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)

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Presentation Outline

- Introduction
- Research Motivation
- Project Objectives and Tasks
- Project Tasks
- Project Timeline

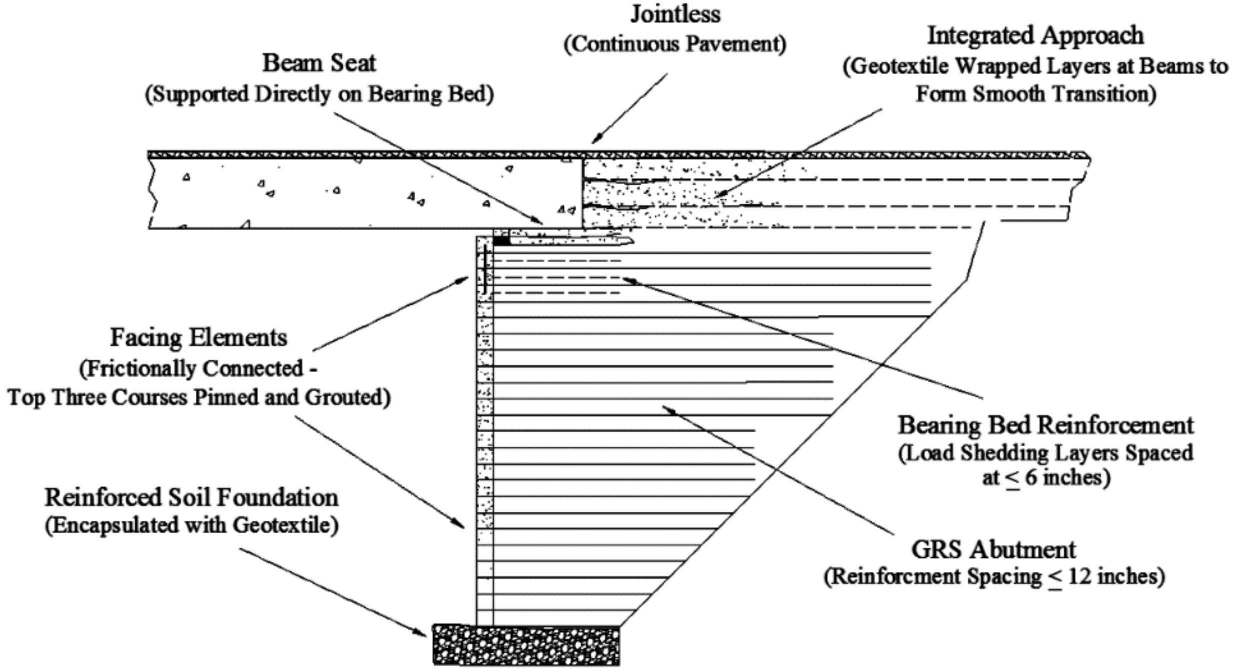
Introduction: What is GRS-IBS?

- 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 soil in distributing loads
- Geosynthetic reinforced soil (GRS) share similarities with geosynthetics mechanically stabilized earth walls (GMSE) in terms of appearance and materials except

GRS	MSEW
Frictional connections	Mechanical connections
Close spacing ≤ 12 inches	Wide spacing 18-24 inches

Introduction: What is GRS-IBS?

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



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

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
  - Single-span bridge with span length less than 140 ft and abutment height less than 30 ft
  - Service limit pressure (loading capacity) up to 4000 lb/ft^2
- There has been an increase in their implementation (more than 300 bridges have been constructed with GRS-IBS in the USA)

Research Motivation

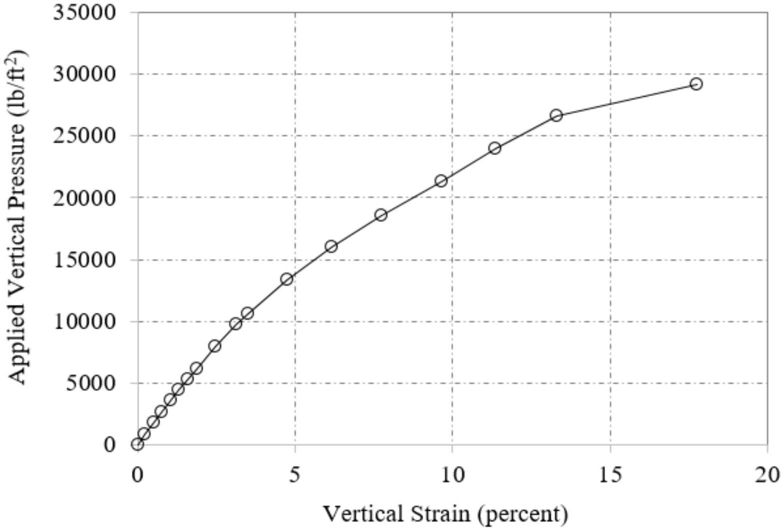
- Limited laboratory and field studies have been conducted
- Limited vertical reinforcement spacing up to 12 inches
- GRS composite behavior depends on:
  - Reinforcement strength & spacing, aggregate size, friction angle, facing elements
- Performance of GRS piers (experimental proxy for GRS-IBS) that utilize materials in Florida has not been evaluated
- 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
  - Task-2: Design experimental plan for performance tests
  - Task-3: Performance tests – Axial load-deformation tests on multiple GRS piers
  - 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

