FAMU-FSU Engineering

Performance Testing of GRS Test Piers Constructed with Florida Aggregates – Axial Load Deformation Relationships (BED30 977-11)

Principal Investigator: Scott Wasman, PhD

Project Manager: Larry Jones, P.E.

Graduate Assistant: Christian Matemu

Florida Department Of Transportation

Geotechnical Research In Progress (GRIP)

State Materials Office

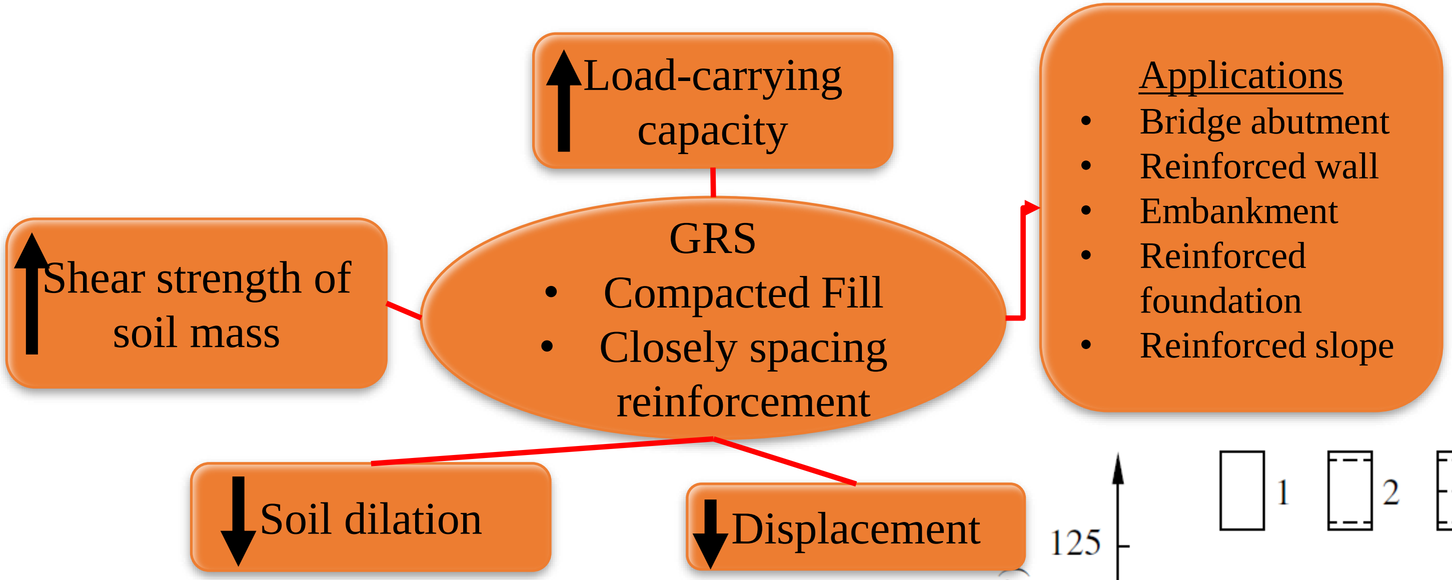
Gainesville, Florida

August 17th, 2023

Presentation Outline

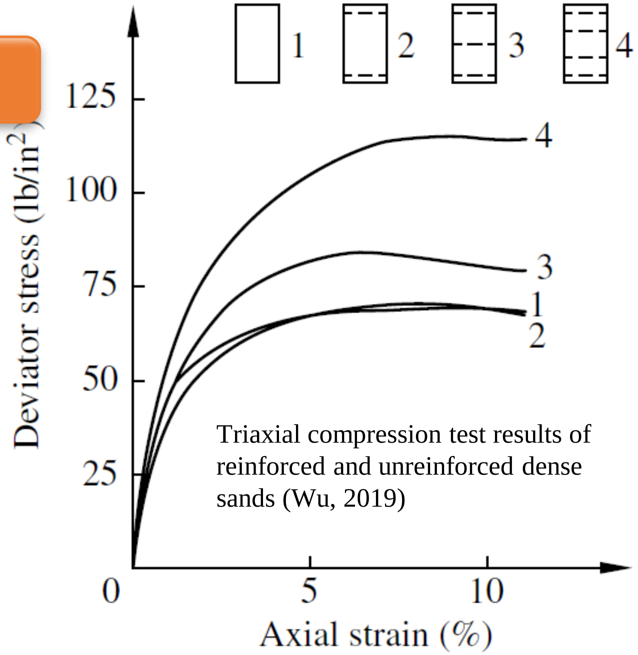
- Introduction
- Research Motivation
- Project Objectives and Tasks
- Experimental Design
- Results and Comparison With Design Methods
- Findings and Conclusions
- Current Work
- Project Timeline and Acknowledgement

Introduction: Geosynthetic Reinforced Soil (GRS)



Bridge abutment
https://www.forconstructionpros.com/concrete/article/22392879/belgard-part-of-oldcastle-apg-how-grsibs-and-anchor-diamond-pro-pin-system-saved-concrete-bridge-project#&gid=1&pid=4

- Reinforcement
  - Provides tensile strength
- Behavior
  - Backfill properties
  - Reinforcement properties
  - Vertical spacing
  - Facing conditions

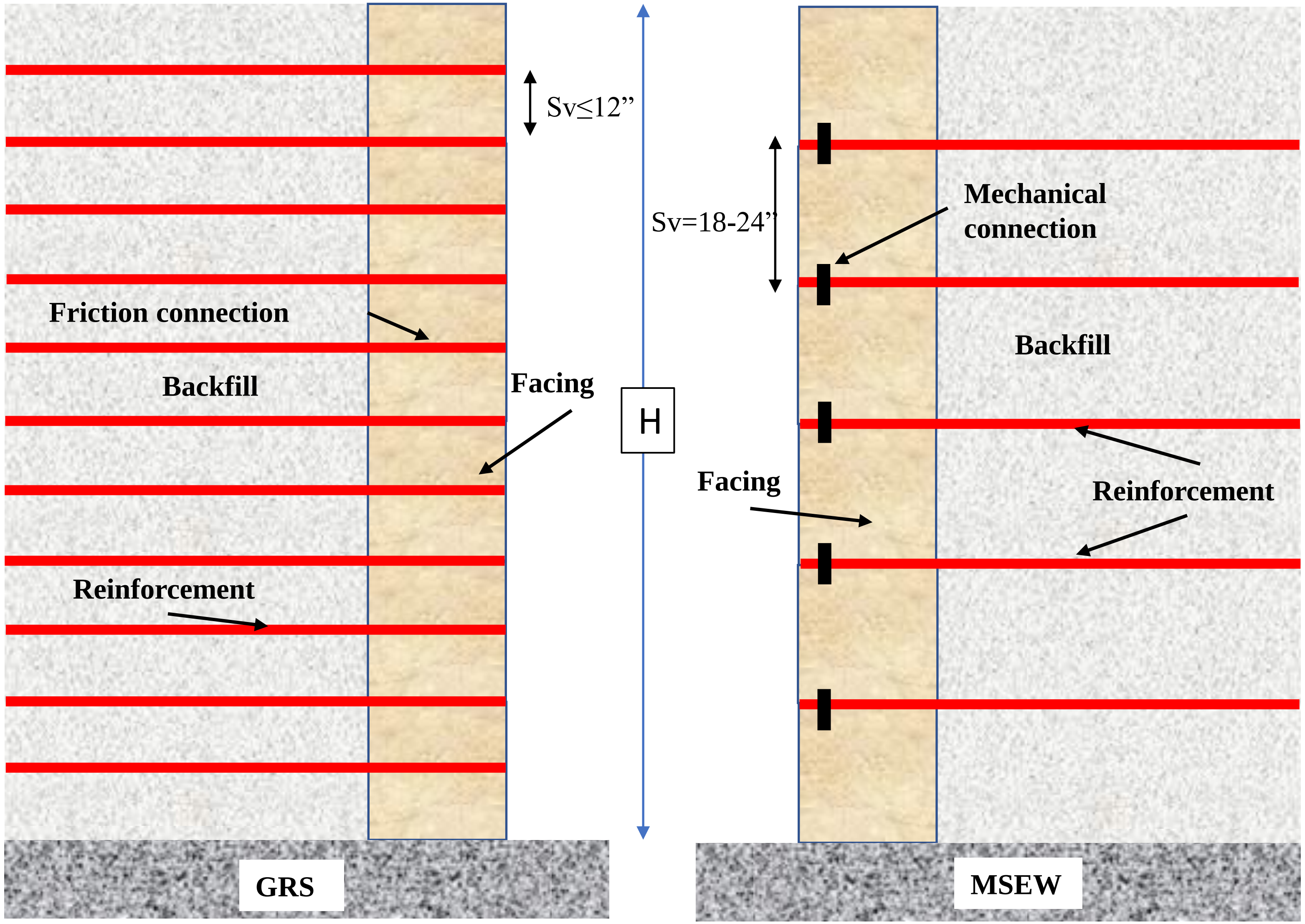


Triaxial compression test results of reinforced and unreinforced dense sands (Wu, 2019)

Reinforced slope
https://geosyntheticsmagazine.com/2019/06/01/geogrid-reinforced-soil-structures-reach-new-heights/

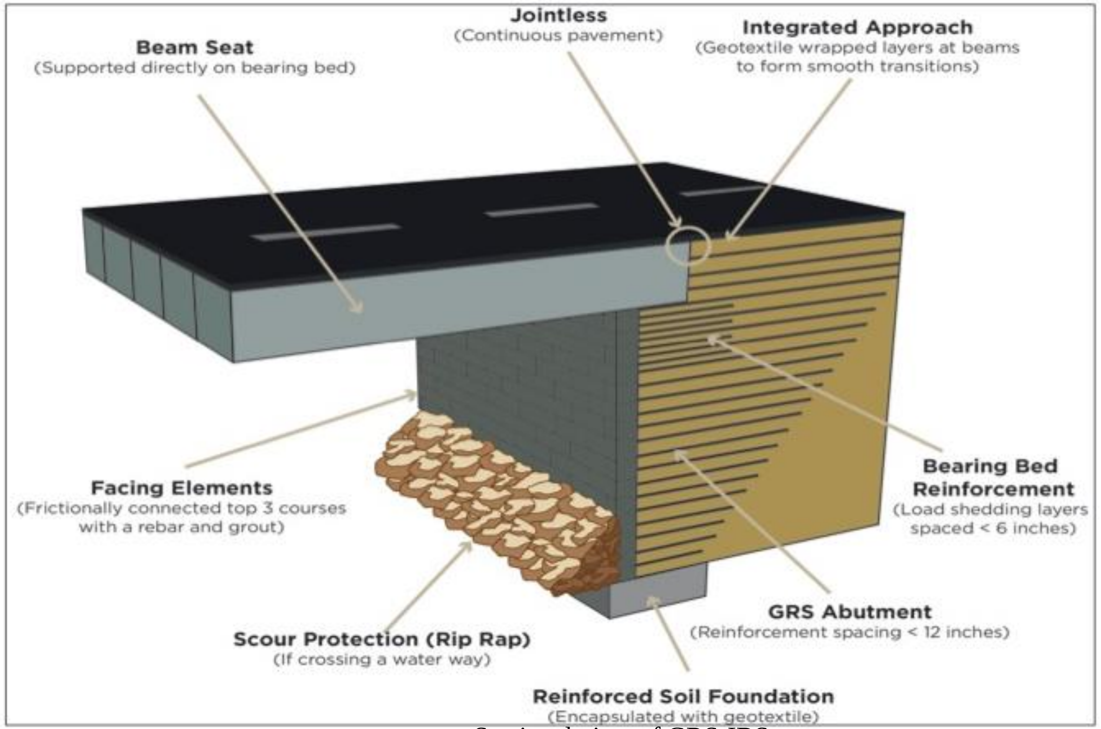
Introduction: Comparison to MSEW

- GRS
  - Friction connections
  - Close spacing ≤ 12 inches
  - Internally stable
  - Composite structure behavior
- MSEW
  - Mechanical connections
  - Wide spacing 18-24 inches
  - Quasi-tieback/External supported
  - Reinforced soil structure behavior



Introduction: What is GRS-IBS?

- FHWA promoted its use to Geosynthetic Reinforced Soil Integrated Bridge system (GRS-IBS):
  - Saving time and cost, eliminates “bump at bridge” problem, flexible design, flexible design



Sectional view of GRS-IBS
https://ncma.org/updates/news/grs-ibs-solutions-to-bridge-construction-challenges/

Construction of U.S. 301 Trail Bridge with multi-span GRS-IBS in Zephyrhills, Florida (Daniyarov et al., 2017)

Single span <140 ft
Abutment height<30 ft
Service limit pressure 4 ksf

>300 bridges with GRS-IBS in USA

Orange Avenue Bridge in Tallahassee, Florida
https://ncma.org/updates/projects/florida-manages-orange-avenue-bridge-with-grs-ibs/

Research Motivation

Facing
- FHWA, CMU
- FDOT, SRB **??**

Reinforcement
FHWA, $T_f \leq 4,800$ lb/ft
FDOT $T_f \geq 4,800$ lb/ft **??**

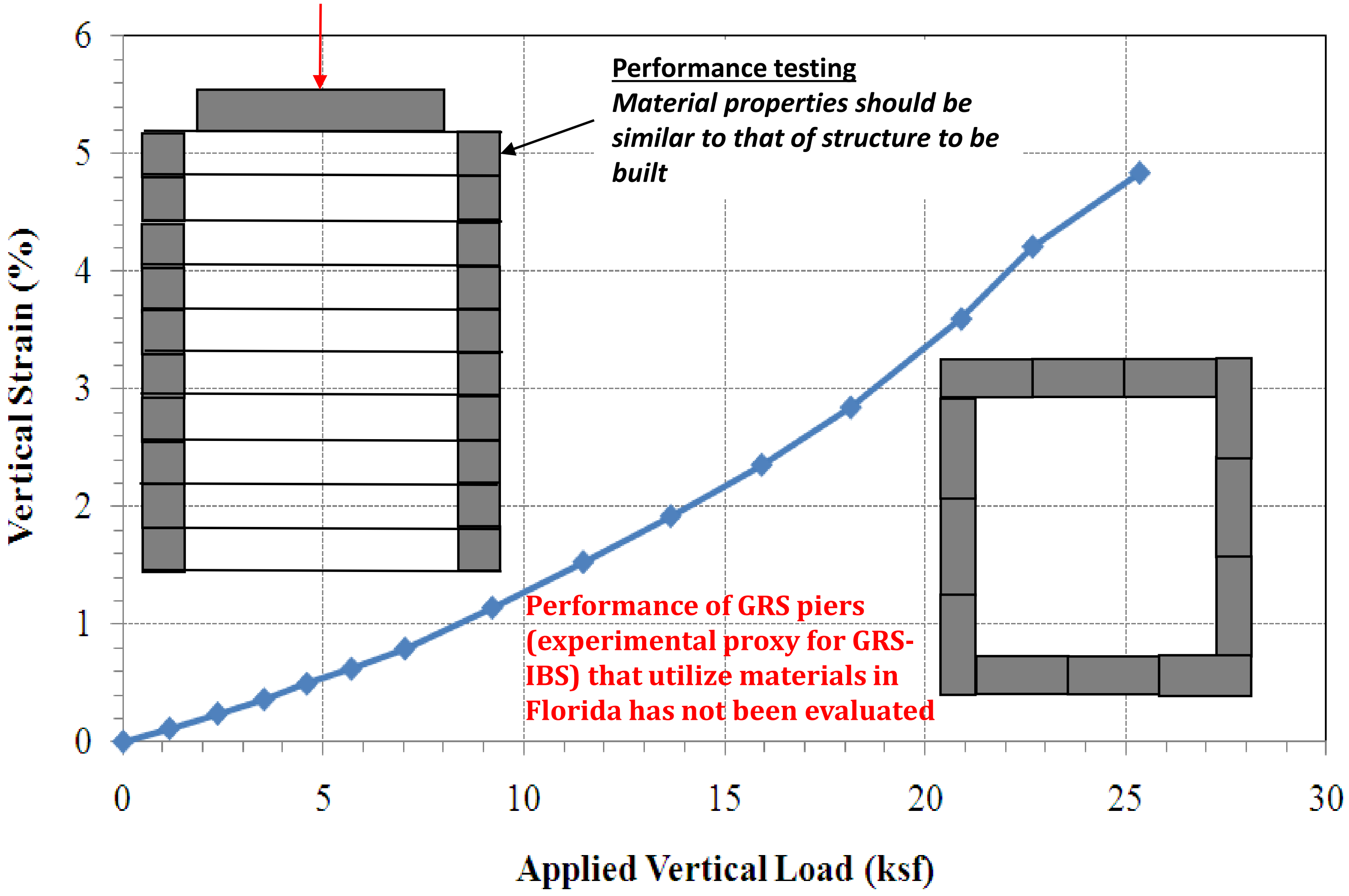
Performance of GRS

Axial load at FHWA Service limits
$\varepsilon_v = 1\%$ and $\varepsilon_H = 2\%$ **??**

Backfill
- Florida aggregates **??**
- Other Materials i.e. FGA**??**

Property	# 57 Florida	#57 Virginia
	Limestone	Limestone
LA Abrasion Loss (5)	38	23
Friction angle (deg)	44.8 SDTX	40.5 LDTX
Max Density	96	108.7
Min Density	82	95.4

SDTX based on small diameter (4”) triaxial test
LDTX based on large diameter (6”) triaxial test



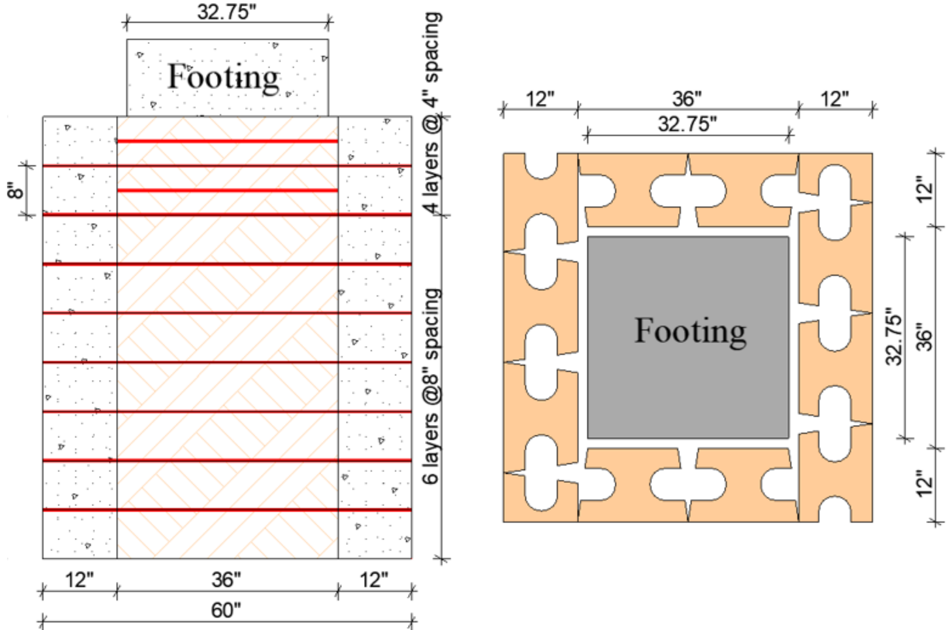
Design envelope (Adams et al., 2012)

Project Objectives and Tasks

- <u>Objectives</u>
  - Measure axial-load deformation behavior of GRS piers through full scale fully instrumented tests to identify their performance when constructed with aggregates used in Florida and typical reinforcement types at different vertical spacing
- <u>Tasks</u>
  - Task-1: Review previous studies on GRS, design methods, material, and construction practices-COMPLETED
  - Task-2: Design experimental plan for performance tests-COMPLETED
  - Task-3: Performance tests – Axial load-deformation tests on GRS piers-COMPLETED
  - Task-4: Compare performance test results with previous results and predictions and make recommendations for GRS design in Florida-In progress
  - Task-5 and 6: Final reports and closeout teleconference-In progress

