Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS)

Rommel Cintrón – Geotechnical Engineering Grad Student
Carlos Pérez – Geotechnical Engineering Grad Student

Module Information

- Module number: 2
- Title: Performance Tests and Results, Design Process, Criteria, and Requirements
- Presentation duration: 1 Hour
- Level of audience: Professionals with knowledge in civil engineering

Acronyms

ASTM	American Standard for Testing Materials
AASHTO	American Association of State Highway and Transportation Officials
ASD	Allowable Strength Design
LRFD	Load and Resistance Factor Design
EDC	Every Day Counts
FHWA	Federal Highway Administration
GRS	Geosynthetic Reinforced Soil
IBS	Integrated Bridge System
MSE	Mechanically Stabilized Earth

Introduction

- EDC is designed to identify and deploy innovation aimed at shortening project delivery, enhancing the safety of our roadways, and protecting the environment.
- These goals are worth pursuing for their own sake, but in challenging times, it is imperative to pursue better, faster, and smarter ways of doing business.

Introduction

- Teams from the FHWA work with the local state and industry partners to deploy the initiatives of EDC and to develop performance measures to gauge their success.
- GRS-IBS uses alternating layers of compacted granular fill material and fabric sheets of geotextile reinforcement to provide support for the bridge.

Introduction

- This technology provides an economical solution to accelerated bridge construction.
- Is easy to build and maintain with common labor, equipment, and materials.
- Has a flexible design that is easily modified in the field for unforeseen site conditions.
- Has significant value when employed for small single-span structures.

Definitions

- MSE – a soil constructed with tensile reinforcing members (steel or geosynthetic) to increase the strength and load-bearing capacity.
- GRS – an engineered fill of closely spaced alternating layers of geosynthetic reinforcement and compacted granular fill material.
- IBS – a fast and cost-effective method of bridge support that blends the roadway into the superstructure using GRS technology.

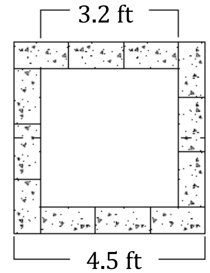
Objectives

- Performance Tests and Results
- Design Process, Criteria, and Requirements

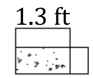
Performance Tests

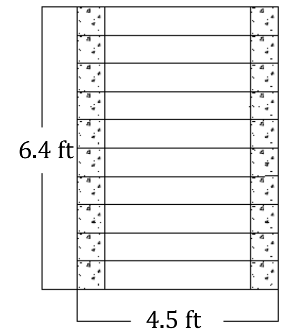
- Also known as "Mini-Pier" experiments
- Provides material strength properties of a particular GRS composite
- Procedure involves axially loading the GRS mass to measure lateral and vertical deformation

Performance Tests



Top View





Side View

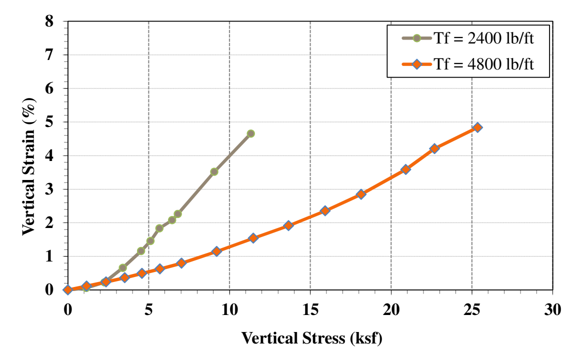
Performance Tests

Before

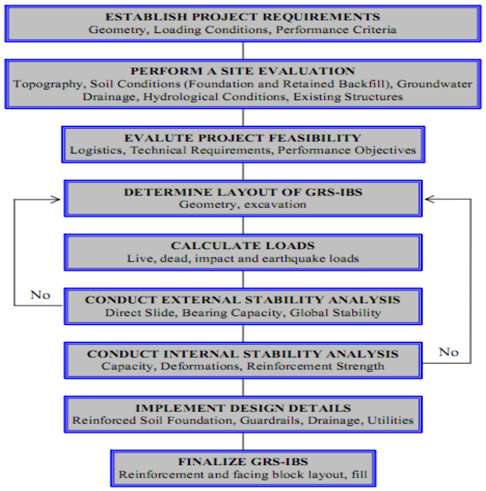
After

Performance Test Results

- S_v = 8"
- AASHTO No. 89
  - C = 0
  - $\phi = 48^o$
- For T_f = 2400 lb/ft
  - q_{ult} = 11,000 psf
- For T_f = 4800 lb/ft
  - q_{ult} = 25,000 psf



