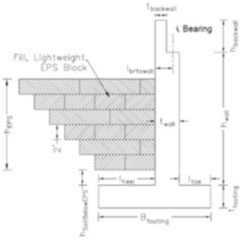
Design of Highway Bridge Abutments and Foundations



Upul Attanayake, Ph.D., P.E.
Professor
Director, MDOT Center of Excellence for Structural Durability

Yufeng Hu, Ph.D., P.E.
Master Faculty Specialist

Michigan Department of Transportation

Center for Technology & Training

SCHEDULE

1:00 – 1:15 Welcome, introduction, and workshop overview

1:15 – 2:00 Abutments with Spread Footings and Piles (Part I)

- Preliminary Abutment Dimensions
- Application of Dead Load
- Application of Live Load
- Application of Other Loads
- Combined Load Effects
- Geotechnical Design of the Footing

2:00 – 2:15 Break

SCHEDULE

2:15 –3:00 Abutments with Spread Footings and Piles (Part II)

- Backwall Design
- Abutment Wall Design
- Structural Design of the Spread Footing
- Pile Size and Layout Design
- Pile Capacity Check
- Structural Design of the Footing Supported by Piles

3:00 – 3:15 Break

SCHEDULE

3:15 – 4:00 Abutment with EPS Backfill and Spread Footing

- Preliminary Abutment Dimensions
- Application of Dead Load
- Application of Live Load
- Application of Other Loads
- Combined Load Effects
- Abutment Wall Design
- Structural Design of the Footing

4:00 – 4:15 Discussions and Q/A

4:15 – 4:30 Evaluation and adjournment

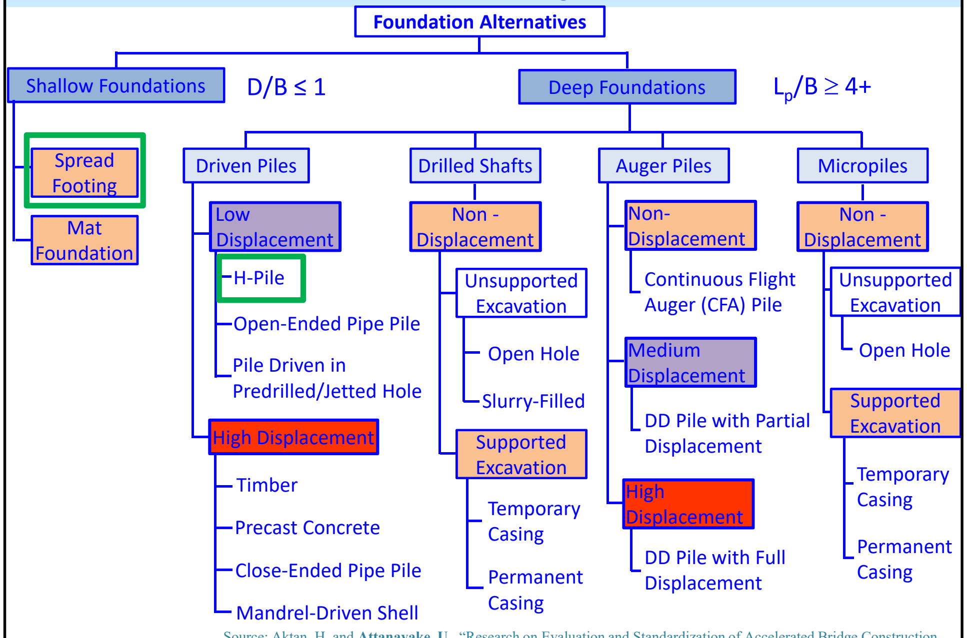
OBJECTIVE

- ❑ Design examples to demonstrate the flow of formulations and decisions that are executed during bridge substructure design.
- ❑ The design is implemented in accordance with the Michigan Department of Transportation (MDOT) policies published as of 09/30/2022.
- ❑ The requirements of the 9th Edition of the AASHTO LRFD Bridge Design Specification; as modified and supplemented by the Bridge Design Manual (BDM), Bridge Design Guides (BDG), and 2020 Standard Specifications for Construction (SSFC); are followed.
- ❑ Certain material and design parameters are selected to be in compliance with MDOT practice reflected in the Bridge Design System (BDS), the MDOT legacy software.

Abutment Types

- ❑ The function of a bridge abutment is to transfer superstructure loads to the foundation.
- ❑ Abutment types (BDM 7.03.01B)
  - ❑ **Cantilever abutment**
  - ❑ Counterfort abutment
  - ❑ Curtainwall abutment (BDG 5.18.01)
  - ❑ Integral and semi-integral abutment (BDG 6.20.04)
  - ❑ Spill-through abutment

Foundation Types



Foundation Alternatives

- Shallow Foundations D/B ≤ 1
  - Spread Footing
  - Mat Foundation
- Deep Foundations $L_p/B \geq 4+$
  - Driven Piles
    - Low Displacement
      - H-Pile
      - Open-Ended Pipe Pile
      - Pile Driven in Predrilled/Jetted Hole
    - High Displacement
      - Timber
      - Precast Concrete
      - Close-Ended Pipe Pile
      - Mandrel-Driven Shell
  - Drilled Shafts
    - Non - Displacement
      - Unsupported Excavation
        - Open Hole
        - Slurry-Filled
      - Supported Excavation
        - Temporary Casing
        - Permanent Casing
  - Auger Piles
    - Non-Displacement
      - Continuous Flight Auger (CFA) Pile
    - Medium Displacement
      - DD Pile with Partial Displacement
    - High Displacement
      - DD Pile with Full Displacement
  - Micropiles
    - Non - Displacement
      - Unsupported Excavation
        - Open Hole
      - Supported Excavation
        - Temporary Casing
        - Permanent Casing

DD - Drilled Displacement

Source: Aktan, H. and **Attanayake, U.**, "Research on Evaluation and Standardization of Accelerated Bridge Construction Techniques," *MDOT RC-1618A*, Report to the Michigan Department of Transportation, Lansing, MI, September 2015.

DESIGN EXAMPLE FORMAT

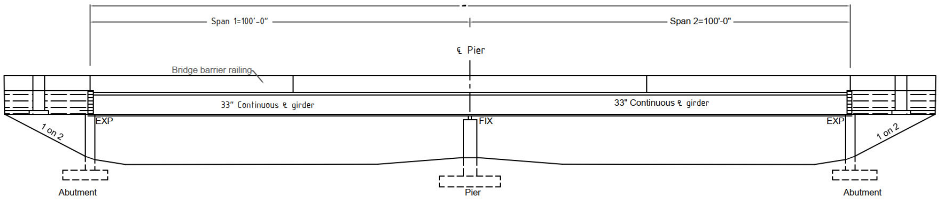
User Input

Design Check

Reference(s)

Bridge design span length	$L_{span} := 100 \cdot ft$	
Number of beams	$N_{beams} := 7$	
Beam spacing	$BeamSpacing := 9ft + 8.625in = 9.72\,ft$	
Out-to-out deck width	$W_{deck} := 63.75ft$	
Roadway clear width	$Rdwy_{width} := 60.5 \cdot ft$	
Number of design traffic lanes per roadway	$N_{lanes} := floor\left(\frac{Rdwy_{width}}{12 \cdot ft}\right) = 5$	**LRFD 3.6.1.1.1**
Deck slab thickness	$t_{Deck} := 9in$	**BDM 7.02.08**
Resistance factor for sliding	$\phi_{\tau} := 0.8$	**BDM 7.03.02.F, LRFD Table 10.5.5.5.2-1**
Sliding resistance	$V_{resistance} := \phi_{\tau} \cdot \mu \cdot F_{VFtLC1StrIMin} = 16.65 \cdot \frac{kip}{ft}$	
Check if $V_{resistance} > V_{sliding}$	$Check := if\left(V_{resistance} > V_{sliding}, \text{"OK"}, \text{"Not OK"}\right) = \text{"OK"}$	

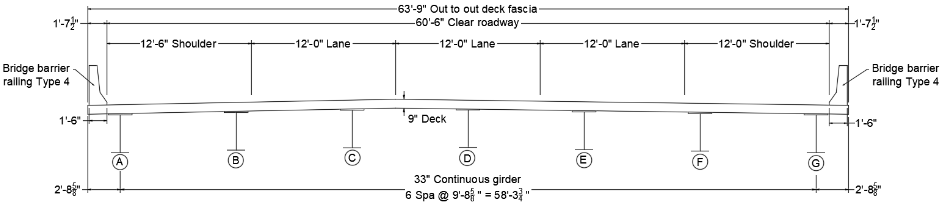
BRIDGE GEOMETRY AND COMPONENTS



Bridge elevation: 2-Span continuous bridge

The example illustrates the design of the abutment of a zero skew, 200 ft long, two-span, continuous, interstate freeway bridge crossing a highway.

BRIDGE GEOMETRY AND COMPONENTS



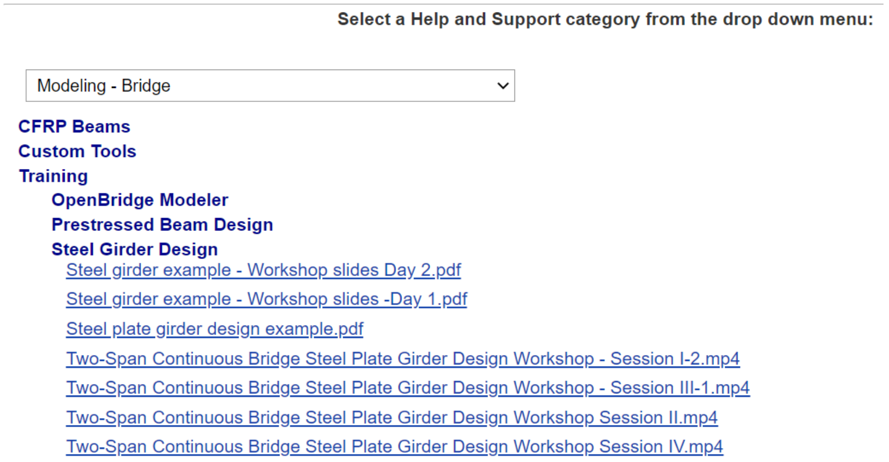
Bridge cross-section

- ❑ Steel plate girders
- ❑ Number of girders: 7
- ❑ Number of 12 ft wide lanes: 3 (5 design lanes)
- ❑ Shoulder width: 12 ft – 6 in. and 12 ft – 0 in.
- ❑ Overhang: 2 ft – 6.125 in.

