Preferred Design Procedure
The Federal Highway Administration (FHWA) has two documents for this technology that contain design guidance information. AASHTO also has a guide specification for this technology:

<table>
<thead>
<tr>
<th>Publication Title</th>
<th>Publication Year</th>
<th>Publication Number</th>
<th>Available for Download</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, 1st Edition</td>
<td>2012</td>
<td>---</td>
<td>No</td>
</tr>
<tr>
<td>Recommended Guide Specification for the Design of Externally Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements</td>
<td>2010</td>
<td>NCHRP 655</td>
<td>Yes</td>
</tr>
<tr>
<td>Design of FRP Systems for Strengthening Concrete Girders in Shear</td>
<td>2011</td>
<td>NCHRP 678</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Summary of Design/Analysis Procedure:
First, the bridge data, material properties, and geometric properties must be defined. It is also necessary to identify the standard or specification that will be used in the design along with which load combinations the design will address.

The solution of the example will follow the following general steps:

Step 1. Calculate Nominal bridge capacity/resistance
Step 2. Calculate desired bridge capacity
Step 3. Design Strengthening System
Step 4. Check Design against limits and requirements

A summary will be given at the end of the example, to give the dimensions and location of the strengthening system and how much capacity was gained.
**Symbols and Notation**

Variables used throughout the design example are listed alphabetically below:

- $A_{frp}$ = effective area of FRP reinforcement for shear-friction (in$^2$)
- $A_s$ = area of nonprestressed tension reinforcement (in$^2$)
- $b_e$ = effective width of beam (in)
- $d$ = effective depth of beam (in)
- $E_a$ = modulus of elasticity of adhesive (ksi)
- $E_c$ = modulus of elasticity of the concrete (ksi)
- $E_{frp}$ = modulus of the FRP reinforcement in the direction of structural action
- $E_{sp}$ = modulus of elasticity of the nonprestressed tension reinforcement (ksi)
- $f_c'$ = 28 - day compression strength of the concrete (ksi)
- $f_{frp}$ = tensile strength of FRP reinforcement (ksi)
- $f_{peel}$ = peel stress at the FRP reinforcement concrete interface (ksi)
- $f_y$ = specified yield stress of steel reinforcement (ksi)
- $G_a$ = characteristic value of the shear modulus of adhesive (ksi)
- $h$ = depth of section (in); overall thickness or depth of a member (in.)
- $I_T$ = moment of inertia of an equivalent FRP transformed section, neglecting any contribution of concrete in tension (in$^4$)
- $k_2$ = multiplier for locating resultant of the compression force in the concrete
- $L_d$ = development length (in)
- $l_{frp}$ = length of FRP reinforcement (ft)
- $M_n$ = nominal moment capacity of the beam (kip-in)
- $M_r$ = factored resistance of a steel-reinforced concrete rectangular section strengthened with FRP reinforcement externally bonded to the beam tension surface (kip-in)
- $M_u$ = factored moment at the reinforcement end-termination (kip-in)
- $n$ = number of required layers of FRP reinforcement
APPLICATION OF FRP: EXTERNAL BONDING

DESIGN EXAMPLE

$N_b =$ FRP reinforcement strength per unit width at a tensile strain of 0.005 (kips/in)

$P_{frp} =$ Tensile strength in the FRP reinforcement at 1\% strain

$t_a =$ thickness of the adhesive layer (in)

$t_{frp} =$ thickness of the FRP reinforcement (in)

$T_{frp} =$ tension force in the FRP reinforcement (kips)

$T_g =$ glass transition temperature (°F)

$\varepsilon_c =$ strain in concrete

$\varepsilon_{frp} =$ strain in FRP reinforcement

$\varepsilon_{frp}^{tu} =$ characteristic value of the tensile failure strain of the FRP reinforcement

$\varepsilon_{frp}^y =$ the strain in the FRP reinforcement when the steel tensile reinforcement yields

$\varepsilon_o =$ the concrete strain corresponding to the maximum stress of the concrete stress-strain curve

$\varepsilon_s =$ strain in steel

$\eta =$ strain limitation coefficient that is less than unity.

