U.S. Department of Transportation
Federal Highway Administration

GEOSYNTHETIC REINFORCED SOIL INTEGRATED BRIDGE SYSTEM

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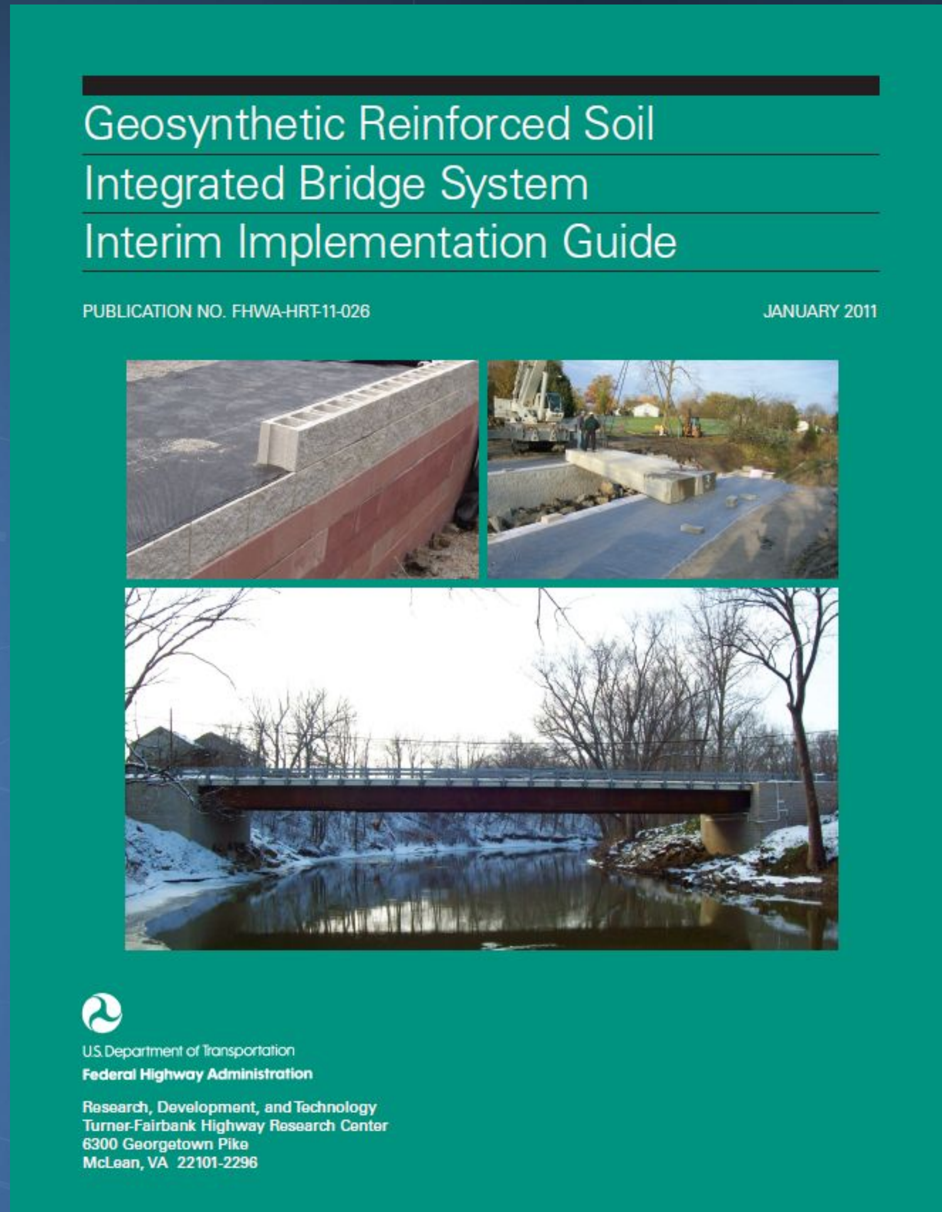
DESIGN OF GRS-IBS


Geosynthetic Reinforced Soil
Integrated Bridge System
Interim Implementation Guide

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Design Process

1) Establish project requirements
2) Perform a site evaluation
3) Evaluate project feasibility
4) Determine layout of GRS-IBS
5) Calculate loads
6) Conduct an external stability analysis
7) Conduct an internal stability analysis
8) Implement design details

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 *Continued*

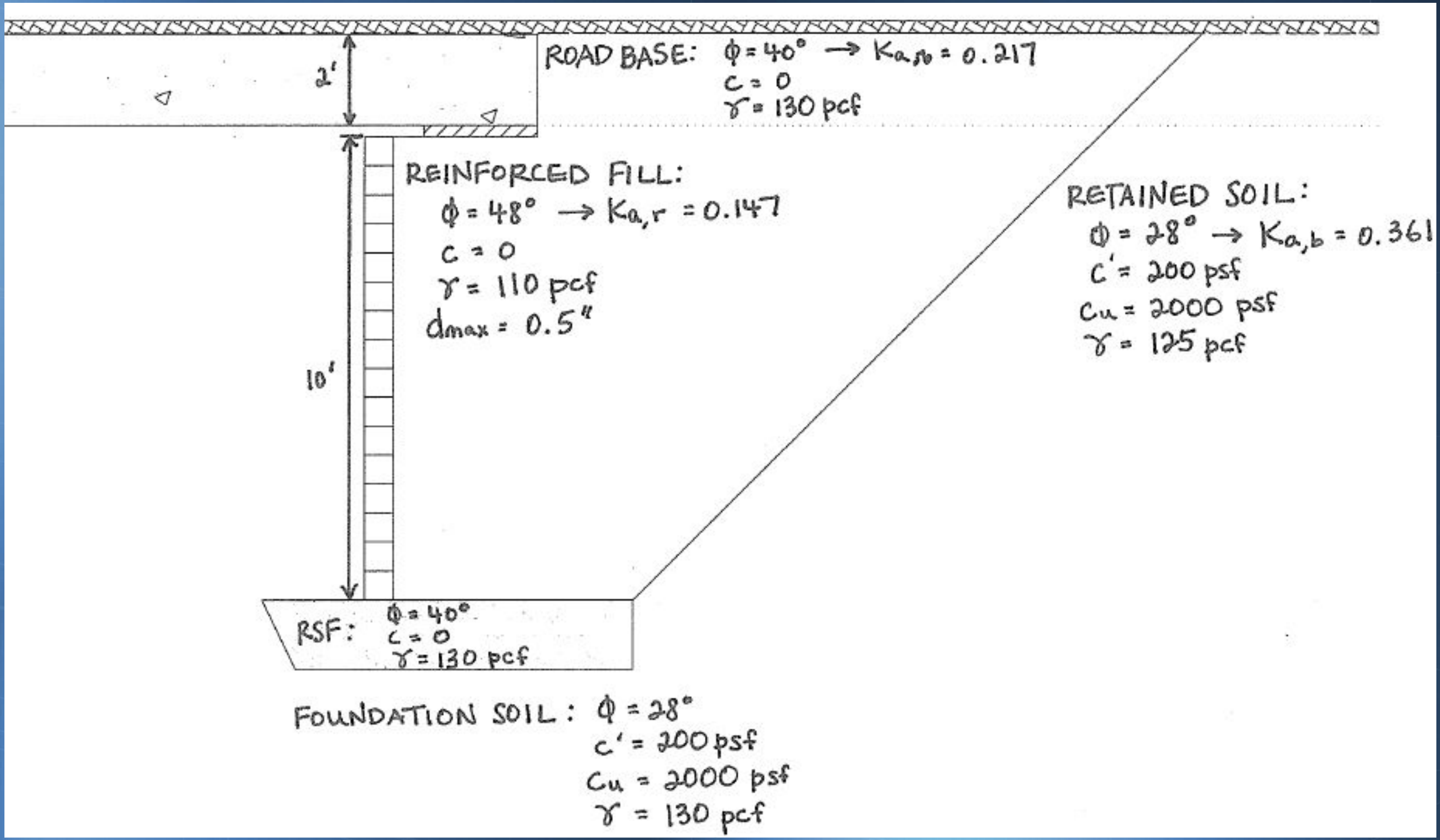
- Evaluate soil properties for the retained earth (soil behind the abutment)
  - Density (γ_b)
  - Friction Angle (φ_b)
  - Cohesion (c_b)

Perform a Site Evaluation *Continued*

- 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})

Design Example

Design Soil Parameters



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.
   — HEC-18, Evaluating Scour at Bridges, Fourth Edition
   — Section 2.6, Hydrology and Hydraulics, AASHTO *LRFD Bridge Design Specifications*

Recommended Hydraulic and Scour Design Considerations

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. The elevation of the design scour depth is to be calculated by projecting the elevation of the depth of scour from the lowest point in the channel to each of the abutments.

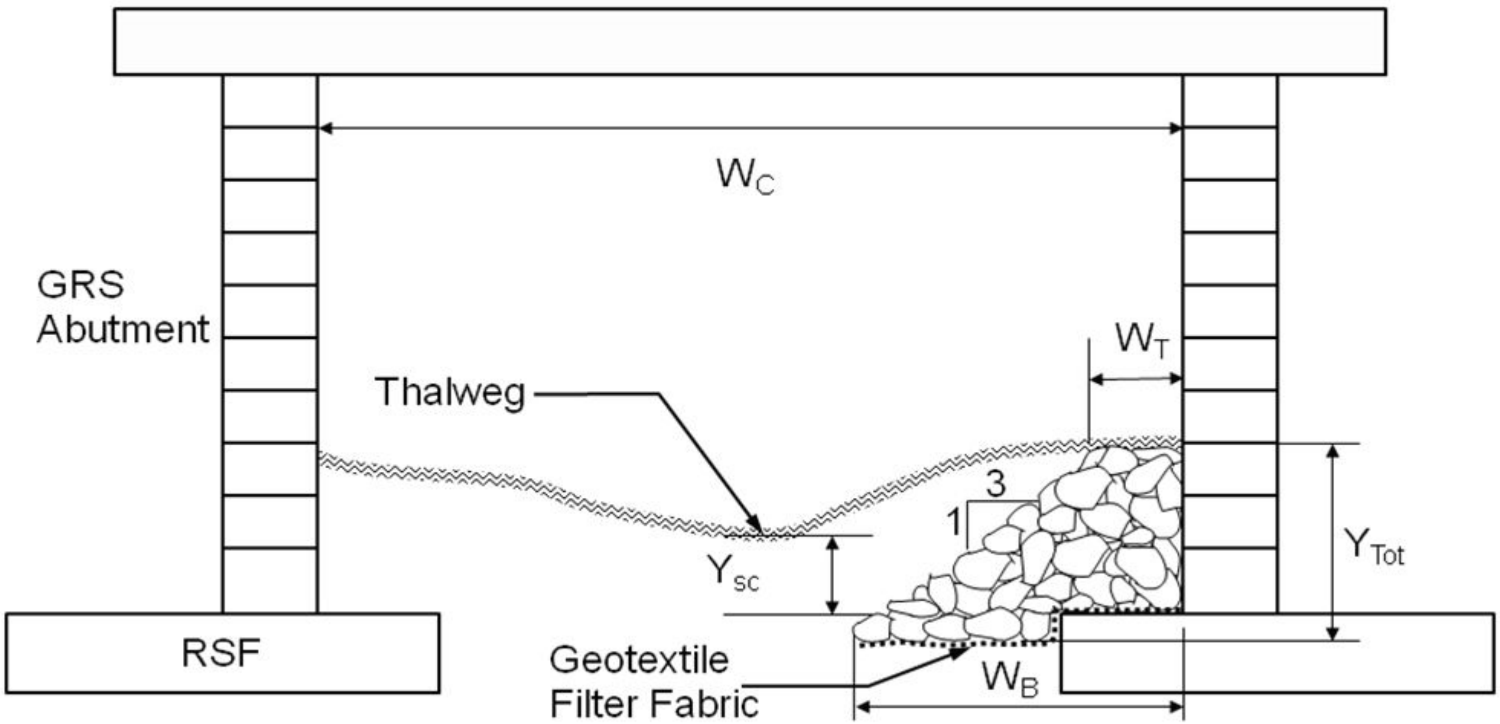
Recommended Hydraulic and Scour Design Considerations

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. The purpose of installing a designed scour countermeasure is to prevent loss of soil from underneath a GRS abutment from scour that occurs at or near the abutment.
   - HEC-23, Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance Third Edition, Vol. 1 & 2

Recommended hydraulic and scour evaluation procedures for GRS

4. Inspection: After construction, scour countermeasure condition and channel instability should be assessed during each regular bridge inspection and after extreme flood events. Any countermeasure failure or significant change in channel condition should be noted and scheduled for repair or stabilization.
   - HEC-20, Stream Stability at Highway Structures, Third Edition
   - HEC-23, Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance Third Edition, Vol. 1 & 2

Scour Design



Constructed Sloping Rock

Y_{sc} = Contraction scour plus long-term degradation referenced to the thalweg.