BRIDGE GEOMETRY AND COMPONENTS

The superstructure design can be found at

https://mdotjboss.state.mi.us/SpecProv/trainingmaterials.htm#2108560



Select a Help and Support category from the drop down menu:

Modeling - Bridge

CFRP Beams

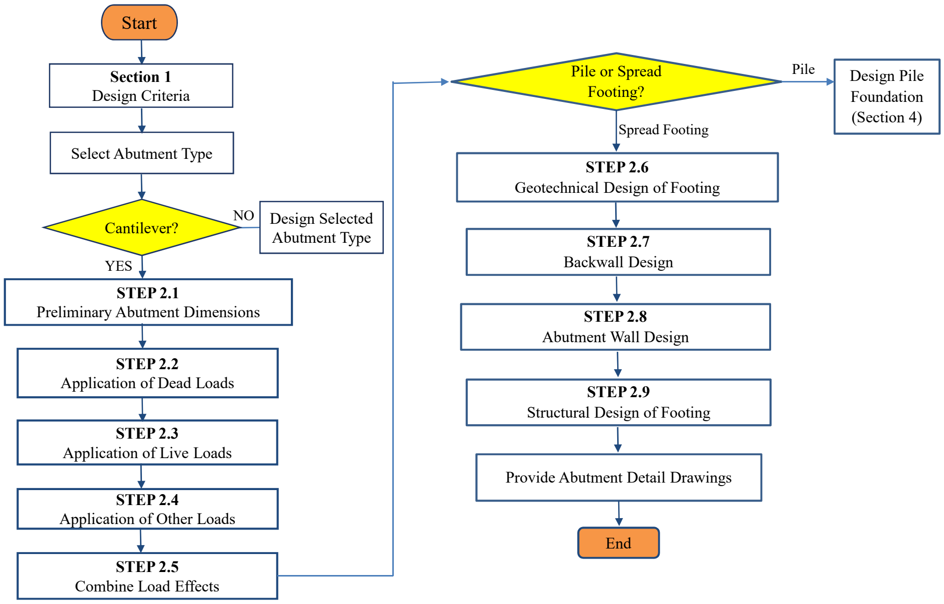
Custom Tools

Training

- **OpenBridge Modeler**
- **Prestressed Beam Design**
- **Steel Girder Design**
  - Steel girder example - Workshop slides Day 2.pdf
  - Steel girder example - Workshop slides -Day 1.pdf
  - Steel plate girder design example.pdf
  - Two-Span Continuous Bridge Steel Plate Girder Design Workshop - Session I-2.mp4
  - Two-Span Continuous Bridge Steel Plate Girder Design Workshop - Session III-1.mp4
  - Two-Span Continuous Bridge Steel Plate Girder Design Workshop Session II.mp4
  - Two-Span Continuous Bridge Steel Plate Girder Design Workshop Session IV.mp4

Cited in this example as the *Steel Plate Girder Design Example*.

DESIGN EXAMPLE MAIN FLOWCHART



Start

Section 1
Design Criteria

Select Abutment Type

Cantilever?

NO

Design Selected Abutment Type

YES

STEP 2.1
Preliminary Abutment Dimensions

STEP 2.2
Application of Dead Loads

STEP 2.3
Application of Live Loads

STEP 2.4
Application of Other Loads

STEP 2.5
Combine Load Effects

Pile or Spread Footing?

Pile

Design Pile Foundation (Section 4)

Spread Footing

STEP 2.6
Geotechnical Design of Footing

STEP 2.7
Backwall Design

STEP 2.8
Abutment Wall Design

STEP 2.9
Structural Design of Footing

Provide Abutment Detail Drawings

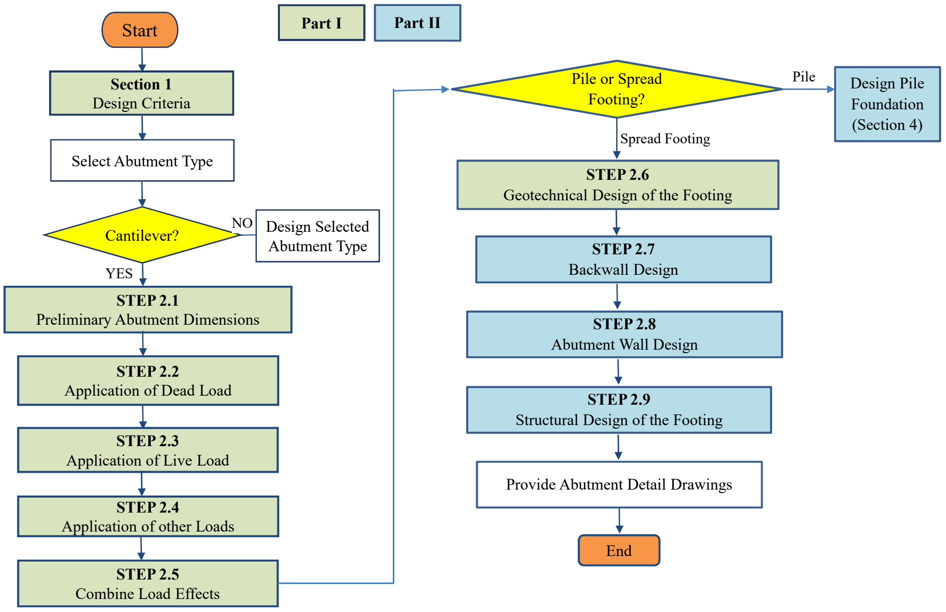
End

SCHEDULE

Abutments with Spread Footings and Piles (Part I)

- Preliminary Abutment Dimensions
- Application of Dead Load
- Application of Live Load
- Application of Other Loads
- Combined Load Effects
- Geotechnical Design of the Footing

DESIGN EXAMPLE MAIN FLOWCHART



DESIGN CRITERIA

Section 1
Design Criteria

Page 5

Material properties:

- Concrete 28-day compressive strength f_c' = 3000 psi
- Reinforcing steel yield strength f_y = 60 ksi

Soil properties:

- Sands
- No groundwater

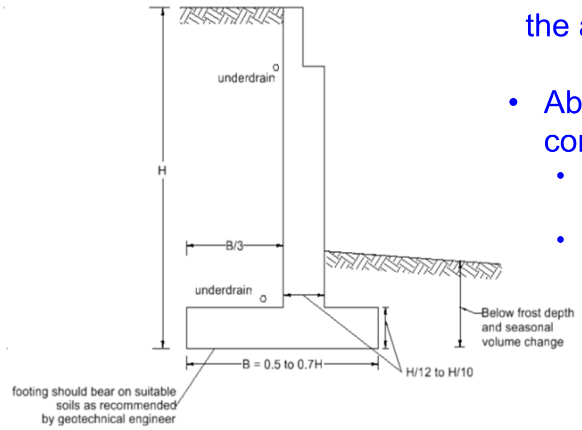
Backfill soil properties:

- Unit weight = 120 pcf
- Coefficient of active earth pressure = 0.3

PRELIMINARY ABUTMENT DIMENSIONS

STEP 2.1
Preliminary Abutment Dimensions

Page 10



- “Rule of thumb” guidelines of the abutment dimension
- Abutment wall thickness is controlled by the need to fit
  - bearings and anchor bolts with adequate edge distances
  - one or more rows of piles or drilled shafts with sufficient spacing and edge distance.

PRELIMINARY ABUTMENT DIMENSIONS

STEP 2.1
Preliminary Abutment Dimensions

Page 11

Minimum requirements in BDM

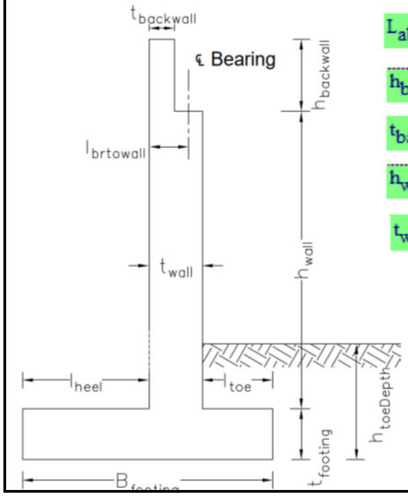
- The minimum wall thickness for abutments is 2 ft. **BDM 7.03.01C**
- The minimum footing thickness is normally 2 ft - 6 in. When the wall thickness at its base becomes 3 ft or greater, the footing thickness is to be increased to 3 ft. **BDM 7.03.02A**
- The minimum footing width is 6 ft for cantilever abutments. **BDM 7.03.01B**

PRELIMINARY ABUTMENT DIMENSIONS

STEP 2.1
Preliminary Abutment Dimensions

Page 12

Preliminary dimensions of the cantilever abutment with an independent backwall.



