Our Team

Project Manager
Chase Smethurst

Transportation Engineering
Veronica Boyce
Alexander Prunchak

Geotechnical Engineering
Josh Hammaker

Structural Engineering
Brian DeRuschi
Tom Katelhon
Jayne Marks
Trevor Ridilla
The Waterfront

The Waterfront is a former steel mill site turned popular riverside shopping destination on the Monongahela.

- Located across the three boroughs of West Homestead, Homestead, and Munhall PA
- The property runs along the Monongahela River and is approximately 256 acres
- Completed in 2002, the site generates roughly $6 million dollars per year in revenues
- Takes what was once a financially distraught area out of municipal bankruptcy
Accessibility Issues
Homestead Grays Bridge

Entering the Waterfront from the Pittsburgh Area
- The main access point from Pitt
- No left turns!
- No truck access on the ramps
Accessibility Issues
Homestead Grays Bridge

Entering the Waterfront from the Homestead
- Cross over two train tracks where 120 trains pass daily
- Back ups occur frequently
- Regularly causing gridlock
Accessibility Issues
E Waterfront Drive Bridge

Entering the Waterfront from the East
- Light is not optimally timed
- Regular back-ups occur
- Trucks are not able to make the sharp bend you see below
Safety Concerns

- Excessive traffic crossing over the two train tracks leads to a higher probability of accidents.

- Limited accessibility leads to limited exits and constricted evacuation plans.

- The Waterfront is part of 40% of Pittsburgh's residents that live in “danger” zone for crude oil train derailment.

- If train were to derail at Amity Street visitors would have only two possible exits – *Both of which trucks are not meant to access.*
Site Visit
Alternative Assessment
Improving Existing Infrastructure

- East Waterfront Drive Bridge Widening and Redesign
  - Improve turning radius
  - Widen road
  - Retime signal
Alternative Assessment
Improving Existing Infrastructure

- Homestead Grays Retrofit
  - Improve turning radius
  - Widen off ramps
  - Allow trucks to access Waterfront directly
  - Retime signal
Alternative Assessment
Homestead Connections

- William Marks Street/McClure Street Connection
  - Connects the Homestead Community directly to the Waterfront
  - Additional access point we were looking for
  - Not much room for new structures
  - Would disrupt the community with construction
  - May have to displace local business
West Homestead
-Riverton to Sandcastle Connection
West Homestead Location

- Had not originally considered this area
- Meetings with the Management of the Waterfront would directly lead us to this location
- This location would be the optimum site for our new alternative
  - Natural topography helps clear the railroads with a flyover structure
  - Allows another access point to be constructed away from the congestion point
  - Enough open space and area for future equipment and material laydown
  - Combination of added access point and bypass of railroads made it the best site alternative
Preliminary Designs

**Straight Bridge Design**
- Straight bridge section connecting Riverton street and Sandcastle Drive
- Uniform lane width of 36’
- Build up of roadway on Sandcastle drive
- Least possible amount of bridge material
- Sloped height down to Sandcastle

**Initial Curved Design**
- Radius of 375’
- Uniform lane width of 36’
- New access route to reroute traffic to Sandcastle Waterpark
- Uniform Height across both railroads
Final Design and Site Layout
Final Design

- Radius of Bridge now increased to 500’
  - Increased sight distance
  - Wider turn radius for trucks

- Bridge approach widened to 42’ until first pier
  - Structure then reduces down to uniform 36’ for the rest of the bridge

- Bridge slopes more uniform with the landscape
  - More cost effective
3D Model
3D Model
Transportation – Data

- 1998 Traffic Impact Study
  - Trans Associates, Inc.
    - Included West Flyover (never built)
    - Preliminary data

- 2015 Traffic Study
  - MS Consultants, Inc.
    - West Flyover & lane reassignments
    - Saturday & PM peak hour volumes
    - Waterfront traffic distributions

- 2015 Waterfront Market Study
  - Waterfront Management
    - Zip-code-of-origin survey
    - Mode Choice

- Supplemental
  - PennDOT iTMS
  - Manual traffic counts
Transportation – Planning

- 2015 Waterfront Market Study
  - Origin/Destination information
  - 193 respondents
  - Allegheny County road map overlay

- Traffic assignment with Google Maps
  - Path-of-least-resistance model
    - Green: High-Level Bridge
    - Red: PA 837 W to Amity Street
    - Blue: East Waterfront Dr. Flyover
  - Redistribute traffic from Amity Street
Transportation – Intersection Location

