GY 5/2), dry, strong HCl reaction, soft consistency, weak cementation, Exist as lenses up to 0.3ft in thickness. Some lenses contain no sand. [Peace River Formation]		
-421.0	421.0							
-422.0	422.0							
-423.0	423.0							
-424.0	424.0							
-425.0	425.0							
-426.0	426.0							
-427.0	427.0							
-428.0	428.0							
-429.0	429.0	S-34	34-50/3 N1(50/3) 80%					
-430.0	430.0						sm	
-431.0	431.0							
-432.0	432.0							
-433.0	433.0							
-434.0	434.0							
-435.0	435.0							
-436.0	436.0							
-437.0	437.0	ST-25	73%				SP-SM	
-438.0	438.0	S-35	26-32-50/4 N1(50/4) 81%					
-439.0	439.0							

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COORDINATES

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GROUND SURFACE ELEVATION: 0.22 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-440.0 -441.0 -442.0 -443.0 -444.0 -445.0 -446.0 -447.0 -448.0 -449.0 -450.0	441.0 442.0 443.0 444.0 445.0 446.0 447.0 448.0 449.0 450.0	S-36	29-50/5 N1(50/5) 95%			320.95-450.5 ft Silty sand, 80% sand, fine to medium, subrounded; 20% fines, low plasticity, medium toughness; pale olive (10Y 6/2) with dusky yellow green (5GY 5/2), moist, weak HCl reaction, dense consistency, weak cementation, [Peace River Formation] interbedded with sandy lean clay, 90% fines, medium plasticity, low toughness; 10% sand, fine; 0% gravel; dusky yellow green (5GY 5/2), dry, strong HCl reaction, soft consistency, weak cementation, Exist as lenses up to 0.3ft in thickness. Some lenses contain no sand. [Peace River Formation]	sm	
-451.0 -452.0 -453.0 -454.0 -455.0 -456.0 -457.0	451.0 452.0 453.0 454.0 455.0 456.0 457.0	R-40	0%			450.5-458.0 ft LIMESTONE, Description based on observation of cuttings only. Core run (R-40) yielded no recovery. Cuttings returned consisted of Shell fragments. Material in this interval is more competent than the above layers; interpreted as the Arcadia formation.		Description below 450.5ft is based on sample S-37 (458.0-459.4ft) and observations of cuttings during destructive drilling. 453-458ft., Core run using conventional NWD4 barrel. No recovery.
-458.0 -459.0	458.0 459.0	S-37	12-5-50/5 N1(50/5) 71%			458.0-458.4 ft Lean clay with sand, 80% fines, medium plasticity, low toughness; 20% sand; light olive gray (5Y 5/2), weak HCl reaction, [Arcadia Formation]	cl	

DATE STARTED: 8/20/13
DATE FINISHED: 9/6/13
FIELD GEOLOGIST: Jason Lee
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
DRILLER: Eddie Palmer

NOTES:

DRILL RIG: DR-16
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N. 396976.23 ft E. 875797.30 ft
GROUND SURFACE ELEVATION: 0.22 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
						458.4-458.9 ft MUDSTONE, dolomitic, soft to moderately hard, slightly weathered, silt to very fine sand particles, weak reaction to HCl, [Arcadia Formation]		
						---- Bottom of Boring at 459.40 ft.----		

DATE STARTED: 8/20/13
DATE FINISHED: 9/6/13
FIELD GEOLOGIST: Jason Lee
CHECKED BY: Rolando Benitez
DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
NOTES:
APPROVED BY: EOT
DRILLER: Eddie Palmer
DRILL RIG: DR-16
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Boring R-7-2

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396966.03 ft **E. 875788.86 ft**

GROUND SURFACE ELEVATION: 0.06 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
						0.0-27.0 ft No Sample Recovered.		0.0 - 27.0 ft., destructively drilled using (2 7/8 inch and 2 15/16 inch) mud rotary bits. Measured water level varied within one foot of ground surface.
-1.0	1.0							
-2.0	2.0							
-3.0	3.0							
-4.0	4.0							
-5.0	5.0							
-6.0	6.0							
-7.0	7.0							
-8.0	8.0							
-9.0	9.0							
-10.0	10.0							
-11.0	11.0							
-12.0	12.0							
-13.0	13.0							
-14.0	14.0							
-15.0	15.0							
-16.0	16.0							
-17.0	17.0							
-18.0	18.0							
-19.0	19.0							

DATE STARTED: 9/10/13
DATE FINISHED: 9/25/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, NWD4
DRILLING CO. Huss Drilling

NOTES: Destructivey drilled and cored (NWD4 Conventional Coring) pockets for Pressuremeter testing.

APPROVED BY: EOT

DRILLER: Ben Huss

DRILL RIG: DR-18

HAMMER ID:

Boring R-7-2

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396966.03 ft **E. 875788.86 ft**
GROUND SURFACE ELEVATION: 0.06 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-21.0	21.0					0.0-27.0 ft No Sample Recovered.		
-22.0	22.0							
-23.0	23.0							
-24.0	24.0							
-25.0	25.0							
-26.0	26.0							
-27.0	27.0							27.0 - 95.0 ft., a combination of destructive drilling using (2 7/8 inch and 2 15/16 inch) mud rotary bits and NWD4 conventional coring were used to create pockets for pressuremeter testing. Cored to produce a better pocket for the pressuremeter testing. Recovery and RQD not to be compared with those from PQ wireline coring.
-28.0	28.0					27.0-45.0 ft BOUNDSTONE, fossiliferous, moderately hard to moderately soft, moderately weathered, very fine sand to silt particles, pitted to vuggy, typical diameter: 0.2 in., max size: 0.8 in., very light gray (N8) to white (N9), strong reaction to HCl, wet, iron oxide staining, Calcareous. Bounstone and wackstone. [Key Largo Limestone]		
-29.0	29.0	R-1	34% (8%)					
-30.0	30.0							
-31.0	31.0							
-32.0	32.0							
-33.0	33.0							
-34.0	34.0	R-2	52% (30%)					
-35.0	35.0					35- ft R.D. = 0°, moderately spaced, slightly open; wet with seepage, filling: not healed, thin calcite, fresh, moderately soft; surface: rough, planar, fresh, moderately hard; Coated with recrystallized calcite.		
-36.0	36.0					36-42 ft R.D. = 60°, widely to moderately spaced, slightly open; wet with seepage, filling: not healed, thin calcite, fresh, moderately soft; surface: rough, planar, fresh, moderately hard; Coated with recrystallized calcite.		
-37.0	37.0			FD4				
-38.0	38.0	R-3	62% (16%)					
-39.0	39.0							

DATE STARTED: 9/10/13
DATE FINISHED: 9/25/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, NWD4
DRILLING CO. Huss Drilling

NOTES: Destructivey drilled and cored (NWD4 Conventional Coring) pockets for Pressuremeter testing.

APPROVED BY: EOT

DRILLER: Ben Huss

DRILL RIG: DR-18

HAMMER ID:

Boring R-7-2

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396966.03 ft **E. 875788.86 ft**

GROUND SURFACE ELEVATION: 0.06 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-41.0	41.0	R-3	62% (16%)	FD4		27.0-45.0 ft BOUNDSTONE, fossiliferous, moderately hard to moderately soft, moderately weathered, very fine sand to silt particles, pitted to vuggy, typical diameter: 0.2 in., max size: 0.8 in., very light gray (N8) to white (N9), strong reaction to HCl, wet, iron oxide staining, Calcareous. Bounstone and wackstone. [Key Largo Limestone]		
-42.0	42.0							
-43.0	43.0							
-44.0	44.0							
-45.0	45.0	R-4	57% (30%)			45.0-51.5 ft PACKSTONE, fossiliferous, moderately hard to moderately soft, moderately weathered, silt to granule particles, pitted to vuggy, typical diameter: 0.3 in., max size: 1.0 in., very light gray (N8) and pale greenish yellow (10Y 8/2), strong reaction to HCl, wet, iron oxide staining, Calcareous. Abundant moldic porosity. Most vugs are a result of this moldic porosity. From 45 to 46 ft the color is light olive gray (5G 6/1). [Fort Thompson Formation]		
-46.0	46.0							
-47.0	47.0							
-48.0	48.0							
-49.0	49.0							
-50.0	50.0	R-5	42% (32%)					
-51.0	51.0							
-52.0	52.0					51.5-58.0 ft PACKSTONE, fossiliferous, moderately hard, moderately weathered, silt to granule particles, pitted to vuggy, typical diameter: 0.01 in., max size: 0.03 in., very light gray (N8) and pale greenish yellow (10Y 8/2), strong reaction to HCl, wet, iron oxide staining, Calcareous. Abundant moldic porosity. Most vugs are a result of this moldic porosity. Packstone to grainstone. [Fort Thompson Formation]		
-53.0	53.0							
-54.0	54.0							
-55.0	55.0	R-6	76% (60%)					
-56.0	56.0							
-57.0	57.0							
-58.0	58.0					58.0-65.0 ft No Sample Recovered.		
-59.0	59.0							

DATE STARTED: 9/10/13
DATE FINISHED: 9/25/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, NWD4
DRILLING CO. Huss Drilling

NOTES: Destructivey drilled and cored (NWD4 Conventional Coring) pockets for Pressuremeter testing.

APPROVED BY: EOT

DRILLER: Ben Huss

DRILL RIG: DR-18

HAMMER ID:

Boring R-7-2

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396966.03 ft E. 875788.86 ft
GROUND SURFACE ELEVATION: 0.06 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
						58.0-65.0 ft No Sample Recovered.		
-61.0	61.0							
-62.0	62.0							
-63.0	63.0							
-64.0	64.0							
-65.0	65.0							
-66.0	66.0					65.0-78.0 ft PACKSTONE, fossiliferous, moderately hard, moderately weathered, silt to granule particles, pitted to vuggy, typical diameter: 0.01 in., max size: 0.03 in., very light gray (N8) and pale greenish yellow (10Y 8/2), strong reaction to HCl, wet, iron oxide staining, Calcareous. Abundant moldic porosity. Most vugs are a result of this moldic porosity. Packstone to grainstone. [Fort Thompson Formation]		Very soft material drilled between 65.5 and 67.5 ft.
-67.0	67.0	R-7	52% (10%)					
-68.0	68.0							
-69.0	69.0							
-70.0	70.0							
-71.0	71.0	R-8	27% (0%)					
-72.0	72.0							
-73.0	73.0							
-74.0	74.0							
-75.0	75.0	R-9	78% (28%)					
-76.0	76.0							
-77.0	77.0							
-78.0	78.0					78.0-90.0 ft No Sample Recovered.		
-79.0	79.0							

DATE STARTED: 9/10/13
DATE FINISHED: 9/25/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, NWD4
DRILLING CO. Huss Drilling

NOTES: Destructivey drilled and cored (NWD4 Conventional Coring) pockets for Pressuremeter testing.

APPROVED BY: EOT

DRILLER: Ben Huss

DRILL RIG: DR-18

HAMMER ID:

Paul C. Rizzo Associates, Inc.
ENGINEERS/CONSULTANTS/CM

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Boring R-7-2

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396966.03 ft E. 875788.86 ft
GROUND SURFACE ELEVATION: 0.06 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
						78.0-90.0 ft No Sample Recovered.		
-81.0	81.0							
-82.0	82.0							
-83.0	83.0							
-84.0	84.0							
-85.0	85.0							
-86.0	86.0							
-87.0	87.0							
-88.0	88.0							
-89.0	89.0							
-90.0	90.0				▨	90.0-95.0 ft GRAINSTONE, calcareous, soft (H6) to moderately soft (H5), moderately (W5) weathered, fine sand to medium sand particles, vuggy, very light gray (N8), strong reaction to HCl, Zones of unconsolidated fine sand infilling of voids [Fort Thompson Formation]		
-91.0	91.0				▨			
-92.0	92.0	R-10	50% (21%)		▨			
-93.0	93.0				▨			Bottom of coring at 95.0ft. Boring continues to 370.0ft, and was destructively drilled alternating between (2 7/8 inch and 2 15/16 inch) mud rotary bits to accomodate pressuremeter testing pocket drilling.
-94.0	94.0				▨			
	95.0					---- Bottom of Boring at 95.00 ft.----		

DATE STARTED: 9/10/13
DATE FINISHED: 9/25/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ, NWD4
DRILLING CO. Huss Drilling
DRILLER: Ben Huss

NOTES: Destructivey drilled and cored (NWD4 Conventional Coring) pockets for Pressuremeter testing.

DRILL RIG: DR-18
HAMMER ID:

Boring R-7-3

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396957.30 ft **E. 875783.79 ft**

GROUND SURFACE ELEVATION: 0.01 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
						0.0-20.0 ft No Sample recovered.		0 - 20.0 ft., destructively drilled using a mud rotary bit. Measured water level varied within one foot of ground surface.
-1.0	1.0							
-2.0	2.0							
-3.0	3.0							
-4.0	4.0							
-5.0	5.0							
-6.0	6.0							
-7.0	7.0							
-8.0	8.0							
-9.0	9.0							
-10.0	10.0							
-11.0	11.0							At 11ft, mud circulation reduced to a minimum.
-12.0	12.0							
-13.0	13.0							
-14.0	14.0							
-15.0	15.0							
-16.0	16.0							
-17.0	17.0							
-18.0	18.0							
-19.0	19.0							

DATE STARTED: 8/14/13
DATE FINISHED: 8/22/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez
DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
NOTES:
APPROVED BY: EOT
DRILLER: Eddie Palmer
DRILL RIG: DR-16
HAMMER ID:

Paul C. Rizzo Associates, Inc.
ENGINEERS / CONSULTANTS / CM

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www.rizzoassoc.com

Boring R-7-3

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396957.30 ft E. 875783.79 ft
GROUND SURFACE ELEVATION: 0.01 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-21.0 -22.0 -23.0 -24.0 -25.0	21.0 22.0 23.0 24.0 25.0	R-1	12% (0%)			20.0-25.6 ft LIMESTONE, moderately soft to moderately hard, moderately to intensely weathered, granule to pebble particles, yellowish gray (5Y 8/1) and very light gray (N8), strong reaction to HCl, wet, Recovered only as rock fragments. [Miami Limestone]		20.0 - 120.0 ft., NWD4 conventional coring.
-26.0 -27.0 -28.0	26.0 27.0 28.0	R-2	100% (47%)			25.6-28.0 ft LIMESTONE, fossiliferous, disturbed, horizontal, moderately soft to moderately hard, moderately weathered, very fine sand to pebble particles, pitted to vuggy, typical diameter: 0.25 in., max size: 1.2 in., light gray (N7) to very light gray (N8), strong reaction to HCl, wet, [Miami Limestone]		Lost circulation at 26.0ft.
-29.0 -30.0 -31.0 -32.0 -33.0 -34.0 -35.0	29.0 30.0 31.0 32.0 33.0 34.0 35.0	R-3	79% (71%)			28.0-35.0 ft LIMESTONE, fossiliferous, moderately hard, moderately weathered, very fine sand to silt particles, pitted to vuggy, typical diameter: 0.2 in., max size: 1.0 in., very light gray (N8) to white (N9), strong reaction to HCl, wet, iron oxide staining, Calcareous. Coralline to mudstone. One inch vugs filled wih moderatety soft to hard grainstone, light brown in color. [Key Largo Limestone]		Tool drop from 33.0 to 34.5 ft.
-36.0	36.0	R-4	100% (27%)			35.0-43.0 ft LIMESTONE, disturbed, moderately hard to moderately soft, moderately weathered, very fine sand particles, pitted to vuggy, typical diameter: 0.7 in., max size: 2.0 in., very light gray (N8) to yellowish gray (5Y 8/1), strong reaction to HCl, wet, Calcareous. Recrystallized calcite coating previously disolved vugs and pits. [Key Largo Limestone]		
-37.0 -38.0 -39.0	37.0 38.0 39.0	R-5	37% (29%)					

DATE STARTED: 8/14/13
DATE FINISHED: 8/22/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez
DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
NOTES:
APPROVED BY: EOT
DRILLER: Eddie Palmer
DRILL RIG: DR-16
HAMMER ID:

Paul C. Rizzo Associates, Inc.
ENGINEERS/CONSULTANTS/CM

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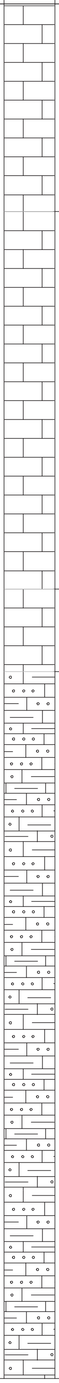
Boring R-7-3

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396957.30 ft E. 875783.79 ft

GROUND SURFACE ELEVATION: 0.01 ft



ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-41.0	41.0					35.0-43.0 ft LIMESTONE, disturbed, moderately hard to moderately soft, moderately weathered, very fine sand particles, pitted to vuggy, typical diameter: 0.7 in., max size: 2.0 in., very light gray (N8) to yellowish gray (5Y 8/1), strong reaction to HCl, wet, Calcareous. Recrystallized calcite coating previously disolved vugs and pits. [Key Largo Limestone]		
-42.0	42.0							
-43.0	43.0	R-6	88% (88%)			43.0-48.5 ft LIMESTONE, fossiliferous, moderately hard, moderately weathered, very fine sand to silt particles, pitted to vuggy, typical diameter: 0.5 in., max size: 2.0 in., very light gray (N8) to grayish yellow (5Y 8/4), strong reaction to HCl, wet, iron oxide staining, Calcareous. Coralline to mudstone. Vugs and pit surfaces coated with recrystallized calcite. [Key Largo Limestone]		
-44.0	44.0							
-45.0	45.0							
-46.0	46.0							
-47.0	47.0							
-48.0	48.0							Tool drop from 48.0 - 48.6ft.
-49.0	49.0	R-7	100% (92%)			48.5-49.7 ft LIMESTONE, disturbed, moderately hard, moderately weathered, silt particles, vuggy, typical diameter: 0.5 in., max size: 1 in., medium gray (N5) and yellowish gray (5Y 8/1), strong reaction to HCl, wet, Calcareous. Almost all vugs are filled with the medium gray mudstone, also moderately hard. [Fort Thompson Formation]		
-50.0	50.0					49.7-62.0 ft MUDSTONE, fossiliferous, moderately hard, moderately weathered, silt particles, pitted to vuggy, typical diameter: 0.4 in., max size: 1.4 in., very light gray (N8) and pale greenish yellow (10Y 8/2), wet, iron oxide staining, Calcareous. Abundant moldic porosity. Most vugs are a result of this moldic porosity. [Fort Thompson Formation]		
-51.0	51.0							
-52.0	52.0							
-53.0	53.0							
-54.0	54.0							
-55.0	55.0							
-56.0	56.0	R-8	98% (96%)					
-57.0	57.0							
-58.0	58.0							
-59.0	59.0							

DATE STARTED: 8/14/13
DATE FINISHED: 8/22/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
DRILLER: Eddie Palmer

NOTES:

DRILL RIG: DR-16
HAMMER ID:

Boring R-7-3

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396957.30 ft E. 875783.79 ft
GROUND SURFACE ELEVATION: 0.01 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	DESCRIPTION	USCS SYMBOL	REMARKS
							Tool drop from 60.0 - 60.6ft.
-61.0	61.0	R-8	98% (96%)				
-62.0	62.0				62.0-72.7 ft LIMESTONE, fossiliferous, disturbed, horizontal, moderately hard, moderately weathered, very fine sand to pebble particles, pitted to vuggy, typical diameter: 0.25 in., max size: 1.0 in., light gray (N7) to very light gray (N8), strong reaction to HCl, wet, [Fort Thompson Formation]		
-63.0	63.0						At 63.0 - 65.0ft, soft zone, slighty faster drilling rate with no tool drop.
-64.0	64.0						
-65.0	65.0						
-66.0	66.0	R-9	53% (28%)				
-67.0	67.0						
-68.0	68.0						
-69.0	69.0						At 68.5- 70.5ft, softer material with faster drilling rates. No tool drop.
-70.0	70.0						
-71.0	71.0	R-10	100% (53%)				
-72.0	72.0						
-73.0	73.0	R-11	100% (70%)		72.7-75.0 ft LIMESTONE, fossiliferous, bioturbated, horizontal, moderately hard, moderately weathered, very fine sand to pebble particles, vuggy to pitted, typical diameter: 0.5 in., max size: 1.5 in., light gray (N7) to very light gray (N8), strong reaction to HCl, wet, Calcareous. Coarser grained than layer above. [Fort Thompson Formation]		
-74.0	74.0						
-75.0	75.0				75.0-101.6 ft LIMESTONE, fossiliferous, disturbed, moderately hard, moderately weathered, very fine sand to granule particles, vuggy to pitted, typical diameter: 0.75 in., max size: 2.5 in., light gray (N7) to very light gray (N8), strong reaction to HCl, wet, iron oxide staining, Gastropod and bivalve fossils. Abundant moldic porosity with white soft silty fine calcareous sand. [Fort Thompson Formation]		
-76.0	76.0						
-77.0	77.0	R-12	85% (25%)				At 77.0 - 78.0 ft, Softer zone with an increase in drlling rate; no tool drop.
-78.0	78.0						At 78.0 ft, abundant secondary moldic porosity associated mostly with bivalves.
-79.0	79.0	R-13	100%				

DATE STARTED: 8/14/13
DATE FINISHED: 8/22/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling

NOTES:

APPROVED BY: EOT
DRILLER: Eddie Palmer
DRILL RIG: DR-16
HAMMER ID:

Boring R-7-3

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396957.30 ft E. 875783.79 ft
GROUND SURFACE ELEVATION: 0.01 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
		R-13	(87%)			75.0-101.6 ft LIMESTONE, fossiliferous, disturbed, moderately hard, moderately weathered, very fine sand to granule particles, vuggy to pitted, typical diameter: 0.75 in., max size: 2.5 in., light gray (N7) to very light gray (N8), strong reaction to HCl, wet, iron oxide staining, Gastropod and bivalve fossils. Abundant moldic porosity with white soft silty fine calcareous sand. [Fort Thompson Formation]		
-81.0	81.0	R-14	100% (60%)					
-82.0	82.0							
-83.0	83.0							
-84.0	84.0							
-85.0	85.0							
-86.0	86.0							
-87.0	87.0	R-15	80% (57%)					
-88.0	88.0							
-89.0	89.0							
-90.0	90.0							
-91.0	91.0							
-92.0	92.0							
-93.0	93.0							
-94.0	94.0							
-95.0	95.0							
-96.0	96.0	R-16	93% (57%)					
-97.0	97.0							
-98.0	98.0							
-99.0	99.0							

DATE STARTED: 8/14/13
DATE FINISHED: 8/22/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez
DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling
NOTES:
APPROVED BY: EOT
DRILLER: Eddie Palmer
DRILL RIG: DR-16
HAMMER ID:

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Boring R-7-3

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396957.30 ft **E. 875783.79 ft**

GROUND SURFACE ELEVATION: 0.01 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-101.0	101.0	R-16	93% (57%)					
-102.0	102.0					101.6-111.0 ft LIMESTONE, fossiliferous, moderately hard to moderately soft, moderately weathered, very fine sand to medium sand particles, pitted to vuggy, typical diameter: 0.3 in., max size: 0.90 in., light gray (N7) to very light gray (N8), strong reaction to HCl, wet, iron oxide staining, Gastropod and bivalve fossils. Very abundant moldic porosity, with white soft silty fine calcareous sand filling. [Fort Thompson Formation]		
-103.0	103.0							
-104.0	104.0							
-105.0	105.0							
-106.0	106.0							
-107.0	107.0	R-17	100% (85%)					
-108.0	108.0							
-109.0	109.0							
-110.0	110.0							
-111.0	111.0					111.0-120.0 ft LIMESTONE, fossiliferous, moderately soft to moderately hard, moderately to intensely weathered, very fine sand to medium sand particles, pitted, typical diameter: 0.2 in., max size: 1.0 in., yellowish gray (5Y 8/1) to very light gray (N8), strong reaction to HCl, wet, iron oxide staining, Gastropod and bivalve fossils. Very abundant moldic porosity, with very light gray soft silty fine to medium calcareous sand filling. [Fort Thompson Formation]		
-112.0	112.0							
-113.0	113.0							
-114.0	114.0							
-115.0	115.0							At 115.0 - 125.0 ft, softer zone.
-116.0	116.0	R-18	35% (20%)					
-117.0	117.0							
-118.0	118.0							
-119.0	119.0							

DATE STARTED: 8/14/13
DATE FINISHED: 8/22/13
FIELD GEOLOGIST: Rolando Benitez
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4
DRILLING CO. Huss Drilling

NOTES:

APPROVED BY: EOT

DRILLER: Eddie Palmer

DRILL RIG: DR-16

HAMMER ID:

Boring R-7-3

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396957.30 ft **E. 875783.79 ft**

GROUND SURFACE ELEVATION: 0.01 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
						120.0-125.0 ft No Sample recovered.		120.0 - 125.0 ft, destructively drilled with mud rotary bit and NWJ drill pipe.
-121.0	121.0							
-122.0	122.0							
-123.0	123.0							Tests continued from 125.0 - 288.2ft, using CPT probe.
-124.0	124.0							
	125.0					---- Bottom of Boring at 125.00 ft.----		

DATE STARTED: 8/14/13

DATE FINISHED: 8/22/13

FIELD GEOLOGIST: Rolando Benitez

CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ, SPT, ST, NWD4

DRILLING CO. Huss Drilling

NOTES:

APPROVED BY: EOT

DRILLER: Eddie Palmer

DRILL RIG: DR-16

HAMMER ID:

Paul C. Rizzo Associates, Inc.
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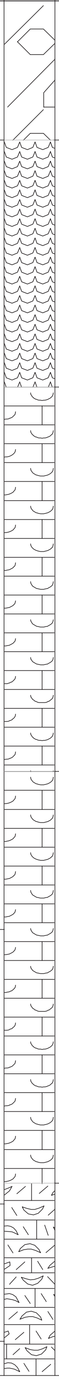
Boring R-7-4

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396958.51 ft E. 875605.22 ft
GROUND SURFACE ELEVATION: -0.53 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-1.0 to -2.53	0.0-2.0					0.0-2.0 ft Crushed stone (Road base layer) Unsampled.		0 - 2.0 ft., Destructively drilled using 5 inch mud rotary bit. Measured water level varied within one foot of ground surface. 2.0 - 126.00 ft., PQ wireline coring.
	2.0-5.6	R-1	70% (0%)	FD0		2.0-5.6 ft Peat, blackish red (5R 2/2) to grayish red (10R 4/2), organic odor, moist, strong HCl reaction, Plastic to Spongy consistency, some celulose	ol/oh	
	5.6-11.2	R-2	86% (40%)	FD0		5.6-11.2 ft GRAINSTONE, calcareous, hard to soft, slightly to intensely weathered, fine sand to very coarse sand particles, pitted, max size: 0.5 in., very pale orange (10YR 8/2) and light bluish gray (5B 7/1), massive bedded, strong reaction to HCl, moist, lower contact is conformable and gradational, Zones of loose sandy limestone in competent hard sandy limestone. Some shells and shell fragments. [Miami Limestone]		
	11.2-17.2	R-3	100% (88%)	FD1		11.2-17.2 ft GRAINSTONE, calcareous, hard to moderately soft, fresh to slightly weathered, fine sand to pebble particles, pitted to cavities, max size: 1.5 in., light bluish gray (5B 7/1) and very light gray (N8), massive bedded, strong reaction to HCl, moist, lower contact is conformable and gradational, Some shells and shell fragments. [Miami Limestone] 13.5- ft Random fracture, R.D. = 0°, slightly open; filling: not healed; surface: rough, undulating, moderately soft.		
	17.2-30.2	R-4	96% (54%)	FD7 FD0		17.2-30.2 ft PACKSTONE, calcareous, hard to moderately soft, slightly to moderately weathered, clay to very coarse sand particles, vuggy to pitted, max size: 1.5 in., white (N9) and light bluish gray (5B 7/1), massive bedded, strong reaction to HCl, moist, lower contact is sharp, Zones of soft loose sandy limestone in competent hard micrite packstone. Loose soft zones break easily. [Miami Limestone] 17.5-19.2 ft Fracture zone, R.D. = 80°, wide; filling: totally healed, thick,		



Elevation scale: -1.0, -2.0, -3.0, -4.0, -5.0, -6.0, -7.0, -8.0, -9.0, -10.0, -11.0, -12.0, -13.0, -14.0, -15.0, -16.0, -17.0, -18.0, -19.0
Depth scale: 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0, 17.0, 18.0, 19.0

DATE STARTED: 9/3/13
DATE FINISHED: 9/5/13
FIELD GEOLOGIST: Doug Raszewski
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ
DRILLING CO. Huss Drilling
DRILLER: Anthony Hudson

NOTES: Angle of boring is 16 degrees toward bearing 115. depth is measured depth in boring.

DRILL RIG: DR-5
HAMMER ID:

Paul C. Rizzo Associates, Inc.
ENGINEERS/CONSULTANTS/CM

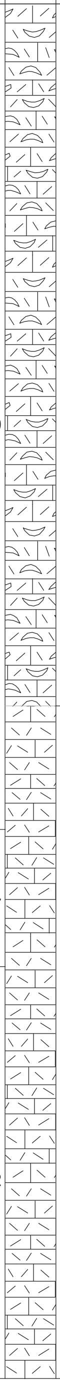
Boring R-7-4

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396958.51 ft E. 875605.22 ft
GROUND SURFACE ELEVATION: -0.53 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY
-20.0				
-21.0	21.0	R-4	96% (54%)	
-22.0	22.0			
-23.0	23.0			
-24.0	24.0	R-5	50% (32%)	
-25.0	25.0			
-26.0	26.0			FD0
-27.0	27.0			
-28.0	28.0			
-29.0	29.0	R-6	86% (86%)	
-30.0	30.0			
-31.0	31.0			
-32.0	32.0			
-33.0	33.0			FD7
-34.0	34.0	R-7	50% (28%)	
-35.0	35.0			
-36.0	36.0			
-37.0	37.0			FD2
-38.0	38.0	R-8	44% (16%)	
-39.0	39.0			

PROFILE



DESCRIPTION

fresh, hard; surface: rough, fresh, hard; Soft sediment fracture filled with black micritic limestone.
19.3- ft Joint, R.D. = 0°, moderately open; filling: not healed, sand; surface: moderately rough, undulating, hard; Sand filling on surface.

17.2-30.2 ft PACKSTONE, calcareous, hard to moderately soft, slightly to moderately weathered, clay to very coarse sand particles, vuggy to pitted, max size: 1.5 in., white (N9) and light bluish gray (5B 7/1), massive bedded, strong reaction to HCl, moist, lower contact is sharp, Zones of soft loose sandy limestone in competent hard micrite packstone. Loose soft zones break easily. [Miami Limestone]

28.7- ft Joint; filling: sandy clay, soft (H6); surface: planar, moderately hard (H4).