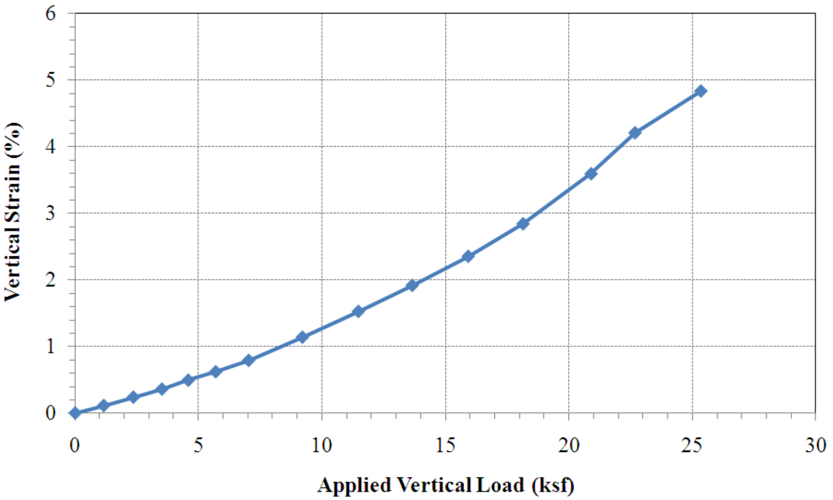
- FDOT requires design of GRS-IBS according to "***Geosynthetic Reinforced Soil Integrated Bridge System Interim Implementation Guide***" FHWA-HRT-11-026
- Internal Stability Analysis
- A: Ultimate Capacity
  - Empirical Method
    - Use of performance test (PT) results
  - Analytical Method
    - $$q_{ult,an} = \left[\sigma_c + 0.7^{\left(\frac{S_v}{6d_{max}}\right)} \frac{T_f}{S_v}\right] K_{pr} + 2c\sqrt{K_{pr}}$$
    - 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, c is the cohesion of reinforced backfill, and K_{pr} is the coefficient of passive earth pressure



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

Task-1: Design Methods and Construction Practices

- B: Deformations
  - Vertical Settlement, D_v
    - Resulting from GRS composite and underlying soil foundation
    - Within GRS fill
      - Empirical
        - Use of PT results.



Design envelope for (Adams et al., 2012)

    - Underlying Soil Foundation
      - Use classic soil mechanics theory
    - Vertical strain limited to 0.5%- FHWA-HRT-11-026,(2012), 1% FHWA-HRT-17-080 (2018)

Task-1: Design Methods and Construction Practices

- B: Deformations
  - Lateral Displacement, D_L
    - Horizontal strain limited to 1%- FHWA-HRT-11-026,(2012), 2% FHWA-HRT-17-080 (2018)
    - If vertical settlement is known
      - $D_L = \frac{2b_{q,vol}D_v}{H}$ FHWA-HRT-11-026 Adams et al. (2012) ,
      - $D_L = \frac{2b_{q,vol}D_v}{H} x \frac{1}{n}$ NCHRP No. 24-41 Zornberg et al. (2018)
    - If vertical is unknown
      - $\delta_R = 11.81\left(\frac{L}{H}\right)^4 - 42.25\left(\frac{L}{H}\right)^3 + 57.16\left(\frac{L}{H}\right)^2 - 35.45\left(\frac{L}{H}\right) + 9.471$
      - $D_L = \frac{\delta_R H}{250}$ $for\ inextensible\ reinforcement,$ $D_L = \frac{\delta_R H}{75}$ $for\ extensible\ reinforcement$
      - $D_L = \left(\frac{\delta_R H}{50\frac{J}{S_v}.\frac{1}{p_O}}\right) x \left(1 + 1.25\frac{q}{p_O}\right)$ Zornberg et al. (2018)
      - Where: δ_R is an empirically derived relative displacement coefficient (dimensionless), J is the reinforcement tensile stiffness defined by the secant modulus at 2% strain, L is the reinforcement length, q is the surcharge magnitude, and p_O is the atmospheric pressure

Task-1: Design Methods and Construction Practices

- C: Reinforcement Strength
  - Adams et al. (2012), Pham (2009)
    - $T_{req,c} = \left(\frac{\sigma_h - \sigma_c - 2c\sqrt{K_{ar}}}{0.7^{\left(\frac{S_v}{6d_{max}}\right)}}\right) S_v$
  - Zornberg et al. (2018)
  - $T_{max,i} \begin{cases} \frac{1}{2} K_{ar} \gamma H S_v + \Delta\sigma_H S_v \quad for\ \ S_v \geq 16" \\ \frac{1}{2} K_{ar} \gamma H S_v + \Delta\sigma_H S_v \quad for\ S_v \leq 8" \\ K_{ar} \gamma S_v \left[z_i + \left(\frac{16" - S_v}{8"}\right)\left(\frac{H}{2} - z_i\right)\right] + \Delta\sigma_H S_v \quad for\ 8" \leq S_v \leq 16" \end{cases}$
  - Where: γ is the backfill total unit weight, H is the total height of GRS composite, z_i is the depth of backfill at position i, and $\Delta\sigma_H$ is the change in the horizontal earth pressure of the backfill due to the applied surcharge

Task-1: Design Methods and Construction Practices

- Backfill Material
  - Granular materials preferred (Most projects have used open graded)
  - Foundation: well graded
  - Abutment: open graded
  - Integrated Approach: well graded

$$\textit{Internal angle of friction}, \Phi \begin{cases} \geq 42^\circ\ FDOT \\ \geq 38^\circ\ FHWA \end{cases}$$

$$\textit{Maximum particle size}, d_{max} = 2\ inches$$

- Reinforcement
  - RFS: Woven geotextile
  - Abutment: biaxial geogrid or woven geotextile reinforcement
  - Minimum ultimate tensile strength, $T_f = 4800\ lb/ft$
- Facing Elements (Facing Blocks)
  - Concrete, timber, natural rock, etc.
  - Concrete Masonry Unit (CMU) & Segmental blocks (SB) are commonly used

Task-1: Design Methods and Construction Practices

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

Encapsulation of fill in RSF (Adams and Nicks, 2018)

Acute corner GRS (Photo by Larry Jones)

Task-2: Design Experimental Plan for Performance Tests

- Through consultation with the FDOT, researchers will design plan for testing 8 GRS piers at Marcus H. Ansley Structures Research Center in Tallahassee, Florida
- Performance tests will utilize reaction frame and hydraulic load application apparatus
- Each pier will be externally and internally instrumented
  - Vertical and horizontal movement measured with linear potentiometers
  - Applied load measured with load cell
  - Geosynthetic tensile strains measured with bonded strain gages
  - Vertical and horizontal earth pressures measured with pressure cells
- Instruments will be read with multi-channel data acquisition system and data backed up with external hard drive

