University of Pittsburgh

pennsylvania
DEPARTMENT OF TRANSPORTATION

Bridge Waterproofing Details

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Overview of Presentation

- Introduction
- Bridge Waterproofing – Design and Details
- Review of Designs from different Departments of Transportation
- Field Visits
- Research Conducted
- Conclusions

Part 1

INTRODUCTION

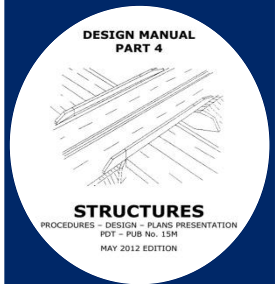
About the Issue

- Bridges very important – Lifeline of the economy
- Maintenance of bridges expensive – both in cost of maintenance and productivity lost due to closure or diversion of traffic
- Leakage in bridges in Pennsylvania – prevalent early in the life of a bridge (within 5 yrs.)

About the Issue

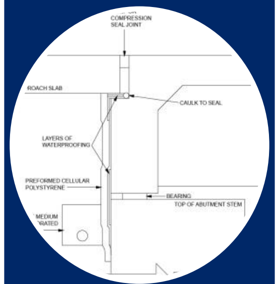
- Deteriorates life of the entire bridge due to issues such as efflorescence widening cracks, corrosion, stagnating water at bridge seats, etc.
- Usually caused due to failure of one or two small components
- Aim: To extend life of components of the bridge tending towards the life of the entire bridge

Where we stand…



Literature Survey

Analysis – Field Visits and Research



Preliminary Recommend-ations

Research and Testing of Recommend-ations

Field Implementa-tion of Recommend-ations

Monitoring of Implementa-tions

Part 2

BRIDGE WATERPROOFING – DESIGN AND DETAILS

Research Outline

Entire research is divided into 3 parts

- Literature Review
  - Current abutment waterproofing implementation in PennDOT, ODOT, MassDOT & MnDOT
  - Current expansion joint implementation in PennDOT, ODOT, MassDOT, MnDOT, IDOT & NYSDOT
  - Current inspection procedures in PennDOT, ODOT, MassDOT & MnDOT

Research Outline

- Field Visits and Research based Analysis
  - Analysis of bridges in PennDOT, MassDOT & MnDOT based on inspection reports
  - Field analysis of 5 operational bridges and 1 under construction bridge in Pennsylvania
  - Simulated and Experimental analysis of critical parts of waterproofing system
- Recommendations
  - Based on inferences from field visits and research based analysis
  - Based on experience and information of engineers from multiple DOTs

Bridge Waterproofing

- Components to protect bridge structure from coming in prolonged contact with water:
  - Expansion joints
  - Abutment waterproofing (in the backfill area) and drainage
  - Deck waterproofing and drainage
- In this research, we do not focus on waterproofing of the deck and focus on the other areas because it is beyond the scope of the current project

Expansion Joints

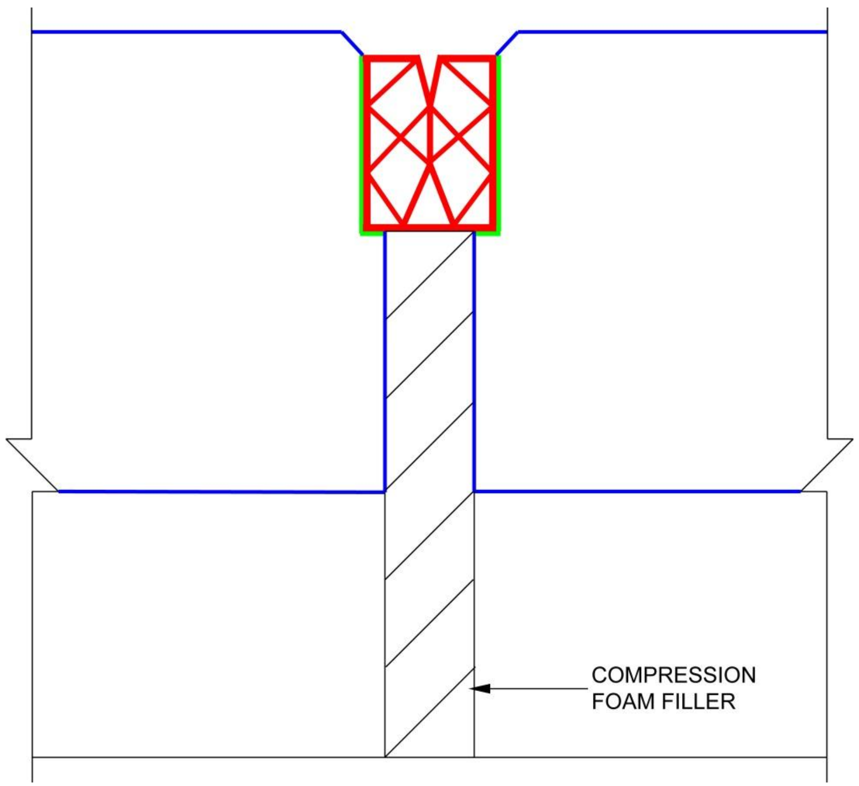
- A non-structural component to accommodate the movement of the deck due to:
  - Concrete shrinkage and creep
  - Post-tensioning shortening
  - Thermal variations
  - Dead and live loads
  - Wind and seismic loads
  - Structure settlements
- Also provides ride comfort, *prevents runoff water* and deicing chemicals from *leaking onto bearings*, *abutments*, and other structural elements underneath the bridge deck

Expansion Joints

- 5 main types of expansion joint systems used:
  - Compression Seal Joint
  - Strip Seal Joint
  - Tooth Expansion Dam
  - Modular Bridge Expansion Joint (MBEJ)
  - Asphaltic Plug Joint
- Research focuses on Compression and Strip seal joints
  - Most common types of joint systems used
  - Allow for relatively small expansion and thus have smaller tolerances for difference between designed (predicted) joint opening and movement, and actual joint opening and movement
  - Tooth Expansion Dam and MBEJ are designed to carry traffic loading and are thus less susceptible
  - Asphaltic Plug Joint is mainly used in temporary fixes

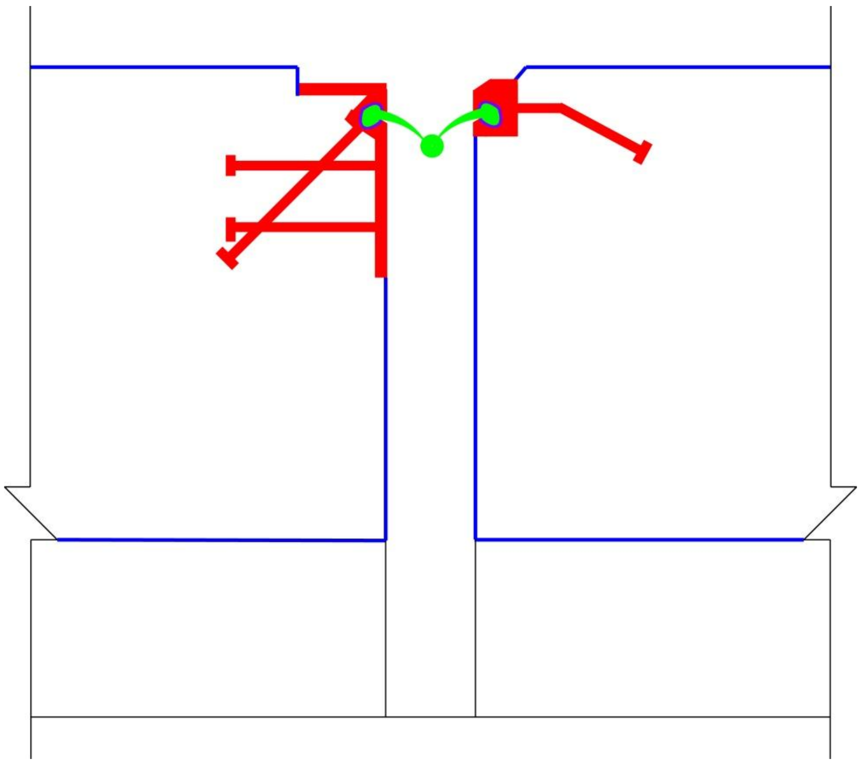
Compression Seal Joint

- Movement Range: 0.5” – 3.0”
- Components:
  - Compression Seal
  - Lubricant-adhesive
  - Block-out or Saw-cut opening
- Note: CSJ steel extrusion and anchorage are not considered – not used in PennDOT



Strip Seal Joint

- Movement Range: 0.5" – 3.0"
- Components:
  - Strip Seal
  - Steal Extrusion and Anchorage
  - Lubricant Adhesive
  - Block-out



Comparison of Compression and Strip Seal Joints

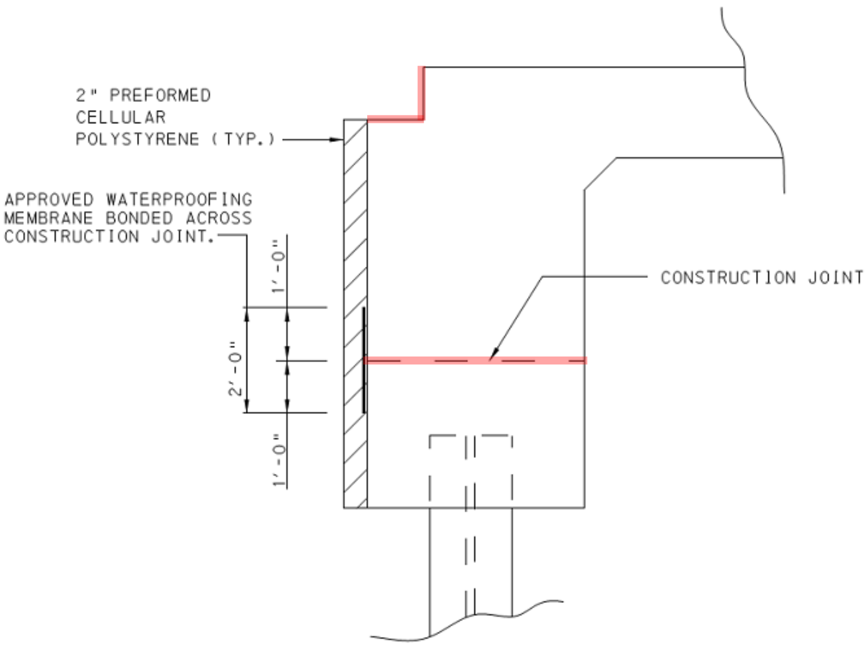
- Compression seal joints are relatively cheap to install and repair than strip seal joints; Also requires lesser time to install and can be done in parts
- Strip seal joints have a better lifespan than compression seal joints
- Strip seal allows for greater skew angles and is more tolerant to difference between predicted and actual joint opening and movement; Also very tolerant to occasional traffic loading

Abutments

- Supports superstructure – retaining wall holds backfill
- Two types: Connection between abutment stem and bridge superstructure
  - Integral/Semi-Integral
  - Parapet

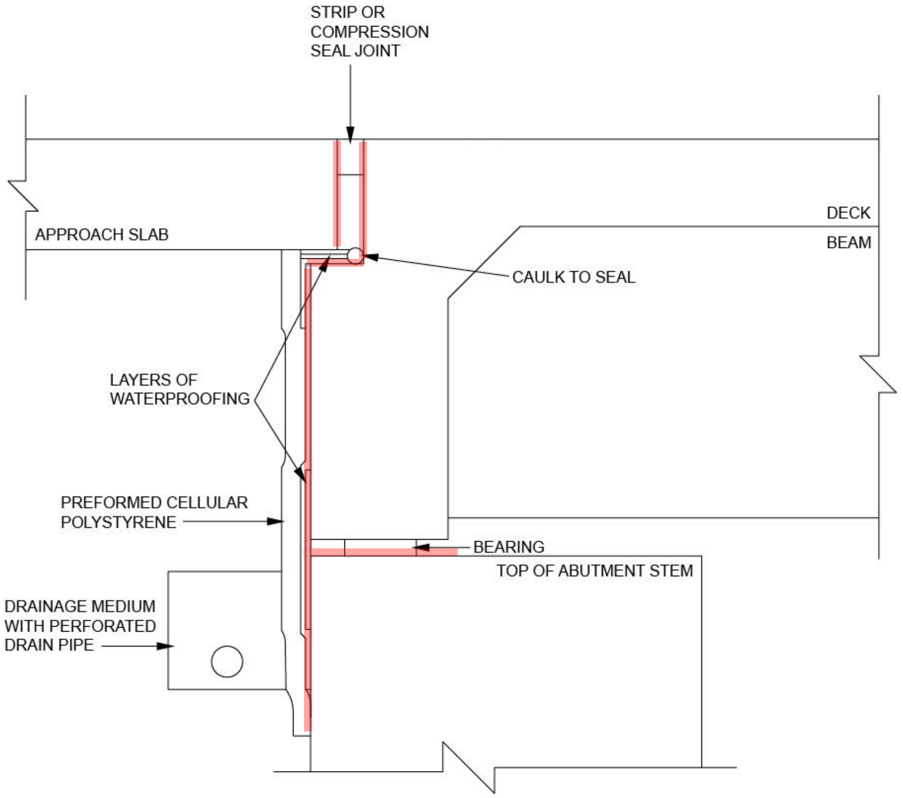
Integral Abutment

- No expansion joint between abutment and superstructure
- Main areas of concern:
  - Leakage at construction joints in:
    - Abutment stem
    - Abutment-Deck interface (Due to poor construction quality)
  - Stress-induced cracks due to inadequate design (difficult to design stress redistribution)



Parapet Abutment

- Expansion joint between abutment and superstructure (on at least one side of bridge)
- Main areas of concern:
  - Leakage at abutment – superstructure interface
  - Leakage at construction joints (Due to poor construction quality)
- Note: Old-new concrete interface in rehab projects also area of concern



Comparison of Integral and Parapet type abutments

- Integral abutments have restrictions such as bridge span, soil strata, loading restrictions, etc. and are more challenging to design
- Parapet abutments are more versatile in the type of retaining wall used, has almost no restrictions and are easy to design
- Integral abutments are cheaper to build, maintain and have a long life
- Parapet abutments are more expensive to build, maintain and have to be repaired or rehabilitated at least once in the lifespan of the structure

