UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

DEPARTMENT OF CIVIL AND
COASTAL ENGINEERING

Performance Testing of GRS Test Piers Constructed with Florida Aggregates – Axial Load Deformation Relationships (BDV31 977-131)

Principal Investigator: Scott Wasman, PhD

Project Manager: Larry Jones, P.E.

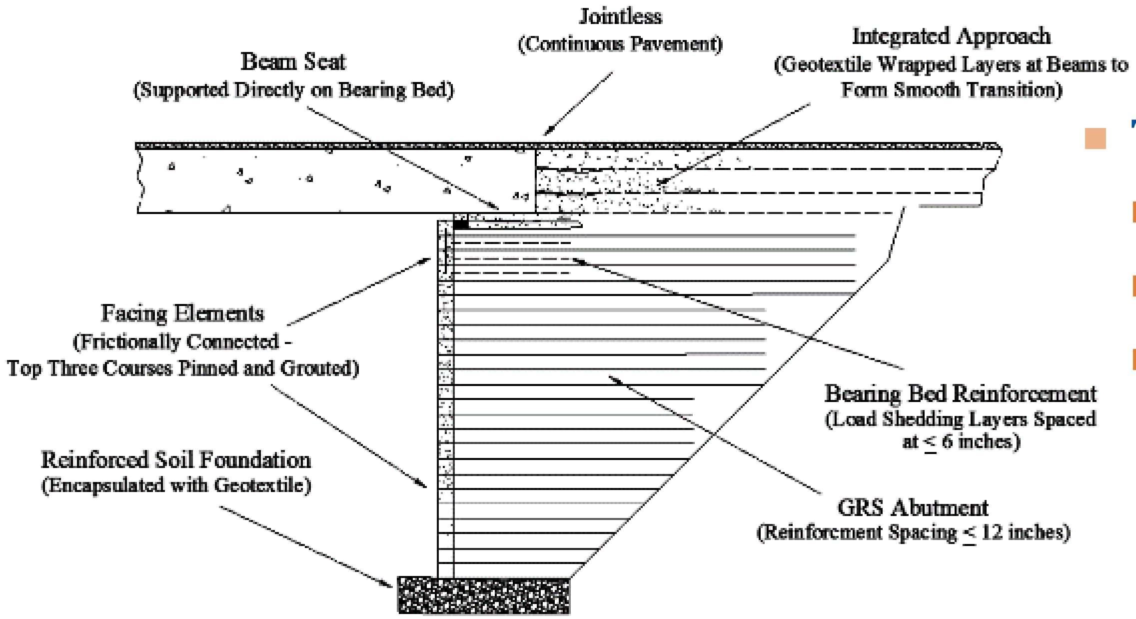
Graduate Assistant: Christian Matemu

Presentation Outline

- Introduction
- Research Motivation
- Project Objectives and Tasks
- Project Tasks 1, 2, and 3
- Project Timeline

Introduction: What is GRS-IBS?

- Consists of compacted fill and closely spaced (≤ 12 inches) geosynthetics reinforcement
- Stability and load carrying capacity
  - Close vertical reinforcement spacing & composite nature of geosynthetics and GRS backfill (typically aggregate) in distributing loads



Typical GRS-IBS cross section (Adams and Nicks, 2018)

- Typical GRS-IBS consist of:
  - Reinforced soil foundation (RSF)
  - GRS abutment
  - Integrated approach

Introduction: Why consider the GRS-IBS?

- Advantages
  - Lower cost & accelerated bridge construction
  - Smooth transition eliminating the “bump at bridge” problem
  - Flexible design
  - Nearly all-weather construction
  - Lower failure rates than MSE walls and earth retaining walls
- Limitations
  - Simple-span bridge with span length less than 140 ft and abutment height less than 30 ft
  - Service limit pressure up to 4000 lb/ft^2
- More than 300 bridges have been constructed with GRS-IBS in the USA

Research Motivation

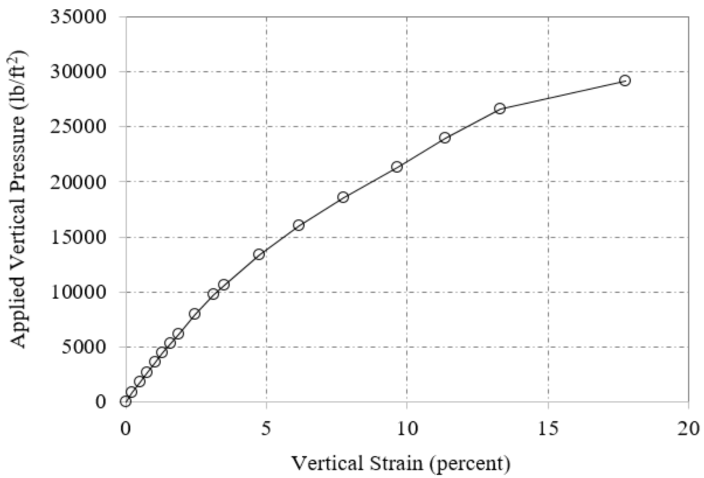
- Performance of GRS piers (experimental proxy for GRS-IBS) that utilize materials in Florida has not been evaluated
- GRS composite behavior depends on:
  - Reinforcement strength & spacing, aggregate size, friction angle, facing elements
- Identify axial loads at limiting service vertical and horizontal strains (ε_v = 1% and ε_H = 2%, respectively), as recommended by FHWA

Project Objectives and Tasks

- Objectives
  - 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
- Tasks
  - 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-IN PROGRESS
  - Task-4: Compare performance test results with previous results and predictions and make recommendations for GRS design in Florida
  - Task-5 and 6:Final reports and closeout teleconference

Task-1: Design Methods and Construction Practices

- FDOT requires LRFD design of GRS-IBS according to "***Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide***" FHWA-HRT-11-026, except as otherwise shown in the *FDOT Structures Design Guidelines.*
- Ultimate Capacity, Deformation and Reinforcement Strength
  - Empirical Method*
    - Performance tests
  - Analytical Method*
    - FHWA & NCHRP eqs.
- Materials
  - Backfill: granular materials
    - $d_{max} = 2\ inches, \Phi_{min} = 42°$
  - Reinforcement: biaxial geogrid or woven geotextile
    - $T_{f,min} = 4{,}800\ lb/ft$



Stress-strain curve for GRS composite (Adams and Nicks, 2018)

* Methods presented in GRIP 2020 presentation

Task-2: Design Experimental Plan for Performance

Experimental plan

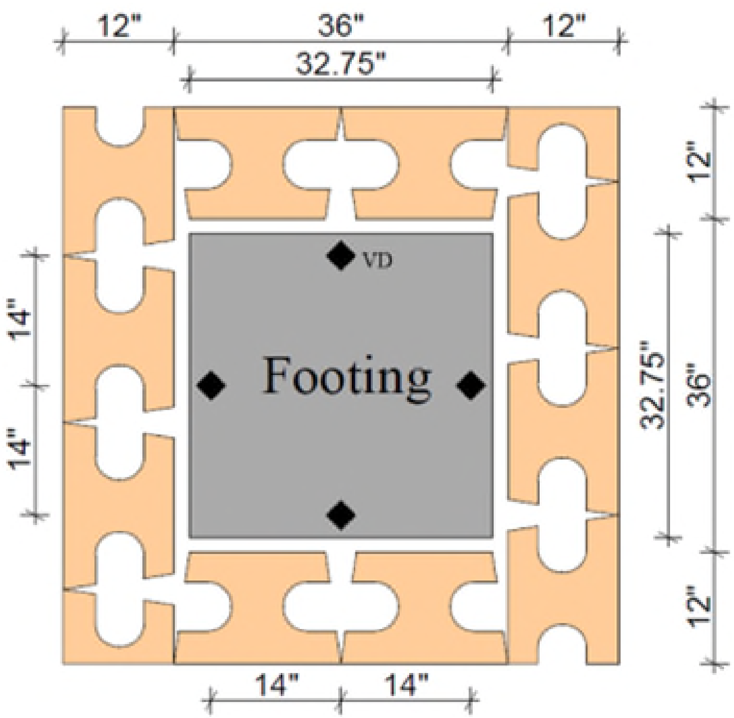
Test	Backfill	Reinforcement	T_f (lb/ft)	S_v (inch)	B (ft)	H/B	Status
PT-1	#57 stone	Biaxial woven geotextile [A]	4,800 x 4,800	8	3	2	Completed
PT-2	#57 stone	Woven geotextile [B]	7,200 x 5,760	8	3	2	Completed
PT-3	#57 stone	Biaxial woven geotextile [C]	4,800 x 4,800	8	3	2	Completed
PT-4	GAB	Biaxial woven geotextile [A]	4,800 x 4,800	8	3	2	Planned
GAB	TBD	Woven geotextile [B]	7,200 x 5,760	8	3	2	Planned
PT-6	GAB	Biaxial woven geotextile [C]	4,800 x 4,800	8	3	2	Planned
PT-7	TBD	TBD	4,800 x 4,800	4	3	2	Planned
PT-8	TBD	TBD	TBD	TBD	3	2	Planned