Y_{Tot} = Distance from top of riprap to bottom of riprap (3 x $D_{50riprap}$ minimum and keyed at least 1 ft (0.3 m) below top of RSF).

$W_T = 3 \times D_{50riprap}$ or 5 ft (1.5 m), whichever is greater.

$W_B = W_T + 3Y_{Tot}$

Top of RSF (footing) elevation at Y_{sc} (or deeper) as recommended in HEC-18.

DESIGN OF GRS-IBS
Step 3: Evaluate Project Feasibility

Project Feasibility

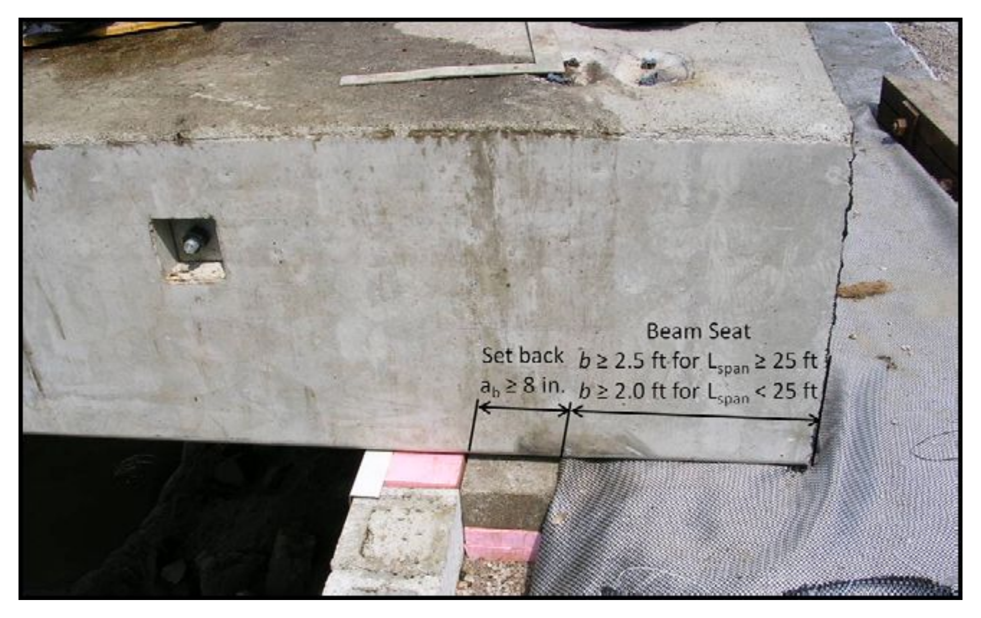
- Is the proposed structure within the limits of the manual
  - Bridge Span < 140 ft
  - Wall height < 30 ft
  - Are the foundation materials competent
- Project cost
- Technical requirements
- Performance objectives
- Scour and/or channel instability

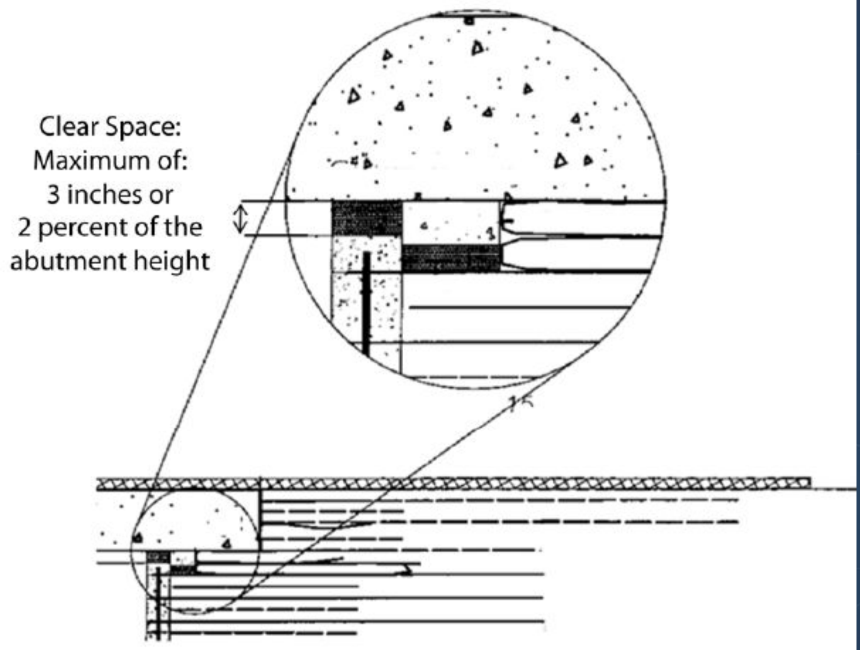
DESIGN OF GRS-IBS
Step 4: Determine Layout of GRS-IBS

Determine Layout of GRS-IBS

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

Beam Seat, Set Back and Clear Space

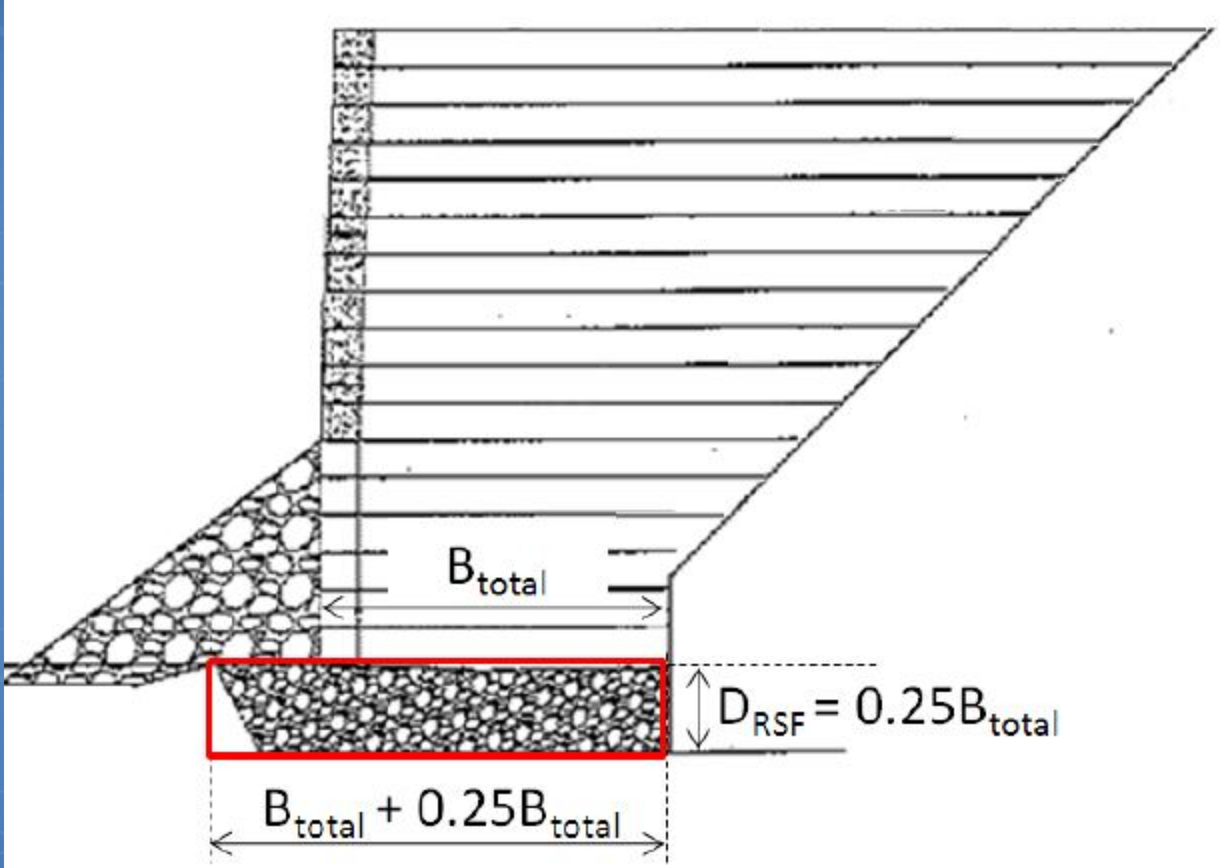




Reinforced Soil Foundation

- Minimum base width of wall (B/H ≥ 0.3)
  - 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.

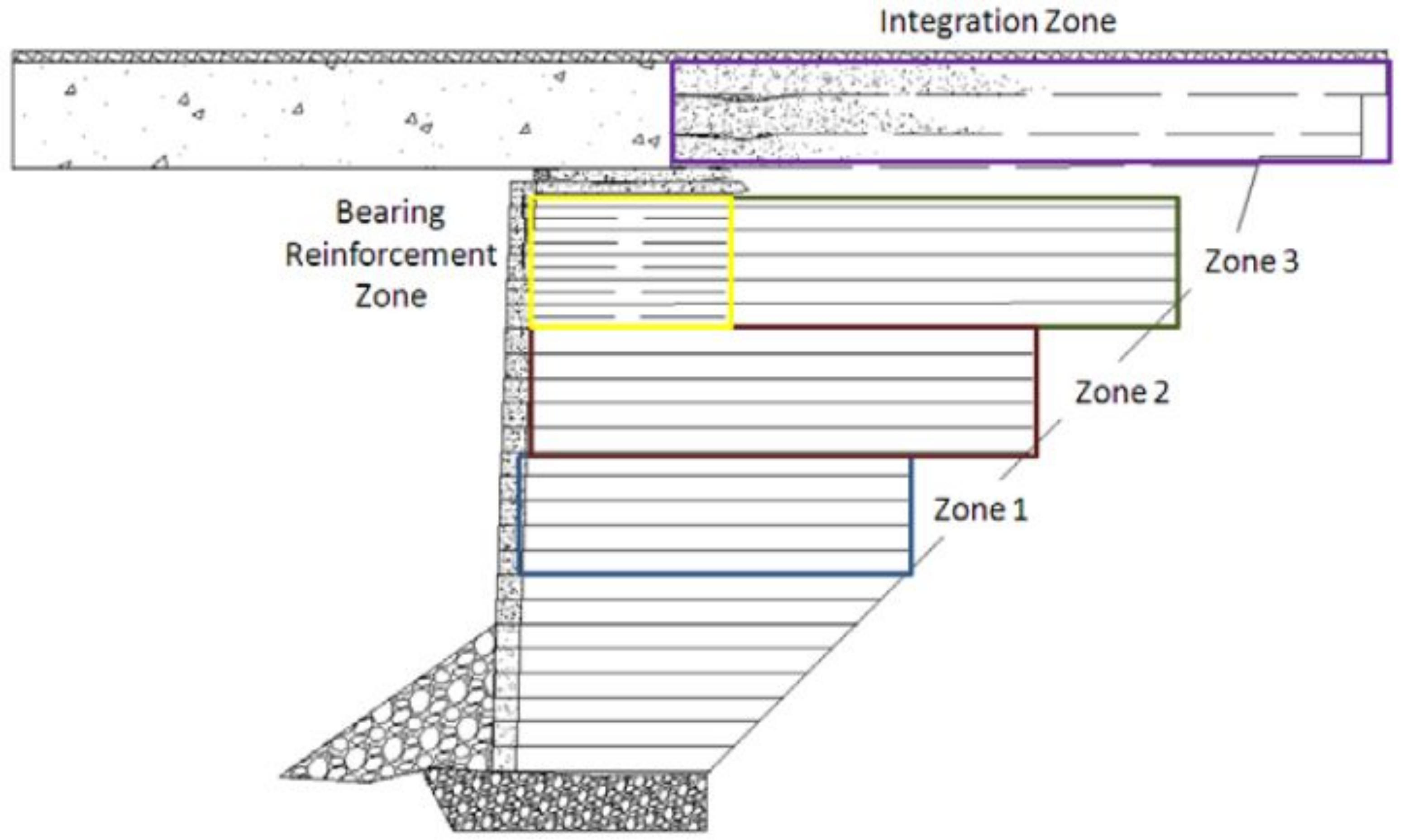
Reinforced Soil Foundation *Continued*



Reinforcement Layout

- Reinforcement Length
  - The minimum length at the lowest level should extend the width of the base (B_{total})
  - The reinforcement should follow the cut slope (if applicable) up to a B/H ratio of 0.7.
  - From there, the length can get progressively longer in reinforcement zones based on external and global stability requirements
  - 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 *Continued*

