Integral Abutment Bridge Design – LA 160 Bridges Project

Zolan Prucz, PhD, PE,
Buck Ouyang, PE and Jason Miles, EI,

Modjeski and Masters, Inc.
Presentation Outline

- Introduction to Integral Abutment Bridges (IAB’s)
- Design Procedure for LA 160 Bridges
- LUSAS 3D Analysis
- Details and Construction
- Summary
Introduction to IAB

• **What is an Integral Abutment Bridge?**

• **Types of Integral Abutment Bridges**
  – Semi-Integral Abutment Bridge
  – Full Integral Abutment Bridge
Introduction to IAB (cont.)

• Why Integral Abutment Bridge?
  – Jointless Deck
  – Less Maintenance
  – Better Rider Experience
  – Potential Cost Saving
    • Initial Construction Cost
    • Life-cycle Cost
• **Most important design objectives:**
  – Accommodate the thermal movements
  – Minimize built-in stresses and any additional stresses

• **Special components:**
  – Abutments and the supporting piles
  – Approach and Sleeper Slabs
  – Granular backfill that is placed behind the abutments
Integral Abutment Bridge Components

Main Components:
- Integral abutment
- Piles
- Approach slab
- Sleeper slab
- Backfill
- Expansion joints

Additional Details:
- Polyethylene sheets (2 layers)
- Expanded polystyrene sheet
- Geotextile fabric
- Drainage
- Pre augured pile casing
Common Application of IAB

- Straight Bridges (or w/ slight skew)
- Concrete Structure Length <= 600 ft.
- Steel Structure Length <= 400 ft.

Use of IAB in Louisiana

- LA 160 Bridges will be the first ones utilizing full integral abutment bridge system
- LADOTD has constructed several prototype semi-integral abutment bridges since 1989. LTRC Report
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Existing LA 160 Bridges

- Bodcau Bayou Bridge
- Caney Creek Bridge
Replacement LA 160 Bridges

• Replacement Bridges on Route 160:
  – Bodcau Bayou Bridge: 600’ Abutment to Abutment
  – Caney Creek Bridge: 300’ Abutment to Abutment

• Replacement Bridges Characteristics:
  – Straight Alignment and Zero Percent Grade
  – 75’ AASHTO Type III PS Girders
  – Expansion Bearings at Intermediate Concrete Pile Bents
  – Integral Abutments, Approach Slabs, Sleeper Slabs
  – Preformed Silicone Joints at Ends of Approach Slabs

• Site Conditions:
  – Generally Good and Stiff Soil
  – Aged and Consolidated Embankment
Overview of Integral Bridge Design Procedures

• Currently, there is no single nationally accepted method for the design of integral abutment bridges

• Not covered by AASHTO LRFD or Standard Specifications

• Some states perform minimal calculations, such as Tennessee

• Other states have complex design procedures, such as Maine
Variability Among Design Procedures and Details

• No agreement from state to state on many aspects:
  – Overall restrictions on total bridge lengths and skews
  – Type of piles, type of backfill and compaction
  – Orientation of H-piles: strong or weak-axis bending
  – Type of connection between H-piles and abutment: fixed or pinned
  – Use and size of pre-augured holes for H-piles
  – Type of fill, if any, to be placed in the pre-augured holes
  – End block details
  – Wing wall arrangement
Design Approach for LA 160 Bridges

• Use PennDOT IAB Procedure as Main Guideline
  – Applicable lengths comparable to LA 160 Bridges
  – Mid of road approach in design complexity
  – Comprehensive and with good design details
  – Familiarity (Procedures were developed by MM)

• Supplement with LUSAS 3D Analysis
  – Verify design procedure
  – Investigate effects unaccounted for in design procedure
  – Perform sensitivity analysis

• Combine PennDOT IAB Details with LADOTD Details
  – End Blocks, Wing Walls, Approach Slabs, Backfill
PennDOT IAB Design Procedure

• Applicable to:
  – Concrete structures of up to 590 feet (180 m)
  – Steel structures of up to 390 feet (120 m)

• Focuses on items that require special attention during integral bridge design:
  – Abutments and Piles
  – End Block
  – Approach slab
  – Granular backfill behind abutments

• Includes details and construction sequence recommendations
Design of H-Piles at the Abutments

- A primary component of integral bridge design is the design of the H-piles supporting the abutment.
- For longer bridges, the abutments can be subjected to relatively large thermal displacements, which in turn induces large stresses in the H-piles.
- The PennDOT design procedure employs two primary checks to ensure integrity of the piles:
  - Evaluation of the pile as a structural member
  - Ductility check based on abutment rotation
Design of H-piles at the Abutments (cont.)