30.2-49.9 ft WACKESTONE, calcareous, interbedded, hard to moderately hard, fresh to moderately weathered, clay to fine sand particles, pitted to cavities, max size: 5.0 in., white (N9) to light gray (N7), moderately to thickly bedded, closely to widely fractured, weak reaction to HCl, moist, lower contact is conformable and gradational, 1-4 inch voids common. 2-3 inch filled voids or soft zones present above ~42 ft. occasional shells/fossils and moldic porosity. Voids are coated with calcite crystals below about 42 feet. Void surfaces coated with dark yellowish brown (10 YR 4/2), sandy clay. [Key Largo Limestone]
interbedded with BOUNDSTONE, calcareous, moderately soft to hard, fresh to slightly weathered, pitted to cavities, max size: 5.0 in., white (N9) to light gray (N7), thinly to moderately bedded, closely to widely fractured, weak reaction to HCl, moist, lower contact is conformable and gradational, Calcite filling fractures and voids below 42.0 ft. [Key Largo Limestone]
32.1-32.4 ft Random fracture, R.D. = 50°, moderately wide; filling: not healed, moderately thick sandy clay, intensely weathered, very soft to soft; surface: rough, undulating, intensely weathered, moderately hard; Likely extends from void to void.
32.6-32.8 ft Random fracture, R.D. = 30°, moderately wide; filling: not healed, moderately thick sandy clay, intensely weathered, very soft to soft; surface: rough, undulating, intensely weathered, moderately hard; Likely extends from void to void.
33- ft Joint, R.D. = 30°, moderately open; filling: not healed, moderately thin sandy clay, intensely weathered, very soft to soft; surface: rough, planar, intensely weathered, moderately hard.
33.1- ft Joint, R.D. = 30°, moderately open; filling: not healed, moderately

USCS SYMBOL

REMARKS

Soft zone with no recovery from approximately 23.0 - 23.3 ft and 24.6-26.6 ft.

SC-1: 27.7-28.7 ft

Soft gray sand at 30.2 ft.

2.5 in. void in core from 32.4-32.6 ft.

Soft zone with no recovery from approximately 34.5-36.5 ft., most likely composed of soft moderate yellowsh brown (10YR 5/4) sandy clay material that covers void surfaces in R-7.

Very soft,no drilling resistance, no recovery from approximately 39.0 - 41.5 ft.

DATE STARTED: 9/3/13
DATE FINISHED: 9/5/13
FIELD GEOLOGIST: Doug Raszewski
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ
DRILLING CO. Huss Drilling
DRILLER: Anthony Hudson

NOTES: Angle of boring is 16 degrees toward bearing 115. depth is measured depth in boring.

DRILL RIG: DR-5
HAMMER ID:

Boring R-7-4

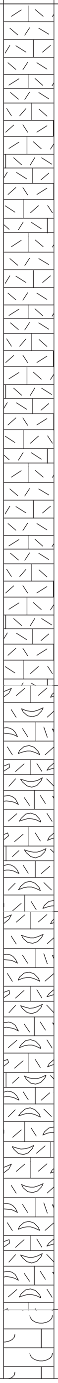
PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396958.51 ft E. 875605.22 ft
GROUND SURFACE ELEVATION: -0.53 ft

ELEVATION (Feet)	DEPTH (Feet)
-40.0	41.0
-41.0	42.0
-42.0	43.0
-43.0	44.0
-44.0	45.0
-45.0	46.0
-46.0	47.0
-47.0	48.0
-48.0	49.0
-49.0	50.0
-50.0	51.0
-51.0	52.0
-52.0	53.0
-53.0	54.0
-54.0	55.0
-55.0	56.0
-56.0	57.0
-57.0	58.0
-58.0	59.0

SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY
R-8	44% (16%)	
R-9	90% (78%)	
R-10	100% (90%)	FD2
R-11	88% (88%)	
R-12	58% (30%)	

PROFILE



DESCRIPTION

thin sandy clay, intensely weathered, very soft to soft; surface: rough, planar, intensely weathered, moderately hard.

33.4-33.6 ft Joint, R.D. = 30°, moderately open; filling: not healed, moderately thin sandy clay, intensely weathered, very soft to soft; surface: rough, planar, intensely weathered, moderately hard.

38.2-38.3 ft Joint, R.D. = 30°, open; filling: not healed, thin sandy clay, intensely weathered, very soft to soft; surface: rough, planar, intensely weathered, moderately hard.

38.3-38.4 ft Joint, R.D. = 30°, moderately open; filling: not healed, moderately thin sandy clay, intensely weathered, very soft to soft; surface: rough, planar, intensely weathered, moderately hard.

30.2-49.9 ft WACKESTONE, calcareous, interbedded, hard to moderately hard, fresh to moderately weathered, clay to fine sand particles, pitted to cavities, max size: 5.0 in., white (N9) to light gray (N7), moderately to thickly bedded, closely to widely fractured, weak reaction to HCl, moist, lower contact is conformable and gradational, 1-4 inch voids common. 2-3 inch filled voids or soft zones present above ~42 ft. occasional shells/fossils and moldic porosity. Voids are coated with calcite crystals below about 42 feet. Void surfaces coated with dark yellowish brown (10 YR 4/2), sandy clay. [Key Largo Limestone]

interbedded with BOUNDSTONE, calcareous, moderately soft to hard, fresh to slightly weathered, pitted to cavities, max size: 5.0 in., white (N9) to light gray (N7), thinly to moderately bedded, closely to widely fractured, weak reaction to HCl, moist, lower contact is conformable and gradational, Calcite filling fractures and voids below 42.0 ft. [Key Largo Limestone]

45.7-46.3 ft Joint, R.D. = 60°, slightly open; filling: partly healed, very thin calcite, fresh, soft; surface: rough, planar, fresh, moderately hard.

45.9-46.2 ft Joint, R.D. = 55°, slightly open; filling: partly healed, very thin calcite, fresh, soft; surface: rough, planar, fresh, moderately hard.

49.9-53.2 ft PACKSTONE, calcareous, very soft (H7) to hard (H3), fresh to slightly weathered, clay to coarse sand particles, vuggy to pitted, max size: 1.0 in., medium gray (N5) to light gray (N7), thickly bedded, strong reaction to HCl, moist, lower contact is unconformable and sharp, This layer is the transition to Ft. thompson formation. Shelly grainstone segments with packstone clasts in lowest ~1.0 ft. Core breaks easily, brittle. [Key Largo Limestone]

52.7- ft Joint, R.D. = 15°.

53.2-59.0 ft PACKSTONE, calcareous, soft to hard, fresh to moderately weathered, clay to coarse sand particles, pitted to cavities, typical diameter: 0.2 in., max size: 12.0 in., white (N9) to very light gray (N8), massive bedded, strong reaction to HCl, wet, Shells are mostly dissolved. Most vugs are moldic porosity. Pale brown (5YR 5/2) sand filled voids up to 12 inches in size. From 56.0 - 59.0ft, abundant shell molds are present. [Fort Thompson Formation]

59.2- ft Incipient fracture, tight; filling: not healed, clean; surface: rough, planar, moderately hard.

USCS SYMBOL

REMARKS

Very broken and voided w/ calcite coating from approximately 44.2 - 44.6ft. Boundstone. Voids aid in mechanical breakage of core.

SC-2: 48.2-49.0 ft.

50.2-51.4 ft: Sample crumbled when transfered to core box.

Contact is erosive extending from 53.0-53.4 ft.

Zero resistance to drilling from 56.4-57.0 ft.

Zero resistance to drilling at approximately 58.2 and 60.0 ft.; loose sand present around rubble zones.

DATE STARTED: 9/3/13
DATE FINISHED: 9/5/13
FIELD GEOLOGIST: Doug Raszewski
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ
DRILLING CO. Huss Drilling

NOTES: Angle of boring is 16 degrees toward bearing 115. depth is measured depth in boring.

APPROVED BY: EOT
DRILLER: Anthony Hudson
DRILL RIG: DR-5
HAMMER ID:

Boring R-7-4

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396958.51 ft **E. 875605.22 ft**

GROUND SURFACE ELEVATION: -0.53 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	USCS SYMBOL	REMARKS
-59.0	61.0	R-12	58% (30%)			
-60.0	62.0					
-61.0	63.0					Loose sand caused inner barrel to get stuck in outer barrel after R-12.
-62.0	64.0					Zero resistance to drilling from 63.7 - 64.7 ft. Open void observed in half of the core recovered for this depth interval. Some loose sand present on surface of the void.
-63.0	65.0	R-13	96% (86%)			
-64.0	66.0					
-65.0	67.0					
-66.0	68.0			FD2		
-67.0	69.0					
-68.0	70.0	R-14	54% (12%)			Zero resistance to drilling from approximately 69.5-70.5 ft.
-69.0	71.0					
-70.0	72.0					Low recovery (in R-14) and broken rock assumed to be due to voids & soft zones
-71.0	73.0	R-15	90% (67%)			
-72.0	74.0					
-73.0	75.0					R-16 is very broken due to voids.
-74.0	76.0	R-16	100% (0%)			
-75.0	77.0					Multiple small soft/void zones noted while drilling R-17. Zero resistance to drilling from 77.0 - 82.0 ft.
-76.0	78.0	R-17	66% (38%)	FD0		
-77.0	79.0					

DESCRIPTION

59.5- ft Joint, tight; filling: not healed, clean; surface: rough, planar, moderately hard.

59.0-122.7 ft GRAINSTONE, calcareous, hard to soft, fresh to slightly weathered, very coarse sand to silt particles, pitted to cavities, typical diameter: 0.25-3 in., max size: 18.0 in., white (N9) to very light gray (N8), thickly to massive bedded, strong reaction to HCl, moist, Shells are mostly dissolved. Most vugs are moldic porosity. Numerous voids with remnants of sand filling. Zones of high void content, breaks easily into rubble. From 77.0 - 87.0ft, abundant shell molds. From 113.0 - 114.5ft, Large shell molds present. [Fort Thompson Formation]
with layers of PACKSTONE, calcareous, soft to hard, fresh to slightly weathered, clay to granule particles, cavities to pitted, max size: 2.0 in., white (N9) to very light gray (N8), thinly to thickly bedded, strong reaction to HCl, moist, lower contact is conformable and gradational, [Fort Thompson Formation]

75.8-76.1 ft Joint, R.D. = 40°, slightly open; filling: not healed; surface: moderately rough, undulating, slightly weathered, moderately soft to moderately hard.
75.9-76.2 ft Joint, R.D. = 40°, slightly open; filling: not healed; surface: moderately rough, undulating, slightly weathered, moderately soft to moderately hard.

DATE STARTED: 9/3/13
DATE FINISHED: 9/5/13
FIELD GEOLOGIST: Doug Raszewski
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ
DRILLING CO. Huss Drilling
DRILLER: Anthony Hudson

NOTES: Angle of boring is 16 degrees toward bearing 115. depth is measured depth in boring.

DRILL RIG: DR-5
HAMMER ID:

Paul C. Rizzo Associates, Inc.
ENGINEERS / CONSULTANTS / CM

Paul C. Rizzo Associates, Inc
500 Penn Center Blvd. Suite 100, Pittsburgh, PA 15235
www.rizzoassoc.com

Boring R-7-4

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396958.51 ft **E. 875605.22 ft**

GROUND SURFACE ELEVATION: -0.53 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY
-78.0				
	81.0	R-17	66% (38%)	
-79.0				
	82.0			
-80.0				
	83.0			
-81.0				
	84.0			
-82.0		R-18	100% (96%)	
	85.0			FD0
-83.0				
	86.0			
-84.0				
	87.0			
-85.0				
	88.0			
-86.0				
	89.0			
-87.0		R-19	94% (66%)	
	90.0			
-88.0				
	91.0			
-89.0				FD6
	92.0			
-90.0				
	93.0			
-91.0				
	94.0			
-92.0		R-20	86% (64%)	
	95.0			
-93.0				
	96.0			
-94.0				FD1
	97.0			
-95.0				
	98.0			
-96.0		R-21	72% (56%)	
	99.0			
-97.0				

PROFILE

DESCRIPTION

59.0-122.7 ft GRAINSTONE, calcareous, hard to soft, fresh to slightly weathered, very coarse sand to silt particles, pitted to cavities, typical diameter: 0.25-3 in., max size: 18.0 in., white (N9) to very light gray (N8), thickly to massive bedded, strong reaction to HCl, moist, Shells are mostly dissolved. Most vugs are moldic porosity. Numerous voids with remnants of sand filling. Zones of high void content, breaks easily into rubble. From 77.0 - 87.0ft, abundant shell molds. From 113.0 - 114.5ft, Large shell molds present. [Fort Thompson Formation]
with layers of PACKSTONE, calcareous, soft to hard, fresh to slightly weathered, clay to granule particles, cavities to pitted, max size: 2.0 in., white (N9) to very light gray (N8), thinly to thickly bedded, strong reaction to HCl, moist, lower contact is conformable and gradational, [Fort Thompson Formation]

91-91.2 ft Joint, R.D. = 50°, open; filling: partly healed, very thin calcite, fresh, moderately soft; surface: rough, planar, fresh, moderately hard; Sand on fracture surface.

92.6-92.7 ft Joint, R.D. = 25°, moderately open; filling: not healed, fresh; surface: slightly rough, planar, fresh, hard.
92.9-93 ft Joint, R.D. = 25°, moderately open; filling: not healed, fresh; surface: slightly rough, planar, fresh, hard.

99- ft Random fracture, R.D. = 30°, tight; filling: not healed, fresh; surface: moderately rough, undulating, fresh, hard.

USCS SYMBOL

REMARKS

3 in. void in core in R-17.

Much moldic porosity in R-18.

SC-3: 83.7-84.6 ft.

Very broken with sand filled voids from approximately 88.0 - 89.0 ft.

Due to the presence of many pits and vugs, core is mechanically broken from approximately 92.5 to 96.0 ft and 102.0 - 104.0 ft.

Driller reports multiple small soft sandy zones during drilling, mostly in upper and lower parts of run R-21.

DATE STARTED: 9/3/13
DATE FINISHED: 9/5/13
FIELD GEOLOGIST: Doug Raszewski
CHECKED BY: Rolando Benitez

DRILLING METHOD: Mud Rotary, PQ
DRILLING CO. Huss Drilling

NOTES: Angle of boring is 16 degrees toward bearing 115. depth is measured depth in boring.

APPROVED BY: EOT

DRILLER: Anthony Hudson

DRILL RIG: DR-5

HAMMER ID:

Boring R-7-4

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES
N. 396958.51 ft **E. 875605.22 ft**
GROUND SURFACE ELEVATION: -0.53 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY
-98.0	101.0	R-21	72% (56%)	FD8
-99.0	102.0			
-100.0	103.0			
-101.0	104.0	R-22	92% (66%)	
-102.0	105.0			
-103.0	106.0			
-104.0	107.0			
-105.0	108.0			
-106.0	109.0	R-23	100% (100%)	
-107.0	110.0			
-108.0	111.0			FD1
-109.0	112.0			
-110.0	113.0			
-111.0	114.0	R-24	100% (78%)	
-112.0	115.0			
-113.0	116.0			
-114.0	117.0			
-115.0	118.0	R-25	44% (28%)	
-116.0	119.0			

DESCRIPTION

59.0-122.7 ft GRAINSTONE, calcareous, hard to soft, fresh to slightly weathered, very coarse sand to silt particles, pitted to cavities, typical diameter: 0.25-3 in., max size: 18.0 in., white (N9) to very light gray (N8), thickly to massive bedded, strong reaction to HCl, moist, Shells are mostly dissolved. Most vugs are moldic porosity. Numerous voids with remnants of sand filling. Zones of high void content, breaks easily into rubble. From 77.0 - 87.0ft, abundant shell molds. From 113.0 - 114.5ft, Large shell molds present. [Fort Thompson Formation]
with layers of PACKSTONE, calcareous, soft to hard, fresh to slightly weathered, clay to granule particles, cavities to pitted, max size: 2.0 in., white (N9) to very light gray (N8), thinly to thickly bedded, strong reaction to HCl, moist, lower contact is conformable and gradational, [Fort Thompson Formation]
101-101.1 ft Fracture zone.

115.4-115.6 ft Joint, R.D. = 50°, slightly open; filling: not healed, fresh; surface: moderately rough, planar, fresh, hard.

USCS SYMBOL

REMARKS

Upper 1.7 ft of R-22 is mostly broken with loose sand present.

Abundant shell molds from 104.5-113.0 ft.

SC-4: 109.4-110.8 ft.

Sand filled void from 112.0-112.3 ft.

Multiple <1 in. voids w/ loose sand present from 115.5-116.5 ft.

Soft sandy zone from approximately 117.2-118.7 ft. just minor sand and rubble recovered.

DATE STARTED: 9/3/13
DATE FINISHED: 9/5/13
FIELD GEOLOGIST: Doug Raszewski
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ
DRILLING CO. Huss Drilling
DRILLER: Anthony Hudson

NOTES: Angle of boring is 16 degrees toward bearing 115. depth is measured depth in boring.

DRILL RIG: DR-5
HAMMER ID:

Boring R-7-4

PROJECT: Turkey Point Units 6 and 7 Site
PROJECT NO.: 13-5054

COORDINATES

N. 396958.51 ft **E. 875605.22 ft**

GROUND SURFACE ELEVATION: -0.53 ft

ELEVATION (Feet)	DEPTH (Feet)	SAMPLE OR RUN NO.	BLOW/6in & (N) OR %REC (%RQD)	FRACTURE DENSITY	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
-117.0	121.0	R-25	44% (28%)	FD1		59.0-122.7 ft GRAINSTONE, calcareous, hard to soft, fresh to slightly weathered, very coarse sand to silt particles, pitted to cavities, typical diameter: 0.25-3 in., max size: 18.0 in., white (N9) to very light gray (N8), thickly to massive bedded, strong reaction to HCl, moist, Shells are mostly dissolved. Most vugs are moldic porosity. Numerous voids with remnants of sand filling. Zones of high void content, breaks easily into rubble. From 77.0 - 87.0ft, abundant shell molds. From 113.0 - 114.5ft, Large shell molds present. [Fort Thompson Formation] with layers of PACKSTONE, calcareous, soft to hard, fresh to slightly weathered, clay to granule particles, cavities to pitted, max size: 2.0 in., white (N9) to very light gray (N8), thinly to thickly bedded, strong reaction to HCl, moist, lower contact is conformable and gradational, [Fort Thompson Formation]		Soft sandy zone from approximately 120.8-121.8 ft.; only minor sand and rubble recovered.
-118.0	122.0	R-26	86% (0%)					
-119.0	123.0							
-120.0	124.0							
-121.0	125.0					122.7-126.0 ft Material not recovered. Upper Tamiami formation.		
-122.0	126.0					---- Bottom of Boring at 126.00 ft.----		

DATE STARTED: 9/3/13
DATE FINISHED: 9/5/13
FIELD GEOLOGIST: Doug Raszewski
CHECKED BY: Rolando Benitez
APPROVED BY: EOT

DRILLING METHOD: Mud Rotary, PQ
DRILLING CO. Huss Drilling
DRILLER: Anthony Hudson

NOTES: Angle of boring is 16 degrees toward bearing 115. depth is measured depth in boring.

DRILL RIG: DR-5
HAMMER ID:

APPENDIX B

KLEINFELDER RCTS TESTING RESULTS

LABORATORY DATA REPORT
RESONANT COLUMN AND TORSIONAL SHEAR (RCTS) TESTING
TURKEY POINT UNITS 6 & 7 SITE
MIAMI-DADE COUNTY, FL
KLEINFELDER PROJECT NO. 136473

February 5, 2014

DCN: 136473.4-ALB14RP001
Rev. 1

Prepared By:

KLEINFELDER
Bright People. Right Solutions.
9019 Washington Street NE, Building A
Albuquerque, New Mexico 87113

LABORATORY DATA REPORT
RESONANT COLUMN AND TORSIONAL SHEAR (RCTS) TESTING
TURKEY POINT UNITS 6 & 7 SITE
MIAMI-DADE COUNTY, FL
KLEINFELDER PROJECT NO. 136473

Prepared by: KLEINFELDER
Bright People. Right Solutions.

9019 Washington Street NE, Building. A
Albuquerque, NM 87113

Author Approval: 2/5/2014
Jed A. Stoken, PE, Project Professional Date

Reviewer Approval: Joseph P. Laird 2/5/2014
Joseph P. Laird, PE, Technical Lead Date

Project Manager Approval: 2/5/2014
John S. North, PE, Project Manager Date

TABLE OF CONTENTS

SECTION **PAGE**

APPENDICES

1.0 INTRODUCTION

1.1 DESCRIPTION OF THE PROJECT

Florida Power and Light (FPL) Company is exploring the possibility of constructing two new nuclear reactor units, Turkey Point Units 6 & 7, in Miami-Dade County Florida. Paul C. Rizzo Associates, Inc. (Rizzo) has been contracted by FPL to perform a supplementary geological, geotechnical, and geophysical site investigation for the proposed units. As part of this site characterization, Rizzo subcontracted with Kleinfelder West Inc. (Kleinfelder) to perform dynamic soil and rock property testing of selected samples collected from the subject site. Dynamic property testing was conducted in accordance with the Kleinfelder Laboratory Testing Work Plan (Kleinfelder, 2013a).

This laboratory data report documents the “Fixed-Free” Resonant Column and Torsional Shear (RCTS) tests performed by Kleinfelder, the scope of which is detailed in the “Agreement for Laboratory Services between Rizzo (Consultant) and Kleinfelder West, Inc. (Laboratory),” dated September 24, 2013.

1.2 PURPOSE AND SCOPE

The primary objective of the laboratory RCTS testing performed by Kleinfelder was to measure the dynamic properties of the site-specific samples. The RCTS test sequence characterizes shear modulus reduction and material damping relationships over a range of small to intermediate shear strains, as well as comparison of values versus time, confining pressures, frequency and number of cycles. It is anticipated that Rizzo will utilize the RCTS laboratory results in conducting subsequent seismic site characterization studies. This laboratory data report is a summary of our work and includes discussion of the following components:

- RCTS Test Background and Test Parameters;
- Sample Handling and Storage;
- Test Specimen Preparation, Including Photographic Records;
- Data Summary Plots and Tables;
- Comparison of RCTS Test Results; and
- Discussion of Quality of Test Data.

1.3 QUALITY ASSURANCE

Kleinfelder personnel performed the work presented in this data report in accordance with the applicable requirements of the Kleinfelder Nuclear Services Quality Management Program (KNS-QMP) as stated in the Kleinfelder Quality Assurance Project Plan (QAPP) (Kleinfelder, 2013b). Quality assurance activities were performed under the general oversight of Kleinfelder's Deputy Director of Quality Assurance, Benjamin Trujillo, CQA.

2.0 STANDARDS AND PROCEDURES

2.1 SAMPLE HANDLING AND STORAGE

Samples for RCTS Testing were received at Kleinfelder’s Dynamics Laboratory in Albuquerque, NM. Samples were handled, labeled and stored in accordance with the requirements of Kleinfelder’s QAPP (Kleinfelder, 2013b) and work plan (Kleinfelder, 2013a). Receipt inspections were performed on the shipments at the time of arrival and prior to sample preparation and testing activities. Soil samples were designated as "Group D" fragile, while rock core samples were designated as “Special Care”.

As required, samples were removed according to standards or procedures specified in Table 2.1-1. Prior to subdividing samples, the identification markings were transferred to the split sample portions to facilitate consistent identification of all pieces. Samples not tested but retained for possible future use, as determined by Rizzo, are stored at Kleinfelder’s dynamic laboratory until final disposition.

Table 2.1-1 Summary of Sample Handling and Storage Standards / Procedures

Name	Standard / Procedure
Measurement of Soil and Rock Dynamic Properties by the Resonant Column and Torsional Shear Method	KNS-TP-8.10
Standard Practices for Preserving and Transporting Soil Samples	ASTM D4220
Standard Practices for Preserving and Transporting Rock Core Samples	ASTM D5079

2.2 LABORATORY TESTING

The “fixed-free” RCTS test measures dynamic properties of individual soil or rock specimens by two independent methodologies, resonant column (RC) and torsional shear (TS). Specifically, the properties that are measured during testing are shear modulus (or shear wave velocity) and material damping ratio. In both the RC and TS tests, the cylindrical specimen is fixed at the base and sinusoidally rotated in torsion at the top, free end. Kleinfelder uses the RCTS device designed by Professor Kenneth H. Stokoe II of the University of Texas at Austin and manufactured by Trautwein Soil Test Equipment (Trauwein). The robust design/construction allows for dynamic property measurement from small (< 0.0001 %) to intermediate (up to about 0.3 %) shearing strains, low to high confining pressures (up to about 400 psi) and varied frequency, number of cycles and time of confinement. Further discussion of the RCTS test methodology is provided in Appendix A, “RCTS Testing of Soil and Rock Samples”.

Kleinfelder developed an internal standard operating procedure (Kleinfelder, 2012) for RCTS testing that is based on the procedures employed by Professor Stokoe and modified to account for the Trautwein Data Acquisition (DAQ) system. All testing was performed by trained and qualified staff in accordance with the standard or procedure shown in Table 2.2-1.

Table 2.2-1 Summary of Laboratory Test Procedures

Test Name	Standard / Procedure
Resonant Column and Torsional Shear (RCTS)	KNS-TP-8.10
Moisture Content	ASTM D2216

2.3 TEST PARAMETERS

The samples selected for testing and their corresponding estimated in-situ mean effective stress (σ'_m) were specified by Rizzo in their laboratory testing work plan (Rizzo, 2013) and shown below in Table 2.3-1.

Table 2.3-1 Estimated In-Situ Mean Effective Stress of RCTS Samples

Boring No.	Sample No.	Sample Depth (Top), ft	Sample Depth (Bottom), ft	Sample Length, ft	Estimated In-Situ Mean Effective Stress		
					σ'_m kPa	σ'_m psf	σ'_m psi
B-615	CS-01	32.6	33.4	0.8	76	1580	11
B-714	CS-01	29.4	30.2	0.8	69	1440	10
B-728	CS-04	53.4	54.2	0.8	124	2590	18
R-7-1	SC-3	40.1	41.0	0.9	97	2020	14
R-6-1b	SC-3	47.2	48.6	1.4	110	2300	16
R-6-1b	ST-1	134.0	136.7	2.0	317	6620	46
R-7-1	ST-5	206.0	208.7	2.7	70	10100	70
R-6-1b	ST-2	144.7	147.7	1.1	338	7060	49
R-6-1b	ST-7	169.9	172.6	2.6	400	8350	58

3.0 RESONANT COLUMN TORSIONAL SHEAR TEST RESULTS

3.1 SAMPLE RECEIPT AND CHAIN-OF-CUSTODY RECORDS

Samples were sent to Kleinfelder's dynamics testing laboratory in six shipments. The first four shipments arrived at about the same time and contained a total of five rock core samples within three padded cardboard containers and one padded plastic container. The first four shipments were received and placed into a secure, climate-controlled storage area prior to receipt inspection. On October 10, 2013, the sample containers for these four shipments were opened and their contents inspected. The chain-of-custody (COC) records were signed and a receipt inspection report (RIR) was completed by Kleinfelder at that time. All five of the rock core samples were accepted and used in the RCTS laboratory testing program, although one sample (R-7-1 SC-3) could not be tested due to insufficient specimen length.

The fifth shipment consisted of three thin-walled, Shelby tube samples contained within a wooden packing crate. They were received and inspected on November 6, 2013. The COC record was signed and a separate RIR was completed at that time. The shipment contained three primary samples containing soil to be used in RCTS testing. All three of the primary samples were used in the RCTS laboratory testing program, although one sample (R-6-1b ST-2) could not be tested due to lack of undisturbed soil.

The sixth shipment consisted of three additional thin-walled, Shelby tube samples contained within a wooden packing crate. They were received and inspected on December 9, 2013. The COC record was signed and a separate RIR was completed at that time. The shipment contained three secondary samples containing soil which could be used for RCTS testing as a substitute for the one unsuitable primary sample received in the fifth shipment as discussed above. One of the three secondary samples was used in the RCTS laboratory testing program.

3.2 RCTS SPECIMEN PREPARATION AND TESTING NOTES

Specimen preparation and testing was conducted in accordance with the most recent project work plan and KNS-TP-8.10. Specimen preparation was conducted by one of two methods depending on whether the sample was a rock core or a soil sample within a Shelby tube.

Rock core specimens were prepared by decreasing the sample diameter to 1.45-inches using a coring machine and core barrel. This is done primarily to increase the maximum shearing strain that can be tested in the RCTS apparatus by decreasing the diameter and therefore reducing the overall total resistance to torsional shear of the specimen. The rock coring process was conducted by first trimming a 6-inch length of core using a rock saw. For most of the samples, there was not enough core length to subdivide and the entire sample was consumed during testing. Upon trimming, the samples were grouted into CMU blocks to fix the sample against rotation during coring. The samples were cored using a portable coring machine with a 1.5-inch Outside Diameter (OD), thin-walled diamond-impregnated core barrel, and then trimmed to their final length of about 4-inches using the rock saw. One Specimen, K2-13-004, broke in the middle during coring due to a natural vug in the sample and consequently could not be tested.

Due to the stiffness of the rock, satisfactory coupling of the rock specimen and the test apparatus platens (top cap and base pedestal) could not be achieved without the use of an epoxy cement bonding agent. A wet surface epoxy (Loctite® Marine Epoxy) was used to provide satisfactory boding with the moist rock. In addition, steel top caps and base pedestals proportioned and fabricated specifically for testing stiffer rock specimens were used.

Soil specimens were prepared by first subdividing the Shelby tube and selecting one portion for testing. The soil within the Shelby tube was examined and visually classified according to the Unified Soil Classification System (USCS). One specimen, K2-13-008, upon subdivision and subsequent examination was determined to consist primarily of highly disturbed borehole material and was unsuitable for testing. Samples were extruded from the Shelby tube using a hand-operated sample extruder.

Due to the sensitive nature of the soil, samples were extruded directly into the testing membranes, the ends were trimmed square, and the specimen placed immediately into the RCTS Testing apparatus.

Isotropic confining pressures applied to the specimens during testing were assigned by Rizzo based on the estimated in-situ mean effective stress (σ'_m). The isotropic confining pressures (σ'_o) used during testing consisted of a sequence of pressures equivalent to about ¼, ½, 1, 2, and 4 times the mean effective stress. Table 3.2-1 presents the specimen numbers, their corresponding midpoint depths, and range of isotropic confining pressures applied during testing. Detailed specimen preparation notes and photographs documenting sample splits, specimen coring, membrane and epoxy placement, and placement into the RCTS apparatus are presented for each specimen in Appendix B through J.

Instances in which abnormal testing results were observed are also discussed in the specimen notes. In particular, there was often difficulty maintaining isotropic confinement around the encapsulated specimens and extreme tilting of the sand specimen upon increases in confining pressure causing the magnets to contact the electrical coils at the free-end of the sample. In some cases, the testing was not able to be completed at the higher pressure stages. However, RCTS test results were completed to at least the estimated mean effective pressure for all seven tested specimens.