Design Process



Design Assumptions

1. The spacing of the reinforcement (12 inches or less) is a principal factor in the performance of GRS-IBS.
2. A GRS mass is a composite material that is stabilized internally.
3. Both the compacted granular fill and the reinforcement layers strain laterally together in response to vertical stress until the system approaches a failure condition.
4. A GRS mass is not supported externally, and therefore, the facing system is not considered a structural element in design.
5. Lateral earth pressure at the face of a GRS mass (i.e., thrust) is not significant, eliminating connection failure as a possible limit state.
6. The facing elements of a GRS mass are frictionally connected to the geosynthetic reinforcement.
7. Under the prescribed granular fill and reinforcement conditions, reinforcement creep is not a concern for the sustained loads.

DESIGN OF GRS-IBS

Step 1: Establish Project Requirements

Design Requirements

- Geometry
  - Bridge layout (length, width, skew, grade, super-elevation)
  - Wall layout (height, length, batter, geometry)
- Loading Conditions
  - Surcharges (soil, traffic)
  - Bridge loads (dead load, live load)
  - Seismic
- Performance Criteria
  - Design format (ASD, LRFD)
  - Design life
  - Tolerable deformations (vertical, lateral, differential)
  - Factors of Safety/Resistance Factors

Performance Criteria

- Design procedure
  - ASD, LRFD
- Design life of 75 to 100 years
- Tolerable deformations
  - Vertical settlement 0.5% of abutment height
    - For H = 18 ft, settlement = 1.1"
  - Horizontal movement of 1% of bearing area plus setback width
    - For a 4 ft bearing area and set back, max. lateral displacement = 0.5"

Factors of Safety

- Factors of safety (ASD)
  - Sliding = 1.5
  - Bearing = 2.5
  - Global stability = 1.5
  - Reinforcement strength = 3.5
  - Capacity = 3.5
- Resistance factors (LRFD)
  - Sliding = 1
  - Bearing = 0.65
  - Global stability = 0.65
  - Reinforcement strength = 0.4
  - Capacity = 0.45

DESIGN OF GRS-IBS

Step 2: Perform a Site Evaluation

Perform a Site Evaluation

- Conduct a subsurface evaluation for the foundation soil: (1 boring per abutment)
  - Density (γ_f)
  - Friction Angle (ϕ_f)
  - Cohesion (c_f)
  - Undrained Shear Strength (c_u)
  - Groundwater conditions
- Refer to:
  - AASHTO (2003): "Standard Practice for Conducting Geotechnical Subsurface Investigations"
  - FHWA (2006): Soils and Foundations Manual

Perform a Site Evaluation

- Evaluate soil properties for the retained earth (soil behind the abutment)
  - Density (γ_b)
  - Friction Angle (ϕ_b)
  - Cohesion (c_b)

Perform a Site Evaluation

- Evaluate soil properties for the reinforced fill
  - Density (γ_r)
  - Friction Angle (ϕ_r)
  - Cohesion (c_r): *Assume cohesionless soil*
  - Maximum aggregate size: (d_{max})

Recommended Hydraulic and Scour Design Considerations

1. Follow FHWA and AASHTO guidance. A hydraulic engineer should be consulted for the proper implementation of these procedures.
2. Scour depth: The scour depth at an abutment is to be calculated as the sum of the depth of contraction scour and long-term degradation.
3. Scour countermeasures: When scour depth is calculated as described in this section, a designed scour countermeasure is included. Design scour countermeasures include riprap aprons, gabion mattresses, and articulating concrete blocks.
4. Inspection: After construction, scour countermeasure condition and channel instability should be assessed during each regular bridge inspection and after extreme flood events.