Pile moment vs depth

A  Ductility check

B  Structural capacity check

\[ 2 \left( \frac{\Delta_{\text{total}}}{2L} - \frac{M_p L}{6EI} \right) + \theta_w \leq \frac{3C_i M_p L}{4EI} \]

\[ C_i = \frac{19}{6} - 5.68 \sqrt{\frac{f_y}{E} \frac{b_f}{2t_f}} \]
Other Design Aspects Unique to IAB

• **Approach Slab Design**
  – Design as simple span w/o counting on soil support
  – Minimize friction
  – Minimize cracking at the connection to the End Block
  – Limit length to 25’ – less than LADOTD Standard

• **Wing Wall Design**
  – Fully integral with the Abutment
  – U Shaped Arrangement (tapered to follow LADOTD 3:1 slope)

• **Expansion Bearings at Intermediate Bents**
  – Accommodate larger thermal movements
  – Modify anchor details and continuity diaphragm details
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Objectives of LUSAS Analysis

• Focus on the behavior of the steel H-piles supporting the abutments

• Confirm PennDOT design procedure

• Investigate certain effects not accounted for in the design procedure

• Perform sensitivity analysis by determining the effect of individual parameters on the design
Analysis Model – Bodcau Bayou Bridge Elevation View

TOTAL BRIDGE LENGTH = 600'-6" (CONTINUOUS UNIT)
1 SPAN @ 75'-3", 6 SPANS @ 75'-0", 1 SPAN @ 75'-3" INTEGRAL TYPE III P.P.C. GIRDER SPANS

END ROADWAY
BEGIN BRIDGE
STA. 210+24.75

2'-3" [68%]
(25'-0"
CONCRETE APPROACH SLAB

PREFORMED SILICONE JOINT

EXCAVATION

BERM EL. 199.5

FLEXIBLE REVETMENT SHALL FOLLOW THE EXISTING GROUND SLOPE

F.S. ELEV. 206.00
H.W. ELEV. (100 YR.)
200.64

MEAN WATER LEVEL
ELEV. 175.5

210+00
211+00
212+00
213+00

ELEVATION
(Scale: 1"=20')

BENT NO. 1, STA. 210+00
8-HP 14x69 STEEL PILES @ 90.5
BENT NO. 2, STA. 211+00
5-30' PCC PILES @ 90.5

BENT NO. 3, STA. 211+75
BENT NO. 4, STA. 212+50
5-30' PCC PILES @ 90.5
Bodcau Bayou LUSAS Model
End Bent and Intermediate Bent Modeling
Overview of the Analysis Procedure

1. Soil Borings
2. FLORIDA PIER Model
3. P–Y Curves
4. Equivalent Linear Springs
5. LUSAS Model
6. Perform Analysis
7. Pile Deflected Shape and Moment Diagram
Florida Pier Model
Equivalent Linear Spring Function Based on P-Y Curves - Example
Verification of Single Pile Model Results - Example
Abutment Backfill Springs

- The effect of backfill pressures on the abutments is not considered in PennDOT design procedure
- A base backfill spring value based on Caltrans full-scale study performed by UC Davis was used
- A range of stiffnesses from 0.25x Caltrans to 4.00x Caltrans base value was investigated
Application of Springs in LUSAS

Springs representing abutment backfill pressure

H-pile equivalent linear spring stiffness varying with depth
Loadings and Conditions

• Strength I loading condition was found to control
  – Note that PennDOT design procedure increases the standard AASHTO Strength I thermal coefficient from 0.50 to 1.00

• Model evaluated at maximum thermal displacement independent of the temperature at installation

• Model evaluated at a range of abutment backfill stiffnesses, including symmetrical and asymmetrical conditions