Table 3.2-1 Summary of RCTS Specimens and Testing Pressures

						Testing Pressures σ'_o (psi)				
Kleinfelder Specimen No.	**Boring No.**	**Rizzo Sample No**	**Specimen Midpoint Depth (ft)**	**Material Type**	**Mean Effective Stress σ'_m (psi)**	**Stage (1)**	**Stage (2)**	**Stage (3)**	**Stage (4)**	**Stage (5)**
K2-13-001	B-615	CS-01	32.9	Limestone (Key Largo)	11	3	6	11	23	45
K2-13-002	B-714	CS-01	29.7	Limestone (Key Largo)	10	3	5	10	20	40
K2-13-003	B-728	CS-04	54.0	Limestone (Fort Thompson)	18	5	9	18	47	72
K2-13-004	R-7-1	SC-3	40.8	Limestone (Key Largo)	14	Test Not Performed (see Appendix E)				
K2-13-005	R-6-1b	SC-3	47.9	Limestone (Fort Thompson)	16	4	8	16	45	64
K2-13-006	R-6-1b	ST-1	136.3	Silty Sand (SM)	46	11	23	46	82	183
K2-13-007	R-7-1	ST-5	208.2	Silty Sand (SM)	70	18	35	70	121	281
K2-13-008	R-6-1b	ST-2	147.3	Disturbed	49	Test Not Performed (see Appendix I)				
K2-13-009	R-6-1b	ST-7	172.0	Silty Sand (SM)	58	14	29	58	101	232

3.3 RCTS TEST RESULTS

The RCTS test summary data plots for the tested specimens are presented in Appendices B through J of this report. Dynamic properties are affected by numerous in-situ conditions. The RCTS method allows for comparisons of critically affecting factors relative to low-amplitude shear modulus (G_{max}) and shear wave velocity (V_s), low-amplitude material damping ratio (D_{min}), as well as nonlinear dynamic properties such as normalized shear modulus (G/G_{max}) and material damping ratio (D). The following summary plots are included in Appendices B through J:

- G_{max} and D_{min} versus time of confinement;
- Void ratio (e) and total unit weight versus time of confinement;
- V_s, G_{max} and D_{min} versus isotropic confining pressure;
- Void ratio (e) and total unit weight versus isotropic confining pressure;
- G, G/G_{max} and D versus:
  - Shearing strain;
  - Number of cycles; and
  - Excitation Frequency.

3.4 COMPARISON OF RCTS TEST RESULTS

The results of the RCTS testing were divided into three groups for comparison. The grouping was based on material classification and consisted of the following general rock/soil types:

- Limestone (Key Largo Formation);
- Limestone (Fort Thompson Formation); and
- Silty Sand (SM).

Low-amplitude (small shearing strain) shear modulus and material damping ratio results are presented in Figures 3.4-1 and 3.4-2. In the figures, the relationship between shear modulus and confining pressure and material damping ratio and confining pressure are presented. Individual specimen results are presented in the graphs with color coding to indicate like material group. The figures show the expected trend of increasing shear modulus with increasing confining pressure and decreasing material damping ratio with increasing confining pressure.

High-amplitude (small to intermediate shearing strain) normalized shear modulus reduction and material damping ratio results are presented in Figures 3.4-3 to 3.4-8. In the figures, the relationship between normalized shear modulus and shearing strain and material damping ratio and shearing strain are presented for specimens at their in-situ mean effective stresses. Results have been grouped together based on material type. The figures show the expected trend of decreasing normalized shear modulus with increasing shearing strain and increasing material damping ratio with increasing shearing strain. For reference purposes, the Electric Power Research Institute (EPRI) nonlinear "degradation curves" for sands at various depths (EPRI, 1993) have been included in the figures.

Curve fits were developed for the high-amplitude results of the three material groups and are presented in Figures 3.4-3 to 3.4-8 as a yellow line. The lines are solid in the range of shearing strain tested in the laboratory and dashed in the projected range beyond that tested. Curve fits were performed using the functions developed by Darendeli (2001) which requires defining the following three parameters:

- 'a' the slope of the curve;
- 'γ_r' the shearing strain at G/G_{max} of 0.5; and
- 'D_{min}' the minimum material damping ratio.

The Darendeli Parameters for the three material groups are presented in text boxes within Figures 3.4-3 to 3.4-8 and summarized in Table 3.4-1 below.

Table 3.4-1 Summary of Darendeli (2001) Curve Fit Parameters by Material Type

		Darendeli (2001) Curve Fit Parameters		
Material Type	**RCTS Specimens**	**a**	**γ_r, %**	**D_{min}, %**
Limestone (Key Largo Formation)	K2-13-001, K2-13-002	1.11	1.62×10^{-1}	0.57
Limestone (Fort Thompson Formation)	K2-13-003, K2-13-005	0.95	8.43×10^{-2}	0.56
Silty Sand (SM)	K2-13-006, K2-13-007, K2-13-009	0.95	1.04×10^{-1}	0.50

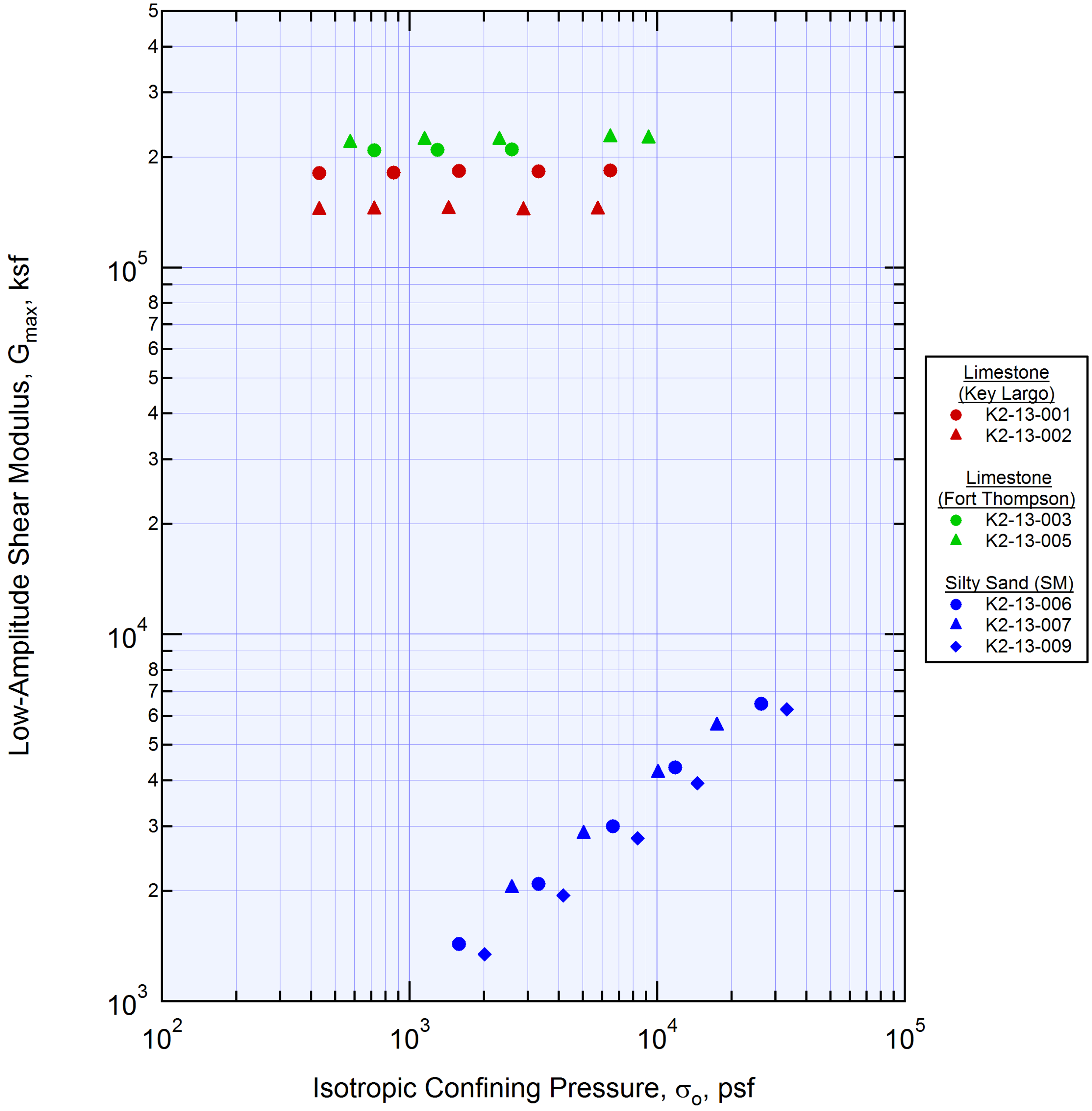


Figure 3.4-1 Variation in Small-Strain Shear Modulus with Confining Pressure

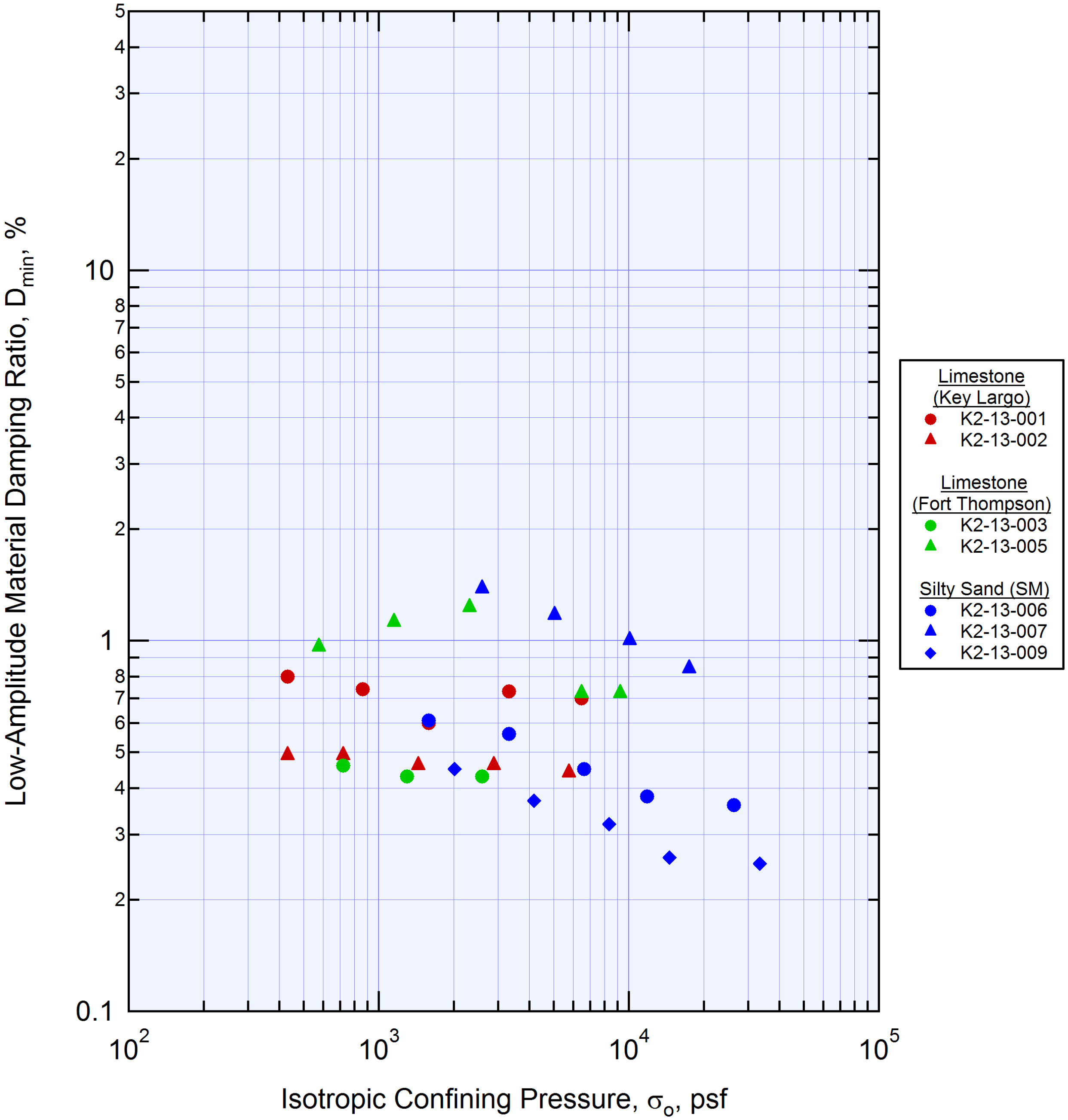
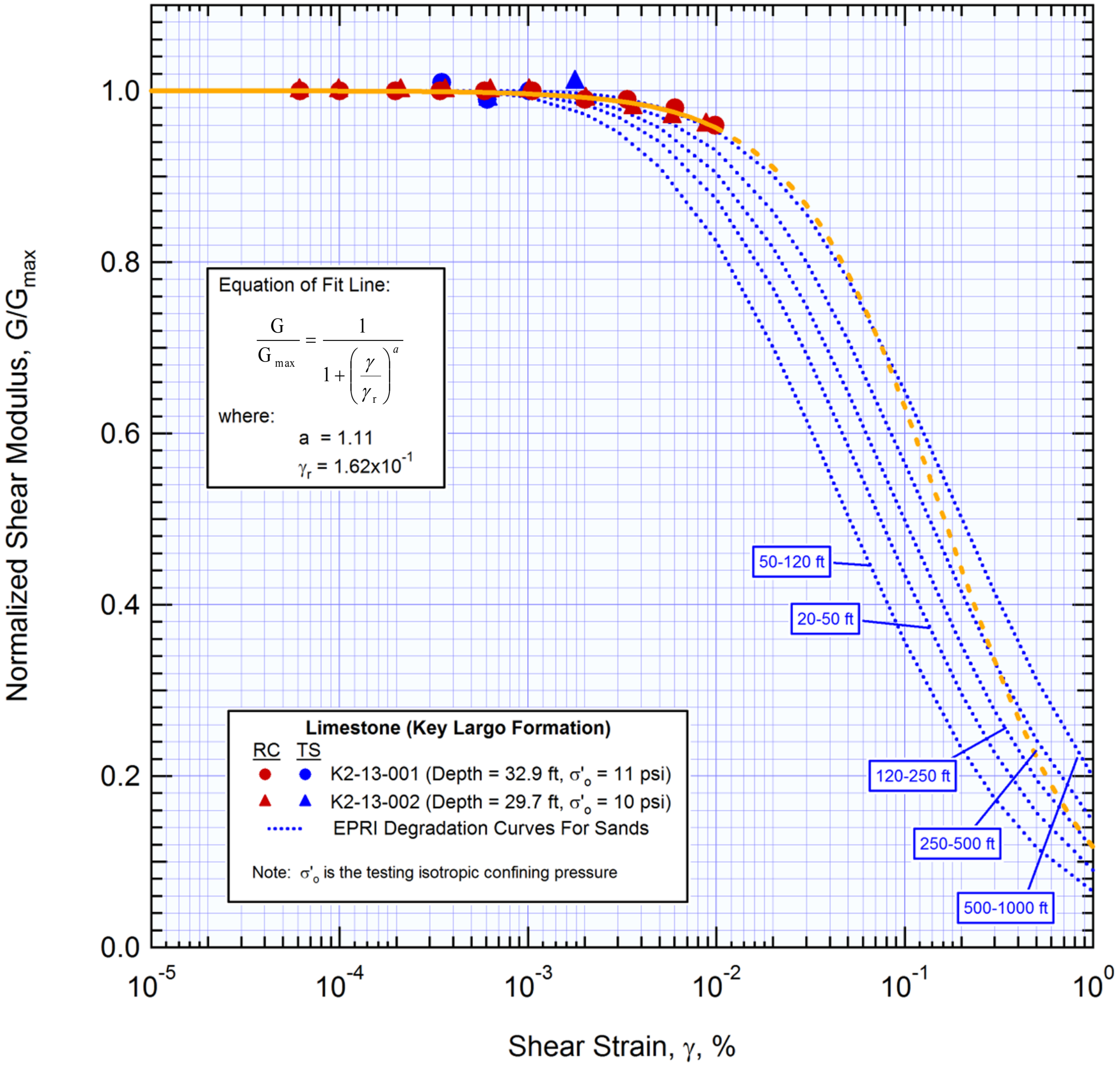


Figure 3.4-2 Variation in Small-Strain Material Damping Ratio with Confining Pressure



$$\frac{G}{G_{\max}} = \frac{1}{1+\left(\frac{\gamma}{\gamma_r}\right)^a}$$

Figure 3.4-3 Variation in Normalized Shear Modulus with Shearing Strain of the Key Largo Limestone Specimens at Their Estimated Mean Effective Stress (Electric Power Research Institute Degradation Curves for Sand Plotted for Reference)

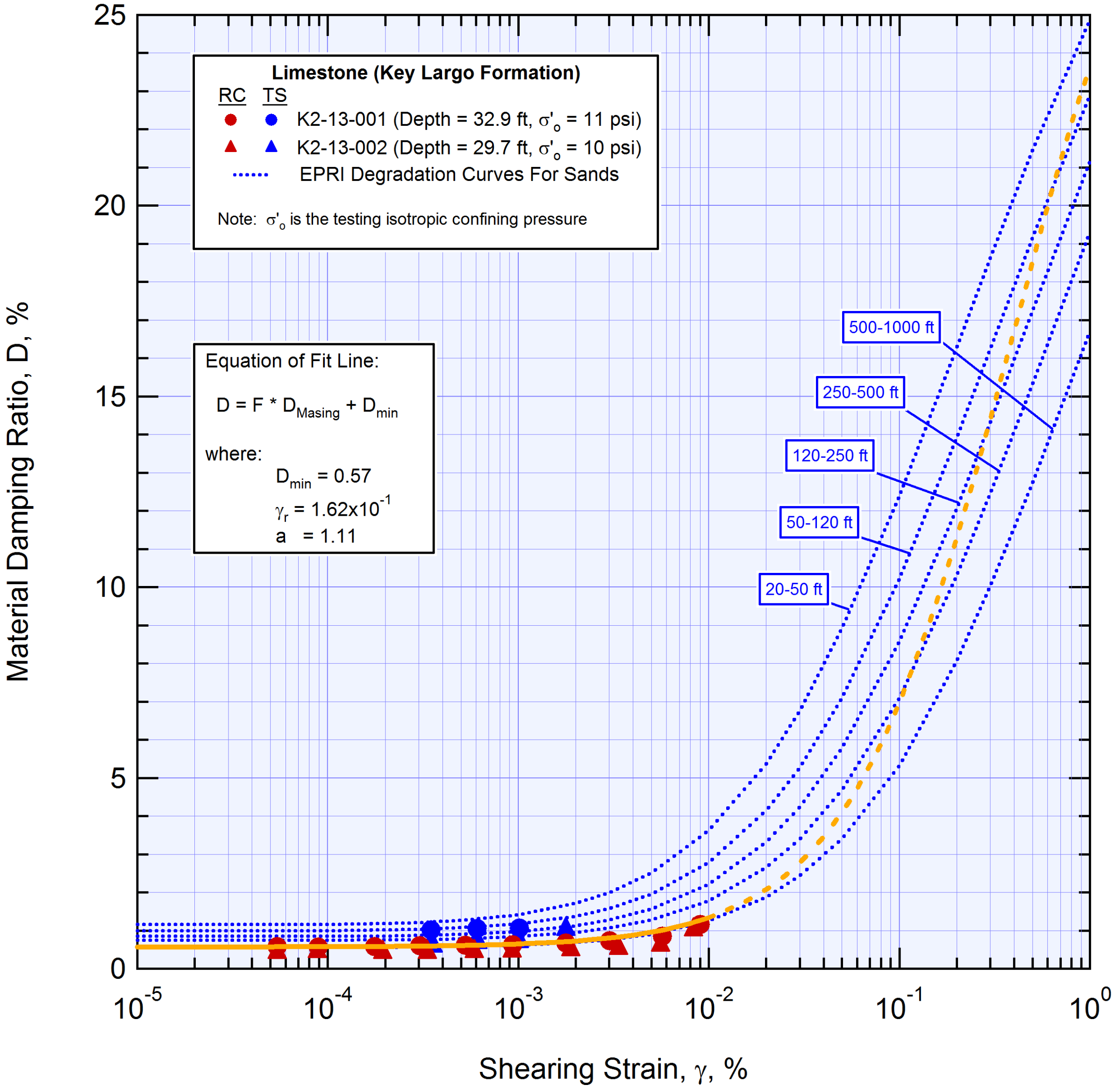


Figure 3.4-4 Variation in Material Damping Ratio with Shearing Strain of the Key Largo Limestone Specimens at Their Estimated Mean Effective Stress (Electric Power Research Institute Degradation Curves for Sand Plotted for Reference)

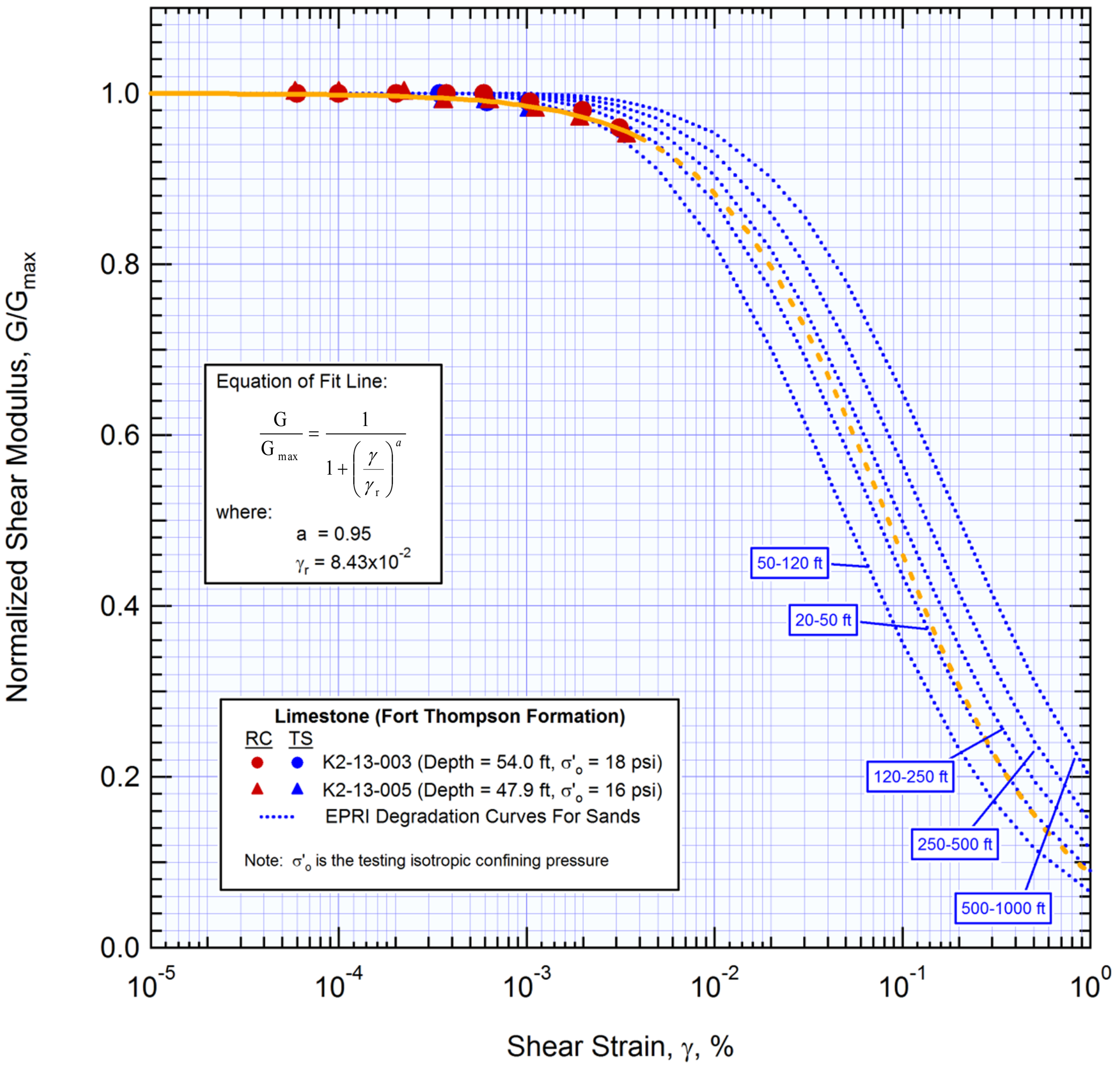


Figure 3.4-5 Variation in Normalized Shear Modulus with Shearing Strain of the Fort Thompson Limestone Specimens at Their Estimated Mean Effective Stress (Electric Power Research Institute Degradation Curves for Sand Plotted for Reference)

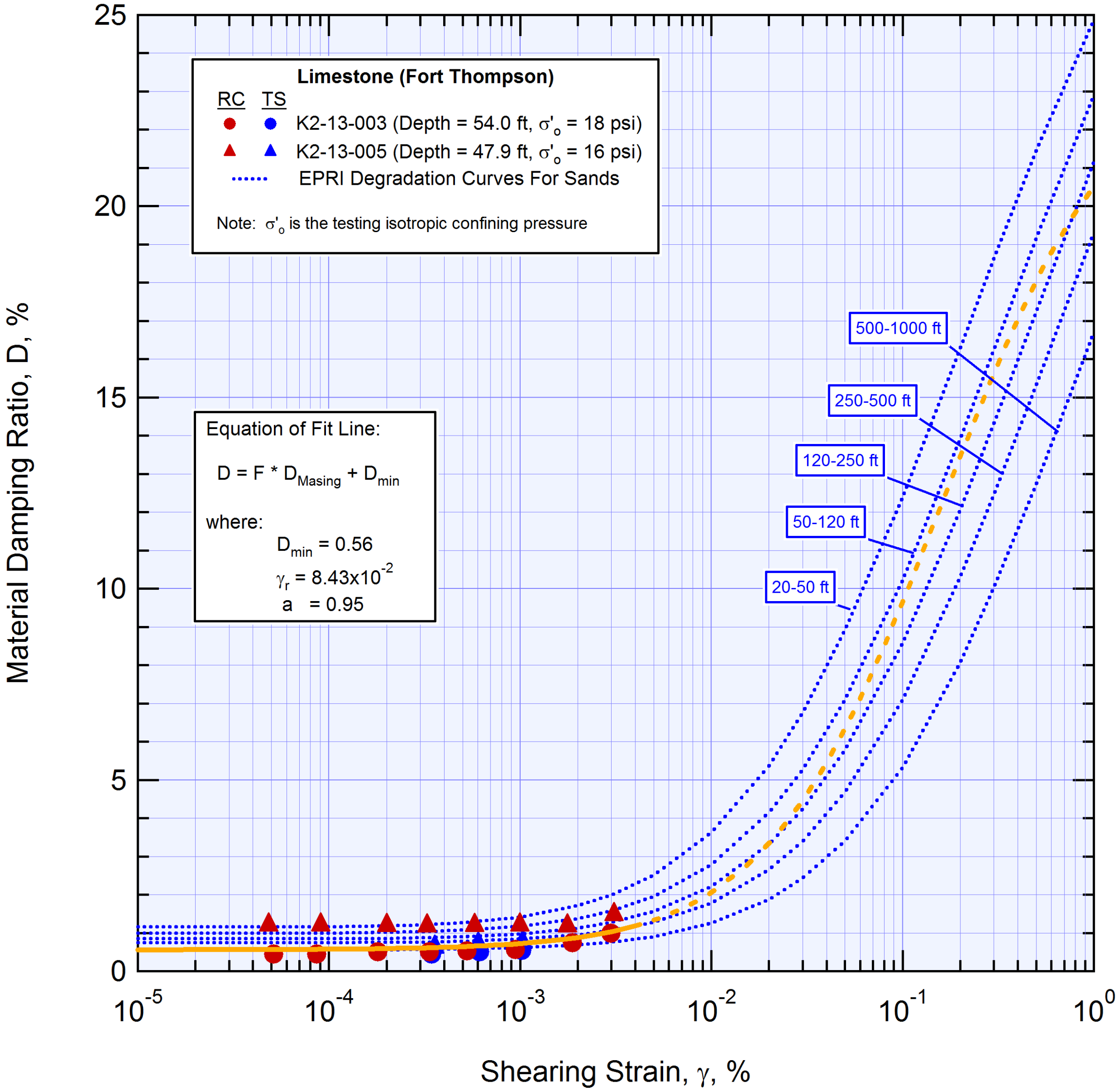


Figure 3.4-6 Variation in Material Damping Ratio with Shearing Strain of the Fort Thompson Limestone Specimens at Their Estimated Mean Effective Stress (Electric Power Research Institute Degradation Curves for Sand Plotted for Reference)

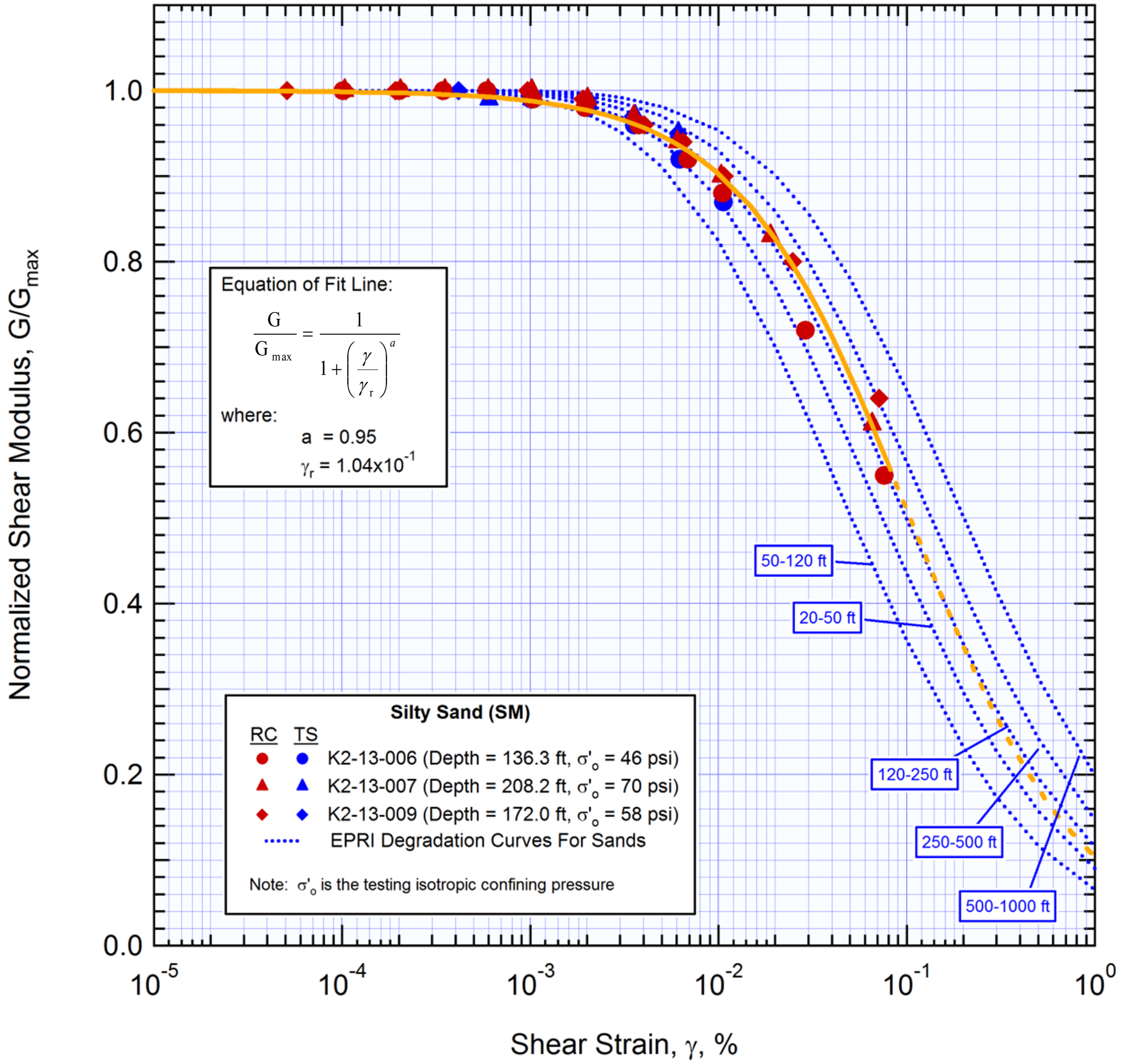


Figure 3.4-7 Variation in Normalized Shear Modulus with Shearing Strain of the Silty Sand Specimens at Their Estimated Mean Effective Stress (Electric Power Research Institute Degradation Curves for Sand Plotted for Reference)

