SCAN TEAM REPORT

NCHRP Project 20-68D, Scan 19-01

Leading Practices for Detailing Bridge Ends and Approach Pavements To Limit Distress and Deterioration

Supported by the

National Cooperative Highway Research Program

The information contained in this report was prepared as part of NCHRP Project 20-68A U.S. Domestic Scan, National Cooperative Highway Research Program.

SPECIAL NOTE: This report IS NOT an official publication of the National Cooperative Highway Research Program, Transportation Research Board, or the National Academies of Sciences, Engineering, and Medicine.

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The purpose of each scan, and of Project 20-68D as a whole, is to accelerate beneficial innovation by facilitating information sharing and technology exchange among the states and other transportation agencies and identifying actionable items of common interest. Experience has shown that personal contact with new ideas and their application is a particularly valuable means for such sharing and exchange. A scan entails peer-to-peer discussions between practitioners who have implemented new practices and others who are able to disseminate knowledge of these new practices and their possible benefits to a broad audience of other users. Each scan addresses a single technical topic selected by AASHTO and the NCHRP 20-68A&D Project Panel. Further information on the NCHRP 20-68A&D U.S. Domestic Scan program is available at

https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1570

This report was prepared by the scan team for Domestic Scan 19-01, *Leading Practices for Detailing Bridge Ends and Approach Pavements to Limit Distress and Deterioration*, whose members are listed below. Scan planning and logistics are managed by Arora and Associates, P.C.; Harry Capers is the Principal Investigator. NCHRP Project 20-68A&D is guided by a technical project panel and managed by Andrew C. Lemer, PhD, NCHRP Senior Program Officer.

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Disclaimer

The information in this document was taken directly from the submission of the authors. The opinions and conclusions expressed or implied are those of the scan team and are not necessarily those of the Transportation Research Board or its sponsoring agencies. This report has not been reviewed by and is not a report of the Transportation Research Board or the National Academies of Sciences, Engineering, and Medicine.

Scan 19-01

Leading Practices for Detailing Bridge Ends and Approach Pavements To Limit Distress and Deterioration

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Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ABC	Accelerated Bridge Construction
AC	Asphalt Concrete
ACP	Asphalt Concrete Pavement
ADT	Average Daily Traffic
APJ	Asphalt Plug Joint
BD	Bridge Design
BDA	Bridge Design Aids
BDM	Bridge Design Manual
BSB	Bridge and Structures Bureau
CALTRANS	California Department of Transportation
CCB	Continuous Concrete Bridge
CCS	Continuous Concrete Slab
cfs	Cubic feet per second
CIP	Cast in place
CWPG	Continuous Welded Plate Girder
deg	Degree
DHV	Design Hourly Volume
DOT	Department of Transportation
ECC	Engineered Cementitious Composites
EOR	Engineer of Record
EPS	Expanded Polystyrene
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FRP	Fiber Reinforced Polymer
ft	Feet

GFRP	Glass Fiber Reinforced Polymer
GRS	Geosynthetic Reinforced Soil
HMA	Hot Mix Asphalt
HP	H-Piles
Hw	Height of Wall (passive pressure calculation)
IAB	Integral Abutment Bridge
IBS	Integrated Bridge System
Iowa DOT	Iowa Department of Transportation
IM	Dynamic Load Allowance
ksf	kips per square foot
LaDOTD	Louisiana Department of Transportation and Development
LRFD	Load and Resistance Factor Design
LTRC	Louisiana Transportation Research Center
MaineDOT	Maine Department of Transportation
MassDOT	Massachusetts Department of Transportation
MDOT	Michigan Department of Transportation
mil	One thousandth of an inch (0.001 inch)
MMFX	Corrosion Resistant Alloy Steel
MnDOT	Minnesota Department of Transportation
MR	Movement Rating
MSE	Mechanically Stabilized Earth
MTD	Memo to Designers
NACE	National Association of County Engineers
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
NYSDOT	New York State Department of Transportation
OGS	Open-Graded Stone
P3	Public-Private Partnership

PCC	Plain/Portland Cement Concrete
PCCP	Portland Cement Concrete Pavement
PCI	Precast Concrete Institute
PCPT	Piezocone Penetration Test
PennDOT	Pennsylvania Department of Transportation
PP	Passive Pressure
PPCB	Pretensioned Prestressed Concrete Beam
PS	Prestressed
PSP	Perforated Steel Pipe
PVC	Polyvinyl Chloride
R/S	Roadway/Slab
RSB	Rolled Steel Beam
RSF	Reinforced Soil Foundation
SDDM	Structures Design and Detailing Manual
SDDOT	South Dakota Department of Transportation
SIAB	Semi-Integral Abutment Bridge
STIC	State Transportation Innovation Council
SE	Settlement Load
SS	Standard Specification
TDOT	Tennessee Department of Transportation
TPB	Treated Permeable Base
TRB	Transportation Research Board
UDOT	Utah Department of Transportation
UHPC	Ultra High Performance Concrete
UMass	University of Massachusetts
VDOT	Virginia Department of Transportation
WS	Wearing Surface
WSD	Working Stress Design
WSDOT	Washington State Department of Transportation

Executive Summary

Introduction

Domestic Scan 19-01, *Leading Practices for Detailing Bridge Ends and Approach Pavements to Limit Distress and Deterioration*, conducted November 18-22, 2019, consisted of representatives from twelve state agencies who shared details and lessons learned in this area of bridge design, construction and maintenance. While the original scan statement focused on details related to deterioration at bridge ends in jointless bridges, most bridge end issues, such as the "bump at the end of the bridge", exist in bridges with or without deck joints.

Summary of Findings and Recommendations

Due to the variety of geological, geotechnical and climate conditions each state is faced with, there is no "one size fits all" solution to resolving the "bump at the end of the bridge." The initial findings are broken into the following categories: abutments, joints, approach slab parameters, embankment treatment and drainage.

Abutments Many state design manuals have a design selection hierarchy organized per parameters such as span length and skew. Nomenclature varied slightly by state, but the main abutment types used in jointless bridges are integral and semi-integral. Abutmentless bridges are also being used, though not as widespread. Pile treatment (preventive measures for pile, jacket, sacrificial loss) was also discussed.

Joints Most states agreed that the preference was to eliminate joints from the bridge deck. Moving joints away from piers and past abutments obviously means movement and drainage is accommodated elsewhere. If the approach slab is detailed as integral with the abutment, the joint exists at the approach slab to pavement transition. If the joint is just past the abutment, drainage and movement is accommodated at the abutment backwall.

Approach Slab In some states, approach slab details are in the contract plans with the backfill and grading plans while in other states they are located with the bridge details. Consequently, the approach design is the responsibility of the road designer in some states and the bridge office in other states. Other variabilities in approach slab parameters are slab depth (at grade or buried), movement, slab length, thickness, reinforcing, use of sleeper slab, embankment separation, skew, barrier rail placement and movement end.

Embankment Treatments Many of the participating host states have spent considerable time investigating and trying alternative embankment parameters. Some of these include the boundaries specified for compaction, the compaction requirements and type of backfill. Recommendations included increase importance of design for backfill compaction and backfill material. Host states indicated clarification is needed as to what states define as "free draining material", since it seems to vary from state to state.

Drainage Controlling and designing for effective drainage management is the key to structure longevity. Drainage on and off the deck was a topic of discussion. Water causes damage when allowed to drain to the wrong place and states presented methods to route water where it will not cause damage such as slope erosion, undercutting corrosion.

PLANNED IMPLEMENTATION ACTIVITIES

The team compiled a preliminary list of state and national conferences which to present the scan findings. Presentations are planned at state conferences such as Pacific Northwest Bridge Maintenance Conference, Tennessee Engineering Conference, Michigan Annual Bridge Conference, Maine Transportation Conference, Ohio Transportation Engineering Conference (OTEC) and Louisiana Transportation Conference. Presentations are also planned at national conferences such as Transportation Research Board (TRB) Annual Conference, AASHTO Bridge Preservation Committee and National Association County Engineers (NACE). Additionally, the team will investigate avenues for presenting workshops and webinars and submitting articles to journals.

Introduction

This chapter presents the background impetus for this scan. The scan objectives and methodology are presented, followed by descriptions of the participating host agencies and the scan team.

1.1 Background

Faced with an aging infrastructure and limited resources, transportation agencies seek ways to minimize maintenance and future repair costs to their inventory. Agencies identify bridge deck joints as a high priority item, in terms of maintenance and potential for adjacent bridge member damage. Therefore, one concept to increase inventory sustainability is to minimize the number of joints on the structure. Moving joints off the bridge means thermal expansion and contraction of the structure once accommodated at deck joints is now all transferred to the bridge ends.

Detailing and maintaining joints at bridge ends is notoriously challenging. The transition from one structure to another often becomes noticeable to road users as a "bump at the end of the bridge". Additionally, the displacements and forces at these locations are particularly prone to cause damage to riding surfaces and structural elements. Bridge owners have adopted a wide variety of design details to avoid this damage and have sought to understand the causes of observed distress.

National Cooperative Highway Research Project (NCHRP) 20-68D Domestic Scan 19-01, ***Leading Practices for Detailing Bridge Ends and Approach Pavements to Limit Distress and Deterioration***, will compile leading design and management practices for minimizing structural distress and surface discontinuity on approaches to jointless bridges.

1.2 Objectives

The scan objective is to gather agencies' experience in dealing with distresses observed on approaches to jointless bridges. The goal is to explore such leading-edge solutions as the Minnesota Department of Transportation's differentiation criteria for the selection of appropriate abutment types based on geometric characteristics, wingwall configurations, abutment height and superstructure beam depth. The key information to be gained is the identification of details that have been implemented at the ends of structures that achieve a jointless bridge while minimizing the structure distress, maintenance and repair costs, considering issues and strategies such as

1. Isolating the approach stab from the backfill material beneath it at the end of the bridge to allow for adequate movement.
2. Connections between components at the ends of bridges including, but not limited to bridge decks, abutment backwalls, abutments, abutment foundations, and the approach pavement.
3. End of bridge drainage systems.
4. Structure length, substructure skew, and other geometric characteristics that dictate the use of unique components or details.
5. Supporting design calculations critical to the resolution of issues.
6. Rehabilitation solutions to repair the deterioration and distress associated with the details at the ends of bridges that are not functioning as anticipated

As such, the topics of interest to the scan team were:

- States' joint location, justification and performance
- Joint location design/movement accommodation
- Approach slab connection (expansion joint fore/aft) and design details
- Backfill requirements
- Abutment type and design
- Drainage
- Bump at the end of the bridge

While the original scan statement focused on details related to deterioration at bridge ends in jointless bridges, the reader will find that most bridge end issues, such as the "bump at the end of the bridge", exist in bridges with or without deck joints.

Scan results will be of specific interest to American Association of State Highway and Transportation Officials (AASHTO) Subcommittee T-9 on Bridge Preservation and the AASHTO Subcommittee T-18 on Bridge Management, Evaluation and Rehabilitation. This report provides current information on best practices for minimizing the "bump at the end of bridge". It also provides valuable information to the AASHTO Committees for future consideration when developing their work plans and research needs. A synthesis of this information would also be of interest to State Departments of Transportation (DOTs) and Federal Highway Administration (FHWA) offices, other Federal and local agencies involved in bridges, university researchers, consultants, county, and local DOTs.

1.3 Methodology

The first action the team conducted was a desk scan to provide an overview of how transportation departments are detailing bridge ends of jointless bridges. The desk scan involved internet-based literature review, review of state bridge design manuals, and interviews with selected departments of transportation. Based on review of state bridge design manuals, jointless bridge design and use among agencies were divided into 4 categories: 1) Prioritizes jointless bridges and working to improve details, 2) Using some form of jointless bridge details, 3) discontinued use because of bad experience, 4) never used. The desk scan also drafted amplifying questions to be sent to selected DOTs.

The team met August 23, 2019 in Washington DC to review the desk scan and to rank and select agencies to invite in terms of perceived benefit to the scan purpose. At this meeting, the team also finalized the amplifying questions. The scan management agency, Arora and Associates, P.C., invited selected agencies and sent confirmed host agencies the amplifying questions. The finalized amplifying questions are presented in Appendix A.

November 18-22, 2019, the scan team and host agencies met to conduct the scan. Attendance consisted of representatives from twelve state agencies who shared details and lessons learned in bridge end design. Each state was given two hours to present details used in their state and answer questions of the scan team and fellow presenters. With a couple of exceptions, all invited agency representatives attended all presentations.

1.4 Host Agencies

The scan team selected participating agencies that would represent diverse geologic and climate regions, agencies with active research programs, innovative designs (new, retrofit, accelerated construction) and stated objectives of jointless bridges. Participating agencies are listed in **Appendix B** and also shown in **Figure 1**. The guiding criteria and the representing states are:

a. Severe climate challenges (cold/freezing conditions) (Massachusetts, Minnesota, Pennsylvania, South Dakota)

b. Successful and/or innovative design details (Iowa, Massachusetts, South Dakota, Virginia)

c. Unique design and/or retrofit procedures (Iowa, Pennsylvania, South Dakota, Utah)

d. Active research programs on “bump at the end of bridge” (Iowa, Minnesota, Louisiana)

e. Long history of integral piers and jointless bridges (South Dakota, Tennessee)

f. Seismic exposure (California, Washington)

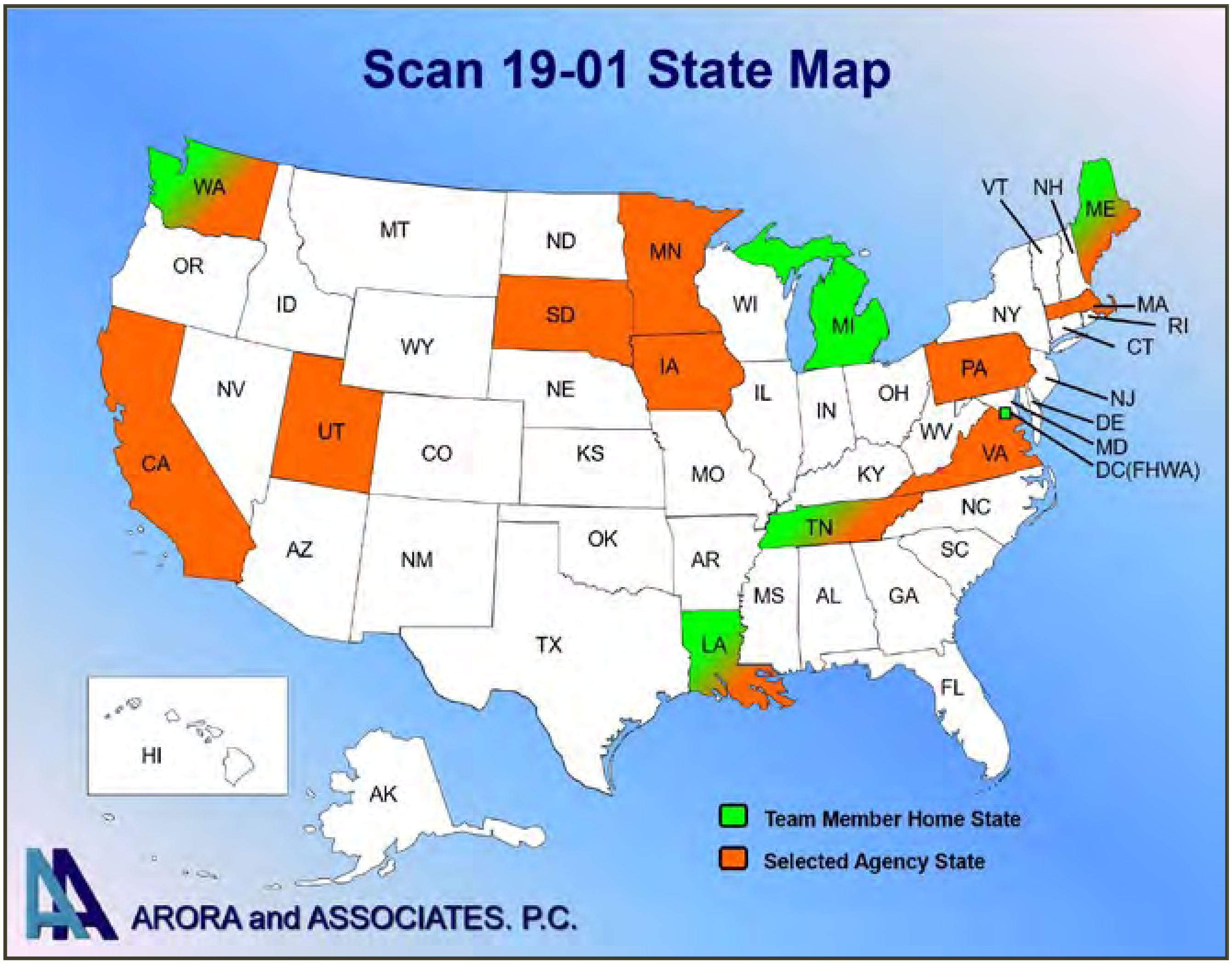


Figure 1 Scan Team and Host Agencies

California Department Of Transportation (Caltrans)

Caltrans *Memo to Designers 5-2: Diaphragm Abutments* specifies integral abutment bridges shall not be used for new bridges without approach slabs, with movement exceeding a ½ inch. The most used abutment is non-integral seat-type. Of the seat-type are short seat and high cantilever. Seat type abutments are more predictable in seismic regions because the seat can be sized for thermal movement, creep, shrinkage and seismic demands and thus can extend 36 feet high before requiring seismic design. Seat type abutments enable separation of superstructure from embankment and the backwall can be designed to break off in a seismic event.

The second most used abutment is integral diaphragm type. Diaphragm abutments are on piles or footings with piles and are basically considered synonymous with integral abutments. Integral abutment stem heights less than 10 feet from soffit to bottom of wall do not require seismic design.

Caltrans had the longest embankment improvement region specifying full width 150 feet beyond each abutment be compacted to at least 95% relative compaction. **Figure 2** shows a typical Caltrans 2-span reinforced concrete box girder bridges with diaphragm abutments

Figure 2 Caltrans Typical Bridge with Diaphragm Abutments

Iowa Department Of Transportation (Iowa DOT)

Iowa has solved their approach slab settlement by a) extending the backwall corbel that the approach slab sits on to 15"; b) using a flooded backfill method for compaction behind wall/under approach slab. Their longest continuous welded steel girder bridge is 426 feet long and built in 2001 (**Figure 3**).

Figure 3 Iowa 426 foot long Continuous Welded Steel Girder

Iowa, long active in integral bridge research and design implementation, is sponsoring a research project on semi-integral abutment performance that involves monitoring in-service semi-integral abutment bridges (see Section 5.1). Additionally, Iowa's Bridge and Structures Bureau director is the chair of AASHTO T-9 bridge preservation committee. T-9 issued NCHRP Synthesis (25-05, Topic 51-02) which closely parallels this scan.

Louisiana Department Of Transportation And Development (LaDOTD)

Louisiana currently has three pilot projects for jointless bridges. While state has not historically done jointless bridges, they actively researched the bump at the end of the bridge by focusing specifically on their approach slab design. The state conducted a full scale research on their Bodcau Bayou bridge by placing pressure cells on the backwall behind abutments, strain gauges on the piles, girders and deck reinforcement, abutment tiltmeters and deformation meters, some of which are shown in **Figure 4.** The research resulted in increased slab thickness and reinforcement, addition of sleeper slabs and reinforced soil in the sleeper slab area.

a) Abutment Pressure Cells

b) Pile Strain Gauges

Figure 4 Louisiana DOTD Bodcau Bayou Instrumentation

Maine Department Of Transportation (MaineDOT)

MaineDOT has been designing jointless structures since 1946. MaineDOT standard practice is to design jointless structures, only installing joints where necessary due to large movements. Buried approach slabs anchored to the backwall with a designed reinforcing bar is the preferred method of transitioning stiffness from the structure to the approach fills. The DOT maintains approximately 4,000 structures. Their longest single span concrete structure is 88 feet (**Figure 5**).

Figure 5 MaineDOT Bourne Avenue Bridge, Wells ME

Massachusetts Department Of Transportation (MassDOT)

MassDOT has been building jointless bridges for 100 years with details evolving over time. They currently use a buried approach slab anchored to the backfill soil with key details while the abutment moves under the slab. This eliminates the "bump at the end of the bridge" by providing a gradual transition of settlement from end of slab to abutment. Their longest steel span with integral abutment, built in 2018, is the 334 foot overall length three-span bridge over Malden River (**Figure 6**).

Figure 6 MassDOT Everett - Medford Route 16

Minnesota Department Of Transportation (MnDOT)

Relatively new to the integral abutment concept, the state's first integral abutment bridge was built in 2001. Several years ago, MnDOT changed their approach panel details to require that barriers be placed integrally on top of the approach panel instead on being mounted on top of parallel wingwalls (**Figure 7**). This has significantly reduced drainage and erosion issues at bridge ends. The state connects the approach slab to the abutment with a bent bar and has standardized backfill details.

Figure 7 MnDOT Semi-Integral Abutment with Barrier on top of Approach Panel

In 2013 MNDOT published Synthesis of Bridge Approach Panels Best Practices Technical Report MN/RC 2013-09. Based on findings from other states the report concluded that MnDOT should consider the use of strip seals at the joint between the end of the approach panel and the pavement. To keep the joint watertight the strip seal would need a "kick-up" at the gutter, which would require running a barrier to the end of the approach panel and beyond, which is not cost effective. In lieu of using strip seals MnDOT has been experimenting with various types of compression seals to improve joint performance on integral and semi-integral bridges.

Pennsylvania Department Of Transportation (PennDOT)

PennDOT has been building integral abutment bridges since 1991. They had a Public-Private Partnership (P3) Rapid Replacement Project that replaced 558 bridges over 4 years, many of which were integral abutment bridges. Their longest jointless concrete bridge is a 524 foot five-span prestressed concrete bulb-tee beam built in 2018. The longest jointless steel bridge is a 373 foot two-span welded plate girder built in 2012 (**Figure 8** PennDOT 373 foot. Steel Jointless Bridge). They have developed a detailed integral abutment design spreadsheet, available on their website, based on AASHTO and PennDOT standards and details.

Figure 8 PennDOT 373 foot. Steel Jointless Bridge

South Dakota Department Of Transportation (SDDOT)

South Dakota has truly diverse geology. The state is divided in half by Missouri River, with the western half dominated by expansive shale and the eastern half is glacial till. Depth of till varies and can be up to 200 feet and underlaid by bedrock. Till generally has low strength and is highly erodible and therefor a large majority of everything east of the river is on deep foundations (100-120 foot long piles) and very few spread footings. SDDOT manages and maintains 1253 state bridges and they currently build 95% of their bridges as integral (**Figure 9**).

Figure 9 SDDOT Steel Girder Bridge with Integral Abutment

Tennessee Department Of Transportation (TDOT)

Since constructing their first integral abutment bridge in 1964, Tennessee has long been recognized as the leader in integral abutments innovation, initially championed by Ed Wasserman. The state has pushed the limits of jointless bridges, by their own account, somewhat via trial and error. At 1,175 feet the SR-50 over Happy Hollow Creek (**Figure 10**) is Tennessee's longest concrete integral abutment bridge. The SR-50 designers took advantage of the flexible towers and the curved alignment to accommodate movement due to creep, shrinkage and temperature changes. The majority of their jointless, integral abutment bridges span 400 feet in steel and 800 feet in concrete.

Figure 10 TDOT SR-50 over Happy Hollow Creek

Utah Department Of Transportation (UDOT)

UDOT has been constructing jointless bridges since 1972, focusing on water containment on bridge decks. The goal being to prevent water from progressing down onto key structural components like bearings which at the time were commonly steel elements, pin and hanger details, and substructure elements. Since the early 1970's UDOT's details have progressed to standardize integral abutments and provide standard detailing for semi integral abutments. Standard details have also been developed to place the bridge expansion joint at the sleeper slab with parapets integrated directly into the approach slab. This channelizes water on the deck all the way to the approach pavement interface. To protect the required expansion joint, catch basins are required to be placed on the upstream side of the expansion joint for any flows larger than 0.1 cfs. Although this has effectively protected structural aelements from water, the "bump at the end of the bridge" is still an ongoing concern. The state is a leader in the use of rapid delivery projects, having done many "moves" and "slides". The 81 foot simple span precast prestressed girder bridge in **Figure 11** was slid into place in 2010 with the approach slabs attached.

Figure 11 UDOT F-973 Bridge Slide Project with Attached Approach Slabs

Virginia Department of Transportation (VDOT)

VDOT is responsible for 21,000 new and existing bridges and initiated full implementation of jointless bridges 8 years ago. Their innovative "Virginia Abutment" (**Figure 12**) moves the joint behind the backwall with a drainage trough. However, due to the cost of construction, the Virginia Abutment is the last detail in the department's abutment selection hierarchy. VDOT believes their use of select backfill is the best solution to mitigate the "bump at the end of the bridge".

Figure 12 Virginia Abutment (courtesy Virginia DOT)

Washington State Department Of Transportation (WSDOT)

A high seismic state, WSDOT uses primarily semi-integral abutments or L-shape abutments depending on the bridge length. Abutments are designed to be independently stable for seismic loading, meaning the state does not use the superstructure to counter seismic loading. For seismic design, they allow the backwall to fuse and be repaired allowing the joints to be sized for only normal design movement (thermal). Like MnDOT, WSDOT places the traffic barrier on the approach slab. WSDOT is a leader in seismic design research and implementation. The Grand Mound to Maytown bridge crossing over I5 (**Figure 13**) consists of an innovative, moment-resisting precast concrete bent system suitable for accelerated bridge construction in high seismic zones.

Figure 13 WSDOT I5 Grand Mound to Maytown Bridge

1.5 Scan Team

The seven member scan team consisted of one FHWA representative, the AASHTO Chair, four DOT representatives and a subject matter expert. Contact information and biographical sketches are given in Appendices C and D and state representation is shown in **Figure 1.**

CHAPTER 2

Historic And Current Practice

This chapter provides background on when states began using jointless bridges. It presents the longest jointless bridge span per state and each state's current inventory per superstructure type. The chapter concludes with specific design manual guidance per state.

2.1 Historical Use and Performance

This section documents when states constructed their first jointless bridge. The terms "integral" and "semi-integral" indicate how the states detail their jointless bridges and are defined in Section 3.1. This section also includes problems states have experienced and discontinued details.

2.1.1 First Jointless Bridge

This section gives the year each state identified that their first jointless bridge was built. Some states provided additional information as to the evolution toward implementing jointless bridges. More detail on evolution of abutment types used is provided in the Section 3.1.1.4 - State Preference.

Caltrans: Caltrans has been using integral abutments since the early 1900's. The oldest recorded bridge with integral abutment (rigid frame) is Carroll Canal (Dell Ave) in Los Angeles, built in 1907.

Iowa DOT: Integral 1965, semi-integral 1963, Longest Prestressed concrete beam bridge, 557 feet x 40 feet built in 1999, Longest Prestressed concrete Bulb-Tee beam bridge, 567 feet x 43 feet built in 2001, Longest Continuous Welded Steel Girder bridge, 426 feet x 30 feet built in 2001.

LaDOTD: LaDOTD's first jointless bridges were three bridges constructed as part of a pilot project in 2013.

MaineDOT: MaineDOT's first jointless bridge is the Wardwell Bridge in Oxford, ME, constructed in 1946.

MassDOT: MassDOT's first "modern" integral abutment bridge, which used pretty much the state's current details, was built in 1990. MassDOT does not have semi-integral abutment bridges in the sense that the beams are encased in a concrete diaphragm/abutment stem that can rotate or move on a footing. They do however use jointless bridges where the beams sit on conventional abutments but are free to rotate and move however there is no joint that extends to the roadway surface. MassDOT has been using such jointless bridges since the formation of the Bridge Section in the early 1920's. All adjacent prestressed concrete bridges have been jointless ever since they first started using them in the mid-1950s to replace bridges that had been destroyed by a hurricane in 1956.

MnDOT: MnDOT began constructing jointless "contraction" style abutments in the 1960's. These were a forerunner to an integral style abutment. They built their first fully Integral abutment bridge in 2001 and their first Semi-integral in 2005.

PennDOT: The state's first integral abutment bridge was constructed in 1991.

SDDOT: SDDOT has had jointless bridges on short spans since 1920's. Integral abutments, with no approach slabs have been used since the late 1940's. They presently have a continuous concrete bridge (CCB/slab bridge) from 1948 in their inventory. Prestressed beams with integral abutments started in the 1960's with no approach slabs. Many integral bridges, regardless of super structure type, are still in service.

TDOT: TDOT's first integral bridge was built in 1964. Jointless became standard policy in 1970.

UDOT: UDOT standardized the use of fully integral abutments around 1972. Although this change in standards addressed the abutments for both precast concrete girders and steel girders, steel girders still allowed the use of joints at in-span hinges. UDOT's first semi-integral abutments were used in 1997 as part of the I-15 Reconstruction Design-Build.

VDOT: First known integral bridge is Hinton Road over Muddy Creek, built in 1982.

WSDOT: WSDOT's first semi-Integral bridge was built in the 1960s.

2.1.2 Problems with Respect to Jointless Bridges

Many problems were similar among states. This section briefly discusses specific issues each state experienced.

Caltrans: Caltrans identified the following issues:

- Embankment Foundation Issues - consolidation of soft foundation soils
- Embankment Issues - erosion of end-slope in front of abutment, consolidation of approach embankment, poor compaction, voids behind the abutment
- Drainage Issues - water intrusion behind the abutment, along the wingwalls, and under the approach slab
- Joint Issues – difficult to build and maintain
- Approach Slab Issues - deflecting due to heavy traffic loads, cracking due to construction methods, rotation due to differential settlement
- Pavement Issues - pavement growth, damaged pavement against new approach slabs.

Iowa DOT: The state identified the following issues:

- Erosion around abutments and berm areas
- Approach pavement falling off paving support
- Corrosion of piling under abutment footing

- Water leaking under abutment and eroding berm
- Failure of paving supports
- Damage to top of deck from snowplow impact at joint due to settlement of approach pavement
- Thermal restraint resulting in deck cracking
- Erosion behind wingwalls.

LaDOTD: Due to the relatively young bridge age of their first integral abutment bridge built in 2013, no problems have been experienced.

MaineDOT: MaineDOT identified the following problems with their jointless bridges:

- Settlement at interface with approach pavement
- Erosion of fill slope exposing steel piles
- Concrete cracking at bridge ends
- Concrete cracking in abutments
- Pavement cracking.

MassDOT: MassDOT has not had any problems with jointless bridges themselves, whether they are integral abutment or just jointless. These have worked very well for decades in preventing the deterioration of the beams and substructures.

MnDOT: MnDOT has experienced some issues with premature failure of the joint between the approach panel and pavement, and some approach panel & deck corner cracking. The approach panel and deck corner cracking has been reduced by improving the integral abutment concrete placement requirements. MnDOT has also noted some issues with settlement of the fill beneath integral abutments resulting in exposure of the piling. This is much more likely to occur over stream crossings where periodic flooding or high water may degrade portions of the embankment causing the rip rap to settle.

PennDOT: PennDOT has settlement and heaving of approach slabs, leaking on outside of facia beams. Also seen hydraulic issues on shorter bridges that led to scour problems and issues with fines material washing out from behind the abutment.

SDDOT: The polyethylene underdrains behind the abutments got plugged, ends silted over and the drains were crushed so SDDOT switched to PVC underdrains. SDDOT has also experienced settlement and voids under approach slabs, settlement of sleeper slabs at the ends of approach slabs, corrosion of piling under integral abutments due to loss of surrounding material from erosion and approach slab cracking. SDDOT also had backwall cracking issues due to beam rotation and they now use a ½” preform around the girder at the interface.

TDOT: Problems they have experienced are damage to end of approach slab from impact as well as occasional beam pullout at backwall.

UDOT: Older inventory of jointless bridges lacked adequately sized expansion joints at the approach slab to pavement interface. Because of this lack of accommodation for thermal expansion, the pavements have required maintenance. Asphalt has required the most maintenance, but cement pavements did allow for some expansion gap and so did not experience as many problems. Newer construction has resolved this issue with proper expansion joint sizing at sleeper slab stems.

VDOT: VDOT reported experiencing problems during retrofits. They use a deck extension to remove the joint at the end. This is problematic when the approach slab is keyed into the backwall.

WSDOT: WSDOT has experienced leaking joints, bearing damages, extensive maintenance and repairs, safety, increase costs, lack of seismic performance and approach slab settlement

2.1.3 Discontinued and Revised Jointless Bridge Details

This section presents details states have discontinued. Brief explanations are provided but more in-depth explanations are provided in subsequent sections.

Caltrans: Caltrans is currently phasing out use of sleeper slabs with diaphragm abutments, Type N(45) for use in jointless bridges. It is typically used for in-kind replacements or widenings.

Iowa DOT: Iowa DOT was seeing the approach slab ledge in the back wall breaking off. It was determined this was due to improper placement of bent rebar in the corbel and voids under the approach slab (**Figure 14**). This seat was only 8 inches in early designs but Iowa DOT has since extended it to be 1 foot-3 inch (**Figure 39**).

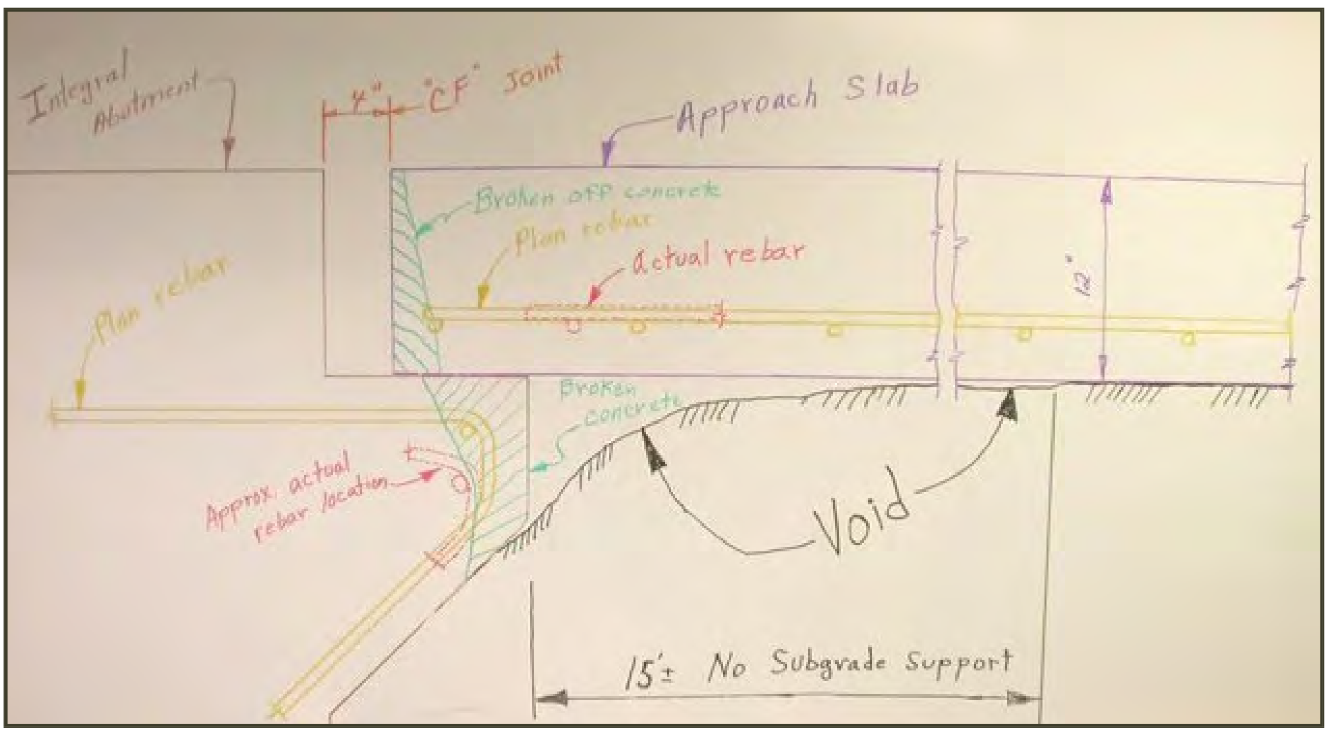


Figure 14 Iowa DOT Discontinued Detail - Broken Seat

Additional changes at Iowa DOT include:

- Initial abutment width of 2 feet-6 inches was increased to 3 feet-0 inches.
- Pile sizes have been updated to use more compact/plastic sections for higher loads and movements. H-Piles, HP10x42 to HP10x57.
- Prebored holes were initially filled with granular material or left open. Bentonite is now used to fill prebored holes. Initially used 8 feet prebored hole depth. The state now uses 10 feet up to 15 feet in special situations.
- Drainage behind the abutment was added, with granular backfill.
- Use epoxy reinforcement in backwall instead of black reinforcement.
- Replaced foam planks in joint with crumb rubber.
- Approach pavement is tied to slab bridges.

LaDOTD: Note that while LaDOTD's response pertains to conventional bridges rather than jointless/integral abutment bridges, LaDOTD directly correlates the bump at the end of the bridge to their approach slab design, and these revisions are intended to provide better approach slab performance. Details they no longer use include:

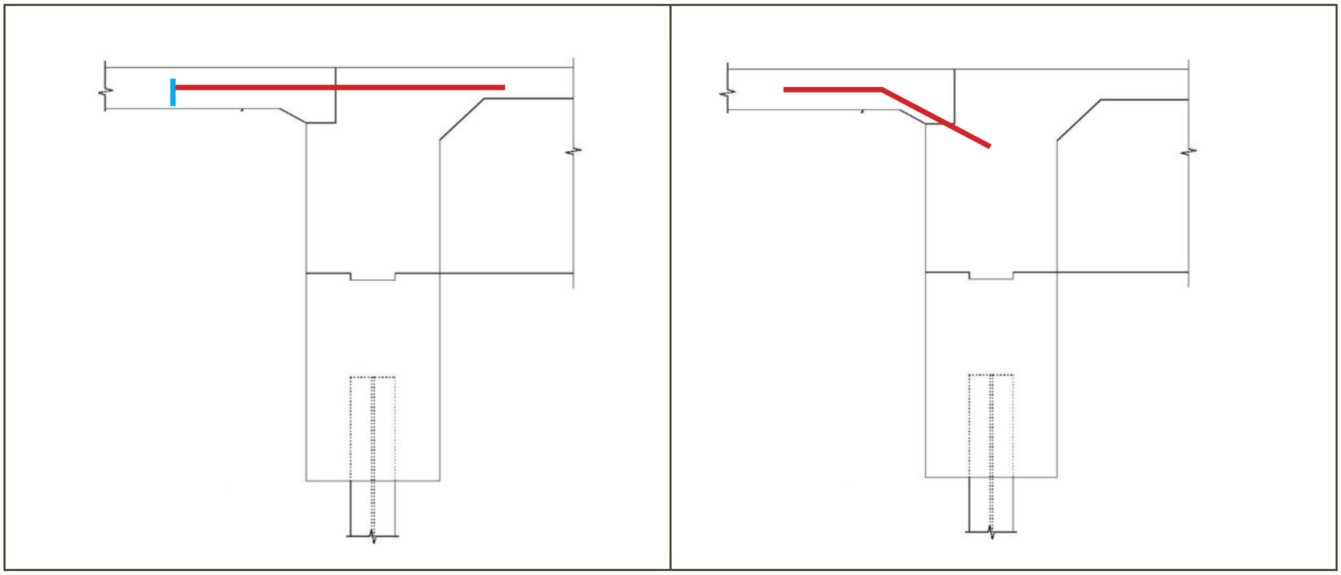
- Approach slab horizontally doweled to pavement
- Double-row of anchor bolts from expansion joint assembly through approach slab into end bent
- Pile-supported approach slabs
- 2 inch asphalt recess layer on top of approach slab.

MaineDOT: Approach slabs are now mandatory because end details without approach slabs have all settled. MaineDOT no longer allows welding steel beams directly to steel piles due to tolerance issues. Frequently steel beams would not line up with piles once driven.

MassDOT: MassDOT has two types of jointless bridges they no longer use:

- Three span abutmentless bridges where the beams cantilever over piers and the ends are embedded in what is a backwall to prevent earth from spilling through but have no abutment stems or footings. These were used from the 1930s to the 1950s, but they were only practical for short spans.
- Trestle type of structures, where reinforced concrete slabs were built integrally with reinforced concrete trestle bent caps that sat on pile bents, mainly of timber. The last of these was constructed about 1981. Generally, the state stopped using timber piles because of the hazardous materials used for preservation.

MnDOT: The first iteration of integral abutment bridges included a horizontal tie bar that connected the approach panel to the back of the abutment (**Figure 15a**). This detail resulted in transverse cracks on the approach panel near the end of the tie bar. The detail has since been updated as shown in **Figure 15b** and the transverse cracking has been eliminated.



a) First iteration connection details *b) Updated connection details*

Figure 15 MnDOT Approach Panel Connection Details

PennDOT: Adjacent prestressed concrete box beams have not been used on PennDOT Standard projects. However, several of these adjacent prestressed (PS) concrete box beam bridges were designed and constructed as part of the P3 Rapid bridge replacement program. PennDOT is reconsidering the use of this bridge type on standard projects.

SDDOT: SDDOT tried and discontinued use of a 6 inch void behind the backwall. They also tried but discontinued use of soil reinforcing, mechanically stabilized earth, (MSE) wraps in the 1990's.

TDOT: The state's details have been generally consistent over the years with small changes being made from time to time. TDOT used to make end of slab 90 degrees (deg) to roadway, but now it is parallel to end of bridge.

UDOT: From abutment to abutment UDOT's details have remained essentially the same over the years. However, the approach slab and sleeper slab have seen several revisions. To control the "bump at the end of the bridge," dowel bars were placed connecting the approach slab to the first precast concrete panel. This detail did not perform as designed because even if these greased dowel bars were lined up perfectly with the direction of motion, which they weren't by and large, any settlement at the end of the approach slab would cause these bars to bind and not translate. Not only did this detail not make the situation better, it made it worse and required replacement projects to remove the dowels.

VDOT: Compression seal joints are not allowed, and silicone use is limited. They do not use approach slabs under sidewalks and feel the sleeper slab value is debatable if select backfill is used.

WSDOT: Many of the state's existing bridges were constructed with ACP to back of pavement seat. Now reinforced concrete approach slabs are required for all new bridges and widenings.

2.2 Current Inventory per State

Most of the host states indicated preference to jointless bridges. Caltrans and LaDOTD, each for different reasons, do not prioritize jointless bridge use. States accomplish jointless bridges with a variety of abutment details which are defined in Section 3.1 . **Table 1** shows each state's predilection toward jointless bridges and the longest jointless bridge in each state, with no skew, for steel and concrete superstructures. State explanation for how they identify need for jointless bridges and preferred abutment detail are presented in Section 3.1, "Abutments".

	Encourage use of Jointless Bridges?	Longest Jointless Bridge (no skew)	
		Steel	Concrete
Caltrans	Neutral	318'	860'
Iowa DOT	Yes	426'	567'
LaDOTD	No	NA	600'
MaineDOT	Yes	Single Span: 206'-8" (Brownville Jct.) Longest bridge: 282'-0" (2-span in Weston)	Single Span, 88'-0" (Wells) Longest bridge: 510'-0" (7 span in York)
MassDOT	Yes, and standard details are intended to make jointless bridges practical for most of the typical span ranges in their bridge inventory.	Non-integral jointless = 104' Integral Abutment = 335'	Non-integral jointless = 176'; Integral Abutment = 417'
MnDOT	Yes, default choice	*327'*	*398'*
PennDOT	Yes	373' bridge with joints at ends of approach slabs (off the bridge). 153' with no joints.	524' bridge with joints at ends of approach slabs (off the bridge). 178' with no joints.
SDDOT	Yes	433'	699'
TDOT	Yes	536'	1175' jointless. 2700' with joints only at abutments.
UDOT	Yes	435'	403' Precast
VDOT	Yes	Route 340 over South Fork Shenandoah River in Warren County (0340-093-1901) at 1,910 feet	-
WSDOT	Requires for new bridges (match for bridge widening)		

Table 1 Longest Jointless Bridge

2.2.1 Superstructure Type

Each state's current inventory per superstructure type is given in **Table 2**, followed by state comments.

Superstructure Distribution, % (quantity)			
	Steel	Cast-in-Place	Precast
Caltrans	12% (3054)	86% (22,914) concrete -	
Iowa DOT	-	-	-
LaDOTD	60%	35%	-
MaineDOT	51.5% (1471)	36.5% (1043)	6.9% (197)
MassDOT	60%	13%	23%
MnDOT	31%	12%	43%
PennDOT	15%	0	85%
SDDOT	33% (412)	52% (657)	14% (180)
TDOT	10%	0	90%
UDOT	33% (640)	27% (538)	40% (776)
VDOT	53%	34%	13%
WSDOT	23%	35%	41%

Table 2 Current Superstructure Inventory in percentage

Caltrans: Caltrans database does not track whether a concrete bridge is cast-in-place or precast. The last 2% (620) are other material types, based on a total inventory of 26,588 bridges.

MnDOT: Over the past 15-20 years, prestressed concrete beam superstructures have been used for approximately 80-85 percent of MnDOT's new bridges.

SDDOT: There are approximately 4,500 non-state bridges that SDDOT is not involved.

UDOT: UDOT noted that if one looks at just the steel and precast prestressed girder bridges, they have 45% steel to 55% precast prestressed.

WSDOT: The WSDOT numbers in **Table 2** represent the state's bridge system based on deck area. Nearly 90% of WSDOT bridges built in the past 10 years are precast prestressed/post-tensioned concrete.

Iowa DOT, LaDOTD, MaineDOT, MassDOT, PennDOT, TDOT and VDOT had no additional comment.

2.3 Design Manual Guidance

This section presents what guidance state design manuals provide for bridge type selection. Following the general guidance are the specific limits states impose on span length, skew, abutment wall heights, slab lengths, and construction sequence. The last two items in this section present design manual calculations and any design amendments included in design manuals.

Caltrans: Caltrans is in the process of updating Memo to Designers (MTD) and Bridge Design Aids (BDA) manuals, but the following is existing design guidance for jointless bridges that can be found on the state's website (2):

- AASHTO Load Factor and Resistance Design (LRFD) 8th Edition CA Amendments Section 3: Loads and Load Factors
- Seismic Design Criteria Section 6: Foundations, Abutments and Soil-Foundation-Structure Interaction
- Memo to Designers (MTD) 5-1: Abutments – type selection of abutments, LRFD requirements, horizontal loading and soil pressure, alternative backfill materials, scour effects, seismic design requirements, limitations on the use of shallow foundations, seismic downdrag and lateral spreading, mechanically stabilized embankment abutments
- MTD 5-2: Diaphragm Abutments – uses and limitations, skewed abutments, drainage
- MTD 5-3: Structure Approach – structure approach types, selection flow charts (shown in Figure 3)
- Bridge Design Aids Section 1: Abutments – abutment design loads, minimum lateral design force for diaphragm abutments, abutment steel reinforcement (Working Stress Design, WSD)
- Bridge Design Aids Section 10: Type Selection – abutment types, slopes at abutments
- Bridge Design Details Chapter 6 – abutment cover and berm, drainage, pile footing, and sealed joints details

Caltrans specifies a structure approach selection process for plain cement concrete (PCC) (shown in **Figure 16**) and asphalt concrete (AC) Pavement. These charts provide guidance on details such as when no approach slab is required or when a sleeper slab required.

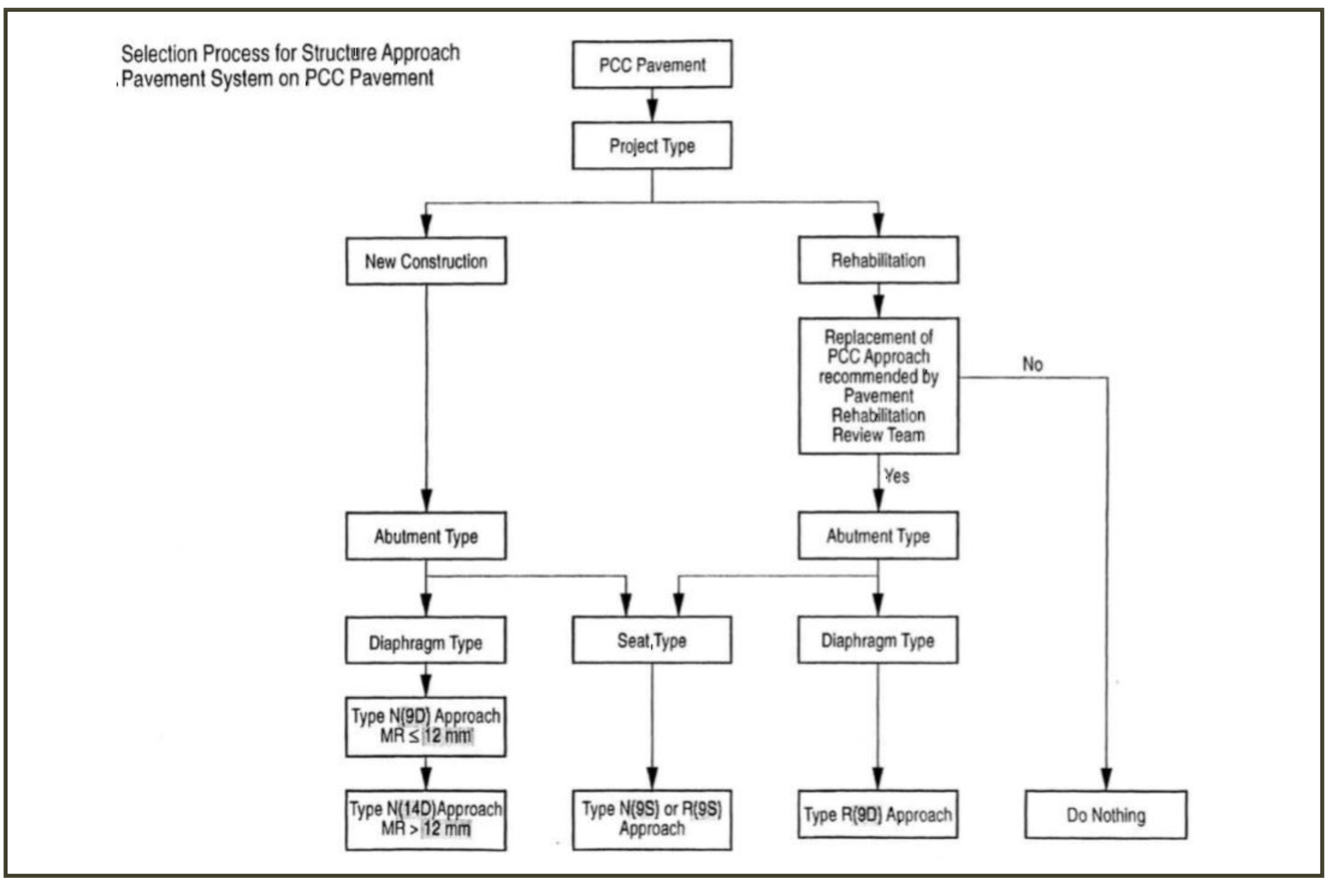


Figure 16 Caltrans Approach Pavement Selection Process (3)

Iowa DOT: Although the office prefers jointless construction, some designs require deck expansion joints because of bridge length, bridge skew, use of stub abutments, use of expansion bearings, or other factors. Where expansion joints are necessary it is important that they be sealed and drained to protect both superstructure and substructure components from deterioration caused by runoff and deicers. (Iowa DOT Bridge Design Manual (BDM) Section 5.8.3). When integral abutment does not work due to bridge size or skew, they use a strip seal joint on the bridge side of the endwall. Their bridge design manual (BDM) provides tables for the superstructure spans. Integral abutments are covered in the substructure plans.

From Section 3.7.2 of their BDM: "Because of lower construction and maintenance costs the Bureau prefers integral abutments as shown on standard sheets and standard plans for bridges. Integral abutments are limited by bridge length, end span length, and soil or rock conditions at abutment sites. For most sites, downdrag due to compressible fills will not affect the use of integral abutments because only the top portions of the piles flex, and the downdrag stresses occur below these regions of high bending. The Bureau generally does not use integral abutments for bridges with horizontally curved girders."

Section 3.7.2 also provides tables for length and skew limits. Section 5.7.1.1 presents the policy overview referencing AASHTO-LRFD 14.6.2 and 14.8.1: "The Bridges and Structures Bureau follows a general design policy of jointless bridges with integral abutments for short and intermediate spans, within length and skew limits established based on research at Iowa State University [BDM Table 6.5.1.1.1]. The jointless policy applies to all typical bridge superstructure types in use by the Bureau—continuous concrete slab (CCS), pretensioned prestressed concrete beam (PPCB), continuous welded plate girder (CWPG), and rolled steel beam (RSB)."

LaDOTD: The state has no current design guidance for jointless bridges but is looking to incorporate jointless bridges as an option for future projects.

MaineDOT: MaineDOT provides guidance for integral abutment systems, slab (deck) over backwall, and semi-integral systems. Two categories for integral abutments are:

- full integral abutments, where the bridge beams are rigidly cast into an end diaphragm and
- integral with hinge abutments, where butted boxes or voided slabs are connected to the abutment with dowels.

Integral abutment bridges (IABs) should be evaluated for use on all bridge replacement projects. MaineDOT most commonly uses 4 piles for each integral abutment substructure unit and traditionally uses the following piles:

- HP 10x42
- HP 12x53
- HP 14x73
- HP 14x89

MassDOT: MassDOT provides standard details and one-way thermal movement limits for selecting jointless details. There are no skew limitations for the jointless details. Other than that, MassDOT does not have any further design guidelines.

MnDOT: Integral type stub abutments are the preferred type of abutment due to their jointless nature and simplified construction. Integral type stub abutments have the lowest initial construction cost, are the fastest abutment type to construct, and eliminate the future maintenance and repair required for strip seal expansion joints. Semi-integral type stub abutments are the preferred type of abutment when the requirements for integral abutments cannot be met. Semi-integral abutments have a lower initial construction cost than parapet (seat) type abutments, and eliminate the future maintenance and repair required for strip seal expansion joints. Parapet type stub abutments use a strip seal or modular expansion device to accommodate movement. The joint is placed at the end of the bridge, in front of the abutment backwall. They are supported by multiple rows of piling, have the highest initial construction cost, and will require future maintenance and repair of the strip seal expansion joints. The move toward jointless abutments has diminished the use of parapet type stub abutments, but this type is still used where appropriate. Chapter 11 of MnDOT's LRFD Bridge Design Manual (4) contains complete abutment type selection criteria including requirements for bridge length, skew, wingwall length, front face exposure, beam depth, and piling type. See Section 2.3.1 for details regarding span length and skew limits and Section 2.3.2 for MnDOT design manual guidance for wall heights.

In addition to the span and skew limits presented in Section 2.3.1, the following is required for 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 (**Figure 17**).
- Maximum abutment stem height ≤ 7 feet
- Depth of beams is ≤ 72 inches

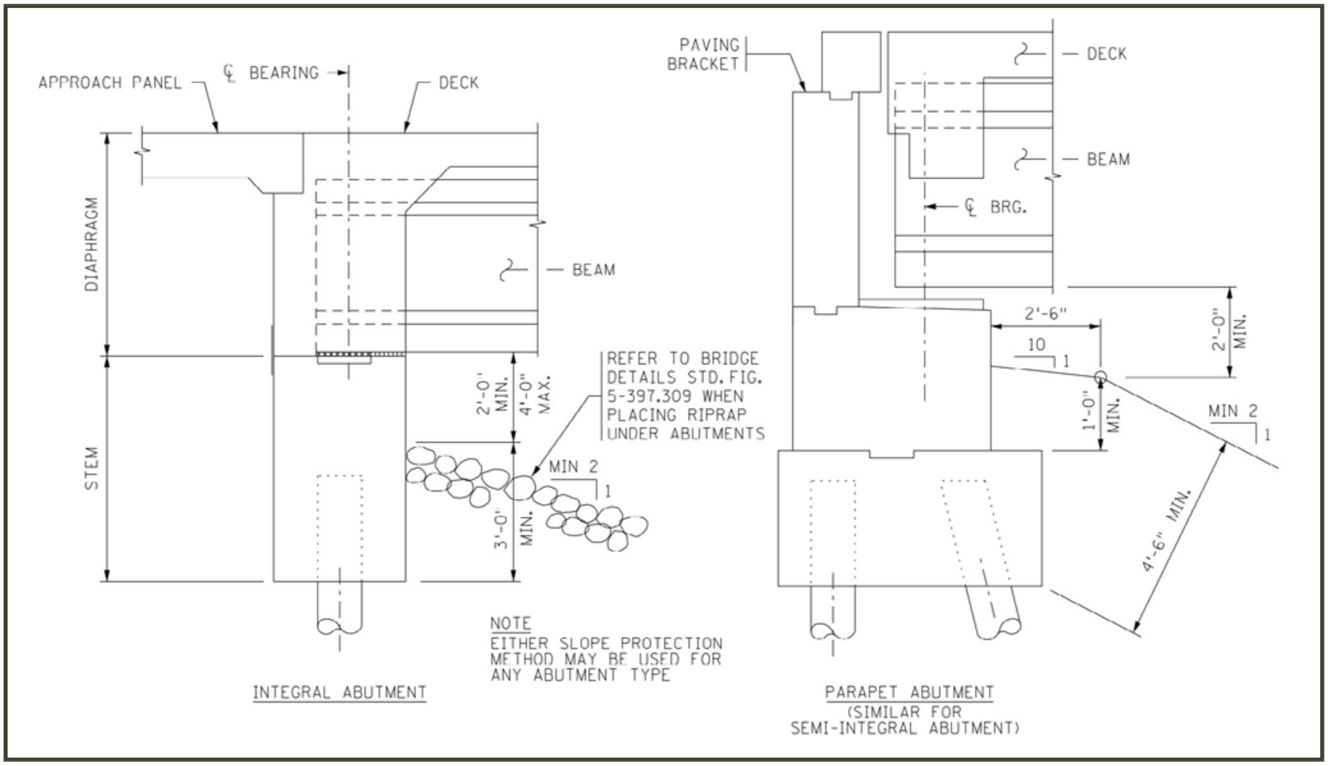


Figure 17 MnDOT Cover and Clearance Requirements (MnDOT Design Manual Figure 11.1.2)

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 in Section 2.3.1 for integral abutments, except that when wingwalls are parallel to the roadway, the maximum skew limit for semi-integral abutments is 30 degrees. (**Figure 20**)
- A guide lug is required for skews greater than 30 degrees to limit unwanted lateral movement

Parapet abutments should only be considered where integral and semi-integral abutment criteria cannot be met.

