Design Considerations for Integral Abutments in Single-Span Steel Bridges

Michael P. Culmo, P.E.
Chief Bridge Engineer
CHA Consulting, Inc.

Purpose of this presentation

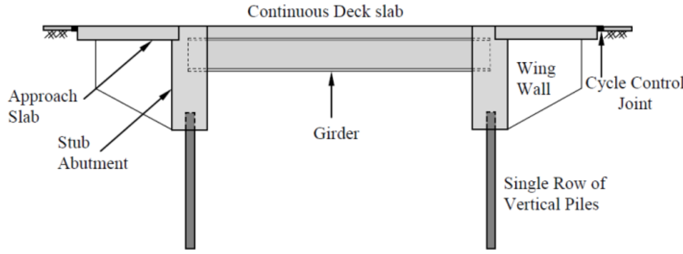
- Definition of an integral abutment
- Benefits of integral abutments
- Where they are appropriate and where they are not
- Design considerations for integral abutments
  - AASHTO LRFD BDS Provisions
  - State DOT Provisions
- Common details
- Example construction projects

Intro to Integral Abutments

3

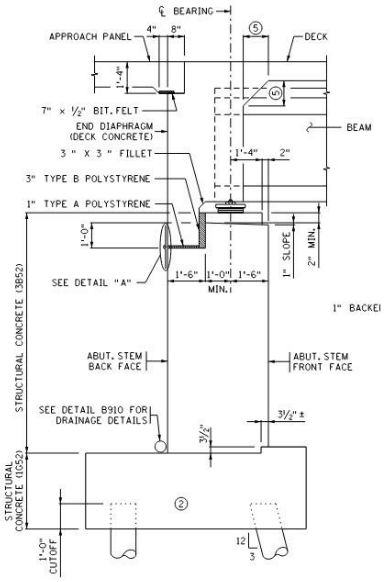
Integral Abutment Definition

- AASHTO LRFD Bridge Design Specifications Definition:
  - Integral abutments are rigidly attached to the superstructure and are supported on a spread footing or a deep foundation capable of permitting necessary horizontal movements
    - Spread footing?: Most likely referring to rigid-frame structures with hinge at wall base
    - Deep foundations: Single line of piles



4

Semi-Integral Abutment Definition



- AASHTO LRFD BDS does not have a definition for semi-integral abutments
- Generally, semi-integral abutments have an integral diaphragm at the abutment that is supported on expansion bearings
- Conventional Abutment below the bearings
- Details vary by state
  - Minnesota DOT details shown

European Experience

Years ago I attended a bridge conference that had a session on Integral Abutments

- The engineers from some Western European countries did not like the US details
  - Concerns regarding potential uneven movement of the bridge
  - They consider a three-sided frame an “integral abutment”. Technically, it is.
- England was building US-style integral abutments
- This was 8 years ago.
  - Designs may have evolved since then.

Pile types

- Most states use steel H-piles
  - Orientation: Most orient the pile for weak axis thermal bending
- Small-diameter drilled shafts
  - Large diameter shafts may be too stiff
- Micropiles?
  - More on that later

Benefits of Integral Abutments

- Elimination of deck expansion joints is the number one benefit
  - Significant durability improvement – The best joint is no joint
- Elimination of bearings at the abutment
  - Some designers use temporary bearings for seating the girders.
- Lower cost
  - Fewer piles
  - No footings
  - Less excavation and typically above the waterline
- Benefits to the superstructure?
  - Designers neglect the stiffness of the Integral Abutment; therefore, there are no structural benefits.
  - Designers typically neglect the compression in the superstructure due to soil forces acting on the abutments.

Where they are appropriate and where they are not

- Appropriate uses
  - Single-span Bridges
  - Continuous multi-span Bridges
  - Maximum lengths between abutments
    - Vary by state
    - Significantly long bridges have been built (TN)
- Inappropriate uses
  - Shallow bedrock:
    - Piles become too short: Cannot achieve pile fixity
    - Use semi-integral abutment
  - Bridges with significant scour? Debatable
  - Long bridges: Soil pressures and pile flexure

Design of Integral Abutments

Design Considerations for Integral Abutments

- There is no national design process for integral abutments
  - Engineering judgement is most often used
- AASHTO LRFD Bridge Design Specifications have limited design specifications
- Some states have specific design requirements in their bridge design manuals

AASHTO LRFD Bridge Design Specifications

- There are no specific design specifications for integral abutments
- The following are excerpts from the BDS

2.5.2.6—Deformations

2.5.2.6.1—General

- Elastic vertical, lateral, and rotational deflections due to applicable load combinations shall be considered to ensure satisfactory service performance of bearings, joints, integral abutments, and piers.

No specifics on how to account for this

AASHTO LRFD Bridge Design Specifications

3.11.5—Earth Pressure: *EH*

3.11.5.1—Lateral Earth Pressure

For most gravity walls which are representative of those used in highway construction, nongravity cantilever retaining walls or other flexible walls which tilt or deform laterally in response to lateral loading, e.g., MSE walls, as well as walls which cannot translate or tilt, e.g., integral abutment walls, significant arching of the backfill against the wall does not occur, and the resultant lateral load due to earth pressure acts at a height of *H*/3 above the base of the wall. Furthermore, where wall friction is not considered in the analysis, it is sufficiently conservative to use a resultant location of *H*/3, even if the wall can translate.

