Dynamic Soil Testing of Cooper Marl: Bridging the Gap in Seismic Design Data

Sufal Biswas, P.E. – South Carolina Department of Transportation
Inthuorn Sasanakul, Ph.D., P.E. – University of South Carolina

Slide 1

IS0 I would use Garnet (Gamecock) color 😊

Sasanakul, Inthuorn, 2025-09-12T12:28:23.325

Dynamic Soil Testing of Cooper Marl: Bridging the Gap in Seismic Design Data

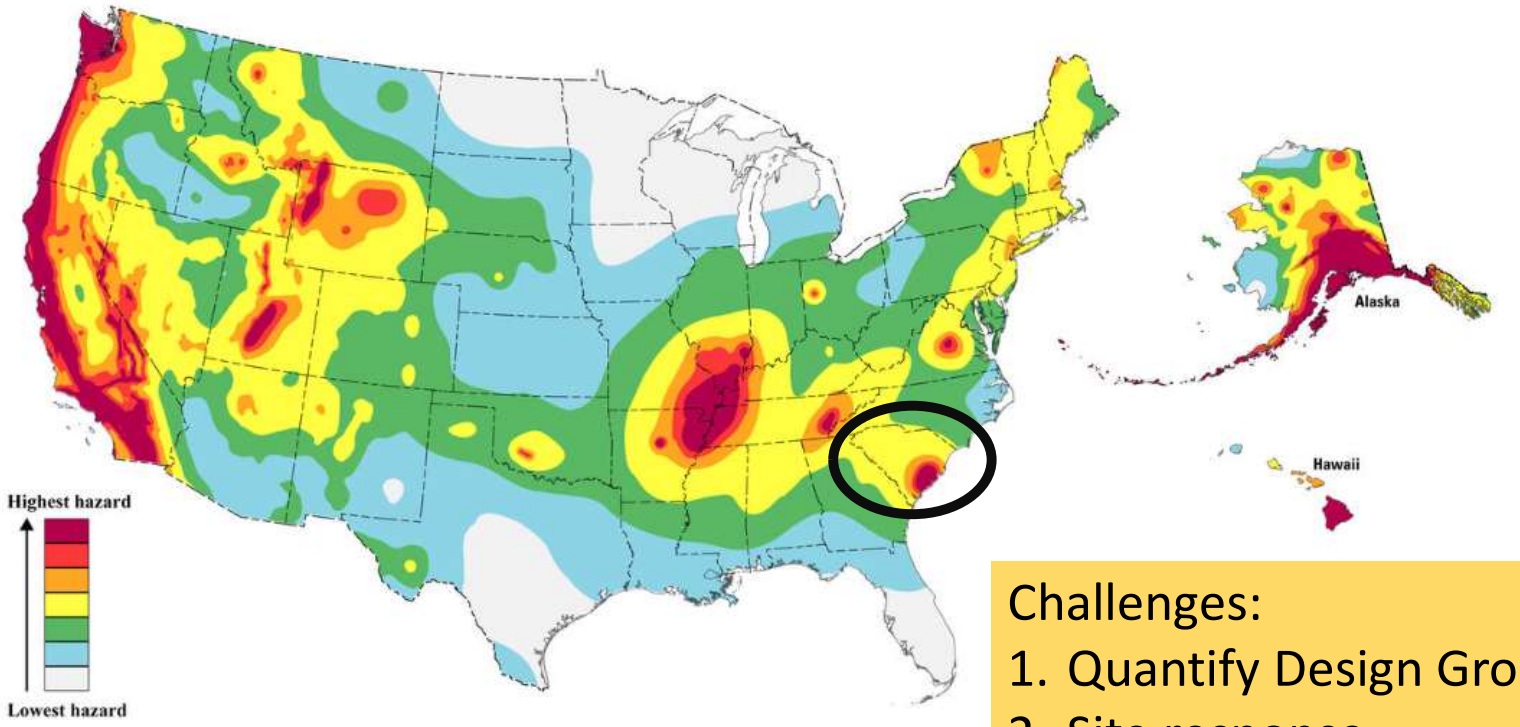
3 - Sections:

1. Background of the Problem and What is Cooper Marl
2. Currently used prediction curve and assumptions
3. Rooms for improvement and test results

Background

Hazard map from the 2023 50-state update of the National Seismic Hazard Model Project

By Communications and Publishing JANUARY 10, 2024



Challenges:

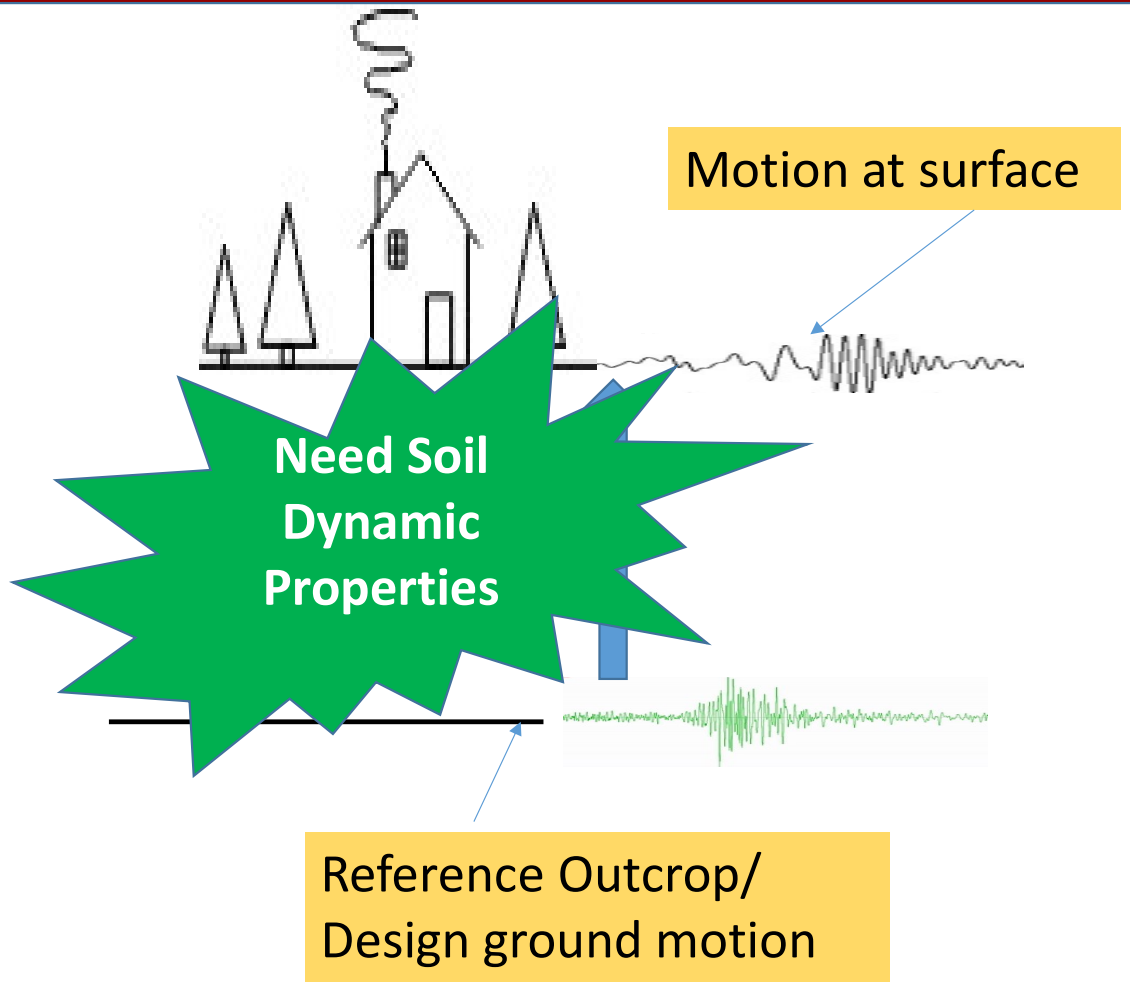
1. Quantify Design Ground Motion
2. Site response

Background

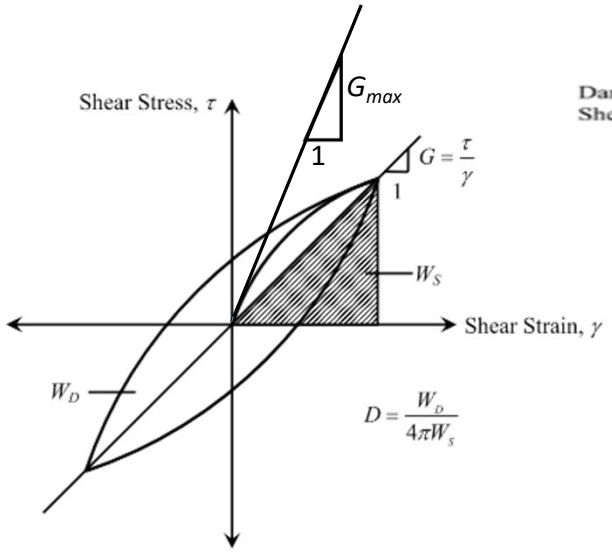
Challenges:

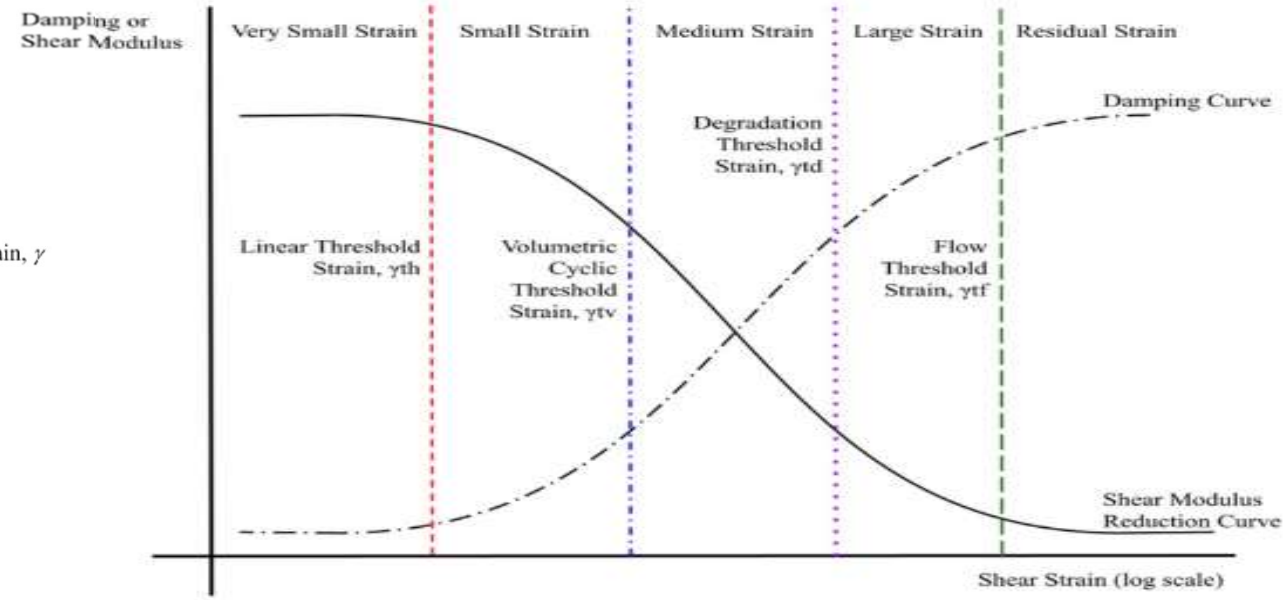
1. Quantify Design Ground Motion
   - Hazard Map
   - Seismic Analysis
   - Motion at rock outcrop or reference outcrop

2. Site response
   - Geotechnical Investigation
   - Soil Dynamic Properties (Strain Dependent)
     - ➢ Shear Wave Velocity
     - ➢ Shear Modulus
     - ➢ Damping Ratio



Soil Dynamic Properties- Shear Modulus and Damping





Ref. Jeanjaquet and Sasanakul, 2023

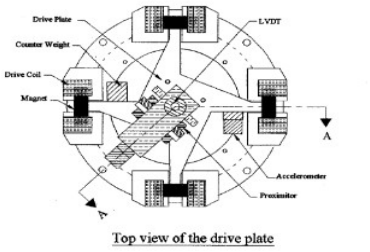
Soil Dynamic Properties- Shear Modulus and Damping

Table 1.1 Typical Strain Levels Associated with Field and Laboratory Measurements

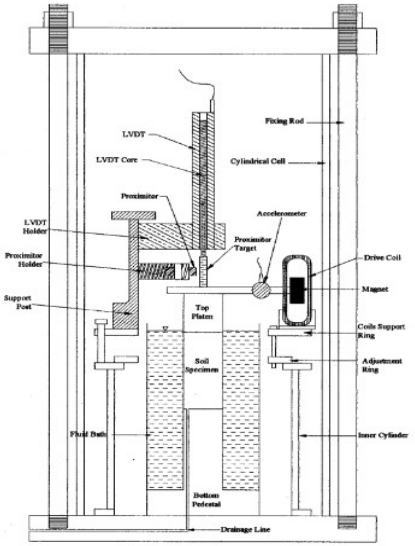
Strain Level (%)		10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10
Field Measurement	Seismic Reflection Test	←	—					
	Seismic Refraction Test	←	—					
	SASW Test	←	—					
	Seismic Crosshole Test	←	—					
	Seismic Downhole Test	←	—					
	Seismic Cone Test	←	—					
Laboratory Measurement	Resonant Column Test	—	—	—	—	—		
	Bender Element Test	←	—					
	Cyclic Triaxial Test				—	—	—	—
	Cyclic Simple Shear Test				—	—	—	—
	Cyclic Torsional Shear Test			—	—	—		

Ref. Sasanakul 2005

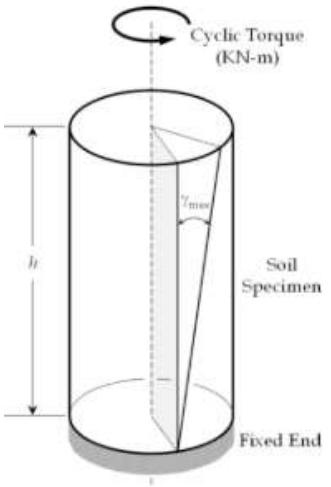
Resonant Column and Torsional Shear Test



Top view of the drive plate



Section A-A with confinement system

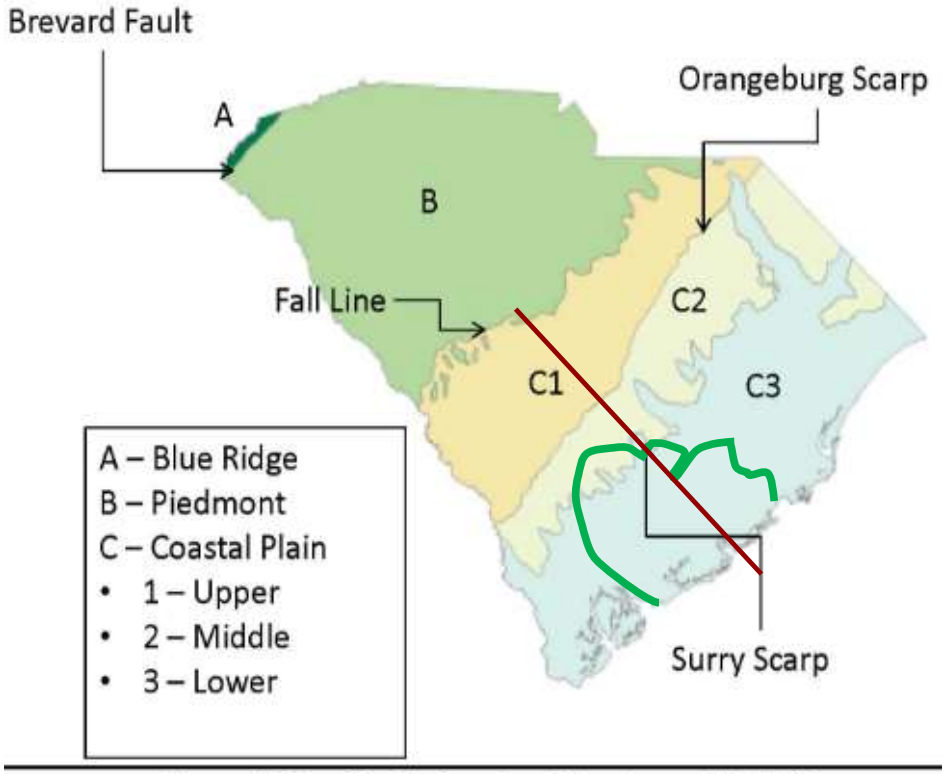


RC: Soil dynamic property = *f* (*resonance frequency*)

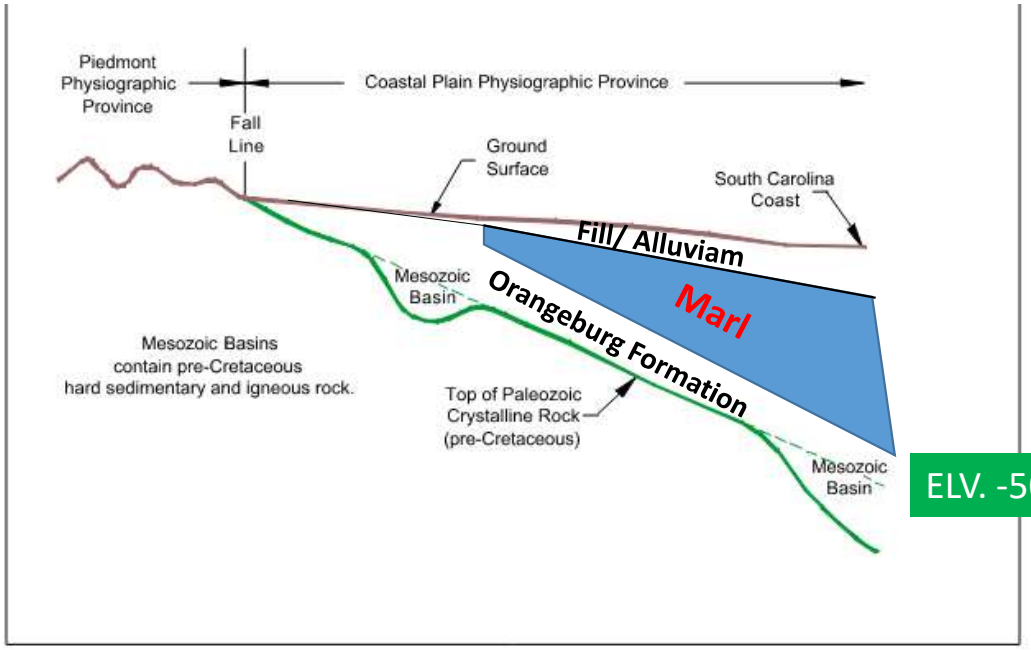
TS: Soil dynamic property = *f* (*fast cyclic stress strain behavior*)

What is Cooper Marl?