PennDOT: Appendix G of PennDOT Design Manual (8) is devoted to integral abutments and includes guidance on purpose, design criteria, superstructure and abutment design, as well as guidance on approach slabs, expansion joints and bearing pads. Bridge length and skew limits are tabulated in **Table 3**.

Use of integral abutments on structures with lengths over state prescribed limits shall be considered on case-by-case basis and shall require the written approval of the Chief Bridge Engineer at the Type, Size and Location stage. Expansion bearings shall be eliminated wherever possible. Span arrangement and interior bearing selection shall be such that approximately equal movements take place at both abutments.

The ratio between the span lengths in the bridge shall be chosen such that no net negative reaction is produced at the abutment at any limit state.

SDDOT: SDDOT's design manual is currently in development.

TDOT: The state does not have bridge type selection guidance since jointless bridges are standard practice unless thermal movements get too large.

UDOT: The UDOT Structures Design and Detailing Manual (SDDM) (13) has been developed assuming bridges will be constructed jointless. There is however separate guidance to determine if the abutment should be integral or semi-integral.

Use integral abutments for bridges meeting the following conditions:

- The displacement due to temperature loads is less than or equal to 3 in.
- The abutment is on a single row of steel pipe piles or H-piles.
- If on drilled shafts or precast piles, the temperature displacements must be accommodated elastically.

From their SDDM: "Integral abutments are the most redundant and robust abutment type and provide good seismic performance. Integral abutments on high skews can transmit significant torsional forces into the girders and deck near the abutments. Use of integral abutments on skewed and/or curved structures results in unbalanced soil pressures because the lines of action of the soil pressures on the two abutments do not coincide. Use of integral abutments on structures with high skews and sharp curvature is permitted but evaluate the effects of the unbalanced loads on the superstructure and intermediate supports. Several mechanisms resist the unbalanced loads."

Use semi-integral abutments for bridges meeting the following conditions:

- An integral abutment is not permitted
- The temperature movements at the abutment do not exceed 0.03H, where H is the height of the semi-integral abutment diaphragm and the temperature movement is:

$$\propto \times \frac{L}{2} \times T$$

Where:

α = the coefficient of thermal expansion

L = the distance from abutment to abutment

T = the temperature change, which is set at 80 degrees for this check

Consider the use of semi-integral abutments when the following conditions are met:

- Bridges with spliced post-tensioned concrete I-girders
- **Acc**elerated bridge construction (ABC) bridges to accelerate construction by eliminating the end diaphragm closure pour

Semi-integral abutments allow the bridge to move over the abutment. The superstructure rests on expansion bearings that minimize loads and movements transferred to the substructure. Use shear keys to provide lateral resistance. Use bolsters or longitudinal shear keys to limit longitudinal movement when required. Because the superstructure rests on bearings, the superstructure can be raised, and bearings replaced or shimmed to accommodate differential settlement.

Semi-integral abutments are not as redundant or robust as integral abutments. A higher risk of abutment failure during a seismic event exists. Semi-integral abutments on high skews can transmit significant torsional forces into the girders and deck near the abutments. Use of semi-integral abutments on skewed and/or curved structures results in unbalanced soil pressures because the lines of action of the soil pressures on the two abutments do not coincide. Use of semi-integral abutments on structures with high skews and sharp curvature is permitted but evaluate the effects of the unbalanced loads on the superstructure and intermediate supports.

VDOT: VDOT publishes an Abutment Type Selection Flow Chart (**Figure 18**). Their selection hierarchy for new bridges follows, with the first two being flexible abutments, the last three being stationary:

1. Full integral Abutment
2. Semi-integral Abutment
3. Conventional Cantilever Abutment with Deck Slab Extension
4. Virginia Abutment
5. Conventional Abutment with Joints (Requires Waiver from State Structure and Bridge Engineer)

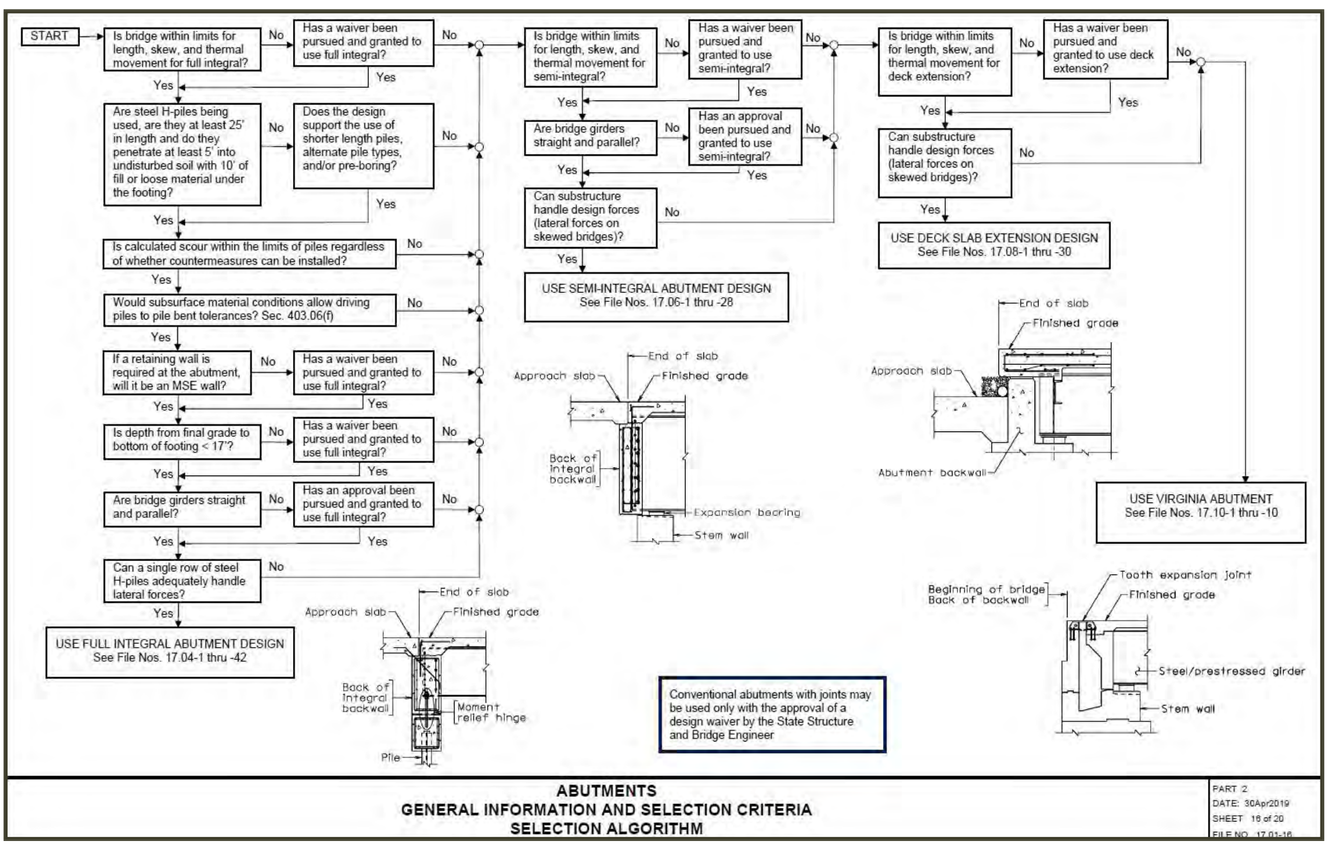


Figure 18 VDOT Abutment Type Selection Flow Chart

WSDOT: WSDOT has implemented jointless bridge design by using semi-integral construction. Office policy for concrete and steel bridge design is as follows:

Concrete Bridges: Semi-integral design is used for prestressed concrete girder bridges under 450 feet long and for post-tensioned spliced concrete girder and cast-in-place posttensioned concrete box girder bridges under 400 feet long. Use L-type abutments with expansion joints at the bridge ends where bridge length exceeds these values. In situations where bridge skew angles exceed 30 degrees, consult the Bearing and Expansion Joint Specialist and the Bridge Design Engineer for recommendations and approval.

Steel Bridges: Use L-type abutments with expansion joints at the ends for multiple-span bridges. Semi-integral construction may be used in lieu of expansion joints for single span bridges under 300 feet with the approval of the Bridge Design Engineer. In situations where the bridge skew exceeds 30 degrees, consult the Bearing and Expansion Joint Specialist and the Bridge Design Engineer for recommendations and approval.

2.3.1 Span Length and Skew Limits

Table 3 shows each state's span and skew limits for their jointless bridges followed by individual state comments.

Span and Skew Limits*				
	Span Limits (ft)			Skew Limits (Degrees)
	Steel	Cast-in-Place	Precast	
Caltrans	-	400	-	≤ 20
Iowa DOT	300-400		425-575	45-0
LaDOTD			Not Currently Imposed	≤ 45
MaineDOT	300	500	600	≤ 20
MassDOT	140	200	-	≤ 30
MnDOT	≤ 300			≤ 20
PennDOT	390	590	-	*
SDDOT	350	700	700**	≤ 30
TDOT	*	*	*	None
UDOT	*	*	*	≤ 60*
VDOT (integral)	300 150	500 250	-	0 ≤ 30
VDOT (Semi-integral)	450	750	-	≤ 30
WSDOT (Semi-integral)	300	400	450	≤ 45

* See corresponding state comments below. **Prestressed

Table 3 Integral Abutment Span and Skew Limits

Caltrans: The designer must consider a refined analysis for bridges on integral abutments that exceed the span and skew limits. Caltrans imposes limits on the movement for integral abutments, which is related to the span. Caltrans has an end stagger detail (Standard Plans B9-2) for approach slabs on skews higher than 20-deg. *Memo to Designers 5-2: Diaphragm Abutments* states that "seat cantilever abutment should be considered, rather than the diaphragm abutment, to resist lateral earth pressures of skewed abutments."

Iowa DOT: Iowa DOT BDM (4) provides Table 3.7.3 (shown in **Figure 19**) for Superstructure Type and Typical HP Pile. There are also tables for maximum bridge lengths and axial structural resistance for piles (Iowa DOT BDM Table 6.5.1.1.1-1 & -2).

Superstructure Type / Typical Pile	Length and Skew Limits for Standard Integral Abutments	Maximum End Span / Prebore Length [(2)] / Minimum Pile Length
PPCB / HP 10x57	575 feet at 0-degree skew to 425 feet at 45-degree skew [(1)]	Maximum A-D and BTB-BTE length / 10 or 15 feet depending on load / 15 feet to bedrock [BDM Table 6.5.1.1.1-1]
CWPG / HP 10x57	400 feet at 0-degree skew to 300 feet at 45-degree skew [(1)]	120 to 150 feet / 10 or 15 feet depending on load / 15 feet to bedrock [BDM Table 6.5.1.1.1-2]
CCS / HP 10x42	400 feet at 0-degree skew to 300 feet at 45-degree skew [(1)]	45.5 feet / 10 feet / 15 feet to bedrock

Table notes:

(1) Use linear interpolation of length for intermediate skew.

(2) Prebore depth is related to axial structural resistance of the pile. Final designer may adjust the depth. The preliminary designer shall show a 10-foot deep by 16-inch wide prebore on the TSL for integral abutments on bridge lengths greater than 130'.

Figure 19 Iowa DOT BDM Table 3.7.2: Bridge Length Limits for Use of integral Abutments

LaDOTD: LaDOTD currently does not impose limits on span lengths for integral abutments. For skew on conventional bridges, standard designed details are limited to 45-degree skews. Larger skews can and have been designed.

MaineDOT: Span lengths reported are per the 2009 Bridge Design Guide. Substructure skew is preferred to be 20 deg or less. MaineDOT has done at least eighteen bridges that were mostly integral with a few precast superstructure semi-integral structures that were 20-degrees or more including an 85-foot bridge on a 36-degree skew and a 98.5-foot span at 35 degrees. No defined limitations for curvature.

MassDOT: MassDOT Bridge Manual defines the "box" within which the state has pre-designed the piles for integral abutments. As a result, for designers, if their structures fit in this box, the design of integral abutments piles is reduced to a gravity problem where Designer only needs to make sure that the piles have the necessary structural or geotechnical resistance. No further modeling or analysis is required. If the structure does not fit within these restrictions, it does not mean that an integral abutment cannot be used, it just means that the Designer needs to do a full 3-D model and analysis, including the piles, for the design.

MnDOT: Limitations for integral abutment bridges: 300 feet or less with up to 20-degree skew, 100 feet for less than 45-degree skew (**Figure 20**). For semi-integral abutments with wingwalls that are parallel to the roadway the maximum skew limit is 30 degrees. Some bridges with skews greater than 30 degrees have been built but require a guide lug between the abutment and end diaphragm for skews greater than 30 degrees to limit unwanted lateral movement.

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

- Bridge length ≤ 300 feet and skew ≤ 20 degrees
- Bridge length ≤ 100 feet and skew ≤ 45 degrees
- Bridge length is between 100 feet and 300 feet, and skew ≤ [45 - 0.125 (L - 100)] degrees, where L is the length of the bridge in feet

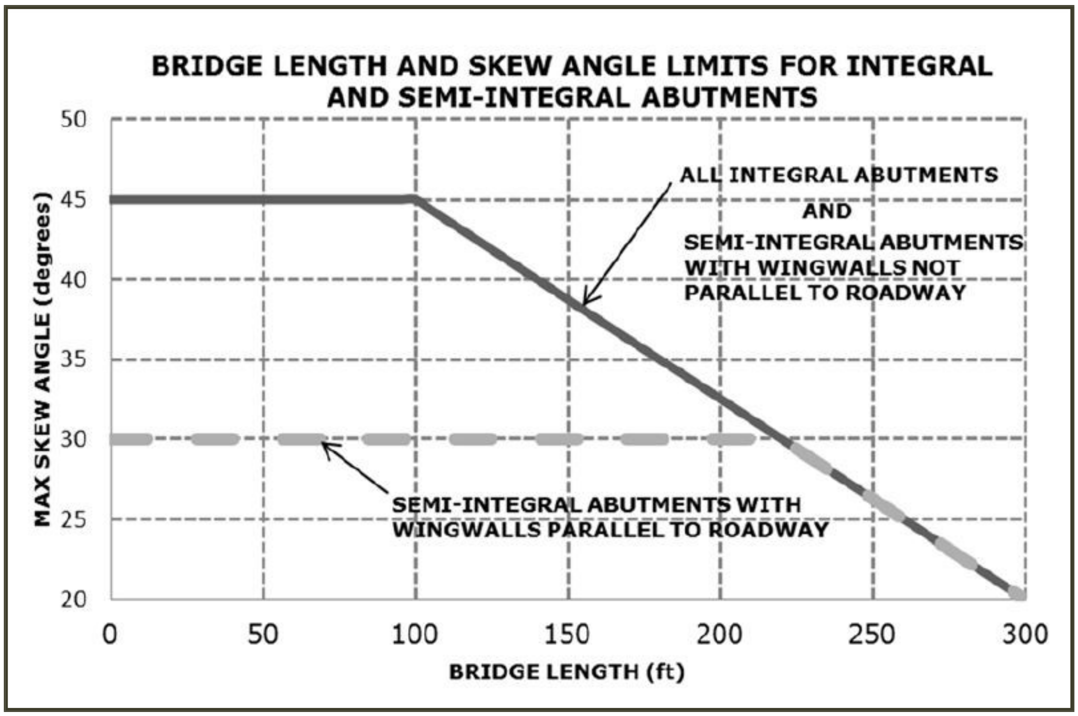


Figure 20 MnDOT Abutment Type Selection Chart (MnDOT BDM Figure 11.1.1)

PennDOT: PennDOT defines maximum allowable bridge total length, for 90° skew, measured between the centerlines of end bearings. Minimum allowable skew angle is: 70° for single span more than 130 feet. or for multiple span structures, 60° for single span more than 90 feet. but no longer than 130 feet., 45° for single spans 90 feet. or less

(Note: PennDOT measures skew from centerline of beam to centerline of bearing, the complementary angle to AASHTO skew.)

Only straight beams may be used. Curved superstructures utilizing straight beams may be used, if approved by the Chief Bridge Engineer. All beams in each span of a curved bridge shall be parallel to each other. Integral abutments shall be allowed for straight bridges with splayed girders when the difference between the length of the two abutments does not exceed 10%.

SDDOT: SDDOT standard skew is 30°, while skews of 35° are not uncommon and the state has even stretched CCB's to 45°.

TDOT: TDOT limits movement to 1 inch in each direction but places no restriction on individual span length.

UDOT: UDOT limits structure length for jointless bridges based on the design displacement at the abutments. The Structures Design and Detailing Manual states: "Use continuous structures. Add expansion joints between continuous frames when a single, continuous frame results in integral abutment movements exceeding [a 3-inch displacement due to temperature]." Regarding skew, UDOT's design manual offers the following guidance: "The maximum permitted skew is 60 degrees. Skews over 45 degrees require prior approval from the Structures Design Manager. Avoid skews over 30 degrees where feasible." "Use of integral abutments on structures with high skews and sharp curvature is permitted but evaluate the effects of the unbalanced loads on the superstructure and intermediate supports."

VDOT: VDOT limits full or semi-integral straight bridges to 30° skew. They limit total movement on full integral to 1 ½ inches, and semi-integral to 2 ¼ inches. Table 4 shows limits for VDOT bridges with conventional cantilever abutment with deck slab extension

	STRAIGHT	CURVED
Steel bridges	450 feet 45° max. skew	300 feet 30° max. skew
Concrete bridges	750 feet 45° max. skew	n/a
Total movement at abutment	2¼"	1½"

Table 4 VDOT Conventional Cantilever Abutment with Deck Slab Extension

WSDOT: WSDOT skew angle is limited to 45° or less with no limit on curvature. Limits are separated Eastern vs Western WA and semi-integral vs L-abutment (**Figure 21**).

Superstructure Type	Maximum Length (Western WA)		Maximum Length (Eastern WA)	
	Semi-Integral	L-Abutment	Semi-Integral	L-Abutment
Concrete Superstructure				
Prestressed Girder*	450 ft	900 ft	450 ft	900 ft
P.T. Spliced Girder**	400 ft	700 ft***	400 ft	700 ft***
C.I.P.–P.T. box girder	400 ft	700 ft ***	400 ft	700 ft***
Steel Superstructure				
Plate Girder Box girder	300 ft	900 ft	300 ft	700 ft

* Based upon 0.16 in. creep shortening per 100 feet of superstructure length and 0.12 inch shrinkage shortening per 100 feet of superstructure length

** Based upon 0.31 in. creep shortening per 100 feet of superstructure length and 0.19 inch shrinkage shortening per 100 feet of superstructure length

*** Can be increased to 800 ft. if the joint opening at 64° F at time of construction is specified in the expansion joint table to be less than the minimum installation width of 1½ inches. This condition is acceptable if the gland is already installed when steel shapes are placed in the blockout. Otherwise (for example, staged construction) the gland would need to be installed at temperature less than 45° F.

Figure 21 WSDOT Maximum Bridge Lengths

2.3.2 Abutment Wall and Approach Slab Limits

States provided abutment wall height limits, approach slab length and thickness limits. States were asked if these limits vary with skew and/or bridge width and if there are other geometric characteristics that dictate the use of unique components or details. Wall height, slab length and slab thickness limits are tabulated in **Table 5**. State comments follow the table.

Abutment Wall Height and Approach Slab Limits				
	Wall Height (feet)	Approach Slabs Mandatory?	Approach Slab Length (feet)	Approach Slab Min. Thickness (in.)
Caltrans	10		30	15
Iowa DOT	-		3x20’	
LaDOTD	None		40	18
MaineDOT	6	Yes	None	Y
MassDOT	15		15	10
MnDOT	7		None	12 min.
PennDOT	6	Yes*	25	18
SDDOT	4.5		20	9
TDOT	None		24.5	12
UDOT	8	Yes	25	13
VDOT	-	Yes	-	
WSDOT	-	No	25	13

* With integral abutments and Average Daily Traffic (ADT) >750

Table 5 Abutment Wall Height and Approach Slab Limits

Caltrans: Non-integral abutments less than 36 feet tall do not require seismic analysis (**Figure 22**). Integral abutment stem heights less than 10 feet from soffit to bottom of wall do not require seismic design. In addition to the standard 30 feet long approach slab, Caltrans has a standard 10 foot long approach slab that is used for seismic purposes only.

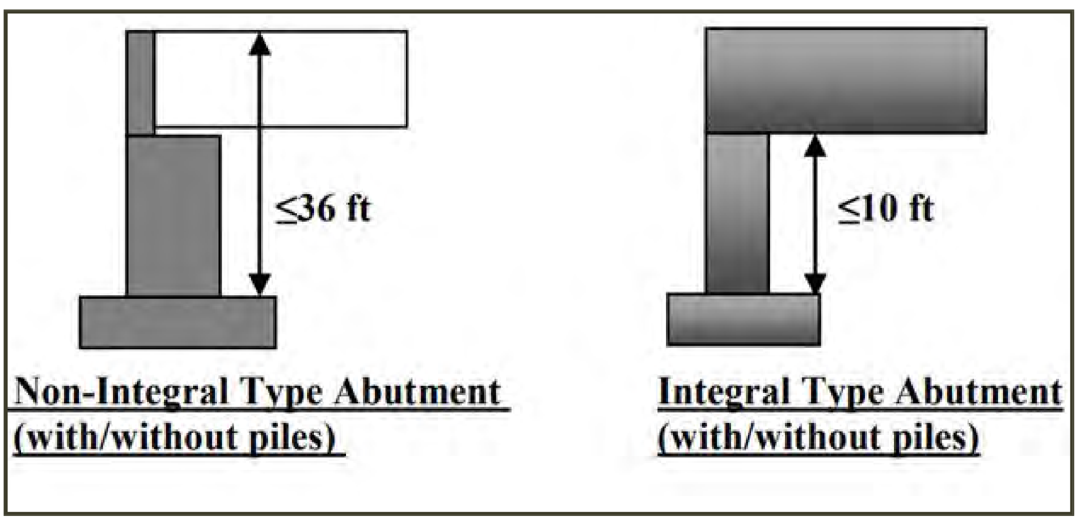


Figure 22 Caltrans Wall Heights per Abutment Types

Caltrans has new LRFD approach slab designs (Standard Plans), 15 inches thick with #10 rebars in the bottom mat, to avoid deflections under heavy traffic loads.

To control cracking, designer can specify fiber reinforced concrete, same shrinkage limitations and curing as bridge deck (new construction only). Good workmanship and maintenance (methacrylate sealers) are essential for crack control. The diagonal bars in the "End Stagger Detail" and acute corner Detail A (B9-5) help control cracking in the corners. Eliminating the stagger, like other states, can also help. Caltrans states that it is hard to control cracks on Rehab projects with Rapid Strength Concrete.

To address rotation due to differential settlement (grade break) Caltrans has increased reinforcement at approach slab-to-pavement joint. Sleeper slabs and Geogrid, as being used by other states, can also help. For rebab projects, existing profile grade corrections should be shown on the plans, rather than being resolved in construction.

Iowa DOT: For abutment wall height limits, the Iowa DOT BDM Section 6.5.4.2.1 states: "Design of a tall backwall for nonstandard stub abutments shall be designed as a retaining wall to fully withstand soil pressures [AASHTO-LRFD 11.6], as well as vertical loads."

Iowa DOT uses two 20' reinforced approach slabs on both their moveable and fixed abutments (**Figure 23**). The first slab on the movable abutment has a pavement lug, to keep the slab stationary while the abutment moves beneath it. The third slab is unreinforced.

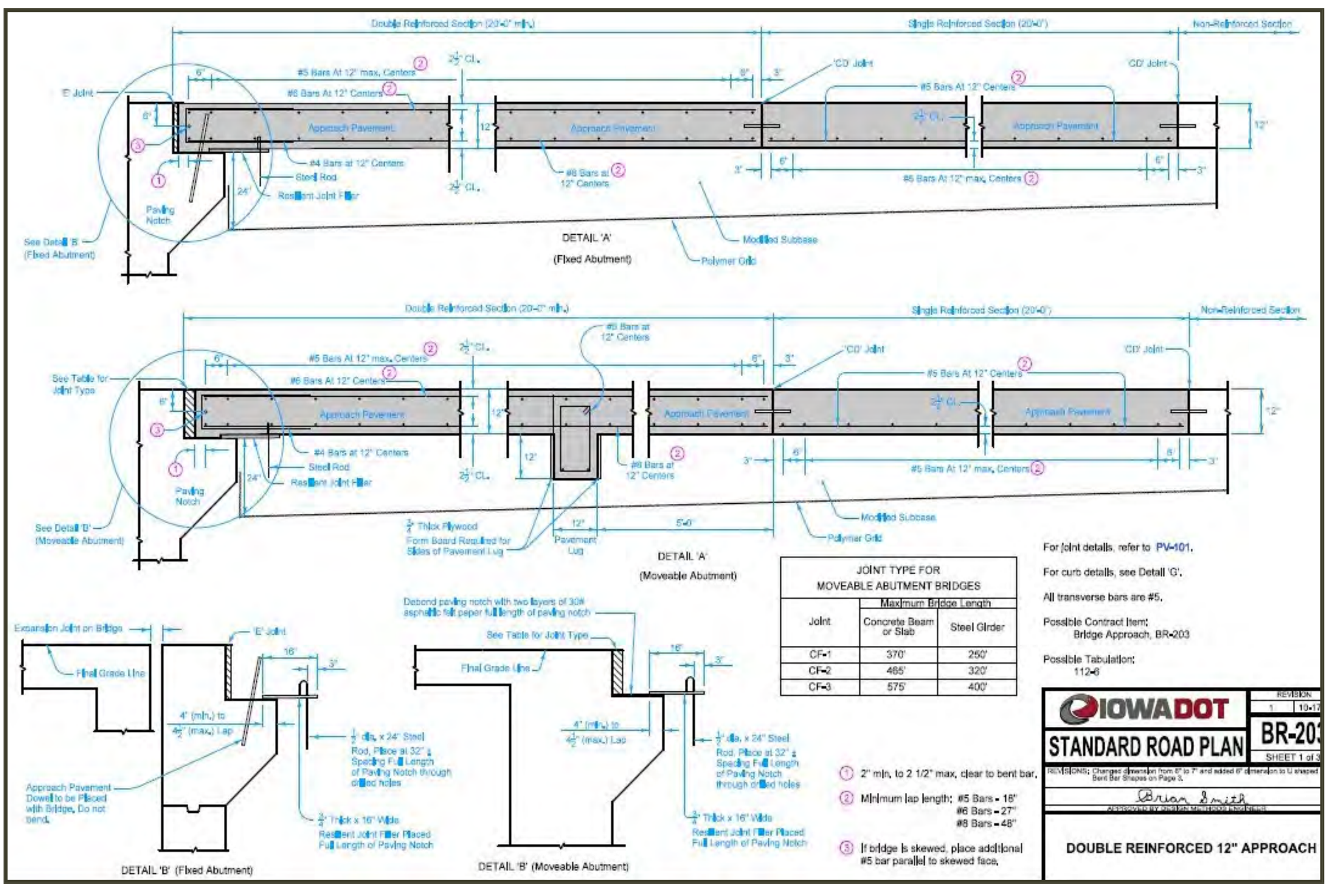


Figure 23 Iowa DOT Approach Slab Details

LaDOTD: LaDOTD does not impose abutment wall height limits. 40 feet at centerline is the maximum length for their standard approach slab details. Longer approach slabs may be allowed but must be specially designed. Shorter approach slabs may be used for well-consolidated approach embankments (existing alignments or cut sections) or for off-system bridges.

With large roadway widths on skews, the limiting centerline length may cause extremely short or extremely long lengths on the edges of the approach slab. This may require a change to the approach slab shape and/or design.

MaineDOT: MaineDOT's standard detail defines a 6 foot abutment wall from bottom chord of superstructure to bottom of wall for integral abutment systems, no limitation for semi-integral systems. The depth of the superstructure is not restricted in most cases.

Standard detail approach slab length is recommended (15 feet-8 inches), no limit to length of approach slab is imposed. This does not vary with the skew of the structure.

Pile length is currently one of the major limiting factors. MaineDOT has several instances of using micropiles or rock socketed piles in short overburden situations.

MassDOT: The abutments should be kept as short as possible to reduce the magnitude of soil pressure developed. A minimum of 3 foot-0 inch for inspection access shall be provided. A minimum fill cover over the bottom of the abutment of 3 foot-0 inch is desirable. MassDOT's abutment heights, measured from the deck surface to the bottom of the cap (see **Figure 82** for deck surface, since MassDOT slabs are buried), shall not exceed 15 feet. The difference in the profile grade elevation at each of the abutments shall not exceed 5% of the bridge length. If the skew angle is less than 45° then the length of the approach slab is 15 feet along the centerline of the roadway. If the skew angle is greater than 45°, then the length of the approach slab is 10 feet measured perpendicular to the back of the abutment. These approach slab lengths are standard for both integral abutment and non-integral abutment bridges. Span lengths varies with skew (as noted above), but not with the width of the bridge.

MassDOT uses crushed stone to allow the pile just under the abutment stem to translate. Previously the state cored a circular hole around the pile and filled it with crush stone but with the 2013 Bridge Manual this was changed to a 2.5-foot-wide by 3-foot-deep trench that is filled with crushed stone after the piles are driven. This accomplishes the same thing but is easier for contractors to build.

The top of bedrock, as per Geotechnical Report, shall be located lower than the established pile tip elevation. At locations where the bedrock elevation is less than five (5) feet below the elevation of the theoretical point of pile fixity, the piles need only be driven to bedrock. At locations where the bedrock is located at an elevation that is higher than elevation of the theoretical point of pile fixity, the site is considered unsuitable for pile supported integral abutments.

MnDOT: MnDOT details a 5 foot minimum, 7 foot maximum integral abutment stem height which is measured from bottom of beam bearing pad to bottom of wall, no limitation for semi-integral systems. The depth of the superstructure is restricted to 84 inches (72 inches max. beam plus 3 inch haunch and 9 inch deck) for integral abutments.

Standard approach slab length is 20 feet (15 feet. for skews > 40 degrees), there is no maximum length limit. Also, for skews > 10 degrees a "Square off" end of approach slab is used with minimum dimension at outside short edge of 10 feet. The approach slab thickness is 12 inches but is thickened where it connects to the bridge and on the opposite end where it rests on a sleeper slab (sill).

PennDOT: Integral abutment details are presented in the nine bridge design (BD) drawings, BD-667M, of PennDOT's Standards for Bridge Design (11). Depth of abutment below construction joint (i.e. beam seat) is 3 foot-3inches at shallowest point. The maximum difference between the minimum and maximum cap depth will not exceed 1 foot-0 inches for skew <80° or 1 foot-6 inches for skew >80°. P3 structures were permitted to exceed this restriction up to a max height of 8 foot-8 inches.

Maximum girder depth for use with integral abutments shall be 72 inches. Deeper girders may be used in integral abutment bridges if approved by the Chief Bridge Engineer.

The 25 feet long approach slab length shown on Standard Drawing BD-628M (Type 5 approach slab), may be reduced to the value indicated in the Minimum Approach Slab Length Table on Standard Drawing BD-667M.

The approach slab skew angle shall match the bridge skew angle and be within the skew limitations listed above. Abutments on large fills, special pile details, approach slab settlement. If total approach slab length exceeds 150', require strip seals. PennDOT has a minimum approach slab length table (**Figure 24**).

MINIMUM APPROACH SLAB LENGTH TABLE			
GIRDER DEPTH (d)	SKEW = 90°	SKEW = 60°	SKEW = 45°
17" ≤ d ≤ 24"	12'-0"	14'-0"	18'-0"
24" < d ≤ 36"	14'-0"	16'-0"	20'-0"
36" < d ≤ 48"	15'-0"	18'-0"	22'-0"
48" < d ≤ 60"	17'-0"	20'-0"	24'-0"
60" < d ≤ 72"	18'-0"	22'-0"	25'-0"
72" < d* ≤ 84"	20'-0"	24'-0"	----
84" < d* ≤ 96"	22'-0"	25'-0"	----

Figure 24 PennDOT Minimum Approach Slab Length Table

SDDOT: SDDOT set limits for CCB's with the berm top set 4 foot-6 inches below low curb and bottom of abutment 1 foot below berm. For girder bridges, berm is set 2 foot below low cord and bottom of abutment is set 1 foot ± below berm.

Approach slab lengths are varied so joints miss guardrail posts. Special approach slab considerations include, for skewed structures: "Square off" end of approach slab, set approach slab at 20 feet on centerline. Minimum approach slab dimension at outside edge is 15 feet, far end is supported on sleeper slab, thickness is 9 inches, reinforced with #8's at 6" and separated from backfill with 2 layers of plastic.

TDOT: The state approach slabs are standard length of 24.5 feet for new construction and a reduced length of 15 feet for some bridge repair type projects. Typically, there are no unique components or details with the exception being some ABC projects where TDOT might use precast slabs with an asphalt overlay.

UDOT: UDOT provides standard details for 25 feet approach slabs for skews up to 45 degrees, which is UDOT's skew limit without a design deviation. UDOT does not step or stagger approach slabs.

If a special design is required on a project, it must meet a few requirements listed in the Structures Design and Detailing Manual shown below and in **Figure 25**:

a. Minimum length is 25 feet
b. A sleeper slab is required
c. Design must assume slab is a simple span between the abutment and the sleeper slab
d. Slab must provide a distance perpendicular to the edge of pavement for a width of at least the width of the parapet, to at most the width of the exterior panel of the approach pavement, usually the shoulder width. This is to make sure that the joint does not conflict with the parapet to the point of parapet capacity loss. On the acute end this will reduce the length of the approach slab to something less than 25 feet, but it may not be reduced to less than 15 feet. Note 1 referenced in Figure 25 acknowledges that depending on geometry, the 15-foot minimum may result in an increase of the typical length of the approach slab to something above 25 feet.

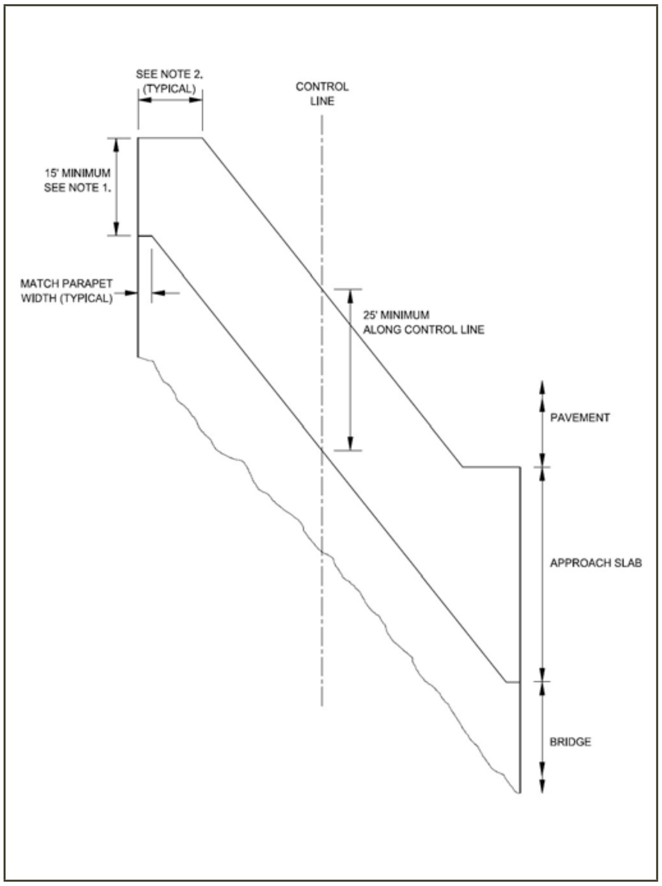


Figure 25 UDOT Approach Slabs

VDOT: VDOT did not address this topic.

WSDOT: WSDOT semi-integral abutments are designed to allow the backwall to fuse in a seismic event and be repaired such that joints are sized based on normal design movement (thermal). For L-shape abutments where the backwall is not designed to fuse, backwall shall conservatively be taken as the depth of the superstructure, unless a more rational soil-structure interaction analysis is performed. Bridge approach slabs are required for all new and widened bridges per BDM Section 10.6.

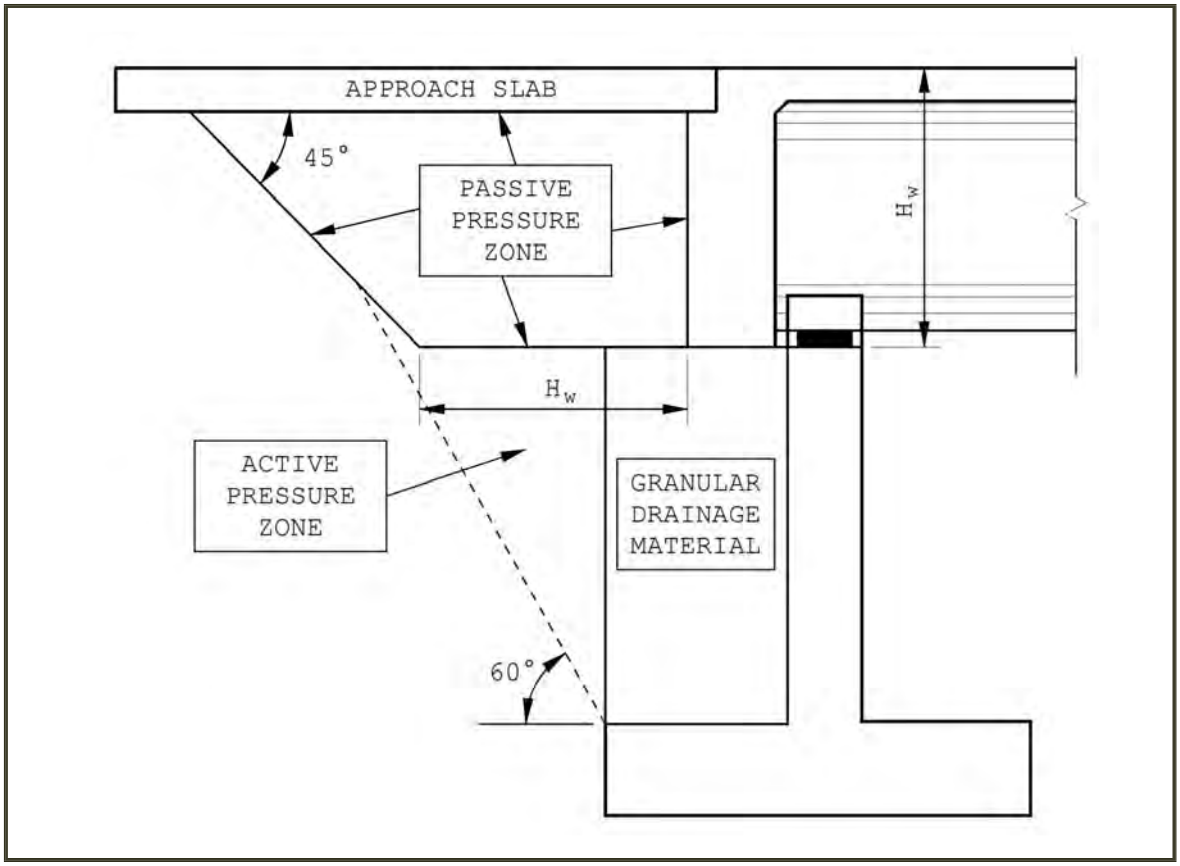


Figure 26 WSDOT Semi-Integral Abutment (WSDOT BDM Figure 4.2.11-1A)

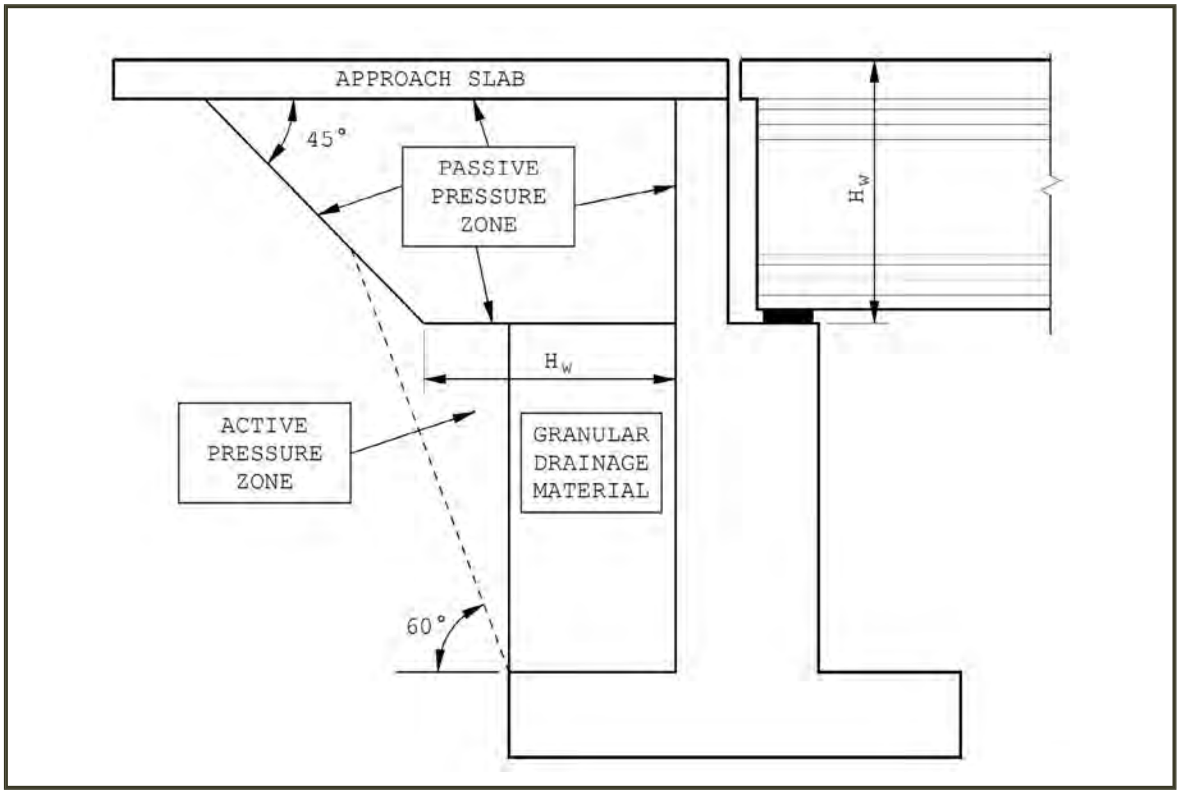


Figure 27 WSDOT L-Shape Abutment Backwall Does Not Fuse (WSDOT BDM Figure 4.2.11-1B)

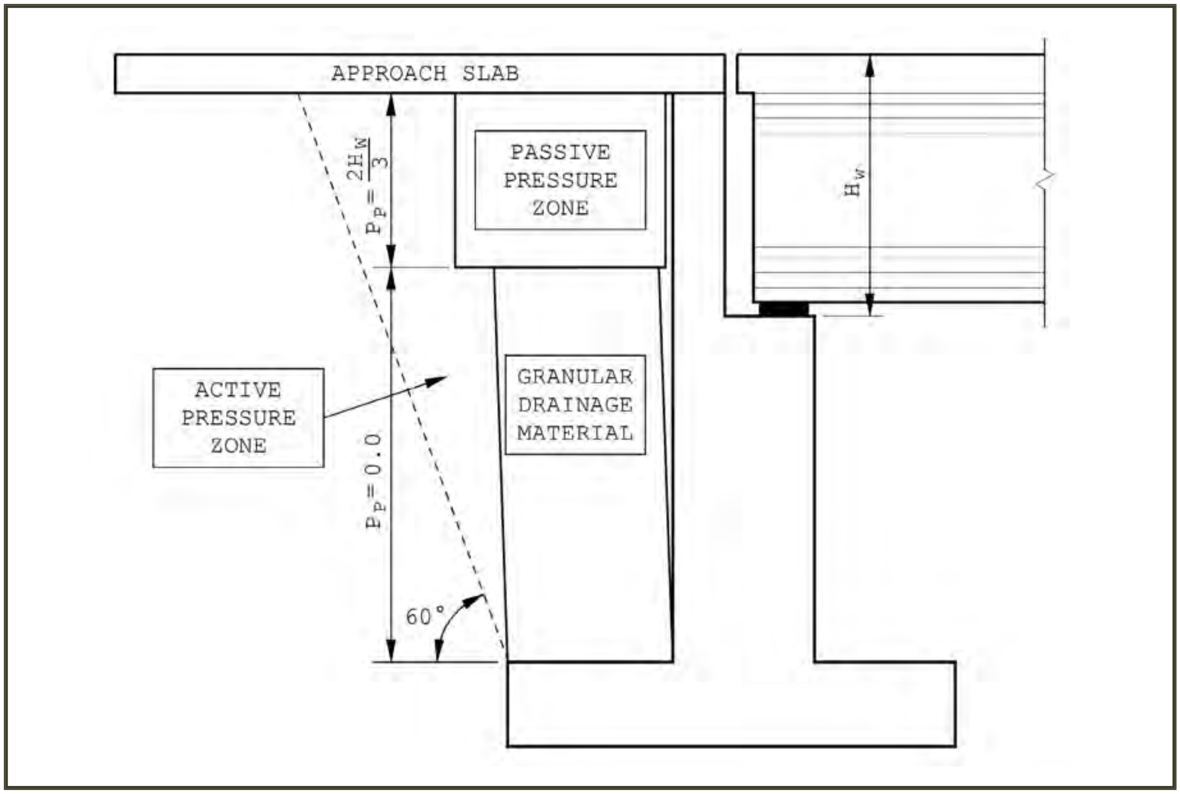


Figure 28 WSDOT L-Shape Abutment Backwall Does Not Fuse (WSDOT BDM Figure 4.2.11-1C)

2.3.3 Construction Sequence

The intent of this section is to review construction sequence specifics as they pertain to jointless bridges. Some information is included that is applicable but not specific to jointless bridges.

Caltrans: Integral abutments can be poured monolithically with the superstructure, or up to the soffit level when the bridge is post-tensioned. It is the designer's responsibility to examine any analysis assumptions versus sequence of construction (including backfilling the abutment and post-tensioning) and notify the specification engineer if any specific construction sequence is required. The plans may call for the wingwall concrete to be placed after prestressing.

Iowa DOT: While not specific to jointless bridges, Iowa DOT BDM provides the typical deck pour sequence guidance. Section 5.4.1.2.5 of their BDM provides the designer with loads to use if a constructability check is required per AASHTO LRFD 6.10.3.

LaDOTD: While not specific to jointless bridges, new embankment must be in place before driving piles, and the state has a suggested sequence of construction for deck placement in continuous span units.

MaineDOT: MaineDOT does depending on the span, geometry, and/or bearing configuration. For example, if the span is long and the anticipated deflections are large enough, MaineDOT will consider a sequence that places the end of the deck/backwall after the main deck

MassDOT: The end diaphragms/integral abutment stems are to be cast integrally with the deck and are cast as the second pour with the positive moment portion of the deck being the first pour.

MnDOT: MnDOT does not specify construction sequence other than requiring that end diaphragms on integral abutment bridges must be cast at the same time as the bridge deck.

PennDOT: PennDOT did not address this topic.

SDDOT: SDDOT does not specify a construction sequence.

TDOT: Top 12 inches of backwall is poured concurrently with the slab. Backfill placed after backwall is complete.

UDOT: UDOT does not explicitly specify a construction sequence but does provide some basic guidance for that needs to be shown in the plans. **Figure 29** is from the UDOT Structures Design and Detailing Manual. It shows a special condition where an end diaphragm is placed to prevent uplift, with calculations assumed to be performed by the engineer of record (EOR) must verify that the sequence is valid. Guidance is general, stating, "Typically, the positive moment regions are placed before the negative moment regions and the integral diaphragms are placed last to permit girder rotation." The designer is required to "verify that the girder design, camber and screed deflections are compatible with a single continuous pour" to allow the contractor to combine the placements, assuming the concrete remains plastic.

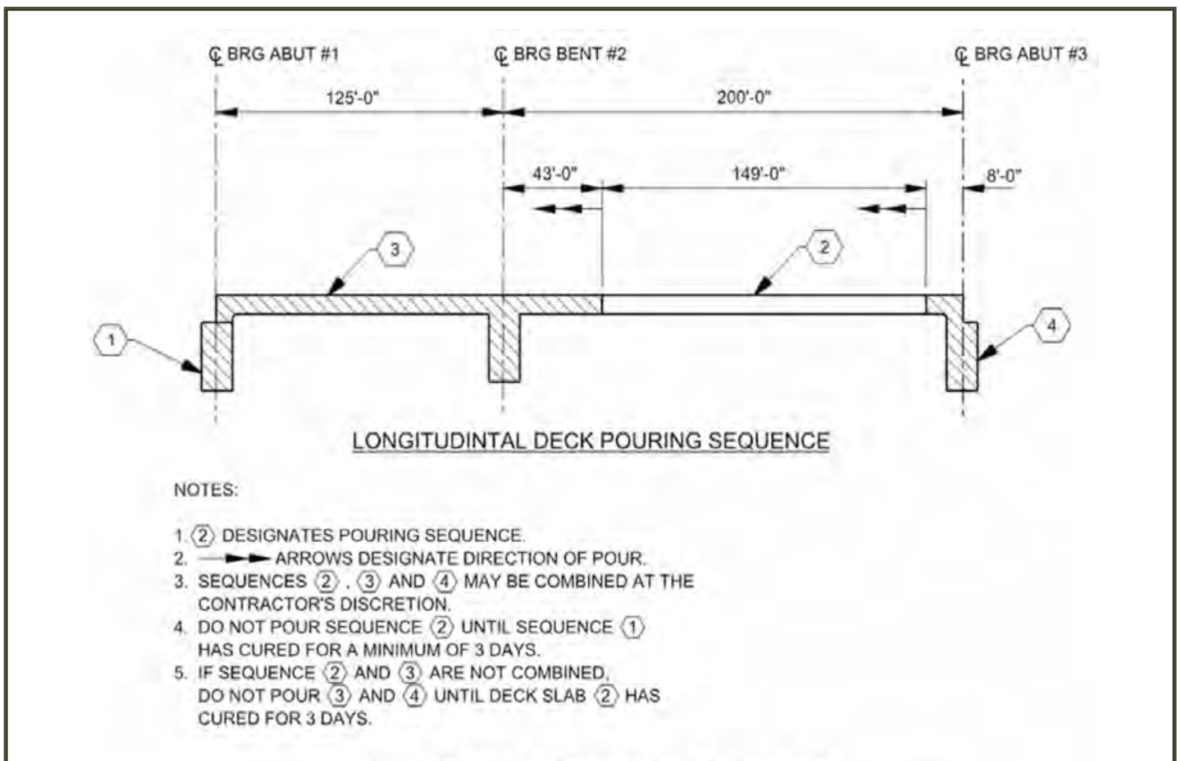


Figure 16.4 — DECK POURING SEQUENCE
(Continuous Steel Girder with Potential Uplift at Abutment #1)

Figure 29 UDOT Deck Pouring Sequence (Continuous Steel Girder with Potential Uplift) (UDOT SDDM Figure 16.4)

VDOT: VDOT did not address this topic.

WSDOT: **Figure 30** and **Figure 31** show construction sequence for single and multiple span prestressed girder superstructures, respectively.

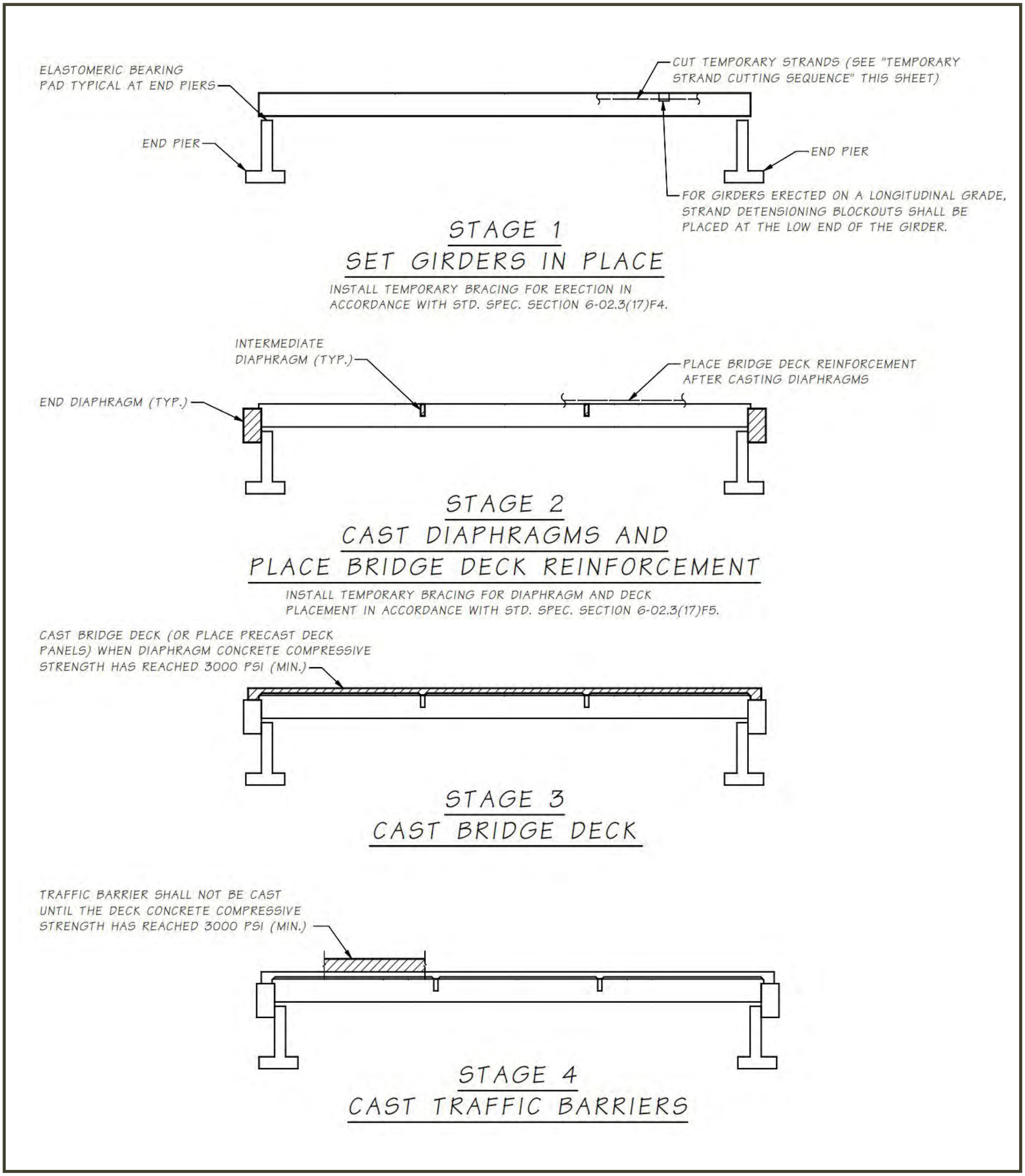


Figure 30 WSDOT Single Span Prestressed Girder Construction Sequence (WSDOT BSD 5.6-A2-1)

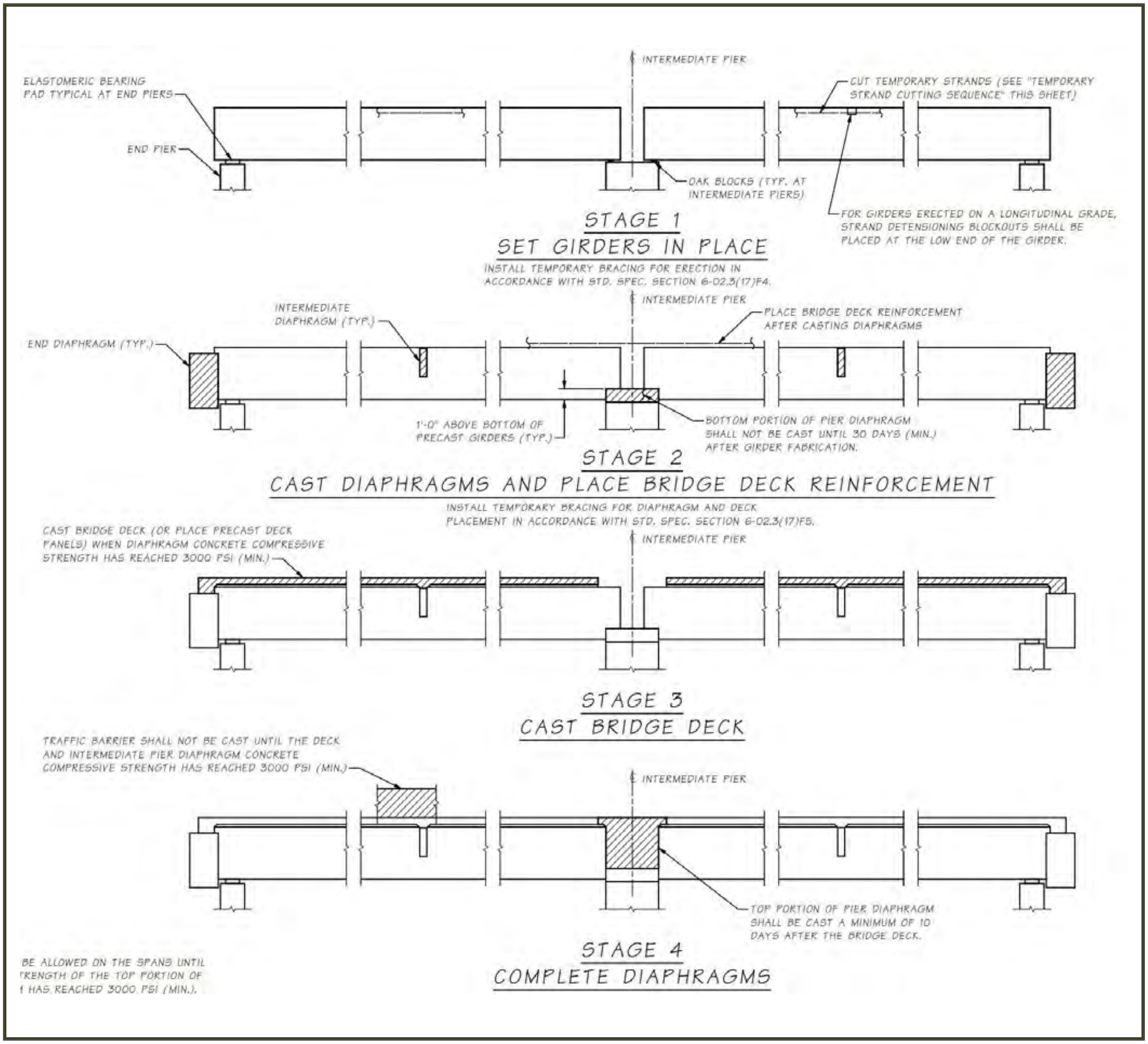


Figure 31 WSDOT Multiple Span Prestressed Girder Construction Sequence (WSDOT BSD 5.6-A2-2)

2.3.4 Design Manual Calculations

The scan team wanted to know if DOTs provided calculations for jointless bridge design, in design manuals or any other means.