$\nu_a =$ Poisson’s ratio of adhesive

$\tau_a =$ characteristic value of the limiting shear stress in the adhesive (ksi)

$\tau_{int} =$ interface shear transfer strength (ksi)

$\varphi_{frp} =$ resistance factor for FRP component of resistance
**Worked Design Example**

**Introduction**: Flexural strengthening of a simply supported cast in-place reinforced concrete girder with FRP strips.

Adapted from *Recommended guide specification for the design of externally bonded FRP systems for repair and strengthening of concrete bridge elements*, by A.H. Zureick et al., 2010, NCHRP 655, p.B-6 – B-18. Copyright [2010] by Transportation Research Board.

**Bridge Data**:
- **Span**: 39 ft
- **Type**: Cast in-place reinforced concrete
- **Year built**: 1957
- **Location**: State of Georgia

**Material Properties**
- **Concrete compression Strength**: $f_c' = 3.9 \text{ ksi}$ (from in-situ testing)
- **Reinforcing steel yield strength**: $f_y = 40 \text{ ksi}$
- **FRP reinforcement**: Shop-fabricated carbon fiber/Epoxy composite plates
  - **Plate thickness**, $t_{frp} = 0.039''$
  - **Glass Transition Temperature**: $T_g = 165° F$
  - **Tensile strain in the FRP reinforcement at failure**: $\varepsilon_{frp} = 0.013$
  - **Tensile strength in the FRP reinforcement at 1% strain**: $P_{frp} = 9.3 \text{ kips / in}$
  - **Shear modulus of the adhesive**: $185 \text{ ksi}$

**Geometrical properties**

**Girder dimensions and Steel Reinforcement**: See Figure 1.

![Figure 1. Bridge cross section at mid-span.](image-url)
APPLICATION OF FRP: EXTERNAL BONDING

DESIGN EXAMPLE

Determine Standards and Loadings
This example will use the Guide Specifications from NCHRP 655.

A Structural Analysis was run under the new loading and the following moments were given:

For Strength I Load Combination: \( M_D = 239 \text{ kip-ft} \) and \( M_{L+I} = 615 \text{ kip-ft} \)

For Fatigue Limit State: \( M_{L+I} = 308 \text{ kip-ft} \)

Special Notes
Hydraulic jacking procedure of the bridge will be used so that strengthening is carried out in an unstressed condition.

**Solution:**

*Step 1. Calculate the flexural strength of the T-beam*

Effective depth
\[
d = 30.5 - 2 - 0.5 - 1.41 = 26.59 \text{ in.}
\]

Effective Flange Width

As per Article 4.6.2.6.1 of AASHTO LRFD Bridge Design Specifications, the effective flange width is taken as the minimum of

- One-quarter of the effective span length;
- Twelve times the average depth of the slab, plus the greater of web thickness or one-half the width of the top flange of the girder; or
- The average spacing of adjacent beams.

\[
b_e = \text{Minimum} \{ \frac{d}{4} = \frac{(39)(12)}{4} = 117 \text{ in.} \}
\]

\[
12t_s + b_w = 12(6) + 18 = 90 \text{ in.}
\]

\[
s = 86 \text{ in.} \}
\]

\[
b_e = 86 \text{ in.}
\]

**Figure 2. Reinforced Concrete T-beam.**
Assumptions:
- A rectangular stress block to represent the distribution of concrete compression stresses (Article 5.7.2.2 of AASHTO LRFD Bridge Design Specifications),
- No contribution of the steel in the compression zone to the flexural strength,
- The strain in the tension steel is greater than the yield strain, and
- The neutral axis is located in the flange of the section

Thus, the compression and tension forces are \( C_c = 0.85 f'c' b_e a \) and \( T = A_s f_y \), respectively, as illustrated in Figure 3.

From the condition of equilibrium of forces:

\[ 0.85 f'c' b_e a = A_s f_y \]

Thus,

\[ a = \frac{A_s f_y}{0.85 f'c' b_e} = \frac{12.48(40)}{0.85(3.9)(86)} = 1.75 \text{ in.} \]

The depth of the neutral axis:

\[ c = \frac{a}{\beta_1} = \frac{1.75}{0.85} = 2.06 \text{ in.} \]

Since \( c = 2.06 \text{ in.} < t_s = 6 \text{ in.} \), the assumption that the depth of the neutral axis fall within the flange is appropriate.
Referring to Figure B-5, the strain in the tension steel can be computed as follows:

\[
\frac{\varepsilon_s}{0.003} = \frac{d - c}{c}
\]

\[
\varepsilon_s = \frac{26.59 - 2.06}{2.06}(0.003) = 0.036
\]

Since \( \varepsilon_s = 0.036 > \frac{f_y}{E_s} = \frac{40}{29,000} = 0.00138 \), the assumption that the tension steel yielded is correct.