- PA 837 & Sandcastle Drive West
  - Three-way intersection
    - West 8th Ave. intersection stop-controlled
    - Unsafe 10° angle (Sight distance issues)
  - Four-way intersection
    - Align with West 8th Ave.
    - Increase safety
    - Prohibit sharp turns
      - Discourage high speed exits

- Sandcastle Drive & Extension
  - Minimize impact to parking
  - Maximize sight distance to intersection
Transportation – Intersection Design

- Sandcastle Water Park traffic
  - Trip Generation Manual
  - Correlate visitors with parking spaces

- Distribution Assumptions
  - Sandcastle & Waterfront traffic

- MUTCD Signal Warrants
  - PennDOT Warrant Analysis Spreadsheet
  - PA 837 & Bridge
    - Warrant 3 – Peak Hour
    - PA-1 – ADT Volume
  - Sandcastle Dr. & Ext.
    - Warrant 3 – Peak Hour

<table>
<thead>
<tr>
<th>W PA 837 &amp; Sandcastle Bridge - Saturday Peak</th>
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</thead>
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| \begin{tabular}{ccc}
<table>
<thead>
<tr>
<th>W Sandcastle Drive</th>
<th>50% SWP / 97% WF</th>
<th>1% WF</th>
<th>50% SWP / 2% WF</th>
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<td></td>
<td>469</td>
<td>4</td>
<td>76</td>
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<td></td>
<td>(&lt;)</td>
<td>(&gt;)</td>
<td></td>
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<tr>
<td>50% SWP / 97% WF</td>
<td>562</td>
<td>750</td>
<td>158</td>
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<tr>
<td></td>
<td>(&gt;)</td>
<td>(&lt;)</td>
<td>654</td>
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<tr>
<td>50% SWP / 2% WF</td>
<td>186</td>
<td>X</td>
<td>0</td>
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<tr>
<td></td>
<td>(&lt;)</td>
<td>(X)</td>
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<tr>
<td>1½ WF</td>
<td>56</td>
<td>4</td>
<td>0</td>
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<tr>
<td>8th Ave.</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>1% WF</td>
<td></td>
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</table>
Transportation – PA 837 & Bridge

- Saturday Peak LOS: “D”
- Saturday Intersection Delay: 38.9 seconds
- PM Peak LOS: “C”
- PM Intersection Delay: 30.9 seconds
Transportation – Sandcastle Dr. & Ext.

- Saturday Peak LOS: “B”
- Saturday Intersection Delay: 11.6 seconds
- PM Peak LOS: “A”
- PM Intersection Delay: 5.5 seconds
Transportation – Horizontal Geometry

- **Design Assumptions**
  - **Design Vehicle:** WB-50
    - Minimum Radius = 45'
  - **Design Speed:** 30 mph
  - **Lane Width:** 12'

- **Curve Design**
  - **Superelevation**
    - Max. = 4%
    - Design = 3%
  - **Side Friction Factor**
    - Max. = 0.16
    - Design = 0.09
  - **Radius** = 500 feet

Exhibit 3-9. Geometry for Ball-Bank Indicator

Transportation – Horizontal Geometry

- **Superelevation Transition**
  - Length of Superelevation Runoff = 55 feet
  - Length of Tangent Runout = 36 feet
  - Overall Transition Length = 91 feet

- **Sight Distance**
  - Stopping Sight Distance = 79 feet
  - Horizontal Sight Offset = 2 feet
    - Limit = 6 feet due to shoulder width
Transportation – Vertical Geometry

- Embankment Start
  - Superelevation Requirement = 91 feet
  - Can put 1/3 in curve
  - Start ramp 75’ after end of curve

- Ramp Characteristics
  - Embankment Grade = 6%
  - Ramp Length = 700 feet
Transportation – Flexible Pavement Design

- **Geotechnical Analysis**
  - Effective Resilient Modulus = 12,571 psi

- **Serviceability**
  - \( \Delta PSI = 2.2 \)

- **Reliability**
  - Reliability = 80%
  - Standard Deviation = 0.45

- **Traffic Analysis**
  - Predicted ADT = 10,132
  - Predicted ADTT = 1,520
  - Design ESALs = 6.21 million ESALs

