Reasoning / funding:

- This bridge was noted to have worsening deck conditions forcing it from a GA of 6A to 5A most recently.
- Increasing ADTT demands in the eastern portion of District 5, this was just reasoning to investigate HL-93 load capacity vs HS-20. Therefore; increased funding was allocated to this site in accordance with the associated need.
- Being a structure within a 4° 45’ curve, a grid analysis would be required as part of the project as per AASHTO Section 4.6.1.2.4b. To avoid must meet:
  - Girder lines concentric
  - Bearing lines not skewed more than 10 degrees  
    - X (19° 32’ 07”)
  - Stiffness of girders is similar
  - Arc span / radius < 0.06 radians  
    - ✓ (0.059 rad. actual)

District 5 standards / challenges:

1. With the superstructure being replaced, the new beam depths were to be compared to those necessary to obtain a minimum 16’-6” vertical clearance. Up from 16’-1” existing.
2. The piers columns being in good general condition, investigate the use of portions of existing substructures combined with abutment widening.
3. M.O.T. for this project was requested to be signalized closing 1-lane of a 2-lane highway.
4. Semi-integral abutment details and scupper details.
Semi-integral bridges are preferred per ODOT BDM section 205.9, but should not be used in combination with a curved structure without special considerations. Design and draft provisions to account for necessary details when using this style of abutment with a curved bridge. A geowall was utilized to provide the necessary clearance behind the diaphragm and give freedom of movement. Also, District preferred, sleeper slabs with armorless free expansion joints were utilized at the ends of approach slabs.
High importance was placed on bridge deck drainage versus minimizing the use of scuppers per BDM section 209.3. Therefore project customized scuppers were detailed to fit this proposed framing plan and used throughout the bridge.
GUE-513-08.65 Design - Overview

Complicating Factors:
- Survey Multiple Data Sets
- Geometrics & MOT
  - Vertical Sag Curve
  - Horizontal Curve
  - Intersections
- Traffic Design
  - Amish Buggies
  - Trucks and Oil & Gas Traffic
  - Ramps & Intersections
  - Vertical Curves
  - Sight Distance
- Structural Design
  - Horizontally Curved Girders
  - Part-Width Construction
  - Temporary Supports
  - Deck Pour Sequencing
GUE-513-08.65 Design - Survey

Survey

- ODOT Provided Aerial Lidar
- Woolpert Ground Lidar & Trad.
- Meshed Both together with control
- Full 3D Bridge Extraction
- Top deck surface to bottom deck surface allowed us to verify existing overlay thicknesses
- Detailed Lidar used to pinpoint vertical clearance – found to be better than listed which reduced the need for profile raising
SR-513 Roadway Criteria

- Design exceptions
  - K value (79 vs. 115)
  - Superelevation rate (6% vs. 7.7%)
  - 2,670 Design ADT, 13% Trucks
  - Rural Major Collector
  - Design/Legal Speed 55 mph

- Maintaining Horizontal/Vertical Geometry
  - Minimizing superstructure depth prevented need for profile raising
  - Increasing superelevation would require additional raising
  - Hills on either side of the interchange along SR-513, concerns with truck stopping, sight distance and advanced warning
  - Practical Design – reaching normal design K and super would increase project size and cost without significantly improving functional conditions
GUE-513-08.65 Design - Intersections

Northern Intersection
- 6-Legs
- Access to Gas Station
- County Highway Dept. on Bridgewater

Southern Ramp Intersection
- Truck Turning Movements
- Sight Distance
Phase 1
Phase 2
Phase 1
Phase 2

![Diagram of an intersection with annotations and estimated quantities table]

### Estimated Quantities

<table>
<thead>
<tr>
<th>REF. NO.</th>
<th>STATION TO STATION</th>
<th>BARRIERS REFLECTOR, TYPE 1 60-DEGREE DIRECTIONAL</th>
<th>OBJECT MARKER, TWO-WAY 60-DEGREE DIRECTIONAL</th>
<th>WORK ZONE EDGE LINE, CLASS 1, 76&quot;-OFL, TYPE 1</th>
<th>WORK ZONE STOP LINE, CLASS 1, 76&quot;-OFL, TYPE 1</th>
<th>PORTABLE BARRIERS, 36&quot;</th>
<th>PORTABLE BARRIER, 3&quot;</th>
<th>TOTALS CHANGED TO GENERAL SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM</td>
<td>202+00</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>0.30</td>
<td>20</td>
<td>360</td>
<td>500</td>
</tr>
<tr>
<td>AM-1</td>
<td>202.30</td>
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<td>2</td>
<td>6</td>
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<td>360</td>
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<td>8</td>
<td>2</td>
<td>6</td>
<td>0.30</td>
<td>20</td>
<td>360</td>
<td>500</td>
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<td>AM-3</td>
<td>203.10</td>
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<td>2</td>
<td>6</td>
<td>0.30</td>
<td>20</td>
<td>360</td>
<td>500</td>
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<tr>
<td>TE-1</td>
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<td>500</td>
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<tr>
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<td>2</td>
<td>6</td>
<td>0.30</td>
<td>20</td>
<td>360</td>
<td>500</td>
</tr>
</tbody>
</table>