The nominal flexural strength of the girder can then be computed from

\[
M_n = A_s f_y \left( d - \frac{a}{2} \right) = (12.48)(40) \left( 26.59 - \frac{1.75}{2} \right) = 12,837 \text{ kip} - \text{in.}
\]

\[
\phi M_n = 0.9(12,837) = 11,553 \text{ kip} - \text{in.}
\]

Check compliance with Article 1.4.4 of the proposed Guide Specifications

\[
\phi M_n = 11,553 \text{ kip} - \text{in.} > M_D + M_{L+I} = 239 + 615 = 854 \text{ kip} - \text{ft} = 10,248 \text{ kip} - \text{in.}
\]

Proceed with the design of an externally bonded FRP reinforcement system.

Step 2. Calculate the desired capacity of the T-beam

The moment capacity of the strengthened T-beam must exceed the moments given by the structural analysis:

For Strength I Load Combination: \( M_D = 239 \text{ kip-ft} \) and \( M_{L+I} = 615 \text{ kip-ft} \)

For Fatigue Limit State: \( M_{L+I} = 308 \text{ kip-ft} \)

The factored moment for Strength I limit state is

\[
M_u = 1.25M_D + 1.75M_{L+I} = 1.25(239) + 1.75(615) = 1,375 \text{ kip} - \text{ft} = 16,500 \text{ kip} - \text{in.}
\]
APPLICATION OF FRP: EXTERNAL BONDING

DESIGN EXAMPLE

Step 3. Design the FRP strip strengthening system

a. Check FRP reinforcement material properties against specifications to ensure it can provide desired capacity.

Determine if the FRP reinforcement material is in compliance with Section 2 (Article 2.2.4.1) of the Guide Specification and be sure that the glass transition temperature is higher than the maximum design temperature plus 40°F.

The maximum design temperature, $T_{\text{MaxDesign}}$, determined from Article 3.12.2.2 of AASHTO LRFD Bridge Design Specifications for the location of the bridge (State of Georgia)

$$T_{\text{MaxDesign}} = 110^\circ F$$

$$T_{\text{MaxDesign}} + 40^\circ F = 110^\circ F + 40^\circ F = 150^\circ F < T_g = 165^\circ F$$

Thus, Article 2.2.4.1 of the Guide Specification is satisfied.

Establish the linear stress-strain relationship of the FRP reinforcement based on the design assumptions specified in Article 3.2 of the Guide and compute the tensile strength corresponding to a strain value of 0.005. Results are presented in Figure 4.

$$N_b = \frac{0.005}{0.01} (9.3) = 4.65 \text{ kip/in}$$

![Figure 4. FRP reinforcement stress-strain diagram for design purposes.](image-url)
b. Estimate the amount of FRP reinforcement required to accommodate the increase in flexural strength
For a preliminary estimate of the amount of FRP reinforcement necessary to resist 1,375 k-ft of moment, the following approximate design equation can be used:

\[
T_{frp} \approx \frac{M_u - \varnothing M_{n\text{unreinforced}}}{h} \approx \frac{(1,375 - 963)(12)}{30.5} = 162 \text{ kips}
\]

\[T_{frp} = nN_b b_{frp}\]

Where \(n\) is the number of FRP reinforcement plates.

Use a reinforcement width of \(b_{frp} = 14\)”, the number of required layers is:

\[n = \frac{T_{frp}}{N_b b_{frp}} = \frac{162}{(4.65)(14)} = 2.5\]

Try 3 layers of the FRP reinforcement, for which \(T_{frp} = 3(4.65)(14) = 195.3\) kips

Step 4. Check design against limits and required capacity

a. Compute the factored flexural resistance of the strengthened T-beam
Location of the neutral axis

The depth of the neutral axis can be determined from both strain compatibility and force equilibrium conditions as follows:

Figure 5. Reinforced concrete T-beam externally strengthened with FRP reinforcement.
APPLICATION OF FRP: EXTERNAL BONDING