Part 3

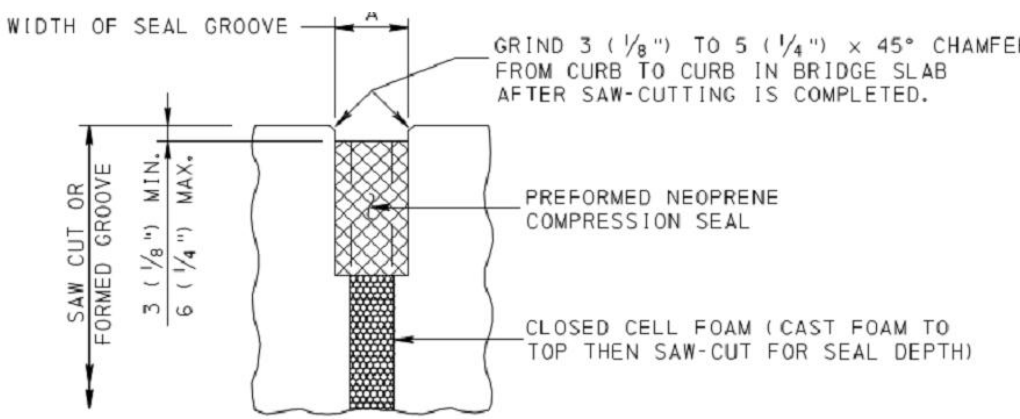
REVIEW OF DESIGNS FROM DIFFERENT DEPARTMENTS OF TRANSPORTATION

State DOT practice

- States selected based on similar weather pattern to Pittsburgh and surrounding areas
- Initial comparison of waterproofing design and inspection procedure from Massachusetts, Minnesota and Ohio
- Further comparison of waterproofing design from New York and Illinois

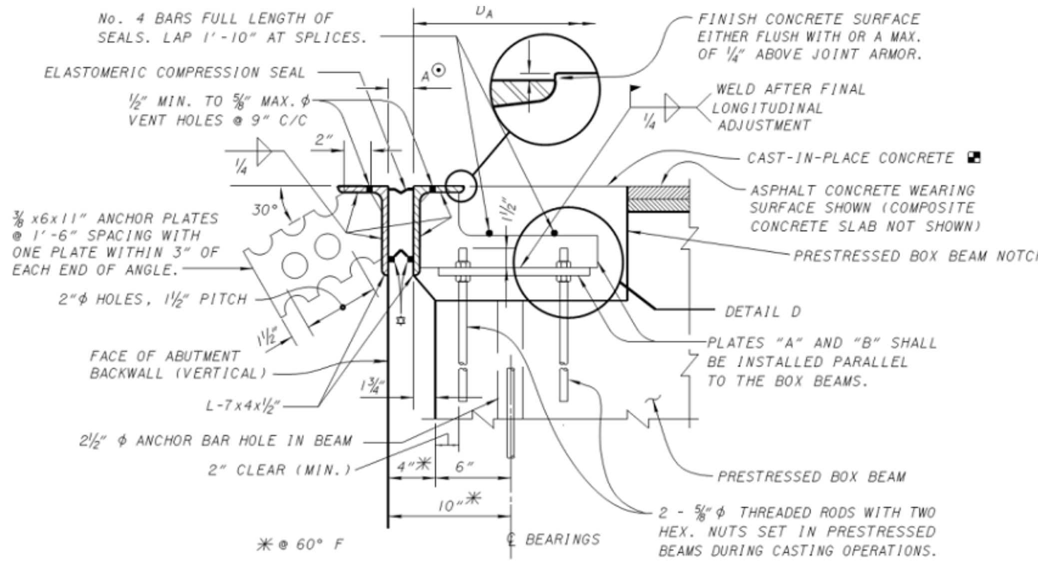
Compression Seal Joint - PennDOT

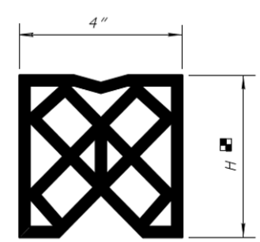
- No skew angle limit
- Fabricator provides joint opening size and compression seal design
- Only unarmored type used



Compression Seal Joint - ODOT

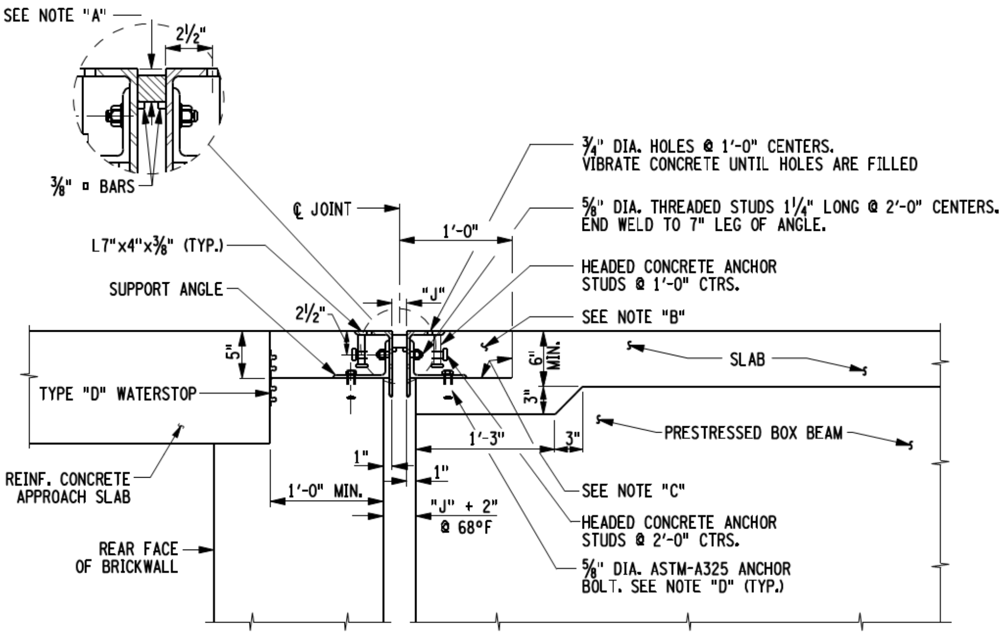
- Skew angle limit – 15°
- Specific about joint opening size (during installation) and compression seal design
- Only armored type used





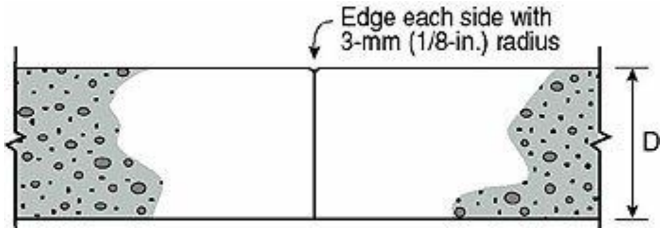
Compression Seal Joint - NYSDOT

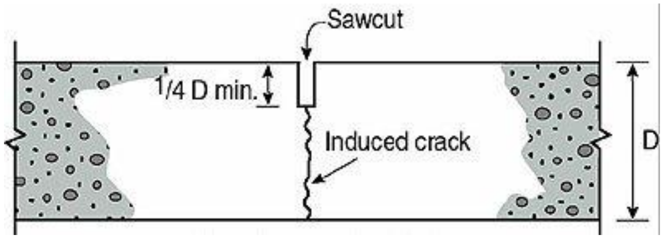
- Skew angle limit – 45^o
- Fabricator provides joint opening size and compression seal design
- Only armored type used



Compression Seal Joint – Summary

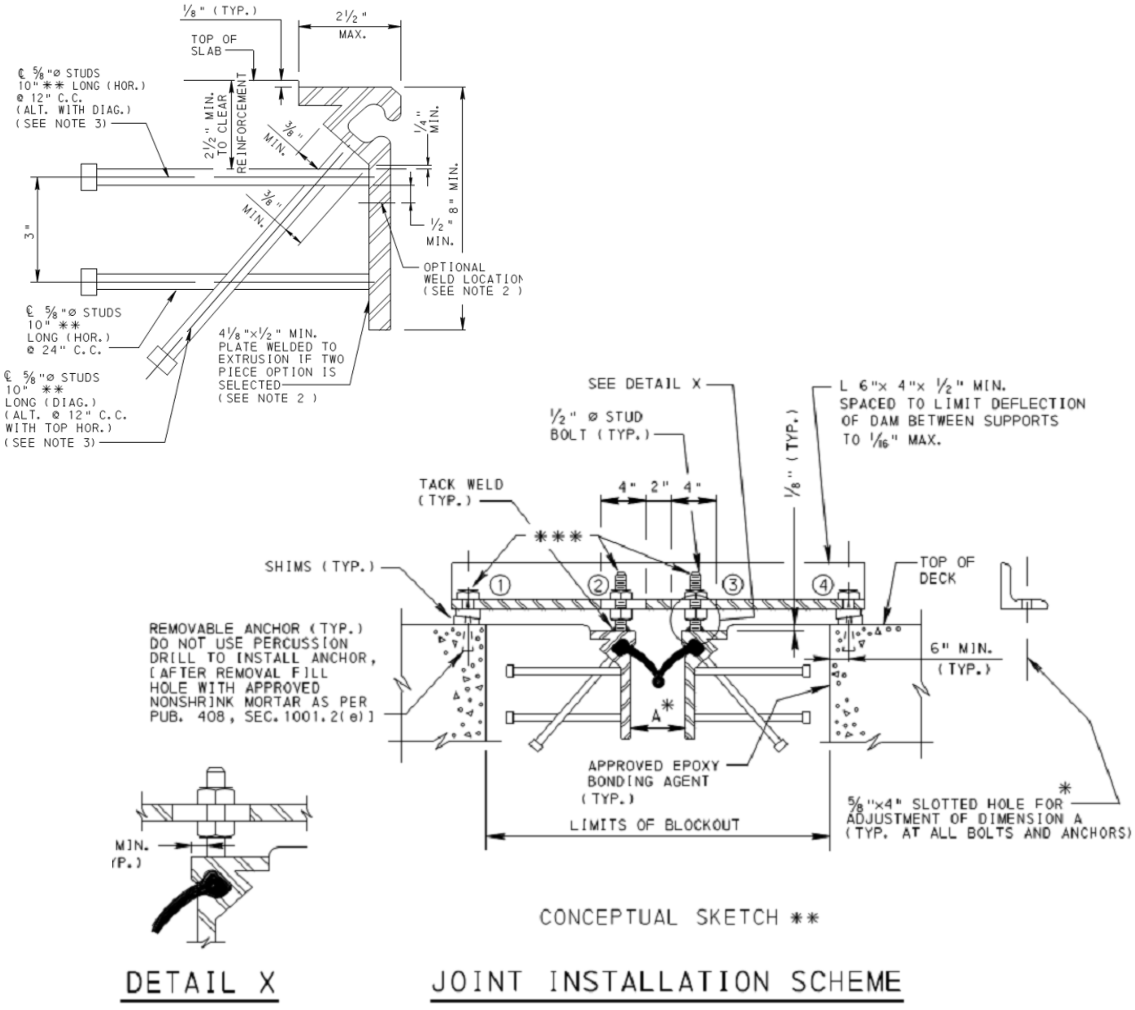
- MnDOT specifies min. 5 cells in compression seal; Only used in contraction joints
- Only PennDOT does not specify skew angle
- PennDOT only uses unarmored joint; ODOT and NYSDOT only use armored joint