$L_{abut} := W_{deck} = 63.75\,\text{ft}$

$l_{toe} := 4\text{ft} + 7\text{in} = 4.58\,\text{ft}$

$h_{backwall} := 4.25\text{ft}$

$l_{heel} := 9\text{ft} + 3\text{in} = 9.25\,\text{ft}$

$t_{backwall} := 1.5\text{ft}$

$l_{brtowall} := 2\text{ft} + 4\text{in} = 2.33\,\text{ft}$

$h_{wall} := 17.54\text{ft}$

$t_{wall} := 3\text{ft} + 2\text{in} = 3.17\,\text{ft}$

$B_{footing} := l_{toe} + l_{heel} + t_{wall} = 17\,\text{ft}$

$L_{footing} := 65.75\text{ft}$

$t_{footing} := 3\text{ft}$

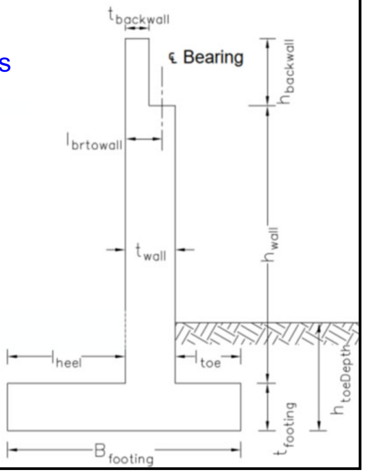
$h_{toeDepth} := 7\text{ft}$

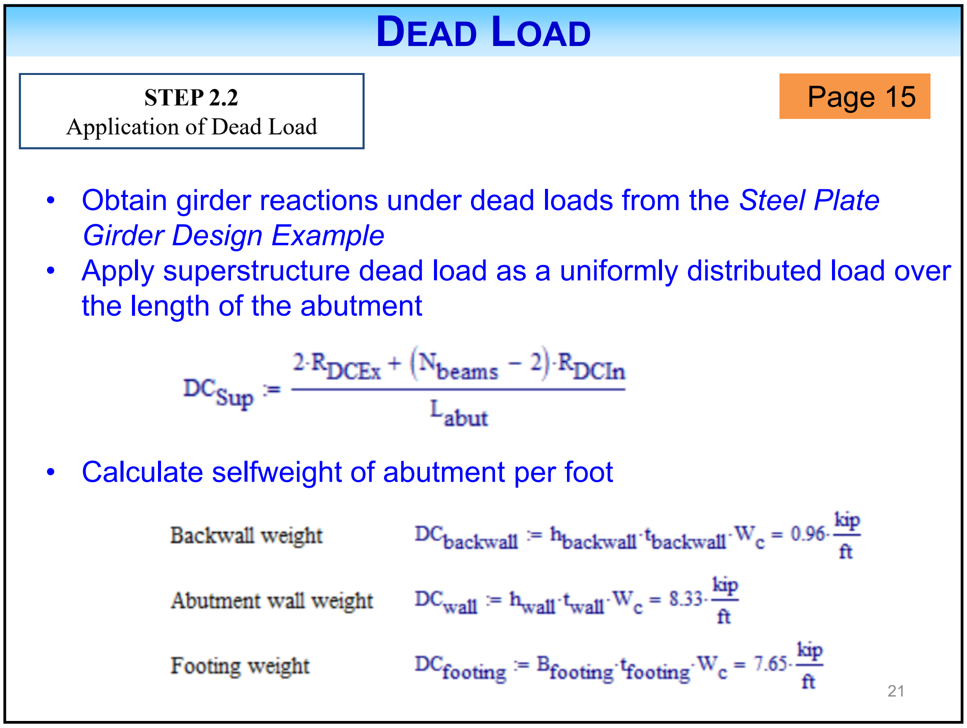
LOADS CASES FOR ANALYSIS

BDM 7.03.01

- Case I - abutment built and backfilled to grade
- Case II - bridge open to traffic with traffic loading on the approach only
- Case III - bridge with traffic on it and no load on approach
- Case IV - loading from Case II plus the effects of temperature contraction in the deck transmitted to the abutment.

Since Case IV always governs over Case II for this abutment, only Cases I, III, and IV are considered in the design example.





DEAD LOAD

STEP 2.2
Application of Dead Load

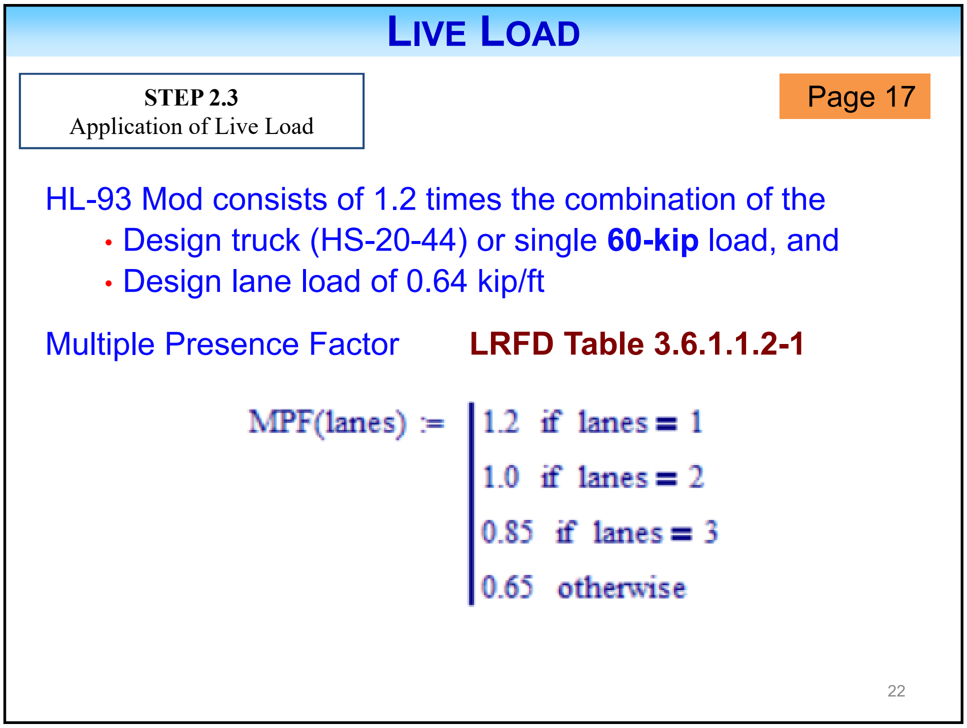
Page 15

- Obtain girder reactions under dead loads from the *Steel Plate Girder Design Example*
- Apply superstructure dead load as a uniformly distributed load over the length of the abutment

$$DC_{Sup} := \frac{2 \cdot R_{DCEx} + \left(N_{beams} - 2\right) \cdot R_{DCIn}}{L_{abut}}$$

- Calculate selfweight of abutment per foot

Backwall weight	$DC_{backwall} := h_{backwall} \cdot t_{backwall} \cdot W_c = 0.96 \cdot \frac{kip}{ft}$
Abutment wall weight	$DC_{wall} := h_{wall} \cdot t_{wall} \cdot W_c = 8.33 \cdot \frac{kip}{ft}$
Footing weight	$DC_{footing} := B_{footing} \cdot t_{footing} \cdot W_c = 7.65 \cdot \frac{kip}{ft}$



LIVE LOAD

STEP 2.3
Application of Live Load

Page 17

HL-93 Mod consists of 1.2 times the combination of the

- Design truck (HS-20-44) or single **60-kip** load, and
- Design lane load of 0.64 kip/ft

Multiple Presence Factor **LRFD Table 3.6.1.1.2-1**

$$MPF(lanes) := \begin{cases} 1.2 & \text{if } lanes = 1 \\ 1.0 & \text{if } lanes = 2 \\ 0.85 & \text{if } lanes = 3 \\ 0.65 & \text{otherwise} \end{cases}$$

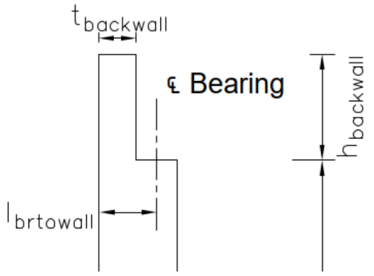
LIVE LOAD

STEP 2.3
Application of Live Load

Page 17

Live load on the backwall

- Live load on the bridge: No impact on the independent backwall
- Live load on the approach: represented as a live load surcharge. Results in a lateral load on the backwall (calculated later).



LIVE LOAD

STEP 2.3
Application of Live Load

Page 17

Live load on the abutment walls

- Live load on the bridge

  Obtain girder reactions under one-lane live load from the *Steel Plate Girder Design Example.* The controlling live load case is all five lanes loaded.

  $$\text{lanes} := 5 \qquad R_{LLWall5} := \frac{\text{lanes}\cdot\left(V_{TruckMax} + V_{LaneMax}\right)\cdot f_{HL93Mod}\cdot MPF(\text{lanes})}{L_{abut}}$$

  Note: Even though the LRFD Specifications recommend including the dynamic impact of live load in the design of substructures that are not completely buried, the current MDOT practice excludes it from the design of bridge abutments.

- Live load on the approach: represented as a live load surcharge. Results in a lateral load on the abutment wall (calculated later).

LIVE LOAD

STEP 2.3
Application of Live Load

Page 18

Live load on the footing

- Live load on the bridge

  Dynamic impact is excluded. **LRFD 3.6.2.1**

  All five loaded lanes control the design.

$$R_{LLFooting5} := \frac{lanes \cdot (V_{TruckMax} + V_{LaneMax}) \cdot f_{HL93Mod} \cdot MPF(lanes)}{L_{footing}}$$

- Live load on the approach
  Results in a lateral load and a vertical downward load on the footing.

OTHER LOAD

STEP 2.4
Application of Other Loads

- Braking force – not considered (see slide 26)
- Wind load – not considered (see slide 27)
- Earth load – lateral and vertical components
- Live load surcharge on the bridge approach
- Temperature load

  45^0 F drop and 35^0 F rise from the construction.

OTHER LOAD

STEP 2.4
Application of Other Loads

Page 20

Braking force

- Abutments have expansion bearings. The braking force is resisted by the pier with fixed bearings.
- Practices are different when dealing with the moment caused by braking force applied at 6 ft above the bridge deck.

OTHER LOAD

STEP 2.4
Application of Other Loads

Page 20

Wind load

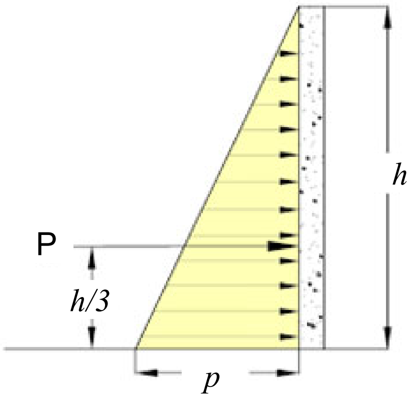
- Abutments have expansion bearings. The longitudinal component of wind load is resisted by the pier with fixed bearings.
- The transverse component of wind load is usually small and does not impact the design of an abutment. MDOT practice is to neglect the wind load on abutments.
- For illustrative purposes, the wind load calculation is included in Appendix 2.A.