DESIGN OF GRS-IBS

Step 3: Evaluate Project Feasibility

Project Feasibility

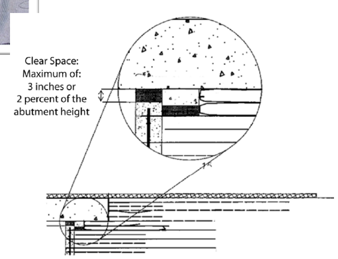
- Is the proposed structure within the limits of the manual
  - Bridge Span < 140 ft
  - Wall height < 30 ft
  - Are the foundation materials competent
- Project cost
- Technical requirements
- Performance objectives
- Scour and/or channel instability

DESIGN OF GRS-IBS

Step 4: Determine Layout of GRS-IBS

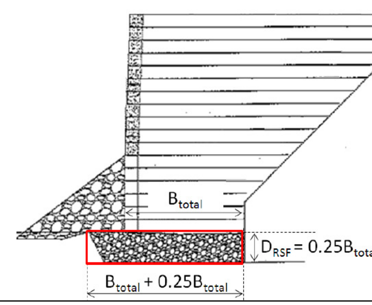
Determine Layout of GRS-IBS

- Define site geometry
  i. Bridge, abutment
- Specific abutment layout
  i. Min. beam seat width (b)
    - 2 ft for span length < 25 ft
    - 2.5 ft for span length ≥ 25 ft
  ii. Min. setback from back of facing (a_b) = 8”
  iii. Min. clear space (d_e) = 2% of total height, 3 inch minimum



Reinforced Soil Foundation

- Minimum base width of wall (B/H ≥ 0.3)
  i. 6 ft min. (including wall width)
- Length in front of facing = 25% bottom reinforcement, 1.5 ft min.
- Depth of excavation = 25% bottom reinforcement, 1.5 ft min.



Reinforcement Layout

- Reinforcement Length
  1. The minimum length at the lowest level should extend the width of the base (*Btotal)*
  2. The reinforcement should follow the cut slope (if applicable) up to a B/H ratio of 0.7.
  3. From there, the length can get progressively longer in reinforcement zones based on external and global stability requirements
  4. The backfill between the reinforced zone and the cut slope or retained soil must be the same structural backfill as the reinforced fill and compacted to the same effort.

Reinforcement Layout

- The reinforcement spacing should be no more than 12”
- The spacing of the bearing bed reinforcement should be less than or equal to 6”
  1. The depth of the bearing bed reinforcement will be determined based on the required reinforcement strength.
  2. At a minimum, there should be 5 bearing bed reinforcement layers.

DESIGN OF GRS-IBS

Step 5: Calculate Applicable Loads

Calculate Loads

- Traffic live loads above embankment
- Road base above GRS abutment
- Bridge loads (from Bridge engineer)
  1. Dead loads from superstructure
  2. Live loads from design vehicle

Traffic Live Load

- AASHTO 2010: $q_t = h_{eq} \times \gamma_b$
- For wing walls (loads parallel to wall), use an equivalent height of soil of 2.0 ft.
- For abutments (load perpendicular to wall), modeled as an equivalent soil height:

Abutment Height (ft)	h_{eq} (ft)
5	4
10	3
≥ 20	2

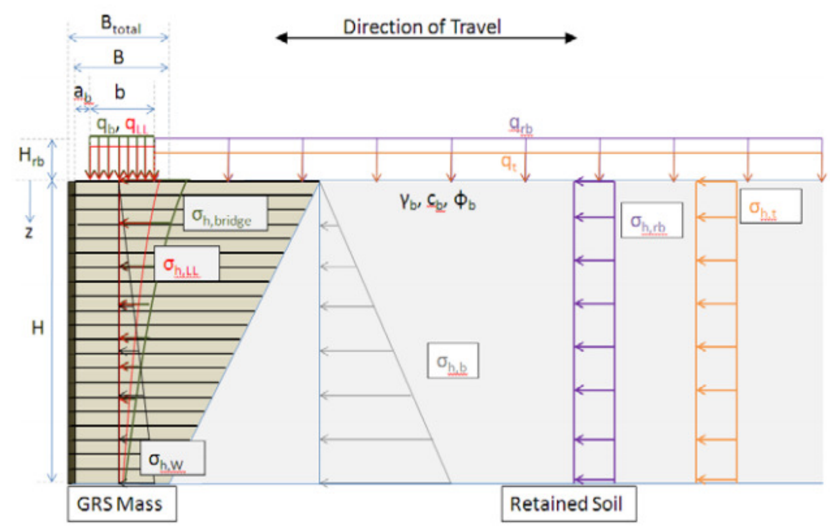
Road Base Dead Load

- Height of soil between the top of wall and top of pavement.
  i. $q_{rb} = h_{rb} \times \gamma_{rb}$