Task-2: Design Experimental Plan for Performance Tests

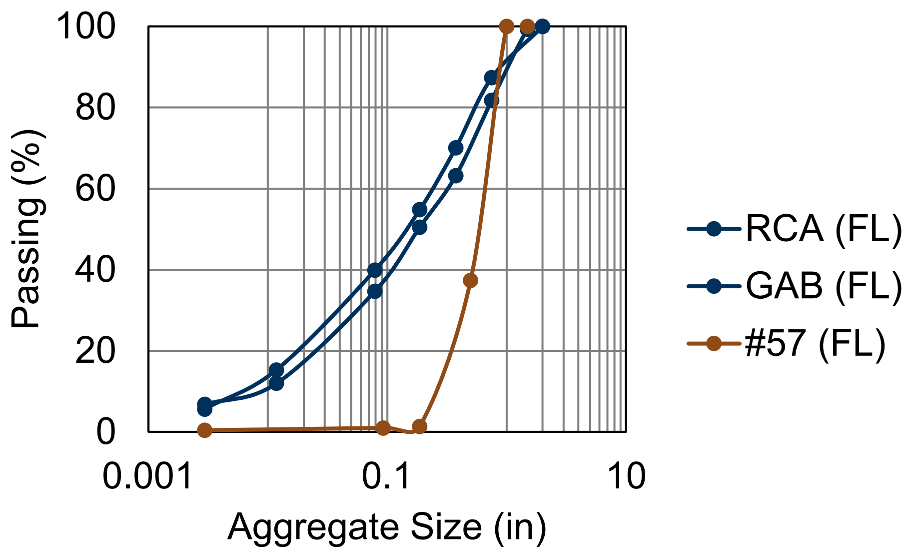
- Preliminary Design: 8 Piers to be tested
- Aggregates
  - Sieving
  - Density
  - Shear strength
- Geosynthetics
  - Tensile strength test
    - ASTM D 4595 for Geotextiles
    - ASTM D 6637 for Geogrids

Aggregate	Geosynthetic	S_v, Vertical Reinforcement Spacing	Facing	B, Width	H/B
#57 stone	4,800 lbs/ft polypropylene woven fabric[A]	4 inch	SB	3.5 feet	2
#57 stone	5,760 lbs/ft polypropylenewoven fabric	4 inch	SB	3.5 feet	2
#57 stone	4,800 lbs/ft polypropylene woven fabric[B]	4 inch	SB	3.5 feet	2
GAB	TBD	4 inch	SB	3.5 feet	2
GAB	4,800 lbs/ft polypropylene woven fabric[A]	8 inch	SB	3.5 feet	2
GAB	5,760 lbs/ft polypropylenewoven fabric	8 inch	SB	3.5 feet	2
GAB	4,800 lbs/ft polypropylene woven fabric[B]	8 inch	SB	3.5 feet	2
RCA	TBD	8 inch	SB	3.5 feet	2

- Instrumentation
  - Internal: strain gages, earth pressure cells, and earth pressure plates
  - External: load cells and displacement transducers

Task-2: Design Experimental Plan for Performance Tests

- Aggregates



- Facing block

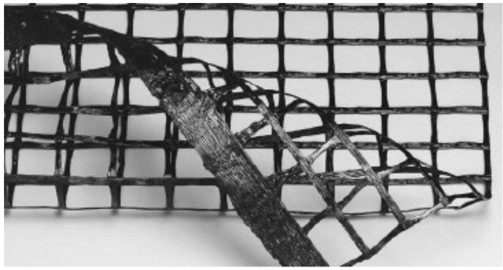
VERTICA® RETAINING WALL SYSTEM

Units	Straight Face
Approximate Dimensions*	8″ x 18″ x 11″
Approximate Weight*	80 lbs.
Coverage	1.00 sq. ft.
Setback/System Batter	9/32″ at 2° or 9/16″ at 4°