Bearing Strata at Charleston Area



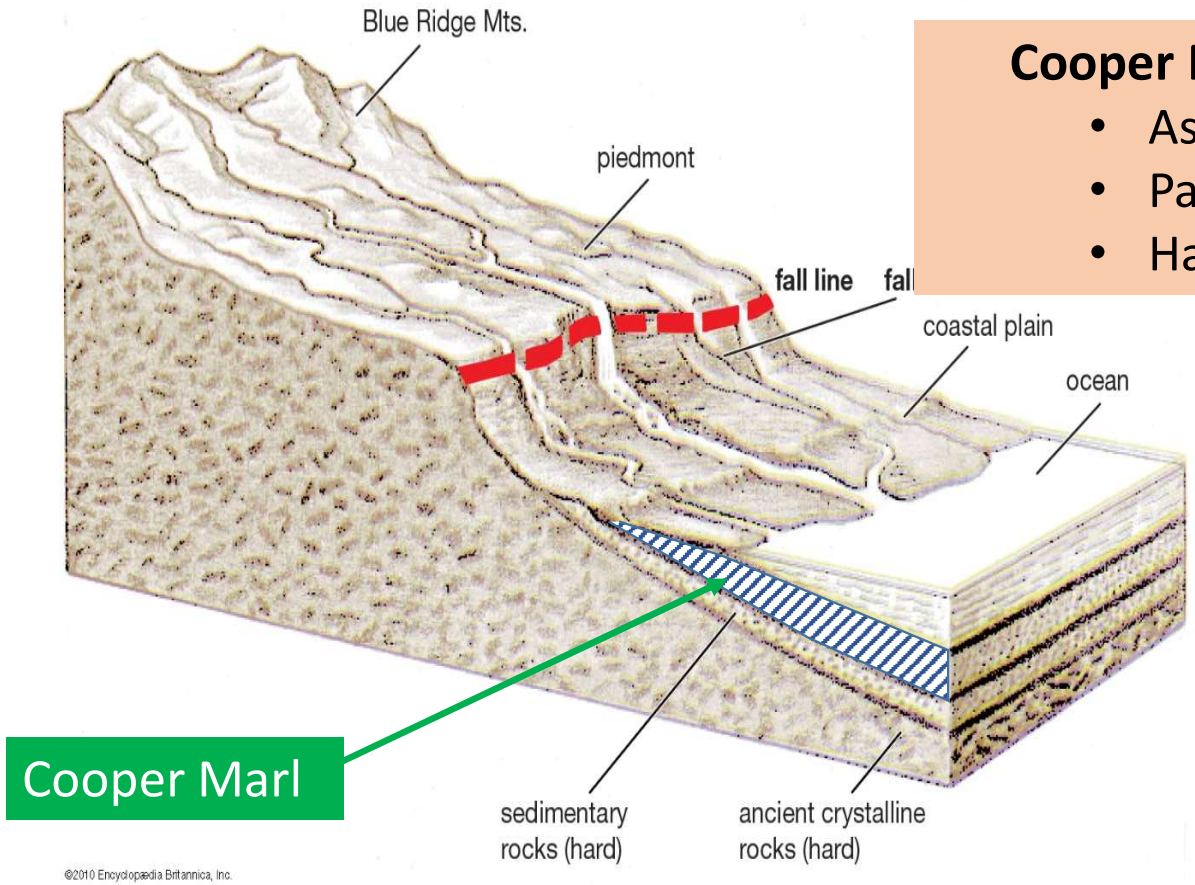
South Carolina Physiographic Units
(SCDNR (2013))



Conceptual profile of South Carolina Coastal Plain sedimentary wedge.
(South Carolina Emergency Preparedness Division, 2001)

What is Cooper Marl?

36.6 MY to 53 MY old Soil Deposit at coastal area of SC



Cooper Marl:

- Ashley Formation (Oligocene-36.6 MYA)
- Parkers Ferry Formation (Late Eocene)
- Harleyville Formation (Eocene- 53 MYA)

Conceptual Cooper Marl Profile

Cooper Marl Seismic Design Assumption and prediction curve

Seismic Design Assumption:

- Non-liquefiable
- Treated as IGM
- Use Prediction curve for Dynamic properties based on a research work performed by Andrus, et al. (2003)

$$G/G_{max} = \frac{1}{1+\left(\frac{\gamma_c}{\gamma_{cr}}\right)^{\alpha}} \qquad \gamma_r = \gamma_{r1}\left(\sigma'_m / P_a\right)^k$$

$$\sigma'_m = \sigma'_v\left(\frac{1+2K'_0}{3}\right)$$

$$\lambda_{min} = \lambda_{min1} * \left(\frac{\sigma'_m}{P_a}\right)^{-0.5*k}$$

$$\lambda = \lambda_{min} + 12.2 * \left[\frac{1}{1+\left(\frac{\gamma_c}{\gamma_{cr}}\right)^{\alpha}}\right]^2 - 34.2 * \left[\frac{1}{1+\left(\frac{\gamma_c}{\gamma_{cr}}\right)^{\alpha}}\right] + 22.0$$

Table 7-29, Recommended Values γ_{cr1}, α, and k for SC Soils (Andrus, et al. (2003))

Geologic Age and Location of Deposits (1)	Variable	Soil Plasticity Index, PI (%)					
		0	15	30	50	100	150
Tertiary Ashley Formation (Cooper Marl)	γ_{cr1} (%)	---	---	0.030 (2)	0.049	0.096 (2)	---
	α	---	---	1.10 (2)	1.15	1.28	---
	k	---	---	0.497 (2)	0.455	0.362 (2)	---

(2) Tentative Values – Andrus et al. (2003)

Table 7-31, Recommended Value λ_{min1} (%) for SC Soils (Andrus, et al. (2003))

Geologic Age and Location of Deposits	Soil Plasticity Index, PI (%)					
	0	15	30	50	100	150
Tertiary Ashley Formation (Cooper Marl)	---	---	1.14 (1)	1.52 (1)	2.49 (1)	---

(1) Tentative Values – Andrus, et al. (2003)

Ref. SCDOT GDM 2022

Limitations of currently used parameters

Basis of Prediction Curve:

- Two samples
- PI =47 and 59
- Soil type: CH
- Two Resonant Column Test
- Not covered whole area where Cooper Marl encountered

Test Ref. Fugro-McClelland (1992)

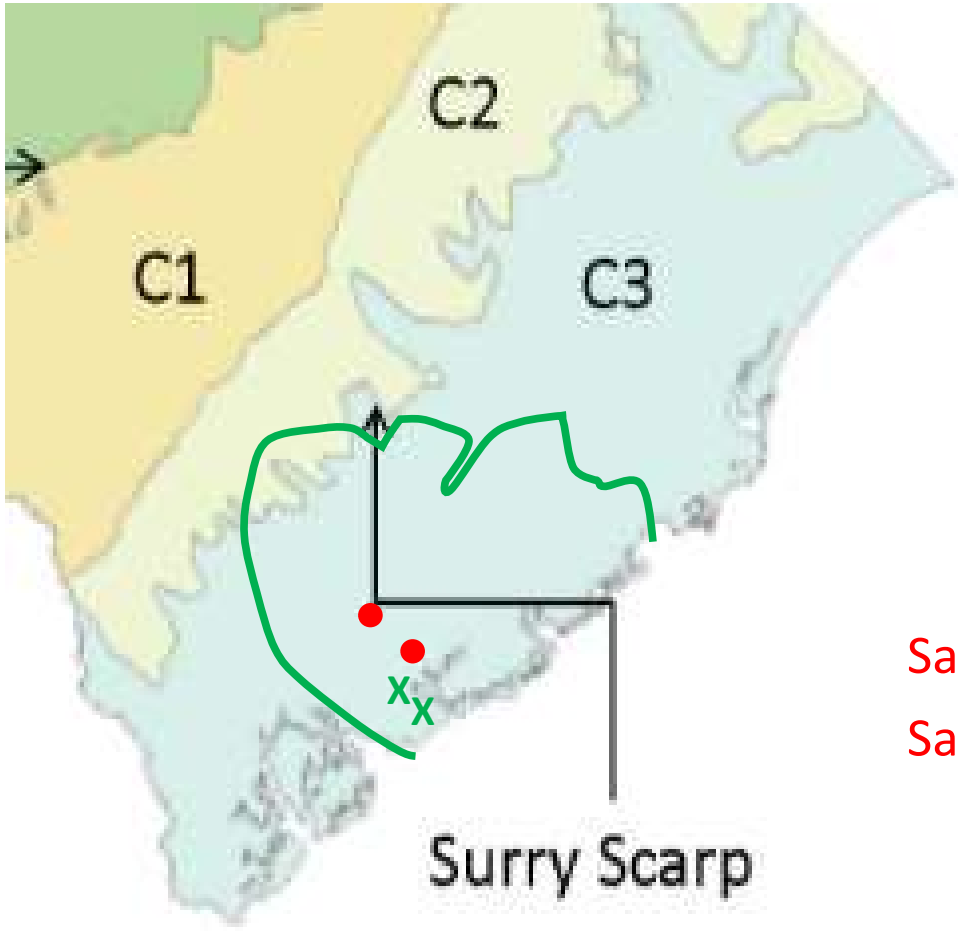
Field Condition:

- PI varies from very low to very high (10 to 70)
- Soil type: CS, CL, CH, ML, MH, SM, SC
- Carbonate Content

Newly tested Sample:

- PI = 12 and 15
- Soil type: SM
- Two RC Column Test with 3 confining pressure
- Two TS Test with 3 confining pressure