Caltrans: No calculations are provided for abutments and approach slabs. WSD abutment details are shown in the existing *Bridge Design Aids Section 1:* Abutments, for preliminary design. This section is being updated for LRFD. Seat abutments can be designed in CTAbut, the in-house LRFD compliant program. CTAbut is in the process of being updated to include LRFD analysis and design of integral abutments. Approach slab details are pre-designed and shown in the Standard Plans B9-1 to B9-6. Movement rating calculations are provided in *MTD 7-10: Bridge Deck Joints and Deck Joint Seals.*

Iowa DOT: Iowa DOT BDM section 5.6.2.4.1 requires the LRFD method for design of CCS superstructures. The BDM also provides an integral abutment design example in their commentary (BDM C6.5.1.1.1).

LaDOTD: Approach slab finite element analysis calculations are provided.

MaineDOT: MaineDOT has no direct calculations provided, only recommendations for calculation of passive earth pressure and resistance factors defined for pile design, etc.

MassDOT: No calculations are provided. The details are pre-designed.

MnDOT: The MnDOT LRFD Bridge Design Manual in Chapter 11 includes a design example for a parapet abutment.

PennDOT: PennDOT has developed an integral abutment spreadsheet (12) intended to be used as an aid in designing and analyzing integral abutments. No user's manual is provided, but explanations of input values are given throughout the spreadsheet. The spreadsheet is intended to be used in conjunction with the computer program LPile or COM624P, which analyze the lateral behavior of piles, and with PennDOT's steel or prestressed concrete girder design programs. Design Specifications for integral abutments are available in PennDOT Design Manual Part 4 (DM-4), Appendix G. References to applicable provisions in the DM-4, as well as to the AASHTO LRFD Bridge Design Specification, 2010, are made. Many dimensions for integral abutments are set forth in PennDOT's BD-667M Standard Drawings. The spreadsheet is written in English units only.

The spreadsheet calculates extreme girder reactions, girder rotations, wind and uplift forces, pile reactions and overturning moments, pile analysis for scour, thermal expansion, plie capacity analysis and area of reinforcement needed for the pile cap.

SDDOT: SDDOT's design manual is currently in development. Currently provide specifications on granular details at the end of bridge.

TDOT: The state manual provides thermal movement calculations.

UDOT: UDOT does not currently provide calculation templates.

VDOT: Chapter 17, "Abutments" of the VDOT Manual of the Structure and Bridge Division (16) provides comprehensive sample calculations for design of both a full integral and a semi-integral abutment. In this section, they also provide a checklist for sample plans, including minimum/maximum component widths, heights, rebar spacings.

WSDOT: The state has extensive bridge design software.

2.3.5 Design Amendments

LaDOTD approach slab design is done with a truck model that is heavier than HL-93, which is based on actual weigh-in-motion data from their roads. Caltrans is considering whether dynamic load allowance, IM should be increased to 75% near the joints, and whether settlement load (SE) should be included in the approach slab design.

CHAPTER 3

Component Design Details

This chapter presents specifics of each state's component details. Findings are divided into sections that align with each bridge end component. These divisions are abutments, joints, approach slabs, embankment treatments and drainage (see **Figure 32**).

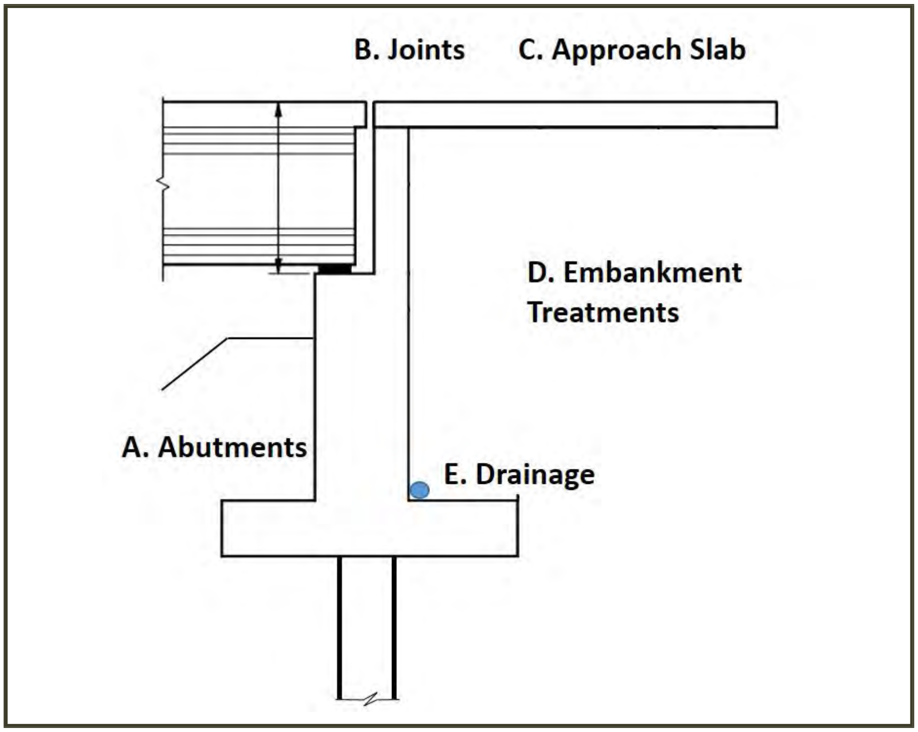


Figure 32 General Bridge End Components

3.1 Abutments

This section defines abutment types, presents various treatments of soil in front of the abutment and pile parameters such as fixity and orientation.

3.1.1 Types and Configurations

Moving joints off the bridge is done via varying degrees of abutment-to-superstructure fixity. Nomenclature varied slightly by state, but in general, states accomplish jointless bridge using some variant of integral abutments, semi-integral abutments, slab-over details. This section presents the basic details of each abutment type, in addition to a new "abutment-less" detail. Since the "bump at the end of the bridge" is not exclusive to jointless bridges, non-integral bridge examples are included. Section 3.1.1 concludes with each state's preference and any detail variations from the basic design details presented.

3.1.1.1 Integral, Semi-Integral and Slab-Over

Integral, semi-integral and slab-over can be differentiated by the depth over which movement occurs. The more integral the structure, the more soil behind the abutment backwall is mobilized during bridge expansion and contraction. For this document, the terms used will be applied to the following definitions. Approach panel fixity varied with state and is presented in Section 3.3.

Integral Backwalls are designed as end diaphragms integral with the superstructure. The abutment back wall and superstructure diaphragm are cast as one and cast around the superstructure beams, forming a continuation of the abutment (**Figure 33**). The superstructure and substructure accommodate movement as a single unit and all movement occurs behind and over the abutment wall height (stem plus diaphragm depth in **Figure 33**).

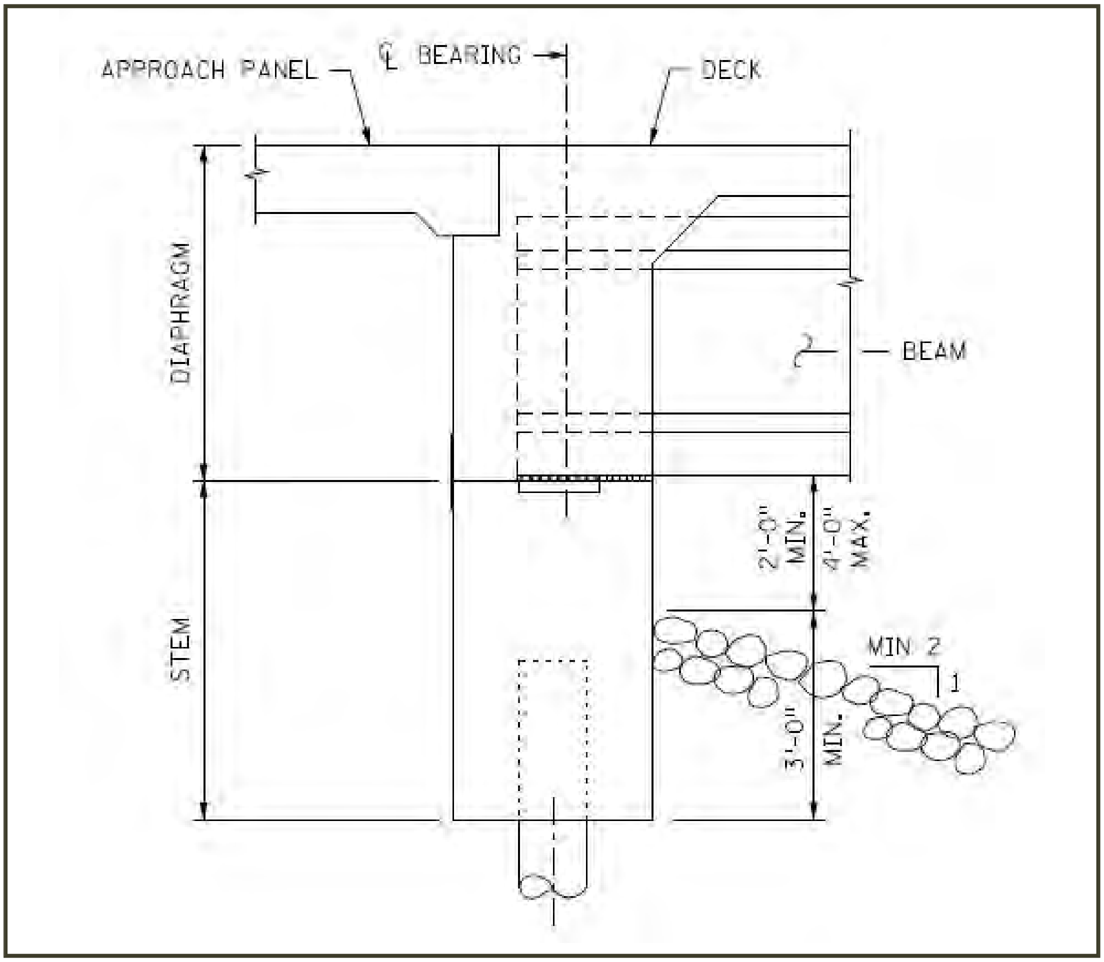


Figure 33 Integral Abutment Detail (courtesy MnDOT)

Semi-Integral Diaphragm concrete is cast around the superstructure beams, however the abutment backwall/superstructure diaphragm is not integral with the abutment (**Figure 34**). The lower abutment remains stationary while the backwall/diaphragm unit moves with the superstructure. Therefore, movement occurs behind the abutment and over the backwall/diaphragm height.

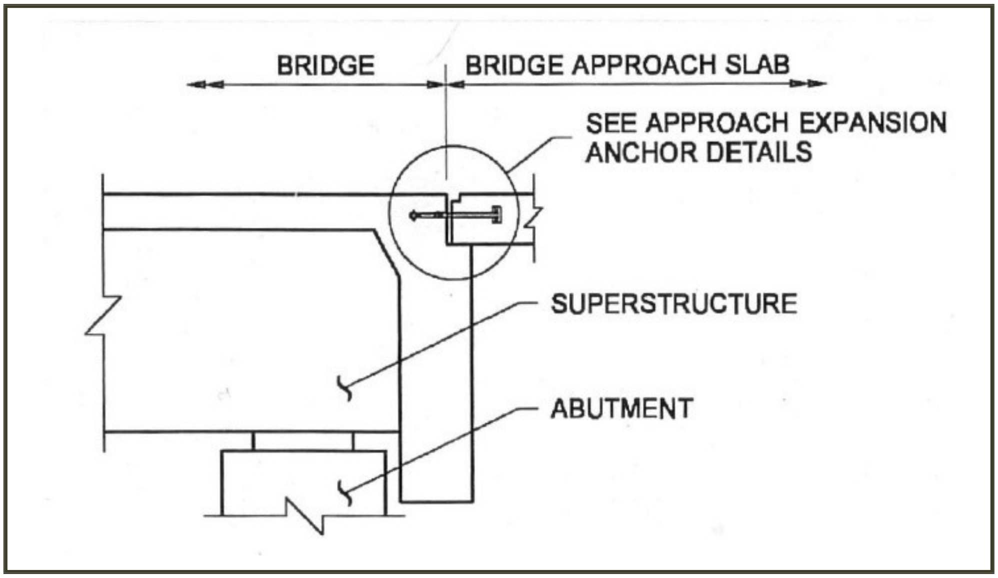


Figure 34 Semi- Integral Abutment (courtesy WSDOT)

Slab-over The slab is cast over and slides over abutment backwalls (**Figure 35**), moving the joint from the end of the girder to beyond the abutment backwall. Drainage is then treated behind the abutment and moved away from bearings. The abutment and backwall remain stationary and all movement occurs over the height of the slab. Slab-over details are often used in joint removal rehabilitations.

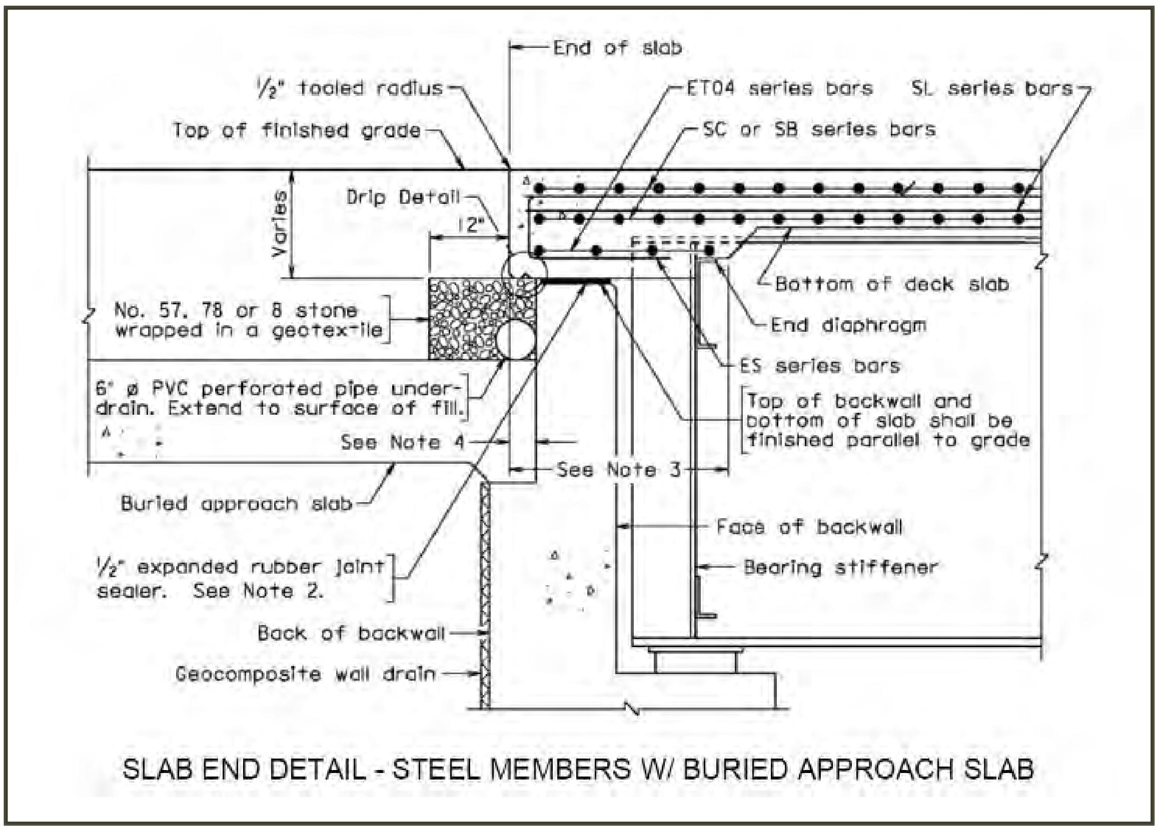


Figure 35 Slab Over Detail (Courtesy VDOT)

3.1.1.2 Abutment-Less

The Federal Highway Administration presented use of Geosynthetic Reinforced Soil – Integrated Bridge System (GRS IBS) as a means of mitigating settlement. The system is being monitored on bridges in Ohio [1]. Caltrans has a similar version of this system in their MTD 5-1, End Bent with Isolated MSE shown in MTD 5-1 and **Figure 36** Other states may call it a bent-type abutment.

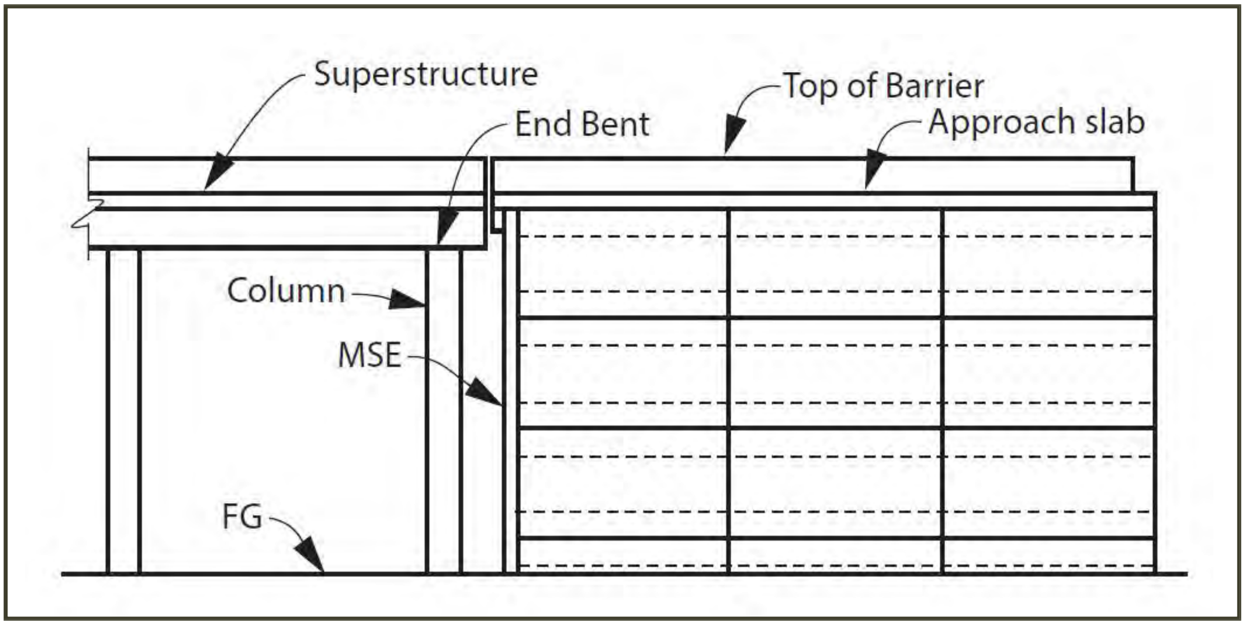


Figure 36 Caltrans End Bent with Isolated MSE on three sides

3.1.1.3 Non-integral

Some non-integral abutments include Seat (**Figure 37**), L Type (similar to seat), Sill Type, Parapet, and Conventional. In the seat abutment shown, the superstructure rests on a bearing on the seat. Superstructure movement is accommodated at the joint between the end of the superstructure and the backwall while the abutment and backwall remain stationary. Use of these conventional abutments must be approved by the State Bridge Engineer in some states.

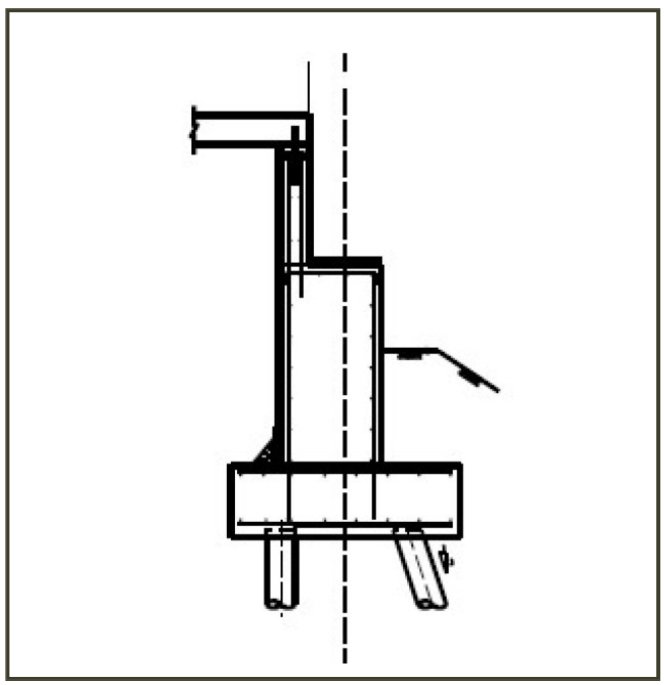


Figure 37 Seat Abutment (Courtesy of Caltrans

3.1.1.4 State Preference

Referring to the details defined in Section 3.1.1.1 – Section 3.1.1.3, Table 6 presents state preferred bridge end detail. State explanations and additional comments follow

State	Abutment Type - First Preference
Caltrans	Seat
Iowa DOT	Integral
LaDOTD	Seat
MaineDOT	Integral
MassDOT	Integral
MnDOT	Integral
PennDOT	Integral
SDDOT	Integral
TDOT	Integral
UDOT	Integral
VDOT	Integral
WSDOT	Semi-Integral

Table 6 Predominate Abutment Type per State

Caltrans: Most Caltrans bridges are non-integral seat type abutments (**Figure 37**). The expansion joint is designed to accommodate thermal, creep and shrinkage movements, and the backwall is designed to break off in a seismic event, minimizing superstructure soil interaction. Additionally, approach pavements are only vertically attached to backwalls. Caltrans prefers to isolate the bridge from the backfill due to seismic concerns. Horizontal attachment would negatively impact mass during a seismic event.

Caltrans Memo to Designers specifies integral abutment bridges shall not be used if movement exceeds ½ inch, for new bridges with no approach slab. When the new structure approach is used, the movement shall not exceed 1 inch at the expansion joint between the approach slab and sleeper slab. They do discourage internal movement (i.e. hinges, in-span joints) and push all movement to the abutments.

Integral abutments are designed for LRFD loads such creep, shrinkage, temperature, braking force, settlement and seismic. Caltrans allows 1 inch of settlement for integral abutments and 2 inches for simple spans with seat abutments, per CA Amendments 8th Edition 3.4.1. Caltrans uses the terms "integral" and "diaphragm" interchangeably. "Backwalls" are used with non-integral seat abutments (thin stem in **Figure 37**) and concrete end diaphragms are used for integral abutments (**Figure 38**).

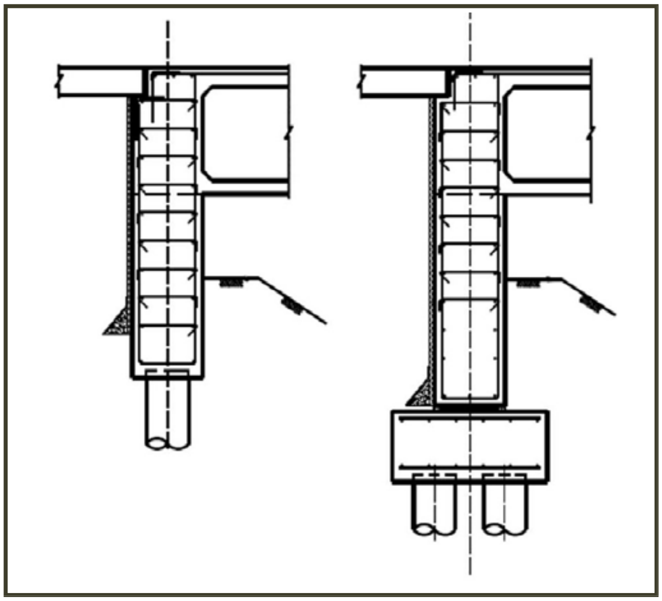


Figure 38 Caltrans Integral (Diaphragm) Abutment

Iowa DOT: Iowa DOT selects integral abutments and continuous construction at piers. The state uses epoxy reinforcement in backwall instead of black reinforcement. Iowa DOT was seeing the approach slab ledge in the back wall breaking off. It was determined this was due to improper placement of bent rebar in the corbel and voids under the approach slab (**Figure 39a**). This seat was only 8 inches in early designs but Iowa DOT has since extended it to be 1 foot-3 inch (**Figure 39b**). There is a keyed joint at the bottom of the corbel/top of vertical backwall. The distance from the bottom of the corbel to the top of the wall is a constant 3 foot-7inch.

There is a keyed joint at the bottom of the corbel/top of vertical backwall. The distance from the bottom of the corbel to the top of the wall is a constant 3 foot-7inch.

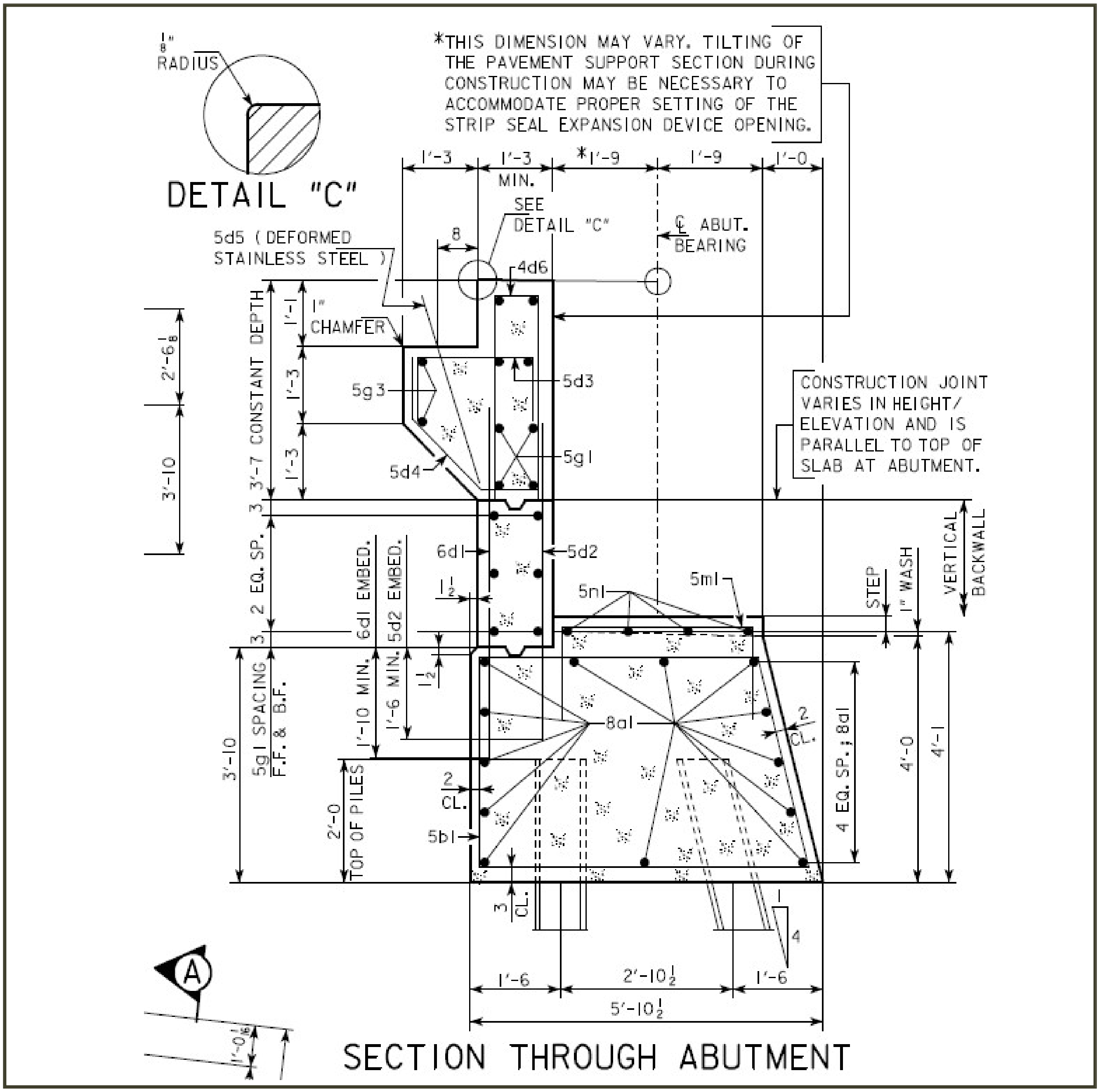


Figure 39 Iowa DOT Abutment/Approach Slab Seat

LaDOTD: Poor soils are the impetus for using non-integral seat type abutments. Details of integral abutments from their pilot project are shown in (**Figure 40**).

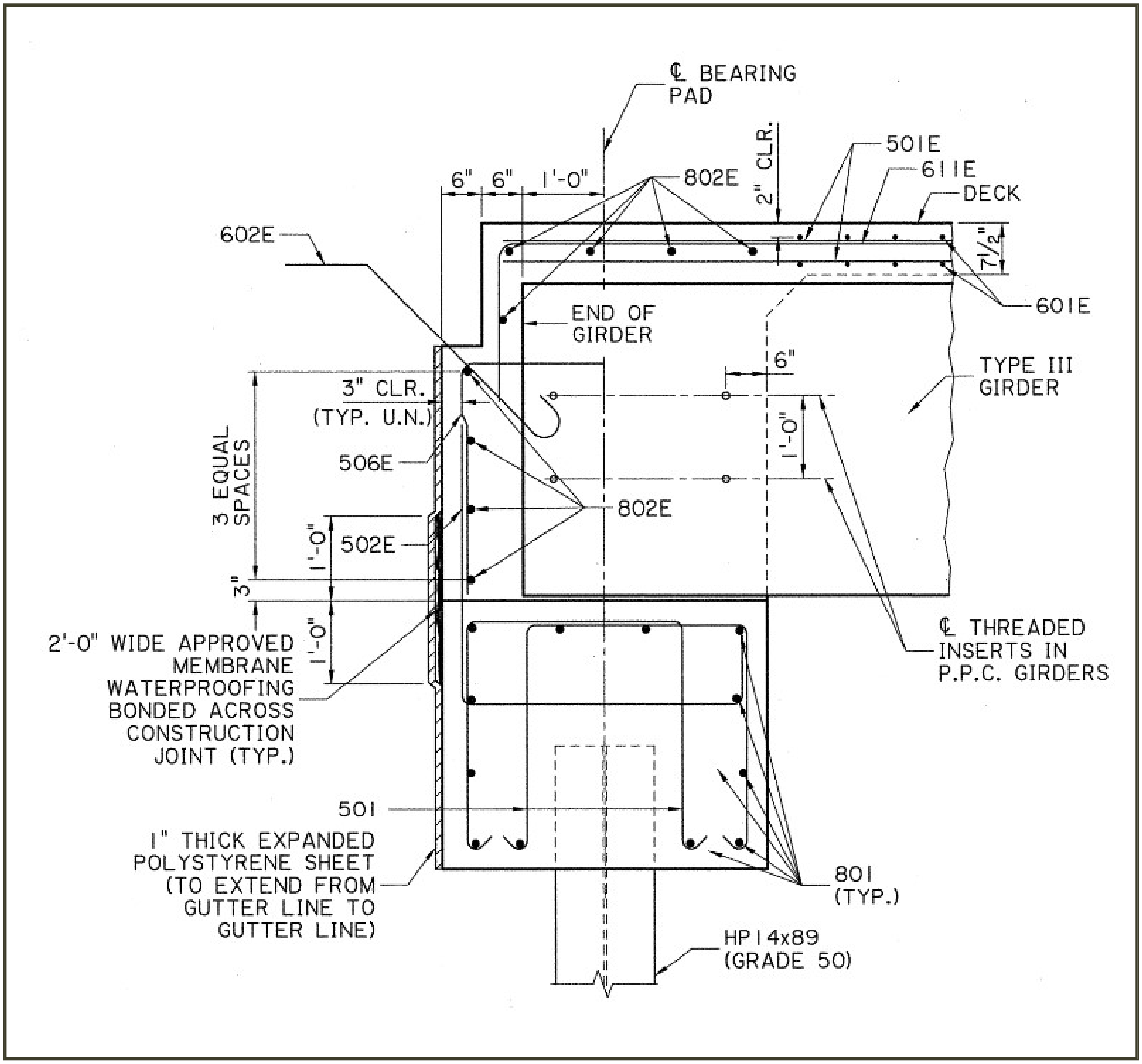


Figure 40 LaDOTD Integral Abutment

MaineDOT: The state preference is to use integral abutments with no deck joints (**Figure 41**). When integral abutment limitations cannot be met, semi-integral abutments are used. The MaineDOT semi-integral abutment is like the WSDOT semi-integral but with a compressible inclusion material between the abutment and backwall.

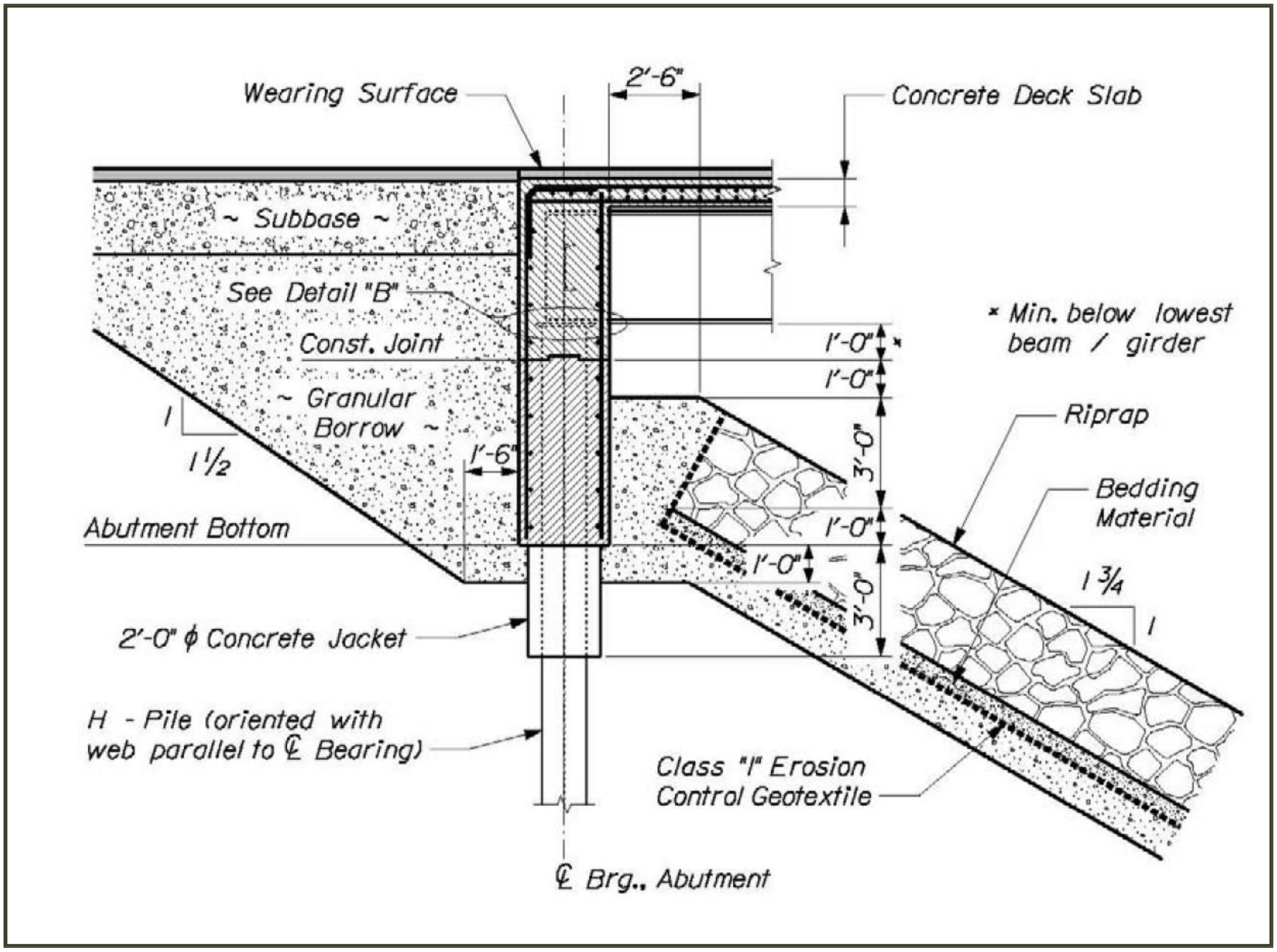


Figure 41 MaineDOT Integral Abutment

MassDOT: The only possible reason to not use an integral abutment would be due to substandard geological strata. Chapter 2 of Part I of MassDOT Bridge Manual has guidelines for identifying appropriate structure types and specific considerations to be explored to determine if a bridge (substructure and superstructure) is appropriate for the site.

Like Caltrans, the backwall of their jointless extends from the bridge seat (**Figure 42**). On the back, it has a shelf for the approach slab and the top is the support for the deck cantilever. Reinforcement is provided front and back and is developed in the abutment stem below the bridge seat. For adjacent beam bridges, the backwall stops at the top of the approach slab since there are not decks with these types of bridges. The backwall is only designed for longitudinal seismic forces from the superstructure. There is a closed cell foam pad that sits on top of the backwall and allows the deck cantilever to rotate without applying load to the backwall.

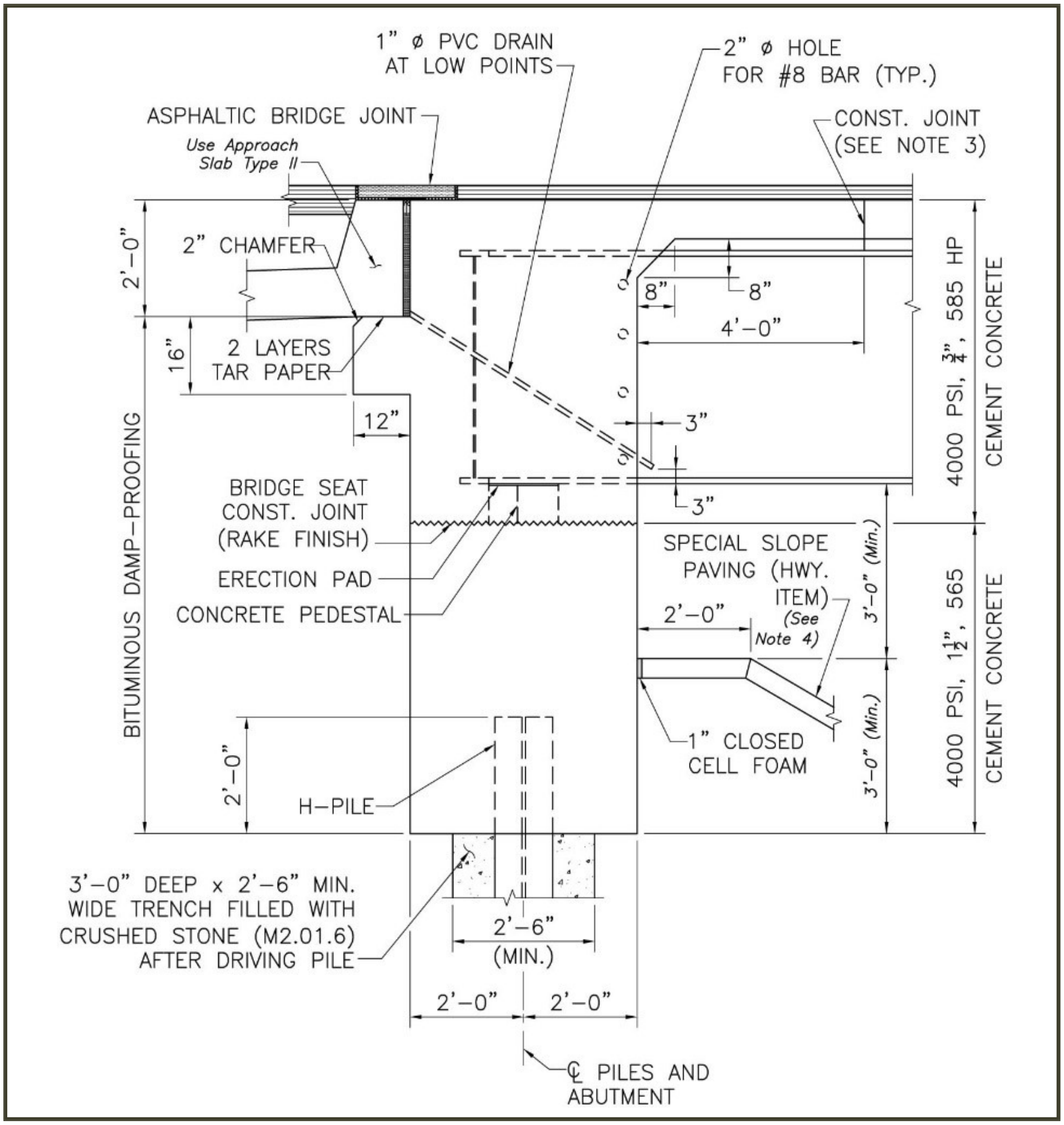


Figure 42 MassDOT 2013 Integral Abutment Details

MnDOT: Integral abutments are the default choice, shown previously in **Figure 33.** If the bridge length, skew, or vertical exposure do not meet the criteria published in the MnDOT Bridge Design Manual, a semi-integral abutment is the next choice. If the wingwall lengths, exposure or superstructure depth do not meet the criteria for a semi-integral abutment, a parapet (seat) type of abutment is selected. Chapter 11 of the MnDOT Bridge Design Manual provides the complete selection criteria, along with the geometric and reinforcement requirements for each abutment type.

PennDOT: Concrete end diaphragms are used at superstructure ends of integral abutments. Beam rotation and thermal superstructure movements are accounted for. Their longest jointless concrete bridge is a 524 feet five-span prestressed concrete constructed in 2018. It used standard details with approach slab and 5 inch neoprene strip seal dams at ends of approach slabs. The longest jointless steel welded plate girder bridge is a two-span 373 feet bridge constructed in 2012. The bridge used standard details with approach slab and 4 inch neoprene strip seal dams at ends of approach slabs.

SDDOT: 95% of SDDOT bridges use integral abutments unless site conditions or structure geometrics are prohibitive. SDDOT researched beam ends cast in to backwalls and determined that small moments were being developed in the beam ends, so they added stiffeners to the beam ends. Integral abutment backwalls are typically 2 feet thick. For semi-integral backwalls, SDDOT places ¾” preformed material beneath the sliding backwall. Girder ends cast into backwall are also encased in ½” preform to mitigate backwall cracking due to beam rotation at interface.

TDOT: The state uses integral abutments as standard procedure for bridges within thermal movement restrictions. TDOT presented the following reasons for using integral abutments (**Figure 43**):

- Increased design efficiency by reducing longitudinal pier forces by 60%
- Redundancy
- Enhanced Load Distribution
- Protection for weathering steel – Paint beam ends with primer
- Greater end span ratios (60% unless uplift is incorporated) on most integral abutment <30-deg. Skew.

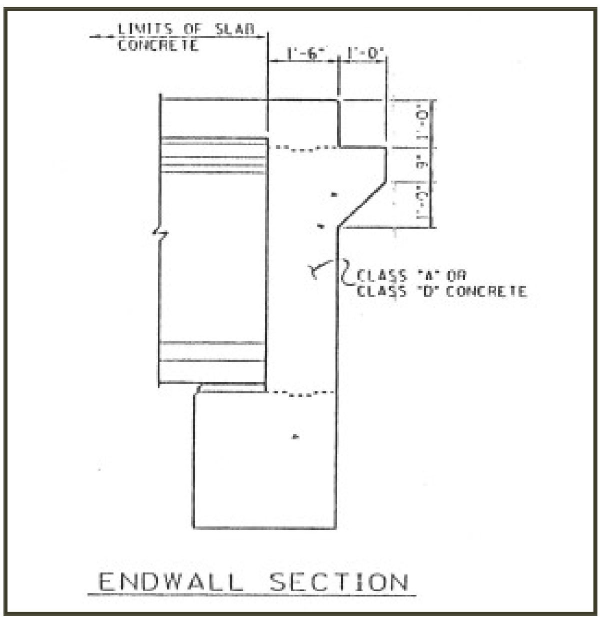


Figure 43 TDOT Integral Endwall Section

UDOT: UDOT defaults to the use of jointless bridges unless there are circumstances that necessitate the inclusion of joints. Some potential reasons to add joints within the bridge limits include excessively large thermal displacements, skews or curvature that lead to undesirable lateral soil response, existing joints in a structure being widened, or other specific need.

UDOT’s integral abutment itself is reinforced with #4 bars vertically and #8 bars horizontally (**Figure 44**). The front face bars pass through the girder webs and are connected by #4 tie bars which run from the front face to the back face of the abutment. These bars and extended strands from precast prestressed girders ensure that the girders are tightly locked into the abutment mass.

The girders extend 9 inches beyond the centerline of the abutment and rest on elastomeric bearings which are cast into the abutment. Depending on the girder size these standard bearings can be 1 7/8 inches thick, 16 inches long and 3 feet wide.

Below the bearings is the first stage of the integral abutment, the pile cap. Typical abutments are 3 feet wide and centered over driven piles. Vertical face reinforcing projects up to the top mat of deck bars and is continuous down to the bottom of the pile cap. Horizontal reinforcing at the top of the first stage is typically #8 bars designed to carry second stage loads.

UDOT does not have an abutment wall height limit, although the pile cap height for an integral abutment is limited to 8 feet without a defined construction sequence and procedure. The soil face of the integral abutment provides a 1 foot seat for the approach slab. The top of seat is a little farther down than the approach slab thickness, this is to facilitate construction and set the seat elevation to match the elevation at top of wingwall which is a little lower than the bottom of the approach slab. The joint at this location is a non-moving joint, forcing thermal expansion to the sleeper slab end of the approach slab.

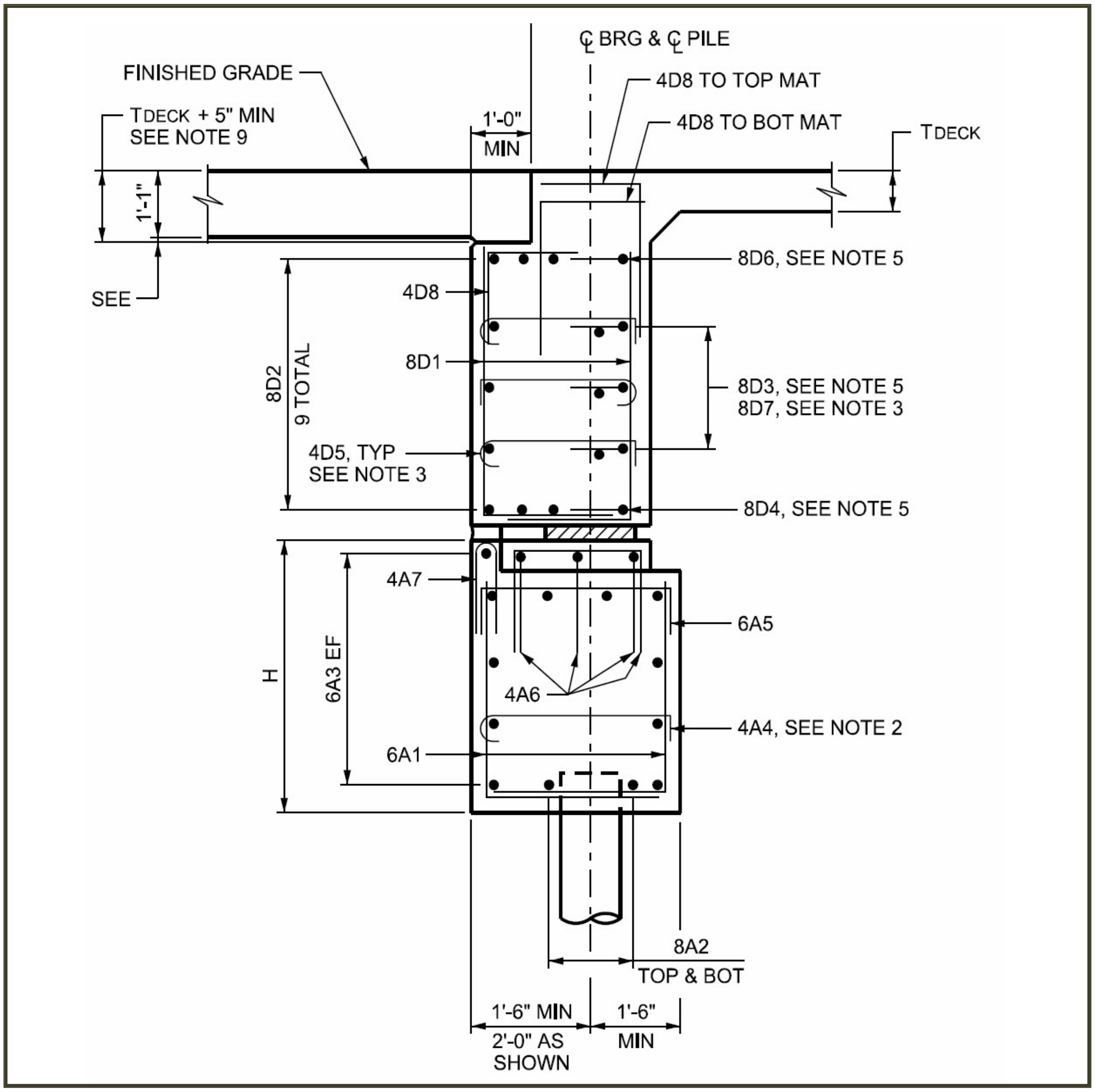
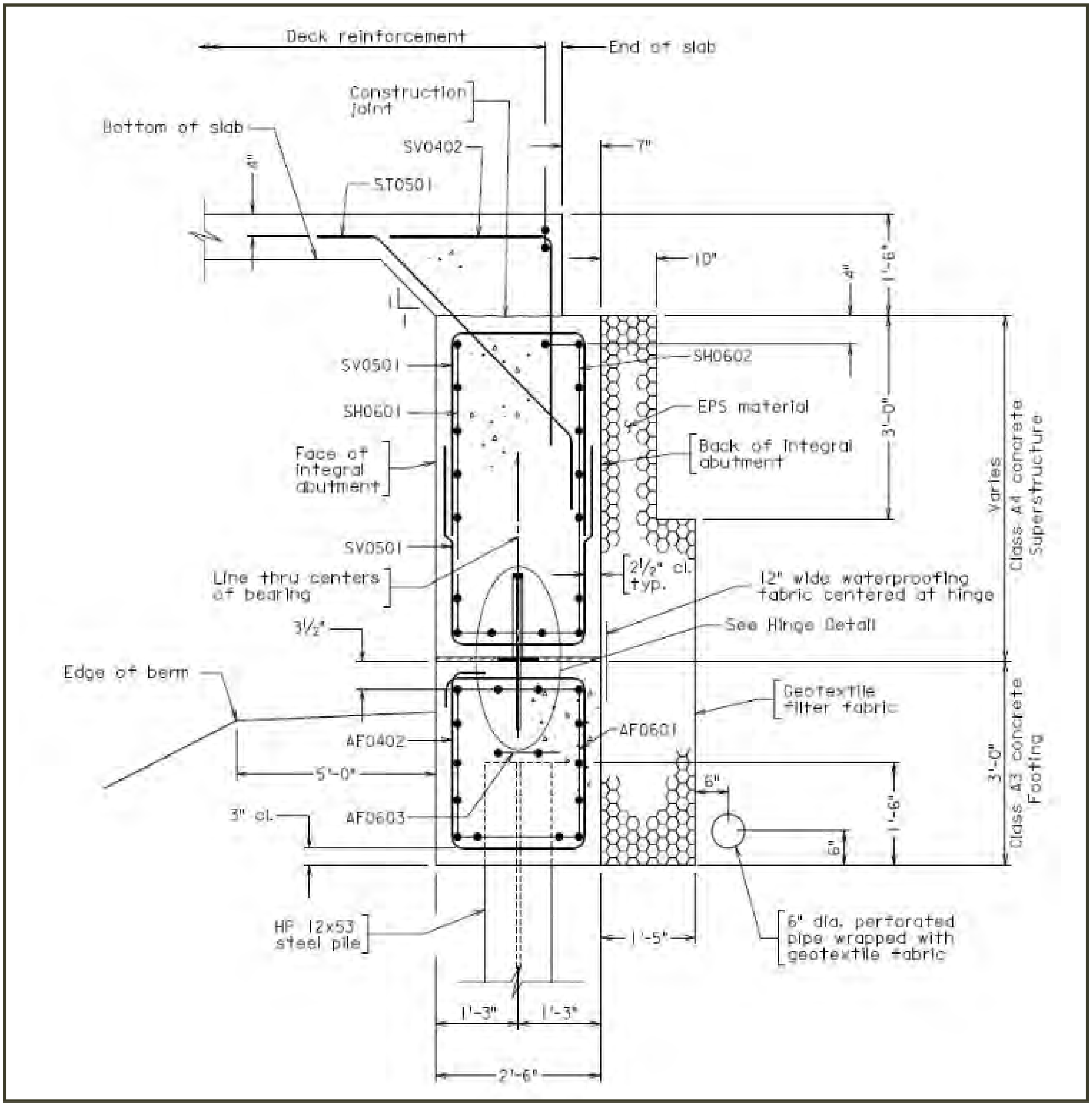


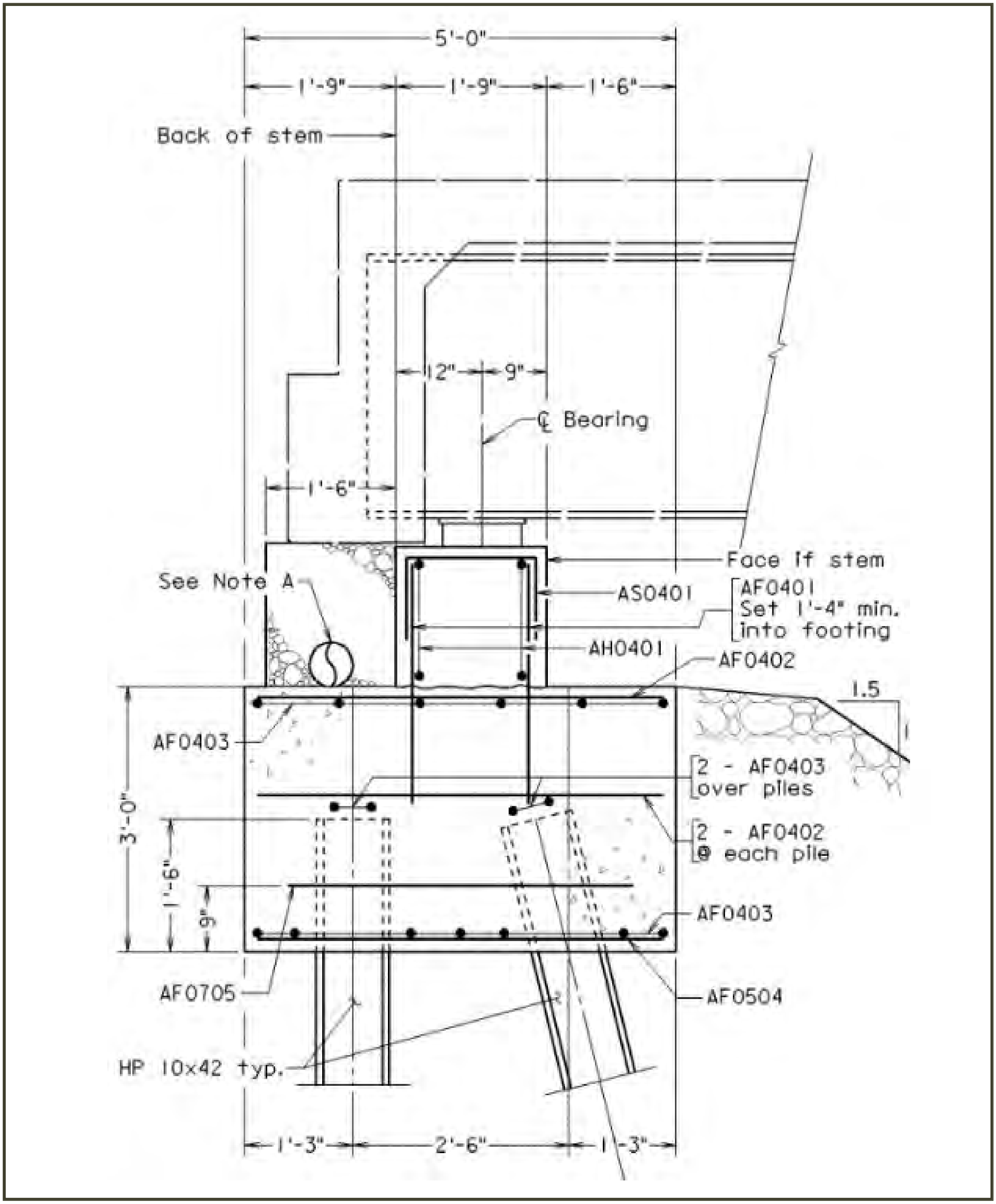
Figure 44 UDOT Semi-Integral Abutment (courtesy Utah DOT)

VDOT: VDOT presented details for (in order of preference) Integral (**Figure 45a**), Semi-Integral (**Figure 45b**) and deck extension (**Figure 35**). The "Virginia Abutment", previously mentioned in Section 1.4 and shown in **Figure 12**, and detailed in **Figure 46**, is a specialty hybrid integral/semi-integral abutment with essentially two back walls: one stationary and one which moves with the superstructure. The joint is directly behind the flexible back wall and drains into a trough that separates the two back walls. This abutment is intended for use on longer span bridges and is last in the selection hierarchy due to high cost.



a) Fully Integral

Figure 45 VDOT Abutment Details



b) Semi-Integral

Figure 45 VDOT Abutment Details

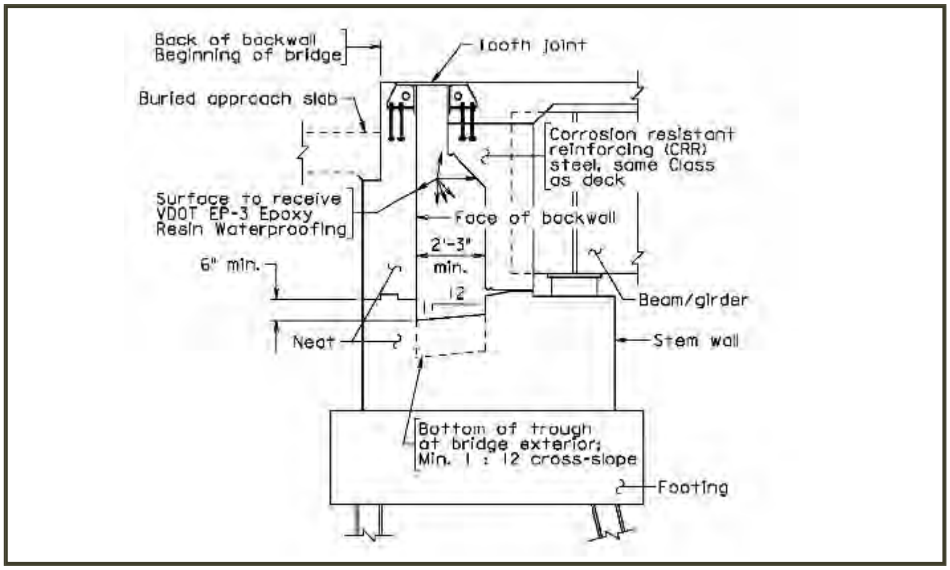


Figure 46 Virginia Abutment Details

WSDOT: WSDOT uses semi-integral abutments at end piers (shown previously in Figure 34), and integral diaphragms at intermediate piers. In addition to satisfactory seismic and service performance, jointless bridges provide a smooth ride resulting in higher safety. WSDOT believes jointless bridges have less maintenance and life cycle costs.

