2017 Elite Engineers Webinar Series

Integral Abutment Bridge Design with Soil Structure Interaction

Thursday, May 11, 2017
3:00 PM – 4:00 PM EST

Speaker Engineer:
Suthichai Saelim
Project Location

WESTBOROUGH

HOPKINTON

Railroad

Flow

Hopkinton Country Club
Project Location
Existing Bridge

Existing Bridge Looking South

- Weight Limit 9 tons for H20, 16 tons for Type 3 and 26 tons for Type 3S2
- Inaccessible Sidewalk (3’-0” sidewalk)
- Substandard Guardrail – Wire Rope Guardrails
• The bridge structurally is deficient.
• The superstructure and substructure are in poor conditions and rated as 4.
**Existing Bridge**

- 4 simply supported spans with total length 184’-3”
- Deck width of 39’-0” out to out.
- Built in 1936 and reconstructed in 1976 (deck slab and deck joint repairs)
- The superstructures in spans 1, 3 and 4 from North consist of 7 concrete T-beams with a reinforced concrete deck
- In Span 2, consisting of 7 steel rolled beams 36WF #240 with a gunite covering
- The bridge has a skew angle of 10°-40’
Existing Bridge Plan and Elevation

- North Gravity Abutment Wall and Concrete Piers 1 and 2 from the North on Timber Piles
- Pier 3 and South Gravity Abutment Wall on Spread Footings
Why are Integral Abutment Bridges considered as the first choice by many DOTs?

- There are no roadway joints at abutments.
- The superstructure and substructure move together to accommodate the required translation and rotation with less induced strain, thus permitting the use of smaller and lighter abutments.
- Less expensive to construct with no footings, no bearings and few piles used (a single row of vertical piles)
- Easy to maintain
- Initial cost saving due to economy of material usage and lifecycle cost saving through reduced maintenance.
Proposed Bridge

- 3-Span continuous superstructure comprised of 7 steel rolled beams (W30x261) supported on integral abutments and piers
- Both end spans between integral abutments and piers are 48’ long each
- Center Span is 90’ long between piers
- The bridge has a curb-to-curb width of 32’, 40’-3” out to out
- The bridge is skewed at 10°-30’-00”.
• Two (2) 11 foot lanes and two (2) 5 foot shoulders and a 5’-6” wide east sidewalk.
• The concrete bridge barriers are CP-PL2 with Type II protective screens.
Bridge Plan
**ELEVATION: Span Length 48’-90’-48’**

- Vertical clearance above tracks is 20’-4”
- Approximately 9.5’ long U-integral wingwalls between integral abutments and end posts
• PTFE Sliding Bearings used at Piers
• 3.5 ft. Integral Abutments on a single of vertical HP12x84 Piles with the webs oriented on parallel to the centerline of the abutment
• Compacted gravel borrow backfill behind integral abutment
• 15’-0” Approach slab with key at each end of the integral abutment
South Bent consists of a bent cap, 3’-0” columns and 4’-0” drilled shaft with 6’-0” rock sockets.

A keeper block used to restrain superstructure lateral movement.
North Pier

- Pier cap, 3’-0” columns, 10 ft. high Crash Wall, drilled cap and 4’-0” diameter drilled shafts with permanent steel casing

- 6’-0” rock sockets into the bedrock
IAB Design and Analysis Approach

INTEGRAL ABUTMENT SECTION

SCALE: ½” = 1’-0”

NOTES:
1. Specify "Varies" or 2'-0" as per Dwg. No. 12.2.8.
2. Connection Plate and Diaphragm are not shown for clarity.
3. For additional Designer Notes see Dwg. No. 12.2.14
4. For Construction Notes and Pile Notes see Dwg. No’s. 12.2.11 and 12.2.12, respectively.
5. Special Slope Paving treatment is shown. if different treatment is required, modify as necessary.
IAB Design and Analysis (Con’t)

• Superstructure Design: The connection between the beams and the abutment shall be assumed to be simply supported for superstructure design and analysis.

