Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS)

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GRS-IBS

- Introduce the concept
- Brief Intro to Design Guide
- Construction Concepts
- FDOT Implementation
- Design Example

GRS – IBS

Why Do This?

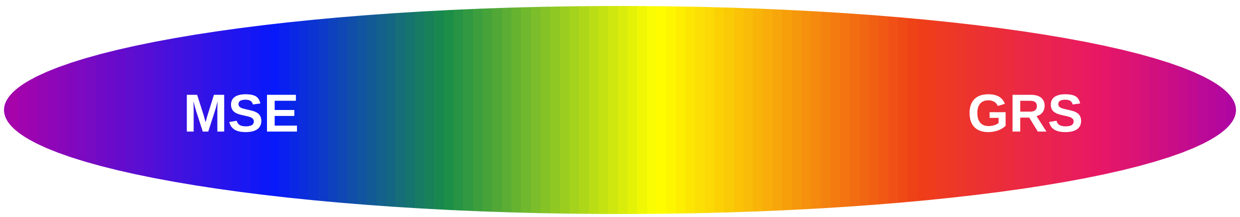
- FHWA & States with experience report:
  - ✓ Reduced construction cost (25 - 60%)
  - ✓ Reduced construction time
  - ✓ Flexible design - easily field modified for unforeseen site conditions (e.g. obstructions, utilities, different site conditions)
  - ✓ Easier to maintain (fewer bridge parts, no erosion)
  - ✓ QA/QC Advantages
  - ✓ Smooth Transition

GRS FUNDAMENTALS

Definitions

- GRS - Geosynthetic Reinforced Soil
  - ✓ An engineered, well compacted granular fill (gravel, not sand) with closely spaced (< 12”) layers of geosynthetic reinforcement
- IBS - Integrated Bridge System
  - ✓ A fast, cost-effective method of bridge support blending the roadway into the superstructure using GRS technology

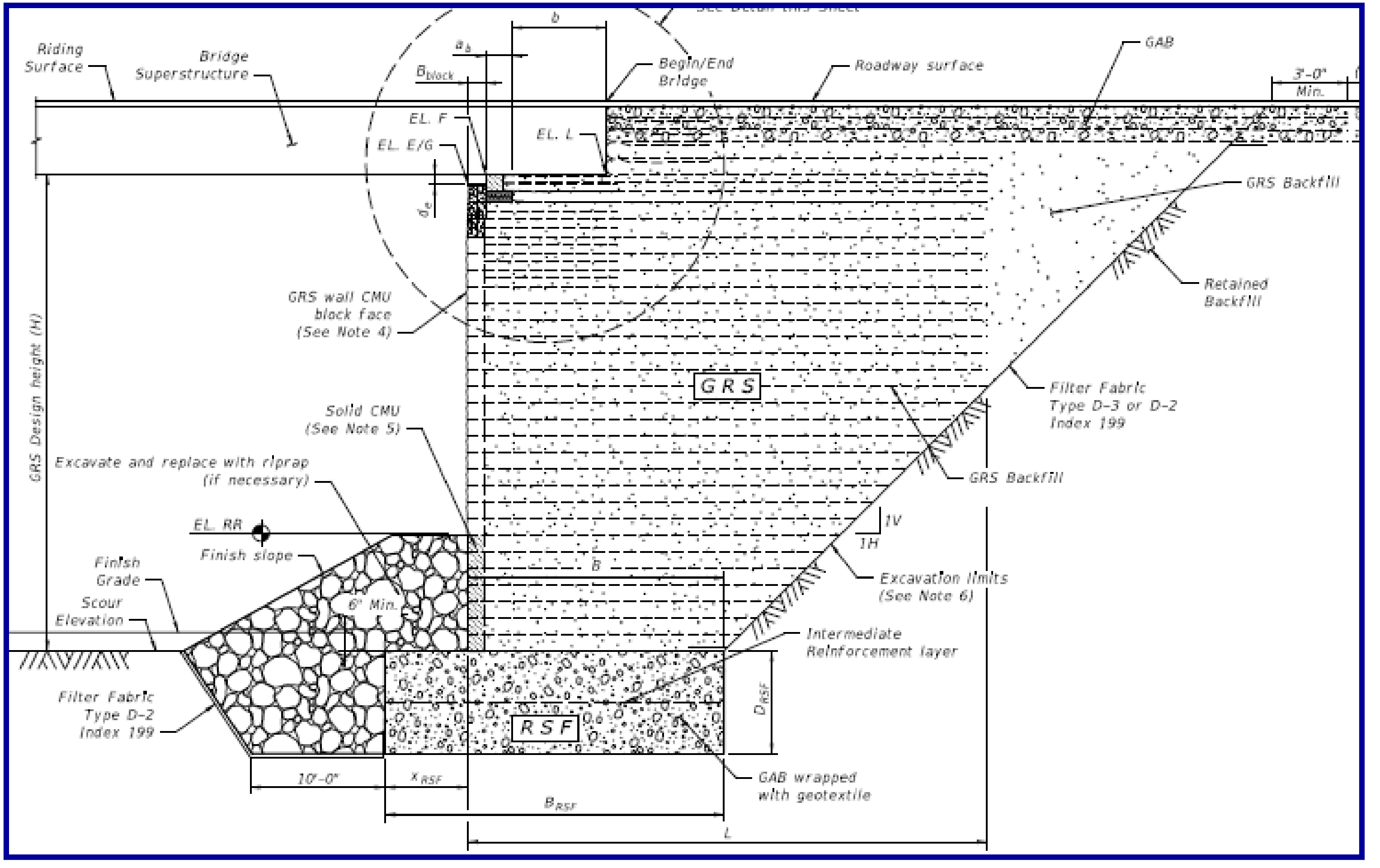
Degree of Composite Behavior



<u>Reinforcement spacing</u>

36”   30”   24”   18”   12”   6”

Cross-Section of GRS-IBS



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Site Selection

- Simple span (currently ≤ 140 ft)
  - ✓ Single or Multiple Span Bridges
- ≤ 30 ft abutment height
- Grade separation
- ≤ 7 fps Water Velocity (B&S rip rap)
- Cost Effective to Excavate Below Scour Elevation?

Site Selection

- Tolerable Settlements
- Steel or concrete superstructures
- New or replacement structures
- On or Off System
- Approval Needed for Interstate or Multi-Lane Roadways

Facing Elements

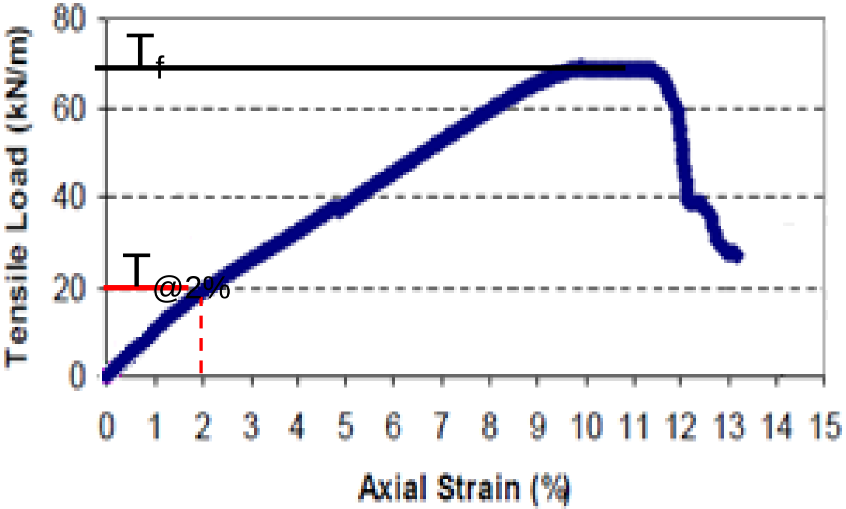
- Split face CMU Block
  - ✓ Dimensions: 7-5/8" x 7-5/8" x 15-5/8" (nominal 8x8x16)
  - ✓ Readily available
  - ✓ Inexpensive
  - ✓ Friction connection to the reinforcement
  - ✓ Material Specifications:
    - Compressive strength ≥ 4,000 psi
    - Water absorption limit: 5%

Specified 8x8x16 CMU facing
Approx 42 lb.

Compatible 8x12x18 SBW facing
Approx 81 lb.

Geosynthetic Reinforcement

- Geosynthetic reinforcements:
  - ✓ HDPE, PP, or PET Geogrids
  - ✓ PP or PET Woven geotextiles
- T_{ult} = 4800 lb/ft (both directions)
- $T_{2\%}$ = Strength at 2% Strain



Granular Backfill

- Well Graded
  - ✓ Specification 204 Graded Aggregate
  - ✓ $\phi \geq 38^o$
- Open Graded
  - ✓ Specification 901 Any Gradation from #57 to #89
  - ✓ $\phi \geq 38^o$