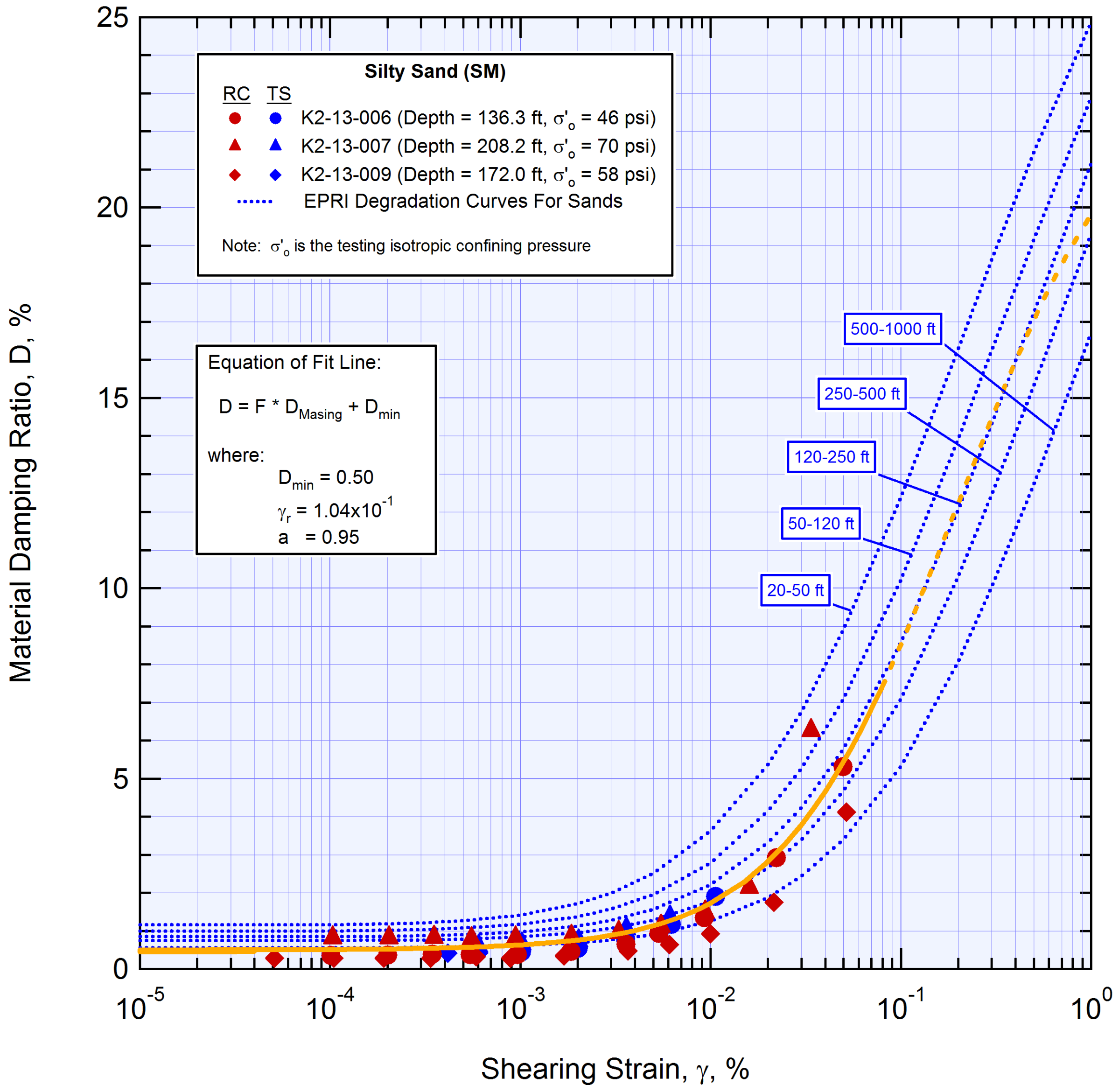


Figure 3.4-8 Variation in Material Damping Ratio with Shearing Strain of the Silty Sand Specimens at Their Estimated Mean Effective Stress (Electric Power Research Institute Degradation Curves for Sand Plotted for Reference)

3.5 QUALITY OF TEST RESULTS

The quality of results for RCTS tests are characterized by evaluating the raw and reduced test data. The following criteria may be considered in the evaluation of test quality.

- Quality of Waveforms;
- Consistency of Sample;
- Expected Data Trends;
- Comparison of RC and TS Data; and
- Comparison of RCTS Data to Field Dynamic Property Measurements.

Although a detailed interpretation of the data is beyond the scope of this data report, the following discussion highlights some considerations of the test data.

3.5.1 Quality of Waveforms

For the seven completed RC tests, one dominant, properly aligned, resonant peak, a valid free vibration decay response, and a low noise to signal ratio in both the time and frequency domain was generally observed from small to intermediate shearing strains, roughly between $1x10^{-4}$% and $1x10^{-2}$% for the limestone samples and between $1x10^{-4}$% and $7x10^{-2}$% for the silty sand samples. For the limestone samples, abnormal resonance curves (e.g. wide curves with ambiguous peaks) were generally observed at strains greater than about $1x10^{-2}$%. Where such conditions were observed, we were not able to measure credible dynamic properties.

For the completed TS tests, proper hysteretic torsional stress – shearing strain loop and low noise to signal ratio were typically also observed from small to intermediate shearing strains, roughly between $3x10^{-4}$% and $2x10^{-3}$% for the limestone samples and $4x10^{-4}$% and $1x10^{-2}$% for the silty sand samples. The TS tests were generally performed at increasing shearing strains until the limit of our power delivery system was reached.

The overall quality of waveforms was excellent for the range of shearing strains noted above.

3.5.2 Consistency of Samples

The limestone samples exhibited variable amounts of solution pitting (i.e. vugs). Due to their random orientation, the consistency of the test specimens were heterogeneous with the more vuggy or porous specimens exhibiting a lower unit weight. There is a trend of increasing small-strain shear wave velocity with corresponding increased unit weight for the four limestone specimens.

The silty sand samples were a uniform, fine-grained sand with a slight plasticity due to the silt content. Little apparent disturbance of the soil was observable in the tested specimens. The initial total unit weights of the three specimens were similar, ranging from about 118 to 120 pounds per cubic feet. Due to the increase of confining pressure at the start of successive low-amplitude pressure stages, these specimens often exhibited differential settlement / tilting. If the specimen distortion was significant, the test had to be temporarily suspended to re-adjust the coils around the magnets/drive plate.

3.5.3 Expected Data Trends

The relatively high shear modulus values and low material damping (about 1 percent or less) are typical for medium strong, intact limestone. The limestone samples exhibited a very slight increase in G_{max} and slight decrease in D with a corresponding increase in confining pressure as anticipated. On the comparison plots illustrating the dynamic non-linear properties, a slight amount of modulus reduction and increase in damping ratio was observed in the range of shearing strains tested. The EPRI reduction curves for sand are shown as a point of reference only since there is a lack of published non-linear dynamic properties for limestone.

The completed tests of silty sand samples exhibited typical sand data trends including an increase of G and decrease of D with increasing time and magnitude of confinement. As shown on the comparison plots, the shapes of the G/G_{max} versus shearing strain and D versus shearing strain curves compare well to the EPRI degradation curves of sandy soils in similar depth ranges to those tested.

Overall, typical data trends for the soil and rock tested were observed.

3.5.4 Comparison of RC and TS Data

For the completed tests, there is an excellent overall corroboration in magnitude of values and similarity of data trends between RC and TS tests. These corroborative measurements from separate tests may be observed on the plots of G and D with increasing excitation frequency and plots of G/G_{max} and D versus shearing strain.

3.5.5 Comparison of RCTS Data to Field Dynamic Property Measurements

Kleinfelder did not review field dynamic properties measurements from the site. However, such a comparison could be useful to document the corroboration between the measured RCTS low-strain shear modulus results and the shear wave velocities recorded in the field.

4.0 LIMITATIONS

The data, and findings contained in this report were developed based on laboratory tests performed on samples collected, provided by, authorized and approved by Rizzo. This report was prepared in accordance with the approved Laboratory Test Plan. No warranty, expressed or implied, is made. It is the client's responsibility to see that all parties to the project, including the designer, contractor, subcontractors, and other authorized users are made aware of this report in its entirety. The use of information contained in this report for design and construction-bidding purposes should be done at the user's option and risk.

Other standards or documents referenced in this report, or otherwise relied upon by the authors of this report, are only mentioned in the given standard; they are not incorporated into it or "included by reference" as that latter term is used relative to contracts or other matters of law.

This report may be used only by the client and their designees only for the purposes stated, within reasonable time from the issuance. Land or facility use, site conditions (both on- and off-site), regulations, or other factors may change over time, and additional work may be required with the passage of time.

As the samples tested were sampled and transported to our laboratory by parties other than Kleinfelder staff, this report makes no representation of whether the samples are representative of the material onsite.

5.0 REFERENCES

Darendeli, M., 2001, “Development of a New Family of Normalized Modulus Reduction and Material Damping Curves,” PhD. Dissertation, Department of Civil Engineering, University of Texas, Austin, pp. 362.

Electrical Power Research Institute (EPRI), 1993, “Guidelines for Determining Design Basis Ground Motions, Vol. 2: Appendices for Ground Motion Estimation”, EPRI TR 102293, Project 3302.

Kleinfelder West, Inc., 2012, “Measurement of Soil and Rock Dynamic Properties by the Resonant Column and Torsional Shear Method”, KNS-TP-8.10, Rev 2, May 30, 2012.

Kleinfelder West, Inc., 2013a, “Laboratory Testing Work Plan, Dynamic Property Testing of Soil and Rock Samples, Turkey Point Nuclear Power Plant Units 6 & 7,” Document Number 136473.3-ALB13WP001, Rev. 2, December 10, 2013.

Kleinfelder West, Inc., 2013b, “Quality Assurance Project Plan Checklist,” Document Number 136473.6-ALB13QP001, Rev. 1, November 28, 2013.

Paul C. Rizzo Associates, Inc., 2013,”Laboratory Testing Work Plan, Supplemental Geological, Geotechnical, and Geophysical Field Investigation Program, Turkey Point Nuclear Power Plant Units 6 and 7,” Document Number 135054/13, Revision No. 4, November 18, 2013.

APPENDIX A

RCTS Testing of Soil and Rock Samples

RCTS TESTING OF SOIL AND ROCK SAMPLES

1.0 INTRODUCTION

Resonant column and torsional shear (RCTS) equipment shall be employed in this investigation for measurement of the deformational characteristics (shear modulus and material damping in shear) of soil and rock specimens. The design of this equipment was developed at The University of Texas at Austin (Isenhower, 1979; Lodde, 1982; Ni, 1987; and Kim, 1991) and construction of the hardware and software was performed by Troutwein Soil Testing Equipment, Inc. The equipment is of the fixed-free type, with the bottom of the specimen fixed and torsional excitation applied to the top. Both resonant column (RC) and torsional shear (TS) tests can be performed in a sequential series on the same specimen over a shearing strain range from about $10^{-4}\%$ to slightly more than $10^{-1}\%$. The primary difference between the two types of tests is the excitation frequency. In the RC test, frequencies above 20 Hz are required and inertia of the specimen and drive system are needed to analyze the measurements. On the other hand, slow cyclic loading involving frequencies generally below 10 Hz is performed in the TS test and inertia does not enter into data analysis.

2.0 RESONANT COLUMN AND TORSIONAL SHEAR EQUIPMENT

The RCTS apparatus can be idealized as a fixed-free system as shown in Fig. 1. The bottom end of the specimen is fixed against rotation at the base pedestal, and top end of the specimen is connected to the driving system. The driving system, which consists of a top cap and drive plate, can rotate freely to excite the specimen in cyclic torsion.

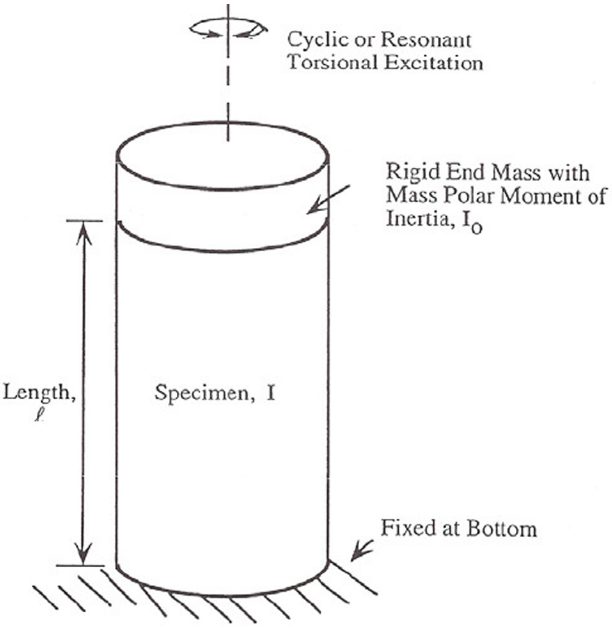


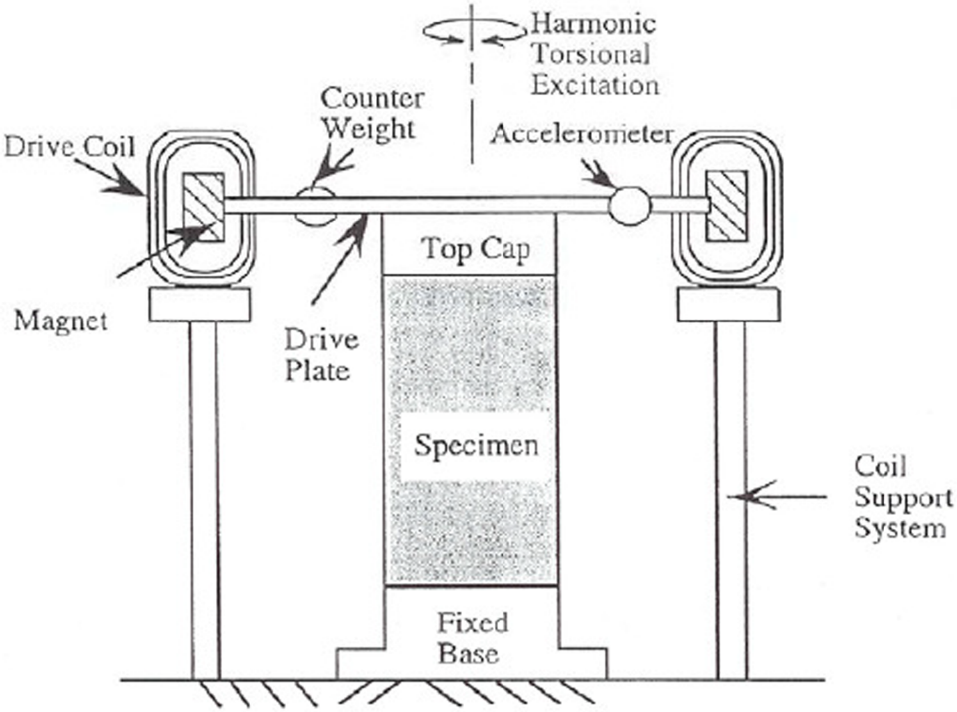
Figure 1. Idealized Fixed-Free RCTS Equipment

A simplified diagram of a fixed-free resonant column (RC) test is shown in Fig. 2. The basic operational principle is to vibrate the cyclindrical specimen in first-mode torsional motion. Harmonic torsional excitation is applied to the top of the specimen over a range in frequencies, and the variation of the acceleration amplitude of the specimen with frequency is obtained. Once first-mode resonance is established, measurements of the resonant frequency and amplitude of vibration are made. These measurements are then combined with equipment characteristics and specimen size to calculate shear wave velocity and shear modulus based on elastic wave propagation. Material damping is determined either from the width of the frequency response curve or from the free-vibration decay curve.

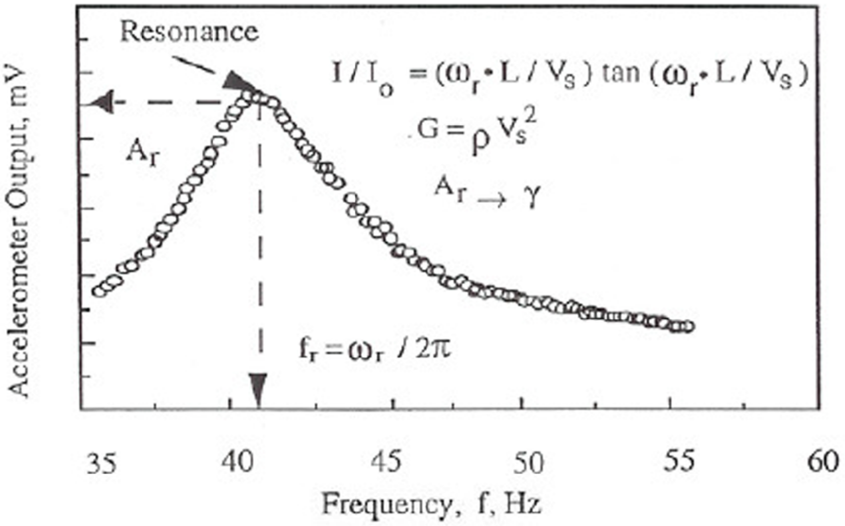
The torsional shear (TS) test is another method of determining shear modulus and material damping using the same RCTS equipment but operating it in a different manner. The simplified configuration of the torsional shear test is shown in Fig. 3. A cyclic torsional force with a given frequency, generally below 10 Hz, is applied at the top of the specimen. Instead of determining the resonant frequency, the stress-strain hysteresis loop is determined from measuring the torque-twist response of the specimen. Proximitors are used to measure the angle of twist while the voltage applied to the coil is calibrated to yield torque. Shear modulus is calculated from the slope of a line through the end points of the hysteresis loop, and material damping is obtained from the area of the hysteresis loop as shown in Fig. 3.

The RCTS apparatus used in this study has three advantages. First, both resonant column and torsional shear tests can be performed with the same set-up simply by changing (outside the apparatus) the frequency of the forcing function. Variability due to preparing “identical” samples is eliminated so that both rest results can be compared effectively. Second, the torsional shear test can be performed over a shearing strain range between 5 x 10^{-4}% and about 1 x 10^{-1}%, depending upon specimen stiffness. Common types of torsional shear tests, which generate torque by a mechanical motor outside of the confining chamber, are usually performed at strains above 0.01% because of system compliance. However, the RCTS apparatus used in this study generates torque with an electrical coil magnet system inside the confining chamber, thus eliminating the problem with an external motor. The torsional shear test can be performed at the same low-strain amplitudes as the resonant column test, and results between torsional shear and resonant column testing can be easily compared over a wide range of strains. Third, the loading frequency in the torsional shear test can be changed easily from 0.01 Hz to 10 Hz. Therefore, the effect of frequency on deformational characteristics can be conveniently investigated using this apparatus.

The RCTS apparatus consists of four basic subsystems which are: 1. a confinement system, 2. a drive system, 3. a height-change measurement system, and 4. a motion monitoring system. The general configuration of the RCTS apparatus (without the confinement system) is shown in Fig. 4. The RCTS is automated so that a microcomputer controls the test, collects the data, and reduces the results. Computer aided subsystems are discussed in the following sections.

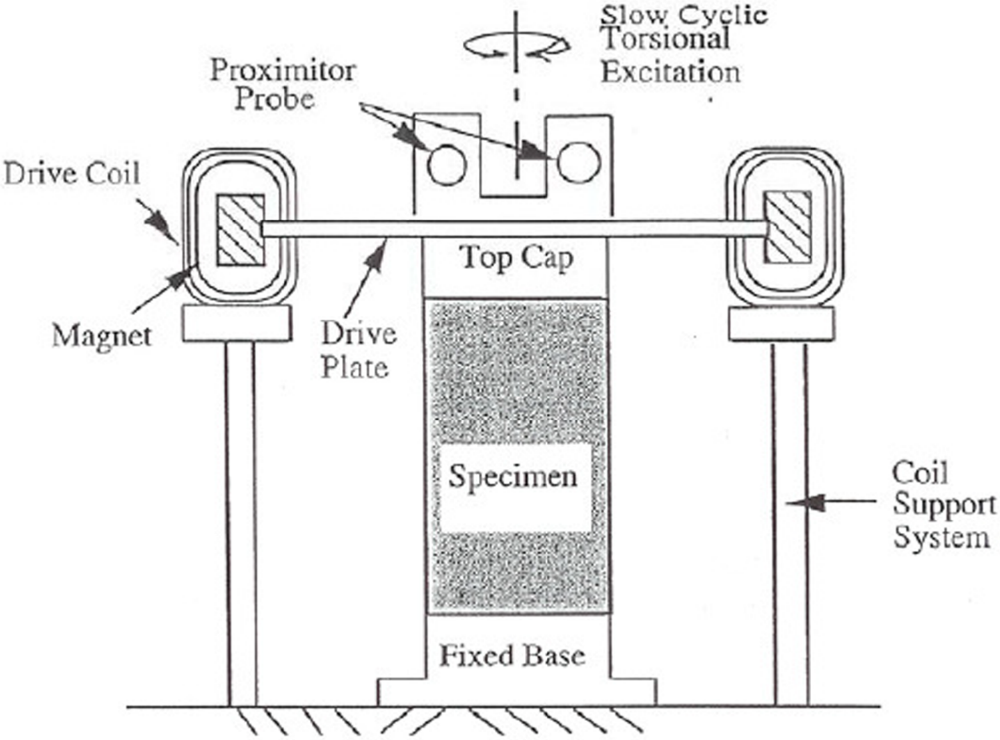


a) Specimen in the Resonant Column Apparatus
(Confinement Chamber Not Shown)

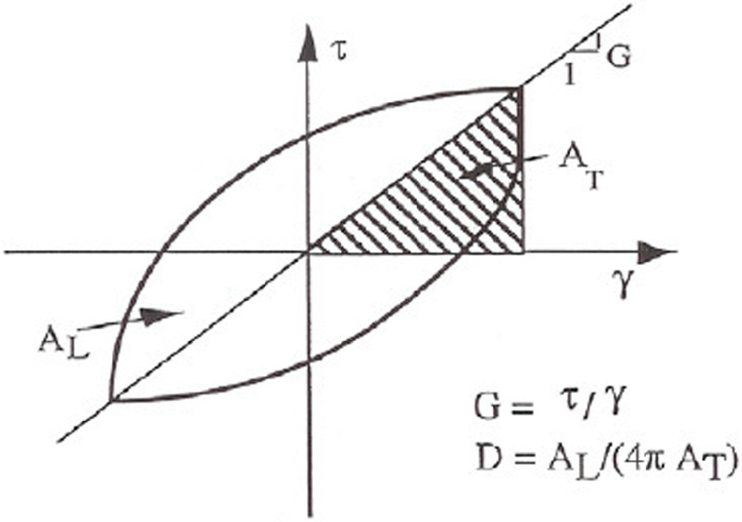


b) Typical Frequency Response Curve

Figure 2. Simplified Diagram of a Fixed-Free Resonant Column Test and an Associated Frequency Response Curve

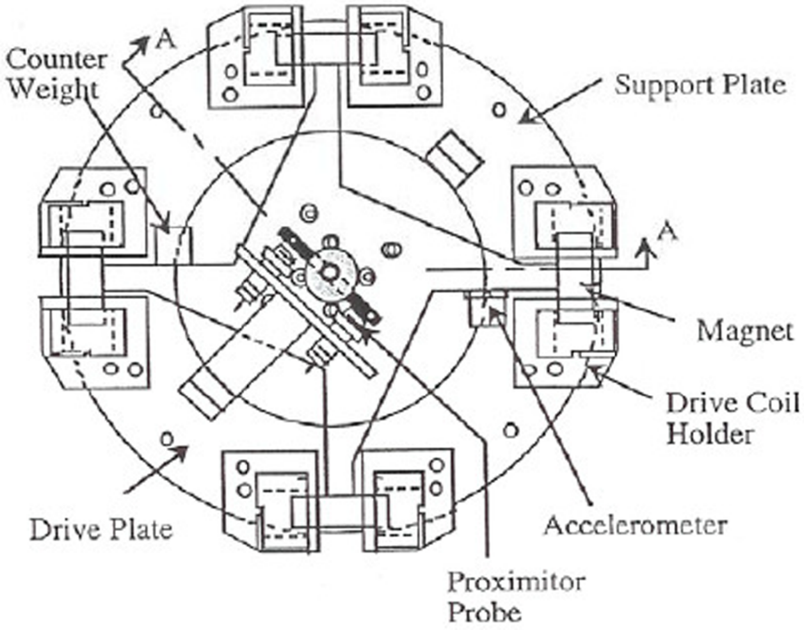


a) Specimen in the Torsional Shear Test Apparatus
(Confinement Chamber Not Shown)

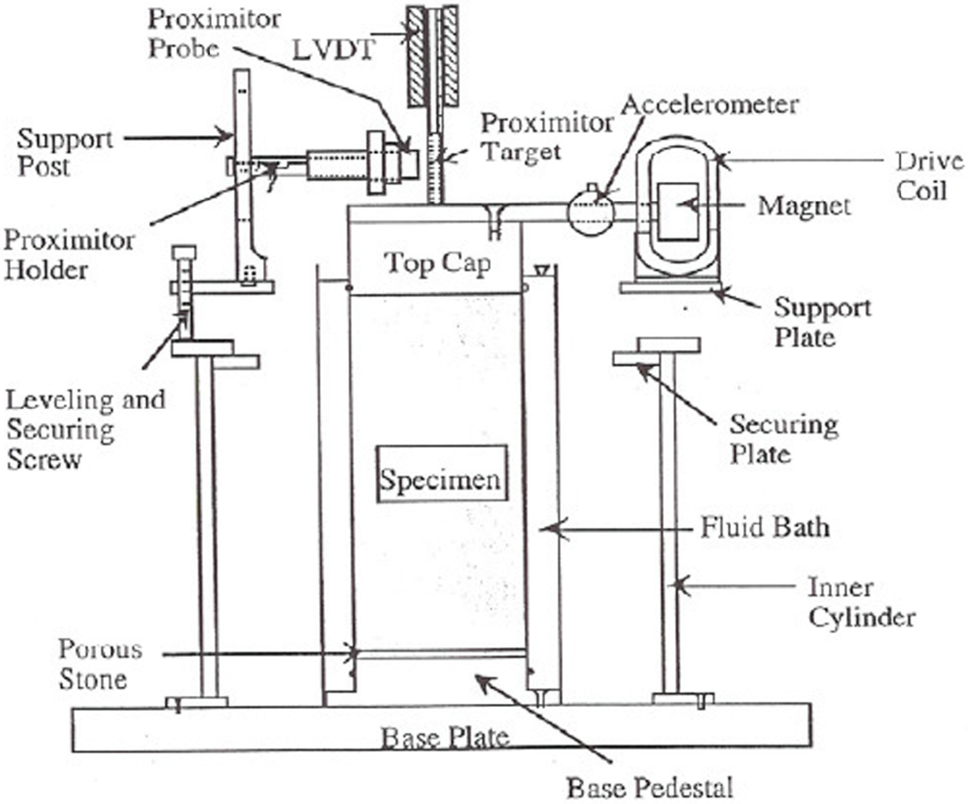


b) Measurement of Shear Modulus and Damping Ratio

Figure 3. Configuration of a Torsional Shear Test and Evaluation of Shear Modulus and Material Damping Ratio



a) Top View



b) Cross Section View

Figure 4. Simplified Configuration of the RCTS Apparatus.

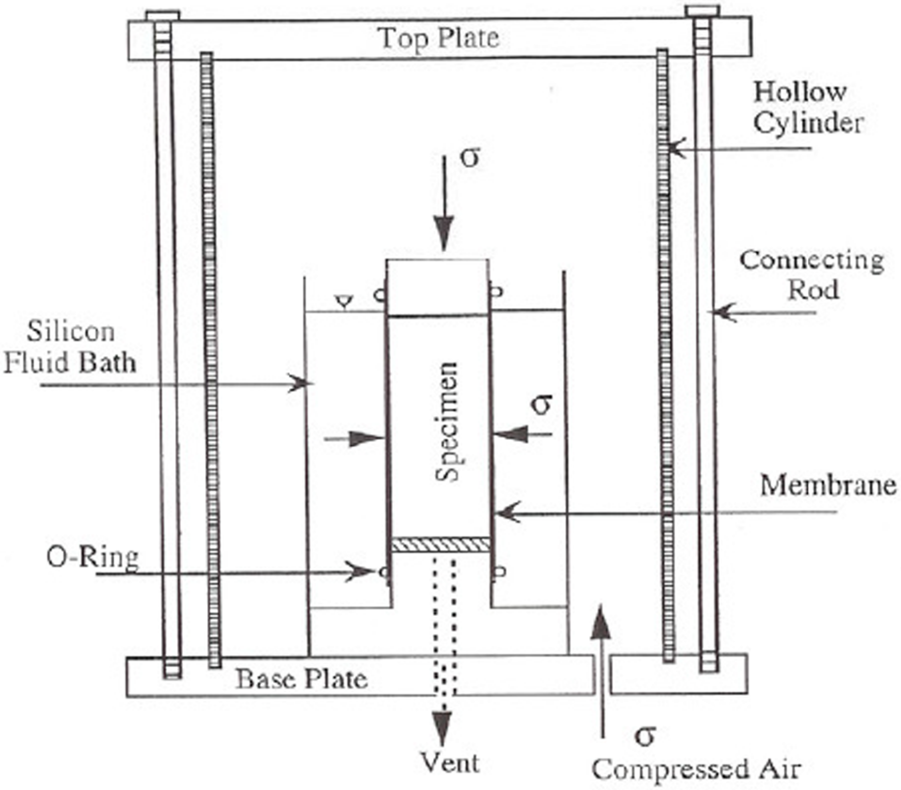


Figure 5. Simplified Configuration of Confinement System

2.2 RCTS Confinement System

The confining chamber is made of stainless steel. A thin walled hollow cylinder fits into circular grooves machined in base and top plates. Six stainless steel connecting rods are used to secure the base and top plates to the hollow cylinder, and O-rings in the circular grooves are used to seal the chamber. In this configuration, the chamber has been designed to withstand a maximum air pressure of about 500 psi (3447 kPa).

Compressed air is used to confine isotropically the specimen in the RCTS device. The air pressure to the chamber generally is regulated by a Fairchild M 10 regulator and air supplied to the regulator is filtered. At high confining pressures, additional regulators are used. The soil specimen is sealed in a membrane and pore pressure in the specimen is vented to atmospheric pressure.

The only calibrated portions of the confinement system are the pressure gauges which are used to read the cell air pressure. These gauges are calibrated every year.