OTHER LOAD

STEP 2.4
Application of Other Loads

Page 20

Lateral earth load



$$p = k_a \gamma_s h$$ **LRFD Eq. 3.11.5.1-1**

$$P = \frac{1}{2} p h$$

OTHER LOAD

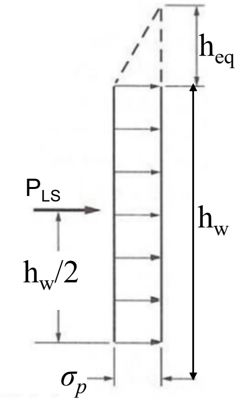
STEP 2.4
Application of Other Loads

Page 21

Live load surcharge

Table 3.11.6.4-1—Equivalent Height of Soil for Vehicular Loading on Abutments Perpendicular to Traffic

Abutment Height (ft)	h_{eq} (ft)
5.0	4.0
10.0	3.0
≥20.0	2.0



Height of the abutment = 24.8 ft, h_{eq} = 2 ft

$$\sigma_p = k_a \gamma_s h_{eq}$$

$$P_{LS} = \sigma_p h_w$$

OTHER LOAD

STEP 2.4
Application of Other Loads

Page 21

Temperature load

- 45^0 F drop and 35^0 F rise from construction
- Bridge superstructure deformation $\Delta_T := \alpha \cdot L_{span} \cdot T_{Range}$
- Horizontal force transmitted through an elastomeric expansion bearing

$$H_{bu} = GA\frac{\Delta_u}{h_{rt}}$$

LRFD Eq. 14.6.3.1-2

The force acting on a bearing due to superstructure contraction

$$H_{buContr} := \frac{G_{bearing} \cdot A_{bearing} \cdot \Delta_{TContr}}{h_{rt}} = 2.53 \cdot kip$$

Total force acting on the abutment due to superstructure contraction

$$TU_{Contr} := \frac{N_{beams} \cdot H_{buContr}}{L_{abut}} = 0.28 \cdot \frac{kip}{ft}$$

LOAD COMBINATION

STEP 2.5
Combined Load Effects

Page 24

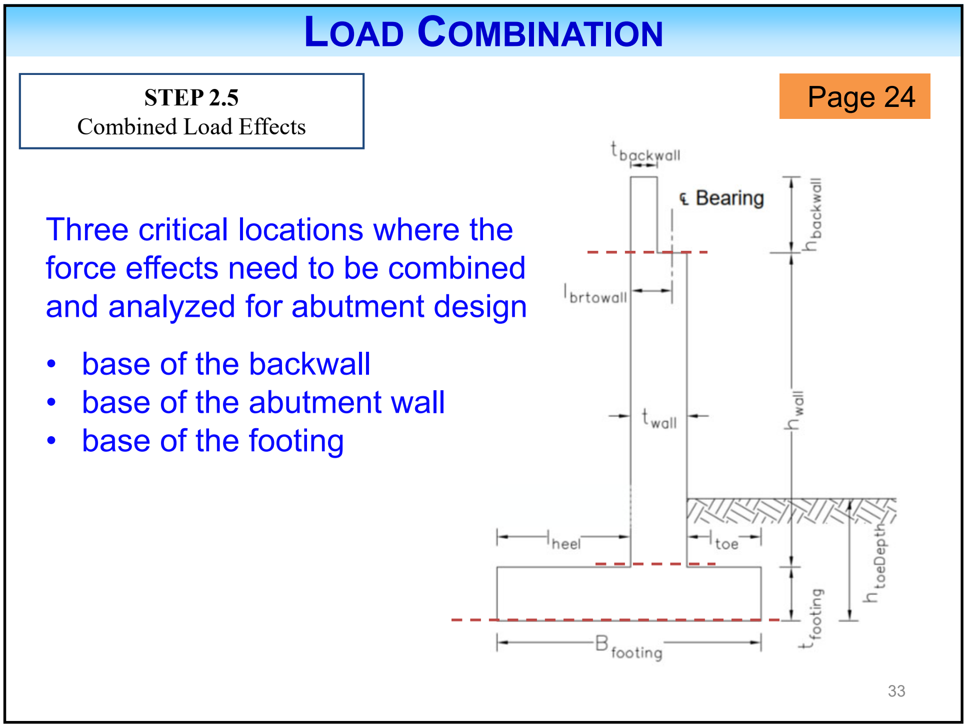
Strength I = 1.25DC + 1.5DW + 1.75LL + 1.75BR + 1.5EH + 1.35EV + 1.75LS + 0.5TU

Strength III = 1.25DC + 1.5DW + 1.5EH + 1.35EV + 1.0WS + 0.5TU

Strength V = 1.25DC + 1.5DW + 1.35LL + 1.35BR + 1.0WS + 1.0WL + 1.5EH + 1.35EV + 1.35LS + 0.5TU

Service I = 1.0DC + 1.0DW + 1.0LL + 1.0BR + 1.0WS + 1.0WL + 1.0EH + 1.0EV + 1.0LS + 1.0TU

Since wind load is not considered for abutment design, only Strength I and Service I limit states are considered.



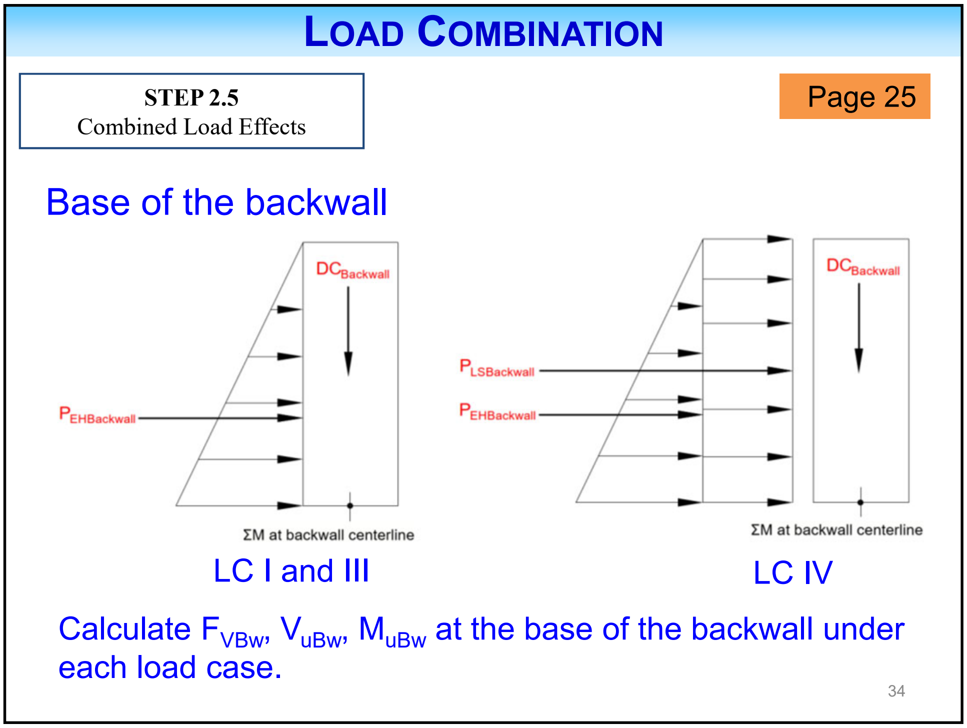
LOAD COMBINATION

STEP 2.5
Combined Load Effects

Page 24

Three critical locations where the force effects need to be combined and analyzed for abutment design

- base of the backwall
- base of the abutment wall
- base of the footing



LOAD COMBINATION

STEP 2.5
Combined Load Effects

Page 25

Base of the backwall

LC I and III

LC IV

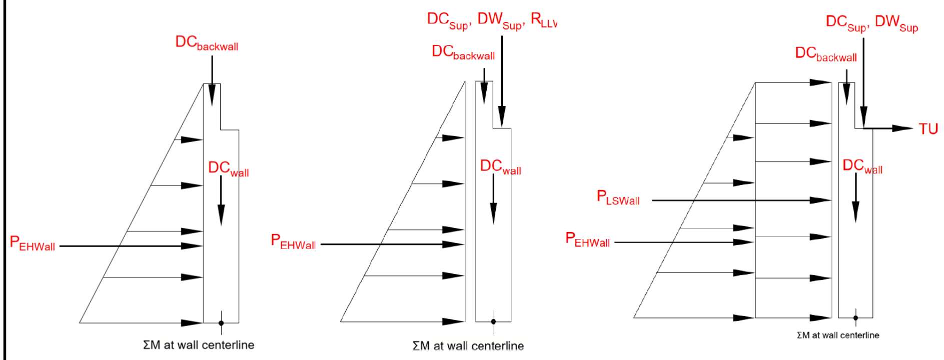
Calculate F_{VBw}, V_{uBw}, M_{uBw} at the base of the backwall under each load case.

LOAD COMBINATION

STEP 2.5
Combined Load Effects

Page 27

Base of the abutment wall



LC I LC III LC IV

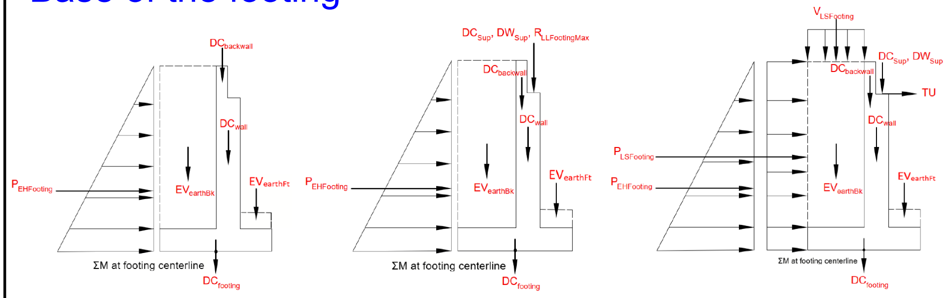
Calculate F_{VWall}, V_{uWall}, M_{uWall} at the base of the abutment wall under each load case.

LOAD COMBINATION

STEP 2.5
Combined Load Effects

Page 31

Base of the footing



LC I LC III LC IV

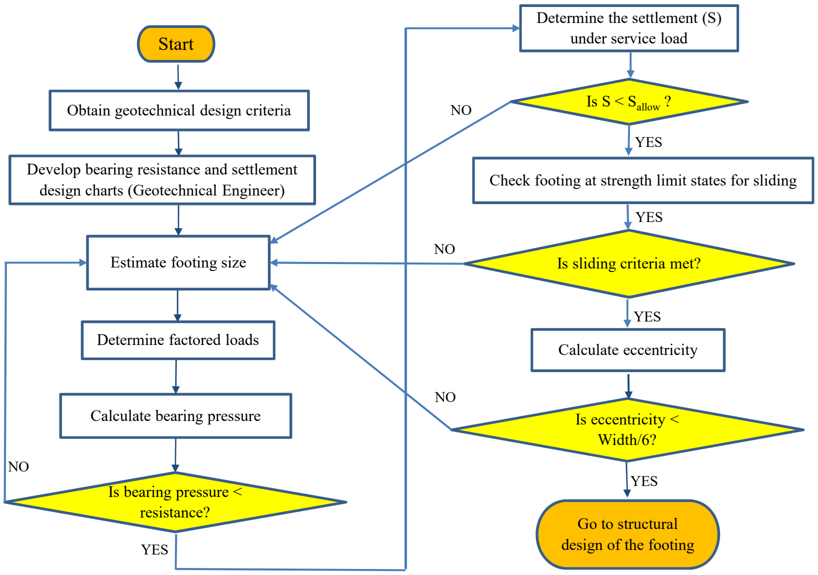
Calculate F_{VFt}, V_{uFt}, M_{uFt} at the base of the backwall under each load case.

Use the minimum load factor for EV when calculating M_{uFt}.

GEOTECHNICAL DESIGN OF FOOTING

STEP 2.6 Geotechnical Design of the Footing

Page 36



Start

Obtain geotechnical design criteria

Develop bearing resistance and settlement design charts (Geotechnical Engineer)

Estimate footing size

Determine factored loads

Calculate bearing pressure

Is bearing pressure < resistance?