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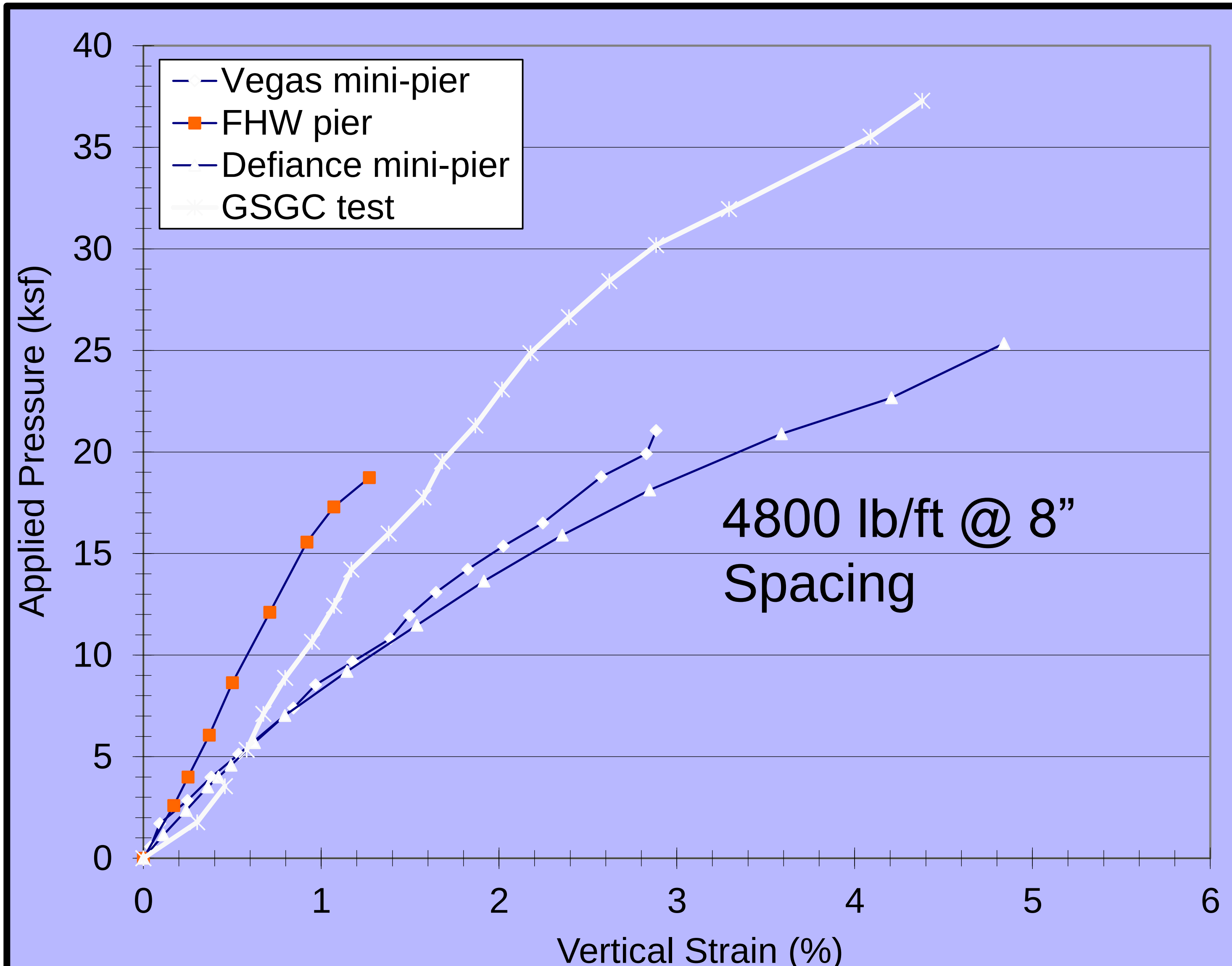
FHWA Research:
Performance
Testing and Monitoring

Performance Test Results



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Performance Tests Continued

Before

After (25.9 ksf)

Test to Failure
half-strength fabric; no CMUs
2400 lb/ft @ 8" Spacing

Before

After

0.5 ksf
(25 kPa)


3.1 ksf
(148 kPa)


4.1 ksf
(196 kPa)
Maximum Design Service Load


8.5 ksf
(407 kPa)
2 x Maximum Design Service Load

11.3 ksf
(541 kPa)

2.8 x Maximum Design Service Load


16.7 ksf
(800 kPa)
4+ x Maximum Design Service Load


18.1 ksf
(867 kPa)

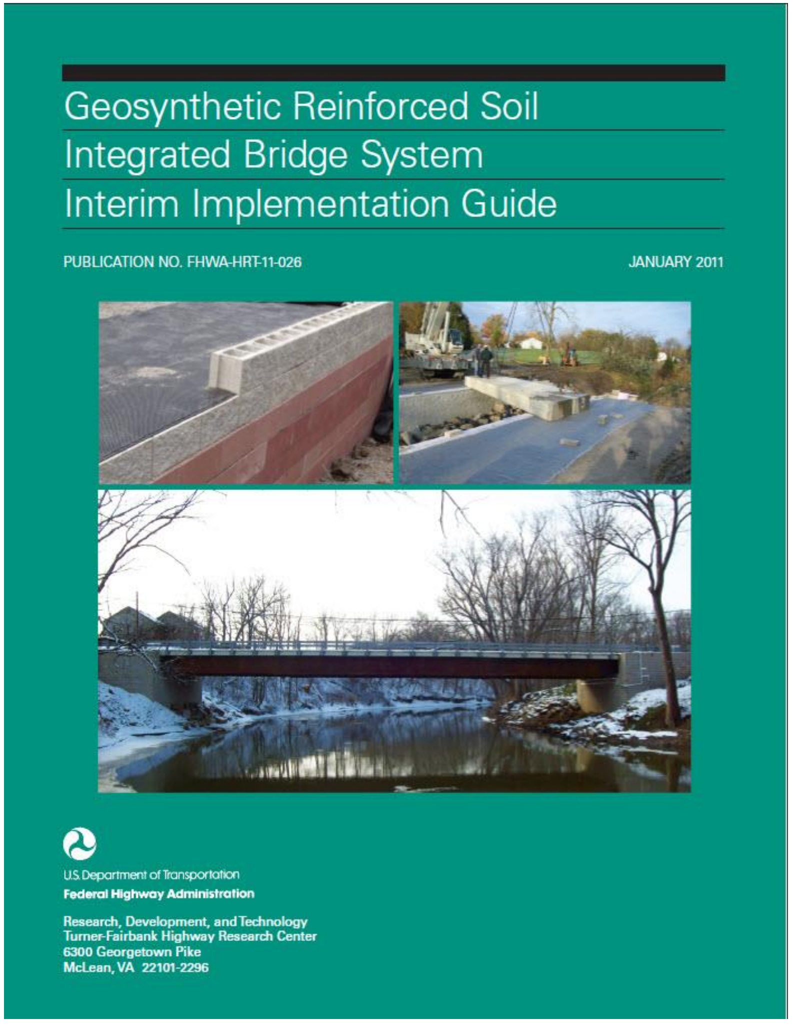
Construction Video

http://www.youtube.com/watch?feature=player_embedded&v=w_5WFoAdoUw

Design Method

- FHWA GRS-IBS Design Guide
- Appendix C – LRFD Design

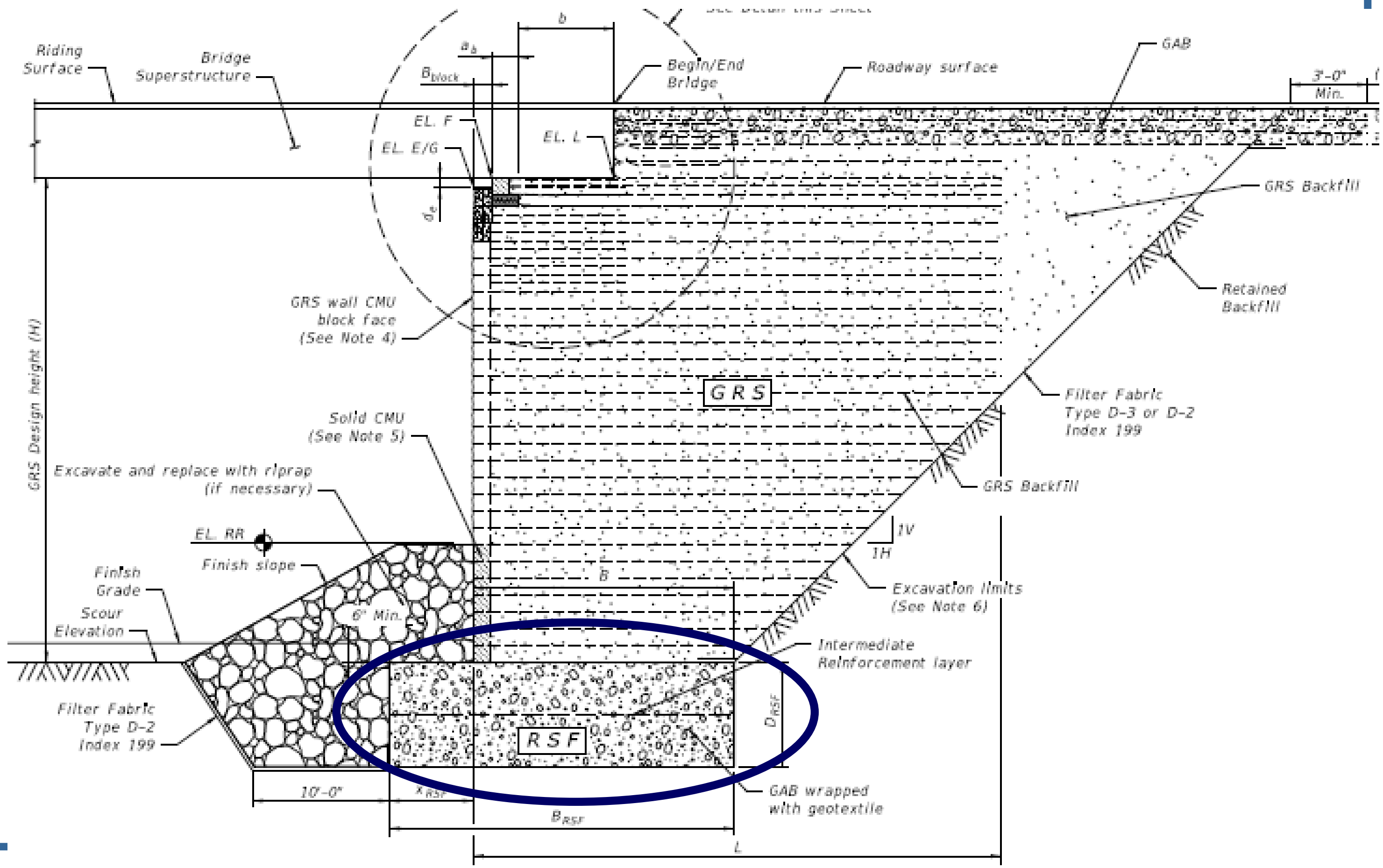
- http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/