AASHTO LRFD Bridge Design Specifications

4.6—STATIC ANALYSIS

4.6.1—Influence of Plan Geometry

4.6.1.2—Structures Curved in Plan

4.6.1.2.1—General

The moments, shears, and other force effects required to proportion the superstructure components shall be based on a rational analysis of the entire superstructure. Analysis of sections with no axis of symmetry should consider the relative locations of the center of gravity and the shear center. The substructure shall also be considered in the case of integral abutments, piers, or bents.

C4.6.1.2.1

Since equilibrium of horizontally curved I-girders is developed by the transfer of load between the girders, the analysis must recognize the integrated behavior of all structural components. Equilibrium of curved box girders may be less dependent on the interaction between girders. Bracing members are conside primary members in curved bridges since they trans forces necessary to provide equilibrium.

Consider the substructure stiffness in the superstructure analysis

- Most engineers neglect the stiffness of the piles
- Some consider the bending moments due to soil pressures on the backwall acting on the superstructure

AASHTO LRFD Bridge Design Specifications

4.6.3.3.3—Curved Steel Bridges

Refined analysis methods should be used for the analysis of curved steel bridges unless the Engineer ascertains that approximate analysis methods are appropriate according to the provisions of Article 4.6.2.2.4.

C4.6.3.3.3

Refined analysis methods, identified in Article 4.4, are generally computer-based. The finite strip and finite element methods have been the most common. The finite strip method is less rigorous than the finite element method and has fallen into disuse with the advent of more powerful computers. Finite element programs may provide grid analyses using a series of beam elements connected in a plane. Refinements of the grid model may include offset elements. Frequently, the torsional warping degree-of-freedom is not available in beam elements. The finite element method may be applied to a three-dimensional model of the superstructure. A variety of elements may be used in this type of model. The three-dimensional model may be made capable of recognizing warping torsion by modeling each girder cross-section with a series of elements.

The stiffness of supports, including lateral restraint such as integral abutments or integral piers, should be recognized in the analysis. Since bearing restraint is offset from the neutral axis of the girders, large lateral forces at the bearings often occur and may create significant bending in the girders, which may lead to lower girder moments than would be computed if the restraints were not present. The Engineer should ascertain that any such benefit recognized in the design will be present throughout the useful life of the bridge.

Consider the substructure stiffness in the superstructure analysis

AASHTO LRFD Bridge Design Specifications

WALLS, ABUTMENTS, AND PIERS

Commentary is opposite the text it annotates.

11.1—SCOPE

This Section provides requirements for design of abutments and walls. Conventional retaining walls, nongravity cantilevered walls, anchored walls, mechanically stabilized earth (MSE) walls, prefabricated modular walls, and soil nail walls are considered.

Definition in Section 11

11.2—DEFINITIONS

Abutment—A structure that supports the end of a bridge span, and provides lateral support for fill material on which the roadway rests immediately adjacent to the bridge. In practice, different types of abutments may be used. These include:

- *Stub Abutment*—Stub abutments are located at or near the top of approach fills, with a backwall depth sufficient to accommodate the structure depth and bearings which sit on the bearing seat.
- *Partial-Depth Abutment*—Partial-depth abutments are located approximately at mid-depth of the front slope of the approach embankment. The higher backwall and wingwalls may retain fill material, or the embankment slope may continue behind the backwall. In the latter case, a structural approach slab or end span design must bridge the space over the fill slope, and curtain walls are provided to close off the open area. Inspection access should be provided for this situation.
- *Full-Depth Abutment*—Full-depth abutments are located at the approximate front toe of the approach embankment, restricting the opening under the structure.
- *Integral Abutment*—Integral abutments are rigidly attached to the superstructure and are supported on a spread footing or a deep foundation capable of permitting necessary horizontal movements.

AASHTO LRFD Bridge Design Specifications

11.6.1.3—Integral Abutments

Integral abutments shall be designed to resist and/or absorb creep, shrinkage, and thermal deformations of the superstructure.

Movement calculations shall consider temperature, creep, and long-term prestress shortening in determining potential movements of abutments.

To avoid water intrusion behind the abutment, the approach slab should be connected directly to the abutment (not to wingwalls), and appropriate provisions should be made to provide for drainage of any entrapped water.

C11.6.1.3

Deformations are discussed in Article 3.12.

Integral abutments should not be constructed on spread footings founded or keyed into rock unless one end of the span is free to displace longitudinally.

Only design requirements
Nothing specific

AASHTO LRFD Bridge Design Specifications

11.6.5.4—Calculation of Seismic Earth Pressure for Nonyielding Abutments and Walls

For abutment walls and other walls that are considered nonyielding, the value of k_h used to calculate seismic earth pressure shall be increased to $1.0k_{h0}$, unless the Owner approves the use of more sophisticated numerical analysis techniques to determine the seismically induced earth pressure acting on the wall, considering the ability of the wall to yield in response to lateral loading. In this case, k_h should not be corrected for wall displacement, since displacement is assumed to be zero. However, k_h should be corrected for wave scattering effects as specified in Article 11.6.5.2.2.