- **Drainage Analysis**
  - Time to Drain
    - 50% Drained = 0.68 hours
    - 85% Saturated = 0.08 hours
  - Pipe Characteristics
    - 6 inch corrugated pipe
    - Capacity = 37,131 cf/day
  - Trench
    - ASTM Crushed Stone #3
    - Width = 8 inches
Transportation – Flexible Pavement Design

- Layered Analysis Method of Design

<table>
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<tr>
<th>Layer</th>
<th>Thickness</th>
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<tbody>
<tr>
<td>19 mm HMA</td>
<td>2 in</td>
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<tr>
<td>25 mm HMA</td>
<td>3 in</td>
</tr>
<tr>
<td>37.5 mm HMA</td>
<td>4.5 in</td>
</tr>
<tr>
<td>ATPBC</td>
<td>4 in</td>
</tr>
<tr>
<td>CABC</td>
<td>5 in</td>
</tr>
<tr>
<td>2A</td>
<td>4 in</td>
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</table>
Structures – Design Parameters

- Specifications
  - 2014 AASHTO LRFD Bridge Design Specifications, Customary U.S. Units, Seventh Edition
  - PennDOT Design Manual 4

- Structural Steel
  - AASHTO M270, Grade 50 (ASTM A709, Grade 50)

- AREMA Standards
  - 23 ft vertical clearance
  - 9 ft horizontal clearance from center of track
<table>
<thead>
<tr>
<th>Girder</th>
<th>Span 1</th>
<th>Span 2</th>
<th>Span 3</th>
<th>Span 4</th>
<th>Span 5</th>
<th>Span 6</th>
<th>Span 7</th>
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<tbody>
<tr>
<td>1</td>
<td>63 ft</td>
<td>139 ft</td>
<td>140 ft</td>
<td>141 ft</td>
<td>171 ft</td>
<td>162 ft</td>
<td>149 ft</td>
</tr>
<tr>
<td>2</td>
<td>63 ft</td>
<td>136 ft</td>
<td>138 ft</td>
<td>140 ft</td>
<td>167 ft</td>
<td>159 ft</td>
<td>149 ft</td>
</tr>
<tr>
<td>3</td>
<td>63 ft</td>
<td>134 ft</td>
<td>135 ft</td>
<td>137 ft</td>
<td>163 ft</td>
<td>156 ft</td>
<td>148 ft</td>
</tr>
<tr>
<td>4</td>
<td>63 ft</td>
<td>131 ft</td>
<td>133 ft</td>
<td>136 ft</td>
<td>160 ft</td>
<td>153 ft</td>
<td>148 ft</td>
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<tr>
<td>5</td>
<td>63 ft</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>6</td>
<td>63 ft</td>
<td>-</td>
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<td>-</td>
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</tbody>
</table>
Structures – Girder Design

Curved Girder Bridge Section

- Steel Plate Girder
  - 4 Girders

  **Dimensions**
  - Web Thickness = 0.625 in
  - Web Depth = 72 in
  - Flange Width = 26 in
  - Flange Thickness = 1.25 in

Tangent Bridge Section

- Steel Beam
  - 6 Girders
  - \( W_{27x281} \)
Structures – Plate Girder Design

Web Proportions

\[ \frac{D}{t_w} \leq 150 \]

\[ D = 72 \text{ in} \]
\[ t_w = 0.625 \text{ in} \]

\[ \frac{D}{t_w} = 115.2 \quad (OK) \]

Flange Proportions

\[ \frac{b_f}{2t_f} \leq 150 \]

\[ b_f = 26 \text{ in} \]
\[ t_f = 1.25 \text{ in} \]

\[ \frac{b_f}{2t_f} = 10.4 \quad (OK) \]

\[ t_f \geq 1.1t_w \]

\[ 1.25 \text{ in} \geq 0.6875 \text{ in} \quad (OK) \]

Flange Proportions

\[ b_f \geq \frac{D}{6} \]

\[ b_f = 26 \text{ in} \]

\[ b_f \geq \frac{D}{6} = 12 \quad (OK) \]

\[ 0.1 \leq \frac{l_{yc}}{l_{yt}} \geq 10 \]

\[ l_{yc} = 1831 \text{ in}^4 \]
\[ l_{yt} = 1831 \text{ in}^4 \]