• Equivalent spring function applied to H-piles based on soil boring data along with the top 12 feet of the pile being surrounded by loose fill
LUSAS Deformed Mesh Under Thermal Expansion and Live Load

Joint element - expansion bearing

H-pile point of fixity
Sensitivity Analysis

Key parameters investigated:

1. Max thermal displacement at abutments
2. Moment in H-piles at connection to abutment
3. Moment in H-piles between 1st and 2nd second inflection points
4. Rotation of abutment
5. Depth to fixity of H-piles
## Analysis Results

<table>
<thead>
<tr>
<th></th>
<th>PennDOT Design</th>
<th>LUSAS with Caltrans Abutment Backfill Springs</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No Abut. Stiffness</td>
</tr>
<tr>
<td>Max. Thermal Displacement (in)</td>
<td>1.71</td>
<td>1.61</td>
</tr>
<tr>
<td>Max. H-Pile Moment at Cap Connection (ft-k)</td>
<td>N/A</td>
<td>387</td>
</tr>
<tr>
<td>Max Moment btw 1st &amp; 2nd Inflection Points (ft-k)</td>
<td>142</td>
<td>121</td>
</tr>
<tr>
<td>Rotation of Abutment (rad.)</td>
<td>0.0022</td>
<td>0.0017</td>
</tr>
</tbody>
</table>
Backfill Symmetry
Effect of Uneven Abutment Stiffnesses

• PennDOT design procedure contains guidelines concerning the backfill used behind the abutments, including that the fill be placed in symmetrical, simultaneous lifts

• What is the importance of having symmetrical backfill conditions?
Effect of Abutment Backfill Stiffness

Displacement at Head of Pile (in)

Fills Uneven, Stiffer Abutment
Fills Even, Both Abutments
Fills Uneven, Looser Abutment

k₂ = kₐvg * 0.67
k₁ = k₂ = kₐvg
k₁ = kₐvg * 1.33

1.35” – Deflection limit to keep max pile moment below plastic moment

Average Backfill Stiffness (kip/in)
Exceedance of H-pile Plastic Moment at Connection to Abutment

• Majority of LUSAS runs resulted in maximum moments that exceeded the H-pile plastic moment, even taking into account the 12’ deep augured hole containing loose fill.

• PennDOT design procedure allows and accounts for this by including a ductility check based on section properties and the maximum expected range of pile head rotation.

• It was determined to be preferable to find a way to keep the maximum pile moments from going beyond plastic.
Main Analysis Findings

• The analysis was able to:
  – Verify the design procedure by producing similar or lower results for five key parameters evaluated
  – Assess the effect of abutment backfill on thermal displacements

• There is a need to:
  – Minimize the potential for uneven abutment stiffnesses due to backfill pressures
  – Minimize the moment experienced by the H-pile at the connection to the bottom of the abutment
Use of Marine Rubber Fender

Elevation View of Pile Casing
Equivalent Linear Spring Functions: Loose Fill vs. D-Shaped Fender

![Graph showing stiffness vs. depth for Loose Fill and D-Shaped Fender]

- **Loose Fill**
- **D-Shaped Fender**
Effect of Rubber Fender

- Effect of Fender Relative to Abutment Stiffness
  - Abutment stiffness
  - 1.60” – Deflection limit with marine fender
  - 1.35” – Deflection limit without marine fender

- Moment reduced
  - From 335 to 267 ft-k

- Depth to Fixity
  - Increased from 15’ to 17’
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Integral Abutment Details

- **Special Thrive Beam Terminal Connector** (see note below)
- **Transition Barrier**
- **Closure Pour**
- **End Block**
- **End Bent & 3/4"x9" Bearing Pad**
- **Required Construction Joint in Deck Slab** (see plan of pouring sequence, Sheet 131)
- **Top of Deck at Gutter Line**
- **1" Thick Expanded Polystyrene Sheet**
- **Type III Girder**
- **Wingwall**
- **Required Construction Joint**
- **Backfill and Drainage** (see Sheet No. 138)
- **Frontfill and Drainage** (see Sheet No. 138)
- **36" Augered Hole with Casing**
- **12"x12" D-Shaped Fender with 6" D-Shaped Bore**
- **Fill with Dry Loose Sand after Pile is Driven**
- **HP 14x89, GR. 50**
- **Fill with Dry Loose Sand after Pile is Driven**
- **(Paid for Under "Nonplastic Embankment (Sand)"**
- **1"x1" Clip (Typ.)**
End Block Details

TROWEL SMOOTH SUR CONSTRUCTION JOINT UNDER GIRDER AND A EXTENDING 2" OUTSIDE AREA, PROVIDE RAKE FOR THE REMAINDER CONSTRUCTION JOINT.