### Notes
- *Signs placed in Phase 1*
- *Remove conflicting temporary pavement markings from Phase 1*
- *Temporary not signing to remain the same as Phase 1 unless otherwise shown.*

**Legend**
- **WORK AREA**
- **ITEM 46 – PAVEMENT FOR MAINTENANCE STATION, CLASS A**
- **DRUMS/CONES**
- **PORTABLE BARRIERS, 36”**
- **PORTABLE BARRIER, 3”**
- **REMOVING EXISTING**
- **ATTENUATOR**
- **TARPED END TREATMENT**
- **PAVE INバラーギー**
- **DIRECTION OF TRAVEL**
Traffic Analysis

- Need to account for both trucks at 55 mph and Amish Buggies at much slower speeds
- Synchro Model Used
- Amish Buggies modeled at 15 mph
- Resulted in longer clear times under all red conditions
Northern Intersection Temporary Signals
GUE-513-08.65 Design – Structural Design

- SR-513 over IR-70
- Curved 4-Span Bridge (60’-11.75”, 2 @ 86’-9”, 60’-10.75”)
- Skewed 19° 32’ 07” to reference chord
- Composite on curved rolled steel beams
- \( R = 1206.23 \text{ ft} \)
- Minimum Girder \( R = 1185.48 \text{ ft} \)
- \( Dc = 4^\circ 45’ 00” \)
- All crossframes and girders radial
- Vertical Sag Curve
- Part-width construction, including pier caps
Note – no fence used as it would cause sight distance issues at the ramps, waiver requested and approved through ODOT OSE
Structure Feasibility Study Performed

- Additional existing overlay and higher existing vertical clearance verified from LiDAR helped minimize profile increase.
- Existing beams = 36WF194, new are W27x307 Grade 50 beams.
- Cross slope at 6% with widened structure and larger exterior beam offset reduced vertical clearance.
- Overall providing 16’-8 ½” clearance, up from existing 16’-0 ½”.
- Total profile adjustment of 2 ½” to account for construction tolerance and future overlays above 16’-6” required. All within bridge limits.
- Other options were a W24x335 with minimal profile raise or W30x261 with 5 ½” raising, but were eliminated as less economical.
- Initial beam design by V-load and girder line analyses
- Verified by finite element analysis in final design (Grillage+), led to 10% increase for curvature effects.
- AISC and NSBA design guidelines and fabricators consulted for constructability.
GUE-513-08.65 Design – Structural Design

Girder Line Modeling with V-load

- Uses standard AASHTO LLDF
- Can be done in minimal time, not a complicated analysis
- Use results to populate a V-Load analysis spreadsheet or hand calculation, and iterate with a target utilization ratio (1.00 – anticipated V-Load increase)
- Typically produces good results for dead load approximations for noncomposite and composite bridges with radial crossframes or bracing
- Live load can be much more variable based on lateral stiffness, geometry, and resulting intermittent influence surface
- Typically a good method for preliminary engineering purposes
- Essentially, straighten girder and analyze based on true length as a straight member, then apply external forces to induce resultant internal forces corresponding to the curved structure under vertical loads
- From past projects, results have been very close to MIDAS Civil or other FEM for larger radii, say R > 1000-ft
- Per AASHTO Section C4.6.2.2.4 has a number of limitations which do not qualify for required analysis methods for curved structures and may underestimate deflections, reactions, twist
2D+ Grillage Analysis/Limited 3D Analysis

- Similar to standard grillage, but with multiple sets of nodes with rigid links (master-slave)
- Beams/girders are modeled using beam elements then rigid linked nodes modeling the deck plates and nodes for crossframe members in 3D
- Provides an accurate distribution of live loads through influence surface
- Lateral stiffness of crossframes and deck are modeled using this approach
- Internal forces are captured using this approach, appropriate for curved girder design
- Seventh degree of freedom included for warping effects
GUE-513-08.65 Design – Structural Design