Research Methodology-Design of experiments

- Review
  - Literature review on GRS experiments,
  - FDOT & FHWA design guideline for GRS-IBS
  - Size of the available reaction frame
- Materials
  - Backfill
    - Crushed limestone (No 57 Florida limestone)
    - Graded aggregate base-recycled concrete aggregate (RCA-GAB)
    - Lightweight foamed glass aggregate (FGA)
  - Reinforcement
    - Woven polypropylene geotextiles: Mirafi HP 570, Mirafi HP 770 and TerraTex HPG 57
  - Facing
    - Segmental retaining blocks (SRB)



Pier layout

Research Methodology-Design of experiments

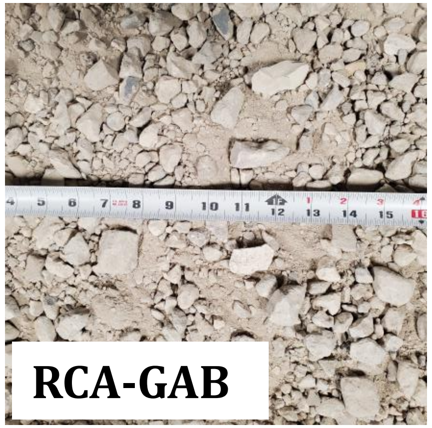
Test No	Backfill					Reinforcement				
	Type	Maximum Dry Unit weight (pcf)	Compacted to Dry Unit weight (pcf)	Friction angle (degrees)	Cohesion (psi)	Type	Ultimate Tensile Strength, T_f (lb/ft) (MD X CD)	S_v (inch)	B (ft)	H/B
PT-01	#57 stone	96.2	96.85	44.7	7.40	Mirafi HP570	4,800 x 4,800	8	3	2
PT-02	#57 stone	96.2	97.59	44.7	7.40	Mirafi HP770	7,200 x 5,760	8	3	2
PT-03	#57 stone	96.2	96.55	44.7	7.40	TerraTex HPG57	4,800 x 4,800	8	3	2
PT-04	RCA-GAB	115.9	113.28	55.4	14.9	Mirafi HP570	4,800 x 4,800	8	3	2
PT-05	RCA-GAB	115.9	113.70	55.4	14.9	Mirafi HP770	7,200 x 5,760	8	3	2
PT-06	RCA-GAB	115.9	113.94	55.4	14.9	TerraTex HPG57	4,800 x 4,800	8	3	2
PT-07	FGA	16.75	18.20	54.0[b]	1.28[b]	Mirafi HP770	7,200 x 5,760	8	3	2
PT-08**	#57 stone	96.2	97.00	44.7	7.40	Mirafi HP570	4,800 x 4,800	8	3	2

** Block cells in the upper three courses of blocks contain concrete and rebar, [b] based on a 12 in x 12 in direct shear box, remaining strength parameters are from 4-in large diameter triaxial tests

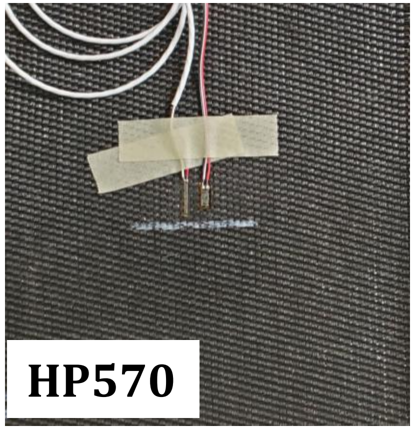
Research Methodology-Design of experiments

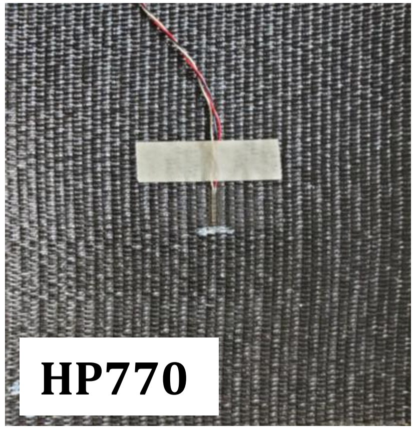
- Materials

Aggregates

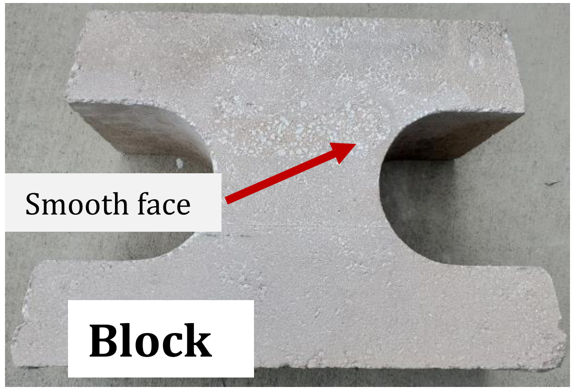


Geotextile



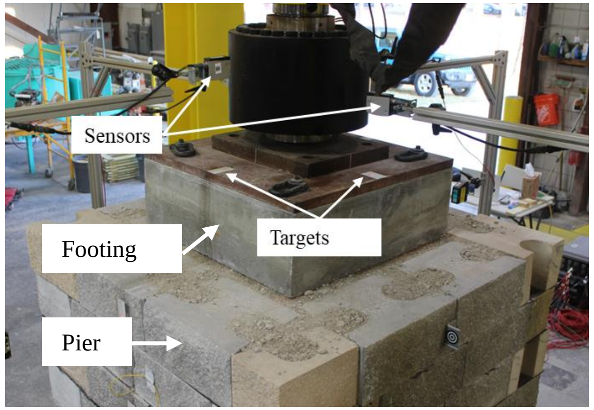


Facing blocks

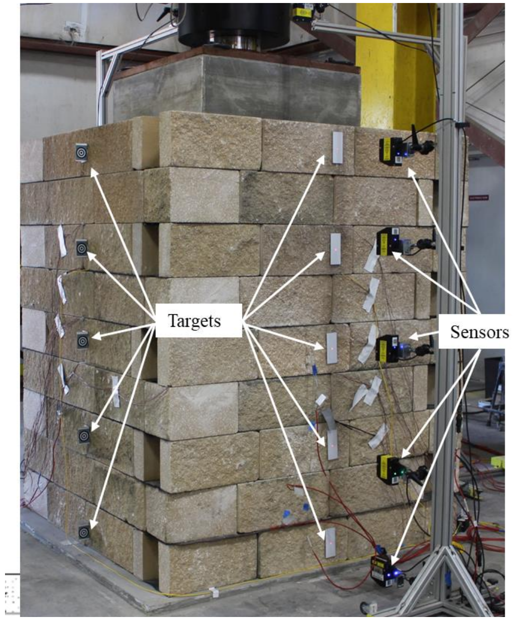


Research Methodology-Instrumentation

- Displacement
  - Vertical: Four at top of footing
  - Lateral: Five on each wall
- Reinforcement strain
  - Strain gauge: First test
  - Fiber optic strain sensor
  - Five geotextiles instrumented
- Earth pressure
  - Vertical: At the bottom
  - Lateral : At the middle of the pier
- Applied load
  - Load cell

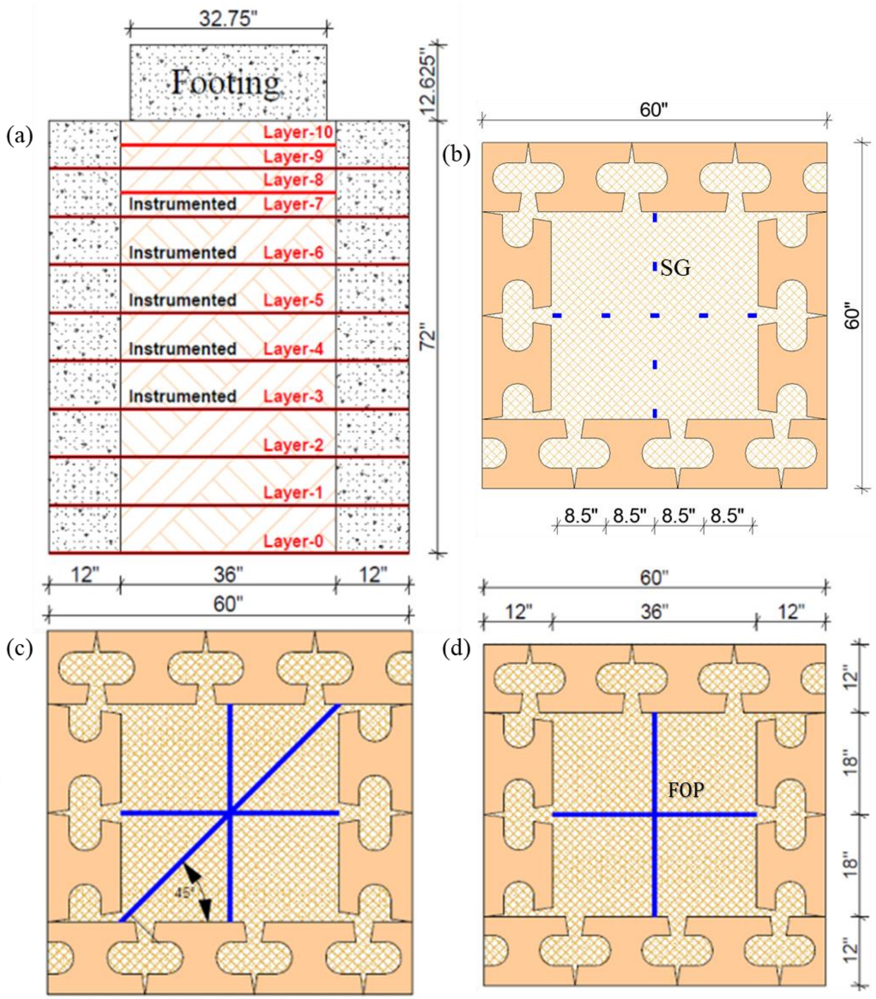


Vertical displacement measurement



Lateral displacement measurement

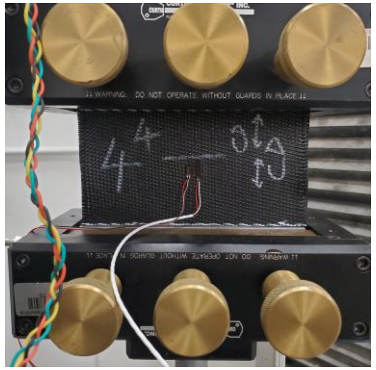

Vertical earth pressure cell

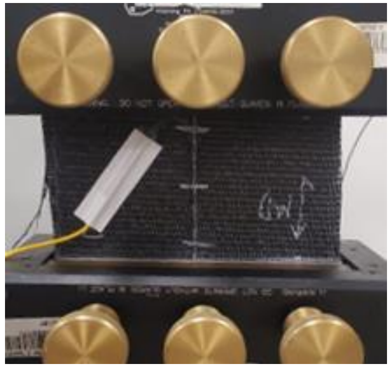


Installation of strain gauges and fiber optic strain sensor
SG: Strain Gauge; **FOP**: Fiber optic cable

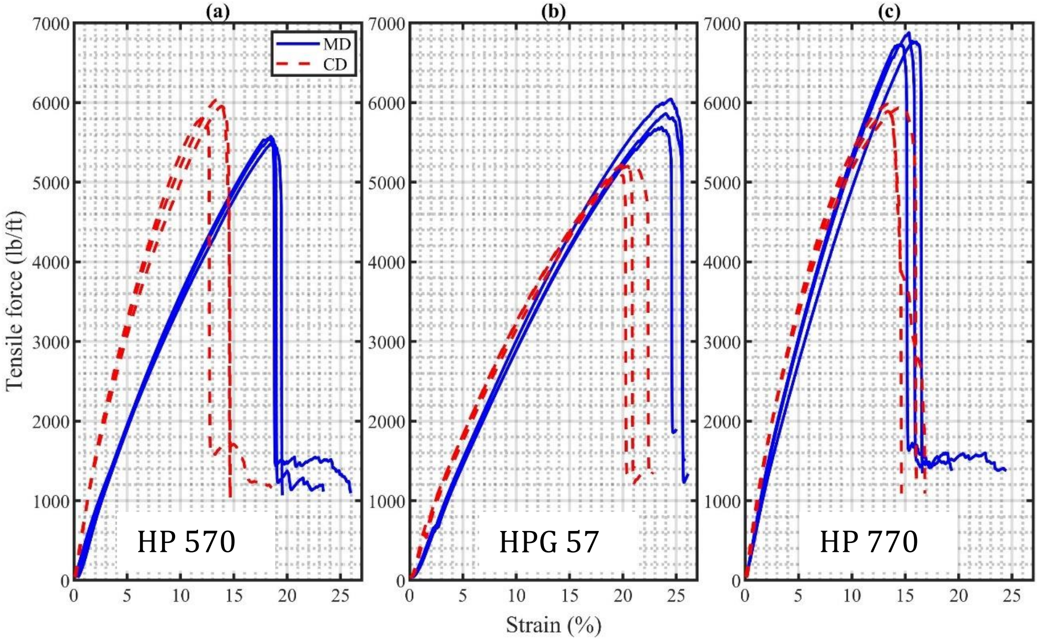
Research Methodology-Materials Testing

- Geotextile





Uniaxial tensile tests of geotextile: Test specimen with strain gauges installed; and Test specimen with fiber strain sensor installed

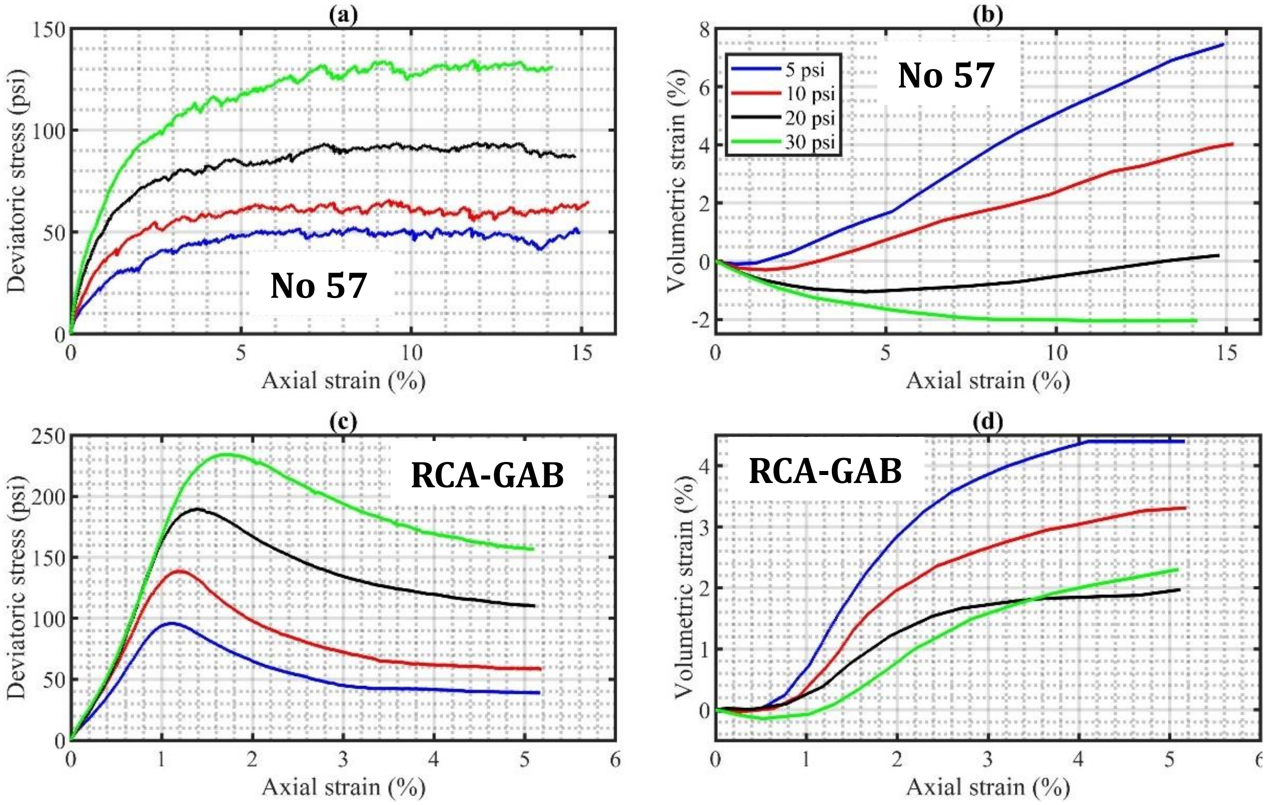


Manufacturer Reported Properties

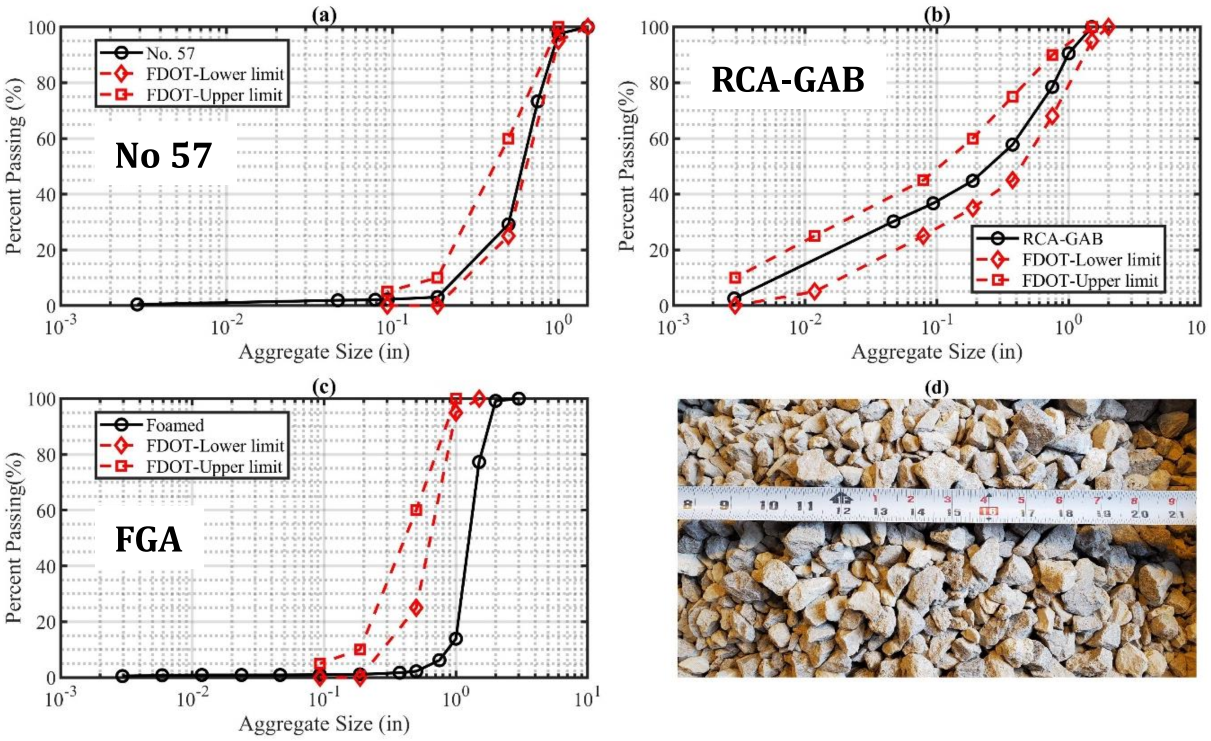
Mechanical Properties	Test Method	Minimum Average Roll Value	
		Machine Direction (MD)	Cross-Machine Direction (CD)
Mirafi HP 570 & TerraTex HPG 57			
Tensile Strength (at ultimate)	ASTM D4595	4,800 lbs/ft	4,800 lbs/ft
Tensile Strength (at 2% strain)	ASTM D4595	960 lbs/ft	1,500 lbs/ft
Tensile Strength (at 5% strain)	ASTM D4595	2,400 lbs/ft	3,000 lbs/ft
Mirafi HP 770			
Tensile Strength (at ultimate)	ASTM D 4595	7,200 lbs/ft	5,760 lbs/ft
Tensile Strength (at 2% strain)	ASTM D 4595	1,370 lbs/ft	1,560 lbs/ft
Tensile Strength (at 5% strain)	ASTM D 4595	3,600 lbs/ft	3,600 lbs/ft