[A] Tencate Mirafi HP570, [B] Tencate Mirafi HP770, [C] Hanes Geo TerraTex HPG 57, TBD = To Be Decided based on results of each test series

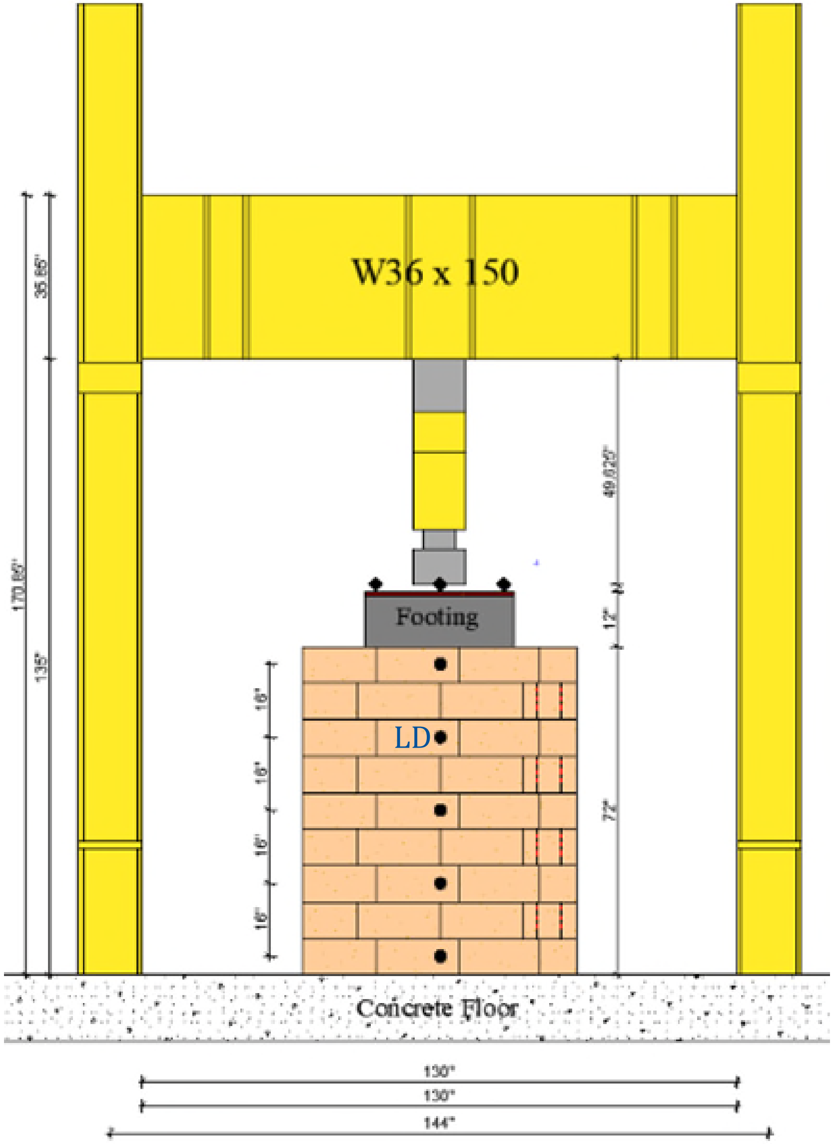
* Design of experiments was presented in GRIP 2021

Task-2: Design Experimental Plan for Performance Tests

- Test setup



Plan view of the pier



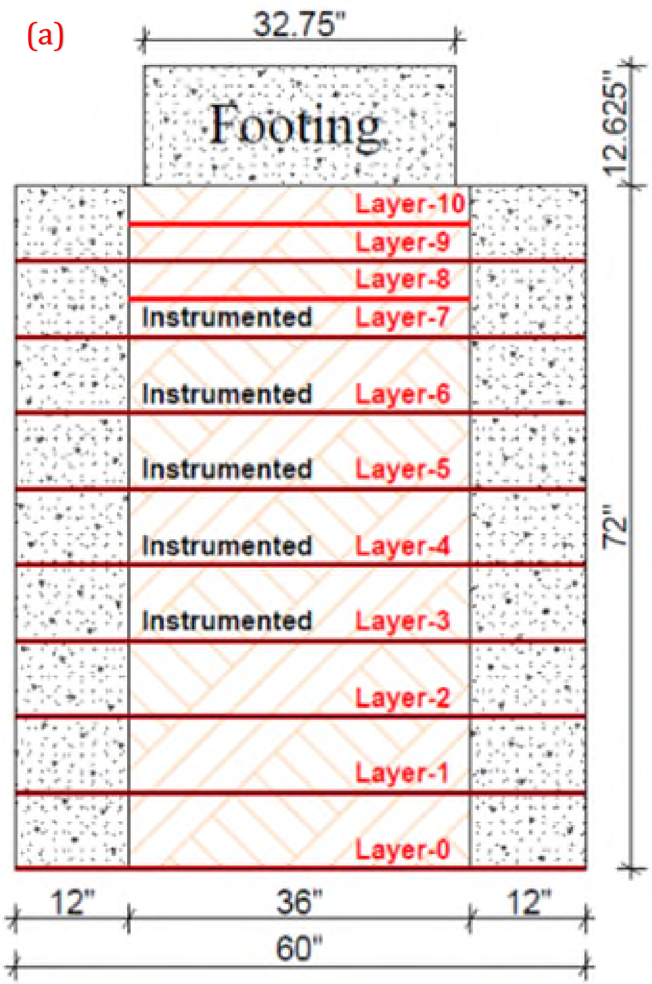
Reaction frame and pier

VD & LD: Instruments for measuring vertical and lateral displacement

Task-2: Design Experimental Plan for Performance Tests

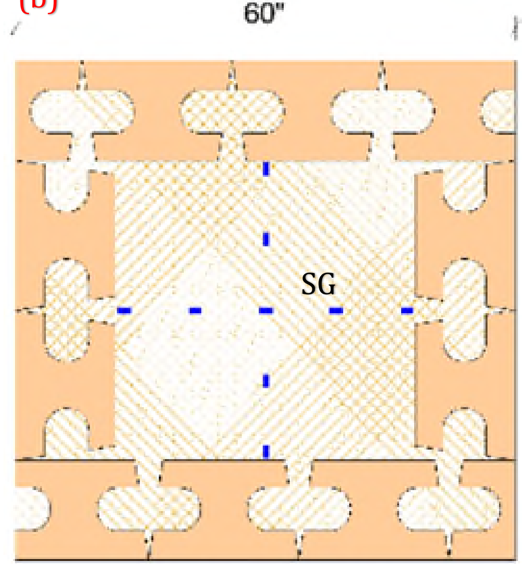
- Strain measurement

(a)