Sample Location



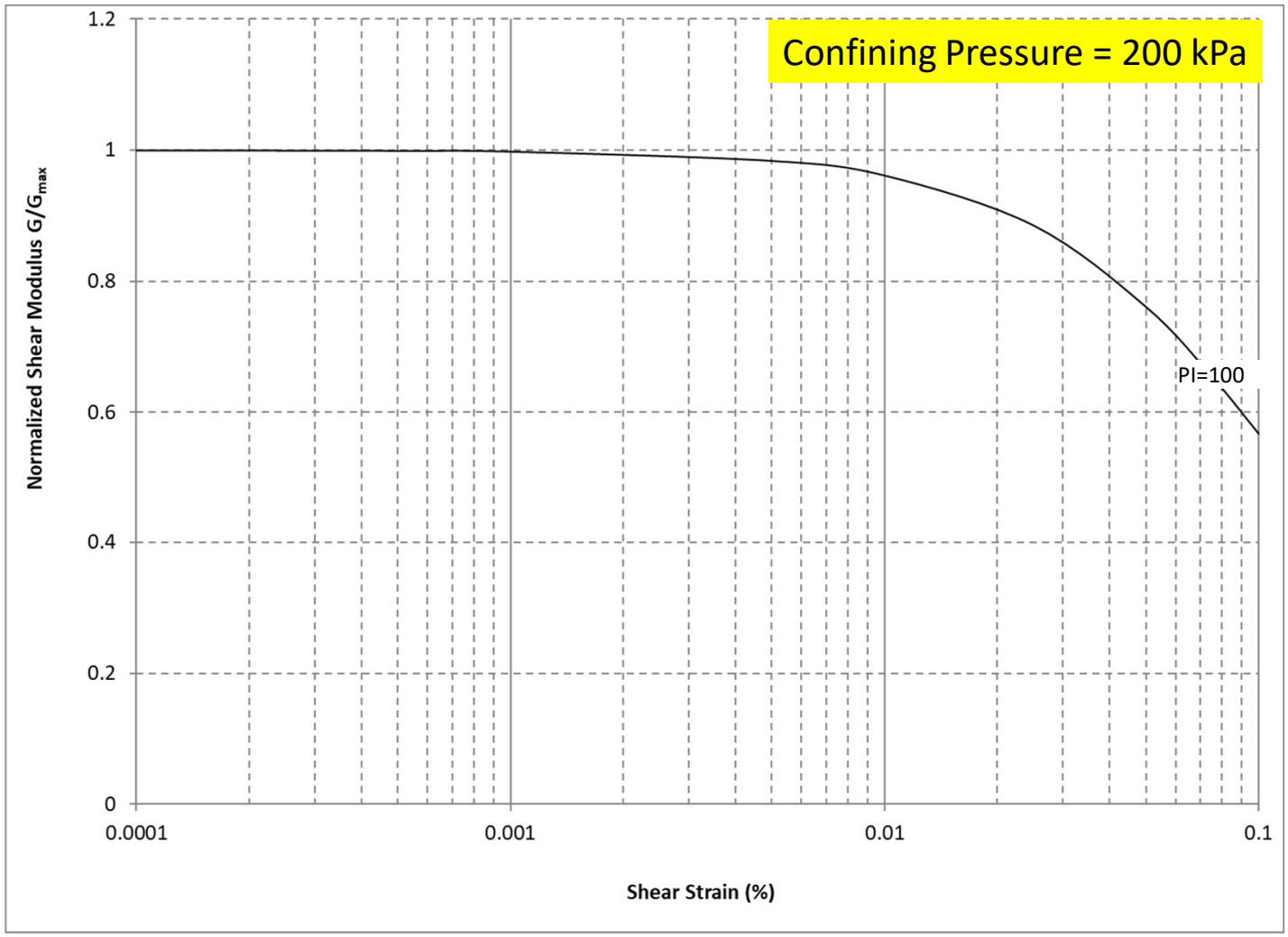
X - Previously Tested Location
Tested by Fugro-McClelland (1992)

● Currently Tested Location
Tested by USC (2024-2025)

Sample 1: Collected by USC research team

Sample 2: Courtesy by **Terracon**

Results

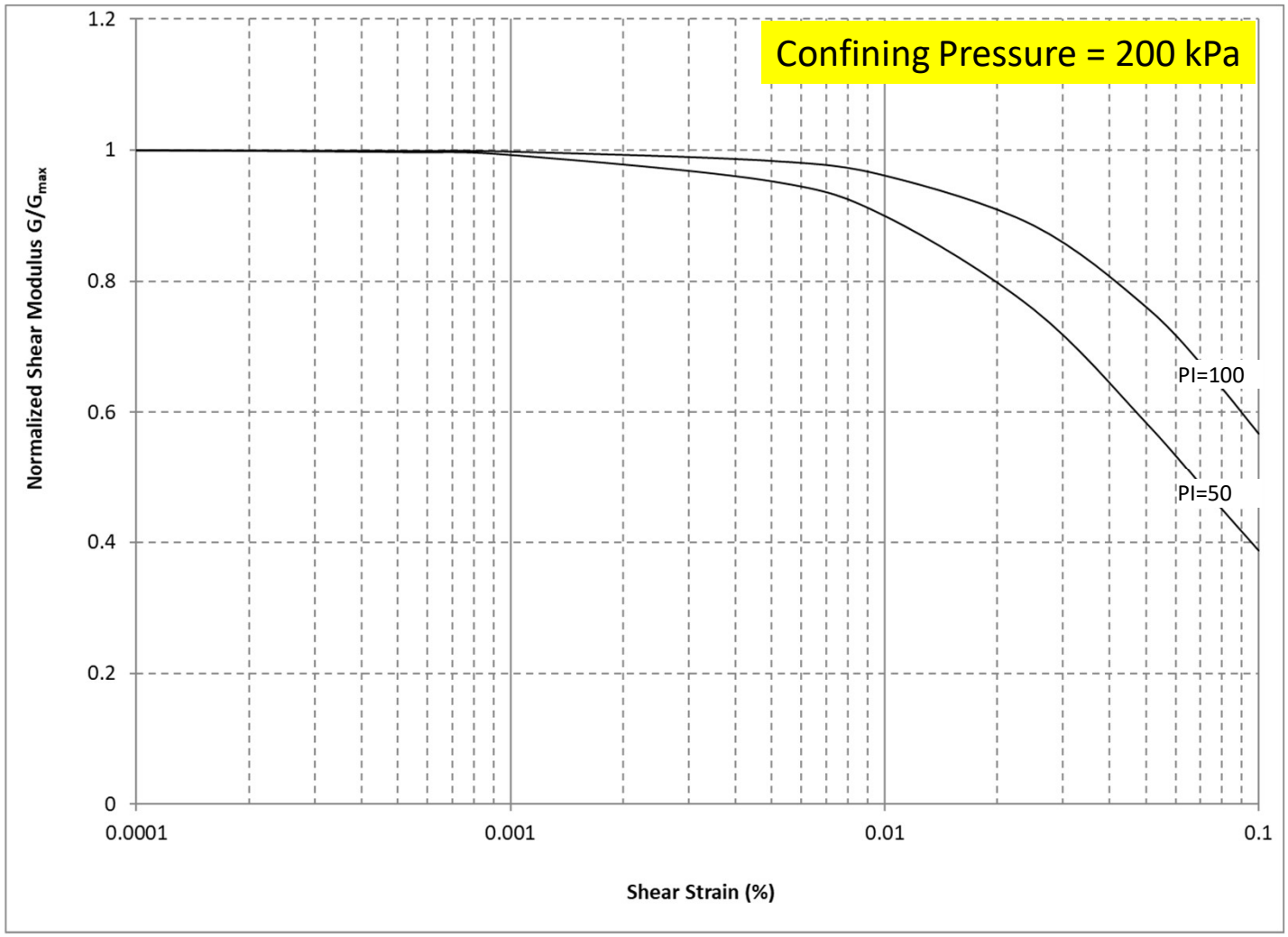


Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

Results



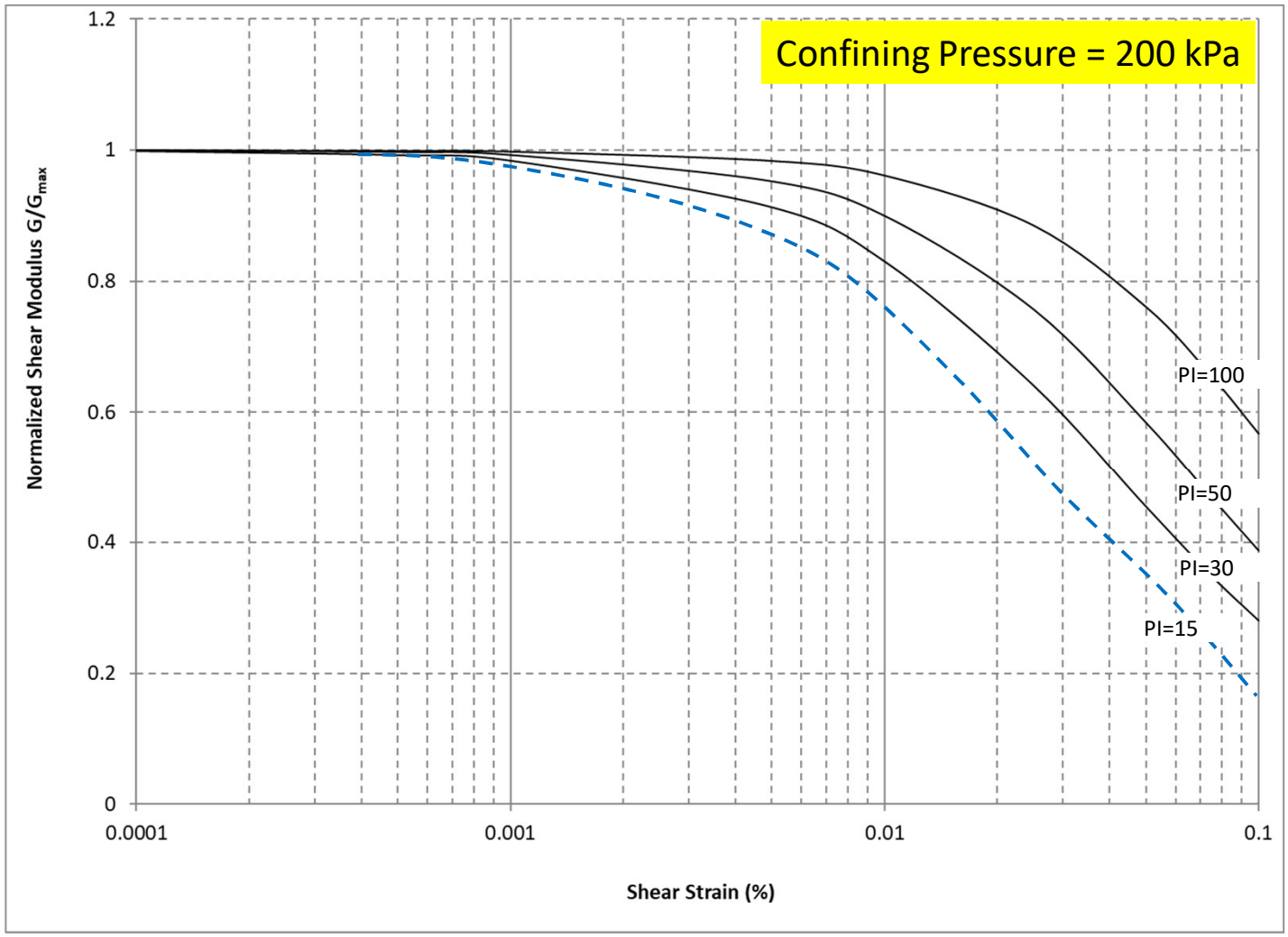
Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