Research Methodology-Materials Testing

- Aggregates



Triaxial results



Sieve analysis results

Research Methodology-Materials Testing

- Shear Strength Properties and Interface Friction

Strength properties at peak (Triaxial test based on a 4-inch diameter cell)

Aggregate type	With cohesion		With no cohesion	
	Friction angle (°)	Cohesion (psi)	Friction angle (°)	Cohesion (psi)
No. 57	38.46	7.86	45.21	0
RCA-GAB	47.03	14.91	55.39	0

Strength properties at peak (Direct shear)

Aggregate type	SDS (4-inch diameter)		Tested at
	Peak Friction angle (°)	Cohesion (psi)	
RCA-GAB	45.44	14.96	FSU
No. 57	55.13	4.84	FSU
	LDS (12 in x 12 in) box		
No. 57	54.4	11.4	FHWA
FGA	54.0	1.28	SGI Testing Services LLC

Interface properties between Geotextile and Backfill

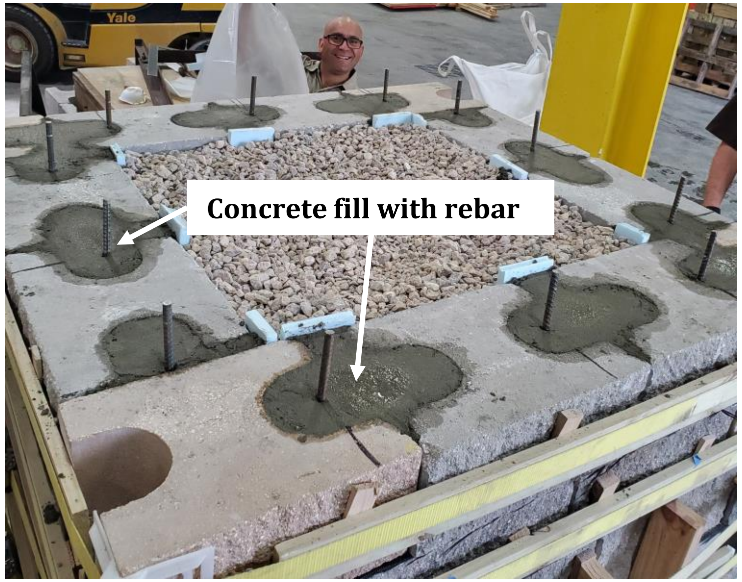
Testing Agency	Geotextile	Interface friction angle (deg)	
		With No 57	With RCA-GAB
FSU	HP570	42.23	40.39
	HPG57	37.95	38.35
	HP770	37.66	37.33

Interface properties between Geotextile and Blocks

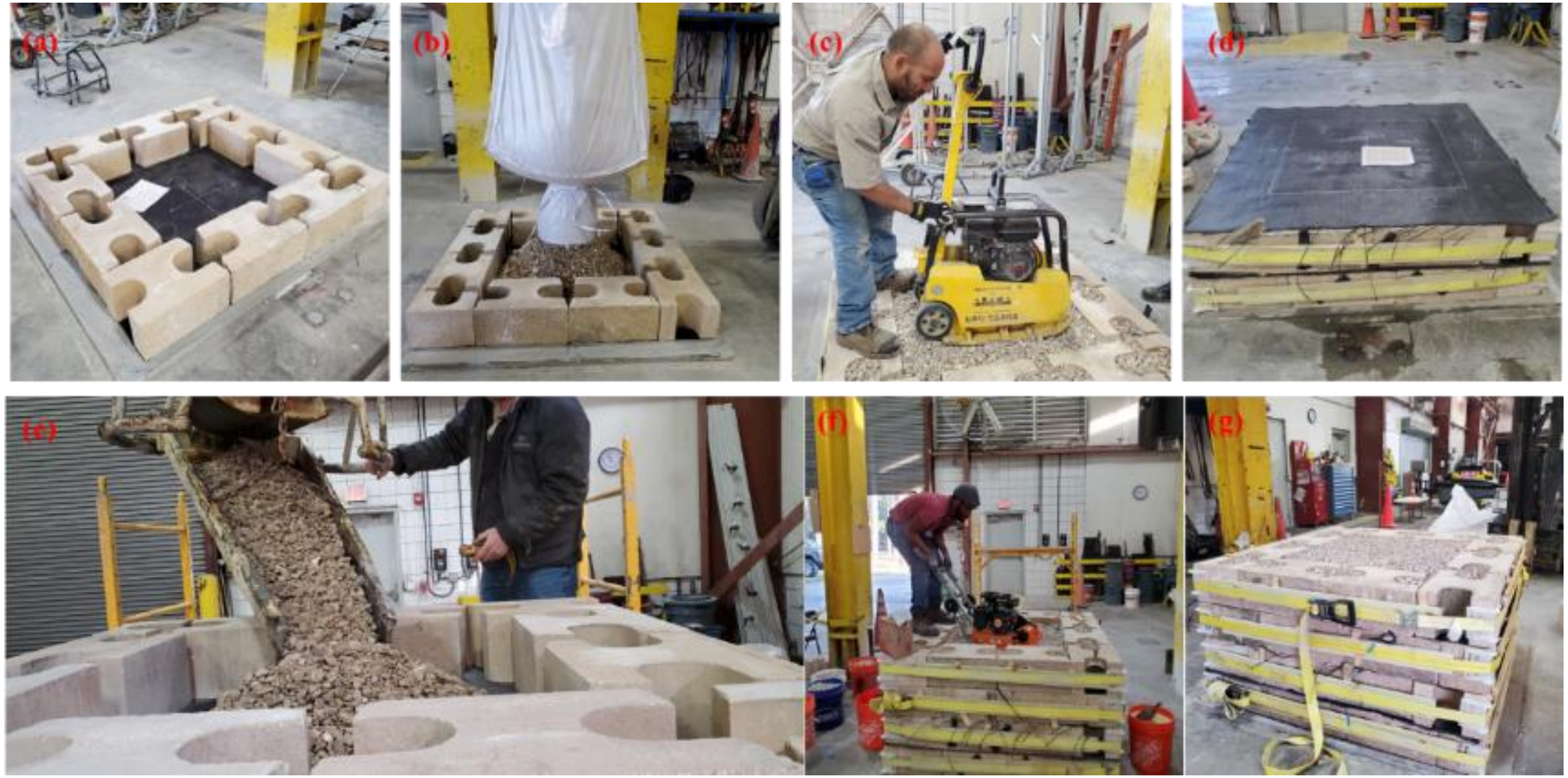
Testing Agency	Geotextile	Interface Friction angle (deg)
FSU	HP570	21.86
	HPG57	22.75
	HP770	21.84

Research Methodology-Construction

- Bottom-Up construction
  - Laying facing blocks
  - Placing and compacting backfill
  - Laying down geosynthetics

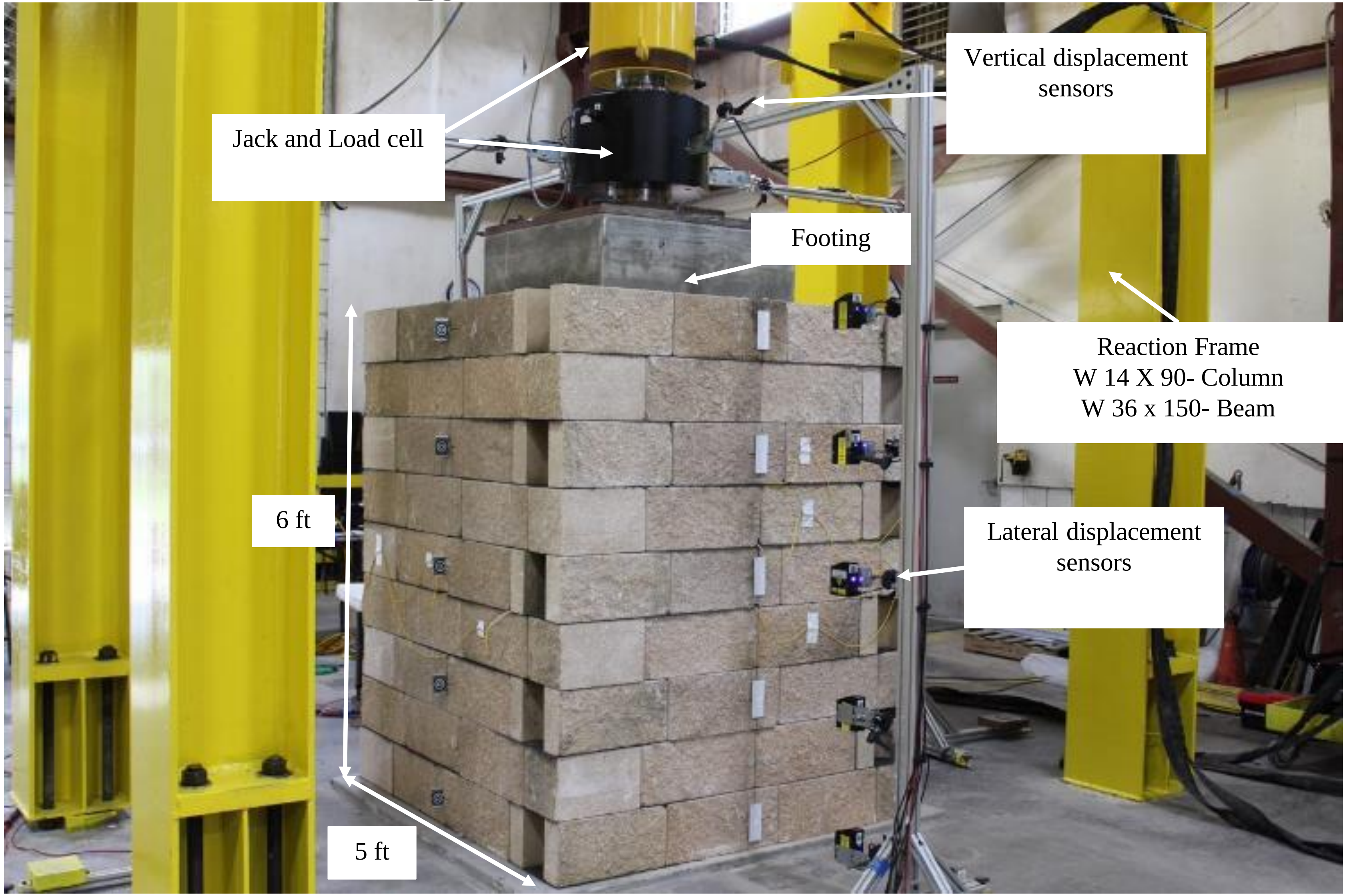


Concrete fill at upper block course- PT-08



GRS test pier construction steps.
Laying the face blocks, (b&c) Placing and compacting backfill, (d) Laying down geosynthetics, (e,f, & g) Repeat A-C until the final height is reached

Research Methodology-Construction



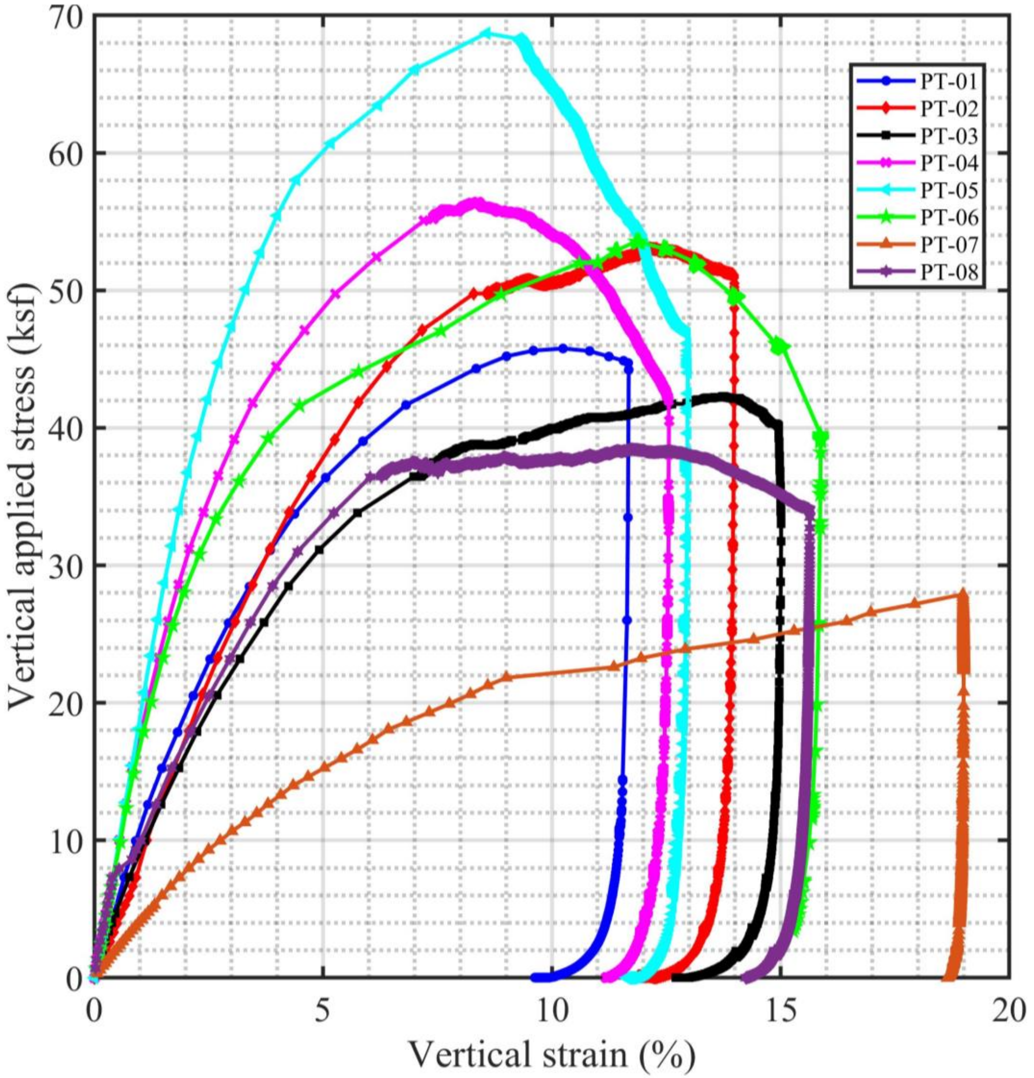
Completed and instrumented pier before testing PT-01

Research Methodology-Loading

Load increments (kips)	Applied vertical stress
2-5 kips	$\leq$ 4 ksf
20 kips	> 4 ksf until failure
Load held for 2-5 minutes	

Failed pier after the PT-01 test

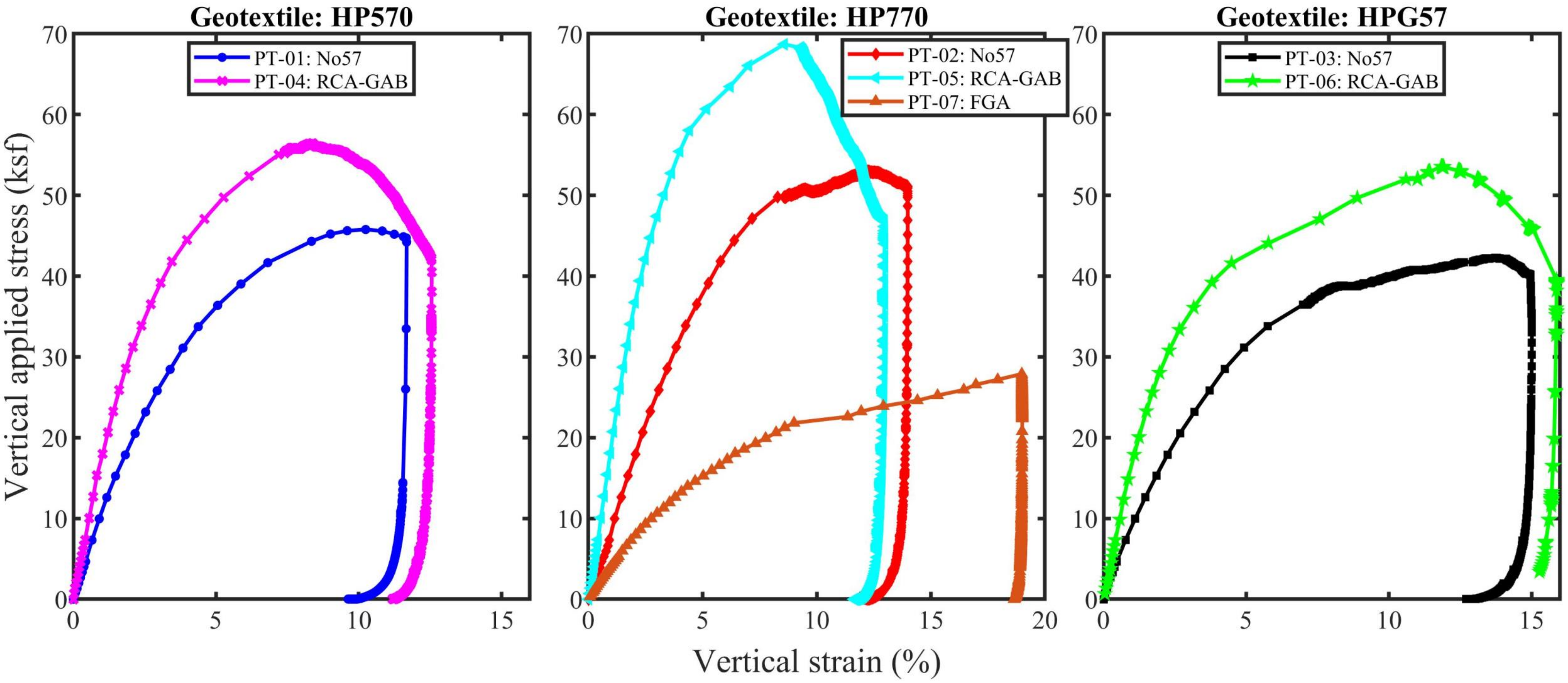
Results:- Load-Deformation



A plot of applied vertical stress versus average vertical strain

Top view of the failed pier after the PT-01 test

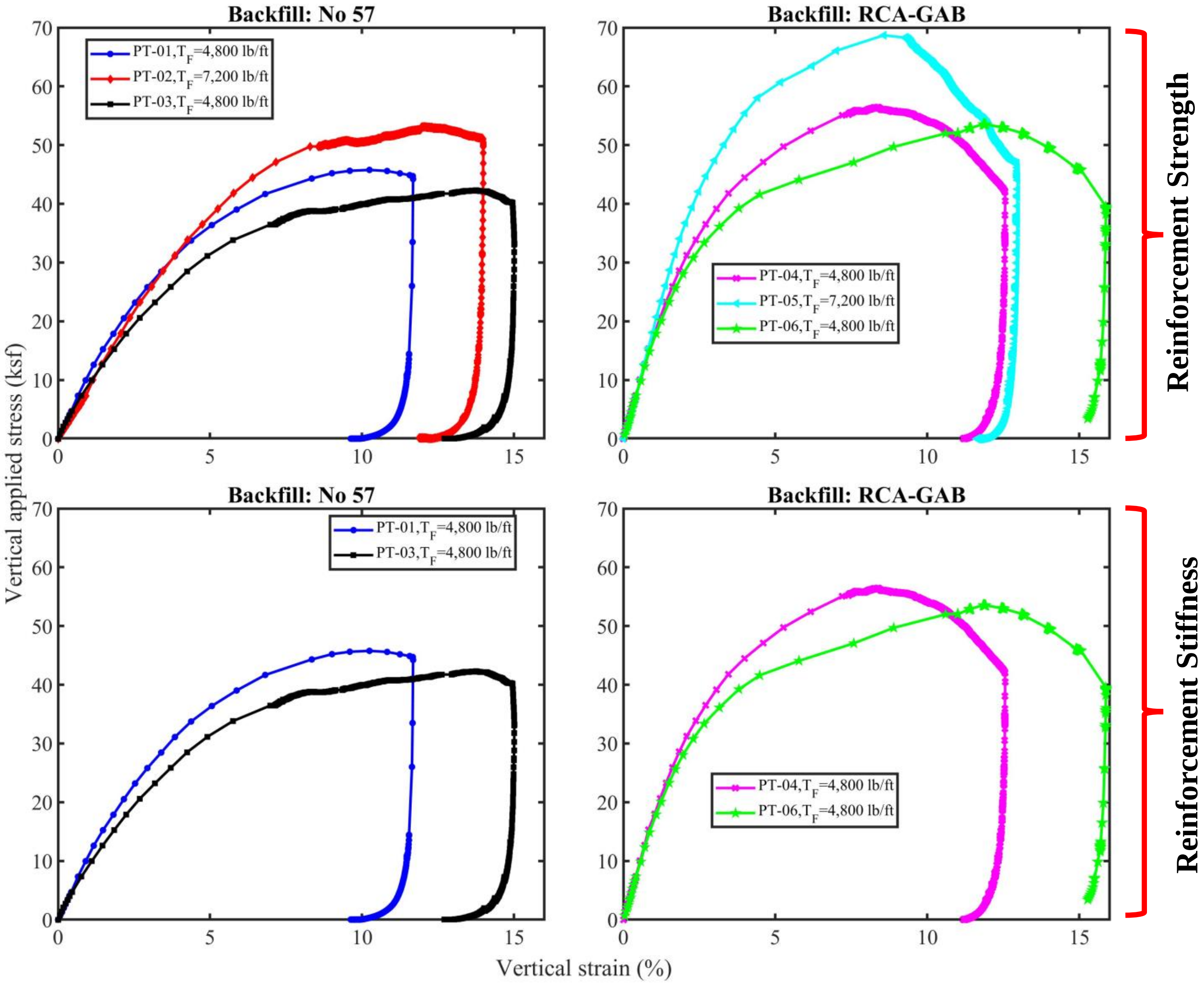
Results:- Load-Deformation: Backfill strength properties