Bridge Loads

- Provided by bridge engineer (AASHTO 2010)
  i. Dead load (max. weight of structure per abutment)
  ii. Live load (max. vehicle loads per abutment)
- Bearing area is sized for a maximum total pressure above the GRS abutment of 4,000 psf.

Design Loads



DESIGN OF GRS-IBS

Step 6: Conduct an External Stability Analysis

External Stability

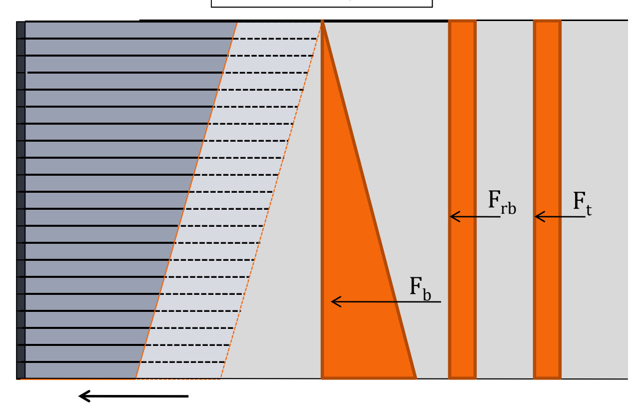
- Sliding
- Bearing Capacity
- Global Stability

External Stability – Forces

- All forces are in units of force/length of wall
- Weight of GRS abutment
- Weight of road base above GRS abutment
- Weight of traffic live load above GRS abutment
- Weight of facing blocks
- Weight of RSF
- Horizontal earth pressure:
  - Retained soil
  - Traffic load
  - Road base

Direct Sliding

$$FS_{slide} = \frac{R_n}{F_n} \geq 1.5$$



Direct Sliding

- Driving Forces (F_n): $F_n = F_b + F_{rb} + F_t$
  - Due to weight of GRS fill: $F_b = 1/2\gamma_b H^2 K_{ab}$ [F/L]
  - Due to traffic surcharge: $F_t = q_t HK_{ab}$ [F/L]
  - Due to road base surcharge: $F_{rb} = q_{rb} HK_{ab}$ [F/L]

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45^o - \frac{\phi}{2}\right)$$

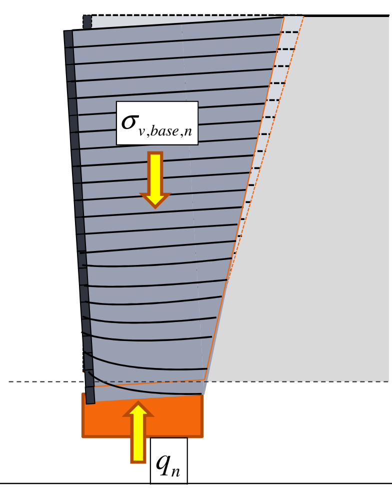
Direct Sliding

- Resisting Forces (R_n): $R_n = W_t \mu$
  - Total Weight (W_T): $W_t = W + DL + W_{rb}$
    - Live loads contribute to the loads but are ignored for the resistance
  - Friction factor (μ): $\mu = \tan\phi_{crit}$
    - Assume sliding along bottom of abutment
    - Critical friction angle found using ASTM D5321
    - If data not available, assume:

$$\mu = \frac{2}{3}\tan\phi_r$$

Bearing Capacity

$$FS_{bearing} = \frac{q_n}{\sigma_{v,base,n}} \geq 2.5$$



Bearing Capacity

- Applied Bearing Pressure ($\sigma_{v,base,n}$):

$$\sigma_{v,base,n} = \frac{\Sigma V}{B_{RSF} - 2e_{B.n}}$$

  - Total vertical load on the GRS mass (ΣV):

$$\Sigma V = W + W_{RSF} + W_{face} + W_{tr} + W_{rb} + DL + LL$$

  - Eccentricity ($e_{B,n}$):

$$e_{B.n} = \frac{\Sigma M_D - \Sigma M_R}{\Sigma V}$$

Bearing Capacity

- Resisting Pressure for Bearing Capacity (q_n):