- Geosynthetics
  - Geotextile

Mirafi® HP-Series High-Performance Geotextile

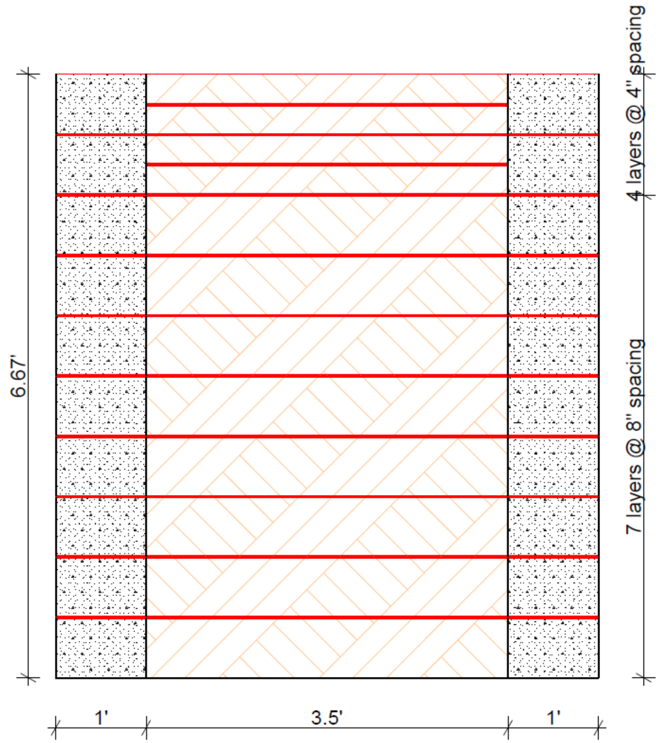
  - Geogrid



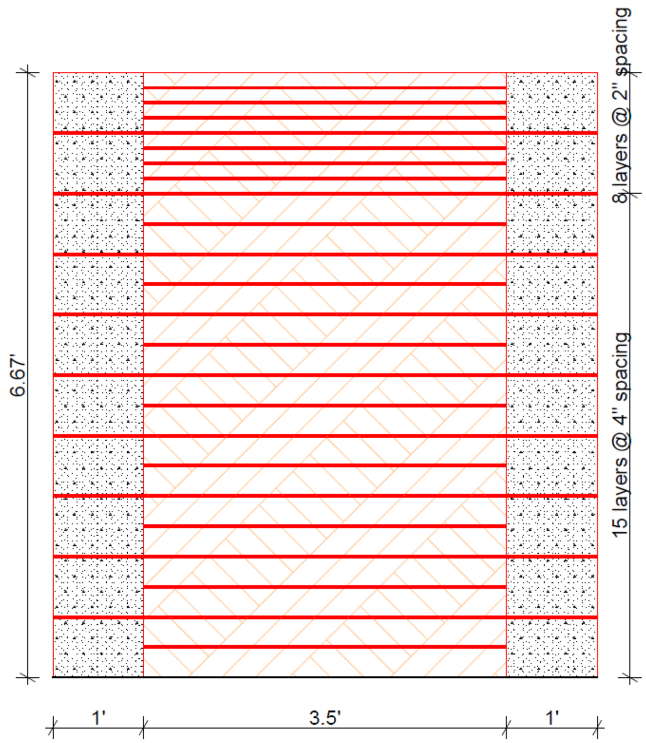
Miragrid® 5XT

Task-2: Design Experimental Plan for Performance Tests

- Geosynthetics layers alignment to fit FDOT requirements



8 inches reinforcement vertical spacing

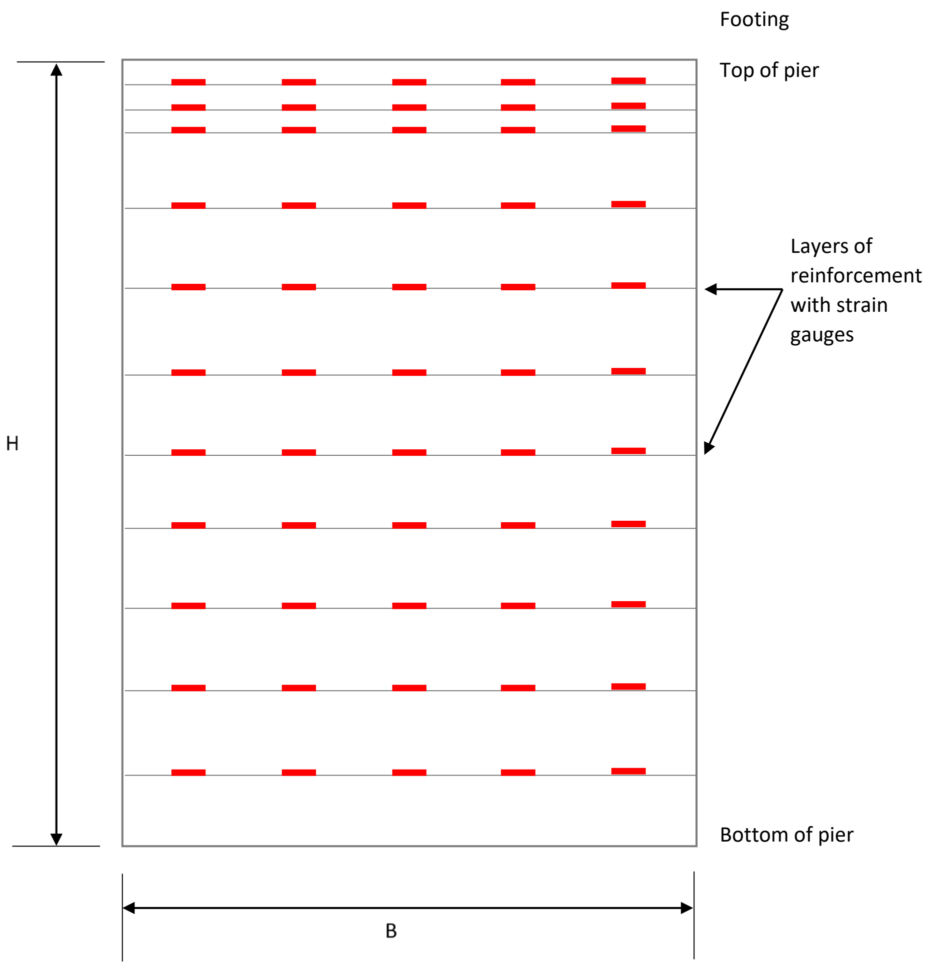


4 inches reinforcement vertical spacing

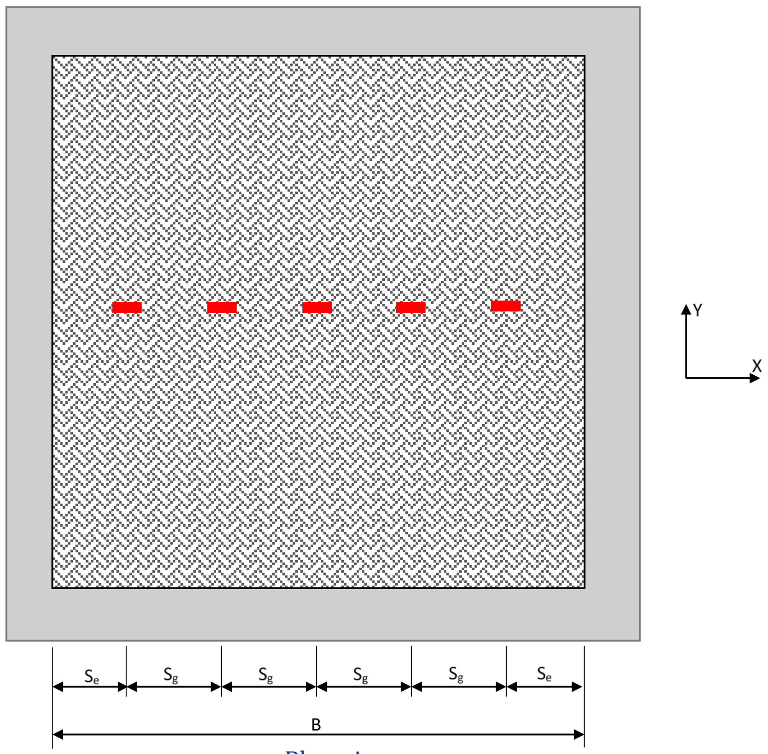
- Measure the lateral soil stress distribution between reinforcement layers

Task-2: Design Experimental Plan for Performance Tests

- Strain gage layout



Profile view



Plan view

- Segmental block facing
- Geotextile reinforcement
- 120 Ohm strain gauge oriented in the X-direction