• Integral Abutment: The superstructure is assumed to transfer moment, and vertical and horizontal forces due to all applicable loads.
IAB Design and Analysis (Con’t)

- The abutment is supported on a single row of vertical H-piles with the webs oriented parallel to the centerline of the abutment.
- Compact Section HP10X57 and HP12X84, Grade 50.
- Piles are considered to be fully braced against lateral torsional buckling and gross Euler buckling, except extremely soft material such as peat.
IAB Load, Load Factor & Load Combination

- **Live Load**: For Abutment and Pile, the largest number of traffic lanes shall be allowed by the total bridge width. Dynamic load allowance is used. No multiple presence factor shall be applied.

For this bridge
- **Case I**: 3 Lanes Loaded as if the sidewalk is the part of travelled way
- **Case II**: 2 lanes loaded + Pedestrian Load
- **Uniform Temperature Load Factor of 1.0** is used all the time.
IAB Load, Load Factor & Load Combination

- Modified interaction equation is used in the pile analysis (HP12X84 and HP10x57)

\[
\frac{P_u}{P_r} + \frac{8.0}{9.0} \left[ \frac{M_{uy}}{\theta_i M_{ry}} + \frac{M_{ux}}{M_{rx}} \right] \leq 1.0
\]

- Coefficient of inelastic rotation capacity factor $\theta_i = 1.75$, accounting for the compact section pile’s ability to undergo inelastic rotation (weak axis bending only) and the associated increase in pile head translation.
Integral Wingwall Design

- Extreme Event II Load Combination
  - 1.5 x Active earth pressure and
  - 1.0 x Vehicular collision (10 kips)
Start Bridge Model
Steel Composite Girder Bridge Wizard - Layout

• Help modeling the initial steel bridge
• Steel bridge wizard also is used as a template for other initial steel bridge projects.
• Layout tab provides span information, steel girder type, bridge width, modeling type and substructure support types to input
Steel Composite Girder Bridge Wizard - Section

- Deck thickness
- Number of girder and girder offsets
- Girder section assignments
- Diaphragm type (diaphragms beam / cross frame types (X and V, K frames))
- Diaphragm layout
Steel Composite Girder Bridge Wizard - Load

- Provide non-composite and composite dead loads
- Design moving load and traffic lanes
- Vehicle selection
Steel Composite Girder Bridge Wizard – Construction Stage

- Provide deck pouring sequence
- Deck reinforcements
Steel Composite Girder Bridge Wizard

- Bridge wizard provides structure groups, boundary groups and load groups
- These groups allow to quickly select and unselect various geometric portions of a structure for reviewing results in particular portions of the structure.
- Groups are also used in the construction stage analysis
**Integral Abutment Bridge and Soil Structure Interaction in Midas Civil**

- Abutment and pile springs can automatically be generated in Midas Civil
- No calculated depth of fixity from iterations between other software such as L-Pile or FB-Multi Pier
- A better approach in analyzing bridge structure with full soil structure interaction
- No hand calculations to determine live load distribution factors used to design bent cap, column and drilled shaft.
Two separate models are used to analyze and design
Model 1: for girder, piers and drilled shaft designs, pinned condition used at each abutment girder end
Model 2: for integral abutment and HP12x84 piles, fixed condition at abutment and girder connection
**Midas Civil Model and Soil Structure Interaction – Abutment Spring (compression only)**

Integral bridge boundary in Midas Civil used to generate non-linear soil springs

- Change boundary groups from Default to Substructure Support
- Select the direction in which elastic Links are to be assigned. Normal(+) or Normal (-)
- Select abutment elements. Plate elements are selected as shown above
- Define abutment geometry, soil parameters and Thermal expansion
Soil Type: Loose Crushed Stone, Alluvial and Glacial Till are input in Midas Civil as loose sand, medium dense and dense sand, respectively.
Soil type (sand, soft clay or stiff clay): Sand or See Profile on previous page
Select elements: HP12x84 and drilled shaft
Ground level: Approximately 3 ft above bottom of abutment pile and 4 ft above drilled shaft cap
Pile Diameter: for HP12x84, \( d = 12.3 \text{ in.} \) for drilled shaft \( d = 48 \text{ in.} \)
Unit Weight of Soil, Earth pressure coefficient at rest, subgrade reaction: input values as shown on previous page
Midas Civil Model Result- Deformation