A plot of applied vertical stress versus average vertical strain

Results:- Load-Deformation: Reinforcement strength and Stiffness

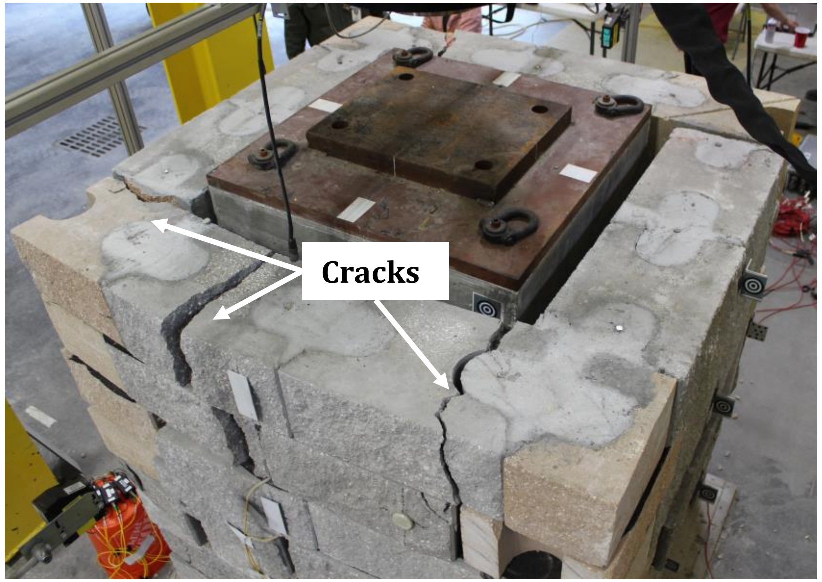
- Higher reinforcement strength
  - Higher vertical capacity
- Higher reinforcement stiffness
  - Stiffer load response

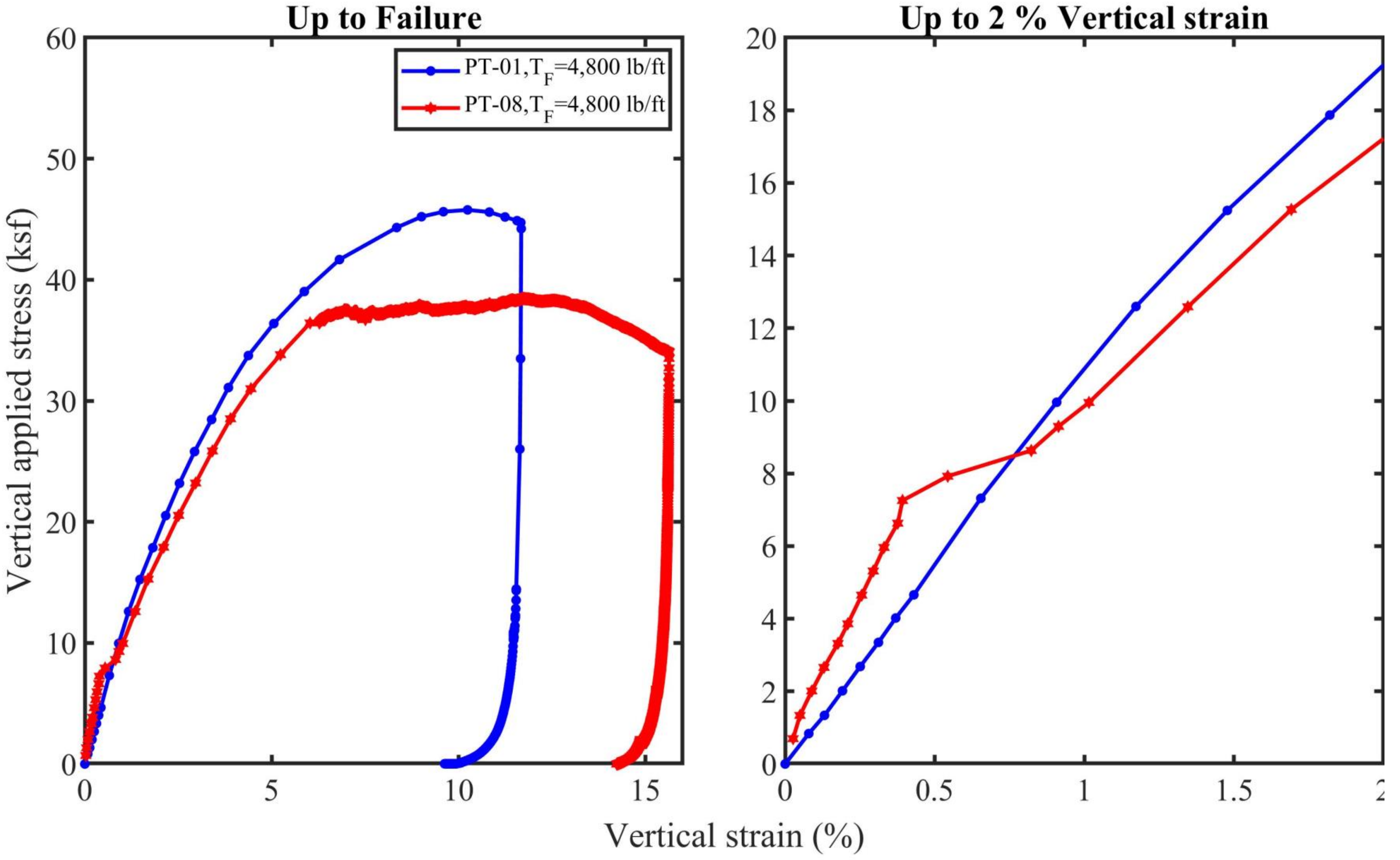


A plot of applied vertical stress versus average vertical strain

Results:- Load-Deformation: Concrete fill

- Concrete fill
  - Increases initial stiffness of the global stress-strain up to 7.25 ksf
  - Reduces the vertical capacity slightly
  - More cracks on blocks

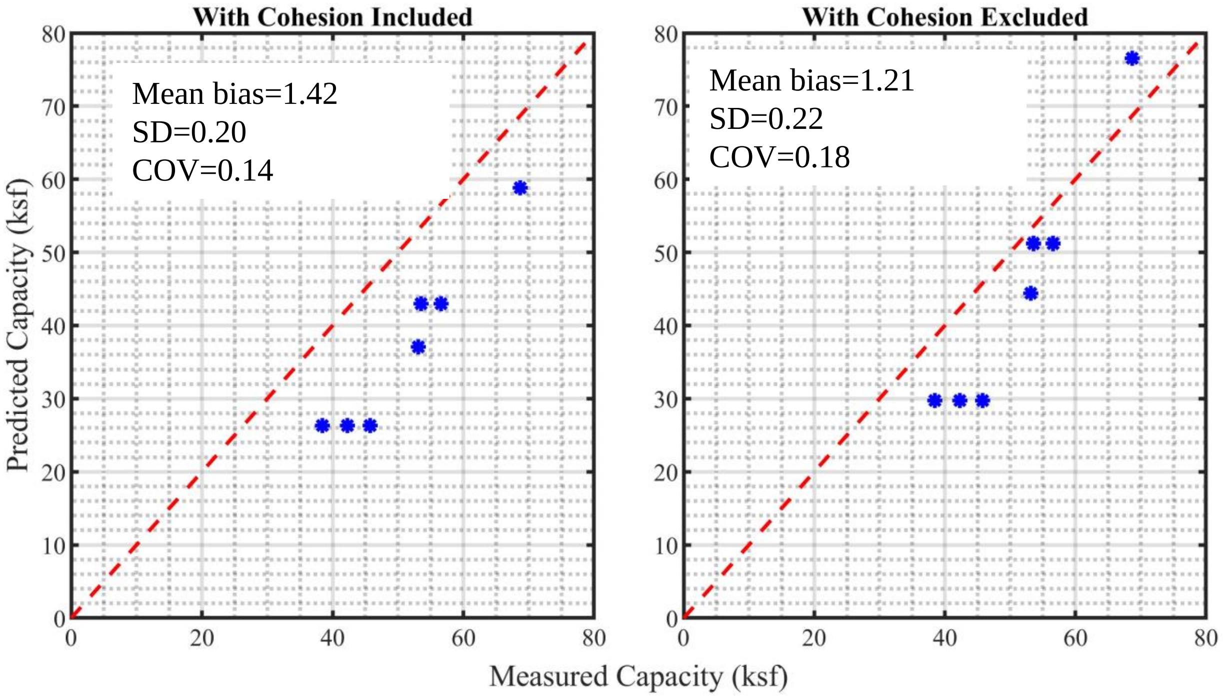




A plot of applied vertical stress versus average vertical strain

Results:- Comparison with design methods: Ultimate Vertical Capacity

Test	Ultimate Capacity (ksf)			Measured/Predicted (With cohesion)	Measured/Predicted (With No cohesion)
	Maximum Measured	Predicted (With cohesion), $q_{ult,an}$	Predicted (With no cohesion), $q_{ult,an}$		
PT-01	45.75	26.34	29.72	1.74	1.54
PT-02	53.13	37.06	44.43	1.43	1.20
PT-03	42.29	26.35	29.73	1.60	1.42
PT-04	56.60	42.97	51.23	1.32	1.10
PT-05	68.70	58.84	76.57	1.17	0.90
PT-06	53.55	42.99	51.25	1.25	1.04
PT-07**	27.90	N/A	N/A	N/A	N/A
PT-08	38.45	26.34	29.72	1.46	1.29



Comparison of the measured and predicted vertical capacities

$$q_{ult,an} = \left[\sigma_c + 0.7^{\left(\frac{S_v}{6d_{max}}\right)}\frac{T_f}{S_v}\right]K_{pr} + 2c\sqrt{K_{pr}}$$

$$K_{pr} = tan^2\left(45 + \frac{\Phi_r}{2}\right)$$

Where $q_{ult,an}$ is the ultimate capacity, σ_c is the external confining pressure caused by the facing, S_v is the reinforcement spacing, d_{max} is the maximum aggregate size, T_f is the tensile strength of reinforcement, Φ_r is the internal friction angle of the reinforced backfill, c is the cohesion of the backfill, γ_b is the unit weight of facing block, δ is the interface friction angle between geosynthetic and the facing block, d is the depth of the facing block unit, and K_{pr} is the coefficient of passive earth pressure

Backfill strength parameters from a 4-in triaxial test were used in calculation

Results:- Lateral displacement

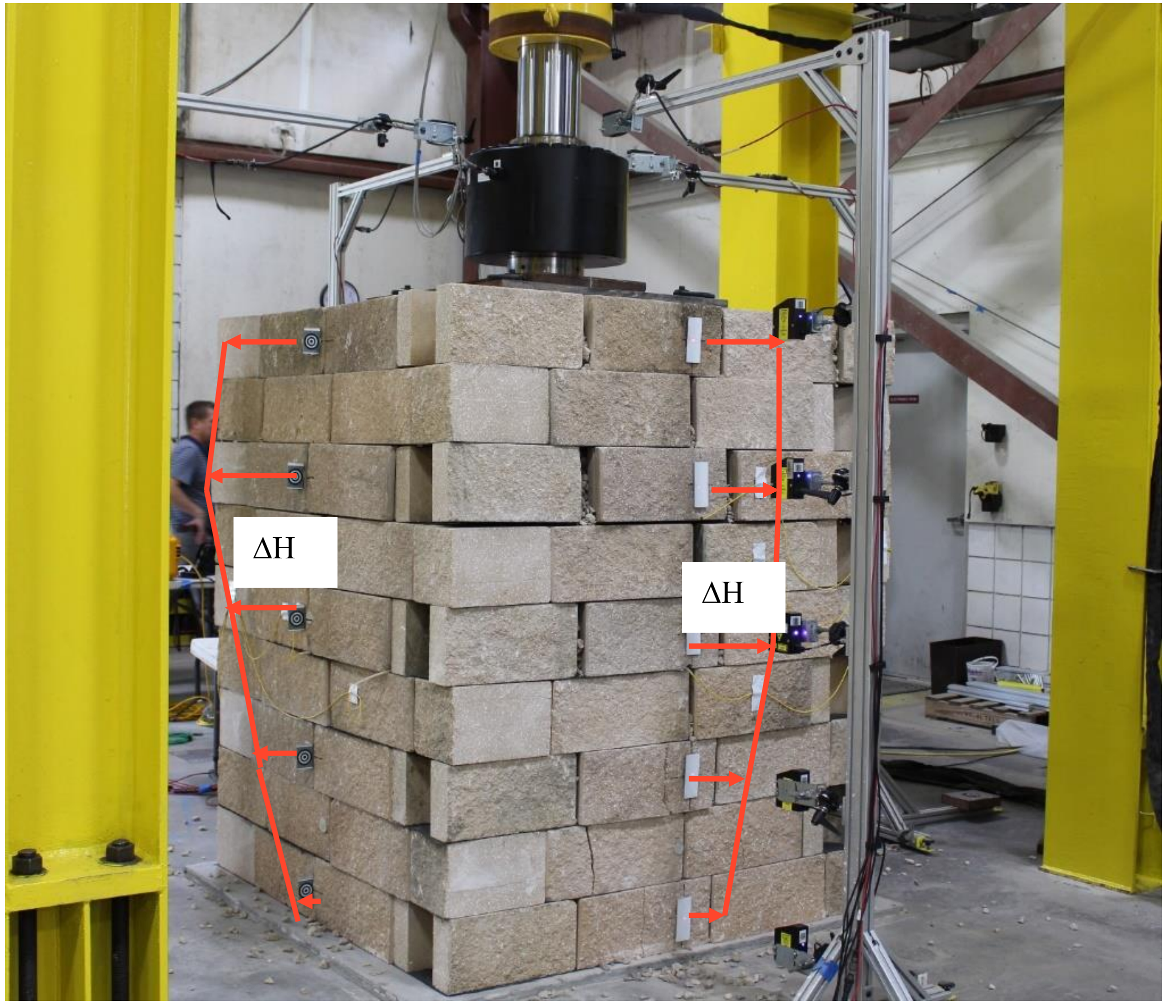
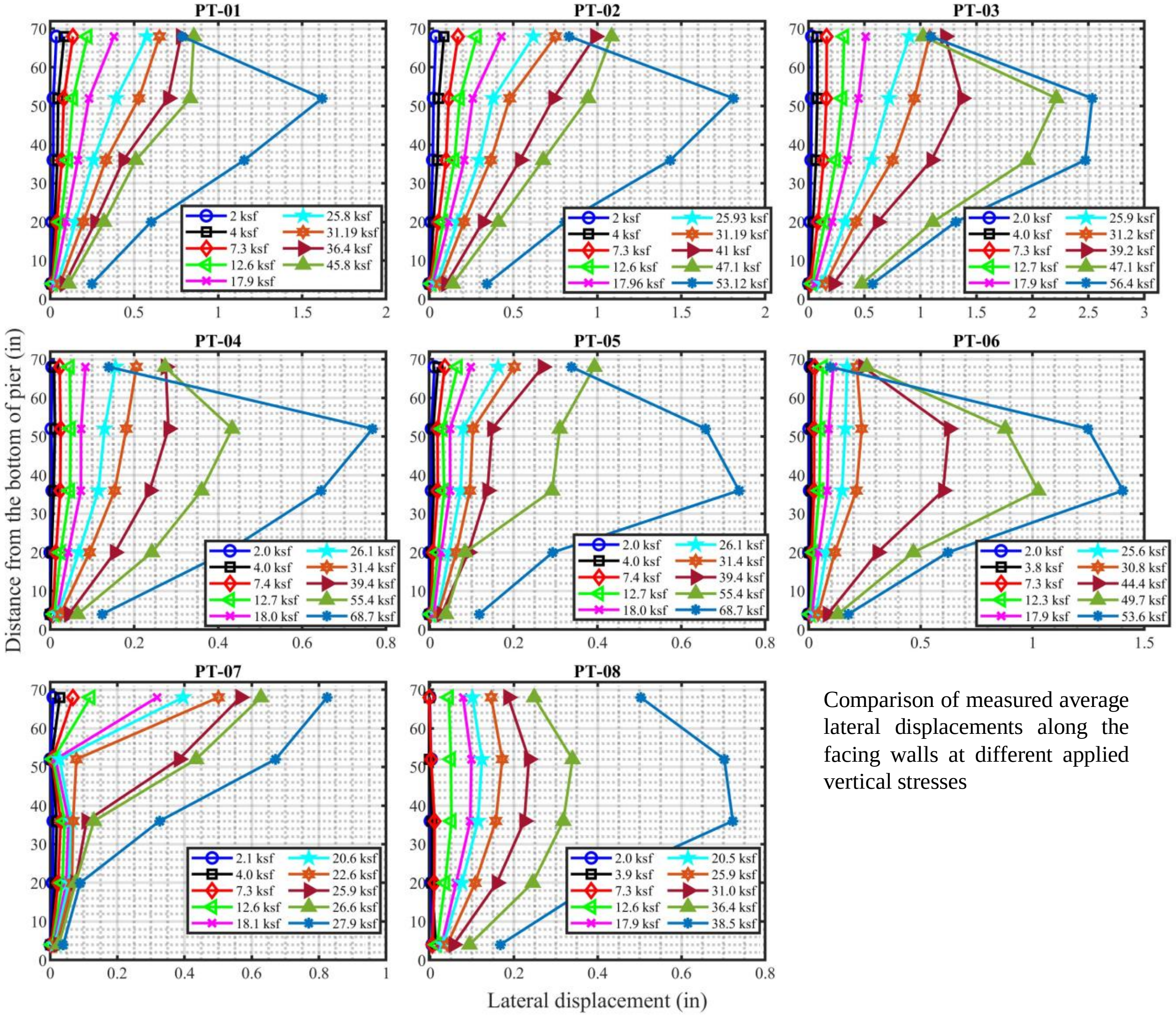