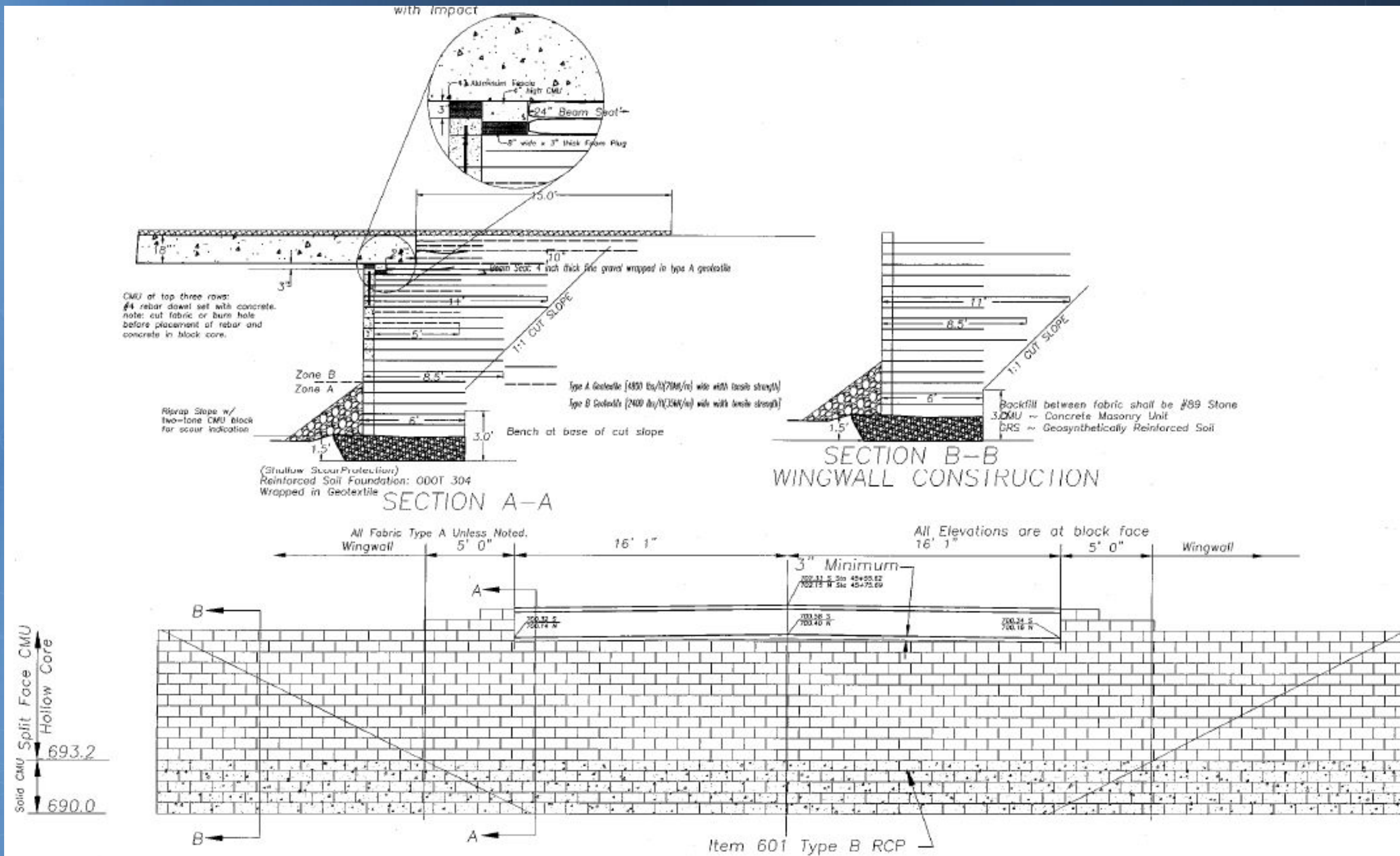


Reinforcement Layout *Continued*

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

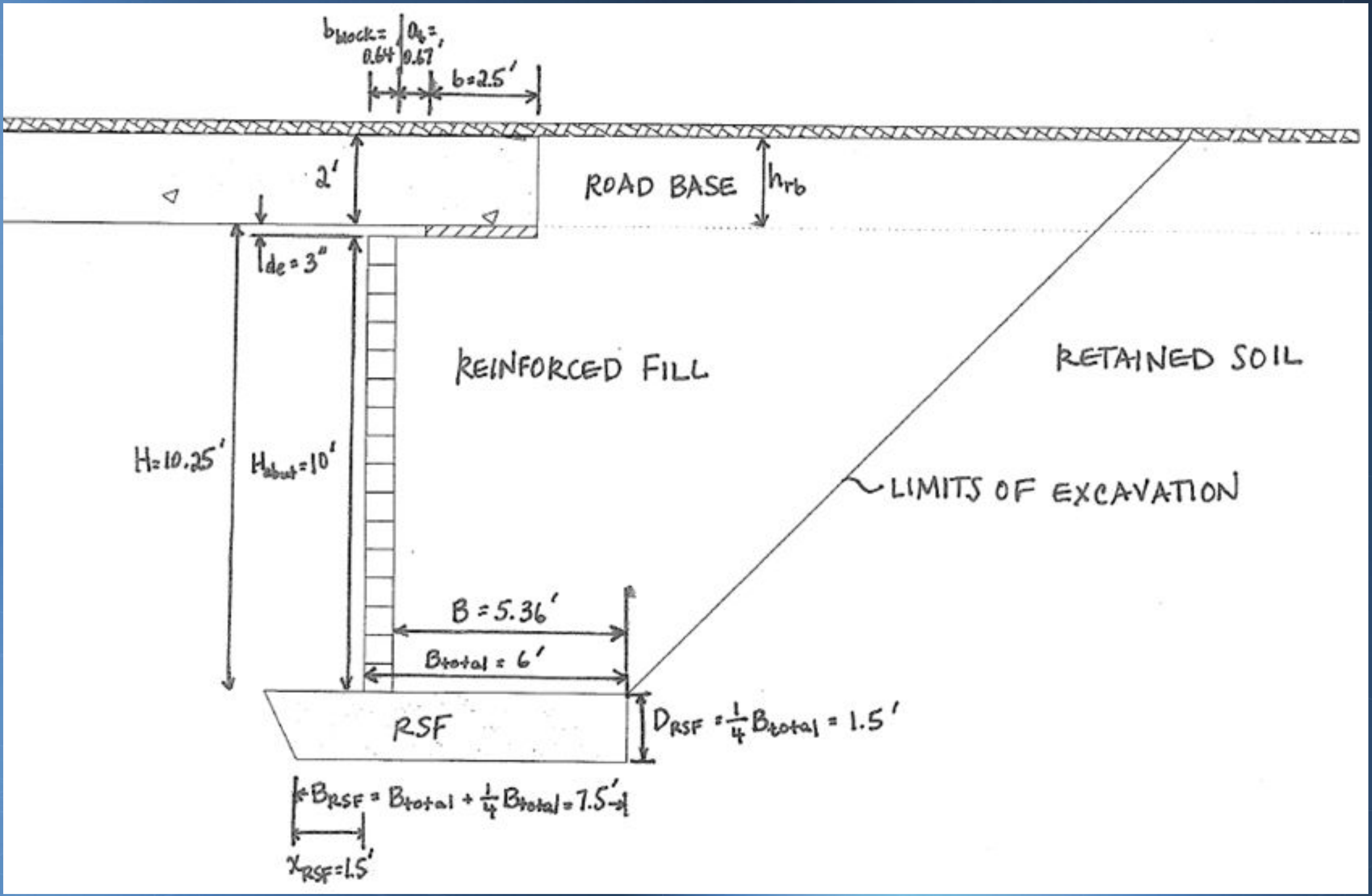
Design Example

Single Sheet Plan



Design Example

GRS-IBS Layout



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)
  - Dead loads from superstructure
  - Live loads from deign 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

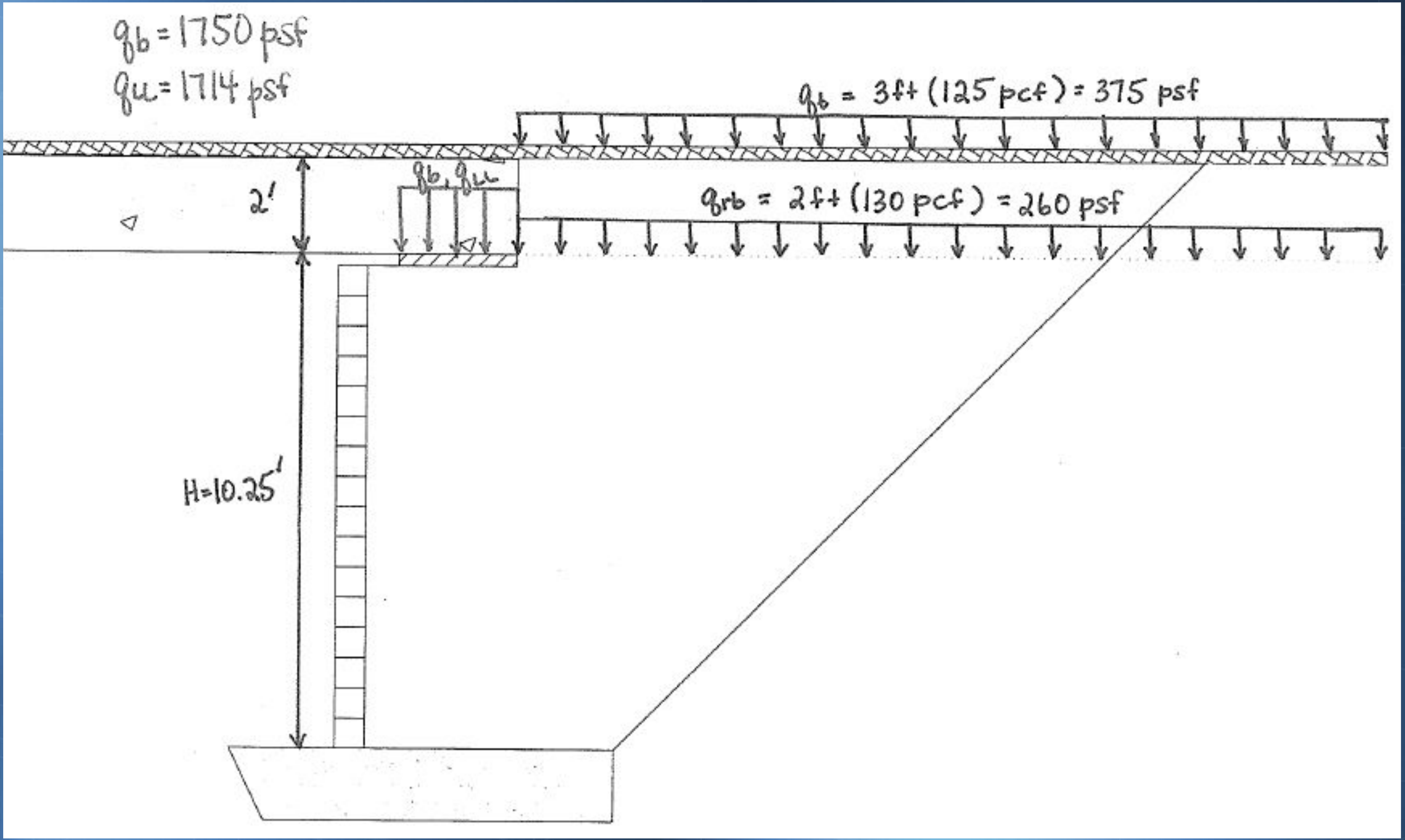
- Height of soil between the top of wall and Top of pavement
- $q_{rb} = h_{rb} \times \gamma_{rb}$