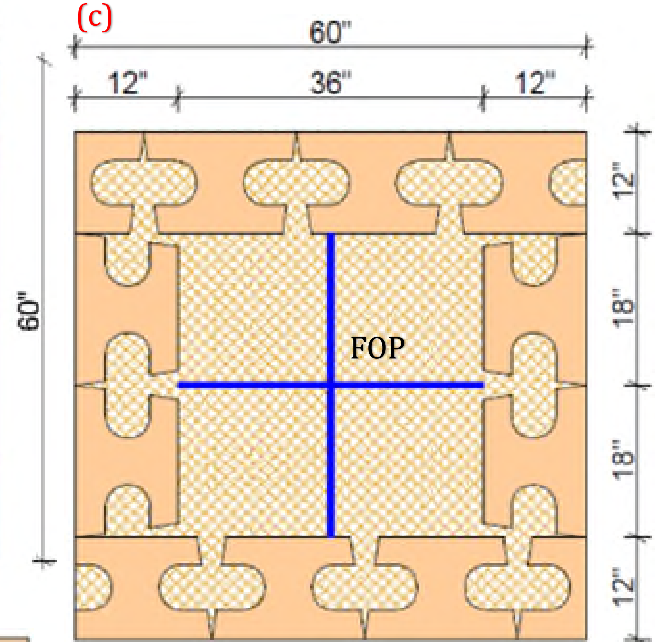


Profile view, 8-inch spacing Pier

(b)



(c)



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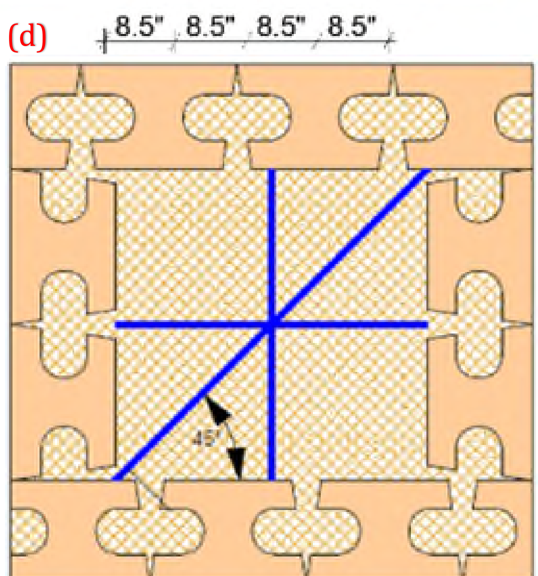


SG: Strain Gauge; **FOP**: Fiber optic cable

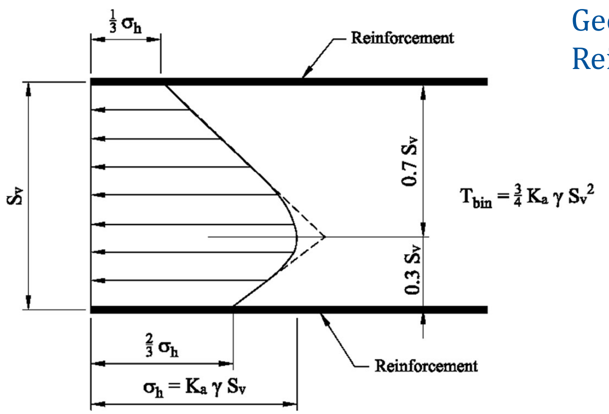
(b) Strain gauge layout (PT-1)
(c &d) Fiber optic cable layout (PT-2)

Strain gauge (EP-Type : Vishay Micro-Measurements):EP-08-250BG-120 & EP-08-500GB-120

Fiber Optic Cable: RTS125

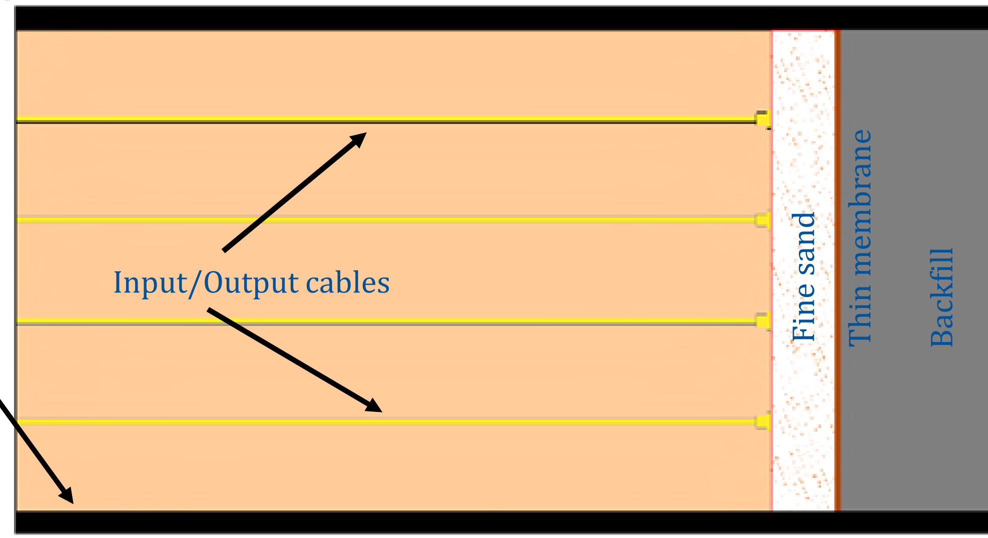
Task-2: Design Experimental Plan for Performance Tests

- Measuring earth pressure distribution

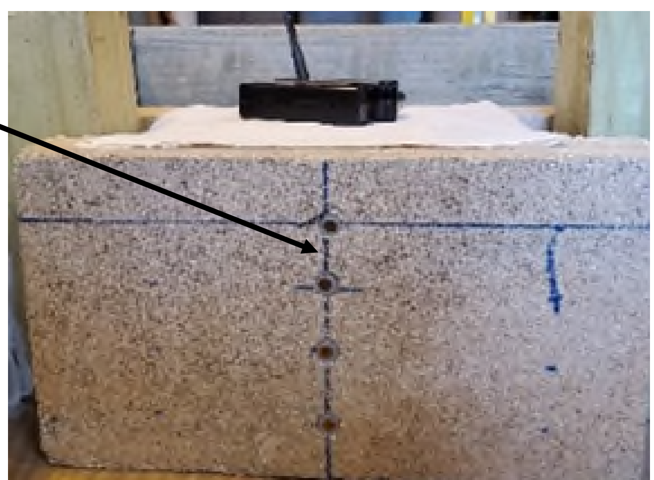


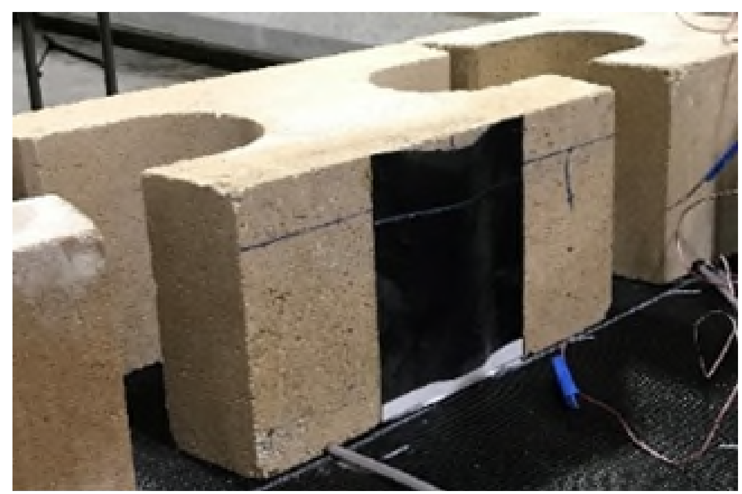
The bin pressure diagram (Wu, 2019)