SECTION C-C
SCALE: ¾" = 1'-0"
**Sleeper Slab and Expansion Joint Details**

**ASPHALTIC CONCRETE PAVEMENT**
(SEE ROADWAY PLANS)

**CONCRETE APPROACH SLAB**

2'-0"

3'-0"

**SLIDING SURFACE**

SEE APPROACH SLAB DETAILS FOR REBAR SPACING

**VARES** 1'-6" MIN. (MAX.)

**ROUGH CONST. JT.**

2 1/2" CLR. (TYP. U.N.)

**1 1/2" Ø SCH. 40 PVC PIPES @ 10'-0" MAX. SPACING**

**GEOTEXTILE FABRIC**

6"Ø PERFORATED PIPE (TYP.) (SLOPE TO DRAIN) (SEE SHEET NO. 119 FOR DETAILS)

**SECTION THRU END OF APPROACH SLAB WITH PREFORMED SILICONE JOINT**

SCALE: 1/4" = 1'-0"

WEL SMOOTH, AND POLYETHYLENE CER.
Continuity Diaphragm and Expansion Bearings at Intermediate Bent
Construction

• Girder aged for 90 days prior to pouring continuity diaphragm

• Deck Pouring Sequence

• Backfill
  – Gradation
  – Compaction
  – Drainage
  – Polyethylene sheets, Expanded polystyrene sheet, Geotextile fabric

• Approach Slab, Sleeper Slab and Expansion Joint
Deck Pouring Sequence

END BLOCK SHALL BE CLASS AAIM) CONCRETE AND SHALL BE Poured WITH THE UPPER PORTION OF THE WINGWALL.

PART SECTION ALONG ROADWAY
SCALE: ¼" = 1'-0"

INTEGRAL UNIT LENGTH = 600'-6"
Approach Slab, Sleeper Slab and Expansion Joint Details

Diagram showing joint details with various annotations and measurements.
Backfill Construction Requirements

- Gradation
- Compaction
- Symmetry
- Drainage
- Use of Polyethylene sheets, Expanded polystyrene sheet, Geotextile fabric
Backfill Material - Modified Gradation

![Graph showing the percentage passing of different materials across various metric sieves. The x-axis represents the metric sieve (mm) ranging from 0.01 to 100.00, and the y-axis represents the percentage passing ranging from 0 to 120. The graph compares different materials such as 1003.08b as is top, 1003.08b as is btm, PA OGS top, PA OGS btm, VDOT, Proposed top, and Proposed btm. Each material is represented by a different line and marker color.]
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Summary

• Design
  – PennDOT design procedure was generally followed
  – Limited moments at the abutment H-pile connection

• 3D Analysis:
  – Verified the PennDOT design procedure
  – Assessed the effect of abutment backfill stiffness
  – Quantified the importance of maintaining symmetrical backfill conditions at each abutment
  – Validated the benefits of using a marine fender to prevent extremely high moments from occurring in the H-piles
Summary (cont.)

• **Detailing**
  – Integral abutment and approach slab details generally followed PennDOT guidelines
  – Continuity diaphragms and expansion bearings use LADOTD’s standards with modifications
  – Special details for expansion joint at sleeper slab

• **Construction**
  – Deck pouring sequence
  – Backfill requirements
  – Approach slab and sleeper slab pouring sequence
Follow-up

• Monitoring - Instrumentation (LTRC)
  – Bodcau Bayou Bridge

• Implementation (LADOTD)
  – LADOTD will develop a simplified “checklist” procedure for the design of fully integral abutment bridges based on the experience of this pilot project
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