Bridge Loads

- Provided by bridge engineer (AASHTO 2010)
  - Dead load (max. weight of structure per abutment)
  - 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 Example

Design Loads



DESIGN OF GRS-IBS
Step 6: Conduct an External Stability Analysis

External Stability

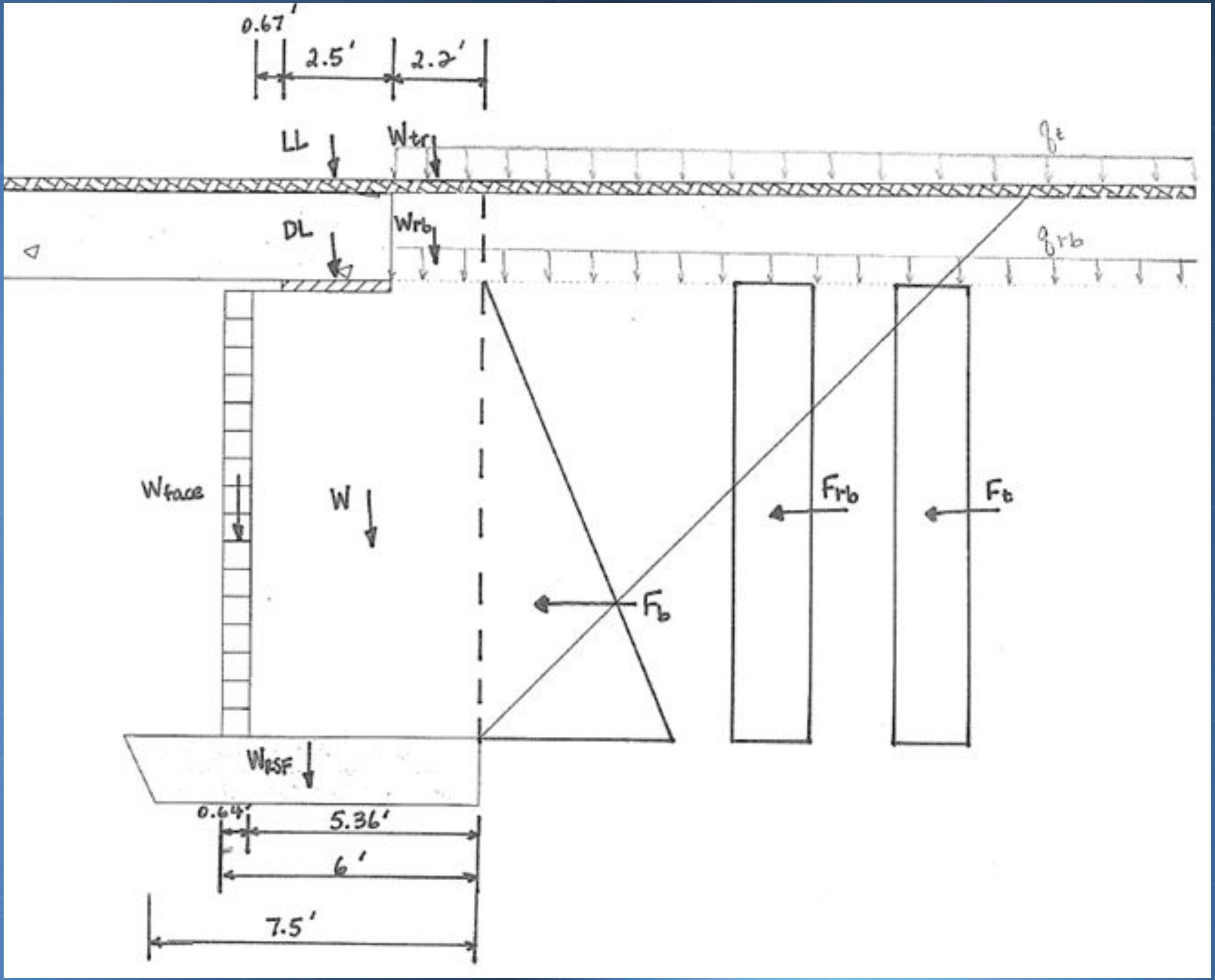
- Sliding
- Bearing Capacity
- Global Stability

External Stability – Forces *Continued*

- 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

Design Example

External Stability – Forces *Continued*



Design Example

External Stability – Forces *Continued*

$$W = \gamma_r HB = (110)(10.25)(5.36) = 6043.4 \text{ lb/ft}$$

$$W_{RSF} = B_{RSF} D_{RSF} \gamma_{rb} = (7.5)(1.5)(130) = 1462.5 \text{ lb/ft}$$

$$W_{face} = N_{block}\left(\frac{W_{block}}{L_{block}}\right) = 16\left(\frac{42}{1.3}\right) = 516.9 \text{ lb/ft}$$

$$W_{rb} = q_{rb} \cdot b_{rb,t} = (260)(2.2) = 572 \text{ lb/ft}$$

$$W_{tr} = q_t \cdot b_{rb,t} = (375)(2.2) = 825 \text{ lb/ft}$$

$$DL = q_b \cdot b = (1750)(2.5) = 4375 \text{ lb/ft}$$

$$LL = q_{LL} \cdot b = (1714)(2.5) = 4285 \text{ lb/ft}$$

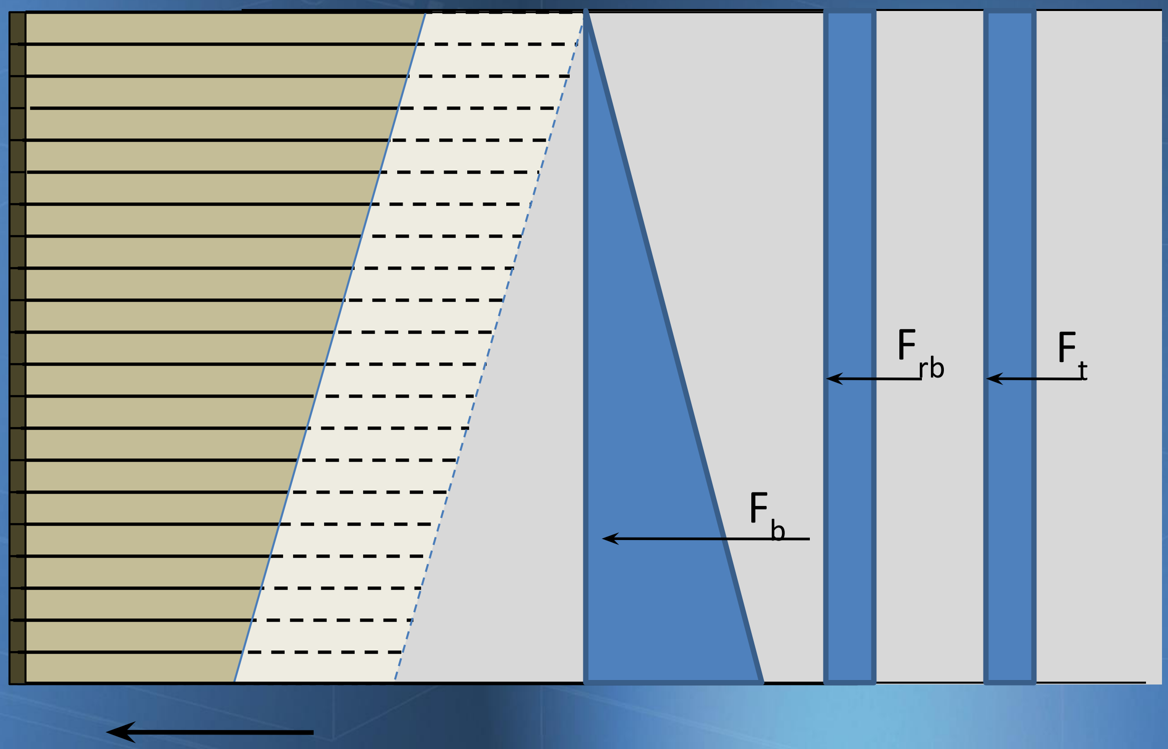
$$F_b = \frac{1}{2}\gamma_b H^2 K_{a,b} = \frac{1}{2}(125)(10.25)^2(0.361) = 2370.5 \text{ lb/ft}$$

$$F_{rb} = q_{rb} H K_{a,b} = (260)(10.25)(0.361) = 962.1 \text{ lb/ft}$$

$$F_t = q_t H K_{a,b} = (375)(10.25)(0.361) = 1387.6 \text{ lb/ft}$$

Direct Sliding

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



Direct Sliding *Continued*

- 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: $F_t = q_t H K_{ab}$ [F/L]
  - Due to road base surcharge: $F_{rb} = q_{rb} H K_{ab}$ [F/L]

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

Direct Sliding *Continued*

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

Design Example

Direct Sliding *Continued*

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

$$F_n = F_b + F_{rb} + F_t = 2370.5 + 962.1 + 1387.6 = 4720.2 \text{ lb/ft}$$

$$R_n = W_t \mu = 10990.4\,(0.74) = 8132.9 \text{ lb/ft}$$

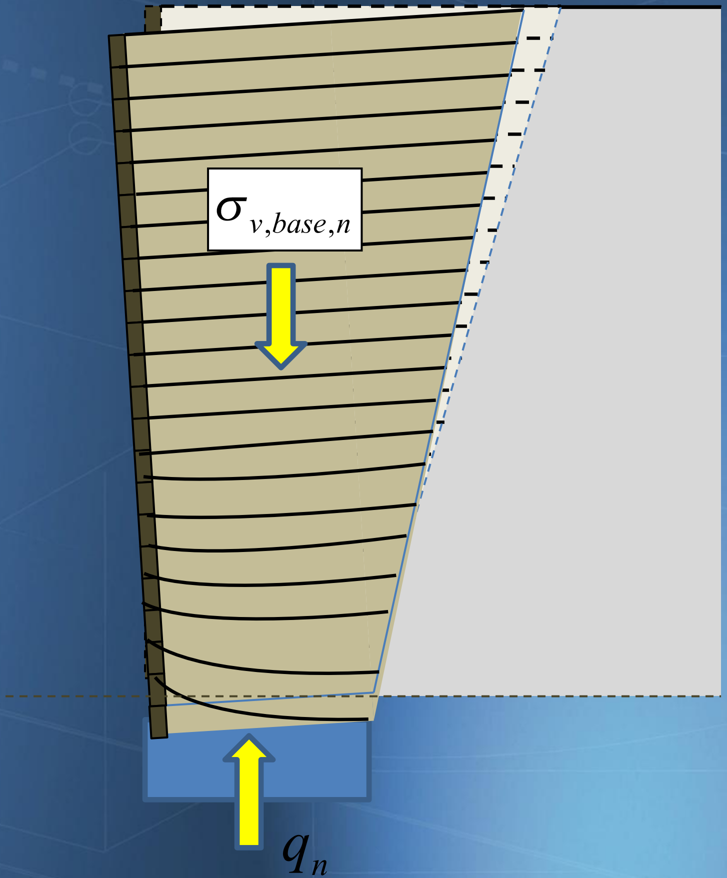
$$\rightarrow W_t = W + DL + W_{rb} = 6043.4 + 4375 + 572 = 10990.4 \text{ lb/ft}$$

$$\mu = \tfrac{2}{3}\tan\phi_r = \tfrac{2}{3}\tan(48°) = 0.74$$

$$FS_{slide} = \frac{R_n}{F_n} = \frac{8132.9}{4720.2} = 1.7 \geq 1.5 \quad \text{OK}$$