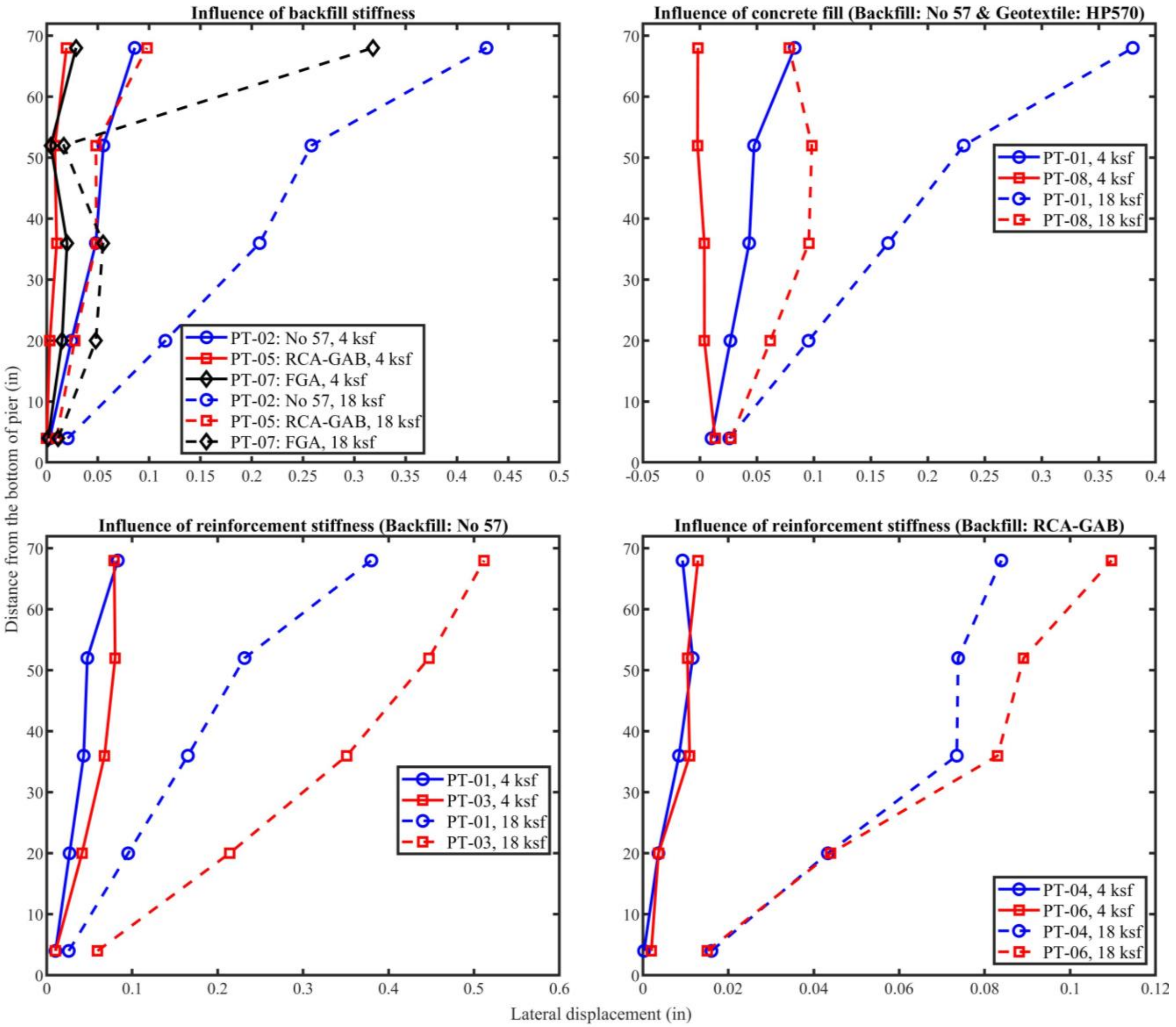
Illustration of lateral displacement after the test



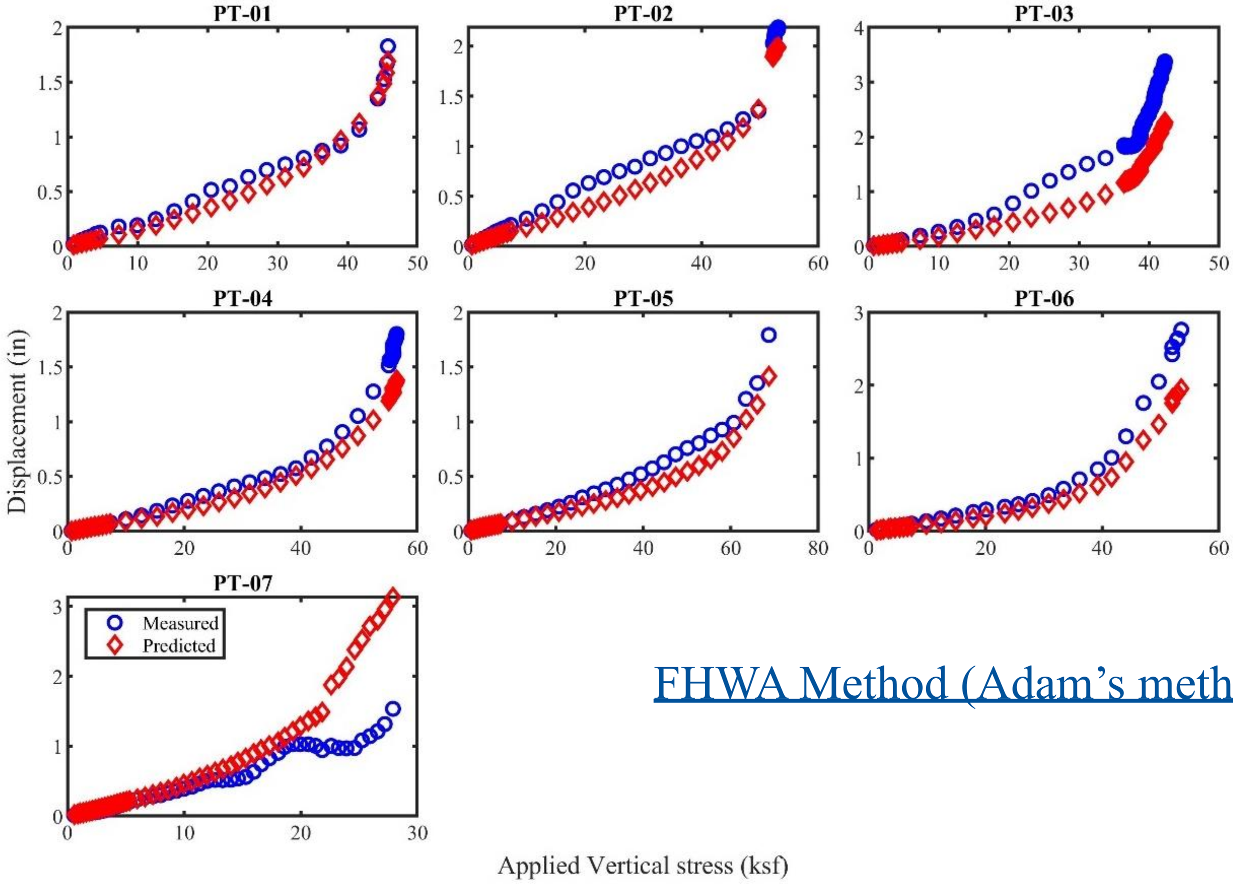
Comparison of measured average lateral displacements along the facing walls at different applied vertical stresses

Results:- Lateral displacement-Backfill and Reinforcement Stiffness

- Higher stiffness of backfill
  - Lower lateral displacement
- Lower geotextile stiffness (HPG 57)
  - Larger lateral displacement
- Concrete fill (in PT-08)
  - Reduces lateral displacement
  - Changes lateral displacement profile
- Higher compressibility (FGA backfill)
  - Changes the displacement profile
  - Less displacement at the seventh block layer at smaller applied vertical stress
  - More compression at the top layer



Results:- Comparison with design methods: Lateral Displacement



A comparison of measured and predicted maximum lateral displacement during loading.

FHWA Method (Adam's method)

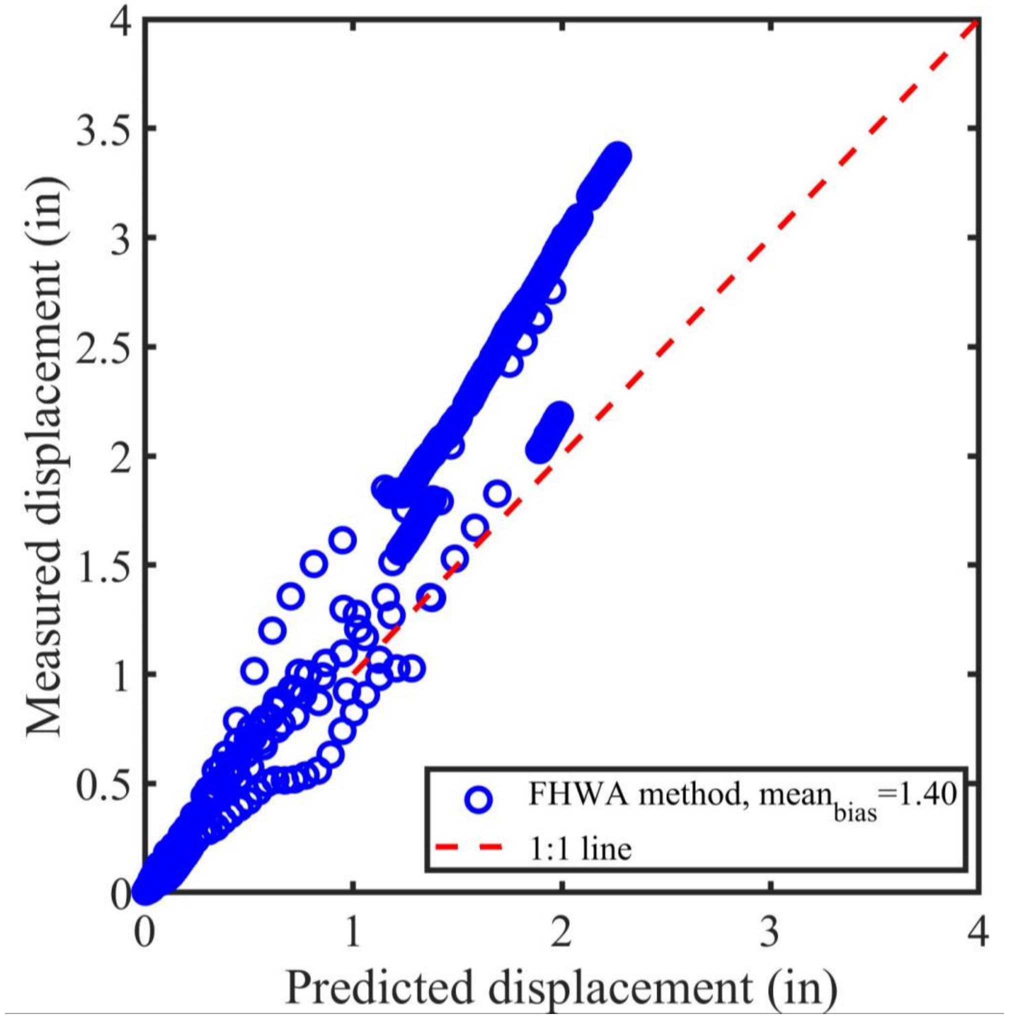
For abutment wall

$$D_L = \frac{2b_{q,vol}D_v}{H}$$

For pier walls

$$D_L = \frac{2b_{q,vol}D_v}{H} x \frac{1}{4}$$

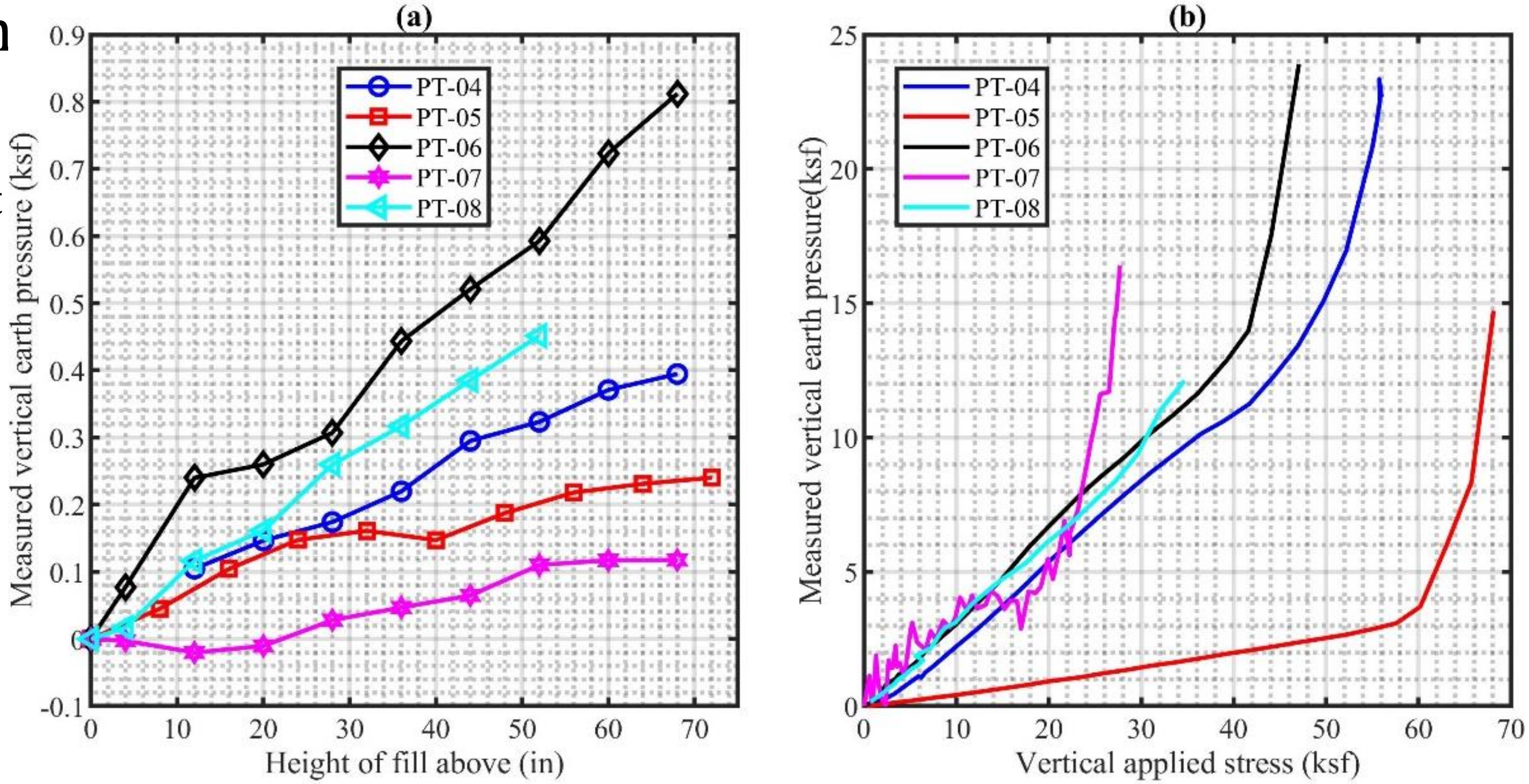
Where D_L is the maximum lateral deformation, D_v is the vertical settlement of GRS abutment, $b_{q,vol}$ is the width of the load along the top of the wall, and H is the height of the abutment.



A comparison of measured and predicted maximum lateral displacement (With outlier removed from PT-07)

Results:- Vertical Earth Pressure

- During construction
  - Earth pressure increases with an increase with fill height
  - Lowest pressure in PT-07 with FGA
- During loading
  - Earth pressure ⇑ applied vertical stress ⇑
  - Pressure fluctuations
    - FGA's pier
      - Crushing of particles



Earth pressure measured during construction and axial loading of the pier.
(a) During construction (b) During axial loading.

Results:- Comparison with design methods: Vertical Earth Pressure

2:1 Approximate method

$$\Delta\sigma_z = \frac{Q_v}{D_1(L+z)}$$

$$D_1 = b_f + z\ , for\ z \le z_1$$

$$D_1 = \frac{b_f + z}{2} + d, for\ z > z_1$$

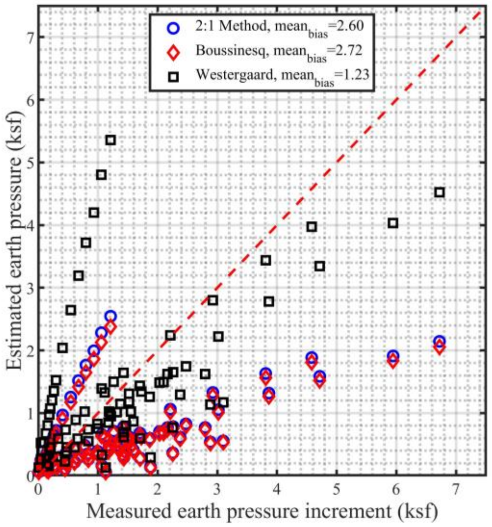
Boussinesq theory

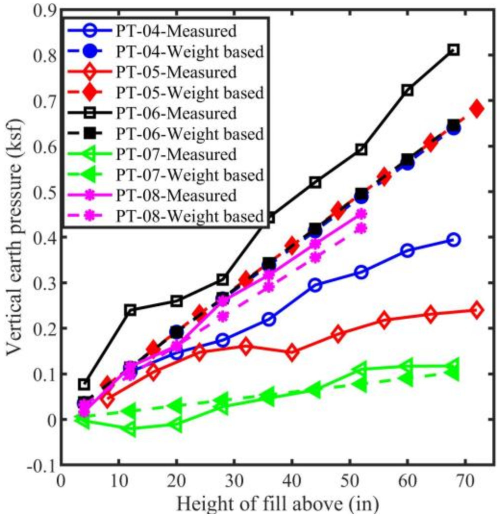
$$\Delta\sigma_z = \frac{q}{4\pi}\left[\left(\frac{2mn(m^2+n^2+1)^{0.5}}{(m^2+n^2+m^2n^2+1)}\right)\left(\frac{m^2+n^2+2}{m^2+n^2+1}\right) + \tan^{-1}\left(\frac{2mn(m^2+n^2+1)^{0.5}}{m^2+n^2-m^2n^2+1}\right)\right]$$