CONSTRUCTION OF GRS-IBS

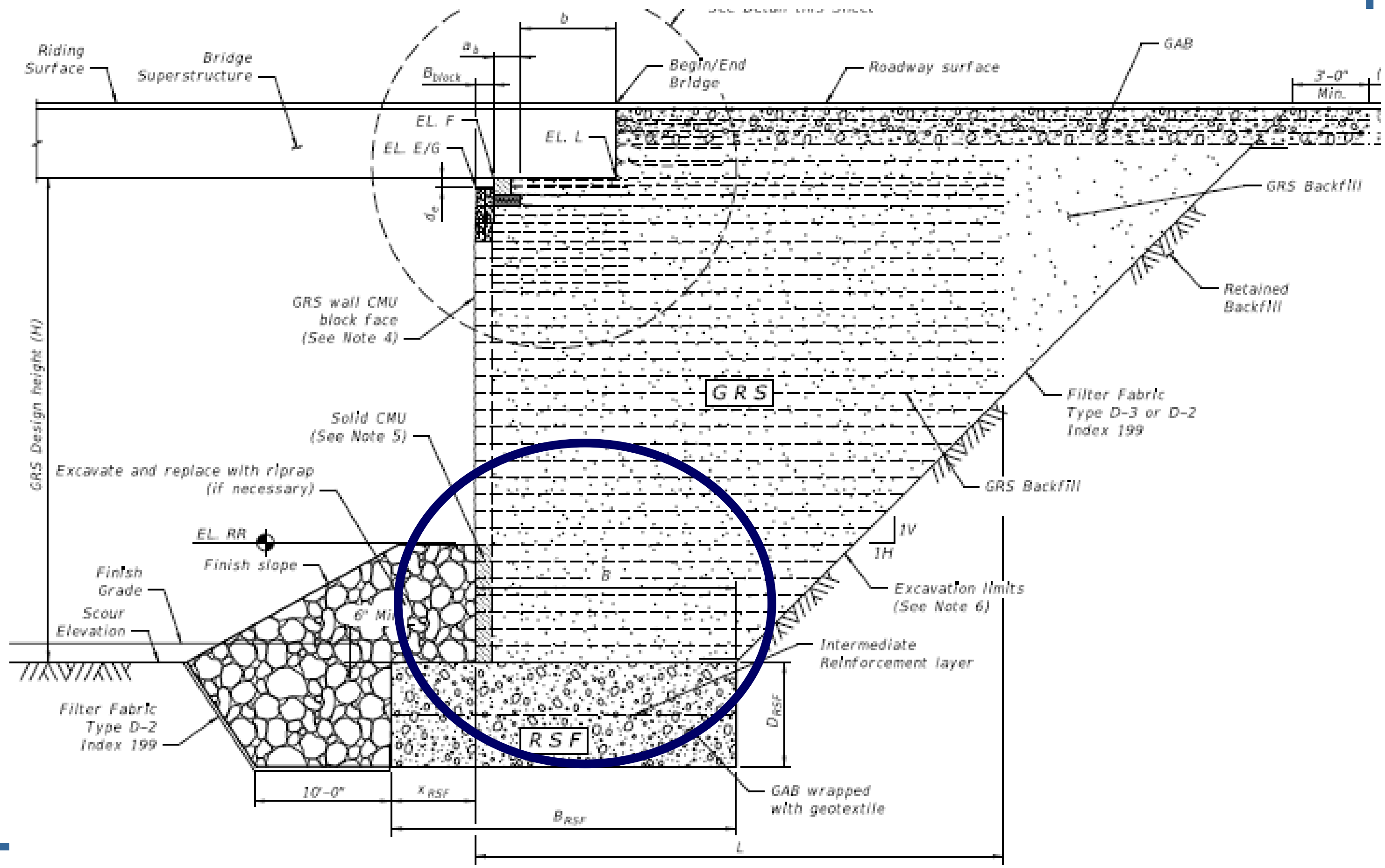
Reinforced Soil Foundation (RSF)

- Provides embedment and increased bearing area



GRS Abutment

- The first layers are important for leveling and alignment



GRS Abutment *Continued*

- Wall Corners:
- Right angle wall corners constructed with CMU corner blocks that have architectural detail on two sides
- Walls with angles ≠ 90 degrees require cutting of the corner blocks resulting in a vertical seam or joint. Fill with reinforced concrete

GRS Abutment *Continued*

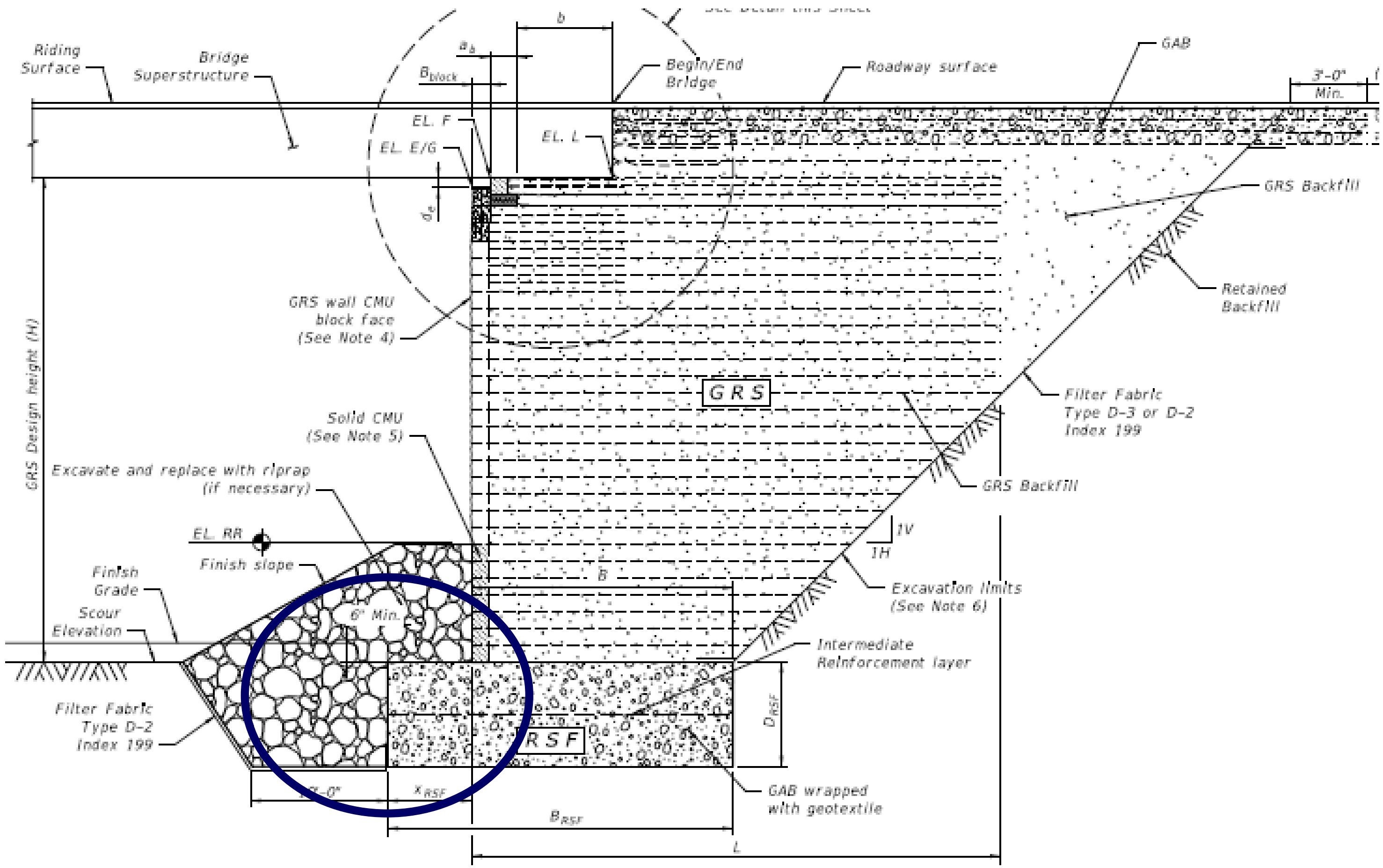
Top of Facing Wall:

- ✓ The top three courses of CMU block are filled with concrete wall mix and pinned together with No. 4 rebar
- ✓ The geotextile in these cells needs to be cleared with a razor knife or 'weed burner' to open the core for placement of concrete wall fill

GRS Abutment *Continued*

- Coping:
  - ✓ After filling the top three courses of block, a thin layer of the same concrete mix is placed on top of the block, to form the coping
  - ✓ Then hand trowel the coping either square or round and slope to drain

Scour Countermeasure



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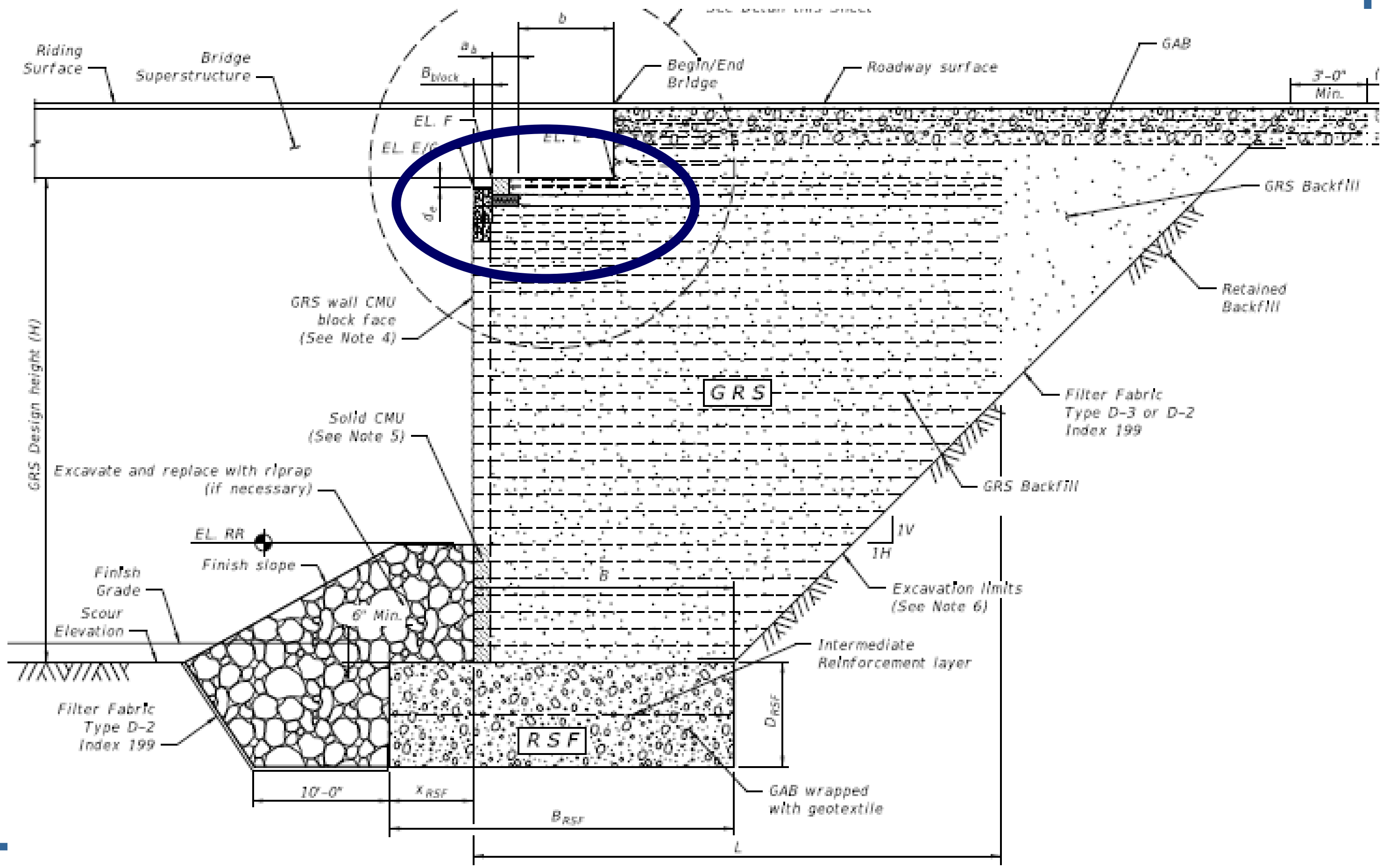
Beam Seat