2.3 Drive System

The drive system consists of a four-armed drive plate, four magnets, eight drive coils, a power amplifier, and a function generator internal to the data acquisition (DAQ) board. Each magnet is rigidly attached to the end of one arm of the drive plate as shown in Fig. 4. Eight drive coils encircle the ends of the four magnets so that the drive plate excites the soil specimen in torsional motion when a current is passed through the coils. The maximum torque that the drive system can develop depends on the strength of the magnets and drive coils, length of the arms of the drive plate, and the electrical characteristics of the function generator and power amplifier.

The DAQ board (NI M-Series PCI6251) within the micro-computer outputs sinusoidal voltage to the power amplifiers (Geotac DV604), which amplify the voltage approximately 15 to 20 times, and outputs the signal to the drive coils. In the resonant column (RC) test, the DAQ board performs frequency sweeps with a constant amplitude, while in the torsional shear test a fixed-frequency N-cycle mode is used.

Two aspects of the drive system in the RCTS equipment system have to be calibrated. First, the mass polar moment of the inertia, I_o, of each drive plate and top cap must be determine. This is done using specimens made of metal rods which are used as fixed-free torsional pendulums as discussed by Isenhower (1979) and Lodde (1982). The second aspect consists of determining the torque-current calibration factor for each drive plate. This process also involves use of the metal rods as discussed by Isenhower and Lodde. These calibrations are performed every year.

2.4 Height-Change Measurement System

The height change of the specimen is measured to account for the changes in the length and mass of the specimen during consolidation or swell. This measurement is also used to calculate change in the mass moment of inertia, mass density, and void ratio during testing (by assuming isotropic strain under isotopic confinement and constant degree of saturation). The height change is measured by a linear variable differential transformer (LVDT). The height change measurement system consists of an LVDT (TransTek Model 0243) and a monitor system (TESTNet). The LVDT core rests on a raised platform at the center of rotation of the drive plate to minimize friction during RCTS testing.

2.5 Motion Monitoring System

Dynamic soil and rock properties are obtained in the RC test at the resonant frequency which is usually above 20 Hz while torsional shear testing is used to measure the low-frequency (below 10 Hz) cyclic stress-strain relationship of soil. Because of the different frequencies applied in the resonant column and torsional shear tests, different motion monitoring systems are used.

Resonant Column (RC) Test

The motion monitoring system in the RC test is designed to measure the resonant frequency, shearing strain, and free-vibration decay curve. This system consists of an accelerometer (Columbia Research Laboratory Model 3021), a charge amplifier (Columbia Research Laboratory Model 4601), and the DAQ Board. The accelerometer and charge amplifier is calibrated once ever two years.

The accelerometer is oriented to be sensitive to torsional vibrations of the drive plate. The charge amplifier conditions the accelerometer output to be linear for all levels of acceleration in the test. The DAQ board reads the output voltage from the accelerometer at each frequency. The resonant frequency is obtained from the frequency response curve. Once the resonant frequency is obtained, the DAQ board outputs a signal to excite the specimen at the resonant frequency and then suddenly stops the current so that the free-vibration decay curve is recorded. The resonant frequencies of soil and rock specimens are typically in the range of 20 Hz to 300 Hz with this equipment.

Torsional Shear (TS) Test

The motion system in the TS test (3300 Proximitor System) is used to monitor torque-twist hysteresis loops of the specimen this system consists of two proximitors (Bently Nevada 3300XL 5/8 mm), two proximitor probes (Bently Nevada M 3300XL 8 mm), a Proximitor Signal Conditioner (PROX) (Geotac AMP804), a DC power supply (Geotac DV604), and a U-shaped target. The U-shaped target is secured to the top of the drive plate, and the two proximitor probes are rigidly attached to the support stand. The entire system is calibrated yearly using a micrometer as discussed in ALB-SOP-8.2.

The function of the proximitor probes is to measure the width of the air gap between the target and the probe tip. Because the proximitor probes do not touch the drive plate, no compliance problems are introduced into the measurement. Two probes are used and the operational amplifier subtracts the signal of one probe from the other so that the effect of bending in the specimen toward the probes can be eliminated. The proximitor system is a very effective low-frequency motion monitoring system which does not introduce any compliance problems into the measurement. With the simultaneous measurement of torque, load-displacement hysteresis loops can be determined.

3.0 METHOD OF ANALYSIS IN THE RESONANT COLUMN TEST

The resonant column test is based on the one-dimensional wave equation derived from the theory of elasticity. The shear modulus is obtained by measuring the first-mode resonant frequency while material damping is evaluated from either the free vibration decay curve or from the width of the frequency response curve assuming viscous damping.

3.1 Shear Modulus

The governing equation of motion for the fixed-free torsional resonant column test is:

$$\frac{\Sigma I}{I_o} = \frac{\varpi_n \cdot \ell}{V_s} \cdot \tan\left(\frac{\omega_n \cdot \ell}{V_S}\right) \qquad \text{(Equation 1)}$$

where:

$\Sigma I = I_s + I_m + \ldots$,
I_s = mass moment of inertia of specimen,
I_m = mass moment of inertia of membrane,
I_o = mass moment of inertia of rigid end mass at the top of specimen,
ℓ = length of specimen,
V_s = shear wave velocity of the specimen, and
ω_n = undamped natural circular frequency of the system.

The value of I_o is known from the calibration of the drive plate. The values of I_s and ℓ are easily determined from the specimen size and weight. Once the first-mode resonant frequency is determined, the shear wave velocity can be calculated from Eq. 1 by assuming the resonant circular frequency and ω_n are equal.

As noted above and shown in Fig. 2 the resonant circular frequency, ω_r, is measured instead of undamped natural frequency, ω_n, and ω_r is used to calculate shear wave velocity. If the damping in the system is zero, ω_r and ω_n are equal. The relationship between ω_r and ω_n is:

$$\omega_r = \omega_n \sqrt{1 - 2D^2} \qquad \text{(Equation 2)}$$

where:

D = material damping ratio.

A typical damping ratio encountered in the resonant column test is less than 20 percent, which corresponds to a difference of less than 5 percent between ω_r and ω_n. The damping measured in the resonant column test is usually less than 10 percent, and ω_r can by used instead of ω_n with less than a two percent error.

Once the shear wave velocity is determined, shear modulus is calculated from the relationship:

$$G = \rho \cdot V_s^2 \qquad \text{(Equation 3)}$$

where:

ρ = total mass density of the specimen (total unit weight divided by gravity).

3.2 Shearing Strain

The shearing strain varies radially within the specimen and may be expressed as a function of the distance from the longitudinal axis as illustrated in Fig. 6. The equivalent shearing strain, γ_{eq} or γ, is represented by:

$$\gamma = \frac{r_{eq} \cdot \theta_{\max}}{\ell} \qquad \text{(Equation 4)}$$

where:

r_{eq} = equivalent radius,
θ_{max} = angle of twist at the top of the specimen, and
ℓ = length of the specimen.

Chen and Stokoe (1979) studied the radial distribution in shearing strain to find a value of r_{eq} for the specimen tested in the RCTS equipment to evaluate an effective strain. They found that the value of r_{eq} varied from $0.82 \cdot r_o$ for a peak shearing strain amplitude below 0.001% to $0.79 \cdot r_o$ for a peak shearing strain of 0.1% for a solid specimen. The value of 0.79 has been adopted for testing.

In the resonant column test, the resonant period (T_r, seconds), and output voltage of accelerometer (A_c, volts (RMS)) at resonance are measured. Accelerometer output is changed to displacement by using the accelerometer calibration factor (CF, volts/in/sec^2) assuming harmonic motion. The accelerometer displacement is divided by the distance (D_{ac}, inches) between the location of accelerometer and the axis of the specimen to calculate the angle of twist at the top of the specimen (θ_{max}). The shearing strain is then calculated by:

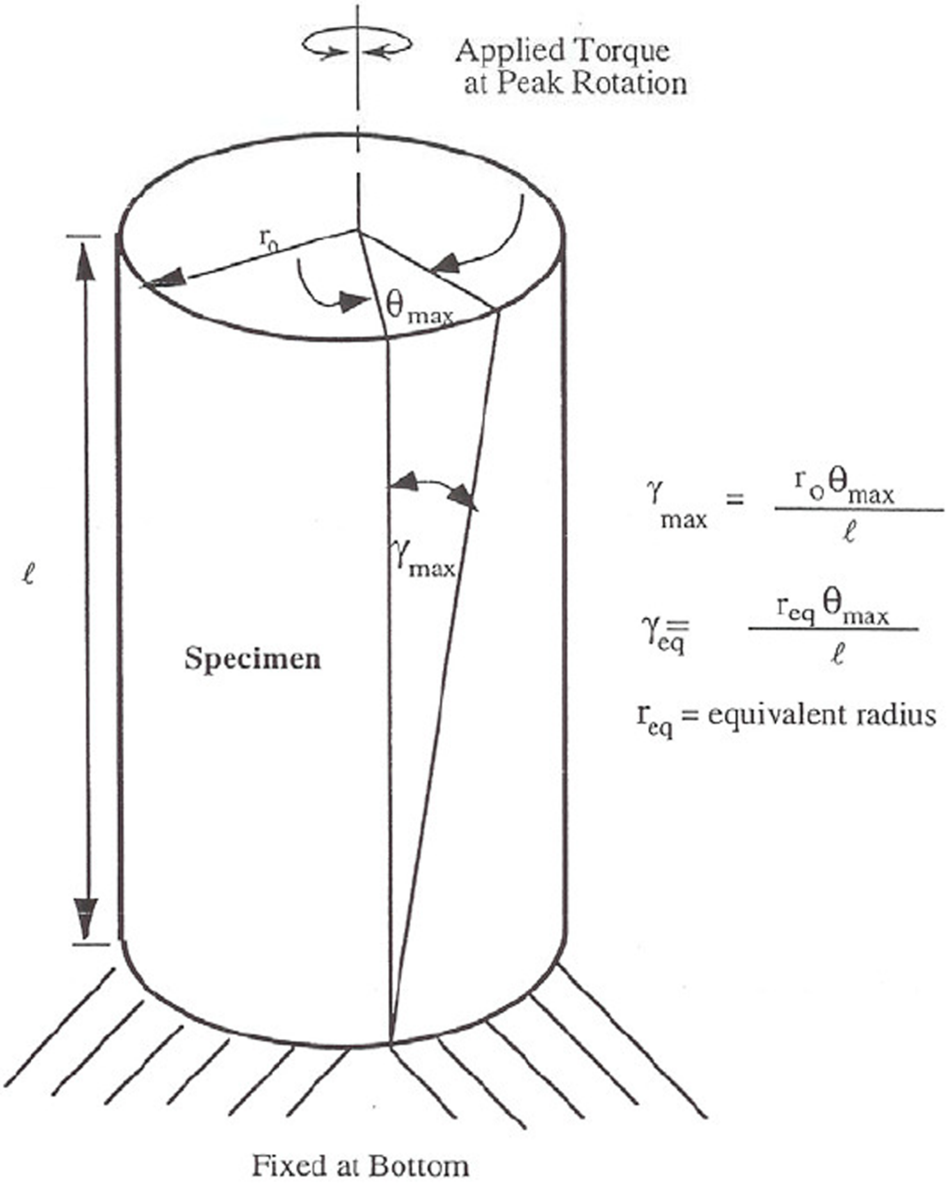


Figure 6. Shear Strain in RCTS Specimen Column

$$\gamma = r_{eq} \cdot \frac{A_c \cdot T_r^{\ 2}}{4 \cdot \pi \cdot CF} \cdot \frac{1}{D_{ac}} \cdot \frac{1}{\ell} \qquad \text{(Equation 5)}$$

where:

r_{eq} = equivalent radius,
A_c = accelerometer output voltage,
T_r = resonant period,
CF = accelerometer calibration factor,
D_{ac} = distance between the accelerometers and specimen axis, and
ℓ = length of the specimen.

3.3 Material Damping

In the resonant column test, material damping ratio can be evaluated from either the free-vibration decay method or from the half-power bandwidth method. Each of these methods is discussed below. It is important to note that, in these measurements, the damping measurement includes material damping in the specimen plus any damping in the equipment. Calibration of equipment damping is discussed in Section 5.

Free-Vibration Decay Method

Material damping in soils and rock specimens can be quite complex to define. However, the theory for a single-degree-of-freedom system with viscous damping is a useful framework for describing the effect of damping which occurs in soil (Richart et al., 1970). The decay of free vibrations of a single-degree-of-freedom system with viscous damping is described by the logarithmic decrement, δ, which is the ratio of the natural logarithm of two successive amplitudes of motion as:

$$\delta = \ln\left(\frac{Z_1}{Z_2}\right) = \frac{2 \cdot \pi \cdot D}{\sqrt{1 - D^2}} \qquad \text{(Equation 6)}$$

where:

Z_1 and Z_2 = two successive strain amplitudes of motion, and
D = material damping ratio

The free-vibration decay curve is recorded by shutting off the driving force while the specimen is vibrating at the resonant frequency. The amplitude of each cycle is measured from the decay curve, and the logarithmic decrement is then calculated using Eq. 6. Material damping ratio is calculated from logarithmic decrement according to:

$$D = \sqrt{\frac{\delta^2}{4 \cdot \pi^2 + \delta^2}} \qquad \text{(Equation 7)}$$

A typical damping measurement from a free-vibration decay curve (from a metal calibration specimen) is shown in Fig. 7.

In this method, it is not certain which strain amplitude is a representative strain for damping ratio calculated by Eq. 7 because strain amplitude decreases during free-vibration decay. In this study, a representative strain amplitude was used as the peak strain, the representative strain is smaller than the peak strain, and the average strain determined for the first three cycles of free vibration was used.

Half-Power Bandwidth Method

Another method of measuring damping in the resonant column damping in the resonant column test is the half-power bandwidth method, which is based on measurement of the width of the frequency response curve near resonance. From the frequency response curve, the logarithmic decrement can be calculated from:

$$\delta = \frac{\pi}{2} \cdot \frac{f_2{}^2 - f_1{}^2}{f_r{}^2} \cdot \sqrt{\frac{A^2}{A_{\max}{}^2 - A^2}} \cdot \frac{\sqrt{1-2D^2}}{1-D^2} \qquad \text{(Equation 8)}$$

where:

f_1 = frequency below the resonance where the strain amplitude A,
f_2 = frequency above the resonance where the strain amplitude A,
f_r = resonant frequency, and
D = material damping ratio

If the damping ratio is small and A is chosen as 0.707 A_{max}, which is called the half power point, Eq. 8 can be simplified as:

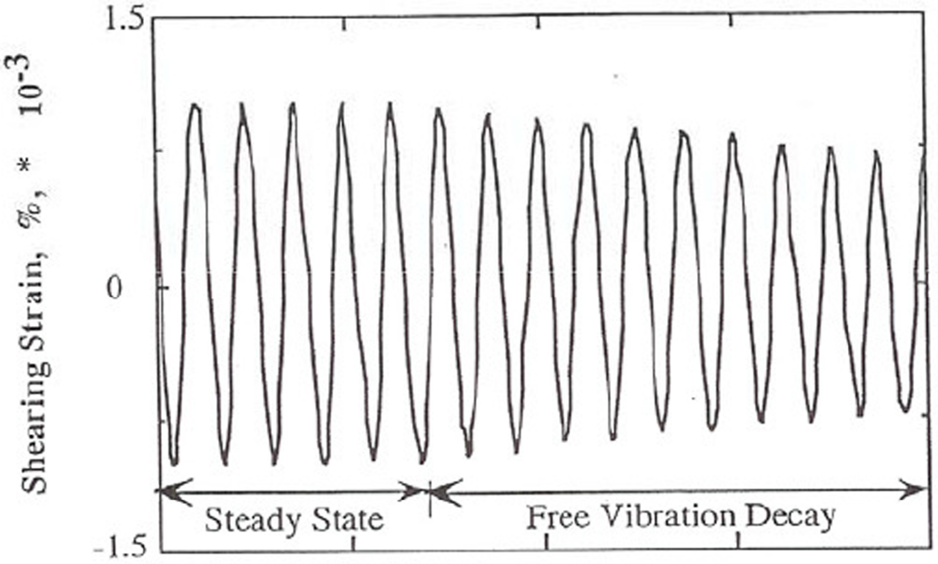
$$\delta = \pi \cdot \frac{f_2 - f_1}{f_r} \qquad \text{(Equation 9)}$$

Therefore, the damping ratio can be expressed as:

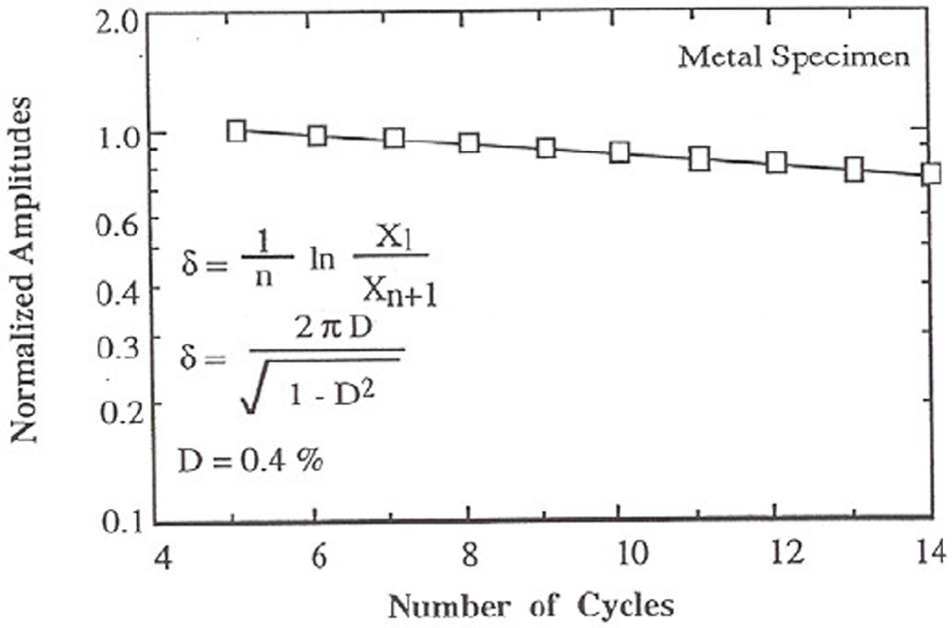
$$D = \frac{f_2 - f_1}{2 \cdot f_r} \qquad \text{(Equation 10)}$$

A typical damping measurement by the half-power bandwidth method (for a metal calibration specimen) is shown in Fig. 8.

Background noise can be a problem in measuring material damping using the free-vibration decay method at strains less than about 0.001%. On the other hand, background noise generally has a smaller effect on the frequency response curve at strains below 0.001%. Therefore, the half-power bandwidth method is preferred to the free-vibration decay method for making small-strain damping measurements. However, at large strains, symmetry in the frequency response curve is no longer maintained, and a serious error can be introduced in the half-power bandwidth method (Ni, 1987).



a) free vibration decay curve



b) analysis of free-vibration decay cuve

Figure 7. Determination of Material Damping Ratio from the Free-Vibration Decay Curve Using a Metal

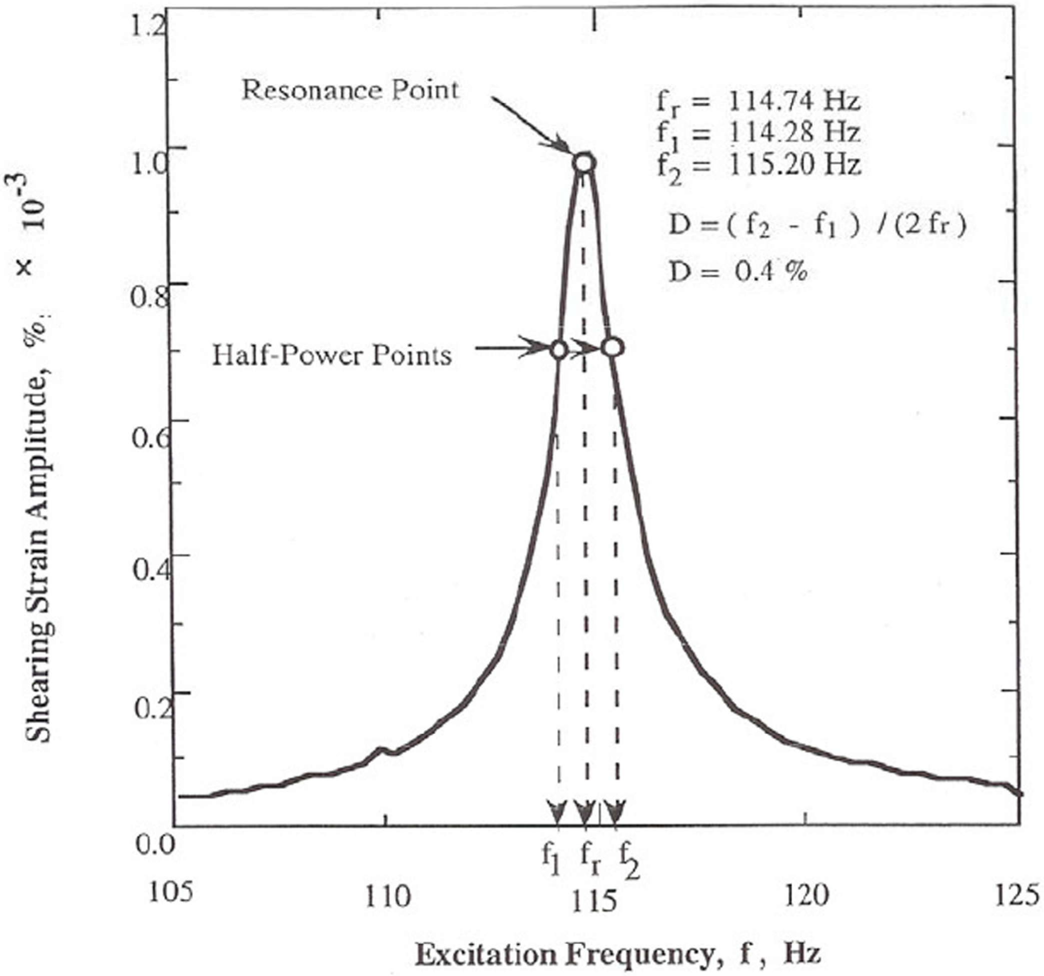


Figure 8. Determination of Material Damping from the Half-Power Bandwidth Method Using a Metal Specimen

4.0 METHOD OF ANALYSIS IN THE TORSIONAL SHEAR

The torsional shear test is another method of determining the deformational characteristics (modulus and damping) of soil and rock specimens using the same RCTS device. Rather than measuring the dynamic response of the specimen, the actual stress-strain hysteresis loop is determined by means of measuring the torque-twist curve. Shear modulus is calculated from the slope of the hysteresis loop, and the hysteric damping ratio is calculated using the area of the hysteresis loop.

4.1 Shear Modulus

Because shear modulus is calculated from the stress-strain hysteresis loop, shearing stress, and shearing strain in the torsional shear test need to be defined.

Shearing Stress

Determination of shearing stress in the torsional shear test is based on the theory of elasticity for circular or tubular rods in pure torsion. Assume that pre torque, T, is applied to the top of the specimen. The torque can be calculated from:

$$T = \int_{r_i}^{r_o} \tau_r \cdot (2 \cdot \pi \cdot r) \cdot r \, dr \qquad \text{(Equation 11)}$$

where:

τ_r = shearing stress at a distance r from the axis of the specimen,
r_o = outside radius, and
r_i = inside radius.

If the shearing stress is assumed to vary linearly across the radius:

$$\tau_r = \tau_m \cdot \left({}^{r}\!/_{r_o} \right) \qquad \text{(Equation 12)}$$

where τ_m is the maximum shearing stress at $r = r_o$. Eq. 12 can be rewritten as:

$$T = \frac{\tau_m}{r_o} \cdot \frac{\pi}{2} \cdot \left(r_o^{\,4} - r_i^{\,4} \right) = \frac{\tau_m}{r_o} \cdot J_p \qquad \text{(Equation 13)}$$

where J_p is the polar moment of inertia. From Eq. 13, one can write:

$$\tau_m = r_o \cdot \frac{T}{J_p} \qquad \text{(Equation 14)}$$

Because shearing stress is assumed to vary linearly across the radius, the average torsional shearing stress is defined as:

$$\tau_{avg} = r_{eq} \cdot \frac{T}{J_p} \qquad \text{(Equation 15)}$$

The value of r_{eq} is the same value as used in the resonant column analysis for calculation of shearing strain (Section 3.2).

The value of applied torque, T, is calculated from the input voltage applied to the drive system, V_T (Volts), and the torque calibration factor, K_T (torque / Volts). Thus, average shearing stress becomes:

$$\tau_{avg} = r_{eq} \cdot K_T \cdot V_T / J_p \qquad \text{(Equation 16)}$$

Shearing Strain

Calculation of shearing strain in the torsional shear test follows the same procedure used in the resonant column test. The proximitor system directly measures the displacement (instead of acceleration measured in the resonant test). Hence, the angle of twist (θ) is calculated from the proximitor output, V_p (volts), and the proximitor calibration factor, K_p (rad/volt). Shearing strain, γ, is then calculated from:

$$\gamma = r_{eq} \cdot \Sigma K_p \cdot V_p / \ell \qquad \text{(Equation 17)}$$

Shear Modulus

Once the stress-strain hysteresis loop is measured, the shear modulus, G, is calculated from the slope of a line through the end points of the hysteresis loop as shown in Fig. 9. Thus, the shear modulus is calculated from:

$$G = \tau / \gamma \qquad \text{(Equation 18)}$$

where:

τ = peak shearing stress and
γ = peak shearing strain.

4.2 Hysteretic Damping Ratio

Hysteretic damping ratio in the torsional shear test is measured using the amount of energy dissipated in one complete cycle of loading and the peak strain energy stored in the specimen during the cycle.

In the torsional shear test, the dissipated energy is measured from the area of the stress-strain hysteresis loop. The energy per cycle, W_d, due to a viscous damping force, F_d, is:

$$W_d = \int_0^T F_d \cdot \dot{x}\, dt \qquad \text{(Equation 19)}$$

where:

$\dot{x}$ = a velocity and
T = a period.

For simple harmonic motion with frequency of ω, i.e. x = A·Cos(ωt-ϕ), W_d becomes:

$$W_d = \pi \cdot c \cdot \omega \cdot A^2 \qquad \text{(Equation 20)}$$

From Eq. 20, the viscous damping coefficient can be expressed as:

$$c = \frac{W_d}{\pi \cdot \omega \cdot A^2} \qquad \text{(Equation 21)}$$

The peak strain energy, W_s, stored by the spring is equal to the area under the secant modulus line Fig. 9 and can be written as:

$$W_s = \frac{k \cdot A^2}{2} \qquad \text{(Equation 22)}$$

The critical damping coefficient, C_c, is:

$$C_c = 2 \cdot \sqrt{k \cdot m} = \frac{2 \cdot k}{\omega_n} \qquad \text{(Equation 23)}$$

where:

k = the elastic spring constant,
m = mass, and
ω_n = the natural frequency of the system.

Using Eq. 22, Eq. 23 can be rewritten as:

$$C_c = \frac{4 \cdot W_s}{\omega_n \cdot A^2} \qquad \text{(Equation 24)}$$

Therefore, the damping ratio, D, can be expressed as:

$$D = \frac{C}{C_c} = \frac{W_d}{4 \cdot \pi \cdot W_s} \cdot \frac{\omega_n}{\omega} \qquad \text{(Equation 25)}$$

For soil or rock materials, damping is often assumed to be frequency independent. Therefore, ω_n / ω is ignored and hysteretic damping is written as:

$$D = \frac{1}{4 \cdot \pi} \cdot \frac{W_d}{W_s} \qquad \text{(Equation 26)}$$

where:

W_d = the area of the hysteresis loop and
W_s = the area of the triangle as shown in Fig. 9.

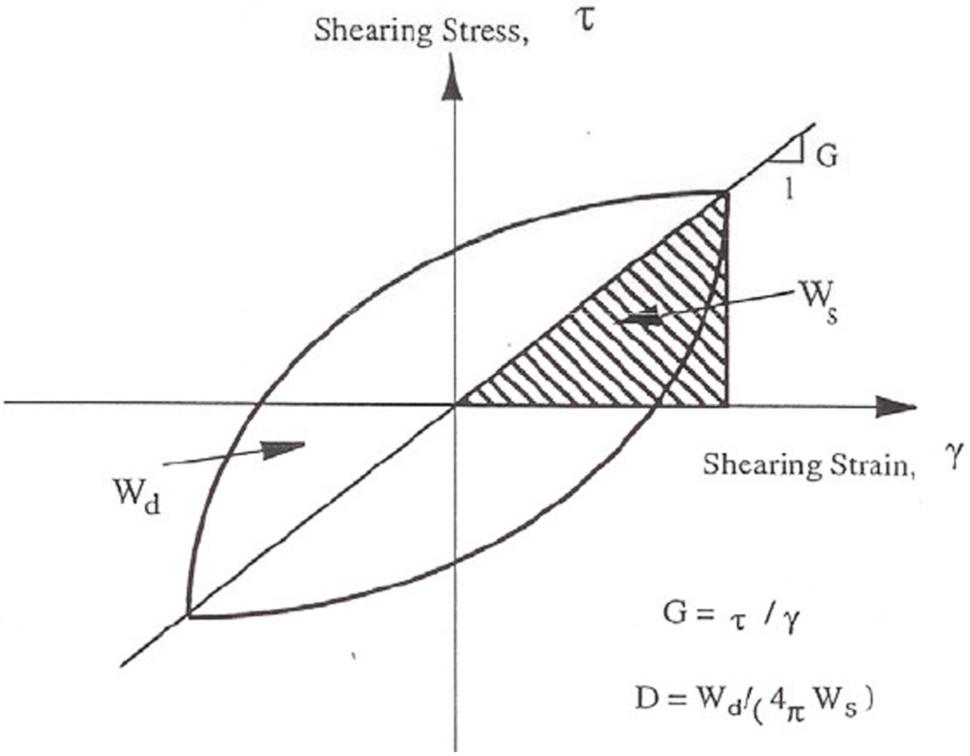


Figure 9. Determination of Shear Modulus and Damping Ratio in the Torsional Shear Test

5.0 REFERNCE

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Richart, F.E.,Jr., Hall, J.R.,Jr., and Woods, R.D. (1970), Vibration of Soils and Foundations, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 414 pp.

APPENDIX B

Results for Kleinfelder Specimen ID K2-13-001

- *Specimen Preparation Notes*
- *RCTS Testing Results*

KLEINFELDER
Bright People. Right Solutions.

SPECIMEN PREPARATION NOTES

Specimen No.: K2-13-001

Project No : 136473

Page 1 **of** 4

Boring No.: B-615

Date of Preparation..: 10/12/2013

Sample No..: 615-CS-01

Depth..: 32.6 - 33.1 feet

Disposition of Rock Core Sample

☒ No Apparent Disturbance ☐ Apparent Disturbance ☐ Apparent Slaking Due to Coring

☒ Other (Describe) Sample consisted of a Limestone of the Key Largo Fomration with Small to Large Sized Vugs

Specimen Preparation Notes

Trimming Method :	Rotary coring with water lubricant, 1.5-inch OD diameter core barrel		**Affixation to Platens :**	Epoxied to 2.8-inch diameter steel top cap and base pedestal	
Ave. Length (in.) :	3.9682	**Ave. Diameter (in.):**	1.449	**L/D**	2.7
Total Unit Weight . (pcf) :	138.4	**Moisture Content (%)**	9.6	**% Saturation (Assume SG = 2.70)**	77.4

Specimen Testing Comments

1) Sample 615-CS-01 was predominately a medium strong rock with small to large sized vugs. One vug extended all the way through the core from one side to the other (see Photo B.3). Due to the rock hardness, the sample could not be trimmed by hand and it was decided to core the nominally 2.5-inch diameter sample with a 1.5-inch outside diameter (OD), thin-walled diamond-impregnated core barrel.