S_e Space between end of reinforcement and center of strain gauge

S_g Center to center spacing between strain gauges

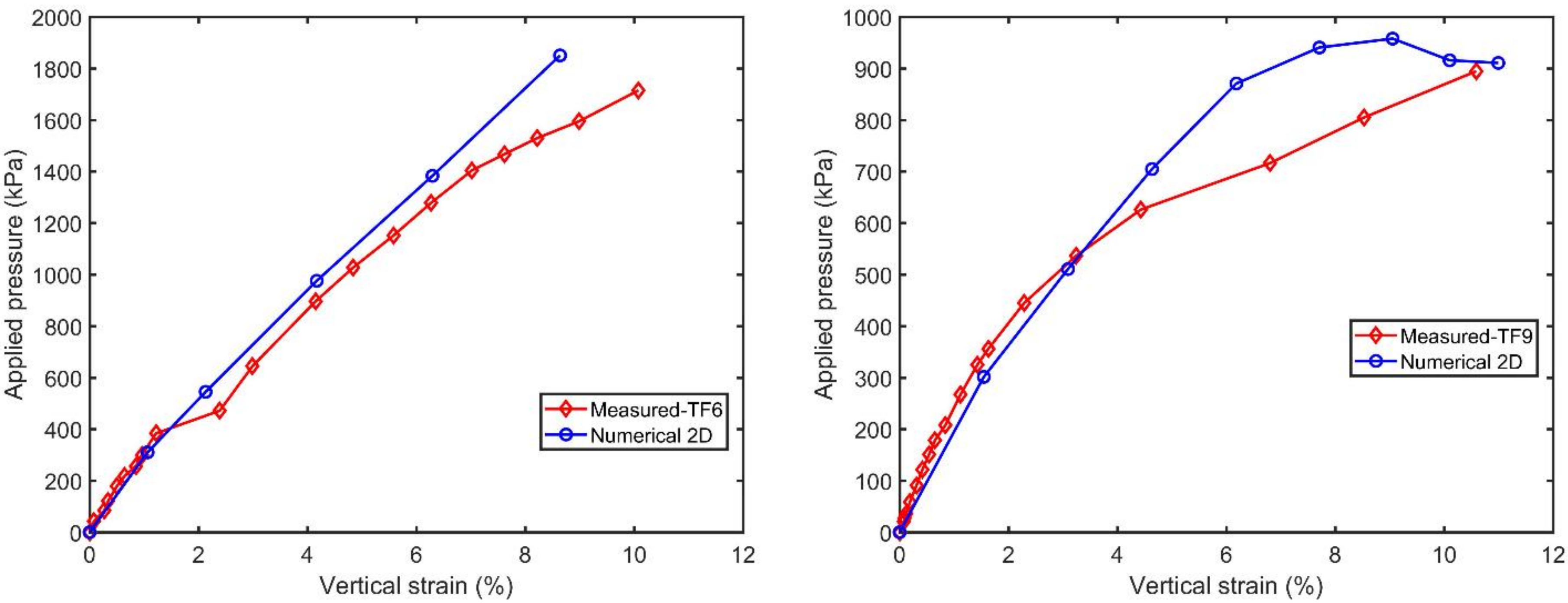
Task-2: Design Experimental Plan for Performance Tests

- Analytical method
  - FHWA equations

Numerical Method

FE Optum Software-Academic License

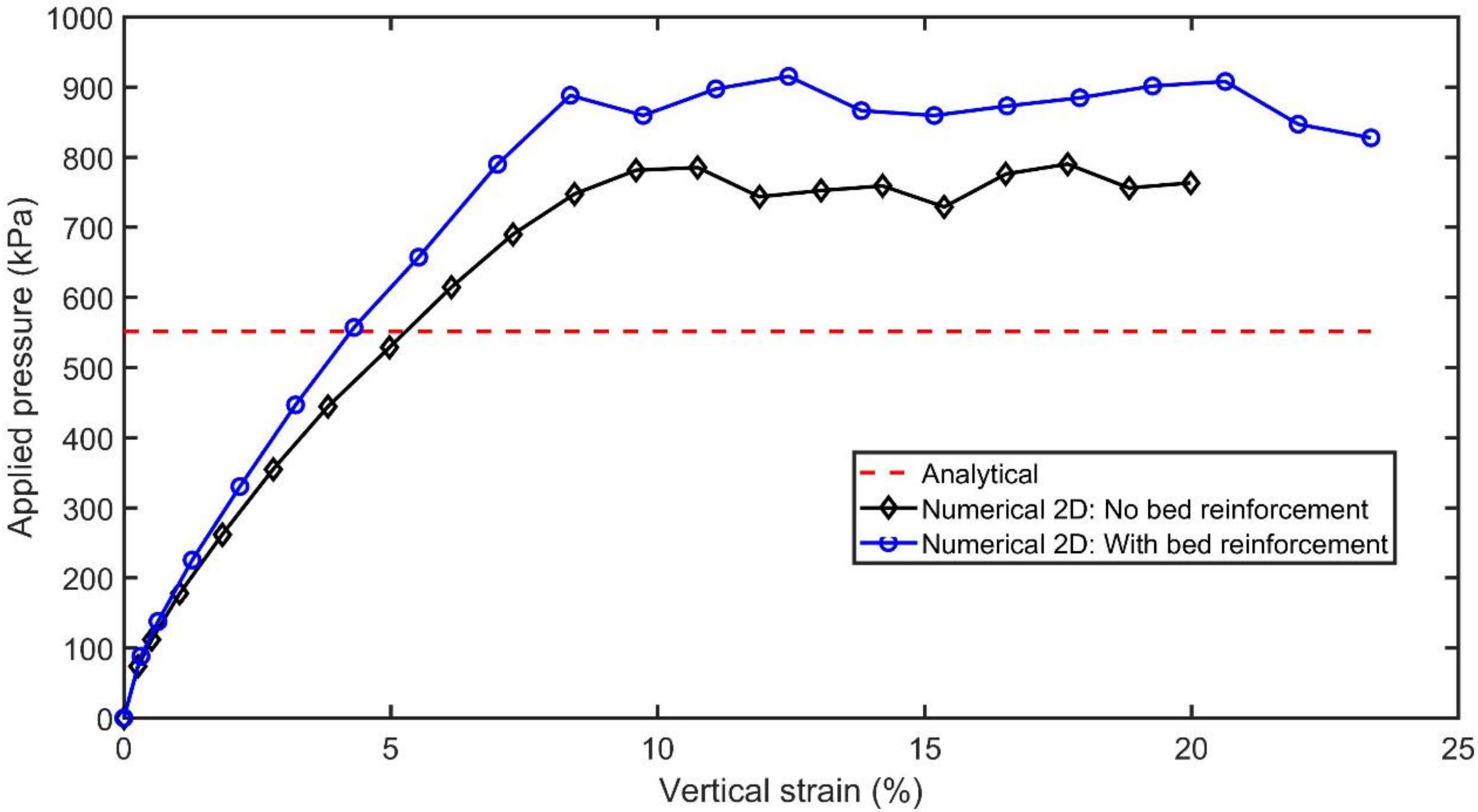
- Numerical model validated with FHWA Experiments (Adams et al., 2012)