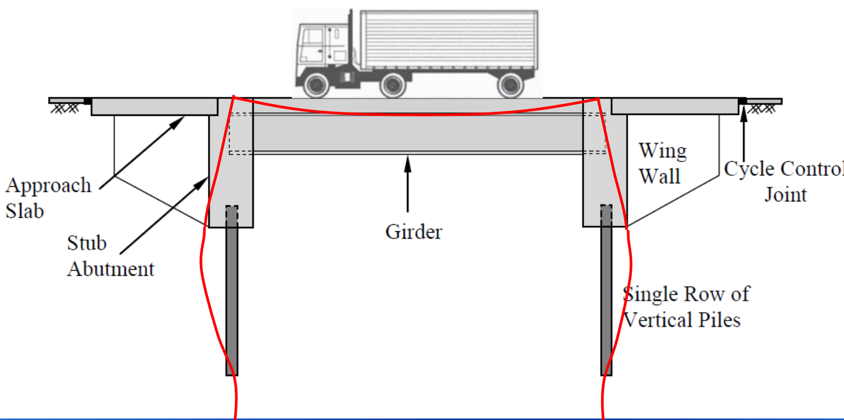
C11.6.5.4

The lateral earth pressure calculation methodologies provided in Article 11.6.5.3 assume that the abutment or wall is free to laterally yield a sufficient amount to mobilize peak soil strengths in the backfill. Examples of walls that may be nonyielding are integral abutments, abutment walls with structural wing walls, tunnel portal walls, and tied back cylinder pile walls. For granular soils, peak soil strengths can be assumed to be mobilized if deflections at the wall top are about 0.5 percent of the abutment or wall height. For walls restrained from movement by structures, batter piles, or anchors, lateral forces induced by backfill inertial forces could be greater than those calculated by M–O or GLE methods of analysis. Simplified elastic solutions presented by Wood (1973) for rigid nonyielding walls also indicate that pressures are greater than those given by M–O and GLE analysis. These solutions also indicate that a higher resultant location for the combined effect of static and seismic earth pressure of $h/2$ may be warranted for nonyielding abutments and walls and should be considered for design. The use of a factor of 1.0 applied to k_{h0} is recommended for design where doubt exists that an abutment or wall can yield sufficiently to mobilize backfill soil strengths. In general, if the lack of ability of the wall to yield requires that the wall be designed for K_0 conditions for the strength limit state, then a k_h of $1.0k_{h0}$ should be used for seismic design.

Seismic earth pressure design requirements

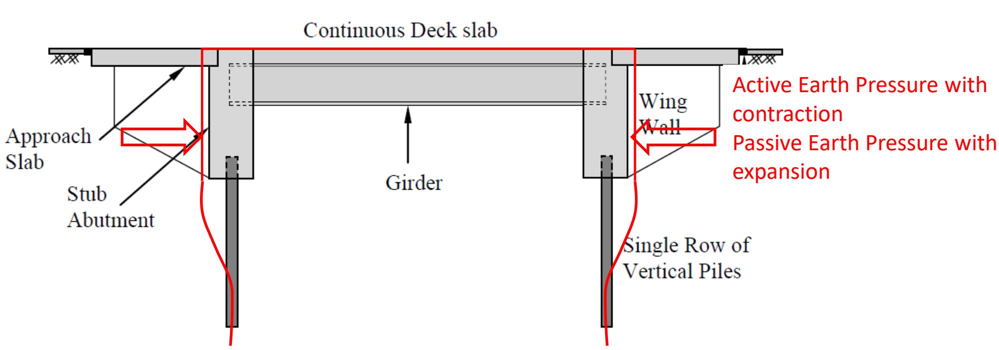
Typical Live Load Analysis Assumptions

- Analyze as simple span
  - The stiffness of piles is so small when compared to the superstructure



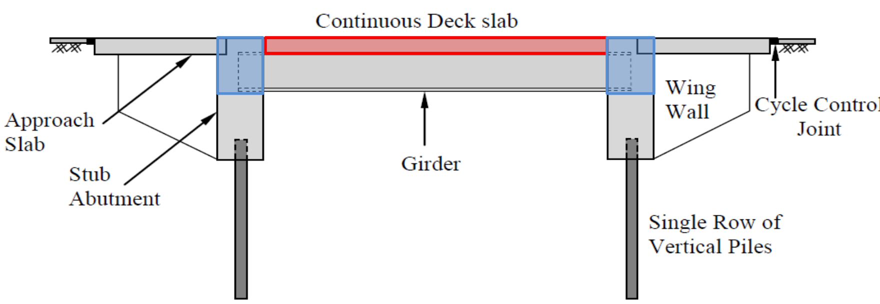
Typical Thermal Movement Assumptions

- Superstructure expands and contracts equally on each end
  - Thermal movement is accommodated by flexure in the piles
  - ½ on each end
  - Soil forces can create negative bending moments in the superstructure



Construction Sequence

- The construction approach needs to consider beam end rotation
  - Pour deck in stages
  - Span first (red), abutment diaphragms second (blue)
  - The second abutment diaphragm can be cast with the deck pour



State DOT Provisions

State DOT Provisions

- Several States have design provisions in their bridge design manuals
  - MassDOT has had design specifications for many years
  - We will focus on MnDOT today

Minnesota DOT LRFD Bridge Design Manual

Abutment Type Selection

Integral abutments are the preferred type of abutment when all of the following criteria are met:

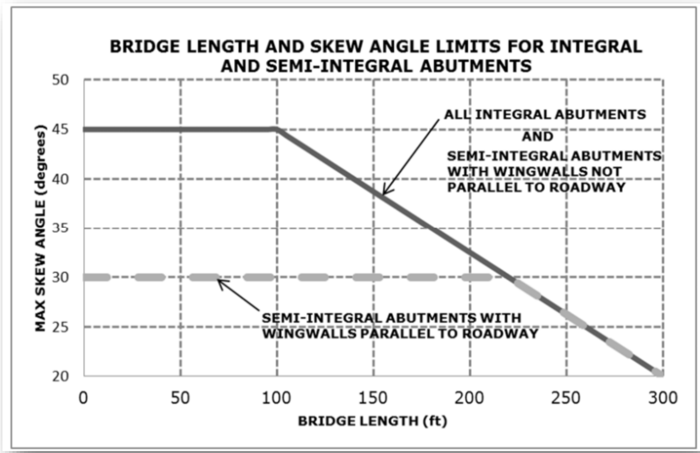
- Bridge length and skew meet one of the following. See Figure 11.1.1.
  - Bridge length ≤ 300 feet and skew ≤ 20 degrees, and the expansion length at the abutment is ≤ 150 feet.
  - Bridge length ≤ 100 feet and 20 degrees < skew ≤ 45 degrees, and the expansion length at the abutment is ≤ 50 feet.
  - Bridge length is between 100 feet and 300 feet, and 20 degrees < skew ≤ [45 - 0.125 · (L - 100)] degrees, where L is the length of the bridge in feet. In addition, the expansion length at the abutment is ≤ 0.5 · L.
- Bridge length ≤ 150 feet for bridges with CIP piling at integral abutments.
- Bridge horizontal alignment is straight. Slight curvature can be allowed, but must be considered on a case-by-case basis.
- The length of wingwall cantilevers are ≤ 14 feet (measured from the back face of abutment to the end of the wingwall).
- Abutment wingwalls do not tie into roadway retaining walls.
- Bridge configuration allows setting the abutment front face exposure on the low side of the bridge at 2 feet. See Figure 11.1.2.
- Maximum abutment stem height ≤ 7′-0″
- Depth of beams is ≤ 72 inches.

Many states limit skew:
Snowplow effect causing lateral movement of the abutments

Note that we are only covering the main provisions today.

Refer to the MnDOT Bridge Design Manual for other requirements.

Minnesota DOT LRFD Bridge Design Manual

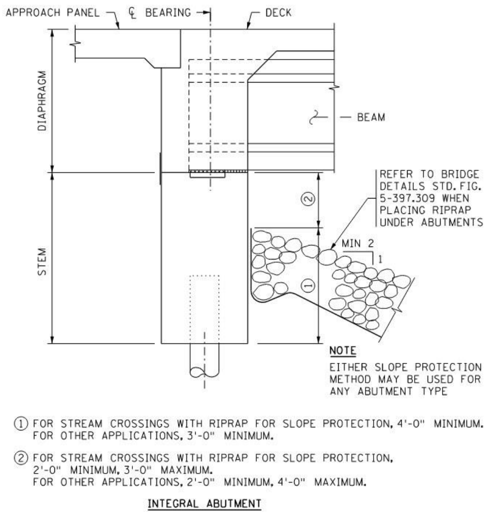


Minnesota DOT LRFD Bridge Design Manual

Semi-integral abutments are the preferred type of abutment when the following circumstances apply:

- The wingwall length, abutment exposure or superstructure depth requirements for integral abutments cannot be met.
- The bridge length and skew meet the requirements given above for integral abutments, except that when wingwalls are parallel to the roadway, the maximum skew limit for semi-integral abutments is 30 degrees. (See Figure 11.1.1.) Also, note that a guide lug is required for skews greater than 30 degrees to limit unwanted lateral movement.

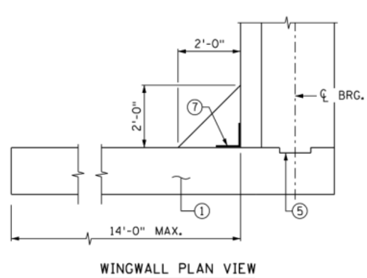
Minnesota DOT LRFD Bridge Design Manual

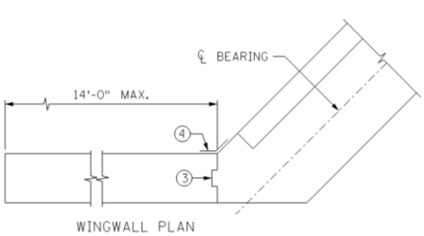


Cover and Clearance Requirements

- Use a minimum thickness of 3 feet for the abutment stem. For skewed bridges, increase the abutment thickness to maintain a minimum of 5 inches between the beam end and the approach slab seat
- Note that the 4'-6" minimum depth below grade requirement for abutment footings does not apply to integral abutment stems.
- Orient H-piling such that weak axis bending occurs under longitudinal bridge movements.
- Minimum pile penetration into abutment stem is 2’-6”.
- Avoid using 16” CIP and HP 14 piles or larger because of limited flexibility.

Minnesota DOT LRFD Bridge Design Manual

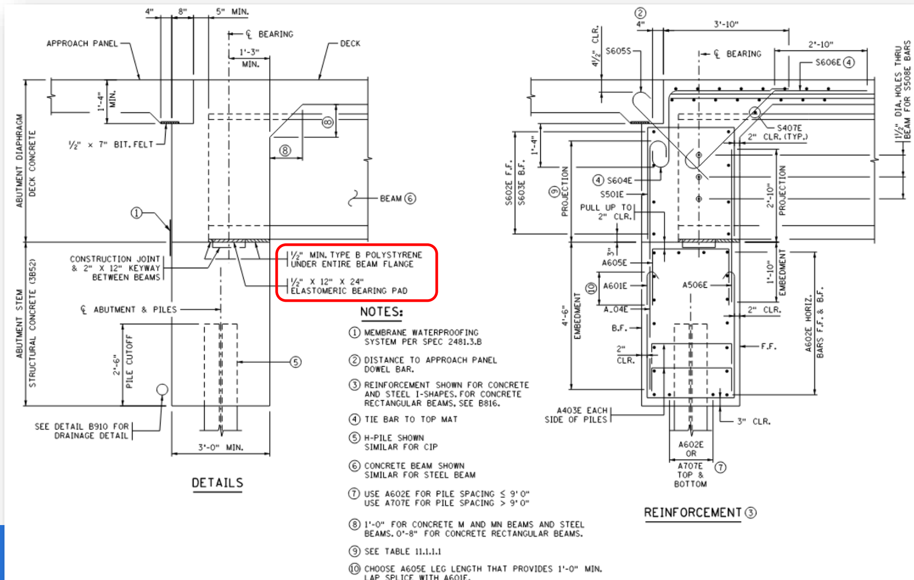




Wingwall detailing:

- Wingwalls and the end diaphragm are intended to move as a single unit.
- Do not include a gap between wingwalls and the abutment diaphragm.
- Detail rebar to cross the joint between the diaphragm and the wingwalls.
- Limit the length of the wingwall cantilever to 14 feet measured from the back face of abutment to the end of the wingwall.

Minnesota DOT LRFD Bridge Design Manual



Typical Details:
- Nominal elastomeric temporary bearing
- Polystyrene under beam flange

Minnesota DOT LRFD Bridge Design Manual

Integral Abutment General Design/Analysis Method

Design piling for axial loads only. Assume that one half of the approach panel load is carried by the abutment. Distribute live load over the entire length of abutment. Apply the number of lanes that will fit on the superstructure adjusted by the multiple presence factor. Use a minimum of four piles in an integral abutment.

For integral abutments that do not meet the **Integral Abutment Reinforcement Design Guide** criteria found in this section, use the methods outlined below to design the reinforcement.

Design vertical shear reinforcement in the abutment stem for the maximum factored shear due to the simple span girder reactions, including the dynamic load allowance of 33%. Consider the stem to act as a continuous beam with piles as supports.

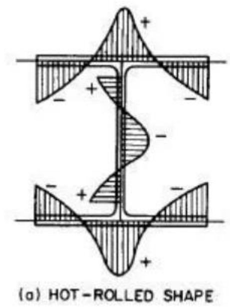
Punching shear of the piles can be assumed to be satisfied and need not be checked.

Some states analyze piles for flexure (more on this in the next slide)

Simple live load distribution approach

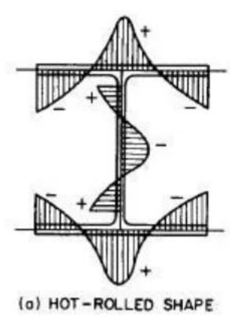
Flexure in Pile design

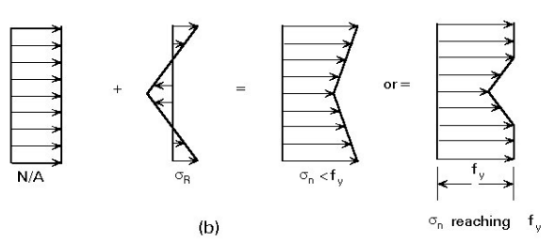
- MnDOT only specifies axial design
- Why not flexure?
  - My thoughts…
  - Flexural stresses can be considered the same as residual stresses in steel
  - Rolled sections can have high residual stresses
    - 10ksi to 15 ksi
  - Is the flexure of piles similar??



Flexure in Pile design

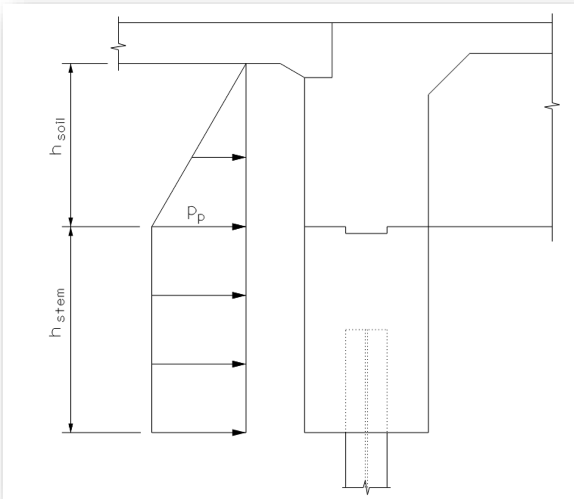
- Residual Stresses
  - We ignore these in design, but why?
    - As you apply compression, the areas with residual compression may yield initially, but…
    - Areas with residual tension have capacity to take more compression
    - Result: Ultimate compression load is As*Fy (if compact)





Combination with axial stresses

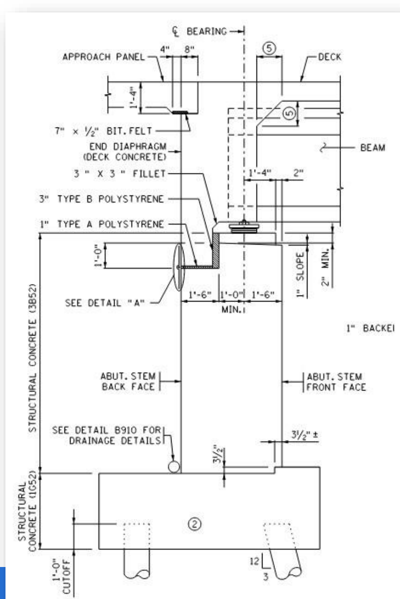
Minnesota DOT LRFD Bridge Design Manual



Geotechnical Design:

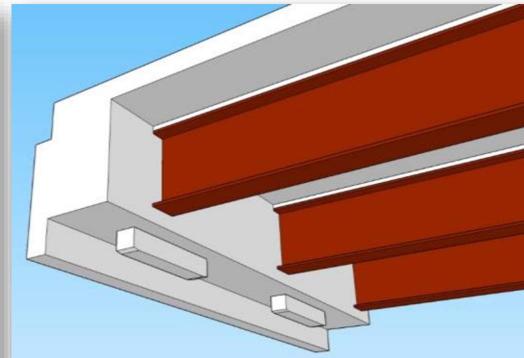
- Design for full passive earth pressure
- This will generate significant negative bending in the superstructure
  - May not work with prestressed concrete beams
  - Steel Beams can handle it
  - Design similar to continuity design for multi-span bridges

Minnesota DOT LRFD Bridge Design Manual

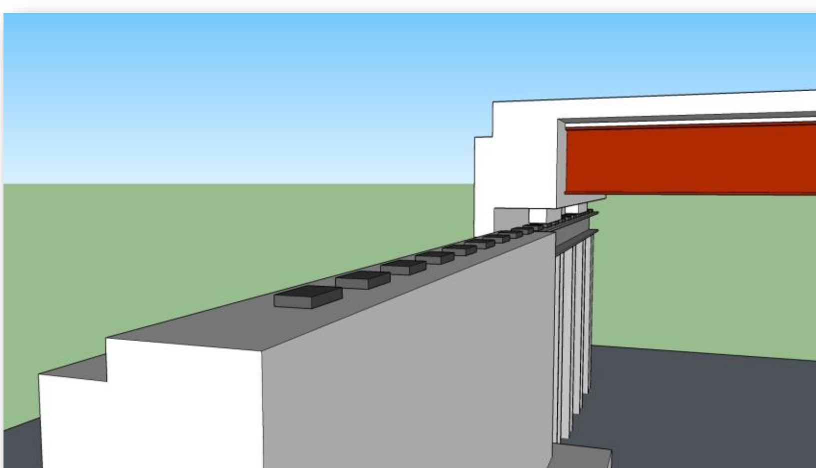


- Semi-integral abutments
- Similar to integral abutment specifications
  - Bearing added for thermal movement
  - Longitudinal forces resisted by backwall and superstructure
  - This detail works well with ABC
    - SPMT and Lateral Slide applications
    - Modular deck beam applications