DESIGN EXAMPLE

Assume \(c = 6 \text{ in.}\)

\[
\varepsilon_c = \frac{c}{h-c} (\varepsilon_{FRP}) = \frac{6}{30.5-6} (0.005) = 0.00122
\]

\[
E_c = 1,820 \sqrt{f_c'} = 1,820 \sqrt{3.9} = 3,594 \text{ ksi}
\]

\[
\varepsilon_o = 1.71 \frac{f_c'}{E_c} = 1.71 \frac{3.9}{3,594} = 0.00186
\]

\[
\frac{\varepsilon_c}{\varepsilon_o} = \frac{0.00122}{0.00186} = 0.66
\]

\[
\beta_2 = \frac{\ln\left[1+\left(\frac{\varepsilon_c}{\varepsilon_o}\right)^2\right]}{\ln(1+0.66)^2} = 0.548
\]

Compression force in the concrete:

\[
C_c = 0.9 f_c' \beta_2 c b_c = 0.9(3.9)(0.548)(6)(86) = 992.5 \text{ kips}
\]

Tension Force in the tension steel:

Strain in the steel:

\[
\varepsilon_s = \frac{d - c}{c} \varepsilon_c = \frac{26.59 - 6}{6} (0.00122) = 0.00418 > \varepsilon_y = \frac{f_y}{E} = \frac{40}{29,000} = 0.001379
\]

Thus,

\[
T_s = A_s f_y = (12.48)(40) = 499.2 \text{ kips}
\]

Tension Force in the FRP reinforcement:

\[
T_{frp} = 3(4.65)(14) = 195.3 \text{ kips}
\]

Total Tension Force

\[
T = T_{frp} + T_s = 195.3 + 499.2 = 694.5 \text{ kips}
\]

Clearly equilibrium of the forces is not satisfied \(C_c - T = 992.5 - 694.5 = 298 \text{ kips},\) and the assumed depth for the neutral axis (\(c = 6 \text{ in.}\)) is incorrect. By trial and error, one can find that by assuming a depth of the neutral axis, \(c = 4.96 \text{ in.}\), and repeating the above calculations, the following values are computed:
APPLICATION OF FRP: EXTERNAL BONDING

DESIGN EXAMPLE

For $c = 4.67$ in.

$\epsilon_c = 0.00097$, $\epsilon_s = 0.0042 > \epsilon_y$, $\frac{\epsilon_c}{\epsilon_o} = 0.53$, $\beta_2 = 0.46$, $Cc = 695.2$ kips,

$T_s = 499.2$ kips, $T_{frp} = 195.3$ kips,

$T = T_{frp} + T_s = 195.3 + 499.2 = 694.5$ kips,

and $Cc - T = 695.2 - 694.5 = 0.7$ kips, close enough to zero.

The factored flexural resistance

$$M_r = 0.9 [A_s f_s (d_s - k_2 c)] + \phi_{frp} T_{FRP} (h - k_2 c)$$

With $k_2 = 1 - \frac{2 \left[ \left( \frac{\epsilon_c}{\epsilon_o} \right) - \arctan \left( \frac{\epsilon_c}{\epsilon_o} \right) \right]}{\beta_2^2 \left( \frac{\epsilon_c}{\epsilon_o} \right)^2} = 1 - \frac{2 \left[ \left( 0.53 \right) - \arctan \left( 0.53 \right) \right]}{0.46 \left( 0.53 \right)^2} = 0.35$ and $\phi_{frp} = 0.85$

$$M_r = 0.9 \left[ (12.48)(40)(26.59 - (0.35)(4.97)) \right] + 0.85(195.3)[30.5 - (0.35)(4.97)] = 15,939$ kips – in.

$M_r = 15,939$ kip – in. $< 16,500$ kip – in.

Increase the width of the FRP reinforcement to $b_{frp} = 17$ in. and re-compute the flexural resistance $M_r$

By doing so, we can find $c = 5.1$ in. and

$M_r = 16,930$ kip – in. $> 16,500$ kip – in.