- Deformation shape due to temperature rise
Midas Civil Model Result – Composite Steel I Girder Report

- Composite steel I girder design reports including strength limit stages of moment shear, service limit stages, fatigue, constructability, shear connectors and stiffeners are generated from Midas Civil Composite Design
- The detailed reports include section properties, the step-by-step computations with equation references
Midas Civil also provide steel detailed code-check reports for End and Intermediate Diaphragms MC18 x 42.7
Midas Civil Model Result – Steel H Pile

Strength I Load Combination with TU load factor of 1.0

Factored Moments at Weak Axis

\(< Mpy\)

Factored Moments at Strong Axis
Midas performed the steel H Pile design code checking and provide the list of members and property to be checked.

AASHTO LRFD moment and axial interaction equation = 0.8 < 1.0, H-Piles remain elastic.
Midas Civil also provide steel detailed code-check reports with step-by-step computations, using formulas and load combinations.
Midas Civil Model – RC Column, Cap and Drilled Shaft Code Check

CT1: Collision Load on the Crash Wall at Exterior Column

Moment Mz

Moment, My

Shear, Fy
Midas Civil Model – RC Column, Cap and Drilled Shaft Moment and Shear Diagrams

CT2: Collision Load on Crash Wall between Columns

Moment Mz

Moment, My

Shear, Fy
Midas Civil Model – RC Column, Cap and Drilled Shaft Code Check

CT3: Collision Load on Crash Wall at Center Column

Moment Mz

Moment, My

Shear, Fy

Why Moment, $M_{bot\ of\ shaft}$ ≠ $F_y \cdot H$ ≠ $F_y \cdot H \pm M_{top\ of\ shaft}$?
Midas Civil Model – RC Column, Pier Cap and Drilled Shaft Code Check

- Midas performed the reinforced concrete design code checking and provide the list of members and property to be checked
- For drilled shaft and column, Midas provides the P-M Interaction Diagram (3D View)
Midas Civil Model – RC Column, Cap and Drilled Shaft Code Check

1. Design Condition

- Design Code: AASHTO-LRFD12
- Unit System: kips, in
- Member Number: 80015
- Material Data: f_c = 4, f_y = 60, f_ya = 60 ksi
- Column Height: 96 in
- Section Property: 36" column (No. 8)
- Rebar Pattern:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Pos 1</th>
<th>Pos 2</th>
<th>Pos 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17 - 20</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Total Rebar Area, As = 13.45 in² (Rho = 0.0132)

2. Applied Loads

- Load Combination: f - AT (f) Point

Pu = 690.850 kips, Mcy = -101.24, Mcz = 101.205, Moc = 190.361 in-kips

3. Axial Forces and Moments Capacity Check

- Concentric Max. Axial Load: P = 2532.55 kips
- Axial Load Ratio: Pu/P = 690.850 / 2532.55 = 0.276 < 1.000 ... OK
- Moment Ratio: Mjy/Mj = -101.24 / 372.091 = 0.272 < 1.000 ... OK
  Mjz/Mj = 161.205 / 523.013 = 0.308 < 1.000 ... OK
  Mj/Mj = 190.361 / 700.083 = 0.272 < 1.000 ... OK

4. P-M Interaction Diagram

\[ P(kips) \]
\[ M(n-kips) \]

Theta=77.89 Deg. \\
(3163.69, 0.00) \\
(2496.14, 7754.09) \\
(2070.43, 11394.25) \\
(1704.42, 12735.73) \\
(1408.05, 13583.14) \\
(1167.42, 13980.83) \\
(1008.13, 14273.45) \\
(885.07, 14388.90) \\
(701.33, 14194.75)
Midas Civil Model – RC Column, Cap and Drilled Shaft Design Report

MIDAS/Civil

PROJECT TITLE: Bridge No. H-23-006 - W-24-016 (BLX)

Company: HDR

Author: [Name]

Client: [Client Name]

NORTH PER COLUMN

* MIDAS/Civil – RC-COLUMN Analysis/Design Program. 
* DESIGN CODE: AASHTO-LRFD12, UNIT SYSTEM: kips, in
* MEMBER: Member Type = COLUMN, MEMBER ID = 90083, LCB = 29, POS = J

* DESCRIPTION OF COLUMN DATA (ISBC): 6; 36° column
  Column Height (h) = 60.000 in.
  Section Type: SOLID ROUND (SR)
  Section Diameter (D) = 36.000 in.
  Concrete Strength (fc) = 4000.000 psi.
  Main Rebar Strength (fy) = 68000.000 psi.
  Tensile/Shear Strength (fya) = 60000.000 psi.
  Modulus of Elasticity (Ea) = 290000.000 psi.