2) Sample was trimmed to an approximate 6-inch length and grouted into an CMU block on 10/12/13. See Photos B.4 through B.6.

3) Sample was cored on 10/13/13. See Photo B.7. One approximately 1.45-inch diameter specimen resulted from the rotary coring. The specimen was of sufficient length for RCTS Testing and the sample ends were trimmed to the final length of about 4.0-inches. The completed specimen still contained the vug that extended through the original sample (see Photo B.8).

4) Specimen was epoxied to the 2.8-inch diameter steel top cap and base pedestal on 12/9/13.

5) Testing commenced on 12/10/13 and was completed on 12/12/13. The full test sequence was completed, with confining pressures ranging from 3 psi to 45 psi.

☒ **See Attached Photographs**

SPECIMEN PREPARATION NOTES

Specimen No: K2-13-001

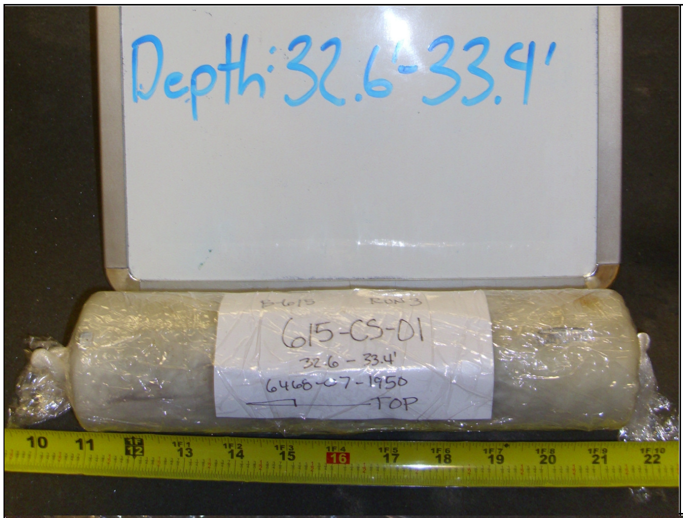


Photo B.1

Sample 615-CS-01 after removal from the protective transport container.

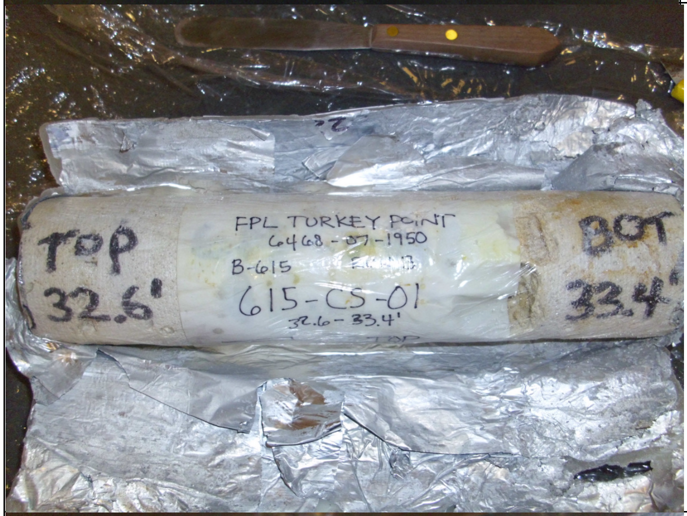


Photo B.2

Sample after removal from the wax casing and aluminum foil.

Photo B.3

Close up of vug in sample that extends all the way through the core

SPECIMEN PREPARATION NOTES

Specimen No: K2-13-001

Photo B.4

Trimming the sample to an approximate 6-inch length as preparation for grouting in a CMU block. Note the modeling clay used to seal off natural vugs in sample to prevent grout infiltration.

Photo B.5

Grouting sample in a CMU block as preparation for down coring the sample. Note the specimen number written on the side of the CMU block to maintain sample control.

Photo B.6

Rotary coring of specimen using the 1.5-inch OD core barrel.

SPECIMEN PREPARATION NOTES

Specimen No: K2-13-001

Photo B.7

Specimen after down coring to an approximate 1.45-inch diameter.

Photo B.8

Close-up of vug still in specimen after down coring.

Photo B.9

Specimen after affixation to the steal top cap and base pedestal using epoxy. Note modeling clay placed in natural vugs to prevent membrane puncture during testing.

Kleinfelder Specimen ID:

K2-13-001

Boring No: B-615
Sample No: 615-CS-01

Limestone (Key Largo Formation)
Depth = 32.6 ft – 33.1 ft (below existing ground surface)
Total Unit Weight = 138.4 lb/ft^3
Natural Moisture Content = 9.6%
Estimated In-Situ Mean Effective Stress = 11 psi

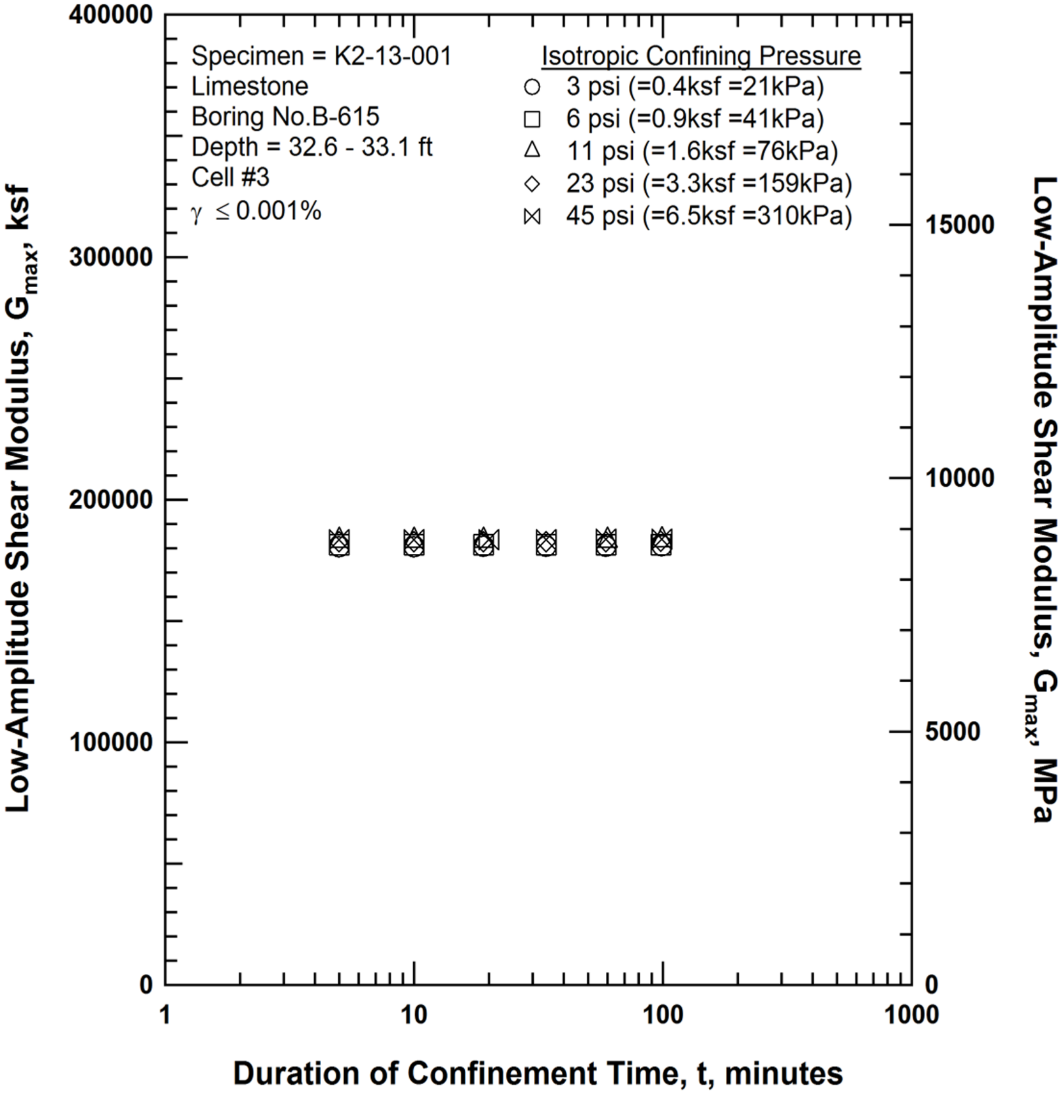


Figure B.1 Variation in Low-Amplitude Shear Modulus with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen K2-13-001

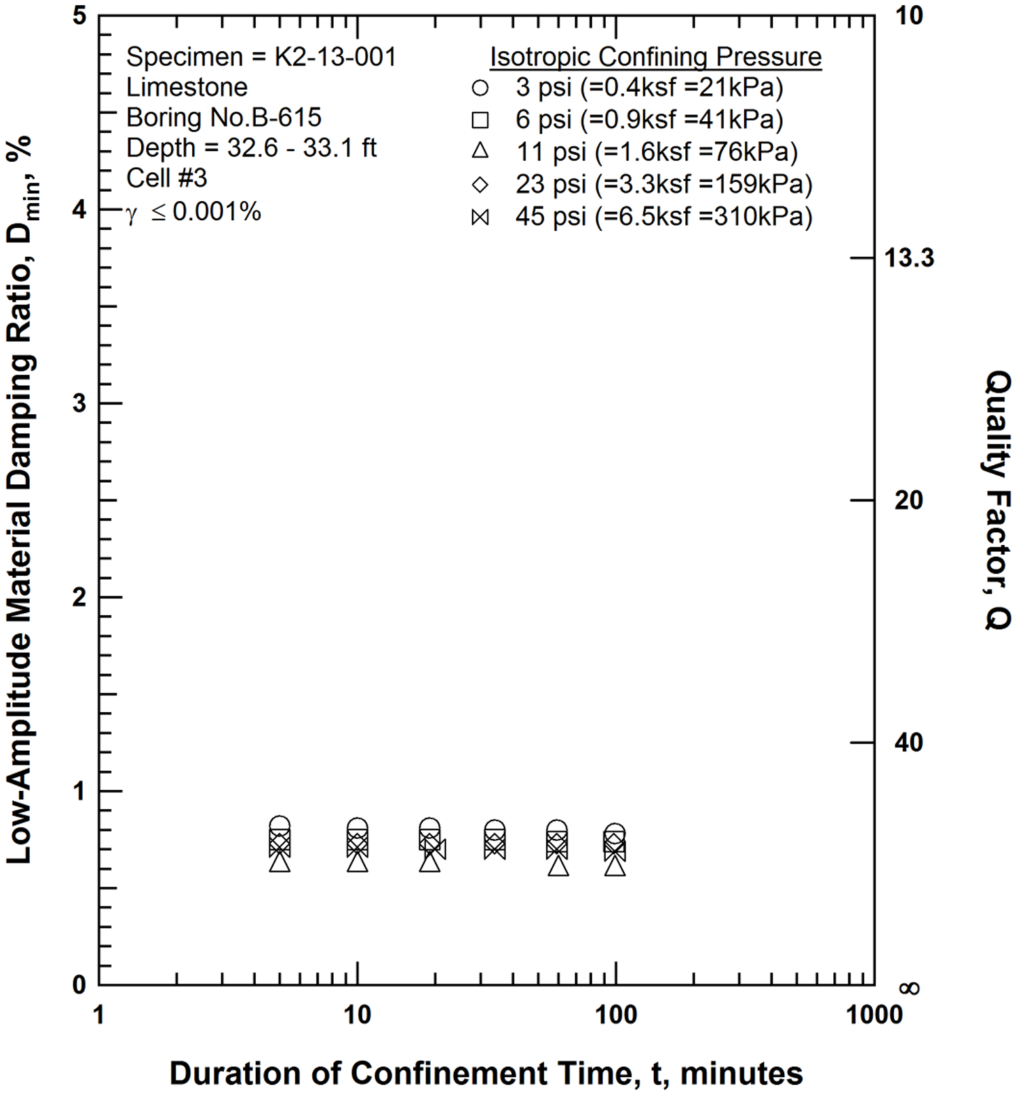


Figure B.2 Variation in Low-Amplitude Material Damping Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen K2-13-001

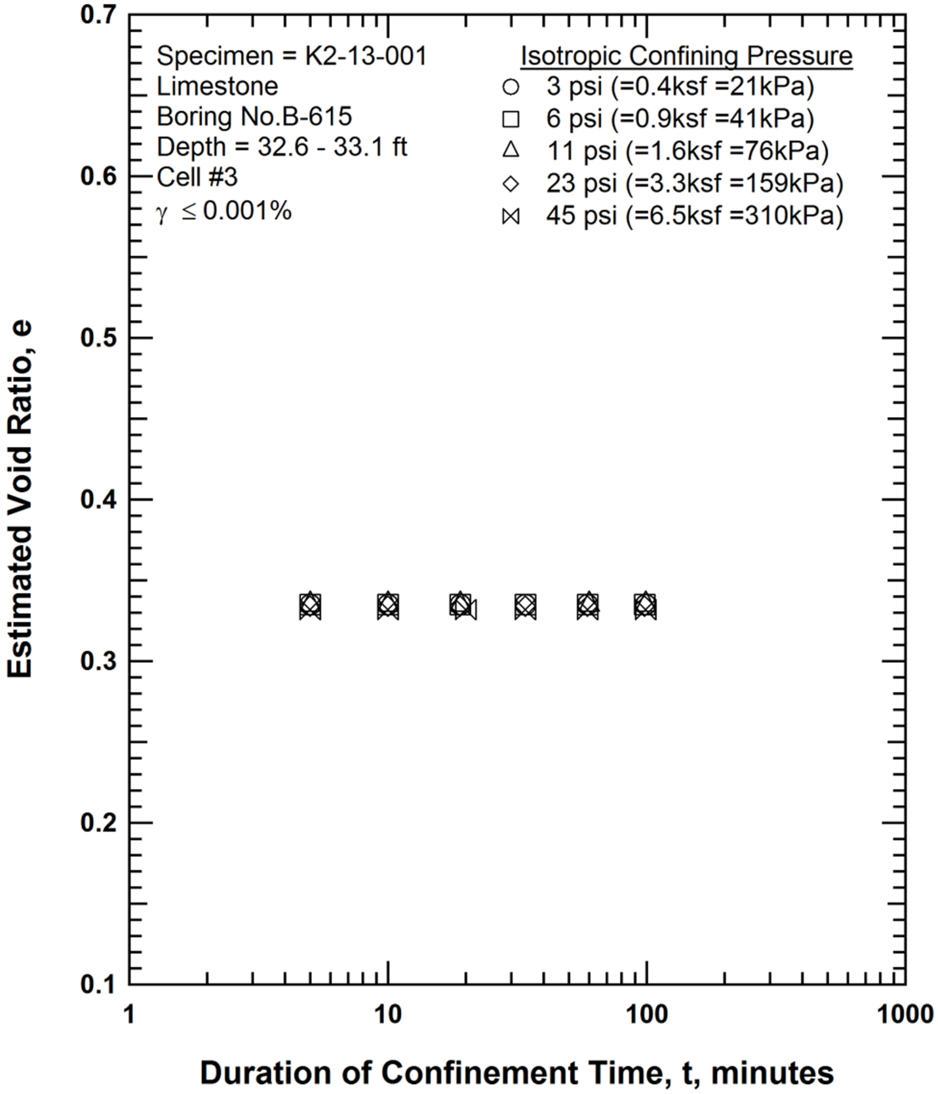


Figure B.3 Variation in Estimated Void Ratio with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Test of Specimen K2-13-001

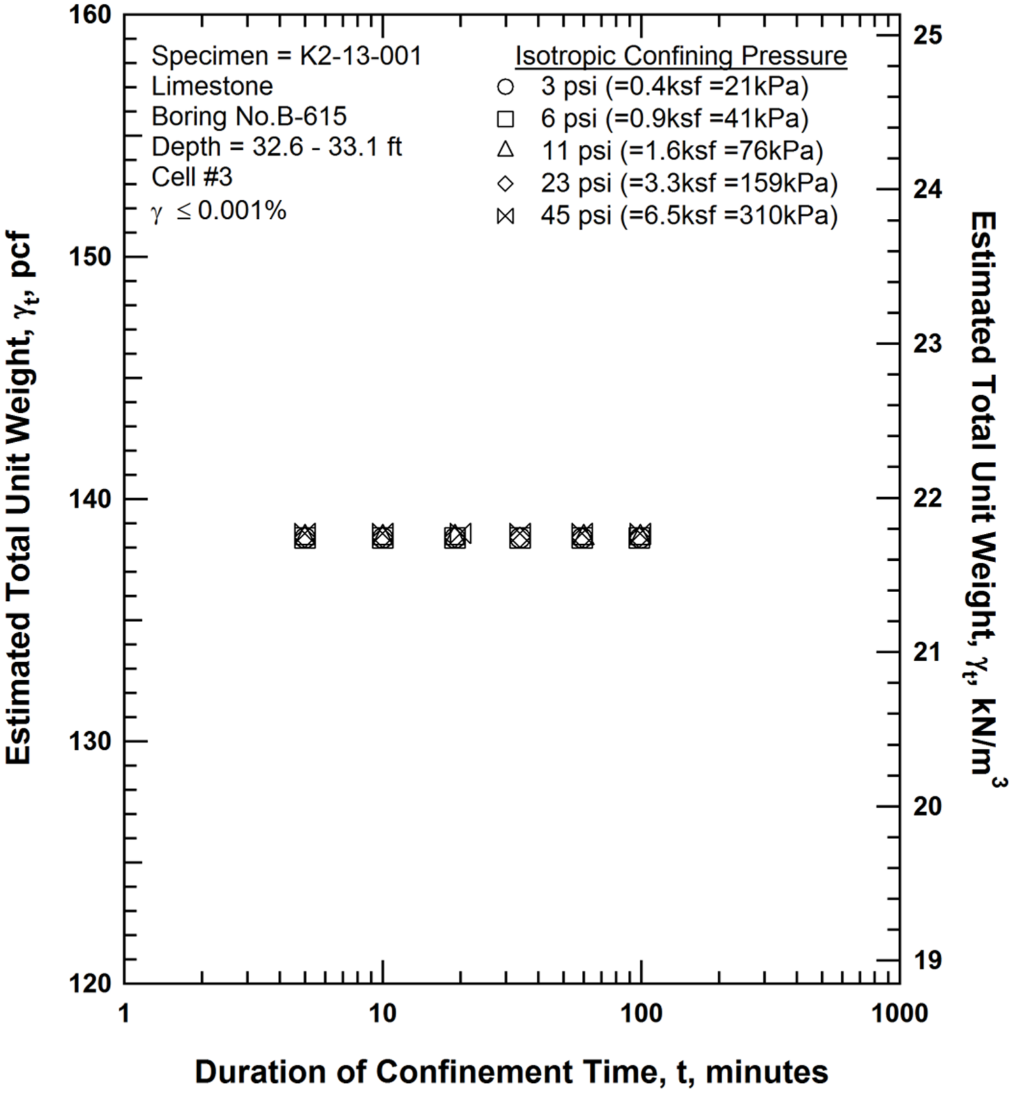


Figure B.4 Variation in Estimated Total Unit Weight with Magnitude and Duration of Isotropic Confining Pressure from Resonant Column Tests of Specimen K2-13-001

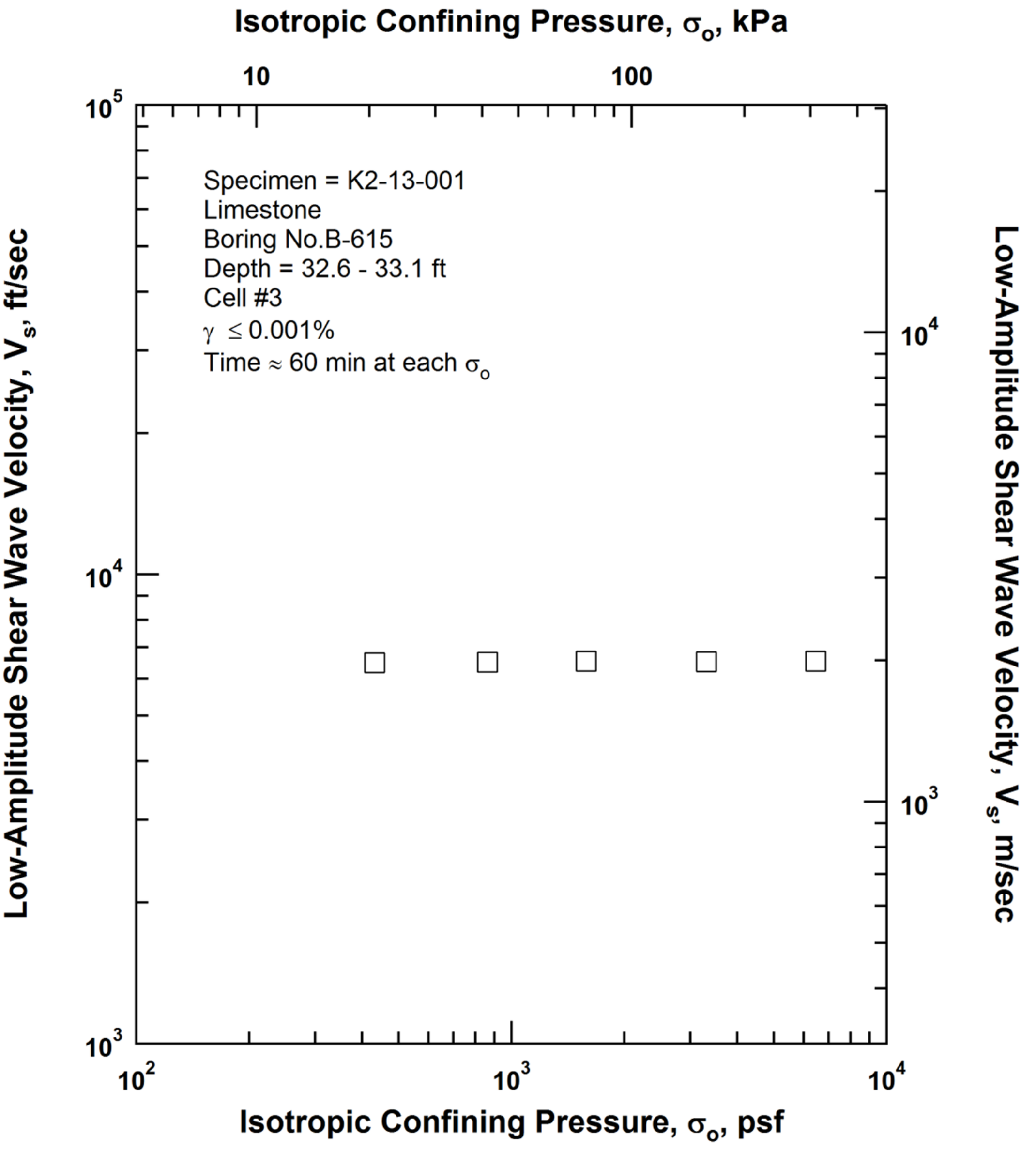


Figure B.5 Variation in Low-Amplitude Shear Wave Velocity with Isotropic Confining Pressure from Resonant Column Tests of Specimen K2-13-001

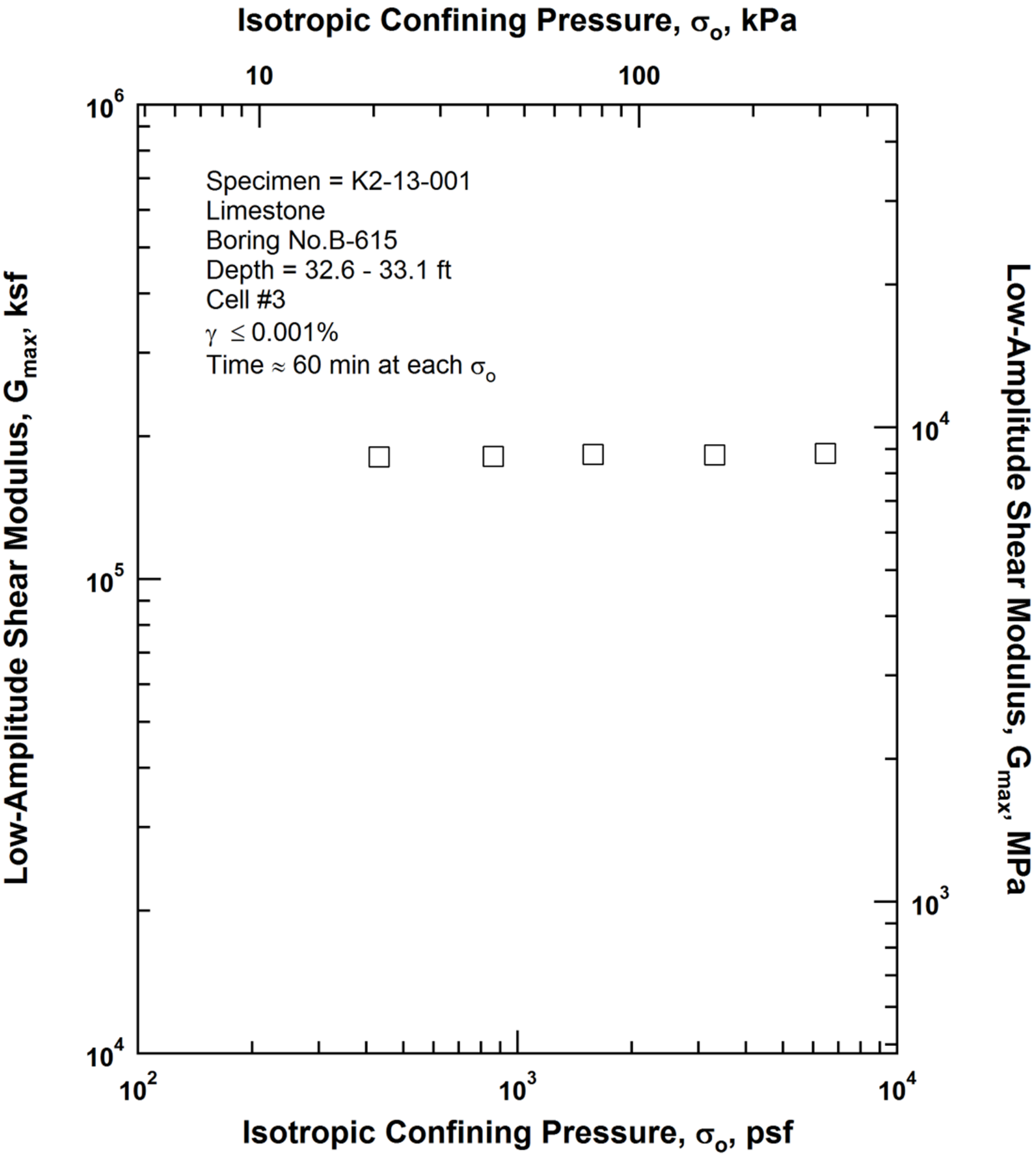


Figure B.6 Variation in Low-Amplitude Shear Modulus with Isotropic Confining Pressure from Resonant Column Test of Specimen K2-13-001

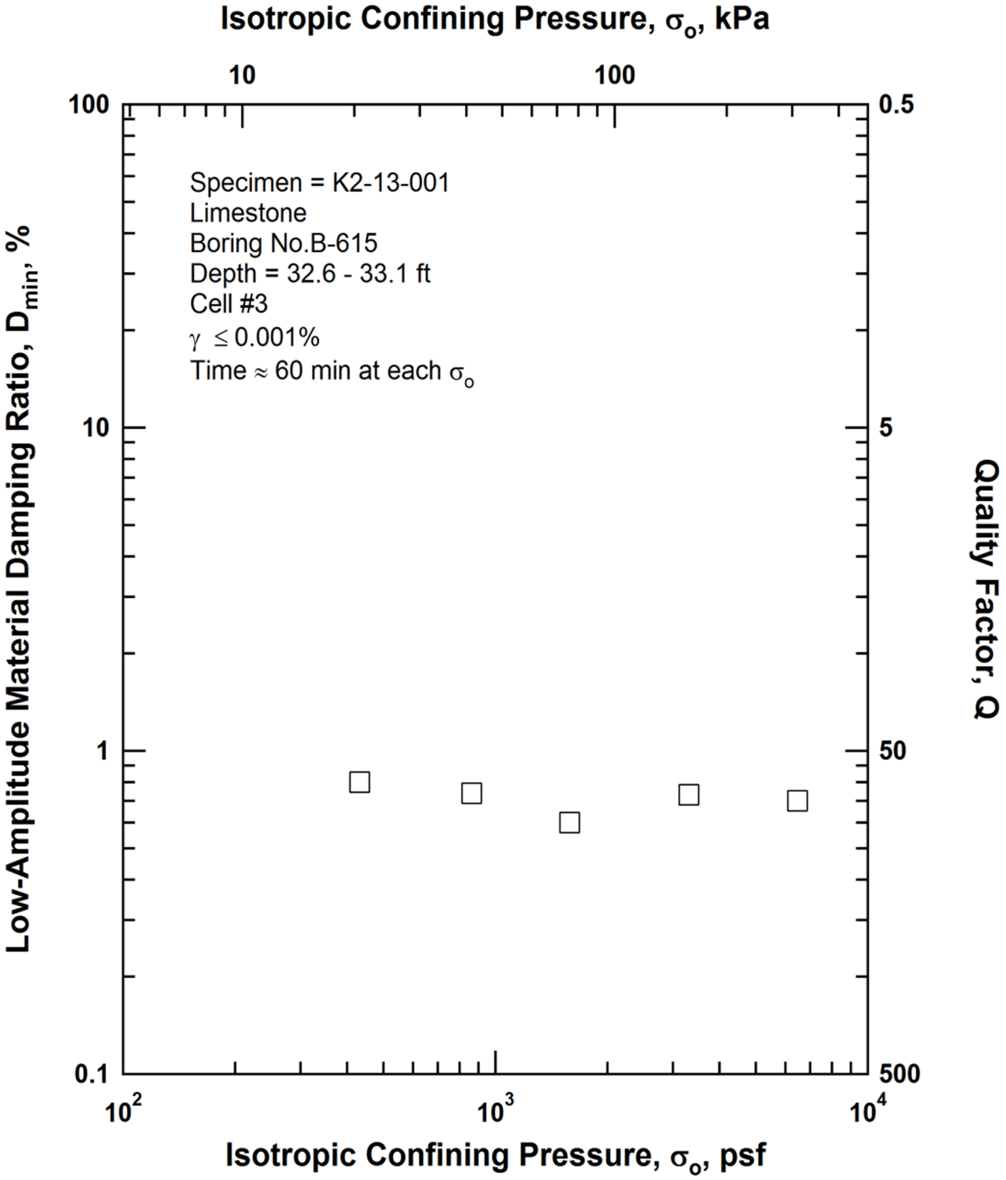


Figure B.7 Variation in Low-Amplitude Material Damping Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen K2-13-001