\[ 0.1 \leq 1 \leq 10 \quad (OK) \]
## Structures – Loading

### Dead Load
- Non-composite
- Deck Placement Sequence
- Superimposed
- Future Wearing Surface

### Live Load
- Vehicular Live Load (HL-93 and Tandem)
- Fatigue
- Impact
- Centrifugal Force
- Braking

<table>
<thead>
<tr>
<th>Load Combination Limit State</th>
<th>DC</th>
<th>DD</th>
<th>BR</th>
<th>FL</th>
<th>TS</th>
<th>CR</th>
<th>SH</th>
<th>TG</th>
<th>SE</th>
<th>EQ</th>
<th>IC</th>
<th>CT</th>
<th>CV</th>
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<tbody>
<tr>
<td>Strength I (unless noted)</td>
<td>γ_P</td>
<td>1.75</td>
<td>1.00</td>
<td>—</td>
<td>—</td>
<td>1.00</td>
<td>0.50/1.20</td>
<td>γ_Tq</td>
<td>γ_SE</td>
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<td>—</td>
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<td>—</td>
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<td>Strength II</td>
<td>γ_P</td>
<td>1.35</td>
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<td>—</td>
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<td>1.00</td>
<td>0.50/1.20</td>
<td>γ_Tq</td>
<td>γ_SE</td>
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<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Strength III</td>
<td>γ_P</td>
<td>—</td>
<td>1.00</td>
<td>1.40</td>
<td>—</td>
<td>1.00</td>
<td>0.50/1.20</td>
<td>γ_Tq</td>
<td>γ_SE</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Strength IV</td>
<td>γ_P</td>
<td>—</td>
<td>1.00</td>
<td>—</td>
<td>—</td>
<td>1.00</td>
<td>0.50/1.20</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Strength V (HL-93 and Tandem)</td>
<td>γ_P</td>
<td>1.35</td>
<td>1.00</td>
<td>0.40</td>
<td>1.0</td>
<td>1.00</td>
<td>0.50/1.20</td>
<td>γ_Tq</td>
<td>γ_SE</td>
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<td>Extreme Event I</td>
<td>γ_P</td>
<td>γ_EQ</td>
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<td>—</td>
<td>1.00</td>
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<td>1.00</td>
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<tr>
<td>Extreme Event II</td>
<td>γ_P</td>
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<td>1.00</td>
<td>—</td>
<td>—</td>
<td>1.00</td>
<td>—</td>
<td>—</td>
<td>1.00</td>
<td>1.00</td>
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<td>1.00/1.20</td>
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<td>Fatigue—LL, LM &amp; CE Only</td>
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### Structures – Loading

#### Moment (kip-ft)

<table>
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<tr>
<th>Location</th>
<th>DC1_{Steel}</th>
<th>DC2_{CONC}</th>
<th>DC2</th>
<th>DW</th>
<th>LL+ I + CF (Positive)</th>
<th>LL+ I + CF (Negative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girder 1 Mid Span 5</td>
<td>653.53</td>
<td>1627.92</td>
<td>370.45</td>
<td>84.74</td>
<td>3736.63</td>
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<tr>
<td>Pier 4</td>
<td>-900.8</td>
<td>-2436.7</td>
<td>-74.96</td>
<td>125.16</td>
<td>997.45</td>
<td>-3289.95</td>
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</table>

#### Shear (kip)

<table>
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<th>Location</th>
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<th>DC2_{CONC}</th>
<th>DC2</th>
<th>DW</th>
<th>LL+ I + CF (Positive)</th>
<th>LL+ I + CF (Negative)</th>
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</thead>
<tbody>
<tr>
<td>Girder 1 Mid Span 5</td>
<td>-2.71</td>
<td>-7.32</td>
<td>-1.95</td>
<td>-1.0</td>
<td>54.05</td>
<td>-69.63</td>
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<tr>
<td>Pier 4</td>
<td>33.02</td>
<td>89.31</td>
<td>19.42</td>
<td>4.44</td>
<td>144.44</td>
<td>-142.66</td>
</tr>
</tbody>
</table>
Structures – Construction

- **Top Flange (Compression)**
  - \( f_l = -7.32 \text{ ksi} \)
  - \( f_{bu} = -27.53 \text{ ksi} \)

*Local Buckling Resistance*
- \( F_{nc} = 47.32 \text{ ksi} \)

*Lateral Torsional Buckling Resistance*
- \( F_{nc} = 47.42 \text{ ksi} \)