* DESCRIPTION OF APPLIED FACTORS FOR DESIGN/CHECKING:
Special Provisions For Seismic Design : Seismic Zone 2.

* REINFORCEMENT PATTERN:
Layer  | Ralli As (in^2) | Posi As (in^2)
--- | --- | ---
1 | 13.430 | 1.08
2 | | 2.00 - 6B3

* Ties: 2.0 - 6B3

* Radii of gyration (Ry) = 9.0000 in.
  - Unbraced lengths (Lr) = 60.000 in.
  - Effective length factors (Kx) = 1.000
  - Slendr. = Ky*Rx/Ry = 6.667 > Syy ----> SLENDER.

() Compute moment magnification factors for major axis (DBy, DSy).
- DBy = 0.85 (Default or user defined value)
- DSy = 249.62 kips.
- Betsay = Msz/Mss = 0.0000
- Elsy = Ec*Psy*(L2.5*1.5Betsay)) = 0.0000
- Peay = (pi^2*Elsy/(Kx*Ly))^2 = 0.00 kips.
- DBy = Cyl/(1.25*(pi^2*Sy)) = 1.00
- DSy = 1.00 (Default value)

() Compute magnified moments.
- No sideways moments.
  QMb,y = My G = 67.96 in-kips.
  Sideways moments.
  QMe,y = My s = 2501.99 in-kips.

() Compute magnified moments.
Ncy = DBy*QMb,y + DSy*QMe,y = 2434.03 in-kips.

() Check slenderness ratios of BRACED/UNBRACED frame.
- End Moments (Mx1) = 30.14 in-kips.
- End Moments (Mx2) = 1872.59 in-kips.
- Slenderness ratio limits.
  SRa(Unbraced) = 22.00
  Radii of gyration (Rz) = 9.0000 in.
  Unbraced/Braced RATIOs, MAGNIFIED FORCES/MOMENTS.
  SRa(Unbraced) = 22.00
  Radii of gyration (Rz) = 9.0000 in.
  Effective length factors (Kz) = 1.000
  Slendr. = Kz*z = 6.667 > Syy ----> SLENDER.

() Compute moment magnification factors for minor axis (DHz, Dzs).
- Dsz = 0.85 (Default or user defined value)
- DHz = 346.22 kips.
- Betsay = Msz/Mss = 0.0000
- Elsy = Ec*(Hz/2.5*(1.25Betsay)) = 0.0000
- Pez = (pi^2*Elzy/(Kx*Ly))^2 = 0.00 kips.
- DHz = Cyl/(1.25*(pi^2*Sy)) = 1.00
- Dsz = 1.00 (Default value)

() Compute magnified moments.
- No sideways moments.
  QMb,z = Msz = 66.76 in-kips.
  Sideways moments.
  QMe,z = Msz = -1939.34 in-kips.

() Compute magnified moments.
Ncz = DHz*QMb,z + Dsz*QMe,z = -1972.59 in-kips.
Wood Armer Moments in Midas Civil and Wall Designs

- Wood Armer method allows moment triads from plates ($M_x$, $M_y$, $M_{xy}$) to be transformed into simple bending moments in two directions for reinforcement design of plate elements. This is important if the twisting moment $M_{xy}$ is significant.

- In general, the reinforced concrete slab is reinforced by an orthogonal system of bars placed in the $x$ and $y$ directions.

- Design forces in the reinforcement directions for skew reinforcement can be calculated using Wood Armer Moments in Midas Civil.
Wood Armer Moments in Midas Civil and Wall Designs

Slab Design Forces

midas Civil provide design forces in the reinforcement directions for skew reinforcement according to the Wood-Armer formula.