Westergaard solution

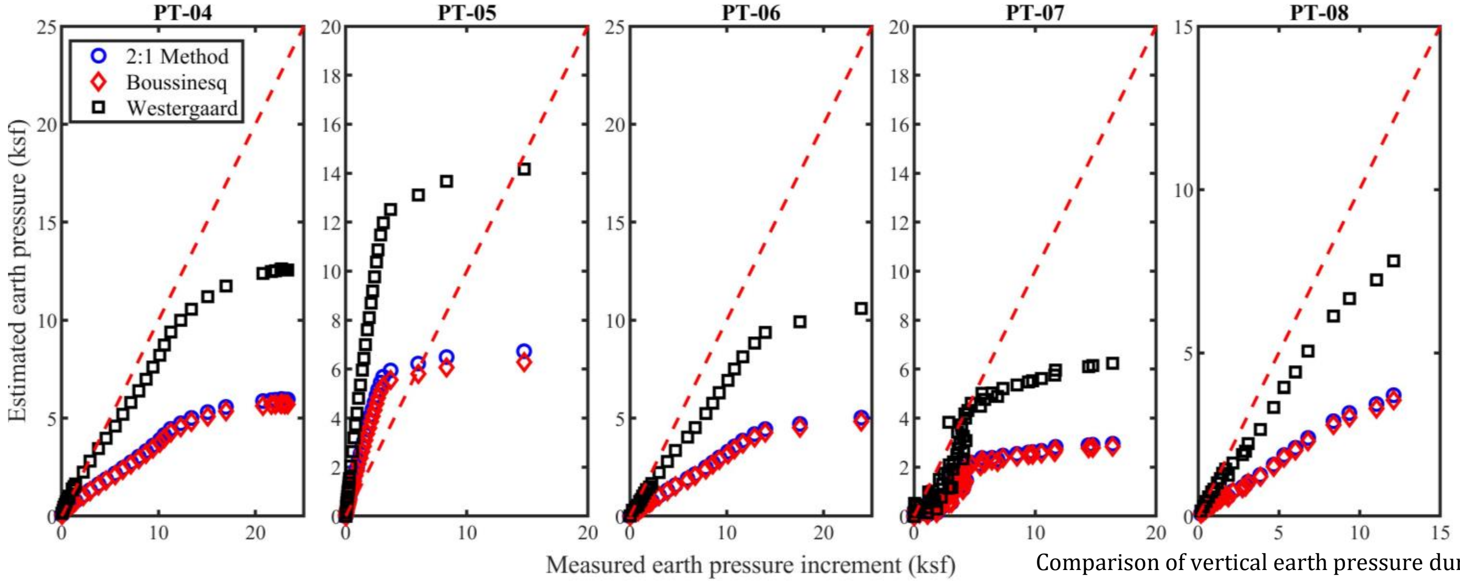
$$\Delta\sigma_z = \frac{q}{2\pi}\left\{\cot^{-1}\left[\eta^2\left(\frac{1}{m^2}+\frac{1}{n^2}\right)+\eta^4\left(\frac{1}{m^2n^2}\right)\right]^{0.5}\right\}$$

Comparison of vertical earth pressure during loading of GRS pier up to elastic range of the stress-strain response





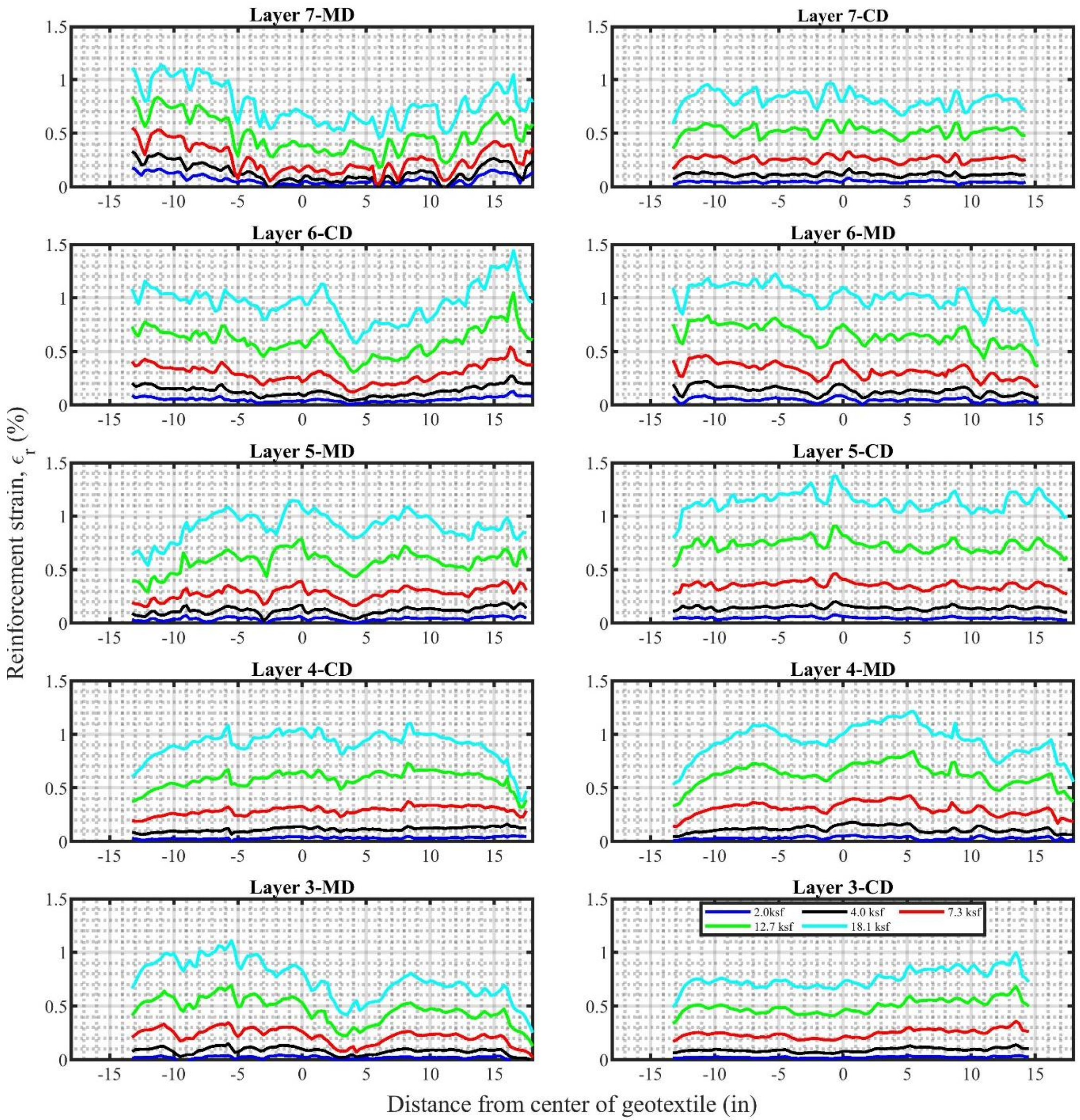
Comparison of vertical earth pressure during construction of GRS pier



Comparison of vertical earth pressure during loading of GRS pier

Results:- Reinforcement Strain

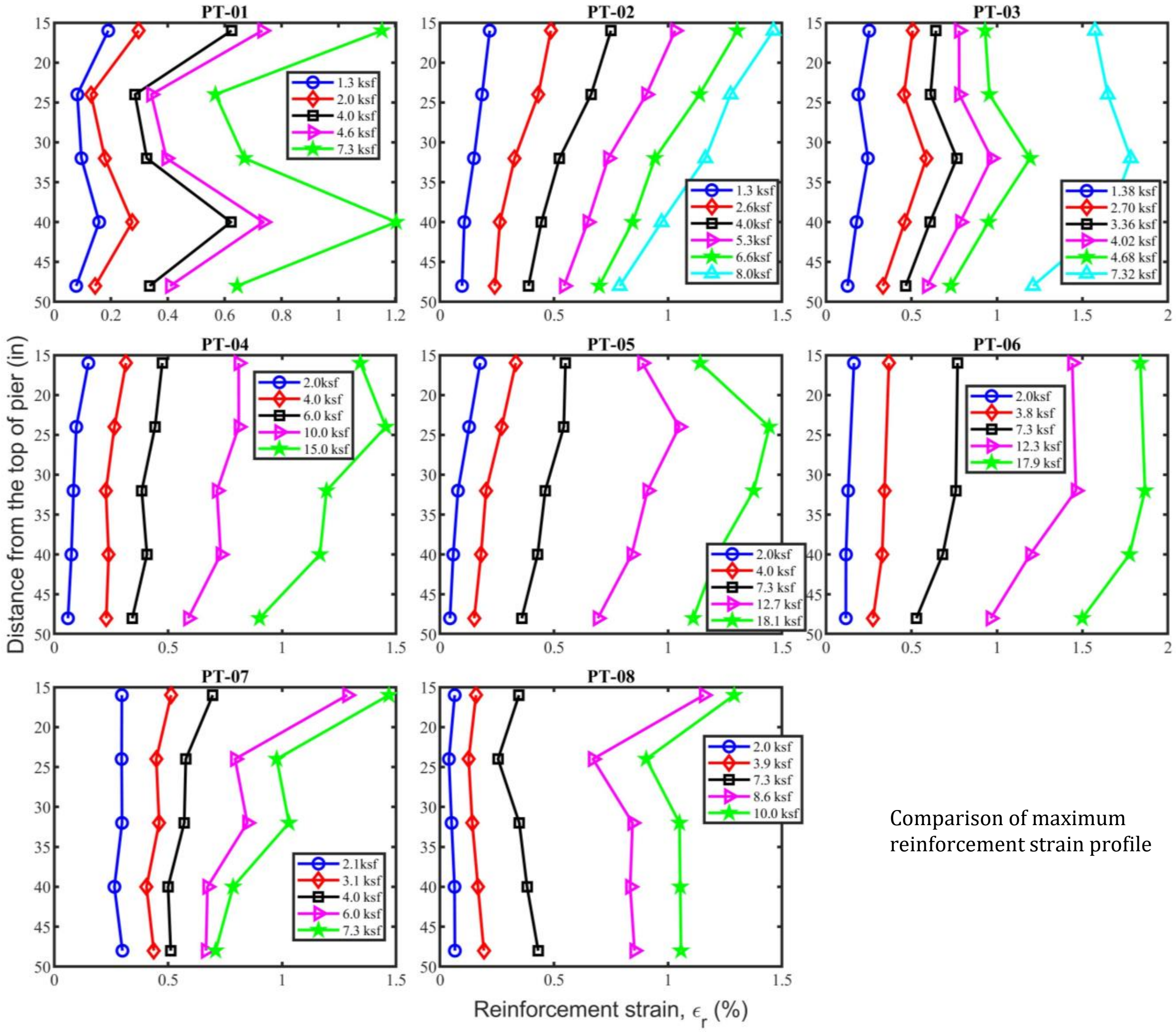
- Tensile strain ↑ Applied load ↑
- Upper layers (Layer 6 & 7)
  - Tensile strains were the greatest near the facing blocks
- Layer 4 & 5
  - Maximum strains were around the center of the geotextile within the soil mass
- Backfill stiffness
  - Affects the magnitude of tensile strain
  - Doesn't affect the nature of strain distribution



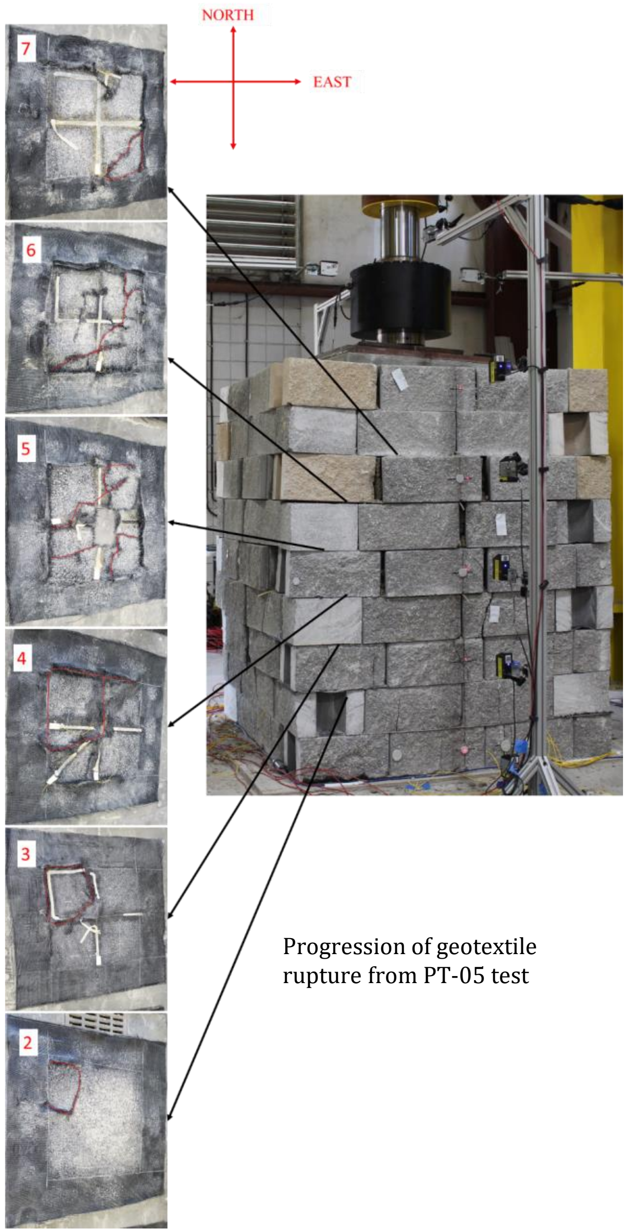
Reinforcement strain distribution in geotextile at different applied vertical stress for PT-05

Results:- Reinforcement Strain Profile

- Maximum reinforcement strain
  - Within the top half of the pier height
  - Initially appears at the seventh layer for lower vertical stresses but shifts to the sixth or fifth layer as more load is applied



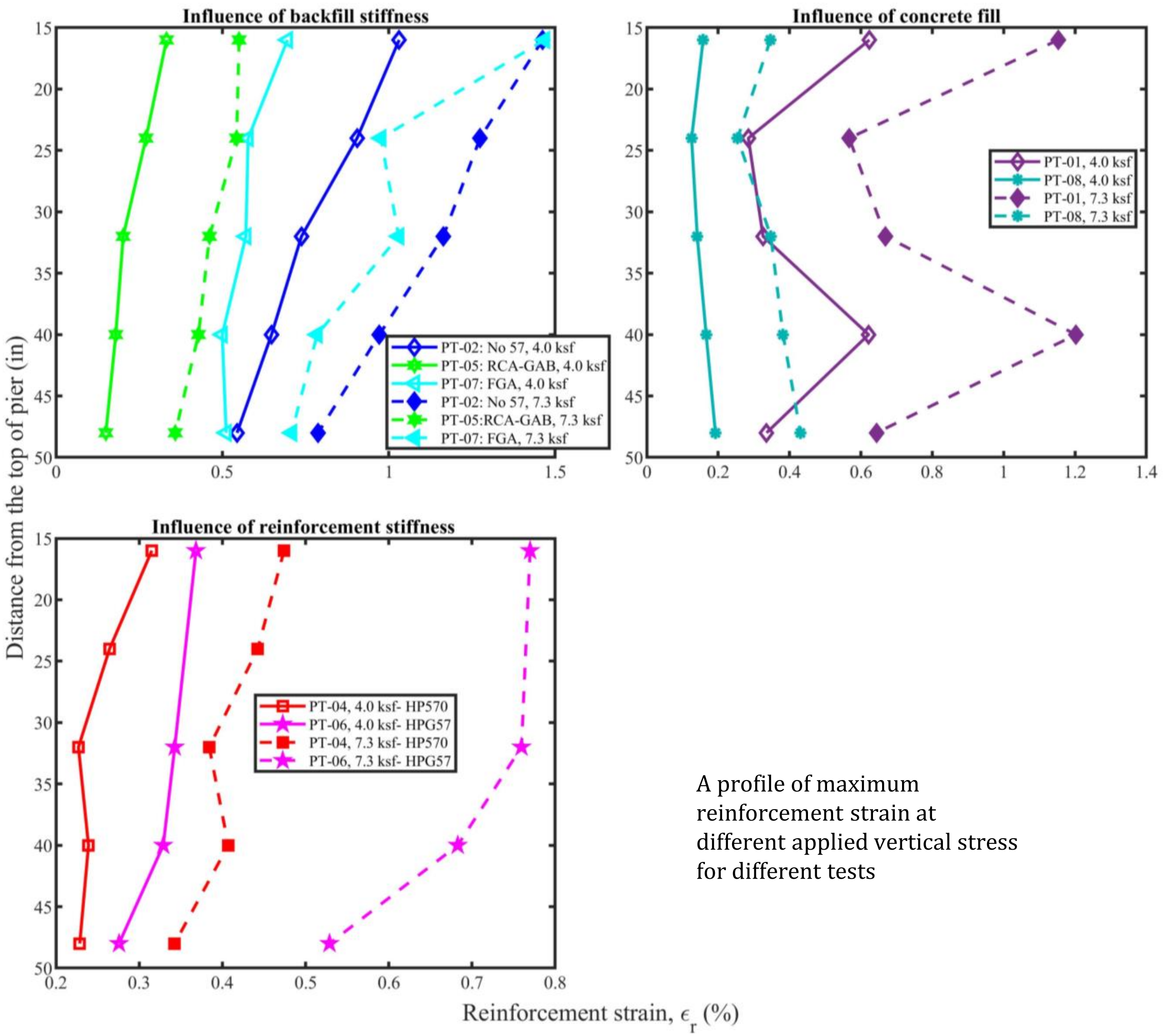
Comparison of maximum reinforcement strain profile



Progression of geotextile rupture from PT-05 test

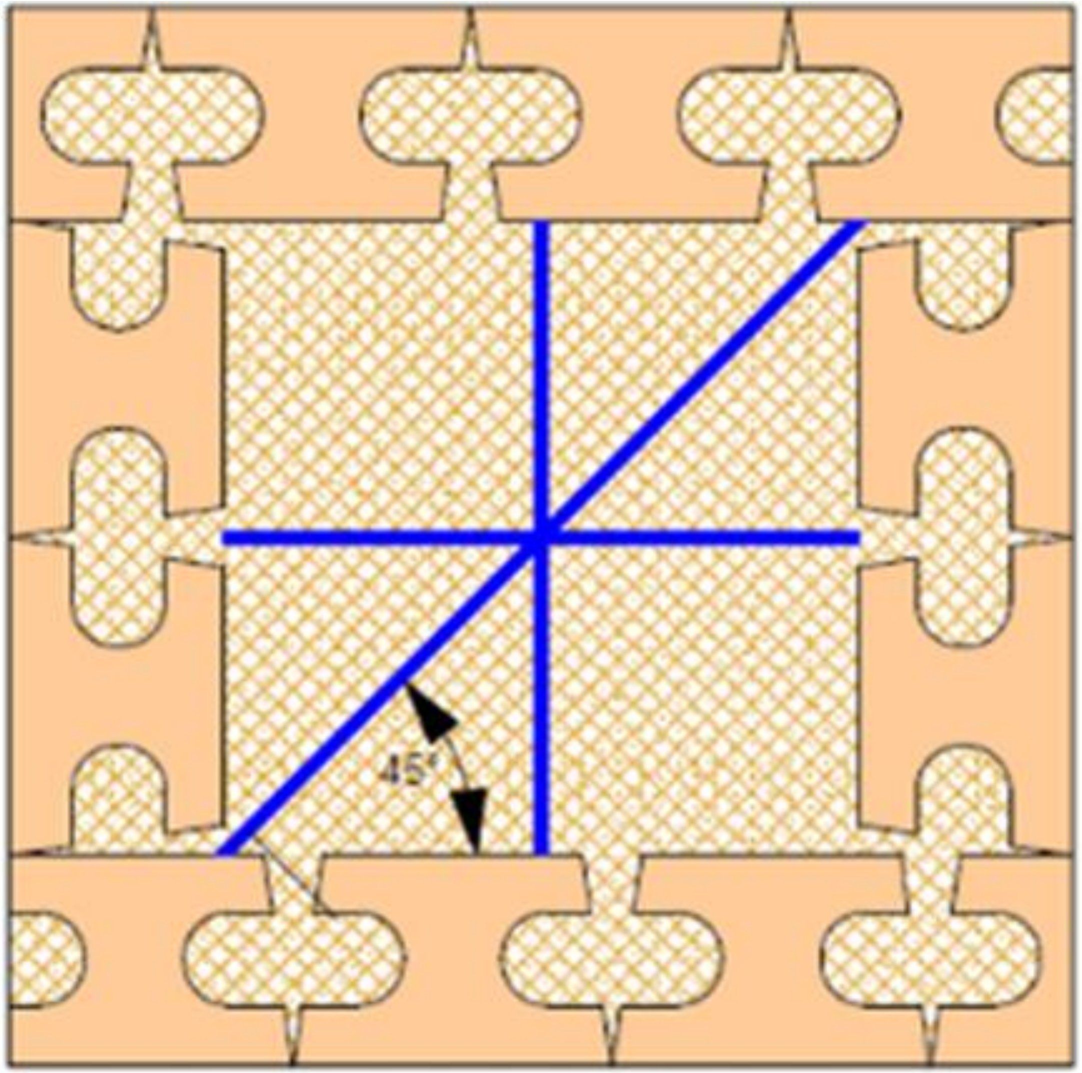
Results:- Reinforcement Strain Profile –Backfill and Reinforcement properties