PI=30 (tentative)

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

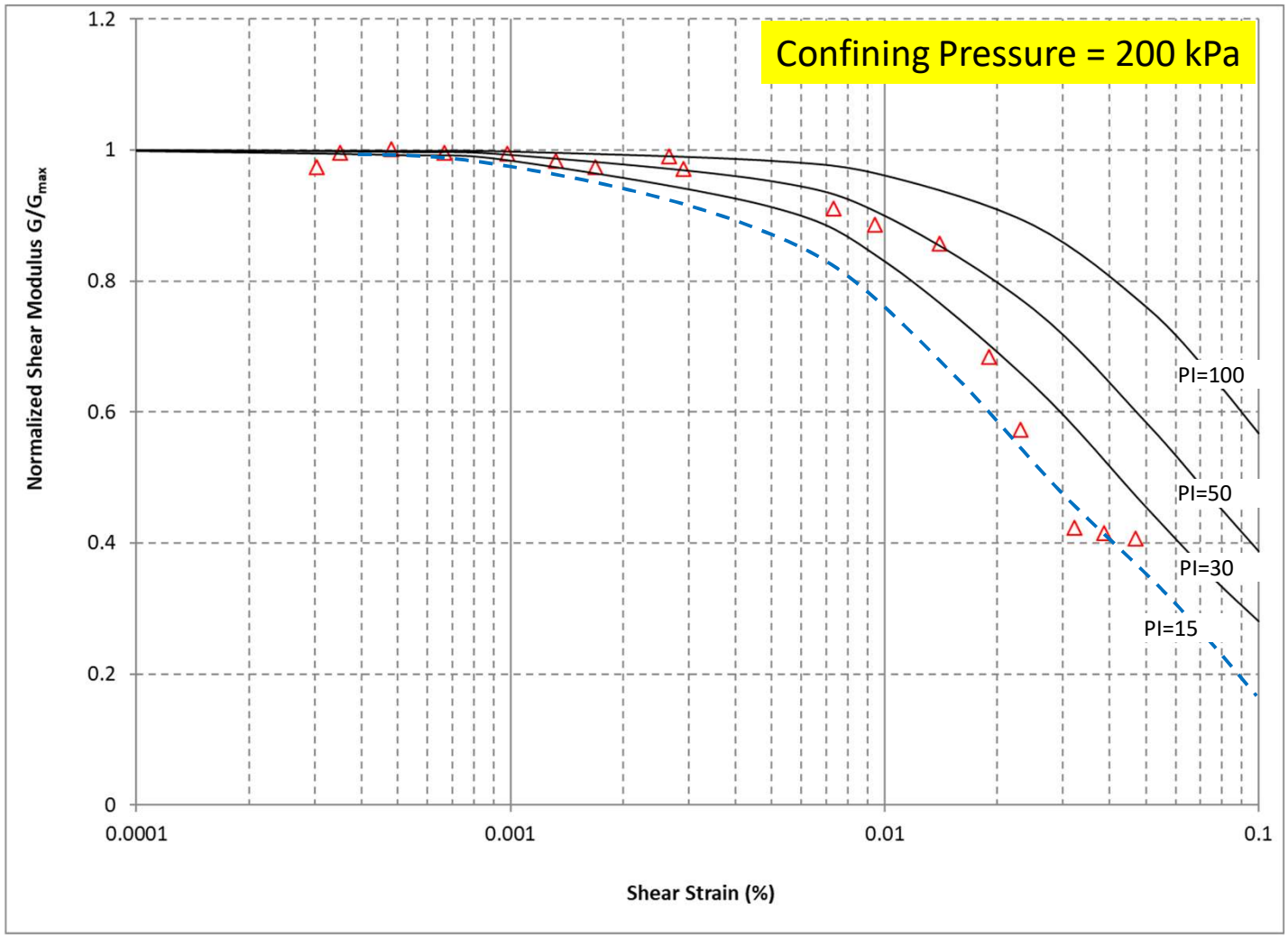
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

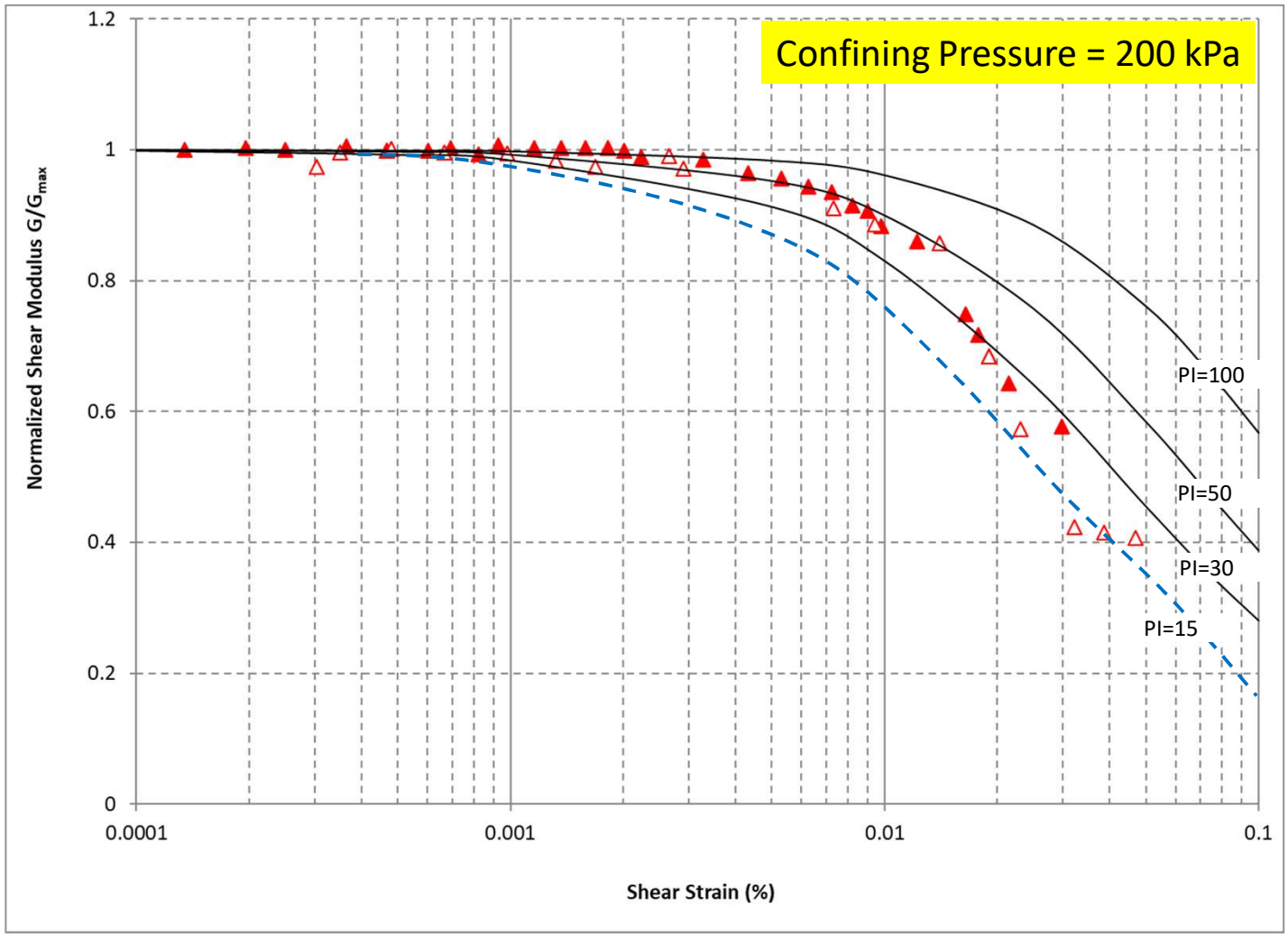
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