NO

YES

Determine the settlement (S) under service load

Is $S < S_{allow}$?

NO

YES

Check footing at strength limit states for sliding

YES

Is sliding criteria met?

NO

YES

Calculate eccentricity

Is eccentricity < Width/6?

NO

YES

Go to structural design of the footing

GEOTECHNICAL DESIGN

STEP 2.6 Geotechnical Design of the Footing

LRFD 10.6.1.1

Geotechnical design of a spread footing considers the following strength and serviceability limit states:

- Bearing resistance – strength limit state
- Settlement – service limit state
- Sliding resistance – strength limit state
- Load eccentricity (overturning) – strength limit state

Structural engineers and geotechnical engineers need to work closely to fulfill geotechnical design requirements.

GEOTECHNICAL DESIGN

STEP 2.6 Geotechnical Design of the Footing

Page 37

Bearing resistance – strength limit state

- LRFD method

LRFD 10.6.1.1

  - Calculate eccentricities in *B* direction
  - Calculate reduced effective area *B' x L*
  - Bearing pressure assumed uniformly distributed over *B'xL*
  - Calculate bearing pressure on the reduced area under strength limit state

$$B' = B - 2e_B$$

- MDOT method
  - For each load cases under strength and service limit states, provide average bearing pressure, and the bearing pressures at the toe and heel (maximum and minimum bearing pressures) to the Geotechnical Service Section.

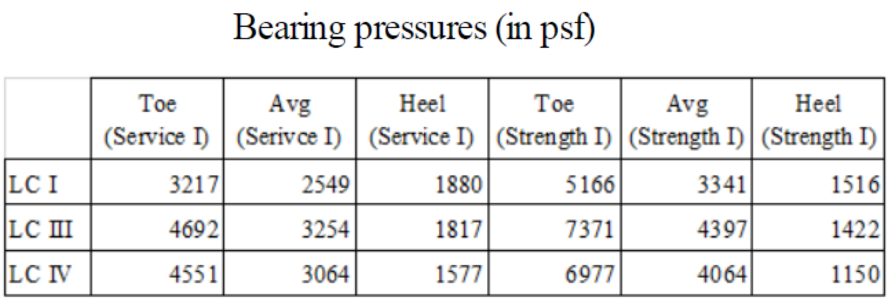
GEOTECHNICAL DESIGN

STEP 2.6 Geotechnical Design of the Footing

Page 37

Bearing resistance – strength limit state

- MDOT procedure



Bearing pressures (in psf)

	Toe (Service I)	Avg (Serivce I)	Heel (Service I)	Toe (Strength I)	Avg (Strength I)	Heel (Strength I)
LC I	3217	2549	1880	5166	3341	1516
LC III	4692	3254	1817	7371	4397	1422
LC IV	4551	3064	1577	6977	4064	1150

GEOTECHNICAL DESIGN

STEP 2.6 Geotechnical Design of the Footing

Page 41

Settlement check – service limit state

Same procedure is used to calculate bearing pressure, but the service limit state loads are used.

Allowable settlement – 1.5 in. **BDM 7.03.02G 2b**

Note: Besides the total settlement, considerations should be given to prevent the differential settlement between the abutments and pier from exceeding the tolerable differential settlement limit.

Differential settlement limits are given in the *Steel Plate Girder Design Example*.

GEOTECHNICAL DESIGN

STEP 2.6 Geotechnical Design of the Footing

Page 41

Sliding resistance check – strength limit state

$$R_R = \varphi R_n = \varphi_\tau R_\tau + \varphi_{ep} R_{ep}$$ **LRFD Eq. 10.6.3.4-1**

$R_{ep} = 0,$ Ignore passive soil pressure **BDM 7.03.02F**

$\varphi_\tau = 0.8$ **BDM 7.03.02.F** **LRFD Table 10.5.5.5.2-1**

$R_\tau = \mu V \;\; (\mu = 0.5)$

- Live load on the bridge is excluded.
- Minimum load factors are used for all vertical loads.
- Maximum load factors are used for the loads that results in horizontal sliding forces.
- For Load Case IV, consider the effects with and w/o live load surcharge.

GEOTECHNICAL DESIGN

STEP 2.6 Geotechnical Design of the Footing

Page 43

Eccentricity check – strength limit state

The eccentricity of loading at the strength limit state, evaluated based on factored loads, shall not exceed one-third of the corresponding dimension of footing on soils for stability.

LRFD 10.6.3.3

- Minimum load factors are used for all vertical loads.
- This replaces the investigation of the ratio of resisting moment to overturning moment
- For Load Case III, consider with and w/o live load
- For Load Case IV, consider with and w/o live load surcharge

---

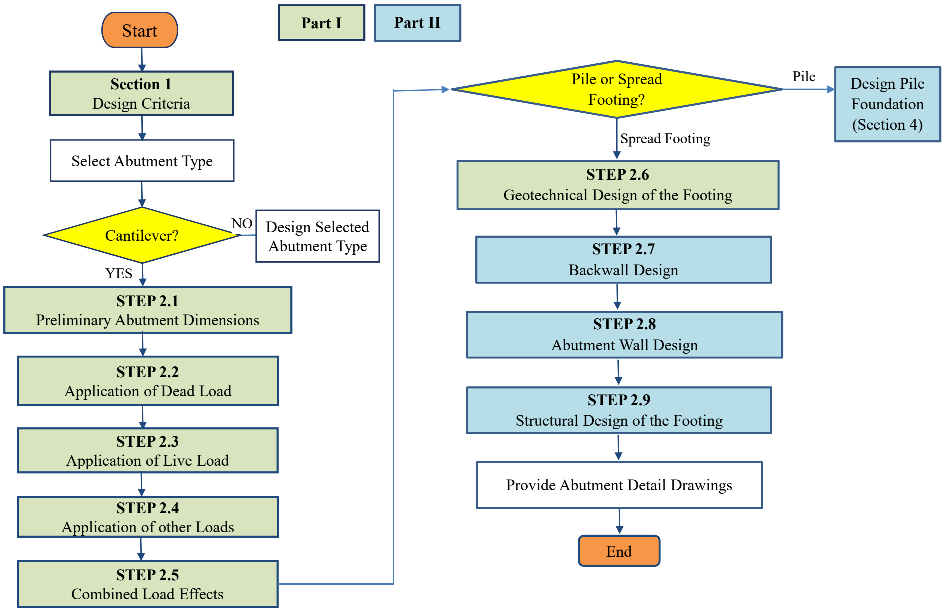
Break

SCHEDULE

Abutments with Spread Footings and Piles (Part I)

- Backwall Design
- Abutment Wall Design
- Structural Design of the Spread Footing
- Pile Size and Layout Design
- Pile Capacity Check
- Structural Design of the Footing Supported by Piles

DESIGN EXAMPLE MAIN FLOWCHART



Start

Part I

Part II

Section 1
Design Criteria

Select Abutment Type

Cantilever?

NO

Design Selected Abutment Type

YES

STEP 2.1
Preliminary Abutment Dimensions

STEP 2.2
Application of Dead Load

STEP 2.3
Application of Live Load

STEP 2.4
Application of other Loads

STEP 2.5
Combined Load Effects

Pile or Spread Footing?

Pile

Design Pile Foundation (Section 4)