*Web Bend Buckling Resistance*
- \( F_{crw} = 50 \text{ ksi} \)

\[
f_{bu} + f_{\ell} \leq \phi f R_h F_{yc} \quad \text{Eq. (6.10.3.2.1-1)}
\]

\[
f_{bu} + \frac{1}{3} f_{\ell} \leq \phi f F_{nc} \quad \text{Eq. (6.10.3.2.1-2)}
\]

\[
f_{bu} \leq \phi f F_{crw} \quad \text{Eq. (6.10.3.2.1-3)}
\]

- **Bottom Flange (Tension)**
  - \( f_l = 7.28 \text{ ksi} \)
  - \( f_{bu} = 40.1 \text{ ksi} \)

\[
f_{bu} + f_{\ell} \leq \phi f R_h F_{yt}
\]
Structures – Strength I Limit State

- **Top Flange (Compression)**
  - \( f_{bu} = -21.52 \text{ ksi} \)
  - \( F_{nc} = 50 \text{ ksi} \)

- **Bottom Flange (Tension)**
  - \( f_{bu} = 38.837 \text{ ksi} \)
  - \( f_{\ell} = 9.88 \text{ ksi} \)
  - \( F_{nt} = 50 \text{ ksi} \)

- **Web Shear Resistance**
  - \( V_u = 100.87 \text{ kips} \)
  - \( V_n = V_c = 444.1 \text{ kips} \)

\[
\begin{align*}
\text{Top Flange (Compression)} & : f_{bu} \leq \phi_f F_{nc} \\
\text{Bottom Flange (Tension)} & : f_{bu} + \frac{1}{3} f_{\ell} \leq \phi_f F_{nt} \\
\text{Web Shear Resistance} & : V_u \leq \phi_v V_n
\end{align*}
\]

\( f_{\ell} \leq 0.6 F_{yf} \)
Structures – Service II & Fatigue II Limit State

■ Bottom Flange Fatigue
  - \((\Delta F)_{n} = 12.0\) ksi
  - \(f_{\text{range, vert}} = 2.54\) ksi
  - \(f_{\text{lateral}} = 0.663\) ksi

■ Web Fatigue
  - \(V_{cr} = 680\) kips
  - \(V_{p} = 1305\) kip
  - \(C = 0.521\)
  - \(V_{u} = 36.5\) kips

■ Permanent Deformations
  - Top Flange
    \[ f_{t} = -16.88\] ksi
  - Bottom Flange
    \[ f_{t} = 29.8\] ksi
    \[ f_{l} = 7.54\] ksi
Structures – Shear Connectors

From span beginning to maximum moment location

- \( d = \frac{7}{8} \text{ in} \)
- \( h = 5 \text{ in} \)
- 3 Studs per Row
- \( P = \text{Total Nominal Shear Force} \)
  \[ P = 3535 \text{ kips} \]
- \( Q_r = \text{Factored Shear Resistance of a single connector} \)
  \[ Q_r = 30.69 \text{ kips} \]
- Number of Studs = 115
- Pitch = 26 in

From maximum moment location to end of span

- \( d = \frac{7}{8} \text{ in} \)
- \( h = 5 \text{ in} \)
- 3 Studs per Row
- \( P = \text{Total Nominal Shear Force} \)
  \[ P = 5408 \text{ kips} \]
- \( Q_r = \text{Factored Shear Resistance of a single connector} \)
  \[ Q_r = 30.69 \text{ kips} \]
- Number of Studs = 177
- Pitch = 18 in
Structures – Shear Connectors

**Fatigue at Maximum Positive Moment**

Factored Shear Range = 68.2 kips

- $d = \frac{7}{8}$ in
- $h = 5$ in
- 3 Studs per Row
- $Z_r = 4.21$ kips
- $V_{sr} = 0.591$ kips/in
- Pitch = 21.4 in/row

**Fatigue at Interior Support**

Factored Shear Range = 98.3 kips

- $d = \frac{7}{8}$ in
- $h = 5$ in
- 3 Studs per Row
- $Z_r = 4.21$ kips
- $V_{sr} = 0.828$ kips/in
- Pitch = 15.3 in/row
Structures – Transverse Stiffeners

- Width = 5.25 in
- Thickness = 0.50 in
- Height = 69.5 in
- Spacing = 100 in (Max)
- Weld Size = 3/16 in
- Place on one side of girder