From the analysis results, following plate forces about the local axis are calculated.

- \( m_{xx} \)
- \( m_{yy} \)
- \( m_{xy} \)

In order to calculate design forces in the reinforcement direction, angle \( \alpha \) and \( \phi \) will be taken as following figure:

\[
\begin{align*}
\text{[Bottom Rebar]} & \\
| m_{ud1} &= m_a - 2m_{ab} \cot \phi + m_b \cot^2 \phi + \frac{m_{ab} - m_b \cot \phi}{\sin \phi} & m_{ud2} &= -\frac{m_b}{\sin^2 \phi} + \frac{m_{ab} - m_b \cot \phi}{\sin \phi} \\
\text{When } m_{ud1} < 0 \text{ and } m_{ud2} > 0, & \\
m_{ud1} &= 0 & m_{ud2} &= \max \{0, m_a + \frac{(m_{ab} - m_b \cot \phi)^2}{m_a - 2m_{ab} \cot \phi + m_b \cot^2 \phi} \} \\
\text{[Top Rebar]} & \\
m_{ud1}' &= m_a - 2m_{ab} \cot \phi + m_b \cot^2 \phi - \frac{m_{ab} - m_b \cot \phi}{\sin \phi} & m_{ud2}' &= \frac{m_b}{\sin^2 \phi} - \frac{m_{ab} - m_b \cot \phi}{\sin \phi} \\
\text{When } m_{ud1}' > 0 \text{ and } m_{ud2}' < 0, & \\
m_{ud1}' &= 0 & m_{ud2}' &= \min \{0, \frac{(m_{ab} - m_b \cot \phi)^2}{m_a - 2m_{ab} \cot \phi + m_b \cot^2 \phi} \} \\
\text{When } m_{ud1}' > 0 \text{ and } m_{ud2}' > 0, & \\
m_{ud1}' &= 0 & m_{ud2}' &= 0 \\
\text{When } m_{ud1}' < 0 \text{ and } m_{ud2}' > 0, & \\
m_{ud1}' &= \min \{0, \frac{(m_{ab} - m_b \cot \phi)^2}{m_a - 2m_{ab} \cot \phi + m_b \cot^2 \phi} \} & m_{ud2}' &= 0 \\
\text{When } m_{ud1}' < 0 \text{ and } m_{ud2}' < 0, & \\
m_{ud1}' &= 0 & m_{ud2}' &= 0
\end{align*}
\]

Wood Armer Moment formula

Source: Midas Civil on-line Manual
Wood Armer moment

- Define Domain
- Name the domain
- Select the required plates in the model
- Click add
- Define sub domain
- Name the sub-domain
- Rebar Direction
- Click add
Active Earth Pressure Moment Comparison

Max. Mxx = 5.2 k-ft/ft (Avg. Nodal)  
= 10.5 k-ft/ft (Element)

Max. Wood Armer Moment  
= 10.5 k-ft/ft (Avg. Nodal)  
= 10.6 k-ft/ft (Element)

**Element**: Display the contour using the internal forces calculated at each node of an element.  
**Avg. Nodal**: Display the contour using the average internal nodal forces of the contiguous elements sharing the common nodes.
**INTEGRAL ABUTMENT WALL DESIGN**

Lateral Passive Earth Pressure

\[ K_p \times \text{unit weight of soil} \]

Midas generates pressure

\[ = 0.5 \times 10.5 \text{ ft} = 5.25 \text{ k/sf} \]
INTEGRAL ABUTMENT WALL DESIGN

Passive Earth Pressure Moment Comparison

\[ Myy = 63 \text{ k-ft/ft @ beam locations (Avg. Nodal)} \]

Wood Armer Moment = \( 80 \text{ k-ft/ft @ beam locations (Avg. Nodal)} \) \( \approx 27\% \) increased
CRASH WALL

- 600 kips at 15° to Crash Wall

Max. $M_{xx} = 140$ k-ft/ft (Avg. Nodal)

Wood Armbr Moment $= 165$ k-ft/ft (Avg. Nodal)

$\approx 18\%$ increased
Q&A

Questions?