Bearing Capacity

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



Bearing Capacity *Continued*

- 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 *Continued*

- Resisting Pressure for Bearing Capacity (q_n):

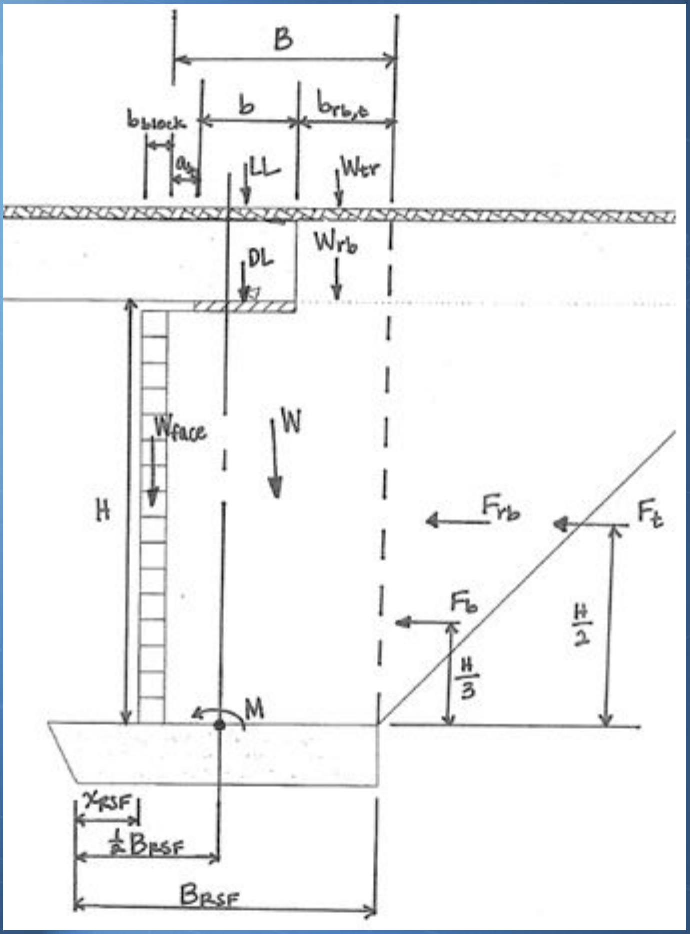
$$q_n = c_f N_c + \frac{1}{2} B' \gamma_f N_\gamma + \gamma_f D_f N_q$$

Bearing Capacity *Continued*

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

Design Example

Bearing Capacity *Continued*



- Include all live loads on resistance sides
- Applied load transferred to bottom of RSF
- Effective base width based on RSF width

DRIVING MOMENTS (↶):

$$M_b = F_b\left(\frac{H}{3}\right) = 2370.5\left(\frac{10.25}{3}\right) = 8099.2\ \text{lb/ft}\cdot\text{ft}$$

$$M_{rb} = F_{rb}\left(\frac{H}{2}\right) = 962.1\left(\frac{10.25}{2}\right) = 4930.8\ \text{lb/ft}\cdot\text{ft}$$

$$M_t = F_t\left(\frac{H}{2}\right) = 1387.6\left(\frac{10.25}{2}\right) = 7111.5\ \text{lb/ft}\cdot\text{ft}$$

$$M_{face} = W_{face}\left(\frac{B_{RSF}}{2} - x_{RSF} - \frac{b_{block}}{2}\right) = 516.9\left(\frac{7.5}{2} - 1.5 - \frac{0.64}{2}\right) = 997.6\ \text{lb/ft}\cdot\text{ft}$$

RESISTING MOMENTS (↷):

$$M_W = W\left(\frac{B_{RSF}}{2} - \frac{B}{2}\right) = 6043.4\left(\frac{7.5}{2} - \frac{5.36}{2}\right) = 6466.4\ \text{lb/ft}\cdot\text{ft}$$

$$M_{DL} = DL\left[\left(\frac{b}{2} + a_b\right) - \left(\frac{B_{RSF}}{2} - x_{RSF} - b_{block}\right)\right] = 4375\left[\left(\frac{2.5}{2} + 0.67\right) - \left(\frac{7.5}{2} - 1.5 - 0.64\right)\right] = 1356.3\ \text{lb/ft}\cdot\text{ft}$$

$$M_{LL} = LL\left[\left(\frac{b}{2} + a_b\right) - \left(\frac{B_{RSF}}{2} - x_{RSF} - b_{block}\right)\right] = 4285\left[\left(\frac{2.5}{2} + 0.67\right) - \left(\frac{7.5}{2} - 1.5 - 0.64\right)\right] = 1328.4\ \text{lb/ft}\cdot\text{ft}$$

$$M_{rb} = W_{rb}\left(\frac{B_{RSF}}{2} - \frac{b_{rb,t}}{2}\right) = 572\left(\frac{7.5}{2} - \frac{2.2}{2}\right) = 1515.8\ \text{lb/ft}\cdot\text{ft}$$

$$M_{tr} = W_{tr}\left(\frac{B_{RSF}}{2} - \frac{b_{rb,t}}{2}\right) = 825\left(\frac{7.5}{2} - \frac{2.2}{2}\right) = 2186.2\ \text{lb/ft}\cdot\text{ft}$$

Design Example

Bearing Capacity *Continued*

$$\Sigma M_D = M_b + M_{rb} + M_t + M_{face} = 8099.2 + 4930.8 + 7111.5 + 997.6 = 21139.1 \text{ lb/ft}\cdot\text{ft}$$

$$\Sigma M_R = M_W + M_{DL} + M_{LL} + M_{rb} + M_{tr} = 6466.4 + 1356.3 + 1328.4 + 1515.8 + 2186.2 = 12853.1 \text{ lb/ft}\cdot\text{ft}$$

$$\Sigma V = W + W_{RSF} + W_{face} + W_{tr} + W_{rb} + DL + LL = 6043.4 + 1462.5 + 516.9 + 825 + 572 + 4375 + 4285 = 18079.8$$

$$e_{B,n} = \frac{\Sigma M_D - \Sigma M_R}{\Sigma V} = \frac{21139.1 - 12853.1}{18079.8} = 0.46 \text{ ft}$$

$$\sigma_{v,base,n} = \frac{\Sigma V}{B_{RSF} - 2e_{B,n}} = \frac{18079.8}{7.5 - 2(0.46)} = 2747.7 \text{ psf}$$

$$q_n = c_f N_c + \frac{1}{2} B' \gamma_f N_\gamma + \gamma_f D_f N_q = 2000(5.14) + \frac{1}{2}(6.58)(130)(0) + 130(1.5)(1) = 10475 \text{ psf}$$

→ $c_f = 2000$ psf

$N_c = 5.14$

$N_\gamma = 0$

$N_q = 1.0$

$B' = B_{RSF} - 2e_{B,n} = 7.5 - 2(0.46) = 6.58$ ft

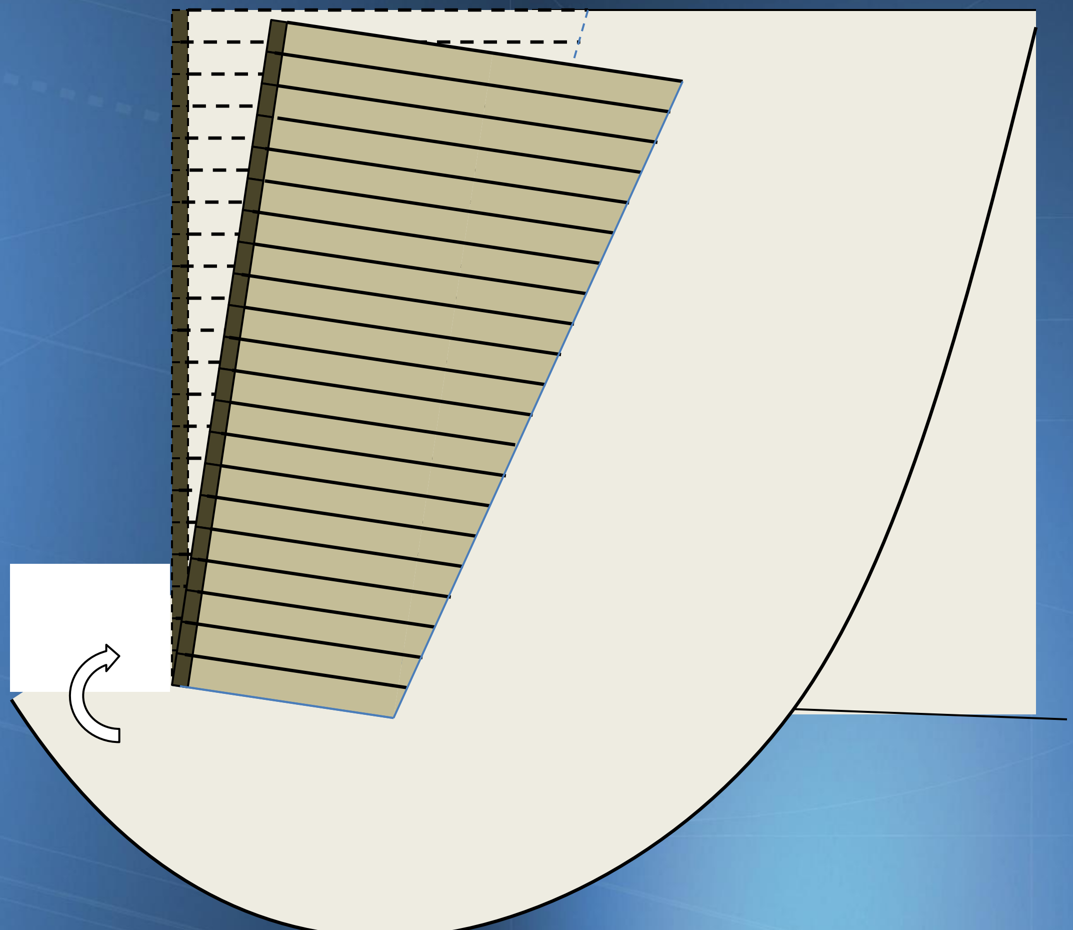
$D_f = D_{RSF} = 1.5$ ft

$\gamma_f = 130$ pcf

$$FS_{bearing} = \frac{q_n}{\sigma_{v,base,n}} = \frac{10475}{2747.7} = 3.8 \geq 2.5 \quad \text{OK}$$