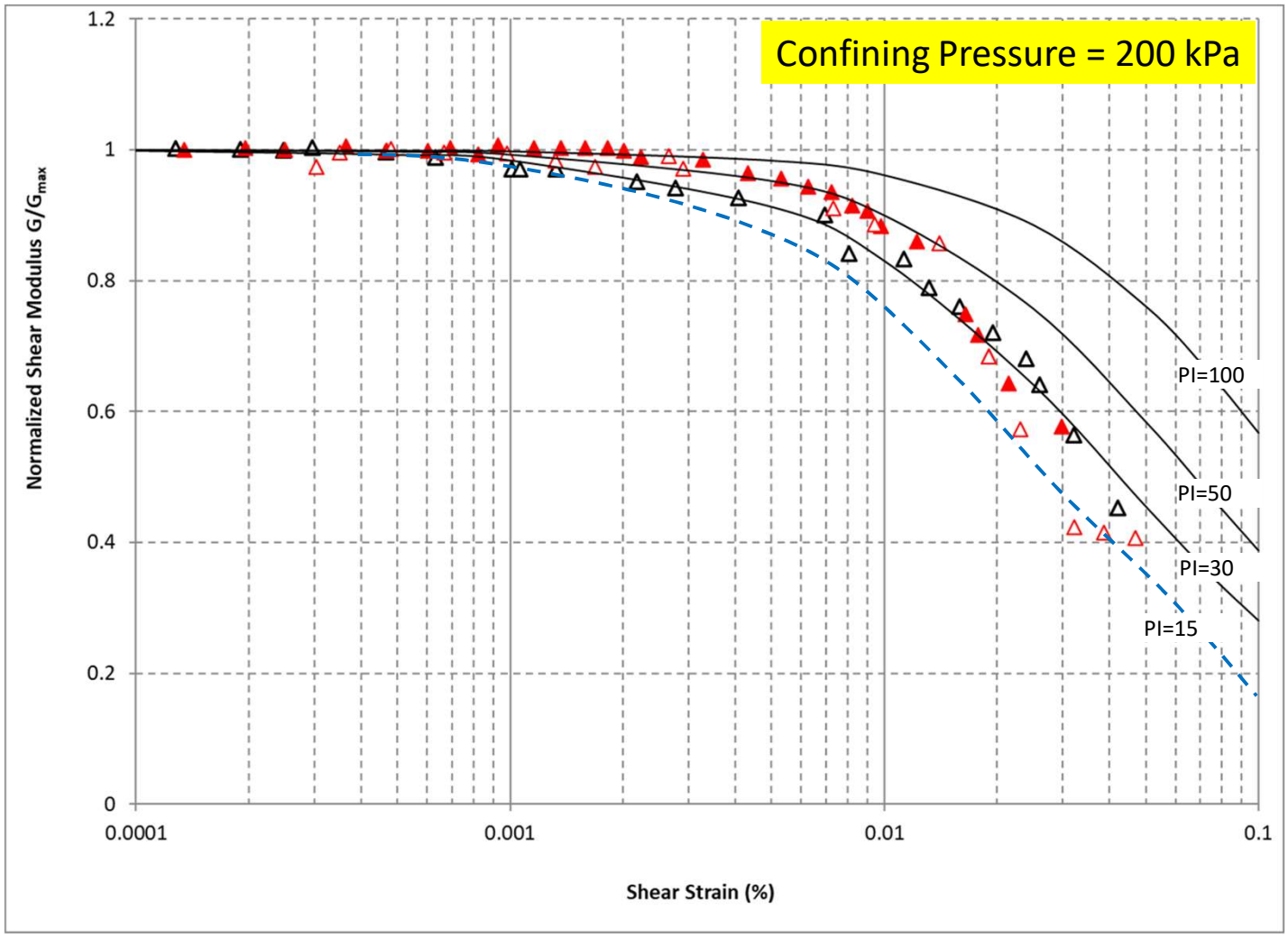
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

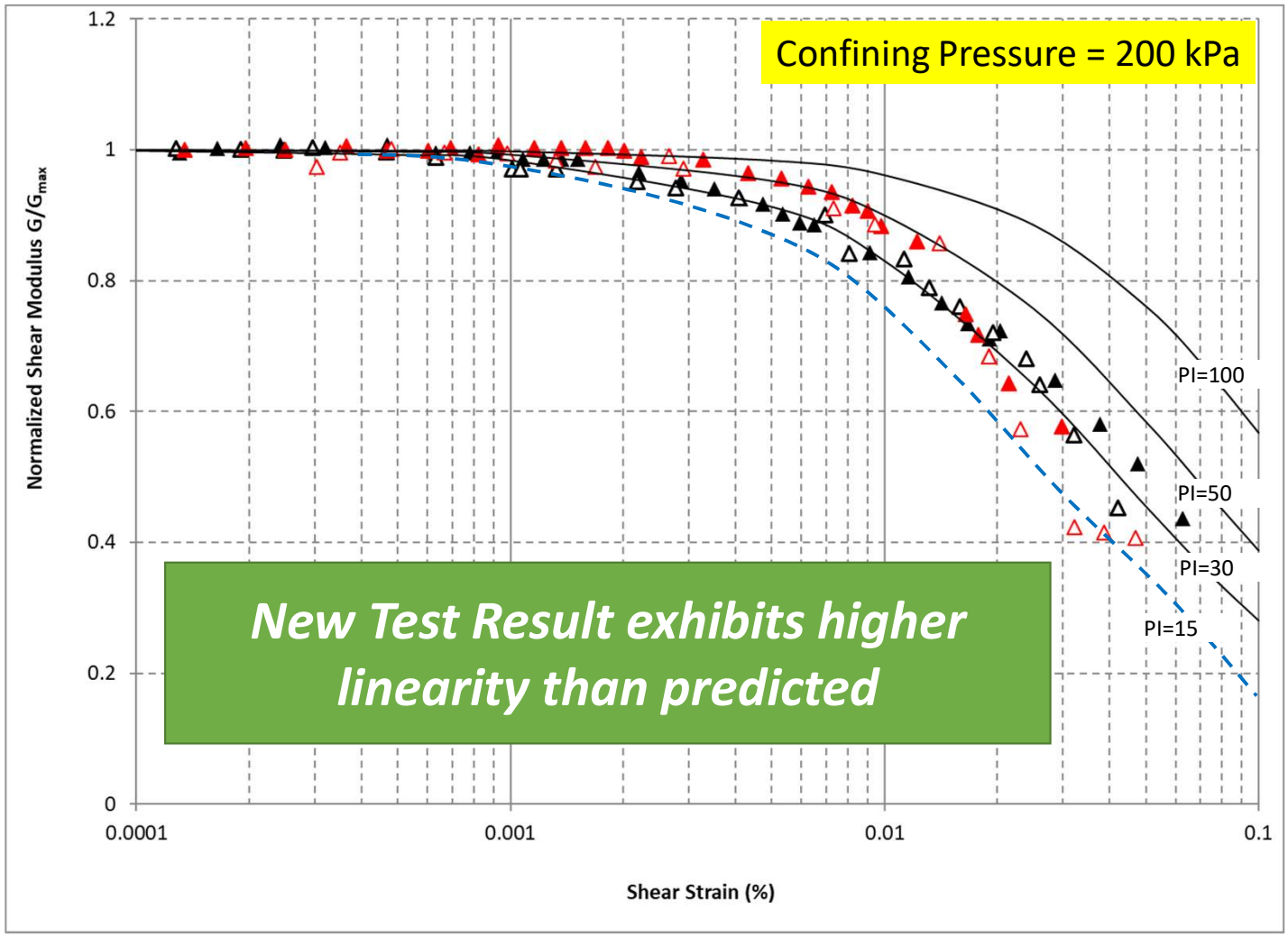
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear
- PI = 12, Resonant Column