- Full 3D Analysis
  - Similar to the Grillage+, but the beam is split into plate elements for each flange and web, in addition to plates for the deck
  - Provides an accurate distribution of live loads through influence surface
  - Lateral stiffness of crossframes and deck are modeled using this approach
  - Internal forces are captured using this approach, appropriate for curved girder design
  - Effects of tension-field action can be captured for shear
  - Girder/Beam rotations can be explicitly extracted – very important for construction cases in highly curved members

Figure 4: Phases in behaviour up to collapse of a typical panel in shear
Curved Beams/Girders

- Plate girders have curves cut from larger flat sheets
- Beams are always produced as straight members from mill, then curved.
- Two primary methods
  - Mechanical rolling using sets of rollers to gradually deform beams
  - Heat curving which is performed by placing the beam on its side on blocking (similar to when producing vertical camber) and applying heat to locally deform the beam.
- Mechanical methods are dependent on fabricator equipment for segment weight and length to avoid crushing rollers and supports.
- Fewer limitations on heat curving and ODOT CMS 513 requires heat curving.
- Beam availability was considered, both from number of suppliers and rolling frequency.
- Interaction between vertical and horizontal camber may need to be considered per AASHTO

<table>
<thead>
<tr>
<th>Beam Size</th>
<th>No. Producers (Domestic)</th>
<th>Nucor-Yamato Production Frequency</th>
<th>Tata Steel/ArcelorMittal Production Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>W30x261</td>
<td>1</td>
<td>4-5 weeks (USA)</td>
<td>(Tata - GB)</td>
</tr>
<tr>
<td>W27x307</td>
<td>1</td>
<td>4-5 weeks (USA)</td>
<td>(Tata - GB)</td>
</tr>
<tr>
<td>W24x335</td>
<td>1</td>
<td>4-5 weeks (USA)</td>
<td>6-8 weeks (AM - LUX)</td>
</tr>
</tbody>
</table>
Curved Beams/Girders

No-Load Fit Used

<table>
<thead>
<tr>
<th>Loading Condition Fit</th>
<th>Construction Stage Fit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-Load Fit (NLF)</td>
<td>Fully-Cambered Fit</td>
<td>The cross-frames are detailed to fit to the girders in their fabricated, plumb, fully-cambered position under zero dead load.</td>
</tr>
<tr>
<td>Steel Dead Load Fit (SDLF)</td>
<td>Erected Fit</td>
<td>The cross-frames are detailed to fit to the girders in their ideally plumb as-deflected positions under bridge steel dead load at the completion of the erection.</td>
</tr>
<tr>
<td>Total Dead Load Fit (TDLF)</td>
<td>Final Fit</td>
<td>The cross-frames are detailed to fit to the girders in their ideally plumb as-deflected positions under the bridge total dead load.</td>
</tr>
</tbody>
</table>

When determining camber, if Radii is less than 1000-ft need to account for additional camber from settling of the curved structure per AASHTO 6.7.7.3. Not required here.

\[
\Delta = \frac{\Delta_{DL}}{\Delta_M} (\Delta_M + \Delta_R) \tag{6.7.7.3-1}
\]

in which:

\[
\Delta_R = \frac{0.02I^2F_s}{EIO} \left( \frac{1,000 - R}{850} \right) \tag{6.7.7.3-2}
\]
Temporary support towers originally used one tower with compression and tension connection (bearings & tension rods).

After discussion with ODOT, added a second tower for redundancy.

Order of preference: Compression -> Tension -> Shear
Temporary Supports – As Designed

- Top: 2-0.5" H-2.5"/8 X 8"  
- Bottom: 2-0.5" H-2.5"/8 X 8"  

### NOTES:

1. Temporary supports shall be placed according to the engineering plans and approved by the engineer.  
2. The temporary supports are designed to resist the total wind loadings and live loadings and are sized to provide adequate support.  
3. The temporary supports shall be designed to resist the total wind loadings and live loadings and are sized to provide adequate support.  
4. All bolts and anchorages shall be ASTM A325 and shall be tightened with a torque wrench.  
5. Stop and check to provide full contact and support to all load areas.  
6. All temporary supports shall be temporary and shall be removed when the permanent support is installed.  
7. See sheet XX for details.  
8. See sheet YY for details.  
9. See sheet ZZ for details.
GUE-513-08.65 Design – Structural Design

- Temporary Supports – As Designed, Stage 1
Stage 2
GUE-513-08.65 Design – Structural Design

- Stage 3
Stage 4
Actual temporary shoring used similar design but some differences

- Larger sections – simplified design
- Reduced cross bracing
- Bracing used bolted moment connections with H shapes rather than angle X-brace
- Jacks at bottom of towers instead of top
GUE-513-08.65 Design – Structural Design
GUE-513-08.65 Design – Structural Design
Questions?