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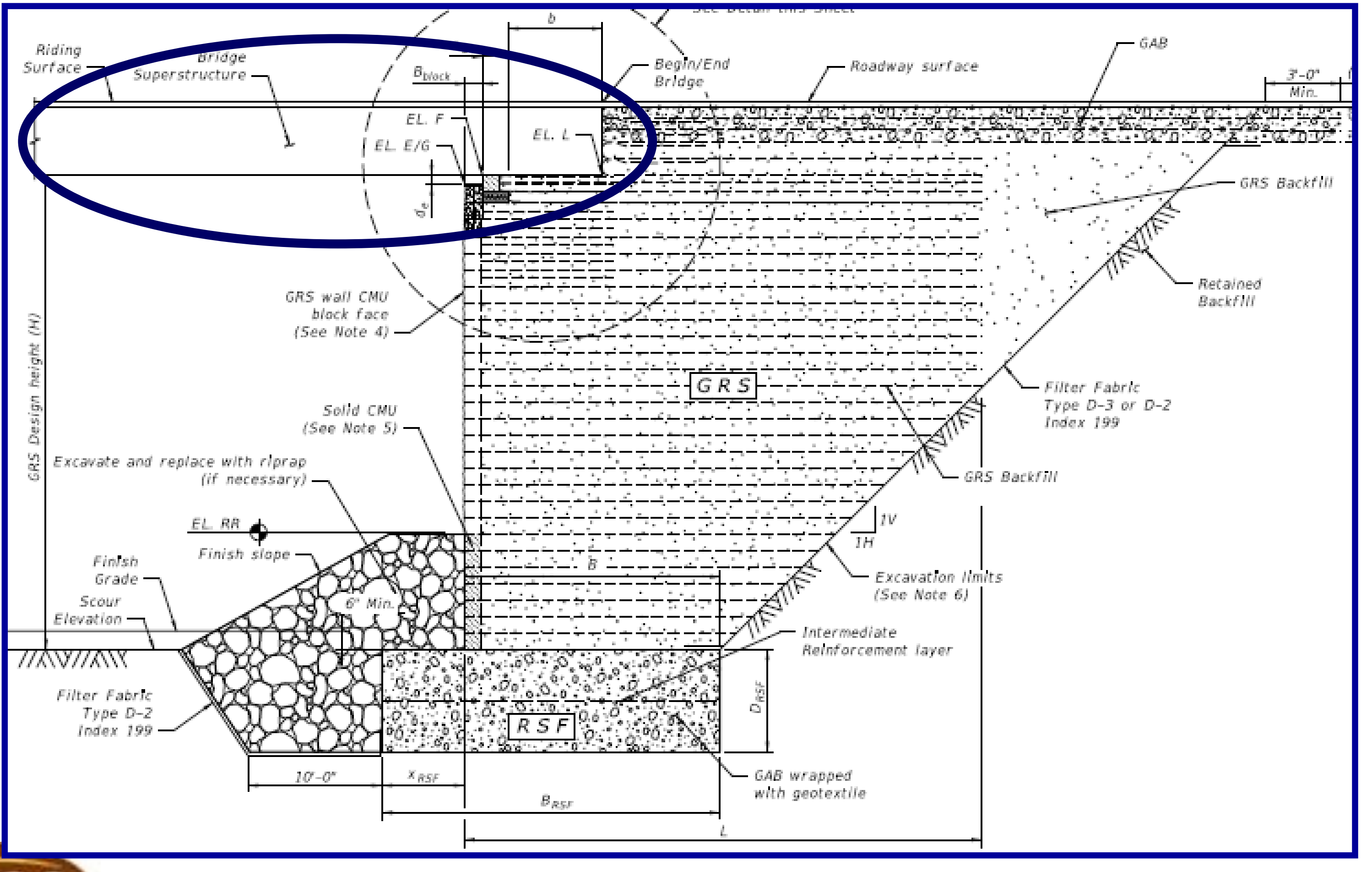
Beam Seat

- 4” thick x 12” wide pre-cut foam board at the top of the bearing bed reinforcement creates the ‘set-back’ distance to ‘beam seat’.

Beam Seat

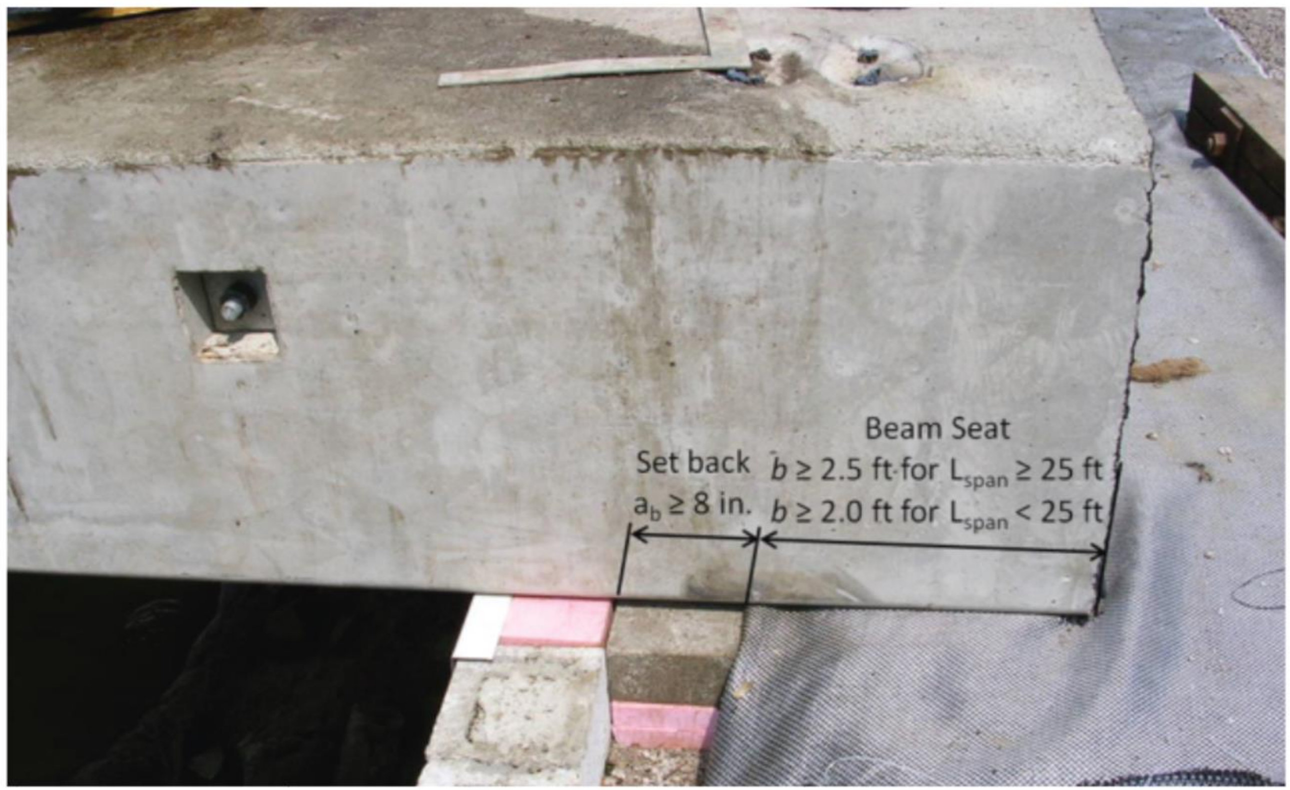
- Grade the surface of the aggregate slightly high (about 0.5”) to seat the superstructure level and maximize contact with the bearing area

Superstructure



Superstructure

- Set Back: The distance between the back of the facing block and the front of the beam seat (use width of foam, currently 12”)



FDOT Implementation

- 2014 Structures Manual Sections 3.12.12 & 3.13.4
- Developmental Design Standard 6025
- Developmental Specification 549

FDOT Implementation

- Needed from Drainage/Hydraulics:
  - ✓ Depth of Scour vs. Opening Width
  - ✓ Design Flow Velocity vs. Opening Width
  - ✓ Peak Water Elevation vs. Opening Width
  - ✓ Scour Countermeasure Details
    - Type
    - Elevation to Install
    - Finish Slope