Thus, AASHTO Strength I Load Combination limit is satisfied.
b. Check ductility requirements (Article 3.4.2 of the Guide)

When reinforcing steel first yields at \( \varepsilon_s = \varepsilon_y = \frac{f_y}{E_s} = \frac{40}{29,000} = 0.00138 \). For such a case, the strain and stress diagrams are shown in Figure 7.

\[
\varepsilon_f = \beta \varepsilon_y
\]

\[
f_y = \beta (0.9 f_y)
\]

By satisfying the conditions of force equilibrium and strain compatibility, the strain in the FRP reinforcement when the steel tensile reinforcement yields can be found numerically to be \( \varepsilon_{frp}^y = 0.0016 \). Thus, the ductility requirement of Article 3.4.2 of the guide specification is:

\[
\frac{\varepsilon_{frp}^u}{\varepsilon_{frp}^y} = \frac{0.005}{0.0016} = 3.1 > 2.5. \text{ OK}
\]
c. Calculate development length

Note: this step may be completed earlier in the design, but to save space on calculations, this step was completed after iterating the FRP area.

\[ L_d = \frac{T_{frp}}{\tau_{int} b_{frp}} = \frac{237.15}{0.065 \sqrt{3.9(17)}} = 109 \text{ in.} = 9.1 \text{ ft} \]

Figure 8. FRP reinforcement location.

Figure 9. FRP reinforcement detail.
d. Check fatigue load combination limit state

For the fatigue load combination: \(0.75ML + I = 0.75(308) = 231 \text{ kip} - ft = 2,772 \text{ kip} - in.\)

Determine the cracking moment: \(M_{cr} = f' r \frac{I_g}{y_t} \text{ with } f' r = 0.24 \sqrt{f_c} = 0.24 \sqrt{3.9} = 0.474 \text{ ksi}\)

Section Properties:
\[ I_g = 78,096 \text{ in}^4 \]
\[ y_t = 20.4 \text{ in} \]
\[ M_{cr} = (0.474) \frac{78,096}{20.4} = 1,815 \text{ kip} - in. < 2,772 \text{ kip} - in. \]

Neglect the concrete part in tension and calculate the moment of inertia of an equivalent transformed FRP section:

From the FRP reinforcement load-strain data:
\[ E_{frp} = \frac{f_{frp}}{\varepsilon_{frp}} = \frac{N_b/t_{frp}}{\varepsilon_{frp}} = \frac{4.65/(0.039)}{0.005} = 23,850 \text{ ksi} \]

Modular ratio for the concrete: \[ n_c = \frac{E_c}{E_{frp}} = \frac{3,594}{23,850} = 0.15 \]

Modular ratio of the steel: \[ n_s = \frac{E_s}{E_{frp}} = \frac{29,000}{23,850} = 1.2 \]

Based on the modular ratios for the concrete and for the steel, an equivalent FRP transformed section is:

![Figure 10. Equivalent FRP transformed section.](image-url)
By summing the moment of areas about reference line 1-1:

\[ A_{frp} \left( h + \frac{t_{frp}}{2} \right) + n_s A_s d + n_c A_c \left( \frac{Z}{2} \right) = (A_{frp} + n_s A_s + n_c A_c)z \]

\[ A_{frp} \left( h + \frac{t_{frp}}{2} \right) + n_s A_s d + n_c b_e z \left( \frac{Z}{2} \right) = (A_{frp} + n_s A_s + n_c b_e z)z \]

\[ z^2 + \frac{2(A_{frp} + n_s A_s)}{n_c b_e} z - \frac{2 \left[ A_{frp} \left( h + \frac{t_{frp}}{2} \right) + n_s A_s d \right]}{n_c b_e} = 0 \]

\[ \frac{2(A_{frp} + n_s A_s)}{n_c b_e} = \frac{2[(3)(17)(0.039) + 1.2(12.48)]}{(0.15)(86)} = 2.6 \text{ in.} \]

\[ \frac{2(A_{frp} h + n_s A_s d)}{n_c b_e} = 2 \left[ (3)(17)(0.039) \left( 30.5 + \frac{0.117}{2} \right) + (1.2)(12.48)(26.63) \right] = 71.22 \text{ in}^2 \]

The equation \( z^2 + 2.6z - 71.22 = 0 \) has the solutions of \( z = 7.24 \text{ in.} \) or \( z = 9.84 \text{ in.} \) and only the positive solution \( z = 7.24 \text{ in.} \) is valid. Because \( z = 7.24 \text{ in.} > 6 \text{ in.} \), the assumption that the neutral axis fall in the flange was incorrect.