Spread Footing

STEP 2.6
Geotechnical Design of the Footing

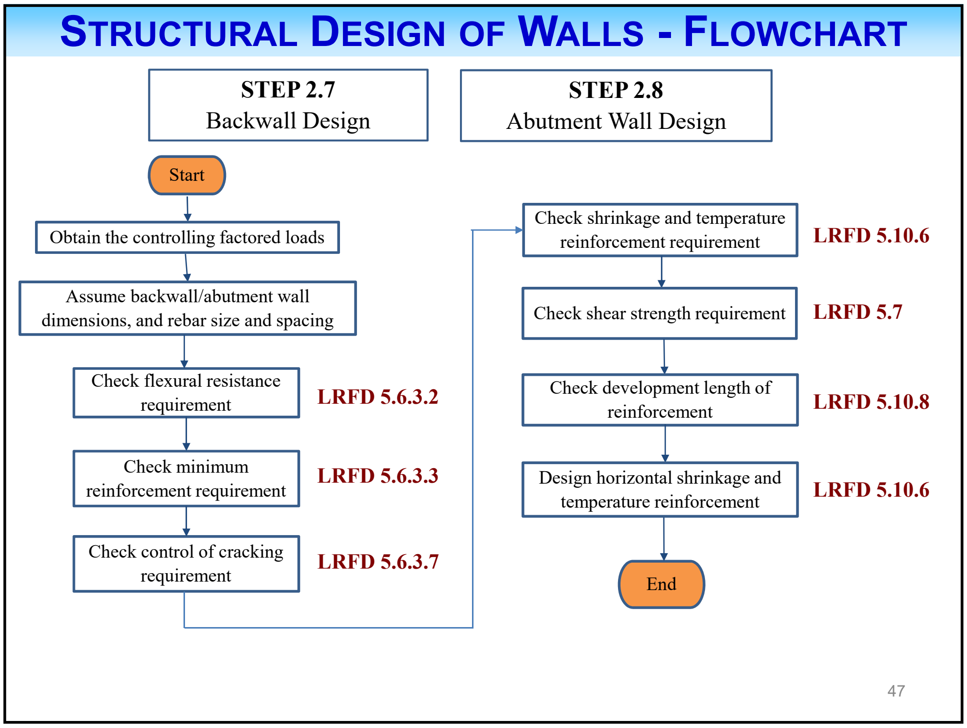
STEP 2.7
Backwall Design

STEP 2.8
Abutment Wall Design

STEP 2.9
Structural Design of the Footing

Provide Abutment Detail Drawings

End



STRUCTURAL DESIGN OF WALLS - FLOWCHART

STEP 2.7
Backwall Design

STEP 2.8
Abutment Wall Design

Start

Obtain the controlling factored loads

Assume backwall/abutment wall dimensions, and rebar size and spacing

Check flexural resistance requirement **LRFD 5.6.3.2**

Check minimum reinforcement requirement **LRFD 5.6.3.3**

Check control of cracking requirement **LRFD 5.6.3.7**

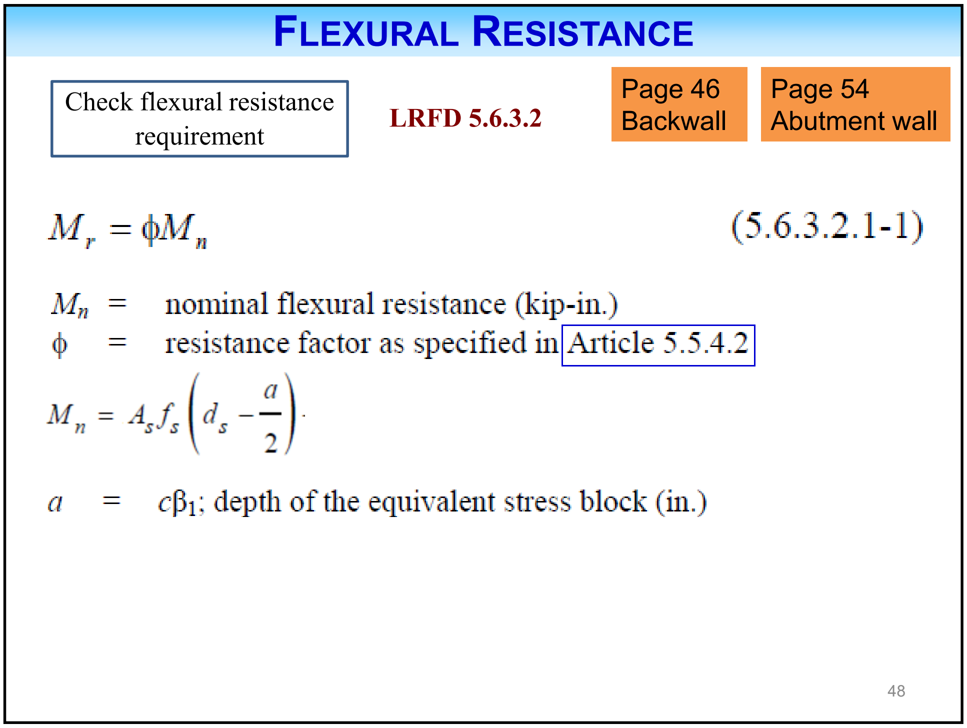
Check shrinkage and temperature reinforcement requirement **LRFD 5.10.6**

Check shear strength requirement **LRFD 5.7**

Check development length of reinforcement **LRFD 5.10.8**

Design horizontal shrinkage and temperature reinforcement **LRFD 5.10.6**

End



FLEXURAL RESISTANCE

Check flexural resistance requirement

LRFD 5.6.3.2

Page 46
Backwall

Page 54
Abutment wall

$$M_r = \phi M_n \qquad (5.6.3.2.1\text{-}1)$$

M_n = nominal flexural resistance (kip-in.)

ϕ = resistance factor as specified in Article 5.5.4.2

$$M_n = A_s f_s \left(d_s - \frac{a}{2}\right).$$

a = $c\beta_1$; depth of the equivalent stress block (in.)

MINIMUM REINFORCEMENT

Check minimum reinforcement requirement

LRFD 5.6.3.3

Page 48
Backwall

Page 57
Abutment wall

The tensile reinforcement provided must be adequate to develop a factored flexural resistance at least equal to the lesser of

- 1.33 times the factored moment required by the applicable strength load combination specified in Table 3.4.1-1;
- $$M_{cr} = \gamma_3\left[\left(\gamma_1 f_r + \gamma_2 f_{cpe}\right)S_c - M_{dnc}\left(\frac{S_c}{S_{nc}} - 1\right)\right] \Longrightarrow \gamma_3 \cdot \gamma_1 \cdot f_r \cdot S_c$$

(5.6.3.3-1)

CRACK CONTROL

Check control of cracking requirement

LRFD 5.6.7

Page 49
Backwall

Page 57
Abutment wall

The actual stress in the reinforcement should not exceed the service limit state stress.

$$s \le \frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c \qquad (5.6.7\text{-}1)$$

in which:

$$\beta_s = 1 + \frac{d_c}{0.7(h - d_c)} \qquad (5.6.7\text{-}2)$$

f_{ss} = calculated tensile stress in nonprestressed reinforcement at the service limit state not to exceed 0.60 f_y (ksi)

SHRINKAGE AND TEMPERATURE REINFORCEMENT

Check shrinkage and temperature reinforcement requirement

LRFD 5.10.6

Page 50 Backwall

Page 58 Abutment wall

For bars or welded wire reinforcement, the area of reinforcement per foot, on each face and in each direction, shall satisfy the following:

$$A_s \geq \frac{1.30bh}{2(b+h)f_y} \qquad (5.10.6\text{-}1)$$

except that:

$$0.11 \leq A_s \leq 0.60 \qquad (5.10.6\text{-}2)$$

where:

A_s = area of reinforcement in each direction and each face (in.^{2}/ft)
b = least width of component section (in.)
h = least thickness of component section (in.)

SHEAR STRENGTH

Check shear strength requirement

LRFD 5.7.3

Page 50 Backwall

Page 59 Abutment wall

Sectional Design Method

- Critical section is d_v from face of the support

$$d_v := \max\left(d_e - \frac{a}{2}, 0.9 \cdot d_e, 0.72 \cdot t_{wall}\right)$$

LRFD 5.7.2.8

$$V_n = V_c + V_s + V_p \qquad (5.7.3.3\text{-}1)$$

$$V_n = 0.25 f'_c b_v d_v + V_p \qquad (5.7.3.3\text{-}2)$$

in which:

$$V_c = 0.0316 \beta \lambda \sqrt{f'_c}\, b_v d_v \qquad (5.7.3.3\text{-}3)$$

β = factor indicating ability of diagonally cracked concrete to transmit tension and shear as specified in Article 5.7.3.4

SHEAR STRENGTH

Check shear strength requirement

LRFD 5.7.3

Simplified procedure

For concrete footings in which the distance from point of zero shear to the face of the column, pier, or wall is less than $3d_v$ with or without transverse reinforcement, and for other nonprestressed concrete sections not subjected to axial tension and containing at least the minimum amount of transverse reinforcement specified in Article 5.7.2.5, or having an overall depth of less than 16.0 in., the following values may be used:

$$\beta = 2.0$$

- Can't be used in the backwall and abutment wall
- Can be used in the footing

SHEAR STRENGTH

Check shear strength requirement

LRFD 5.7.3

Page 50
Backwall

Page 59
Abutment wall

General procedure

When sections do not contain at least the minimum amount of shear reinforcement, the value of β may be as specified in Eq. 5.7.3.4.2-2:

$$\beta = \frac{4.8}{(1+750\varepsilon_s)}\frac{51}{(39+s_{xe})} \qquad (5.7.3.4.2\text{-}2)$$

$$\varepsilon_s = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps}f_{po}\right)}{E_sA_s + E_pA_{ps}} \qquad (5.7.3.4.2\text{-}4)$$

$$s_{xe} = s_x\frac{1.38}{a_g + 0.63} \qquad (5.7.3.4.2\text{-}7)$$

$$12.0\text{ in.} \le s_{xe} \le 80.0\text{ in.}$$

SHEAR STRENGTH

Check shear strength requirement

LRFD 5.7.3

Page 59
Abutment wall

Abutment wall: General Procedure

Find M_u, N_u, and V_u at the critical section

$$\varepsilon_s := \frac{\left(\frac{M_{uWallShear}}{d_v} + 0.5\cdot N_{uWallShear} + V_{uWallShear}\right)}{E_s\cdot\frac{A_{sProvided}}{ft}} = 1.24\times 10^{-3}$$

LRFD Eq. 5.7.3.4.2-4

Crack spacing parameter $s_x := d_v = 2.83\ ft$

SHEAR STRENGTH

Check shear strength requirement

LRFD 5.7.3

Page 59
Abutment wall

Abutment wall: General Procedure (cont'd)

Maximum aggregate size (in.) $a_g := 1.5$

MDOT Standard Specifications for Construction Table 902-1

Crack spacing parameter as influenced by aggregate size

$$s_{xe} := \min\left[\begin{pmatrix} (80in) \\ \max\left[\begin{pmatrix} (12in) \\ \left(s_x\cdot\frac{1.38}{a_g + 0.63}\right)\end{pmatrix}\right]\end{pmatrix}\right] = 22.04\cdot in$$

LRFD Eq. 5.7.3.4.2-7

Factor indicating the ability of diagonally cracked concrete to transmit tension and shear

$$\beta := \frac{4.8}{\left(1 + 750\cdot\varepsilon_s\right)}\cdot\frac{51}{\left(39 + \frac{s_{xe}}{in}\right)} = 2.08$$

LRFD Eq. 5.7.3.4.2-2

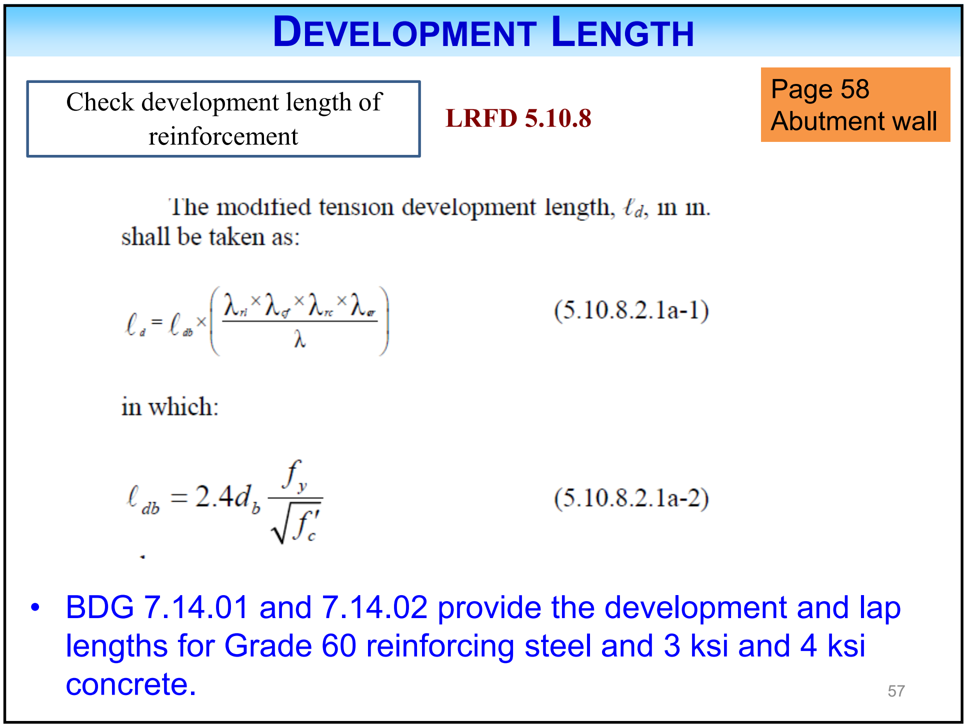
$$V_{c1} := 0.0316\cdot\beta\cdot\sqrt{f_c\cdot ksi}\cdot b\cdot d_e = 47.7\cdot kip$$