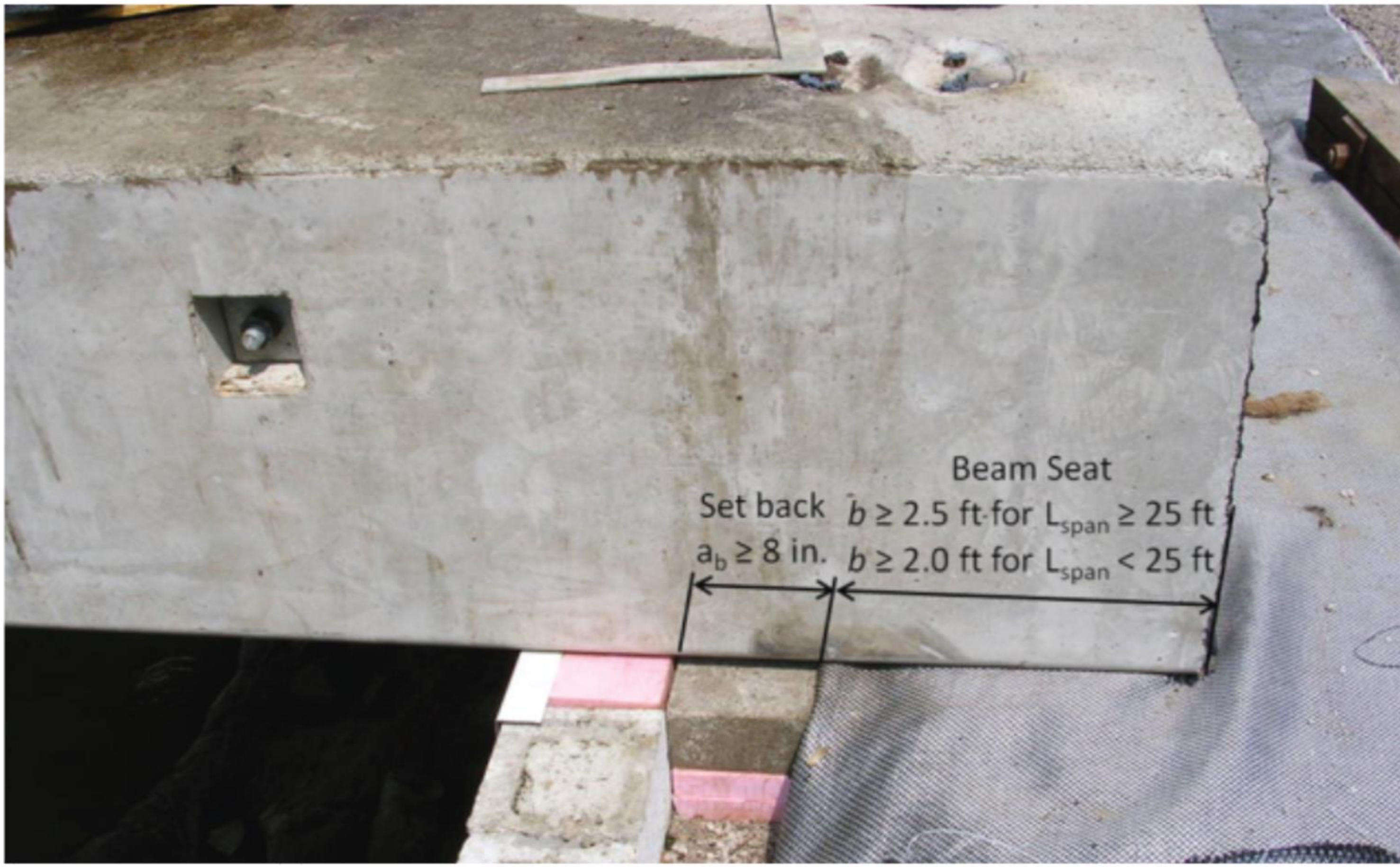
DESIGN EXAMPLE

Design Example

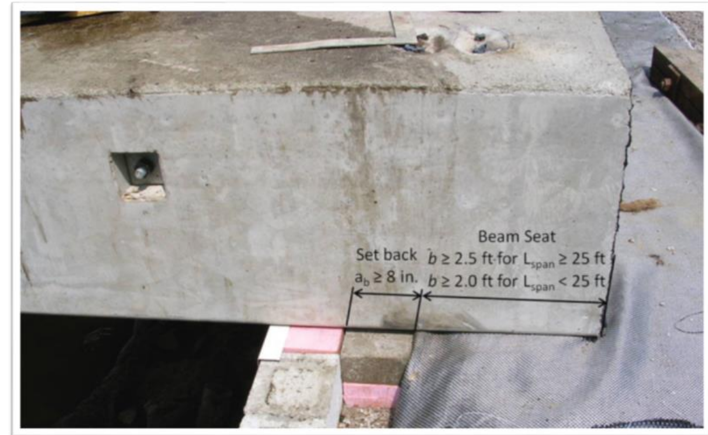
- Two 12’ Lanes + 8’ Shoulders
- Barriers per D6025
- Bridge Width = 12’ + 8’ + (2 * 1.5’) = 43’
- GRS Height = 15’
- Wall Spacing = 30’
- Single Span 16” Flat Slab Bridge with 6” CIP Topping

Bridge Length

- Wall spacing + 2 x (distance behind wall face)



Design Example



- Bridge Length =
  - ✓ 30' Wall Spacing +
  - ✓ 2 x 2.5'(min) bearing seat +
  - ✓ 2 x 1' set back (foam width) +
  - ✓ 2 x facing block (8" CMU or 12" SBW block)+
  - ✓ 2 x front batter? (12" SBW block uses 2^o batter)
  - ✓ 30' + 5' + 2' + 2' = 39'
- Bearing Area = 43 x 2.5 = 107.5 sf

1.5' for CMU
2' for SBW plumb
2'-8" SBW at 2^0 batter

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Design Example

- Bridge Dead Loads =
  - ✓ Deck: 22”/12” x 39’ x 43’ x 150 pcf = 461.175 k
  - ✓ Barriers: 39’ x 2 x 420 plf = 32.76 k
  - ✓ Service DL = 493.935 k, 246.967 k/abut, 2297.4 psf

Design Example

- Bridge Live Loads =
  - ✓ Traffic + Design Truck
  - ✓ (40' inside of barriers)/12' = 3.33 => 3 Lanes Traffic
  - ✓ Traffic = 640 plf x Lspan/2 x 3 Lanes = 37.44 k/abut
  - ✓ Truck at abutment = 32+32((Lspan-14)/Lspan)+8((Lspan-28)/Lspan) x 3 Lanes = 164.307k/abut
  - ✓ Service LL = 201.747 k/abut, 1876.7 psf

Design Example

- Bridge Service Loads =
  - ✓ Service DL = 2297.4 psf
  - ✓ Service LL = 1876.7 psf
  - ✓ Service = 4174.1 psf > 4000 psf No Good
- Try Beam Seat = 3 ft
  - ✓ (Bridge Length increases to 40 ft)
  - ✓ Service = 3545 psf **ok**

Design Example

- Soil Parameters:
  - Foundation Soil
    - γ_f = 55 pcf
    - φ_f = 33º
    - C_f = 0
    - K_{af} = .29, K_{pf} = 3.39
  - Reinforced Fill
    - γ_r = 115 pcf
    - φ_r = 38º
    - K_{ar} = .24, K_{pr} = 4.20
  - Retained Soil
    - γ_b = 125 pcf
    - φ_b = 34º
    - C_b = 0
    - K_{ab} = .28
  - Road Base
    - γ_{rb} = 140 pcf
    - φ_{rb} = 38º
    - K_{arb} = .24

External Stability

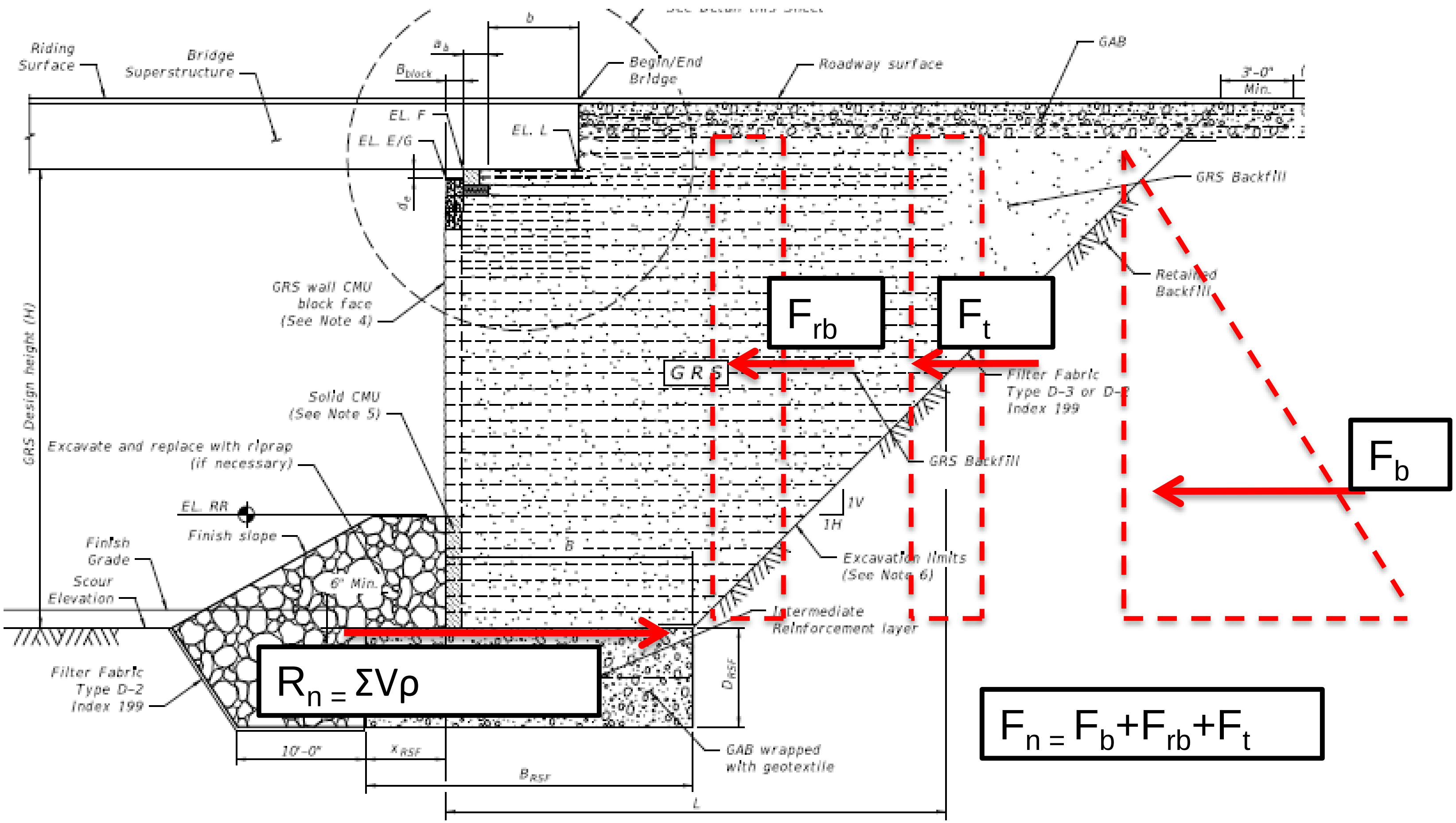
- Sliding on RSF
- Sliding at Base of RSF
- Eccentricity
- Bearing
- Global