- Maximum Shear
  - $V_u = 481$ kips

- Plastic Shear Force
  - $V_p = 1305$ kips

- Ratio of Shear Buckling Resistance
  - $C = 0.504$

- Nominal Shear Resistance
  - $V_n = 658.16$ kips

\[
V_p = 0.58 \cdot F_{yw} \cdot D \cdot t_w
\]

\[
C = \frac{1.52}{D^2} \left( \frac{E \cdot k}{F_{yw}} \right)
\]

\[
V_n = \max \left[ R \cdot V_p \left[ C + \frac{0.87 \cdot (1 - C)}{\sqrt{1 + \left( \frac{d_p}{D} \right)^2}} \right], C \cdot V_p \right]
\]
Structures – Bearing Stiffeners

- Width = 8 in
- Thickness = 0.75 in
- Height = 72 in
- Stiffener Clip = 1 in
- Weld Size = ¼ in
- Place on both sides of girder

- Nominal Bearing Resistance
  \((R_{sb})_n = 735 \text{ kips}\)

- Factored Bearing Resistance
  \((R_{sb})_f = 714 \text{ kips}\)

- Elastic Critical Buckling Resistance
  \(P_e = \frac{\pi^2 E}{K} \frac{A_s}{b_t}
  \begin{array}{c}
  P_e = 735 \text{ kips}
  
  \end{array}\)

- Nominal Axial Compression Resistance
  \(P_n = 951 \text{ kips}\)

- Factored Bearing Resistance
  \(P_r = 891 \text{ kips}\)

\[
(R_{sb})_f = \phi_c (R_{sb})_n
\]
Structures – Cross Bracing

- Ensures stability through steel bridge girders
- Plays important role for horizontally curved girder bridges
- Critical to both design and constructability of bridge life.
Structures – Cross Frame Design

- Oriented in radial manner throughout span
- Detailed to between girders at no-load stage only
- “X-Frame” design generally most economical
Structures – Cross Frame Design

- L8”x8”x3/4” Angle Members
- 6”x1”x72” exterior Stiffeners
- 5”x5”x72” Transverse Stiffeners
- Factored Axial Resistance
  - $P_r = 204.1426$ kips
Structures – Field Splices

- Used for girders unable to be fabricated, handled, or shipped in one entire piece
- Designed to be capable of transmitting shear and moment in girder at point of splice
- Generally bolted – welding brings economic and field issues
Structures – Splice Design

- Located at points of contraflexure along span of bridge
  - Allows minimal shear and moment transfer along the splices
- Adequate sweep for approved shipment
- Designed under splice location at largest live load bending case
- Max. bending case = -19 ksi
Structures – Splice Design

- Web Plate
  - 3/8”x14 ¼”x66”=

- Bolts
  - Type A325
  - 7/8” Diameter

- Slip Resistance
  - 39 kips/bolt

- Shear Resistance

- Constructability – PASS

- Service Limit State – PASS

- Strength Limit State – PASS
Structures – Splice Design

- Flange Plates Plates
  - ½”x26”x28”
- Bolts
  - Type A325
  - 7/8” Diameter
- Slip Resistance
  - 39 kips/bolt
- Shear Resistance
- Constructability – PASS
- Service Limit State – PASS
- Strength Limit State – PASS
Structures – Deck Design

Deck Design

- 9" cast-in-place concrete deck
- 0.5" wearing surface
- Simple span 1, continuous along the curve from spans 2 through 7
- Transversely and longitudinally reinforced using No. 4, No. 5, and No. 6 rebar
- Used PennDOT BD601M to determine many of the rebar configurations, sizes, and spacings.

Deck Analysis

- Equivalent Strip Method
- Stresses and moments found using LEAP Bridge Steel program
- Separate reinforcement requirements for positive and negative moment regions
Structures – Deck Cross Section

STEEL BEAMS
PROVIDE WHEN HAUNCH THICKNESS IS 3" OR GREATER ANYWHERE ACROSS WIDTH OF HAUNCH
Structures – Positive Moment Regions

- 4 #6s
- 6 #5s
- #4 @ 12
- #4 @ 12
- #5 @ 5.5
- Lap: 2' 7"
- #5 @ 9
- #5 @ 6
- 2 #4s
- #3 @ 12
Structures – Negative Moment Regions

#4 @ 12
6 #5s

#5 @ 5.5
Lap: 2'-7"

#5 @ 6
2 #4s

#3 @ 12
Structures – Movement

Causes of Structure Movement:
- Thermal
- Creek
- Shrinkage
- Loads
- Curvature
- Installation, Settlement, Tolerances, etc.