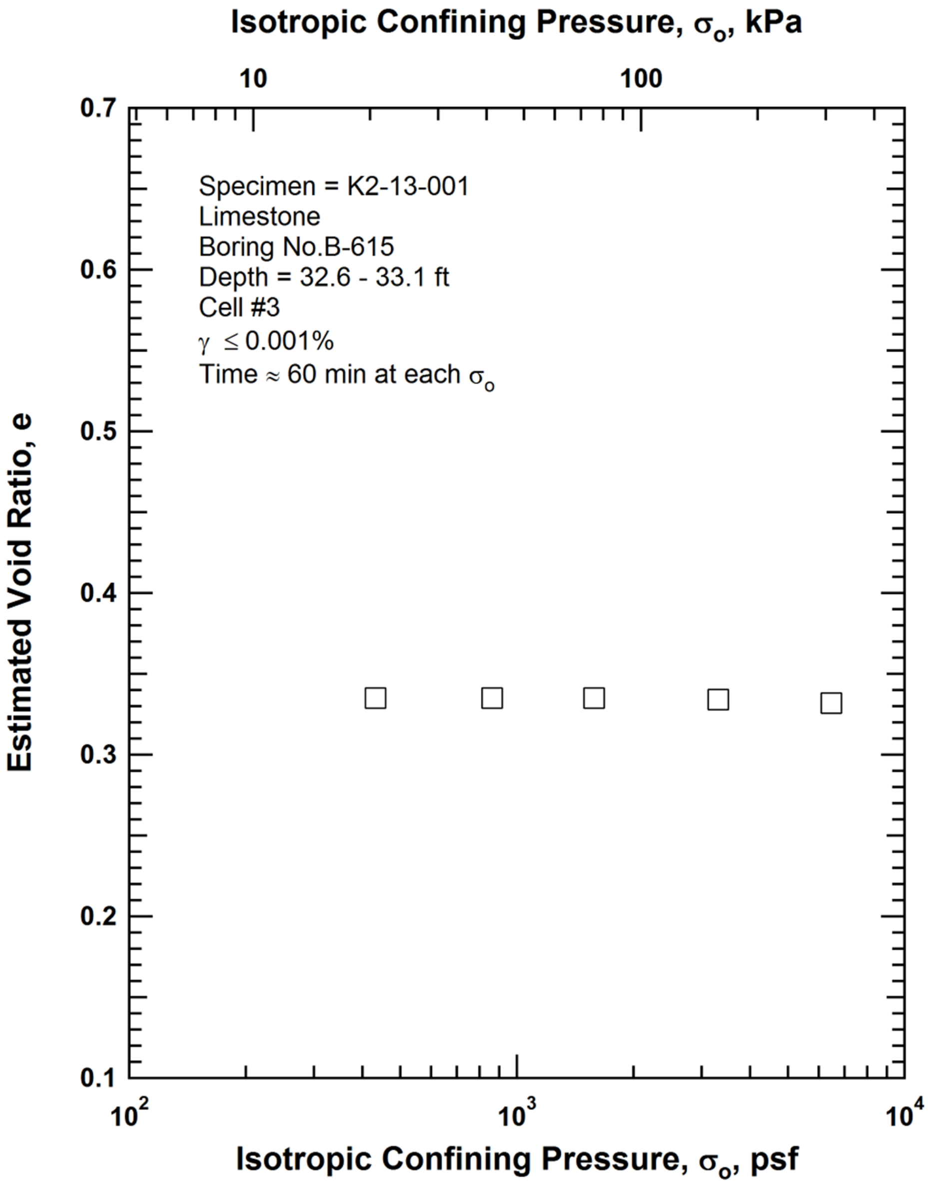


Figure B.8 Variation in Estimated Void Ratio with Isotropic Confining Pressure from Resonant Column Tests of Specimen K2-13-001

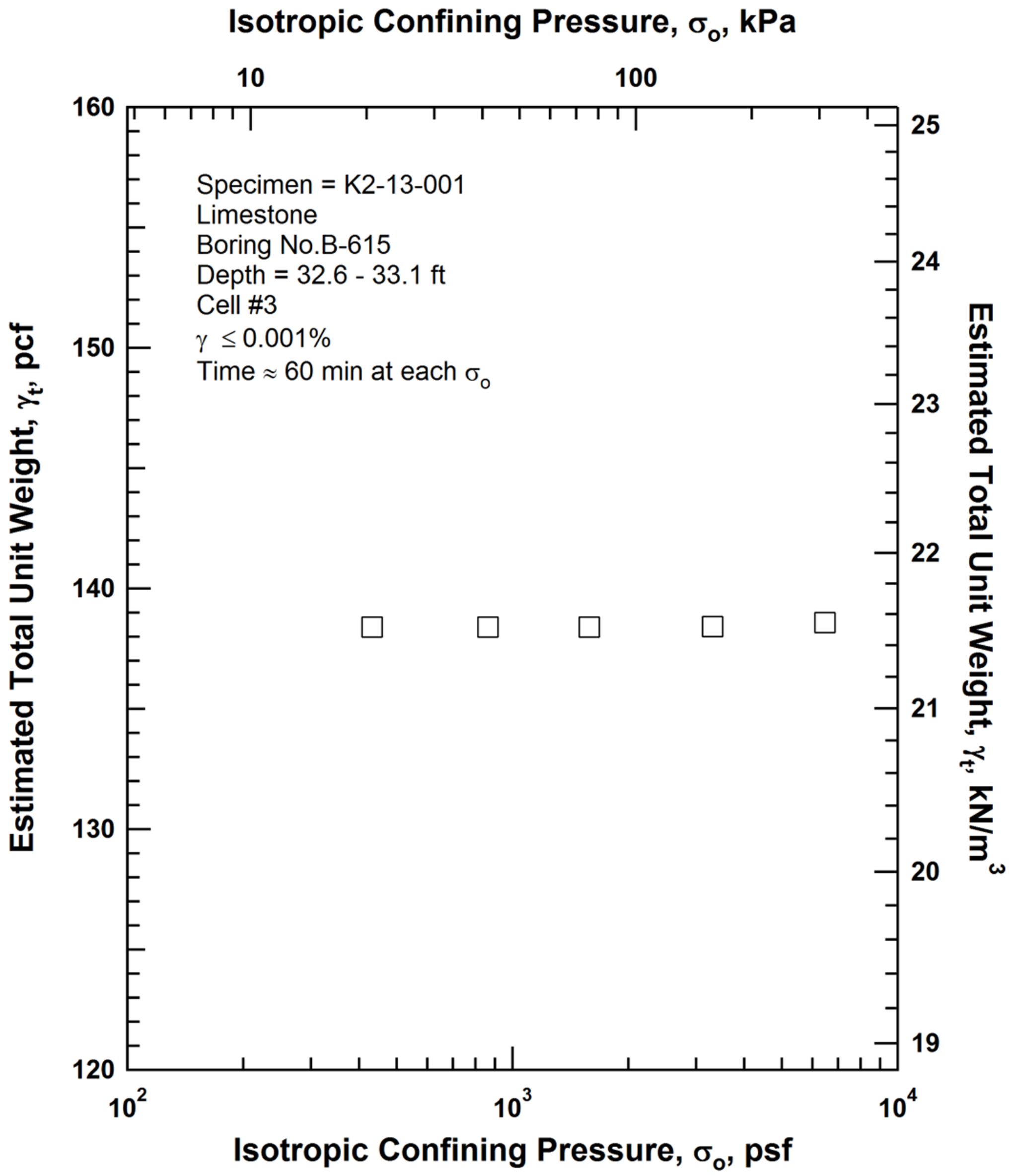


Figure B.9 Variation in Estimated Total Unit Weight with Isotropic Confining Pressure from Resonant Column Tests of Specimen K2-13-001

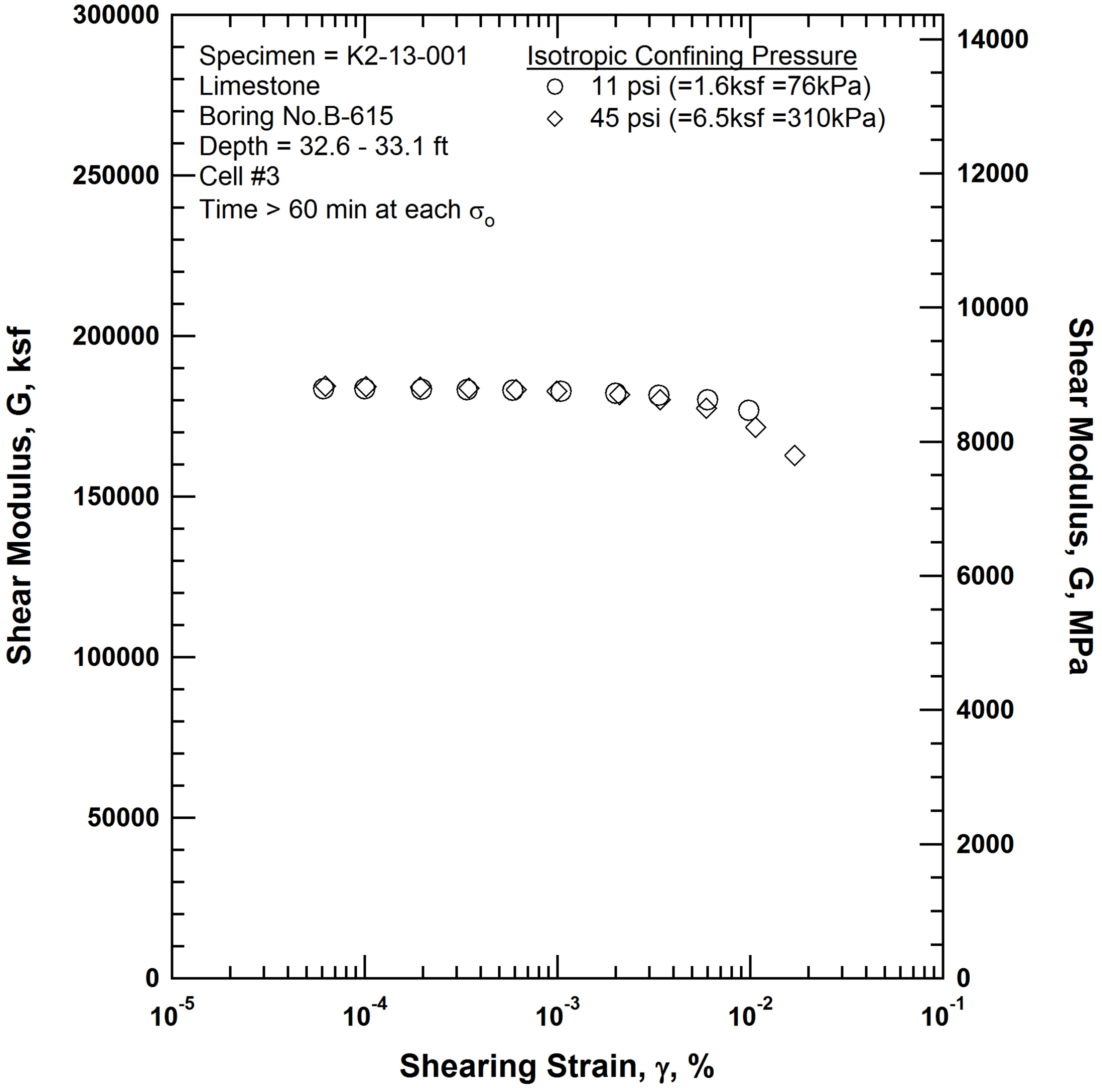


Figure B.10 Comparison of the Variation in Shear Modulus with Shearing Strain and Isotropic Confining Pressure from the Resonant Column Tests of Specimen K2-13-001

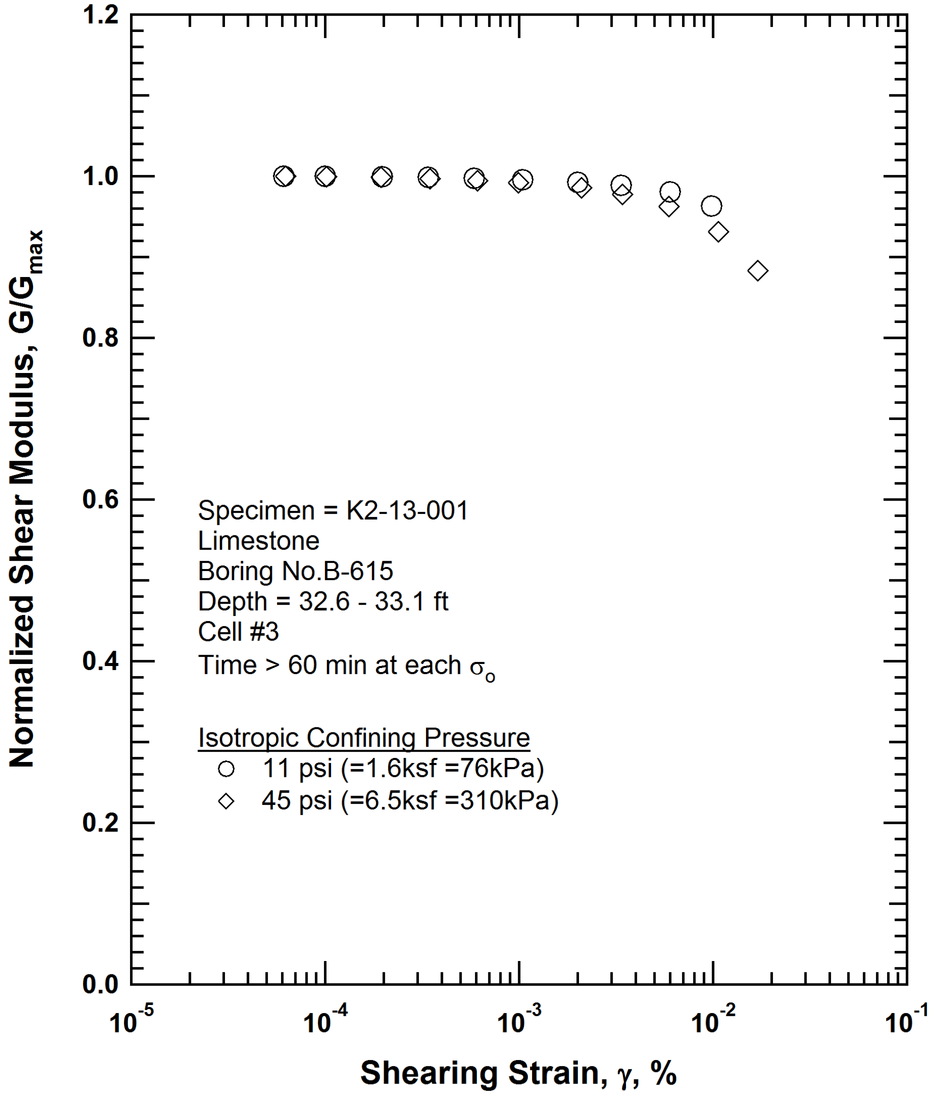


Figure B.11 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain and Isotropic Confining Pressure from the Resonant Column Tests of Specimen K2-13-001

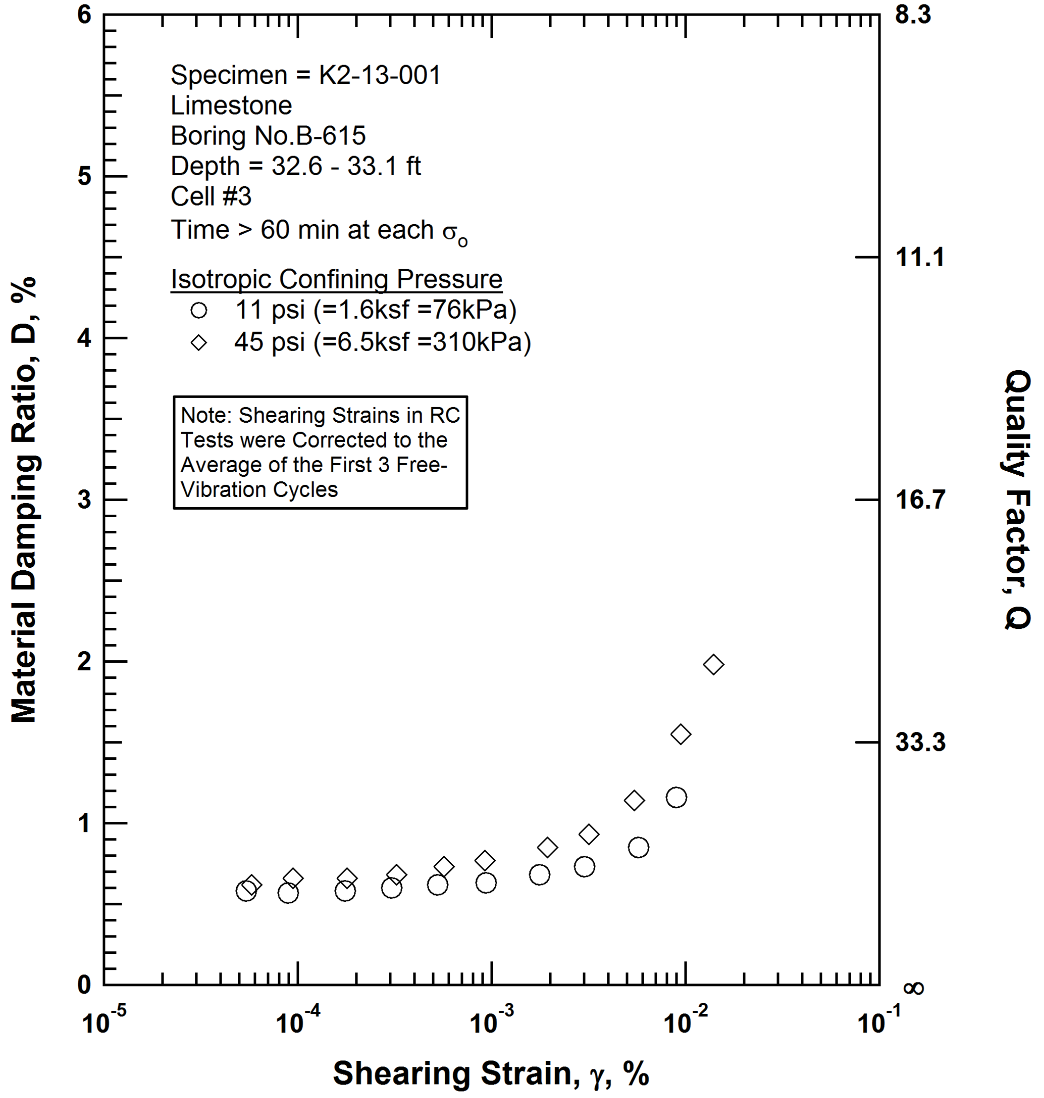
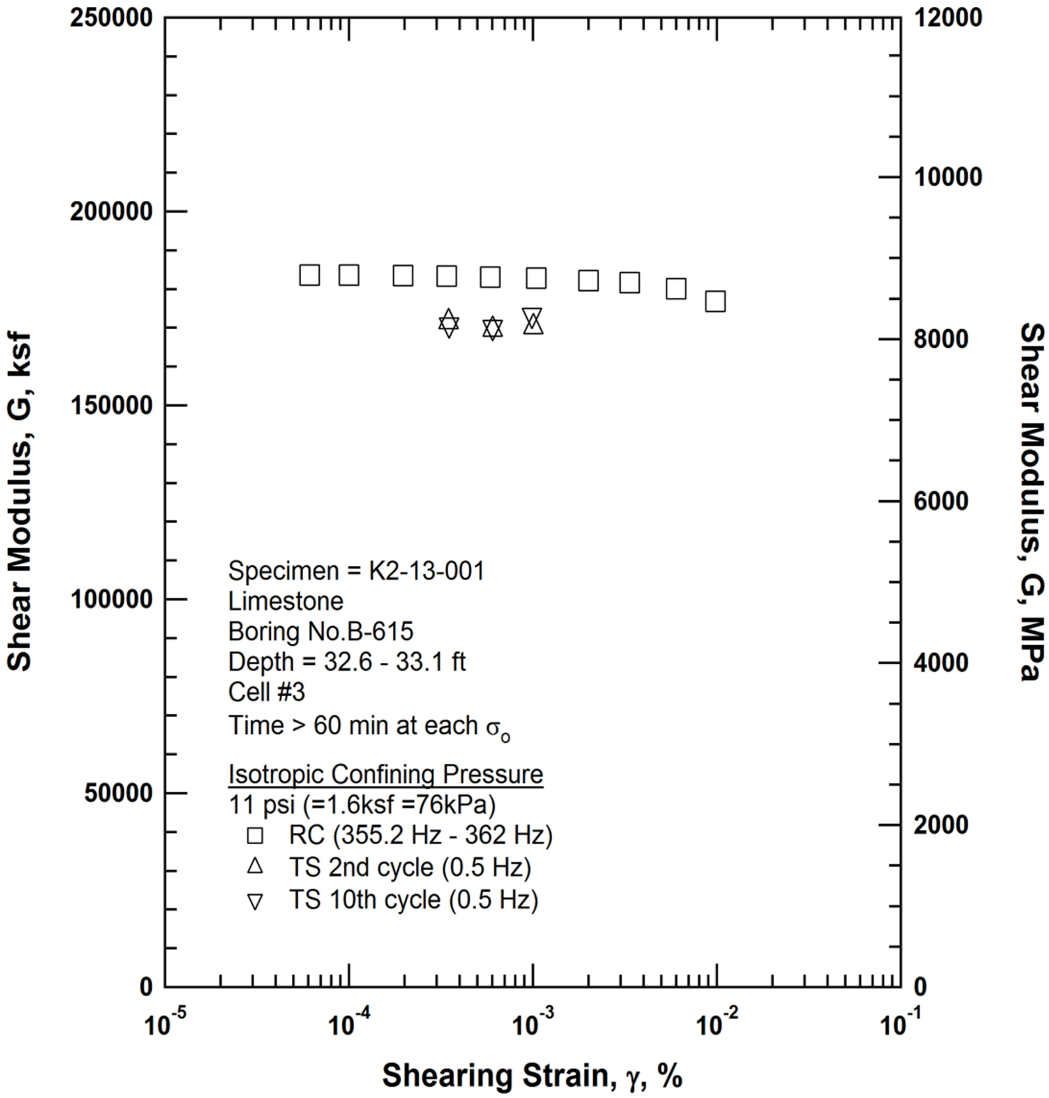


Figure B.12 Comparison of the Variation in Material Damping Ratio with Shearing Strain and Isotropic Confining Pressure from the Resonant Column Tests of Specimen K2-13-001



Note:
* Average result of first ten cycles.

Figure B.13 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 11 psi (=1.6ksf =76kPa) from the Combined RCTS Tests of Specimen K2-13-001

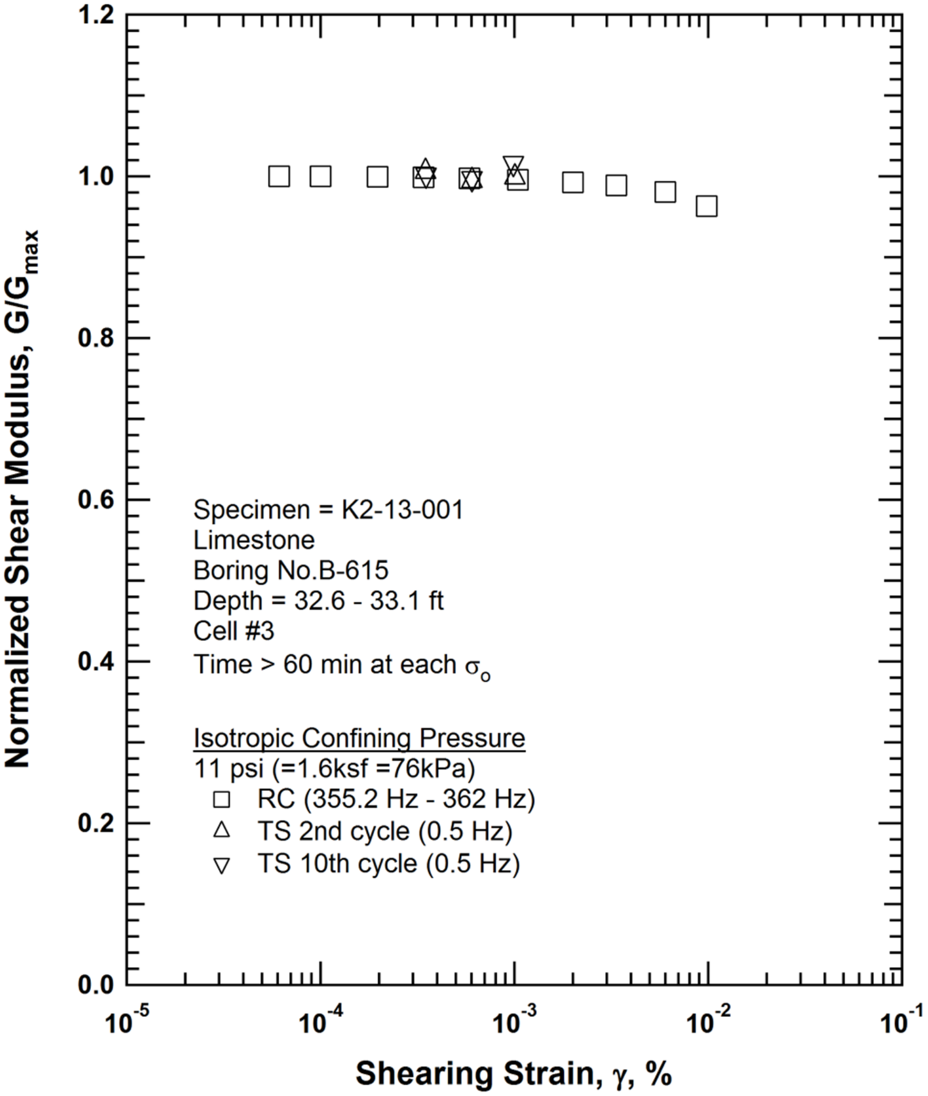
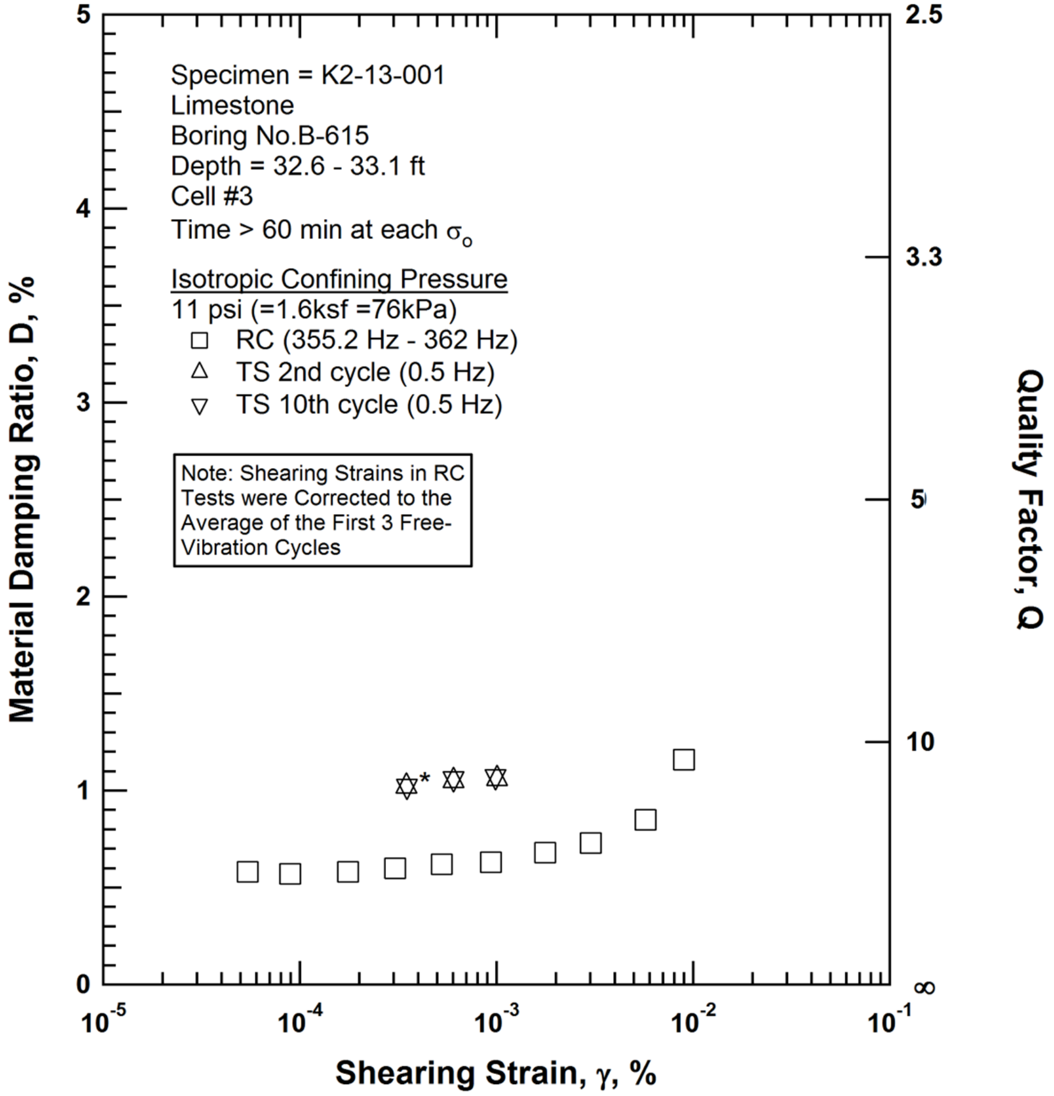


Figure B.14 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 11 psi (=1.6ksf =76kPa) from the Combined RCTS Tests of Specimen K2-13-001



Note:
* Average result of first ten cycles.