Table 11.5.7-1—Resistance Factors for Permanent Retaining Walls

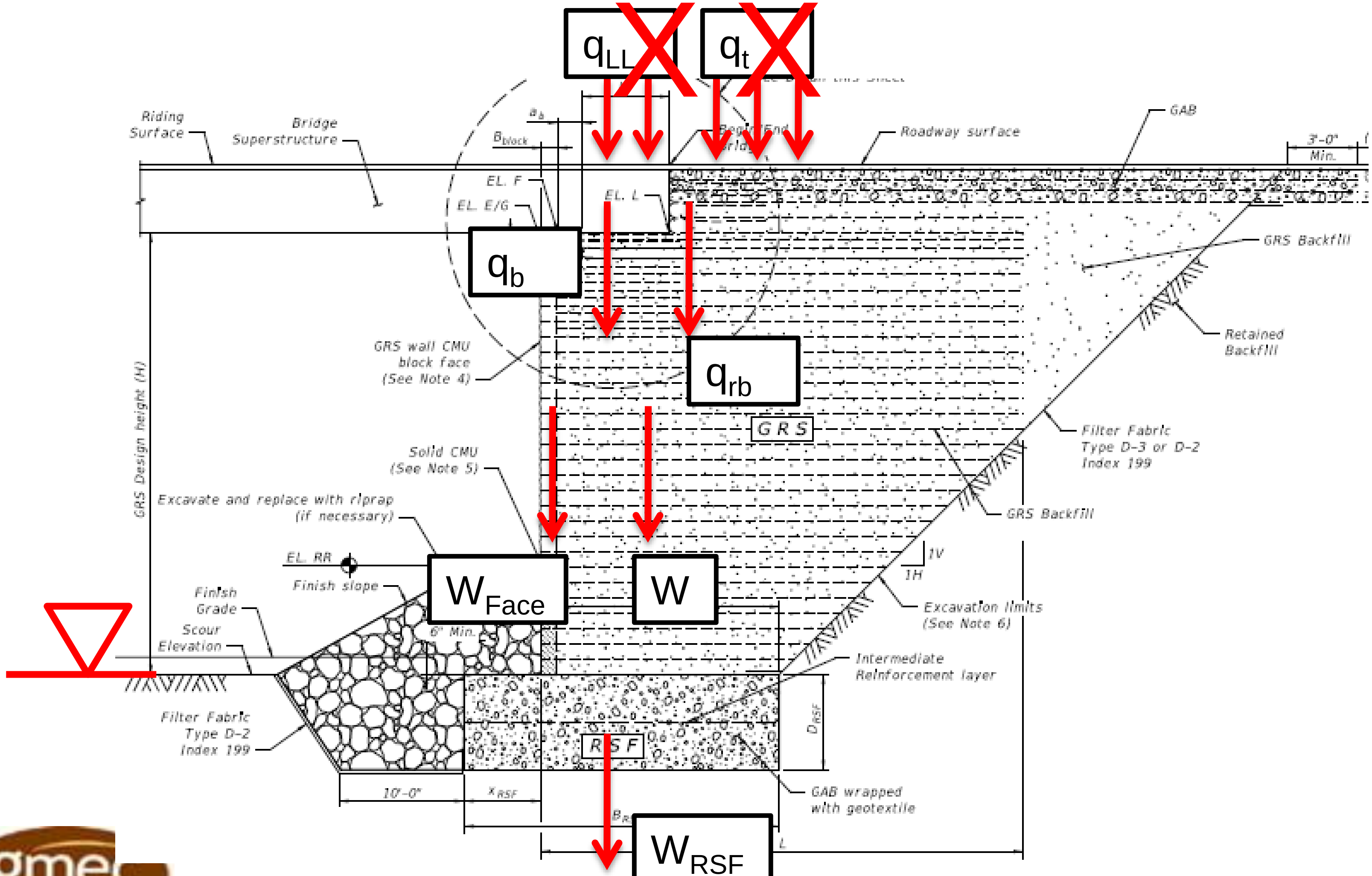
Mechanically Stabilized Earth Walls, Gravity Walls, and Semigravity Walls		
Bearing resistance	• Gravity and semigravity walls • MSE walls	0.55 0.65
Sliding		1.0
Tensile resistance of metallic reinforcement and connectors	Strip reinforcements [4] • Static loading Grid reinforcements [4] [5] • Static loading	 0.75 0.65
Tensile resistance of geosynthetic reinforcement and connectors	• Static loading	0.90
Pullout resistance of tensile reinforcement	• Static loading	0.90

Passive earth pressure component of Sliding Resistance 0.50

External Stability - Sliding



External Stability - Sliding



External Stability – Sliding on RSF

- Sliding Forces:
  - ✓ $F_R = \gamma_{EH\_MAX} F_b + \gamma_{EH\_MAX} F_{rb} + \gamma_{LS} F_t$
  - ✓ $F_R = 9451.5$ lb/ft
- Resisting Forces (B=10'):
  - ✓ $R_R = (\gamma_{EV\_MIN} W_{GRS} + \gamma_{DC\_MIN} q_b b_{sw} + \gamma_{DC\_MIN} {}^{*}W_{face} + \gamma_{EV\_MIN} q_{rb} b_{rb\_\_bt} - H_w \gamma_w B)\ (\boldsymbol{\rho})$

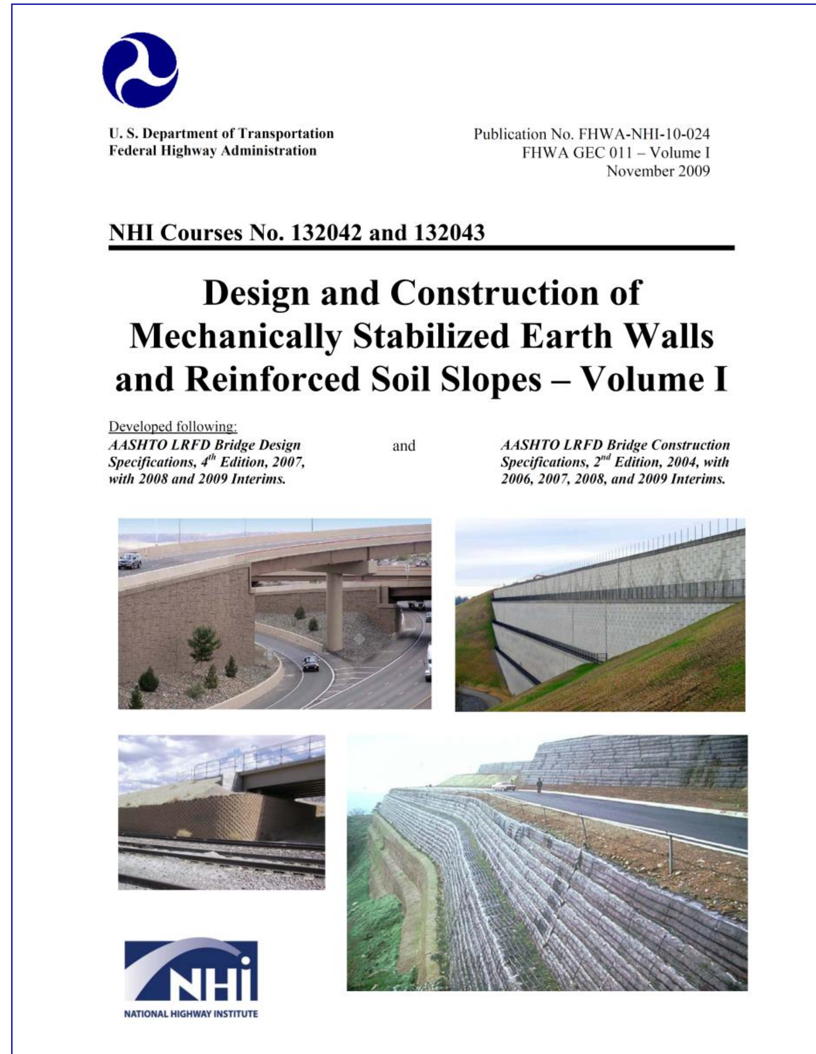
    $R_R = (19832.1 \text{ lb/ft})\ (2/3 \tan \varphi r)$
  - ✓ $R_R = 10329.7$ lb/ft
- $R_R/F_R = 10329.7 / 9451.5 = 1.09$ OK

External Stability – Sliding at Base of RSF

- Sliding Forces:
  - ✓ F_R = 12103.6 lb/ft
- Resisting Forces (B_{RSF}=12.5'):
  - ✓ R_R = (24766.96 lb/ft) (0.8 tan φf)
  - ✓ R_R = 12867.08 lb/ft
- R_R/F_R = 12867.08 / 12103.6 = 1.06 OK
- (w/ Passive Resistance R_R/F_R = 1.11)

External Stability - Eccentricity

- Eccentricity check not shown in Guide, but required by AASHTO LRFD Bridge Design Specification
- $e = (\Sigma M_D - \Sigma M_R)/\Sigma V$
  - ✓ **Sum Moments about center of base of RSF**
  - ✓ **γ_{Max} for ΣM_D**
  - ✓ **γ_{MIN} for ΣM_R & ΣV**
  - ✓ If $e \leq B/4$ OK


U. S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-NHI-10-024
FHWA GEC 011 – Volume I
November 2009

NHI Courses No. 132042 and 132043

Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volume I

Developed following:

AASHTO LRFD Bridge Design Specifications, 4th Edition, 2007, with 2008 and 2009 Interims.

and

AASHTO LRFD Bridge Construction Specifications, 2nd Edition, 2004, with 2006, 2007, 2008, and 2009 Interims.