Thermal Expansion

\[ \Delta_T = \alpha \ L \ (T_{\text{MaxDesign}} - T_{\text{MinDesign}}) \]

where:

\( L = \text{expansion length (in.)} \)
\( \alpha = \text{coefficient of thermal expansion (in./in.}^\circ\text{F}) \)

\( \alpha = 6.5 \times 10^{-6} \)
\( T_{\text{Max}} = 120^\circ\text{F} \)
\( T_{\text{Min}} = -30^\circ\text{F} \)

\( L = \text{the distance from the expansion joint to the point of assumed zero movement (fixed bearings)} \)
Structures – Movement

**Slab 1**
Expansion Length $L = 63$ ft

$$\Delta_{T,1} = 1''$$

**Slab 2**
Expansion Length $L = 904$ ft

$$\Delta_{T,2} = 11''$$

**Thermal Expansion**

$$\Delta_T = \alpha \cdot L \cdot (T_{MaxDesign} - T_{MinDesign})$$  \hspace{1cm} (3.12.2.3-1)

where:

- $L = \text{expansion length (in.)}$
- $\alpha = \text{coefficient of thermal expansion (in./in.}^\circ\text{F})$

- $\alpha = 6.5 \times 10^{-6}$
- $T_{Max} = 120^\circ\text{F}$
- $T_{Min} = -30^\circ\text{F}$

$L = \text{the distance from the expansion joint to the point of assumed zero movement (fixed bearings)}$
Structures – Joints for Slab 1

- Small amount of thermal expansion
- Must also include a contingency for rotation due to girder loads (0.5”) and a contingency for joints at abutments (0.5”)

\[ \delta = \frac{4AD}{L} \]  
(14.5.3.2-3P)

where:

- \( \Delta \) = L/800 or L/1000 (ft.)
- \( L \) = length of end span (ft.)
- \( D \) = superstructure depth from bearing to top of deck (in.)
- \( \delta \) = change in joint opening (in.)

- Joints located above abutment 1 and pier 1
  - Connects the two slabs
  - Connects bridge deck to road surface

- PennDOT DM4 Article 14.5.3.2 “Minimum movement classification shall be 3 in., even if less movement is anticipated...”
Structures – Joints for Slab 1

- Use Neoprene Strip Seal
- PennDOT BC767M
Structures – Joints for Slab 2

- Relatively large expansion
- Two alternatives considered to accommodate the deck movement
  - Open Finger Steel Joints
  - Modular Expansion Joint System (MEJS)

- Joints located above pier 1 and above abutment 2
  - Connects large, continuous, curved bridge deck to ramp surface
Structures – Bearings

- Resting surface between bridge piers and the bridge deck
- Allows controlled movements of the deck in order to reduce stress
- Must work together to facilitate the expansion and contraction of the bridge in addition to joints
Structures - Bearings

1. Define Design Requirements
   *Loads, Translations, and Rotations*

2. Evaluate Bearing Types

3. Select Most Efficient Bearing Type and Arrangement

4. Bearing Design
## Structures – Bearing Loads

- **LEAP Bridge Steel**

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<tr>
<th>Combination Name</th>
<th>Combination Type</th>
<th>Factor</th>
<th>Mx (kip-ft)</th>
<th>My (kip-ft)</th>
<th>Mz (kip-ft)</th>
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<th>Fy (kip)</th>
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* Fatigue forces and moments are not factored.
There are three basic alignments that may be considered:

1. Provide guidance such that the deck expands radially in plan from one fixed point
2. Provide guidance such that there is radial expansion and rigid body rotation in plan
3. Provide guidance such that the deck moves in plan tangentially to the curve of the structure at each bearing
Structures – Bearing Orientation

- Pot Bearing - Multidirectional
- Pot Bearing - Unidirectional
Structures – Bearing Orientation

- Pot Bearing - Multidirectional
- Pot Bearing - Unidirectional
Structures – Pier Design

- **Preliminary Pier Dimensions**
  - Cap Length: 42' for Pier 1, 36' for Rest
  - Cap Width: 5'
  - Cap Depth: 7'
  - Minimum Cap Depth: 4'
  - Overhang: 1/3 of Cap Width
  - Column Length: 1/3 of Cap Width
  - Column Height: Varies with Elevations of Pier and Height
  - Column Width: 5'

- **Concrete** – $f_{c'} = 3.5$ ksi
- **Rebar** – $f_y = 60$ ksi
Structures – Pier Cap Design

- Strut-and-Tie Model
  - Followed AASHTO LRFD Specs.