Comparison of Applied vertical-stress strain curve for GRS pier

Task-2: Design Experimental Plan for Performance Tests

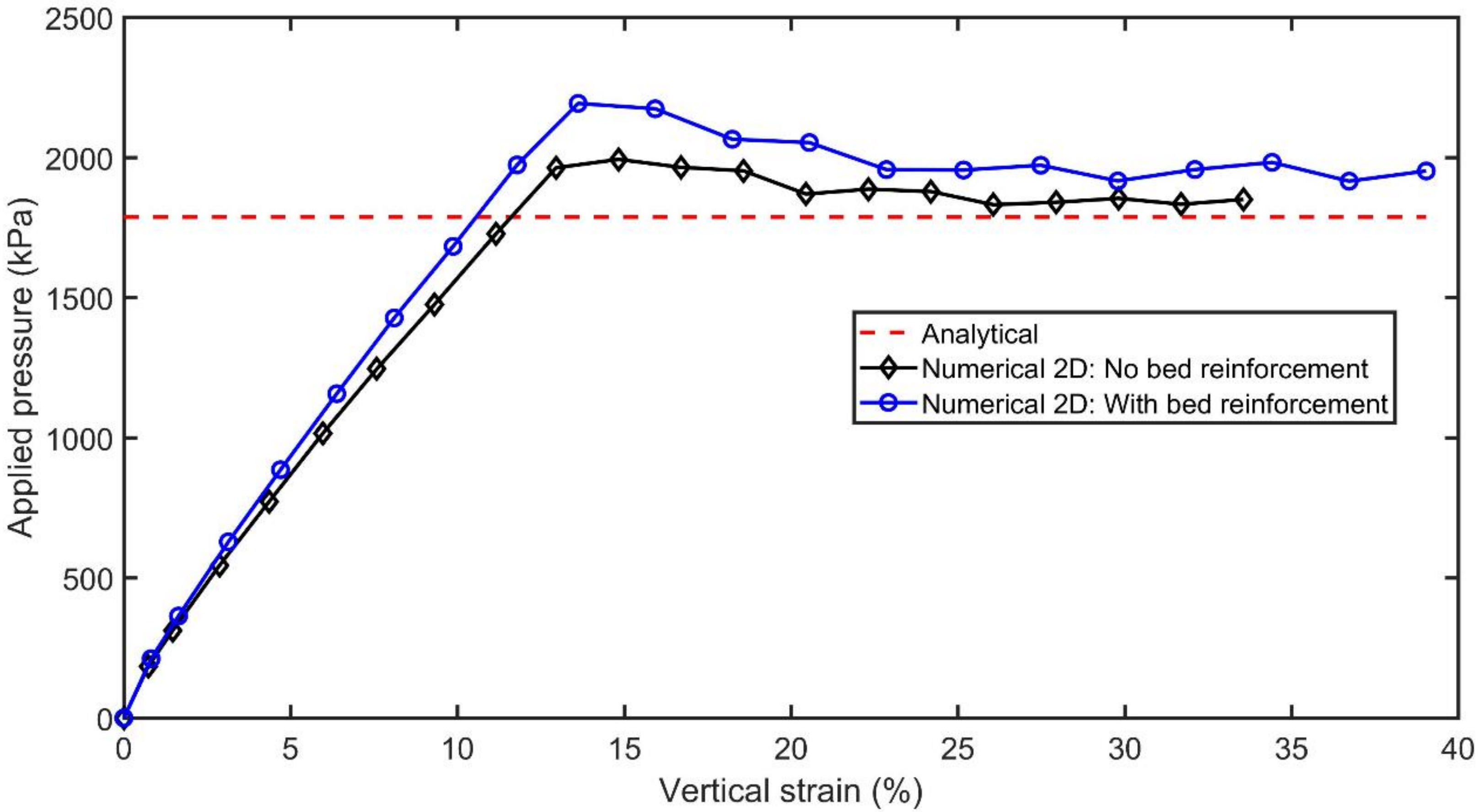
- 8 inches vertical reinforcement spacing