Global Stability

$$FS_{global} \geq 1.5$$

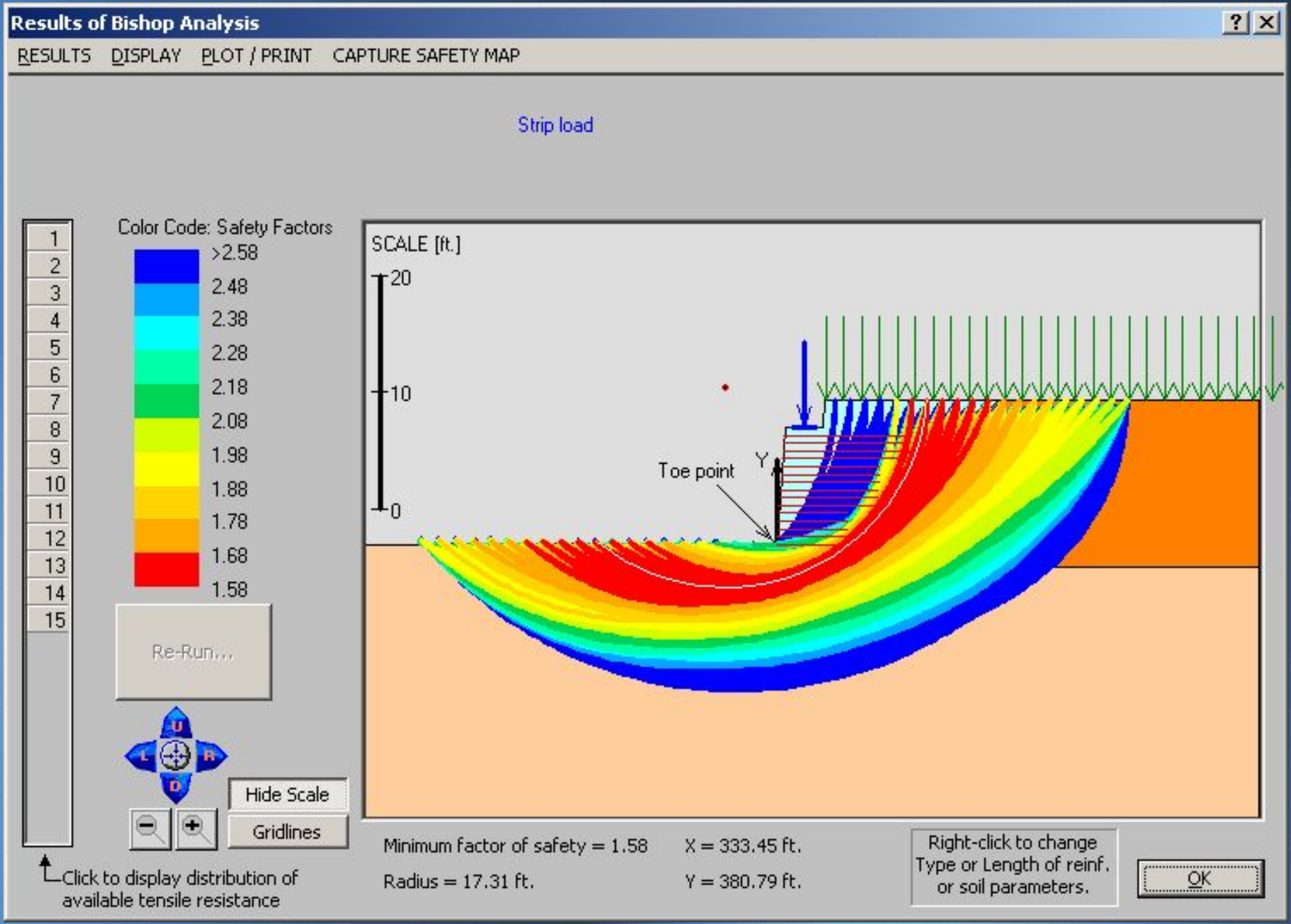


Global Stability *Continued*

- 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)

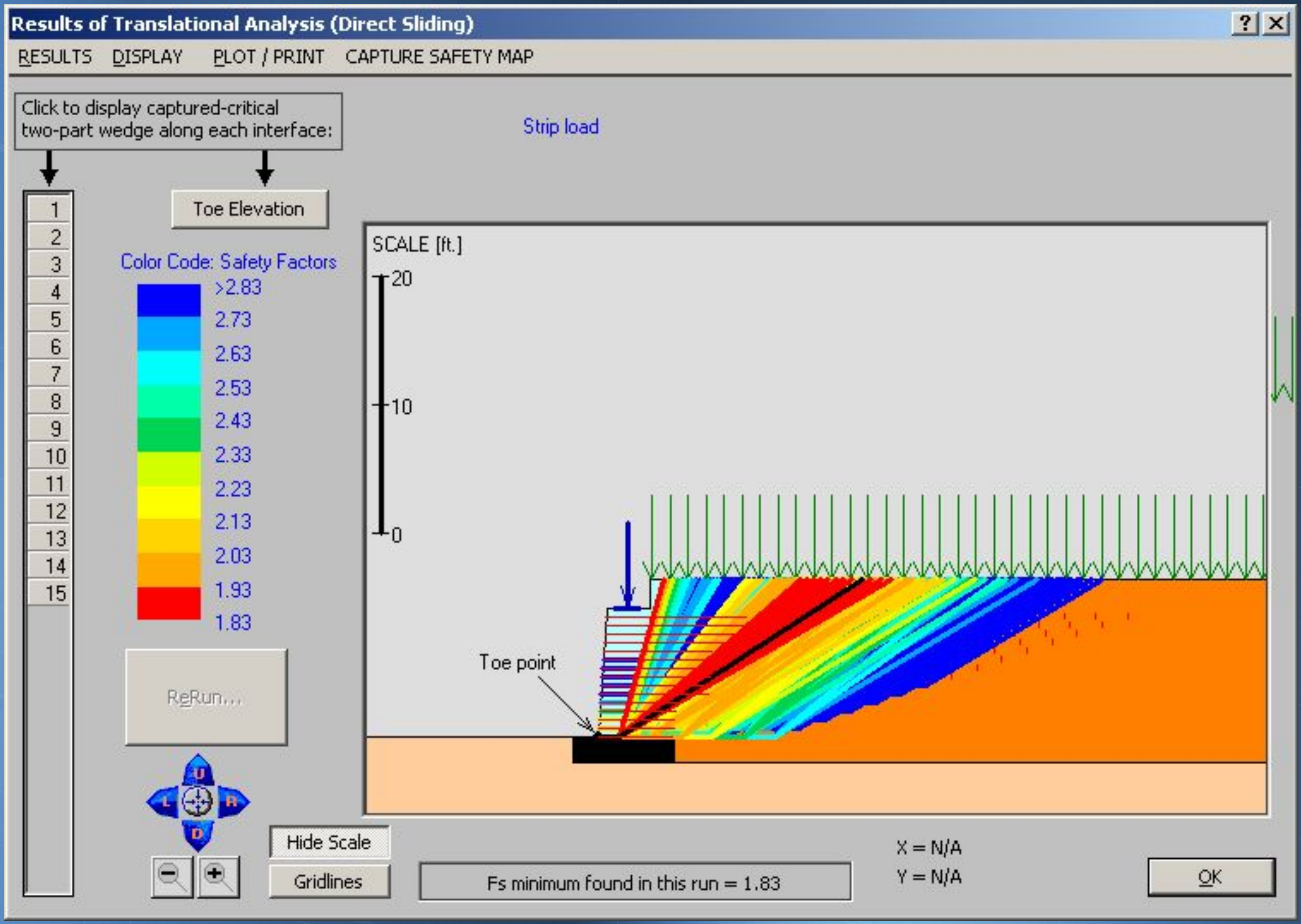
Design Example

Global Stability *Continued*



Design Example

Global Stability *Continued*



DESIGN OF GRS-IBS
Step 7: Conduct an Internal Stability Analysis

Internal Stability Analysis

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

Ultimate Capacity

- Empirical Method
  - Use results from performance test
    - $q_{ult,emp}$ = Stress at 5% vertical strain
  - Check that applied load ($V_{applied} = q_b + q_{LL}$) is less than allowable load ($V_{allow,emp}$)

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

Design Example

Ultimate Capacity *Continued*

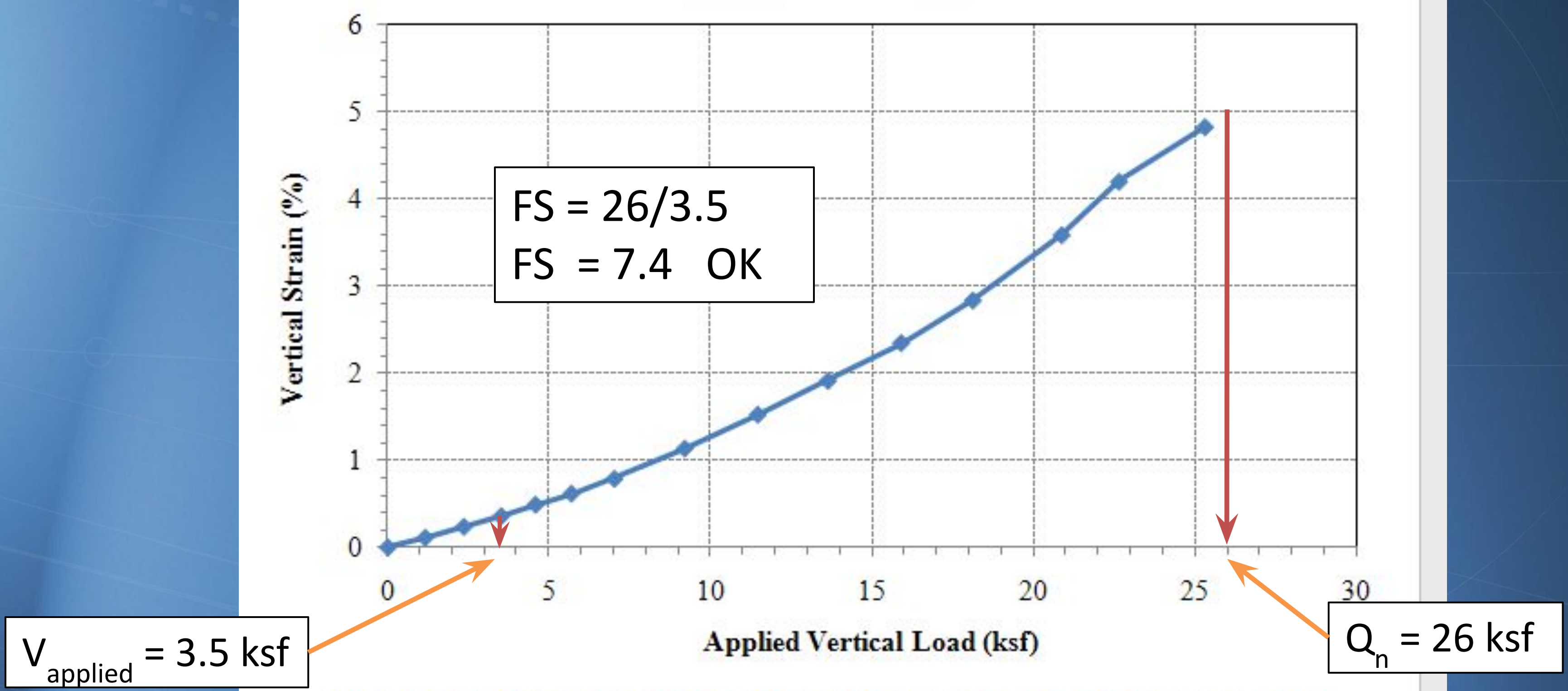


Figure 4-17 - Design Envelope for Vertical Strain at 8 in. Reinforcement Spacing

Ultimate Capacity *Continued*

- Analytical Method

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

  - 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 ($V_{allow,an}$)

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

Design Example

Ultimate Capacity *Continued*

$$q_{ult,an} = \left[0.7^{\frac{S_v}{6 d_{max}}}\left(\frac{T_f}{S_v}\right)\right]K_p = \left[0.7^{\frac{8}{6(0.5)}}\left(\frac{4800}{(8/12)}\right)\right]6.8 = 18913.4 \text{ psf}$$

$\rightarrow S_v = 8$ in.