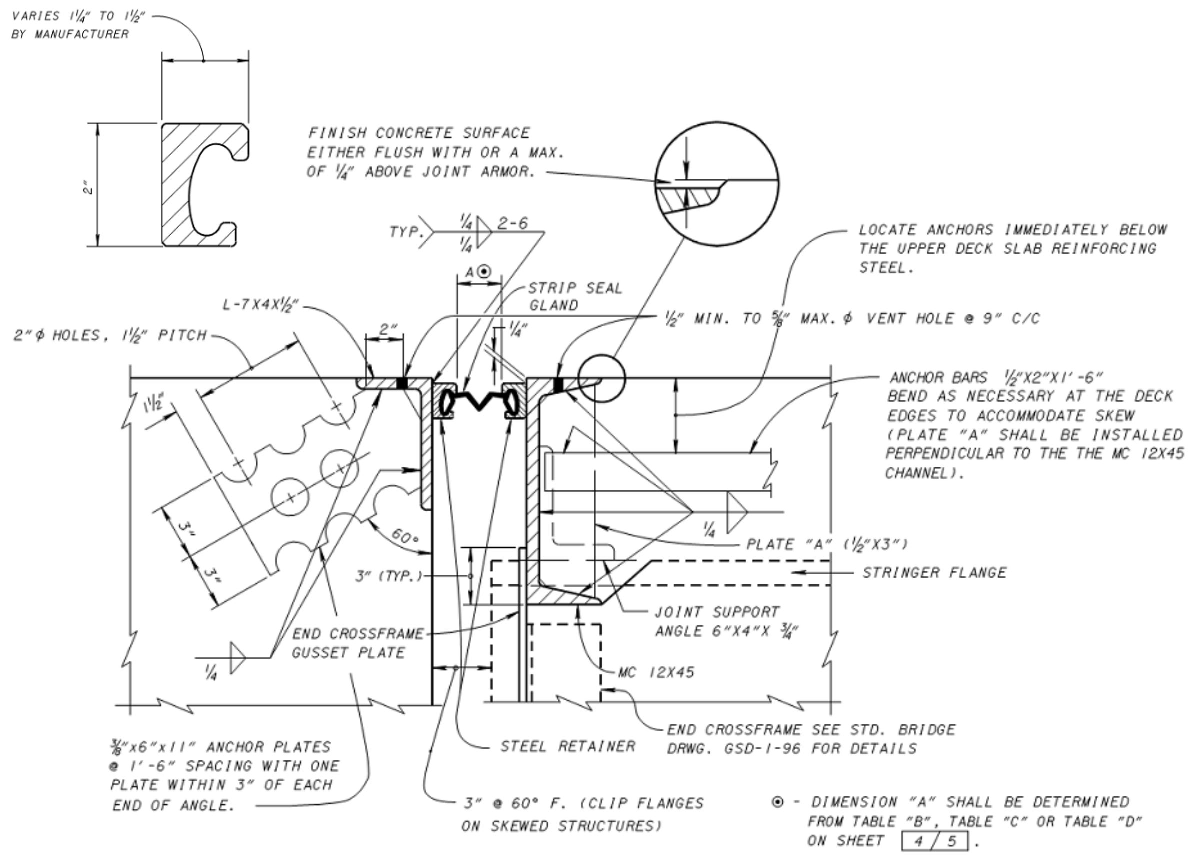
Strip Seal Joint - PennDOT

- No skew angle limit
- Fabricator to provide opening size and strip seal design



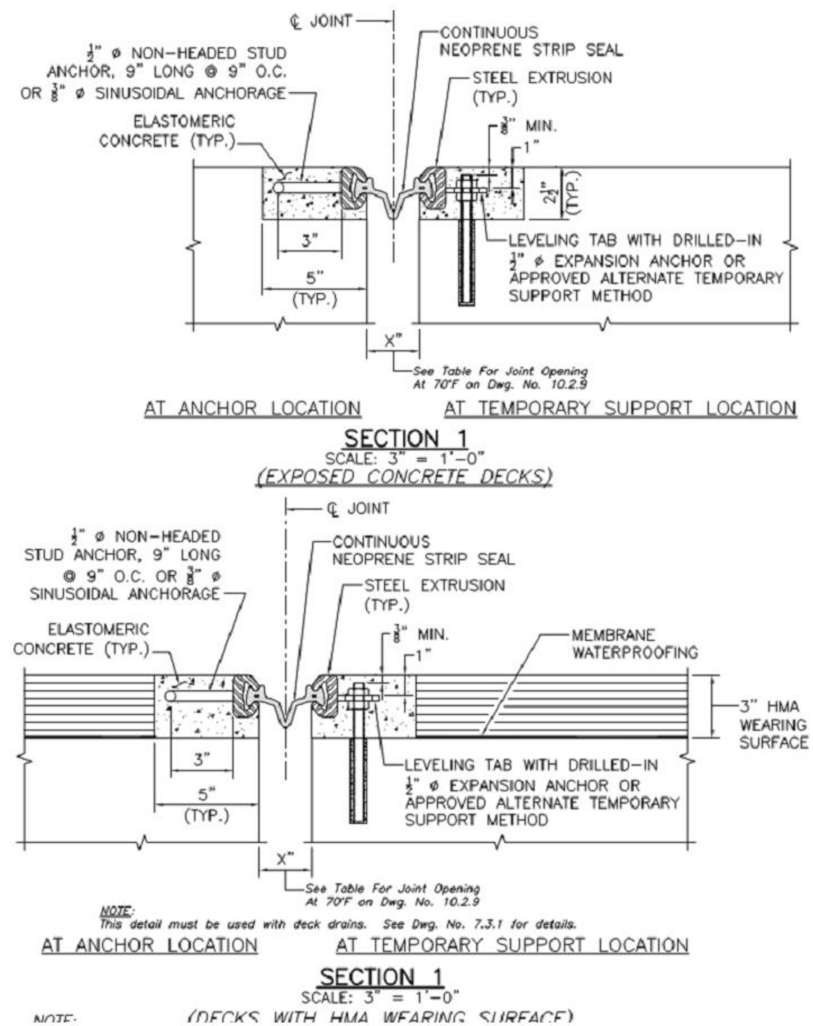
Strip Seal Joint - ODOT

- Skew angle limit – 60º
- Specific about joint opening size (during installation) and strip seal design



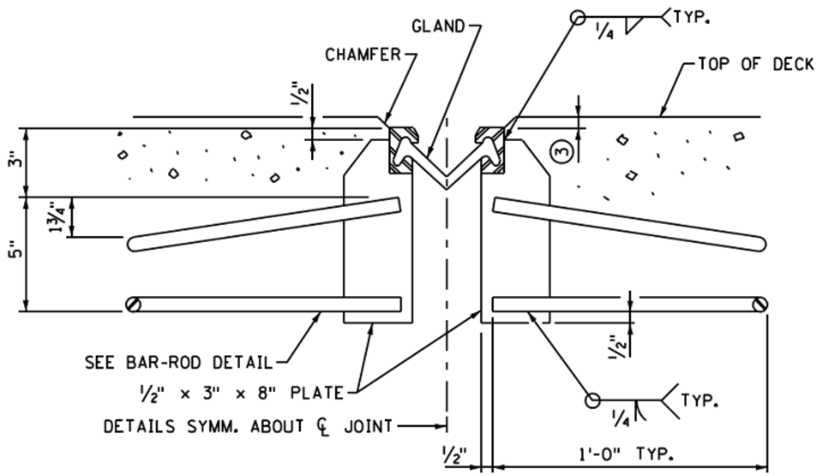
Strip Seal Joint - MassDOT

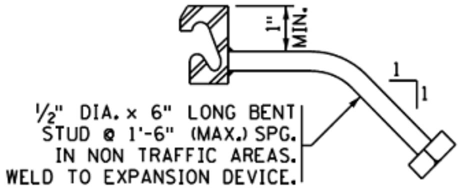
- No skew angle limit
- Fabricator to provide opening size and strip seal design



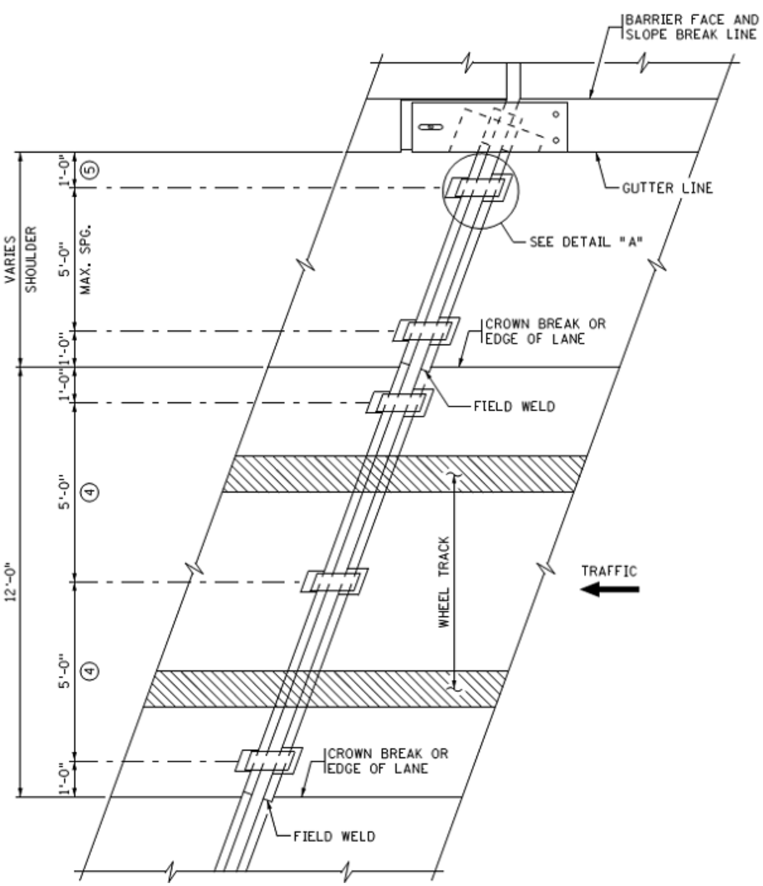
Strip Seal Joint - MnDOT

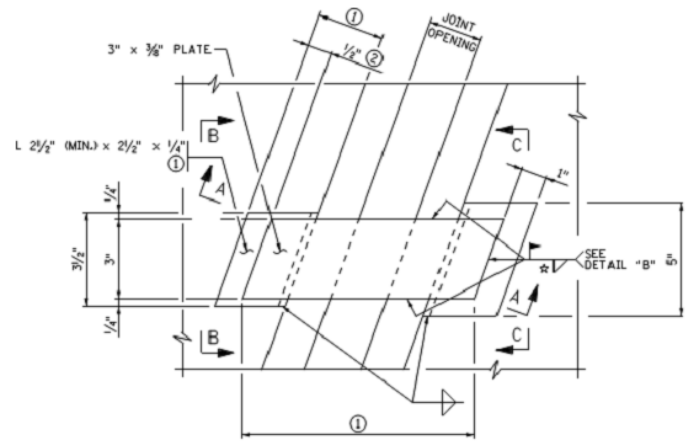
- No skew angle limit
- Fabricator to specify opening size
- Plow finger provided to protect against snow plows only in skew angles from 15º to 50º



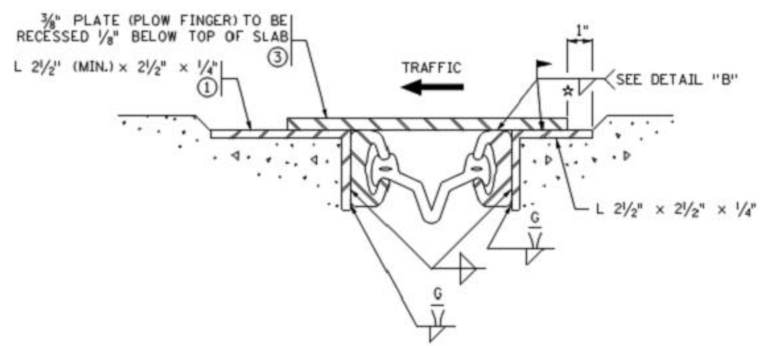


Strip Seal Joint - MnDOT



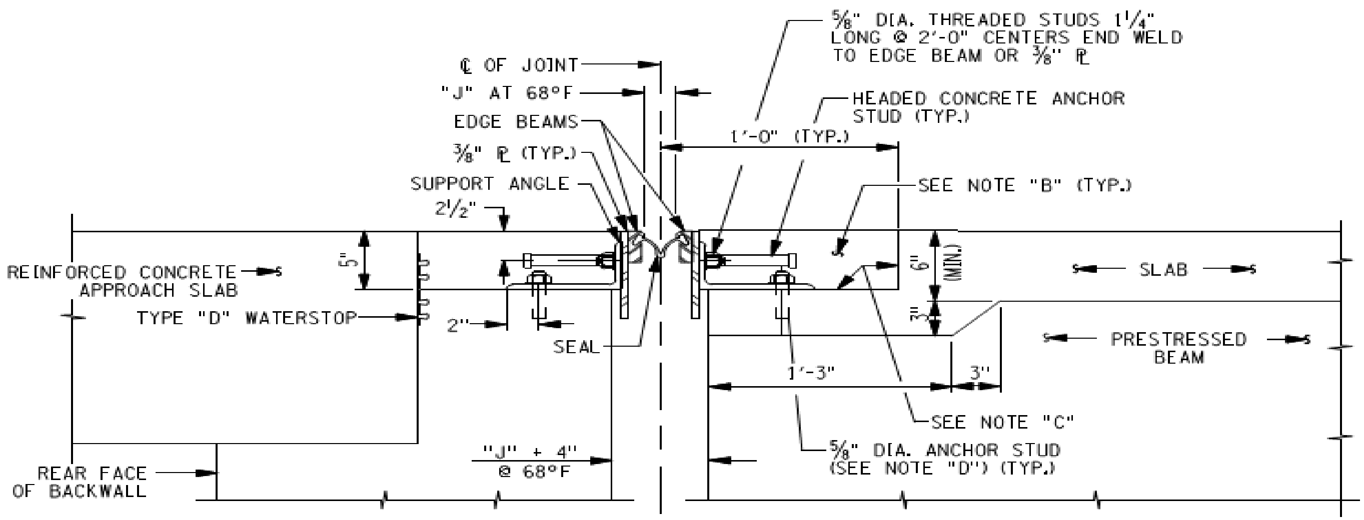


DETAIL "A"