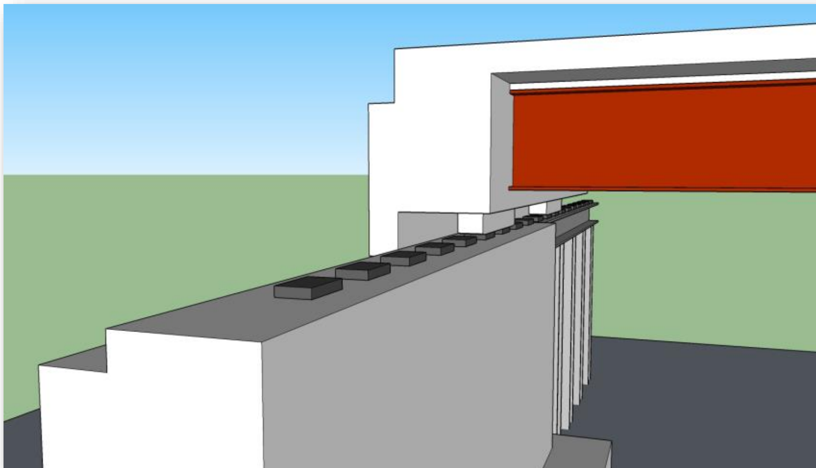
ABC with Semi-Integral Abutments



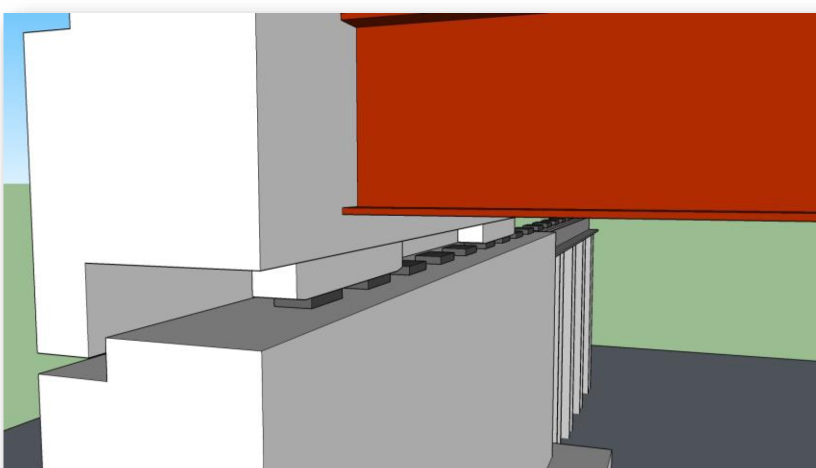
Simplified Lateral Slide Details



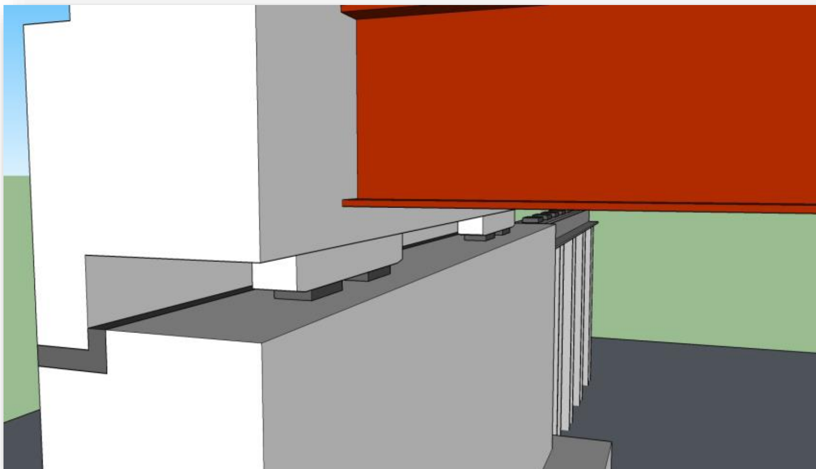
Simplified Lateral Slide Details



Simplified Lateral Slide Details



Simplified Lateral Slide Details

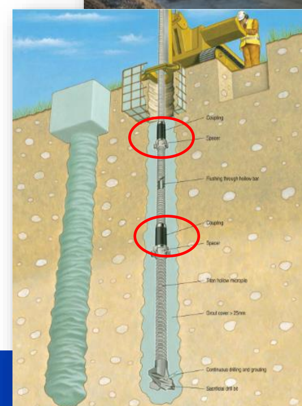


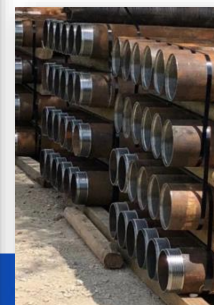
A Few Example Projects

40

Champeaux Road Bridge

- Sturbridge, Massachusetts
  - MassDOT first use of micropiles for IA bridges
  - Concerns over bending moments at pile couplers
    - Potential for fracture of pile at to coupler threads
  - Design
    - Specified a minimum coupler depth
    - Low moment region
  - CHA is studying this
    - Numerous sensors were installed
    - Monitoring continues
  - Univ. of Maine is researching this issue also
    - Lab testing



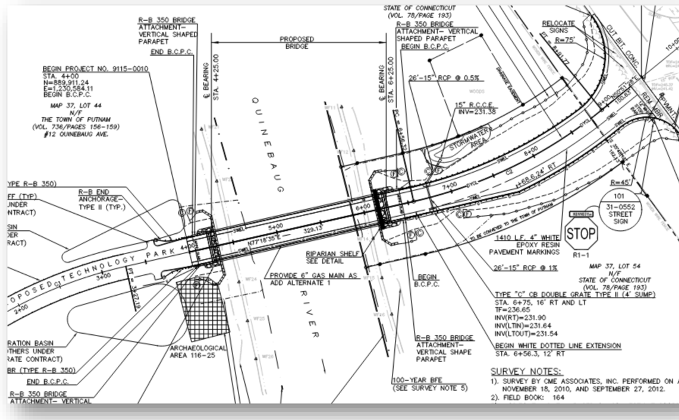


Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Medium-span steel bridge
  - 200 foot single span
  - Integral abutments

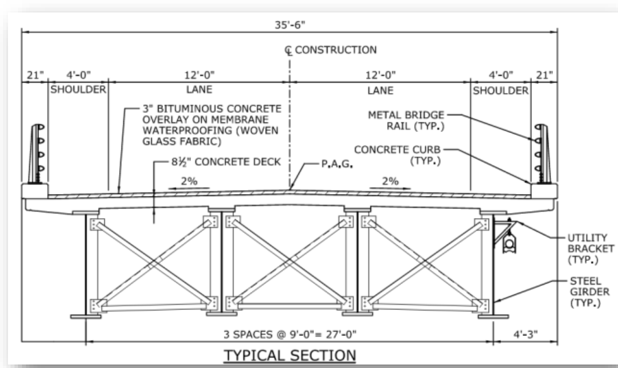
Example Construction Projects

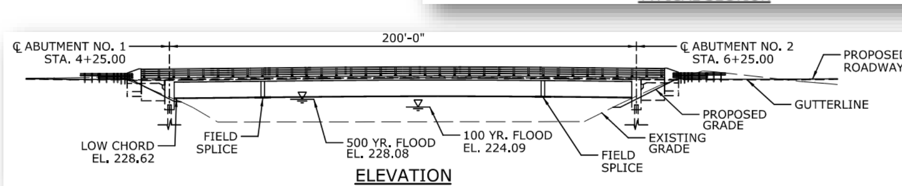
- Putnam Industrial Park Entrance Road, Putnam, CT
  - Site plan



Example Construction Projects

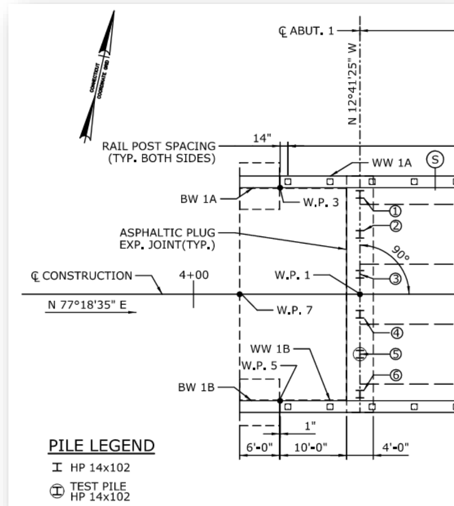
- Putnam Industrial Park Entrance Road, Putnam, CT
  - Bridge details