- Higher backfill stiffness (RCA-GAB)
  - Small reinforcement strain
- Lower backfill stiffness (No 57 & FGA)
  - Greater reinforcement strain
- Higher reinforcement stiffness
  - Lower reinforcement strain
- Concrete fill (in PT-08)
  - Reduces reinforcement strains
  - Reduces the reinforcement strain at the top

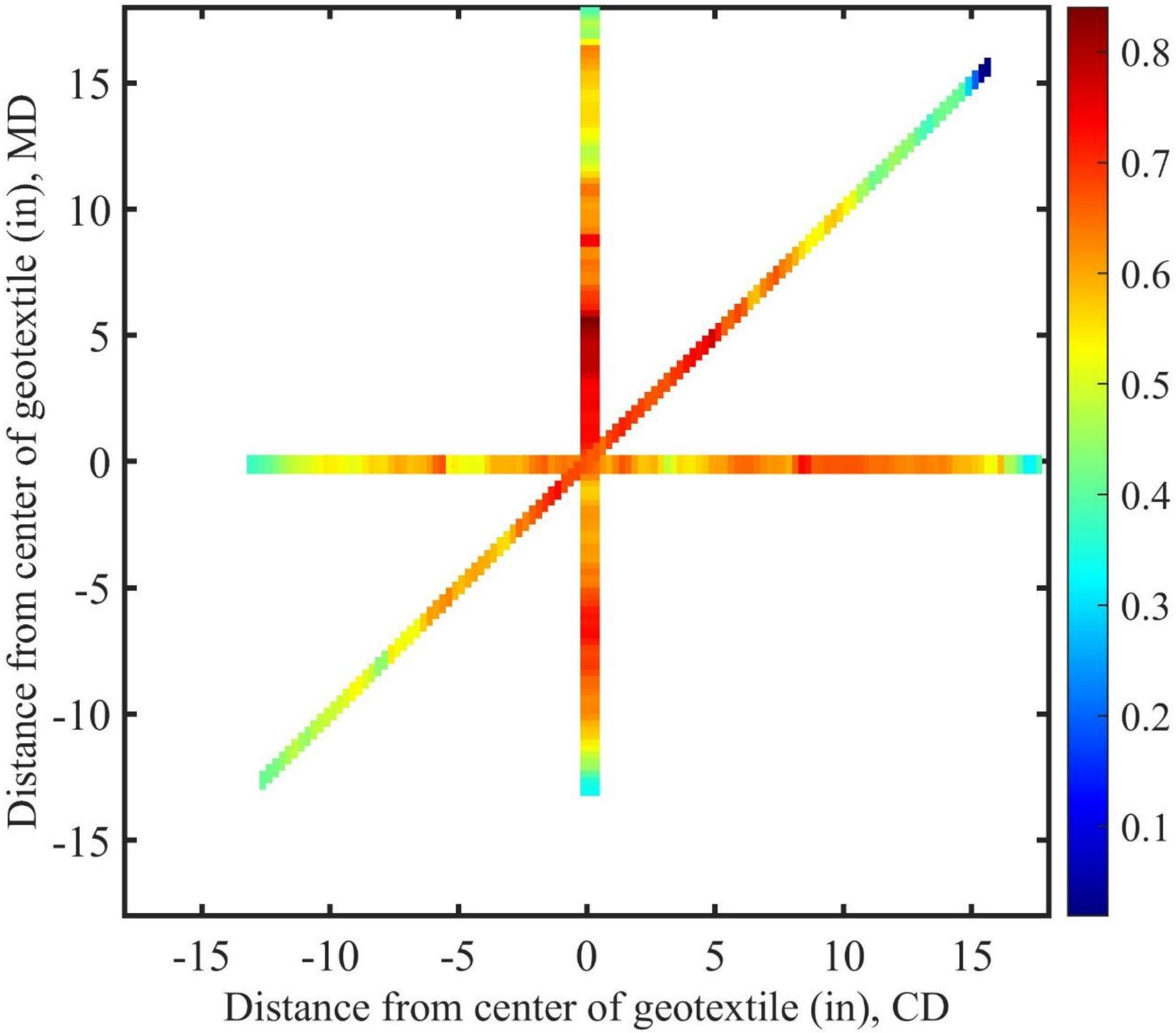


A profile of maximum reinforcement strain at different applied vertical stress for different tests

Results:- Reinforcement Strain at 4th layer



Reinforcement strain measurement in the fourth geotextile



Distribution of reinforcement strain in the fourth geotextile when the vertical applied stress is 12.7 ksf for PT-05

FAMU-FSU Engineering

Results:- Comparison with design methods: Reinforcement Strain

AASHTO Method

$$T_{max,i} = \sigma_H \times S_v$$

FHWA GRS-IBS Method

$$T_{req,i} = \left(\frac{\sigma_h - \sigma_c}{0.7^{\left(\frac{S_v}{6d_{max}}\right)}}\right) S_v$$

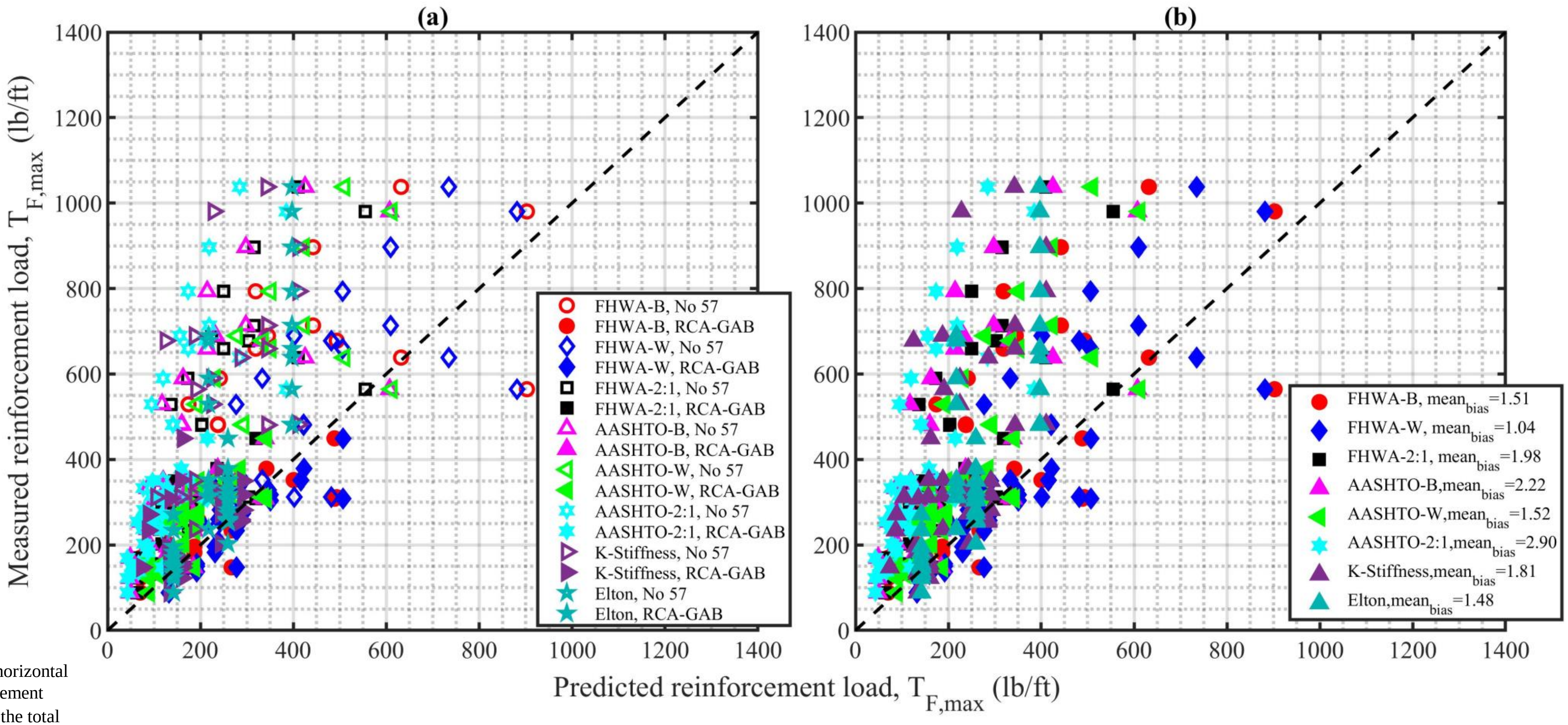
Elton and Patawaran (2005)

$$T_{max,AU} = (\sigma_V x K) x\, S_v x SDF$$

K-Stiffness Method (Allen and Bathurst (2003)

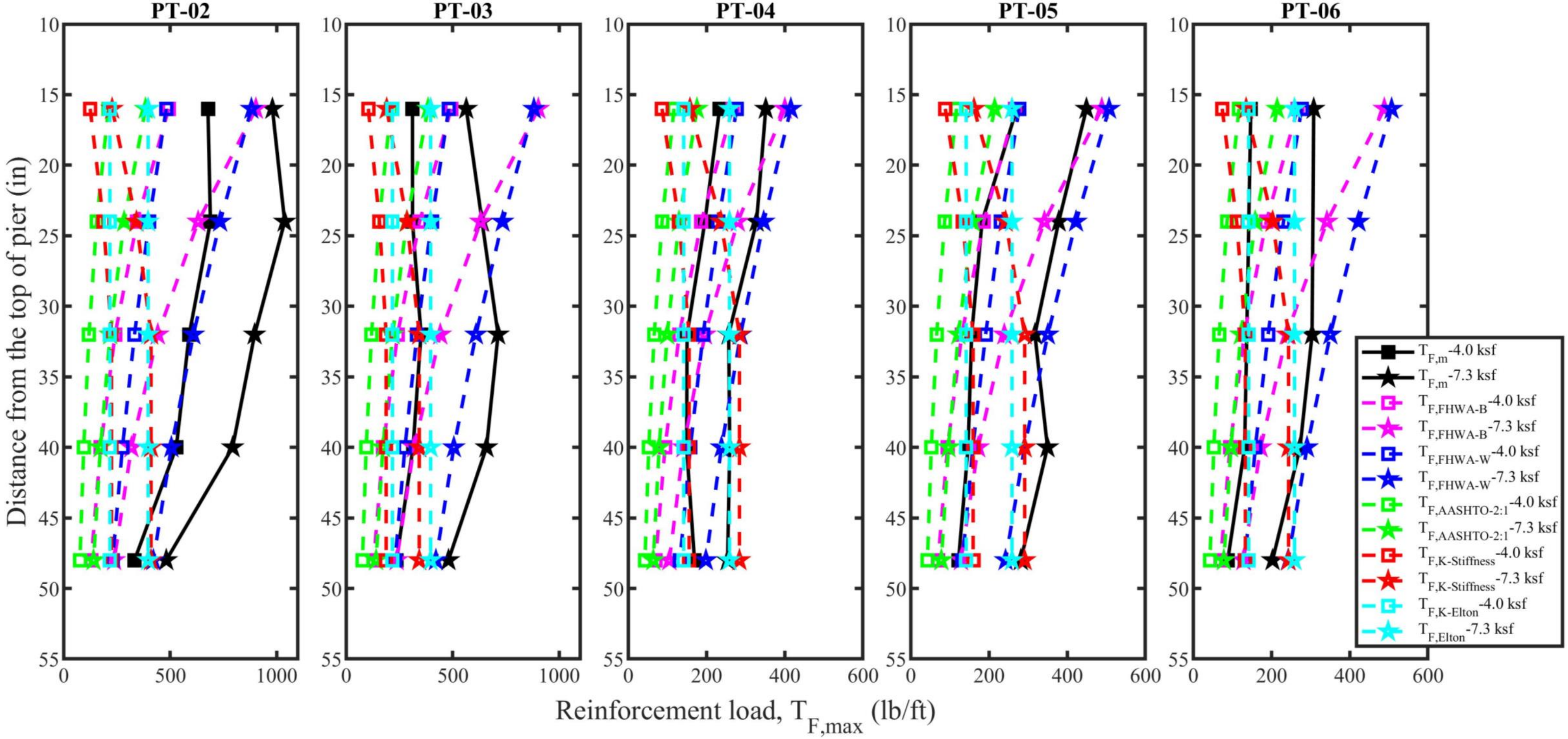
$$T_{max,i} = \frac{1}{2} K\gamma(H + S) S_v^i D_{tmax} \Phi$$

Where S_v is the vertical spacing of reinforcement, σ_H is the horizontal soil stress at the reinforcement, $T_{req,i}$ is the required reinforcement strength in the direction perpendicular to the wall face, σ_h is the total lateral stress within the GRS composite at a given depth and location, σ_c is the external confining pressure, d_{max} is the maximum particle size, Φ. Is the influence factor, D_{tmax} is the load distribution factor, S equivalent height of uniform surcharge pressure, γ is unit weight of the soil, H is height of the wall, K is lateral earth pressure coefficient, and SDV is strain distribution factor from the strain distribution curve



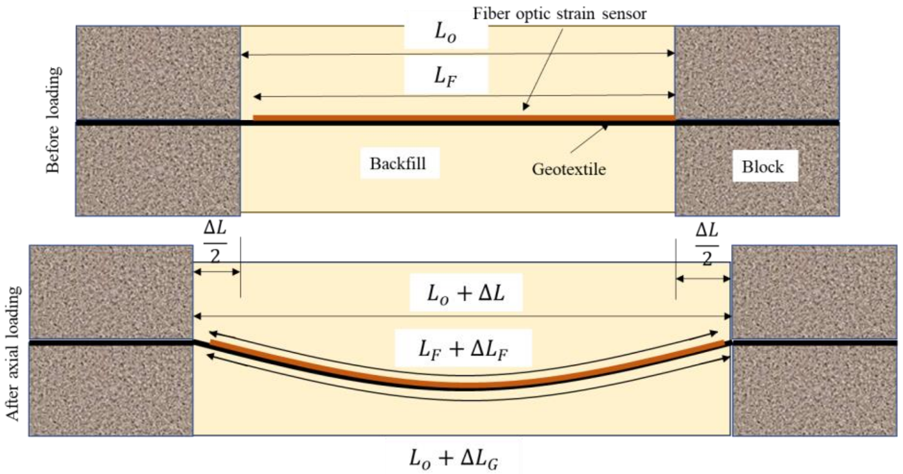
A plot of measured versus predicted reinforcement load. (a) Based on backfill type; (b) All combined.
(FHWA-B is from reinforcement loads based on FHWA and Boussinesq method, FHWA-W is from reinforcement loads based on FHWA and Westergaard solution, FHWA-2:1 is from reinforcement loads based on FHWA and approximate 2:1 method, AASHTO-B is from reinforcement loads based on AASHTO and Boussinesq method, AASHTO-W is from reinforcement loads based on AASHTO and Westergaard solution, and AASHTO-2:1 is from reinforcement loads based on AASHTO and approximate 2:1 method).

Results:- Comparison with design methods: Reinforcement Strain



Comparison of the estimated and predicted reinforcement load profile

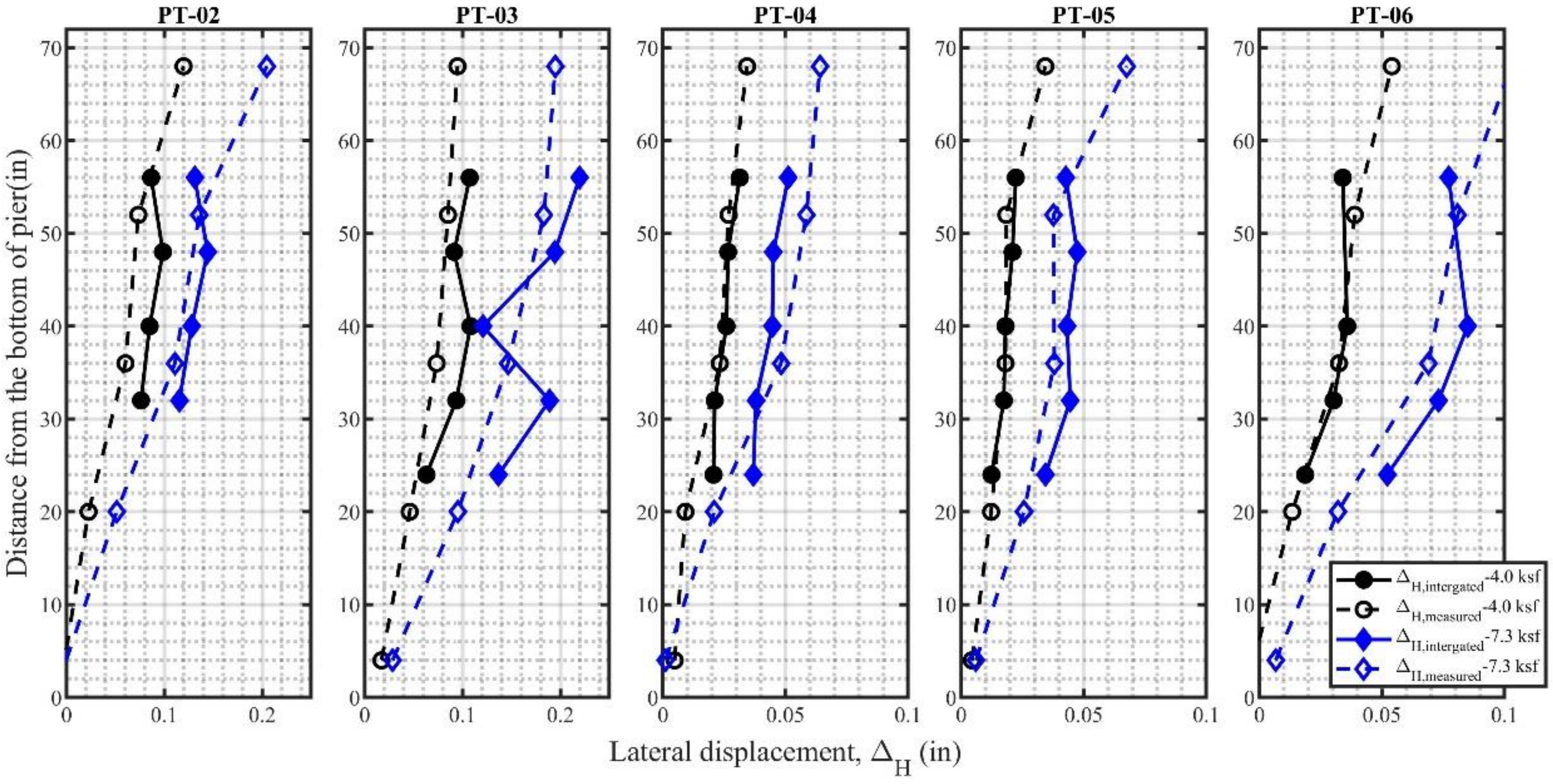
Results:- Comparison with design methods: Reinforcement Strain Displacement