LRFD Eq. 5.7.3.3-3

$$V_{c2} := 0.25 f_c\cdot b\cdot d_e = 315\cdot kip$$

LRFD Eq. 5.7.3.3-2

$$V_n := \min\left(V_{c1}, V_{c2}\right) = 47.73\cdot kip$$



DEVELOPMENT LENGTH

Check development length of reinforcement

LRFD 5.10.8

Page 58
Abutment wall

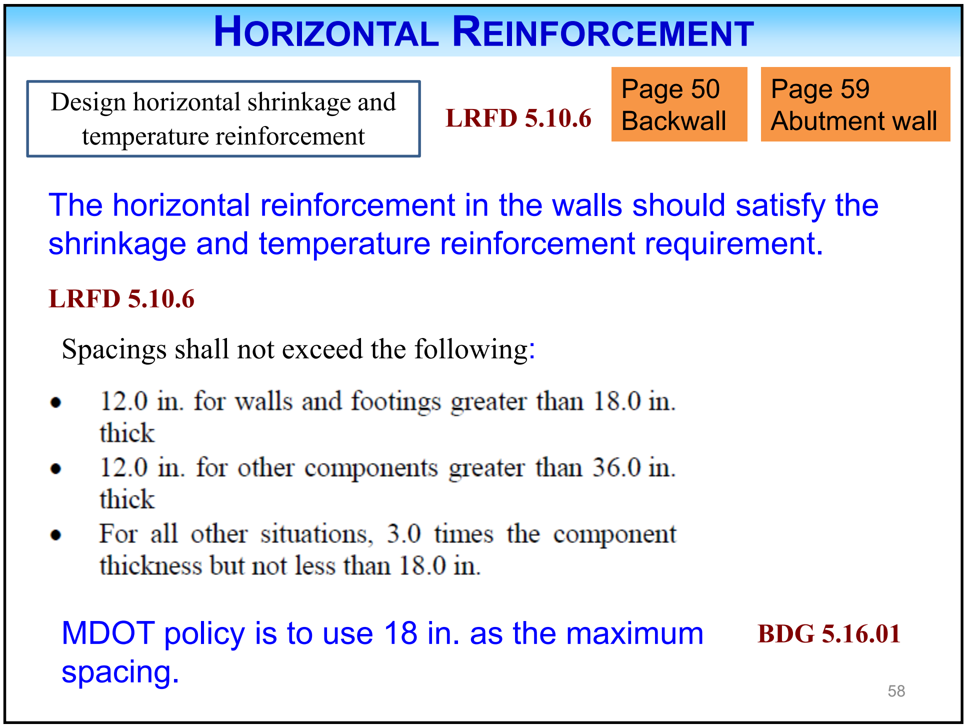
The modified tension development length, ℓ_d, in in. shall be taken as:

$$\ell_d = \ell_{db} \times \left(\frac{\lambda_{rl} \times \lambda_{cf} \times \lambda_{rc} \times \lambda_{er}}{\lambda} \right) \qquad (5.10.8.2.1a\text{-}1)$$

in which:

$$\ell_{db} = 2.4 d_b \frac{f_y}{\sqrt{f'_c}} \qquad (5.10.8.2.1a\text{-}2)$$

- BDG 7.14.01 and 7.14.02 provide the development and lap lengths for Grade 60 reinforcing steel and 3 ksi and 4 ksi concrete.



HORIZONTAL REINFORCEMENT

Design horizontal shrinkage and temperature reinforcement

LRFD 5.10.6

Page 50
Backwall

Page 59
Abutment wall

The horizontal reinforcement in the walls should satisfy the shrinkage and temperature reinforcement requirement.

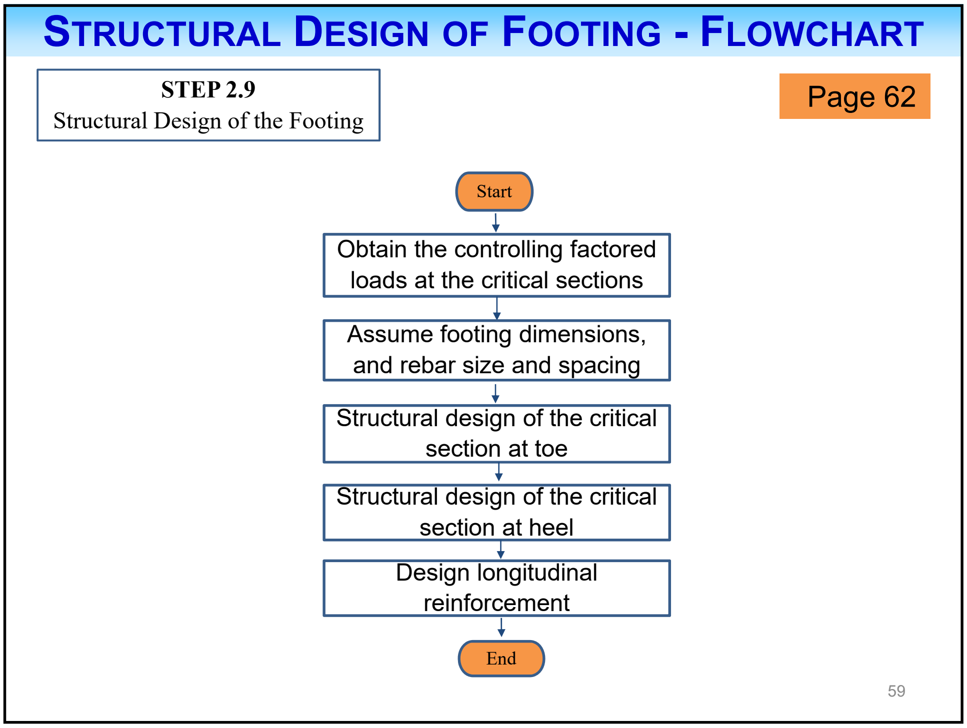
LRFD 5.10.6

Spacings shall not exceed the following:

- 12.0 in. for walls and footings greater than 18.0 in. thick
- 12.0 in. for other components greater than 36.0 in. thick
- For all other situations, 3.0 times the component thickness but not less than 18.0 in.

MDOT policy is to use 18 in. as the maximum spacing.

BDG 5.16.01



STRUCTURAL DESIGN OF FOOTING - FLOWCHART

STEP 2.9
Structural Design of the Footing

Page 62

Start

Obtain the controlling factored loads at the critical sections

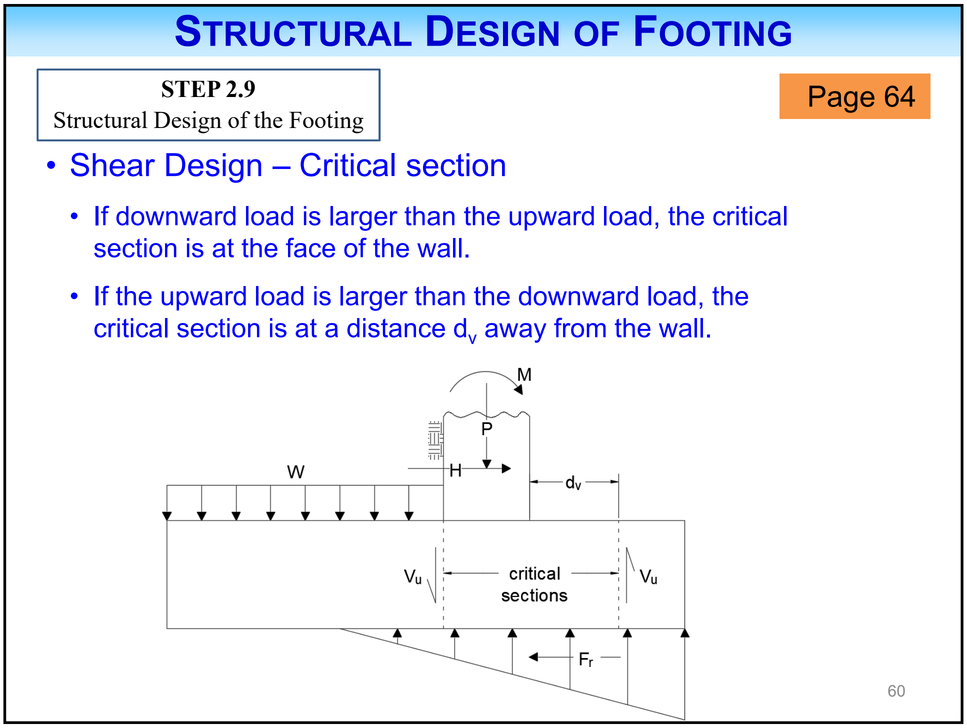
Assume footing dimensions, and rebar size and spacing

Structural design of the critical section at toe

Structural design of the critical section at heel

Design longitudinal reinforcement

End



STRUCTURAL DESIGN OF FOOTING

STEP 2.9
Structural Design of the Footing

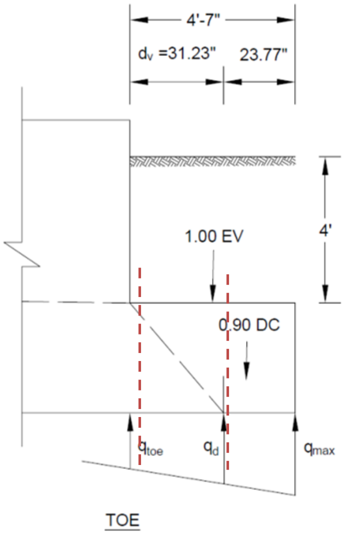
Page 64

- Shear Design – Critical section
  - If downward load is larger than the upward load, the critical section is at the face of the wall.
  - If the upward load is larger than the downward load, the critical section is at a distance d_v away from the wall.

STRUCTURAL DESIGN OF FOOTING

STEP 2.9
Structural Design of the Footing

Page 64



For structural design of an eccentrically loaded foundation, a triangular or trapezoidal bearing pressure distribution based on the factored loads shall be used.

LRFD 10.6.5

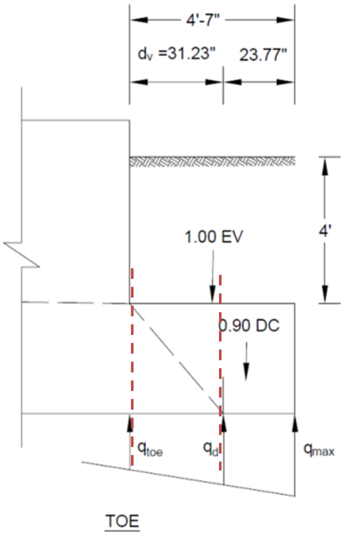
Toe

- Use minimum load factors for the weight of the footing and EV
- Critical section for flexure is at face of the wall.
- Critical section for shear is at a distance d_v from face of the wall.