SECTION A-A

Strip Seal Joint - NYSDOT

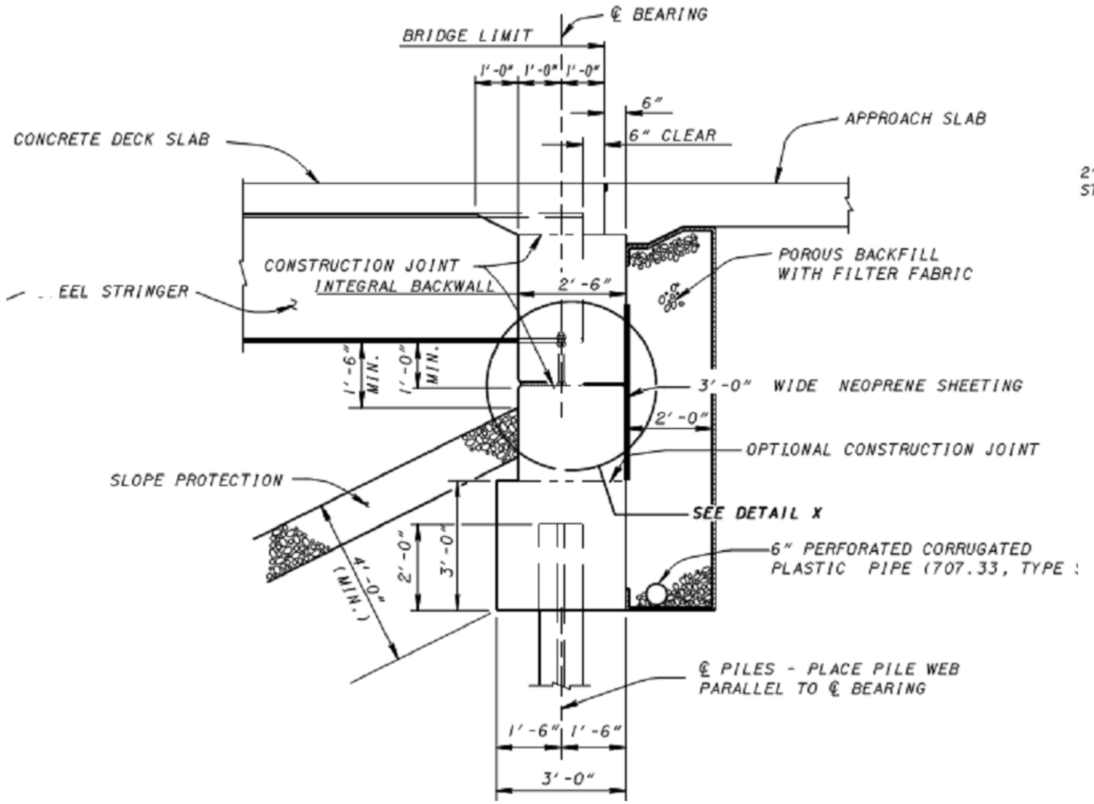


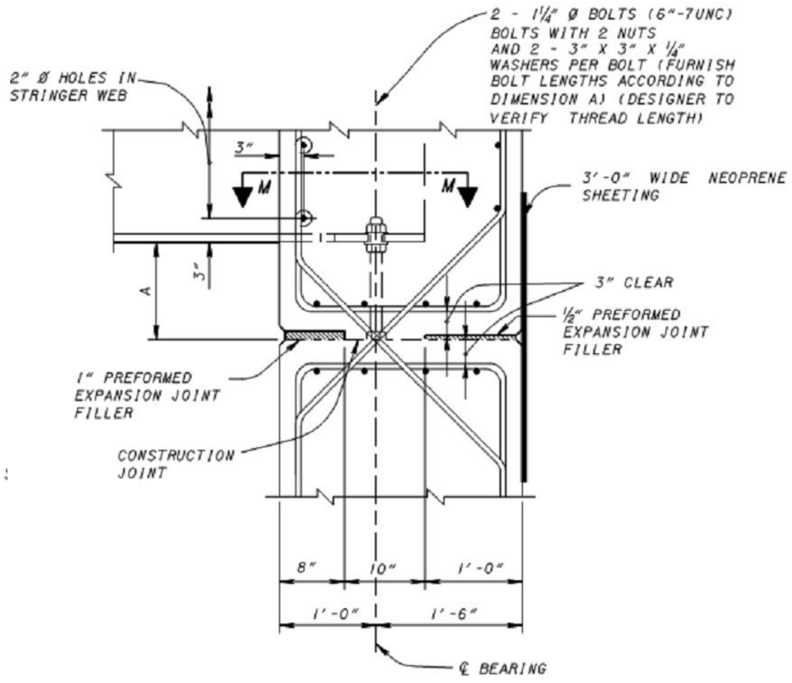
- No armor on block-out
- Fabricator to provide opening size and strip seal design
- Span of deck restricted based on skew angle

Strip Seal Joint - Summary

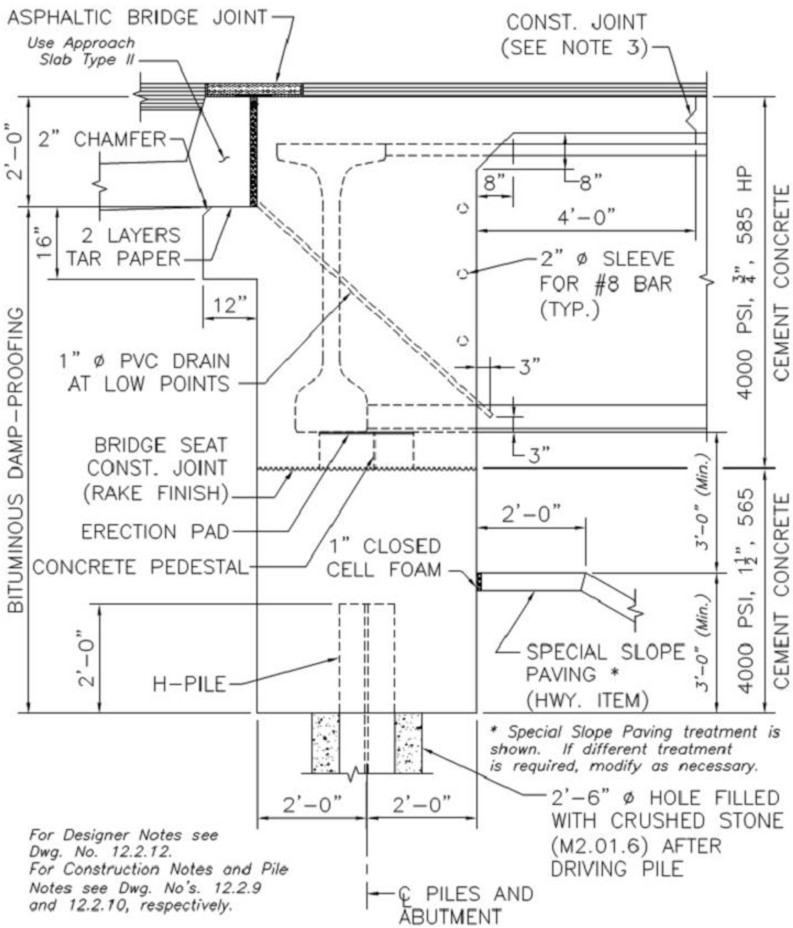
- Only ODOT limits skew angle (60°)
- MnDOT uses plow finger
- Only ODOT and MnDOT specify joint opening size during installation
- Except for MassDOT and ODOT, all other states use the same concrete in the block-out and deck; MassDOT specifies Elastomeric concrete and ODOT specifies the strength to be 4.5 ksi for the block-out

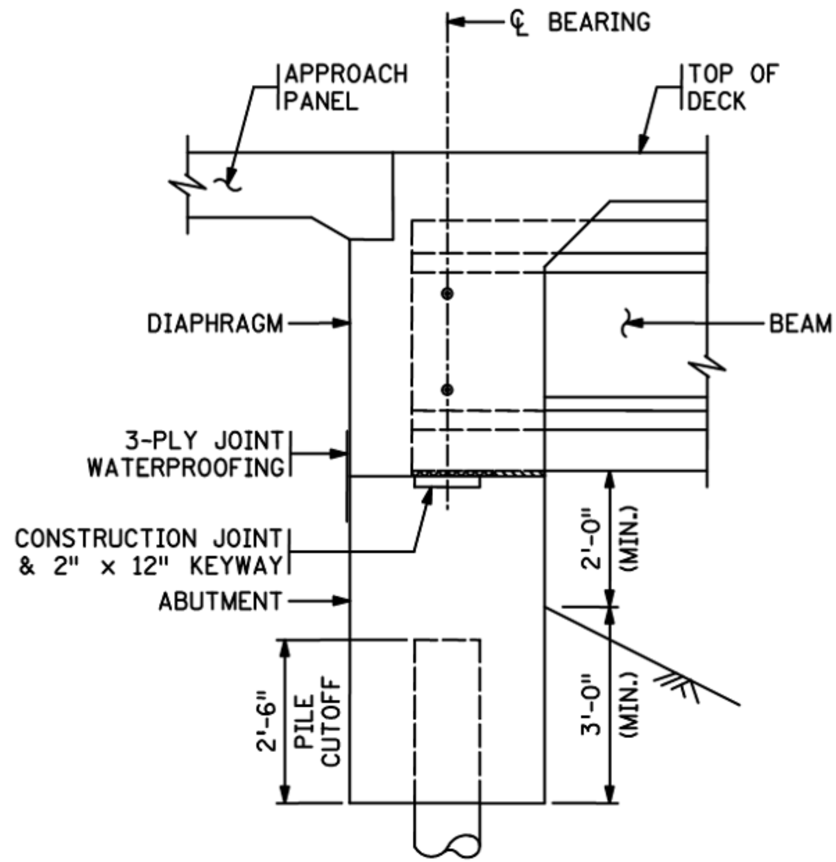
Integral Abutment - ODOT





Integral Abutment – MassDOT & MnDOT

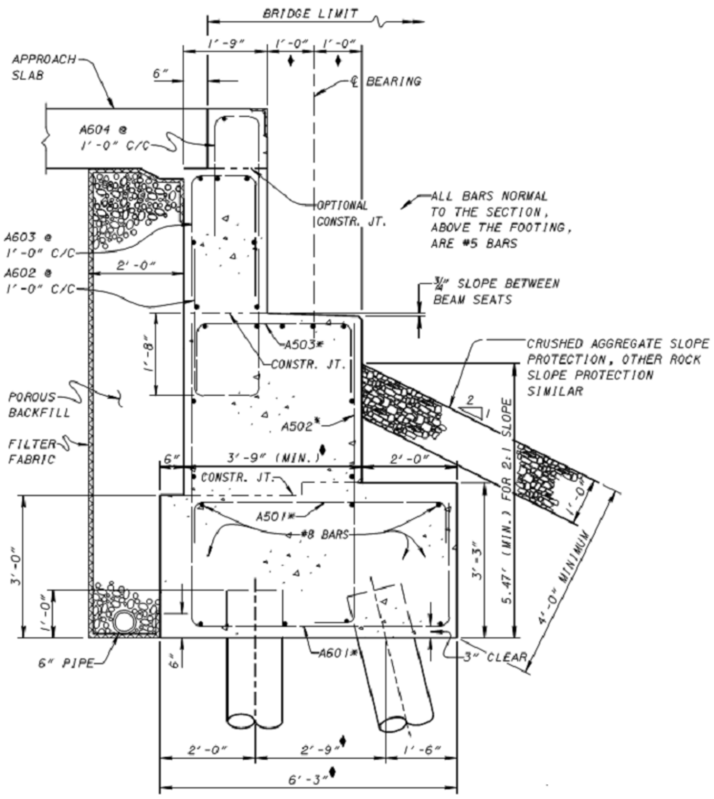


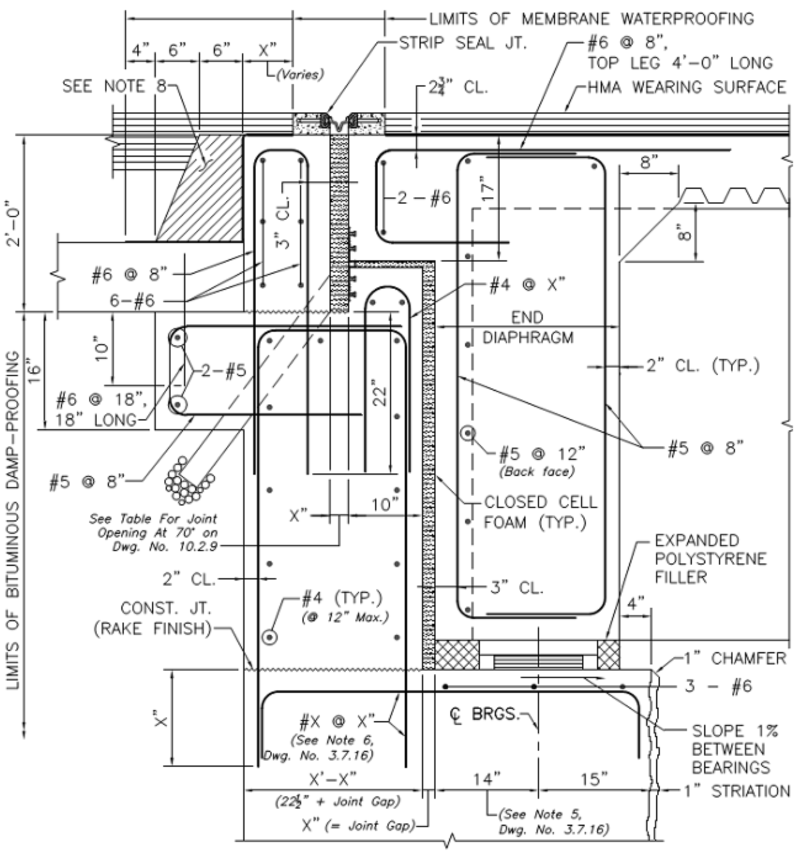


Integral Abutment – Summary

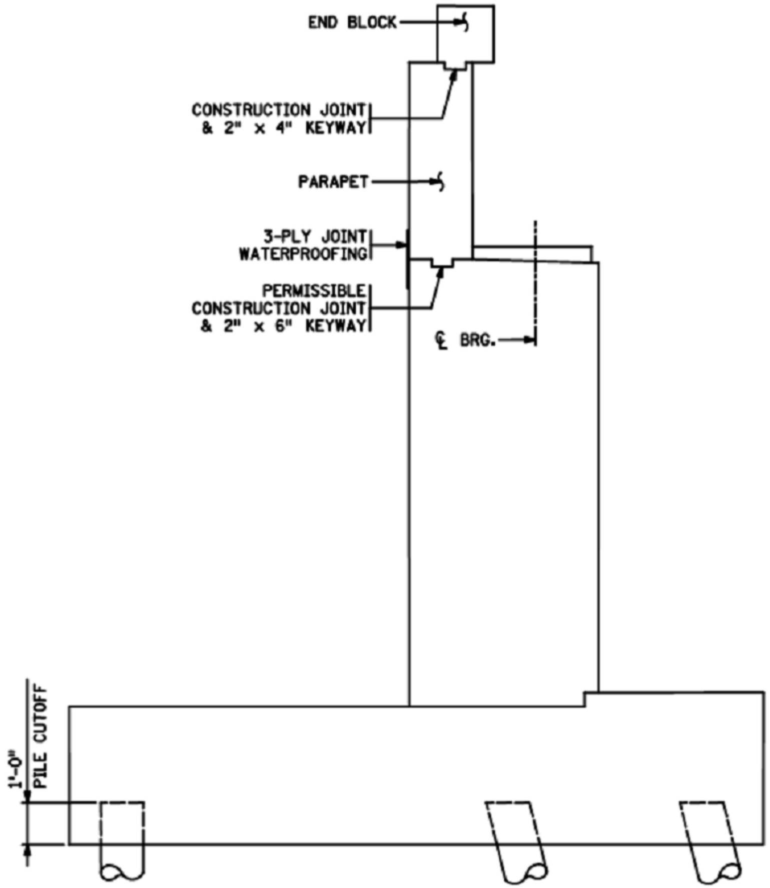
- Only MassDOT provides a coated water proofing. Other DOTs use (some sort of) waterproofing sheet
- PennDOT is least specific in waterproofing design detail

Parapet Abutment – ODOT & MassDOT





Parapet Abutment - MnDOT



- MassDOT – min. 2" thick membrane waterproofing; Waterstop in construction joints
- MnDOT - Membrane waterproofing – rubberized asphalt integrally bonded to polyethylene sheeting