Lateral displacement from reinforcement strain

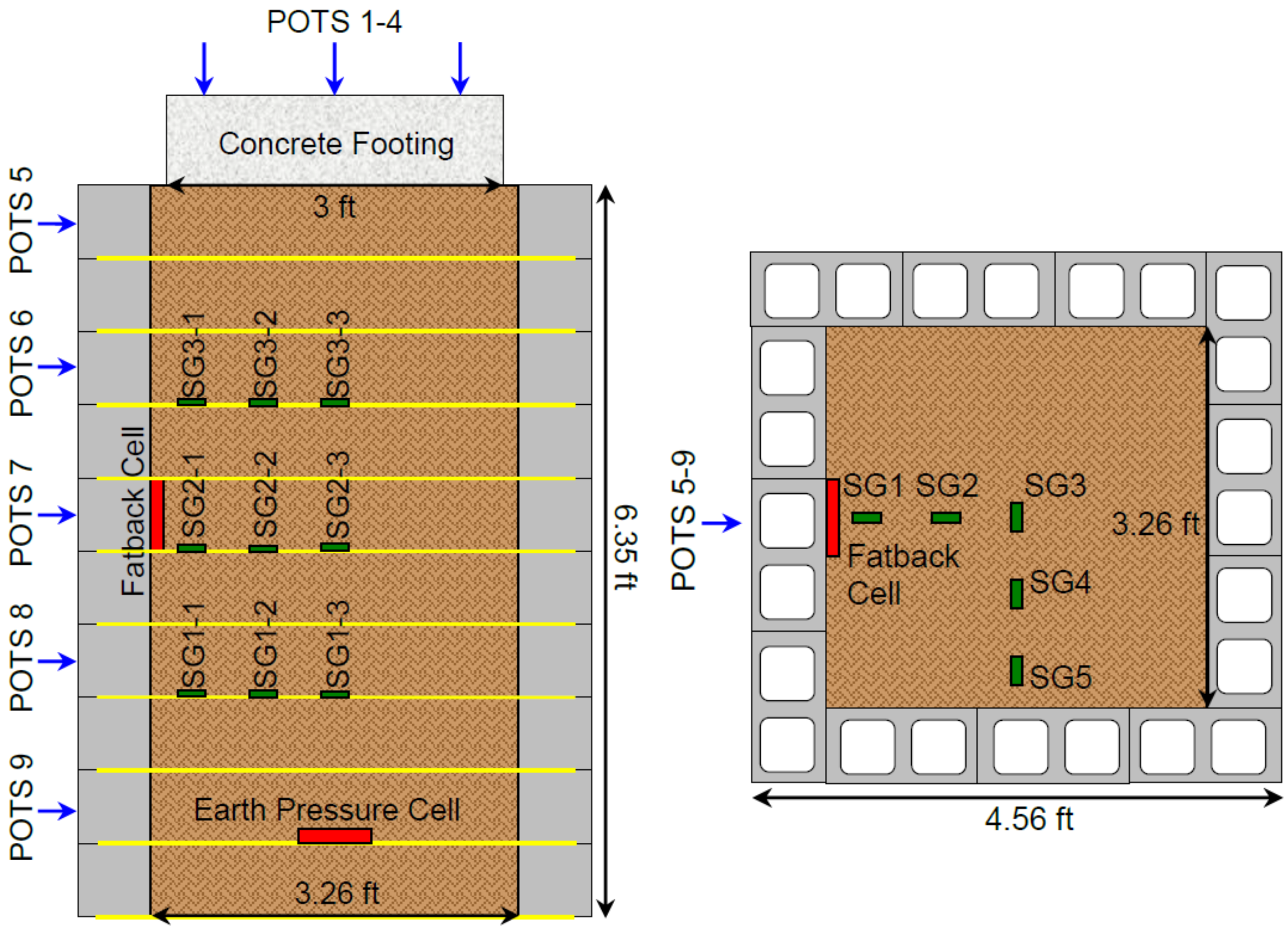
$$\Delta_{H_{integrated}} = \Delta L_F = \int_0^{L_F} \varepsilon_r \, \mathrm{d}x$$

Where ε_r is the measured reinforcement strain, L_F is the total length of section that fiber optic strain sensor is being considered, and $\Delta_{H_{integrated}}$ is the computed lateral displacement from measured reinforcement strain.



Comparison of lateral displacement estimated from the integration of reinforcement strain with measured lateral displacement at different applied vertical stresses

Results:- Comparison with Other Experiments: FHWA GRS Piers



Plan and profile schematic of TF-6 (Lwamoto, 2014)

Comparison of applied vertical stress versus average vertical strain (Nicks et al, 2013))

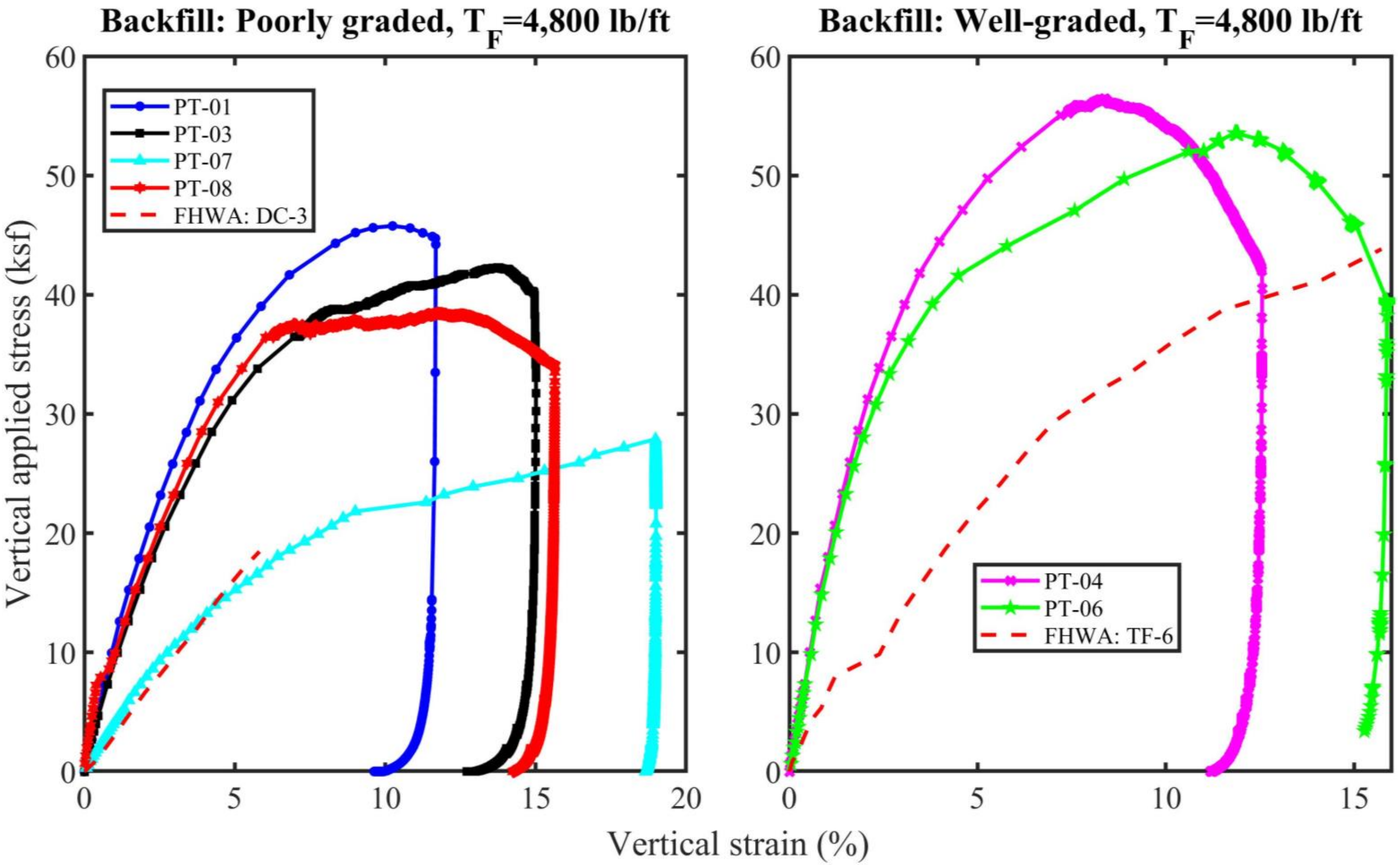
FAMU-FSU Engineering

Results:- Comparison with Other Experiments: FHWA GRS Piers

Parameter	FDOT	FHWA ((Nicks et al, 2013))
Height (in)	72	76.25
Inside width (in)	36	39.25
S_v (in)	8	8
T_F (lb/ft)	4,800	4,800
Facing block type	SGR	CMU
Block size	8 x 12 x 18	7.625 x 7.625 x 15.625
Block weight (lb)	86	42
Backfill: Well graded		
Friction angle (deg)	47.3[b]	54[a]
Cohesion (psf)	2,148.6[b]	115[a]
Max dry unit weight (pcf)	115.9	148.9
Backfill: Open-graded		
Friction angle (deg)	54.4[a]	52[a]
Cohesion (psf)	0	0
Max dry unit weight (pcf)	96.17	108.69

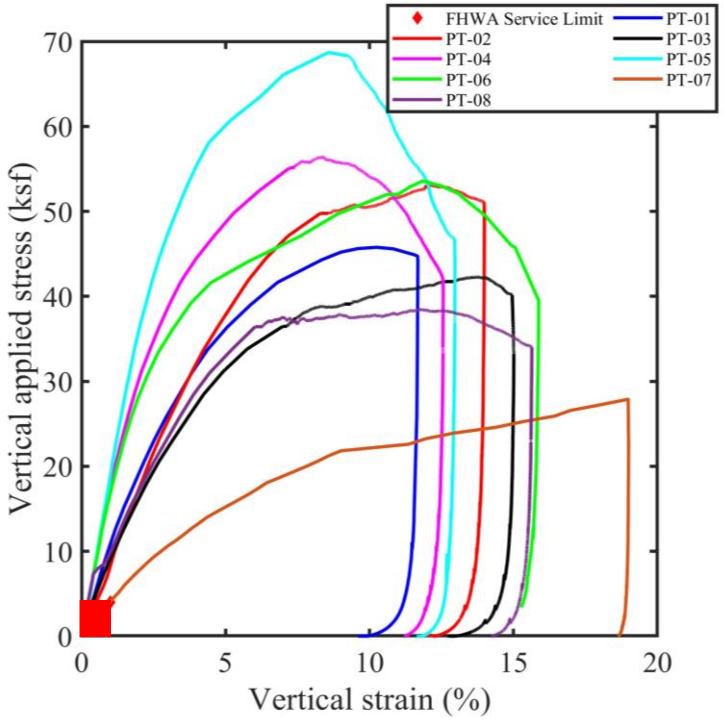
[a] :based on 12 x12 large direct shear test

[b] :based on 4-inch diameter triaxial tests

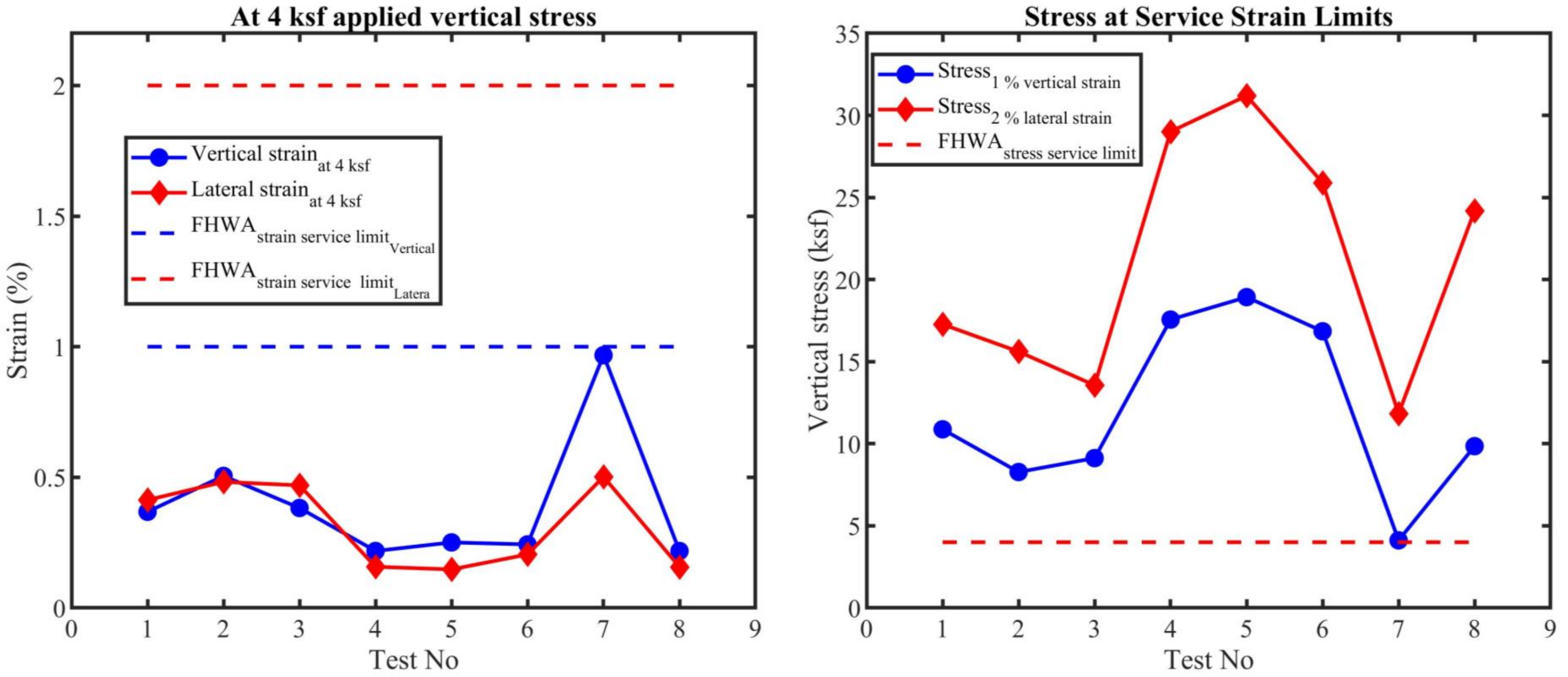


Comparison of applied vertical stress versus average vertical strain

Findings and Conclusions: At FHWA Service Limits



Stress and vertical strain at FHWA service limits



Stress and strain at FHWA service limits

- GRS piers performed well at service limits

- At 4 ksf
  - Vertical strain were less than 1 %
  - Lateral strain were less than 0.51 %

- At 1 % vertical strain
  - Applied vertical stress (4.1-19 ksf)
- At 2 % lateral strain
  - Applied vertical stress (11-32 ksf)

Findings and Conclusions

- Influence of aggregate and geotextile:
  - GRS piers constructed with high strength geotextiles (HP 770) exhibited higher load capacity than those with low strength geotextiles (HP 570 and HPG 57).
  - GRS piers constructed with well graded RCA-GAB exhibited higher load capacity and stiffness than those with poorly graded No 57.
  - GRS piers constructed with RCA-GAB aggregate exhibiting less lateral displacement than those constructed with No 57 aggregate.
  - Reinforcement strain distribution independent of aggregate type.
  - Less reinforcement strains in well graded RCA-GAB aggregate piers than poorly graded No 57 aggregate piers.

Findings and Conclusions

- Concrete fill in top three courses of facing blocks provided additional confinement increasing pier stiffness and strain performance to about twice service pressure.
- Fiber optic strain sensors capture the strain distribution in the geotextile reinforcement and survive well into elastic range of pier response.
- The greatest strains generally developed around the center of the reinforcement layers, except in the upper layers where there was high strains near the facing blocks (highest lateral displacements before yielding).
- Integrated strain measurements estimate the lateral displacements.

Current Work

- Since larger particles were not removed during the construction phase, a large-scale triaxial test is being conducted without eliminating these larger particles in order to replicate the conditions of the pier.
- The Westergaard method predicts the tensile forces and is being analyzed for performance against other methods for extensible reinforcement.
- The ultimate capacity equation was found to underpredict the measured vertical capacity of the GRS pier tested in this study. The effects of bed reinforcement is being analyzed.

FAMU-FSU Engineering

Acknowledgements

- The researchers would like to thank:
  - Florida Department of Transportation (FDOT) for the financial support.
  - FDOT Marcus Structure Research Center for providing access and assistance in construction, instrumentation, and testing of the GRS piers.
  - FDOT State Material Office for their assistance in testing the materials.
  - Dr. Rawlinson at UF Structural lab for his assistance during the preparation of the materials and casting of the footing.
  - Michael Adams and Dr. Jennifer Nicks Adams at FHWA Turner-Fairbank Highway Research Center-Geotechnical Laboratory for their valuable inputs during design of the GRS piers and for conducting large direct shear tests of No 57 aggregate.

Project Timeline

Deliverable # / Description as provided in the scope (included associated task #) Project start date 2/27/2020	Anticipated Date of Completion	Status
Kickoff Teleconference	3/2020	Completed
Deliverable #1/ Task 1- Report on previous studies on GRS piers, design methods, and construction practices	7/1/2020	Completed
Deliverable #2/Task 2 – Report on the design experimental plan for GRS performance tests	10/1/2020	Completed
Deliverable #3a/Task 3 – Report on GRS performance tests (axial load-deformation tests)	4/1/2022	Completed
Deliverable #3b/Task 3 – Report on GRS performance tests (axial load-deformation tests)	6/1/2023	Completed
Deliverable #3c/Task 3 – Report on all GRS performance tests (axial load-deformation tests)	07/2023	Completed
Deliverable #4/Task 4- Report on comparison of GRS performance test results with published results and predictions based on available design methods	10/2023	In-progress
Deliverable #5/ Task 5 –Draft final report: a comprehensive description of the work performed and will include a summary of piers tested: including dimensions (H/B), facing elements, geosynthetics, and aggregates as well as all measured results. Also provided will be a comparison of the pier's measured and predicted axial capacities and recommendations on their construction and design with Florida aggregates.	10/31/2023	In-progress
Deliverable #6a/Task 6 – PowerPoint presentation- closeout teleconference to review project performance, the deployment plan, and next steps.	11/2023	
Deliverable #6b/Task 6 – Final Report to the FDOT	01/31/2024	

References

- Adams, M., Nicks, J. (2018). Design and Construction Guidelines for Geosynthetic Reinforced Soil Abutments and Integrated Bridge Systems, Report No. FHWA-HRT-17-080. Federal Highway Administration, Washington, DC.
- Adams, M.T., Nicks, J.E., Stabile, T., Wu, J.T.H., Schlatter, W., and Hartmann, J. (2012). Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide, Report No. FHWA-HRT-11-026, Federal Highway Administration, Washington, DC.
- Allen, T. M., & Bathurst, R. J. (2003). Prediction of reinforcement loads in reinforced soil walls (No. Final Research Report,). Washington State Transportation Center (TRAC).
- Daniyarov, A., Zelenko, B., Derian, A., 2017. Deployment of the Geosynthetic Reinforced Soil Integrated Bridge System from 2011 to 2017, Report No. FHWA-HIF-17-043. Federal Highway Administration, Washington, DC.
- Das, B.M., 2019. Advanced soil mechanics. CRC press.
- Doger, R., 2020. Influence of Facing on the Construction and Structural Performance of GRS Bridge Abutments. The University of Oklahoma.
- Elton, D. J., & Patawaran, M. A. B. (2005). Mechanically stabilized earth (MSE) reinforcement tensile strength from tests of geotextile reinforced soil. Alabama Highway Research Center, Auburn University.
- FDOT, 2020. Standard specifications for road and bridge construction. Florida DOT Tallahassee, FL.
- FDOT. (2021). Structures Manual: Volume 1 – Structures Design Guidelines.
- Lwamoto, M.K., 2014. Observations from load tests on geosynthetic reinforced soil. University of Hawaii at Manoa.
- Matemu, C. H., Wasman, S. J., & Jones, L. Axial Load Tests of Geosynthetic Reinforced Soil (GRS) Piers Constructed with Florida Limestone Aggregate and Woven Geotextile. In Geo-Congress 2023 (pp. 369-378).
- Nicks, J.E., Adams, M., Ooi, P., Stabile, T., 2013. Geosynthetic reinforced soil performance testing—Axial load deformation relationships, Report No. FHWA-HRT-13-066. Federal Highway Adminstration- Research, Development and Technology, McLean, VA.
- Wu, J. T. H. (2019). Characteristics of geosynthetic reinforced soil (GRS) walls: an overview of field-scale experiments and analytical studies. Transportation Infrastruct. Geotechnol. 6 (2), 138–163 (2019).

Thank You!