Geotextile Reinforcement



Pressure Transducer (PDB-PB)

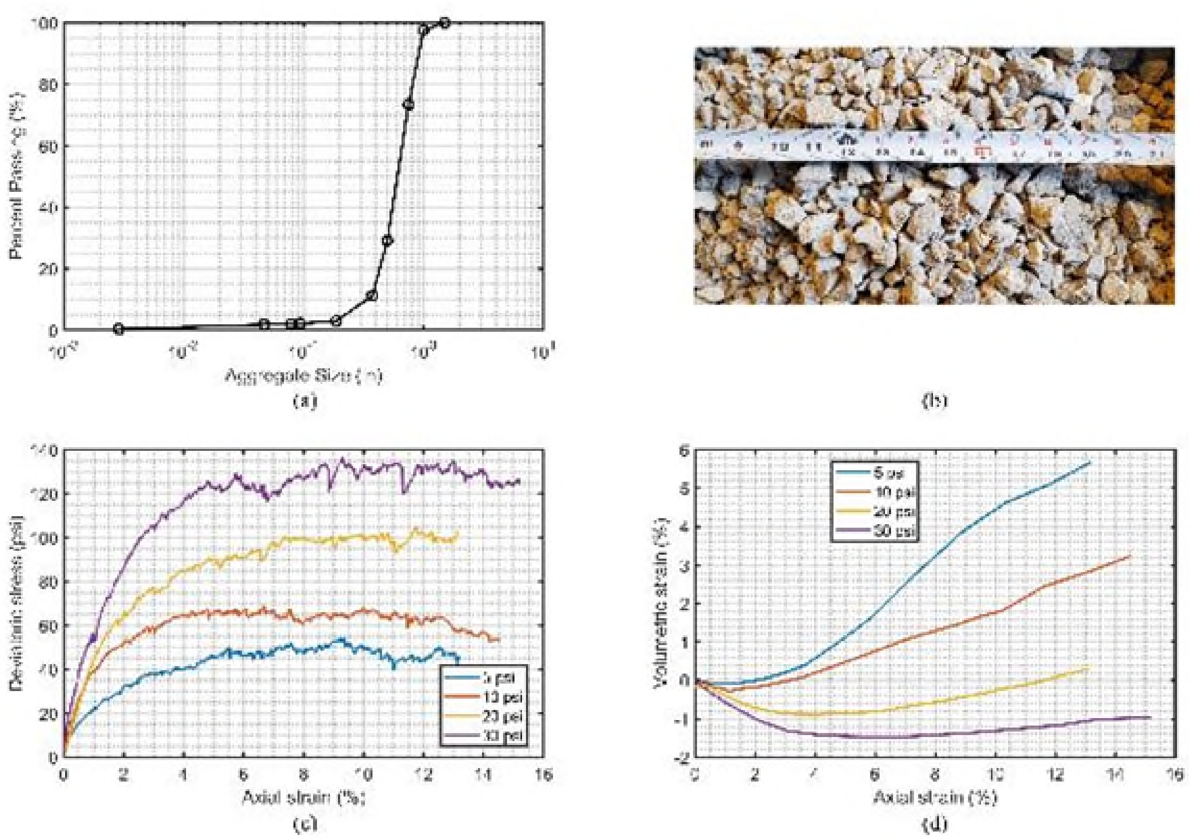




Installation of earth pressure transducer

Task-3: Axial load-deformation tests on GRS piers

- Material Testing
  - Aggregates



Maximum particle size, d_{max}=1.3”
Minimum density=83 pcf
Maximum density=97.5 pcf
Peak Internal friction angle,Φ=45.2°
Cohesion, C=0 kPa

Test	Relative density (%)
PT-01	95.9
PT-02	98.8
PT-03	94.4

Task-3: Axial load-deformation tests on GRS piers

Properties of Geotextiles

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

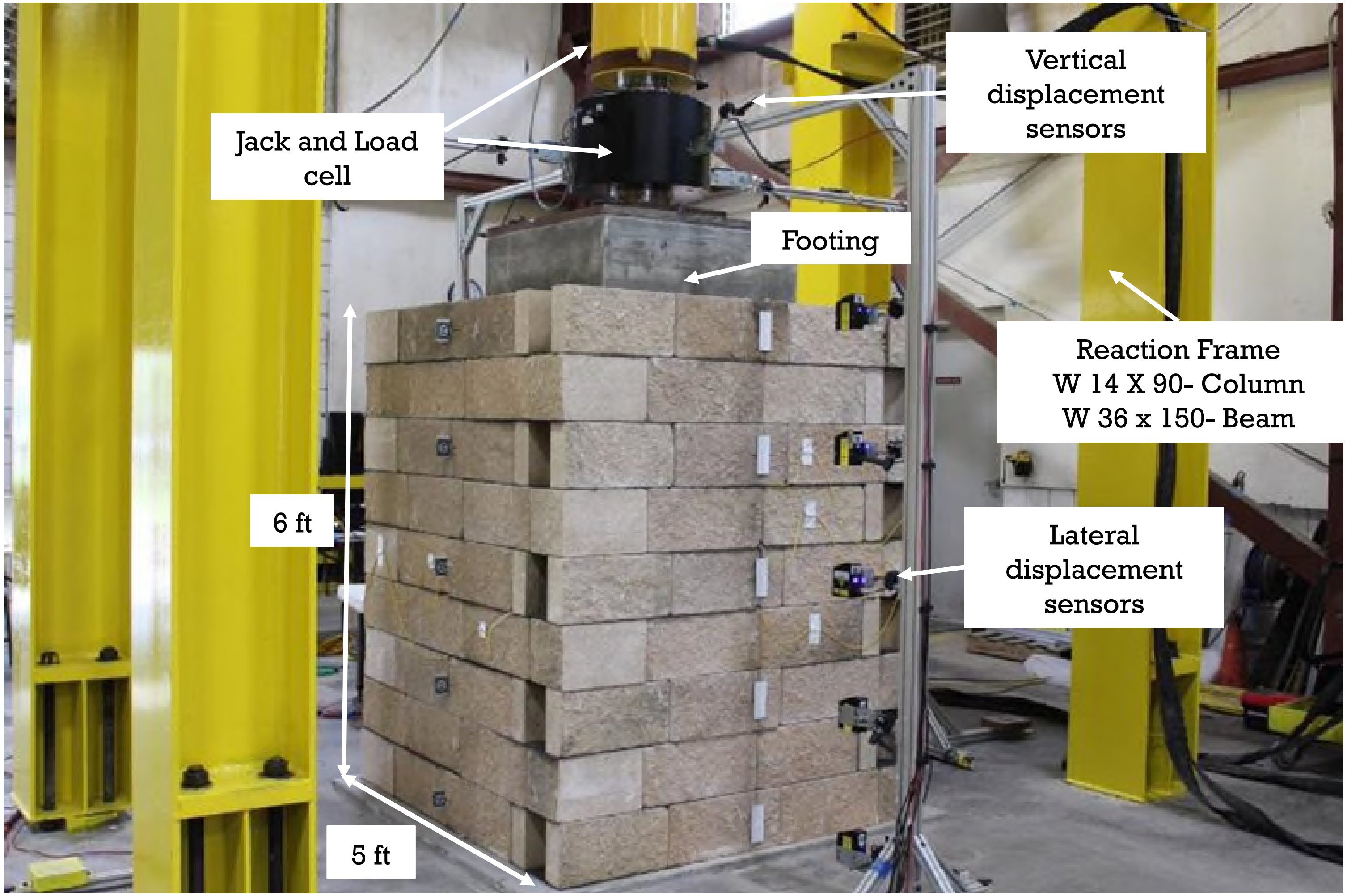
Task-3: Axial load-deformation tests on GRS piers