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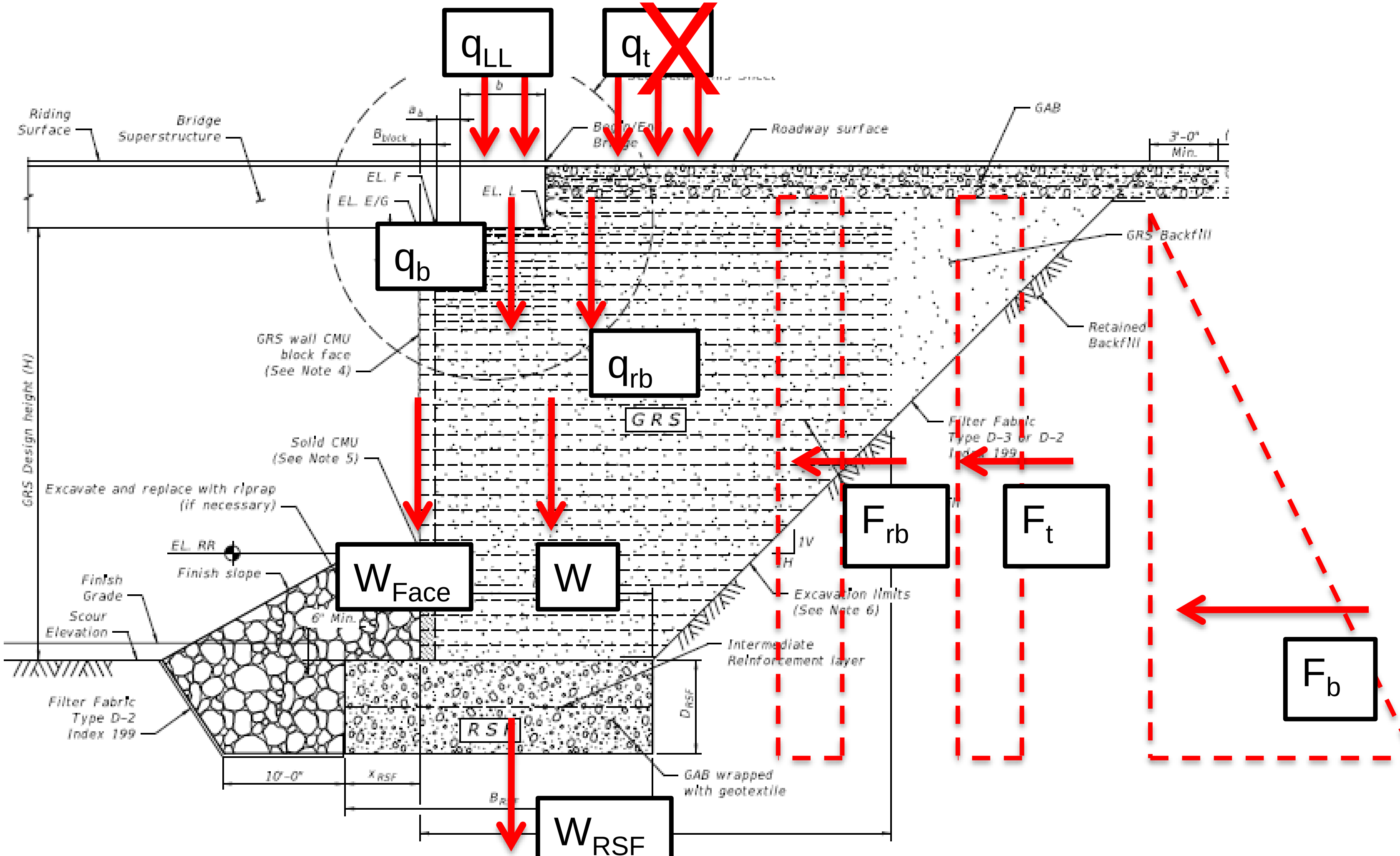
External Stability - Eccentricity



External Stability - Eccentricity

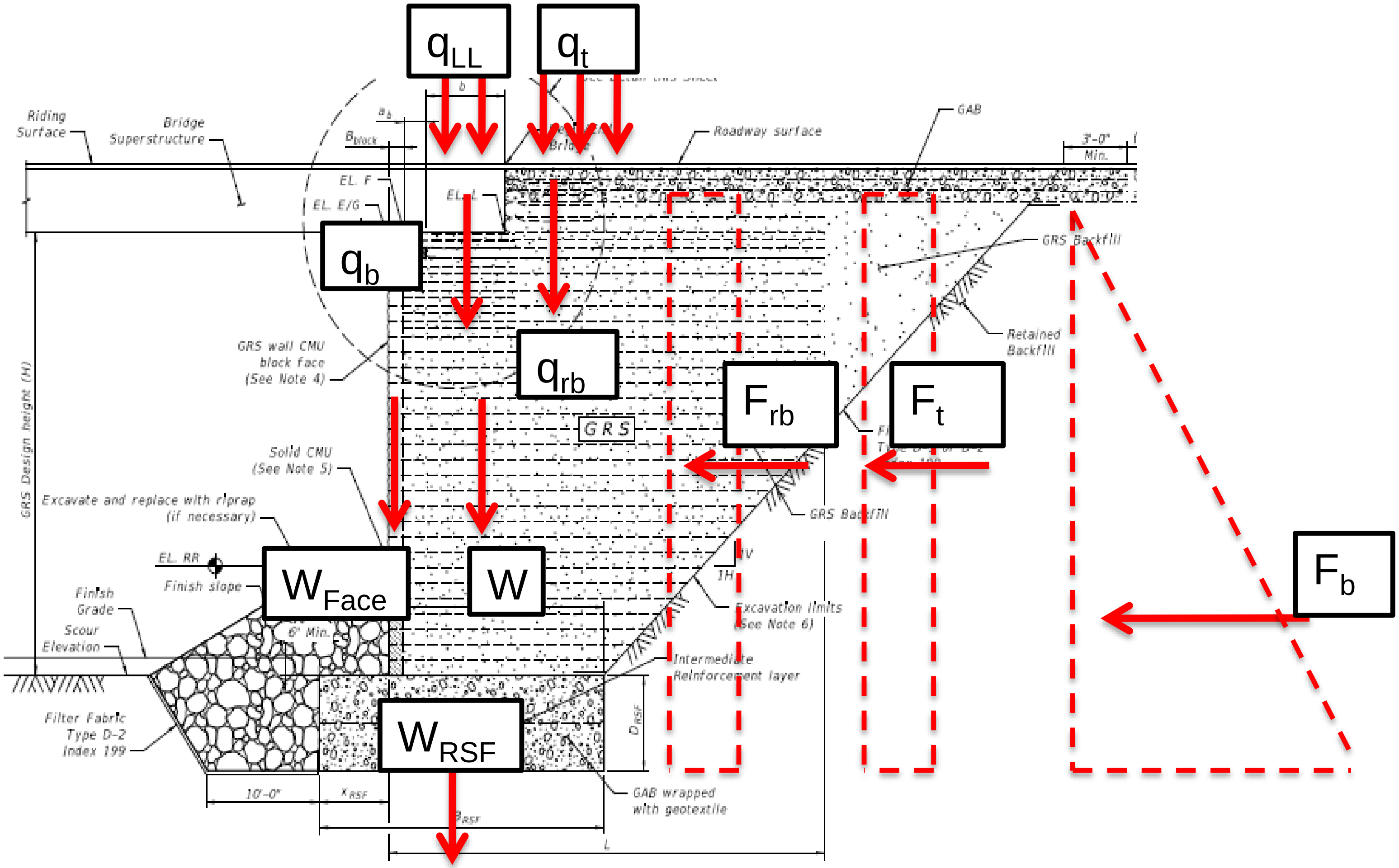
- ΣM_D =
  - γ_{DC_MAX}*W_{face}(3.25') +
  - γ_{DC_MAX}*q_{bridg}*b_{sw}(0.25') +
  - γ_{LS}*q_{LL}*b_{sw}(0.25') +
  - γ_{EH_MAX}*F_{rb} (8.75') +
  - γ_{LS}*F_t(8.75') +
  - γ_{EH_MAX}*F_b(5.88') = 87.23 k-ft/ft

External Stability - Eccentricity

- $\Sigma M_R =$
  - $\gamma_{EV\_MIN} * q_{rb} * b_{rb\_\_bt}(3.75') +$
  - $\gamma_{EV\_MIN} * W(1.25')$
  - $= 24.2$ k-ft/ft
- $\Sigma V = 35.0$ k/ft
- $(\Sigma M_D - \Sigma M_R)/\Sigma V = 1.80$ ft $< B_{RSF}/4$ **OK**
- *Also check Eccentricity of GRS on RSF*

External Stability - Bearing

- Compute Eccentricity using γ_{Max} for all permanent and transient loads (assumed worst case for bearing).