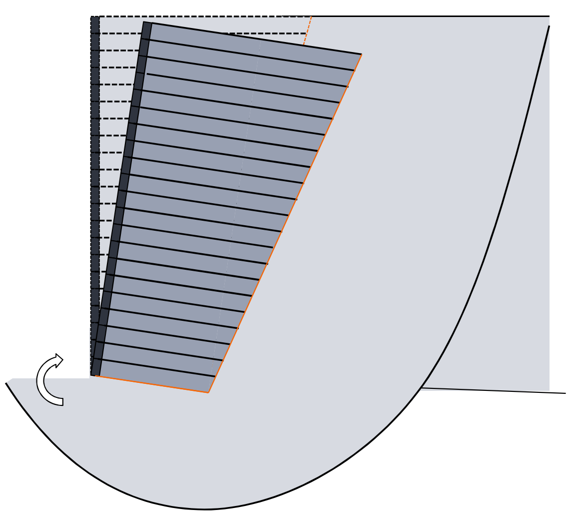
$$q_n = c_f N_c + \frac{1}{2} B' \gamma_f N_\gamma + \gamma_f D_f N_q$$

Bearing Capacity

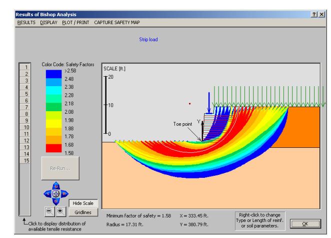
ϕ_f	N_c	N_q	N_γ	ϕ_f	N_c	N_q	N_γ
0	5.14	1.0	0.0	23	18.1	8.7	8.2
1	5.4	1.1	0.1	24	19.3	9.6	9.4
2	5.6	1.2	0.2	25	20.7	10.7	10.9
3	5.9	1.3	0.2	26	22.3	11.9	12.5
4	6.2	1.4	0.3	27	23.9	13.2	14.5
5	6.5	1.6	0.5	28	25.8	14.7	16.7
6	6.8	1.7	0.6	29	27.9	16.4	19.3
7	7.2	1.9	0.7	30	30.1	18.4	22.4
8	7.5	2.1	0.9	31	32.7	20.6	26.0
9	7.9	2.3	1.0	32	35.5	23.2	30.2
10	8.4	2.5	1.2	33	38.6	26.1	35.2
11	8.8	2.7	1.4	34	42.2	29.4	41.1
12	9.3	3.0	1.7	35	46.1	33.3	48.0
13	9.8	3.3	2.0	36	50.6	37.8	56.3
14	10.4	3.6	2.3	37	55.6	42.9	66.2
15	11.0	3.9	2.7	38	61.4	48.9	78.0
16	11.6	4.3	3.1	39	67.9	56.0	92.3
17	12.3	4.8	3.5	40	75.3	64.2	109.4
18	13.1	5.3	4.1	41	83.9	73.9	130.2
19	13.9	5.8	4.7	42	93.7	85.4	155.6
20	14.8	6.4	5.4	43	105.1	99.0	186.5
21	15.8	7.1	6.2	44	118.4	115.3	224.6
22	16.9	7.8	7.1	45	133.9	134.9	271.8

Global Stability

$$FS_{global} \geq 1.5$$



Global Stability



- Rotational and wedge analysis
- Limit equilibrium analysis
- Many different methods (Bishop most common)
- Use a standard slope stability computer program (e.g. ReSSA, SLIDE, SLOPE/W)

DESIGN OF GRS-IBS

Step 7: Conduct an Internal Stability Analysis

Internal Stability Analysis

- Ultimate Capacity (Empirical and Analytical)
  - i. Empirical Method
  - ii. Analytical Method
- Deformations
  - i. Vertical
  - ii. Lateral
- Required Reinforcement Strength