$d_{max} = 0.5$ in

$T_f = 4800$ lb/ft

$$K_p = \frac{1}{K_{a,r}} = \frac{1}{0.147} = 6.8$$

$$V_{allow,an} = \frac{q_{ult,an}}{FS_{capacity}} = \frac{18913.4}{3.5} = 5403.8 \text{ psf}$$

$$V_{applied} = q_b + q_{LL} = 1750 + 1714 = 3464 \text{ psf} < V_{allow,an} \quad \text{OK}$$

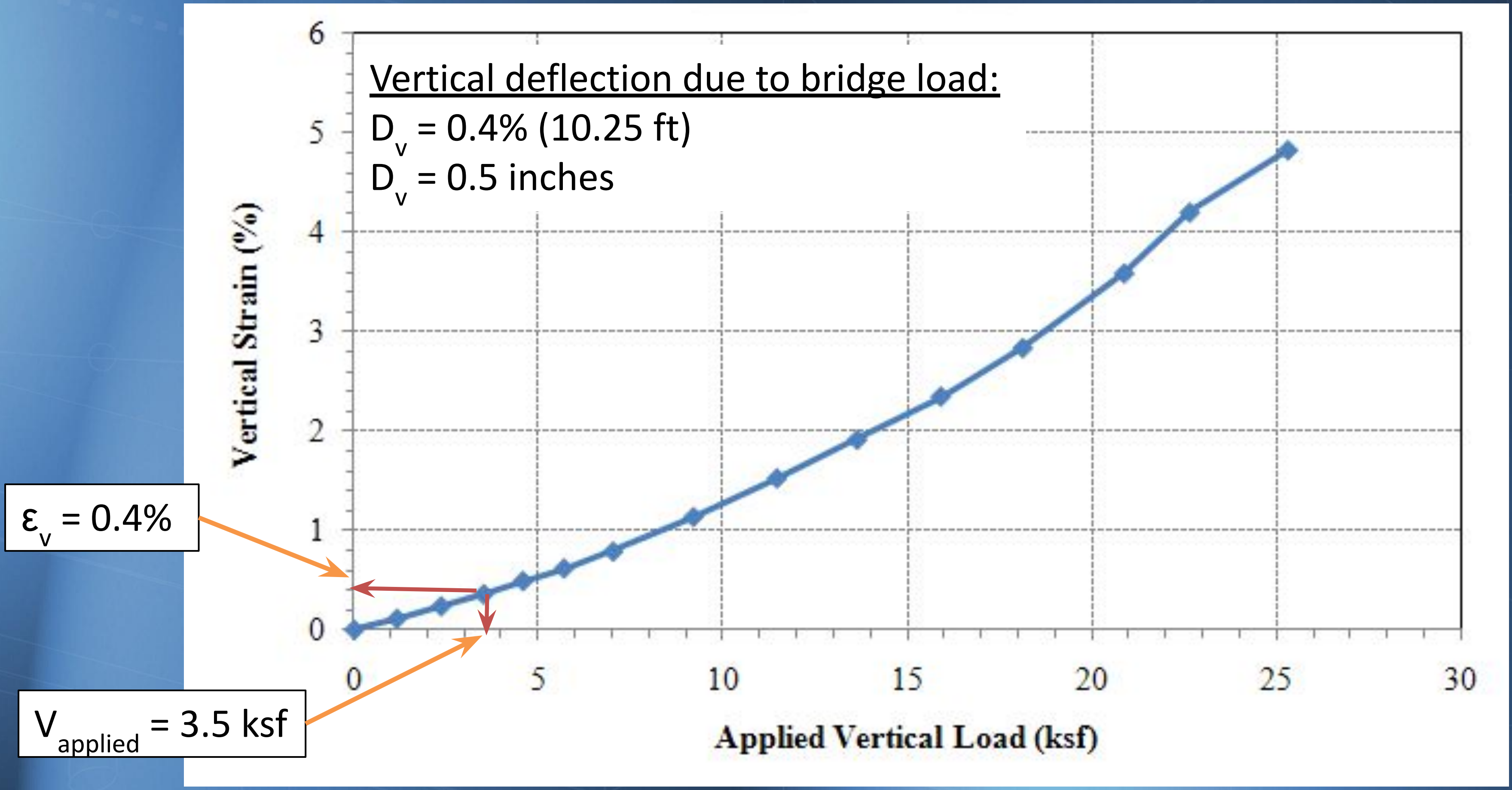
Vertical Deformation

- Use results from performance test
- 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