Parapet Abutment - Summary

- Only PennDOT prefers abutment without backwall
- MnDOT lacks detail in abutment design – Presumably left to the designer
- Only ODOT uses a full length drainage backfill with filter fabric and perforated drain pipe
- Construction joints differ: Stepped/Flat type in ODOT, Raked in MassDOT & Keyed in MnDOT

Part 4

FIELD VISITS

Introduction

- 5 bridges selected – no older than 5 years – leakage issues
- 25 ft. to 225 ft. in length; 45 – 90 degrees skew angle;
- 3 field visits per bridge:
  - First visit on a sunny day
  - Second visit two days after rain
  - Third visit on a rainy day
- In addition, a construction site was visited to investigate waterproofing implementation

Little Creek Road Bridge

- Built 2010
- Skew angle: 70°
- Deck: 2 spans – 105 ft. & 120 ft.
- Compression seal: 0.5 in. movement

Little Creek Road Bridge

- Cracking & Erosion of joint edges
- Damage of silicone sealant at surface
- Leakage at construction joint at beam – deck interface

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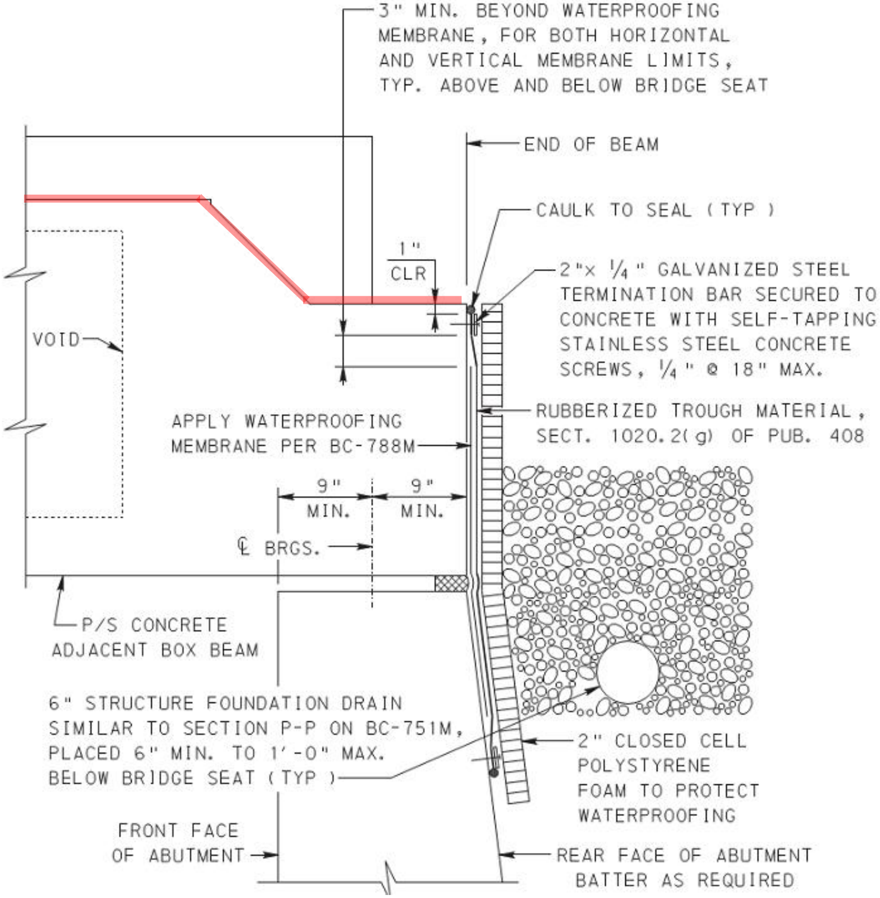
Little Creek Road Bridge



Little Creek Road Bridge

- Vegetation in joints
- Water seeping through joints
- Main cause of leakage
  – Expansion joint
- Leakage due to abutment possible as well

Prospect #1 Bridge

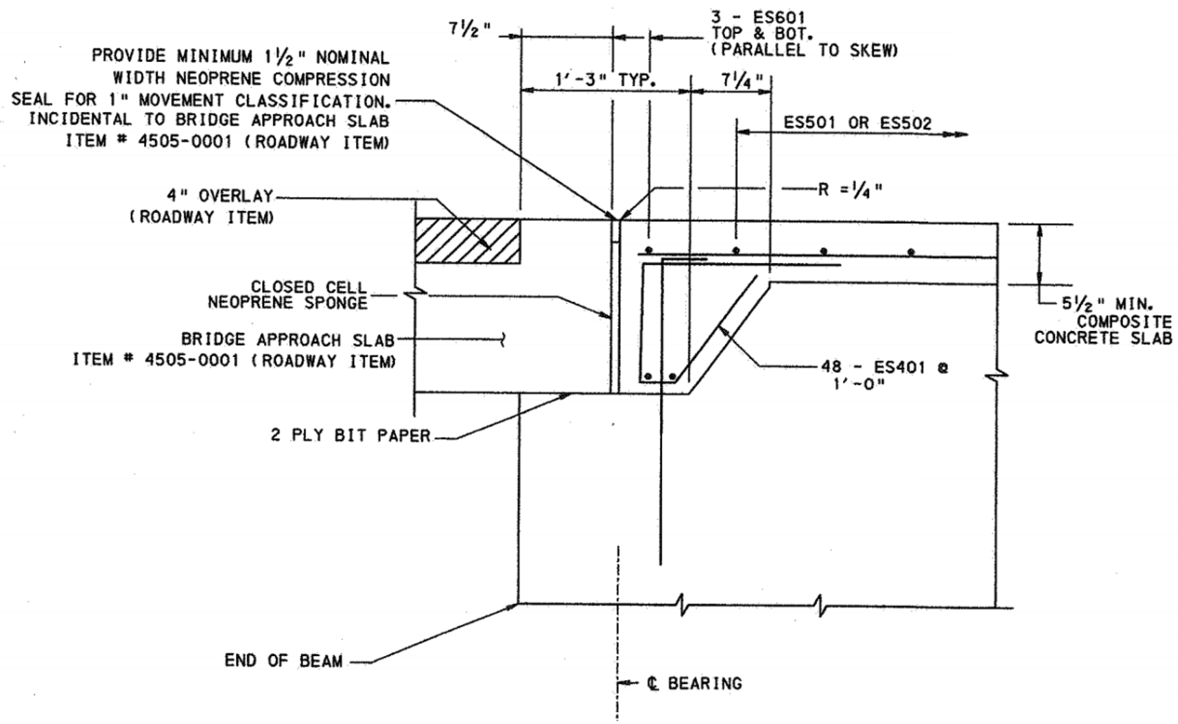
- Built 2009
- Skew angle: 70°
- Deck span: 104 ft.
- Compression seal: 1 in. movement (different from Little Creek Bridge)

Prospect #1 Bridge

- Debris accumulation on compression seal joint – Due to recent road maintenance work – Hinders drainage of water on deck
- Water staining on abutment – more severe near edges

Prospect #1 Bridge

Prospect #1 Bridge



Prospect #1 Bridge

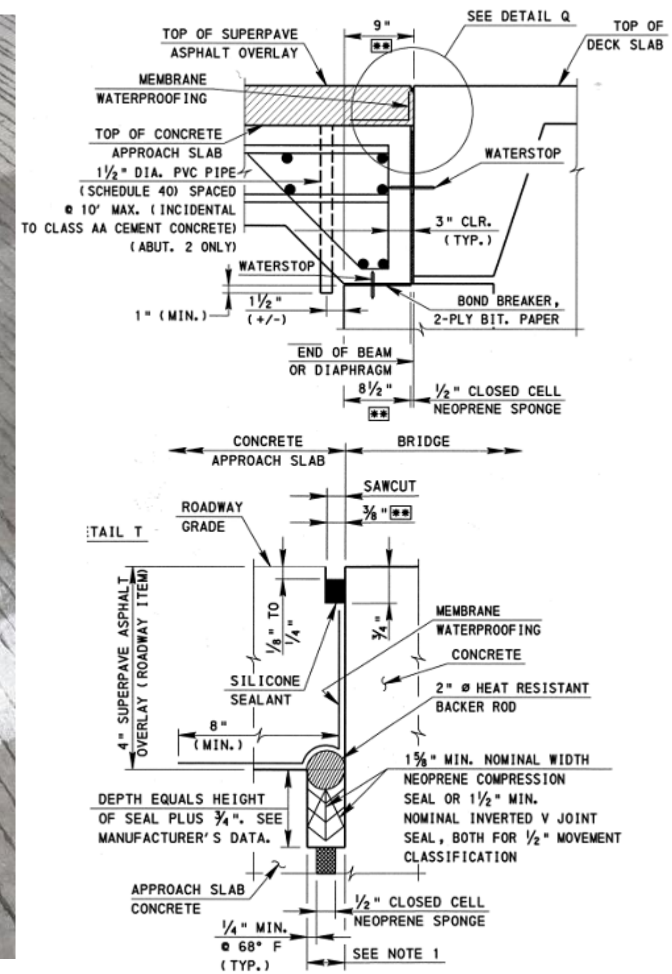
- Main cause:
  - Failure of concrete block-out – evident through leakage on edges
  - Leakage through box girder – both from expansion joint and backfill
- Debris accumulation exacerbates leakage issue
- Possible leakage of water through backwall – from sloped backfill – evident through weep hole leakage

SW of Boydstown Bridge

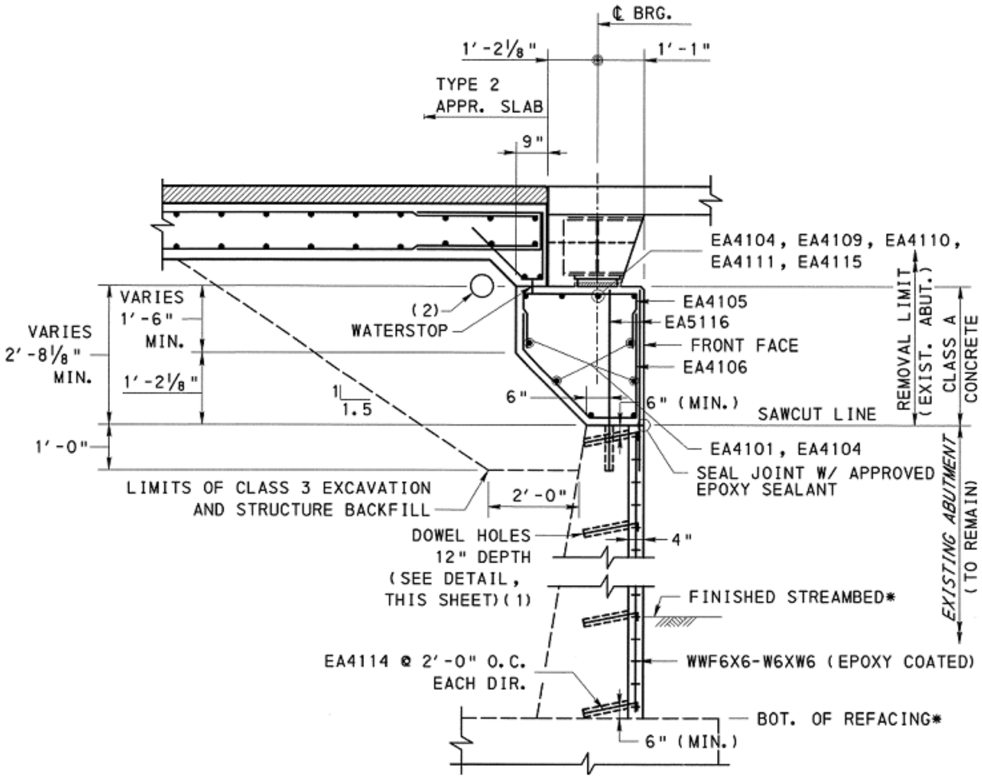
- Built 2012 – Rehab
- Skew angle: 60°
- Deck span: 25 ft.
- Compression Seal: 0.5 in. movement

SW of Boydstown Bridge

- Initial signs of deterioration of silicone sealant in joint observed
- Leakage observed in old-new concrete interface on abutment
- Leakage at construction joint on abutment
- Deck slope insufficient to drain silt
- Silt found in weep holes



SW of Boydstown Bridge



SW of Boydstown Bridge

SW of Boydstown Bridge

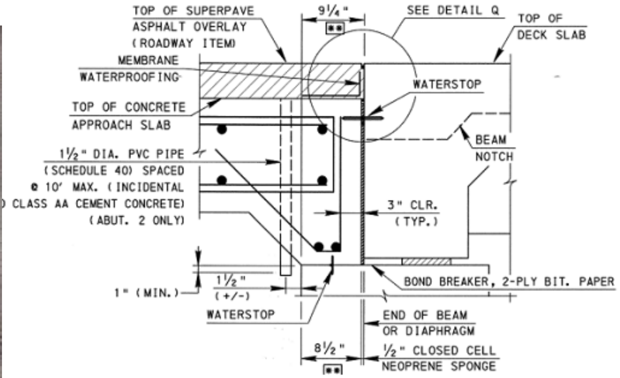
- Main cause: Backfill through old-new concrete interface and construction joint
- Cracks due to differential shrinkage between new and old concrete – efflorescence exacerbating the situation
- No redundancy in abutment waterproofing
- Expansion joint not ruled out but highly unlikely – compression seal not visible – deck not sloped sufficiently

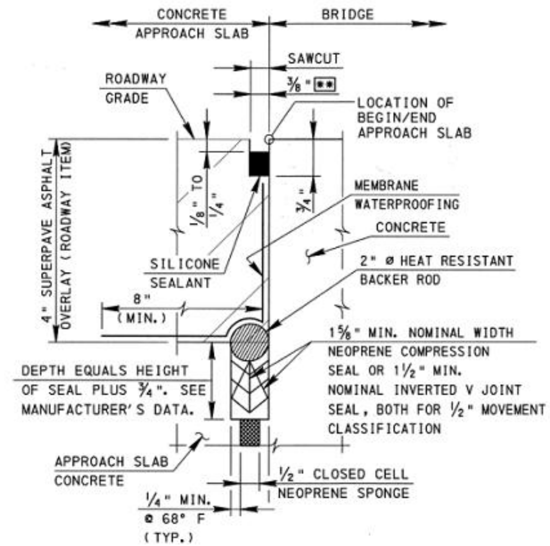
Little Connoquenessing Bridge

- Built 2012
- Skew angle: 45°
- Deck Span: 34 ft.
- Compression Seal: 0.5 in. movement