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

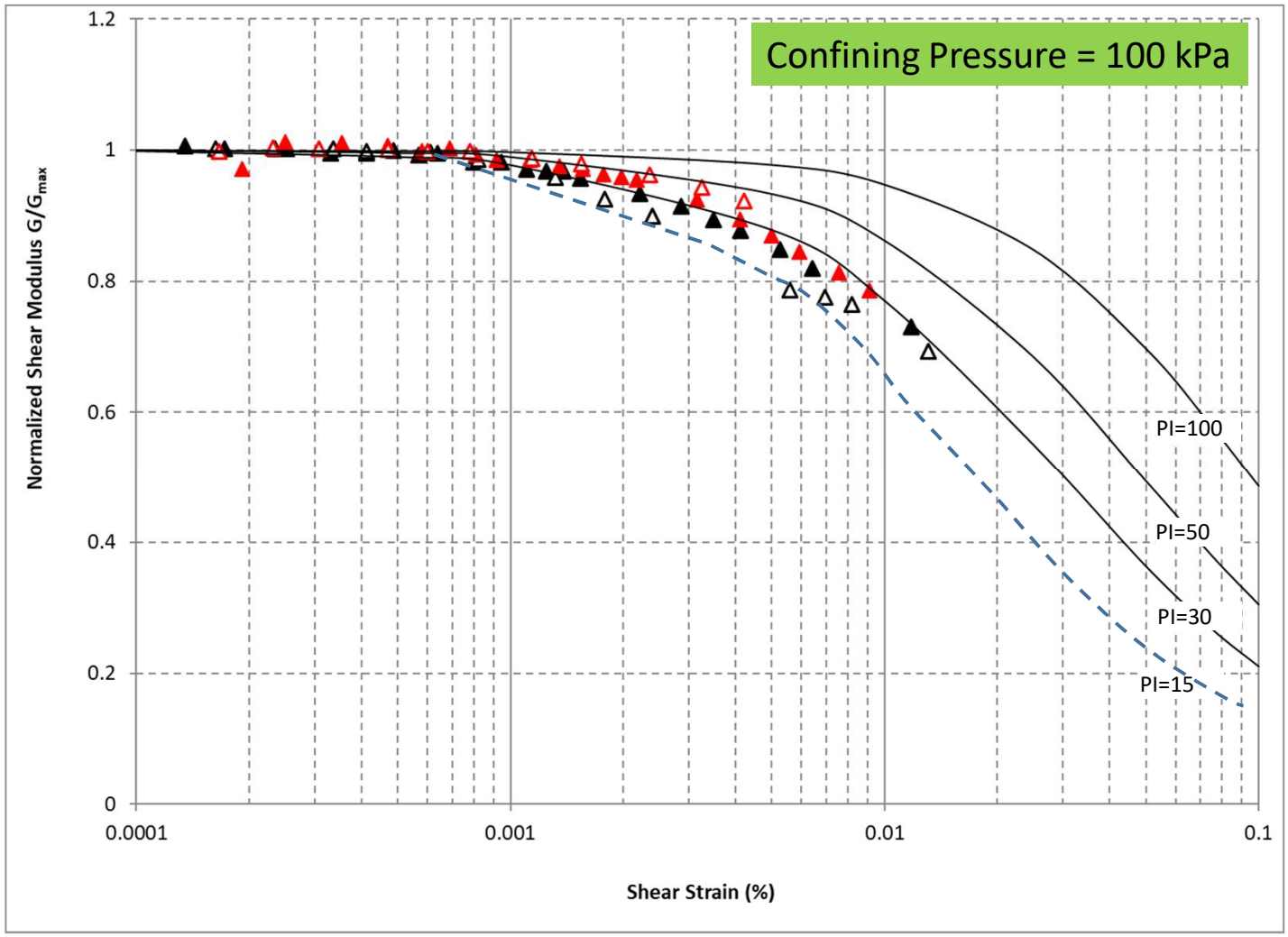
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear
- PI = 12, Resonant Column

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

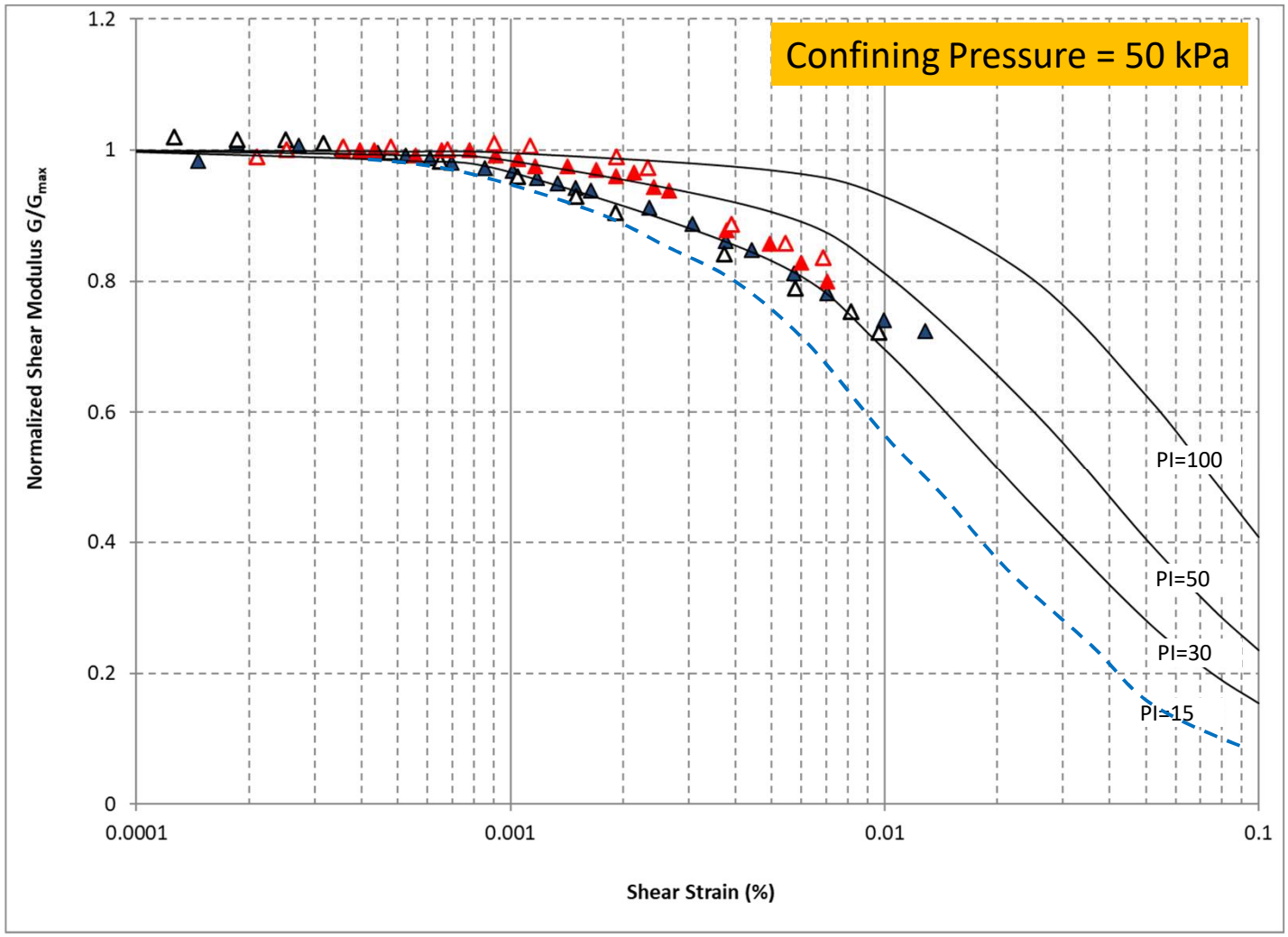
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear
- PI = 12, Resonant Column

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

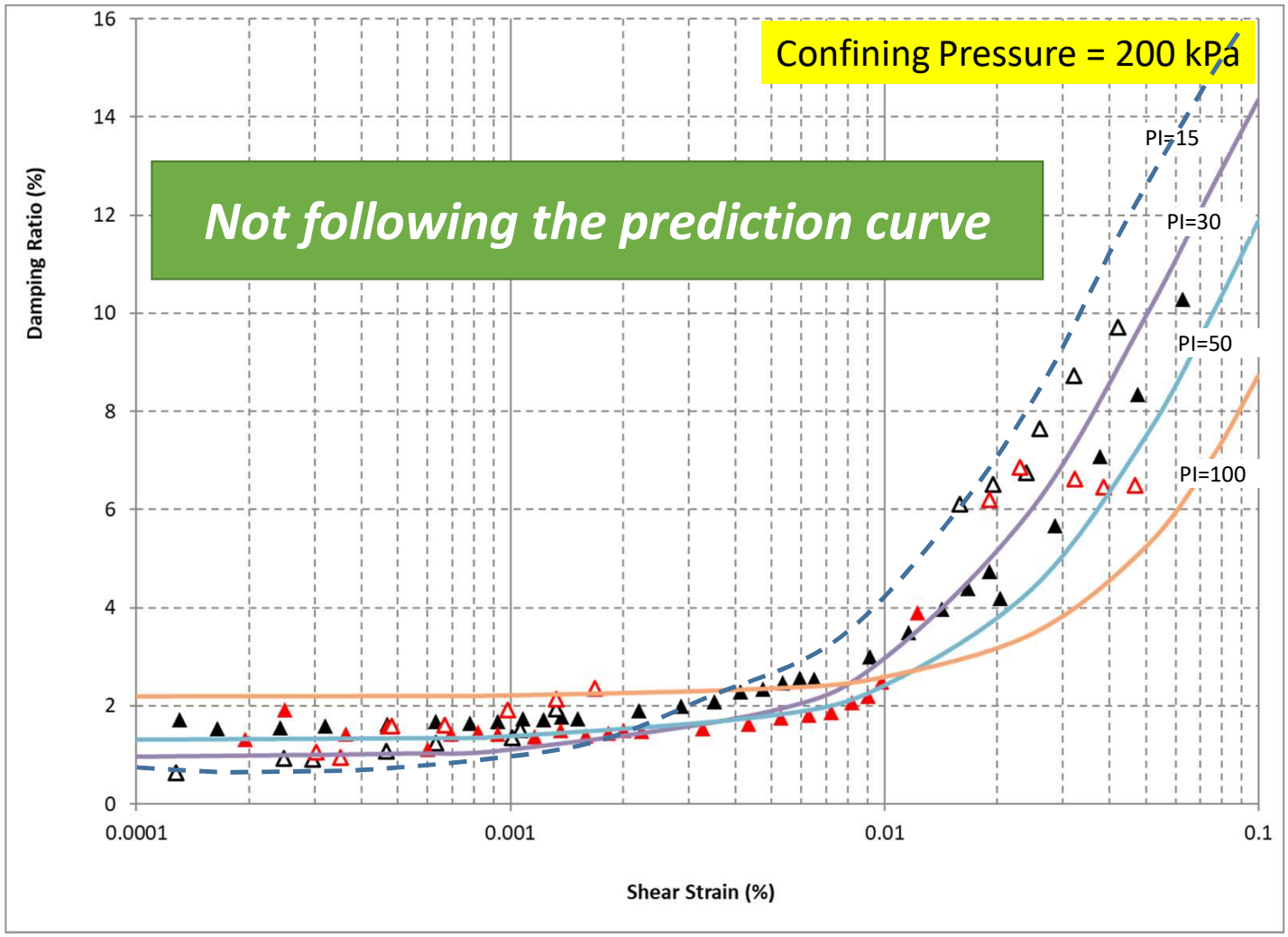
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear
- PI = 12, Resonant Column