Comparison of Applied vertical-stress strain curve for GRS pier-Preliminary

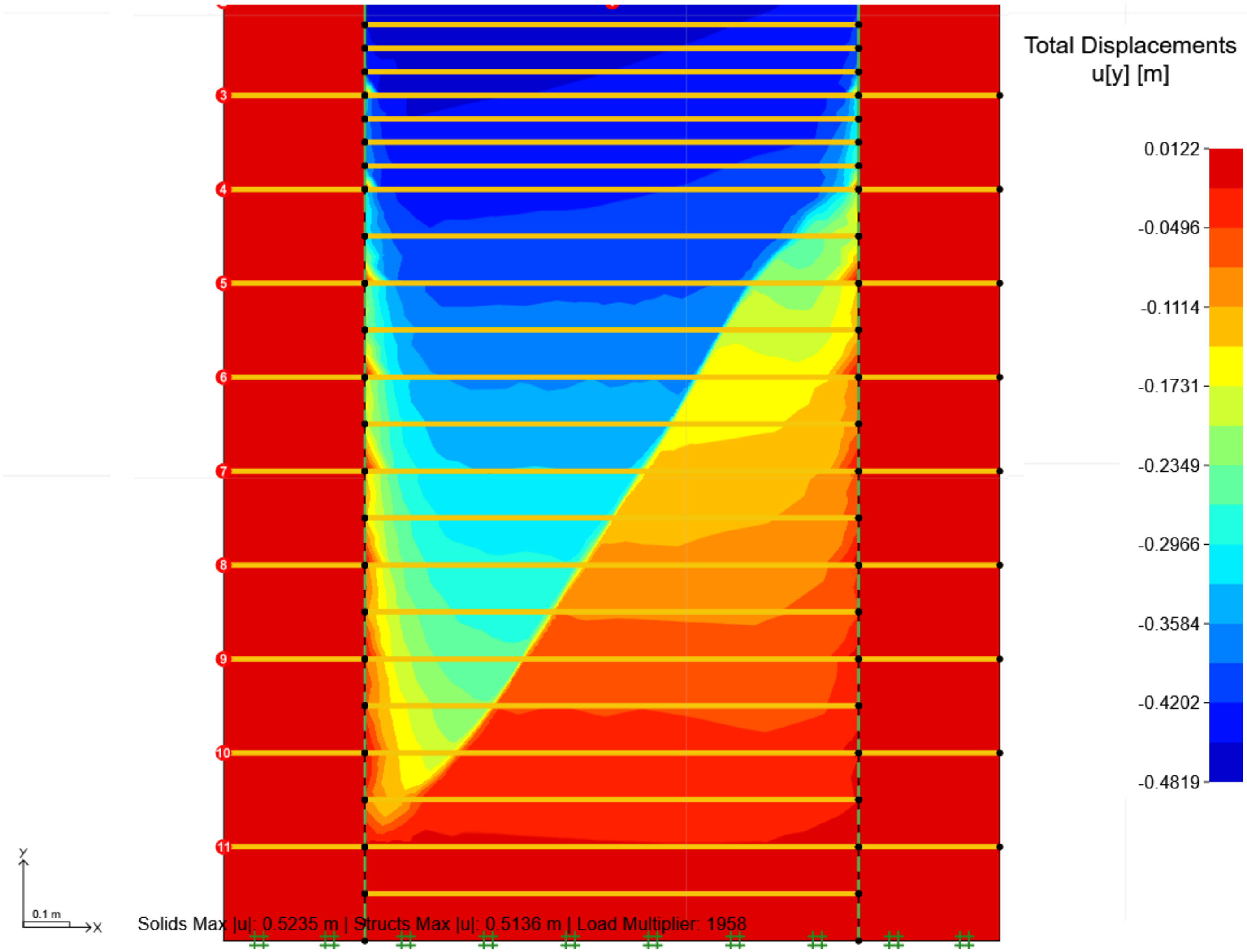
Task-2: Design Experimental Plan for Performance Tests

- 4 inches vertical reinforcement spacing



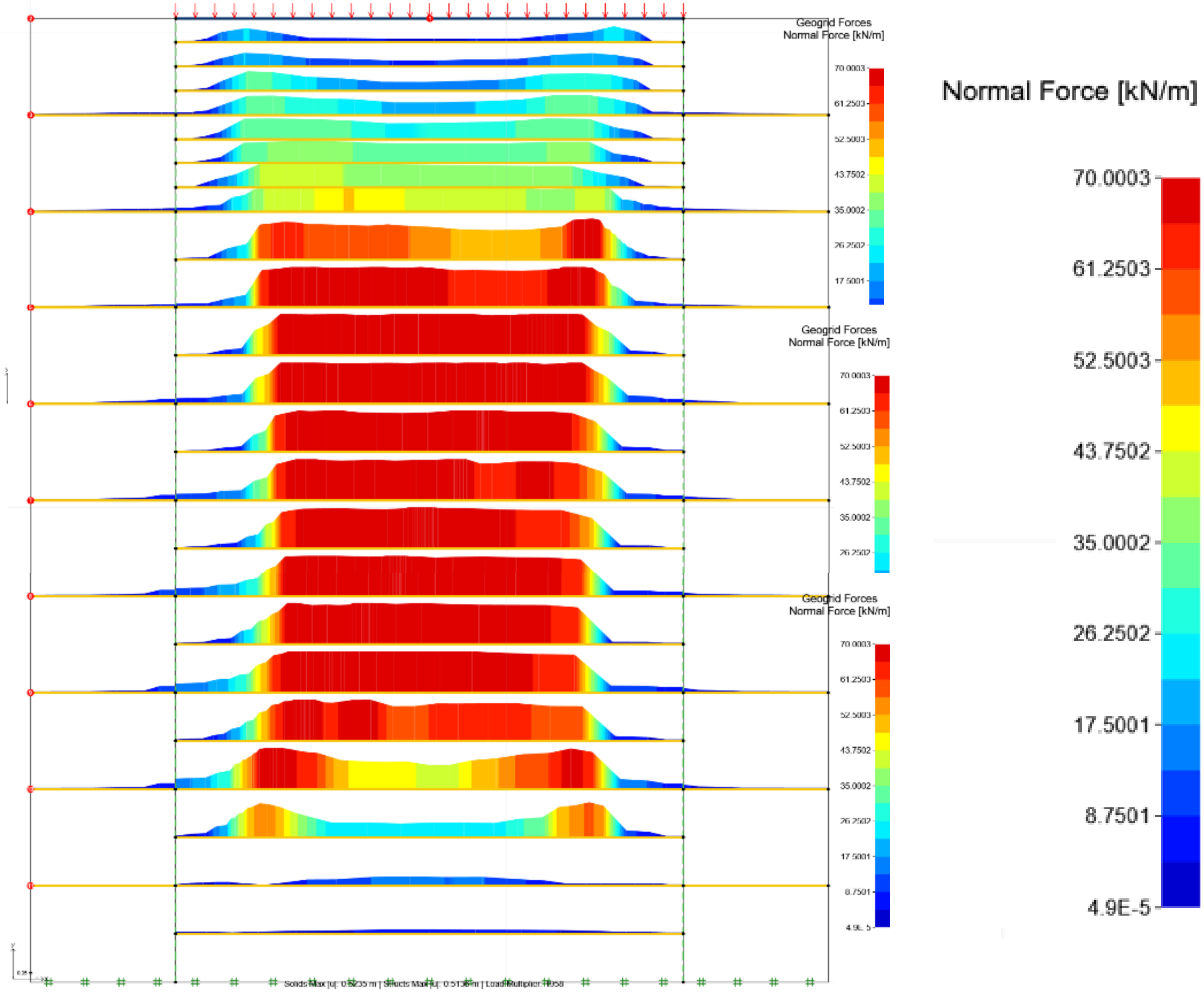
Comparison of Applied vertical-stress strain curve for GRS pier-Preliminary