Ultimate Capacity

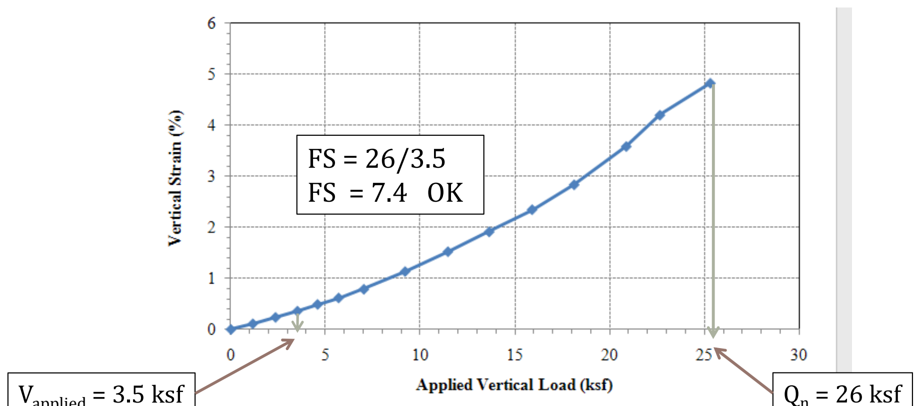


Figure 4-17 - Design Envelope for Vertical Strain at 8 in. Reinforcement Spacing

$$V_{allow,emp} = \frac{q_{ult,emp}}{FS_{capacity}} = \frac{q_{ult,emp}}{3.5}$$

Ultimate Capacity

- Analytical Method
  - Function of:
    - Confining stress (σ_c)
    - Reinforcement spacing (S_v)
    - Ultimate reinforcement strength (T_f)
    - Maximum aggregate size (d_{max})
    - Aggregate friction angle (ϕ)
  - Check that applied load ($V_{applied} = q_b + q_{LL}$) is less than allowable load ($V_{allow,an}$)

$$q_{ult,an} = \left[0.7^{\frac{S_v}{6d_{max}}} \frac{T_f}{S_v} \right] K_p$$

$$V_{allow,an} = \frac{q_{ult,an}}{FS_{capacity}} = \frac{q_{ult,an}}{3.5}$$

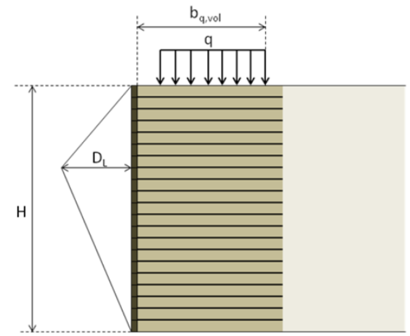
Vertical Deformation

- Use results from performance tests
- Find corresponding vertical strain (ε_v) for applied dead load (q_b)
- Multiply by the height to estimate vertical deformation (D_V) within GRS abutment

$$D_V = \varepsilon_v H$$

Lateral Deformation

- Estimate from vertical deformation
- Based on concept of zero volume change



$$\Delta V_{top} = b_{q,vol} L D_v = \Delta V_{face} = \frac{1}{2} H L D_L$$

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

$$\varepsilon_L = \frac{D_L}{b_{q,vol}} = \frac{2 D_V}{H} = 2\varepsilon_V$$

Required Reinforcement Strength

- Use analytical equation
- Function of:
  - Lateral stress (σ_h)
    - Measured beneath the centerline of the bridge load
  - Reinforcement spacing (S_v)
  - Ultimate reinforcement strength (T_f)
  - Maximum aggregate size (d_{max})
  - Aggregate friction angle (ϕ)

$$T_{req} = \left[\frac{\sigma_h}{0.7^{\frac{S_v}{6 d_{\max}}}} \right] S_v$$

Required Reinforcement Strength

- The required reinforcement strength must satisfy two criteria:

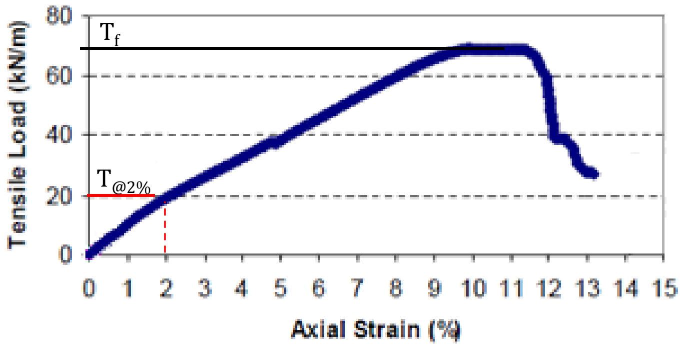
1) It must be less than the allowable reinforcement strength (T_{allow})

2) It must be less than the strength at 2% reinforcement strain ($T_{@\varepsilon=2\%}$)

$$T_{allow} = \frac{T_f}{FS_{\text{reinf}}} = \frac{T_f}{3.5}$$

Required Reinforcement Strength

- Recommended: $T_f \geq 4800$ lb/ft
- To get $T_{@\varepsilon=2\%}$, use results of ASTM D-4595 (geotextiles) or ASTM D-6637 (geogrids)



Bearing Bed Reinforcement

- Depth of bearing bed reinforcement determined by calculating T_{req} for each reinforcement layer
  - If $T_{req} > T_{allow}$ or $T_{req} > T_{@\varepsilon=2\%}$, then decrease spacing to 4" until $T_{req} < T_{allow}$ and $T_{req} < T_{@\varepsilon=2\%}$
  - Remember, minimum bearing bed reinforcement depth is through 5 courses of block

DESIGN OF GRS-IBS

Step 8: Implement Design Details

Design Details

- Develop specific project details for:
  1. Corners
  2. Drainage
  3. Surface drainage and collection
  4. Erosion protection
  5. Scour countermeasures
  6. Skews and superelevations
  7. Accommodate for obstructions such as guardrails, drainage, and utilities.
  8. Others as required to accommodate structure

Conclusions

- Performance tests involve axially loading the GRS mass to measure lateral and vertical deformation .
- These provide us with material strength properties of a particular GRS composite.
- GRS-IBS Design Process is most commonly divided in 8 steps:

1. Project Requirements
2. Site Evaluation
3. Project Feasibility
4. GRS-IBS Layout
5. Calculating Loads
6. External Stability Analysis
7. Internal Stability Analysis
8. Design Details

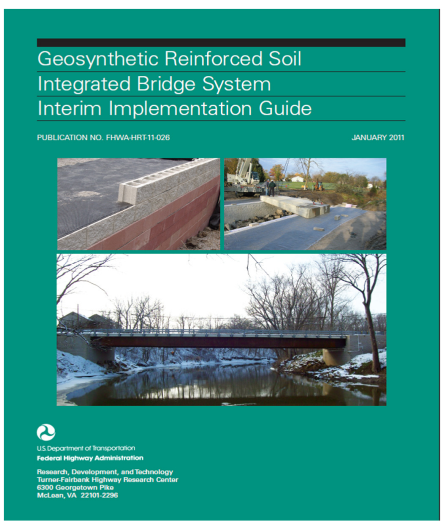
- Important Design Considerations for Optimal GRS-IBS Performance:

I. Reinforcement spacing should be no more than 12”.
II. Spacing of the bearing bed reinforcement should be less than or equal to 6”.
III. Bearing area is sized for a maximum total pressure above the GRS abutment of 4,000 psf.
IV. The recommended ultimate reinforcement strength has to be $T_f \geq 4800$ lb/ft.

Acknowledgements

- Benjamin Colucci, PhD, JD, PE
- Michael Adams, PE
- Jennifer Nicks, PE
- Daniel Alzamora, PE
- Alvin Gutierrez, PE
- Transportation Technology Transfer Center Staff

References



www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/index.cfm

Contact Information

Benjamín Colucci, PhD, JD, PE
Principal Investigator
benjamin.colulcci1@upr.edu

Irmalí Franco
Administrative Officer
irmali.franco1@upr.edu
(787)834-6385 / (787)832-4040 x 3393 or 3403

María C. Fumero
marifumero@hotmail.com
(787)519-0029