- GRS Pier Construction

GRS test pier construction steps. (a) 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

Task-3: Axial load-deformation tests on GRS piers

- External Instrumentation



Completed and instrumented pier before testing

Task-3: Axial load-deformation tests on GRS piers

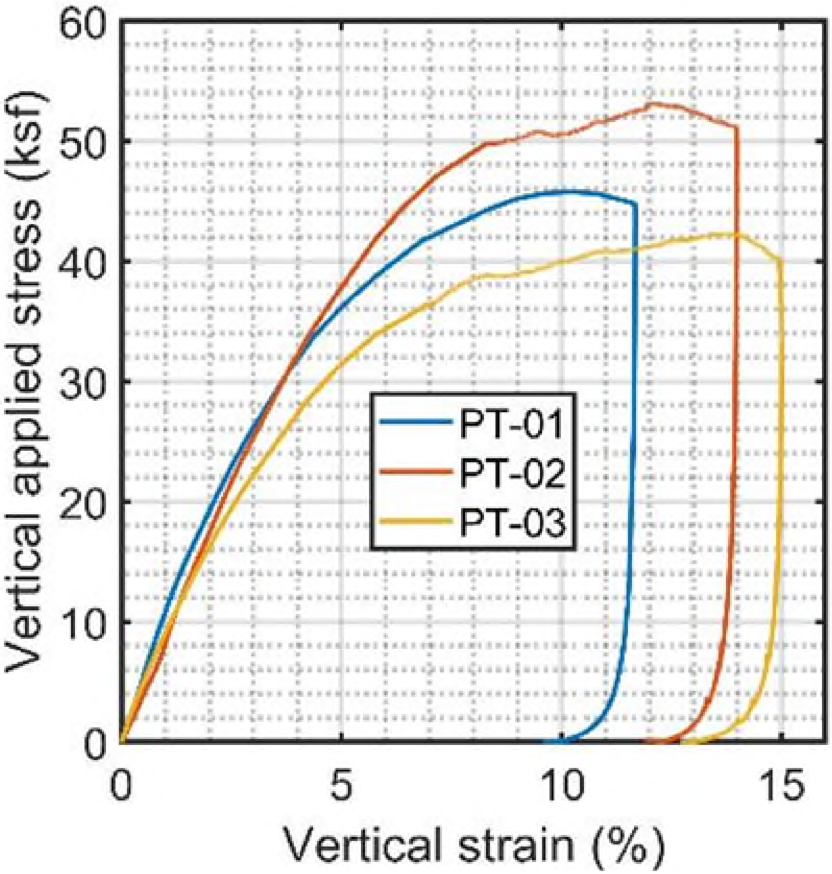
- Loading

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

Task-3: Axial load-deformation tests on GRS piers

- Experimental Results
  - Capacity and vertical displacements

Top view of the failed pier after the test



A plot of applied vertical stress versus average vertical strain for both tests

Task-3: Axial load-deformation tests on GRS piers

- Experimental Results
  - Capacity and vertical displacements
    - Strength limit

Test	Ultimate Capacity (ksf)		Measured/ Predicted
	Maximum Measured	Predicted	
PT-01	45.75	30.01	1.52
PT-02	53.13	44.71	1.19
PT-03*	42.29	30.01	1.41

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

$$K_{pr} = tan^2\left(45 + \frac{\Phi_r}{2}\right) \qquad \sigma_c = \gamma_b d \tan\delta$$

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

  - Service limit

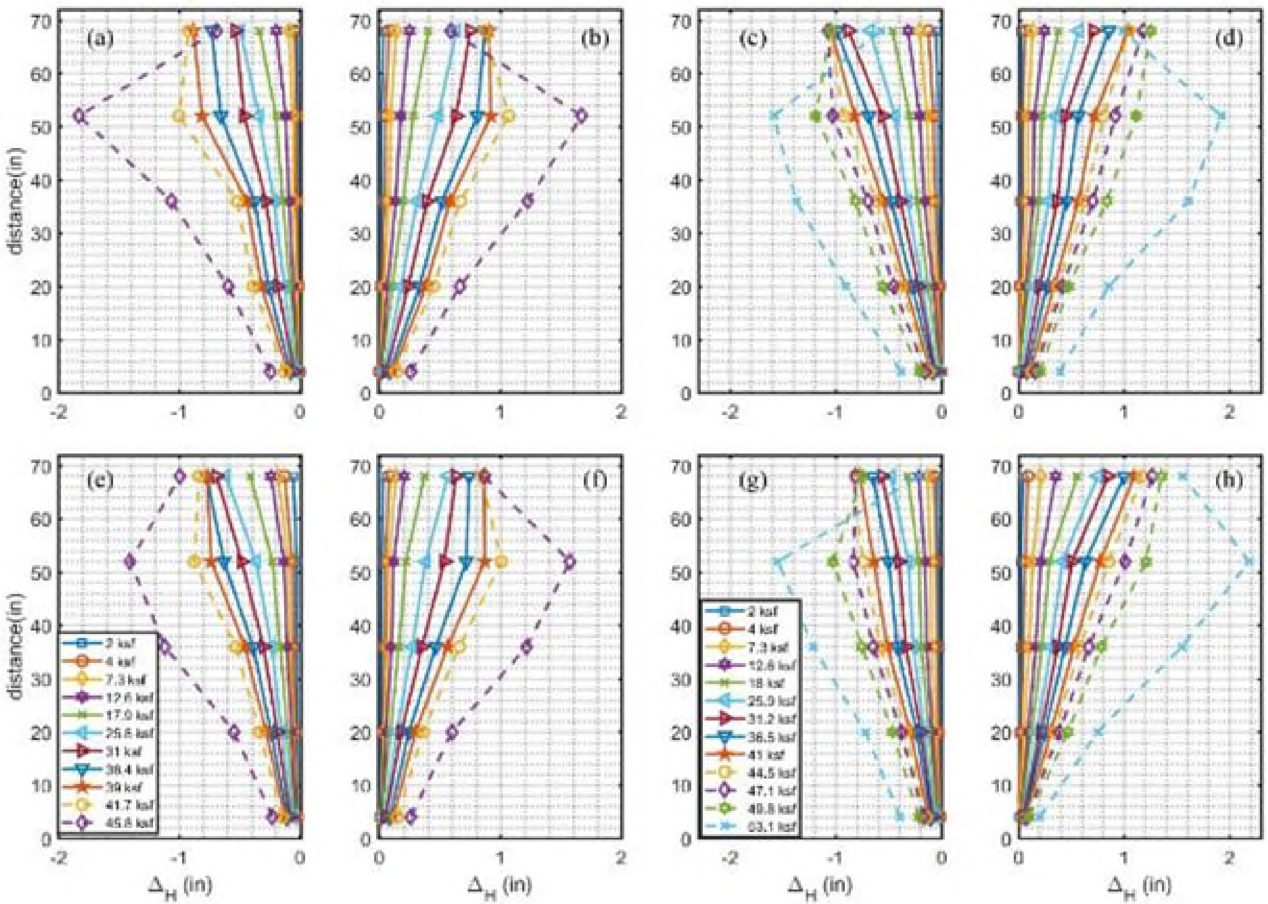
Test	Vertical Stress (ksf)
	At 1% vertical strain
PT-01	11
PT-02	8.5
PT-03*	9.2

PT-03*: eccentricity developed

Test	Vertical Strain (%)
	At 4 ksf vertical stress
PT-01	0.36
PT-02	0.5
PT-03*	0.38

Task-3: Axial load-deformation tests on GRS piers

- Experimental Results



(a) South wall-PT-01
(b) North wall-PT-01
(c) South wall-PT-02
(d) North wall-PT-02
(e) West wall-PT-01
(f) East wall-PT-01
(g) West wall-PT-02
(h) East wall-PT-02