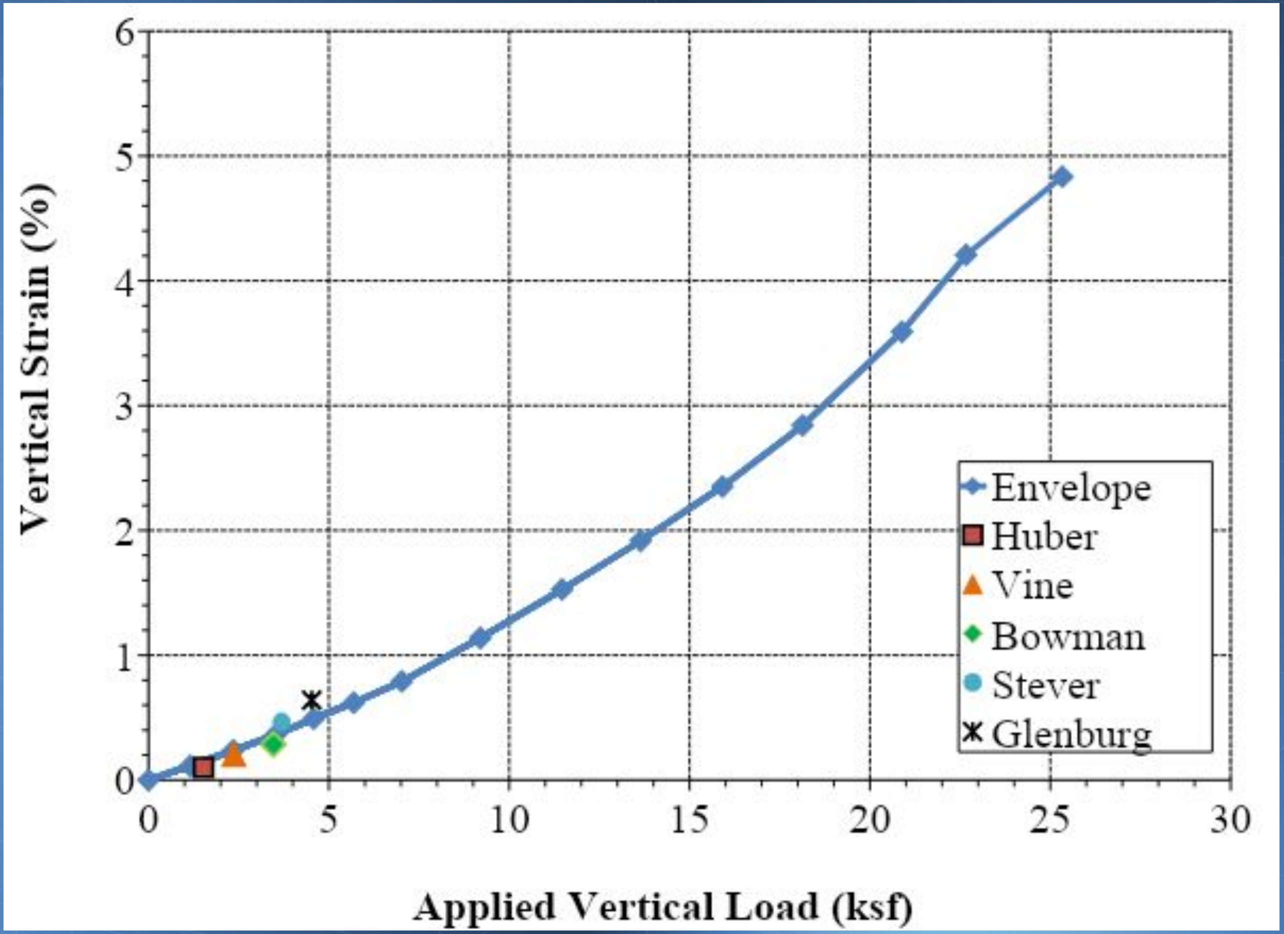
$$D_V = \varepsilon_v H$$

Design Example

Vertical Deformation *Continued*

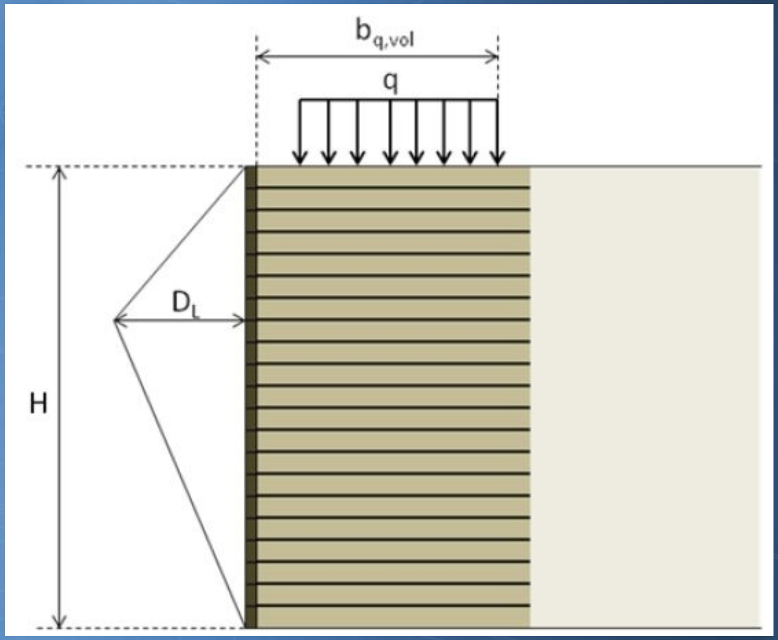


Vertical Deformation *Continued*



Lateral Deformation

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



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

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

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

Design Example

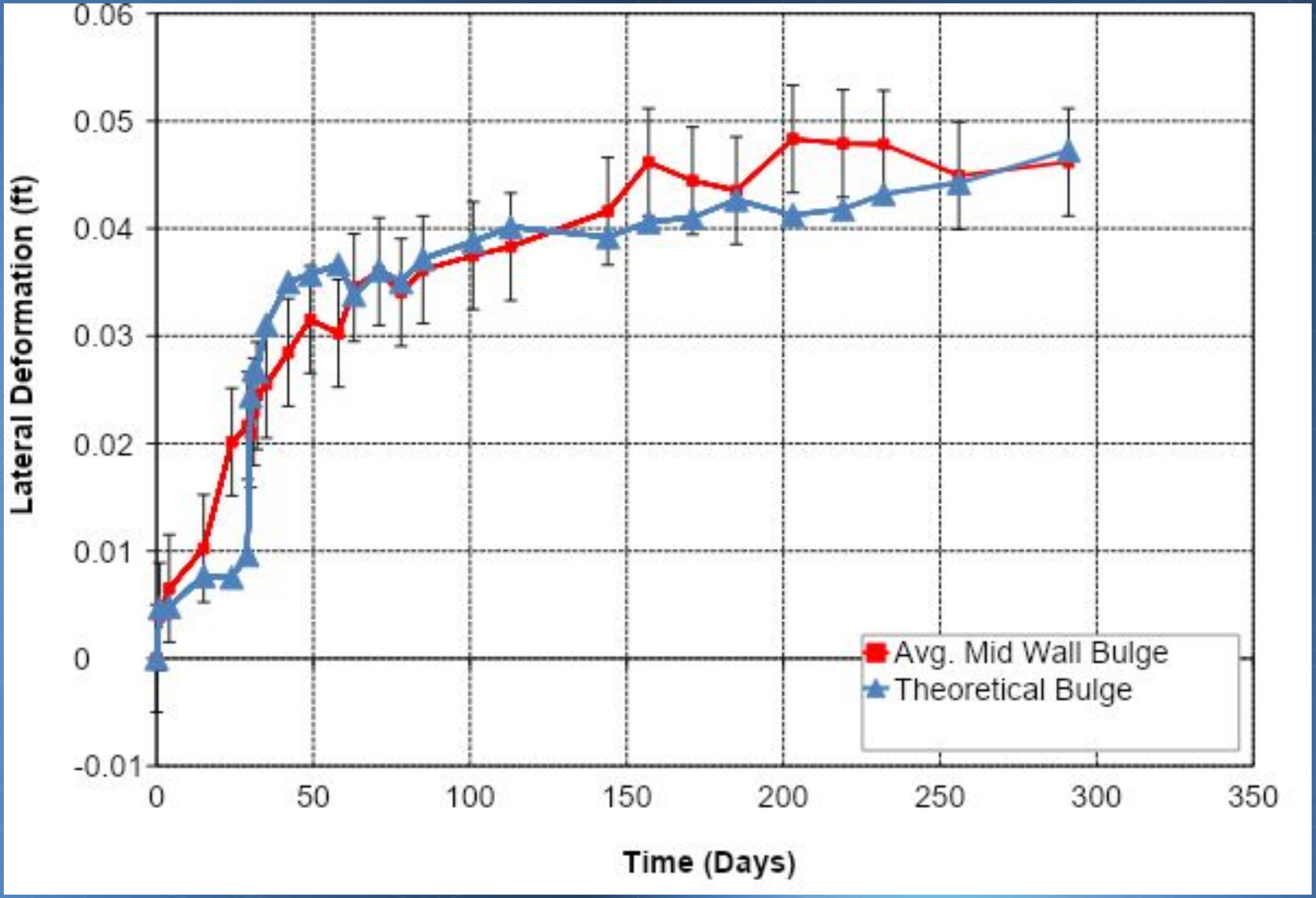
Lateral Deformation *Continued*

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

$$D_L = \frac{2b_{q,vol} D_V}{H} = \frac{2(b + a_b) D_V}{H} = \frac{2(2.5 + 0.67)(0.5/12)}{10.25} = 0.31 \text{ in.}$$

$$\varepsilon_L = \frac{D_L}{b_{q,vol}} = \frac{(0.31/12)}{(2.5 + 0.67)} = 0.8\% = 2\varepsilon_V \leq 1\% \text{ OK}$$

Lateral Deformation *Continued*



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

Continued

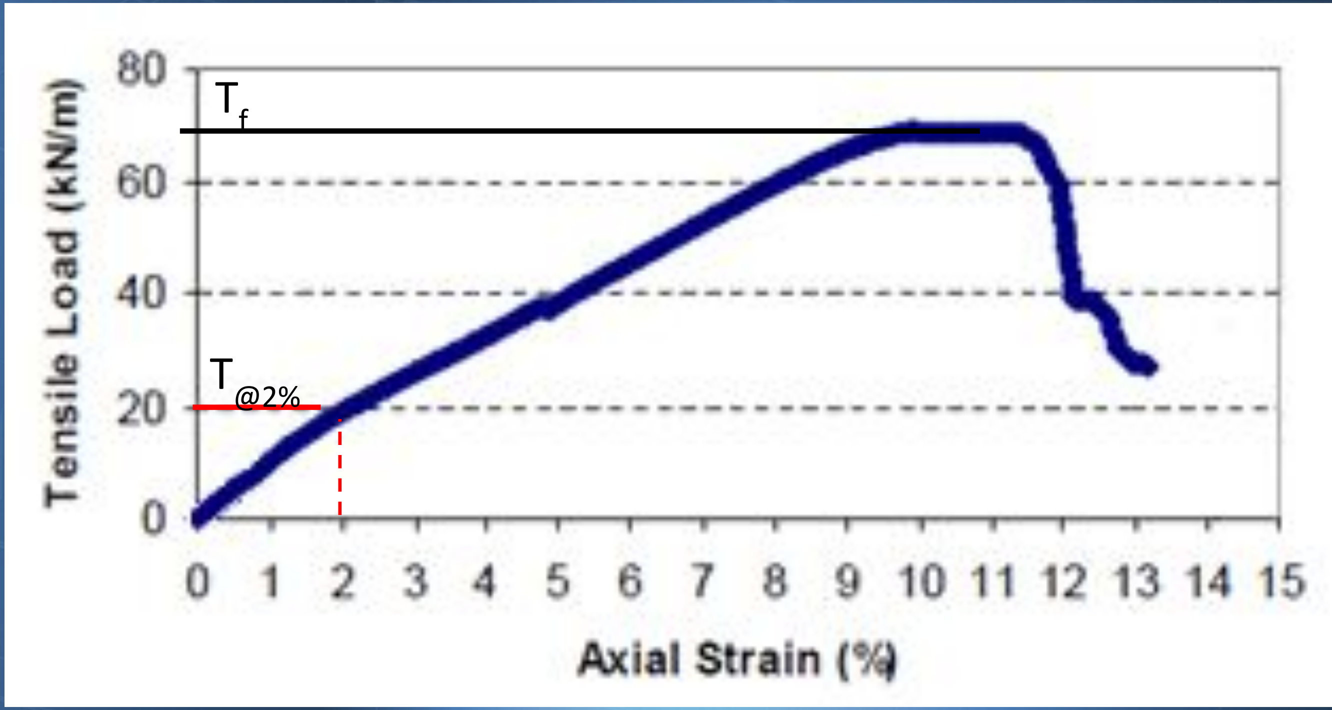
- The required reinforcement strength must satisfy two criteria:
  1) It must be less than the allowable reinforcement strength (T_{allow})

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

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

Required Reinforcement Strength
Continued

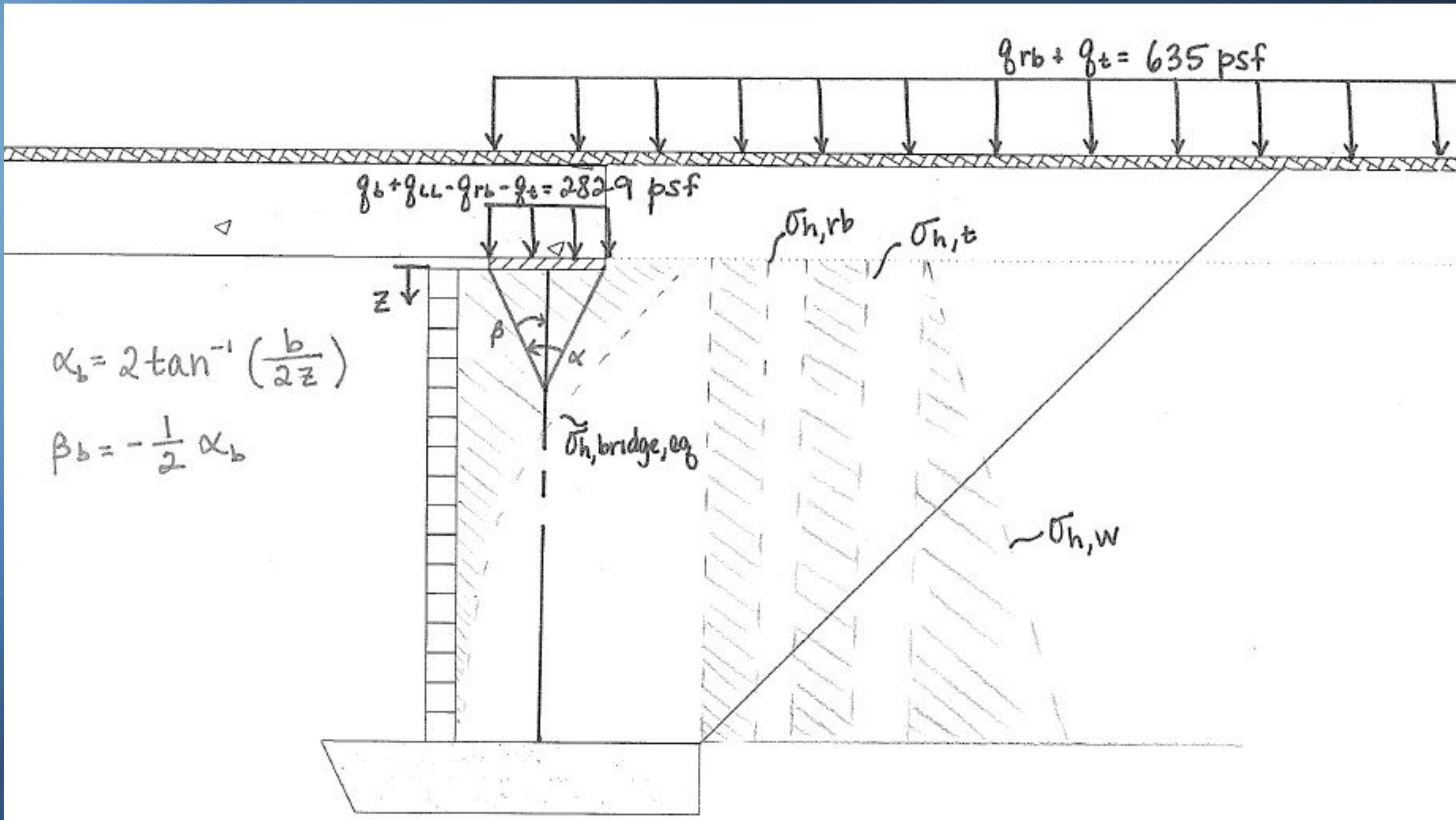
- Recommended: $T_f \geq 4800$ lb/ft
- To get $T_{@\varepsilon=2\%}$, use results of ASTM D-4595 (geotextiles) or ASTM D-6637 (geogrids)



Design Example

Required Reinforcement Strength

Continued



Design Example

Required Reinforcement Strength

Continued

@ $z = 2.7\ ft$:

$$\alpha_b = 2\tan^{-1}\left(\frac{b}{2z}\right) = 2\tan^{-1}\left(\frac{2.5}{2(2.7)}\right) = 0.87\ rad$$

$$\beta_b = -\frac{1}{2}\alpha = -\frac{1}{2}(0.87) = -0.43\ rad$$

$$\sigma_h = \sigma_{h,w} + \sigma_{h,bridge,eq} + \sigma_{h,rb} + \sigma_{h,t} = 43.7 + 216.3 + 38.2 + 55 = 353.2\ psf$$

$$\rightarrow \sigma_{h,w} = \gamma_r z K_{a,r} = 110(2.7)(0.147) = 43.7\ psf$$

$$\sigma_{h,bridge,eq} = \frac{(q_b + q_{LL}) - (q_{rb} + q_t)}{\pi}\left[\alpha_b + \sin\alpha_b \cos(\alpha_b + 2\beta_b)\right]K_{a,r}$$

$$= \frac{(1750 + 1714) - (260 + 375)}{\pi}\left[0.87 + \sin(0.87)\cos(0.87 + 2(-0.43))\right]0.147 = 216.3\ psf$$

$$\sigma_{h,rb} = q_{rb} K_{a,r} = 260(0.147) = 38.2\ psf$$

$$\sigma_{h,t} = q_t K_{a,r} = 375(0.147) = 55\ psf$$

$$T_{req} = \left[\frac{\sigma_h}{0.7^{\frac{S_v}{6d_{max}}}}\right]S_v = \left[\frac{353.2}{0.7^{(8/6(0.5))}}\right]\left(\frac{8}{12}\right) = 609.5\ lb/ft \le \begin{cases} (1)\ T_{allow} = \frac{T_f}{FS_{reinf}} = \frac{4800}{3.5} = 1371.4\ lb/ft \\ (2)\ T_{@\varepsilon=2\%} = 1370\ lb/ft \end{cases}$$

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:
  - Corners
  - Drainage
  - Surface drainage and collection
  - Erosion protection
  - Scour countermeasures
  - Skews and superelevations
  - Accommodate for obstructions such as guardrails, drainage, and utilities.
  - Others as required to accommodate structure