Figure B.15 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 11 psi (=1.6ksf =76kPa) from the Combined RCTS Tests of Specimen K2-13-001

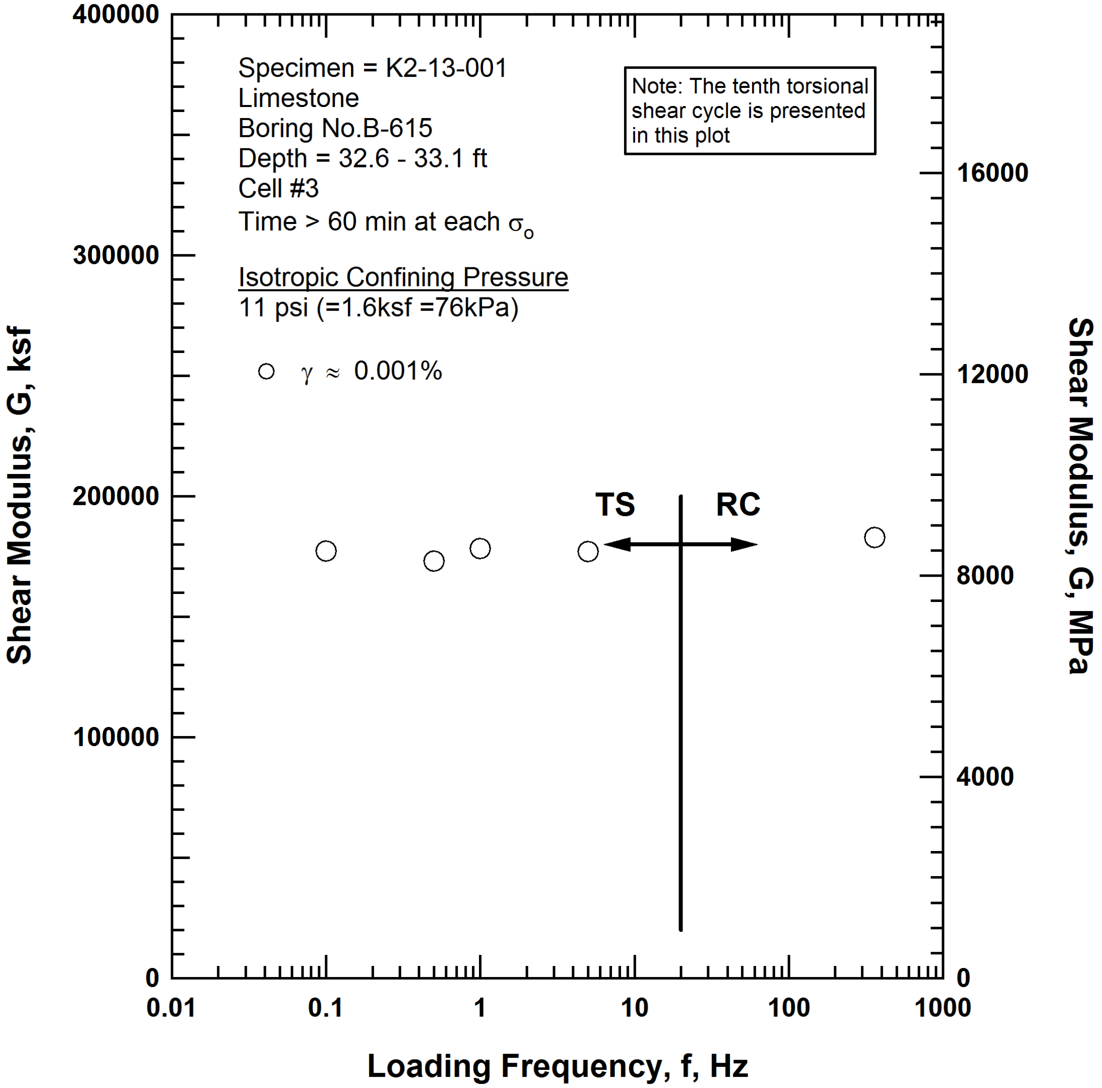


Figure B.16 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 11 psi (=1.6ksf =76kPa) from the Combined RCTS Tests of Specimen K2-13-001

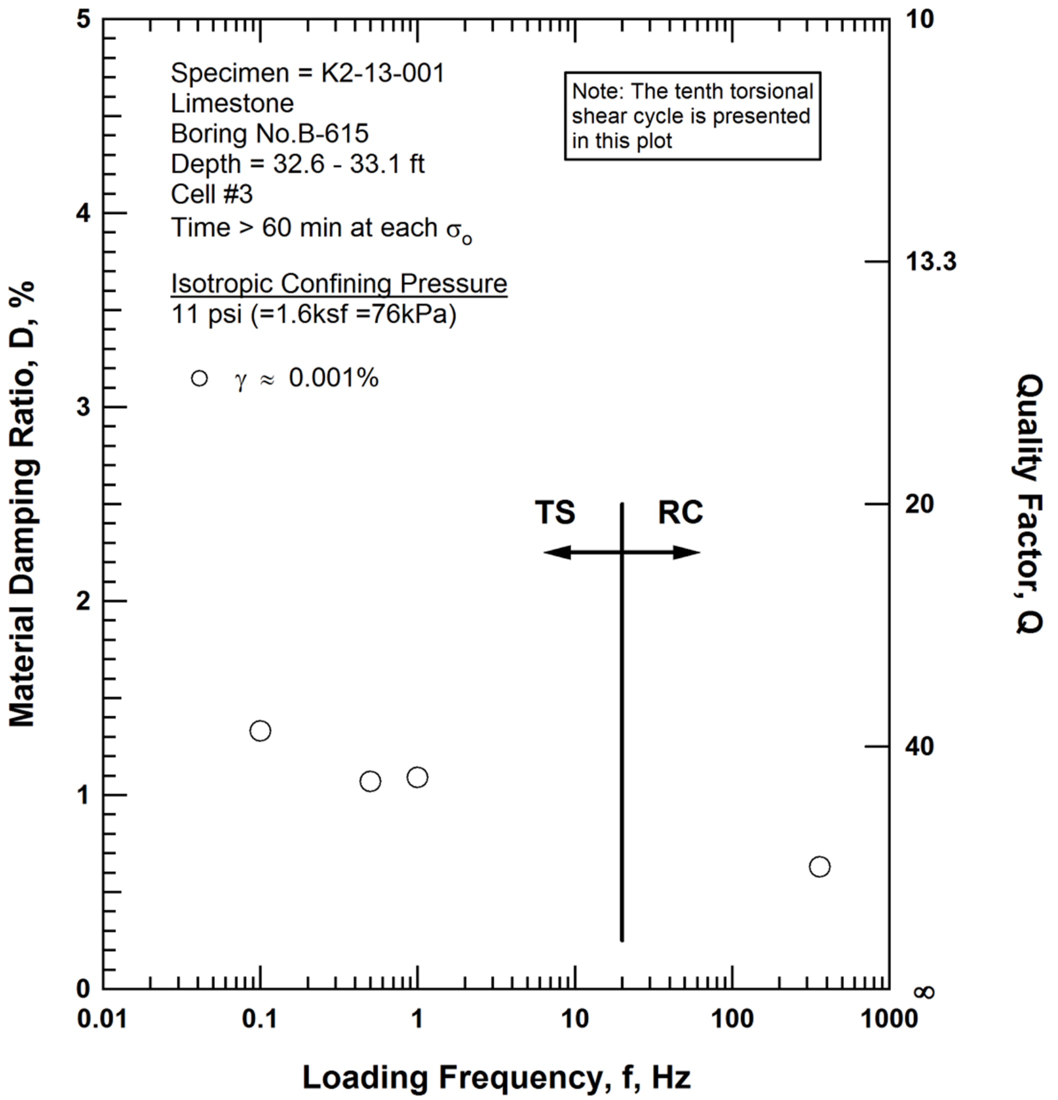


Figure B.17 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure of 11 psi (=1.6ksf =76kPa) from the Combined RCTS Tests of Specimen K2-13-001

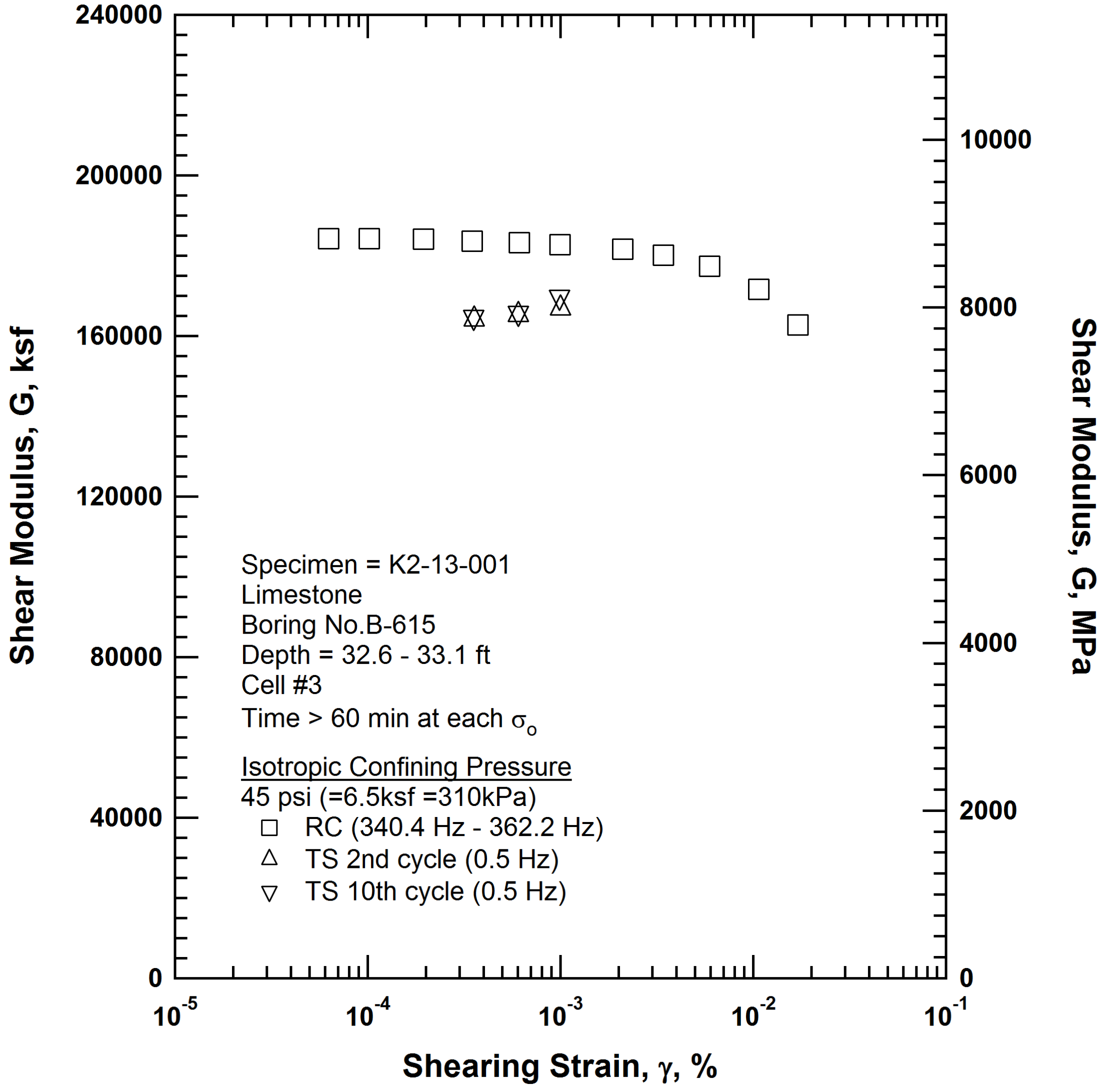


Figure B.18 Comparison of the Variation in Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 45 psi (=6.5ksf =310kPa) from the Combined RCTS Tests of Specimen K2-13-001

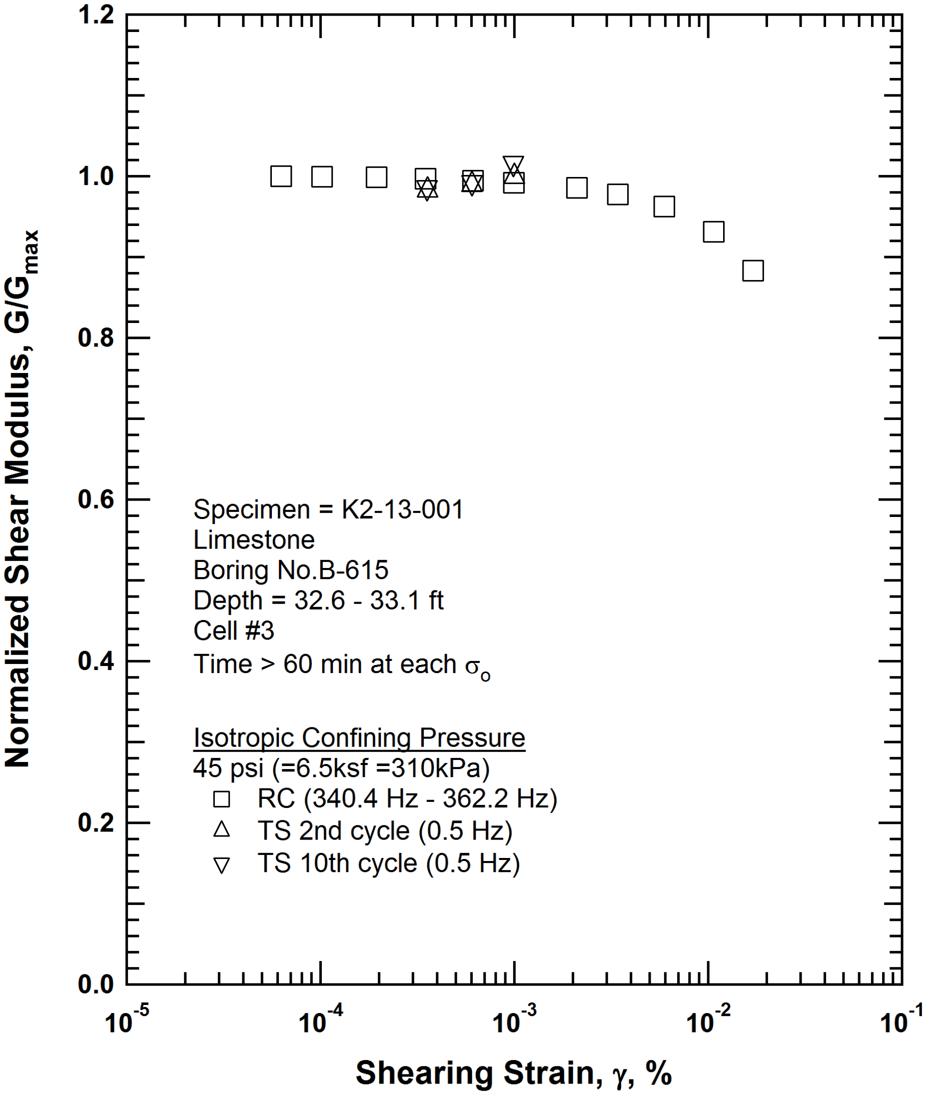


Figure B.19 Comparison of the Variation in Normalized Shear Modulus with Shearing Strain at an Isotropic Confining Pressure of 45 psi (=6.5ksf =310kPa) from the Combined RCTS Tests of Specimen K2-13-001

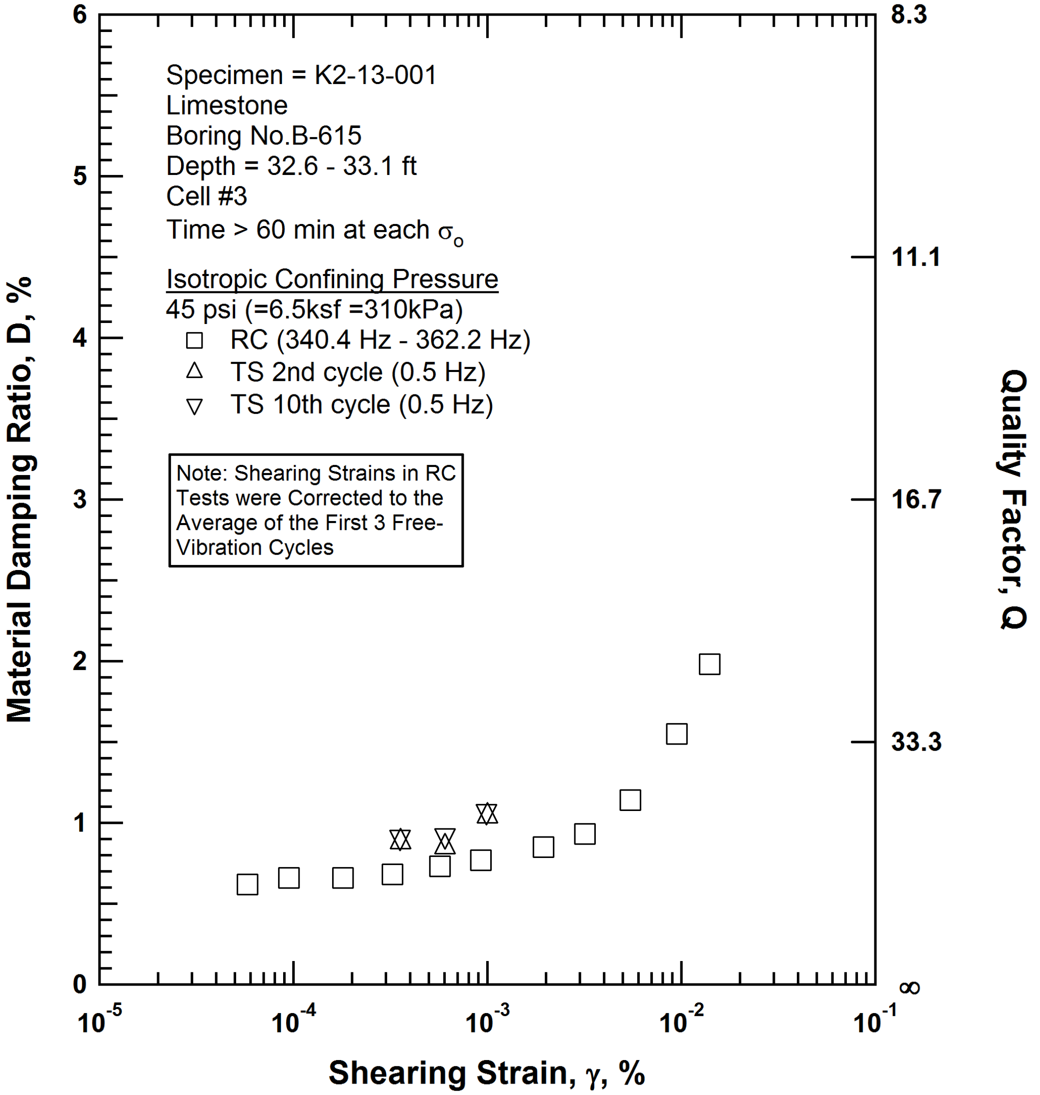


Figure B.20 Comparison of the Variation in Material Damping Ratio with Shearing Strain at an Isotropic Confining Pressure of 45 psi (=6.5ksf =310kPa) from the Combined RCTS Tests of Specimen K2-13-001

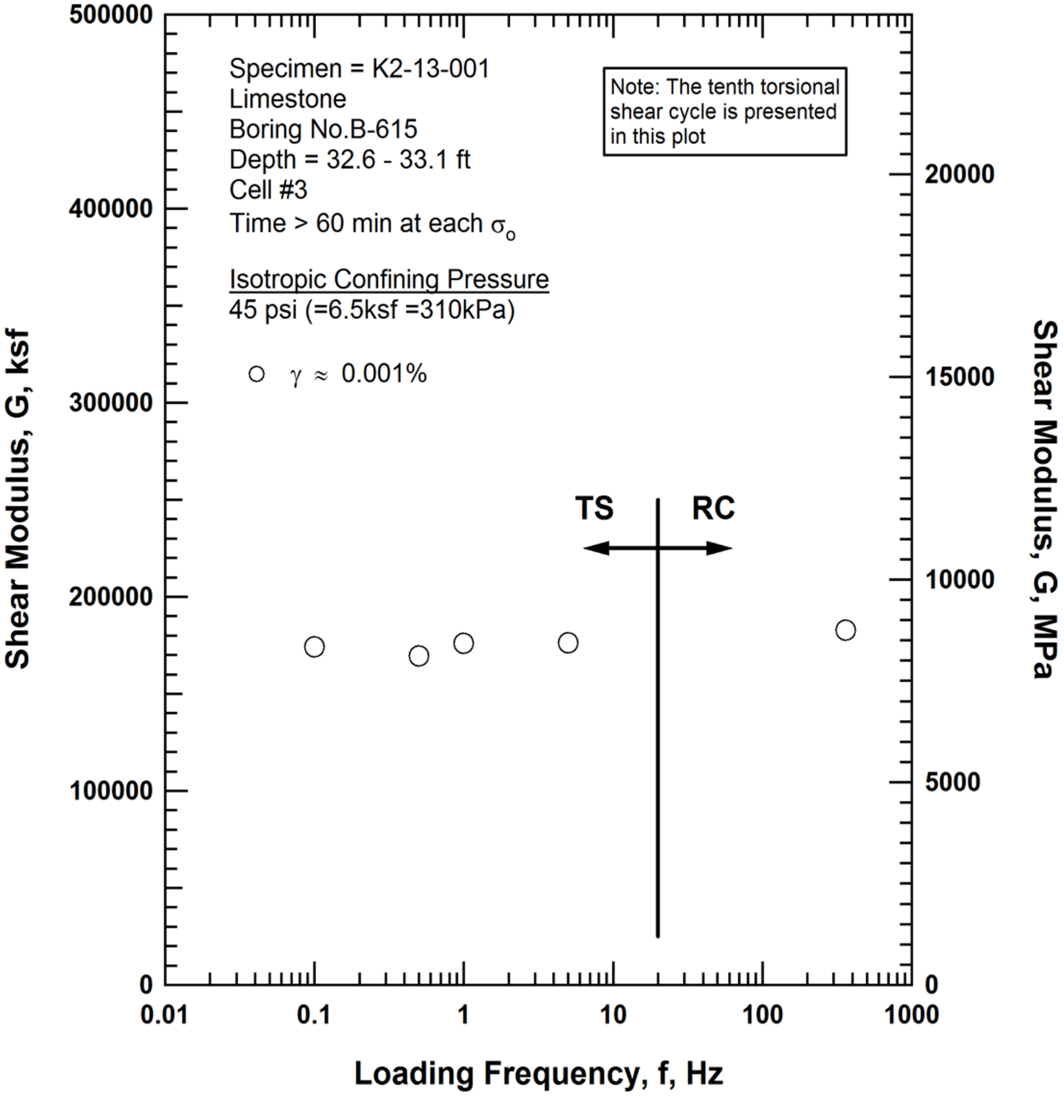


Figure B.21 Comparison of the Variation in Shear Modulus with Loading Frequency at an Isotropic Confining Pressure of 45 psi (=6.5ksf =310kPa) from the Combined RCTS Tests of Specimen K2-13-001

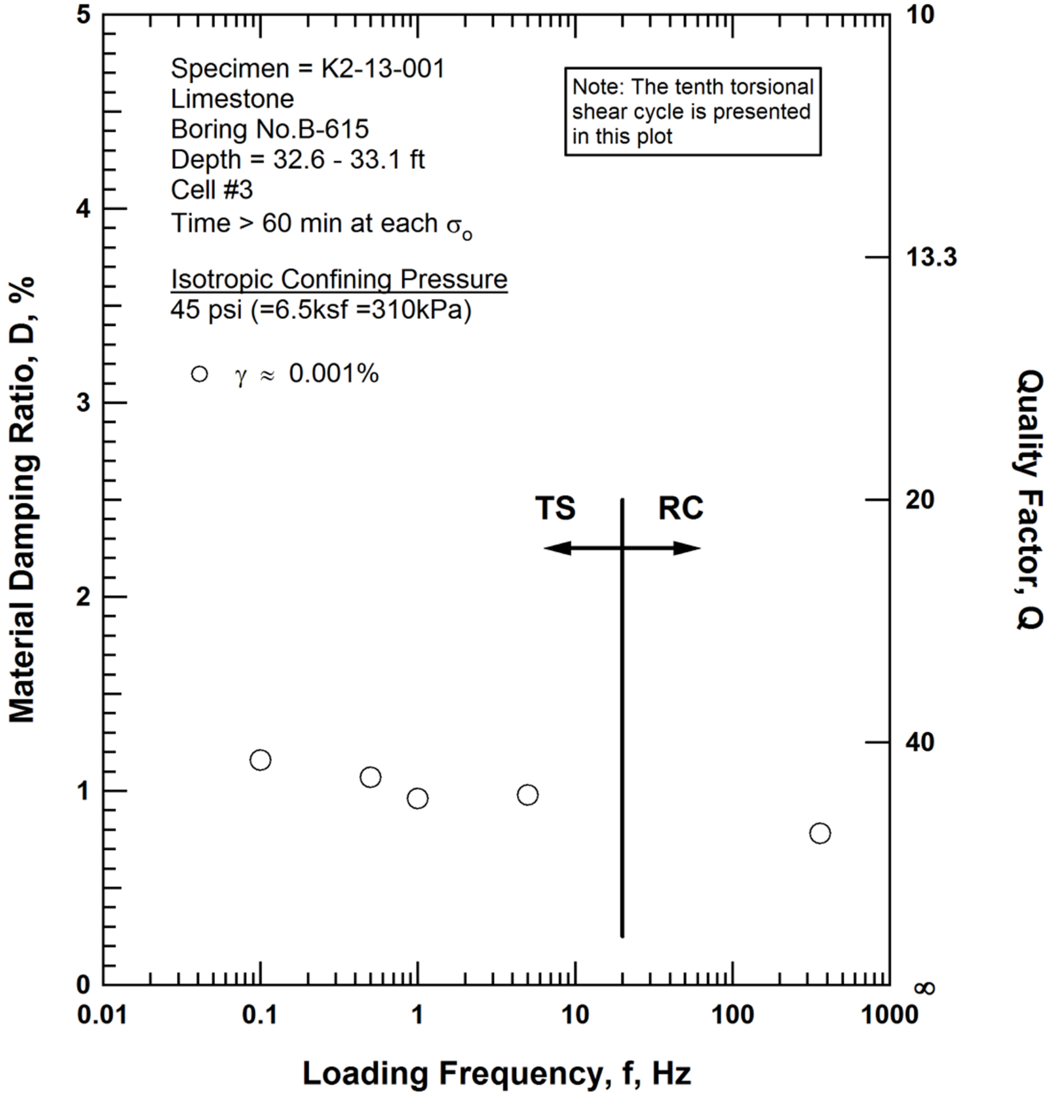


Figure B.22 Comparison of the Variation in Material Damping Ratio with Loading Frequency at an Isotropic Confining Pressure of 45 psi (=6.5ksf =310kPa) from the Combined RCTS Tests of Specimen K2-13-001

Table B.1 Variation in Low-Amplitude Shear Wave Velocity, Low-Amplitude Shear Modulus, Low-Amplitude Material Damping Ratio, Estimated Void Ratio, and Estimated Total Unit Weight with Isotropic Confining Pressure from RC Tests of Specimen K2-13-001

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	Estimated Total Unit Weight, γ_t
(psi)	(psf)	(kPa)	(ksf)	(MPa)	(fps)	(%)	(Unitless)	(pcf)
3	432	21	180900	8662	6490	0.80	0.335	138.4
6	864	41	181500	8689	6500	0.74	0.335	138.4
11	1584	76	183200	8772	6530	0.60	0.335	138.4
23	3312	159	182800	8750	6520	0.73	0.334	138.4
45	6480	310	183700	8795	6530	0.70	0.332	138.6

Table B.2 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen K2-13-001; Isotropic Confining Pressure σ_o = 11 psi (=1.6 ksf = 76 kPa)

Second Cycle				Tenth Cycle			
Peak Shearing Strain, γ, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, γ, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
3.48E-04(1)	171500	1.01	1.02	3.49E-04(1)	170800	1.00	1.02
6.05E-04	169500	0.99	1.05	6.04E-04	170000	1.00	1.06
1.01E-03	170200	1.00	1.06	9.88E-04	173200	1.02	1.07

(1) Damping Results were Averaged for the First Ten Cycles at this Shearing Strain

Table B.3 Variation in Shear Modulus, Normalized Shear Modulus, and Material Damping with Shearing Strain from RC Tests of Specimen K2-13-001; Isotropic Confining Pressure σ_o = 11 psi (=1.6 ksf = 76 kPa)

Peak Shearing Strain, γ, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average Shearing Strain, %⁽¹⁾	Material Damping Ratio, D, %⁽²⁾
6.13E-05	183600	1.00	5.43E-05	0.58
9.97E-05	183600	1.00	8.90E-05	0.57
1.97E-04	183400	1.00	1.76E-04	0.58
3.40E-04	183300	1.00	3.04E-04	0.60
5.86E-04	183100	1.00	5.25E-04	0.62
1.05E-03	182800	1.00	9.34E-04	0.63
2.00E-03	182200	0.99	1.77E-03	0.68
3.36E-03	181600	0.99	3.01E-03	0.73
6.02E-03	180100	0.98	5.71E-03	0.85
9.84E-03	176800	0.96	8.99E-03	1.16
1.70E-02	162770	0.88	1.40E-02	1.98

(1) Average Shearing Strain from the First Three Cycle of the Free Vibration Decay Curve or from Half Power Damping for shearing strains less than 0.001%

(2) Average Damping Ratio from the First Three Cycle of the Free Vibration Decay Curve or from Half Power Damping for shearing strains less than 0.001%

Table B.4 Variation in Shear Modulus and Material Damping with Frequency from RC/TS Tests of Specimen K2-13-001; Isotropic Confining Pressure σ_o = 11 psi (=1.6 ksf = 76 kPa)

Approximate Shearing Strain, γ, %	Frequency, Hz	Shear Modulus, G, ksf	Material Damping Ratio, D, %
0.001	0.1	177400	1.33
	0.5	173200	1.07
	1.0	178400	1.09
	5.0	177000	--(1)
	361.2	182800	0.63

(1) Material Damping Ratio Results Not Obtained at 5.0 Hz

Table B.5 Variation in Shear Modulus, Normalized Shear Modulus and Material Damping Ratio with Shearing Strain from TS Tests of Specimen K2-13-001; Isotropic Confining Pressure σ_o = 45 psi (=6.5 ksf = 310 kPa)

Second Cycle				Tenth Cycle			
Peak Shearing Strain, γ, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %	Peak Shearing Strain, γ, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Material Damping Ratio, D, %
3.56E-04	164100	0.98	0.88	3.55E-04	164600	0.99	0.91
6.06E-04	165200	0.99	0.85	6.04E-04	165700	0.99	0.92
1.00E-03	166900	1.00	1.04	9.87E-04	169700	1.02	1.07

Table B.6 Variation in Shear Modulus, Normalized Shear Modulus, and Material Damping with Shearing Strain from RC Tests of Specimen K2-13-001; Isotropic Confining Pressure σ_o = 45 psi (=6.5 ksf = 310 kPa)

Peak Shearing Strain, γ, %	Shear Modulus, G, ksf	Normalized Shear Modulus, G/G_{max}	Average Shearing Strain, %(1)	Material Damping Ratio, D, %(2)
6.26E-05	184300	1.00	5.81E-05	0.62
1.02E-04	184200	1.00	9.49E-05	0.66
1.95E-04	184100	1.00	1.80E-04	0.66
3.47E-04	183700	1.00	3.24E-04	0.68
6.12E-04	183300	0.99	5.71E-04	0.73
9.92E-04	182800	0.99	9.23E-04	0.77
2.10E-03	181700	0.99	1.95E-03	0.85
3.42E-03	180200	0.98	3.19E-03	0.93
5.94E-03	177400	0.96	5.45E-03	1.14
1.07E-02	171600	0.93	9.45E-03	1.55

(1) Average Shearing Strain from the First Three Cycle of the Free Vibration Decay Curve or from Half Power Damping for shearing strains less than 0.001%

(2) Average Damping Ratio from the First Three Cycle of the Free Vibration Decay Curve or from Half Power Damping for shearing strains less than 0.001%

Table B.7 Variation in Shear Modulus and Material Damping with Frequency from RC/TS Tests of Specimen K2-13-001; Isotropic Confining Pressure σ_o = 45 psi (=6.5 ksf = 310 kPa)

Approximate Shearing Strain, γ, %	Frequency, Hz	Shear Modulus, G, ksf	Material Damping Ratio, D, %
0.001	0.1	174300	1.16
	0.5	169700	1.07
	1.0	175900	0.96
	5.0	176300	0.98
	360.7	182800	0.78