3.1.2 Front Treatment

Treatment in front of the abutment varied among states. Parameters such as berm height and shelf width, slope angle and protection were discussed as well as wingwall design requirements and limitations.

Caltrans: Caltrans uses a 1.5:1 maximum slope with a 5-foot berm or alternatively slope paving (Bridge Standard Details).

Iowa DOT: For the typical Iowa bridge there is adequate space for a relatively shallow embankment slope, and the abutment will need to retain soil only near the top of the embankment. Iowa DOT standard abutment footings supported by piles should have a bottom elevation 2 feet below berm elevation [BSB SS 2099-2105]. Iowa DOT places dirt in front of the abutment with no slope protection and as a result erode due to water leakage under abutment. Abutment footings subject to frost heave are required to have a bottom elevation a minimum of 4 feet below ground line. Iowa DOT has seen erosion in berms (**Figure 47**).

Figure 47 Iowa DOT Berm Erosion

Figure 48 shows a solution Iowa DOT has used at their wingwalls, with engineering fabric and a 9” thick erosion stone with subdrain.

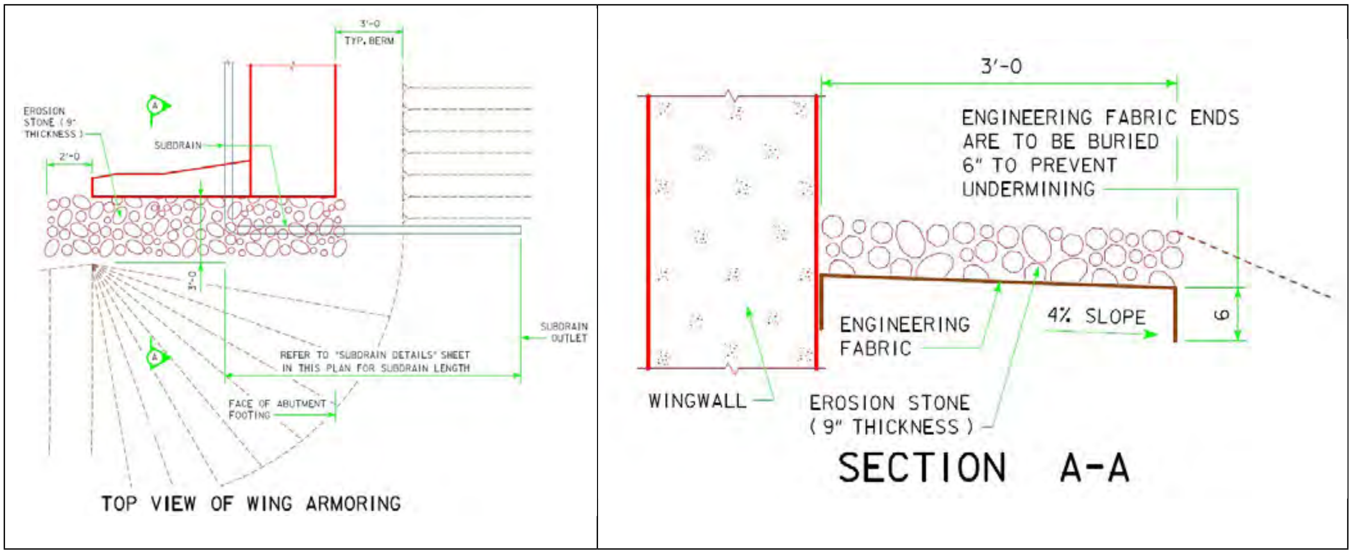


Figure 48 Iowa DOT Wing Armoring

MaineDOT: MaineDOT leaves 2 feet of the abutment front face (between top of berm and superstructure soffit) exposed for access with 2’-6” berm seat in front, shown in **Figure 41**. **Figure 49** shows the slope protection details, which consist of a geotextile beneath 12” minimum protective aggregate cushion topped with 3 to 4 feet thickness of riprap at a 1.75:1 slope.

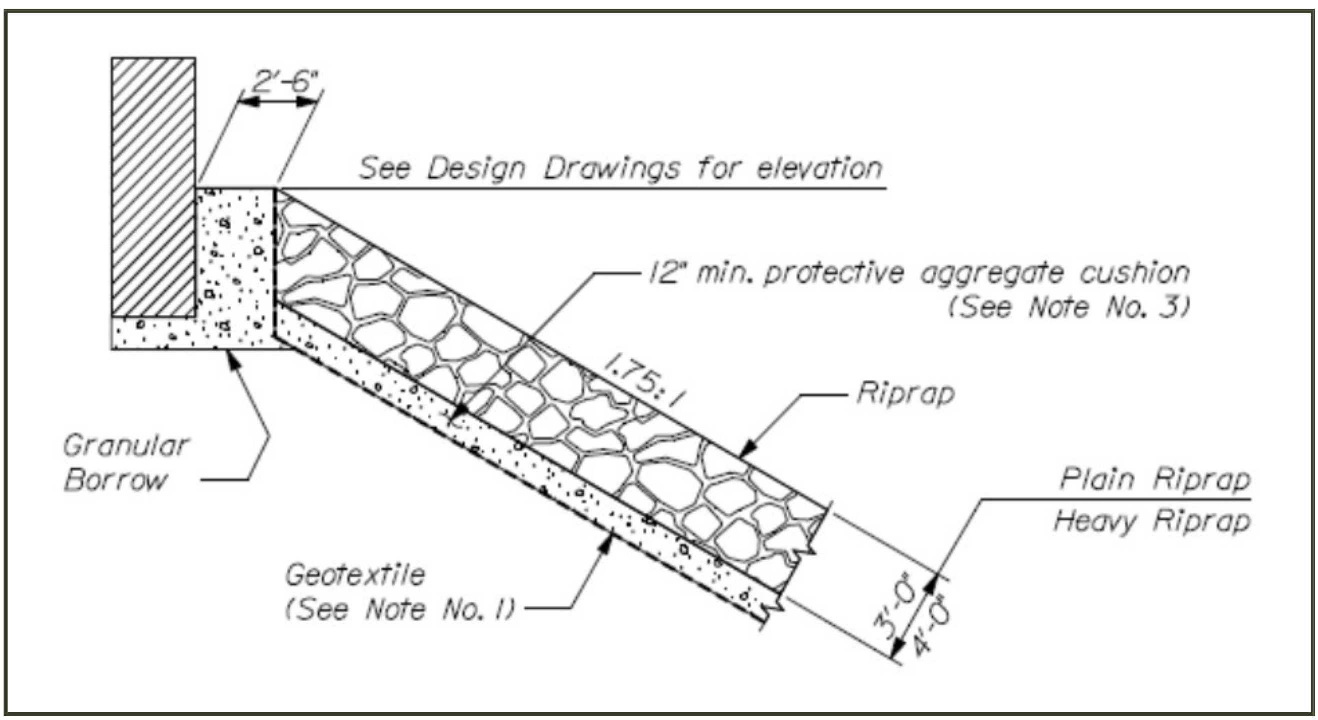


Figure 49 MaineDOT Riprap Slope Integral Abutment

MnDOT: MnDOT integral abutment front treatment and exposure requirements are shown in **Figure 17**.

TDOT: Berm width is typically set at 4 feet and can be wider based on thickness of abutment slope protection. Typical abutment slope is 2:1 parallel to the abutment beam. Cantilever wingwalls are designed to resist lateral pressure while MSE wall abutments designed so abutment moves independent of wall. Typical wingwall is pile supported and orientated parallel to the roadway. They have, on occasion, designed cantilever wingwalls to resist lateral pressure in high seismic areas. hen retaining walls are wrapped around abutments, the abutments are designed to move independent of wall system.

UDOT: Two standard treatments are expected at the front face of the abutment. Either a sloped fill with a maximum slope of 1.5 to 1, or a 3.5 foot shelf at the top of an MSE wall. For the sloped fill condition, addition of a berm is not preferred, however a 2 foot minimum vertical clearance must be provided at the abutment face. Slope paving is required where the slope exceeds 2:1. In the case of an MSE wall, a 3 foot minimum vertical clearance must be provided to allow for inspector access.

VDOT: VDOT has a 5-foot berm in front of its integral abutments with a 1.5: 1 slope.

WSDOT: WSDOT requires exposed faces of wingwalls to be vertical and has standards for 15 feet, 20 feet and 25 feet long wingwalls depending on the front fill slope. The minimum clearance between the bottom of the superstructure and the embankment below shall be 3'-0" for girder bridges and 5'-0" for non-girder, slab, and box girder bridges. The presence of a horizontal landform shelf beneath the superstructure at the abutment face may constitute an attractive nuisance **Figure 50** shows WSDOT front treatment.

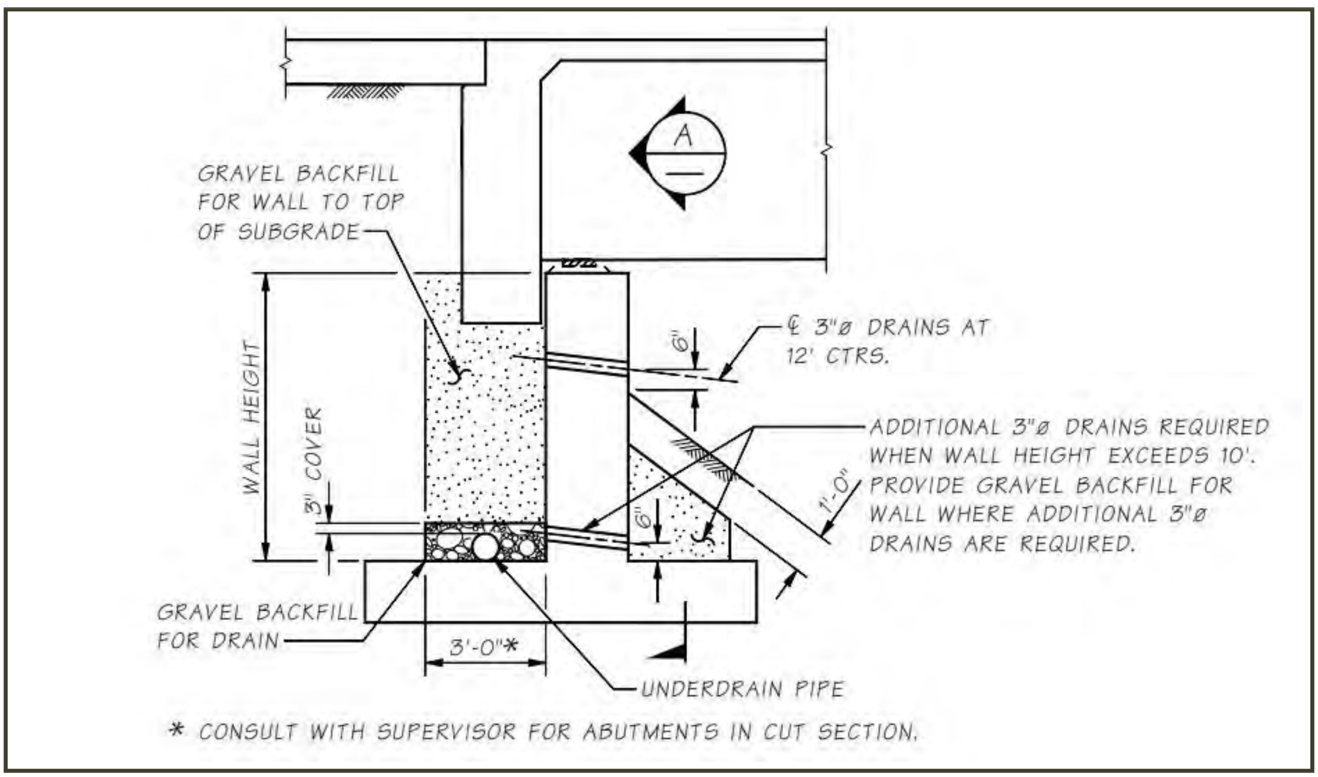


Figure 50 WSDOT Drainage and Backfill Detail (BDM Fig. 7.5.11-1)

3.1.3 Piles

Single-row pile groups are common practice for integral abutments. Pile fixity and orientation are presented followed by corrosion protection measures.

3.1.3.1 Pile Fixity and Orientation

Most states refer to the beam axis of bending when it bends in the longitudinal bridge direction (about the transverse bridge axis). Most host states oriented piles for the weak axis bending (Minnesota, South Dakota, Pennsylvania, Massachusetts, Maine, Iowa) while TDOT noted their piles are oriented for strong axis bending. Methods of attaining pile fixity varied among states. Some parameters that varied included the depth of pile embedment into abutment and pile pre-boring. This section presents state methods of pile fixity and orientation.

Caltrans: Pile embedment into the abutment is 3” for concrete piles and 5” for steel piles. The bottom portion of abutments on piles without footings, must be embedded into the soil a minimum of 3.5 feet at the face of the abutment when there is no berm (with slope paving). If the slope is flatter than 1½:1 (horizontal: vertical), the embedment can be decreased to as little as 2’-0”. Bridge Design Details 6.2 show (**Figure 51**):

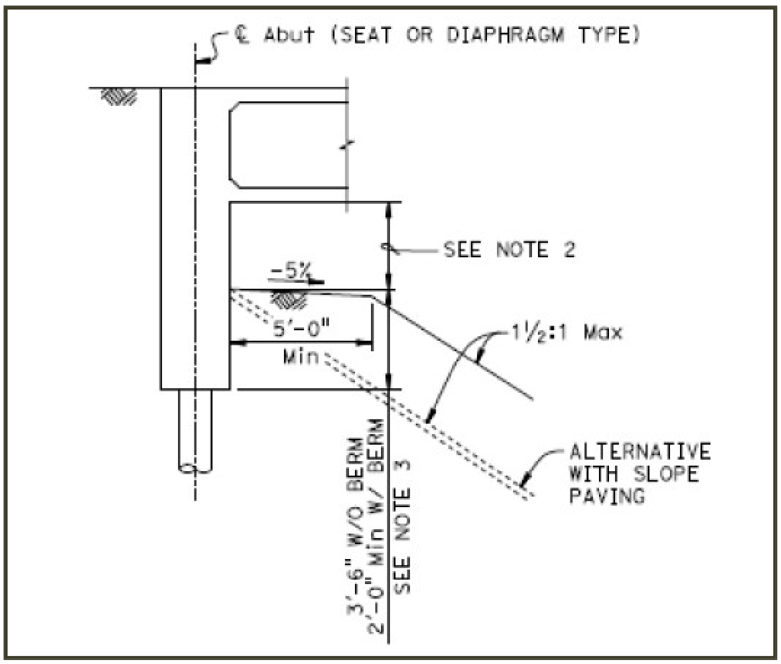


Figure 51 Caltrans Abutment on Piles without Footing

Iowa DOT: For bridges with skews of 30 degrees or less, H-piles are rotated to align the pile webs with the centerline of abutment bearings. At skews above 30 degrees, piles shall be aligned with pile webs perpendicular to centerline of roadway. Iowa DOT piles are embedded into the abutment 2’. Piles installed behind MSE walls are installed through corrugated pipe filled with bentonite. Pile sizes have been updated to use more compact/plastic sections for higher loads and movements (HP10x42 to HP 10x57). Prebored holes were initially filled with granular material or left open. Bentonite is now used to fill prebored holes. Initially used 8’ prebored hole depth. Now Iowa DOT uses 10’ up to 15’ in special situations.

LaDOTD: The pilot project jointless bridges used 14" H piles oriented with weak axis bending. The top 12' were encased in 36" diameter steel pipe casings, and D-shaped rubber fenders were placed inside the flanges, against the web, in order to lower the point of fixity of the pile without using a stiffer pile.

MaineDOT: H-Pile oriented for bending about the weak axis. Piles embedded a minimum of 2'-0" for all pile types. MaineDOT does not place piles under wingwalls. Wingwalls are designed as cantilevers supported off the abutment. Concrete piles have a 2 foot diameter jacket around them for the first three feet below the abutment.

MassDOT: MassDOT predrills the top 8 feet of the piles and surrounds them in crushed stone to increase pile flexibility.

MnDOT: Piles are embedded 2'-6" into the abutment stem. If steel shell piles (cast in place (CIP) piles) are used the bridge length is limited to 150 feet due to the stiffness of the piles. H-piles are oriented with the weak axis in bending are limited HP12 and smaller sections.

PennDOT: In their PA Public Private Partnership, to protect against scour, PennDOT embedded piles into abutment at least 1 foot and surrounded them with a corrugated pipe for a depth below abutment to anticipated scour depth (**Figure 52**). Piles are orientated about the weak axis.

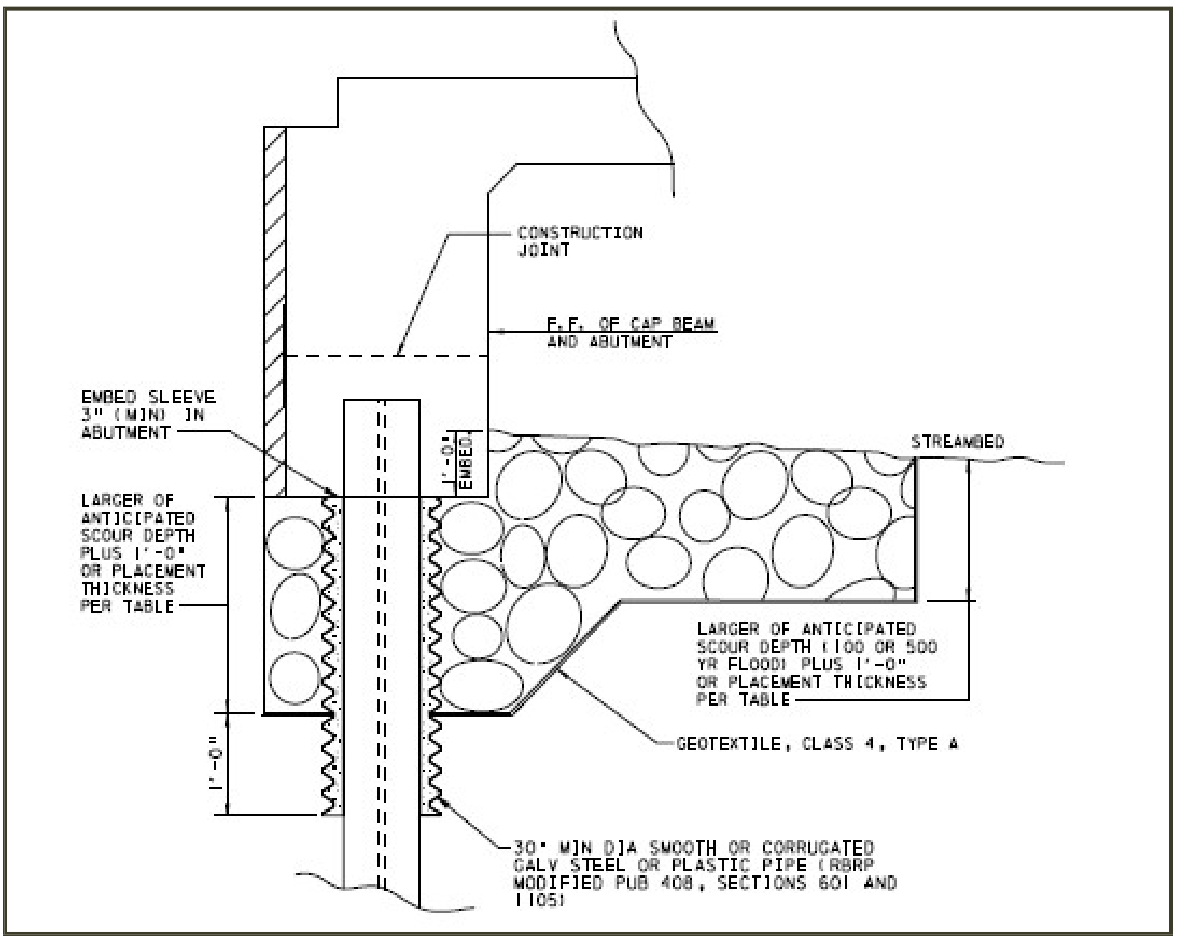
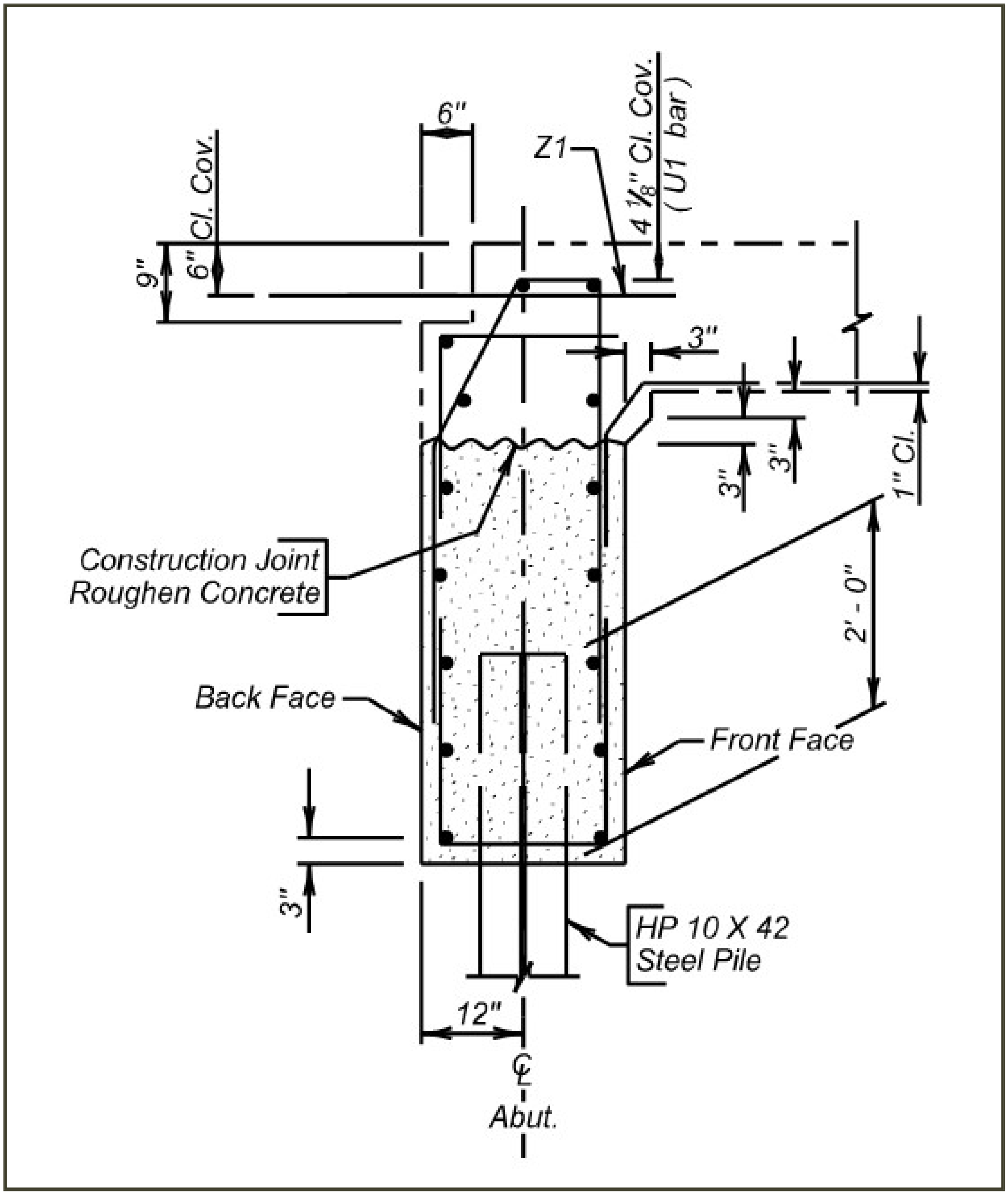


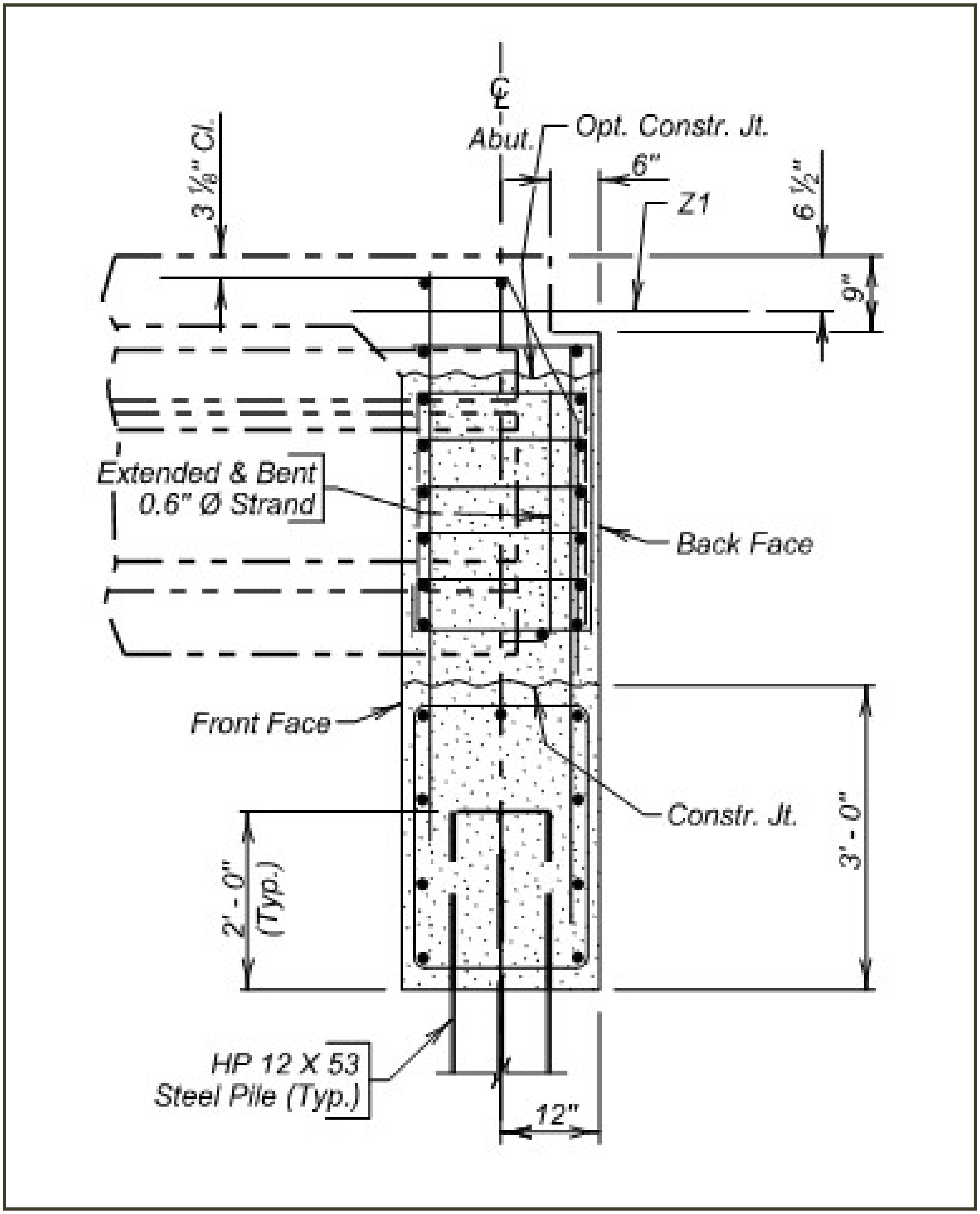
Figure 52 PennDOT Alternate Scour Protection Detail

SDDOT: Piles are orientated about the weak axis at the abutments (**Figure 53a**). SDDOT typically uses 10” piles and tries to avoid 14” piles. Piles in continuous concrete bridges (**Figure 53**) and prestressed girder bridges are embedded into the abutment 2’. Piles are pre-bored for the first 10 feet.



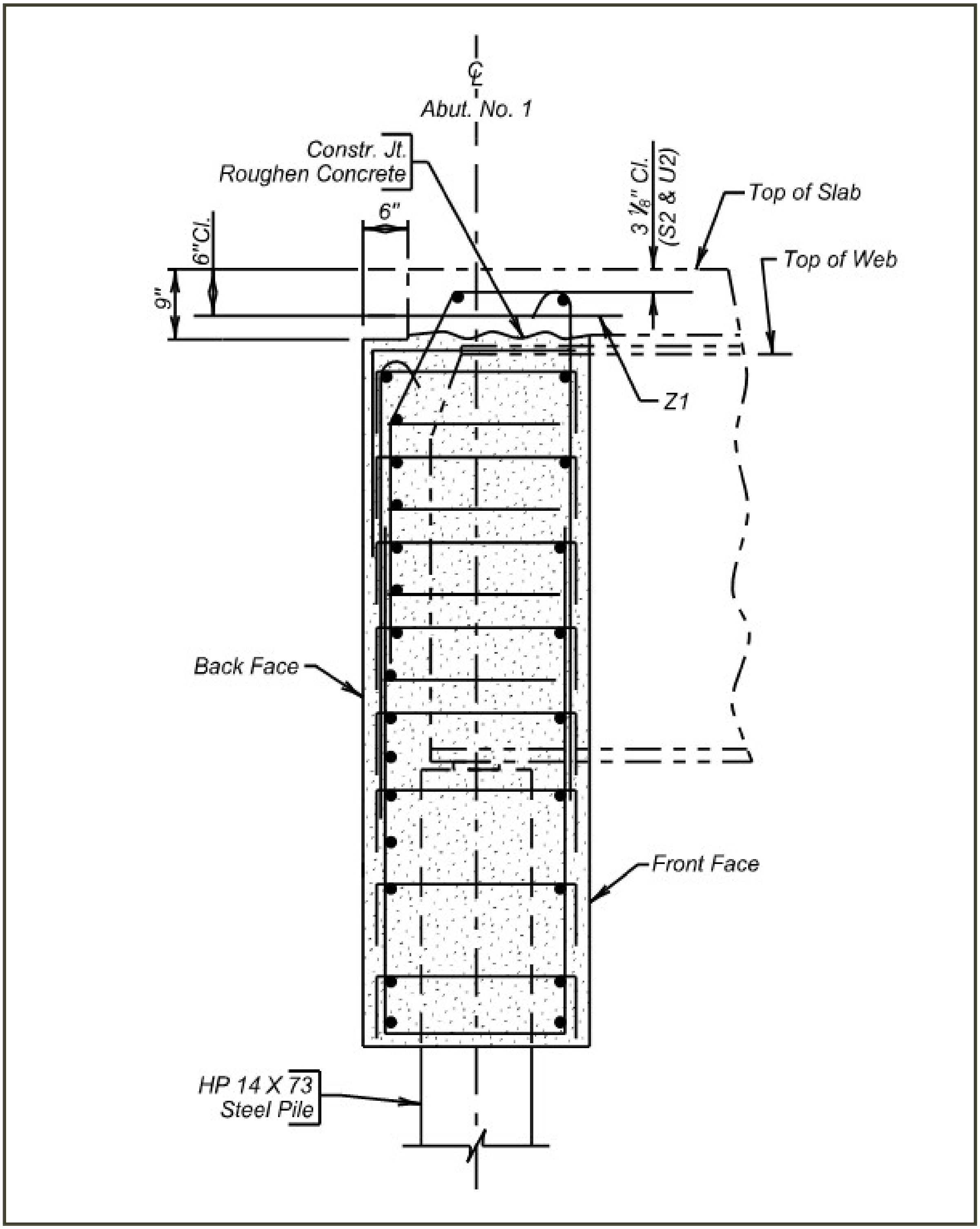
a) Continuous Concrete

Figure 53 SDDOT Abutments



b) Prestressed

Figure 53 SDDOT Abutments



c) Steel

Figure 53 SDDOT Abutments

TDOT: TDOT embeds concrete piles 1 foot and steel piles usually 2 feet into the abutment beam. Seismic attachments are used where appropriate for seismic loading or uplift. A minimum pile length of 10 feet is specified and the state will pre-drill when necessary to achieve this length. Wingwalls are designed as cantilevers from the corner of the abutment. Wingwalls do not even need footings in some cases because in this approach the abutment corner / wingwall interface is designed as a full moment connection. Considering abutment translation, not rotation, as the realistic movement, piles deform in double curvature. Modelling shows pile unbraced lengths between 10 and 14 feet due to the lateral translation.

UDOT: UDOT provides standard details for driven pile, top fixity connections. For a fixed connection, the steel pile is embedded 2 feet into the pile cap.

VDOT and WSDOT had no additional comment.

3.1.3.2 Corrosion Protection

The following section addresses state actions to protect against corrosion.

Iowa DOT: Iowa DOT has seen pile corrosion at the top of the pile (**Figure 54**).

Figure 54 Iowa DOT Pile Corrosion Example

MaineDOT: MaineDOT encases the top 3 feet of pile with a concrete jacket as well as embedding pile additional 2 feet into abutment.

MnDOT: MnDOT is looking at galvanizing pile ends to protect against corrosion.

PennDOT: PennDOT requires steel piles to be hot dipped galvanized for protection.

SDDOT: SDDOT is currently considering protecting the piles with cold tar epoxy paint. Maybe protecting the top 10 feet of the pile – applied after the pile is in place and cleaned up.

UDOT: UDOT's corrosion concerns stem from the application of deicing salts. The Structures Design and Detailing Manual requires the "use [of] coated reinforcing in all locations except for reinforcing in piles."

WSDOT: The state's BDM Section 6.7 presents requirements for corrosion of steel foundations and buried structures (**Table 7**).

Location	Marine or Non-Marine: Corrosive	Non-Marine: Non-Corrosive
Soil embedded zone (undisturbed soil)	0.001	0.0005
Soil embedded zone (fill or disturbed soils)	0.0015	0.00075
Immersed zone	0.003	0.0015
Tidal zone	0.004	---
Splash zone	0.006	---
Atmospheric	0.002	0.001

Table 7 WSDOT Requirements for Corrosion of Steel Foundations and Buried Structures

Caltrans, LaDOTD, MassDOT, TDOT and VDOT had no additional comment.

3.2 Joint and Connection Details

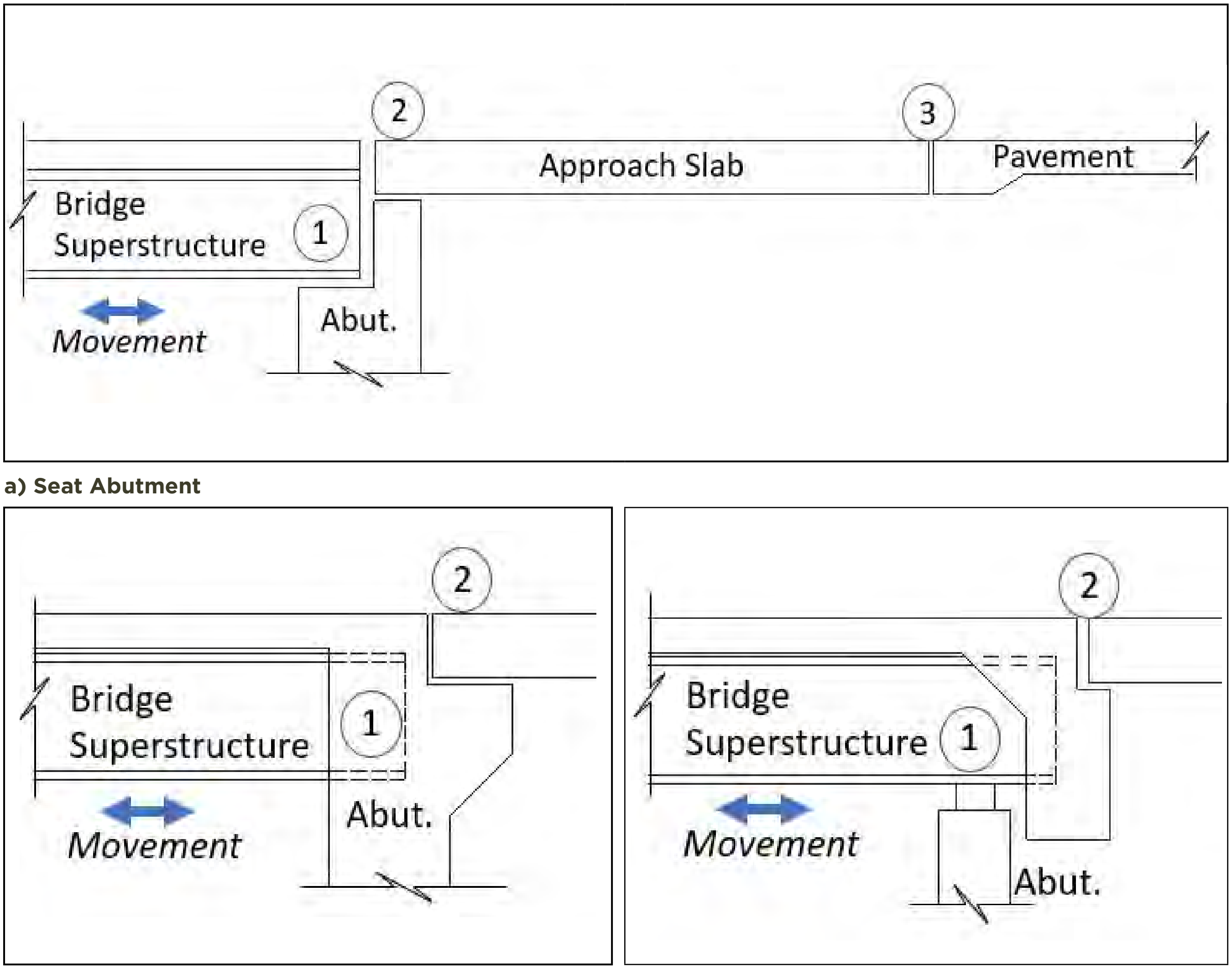
Beam end and bearing damage were stated as the main impetus for moving joints away from the bridge. Additional reasons cited for moving joints off the bridge are:

- Joints are expensive
- Periodically need to be raised
- Generally, joints fail. They leak, stain, cause corrosion
- Deck deterioration
- Water born salts into joints.
- Leakage causes deterioration of beam ends, bearings, substructures, on-going maintenance.
- Span misalignment (especially along skew)
- Bearings seize, tip over, pads walk
- Unseating in seismic event

This section presents where states prefer to allow movement as well as how states detail their movement location, stationary connections and joint types.

3.2.1 Location

There are three locations at bridge ends to accommodate movement: between superstructure and abutment (Location 1 in **Figure 55**), between abutment and approach slab (Location 2), and between approach slab and roadway pavement (Location 3). Drainage must be accommodated at joint location and connections must be detailed at the remaining two locations.



b) Integral Abutment

c) Semi-Integral

For b) and c), detail beyond Joint 2 is similar to seat abutment

Figure 55 Possible Joint/Connection Locations

For seat abutments (**Figure 55a**), movement occurs between the superstructure and abutment. The abutment, approach slab and pavement remain stationary. Therefore, the joint is between the superstructure and the abutment/approach slab (between location 1 and 2 in the figure).

For integral abutments (**Figure 55b**), the superstructure and abutment move together. The joint can be located at location 2 or 3 in the figure. If the joint is at location 2, the approach slab is stationary while the abutment slides beneath it. If the joint is at location 3, the approach slab slides along with the abutment and thus needs to be connected at location 2 and detailed to slide between location 2 and 3.

In semi-integral abutments (**Figure 55c**), the superstructure is integral with the top portion of the abutment (discussed in detail in Section 3.1.1) and the lower portion of the abutment remains stationary. Like integral abutments, the approach slab can be detailed to remain stationary while the superstructure diaphragm slide beneath it or detailed to move with the superstructure.

This section looks at each potential joint location individually and how the state details it depends on their desired location of movement. These are divided into three interface locations: bridge deck to abutment/backwall, abutment/backwall to approach slab, and approach slab to roadway pavement.

3.2.1.1 Location 1: Bridge Deck and Abutment Backwall/Superstructure Dia phragm Interface

Movement at this interface indicates non-integral abutments, such as seats. For integral and semi-integral abutments, the bridge deck moves with the backwall/diaphragm.

Caltrans: For non-integral seat abutments, the deck and backwall are separated with an expansion joint. For integral abutments, the deck and end diaphragm are connected with #5's @6", as shown in Bridge Design Aids Section 1: Abutments (this section of their manual is being updated).

Iowa DOT: Iowa DOT embeds girders in a reinforced abutment cap beam-diaphragm (**Figure 56**).

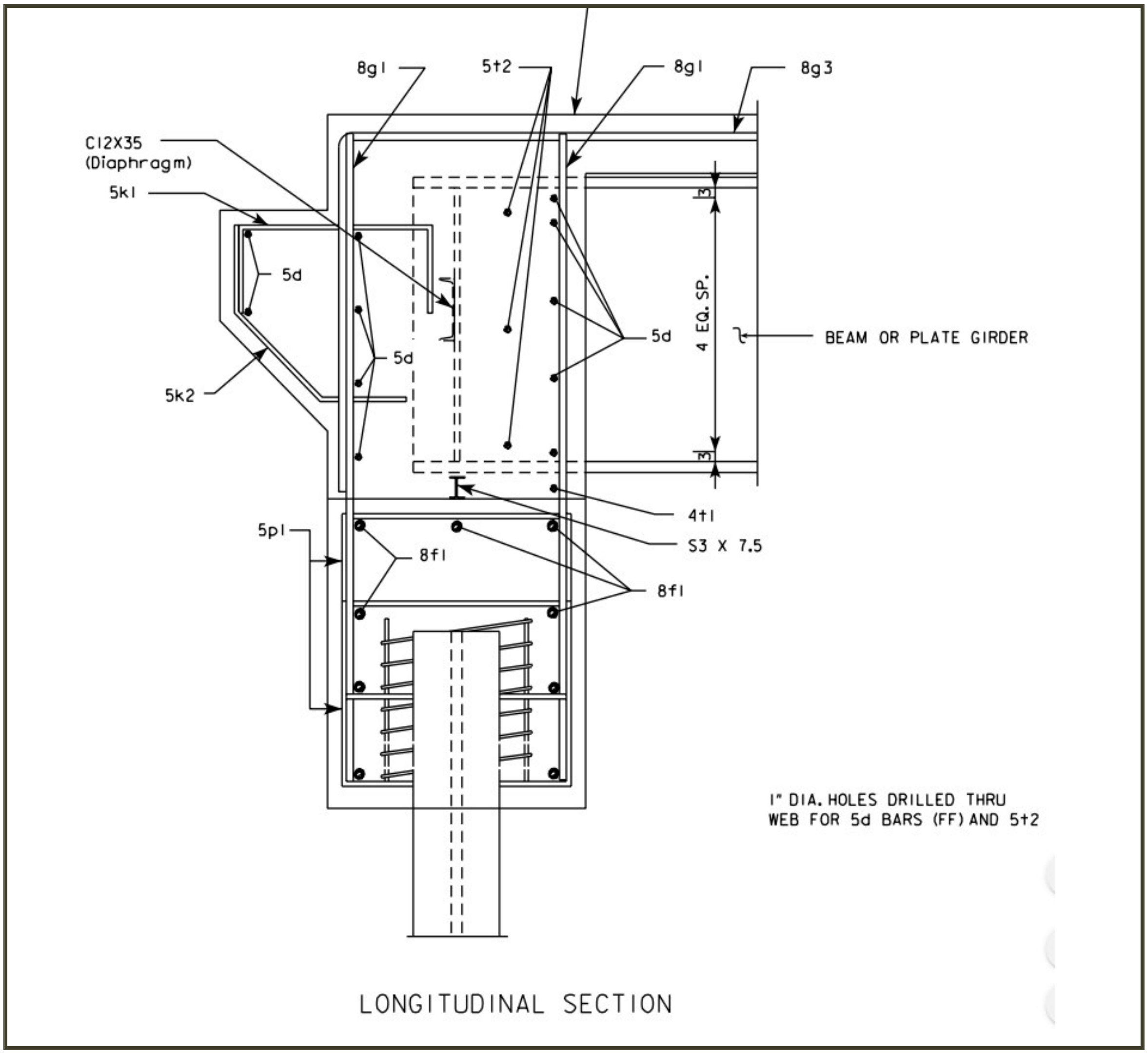


Figure 56 Iowa DOT Integral Abutment Section for a Steel Girder Bridge (Iowa DOT BDM)

LaDOTD: Historically, LaDOTD places a joint at this interface (**Figure 57**). LaDOTD integral abutment detail (pilot project) is shown in **Figure 40**.

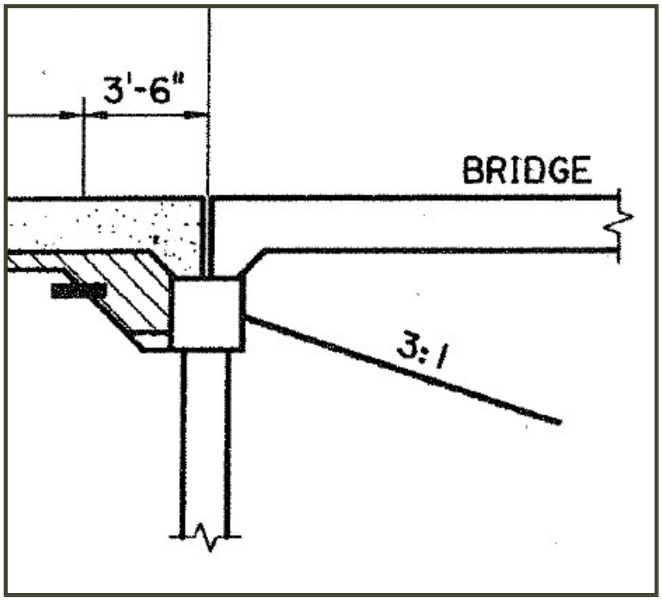


Figure 57 LaDOTD Bridge /Abutment Interface

MaineDOT: MaineDOT is using asphalt plug joints (APJ) on almost all jointless, expansion ends. Semi-integral backwalls will also a lot of times have a compressible inclusion in an area that allows movement. They use bond breaker under slab for slab-over backwall systems.

MassDOT: For integral abutment bridges, the beams are embedded in the CIP concrete abutment diaphragm and the reinforcement is extended from the stem below as well as from the bridge deck down into this diaphragm. For jointless bridges, the backwall extends up from the bridge seat and forms both a shelf for the approach slab and the deck overhang. The beams are encased in an end diaphragm that is cast against a closed cell foam liner that is attached to the backwall that is free to move and rotate. The deck cantilever is formed from the back of this diaphragm.

MnDOT: For integral and semi-integral, the deck and backwall/diaphragm are connected as shown in **Figure 17**. The tie bar is a stainless steel #6 bar spaced at 12".

PennDOT: PennDOT Standard drawing BD-656M shows bridge to backwall connections for various diaphragm depth, backwall configurations, fixed and expansion, and various superstructure types (**Figure 58**).

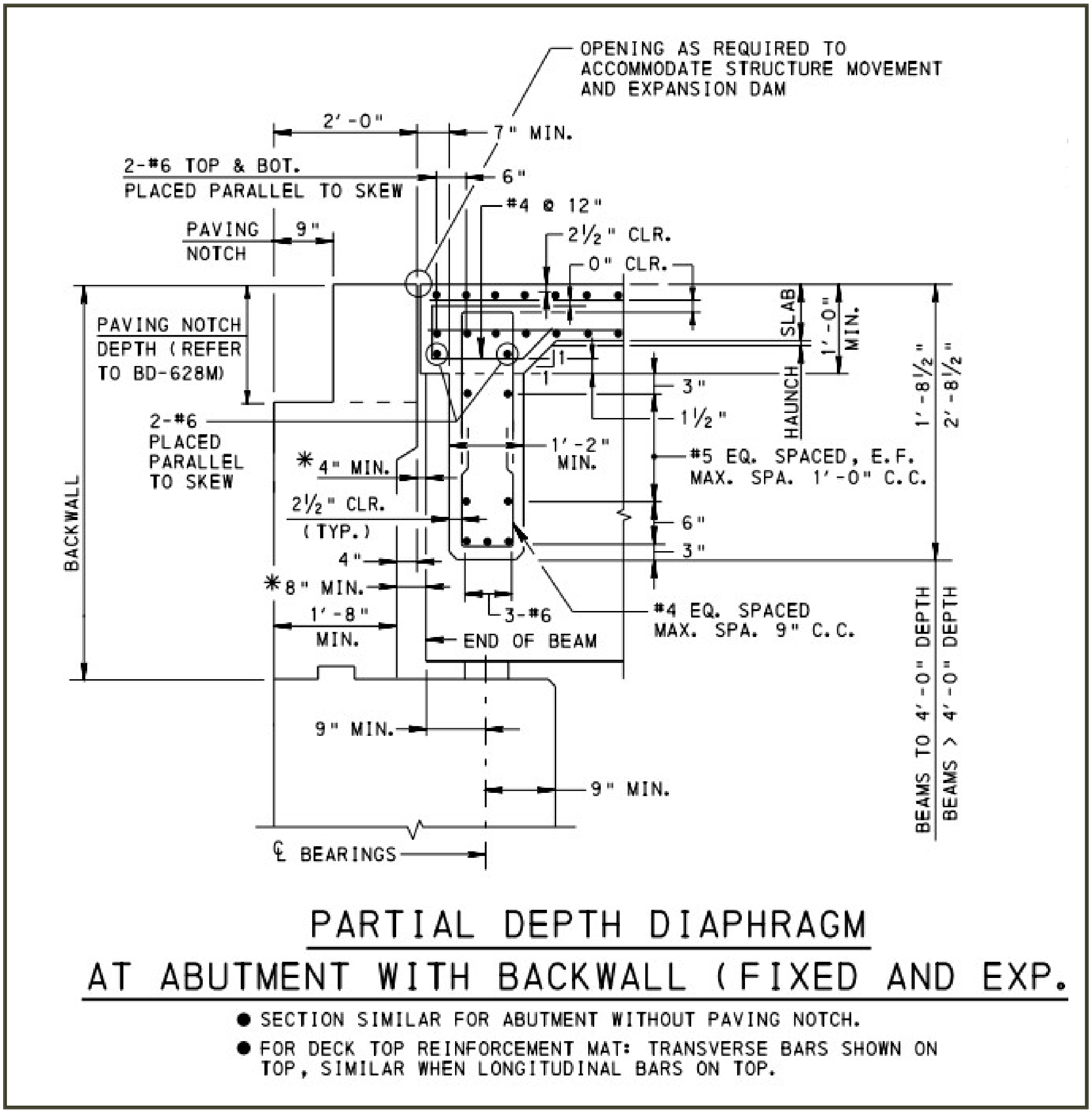


Figure 58 PennDOT Diaphragm at Abutment (PennDOT BD656M)

SDDOT: For their continuous concrete bridges, SDDOT places a construction joint in the abutment backwall approximately 6" below the deck soffit (**Figure 53** and **Figure 59**).

SDDOT embeds precast beams into the abutment endwall. They use ½" preform around the beam (6-9" wide) to inhibit cracking and have found it works well. Prestressed girders sit above construction joint and strands are extended, bent and cast into the second pour of the abutment back wall and deck (**Figure 53**).

Steel girders sit on top of steel piles and back wall is cast around them up to top flange. The typical detail is to place a pile under each beam at the abutment, weld the beam to the pile and then complete the construction work. The deck is then cast over the roughened construction joint (**Figure 59**).

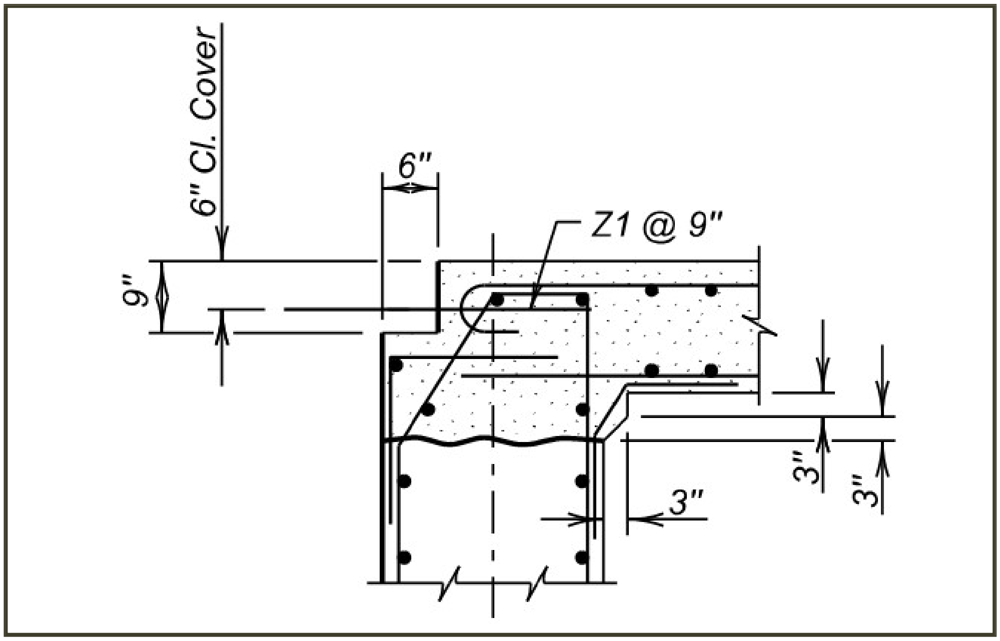


Figure 59 SDDOT Continuous Concrete Bridge Abutment to Bridge Deck Details

TDOT: Bridge deck slab is integral with backwall (**Figure 43**). TDOT accounts for thermal movements because their superstructure translates more than rotates. Face steel in backwall goes through the steel beams. Concrete beams are not cast into backwalls of integral bridges

UDOT: **Figure 60** is a selection from UDOT's Structures Detail drawings and depicts typical integral abutment details. These drawings are provided as general guidance and not as an explicit design. In this detail the typical deck reinforcing is expected to extend back to the approach slab seat. The bars in the front face of the integral abutment extend up and horizontally lap at the top mat elevation. Another set of bars is added to close tie the reinforcing at the bottom mat to the reinforcing along the back face of the abutment. The only joint is a non-translating cold joint at the approach slab where it sits on a reinforced corbel.