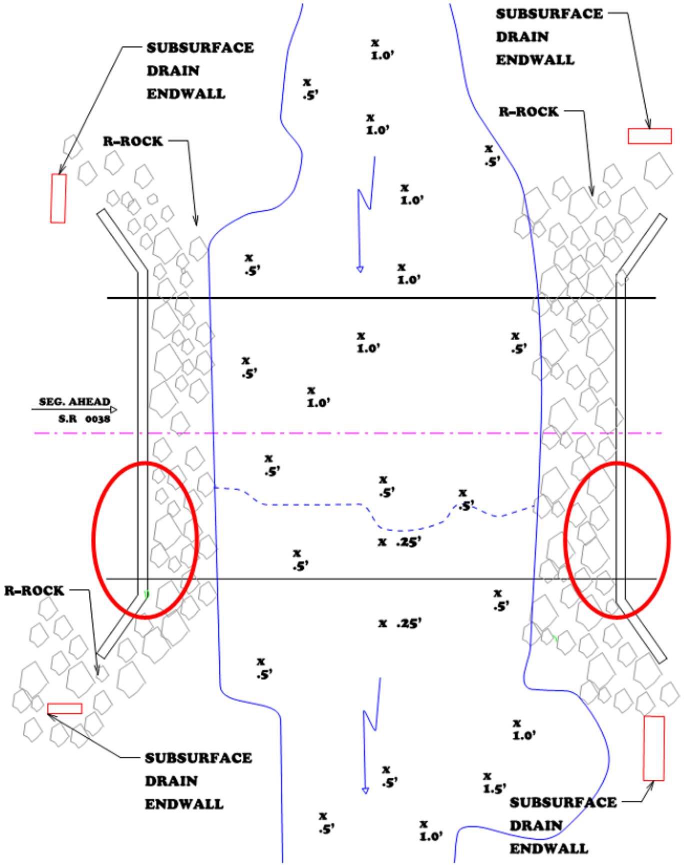
Little Connoquenessing Bridge

- Bridge still new; However showing initial signs of edge chipping
- Water staining on abutment stem more so on the east side





Little Connoquenessing Bridge



Little Connoquenessing Bridge

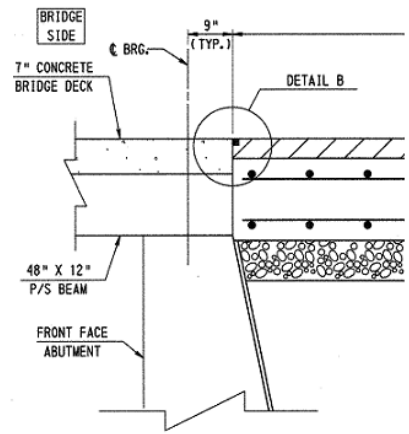
- Main Cause: Backfill through abutment seat
- Possible role of surrounding terrain
- Possible waterstop failure

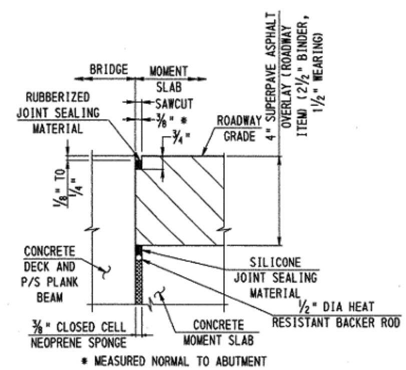
Beechton Bridge

- Built 2011 – Rehab
- Skew angle: 90°
- Deck Span: 31 ft.
- Rubberized joint sealing material

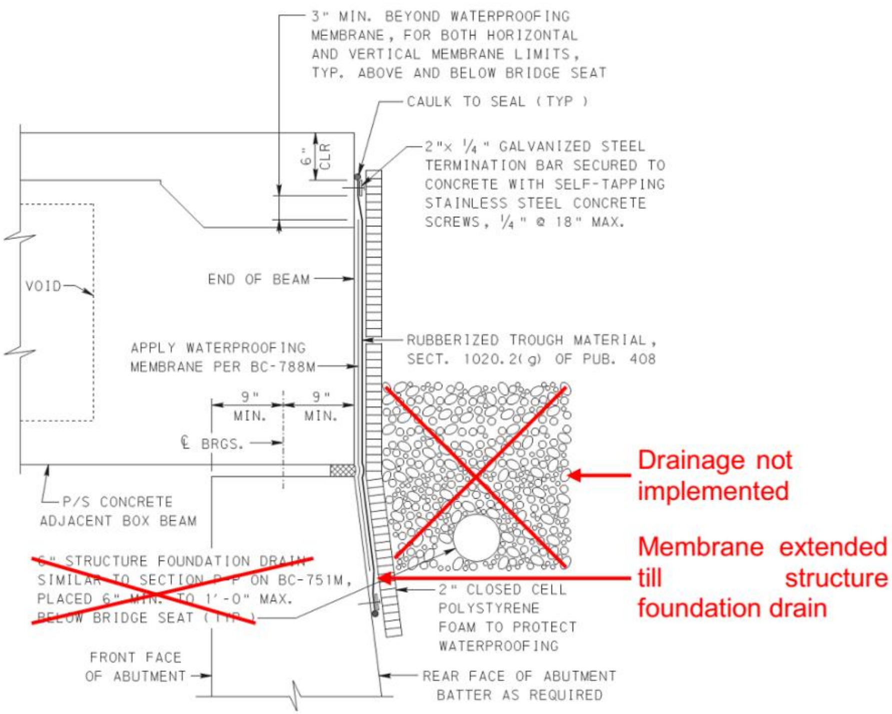
Beechton Bridge

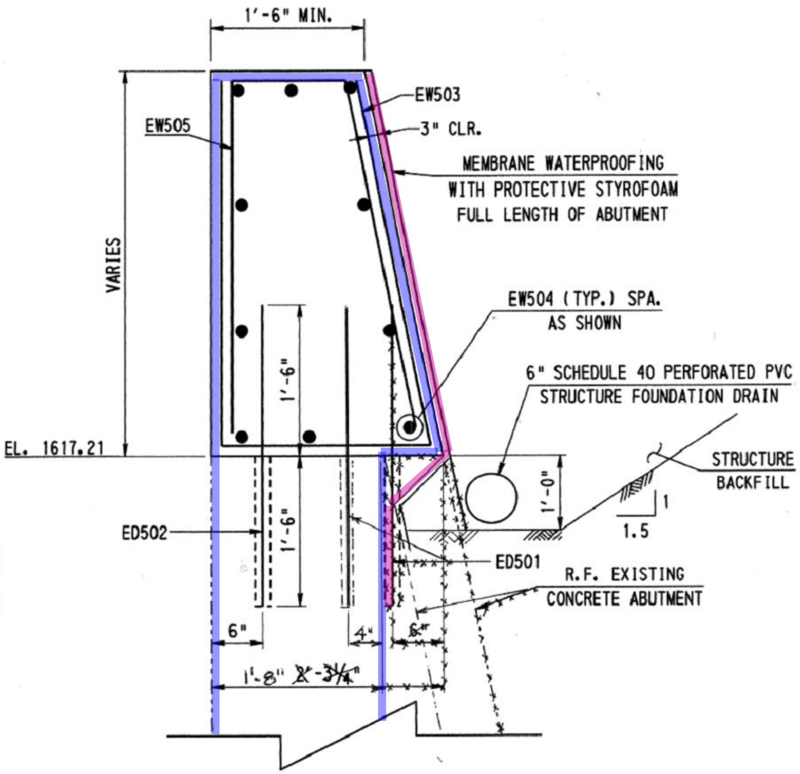
- Severe leakage at old-new concrete interface on abutment
- Leakage at cracks propagating from the interface





Beechton Bridge





Beechton Bridge

- Main cause: Backfill through old-new concrete interface
- Waterproofing membrane bent – mostly failed
- Crack in new concrete due to differential shrinkage
- Only drainage at old-new concrete interface – not at bearing (explain observation of leakage at bearing seat)

Bridges from MassDOT, MnDOT, IDOT & NYSDOT

- No leakage in bridges from MassDOT; Only one integral abutment bridge shows leakage – mostly due to stress-induced cracks (stress redistribution is a design challenge)
- Strip seal preferred over compression seal in MnDOT; No leakage found even with cracks on abutment stem – mostly due to redundancy in waterproofing
- Strip seal reduces leakage in IDOT compared to compression seal
- Good performance of bridges with strip seal up to 15 years and compression seal up to 10 years (sizing is essential); Main issue with relatively early block-out failure compared to joint;

Part 5

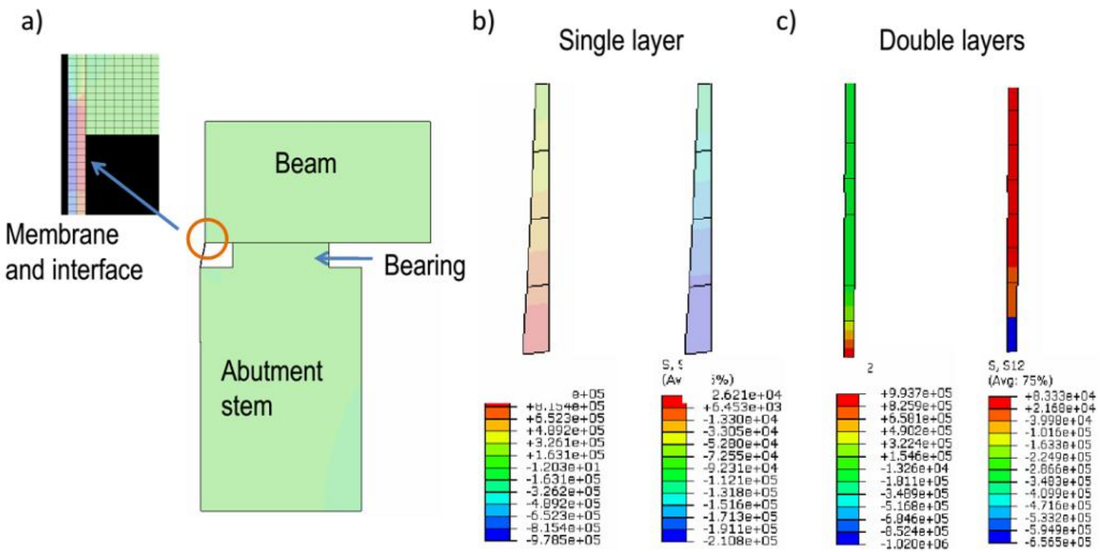
RESEARCH CONDUCTED

Research based Analysis

- Finite Element Modelling (FEM) of membrane peel off
- FEM of skew angle effect on compression seal joint
- FEM of traffic (impact) loading on steel extrusion (strip seal joint)
- Seal push out test of Strip seal (to check for safety against traffic loading with debris in seal)

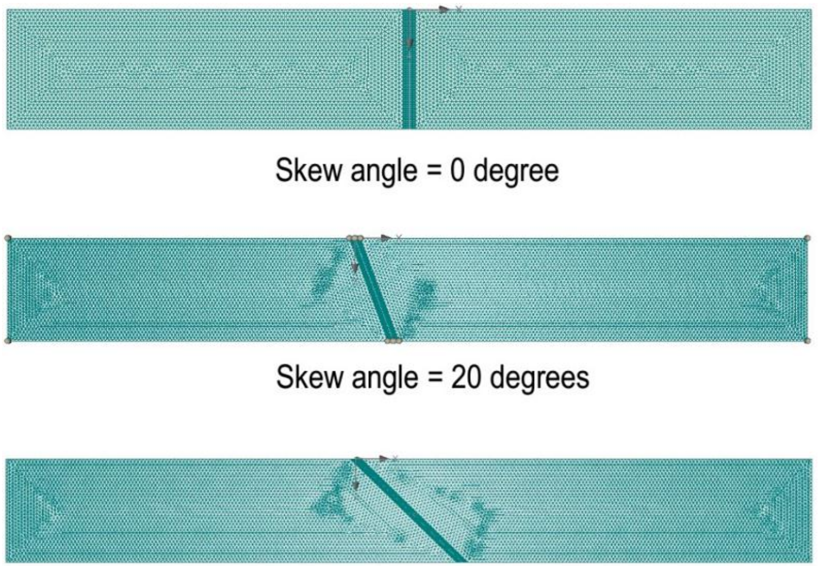
Finite Element Modelling (FEM) of membrane peel-off

- To analyze effect of movement on waterproofing membrane at abutment seat
- Membrane extending 1 ft. on either side
- 100 ft. span – temp. variation of 104°F – 0.6 in. movement
- High stresses at membrane and interface – expected
- Double membrane layer – greatly increases stress concentration – possible adhesive failure



FEM of skew angle effect on compression seal joint

- To analyze effect of skew angle on compression seal joint
- 100 ft. span – temp. variation of 86°F – 0.4 in.
- Shear stress:
  - 20° – 75 psi
  - 45° – 139 psi
- Reduced safety margin at higher angles