External Stability - Bearing

- $\Sigma M_D =$
  - $\gamma_{DC\_MAX}*W_{face}(3.25') +$
  - $\gamma_{DC\_MAX}*q_{bridg}*b_{sw}(0.25') +$
  - $\gamma_{LS}*q_{LL}*b_{sw}(0.25') +$
  - $\gamma_{EH\_MAX}*F_{rb}\ (8.75') +$
  - $\gamma_{LS}*F_{t}(8.75') +$
  - $\gamma_{EH\_MAX}*F_{b}(5.88') = 87.23$ k-ft/ft

External Stability - Bearing

- ΣM_R =
  - γ_{EV_MAX}*q_{rb}*$b_{rb\_\_bt}$(3.75') +
  - γ_{LS}*qt*brb__bt(3.75') +
  - γ_{EV_MAX}*W(1.25')
  - = 40.90 k-ft/ft
- ΣV = 43.95 k/ft
- $e = (\Sigma M_D - \Sigma M_R)/\Sigma V$ = 1.05 ft

External Stability - Bearing

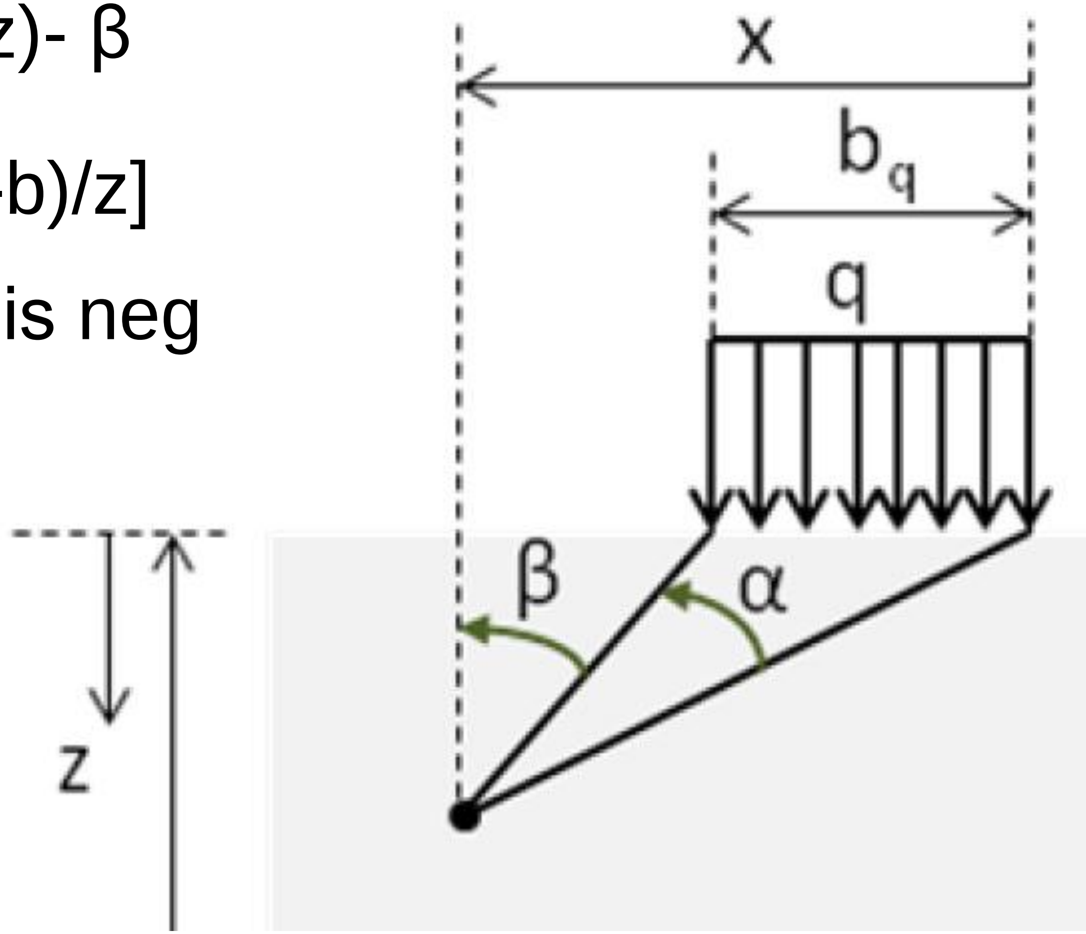
- Bearing Pressure at Base
  - ✓ $\Sigma V/(B_{RSF} - 2e)$=(43,949 lb/ft)/10.4 ft =4,229 psf
- $q_n = \varphi_{bc}(C_f N_c + 1/2(B_{RSF} – 2e)\gamma_f N_\gamma)$
- q_n = (0.65)[0+1/2(10.4’)(55pcf)(35.2)]= 8,871 psf
- $q_n / \sigma_v = 2.10 \geq 1$ **OK**

Internal Stability – Tension in Geotextile

- Use Boussinesq Method to determine stress under footing
- Add to Tension due to:
  - ✓ GRS Gravel
  - ✓ Road Base
  - ✓ Traffic Surcharge on Road

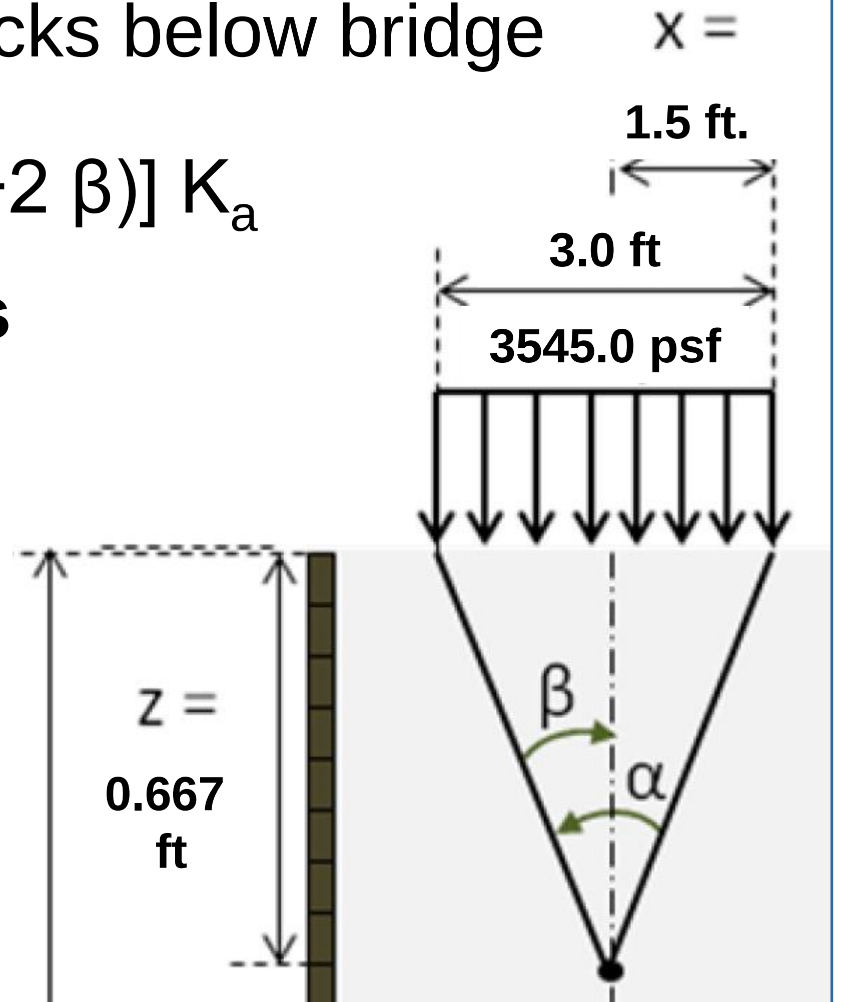
Internal Stability – Tension in Geotextile

- Max stress under center of footing ($x = b_q/2$)
- α = ARCTAN(x/z)- β
- β = ARCTAN[(x-b)/z]
  - ✓ When b>x, β is neg



Internal Stability – Tension in Geotextile

- Tension due Service Load on Beam Seat at bottom of 1st course of blocks below bridge
- $\sigma_h = (q/\pi)\ [\alpha + \sin\alpha \cos(\alpha+2\beta)]\ K_a$
  - ✓ **Input α & β in Radians**
  - ✓ $\alpha = 2.305$ Rad
  - ✓ $\beta = -1.15$ Rad
- $\Sigma_{h,\ ftg} = 818$ psf



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Internal Stability – Tension in Geotextile

- Tension due Service Load at bottom of 1st course of blocks below beam seat
- $\sigma_{h,\ GRS} = z\gamma_r K_{ar} = 18.24$ psf
- $\sigma_{h,\ RB} = q_{rb} K_{ar} = 61.06$ psf
- $\sigma_{h,\ T\ on\ RB} = q_t K_{ar} = 59.47$ psf
- $\Sigma\sigma_h = 956.77$ psf

Internal Stability – Tension in Geotextile

- Tension due Service Load at bottom of 1st course of blocks below beam seat

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

psf

FEET

Same units for S_v & d (inches ok)

  - ✓ Σσh = 956.77 psf
  - ✓ Sv = 8.0 inch = 0.667 ft
  - ✓ d_{max} = 1.0 inch (#57 stone D_{100}=1.0)

- T = 1026.25 lb/ft

Internal Stability – Tension in Geotextile

- Tension due Strength I Loads at bottom of 1st course of blocks below beam seat
- $\sigma_{h,\ ftg}$ = 1,224.96 psf, (γ_{DC_MAX} & γ_{LS})
- $\sigma_{h,\ GRS}$= 27.36 psf, (γ_{EH_MAX})
- $\sigma_{h,\ RB}$ = 82.43 psf, (γ_{EH_MAX})
- $\sigma_{h,\ T\ on\ RB}$ = 104.07 psf, (γ_{LS})
- $\Sigma\sigma h$ = 1418.82 psf
- T = 1521.85 lb/ft, w/o bearing bed reinf

Internal Stability – Tension in Geotextile

- Require in Plans: $T_{ult} \geq$ larger of
  - ✓ 4,800 lb/ft
  - ✓ [Max Tension due to $\Sigma_{\text{Factored Loads}}$] / 0.4
- Require in Plans: $T_{2\%} \geq$
  Max Tension due to $\Sigma_{\text{Service Loads}}$

Internal Stability – Tension in Geotextile

- For $T_{factored}$ = 1521.58 lb/ft
  - ✓ $T_n = (T_{factored})/0.4$ = 3804.62 lb/ft
  - ✓ $T_{2\%} = (T_{service})$ = 1026.25 lb/ft
- With Bearing Bed Reinforcement
  Min 5 layers required (GRS Guide)
  - ✓ Sv = 0.33 ft
  - ✓ $T_n = (T_{factored})/0.4 \approx$ 1519 lb/ft (top)
  - ✓ $T_n = (T_{factored})/0.4 \approx$ 2545 lb/ft (base)
  - ✓ $T_{2\%} = (T_{service}) \approx$ 677 lb/ft (base of wall)

Questions?

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2014

GRIP (Geotechnical Research in Progress)

Where: State Materials Office, Gainesville

When: July 31 – August 1, 2014

Videoconference - District Materials Offices in:

District 1, Bartow

District 3, Chipley

District 4/6 Materials, Davie

District 5, Deland

Turnpike, Turkey Lake Plaza