LINK SLAB DESIGN

The NYSDOT Office of Structures has developed an innovative link slab design utilizing Ultra High Performance Concrete (UHPC). Based on our analysis that considered the distribution of strain due to girder end rotation, it was found that all translation will occur at the bearings. The force required to strain the UHPC in pure tension is extremely large and even a typical fixed bearing will displace long before generating enough force to elongate the UHPC. Therefore, the link slab design assumes that the UHPC section is subject to bending only. Although not accounted for in the design, the link slab also acts as a semi-rigid link between spans transferring compressive, tensile, and shear stresses due to horizontal loads.

The ability of UHPC to develop ultimate tensile strains up to 0.007, by developing micro cracking within, is what allows the link slab to accommodate girder end rotations. A maximum design strain of 0.0035 at the extreme tensile fiber was chosen in order to control the crack width. The crack spacing associated with a strain of 0.0035 is approximately 3/16", resulting in extremely fine cracks that are invisible to the naked eye. Limiting the tensile strain will increase the service life of the link slab by preventing the penetration of moisture and chlorides.

The design of the link slab is influenced by variables such as span arrangement, bearing type and arrangement, girder end rotation due to live load, and bridge skew. The following guidance is provided to help ensure proper structural functioning of the bridge as a system and the durability of the link slab.

Span Arrangement
The span arrangement shall be such that the overall bridge expansion and contraction is accommodated. Link slabs at intermediate supports with integral/jointless abutment details is the best possible combination, followed by link slabs at the interior supports with a joint at one abutment and a jointless deck at the other. For long bridges, which need more than one joint to accommodate thermal movement, link slabs at the interior supports and joints at both abutments is preferred. Joints at intermediate supports are unavoidable for long bridges with a large number of spans where thermal movements are too large to be accommodated by expansion joints at the abutments alone.

Bearing Type & Arrangement
Link slabs shall not be used with two lines of fixed bearings on intermediate supports. Furthermore, steel rocker as well as steel sliding bearings are unsuitable for link slabs due to the repetitive horizontal movement induced by girder live load deflections.

Rotation Demand
The main function of the link slab is to provide continuity of the deck slab yet offer negligible resistance against the girder end rotation. It is intended to act as a pinned connection within the deck slab. The link slab shall be designed to allow for the rotation due to the factored live load deflection of the superstructure without exceeding a maximum strain of 0.0035 in tension and a maximum stress of 14 ksi in compression. A standard link slab thickness of 4" shall be used, leaving only the unbonded length to designed based on these strain and stress limitations. For computation purposes, the modulus of elasticity of the UHPC shall be taken as 8000 ksi and the UHPC tensile cracking stress shall be taken as 1.2 ksi.

Reinforcement
Due to the steel fibers present in UHPC conventional reinforcing bars are not required within the link slab for strength. However, to improve the overall toughness of the system one layer of longitudinal reinforcement is provided in the center of the link slab. The size, spacing, and type should match that of the adjacent concrete deck.

Anchoring of Link Slab
The portion of the link slab beyond the unbonded length is used to anchor it into the concrete deck slab. The concrete deck slab in this region shall be roughened to amplitude of 1/2". An exposed aggregate surface can be used to obtain the required roughness for new decks, precast or cast in place. Reinforcing bars from the concrete deck shall extend into the link slab to a sufficient embedment length to establish a proper connection between the link slab and the deck. Link slabs shall only be used with new decks, or existing decks that are in fair condition.
Restrictions on Skew
Due to a limited experience with the use of UHPC link slabs, its usage is limited to supports not exceeding a skew of 30 degrees.