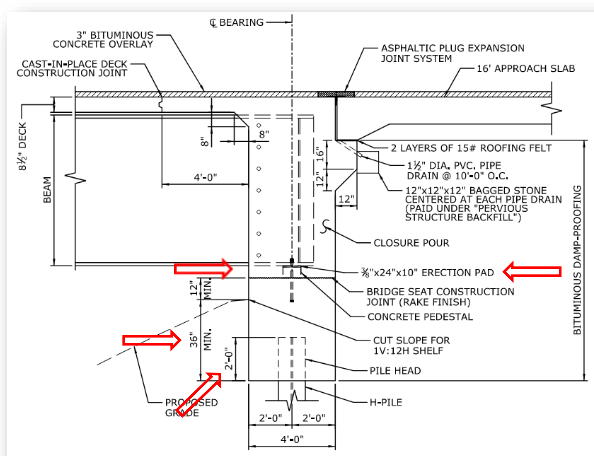
Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Abutment details
    - 6 piles
    - HP14x102
    - Weak axis bending



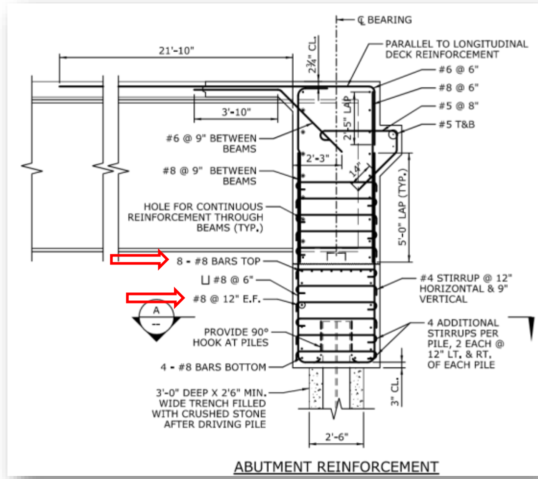
Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Abutment details



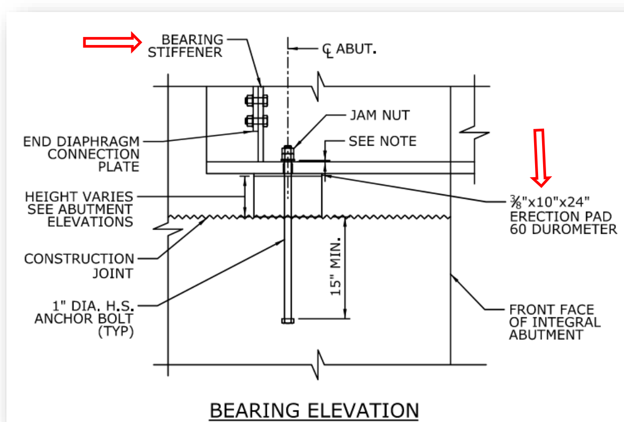
Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Abutment details



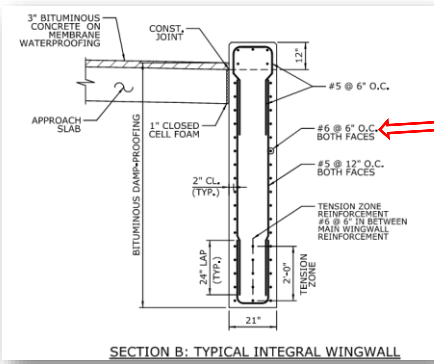
Example Construction Projects

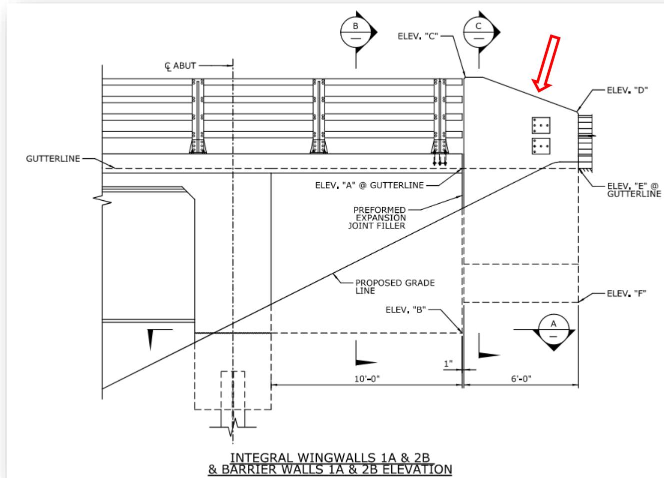
- Putnam Industrial Park Entrance Road, Putnam, CT
  - Abutment details



Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Wingwall details





Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Construction Site
  - Integral abutment excavation (far side)
  - No cofferdams
  - Steel Erection Bents

Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Pile installation
  - Construction far above waterline

Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Steel Erection Complete

Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Integral abutment details
  - Things to note:
    - Vertical bars between girders
    - Holes in girder web for reinforcing bars
    - Painted weathering steel at integral abutment interface

Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Integral abutment details

Example Construction Projects

- Putnam Industrial Park Entrance Road, Putnam, CT
  - Integral abutment details
  - Temporary erection bearings

Conclusions

- Integral abutments should be your first choice for abutment substructures
  - Elimination of deck expansion joints
  - Elimination of bearings at the abutment
  - Lower cost, construction in the dry
- Ideal for steel bridges
  - Steel girders can handle the negative moments caused by passive earth pressure
- Various pile types can be used
  - Steel H-piles are popular
- The AASHTO LRFD Bridge Design Specification has limited design requirements
  - Some owners have design requirements
  - MnDOT Bridge Manual has extensive design requirements
- Questions?