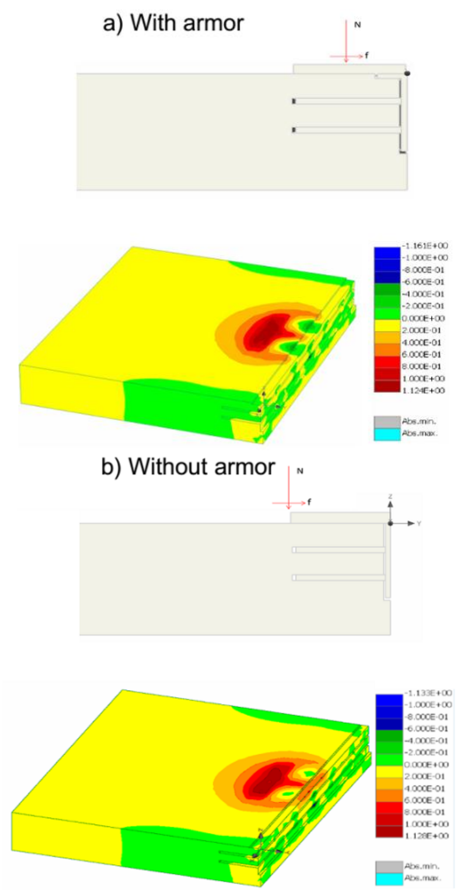
Skew angle = 0 degree

Skew angle = 20 degrees

Skew angle = 45 degrees

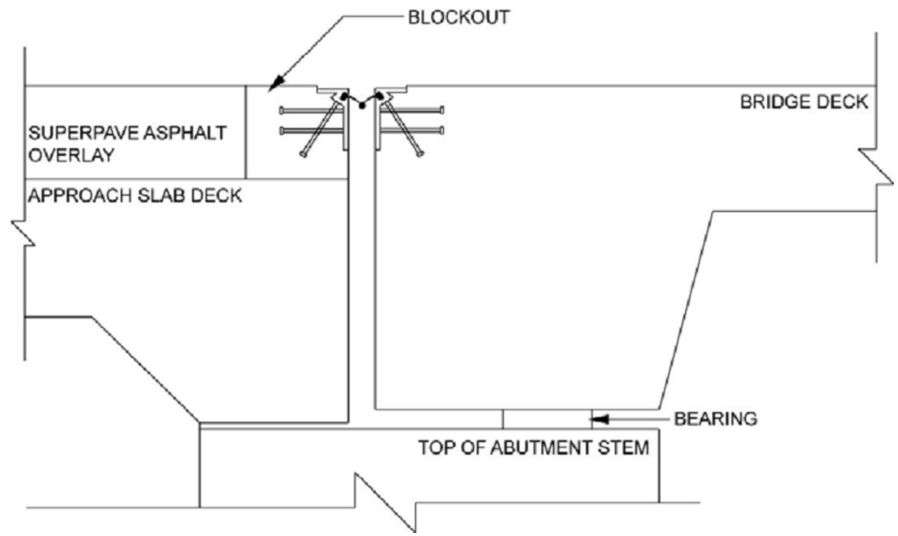
FEM of traffic (impact) loading on steel extrusion (strip seal joint)

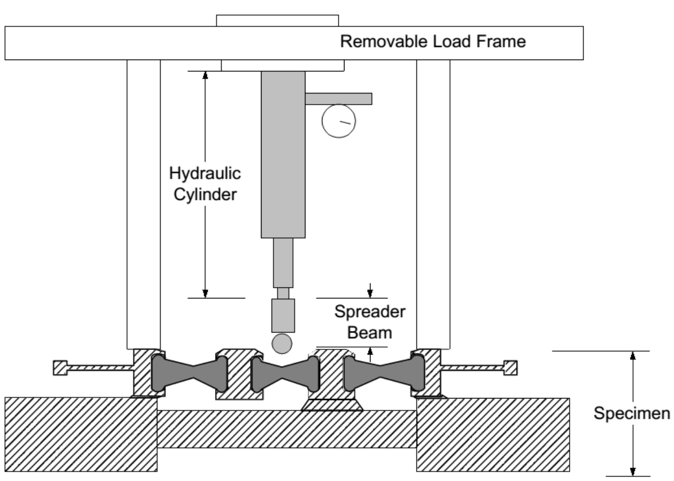
- To analyze effect of traffic loading on anchorage stud of steel extrusion – with and without armor
- Max. stress in stud: 2118 psi
- Max. stress in extrusion: 1336 psi
- Max. block-out tensile stress: 163 psi
- Anchorage has very high safety margin when compared to the strip/compression seal it supports



Seal push out test of Strip seal

- Test to simulate loading of strip seal
- Reason is to test strength in case of traffic loading due to debris accumulation
- Modification of seal push out test by University of Minnesota (NCHRP Report 467)





Seal Push out test of Strip seal

- Sample from PennDOT approved manufacturer
- 3 ft. specimen; Spacing of 3 in. at top of the specimen
- Reaches around 4 in. of deflection and 2700 lb. of loading (1600 lb. reqd.)
- Great ductility and thus great tolerance to debris compared to compression seal

Part 6

CONCLUSIONS

Recommendations

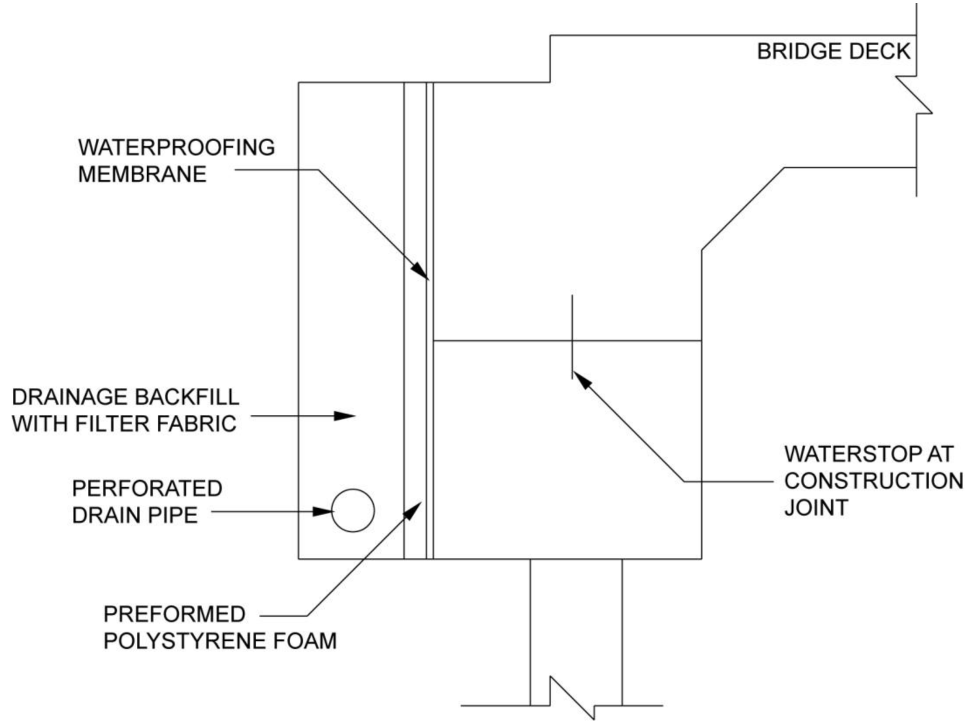
- Based on study of design, field observations, analysis and testing, two kinds of recommendations are made:
  - Design based
  - Monitoring based

Design Recommendations

- Based on current design information
- Based on evaluation of design performance of other DOTs
- Based on research findings
- Six recommendations given based on broad categorization of project type and abutment type.
- Note: These are theoretical design guidelines; Actual design and other specifics need to be probed

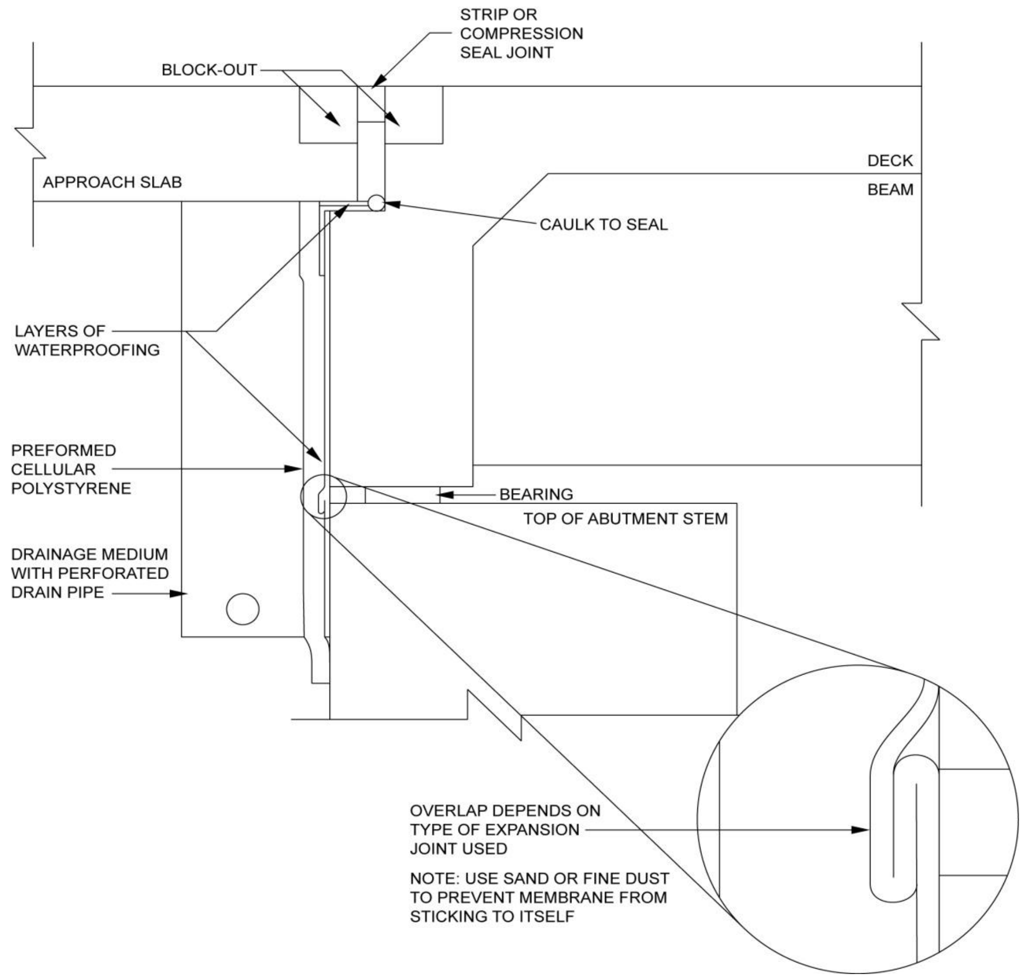
Integral Abutment

- Waterstop, membrane and full length drainage material for redundancy



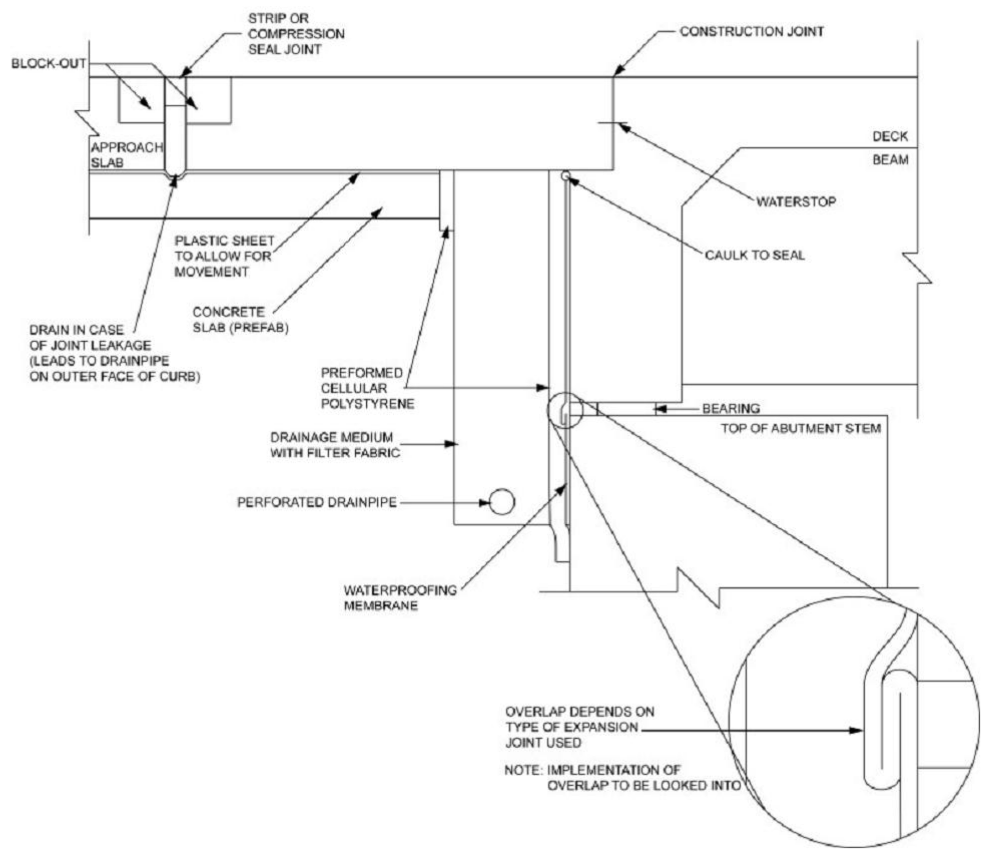
Parapet Abutment – Without Backwall

- Single layer of membrane at top of abutment stem area
- Joint is visually accessible
- Compression or Strip seal based on span and skew of deck
- Full height drainage layer with filter fabric