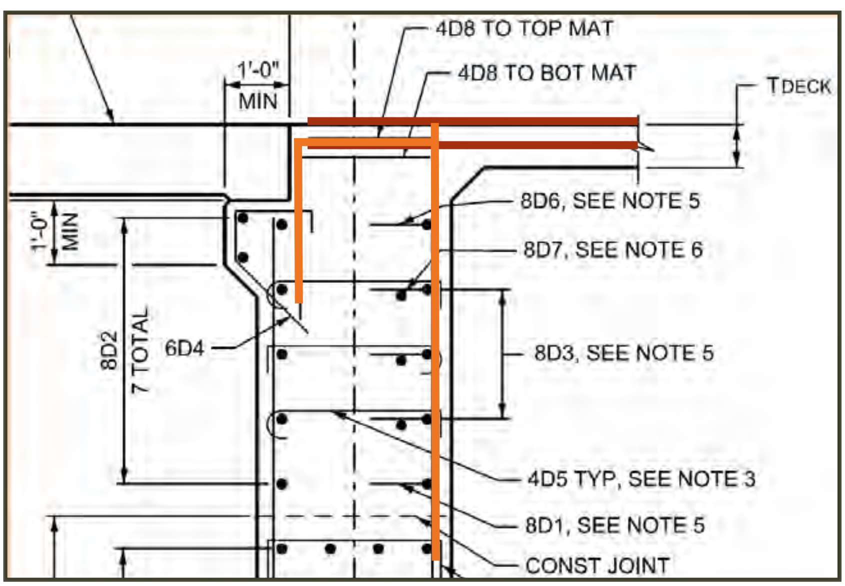


Figure 60 UDOT Bridge Deck to Backwall Details

VDOT: Bridge deck to backwall details vary based on abutment type.

WSDOT: For semi-integral, the deck and backwall/diaphragm are integral (**Figure 61**). A diaphragm is cast around the girder ends and moves with the superstructure. **Figure 62** shows the detail the state uses in the instance they cannot use semi-integral abutments.

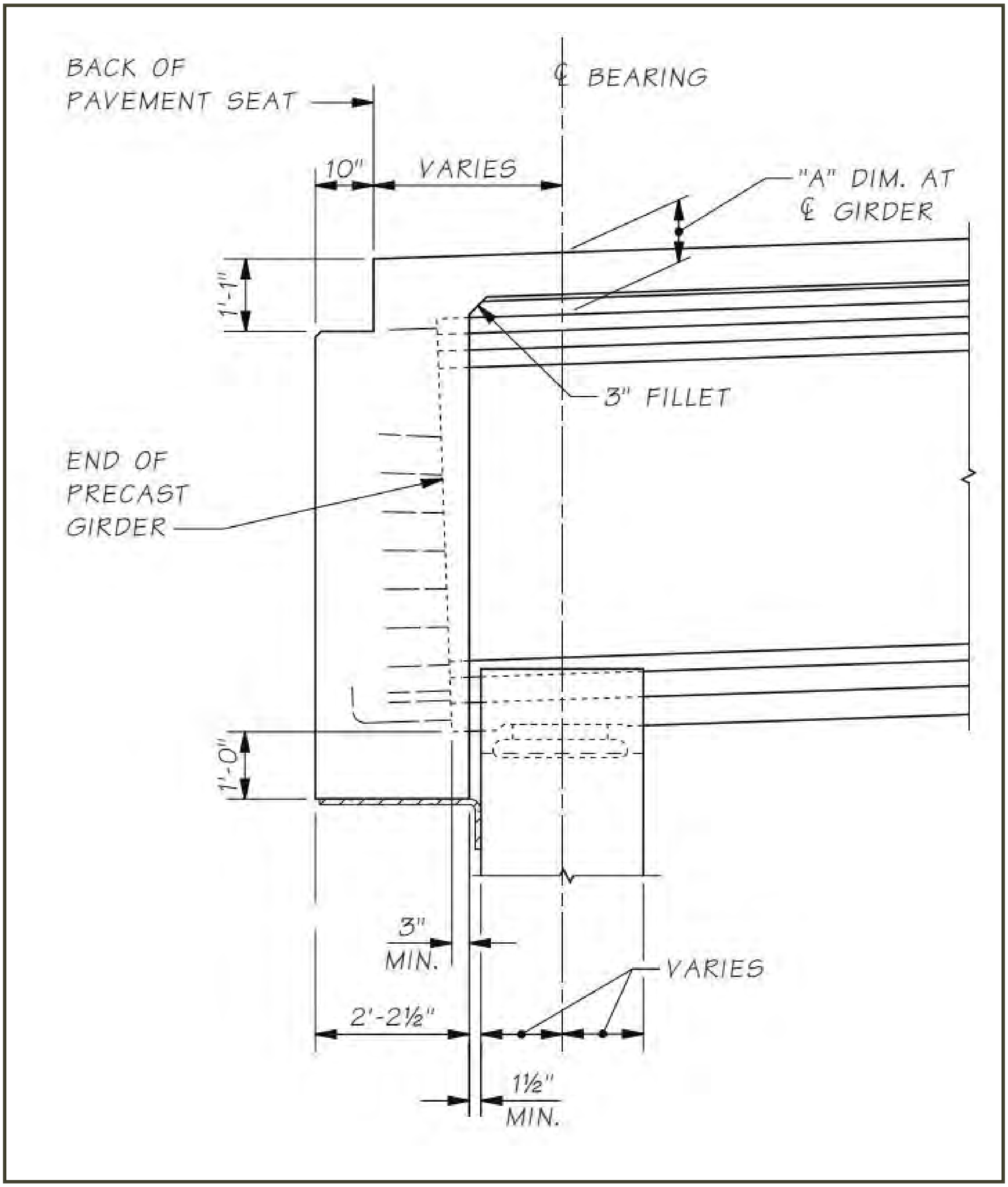


Figure 61 WSDOT End Diaphragm on Girder (BDM Fig. 5.6.2-3)

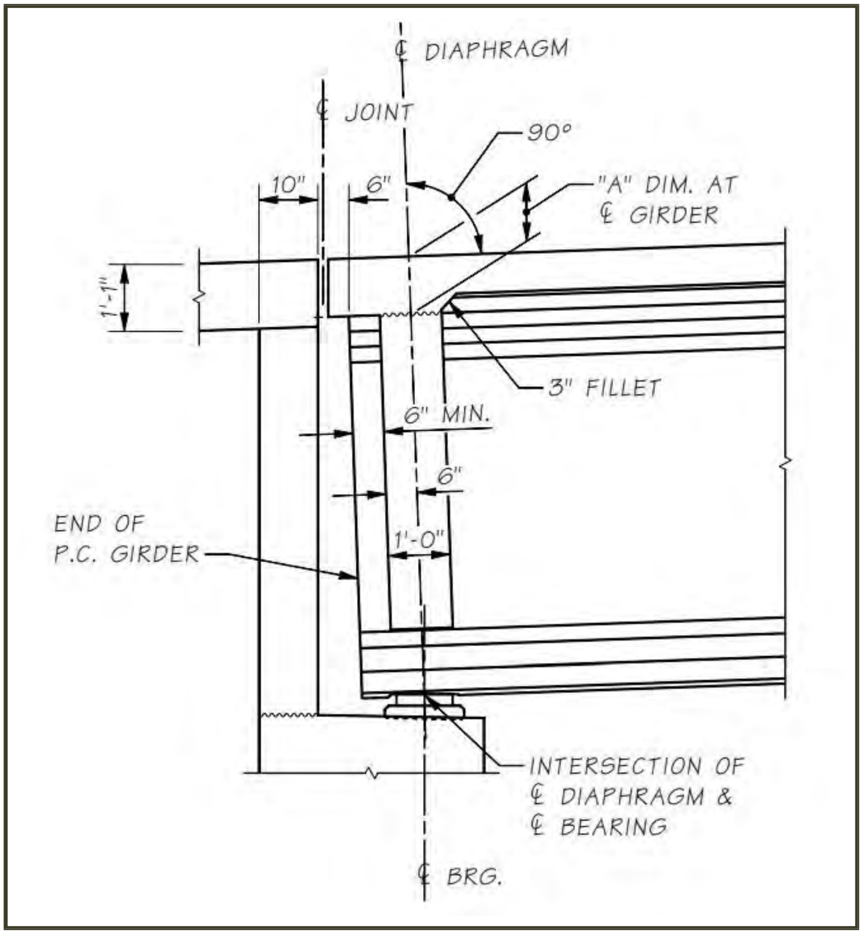


Figure 62 WSDOT L-Shaped End Pier (BDM Fig. 5.6.2-4)

3.2.1.1.1 Bridge Deck Continuous over Backwall

For states with bridge decks continuous over the backwall, the scan team wanted to know how slab movement over the top of the back wall was accommodated, if design accounts for the negative moment and if the deck support on the top of the backwall accounts for superstructure rotation. The team also wanted to know if the continuous deck had been designed for the tension forces due to superstructure thermal contraction overcoming the dead weight of the continuous deck and the friction forces between the slab bottom and backfill material.

Iowa DOT: Iowa DOT did not address this topic.

MaineDOT: MaineDOT applies bond breaker between the slab and the backwall to facilitate movement. APJs or nothing is used at the structure to approach roadway interface. Their design accounts for the negative moment and the deck support on the top of the backwall accounts for superstructure rotation.

MassDOT: At MassDOT, deck cantilever is short and does not rest on the backwall directly, but on a closed cell foam pad which allows the deck to move and rotate independently thus does not generate negative moments. The deck cantilever is only if the top of the backwall is wide and it is not attached to the approach slab, therefore no tensile forces will be generated. This was a consideration when MassDOT decided to use buried approach slabs with integral abutment bridges.

PennDOT: PennDOT accommodates slab movement over back wall by using the details shown on approach slab length shown in Standard Drawing BD-628M or substitute steel plates for sliding surfaces. The design accounts for negative moment by increasing deck slab thickness and having a short cantilever with a deck support that allows superstructure rotation. Deck is not extended over backfill.

SDDOT: When replacing the deck, the expansion abutments are made integral. Beam ends get encased in a new full depth / width abutment block.

UDOT: UDOT's deck is integral with the integral abutment and terminates at the approach slab seat. Thermal motions are carried into the approach slab through longitudinal bars which connect the abutment to the slab.

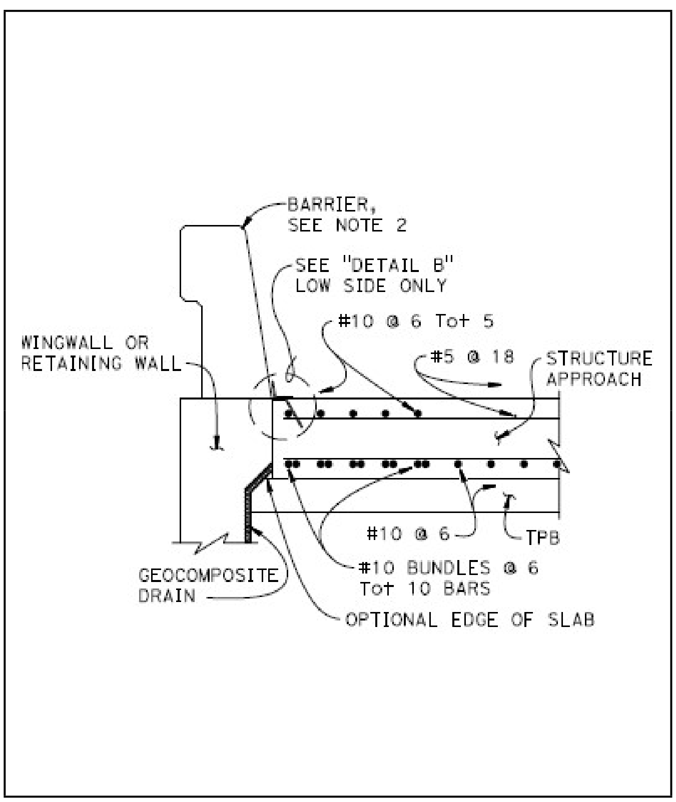
VDOT: VDOT deck extension details are shown in (**Figure 45**). VDOT specifies the top of backwall and bottom of slab shall be finished parallel to grade. Additionally, they place a ½" expanded rubber joint sealer on top of backwall under deck extension.

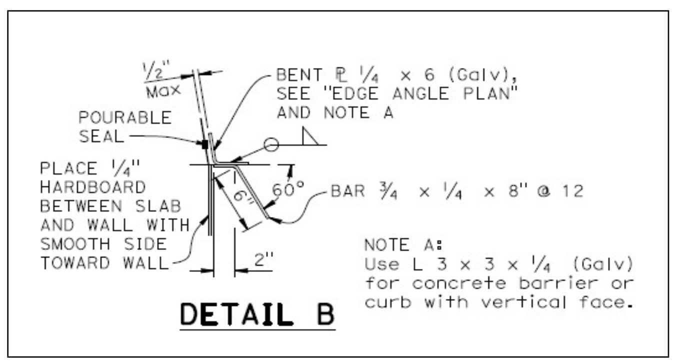
Bridge decks continuous over backwalls are not applicable to Caltrans, LaDOTD, MnDOT, TDOT, WSDOT.

3.2.1.1.2 Expansion Joint Detail at Joint/Shoulder interface

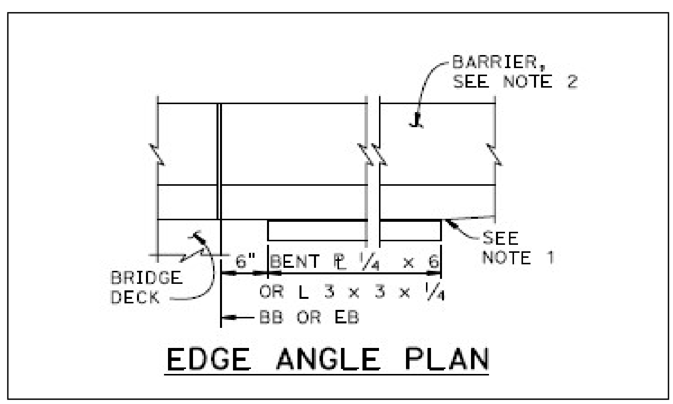
The scan team sought details at expansion joint and shoulder interface.

Caltrans: For new construction, the approach slabs run full roadway width, over the wingwalls or retaining walls. For rehab projects, when the approach slabs run barrier to barrier, Caltrans uses an edge angle on the low side (**Figure 63**).





b) Detail B



a) Approach Slab at Wingwall **c) Edge Angle -Plan View**

Figure 63 Caltrans Expansion at Shoulder (Caltrans Standard Plan B9-5)

Iowa DOT: Iowa DOT did not address this topic.

LaDOTD: LaDOTD approach slab and sleeper slab cover the full width of the roadway, including the shoulders. The expansion joint seal extends for this full width. At the edges of the joint/ approach slab/sleeper slab, there are end drains (either open paved ditch-type, or closed drains with catch basin and underground pipe) that are used to collect the water from the ends of the bridge, approach slab and expansion joint and carry it down the embankment.

MaineDOT: MaineDOT typically buries approach slabs and does not extend to the wing walls. When they do, a preformed filler is typically installed to allow movement.

MassDOT: Since MassDOT's approach slabs are buried, the interface is below ground. Where the approach slab is up against a wingwall, a closed cell foam is used between the slab and wingwall to allow movement. Where the approach slab is not up against a wingwall, such as is the case at the sidewalk side, no interface material is needed.

MnDOT: MnDOT standards include casting the barrier on top of the approach panel, so there is not an issue with the joint between the approach panel and the wingwall.

PennDOT: PennDOT example in **Figure 64**.

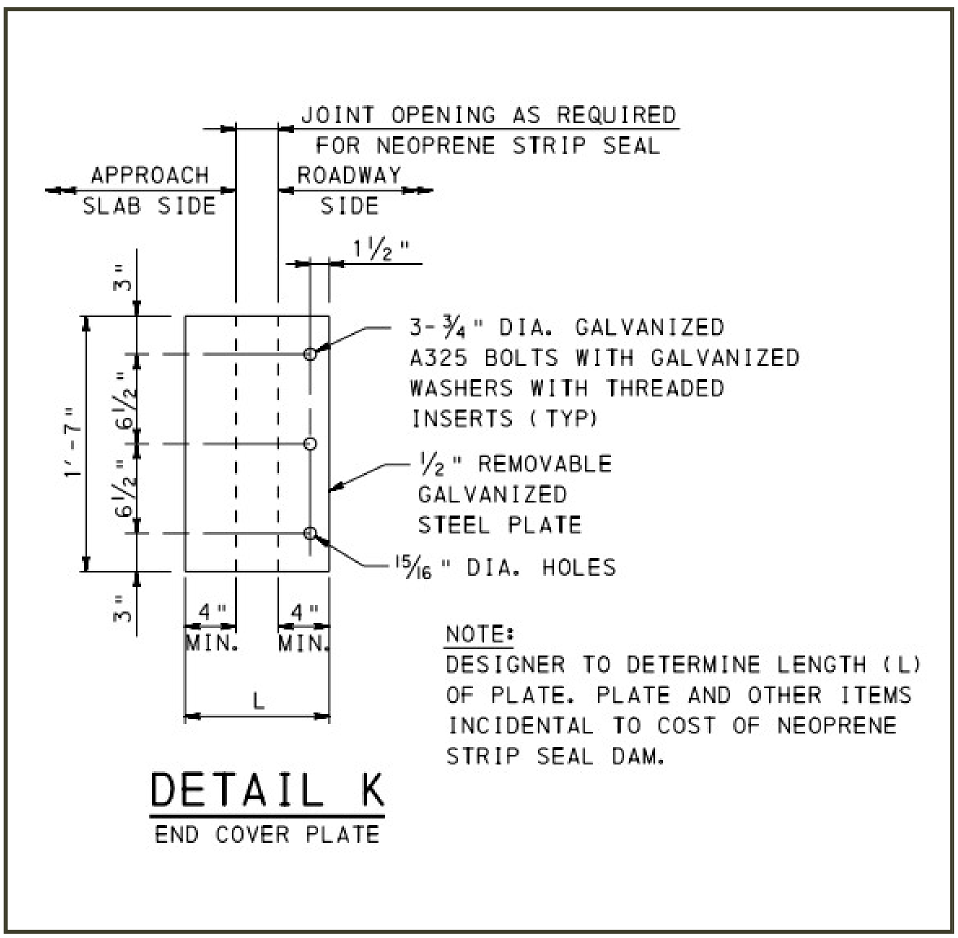


Figure 64 PennDOT End Cover Plate Detail (BD-628, sheet 20, Detail K)

SDDOT: SDDOT places a 2"x3" membrane sealant between approach slab and end block (**Figure 65**).

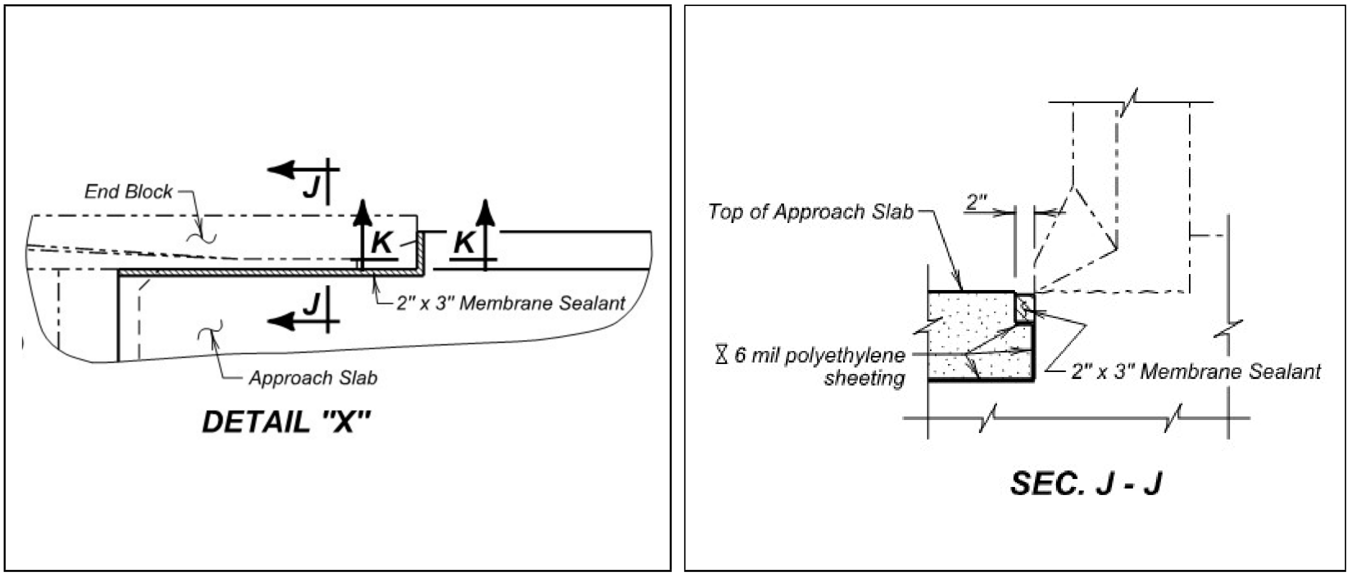


Figure 65 SDDOT Approach Slab/Wing Wall Detail

TDOT: The state's approach slabs run full roadway width.

UDOT: UDOT mounts the parapet directly to the approach slab so that there is no vertical joint between the parapet and the slab. To permit sliding and to make an allowance for settlement a 5 inch open joint is located between the bottom of the approach slab and top of wingwall.

VDOT: For integral and semi-integral abutments, VDOT's expansion joint is between the far end of the approach slab and the T-stem of the sleeper slab. The approach slab sits on 2 1/8" preformed bedding pads of the sleeper slab ledge and joined to the sleeper slab stem with a closed cell joint.

WSDOT: WSDOT has no detail for this.

3.2.1.2 Location 2: Abutment/Backwall and Approach Slab Interface

For seat abutments and other types with a joint at this location, the slab is stationary. If there is a connection between approach slab and abutment in integral/semi-integral, the slab moves with the superstructure.

Caltrans: For seat type abutments, the approach slab sits on the backwall (12") and is connected with #5's @12" or #5's @9" for movement rating, MR>2". For diaphragm type abutments, the approach slab sits on a 6" minimum paving notch and is connected with 3/4" dia. galvanized rods @24", encased in polyvinyl chloride (PVC) conduit to allow for movement (**Figure 66**).

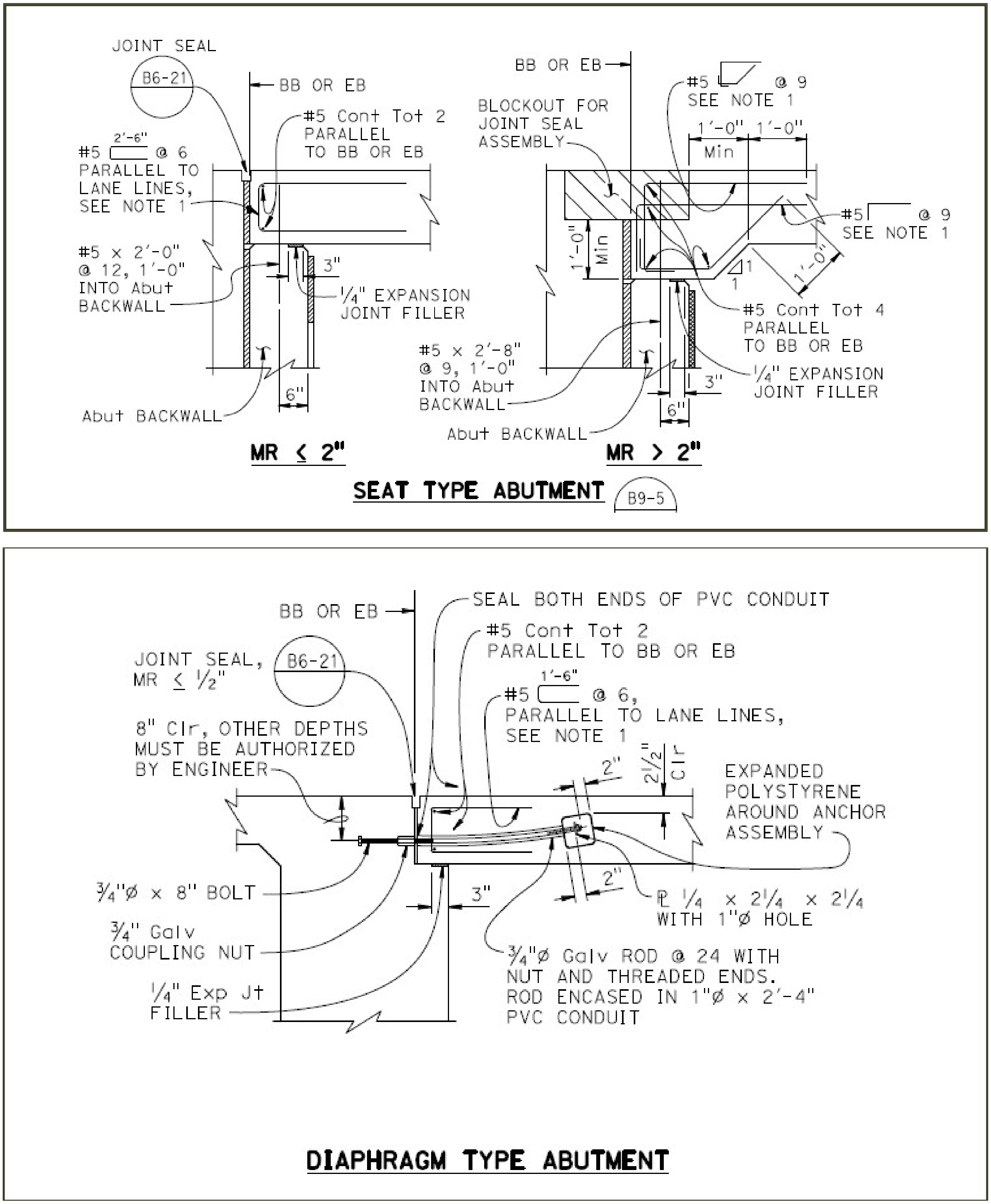


Figure 66 Caltrans Structure Approach Type N (30) (Standard Plan B9-1)

Iowa DOT: Current approach slab standard does not tie the approach slab to the bridge but uses a shear lug so the bridge does not have to drag the slab as the bridge moves. For non-integral abutments, the approach pavement attaches to the abutment with a dowel extending from the corbel (**Figure 23**).

LaDOTD: The state's pilot project integral abutment/jointless bridges used #6 black steel bars at 7" spaces to attach the approach slab to the end bent. Conventional bridges use #6 bars at 1'-6" spaces.

MaineDOT: A positive connection is required, typically satisfied with a designed bent bar.

MassDOT: For integral abutments, the approach slab is cast on top of a one foot wide shelf formed in the back of the integral abutment stem or it is a precast approach slab that is set on the shelf. In either case, there are two layers of tar paper separating the approach slab from the shelf to allow the slab to slide on top of the shelf.

MnDOT: Approach slab is connected to the abutment with a bent stainless steel rebar at the bridge end and the approach panel rests on a sleeper slab (sill) at the pavement end (**Figure 68)**.

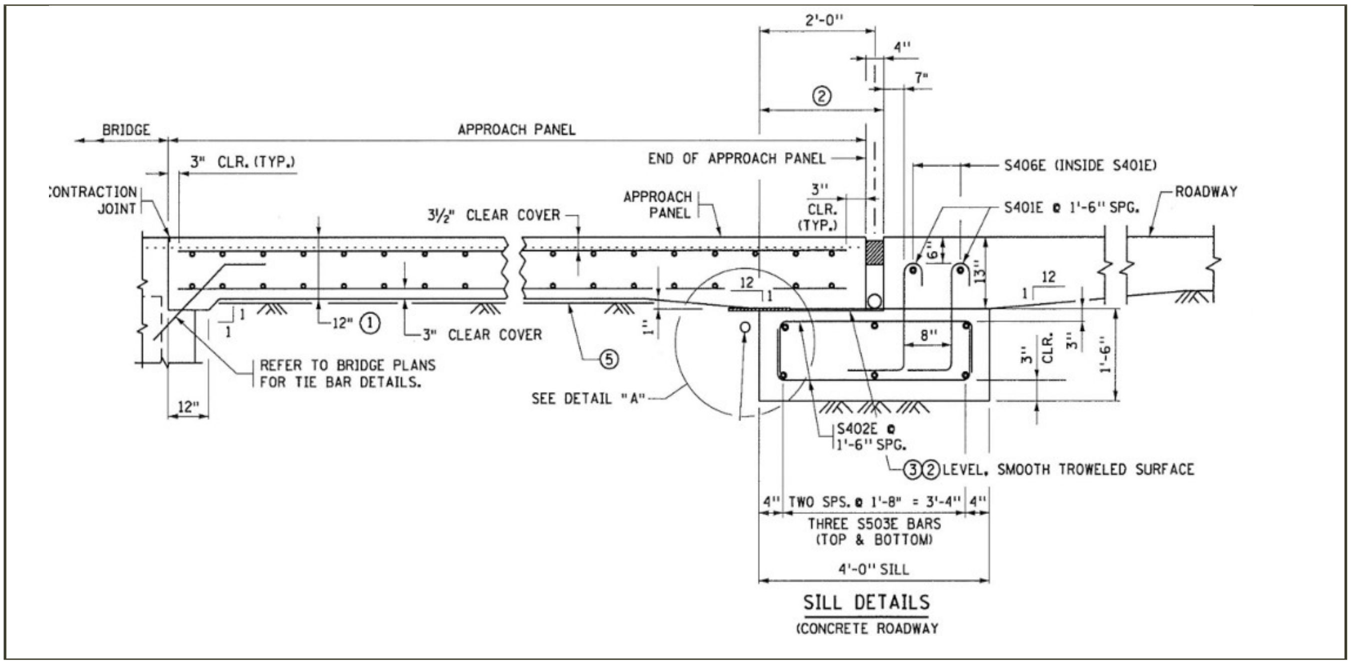


Figure 67 MnDOT Approach Slab Connections

PennDOT: PennDOT places notch in back face of abutment with steel (**Figure 68**).

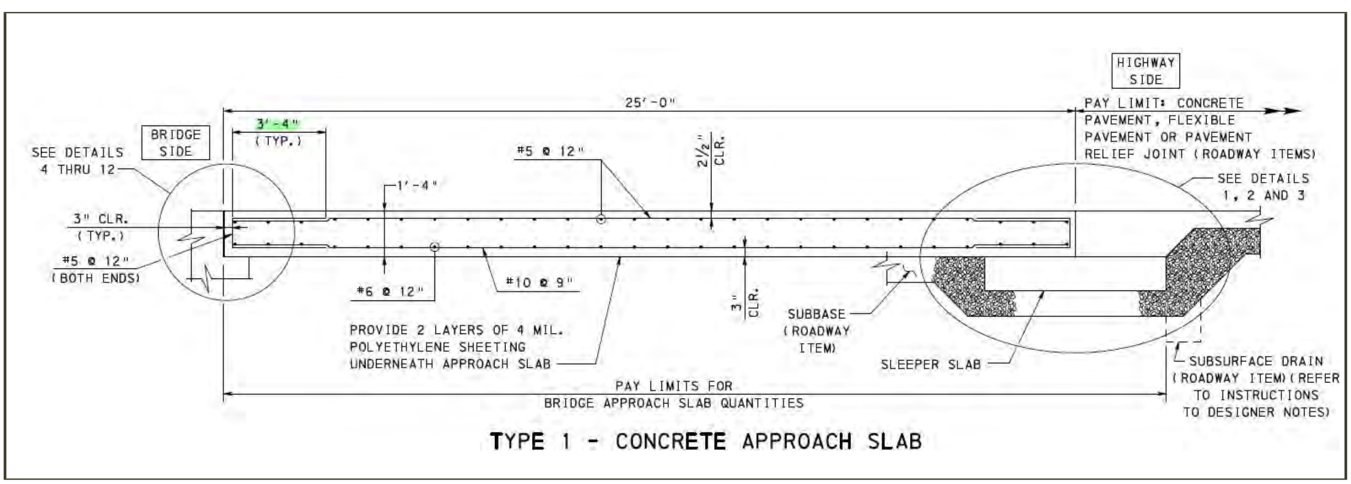


Figure 68 PennDOT Concrete Approach Slab

SDDOT: SDDOT connects approach slabs to abutments with a straight bar located mid depth, place 18" on center (**Figure 69**). While the bar is shown mid-depth in drawing, in practice it is closer to the bottom mat of reinforcing steel in the approach slab.

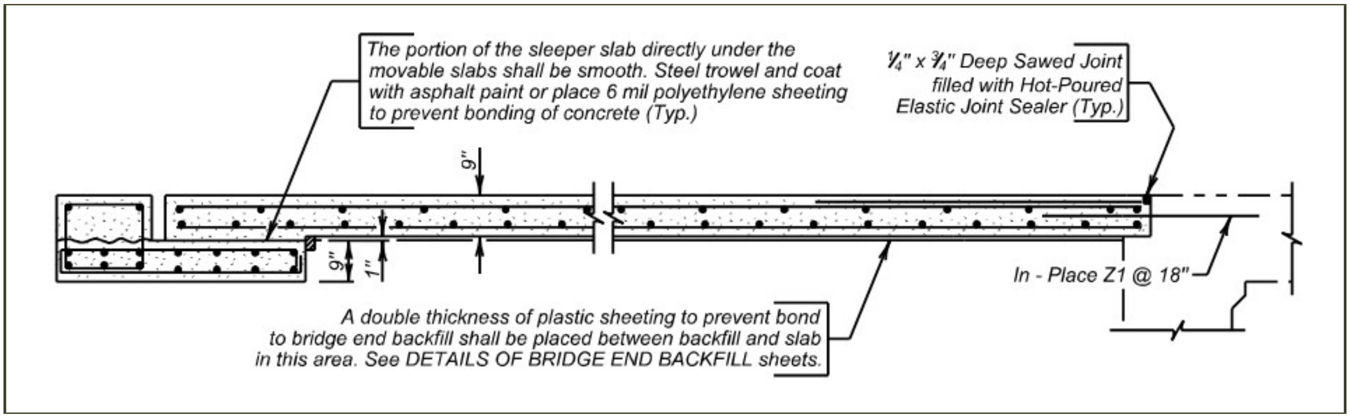
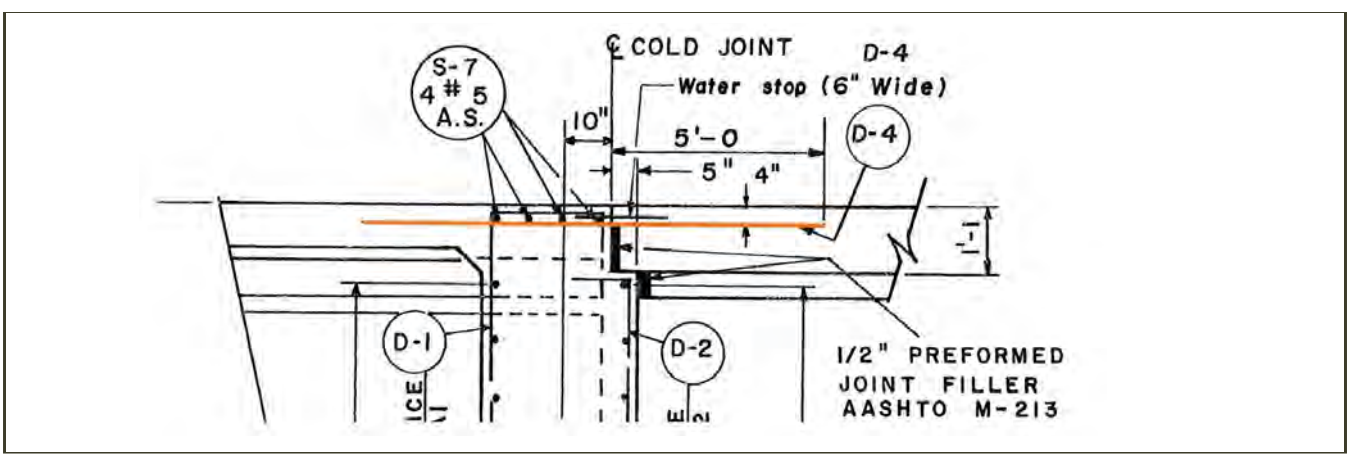


Figure 69 SDDOT Approach Slab

TDOT: TDOT has a cold joint, approach slab rests on roadway bracket, tied with rebar.

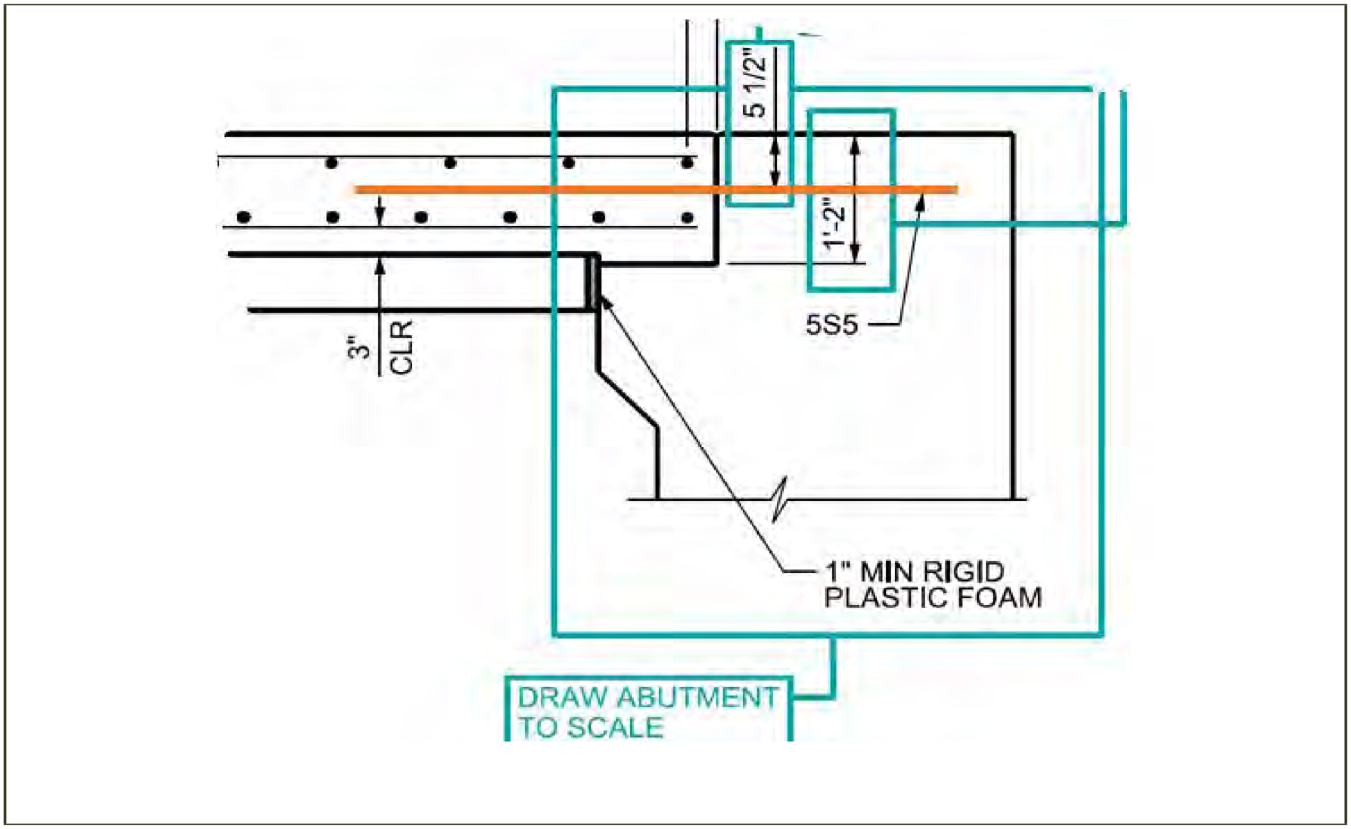
UDOT: UDOT's design at the abutment to approach slab joint has moved through several different details. Early approach slabs used bent bars passing through the bottom of the slab to connect the slab to the seat at the abutment. That detail was replaced by a straight connection bar located in the top half of the slab and embedded 5 feet into the approach slab (**Figure 70a**) along with the addition of a waterstop. The intent of both changes appears to be focused on keeping water from getting under the approach slabs.

That detail too has been revised and UDOT now connects the approach slab to the abutment using a coated #5 bar at 12 inches, embedded 2.5 feet into the slab, and places that bar at approximately the approach slab centerline (**Figure 70b**). In the current UDOT detail, this joint no longer includes the waterstop detail as the waterstop caused delamination at the header location. This detail has been in use for about 2 and a half years and has shown good performance in that limited time frame.



a) Early Detail

Figure 70 UDOT Approach Slab to Abutment



b) Lowered Bar

Figure 70 UDOT Approach Slab to Abutment

VDOT: VDOT sets approach slabs on a seat in the backwall and casts a bent rebar in the slab and backwall (**Figure 71**).

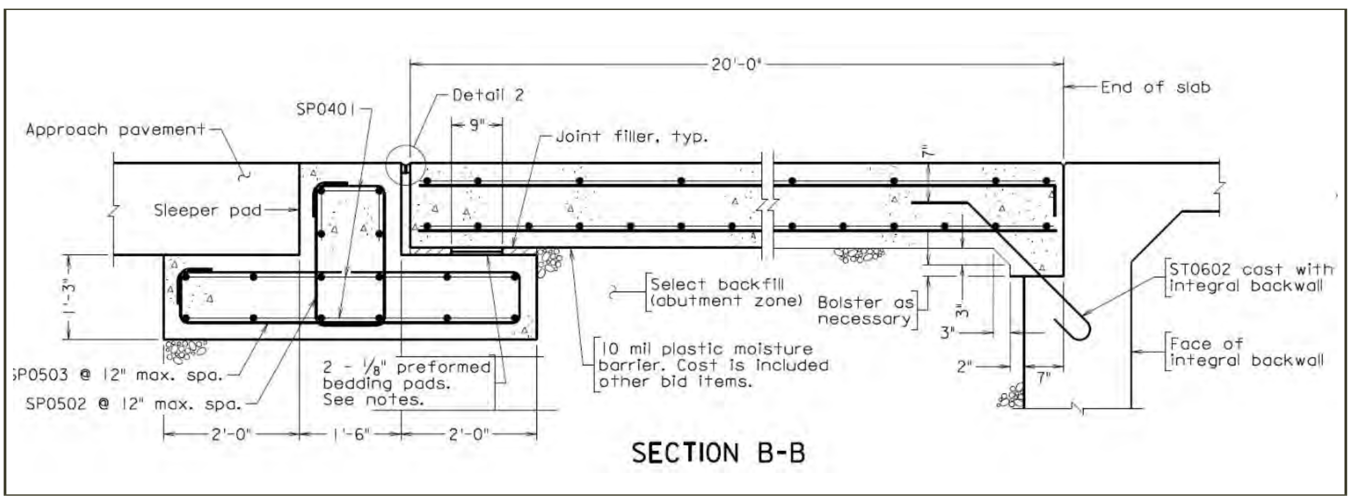
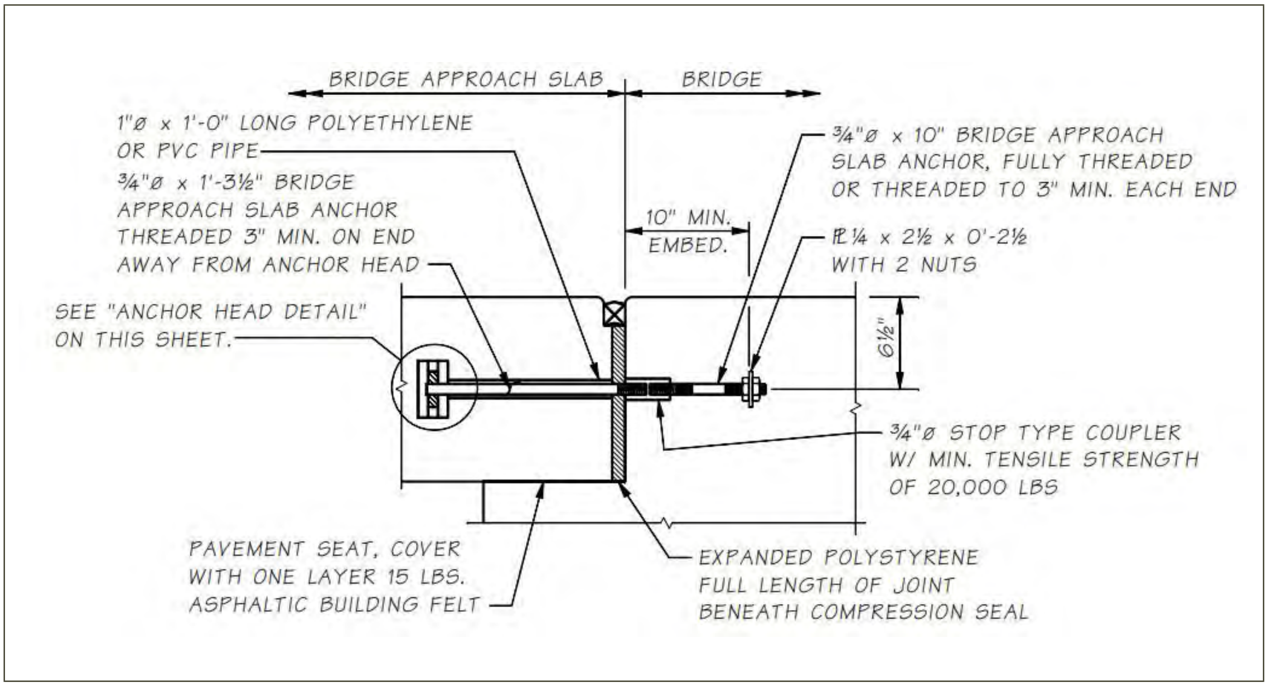
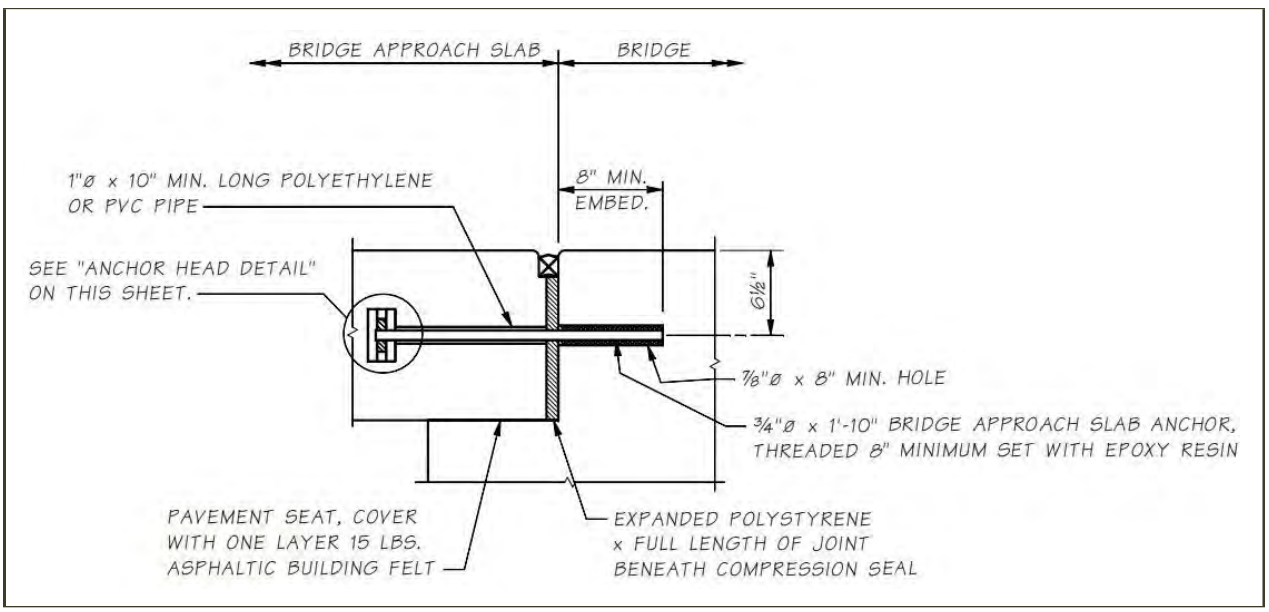


Figure 71 VDOT Approach Slabs for Integral and Semi-Integral Abutments

WSDOT: WSDOT uses an anchor rod to attach the approach slab to the bridge. Two methods are shown in **Figure 72**.



a) Method A – Semi-Integral Type Only



b) Method B – Semi-Integral Type Only

Figure 72 WSDOT Approach Slab to Bridge Expansion Anchor (WSDOT Standard Dwg. 10.6-A1-3)

3.2.1.3 Location 3: Approach Slab and Roadway Pavement Interface

This section presents each state's interface detail at the approach slab to pavement interface.

Caltrans: Caltrans does not use expansion joints or pavement relief joints between the approach slab and roadway pavement. Caltrans does not set the roadway pavement on a sleeper slab. For new concrete pavement, Caltrans uses additional longitudinal bars (#6's) (**Figure 73**). Spacing varies with pavement thickness and is tabulated in Standard Plan P4. For existing concrete pavement, Caltrans uses drill and bond dowels @12” (dowel bar diameter varies with pavement thickness) (**Figure 74**).

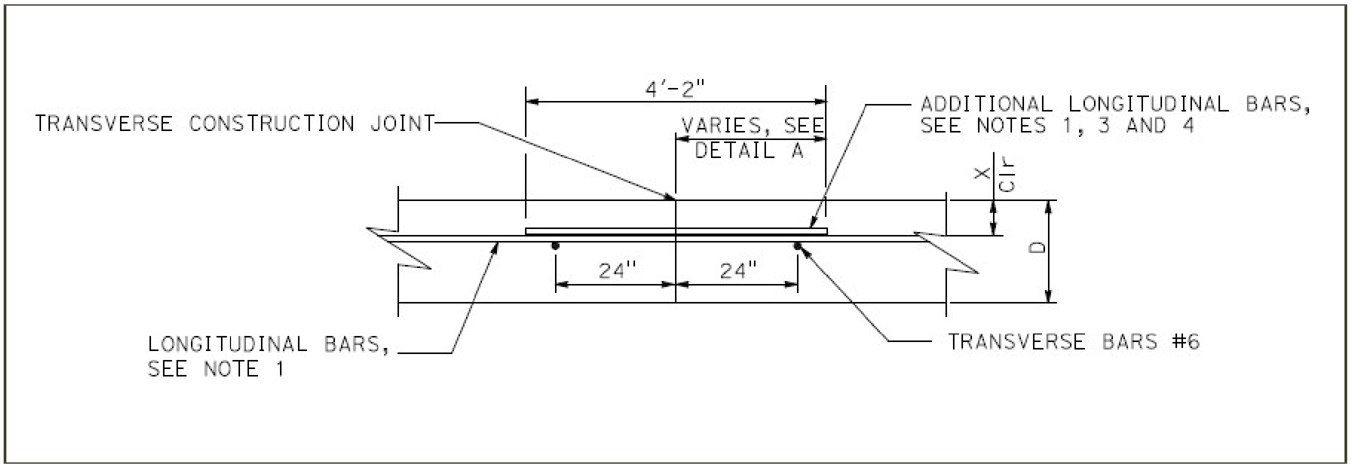


Figure 73 Caltrans Detail at New Pavement (Caltrans Standard Plan P14)

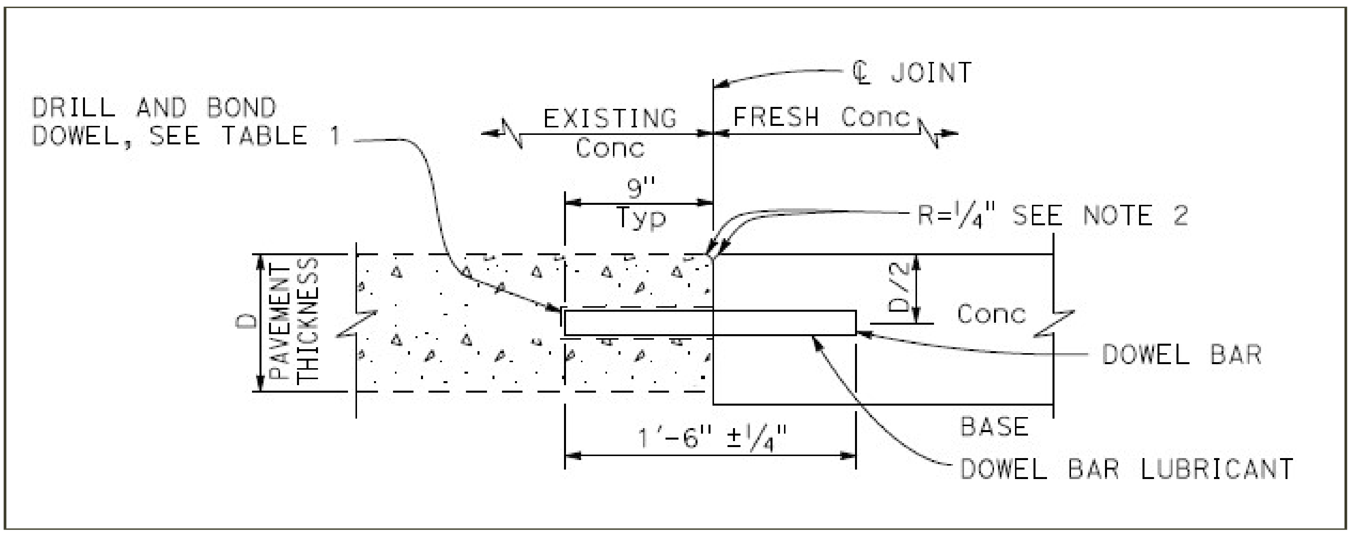


Figure 74 Caltrans Transverse Construction Joint at Existing Pavement (Caltrans Standard Plan P10)

Iowa DOT: Their current standard has resolved the issue with the dropped slab, but there is still an issue with settlement at the end of the slab. The total length of the approach slabs is 60 feet in three pieces with the third piece being unreinforced. This is used regardless of the approaching pavement type except that if using PCC, there is an extra 10-foot transition piece.

Approach pavements are tied to slab type bridges and the joint is moved to the sleeper slab. This is the only type of bridge where a sleeper slab is used. They do not use a sleeper slab on all approach pavement cases (**Figure 75**).

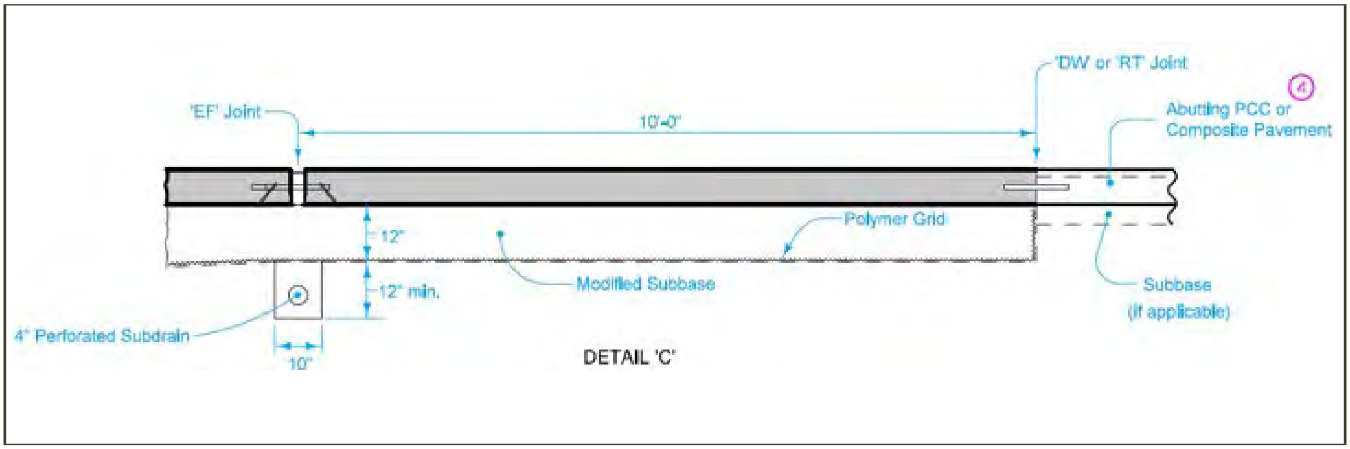


Figure 75 Iowa DOT Slab to Pavement Connection

LaDOTD: LaDOTD uses preformed silicone seal with steel end dam plates and an L-shaped sleeper slab (**Figure 76**).