Assume that the neutral axis is located at a distance \( z > 6 \text{ in.} \). By summing the moment of areas about reference line 1-1:

\[ A_{frp} \left( h + \frac{n_t_{frp}}{2} \right) + n_s A_s d + n_c (b_e - b_w) t_s * \frac{t}{2} + n_c b_w z * \frac{Z}{2} = [A_{frp} + n_s A_s + n_c (b_e - b_w) t_s + \]

\[ \ldots \]
Strain in the concrete, steel reinforcement, and FRP reinforcement, respectively, due to the fatigue load combination:

\[
\varepsilon_c = \frac{M_f z}{l_T E_{frp}} = \frac{(231)(12)(7.31)}{(8,345)(23,850)} = 0.00010 < 0.36 \frac{f_y}{E_c} = 0.36 \frac{3.9}{3,595} = 0.00039
\]

\[
\varepsilon_s = \frac{M_f (d - z)}{l_T E_{frp}} = \frac{(231)(12)(26.63 - 7.31)}{(8,345)(23,850)} = 0.0003 < 0.8\varepsilon_y = 0.8 \frac{40}{29,000} = 0.0011
\]

\[
\varepsilon_{frp} = \frac{M_f (h + t_{frp} - z)}{l_T E_{frp}} = \frac{(231)(12)[30.50 + 3(0.039) - 7.31]}{(8,345)(23,850)} = 0.00032 < \eta \varepsilon_{frp}^u = 0.8(0.013) = 0.0104
\]

\[
e. \text{ Check reinforcement end termination peelings}
\]

The reinforcement end terminates at a distance of 19.5-12 = 7.5 ft from each of the end supports.

It is required to calculate the moment and shear at 7.5 ft from the end support. From analysis, we will use the following combinations:

\[
M_u = 1.25 M_D + 1.75 M_L + I = 503 \text{ kips} - ft
\]

\[
V_u = 1.25 V_D + 1.75 V_L + I = 112 \text{ kips}
\]

Calculate the peel stress from the equation:

\[
f_{peel} = \tau_{av} \left[ \left( \frac{3E_a}{E_{frp}} \right) \frac{l_{frp}}{t_a} \right]^{\frac{1}{2}}
\]

\[
E_a = 2G_a \left( 1 + \nu_a \right)
\]

\[
\tau_{av} = \frac{V_u + \left( \frac{G_a}{E_{frp} t_{frp} t_a} \right) M_u}{t_{frp} (h - z) / l_T}
\]

\[
\tau_{av} = \left[ 112 + \left( \frac{185}{(23,850)(0.117)(0.125)} \right) \left( \frac{0.117(30.5 - 7.31)}{8,345} \right) \right]^{\frac{1}{2}} = 1.5 \text{ ksi}
\]

\[
f_{peel} = (1.5) \left[ \left( \frac{3(500)}{23,850} \right) \left( \frac{0.117}{0.125} \right) \frac{0.117}{0.125} \right]^{\frac{1}{2}} = 0.740 \text{ ksi} > 0.065 \sqrt{3.9} = 0.128 \text{ ksi}
\]

Provide mechanical anchors at the FRP reinforcement ends.
**Summary:**

Externally bonded carbon FRP sheets were designed in this example. The FRP sheets are applied to the soffit of the RC T-beam along the longitudinal axis to increase the flexural capacity. The final design is summarized as:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use number of plies of FRP sheets</td>
<td>( n = 3 )</td>
</tr>
<tr>
<td>Use the width of FRP sheets</td>
<td>( b_{frp} = 17 \text{ in.} )</td>
</tr>
<tr>
<td>Use the length of FRP sheets, centered on the girder</td>
<td>( l_{frp} = 24 \text{ ft.} )</td>
</tr>
<tr>
<td>Use of end anchorage needed?</td>
<td>Yes</td>
</tr>
<tr>
<td>Final factored flexural resistance of T-beam</td>
<td>( M_r = 16,930 \text{ kip} - \text{in.} )</td>
</tr>
</tbody>
</table>

![Figure 11. Final design of FRP strengthening.](image)

**Figure 11.** Final design of FRP strengthening.
References Page

AASHTO (2014). *AASHTO LRFD bridge design specifications, customary U.S. units* (7th ed.).