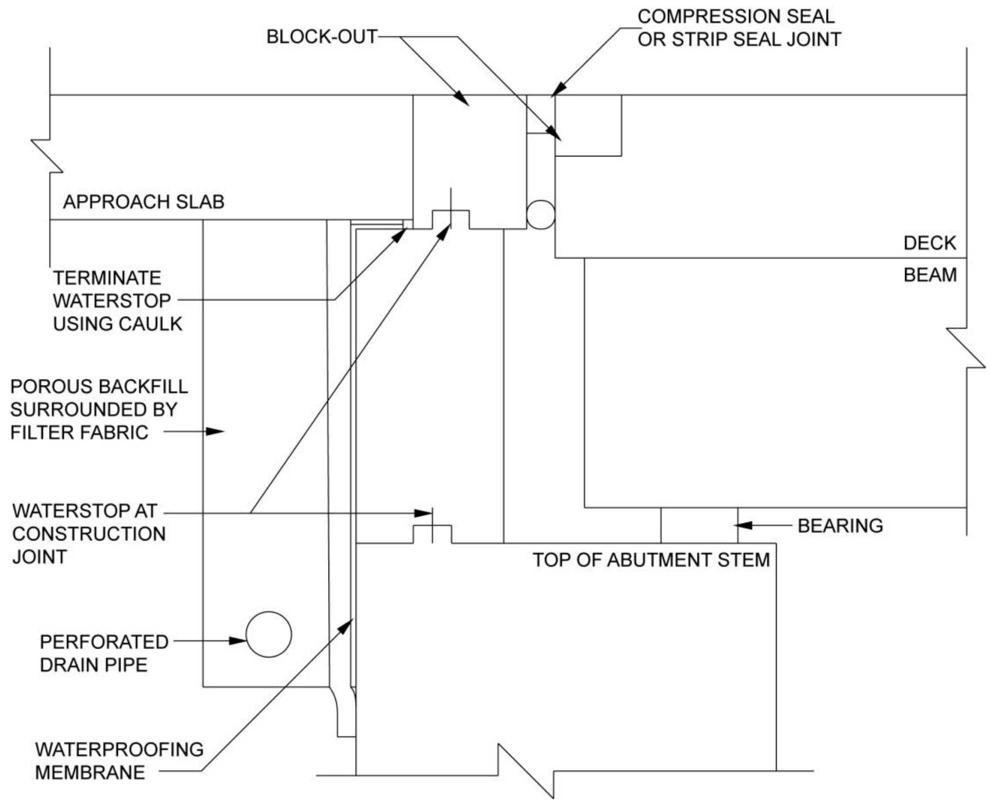
Parapet Abutment – Without Backwall

- Expansion Joint moved away from the abutment
- Joint is visually accessible
- Compression or Strip seal based on span and skew of deck
- Waterstop at all construction joints
- Full height drainage layer with filter fabric
- Requires higher levels of construction quality



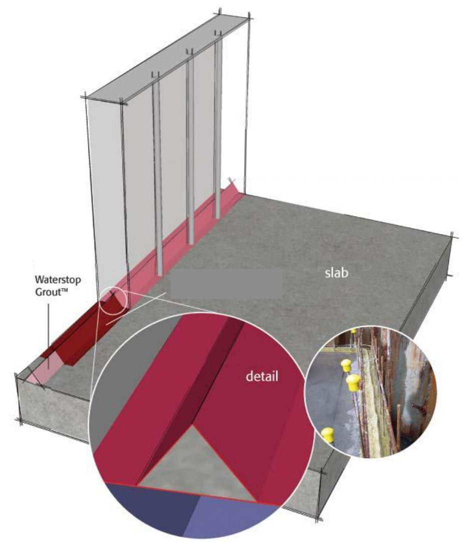
Parapet Abutment – With Backwall

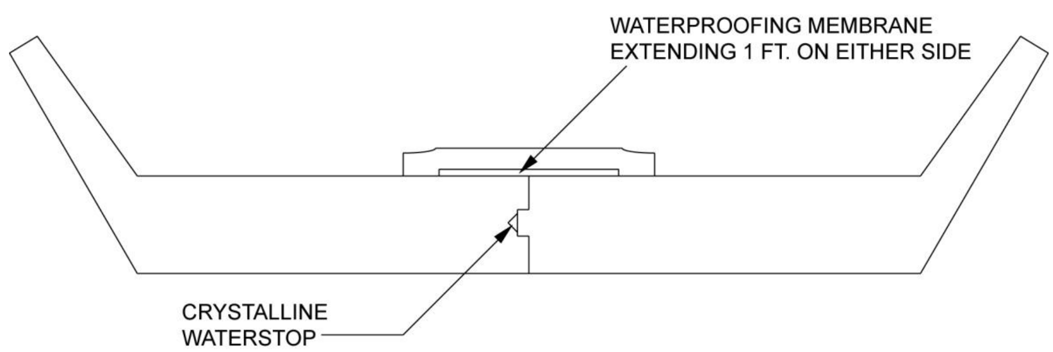
- Idea is to be able to predict source of leakage
- Joint is visually accessible
- Compression or Strip seal based on span and skew of deck
- Waterstop at all construction joints
- Full height drainage layer with filter fabric



Construction joint (in abutment)

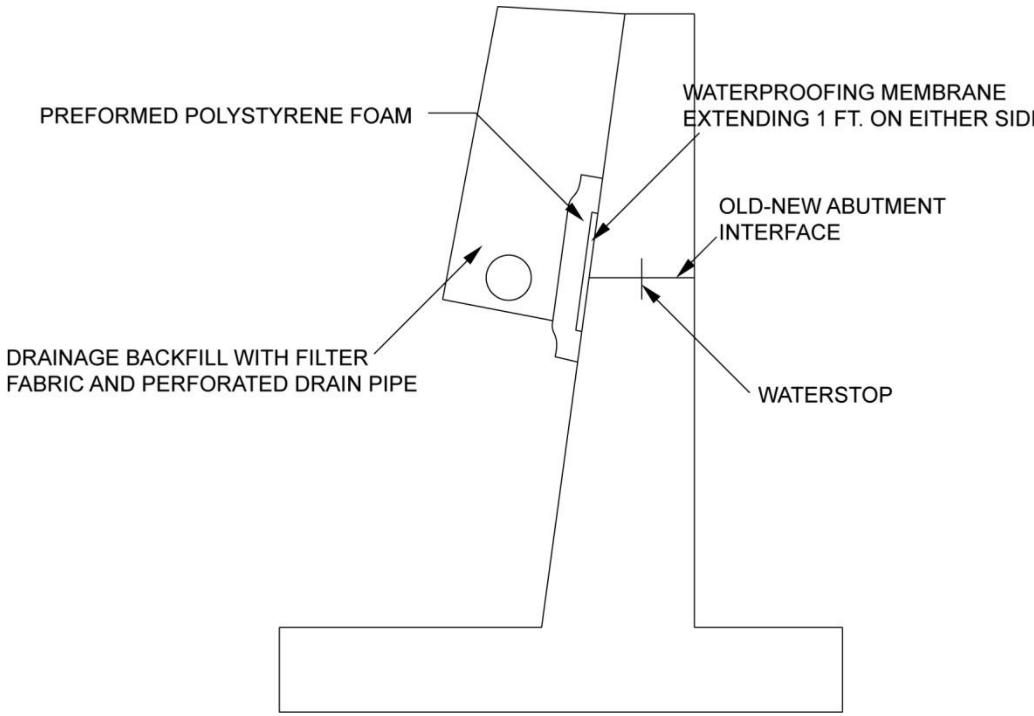
- PVC waterstop difficult to install – highly dependent on worker skill
- Crystalline waterstop suggested
- Waterproofing membrane suggested for full length (along with preformed cellular polystyrene) for redundancy





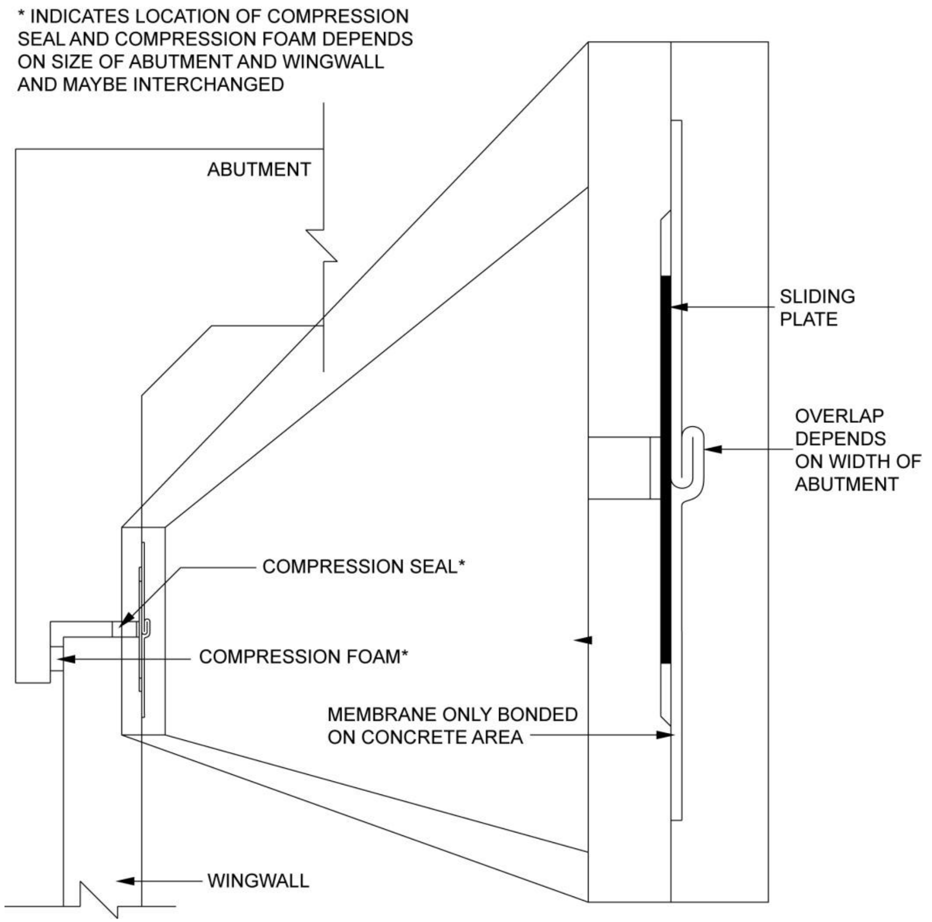
Old – New Concrete Interface

- Drainage backfill along with waterproofing membrane and waterstop for redundancy
- PVC waterstop installation to be further researched – Alternatively can use crystalline waterstop



Abutment – Wingwall Joint

- Primarily in integral abutments
- Waterproofing membrane with overlap
- Positioning of compression seal and foam depend on angle and size abutment and wingwall

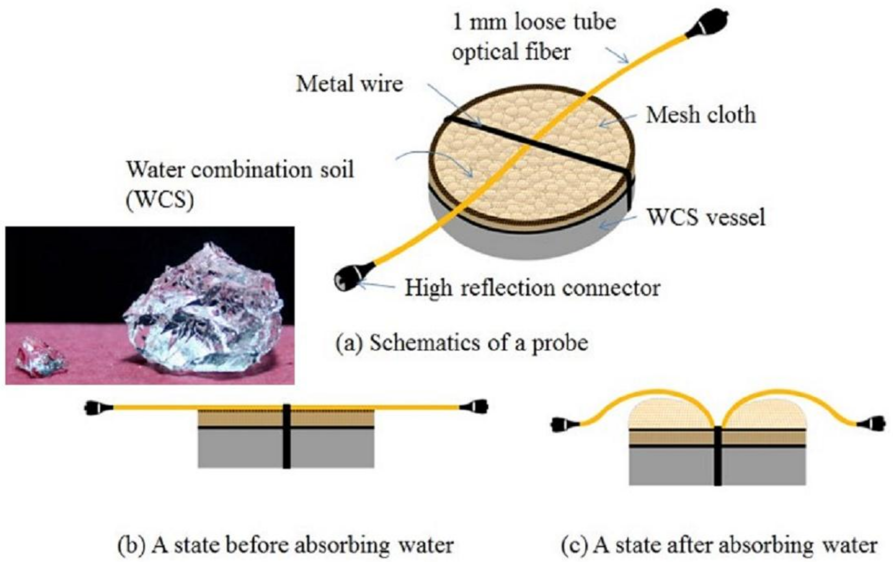


Monitoring Recommendations

- Based on issues encountered during field visits
- Based on currently available technology
- Fiber optics based testing
  - Optical Fiber Sensor
  - Evanescent Field Fiber Loop Ringdown (EF-FLRD)
- Strain gauge monitoring

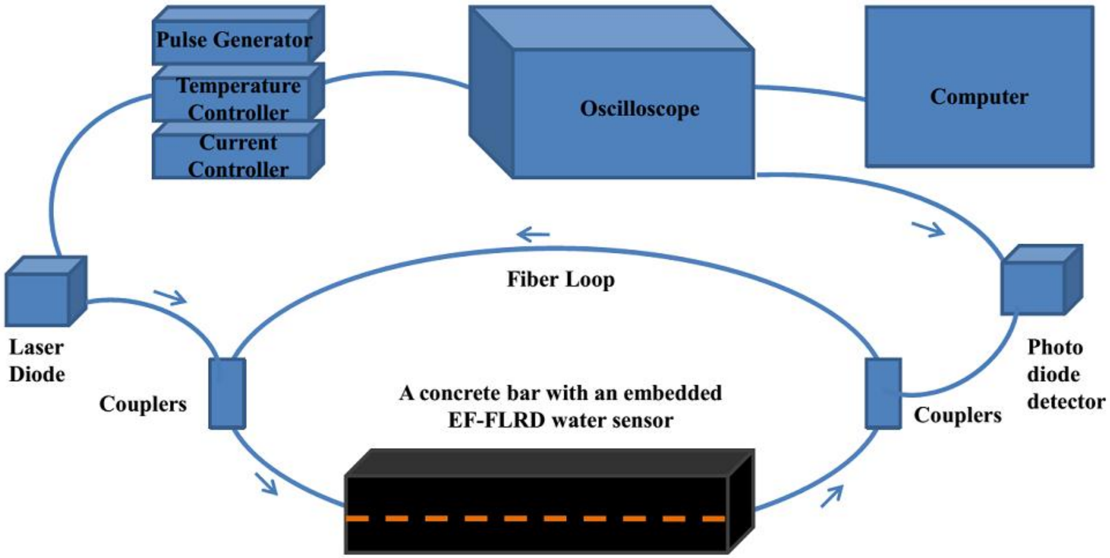
Optical Fiber Sensor

- Based on change of volume of a water absorption material
- One time use to detect leakage – does not require immediate recording of data



Evanescent Field Fiber Loop Ringdown (EF-FLRD)

- Change in water content will affect optical refractive index of fiber loop
- Reusable and thus can be used for monitoring – needs timely attention in collection of data



Strain Gauge Monitoring

- Can be used to measure expansion joint opening
- To assess prediction of joint opening (especially for Compression seal joint) and verify with actual joint opening
- Many ways to go about this – mature technology

Concluding Remarks

- Selection of compression seal or strip seal depends on various factors
- Block-out a very important parameter; Needs further research with elastomeric concrete, reinforced concrete, etc.
- Backwall recommended to be used – reduces source of leakage to only joint
- Monitoring needed to find out if poor construction is the cause of leakage or if inadequate design is the cause

University of Pittsburgh

Questions or Comments

Thank you