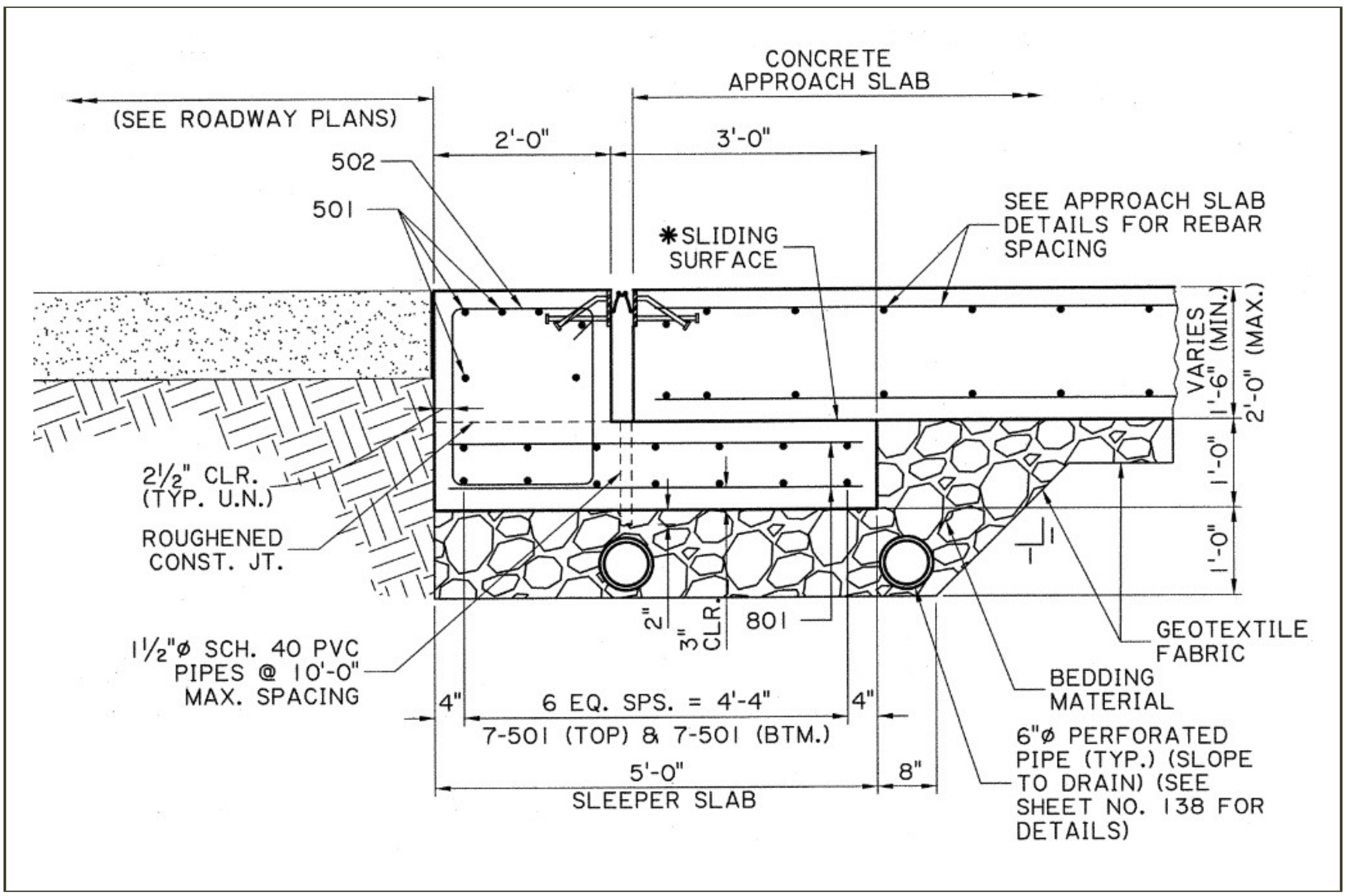


Figure 76 LaDOTD Slab to Pavement Connection

MaineDOT: MaineDOT standard practice is to use a buried approach slab. At grade approach slabs are occasionally used.

MassDOT: Since MassDOT's approach slabs are buried, there are no expansion joints between the approach slab and roadway pavement.

MnDOT: Approach slab (panel) is set on sleeper (sill). Roadway is set on sleeper.

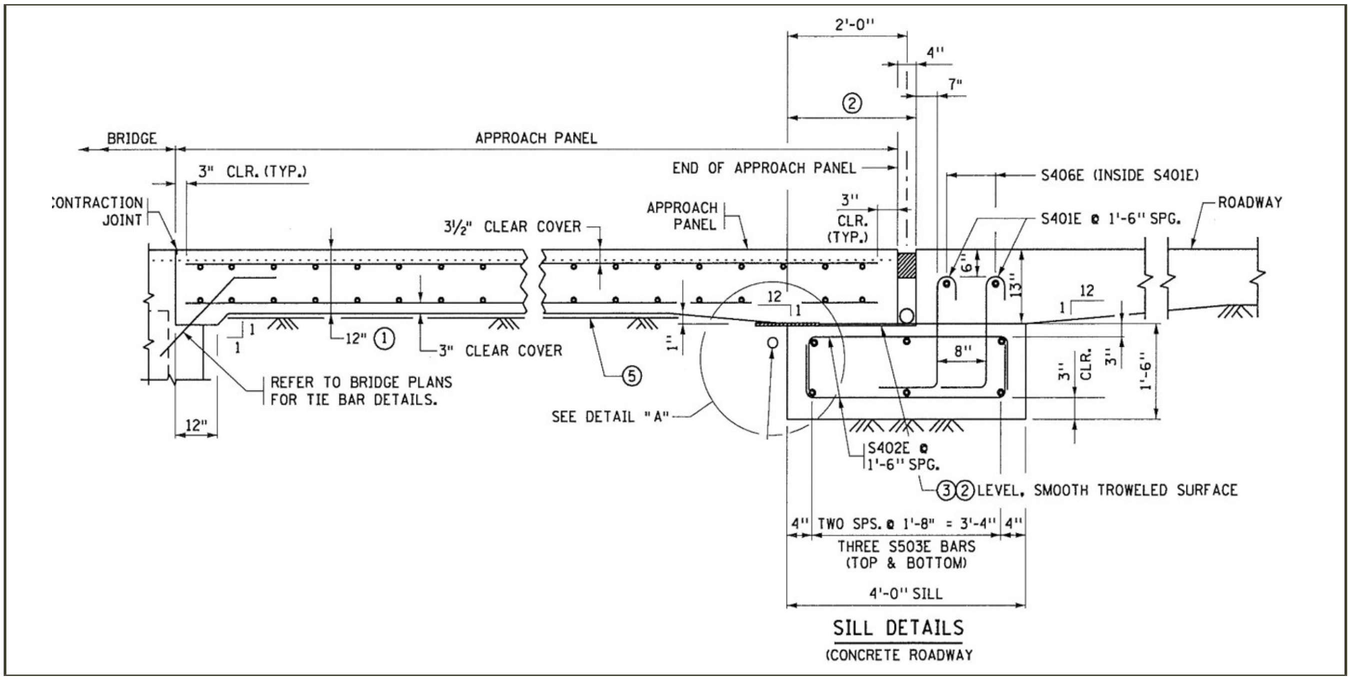


Figure 77 MnDOT Approach Slab and Connection Details

PennDOT: PennDOT drawing BD-628M is 35 sheets of approach slab details and connections. There are numerous joints, including a joint sealing material.

SDDOT: SDDOT sits the far end of the approach slab on an L-shaped sleeper slab (**Figure 78**). The asphalt pavement is then cast against the opposite edge of the sleeper slab. When approach pavement is concrete, the sleeper slab in an inverted "T" (**Figure 79**).

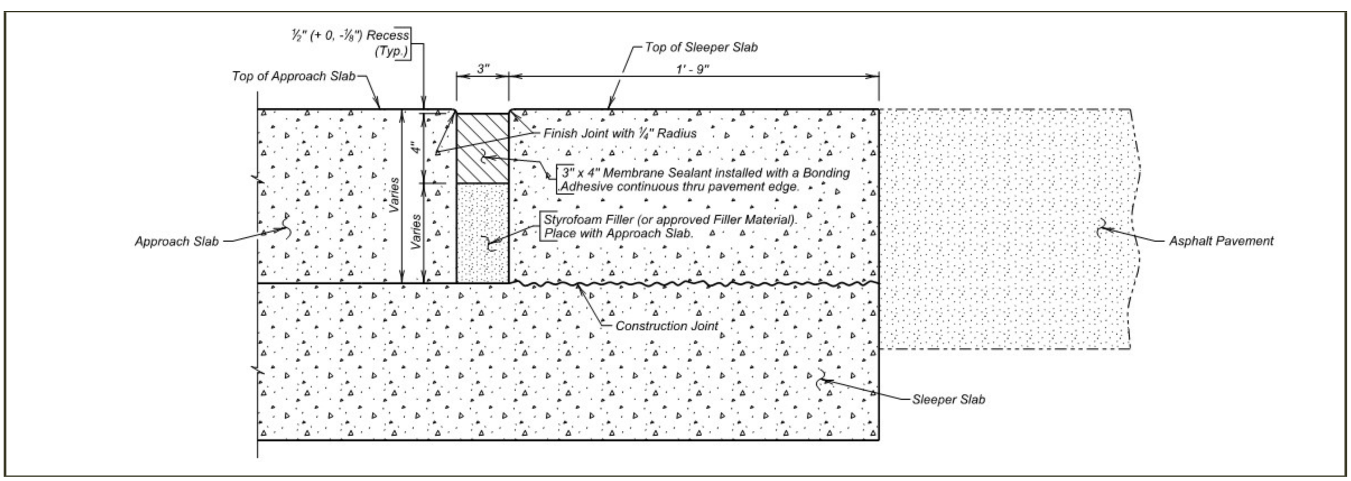


Figure 78 SDDOT Sleeper Slab to Asphalt Transition

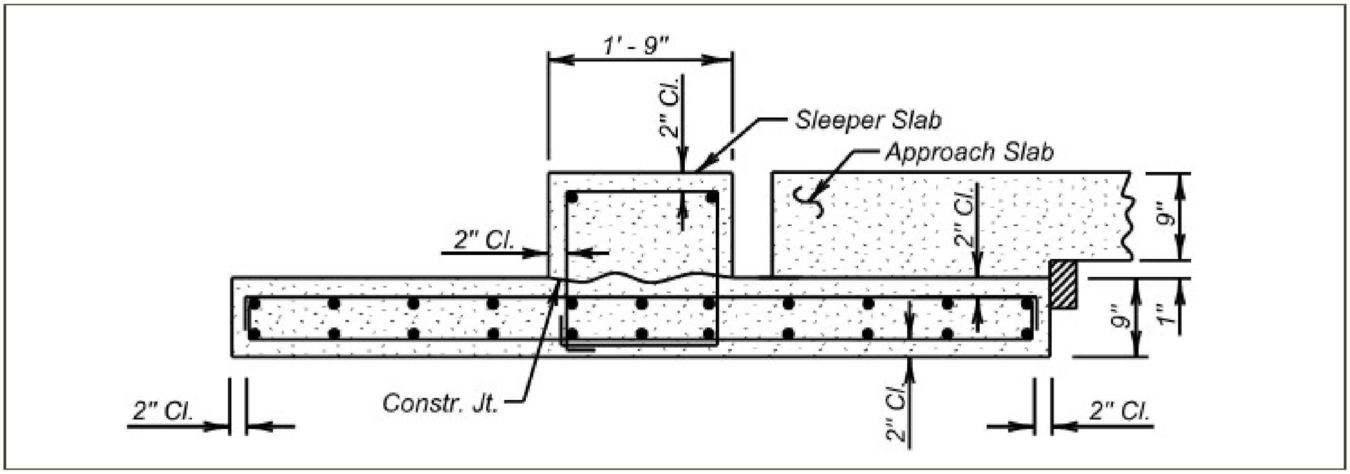


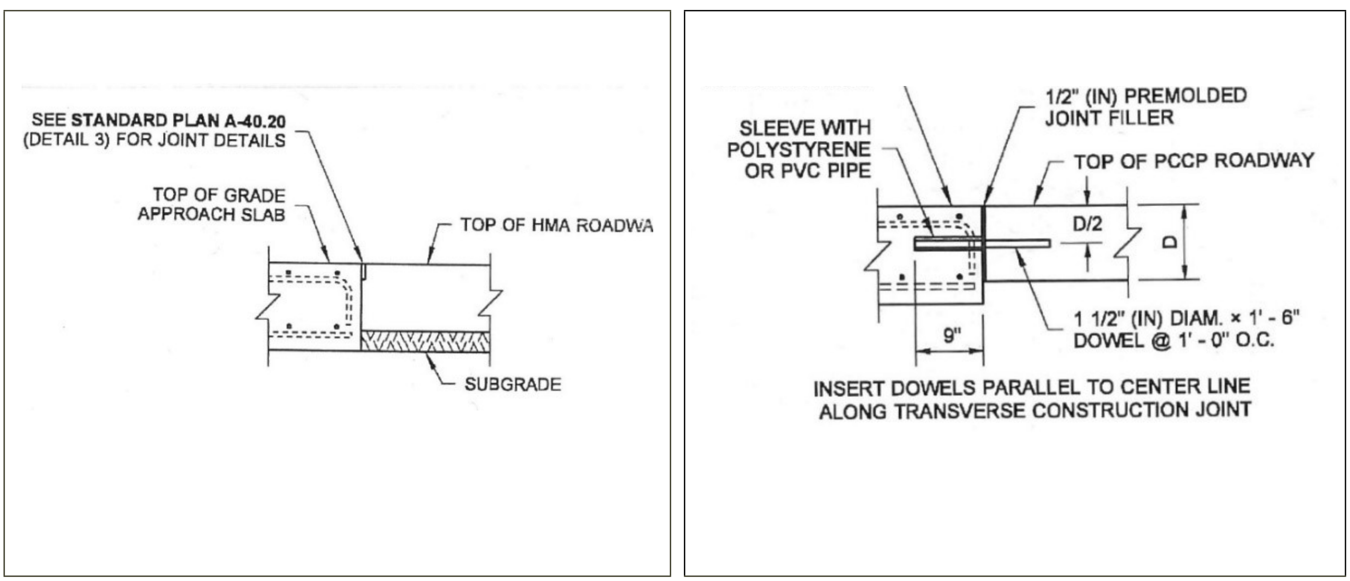
Figure 79 SDDOT Sleeper Slab for Concrete Pavement

TDOT: TDOT uses a sleeper slab with joint details for concrete and asphalt roadway interface.

UDOT: The approach slab to roadway pavement interface requires a sleeper slab. UDOT attaches the approach slab to the abutment and accommodates thermal motions at the sleeper slab. To establish an adequately sized gap the sleeper slab when adjacent to asphalt roadway pavement, a sleeper slab stem is provided to establish vertical concrete surfaces for expansion joint installation. The sleeper slab stem is not required for Portland cement concrete pavement (PCCP) approaches.

VDOT: Shown in **Figure 71**, VDOT places a sleeper pad on the approach pavement side of the sleeper slab stem. The value of the sleeper slab is under debate, however, because VDOT feels select backfill is the best settlement mitigation.

WSDOT: See **Figure 80**.



a) HMA Roadway Joint **b) PCC Roadway with Dowel Bar**

Figure 80 WSDOT Approach Slab to Pavement Connection

3.2.2 Joint Types

This section presents the type of joints used by each state. Types states use are asphaltic plug joints, membrane sealants, open cell polyurethane foam, strip seals, modular finger/tooth joints and special seismic joints. Each state and joint type are tabulated in **Table 8**. State comments follow the table.

	Joint Type*					
	APJ	Membrane Sealant	Open Cell	Strip Seal	Tooth Joint	Seismic
Caltrans	Y			Y	Y	Y
Iowa DOT				Y		
LaDOTD	N		Y	Y	Y	
MaineDOT	Y	N	Y	Y	Y	N
MassDOT	Y					
MnDOT	N			Y		
PennDOT	Y			Y		
SDDOT	-	Y				
TDOT	N	Y	N	Y	N	
UDOT	Y*		Y	Y		
VDOT	Y		Y	Y	Y	
WSDOT	Y			Y		

* See corresponding state comments below.

Table 8 Joint Types

Caltrans:

Caltrans identified the following types of expansion joints and their use:

- Open joints - not appropriate
- Sealed Joints - Standard Plans B6-21: Type A (MR ≤ 1”) – silicone (glazed polyethylene foam), and Type B (MR ≤ 2”) – compression (waterstop)
- Joint Seal Assemblies: Strip Joint Seal (MR = 2.5” - 4”) and Modular (MR > 4”)
- Longitudinal Joints - Standard Plans B6-21: Type AL - silicone
- Finger Joints - not for new work (also known as tooth joints)
- Seismic Joints - Bridge Standard Details: Type I (MR ≤ 4”), Type II (MR > 4”)

Caltrans uses asphaltic plug joints only with AC overlays, on rehab projects. Caltrans has standard waterstop/strip waterstop details for expansion joints in SP B0-1 and SP B0-3. Joint seals turn into barrier as shown in SP B6-21.

Iowa DOT: When integral abutment does not work due to bridge size or skew, they use a strip seal joint on the bridge side of the endwall.

LaDOTD: For the joint at the end of the approach slab to roadway interface, the state's pilot project jointless bridges used a preformed silicone seal (strip seal) attached to end dam plates between the approach slab and L-shaped sleeper slab. The roadways were asphaltic concrete. If the roadways had been PCCP, a 4" joint filled with closed or semi-open cell foam would have been used between the sleeper slab and the roadway, in addition to the silicone seal between the sleeper and approach slab

MaineDOT: Asphaltic plug joint is the standard joint with integral abutment bridges utilizing a bituminous WS. Concrete WS bridges typically do not use a joint and just pave the approach right up to the concrete WS, however asphaltic plug joints, are used on occasion. When integral abutments are not applicable strip seals or finger joints are typically used.

MassDOT: Asphaltic plug joint has been the standard detail for all MassDOT integral abutment bridges, and the intent was to prevent material from falling into the gap between the integral abutment wall and the approach slab header. However, MassDOT is now considering eliminating the asphaltic plug joint for short span bridges where the thermal movement is small.

MnDOT: MnDOT uses strip seal on parapet (seat) abutments. A compression seal is used for the joint between the approach panel and pavement for integral and semi-integral abutment bridges. A list of approved compression seal joint materials is available on the department's webpage (8). A 2" drainpipe is also placed beneath the length of the joint.

PennDOT: PennDOT provides a pavement relief joint between concrete pavement and approach slab. Could be a dowel type joint or a plug type joint. Also have details to put a strip seal joint at the end of the approach slab.

SDDOT: SDDOT installs a 3" x 4" membrane sealant at sleeper slab/approach interface. Past use includes strip seals, compression seals and asphalt joints.

TDOT: TDOT had no further comment.

UDOT: UDOT's preferred expansion joint type is an open cell, polyurethane foam with integrated silicone seal (**Figure 81**). It does not require any special forming for concrete placement or anchored extrusions and can be installed against the sleeper slab stem or concrete pavement face. The main concern with this joint type is the installation process which requires proper surface cleaning, adhesive, recess depth and sealant bands. Aside from the preferred joint, UDOT uses pourable joint seals for smaller joint movements, but the durability of those joints has not been particularly good and UDOT is considering reducing the application of pourable joint seals in favor of compression joint seals.

Asphaltic plug joints are permitted for rehabilitations only; mainly because new structures should not have asphalt on them. They are also limited in application because the joint manufacturer recommends that the joint have concrete substrates on either side of the gap. This works well when the expansion joint is at an abutment backwall, at a bent, or in span hinge, but since UDOT's standard bridge design is jointless, the applicability of the asphaltic plug joint is limited to older inventory.

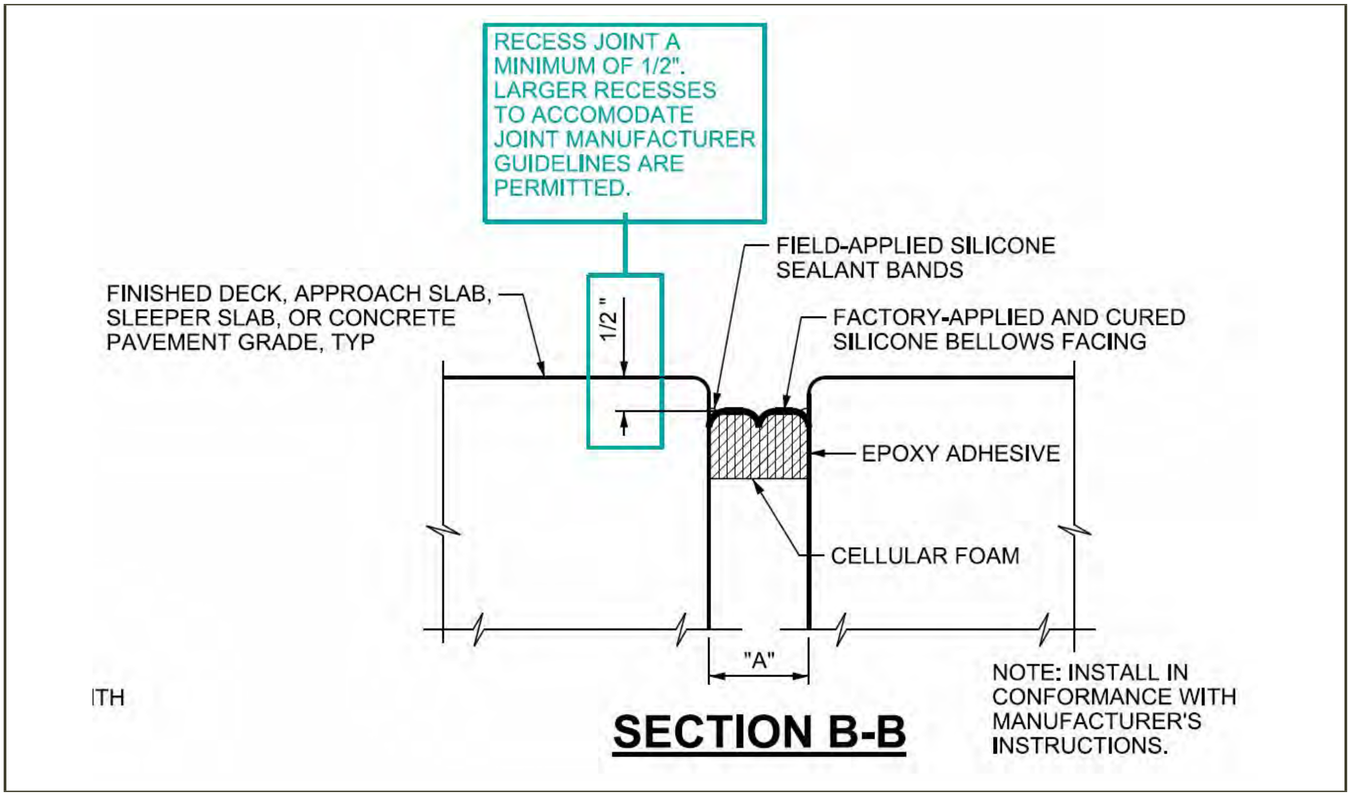


Figure 81 UDOT Compression Joint Seal Type A

VDOT: VDOT uses tooth joints on their Virginia abutments. For deck extensions, VDOT uses buried slabs with a stone wrapped geotextile for drainage (see Section 3.4.1). At the approach slab and sleeper slab stem, VDOT uses open-cell joints. Silicon use is limited but compression seal joints are not allowed.

WSDOT: WSDOT had no further comment.

3.3 Approach Slab Variations

The number of states with buried approach slabs was comparable to the number of states who had never heard of buried approach slabs. Some states include approach slab details with the backfill and grading of their contract plans, while other states include them with structural details. Consequently, the approach slab design is the responsibility of the road designer in some states and the bridge office in other states.

Approach slab length and thickness limits are presented in **Table 5.** Table 9 includes if a state buries approach slabs, uses precast slabs, applies overlays, use of corrosion protection on reinforcement and use of sleeper slabs. State comments follow the table.

Approach Slab Variations					
	Buried	Use Precast?	Overlay	Epoxy Reinforcement	Sleeper Slab
Caltrans	N	N	Y	Y	N
Iowa DOT	N	N	Y		N
LaDOTD	N	N	N	N	Y
MaineDOT	Y	Y	Y	Y	Occasionally
MassDOT	Y	Y	N		
MnDOT	N	N	Y*	Y	Y (Sill)
PennDOT	N	N	N*	Y	Y
SDDOT	N	-	N		Y
TDOT	N	Y	N*	Y	Y
UDOT	N	Y	Y	Y	Y
VDOT	Y	-	Y	N	Y
WSDOT	N	N*	N	Y	N

* See state comments

Table 9 Approach Slab Variations

Caltrans: Caltrans does not use buried or precast approach slabs. Overlays can be used as rehab strategies. Caltrans uses mostly polyester concrete overlays on approach slabs, and profilographs before and after overlay placement. Caltrans also has smoothing specifications for approach slabs. All approach slab reinforcement shall be epoxy coated and minimum top mat cover 2.5” in Freeze-Thaw Area, as shown in Standard Plan B9-1.

Caltrans designed the new approach slab as a slab bridge, supported by the abutment at one end and the last 1/3 of the slab length supported on soil at the other end, designed for Permit loads and HL93 with dynamic load allowance (IM). The questions were raised whether IM should be increased to 75% near the joints, and whether settlement load (SE) should be included in the approach slab design.

Iowa DOT: The total length of the approach slabs is 60 feet in three pieces with the third piece being unreinforced. This is used regardless of the approaching pavement type except that if using PCC, there is an extra 10-foot transition piece. Iowa DOT has tried precast approach slabs twice and they do not like either installation. Iowa DOT has a pavement lug for moveable abutments (**Figure 23**).

LaDOTD: LaDOTD does not use epoxy coated rebar or other corrosion resistant materials. The state’s approach to solving the bump at the end of the bridge problem has been entirely composed of analyzing their approach slab design with a truck model that is heavier than HL-93, which is based on actual weigh-in-motion data from their roads. The approach slab was then treated as a simply supported “span”, with the assumption that over time, the bottom of the slab will lose contact with the underlying soil and behave more as a span, rather than just a section of pavement that is attached to the bridge. This analysis resulted in an approach slab that is 18” thick for a 40’ long slab.

MaineDOT: MaineDOT allows precast in most cases. Typically shown as cast-in-place and allowed if requested by the Contractor. Standard practice is to bury approach slabs 2+ feet below finished grade, at grade approach slabs are both overlayed and concrete wearing surface (WS). APJ is used in most hot mix asphalt (HMA) overlay situations with integral abutment structure.

MaineDOT allows plain bar, epoxy coated, stainless steel, glass fiber reinforced polymer (GFRP) reinforcing, corrosion resistant alloy steel (MMFX). Trend is to avoid epoxy coated as it is subjective to installation care and has not shown consistent lifespan

MassDOT: Precast approach slabs are allowed and are found in Part III of MassDOT's Bridge Manual. MassDOT uses buried approach slabs for all their bridges, including integral abutment bridges (**Figure 82**). The approach slabs are first buried under gravel and then the pavement is applied over this gravel base. All approach slabs are 10 inches thick and the top of the approach slab is 14 inches below the top of deck elevation (before any pavement is applied).

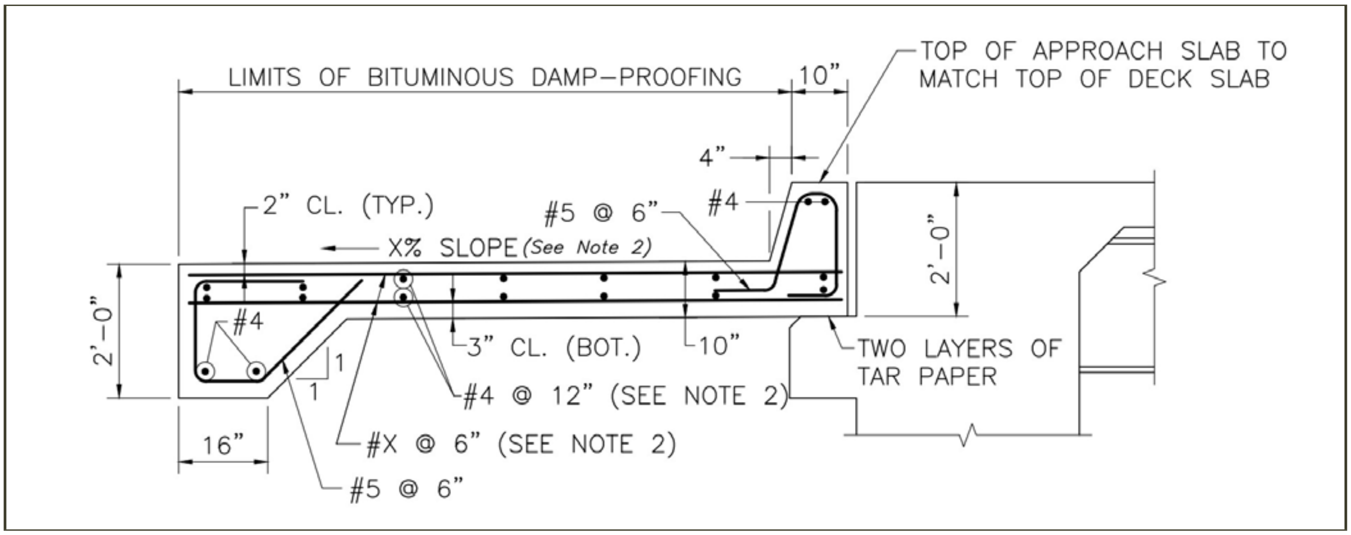


Figure 82 MassDOT Approach Slab Details (MassDOT Drawing Number 3.1.14)

For integral abutment bridges, MassDOT does not tie the approach slab to the bridge but fixes the tail end in the approach backfill while allowing the toe of the approach slab to slide on a shelf built into the integral abutment stem. For jointless bridges with stationary abutments, MassDOT specifies coated bars, which can be either epoxy coated or galvanized. These are always epoxy coated.

MnDOT: MnDOT places 2" thick concrete overlays on approach slabs if the bridge will receive a concrete overlay. All reinforcing bars are epoxy coated. They do not use asphaltic plug joints due to potential issues with motorcycle traffic.

PennDOT: Approach slabs required for ADT > 750. If providing an approach slab eliminates a joint, then an approach slab is required. Approach slabs are required with integral abutments and five types are detailed on their standard drawing BD-628M. While Type 2 includes superpave asphalt overlay, overlay is not standard.

PennDOT sometimes uses asphalt plugs over joints or at the end of the approach slab when there is bituminous pavement. The thickness of PennDOT approach slabs shall be 1'-6". Boundary conditions are simple-simple design, independent of wingwalls. Per BD-667 Note 11: "All reinforcing bars are to be epoxy coated."

SDDOT: Far end of approach slab supported on sleeper slab, thickness is 9", use #8's at 6" spacing, separated from backfill with 2 layers of plastic.

TDOT: TDOT has used precast slabs on ABC projects. TDOT typically does not overlay approach slabs but will use asphalt over precast on ABC projects. TDOT approach slabs are 12" and it is assumed half the span will have settlement. TDOT uses epoxy coated bars.

UDOT: Standard details for cast-in-place approach slabs are provided for slabs with skews up to 45 degrees. UDOT does not step approach slabs but has the approach pavement and sleeper slab parallel the skew of the abutment. UDOT does have and use precast approach slabs and precast sleeper slabs with ABC bridge installations although standard designs are not provided for them. For precast approach slab applications, UDOT has tried minimizing the size of closure pours by using ultra high performance concrete (UHPC) and has seen good performance with those joints. Match cast panels have also been used which require no closure pours at all.

Approach slabs are designed as a simple span between the abutment and the sleeper slab, and aside from the bond breaker between the sleeper slab and the approach slab, there are no special interface details. As the sleeper slab settles, the approach slab settles with it.

Overlays are placed on all new bridge and approach slab construction. It is a requirement to provide initial polymer overlays on all bridges except for bridges using stainless steel reinforcing or fiber reinforced polymer (FRP) reinforcing in the deck. UDOT first started applying thin bonded polymer overlays to structures in 2003 and now these overlays are standard for almost all new bridge construction. The thin bonded polymer overlay is a two-layer 3/8 thick overlay with a basalt aggregate wearing course applied to the deck, approach slabs and tops of sleeper slab stems. UDOT occasionally specifies calcined bauxite, but so far that has been only in areas where a high friction surface is seen as a project safety benefit. Polyester polymer concrete overlays have also been applied to a few bridges. It is not truly standard yet, but it is something that UDOT is looking into right now for high volume roads. Asphalt overlays are not allowed on new structures.

UDOT requires the use of coated reinforcing in all locations except for reinforcing in piles, and that includes the abutment to approach slab connection. The coating on bars is permitted to be either epoxy coated or galvanized at the contractor's discretion, but UDOT does find that nearly all the state's projects get constructed with epoxy coated reinforcing steel. Stainless reinforcing steel can be substituted, but it is expensive, so it is only used if specified in the design.

VDOT: Approach slab requirements are based on system and traffic. For integral and semi-integral: approach slabs are at grade, sleeper pads acceptable but not part of standards. For stationary abutments, approach slabs must be buried unless waived by district bridge engineer. For approach slabs with asphalt overlay supported on backwall, new latex modified overlay to be placed on bridge.

VDOT requires sleeper slabs on all Initial Construction of Freeway & Arterials and all Initial Construction on non-Secondaries with design hourly volume (DHV) > 250 and ADT/Lane > 1,700. May be used on Secondaries with District Bridge Engineer Approval.

Main bars in the direction of bending are #7 @ 6”. They have 3 ½” cover to centerline and are not epoxy coated.

WSDOT: WSDOT does not commonly use precast approach slabs but they do in some ABC projects or rapid approach slab replacement. WSDOT has approach slab design assumptions and uses epoxy coated rebar for both top and bottom layers of bridge decks.

In seismic events, bridge approach slabs can:

- provide resistance with friction between ground and slab which can help reduce demand on the columns
- provide dynamic active pressure with movement away from the backfill
- have passive pressure with movement pushing into the backfill

The participation of the bridge approach slab in the overall dynamic response of bridge systems to earthquake loading and in providing resistance to seismically induced inertial loads may be considered permissible upon approval from both the WSDOT Bridge Design Engineer and the WSDOT Geotechnical Engineer.

3.3.1 Sleeper Slab

Not all states use sleeper slabs and those that do presented different shapes and details. Some states used an inverted “T” with 3’ to 8’ width. Some states use sleeper slabs only if they have a joint or are expecting significant differential settlement while another state always includes sleeper slabs.

Caltrans: Caltrans is phasing out use of sleeper slabs. Caltrans introduced sleeper slabs in 1972. Caltrans had a standard 15 foot sleeper slab detail, Type N(45D) that was used with diaphragm abutments only. This detail was not updated for LRFD and is no longer used in new construction because the benefit-cost ratio was low, and maintenance was high.

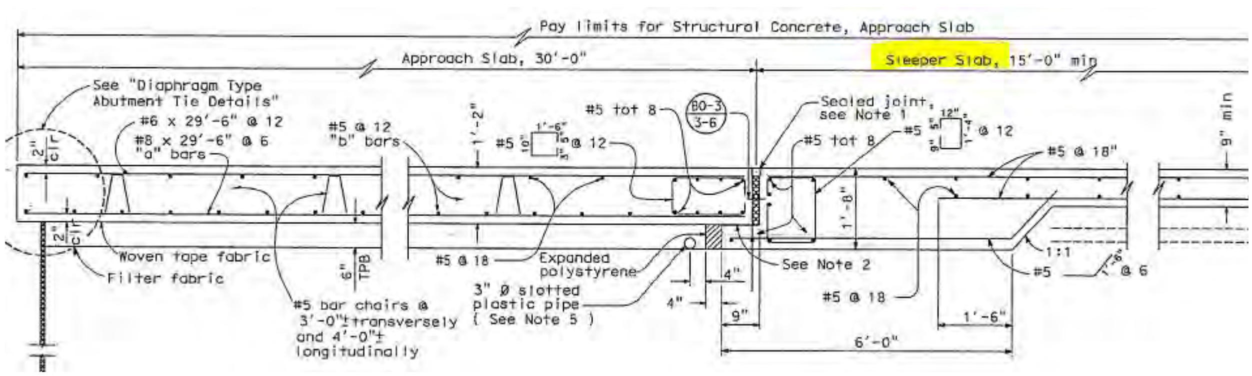


Figure 83 Caltrans Sleeper Slab Detail

Iowa DOT: Iowa DOT only uses sleeper slabs on slab bridges.

LaDOTD: LaDOTD uses a geosynthetic reinforced soil "foundation" layer under the sleeper slab to distribute loads to minimize local settlement of the approach slab end for higher embankments.

MaineDOT: The state uses a sleeper slab, close cell foam and asphaltic plug joint (**Figure 84**).

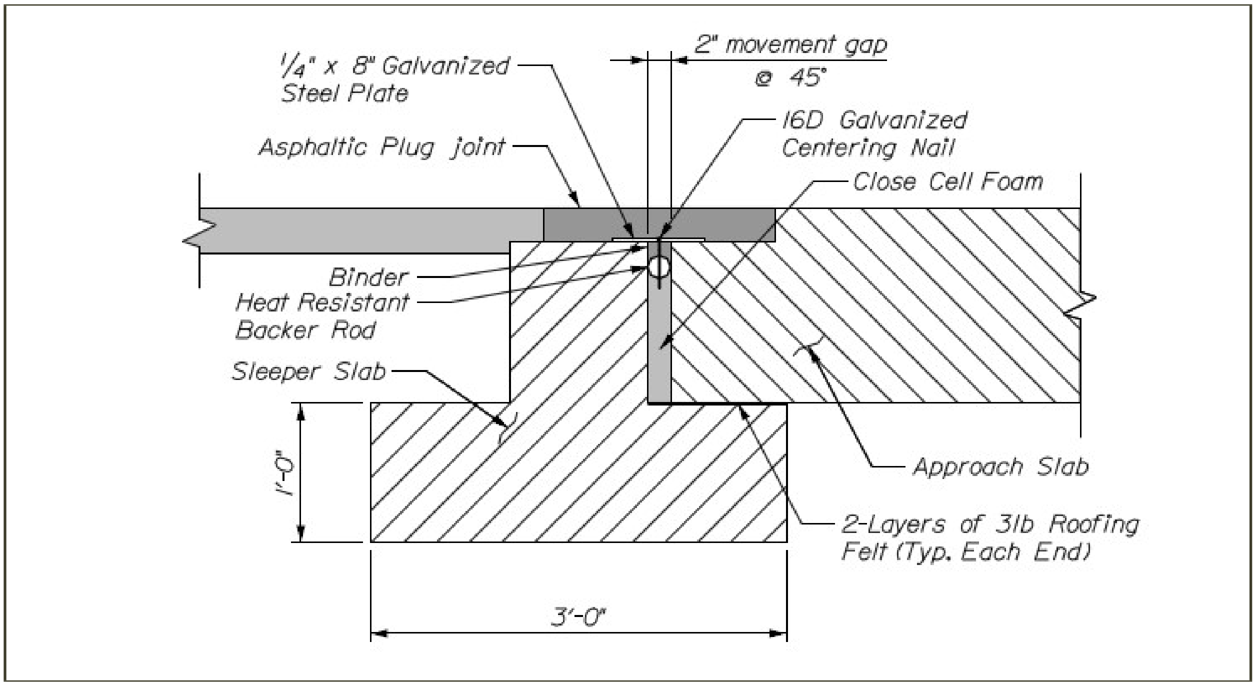


Figure 84 MaineDOT Typical Sleeper Slab Detail (5)

MnDOT: MnDOT uses sleeper slabs, called "sills". Details are shown in **Figure 77**.

PennDOT: PennDOT has no special considerations for their sleeper slabs.

SDDOT: SDDOT has an L-shaped sleeper slab for asphalt pavement (**Figure 78**) and an inverted T for concrete pavement (**Figure 79**).

TDOT: TDOT currently uses an inverted T for asphalt approach roadways and flat sleeper slabs for concrete roadway approaches. They assume that slab will span between sleeper slab and the abutment if settlement occurs. TDOT is currently conducting research on reinforced fill under approach slab and extending limits well beyond the sleeper slab.

UDOT: In 2002 with the Legacy Parkway Design-Build, UDOT switched to a sleeper slab alternative for the end of approach slab joints. It was refined a little bit outside of the Design Build environment and by 2005 UDOT started using sleeper slabs in Design-Bid-Build projects. Figure 85 shows the sleeper slab with stem detail.

The sleeper slab supports the pavement end of the approach slab. The sleeper slab is 5 feet long with a 3-foot bearing area for the approach slab. A bond breaker is located at the bearing interface. The sleeper slab shown in **Figure 85** includes a stem to separate the slab from the adjacent pavement and allow for the installation of an expansion joint. This sleeper is applicable to placements next to concrete or asphalt pavements.

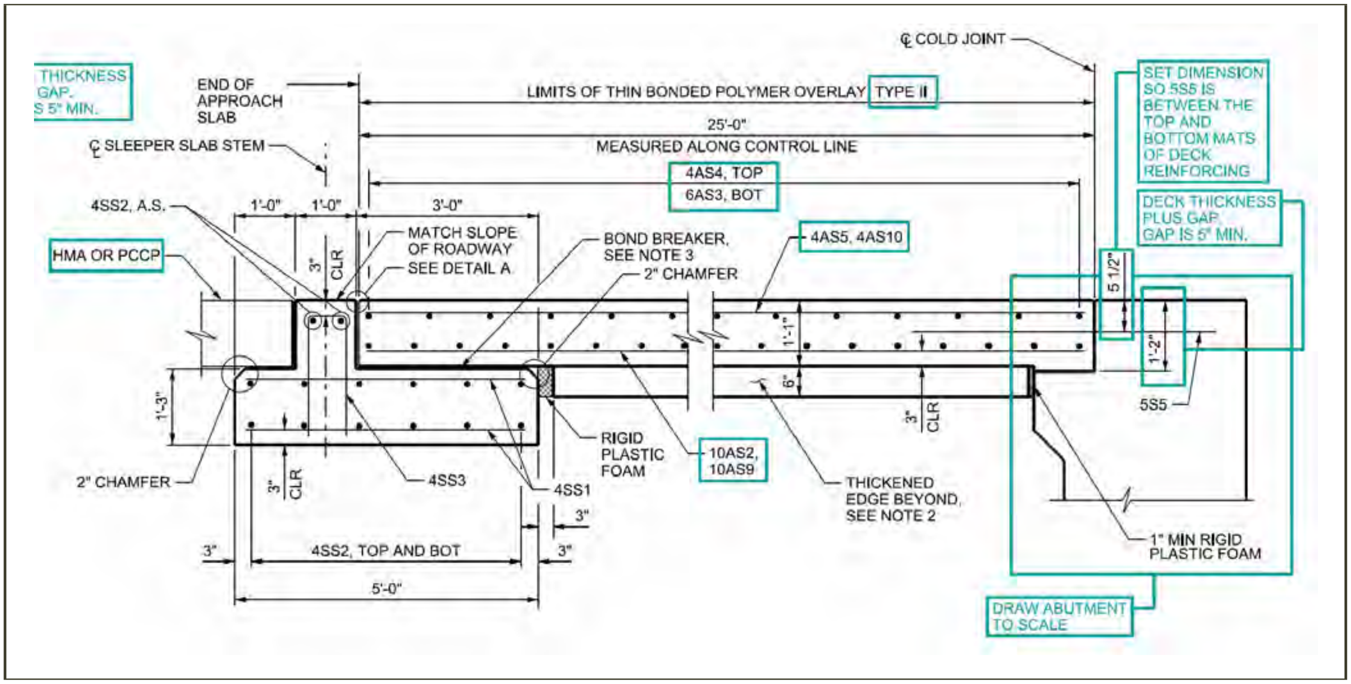


Figure 85 UDOT Sleeper Slab Details

VDOT: VDOT uses an inverted T sleeper slab (called "sleeper pad") on integral and semi-integral bridges but questions their value, especially if select backfill is used. Sleeper slabs are not required. Figure 71 shows the sleeper slab details.

MassDOT and WSDOT do not use sleeper slabs.

3.3.2 Embankment Separator

This section applies to states that detail the approach slab to move. There was no consensus on the effectiveness of placing separators between the approach slab and the embankment. For the states that did it, it was an inexpensive way to possibly reduce the sliding friction.

Caltrans: Caltrans uses woven tape fabric, as shown **Figure 86**.

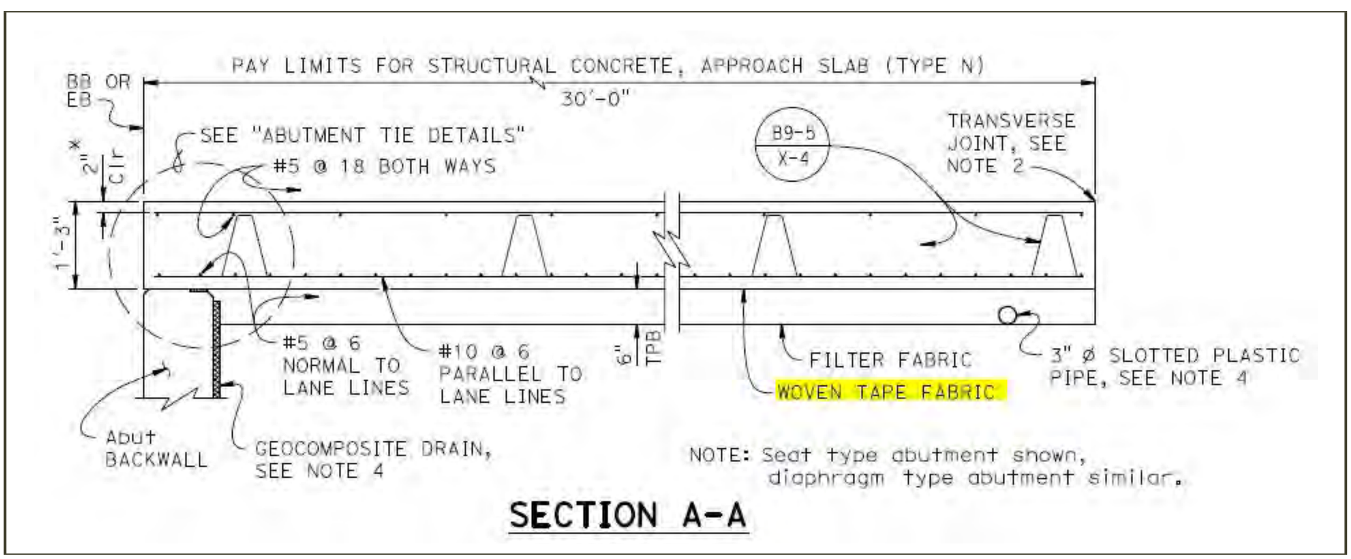


Figure 86 Caltrans Embankment Separator (Caltrans Standard Plan B9-1)

Iowa DOT: Iowa DOT's sleeper slabs are not detailed to move.

LaDOTD: LaDOTD uses a drainage layer and polyethylene sheeting.

MaineDOT: At MaineDOT, approach slab is typically placed on plastic as a bond breaker with the soil, otherwise the approach slab is buried and acts as a stiffness transition from the approach fill to the bridge.

MassDOT: MassDOT does not separate the approach slab from the embankment material, they bury it in the embankment material.

MnDOT: MnDOT copied details from South Dakota and places 12 mil polyethylene sheeting (or 2 layers of 6 mil) under the limits of the approach panel to allow the panel to move longitudinally on the grade.

PennDOT: PennDOT separates embankment from approach slab with 2 layers of 4 mil polyethylene sheeting.

SDDOT: SDDOT places a double thickness of plastic sheeting to prevent bond to bridge end backfill. It shall be placed between backfill and slab (**Figure 69**).

TDOT: TDOT does not separate the approach slab from the embankment material but are currently conducting research on that option.

UDOT: UDOT does not require separation material between the approach slab and embankment material.

VDOT: VDOT places a 10 mil plastic moisture barrier between the approach slab and backfill.

WSDOT: WSDOT does not isolate approach slab from backfill material.

3.3.3 Barrier Rail

Some states found that placing the barrier on the slab improves drainage and eliminates undercutting. The following is each state's preference.

Caltrans: For new construction, Caltrans places the barrier on the slab (**Figure 87**) and considers impact load.

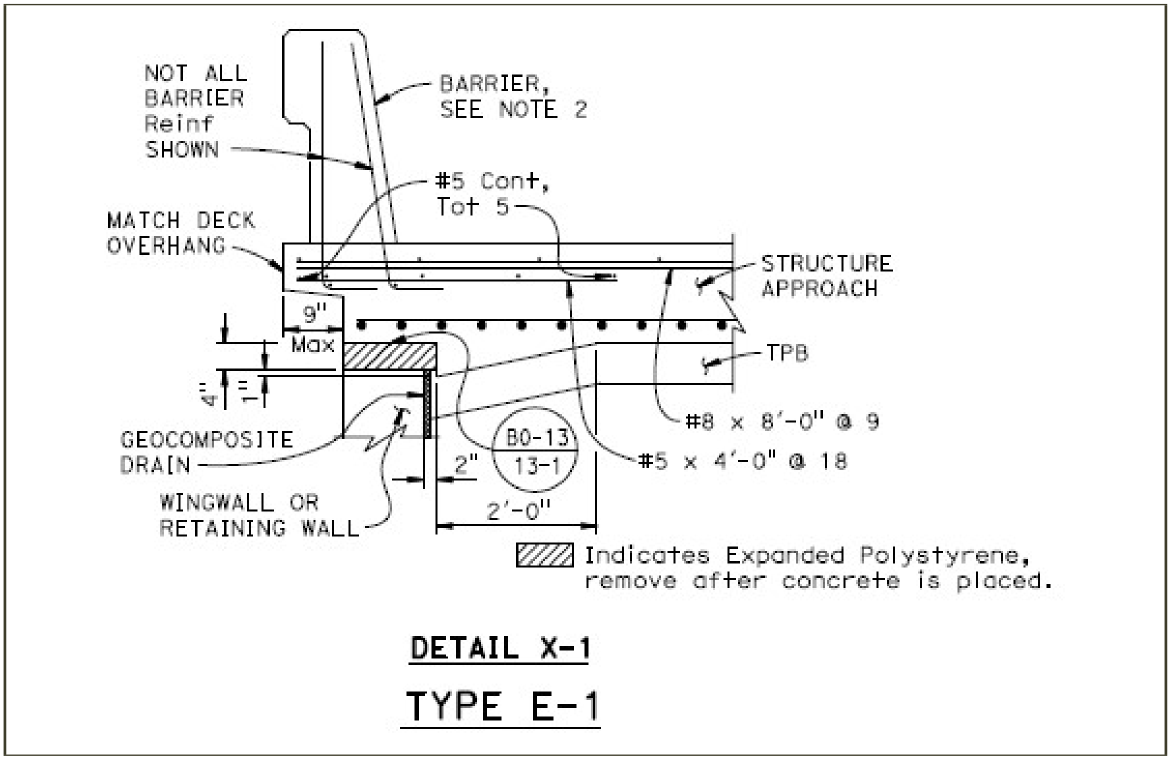


Figure 87 Caltrans Barrier Rail (Caltrans Standard Plan B9-5)

Iowa DOT: Iowa DOT did not address this topic.

LaDOTD: LaDOTD places the barrier on top of wingwall. Impact load is considered for the barrier impact, but not for the wingwall, as that is not required for buried elements.

MaineDOT: MaineDOT uses buried approach slabs for almost all structures, so there are no details for an approach slab to barrier connection. MaineDOT places barrier on top of wingwall, though this is not preferred as common practice is to try to put wingwall outboard of guardrail posts. They do consider impact although it is not preferred.

MassDOT: For MassDOT's U-shaped wingwalls, the backwall abuts the wingwall, while the barrier sits on top of the wingwall. For splayed wingwalls, the bridge rails – guardrail transition, which is usually precast, sits in a pocket that is cast into the back of the wingwall. The barrier is always on top of the wingwall. Impact load is applied to the wingwall that supports the barrier, but MassDOT uses an equivalent static force using the methodology and load from NCHRP Report 663. This considers the inertial mass of the wall.

MnDOT: MnDOT places barrier on top of approach slab and considers impact load. Placing the barrier on the slab has significantly reduced the issues related to drainage and erosion at bridge ends.

PennDOT: For PennDOT's integral abutments, approach slabs are independent of wingwall. See BD-628M for all other approach slab details. The barrier is on top of the wingwall and they do consider impact load.

SDDOT: SDDOT past practice was to places barriers on flared abutment wings. Current practice is to set flared abutment wing, when used, beyond approach guard rail.

TDOT: TDOT places barrier on top of wingwall and considers impact load. Looking at revised details that place approach slab above wingwalls and places barrier rail along full length of approach slab.

UDOT: Since 1986, UDOT has been mounting parapets directly to the approach slab. **Figure 88** is UDOT standard 10.8-degree single slope TL-4 parapet taken from working standard sheet WS-20A. It is anchored to the same thickness of concrete as the bridge overhang, meets all the same design requirements as the parapet on bridge and uses the same design which is a vertical #4 bar at 4 inches in end regions and #4 at 12 inches in interior regions.

A minimum 5 inch gap is required between the top of the wingwall and the bottom of the approach slab to allow for approach slab settlement. Matching the thickness of the deck overhang allows for an aesthetic line from the superstructure to the end of the wingwall.

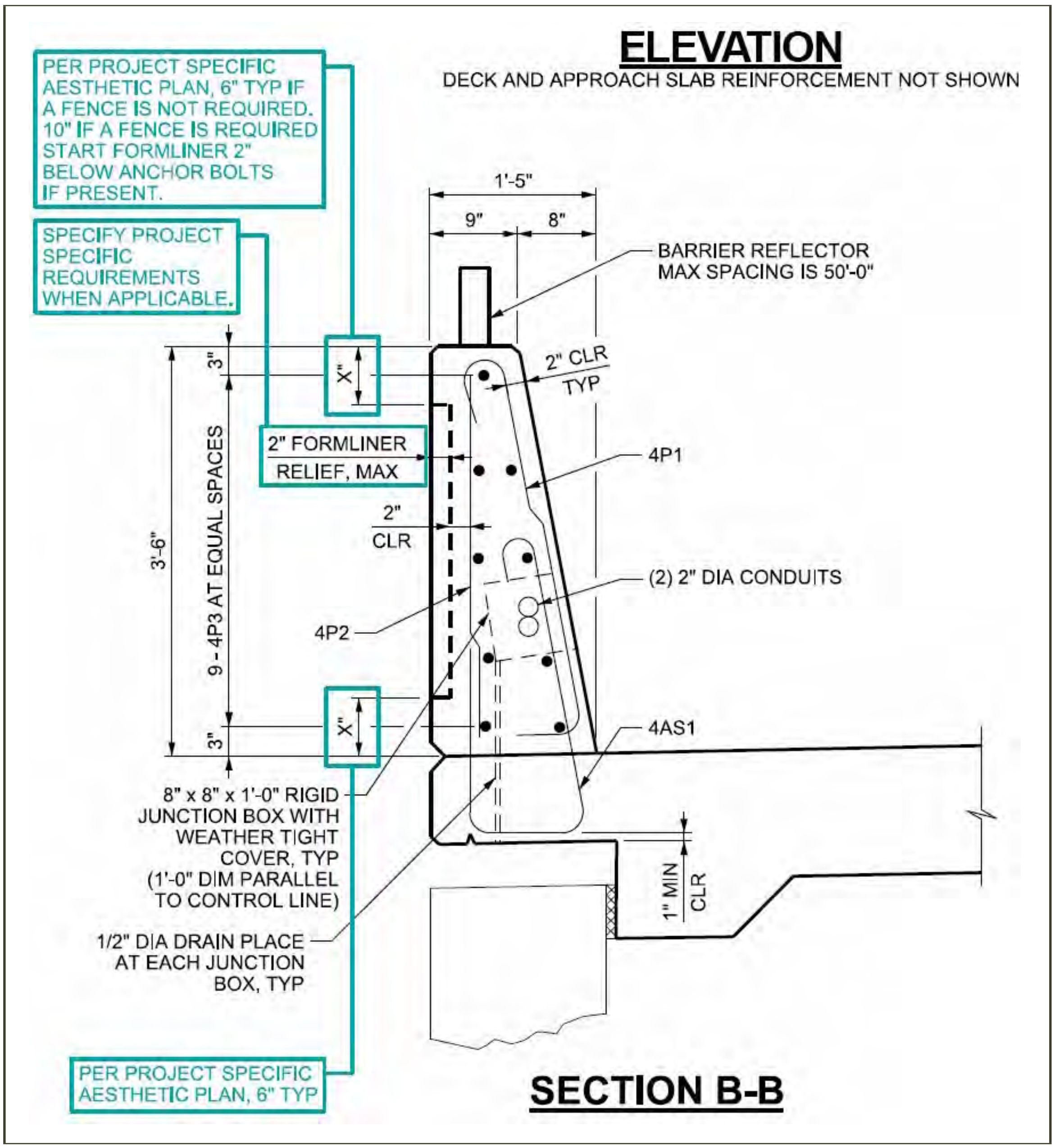


Figure 88 UDOT Barrier Rail

VDOT: Since VDOT buries approach slabs, barriers are not attached to them.

WSDOT: WSDOT places barrier on top of approach slab and considers impact load (**Figure 89**).