ILLUSTRATIVE EXAMPLE

User Inputs

- Indicates User Input

Note: The following inputs are standard and not editable by the user.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_y )</td>
<td>60 ksi</td>
<td>rebar yield strength</td>
</tr>
<tr>
<td>( E_s )</td>
<td>29000 ksi</td>
<td>rebar modulus of elasticity</td>
</tr>
<tr>
<td>( A_s )</td>
<td>( \frac{.31\text{in}^2}{6\text{in}} = 0.62\text{in}^2/\text{ft} )</td>
<td>area of longitudinal steel at joint</td>
</tr>
<tr>
<td>( L_{unb} )</td>
<td>16 in</td>
<td>unbonded length of UHPC</td>
</tr>
<tr>
<td>( E_c )</td>
<td>8000 ksi</td>
<td>UHPC compressive modulus of elasticity</td>
</tr>
<tr>
<td>( f_{uhpc,t,all} )</td>
<td>1.2 ksi</td>
<td>UHPC tensile cracking stress</td>
</tr>
<tr>
<td>( f_{uhpc,c,all} )</td>
<td>-14 ksi</td>
<td>maximum allowable UHPC compressive stress</td>
</tr>
<tr>
<td>( \varepsilon_{uhpc,t,all} )</td>
<td>( 3500 \times 10^{-6} )</td>
<td>maximum allowable UHPC tensile strain</td>
</tr>
<tr>
<td>( d_{uhpc} )</td>
<td>4 in</td>
<td>depth of UHPC</td>
</tr>
</tbody>
</table>
L_{span1} := 80ft  
- length of span

\Delta_{LL1} := 1.25\text{in}  
- unfactored live load
deflection at midspan, including impact

L_{span2} := 80ft

\Delta_{LL2} := 1.25\text{in}

**UHPC in Flexure Only**

- Area of reinforcement within section: \( A_s := A_s \cdot 1\text{ft}^2 = 0.62\text{in}^2 \)
- Width of section: \( b := 1\text{ft} \)
- Depth of UHPC: \( h := d_{uhpc} = 4.00\text{in} \)
- Assumed maximum tensile stress of UHPC: \( f_t := f_{uhpc,t,all} = 1.20\text{ksi} \)

\[ \theta := 1.75 \left( \frac{2 \cdot \Delta_{LL2}}{0.5 \cdot L_{span2}} + \frac{2 \cdot \Delta_{LL2}}{0.5 \cdot L_{span2}} \right) = 1.04\text{deg} \]

Strength I approximate girder end rotation

\( e := 1 \times 10^{-6} \)
\( ec := 1 \)
\( i := 1 \)

while \( ec < \mid ec \mid \)

\[ fc := ec \cdot E_c \]
\[ c := \frac{\sqrt{A_s^2 \cdot E_s^2 \cdot eci^2 + fc \cdot A_s \cdot E_s \cdot b \cdot h \cdot eci + b^2 \cdot f_t^2 \cdot h^2 + b \cdot f_t \cdot h - A_s \cdot E_s \cdot eci}}{b \cdot fc + 2 \cdot b \cdot f_t} \]
\[ ec := \frac{-\theta \cdot c}{L_{unb}} \]
\[ eci := ec + 0.1 \times 10^{-6} \]
\[ i := i + 1 \]

out := "Error" if (\( c < 0\in\)) \( \lor \) (\( c > d_{uhpc} \)) \( \lor \) \( \left( \frac{\max(\mid ec \mid, eci)}{\min(\mid ec \mid, eci)} - 1 > 5\% \right) \)

out := c otherwise

return out
Distance from bottom of section to neutral axis
c = 1.06\text{ in}

Tensile strain in UHPC
\[ \varepsilon_{_{\text{uhpc.t}}} := \frac{\theta \left( d_{\text{uhpc}} - c \right)}{L_{\text{unb}}} = 3349 \times 10^{-6} \]

Tensile strain & stress in steel
\[ \varepsilon_{_{\text{steel.t}}} := \frac{\theta \left( \frac{d_{\text{uhpc}}}{2} - c \right)}{L_{\text{unb}}} = 1070 \times 10^{-6} \]
\[ f_{\text{steel.t}} := \varepsilon_{_{\text{steel.t}}} E_s = 31.03 \text{ ksi} \]

Compressive strain & stress in UHPC
\[ \varepsilon_{_{\text{uhpc.c}}} := \frac{\theta \cdot c}{L_{\text{unb}}} = 1209 \times 10^{-6} \]
\[ f_{\text{uhpc.c}} := \varepsilon_{_{\text{uhpc.c}}} E_c = 9.67 \text{ ksi} \]

Analysis Results

\[
R = \begin{pmatrix}
"\text{Analysis Criteria}" & "\text{Actual}" & "\text{Allowable}" & "\text{Design Ratio}" & "\text{Pass/Fail}"
\hline
"\text{Tensile Strain in UHPC}" & 3348.52 & 3500.00 & 1.05 & "Pass"
"\text{Stress in Rebar}" & 31.03 & 60.00 & 1.93 & "Pass"
"\text{Compressive Stress in UHPC}" & 9.67 & -14.00 & "NA" & "Pass"
\end{pmatrix}
\]