- Ties Zones are analyzed to find tension and compression members

- Struts carry Load into the Column
Structures – Pier Cap Design

- Clear cover of 2.5”
- Top tension designed
- Plus 6 rows of crack control
- Stirrup spacing designed with max tension found in the tie zones
- Spacing may change depending on Pier
- Bars from column extend into pier cap

Diagram:
- 2 Layers 10 - #9
- 6 - #6 @ 12”
- #6 Stirrup @ 14”
- 5 Eq. Sp. #6
- R2
- R3
- R4
- 5'-6.0”
- 2 rows of 10 #9 Bars
- #6 Stirrups
- #6 @12”
- #11 Bars extended from Col.
Structures – Pier Column Design

- Clear Cover 2.5”
- 44 #11 Bars Eq. Spaced around Perimeter
- # 6 stirrups at 10”
  - Each Tie Consists of three hoops
Structures – Pier Design

- 36''
- R4
- R3
- R2
- R1
- 5'6.0''
- #6 Stirrups
- 10'' Sp.
- Varies
- 5''
- 7''
- 4''
- 3''
- 1''
- 11''
Geotechnical

- Multiple different boring logs
  - Notable sections

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<th>ELEV.</th>
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S-4, contains loose metal fragments.
homogeneous, low plastic fines, dark gray, alluvium.

Class on S-12 to S-16 (16.5-24.0) N.M.C. = 26.8%.

S-16, more clay.

S-19, coarser sand.

SAND and GRAVEL, little Silt, loose to dense, wet, heterogeneous, well graded, rounded, brown to gray, glacial outwash.
Pier Foundations

- Considered Shallow Foundation and Pile Supported
- We will be using pile supported foundations for all 6 piers
  - Due to weaker soil below the surface
- Piles will be driven to bedrock ≈ 70 ft below surface
Pile and Cap Design

HP 12x74 Pile

Column Perimeter
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<th>Pier 3</th>
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<td>-160</td>
<td>-163</td>
<td>-176</td>
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</tbody>
</table>
Pile Cap Reinforcement

#6 bars at 12"

HP piles
Pile Cap Reinforcement

#6 x bars at 12"

#8 bars at 12"

2'-8.0"

1'

11'

4'
Driving Piles

- GRLWEAP
  - Used for hammer selection for pile driving
  - Database of more than 1500 hammers
  - Selection Criteria
- Ape D12-42
### GRLWEAP Output

**University of Pittsburgh-C.E. Bridge**

**GRLWEAP Version 2010**

**Gain/Loss 1 at Shaft and Toe 1.000 / 1.000**

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Ultimate Capacity (kips)</th>
<th>Friction (kips)</th>
<th>End Bearing (kips)</th>
<th>Blow Count (blows/ft)</th>
<th>Comp. Stress (ksi)</th>
<th>Tension Stress (ksi)</th>
<th>Stroke (ft)</th>
<th>ENTHRU (kips-ft)</th>
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</tbody>
</table>

Total Continuous Driving Time: 61.00 minutes; Total Number of Blows: 2492
Abutment Design
Abutment Design

- Very large soil bearing capacities (60,000+ lbs/SF)
  - Meyerhof method

- Abutment with spread footing proved sufficient
Girder Stability and Erection

- Stability of curved girders during the bridge erection process were a key issue facing our project.
- The curved effect of the girder is highly contusive to lateral torsion, making the girder want to rotate out of plane when set.
- To best combat this effect, we believed that constructing the girders in tandem was the most stable option.

Figure 2.9.18 Curved Beam Action
Typical Erection Sequence of a Span
Typical Erection Sequence of a Span
Typical Erection Sequence of a Span
Preliminary Estimate and Schedule

■ Project Estimate
  - $10,000,000

■ Project Length
  - Total Days: 443 (21 months)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost</th>
<th>Cost/SF of Bridge</th>
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</thead>
<tbody>
<tr>
<td>Piling</td>
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<td>Piers</td>
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<td>Abutments</td>
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<td>Bearings</td>
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<td>Deck</td>
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<td>Traffic Signals</td>
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<td>Other Misc Costs (overhead)</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$9,435,735.10</strong></td>
<td><strong>$260.28</strong></td>
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Preliminary Estimate and Schedule
THANK YOU

Questions?