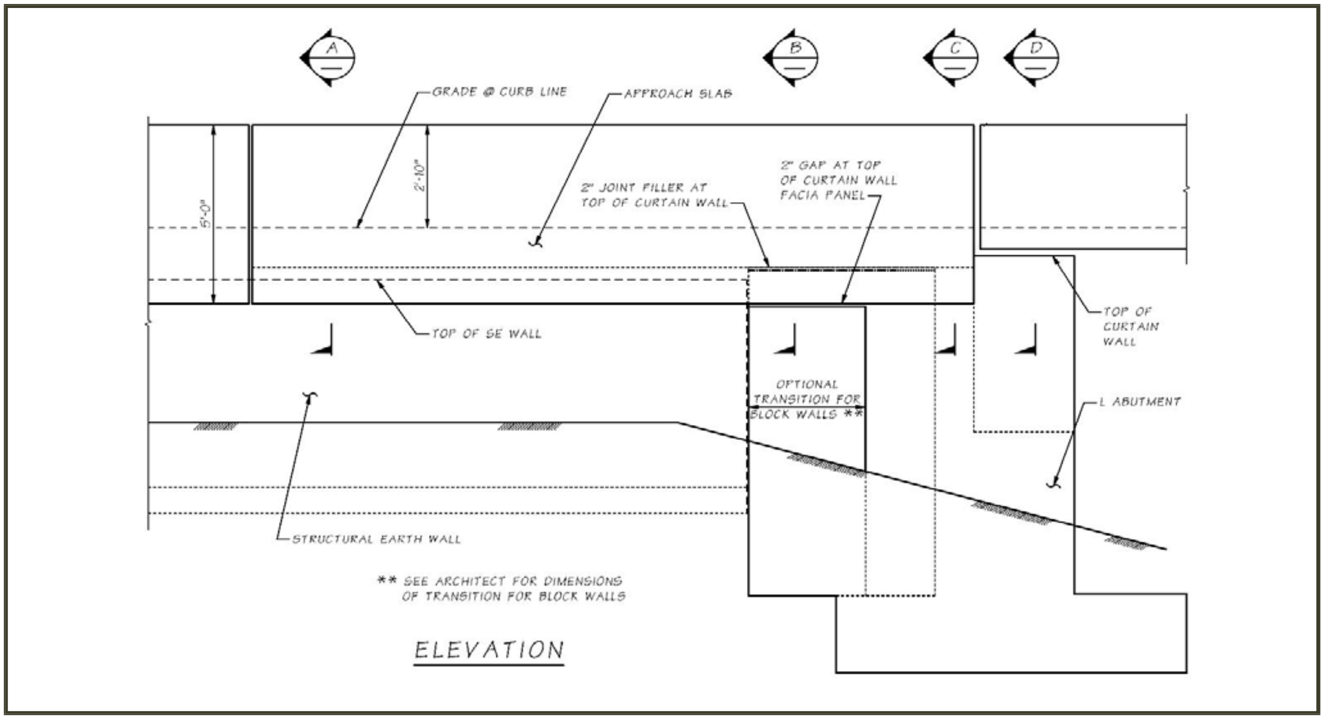


Figure 10.7.2-1

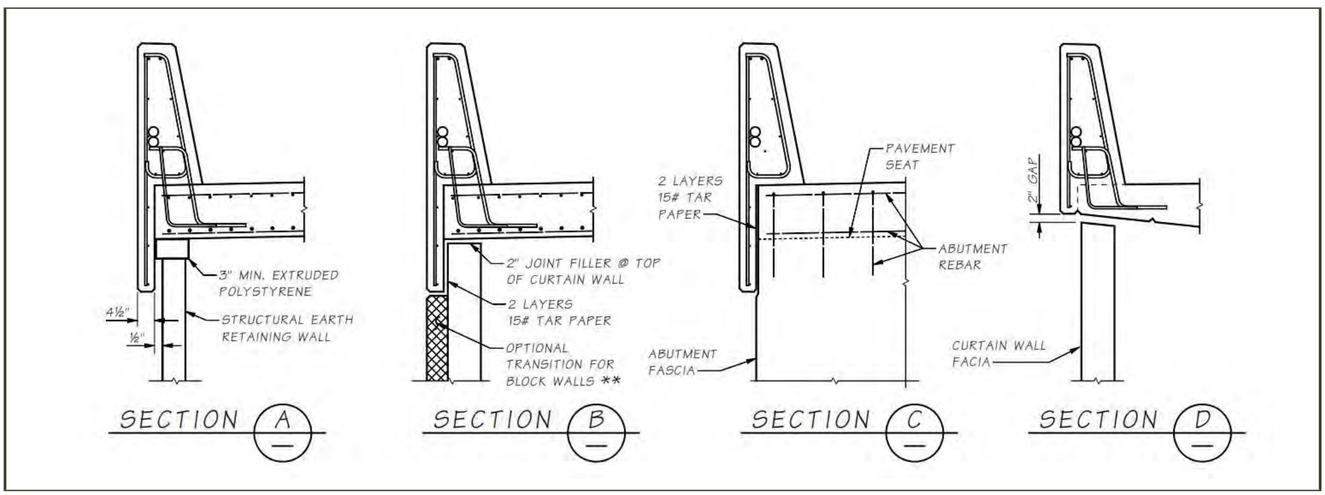


Figure 10.7.2-2

Figure 89 WSDOT Barrier Variations (BDM Fig. 10.7.2)

3.4 Embankment Treatments

Many states have spent considerable time investigating and trying alternative embankment parameters. Some of these include the boundaries specified for compaction, the compaction requirements and type of backfill. Some states use an expanded fill zone to move the differential settlement away from the bridge end. This section presents which states have an inclusion at the abutment backwall, if the state has compaction requirements, which states use structural backfill versus embankment and any soil improvement techniques employed.

3.4.1 Inclusion at Abutment Backwall

This section presents state use of inclusions at abutment backwalls.

Caltrans: To address voids behind the abutment, Caltrans designs to span the void. Based on Research by UC Davis – *Evaluation of Structural Performance of Bridge Approach Slabs* (2010), using Caltrans previous approach slab design (12 inches thick, 30 feet long, #8's at bottom mat), the allowable washout length was 12 feet, for a slab deflection of 1inch. The question is: what is tolerable slab deflection and rotation? The new LRFD approach slab design is more robust and would likely produce smaller deflections at the same washout length.

Iowa DOT: Iowa DOT does not use inclusions behind abutment backwall.

LaDOTD: LaDOTD used a 1inch thick expanded polystyrene sheet behind the abutments for their pilot project jointless bridges.

MaineDOT: MaineDOT does not typically use inclusions on the approach side of integral abutments. The abutment wall is designed for passive pressure directly on the wall. If an inclusion is included, the department has a preapproved product list.

MassDOT: MassDOT does not use inclusions, rather they consider the behavior of the soil as soil springs in the design of the integral abutment.

MnDOT: MnDOT does not use inclusions but is considering the use of a geo-composite sheet drain attached to the back face of the abutment.

PennDOT: PennDOT is trying detail with 6 inches expanded polystyrene fill with geosynthetic wrapped backfill.

SDDOT: SDDOT used to place a 6" void behind the backwall. Their current detail is shown in **Figure 90**. It consists of a vertical composite drain between the backwall back face and a 3 foot (shown as 3 foot-2 5/16inch in **Figure 90**) granular backfill region. The backfill sits on a Type B drainage fabric overlain on a porous backfill.

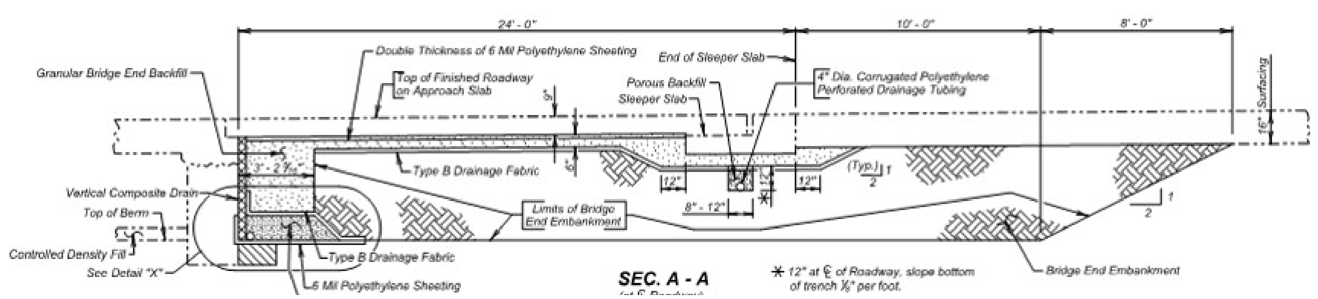


Figure 90 SDDOT Granular Bridge End Backfill

TDOT: TDOT currently has research projects looking at this topic.

UDOT: UDOT does not use inclusions, rather they simply use 3 feet of granular backfill borrow behind the backwall. This is specified as a well-graded, 2 inch max, nearly cohesionless, A-1-a soil.

VDOT: For integral and semi-integral, VDOT requires Expanded Polystyrene (EPS) behind abutment and a geotextile filter fabric.

WSDOT: WSDOT places backfill against end diaphragms.

3.4.2 Compaction Requirement

Strict specifications on compactions have minimized the differential settlement for some states. By requiring lift heights, one state reported marked reduction in differential settlement. This section presents compaction requirements and methods of achieving per state.

Caltrans: Caltrans uses superior compaction in the fills approaching the structure. The following criteria are from their standard specification, with section noted in parenthesis:

- Structure Backfill is to be compacted to at least 95% relative compaction (SS 19-3.02C).
- Backfill layers must be at most 0.67 foot thick before compacting (SS 19-3.03E(1) General).
- Compact full width and depth of embankment within 150 feet of each bridge abutment (SS 19-5.03B Relative Compaction (95 Percent)).

To address voids behind the abutment, Caltrans uses compressible material behind abutment, designed to span, based on research by UC Davis, *Evaluation of Structural Performance of Bridge Approach Slabs* (2010).

Iowa DOT: Iowa DOT uses a stone and sand base that is flooded to achieve compaction (**Figure 91**), and this has helped with settlement under the panel next to the abutment. First, they make a tub to contain the water and the only way to drain the water is to drain through a pipe. Second, sand is placed in lifts and flooded until water stands. Third, it is drained, and the next layer is added. The process as presented in their standard drawings is shown in **Figure 92.** Their rock flume details work well when the water goes to them.

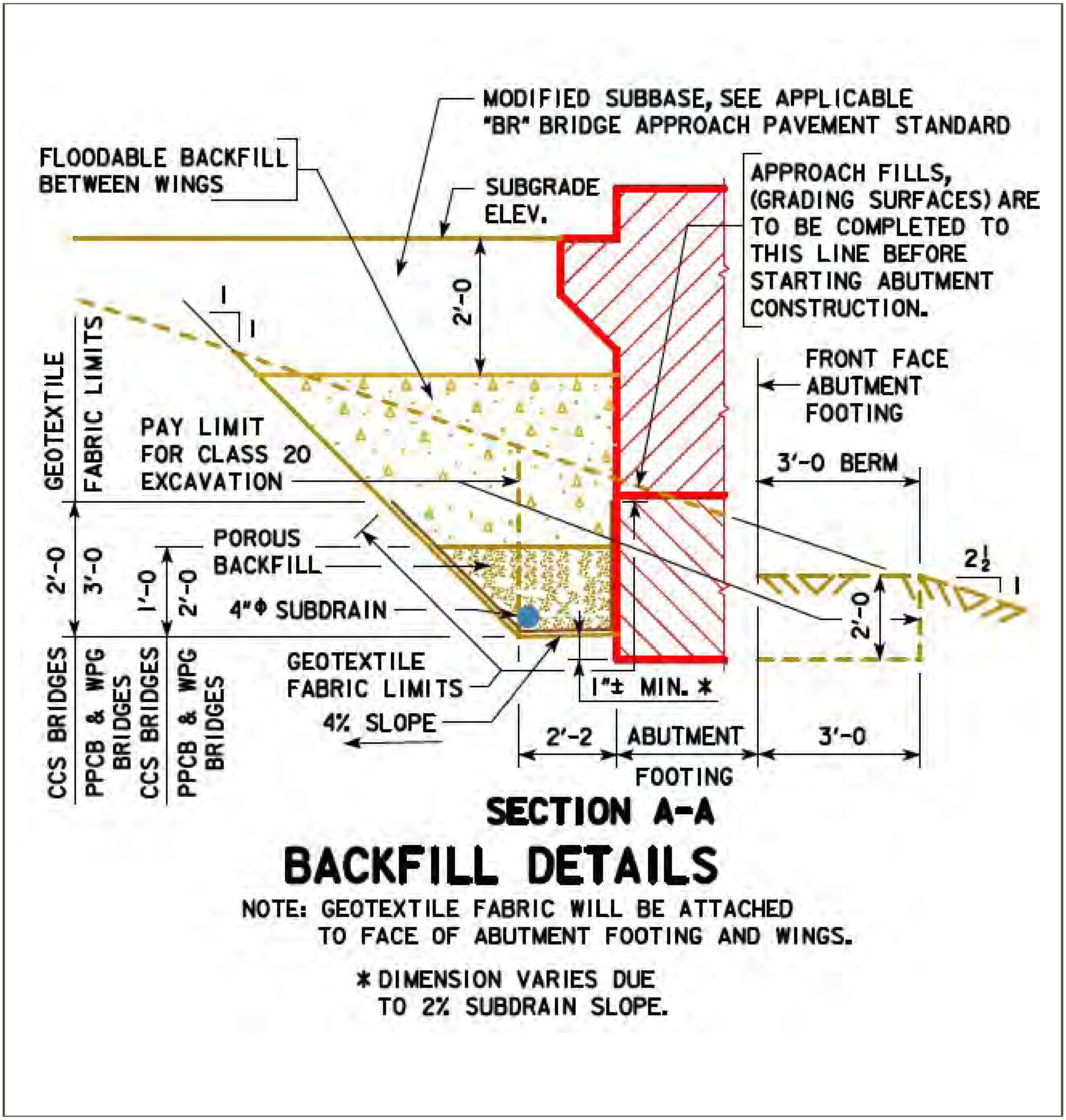


Figure 91 Iowa DOT Backfill Details

ABUTMENT BACKFILL PROCESS:

THE BASE OF THE EXCAVATION SUBGRADE BEHIND THE ABUTMENT IS TO BE GRADED WITH A 4% SLOPE AWAY FROM THE ABUTMENT FOOTING AND A 2% CROSS SLOPE IN THE DIRECTION OF THE SUBDRAIN OUTLET. THIS EXCAVATION SHAPING IS TO BE DONE PRIOR TO BEGINNING INSTALLATION OF THE GEOTEXTILE AND BACKFILL MATERIAL.

AFTER THE SUBGRADE HAS BEEN SHAPED, THE GEOTEXTILE FABRIC SHALL BE INSTALLED IN ACCORDANCE WITH THE DETAILS SHOWN. THE FABRIC IS INTENDED TO BE INSTALLED IN THE BASE OF THE EXCAVATION AND EXTENDED VERTICALLY UP THE ABUTMENT BACKWALL, ABUTMENT WING WALLS, AND EXCAVATION FACE TO A HEIGHT THAT WILL BE APPROXIMATELY 1 TO 2 FOOT HIGHER THAN THE HEIGHT OF THE POROUS BACKFILL PLACEMENT AS SHOWN IN THE "BACKFILL DETAILS" ON THIS SHEET. THE STRIPS OF THE FABRIC PLACED SHALL OVERLAP APPROXIMATELY 1 FOOT AND SHALL BE PINNED IN PLACE. THE FABRIC SHALL BE ATTACHED TO THE ABUTMENT BY USING LATH FOLDED IN THE FABRIC AND SECURED TO THE CONCRETE WITH SHALLOW CONCRETE NAILS. THE FABRIC PLACED AGAINST THE EXCAVATION FACE SHALL BE PINNED.

WHEN THE FABRIC IS IN PLACE, THE SUBDRAIN SHALL BE INSTALLED DIRECTLY ON THE FABRIC AT THE TOE OF THE REAR EXCAVATION SLOPE. A SLOT WILL NEED TO BE CUT IN THE FABRIC AT THE POINT WHERE THE SUBDRAIN EXITS THE FABRIC NEAR THE END OF THE ABUTMENT WING WALL.

POROUS BACKFILL IS THEN PLACED AND LEVELED, NO COMPACTION IS REQUIRED.

THE REMAINING WORK INVOLVES BACKFILLING WITH FLOODABLE BACKFILL, SURFACE FLOODING, AND VIBRATORY COMPACTION. THE FLOODABLE BACKFILL MATERIAL SHALL BE IN ACCORDANCE WITH THE STANDARD SPECIFICATIONS. THE FLOODABLE BACKFILL SHALL BE PLACED IN INDIVIDUAL LIFTS, SURFACE FLOODED, AND COMPACTED WITH VIBRATORY COMPACTION TO ENSURE FULL CONSOLIDATION. LIMIT THE LOOSE LIFTS TO NO MORE THAN 2 FEET OF THICKNESS.

START SURFACE FLOODING FOR EACH FLOODABLE BACKFILL LIFT AT THE HIGH POINT OF THE SUBDRAIN AND PROGRESS TO THE LOW POINT WHERE THE SUBDRAIN EXITS THE FABRIC. TO ENSURE UNIFORM SURFACE FLOODING, WATER RUNNING FULL IN A 2-INCH DIAMETER HOSE SHOULD BE SPRAYED IN SUCCESSIVE 6-FOOT TO 8-FOOT INCREMENTS FOR 5 MINUTES WITHIN EACH INCREMENT.

FLOODABLE BACKFILL LIFT PLACEMENT, FLOODING, AND COMPACTION SHALL PROGRESS UNTIL THE REQUIRED FULL THICKNESS OF THE ABUTMENT BACKFILL HAS BEEN COMPLETED.

WATER REQUIRED FOR FLOODING, SUBDRAINS, POROUS BACKFILL, FLOODABLE BACKFILL, AND GEOTEXTILE FABRIC FURNISHED AT THE BRIDGE ABUTMENTS WILL NOT BE MEASURED SEPARATELY FOR PAYMENT.

THE COST OF WATER REQUIRED FOR FLOODING, SUBDRAINS, POROUS BACKFILL, FLOODABLE BACKFILL, AND GEOTEXTILE FABRIC FURNISHED AT THE BRIDGE ABUTMENTS SHALL BE INCLUDED IN THE CONTRACT UNIT PRICE BID FOR STRUCTURAL CONCRETE.

Figure 92 Iowa DOT Backfill Process

LaDOTD: LaDOTD 2016 Standard Specifications state to place backfill in "horizontal layers not exceeding 9-inch loose thickness and uniformly compact by approved methods to the satisfaction of the Project Engineer".

MaineDOT: MaineDOT specifies granular borrow as backfill around integral abutments. MaineDOT Standard Specifications limits layers to 8 inch loose thickness.

MassDOT: For their integral abutment backfill, MassDOT specifies standard "Gravel Borrow for Bridge Foundation" that is in their Standard Specifications. The compaction for this is also specified in the Standard Specifications.

MnDOT: MnDOT backfill requirements shown in **Figure 93**. The maximum lift thickness is 6 inches compacted (8 inches loose). Additional details are available in the 200 section of the state standard plans (9). **Figure 94** shows boundaries of fill.

D.2 Structural Backfill

Provide 100% virgin structural backfill meeting the requirements of Table 3149-3, and the following.

Table 3149-3 Structural Backfill Requirements	
% Passing ¾ in Sieve	100%
Percent Passing Ratio No. 40/No. 10	0 - 65%
Percent Passing Ratio No. 200/No. 10	0 - 10%

(1) Provide screened material meeting the requirements of 3137.2.B.3, "Classification," for Class C.
(2) Provide material with a minimum angle of friction (Φ) of 34° in accordance with AASHTO T 236.

Figure 93 MnDOT Backfill Requirements

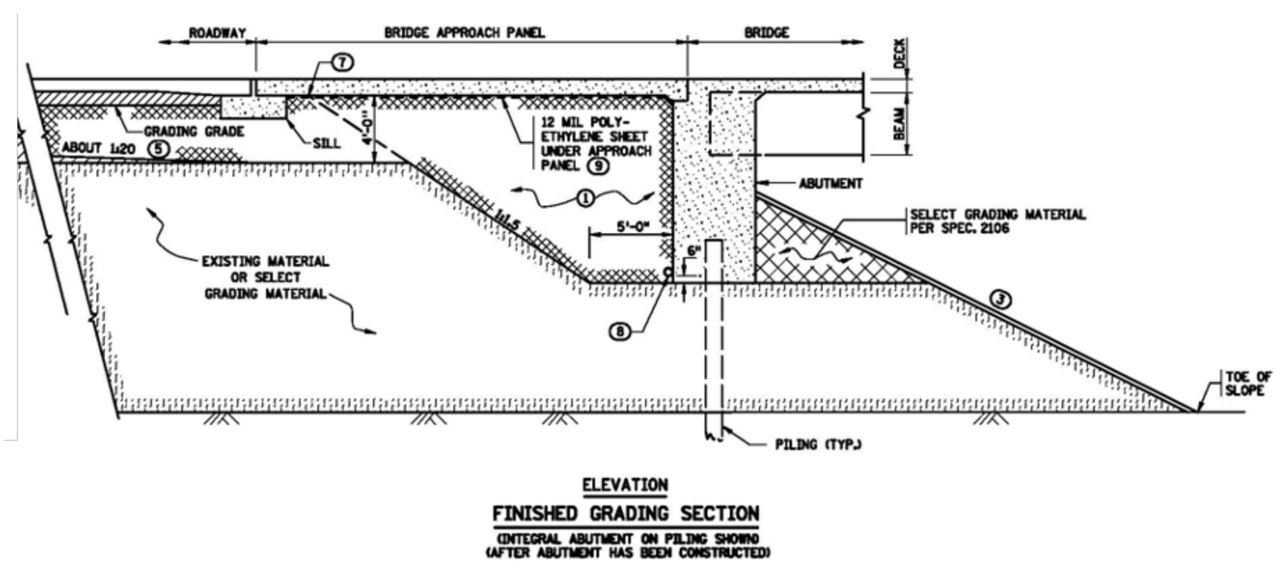


Figure 94 MnDOT Finished Grading Section

PennDOT: Within 24inches from the rear face of the abutment (**Figure 95**), PennDOT specifies the following:

- Place backfill in loose lifts
- 6 inch lifts for open graded stone (OGS), AASHTO No. 3, 5, or 57 Coarse Aggregate
- 9 inch lifts for AASHTO No. 1
- 12 inch lifts for R-3 Rock
- Compact each layer with 2 passes of a walk-behind vibratory plate soil compactor

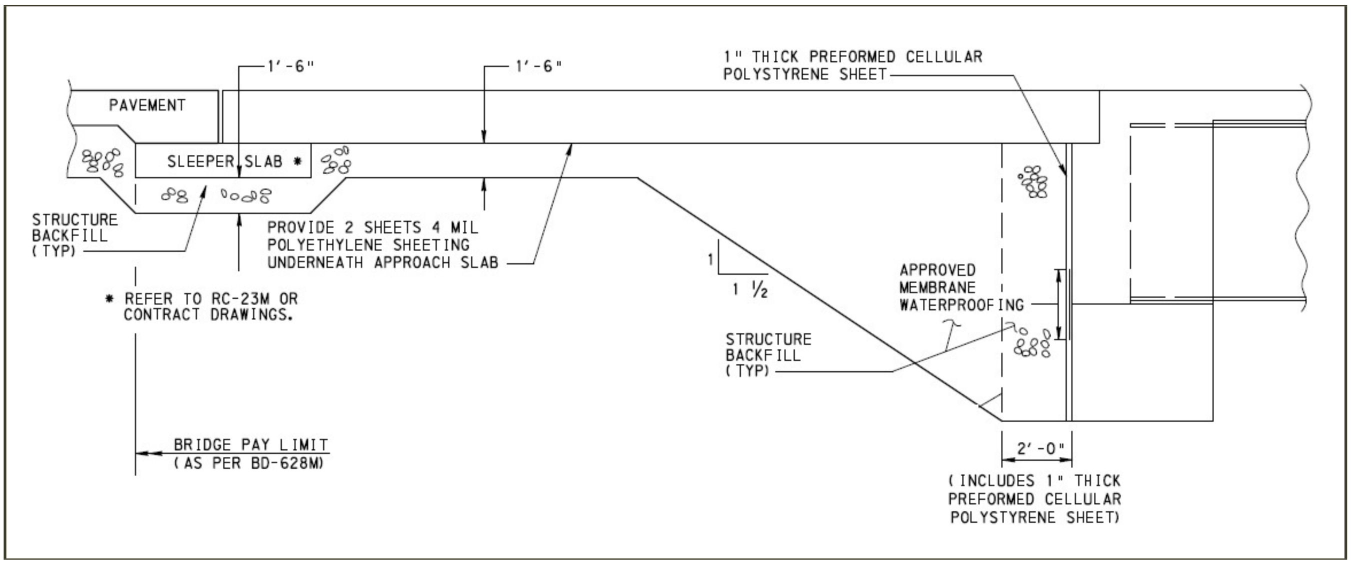


Figure 95 PennDOT Structural Backfill

SDDOT: SDDOT extends the compacted fill the full depth for a minimum of 10 feet beyond the end of the sleeper slab, shown in **Figure 96**. At the end of that 10', the embankment is sloped 2:1.

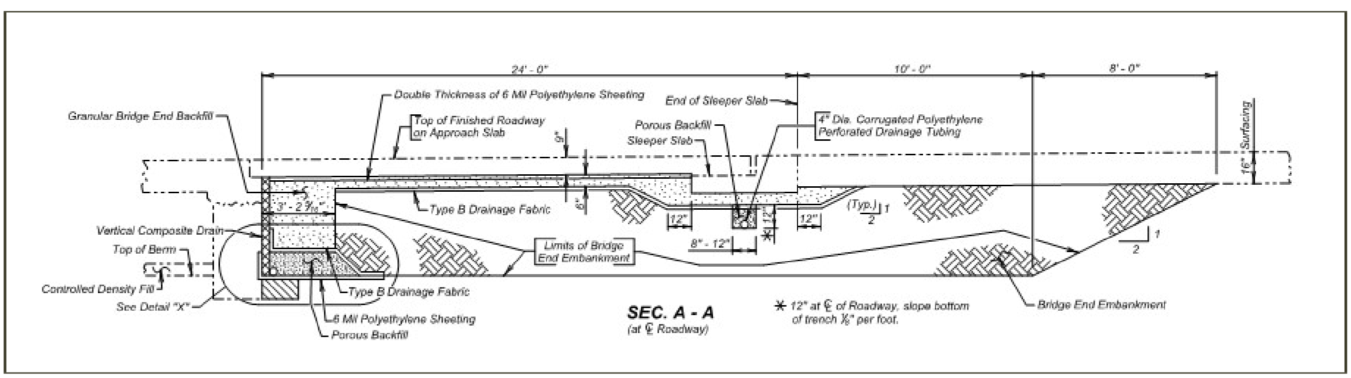


Figure 96 SDDOT Grading and Embankment Limits

TDOT: TDOT specifies 95% maximum proctor. The TDOT 2015 standard specification states, "Place Granular Backfill Material for Structures (Class A, Grading D) so that the compacted depth does not exceed 6 inches per layer. Compact every 6-inch layer to 100% density."

UDOT: UDOT's Embankment for Bridge specification state density requirements must "meet minimum density test average of 96 percent of maximum laboratory density with no single determination lower than 92 percent."

VDOT: VDOT's 2016 Standard Specification states select backfill shall be placed in horizontal layers 6 inches or less in loose thickness and then "compacted at ±20 percent of optimum moisture to a density of at least 95 percent as compared to the theoretical maximum density."

WSDOT: If presumptive passive pressures (PP) are to be used for design, then the following criteria shall apply:

- Soil in the "passive pressure zone" shall be compacted in accordance with Standard Specifications Section 2-03.3(14)I, which requires compaction to 95 percent maximum density for all "Bridge Approach Embankments".
- For cohesionless, nonplastic backfill (fines content less than 30 percent), the PP may be assumed equal to 2Hw/3 kips per square foot (ksf) per foot of wall length.

3.4.3 Structural Backfill vs Embankment

Some host states have found that specifying structural backfill has helped to minimize the differential settlement. This section presents each state's standard specifications.

Caltrans: Caltrans Memorandum to Designers *(MTD) 5-1: Abutments* states "the use of slurry cement backfill for abutments is not permitted. Slurry cement backfill may exert higher lateral forces to the abutment (when fresh and compared to earth backfill) and cause long-term drainage problems. Furthermore, nonlinear soil springs, commonly used to model the resistance of the abutment backwall and adjacent soil for seismic analysis of the superstructure are likely to be inaccurate with slurry cement backfill. Application of lightweight concrete (such as cellular concrete) as backfill will require a design exception." Standard Specification Section 19-3.02C Structural Backfill is reprinted in **Figure 97**.

Structure backfill compacted to a relative compaction of at least 95 percent and material placed behind retaining walls must have a sand equivalent value of at least 20 and comply with the gradation requirements shown in the following table:

Sieve size	Percentage passing
3"	100
No. 4	35–100
No. 30	20–100

Figure 97 Caltrans Structural Backfill (SS 19-3.02C)

Iowa DOT: Bottom layer is a porous backfill, topped by a floodable backfill, topped by a modified subbase (**Figure 91**).

LaDOTD: LaDOTD has material specifications for concrete, geosynthetic soil reinforcement, drainage pipe, backfill material. For their jointless bridge pilot projects, the backfill behind the abutments was a specified sand aggregate with modified gradations placed in 4 inch lifts. The fill within 2 feet behind the abutment and adjacent to the wing walls was nominally compacted using two passes of a walk-behind vibratory plate soil compactor.

MaineDOT: MaineDOT Standard Specifications and subsequent special provisions define material specifications and minimums.

MassDOT: MassDOT uses their standard material specifications.

MnDOT: See Section 3.4.2.

PennDOT: See Section 3.4.2.

SDDOT: See **Figure 96** for granular bridge end backfill details.

TDOT: TDOT has material specifications for backfill granular material.

UDOT: Within 3 feet of the back of approach slab A-1-a material is required. UDOT standard specifications require that the backfill beyond the 3 feet of granular backfill borrow is a 3-inch max, nearly cohesionless A-1 soil which allows more fines than the A-1-a adjacent to the bridge.

VDOT: VDOT specifies select backfill under approach slabs. **Figure 98** shows VDOT select backfill details for both cut and fill sections.

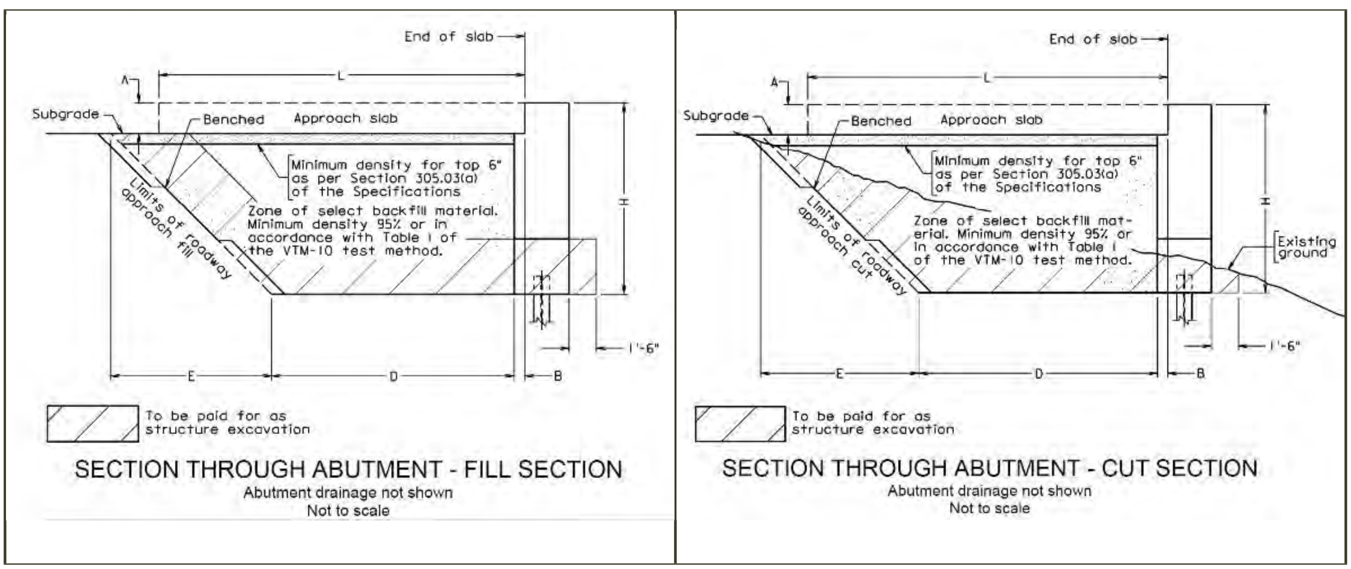


Figure 98 VDOT Select Backfill

WSDOT: See previous section.

3.4.4 Soil Improvement Techniques

Some participating states used soil improvement techniques such as geotextile fabric. This section describes how each state prepares soil behind the abutments.

Caltrans: At Caltrans, Geotechnical Services conducts site investigations, analyzes foundation soils, and provides improvement recommendations, when needed. Some techniques that can be used to minimize consolidation of soft foundation soils after construction are:

- Relocate the bridge or bridge ends to reduce fill, or use lightweight fill
- remove and replace unsuitable material if near the surface,
- delay construction of critical permanent design components to allow for soil precompression,
- construct embankment to a height more than final elevation for pre-settlement by soil surcharge.

Soil reinforcement can be used to improve the approach embankment. Caltrans' End Bent with Isolated MSE abutment type is shown in **Figure 36**. **Figure 86** shows the 6 inch layer of TPB (treated permeable base) Caltrans uses under the approach slab.

Iowa DOT: Iowa DOT has seen good results with their flooded backfill as presented in Section 3.4.2.

LaDOTD: LaDOTD specifies improvement techniques where natural ground is particularly poor, which is more prevalent in the southern parts of the state. Layers of geotextile fabric are placed between layers of backfill underneath the sleeper slab to distribute the approach slab loads into a wider area of the backfill and reduce approach slab settlement at the roadway end (see section 5.1.2 for discussion of demonstration project).

MaineDOT: MaineDOT has become more sensitive to this than in the past, and thus evaluates the need based on site conditions on a project-to-project basis.

MassDOT: For integral abutment backfill, MassDOT specifies their standard "Gravel Borrow for Bridge Foundation" that is in their Standard Specifications.

MnDOT: MnDOT has used layers of geotextile wrap although it is not standard practice.

PennDOT: PennDOT does not specify soil improvement techniques in standards, but 8 inch layers with geotextile is used. No. 57 coarse aggregate with geotextile in 12 inch lifts for 4 feet below bottom of pile cap. Structural backfill or OGS behind integral abutments, typically.

SDDOT: Early integral abutments were simply backfilled. In the 1970's, SDDOT added drains to the backfill. In the 1990's they started using reinforced backfill. They enlarged the envelope in the 2000's but the state no longer uses reinforced fill because of complaints from contractors and the poor quality of the installation. Figure 96 shows the extended bridge end embankment limits, granular bridge end backfill, composite drain, drainage fabric, porous backfill limits and polyethylene sheeting.

TDOT: TDOT does not generally do soil improvement techniques but is starting to use geogrid layers under approach slab/pavement interface.

UDOT: UDOT does not specify anything special for subgrade or soil improvement. A Structure Foundation Recommendations Memo is required to be provided with every structure, which may recommend soil improvement due to specific site conditions. This memo would not necessarily address special criteria under the approach slab specifically.

VDOT: VDOT uses select backfill for all abutments. See previous section.

WSDOT: An option to reduce seismic load from approach fill to abutment's wall is to isolate the fill with isolated abutments by providing a six-foot gap between the soil and the abutment wall. **Figure 99** shows an isolated abutment with a separate retaining system to support the embankment. **Figure 100** shows a similar concept but with a fascia wall to provide separation

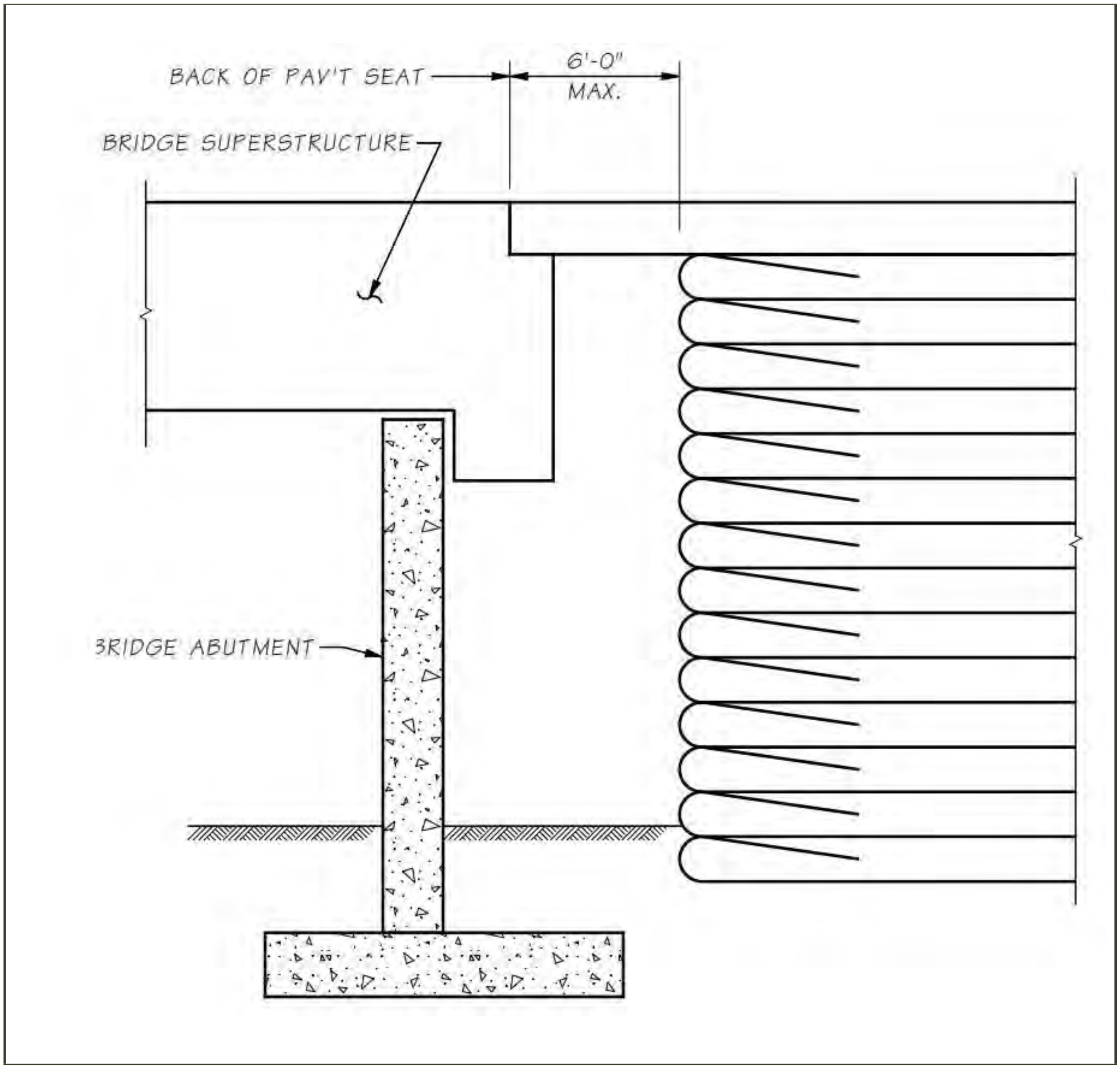


Figure 99 WSDOT Isolated Abutment (BDM Fig 7.5.1-5)

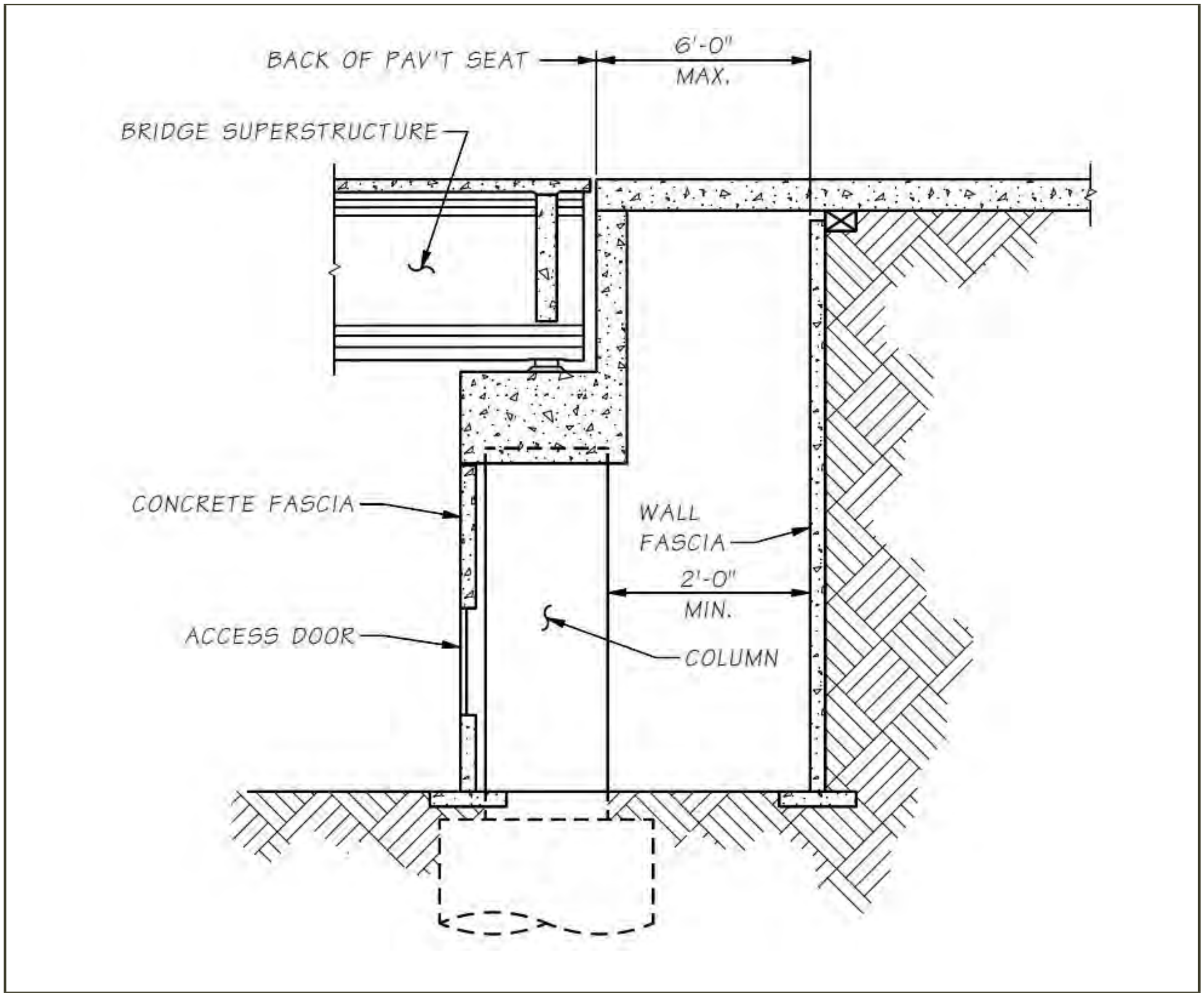


Figure 100 WSDOT Isolated Bent-Type Abutment (BDM Fig. 7.5.1-4)

3.5 Drainage

Controlling and designing for effective drainage management is the key to structure longevity. Some states are not allowed to place drains on the bridge deck (MnDOT). Water causes damage when allowed to drain to the wrong place. Hence the need to route water where it will not cause damage such as slope erosion, undercutting corrosion. Geo-composite drains behind the abutment provide safe route for water. This section presents how states handle drainage at the bridge ends.

Caltrans: The current structure approach is designed to prevent water from entering behind the abutment and along the wingwalls. An underlying drainage system provides additional insurance against erosion. Caltrans provides the following drainage details:

- SP B9-6: Structure Approach Drainage Details
- SP B0-3: Bridge Details – 8 inch perforated steel pipe (PSP) and Permeable Material to be used when there is water bearing material behind the abutment
- SP B0-3: Bridge Details - Weep Hole and Pervious Backfill
- Bridge Design Details 6.3, Weep Hole and Geocomposite Drain

Good workmanship and maintenance are essential to prevent water intrusion.

Iowa DOT: Iowa DOT has details for rock flumes that work well if you can get the water to them.

LaDOTD: Under the sleeper the state uses a bedding material and 6inch diameter perforated pipes. From the trough between the approach slab and the sleeper slab, a paved open drain takes the water down the embankment.

MaineDOT: French drains or drainage geocomposite is specified behind the abutment wall. 4inch PVC weep holes installed through the abutment wall are also utilized. At finished grade the shoulders & berms (widenings) are paved to allow sheet flow to the hinge point of the slope. Riprap downspouts are provided at the low points to collect most of the flow. Details do not usually change based on type of wearing surface, but project specific concerns are addressed as they arise.

MassDOT: If a closed drainage system is required, MassDOT will place the catch basin behind the approach slab. Otherwise, MassDOT allow the water to sheet off the bridge and provide country drainage off the roadway. Details do not change based on type of wearing surface.

MnDOT: MnDOT is considering adding a geocomposite drain at the back face of the abutment. A drainpipe is installed at the base of the abutment (see **Figure 45**). MnDOT is also looking to add details for a ditch flume off the end of the bridge.

PennDOT: PennDot details a drainage trough behind abutment (**Figure 101**).

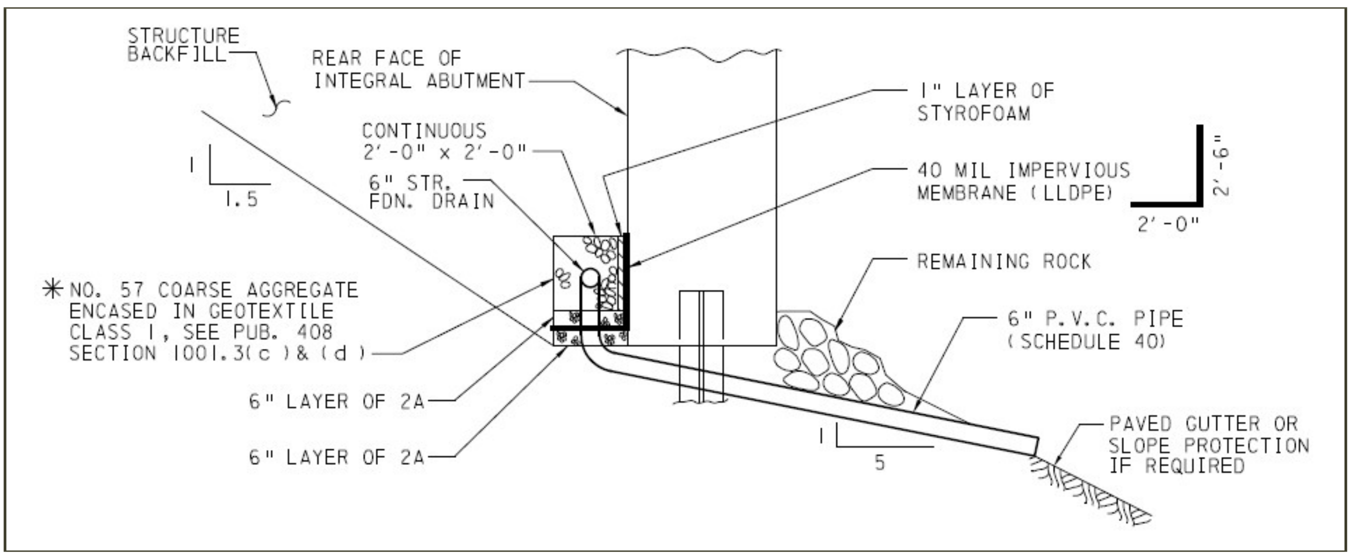


Figure 101 PennDOT Enhanced Drainage Detail for Abutments without Approach Slab

SDDOT: SDDOT has a vertical composite drain at the abutment backwall, which drains into a porous backfill and away from the abutment (**Figure 96**). There is also a polyethylene perforated drainage tubing beneath the sleeper slab, also placed in a porous backfill.

TDOT: TDOT uses a rectangular drain like a catch basin, with pipe daylighting out of side slope. Oftentimes the state works with roadway designers to put catch basin just off end of approach slab. When a sleeper slab is used, it is an inverted T with asphalt and it is flat with concrete surface. The state has initiated new details that eliminate drains in approach slabs and uses a rock flume at end of barrier rail or approach slab.

UDOT: UDOT does not permit deck drains on new bridges and places a sized approach slab drain upstream of the expansion joint with the grate placed 2 inches from the parapet and the box placed 3 to 12 inches from the sleeper slab, basically as close as possible to the joint. Drainage is required when the flow over the joint would be greater than 0.10 cfs, regardless of spread.

VDOT: The Virginia abutment has a trough to catch water run-off. This is preferred when a joint is required.

WSDOT: 3 inch diameter weep holes shall be provided in all bridge abutment walls. These shall be located 6 inches above the finish ground line at about 12 feet on center. The gravel backfill for wall shall be provided behind all bridge abutments. The underdrain pipe and gravel backfill for drain shall be provided behind all bridge abutments except abutments on fills with a stem wall height of 5 feet or less.

CHAPTER 4

Construction, Repair, Inspection And Maintenance

The sections in this chapter identify specific issues or requirements specific to jointless bridges with respect to construction considerations, repair, inspection and maintenance.

4.1 Construction

This section presents special construction considerations states require to ensure expected performance. A subsection of this section presents field comments.

Caltrans: Caltrans Standard Plans, Standard Specifications, project specific special provisions, and regular construction inspections are used to cover this. For example, to address the bump at the end of the bridge, Caltrans has a surface smoothness specification, shown in **Figure 102**. This specification directs the Engineer to test the final surface smoothness of the bridge, approach slabs and the adjacent 50 feet of approach pavement.

51-1.01D(3)(b)(ii) Surface Smoothness

The Engineer tests the surface smoothness of the following:

1. Completed roadway concrete surfaces of structures and approach slabs and the adjacent 50 feet of approach pavement
2. Surfaces of concrete decks to be covered with another material
3. Completed concrete deck surfaces, including ramps and landings of POCs

Deck surfaces must comply with the following smoothness requirements:

1. Profile trace having no high points over 0.02 foot
2. Profile count of 5 or less in any 100-foot section for portions within the traveled way
3. Surface not varying more than 0.02 foot from the lower edge of a 12-foot-long straightedge placed transversely to traffic

Figure 102 Caltrans Surface Smoothness Specification (SS51-1.01D(3)(b)(ii))

LaDOTD: LaDOTD has backfill compaction specifications (described in Section 3.4.2) for their typical bridges.

MaineDOT: MaineDOT Standard Specifications and Standard Details, and project specific special provisions are used to cover this.

MassDOT: These are reflected in the standard details and construction notes that are put on the plans

PennDOT: PennDOT specifies a rotational tolerance on pile alignment of 15 degrees.

SDDOT: SDDOT tried GRS then moved away from it. The actual design is done by Geotechnical Engineering Staff. Soil reinforcing spacing was 9 inches and recommended fill. 6” gap was from size of spacer available. They doubled compaction testing requirement because contractors liked it better.

TDOT: No special inspection considerations, this is normal practice.

UDOT: Quality of workmanship is critical to long term success, but UDOT does not currently have anything related to this topic.

Iowa DOT, MnDOT, VDOT and WSDOT had no comment.

4.1.1 Field Comments

This section presents comments on constructability concerns, from the field or otherwise.

Caltrans: At the ends of bridges, Caltrans has some constructability concerns with:

- Precast approach slabs – difficult to level and grout underneath; maybe works better with overlays.
- Joints – keeping them protected during construction and installation of water stops
- Geocomposite drain – installing drain or filter fabric incorrectly
- Compaction directly behind the abutment – difficult to compact against abutment backwall/diaphragm
- End stagger detail – installing the diagonal bars with staged construction
- Paving notch extension – difficult to build

LaDOTD: LaDOTD has not received comments related to jointless bridges.

MaineDOT: MaineDOT receives comments about specific details used and tries to incorporate/address the comments as much as possible. Some comments involve running reinforcing bars through the superstructure beams (end diaphragm reinforcing) and tolerances (mostly in camber of the beams), among others.

MassDOT: None, MassDOT has been building both jointless and integral abutment bridges for so many years that contractors and construction personnel are familiar with their construction.

MnDOT: None other than concerns regarding premature joint failure

PennDOT: Reviewed during constructability reviews, biggest concern is phased construction.

SDDOT: SDDOT contractors like double compaction requirements better than installing Geotech reinforcing systems.

UDOT: The first one is the connection bar between the abutment and approach slab. This has already been responded to, and quite recently as of 2017, but as a constructability concern it is still occasionally raised. The reinforcing steel extending from the deck makes access to this area for compacting the backfill difficult. Before 2017 this was a #8 bar spaced at 12 inches extending 4 feet behind the abutment. In order to compact the backfill in this area, the #8 bars were field bent to get them out of the way and then bent back into place, which is difficult to do with a #8 bar and bad for the steel and coating. It is also bad for the concrete that the bar anchored to as the bar gets wrenched out of the way. The bar was revised to a #5 bar in 2017 that projects about two feet past the abutment. The bar is not completely gone so there are still comments about constructability, but it is an improvement.

In 2018 UDOT began requiring the use of fiber reinforced concrete in all bridge decks. It seemed like a simple change implemented to combat the deck shrinkage cracking, but it introduces a twist into pouring sequence. UDOT does not require the more expensive fiber reinforced concrete in any of the diaphragms below the thickness of the deck, so trying to place a non-fiber reinforced abutment diaphragm under a fiber reinforced deck, while everything needs to stay plastic is difficult. It is acceptable to place the fiber through the full depth of the abutment, but the additional cost can come in as a change order since it is not required by the base design. Still considering how to make this fair for everyone but are working to make sure the use of fiber reinforced concrete in abutments is allowed.

Another issue is regarding our sleeper slabs. The sleeper slabs are intended to provide a level sliding surface for the approach slab to rest on with an elevation that is directly tied to the elevation of the abutment. But they are an isolated structural element, so getting the elevations right can be a challenge. Then there is the issue of timing with getting the sleeper slabs cured prior to approach slab placement.

Iowa DOT, TDOT, VDOT and WSDOT had no comment.

4.2 Repair and Rehabilitation

This section identifies the rehabilitation solutions used to repair the deterioration and distress associated with the details at the ends of bridges that are not functioning as anticipated. It also addresses if DOTs modify existing bridges during rehabilitation projects to move existing joints off bridges.

Caltrans: Typical repairs at bridge ends are:

- mud jacking settled approach slabs with grout or polyurethane;
- patching approach slab concrete, sealing cracks with methacrylate;
- overlaying approach slab, mostly with polyester concrete;
- repairing slope/slope paving in front of abutment;
- filling voids behind the abutment, usually with rapid set concrete;
- unplugging drains/weep holes; and
- cleaning joints, replacing joint seals.

On major rehabilitation projects, approach slabs may be replaced. When approach slabs are replaced, the existing profile grade should be corrected to eliminate grade breaks. This requires pavement conform tapers. Caltrans is looking at surveying ahead of time to show existing grade corrections on the plans and avoid unexpected expensive tapers in construction. When approach slabs are replaced, spalls at the paving notch are repaired, and a paving notch extension is required if existing paving notch is less than 6”, as shown in SP B9-2.

Caltrans does not encourage asphalt concrete (AC) overlay on concrete because it retains water and causes unsound concrete, however if a rehabilitation project includes AC overlay, asphaltic plug joints may be used to remove joints.

Caltrans does not typically modify existing bridges during rehabilitation to move existing joints off bridges, but Caltrans is looking at using Engineered Cementitious Composite (ECC) to remove joints in steel bridges. ECC is essentially ductile concrete that produces microcracks. The only downside is the high cost.

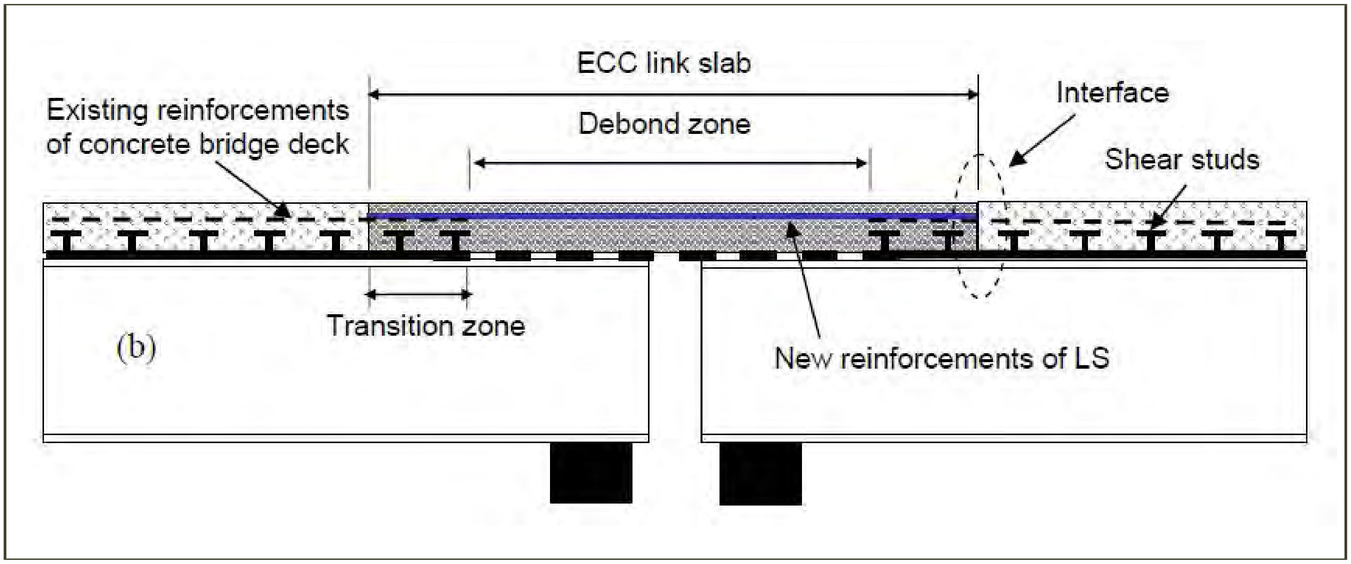


Figure 103 Caltrans SP B9-2

Iowa DOT: Iowa DOT uses semi-integral abutments for retro-fit projects.

LaDOTD: Previously, an asphalt overlay was used to level out poorly performing approach slabs. This is no longer used. LaDOTD now has the option to add a pavement relief joint where one had closed up or does not exist. LaDOTD does not modify existing bridges during rehabilitation to move existing joints off bridges.

MaineDOT: If significant issues are occurring, regional maintenance crews will attempt to perform localized concrete repairs to alleviate the issue, otherwise the structure is added to the Work Plan and becomes a capital project for rehabilitation. MaineDOT frequently removes expansion joints in favor of slab over backwall systems with APJ's. Other modifications are done on a project specific basis.

MassDOT: Some MassDOT Districts use asphaltic joints as a retrofit for deteriorated, failed armored joints. If the road can be closed, the existing joints are cut out and the bridge is retrofitted with a version of their deck over backwall detail. MassDOT does modify existing bridges during rehabilitation to move existing joints off bridges.

MnDOT: No specific repairs needed beyond crack sealing and some concrete patching. MnDOT does not generally modify existing bridges during rehabilitation to move existing joints off bridges.