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

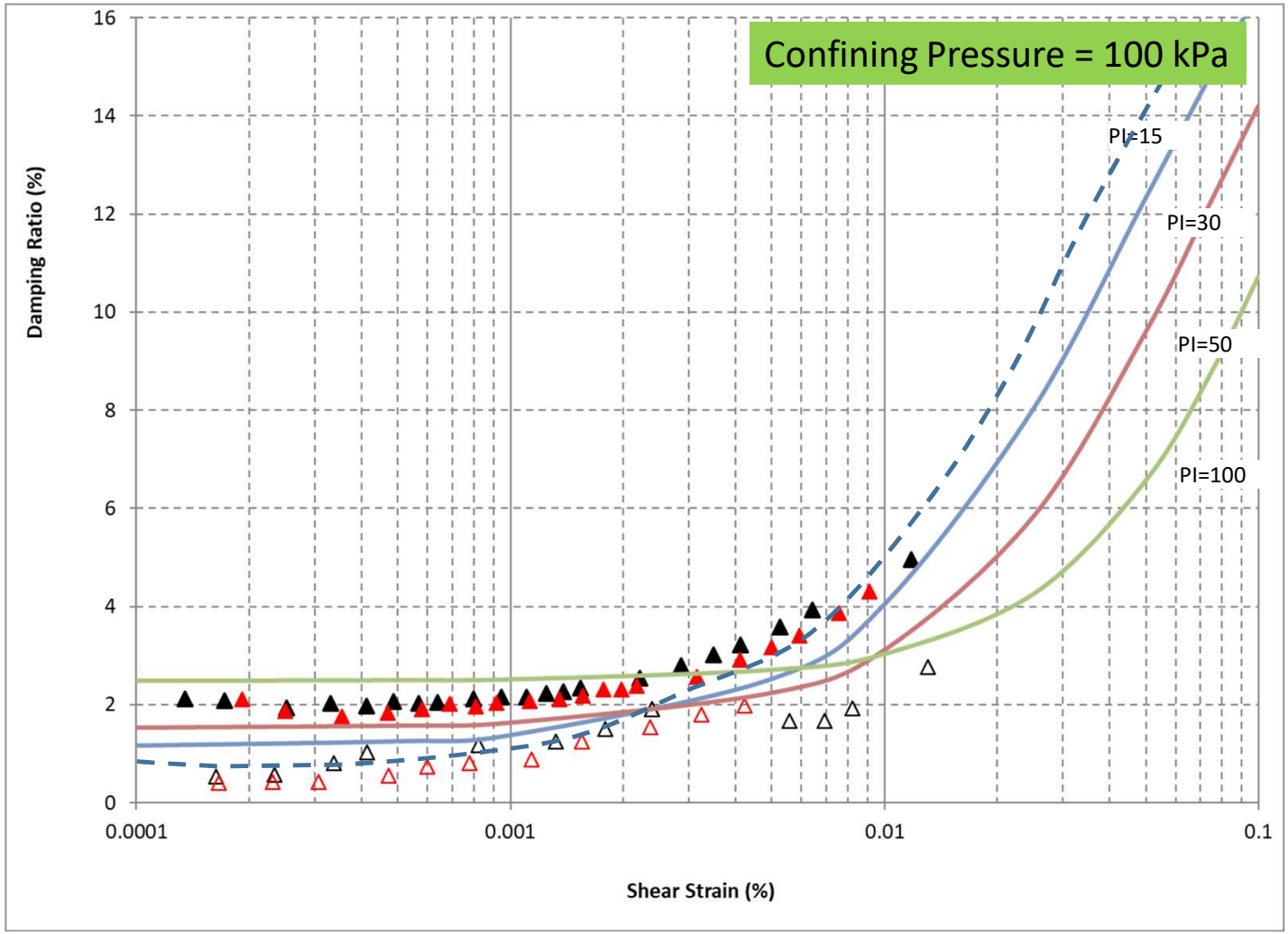
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear
- PI = 12, Resonant Shear

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

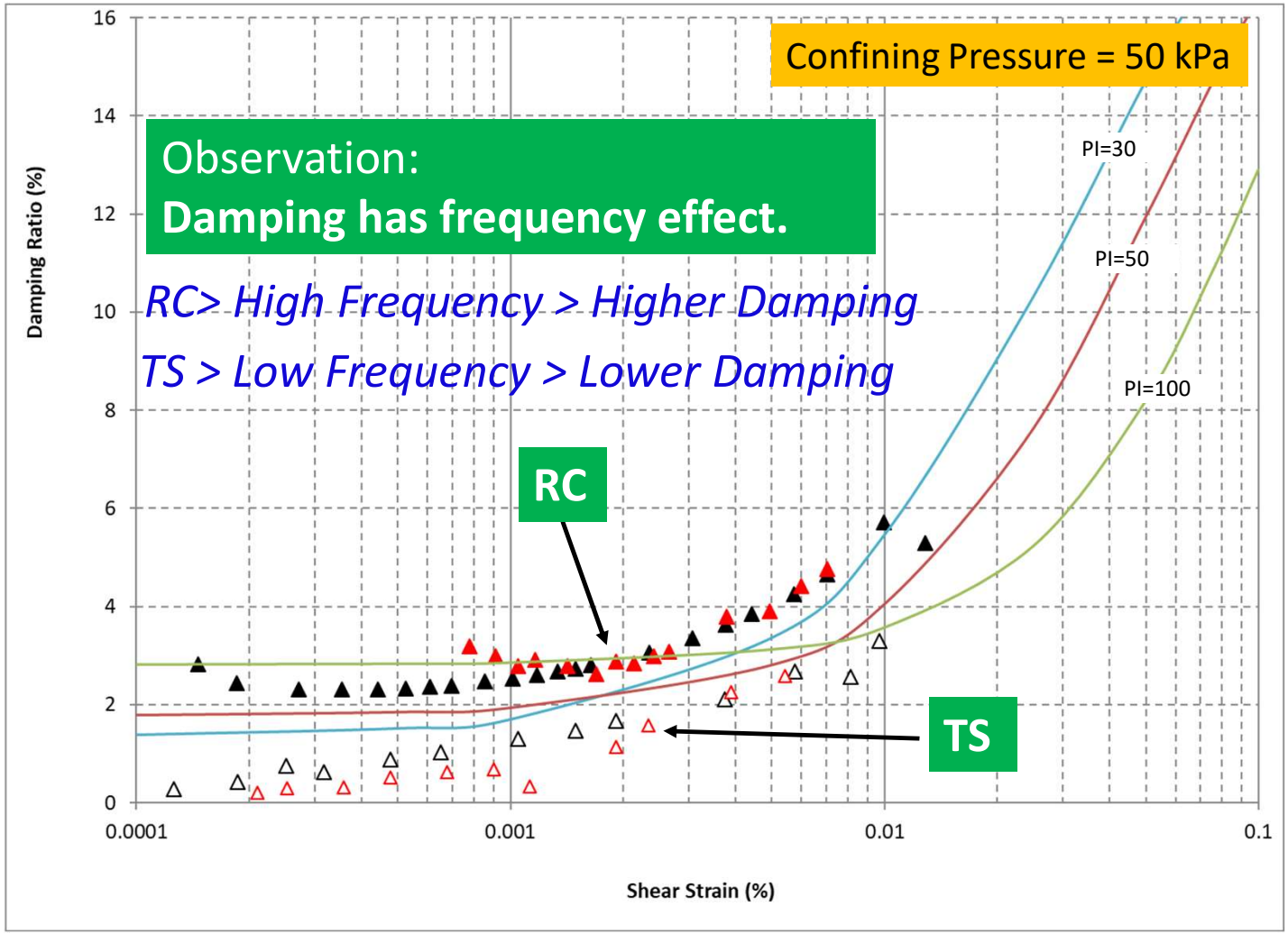
PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear
- PI = 12, Resonant Shear

Results



Prediction Curve (Andurs et,al 2003):

PI= 100 (tentative)

PI=50

PI=30 (tentative)

PI=15 (tentative-extrapolated)

Test Result:

- PI = 15, Torsional Shear
- PI = 15, Resonant Column
- PI = 12, Torsional Shear
- PI = 12, Resonant Shear

Conclusion

- New set of data *doesn't match* the currently used prediction curve
- Previous *two test* samples were *CH* but Cooper Marl can be CH, CL, ML, SC, SM.
- *Carbonate Content* might have an influence in dynamic properties
- This research is currently ongoing effort to understand the *dynamic properties* of Cooper Marl and *supplement* the currently used parameter to be more efficient
- More *small strain dynamic tests* are needed to improve the seismic design parameters for Cooper Marl

References

References:

- Andrus, R. D., Zhang, J., Ellis, B. S., & Juang, C. H. (2003), "*Guide for estimating the dynamic properties of South Carolina soils for ground response analysis* (No. FHWA-SC-03-07,)"
- Camp, III, W. M. (2004), "Site characterization and subsurface conditions for the Cooper River Bridge". In *Geotechnical Engineering for Transportation Projects* (pp. 347-360).
- South Carolina Emergency Management Division (2012), "*South Carolina Earthquake Guide* ".
- FEMA (2023), "*Hazus Estimated Annualized Earthquake Losses for the United States*".
- SCDOT (2022) , "*Geotechnical Design Manual*".
- Jeanjaquet, J (2023), "*Investigation of Shear Modulus and Material Damping of a Lightly Cemented Silty Sand Representing Offshore Soil"*

Question/ Comment

Thank You

biswssk@scdot.org

skbiswas@email.sc.edu