A plot of lateral displacement at different applied vertical stress for PT-01 and PT-02

Task-3: Axial load-deformation tests on GRS piers

- Experimental Results
  - Lateral displacements

Test	Maximum lateral displacement during the test (in)
	Occurs at 52 inches from bottom of pier
PT-01	2.25
PT-02	2.6
PT-03	

  - Service limit

Test	Maximum lateral strain (%)
	At 4 ksf vertical stress
PT-01	0.52
PT-02	0.48
PT-03	0.53

Photo of the failed pier after the test

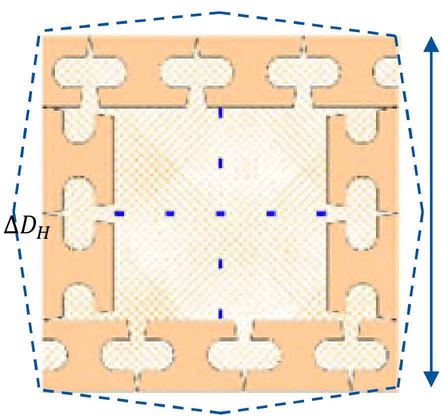
Task-3: Axial load-deformation tests on GRS piers

- Experimental Results:
  - Volumetric behavior
    - Vertical volume change

$$\Delta V_V = A_S \; x \; \Delta D_v$$

$$A_S = B \; x \; B$$

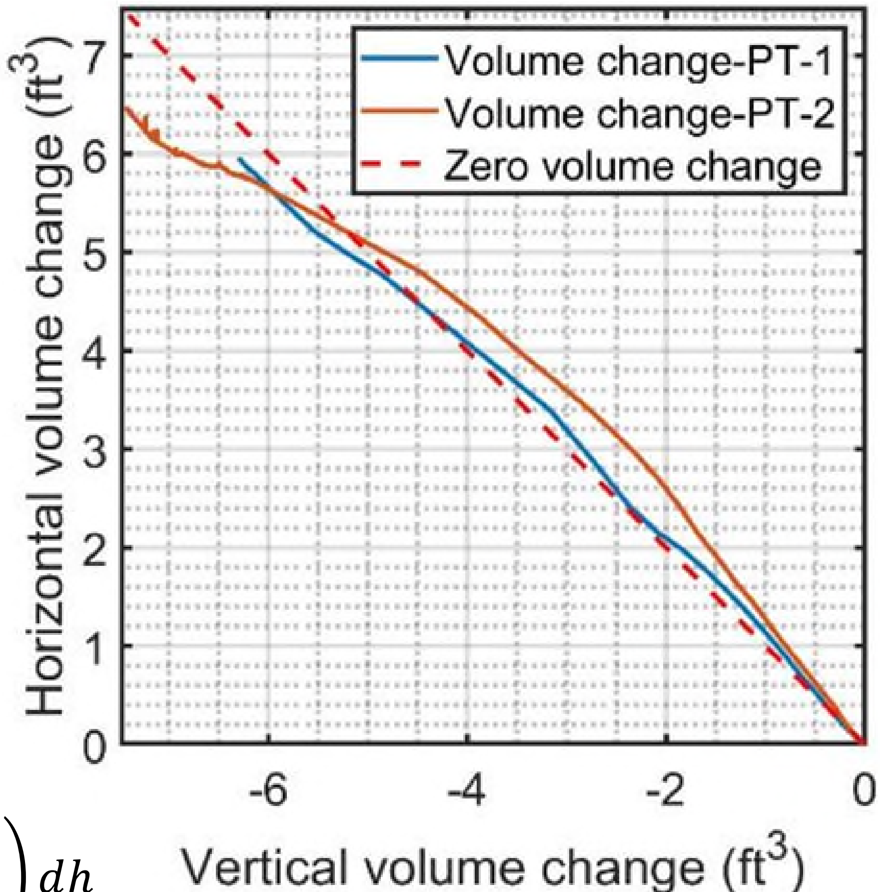
    - Lateral volume change



$$\Delta V_H = \sum_{i=1}^{4} \Delta V_{L_i}$$

$$\Delta V_{L_i} = \int_0^H \left(\frac{1}{2} x \; B_{total} \; x \; \Delta D_H\right) dh$$

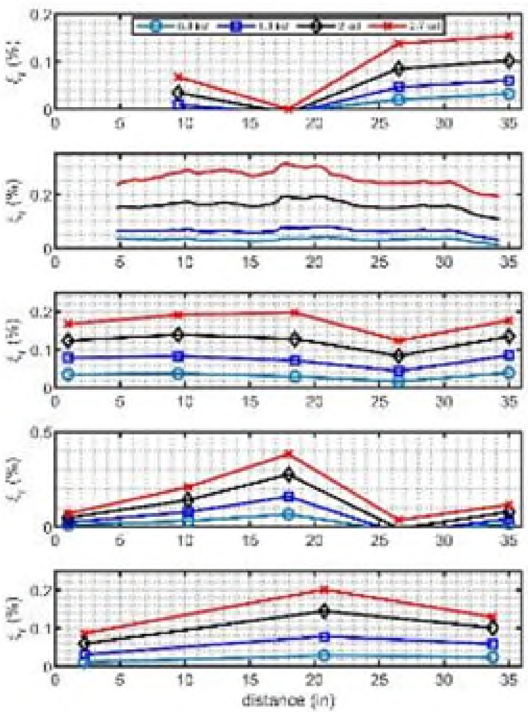
Where; ΔV_V is the vertical volume change, ΔV_H is the lateral volume change, A_S is the plan area of the backfill soil, B is the inside width of the pier, ΔV_{L_i} is the lateral volume change on each wall, ΔD_H is the lateral displacement of the wall, ΔD_v is the vertical settlement of the footing, and H is the height of the pier.



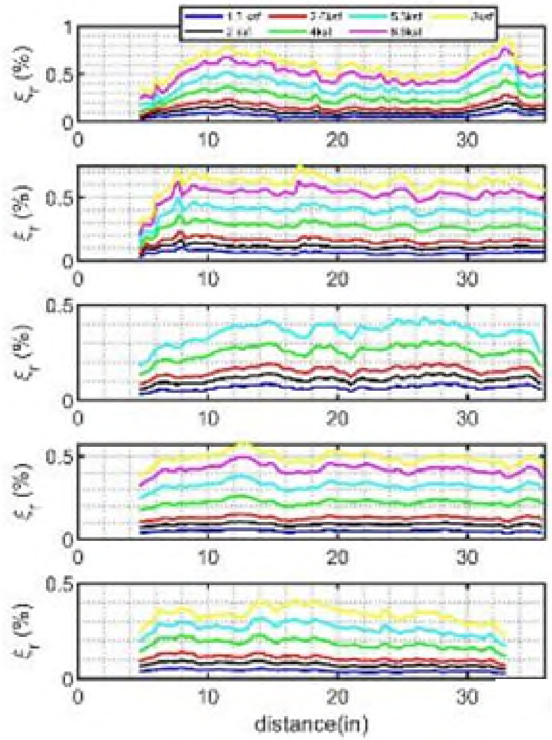
Volume change behavior of GRS piers

Task-3: Axial load-deformation tests on GRS piers

- Experimental Results: Reinforcement strain



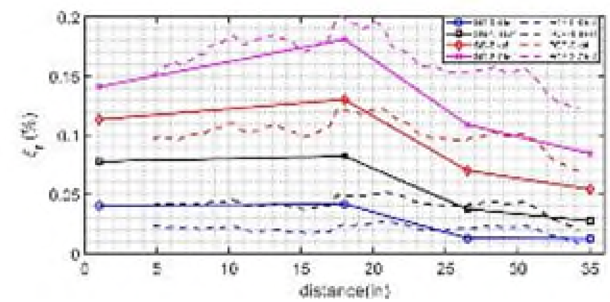
(a)