PennDOT: PennDOT performs mill and repave for bituminous approaches and use asphaltic plug joints. PennDOT modifies existing bridges during rehabilitation with a deck extension (**Figure 104**)

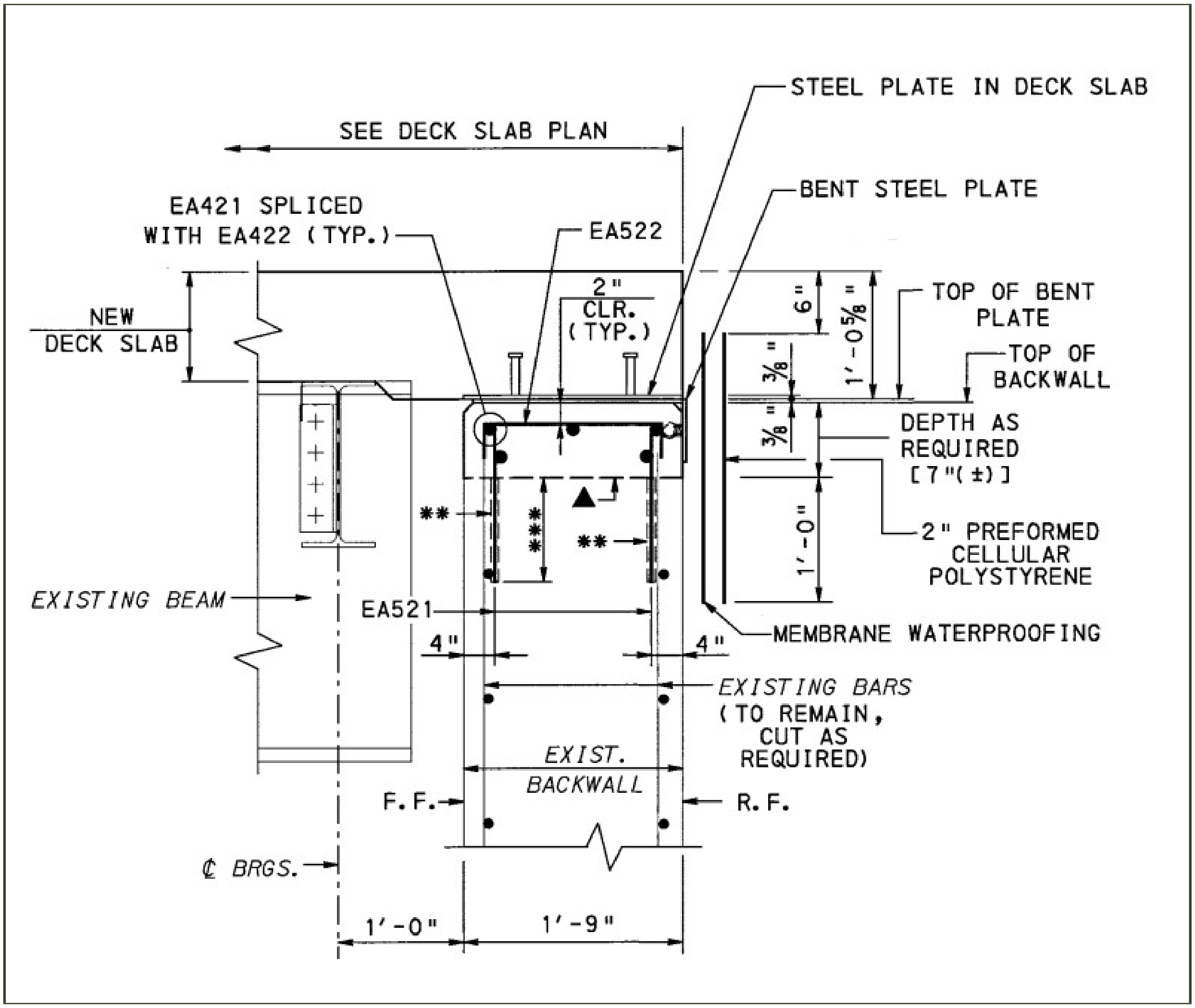


Figure 104 PennDOT Deck Extension/Eliminating Joints

SDDOT: SDDOT is converting existing bridges with expansion joints in the deck to be "semi integral". Most of these are 750ADT and outside Sioux Falls. When fixing the abutment, they shut the bridge down and embed girders in 2 feet thick back wall of the integral abutment. The approach slab is tied to semi-integral abutments and expansion accommodated at far end of approach slab.

TDOT: Typical repairs will add / modify / replace joints at the end of the approach slabs. Where spalls are present on abutments, those will be repaired as needed. In extreme cases where beam ends are damaged, bridge movement is evaluated. The state will rebuild the end walls, or as a last resort, add an expansion joint where bridge movement is excessive. TDOT will lock up expansion joints and pour full width backwall with reinforcement extending into abutment beam on older bridges with existing expansion joints.

UDOT: Spring / Fall cycle involves removing debris from drains/drain boxes, around bearings and from joints. UDOT sweeps deck, seals slope protection joints, roadway to structure relief joints and crack seal deck asphalt. They repair chain link fence and extend drains below superstructure. UDOT will also remove graffiti, remove debris and vegetation growth from channel and repair erosion.

UDOT modifies older inventory of bridges that still have expansion joints to turn them into jointless structures by using link slabs (**Figure 105**). UDOT does not have standard details for joint closures like this, but the intent is to provide a relatively ductile concrete slab over the ends of the girders, closing the joint without a significant change in load path. To do this the slab is separated from the girder in the region near the joint. Although there are efflorescence issues at the cold joint, UDOT has not seen structural issues with the performance of these details.

Like the bent locations, at the abutments UDOT wants to close the expansion joint at the existing backwall. The concept at the abutment is like what was done at the bent except foam and sheet metal is placed to detach the deck from the girder and approach slab from backwall.

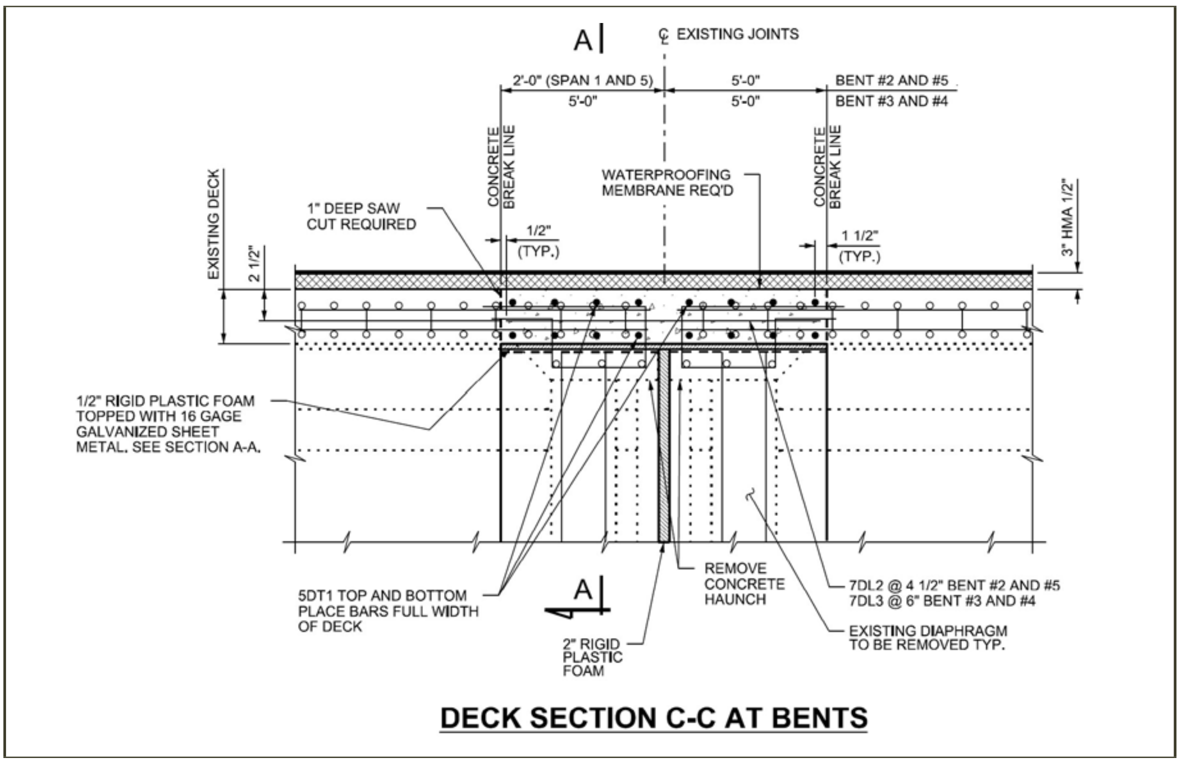


Figure 105 UDOT Repair

VDOT: If VDOT sees existing approach slab rotating and/or deck extension retrofit is desired, they will consider flowable fill under bridge side of approach slab and permit asphalt placement as necessary to correct for settlement. On existing bridges with joints, they look at options to remove joints

To get rid of joints at bents, they use link slabs and are looking at using partial depth link slabs with UHPC (a New York detail).

WSDOT: WSDOT does not typically modify existing bridges during rehabilitation to move existing joints off bridges

4.3 Inspection

This section identifies deviations from standard inspection protocols applied to inspection of integral bridges.

Caltrans: Caltrans inspects in accordance with the national bridge inspection standards (NBIS) (usually every two years), and integral abutment bridges are treated as regular bridges for inspection purposes.

LaDOTD: LaDOTD inspects 2 years for every bridge, and 1 year for fracture critical bridges

MaineDOT: MaineDOT inspects bi-annually unless the structure has been flagged for more frequent inspections. There is no “special elements of integral bridges” inspection protocol but typical areas of interest to take extra note of are the pile protection (riprap) and looking for cracking in the end diaphragm

MassDOT: MassDOT inspects in accordance with the NBIS, every two years and integral abutment bridges are treated as regular bridges for inspection purposes.

MnDOT: MnDOT inspects bridges every 2 years and added new elements 855 and 816 to their inspection program. Element 855 is for “Secondary Members” and documents the condition of the end diaphragm on integral and semi-integral abutment bridges. Element 816 is for the “Approach Relief Joint” and documents the condition of the joint between the approach panel and the pavement (see **Figure 36**).

PennDOT: PennDOT inspects in accordance with the NBIS, every two years and integral abutment bridges are treated as regular bridges for inspection purposes

SDDOT: SDDOT has the standard inspection protocol with nothing specific to integral bridges.

TDOT: TDOT inspects in accordance with the NBIS, every two years and integral abutment bridges are treated as regular bridges for inspection purposes.

UDOT: UDOT does not have any deviations from standard inspection protocols for the inspection of integral abutment bridges.

WSDOT: WSDOT inspects in accordance with WSDOT BDM and integral abutment bridges are treated as regular bridges for inspection purposes.

Iowa DOT and VDOT had no comment.

4.3.1 Inspection Checklists

States were asked if they had checklists for jointless bridge inspections.

Caltrans: Caltrans does not have a specific inspection checklist for jointless bridges. Caltrans has a Field Construction Practices Manual that covers many essential elements including Abutments, Wingwalls, and Approach Slabs. It has one note for end diaphragm abutments: “the plans may call for the wingwall concrete to be placed after prestressing.”

MaineDOT: MaineDOT stated typically not any different than a standard bridge inspection, extra attention is paid to checking for exposed piles and cracking at the end diaphragm.

MassDOT: MassDOT's jointless bridges are treated as regular bridges for inspection purposes.

MnDOT: Other than the 2 inspections elements that were added (see section 2.8.1) MnDOT does not.

TDOT: Nothing special since this is TDOT's typical bridge type.

UDOT: UDOT does not have a checklist yet but is something they are actively working to develop.

Iowa DOT, VDOT had no comment. LaDOTD, PennDOT, SDDOT and WSDOT do not have jointless bridge-specific checklists.

4.3.2 Tracking Performance

This section presents how states track system performance.

Caltrans: Caltrans tracks performance through bridge inspection reports, where condition states are reported for elements such as abutment, approach slabs and joint assemblies.

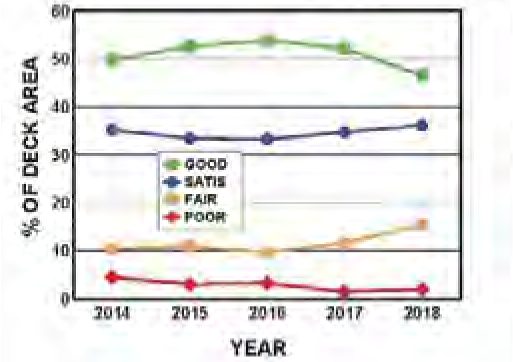
LaDOTD: LaDOTD has two pilot project jointless bridges that were heavily instrumented to track bridge movements and stresses. That data has not yet been processed.

MaineDOT: At MaineDOT, tracking is typically done as part of the bi-annual inspection process. All structures are inspected in advance of their construction warranty expiring. MaineDOT utilizes the online AssetWise (formerly Inspectech) system from Bentley to provide access to all inspection reports and bridge information. This system can be used to generate queries to pull in all structures by several different filter options.

MassDOT: In MassDOT's state bridge inventory that is a companion to the national bridge inventory (NBI) inventory, MassDOT does track jointless bridges and integral abutment bridges. MassDOT can track system performance through the bridge inspection findings. Unfortunately, MassDOT started tracking these types of bridges only since 2005, so it is not a complete record and unfortunately, and MassDOT has not had the resources to fully populate these fields.

MnDOT: In 1997, the Bridge Office developed a set of Bridge Performance Measures and Targets to use in focusing proposed investments on projects that will improve or attain stated Performance Targets. The 3 bridge performance measures are: Structural Condition Rating, Geometric Rating, and Load Carrying Capacity Rating. An example is shown here:

STRUCTURAL CONDITION



TARGETS	55% GOOD CONDITION					
	2% POOR CONDITION (STRUCTURALLY DEFICIENT)					
MEASURES	CONDITION CODES				APPRAISAL RATINGS	
	DECK	SUPER STRUCTURE	SUB STRUCTURE	CULVERT	STRUCT EVAL	WATERWAY ADEQUACY
GOOD	≥7	≥7	≥7	≥7	≥6	≥6
POOR	≤4	≤4	≤4	≤4	≤2	≤2

HISTORY	2014	2015	2016	2017	2018
GOOD	49.9%	52.6%	53.8%	52.2%	46.6%
SATIS	35.2%	33.5%	33.3%	34.8%	36.2%
FAIR	10.4%	10.9%	9.6%	11.6%	15.3%
POOR	4.5%	3.0%	3.3%	1.4%	1.9%
ANALYSIS					

Figure 106 MnDOT Bridge Performance Measures and Targets

PennDOT: PennDOT tracks through NBIS Inspections.

TDOT: TDOT tracks through inspection reports.

UDOT: UDOT uses Health Index based on element conditions and weights. Long term trends are monitored through health index and NBI history. Element data can also be pulled for each element and be compared for condition versus age of structure.

VDOT: VDOT is currently conducting a performance survey of existing jointless bridges in Virginia. The intent is to identify any problems, revise design criteria if necessary, improve service life of bridges and improve rideability of the roadway.

WSDOT: WSDOT tracks through bridge preservation and maintenance reports.

Iowa DOT and SDDOT had no comment.

4.4 Maintenance

States were asked if they had specific maintenance issues with jointless bridges. The scan team sought information on specific winter maintenance issues and what the state's maintenance program is.

Caltrans: Common maintenance issues at bridges ends are settlement and cracking of approach slabs, erosion in front of the abutments, voids behind the abutment, plugged drains/weep holes, and premature failure of expansion joints, sometimes caused by snowplows. The maintenance program is reactive, based on needs identified in routine inspections. Expansion joints are typically replaced every 30 years, except strip joint seals in marine and freeze-thaw areas that are typically replaced every 20 years, compression joint seals every 15 years, and pourable joint seals every 10 years. Approach slabs are typically replaced after 50 years.

LaDOTD: LaDOTD stated they had no specific jointless bridge maintenance issues and that their scheduled maintenance program is reactive/ as needed.

MaineDOT: In the earlier years when MaineDOT was not using approach slabs everywhere, settlement was a common problem. Scour and erosion in front of integral abutments, exposing the H-piles was also an issue. MaineDOT would minimize the span length by encroaching on the stream at times. MaineDOT utilizes well-draining material behind structural components (abutments, etc.) to help alleviate frost heaving. Bi-annual inspections will flag any issues the structure may be experiencing, otherwise the regional maintenance crews will go out in the spring for routine clean up and general repairs.

Deck over backwalls at fixed bearings have performed very well over a long history.

MassDOT: MassDOT stated they had no specific jointless bridge maintenance issues. With no leaking joints, they do not have icing problems on the bridge seats. Also, MassDOT does not have problems with plows hitting and damaging armored roadway joints. MassDOT does not have a set scheduled maintenance program.

MnDOT: MnDOT has seen some increased approach panel cracking. Occasionally need to slab jack settled approach panels and seeing some damage from snowplows. Premature failure of the compression seal expansion joint material between the approach panel and roadway has also been noted. MnDOT has no specific winter maintenance issues and their scheduled maintenance program consists of crack sealing, and concrete patching every 5 years.

PennDOT: PennDOT's specific winter maintenance issues include settlement at approaches causing issues with snowplows. Scheduled maintenance program consists of yearly cleaning/flushing of deck. On-demand maintenance if needed for repair such as settlement.

SDDOT: The state's goal is to sweep every deck every year. Does not always get done. Joints, if present, are cleaned in conjunction with sweeping.

TDOT: TDOT has freeze/thaw cycles, but the use of free draining granular backfill minimize detrimental effects. Maintenance program is not scheduled, but rather completed as needed.

UDOT: UDOT cites the only maintenance issue specific to jointless bridges is damage to approach pavements due to the thermal expansion and contraction of our structures when an adequate expansion joint is not provided.

UDOT does see long term potential performance issues with bridges where simple span bridge joints were closed at the abutments and bents to create a jointless superstructure. In these bridges the cold joints between the original deck and the link slab start to build up heavy efflorescence. This is seen in **Figure 107**, which shows a joint at time of repair and 2 years after the work was completed. You can clearly see the cold joint where the new concrete was placed against the existing concrete and the efflorescence that is starting to come through at that joint.

Specific to winter, UDOT checks to make sure the drains are clean, and joints are functioning. But for the travelling public UDOT focus on snow removal and ice prevention.

Figure 107 UDOT Maintenance

WSDOT: WSDOT stated they had no specific jointless bridge maintenance issues and that their scheduled maintenance program is every two years. Specific winter issues concern snowplows.

Iowa DOT and VDOT had no comment.

CHAPTER 5

Overarching Issues

This chapter presents items of interest that came out of the scan including state sponsored research, cost equivalency analysis and sustainability practices.

5.1 State Sponsored Research

States such as Louisiana, Massachusetts, Caltrans and WSDOT have conducted or currently have research projects related to the bump at the end of the bridge with topics such as monitoring voids behind the abutment, washouts under approach slabs. Iowa DOT is conducting long term monitoring on integral bridges and UDOT performed a behavior and analysis of integral abutment bridges. The following two sections present state sponsored research related to integral and/or semi-integral abutment bridges and approach slabs.

5.1.1 Integral and/or Semi-integral Abutments

This section presents research pertaining to integral and/or semi-integral abutments that the states have sponsored.

Caltrans: Since Caltrans does not use integral abutments, they have no current research for integral abutments.

Iowa DOT: Iowa DOT has a highly active program for transportation research. The inception of the Iowa Highway Research Board In 1950 has helped the Iowa DOT remain on the leading edge of design technologies. From their research website, their mission is a quality research program that delivers targeted solutions for Iowa's transportation future. Much of their bridge related research, and hence integral abutment research, is done at Iowa State University.

One study Iowa State started in 2008 and finished in 2014 was called *Field Monitoring of Curved Girder Bridges with Integral Abutments* [20]. This project found thermal strains in integral abutment and semi-integral abutment bridges were not noticeably different. The choice between IAB and semi-integral abutment bridges (SIAB) should be based on life – cycle costs (e.g., construction and maintenance). Additionally, for the one curved integral abutment bridge studied at length, the stresses in the girders significantly vary with changes in skew and curvature. With a 10º skew and 0.06 radians arc span length to radius ratio, the curved and skew integral abutment bridges can be designed as a straight bridge if an error in estimation of the stresses of 10% is acceptable.

Another project, conducted between 2006-2010, was done on the first integral abutment bridge in Iowa. *Testing and Long-Term Monitoring of 9th Street Bridge Over I-235 in Des Moines: Integral Abutments Supported on Steel Pile/Concrete Drilled Shaft in Glacial Clay* was conducted to validate the design and behavior assumptions on the behavior of the integral abutment. There is no formal report available but contact information is available at the link [21]

Two in progress research projects of interest to the scan team are *Limitations for Semi-Integral Abutment Bridges* [22] and *Increase Service Life at Bridge Ends through Improved Abutment and Approach Slab Details and Water Management Practices* [23].

According to the project website, this project will pursue three main objectives: literature review, inspection reports and a field monitoring program for semi-integral bridges. Project end date is October 2022.

The second in progress research will consist of a comprehensive literature review of bridge ends in jointless bridges. The document will include recommended design guidelines and identify options using results from a year-long monitoring of bridge end performance. Project end date is September 2021.

LaDOTD: Being new to integral bridges, LaDOTD employed a monitoring program for their first two integral abutment bridges that were constructed on soft and stiff soil conditions. Louisiana Transportation Research Center (LTRC) Final Report 517 – "*Integral Abutment Bridge for Louisiana's Soft and Stiff Soils*" [24] presents the field instrumentation plans and monitoring results for two bridges: Caminada Bay Bridge, constructed on mainly fine sand and silty sand deposit, and Bodcau Bayou Bridge, on a relatively lean and fat clay with low plasticity. Analysis included finite element modeling and 3D numerical models to consider the pile-soil and abutment-backfill interaction behaviors. A parametric study examined effects on the bridge thermal performances under the other complicated structural and geotechnical conditions.

MaineDOT: MaineDOT did a short pile integral abutment research project that resulted in a design methodology investigating shear pile resistance at the tip. The Department is currently sponsoring a research project at the Transportation Infrastructure Durability Center (TDIC) at the University of Maine investigating micropile-supported integral abutment bridges [25]. Because Maine bridge sites commonly have shallow bedrock, piles are typically used. The scope of the project is to develop design methodology and engineering recommendations for micropile-supported integral abutment bridges. Project end date is May 2022.

MassDOT: MassDOT has directly sponsored the following research at University of Massachusetts (UMass) Transportation Center: Passive Earth Pressures in Integral Abutment Bridges, Report No. UMTC-97-16 [25] and *Streamlined Analysis and Design of Integral Abutment Bridges*, Report No. UMTC-97-13, [27]

2016 UMass Amherst Dissertation, Detailed Study of Integral Abutment Bridges and Performance of Bridge Joints in Traditional Bridges [28], compares five years of data from three bridges with predictions from a three dimensional finite element model.

MnDOT: MnDOT sponsored *Behavior of Concrete Integral Abutment Bridges*, research conducted at the University of Minnesota in 2004. [29]. This report presents a field investigation of a single bridge for eight years (1996-2004) focusing on movement from earth pressure, thermal gradients and weather.

PennDOT: Research performed by Pennsylvania State University makes up the immense report, *Monitoring of Integral Abutment Bridges and Design Criteria Development*, [30]. This report uses field measurements to develop and calibrate 2D and 3D finite element analysis which are used to conduct numerical parametric studies. The results are integral abutment design aids, criteria and guidelines, including an integral abutment design spreadsheet.

SDDOT: Solutions to the "bump at the end of the road" are the subject of the report Use of Fabric Reinforced Soil Wall for Integral Abutment Bridge End Treatment [31]. From the abstract:

> Previous research has shown that the bump was caused by the development of voids under the bridge approach slabs in integral abutment bridges. Void development was shown to be a direct consequence of the thermal-induced movement of the bridge beam/abutment system. To accommodate this mechanism, the state of South Dakota implemented a new design using a geotextile reinforced soil wall in the abutment backfill to create a gap between the backfill soil and bridge abutment. The objective of this research was to determine if constructing an approach fill to an integral abutment structure with a void between the abutment wall and the fill would alleviate development of voids under the approach slabs to the end of the bridge. Additionally, the research was to investigate alternative design methodologies. The work included the monitoring of three bridges constructed with a gap installed between the abutment and the backfill to document the performance of the newly implemented design. A review of designs used by other states was conducted and alternative backfill materials were studied for use in the model test. Additionally, the feasibility of using an alternative backfill was investigated using the SDDOT model integral abutment system at the Brookings Department of Transportation Maintenance Yard.

TDOT: In the mid 1990's Ed Wasserman wrote Chapter 5 of *Highway Structures Design Handbook*, Vol 3. TDOT conducted research on pile performance under thermal loading cycles. They also did some research for AISC and NSBA to verify the performance of the piles at the abutment, examining how the piles perform and where they become fixed in the soil. Based on the results of the research, TDOT assumes 2" total pile movement per abutment (1" in each direction).

The field study showed that pile performance was much better that what TDOT was assuming. That validated the assumptions made in the pile capacity were valid.

UDOT: In the report UT-13.12: *Behavior and Analysis of an Integral Abutment Bridge* [32], Utah State University analyzed the behavior of an existing integral abutment bridge over the course of a year and calibrate a finite element model to better understand bridge behavior.

VDOT: As stated in Section 4.3.2, VDOT is currently conducting a performance survey of existing jointless bridges in Virginia. The intent is to identify any problems, revise design criteria if necessary, improve service life of bridges and improve rideability of the roadway.

WSDOT: WSDOT does not have sponsored research in this area.

5.1.2 Approach Slabs

This section presents research pertaining to approach slabs that the states have sponsored.

Caltrans: Research by UC Davis – *Evaluation of Structural Performance of Bridge Approach*

Slabs (2010) [33] found that the use of steel and polyvinyl alcohol fibers, at dosage of 0.5% and 0.2% by volume, in the fiber-reinforced concrete slab, respectively, showed better crack control. Compared to the conventional steel reinforcement slab, fiber-reinforced concrete slab shows smaller deflection and end rotation, but the difference is not significant.

Iowa DOT: As with their integral abutment research, a large portion of Iowa DOT approach slab research is done at Iowa State University.

Identification of the Best Practices for Design, Construction, and Repair of Bridge Approaches [37] was undertaken to investigate bridge approach problems and develop new concepts for design, construction, and maintenance that will reduce this costly problem. The report suggested a few pilot test topics: porous backfill behind the abutment and/or geocomposite drainage systems, connect the approach slab to the bridge abutment, change the expansion joint at the bridge to a construction joint of 2 inch, use a more effective joint sealing system at the CF joint, change the abutment wall rebar from #5 to #7 for non-integral abutments. For bridges with soft foundation or embankment soils, implement practices of better compaction, preloading, ground improvement, soil removal and replacement, or soil reinforcement that reduce time-dependent post construction settlements.

Development of an Improved integral Abutment-to-Approach Slab Connection (2005) [36] resulted in technical transfer summaries in 2008 "Integral Bridge Abutment-to-Approach Slab Connection". The authors recommend that additional bridges are constructed using the approach slabs and connections studied in this research project and that these new bridges be similarly monitored.

Notably, Iowa State has instrumented and monitored precast approach slabs, presented in *Instrumentation and Monitoring of Precast Bridge Approach Tied to an Integral Abutment in Bremer County* [34]. This study sought to supplement a previous project by instrumenting, monitoring, and analyzing the behavior of an approach slab tied to an integral abutment bridge. The primary objective of this investigation was to evaluate the performance of the approach slab.

The research project *Instrumentation and Monitoring of Precast, Post-tensioned Bridge Approach Pavement* [35]) produced the report *Integral Bridge Abutment -to-Approach Slab Connection* (2008). Two different approach slabs, one being precast concrete and the other being cast-in-place concrete, were integrally connected to side-by-side bridges and investigated. The primary objective of this investigation was to evaluate the approach slab performance and the impacts the approach slabs have on the bridge.

LaDOTD: LTRC Project No. [05-1GT], *Field Demonstration of New Bridge Approach Slab Designs and Performance* [37] was part of a major effort by LaDOTD to minimize the bridge end bump problem associated with differential settlement. This research examined effects of increasing the slab flexural rigidity (EI) and using reinforced soil foundation (RSF) in the soil supporting the slab. Bayou Courtableau Bridge was selected as a demonstration project. Schematic detail is shown in **Figure 108**.

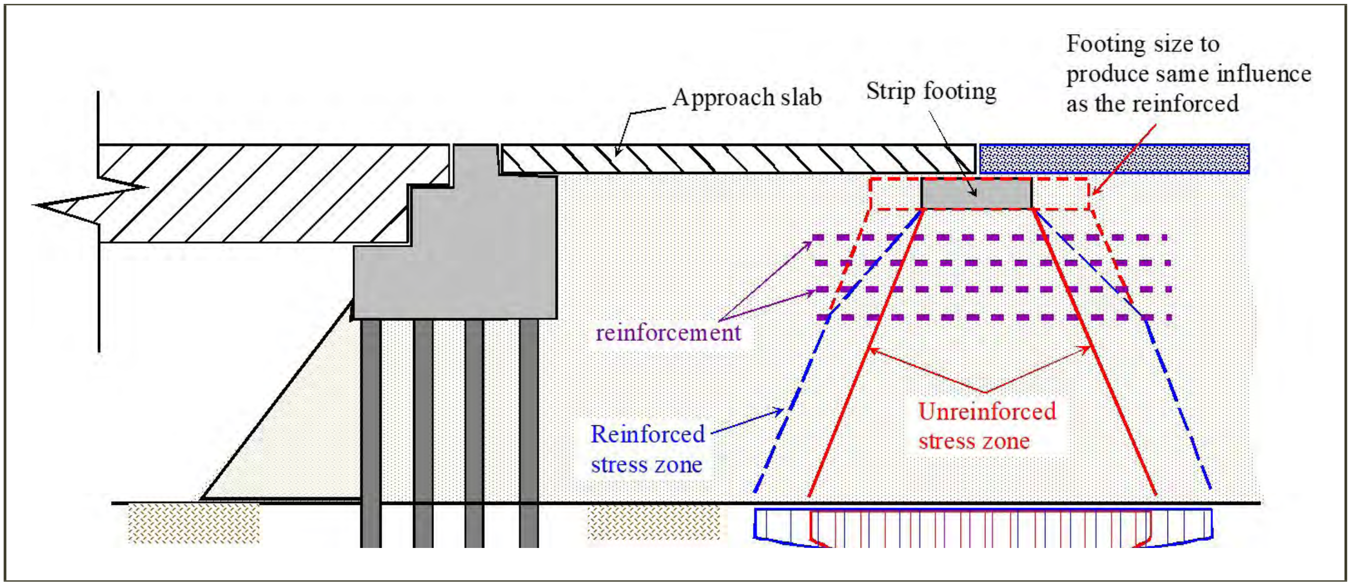


Figure 108 LaDOTD Bayou Courtableau Bridge Demonstration Project

MaineDOT: MaineDOT did not have any to report.

MassDOT: MassDOT has no approach slab research to report as they have been using buried approach slabs in their current form since the mid-1940s. Recently, as part of work on the next edition of their Bridge Manual, MassDOT looked at the effect of approach slabs on reducing live load surcharges on abutments and found that, based on the soil stress effects, approach slabs do reduce the stress felt by the abutment and lower it so that it contributes little to the soil load on the abutment. This was not a published study.

MnDOT: *Synthesis of Bridge Approach Panels Best Practices* [39] recommended use strip seals at joint. However, this cannot be implemented without barrier extending to end of approach panel, which is not cost effective.

SDDOT: In 1990 SDDOT supported research in Void Development under Bridge Approaches [40]. The abstract describes the research involving an extensive survey of some 140 bridges across South Dakota to determine and document the prevalence of void development beneath slabs; a review of previous work related to bridge approach settlement; a survey of state transportation departments concerning approach system and bridge abutment problems and design methodology; and development of a field scale model of an integral abutment bridge/approach system to isolate and determine the mechanisms controlling backfill subsidence.

The 2019 research *Bridge Approach Design and Performance* is still underway.

TDOT: TDOT currently has two studies underway to look at root cause of slab settlement and recommendations for reinforced soil options under approach slabs.

UDOT: See paper mentioned in Section 5.1.1.

WSDOT: In 1991, WSDOT sponsored *Bridge Approach Slab Effectiveness* [41]. As titled, this study assessed the effectiveness of bridge approach slabs, identify appropriate site conditions for their use and develop recommendations. The study concluded that the decision to use approach slabs should be made on a site-specific basis.

PennDOT and VDOT had no comment.

5.2 Cost Equivalency Analysis

States were asked if they perform cost equivalency analysis on jointless bridges.

Caltrans: *Memo to Designers 5-1: Abutments* states that the main advantage of integral abutments is the lower initial construction cost. No long-term maintenance cost data available.

LaDOTD: No cost equivalency analysis of lifecycle costs has been conducted between jointed and jointless bridges.

MaineDOT: With the type of environment in Maine, it is always qualitative. MaineDOT prefers jointless bridges in all cases.

MassDOT: MassDOT has never undertaken such a study since jointless bridges have been a standard type of bridge for us for decades. The state does know that jointless bridges do not have the same end of beam and substructure deterioration that bridges with joints have. The state is continually facing situations requiring posting to restrict use or close jointed bridges to perform emergency repairs, while jointless bridges do not have these associated problems.

MnDOT: MnDOT reported 10-15% total bridge cost reduction when constructing integral abutment bridges compared to similar sized parapet (seat) type abutments. No long-term maintenance cost data is available.

PennDOT: PennDOT has conducted on a case by case basis.

SDDOT: SDDOT does not factor in cost when deciding to go jointless as that is their preferred method.

TDOT: TDOT feels that joint maintenance and damage to girders greatly exceeds the cost of jointless bridge, which is minimal.

UDOT: UDOT has no records of a cost equivalency analysis, but the programmatic change in the early 1970’s is evidence that value was found in making the transition to jointless bridges.

WSDOT: WSDOT had not done a cost equivalency analysis.

Iowa DOT and VDOT had no comment.

5.3 Sustainability

5.3.1 New Idea Implementation

This section presents how states implement new ideas.

Caltrans: Typically, a new idea starts with a Champion, who rallies support for research and/or pilot projects. Most of the time, a technical team of Caltrans engineers monitors the research progress. If the research or pilot projects show benefits to the state, policy, guidance, standard details and specifications may be developed. Standardizing a new idea is a long formal process that goes through the Bridges and Structures Technical Organization.

For new products and technology, vendors may go through the New Products Evaluation program. New products are evaluated by the Technical Specialists/Committees and may be added to the Approved Materials List.

Iowa DOT: From Chapter 2 of their Bridge Design Manual:

"The Bridges and Structures Bureau (BSB) follows established Iowa Department of Transportation (Iowa DOT) guidelines, in providing, promoting and using sustainable practices. The Iowa DOT has always been at the forefront of sustainable design and maintenance practices. Sustainability considers the long view of projects, considering costs and benefits over lifetimes rather than concentrating on a one or two year cost life cycle. Incorporating sustainability into decision-making can have positive effects for stakeholder relations, for the bottom line, and for the natural resources of the state."

From Section 2.1.2 Sustainability Goals: "The goals of providing sustainable features in the design and construction of bridge projects are to:

- Minimize impacts to environmental resources
- Minimize consumption of material resources
- Minimize energy consumption
- Preserve or enhance the historic, scenic and aesthetic context of a bridge project
- Integrate bridge projects into the community in a way that helps to preserve and enhance community life
- Encourage community involvement in the transportation planning process
- Encourage integration of non-motorized means of transportation into a highway project

Sustainable bridge design should strive to find a balance between what is important:

- to the transportation function of the facility
- to the community
- to the natural environment, and is economically sound

While encouraging the use of new and innovative approaches in achieving these goals."

LaDOTD: LaDOTD typically decides to do a test project, and/or a research project or series of research projects. Eventually the new detail may be adopted into policy or standardized.

MaineDOT: MaineDOT has embraced trying new technologies for years. New technologies are received and vetted through the Bridge Management Team. The decision to use the technology must be justified, and approved by this team, before being implemented in the design process of the project. This panel is typically comprised of the Chief Engineer, Bridge Program Manager, Director of Bridge Maintenance and Bureau Director.

MassDOT: MassDOT has a Bridge Manual Committee that works on developing details and design guidelines. The consultants who are on this committee work in other states and are on national committees, so they bring a lot of experience and new ides to the table. The state also looks to improve what has not proven to be as good as originally thought or details and materials that have been considered good ideas but have been found with shortcomings once put into practice. All of this goes into updating their Bridge Manual.

MnDOT: MnDOT has bridge crews in each district that provide feedback to the Bridge Office. The office also holds biennial meetings with Resident Construction Engineers to get their feedback. The office has an internal committee that meets every 2 months to review proposed changes to standards and policies and to suggest updates as needed.

PennDOT: PennDOT does so currently, through the State Transportation Innovation Council (STIC).

SDDOT: SDDOT indicated freedom to experiment with design ideas.

TDOT: TDOT usually does a trial of new ideas when deemed beneficial / economical. Will also look at research options to evaluate proposed new ideas.

UDOT: In general, new ideas require a champion within the UDOT Structures Division. That champion needs to satisfy questions and concerns from the Chief Structural Engineer, Project Development Director and others in the Structures, Materials, and other relevant divisions. It is up to the discretion of the Chief Structural Engineer and the Project Development Director to work with something different from Standard. Once everyone is happy with the idea the construction package will need to follow all the usual rules and develop special provisions and plans that need to show the intent appropriately. If that new idea works well, then can proceed to standardization.

Standardizing specifications requires a similar but much more formal process including a review of the changes by all UDOT Divisions in the Standards Committee and an external review by the contracting and consulting communities. Assuming everything goes smoothly those new ideas become standards.

VDOT: VDOT has research advisory committees, consisting of practical researchers and subject matter experts, who meet semi-annually to discuss and initiate implementation-oriented research relating to bridges, concrete and steel. The research is conducted through the Virginia Transportation Research Council, which is associated with the University of Virginia. After initial study, promising ideas are implemented on a trial basis using implementation funds.

WSDOT: Through FHWA Innovative Bridge Research and Construction, Innovative Bridge Research and Deployment, Highways for Life and State innovation implementation program.

5.3.2 Maintaining Technical Competency

This section presents how states maintain technical competency to ensure success of their jointless bridges.

Caltrans: At Caltrans, integral abutments have been used for a long time, so the continued policies, design guidance, details, specifications, and records have helped maintain technical knowledge. Caltrans also maintains technical competencies through training, succession planning, and the Bridges and Structures Technical Organization, which consists of technical committees, technical teams and Technical Specialists.

MaineDOT: At MaineDOT, integral abutments have been used for a significant amount of time, so the continued design and construction of integral systems has helped to refine the process. As built design computations and details are archived and referenced as needed.

MassDOT: At MassDOT jointless bridges and now integral abutment bridges have been used for decades so that they are a part of their standards. The technology that has been used to develop these standards is archived in the pre-designed details and guidelines of MassDOT Bridge Manual.

MnDOT: MnDOT maintains technical competency though brown bag seminars – including research findings and design/construction details from other states. MnDOT also hosts a Bridge Designers Workshop with its design consultants and in-house design staff every 5 years to discuss new standards, guidance, and policies.

PennDOT: PennDOT offers training about every 2 years on the design of integral abutment bridges.

TDOT: TDOT does not consider this to be a problem.

UDOT: Most UDOT design work is handled by the consulting community. The UDOT Structures Design and Detailing Manual provides guidance and establishes the baseline of what the state is looking for from designers. Their SDDM has Sample Drawings that provide examples of previous work, Structures Design Drawings that provide guidance, and Working Standard Drawings to provide templates for the actual sheets. Not all of that is jointless bridge specific, but because jointless has been standard practice in Utah for over 40 years it is all compatible with that design philosophy. As the state thinks of improvements, they revise the details. They do not have any established UDOT training protocols for design and construction of jointless bridges, but do hold regular consultant and contractor workshops

The Structures Division tries to hold multiple workshops each year to keep communication open, and as a DOT they host an Annual 3 day conference to talk about any number of technical and administrative topics.

VDOT: VDOT maintains technical competency through the publication and regular update of standards and specifications. VDOT has a team of engineers in its Central Office whose role is to constantly improve and refine its office practices. These publications are used by in-house engineers, consultants, contractors, field personnel, and inspectors.

WSDOT: By providing training and just in time project basis training.

Iowa DOT, LaDOTD and SDDOT had no additional comment.

CHAPTER 6

Notable Practices And Scan Implementation Plan

Following the presentations, the scan team concluded that due to the variety of geological, geotechnical, seismic and climate conditions each state is faced with, there is no "one size fits all" solution to resolving the "bump at the end of the bridge." There were, however, many notable practices of interest. The first section of this chapter summarizes the most notable practices, following the report outline. The second section presents the scan team's plan to disseminate the information gained from the same.

6.1 Notable Practices of Interest

Practices that were notable to the scan team are presented in this section, roughly following the same order as the report.

Design Manual Guidance – Abutment Type Selection Manuals providing span and skew limits for integral bridge selections (Section 2.3.1), as well as limits on abutment wall heights and approach slab length and thickness (Section 2.3.2). VDOT design manual includes a clearly defined abutment type selection flow chart (**Figure 18**). MnDOT developed an easy to read abutment type selection chart based on span and skew conditions (**Figure 20**).

Design Manual Guidance – Design Amendments and Calculations LaDOTD specifies the design of the approach slab as a simply supported slab and utilizes a higher load than HS-20. Iowa DOT design manual includes an integral abutment design example and LaDOTD design manual provides approach slab finite element analysis calculation. MnDOT design manual has sample calculations for parapet design. PennDOT has developed an integral abutment design sheet. VDOT manual includes comprehensive sample calculations for design of both a full integral and a semi-integral abutment. In this section, they also provide a checklist for sample plans, including minimum/maximum component widths, heights, rebar spacings.

Abutments – Types All host states prioritize integral abutments for jointless bridges, except for Caltrans (seat), LaDOTD (seat) and WSDOT (semi-integral). Caltrans cites seismic concerns and LaDOTD cites poor soils for not using integral abutments. LaDOTD is venturing into incorporating semi-integral abutments in their inventory with a recently completed pilot project. WSDOT's semi-integral abutments are designed to allow the backwall to fuse in a seismic event (**Figure 26**) with no damage to lower abutment, which makes for easy repair (bearing replacement) following a seismic event thus shortening structure down time.

Abutments – Front Treatment Slopes range from 1.5:1 to 2:1, with slope paving required beyond these limits. Berm widths range from 2 feet to 5 feet. Minimum vertical clearance of superstructure above the berm is 2 feet, consistently, to allow for inspection access. Iowa DOT places soil with no slope protection in front of abutment and uses engineering fabric beneath riprap at wingwalls. TDOT and MaineDOT wingwalls are not supported on piles, rather they are designed as walls cantilevered from the abutment.

Piles – Fixity and Orientation With the exception of Iowa DOT and TDOT, states orient pile for weak axis bending. For skews 30 degrees or less, Iowa DOT aligns pile webs with centerline of abutment bearings.

Piles – Corrosion MaineDOT encases top 3 feet with concrete jacket and embeds piles additional 2 feet into abutment. PennDOT hot dip galvanizes steel piles, a practice MnDOT is considering.

Approach Slabs Due to placement of approach slab details in the contract plans, the approach slab design is the responsibility of the road designer in some states and the bridge office in other states. Regardless of who designs it, the many parameters presented gave a resounding impression that attention should be given to how the approach slab is designed and supported. MaineDOT (2+ feet below), MassDOT (14" below) and VDOT (on their stationary/seat abutments only) all use buried approach slabs, something many host states had not heard of. The states that bury approach slabs do so because they feel it has solved their "bump at the end of the bridge" issue. Typically, one end of the buried slab sits on the abutment, so that it does not settle and therefore settlement at the other end is gradually accommodated over the length of the slab.

Caltrans uses polyester concrete overlays on approach slabs, and profilographs before and after overlay placement as well as having smoothing specifications for approach slabs. Profilographs are used to measure and quantify the bump at the end of the road and could provide an equalizing level for discussion of parameter effectiveness (i.e., quantitative measures of performance for comparison rather than anecdotal qualitative assessments).

LaDOTD treats approach slabs as a simply supported "span", with the assumption that over time, the bottom of the slab will lose contact with the underlying soil and behave more as a span, rather than just a section of pavement that is attached to the bridge. This treatment results in an 18" thick approach slab that is 40' long.

Approach Slabs – Sleeper Slabs Caltrans is phasing out sleeper slabs. Iowa DOT only uses sleeper slabs on slab bridges. LaDOTD, MaineDOT, MnDOT (called sills), PennDOT, SDDOT, TDOT, UDOT, VDOT use sleeper slabs. MassDOT and WSDOT do not use sleeper slabs.

Approach Slabs – Subsurface Separation Iowa DOT, MassDOT, TDOT (although currently researching it), UDOT and WSDOT do not require embankment separation. The remaining states provide a woven tape fabric (Caltrans) or some form/thickness/layers of polyethylene sheeting.

Approach Slabs – Abutment Connection Caltrans, LaDOTD, MaineDOT, MnDOT, PennDOT, SDDOT, TDOT, UDOT, VDOT and WSDOT connect the approach slab to the abutment. At Iowa DOT and MassDOT, the abutment slides under the approach slab.

Barriers LaDOTD, MaineDOT, MassDOT, PennDOT, SDDOT and TDOT place barrier on wingwall. Caltrans, MnDOT, UDOT and WSDOT place the barrier on the approach slabs. MnDOT believes that placing the barrier on the slab has significantly reduced the issues related to drainage and erosion at bridge ends.

Embankment – Inclusions Behind Backwall Caltrans (designs to span backwall voids), Iowa DOT, MaineDOT (typically), MassDOT, MnDOT (although considering incorporating a geo-composite sheet drain), TDOT (but currently researching), UDOT and WSDOT do not use inclusions. LaDOTD (on their pilot project), PennDOT and VDOT use a form of expanded polystyrene fill. SDDOT has a vertical composite drain and granular backfill region. UDOT also has a granular backfill behind the backwall.

Embankment – Compaction Requirements Caltrans specifies 95 percent relative compaction full width and depth of embankment within 150 feet of each bridge abutment.

Iowa DOT specifies a flooded backfill procedure to achieve compaction requirements was most notable. This method has proven to work well, and they believe has minimized their settlement issues.

SDDOT extends the compacted fill the full depth for a minimum of 10 feet beyond the end of the sleeper slab.

Embankment – Structural Backfill vs Embankment Caltrans specifies structural backfill (sand equivalent) compacted to relative compaction of 95 percent and prohibits use of slurry cement backfill. LaDOTD, SDDOT, TDOT, UDOT all specify granular backfill material.

Drainage Since MnDOT and UDOT place no drains on the bridge deck, all drainage occurs behind the abutment. VDOT's Virginia Abutment, while costly, is the most structurally robust method of safely moving water away from easily damaged structural components.

Repair and Rehabilitation Many states use the opportunity during rehabilitation to move existing joints off bridges. Mid-span this is done with ECC link slabs (Caltrans, UDOT, VDOT). At abutments, this is done with slab over backwall details (MaineDOT, PennDOT). MassDOT and SDDOT will not modify during rehabilitation, only if road can be closed.

Research Iowa DOT and LaDOTD have both sponsored and conducted significant research into integral abutments and approach slabs.

6.2 Implementation Plan

To share the scan findings, the team compiled a list of state and national conferences which to present the scan findings. Presentations are planned at state conferences such as Pacific Northwest Bridge Maintenance Conference, Tennessee Engineering Conference, Michigan Annual Bridge Conference, Maine Transportation Conference and Louisiana Transportation Conference. Presentations are also planned at national conferences such as Transportation Research Board (TRB) Annual Conference, AASHTO Bridge Preservation Committee and National Association County Engineers (NACE). Additionally, the team will investigate avenues for presenting workshops and webinars and submitting articles to journals.

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Appendix A
Amplifying Questions

This appendix presents the amplifying questions as they were sent to host agencies prior to the scan. The responses were assembled in a spreadsheet and incorporated in the body of this report along with information from host presentations and discussions during the scan.

TOPIC 1: HISTORICAL USE, GOALS AND CURRENT CRITERIA USED BY OWNERS AND STATES TO DICTATE USE

1.1 Historical Use and Performance

1.1.1 What year was your first integral or semi- integral abutment?

1.1.2 What problems have your state experienced with regards to jointless bridges?

1.1.3 What details do you no longer use? Why?

1.2 Goals

1.2.1 Does your state encourage use of jointless bridges?

1.3 Current Criteria

1.3.1 Geometric Parameters

1.3.1.1 Do you impose limits on span lengths or total bridge lengths for integral abutments?

1.3.1.2 Do you impose limits on substructure skew or superstructure curvature?

1.3.1.3 Do you impose abutment wall height limits?

1.3.1.4 Do you impose approach slab length limits?

1.3.1.4.1 Does this vary with skew and bridge width?

1.3.1.5 Are there other geometric characteristics that dictate the use of unique components or details?

1.3.2 Materials

1.3.2.1 Superstructures

1.3.2.1.1 What approximate distribution (percentage) are your superstructures:

1.3.2.1.1.1 Steel

1.3.2.1.1.2 Cast-in-Place

1.3.2.1.1.3 Precast

1.3.2.2 Abutment to Approach Slab Connection

1.3.2.2.1 Do you use epoxy coated rebar or other corrosion resistant materials?

1.3.2.3 Backfill

1.3.2.3.1 Does your state make use of a resilient/compressible inclusion behind the abutment backwall in combination with other geosynthetics to control soil-abutment interaction? If so, what kind of compressible inclusion is used and to what extent is this technology used and how is it performing?

1.3.2.3.2 Do you specify particular subgrade layers or other soil improvement techniques?

1.3.2.4 Approach Slabs

1.3.2.4.1 Do you use pre-cast approach slabs?

1.3.2.4.2 Do you overlay approach slabs?

1.3.2.4.3 Do you use an asphaltic plug joint?

1.4 Current Inventory

1.4.1 What's your longest steel jointless bridge?

1.4.2 What's your longest concrete jointless bridge?

1.5 Research

1.5.1 What research has your state performed (please provide links and abstracts) for:

1.5.1.1 Integral and/or semi-integral Abutments?

1.5.1.2 Approach Slabs?

TOPIC 2: DESIGN DETAILS, STANDARDS AND "BEST PRACTICES" FOR EXISTING AND NEW BRIDGE ENDS AND APPROACH PAVEMENTS

1.1 Design Details

1.1.1 What is your detail at the bridge deck / backwall interface?

1.1.2 What are your backwall details?

1.1.2.1 What superstructure movements are accounted for on your dependent backwalls? (Beam rotation? Thermal?)

1.1.3 What is your detail at the barrier wall / backwall / return wall interface?

1.1.3.1 Is barrier on top of wingwall or approach slab?

1.1.3.2 Do you consider impact load?

1.1.4 If your deck is continuous over the backwall:

1.1.4.1 How do you accommodate slab movement over the top of the backwall?

1.1.4.2 Does your design account for the negative moment?

1.1.4.3 Does the deck support on the top of the backwall account for superstructure rotation?

1.1.4.4 Has your continuous deck been designed for the tension forces due to superstructure thermal contraction overcoming the dead weight of the continuous deck and the friction forces between the slab bottom and backfill material?

1.1.5 Do you have approach slab design assumptions (i.e., approach slab thickness, boundary conditions)?

1.1.5.1 Do you isolate approach slab from backfill material?

1.1.5.2 What is your abutment to approach slab interface detail?

1.1.5.3 What special considerations do you have for your sleeper slab? (i.e., if your sleeper slab settles, your bridge approach may not.)

1.1.5.4 What is your expansion joint detail on your approach slab to roadway pavement interface detail?

1.1.5.5 What is your expansion joint detail at the joint / shoulder interface?

1.1.6 What is your end of bridge drainage system?

1.1.7 Do details change based on type of wearing surface (i.e., for concrete vs bituminous)?

1.2 Standards

1.2.1 Does your state design manual provide jointless bridge design guidance?

1.2.2 What calculations are provided?

1.2.3 Are there material specifications?

1.2.4 Are backfill compaction requirements specified?

TOPIC 3: CONSTRUCTION, MAINTENANCE, REPAIR AND INSPECTION

3.1 Construction

3.1.1 Have you evaluated cost equivalency (i.e., joint maintenance vs jointless bridge)

3.1.1.1 If so, what is the result?

3.1.2 Do you specify construction sequence?

3.2 Maintenance

3.2.1 Do you have maintenance issues specific to jointless bridges?

3.2.1.1 Do you have specific winter maintenance issues (i.e. freeze/thaw)? If so, what considerations have you made?

3.2.2 What is your scheduled maintenance program?

3.3 Repair

3.3.1 What rehabilitation solutions are used to repair the deterioration and distress associated with the details at the ends of bridges that are not functioning as anticipated?

3.3.2 Do you modify existing bridges during rehabilitation projects to move existing joints off the bridge?

3.3.2.1 If yes, can you provide details?

3.4 Inspection

3.4.1 What is your scheduled inspection program?

3.4.2 Is there a "special elements of integral bridges" inspection protocol?

TOPIC 4: QA/QC

4.1 Do you have a checklist for jointless bridge inspections?

4.2 Do you have essential construction considerations to ensure expected performance?

4.3 Have you received comments, field or otherwise, on constructability concerns?

TOPIC 5: SUSTAINABILITY

5.1 How does your state implement new ideas?

5.2 How does your state maintain technical competencies regarding jointless bridges to ensure success?

TOPIC 6: SYSTEM PERFORMANCE

6.1 What do you use to identify need for jointless bridges?

6.2 How do you track system performance?

Appendix B
Host Agency Contacts

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Appendix C
Scan Team Contact Information

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Appendix D
Scan Team Biographies

Jason DeRuyver *(Chair)* is currently an Engineer Manager for the Priority Preservation Support Unit in the Michigan Department of Transportation Bureau of Bridge and Structures, Structure Preservation. His responsibilities include supporting bridge inspectors, bridge engineers, bridge designers and bridge maintenance workers in selecting timely bridge preservation activities. His unit designs high priority and emergency maintenance repairs, as well as testing and approving new structure preservation maintenance techniques, materials and technologies. He served as the chair of the AASHTO TSP2 Midwest Bridge Preservation Partnership (MWBPP) and is currently the MWBPP representative on the FHWA Bridge Preservation Expert Task Group. He received a Bachelor of Science in Civil Engineering from Michigan Technological University and a Master of Science in Structural Engineering from the University of Michigan. He is a licensed Professional Engineer in Michigan.

Bijan Khaleghi is the State Bridge Design Engineer with the Washington State Department of Transportation (WSDOT) Bridge and Structures Office, responsible for administering the statewide structural design program for bridge and tunnel projects from preliminary design through the final PS&E preparation and QC/QA implementation. Establish design policies directing WSDOT designers, design consultants, design-builders and other bridge divisions in Washington State. Manage research projects for bridges and tunnels incorporating seismic requirements, accelerated bridge construction, innovative materials and designs. He received his Master and Doctor of Engineering degrees from the National Institute of Applied Sciences, Lyon, France. He is a member of many committees and task forces, including the American Association of State Highway and Transportation Officials (AASHTO) Technical Committees on Moveable Bridges T-8, Concrete Bridges T-10, Tunnels T-20, TRB, ASBI and Precast Concrete Institute (PCI) Bridge Technical Committees. He is a registered Civil and Structural Engineer in State of Washington.

Adam Lancaster is with Louisiana Department of Transportation & Development HQ Section 25 - Bridge Design, 606D. He is the son of a career military officer, and after moving around the country while growing up, he settled in southern Louisiana to earn his engineering degree from Louisiana State University (LSU). After helping build the hurricane wind tunnel at LSU, Adam spent a year designing residential and commercial foundations for a small engineering firm, and then spent several years designing structures in the petro-chemical industry. Most recently, Adam has worked at the Louisiana Dept. of Transportation and Development for over a decade, and is currently responsible for organizing, updating and maintaining the DOTD's catalog of Standard Plans. He is a licensed Professional Engineer in Louisiana.

Devan Eaton attended the University of Maine, graduating in 2010 with a Bachelor of Science degree in Civil Engineering. He began his career at MaineDOT in 2010 as an Assistant Engineer in the Bridge Program working on structural bridge design. He became a licensed PE in 2014 and was promoted to Civil Engineer II. Devan has served as the Pavement Engineer for the Bridge program since 2011 performing all the roadway approach designs and reviews within the Bridge Program. He has been in his current role of a Project Manager for the Bridge Program since 2018.

Ted Kniazewycz is the Director of the Structures Division at the Tennessee Department of Transportation. Ted is a graduate of Tennessee Tech and began his engineering career with the Tennessee Department of Transportation in the Structures Division. He also served as Metro Nashville's Bridge Engineer and as the transportation structural lead at Gresham Smith prior to rejoining TDOT in 2017. Ted has been active in ASCE since his student chapter days at Tennessee Tech He has served as Nashville Branch President and continues to serve the Tennessee Section as Treasurer and ASCE at the societal level as Region 4 Past-Governor after 11 years of service.

Romeo Garcia is a bridge construction engineer with the construction management team in FHWA's Office of Preconstruction, Construction, and Pavements in Washington DC. In this position, he leads the advancement of highway bridge construction activities with transportation agencies and private industry. This includes identifying and deploying leading practices and technologies associated with highway bridge construction (i.e. contracting mechanisms, scheduling, equipment, labor, materials, and quality). He has worked with FHWA since 1975 in various States across the country providing oversight of highway and bridge construction projects with a major emphasis on the quality of the completed product. Garcia holds a bachelor's degree in civil engineering from the University of Minnesota and a master's degree in Public Administration from Rutgers University.

Jill Walsh (Subject Matter Expert) is an Assistant Professor of Structural Engineering in the Civil Engineering Department at Saint Martin's University in Lacey, Washington. She holds a bachelor's degree in civil engineering from California State University, Fresno and received her Master and Doctor of Structural Engineering degrees from the University of California, San Diego. Jill was a Senior Bridge Engineer at T.Y. Lin International (Olympia, Washington office) for 13 years prior to joining Saint Martin's in 2015. She is a registered civil engineer in California, Oregon and Washington.