Task-2: Design Experimental Plan for Performance Tests



Vertical displacement of GRS Pier with Vertical spacing of 4 inches-Preliminary design

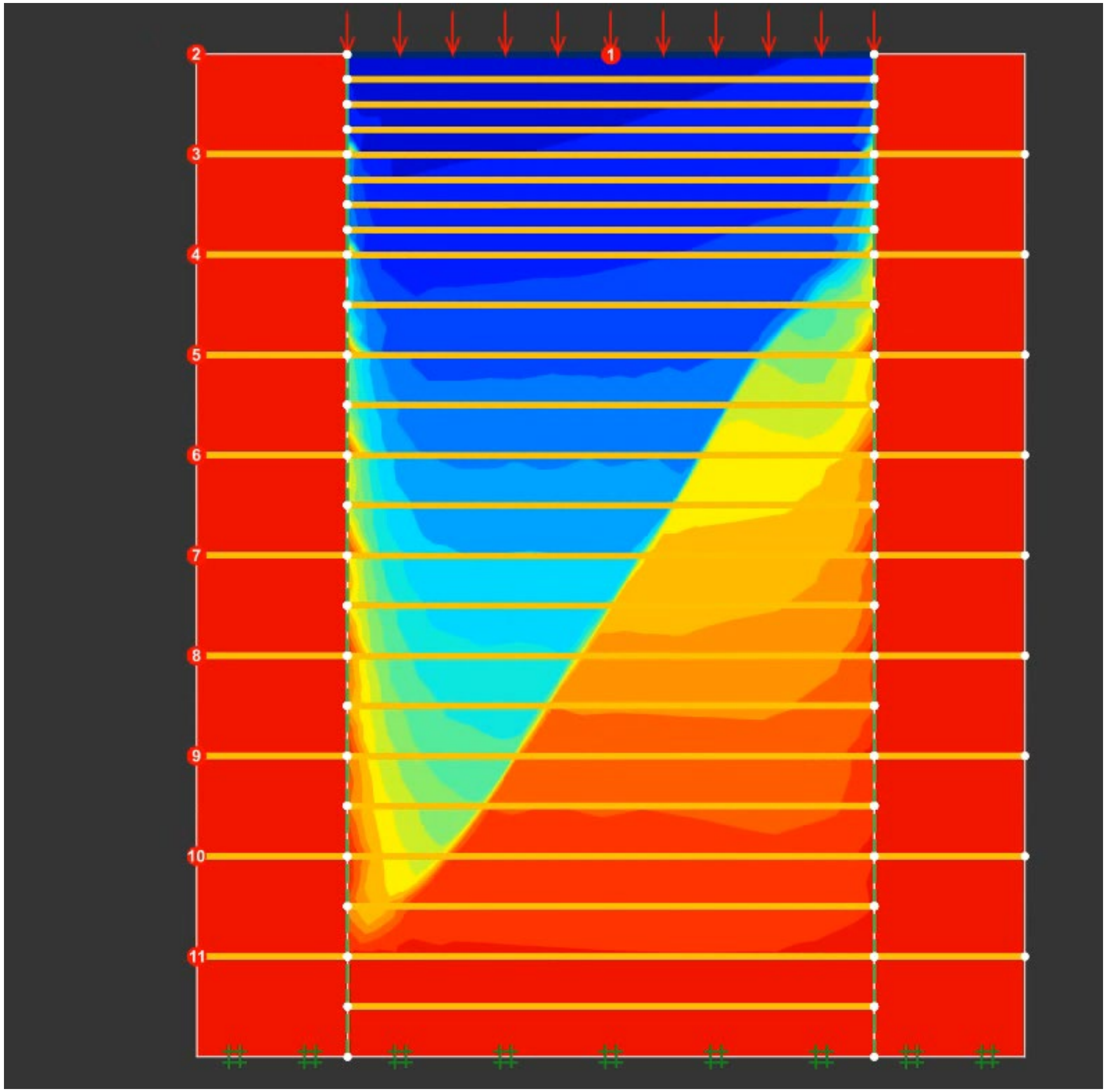
Task-2: Design Experimental Plan for Performance Tests



Tensile forces in the reinforcement for a GRS Pier with Vertical spacing of 4 inches-Preliminary design

Task-2: Design Experimental Plan for Performance Tests

Deformation mechanism



Project Timeline

Deliverable # / Description as provided in the scope (included associated task #) Project start date 2/27/2020	Anticipated Date of Deliverable Submittal (month/year)	TO BE COMPLETED BY RESEARCH CENTER (performance monitoring)
Kickoff Teleconference	3/2020	
Deliverable #1/ Task 1- Report on previous studies on GRS piers, design methods, and construction practices	7/1/2020	
Deliverable #2/Task 2 – Report on the design experimental plan for GRS performance tests	10/1/2020	
Deliverable #3a/Task 3 – Report on GRS performance tests (axial load-deformation tests)	4/1/2021	
Deliverable #3b/Task 3 – Report on GRS performance tests (axial load-deformation tests)	10/1/2021	
Deliverable #3c/Task 3 – Report on all GRS performance tests (axial load-deformation tests)	12/1/2021	
Deliverable #4/Task 4- Report on comparison of GRS performance test results with published results and predictions based on available design methods	4/1/2022	
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.	6/1/2022	
Deliverable #6a/Task 6 – PowerPoint presentation- closeout teleconference to review project performance, the deployment plan, and next steps.	8/15/2022	
Deliverable #6b/Task 6 – Final Report to the FDOT	9/1/2022	

References

- FDOT. (2019). 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.
- Zornberg, J.G., Morsy, A.M., Kouchaki, B.M., Christopher, B., Leshchinsky, D., Han, J., Tanyu, B.F., Gebermariam, F.T., Shen, P., and Jiang, Y. (2018). Defining the Boundary Conditions for Composite Behavior of Geosynthetic-Reinforced Soil Structures. Project No. 24-41, National Cooperative Highway Research Program (NCHRP) Transportation Research Board, National Academies of Sciences, Engineering, and Medicine.
- Pham, T.Q., 2009. Investigating composite behavior of geosynthetic-reinforced soil (GRS) mass. University of Colorado Denver.

Thank You!