(b)

Test	Maximum reinforcement strain (%) At 4 ksf vertical stress
PT-01	0.33
PT-02	0.44
PT-03	0.48

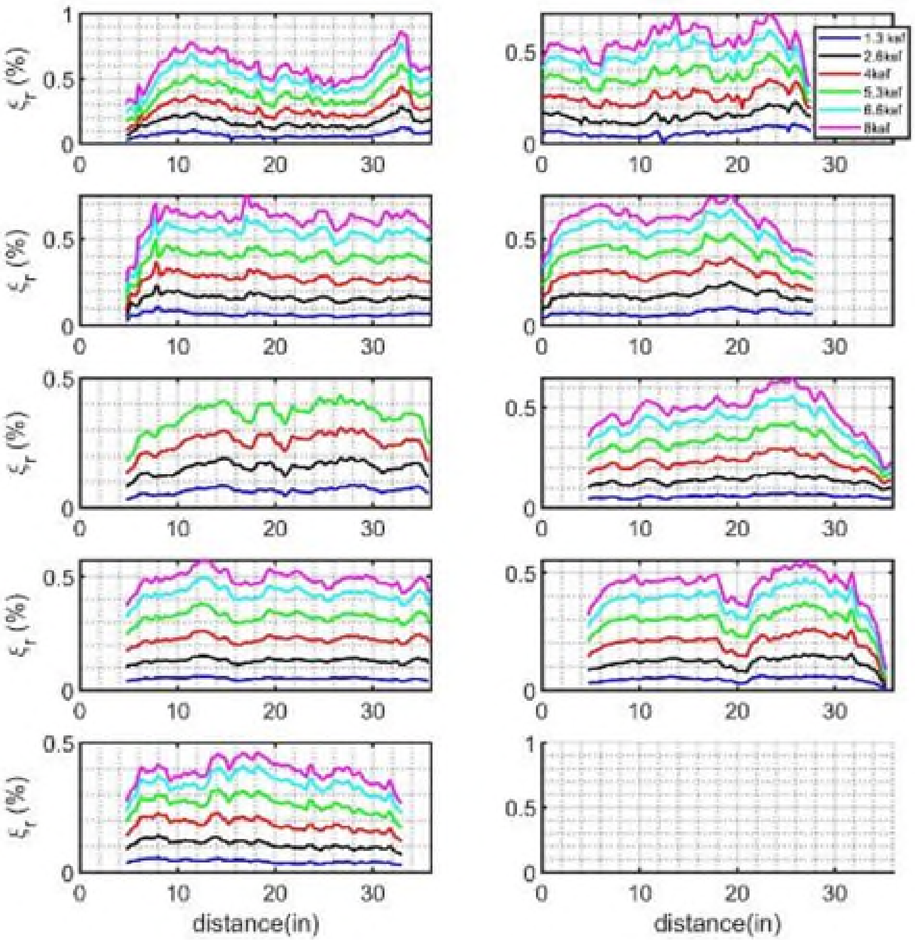
Plot of reinforcement strain distribution at different vertical stresses (Top subplot is the seventh geotextile layer and bottom one is the third geotextile layer, distances are measured from the edges of the blocks, ξ_r is the reinforcement strain)
(a) PT-01 (b) PT-02



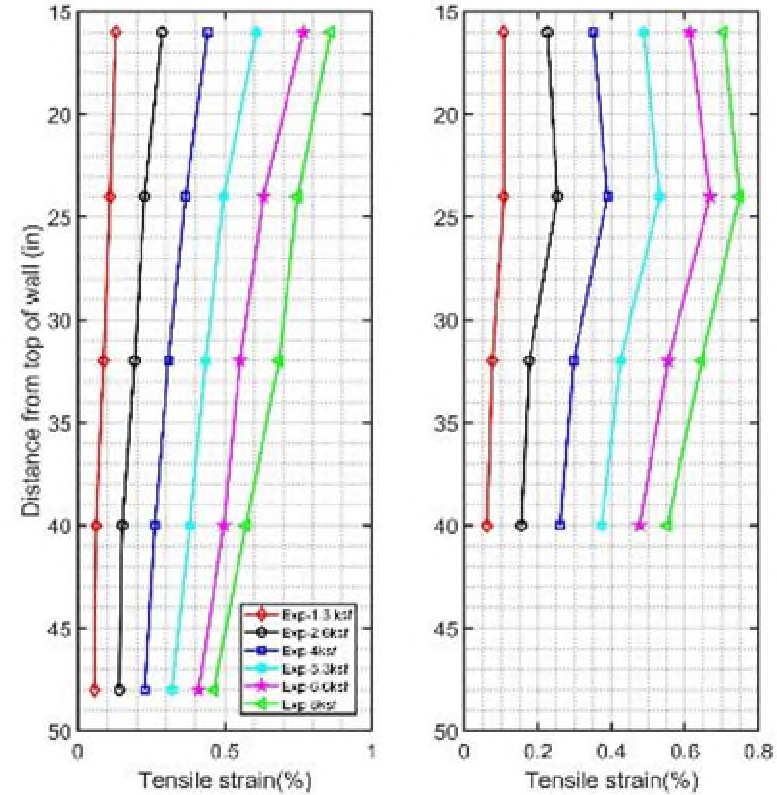
Comparison of strain from strain gauge and from fiber optic cables

Task-3: Axial load-deformation tests on GRS piers

- Experimental Results: Reinforcement strain



Plot of reinforcement strain distribution at different vertical stresses (PT-02)
(a) West-East view (b) South-North view



Profile view of reinforcement strain at different vertical stresses (PT-02) (a) West-East view (b) South-North view

Task-3: Axial load-deformation tests on GRS piers

- Geotextile after the test

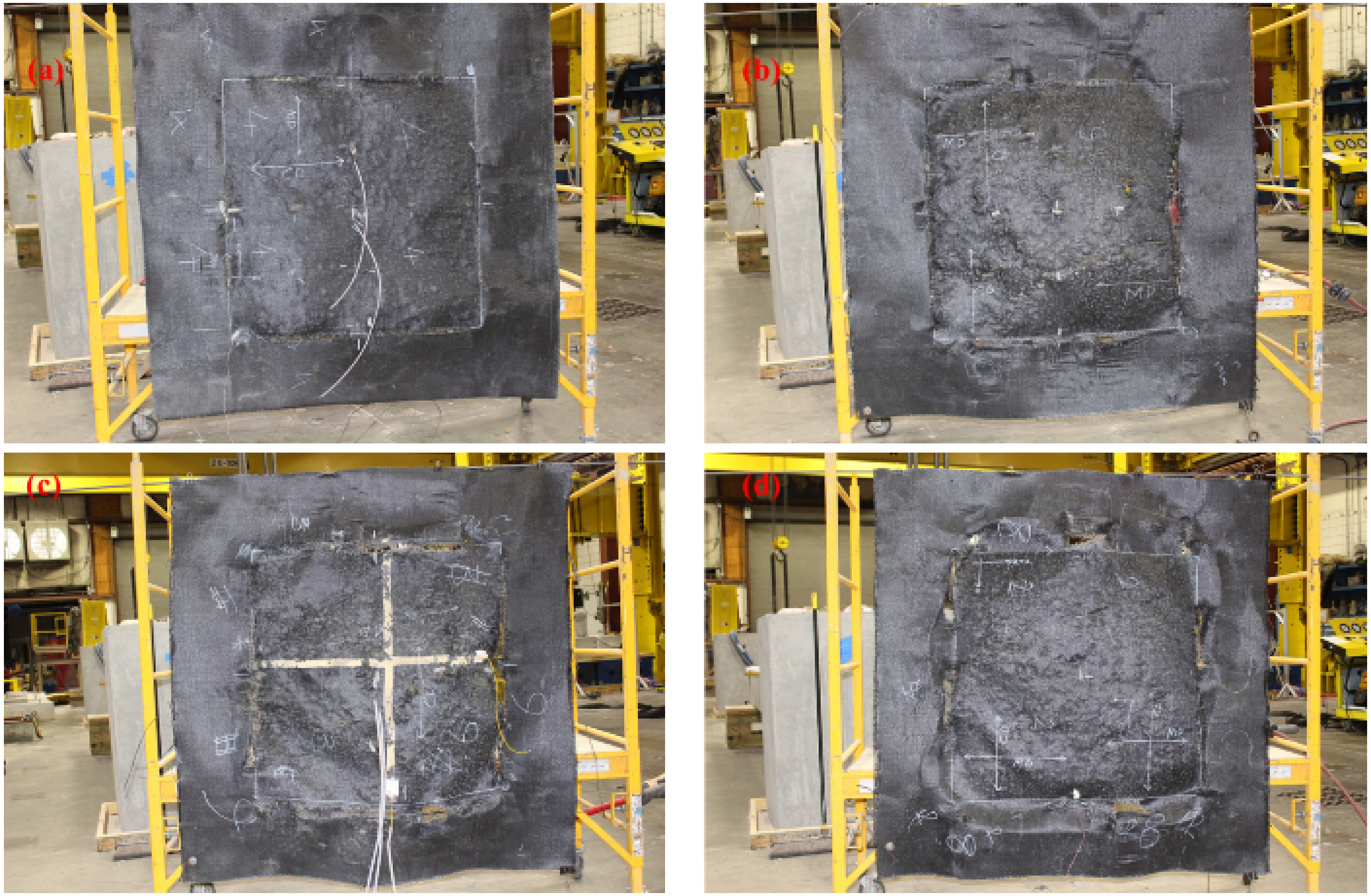
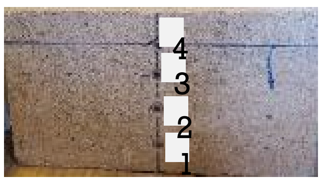
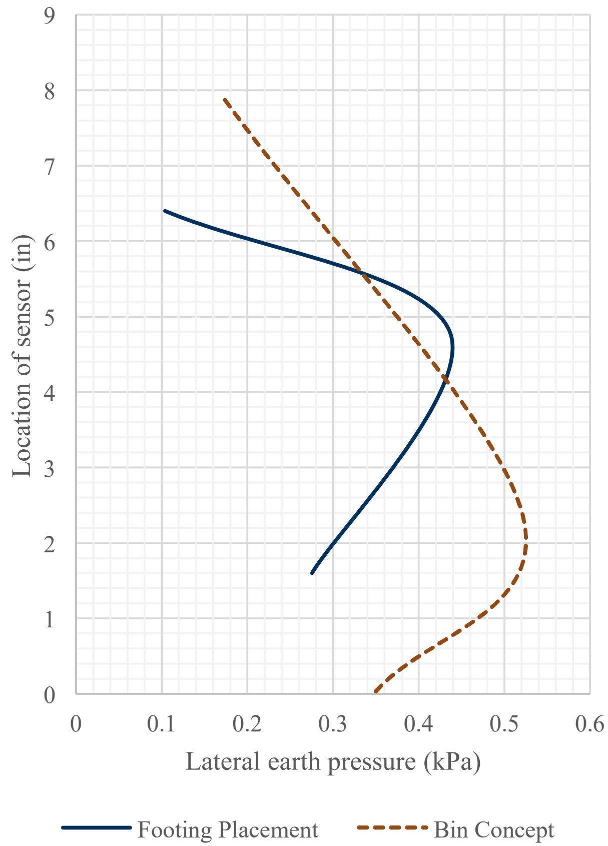


Photo of geotextile after the test-PT-1

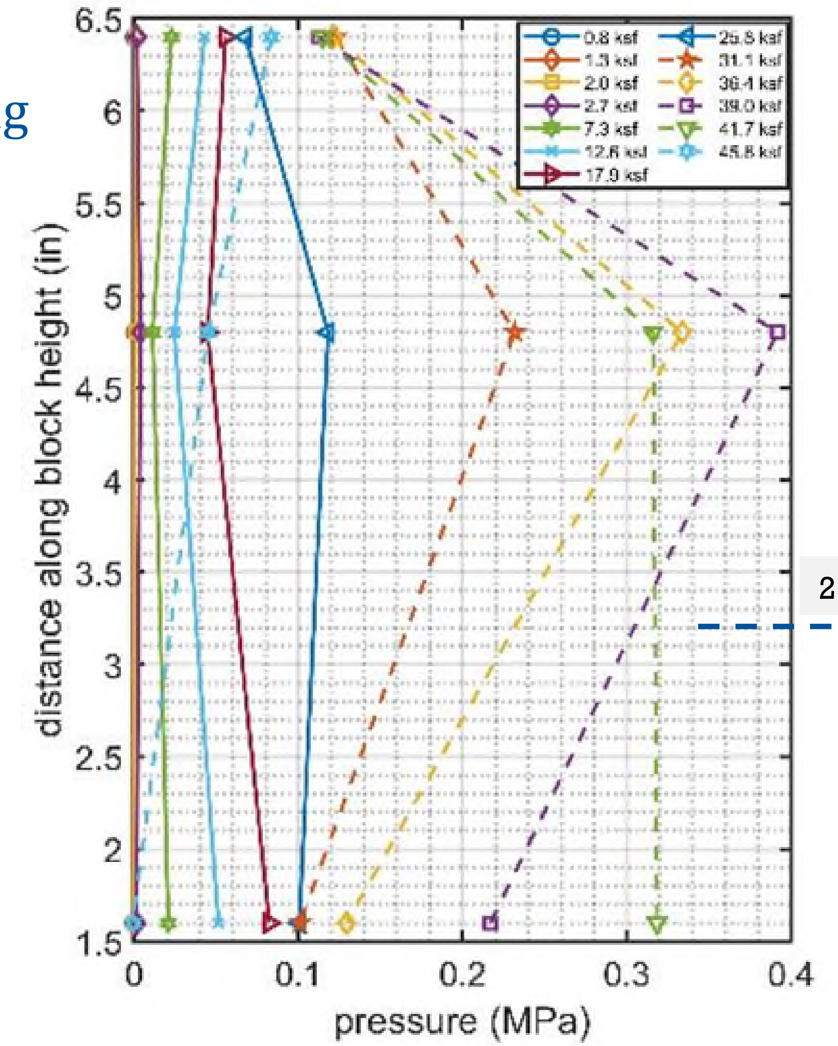
Task-3: Axial load-deformation tests on GRS piers

- Earth pressure along the block
  - Sensor 2 at 3.2 inches stopped working





Comparison of lateral earth pressure change and bin pressure concept during footing placement



Profile of horizontal earth pressure change due to applied load

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)	4/1/2021	Completed/Active
Deliverable #3b/Task 3 – Report on GRS performance tests (axial load-deformation tests)	6/1/2022	Active
Deliverable #3c/Task 3 – Report on all GRS performance tests (axial load-deformation tests)	10/1/2022	
Deliverable #4/Task 4- Report on comparison of GRS performance test results with published results and predictions based on available design methods	1/1/2023	
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.	2/1/2023	
Deliverable #6a/Task 6 – PowerPoint presentation- closeout teleconference to review project performance, the deployment plan, and next steps.	4/15/2023	
Deliverable #6b/Task 6 – Final Report to the FDOT	5/1/2023	

References

- FDOT. (2021). Structures Manual: Volume 1 – Structures Design Guidelines.
- 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.
- 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.
- 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).

Publications

- Matemu, C., Wasman, S., and Jones, L. (2022). Axial Load Tests of Geosynthetic Reinforced Soil (GRS) Piers Constructed with Florida Limestone Aggregate and Woven Geotextile. Geo-Congress (2023)

Thank You!