STRUCTURAL DESIGN OF FOOTING

STEP 2.9
Structural Design of the Footing

Page 64



Toe

- Design includes flexure design, shear design, reinforcement development length check, shrinkage and temperature reinforcement.
- Simplified procedure can be used in shear design.

LRFD 5.7.3.4.1

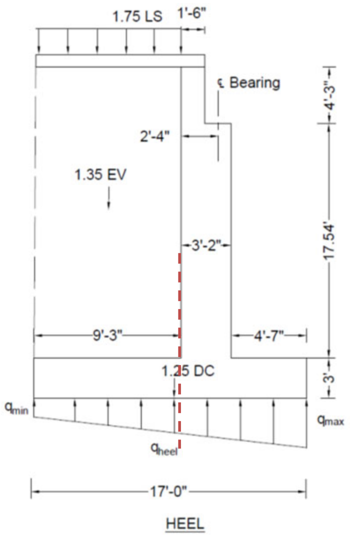
- Shear in the footing – simplified procedure

For concrete footing in which the distance from point of zero shear to the face of the wall is less than $3d_v$, the simplified procedure for nonprestressed sections can be used.

STRUCTURAL DESIGN OF FOOTING

STEP 2.9
Structural Design of the Footing

Page 70



Heel

LRFD C5.12.8.6.1

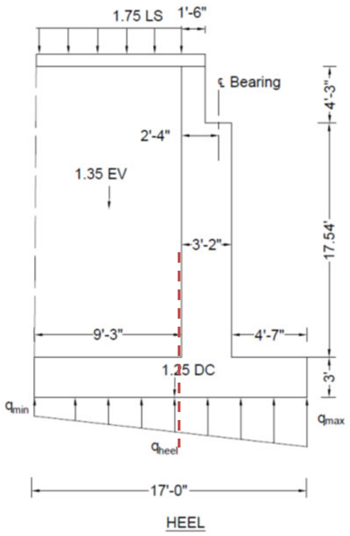
- In the general case of a cantilever abutment wall, where the downward load on the heel is larger than the upward reaction of the soil under the heel, the top of the heel is in tension.

- The critical section for flexure and shear is at the back face of the abutment wall.

STRUCTURAL DESIGN OF FOOTING

STEP 2.9
Structural Design of the Footing

Page 70



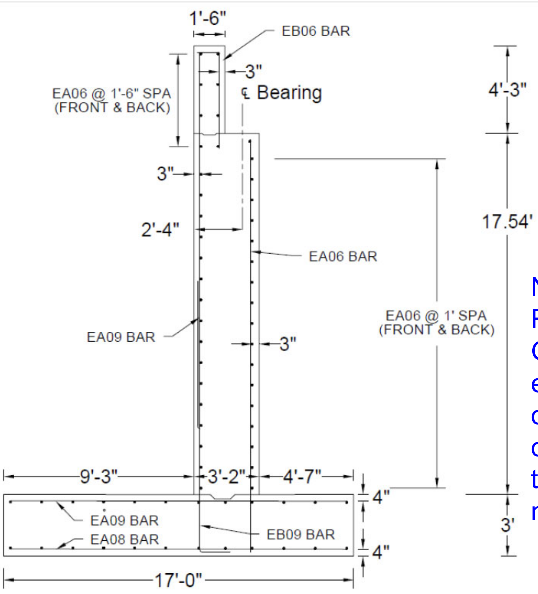
Heel

- The critical load combination for the heel design selects the load factors that produce the minimum axial loads and maximum eccentricities resulting in the minimum bearing pressure at the bottom of the footing.

- Use maximum load factors for the weigh of the footing and EV.

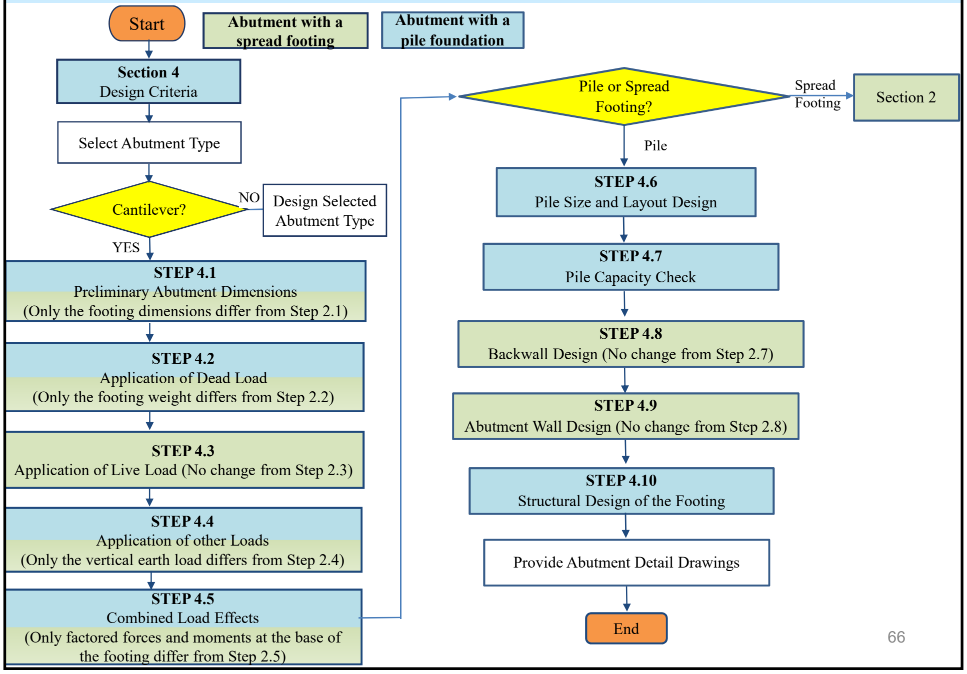
STRUCTURAL DESIGN OF FOOTING

Page 80



Note:
Refer to MDOT Bridge Design Guides for additional bars, laps, embedment, keyway dimensions, and drainage details. They are not shown in this drawing for clarity of the main reinforcement detail.

DESIGN OF ABUTMENT WITH PILES - FLOWCHART



Start

Abutment with a spread footing

Abutment with a pile foundation

Section 4
Design Criteria

Select Abutment Type

Cantilever?

NO

Design Selected Abutment Type

YES

STEP 4.1
Preliminary Abutment Dimensions
(Only the footing dimensions differ from Step 2.1)

STEP 4.2
Application of Dead Load
(Only the footing weight differs from Step 2.2)

STEP 4.3
Application of Live Load (No change from Step 2.3)

STEP 4.4
Application of other Loads
(Only the vertical earth load differs from Step 2.4)

STEP 4.5
Combined Load Effects
(Only factored forces and moments at the base of the footing differ from Step 2.5)

Pile or Spread Footing?

Spread Footing

Section 2

Pile

STEP 4.6
Pile Size and Layout Design

STEP 4.7
Pile Capacity Check

STEP 4.8
Backwall Design (No change from Step 2.7)

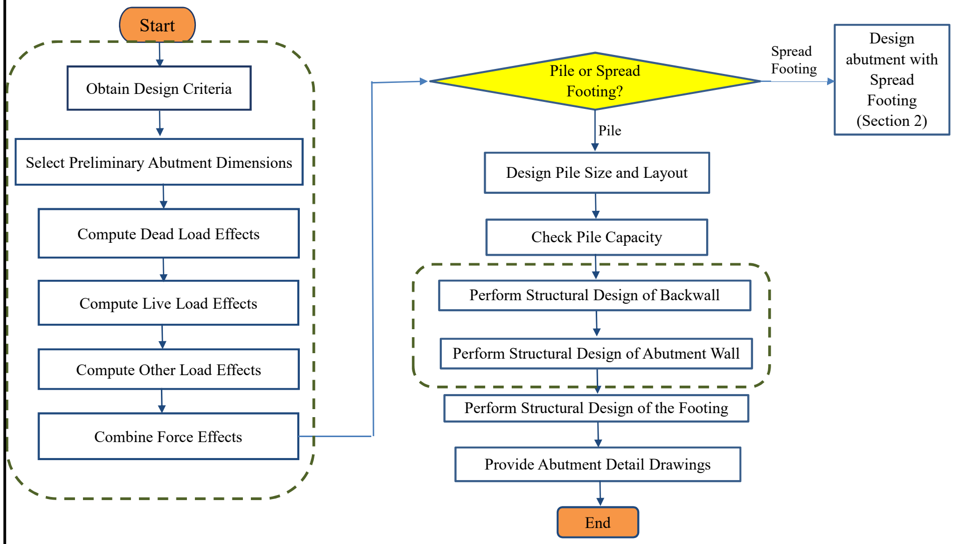
STEP 4.9
Abutment Wall Design (No change from Step 2.8)

STEP 4.10
Structural Design of the Footing

Provide Abutment Detail Drawings

End

DESIGN OF ABUTMENT WITH PILES



Start

Obtain Design Criteria

Select Preliminary Abutment Dimensions

Compute Dead Load Effects

Compute Live Load Effects

Compute Other Load Effects

Combine Force Effects

Pile or Spread Footing?

Spread Footing

Design abutment with Spread Footing (Section 2)

Pile

Design Pile Size and Layout

Check Pile Capacity

Perform Structural Design of Backwall

Perform Structural Design of Abutment Wall

Perform Structural Design of the Footing

Provide Abutment Detail Drawings

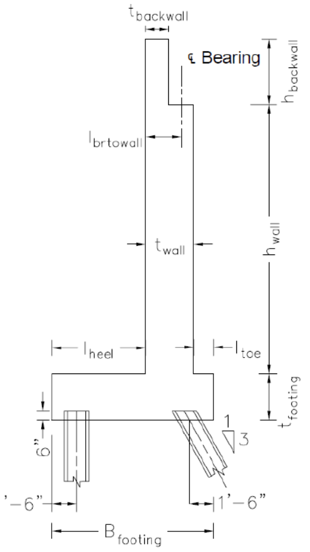
End

Steps are the same as spread footing

DESIGN OF ABUTMENT WITH PILES

Preliminary Abutment Dimension

Page 151



Abutment supported by piles can use smaller footing width compared to spread footing

$$l_{toe} := 1ft + 3in = 1.25\ ft$$

$$l_{heel} := 6ft + 7in = 6.583\ ft$$

$$B_{footing} := l_{toe} + l_{heel} + t_{wall} = 11\ ft$$

Other dimensions are the same as spread footing

DESIGN OF ABUTMENT WITH PILES

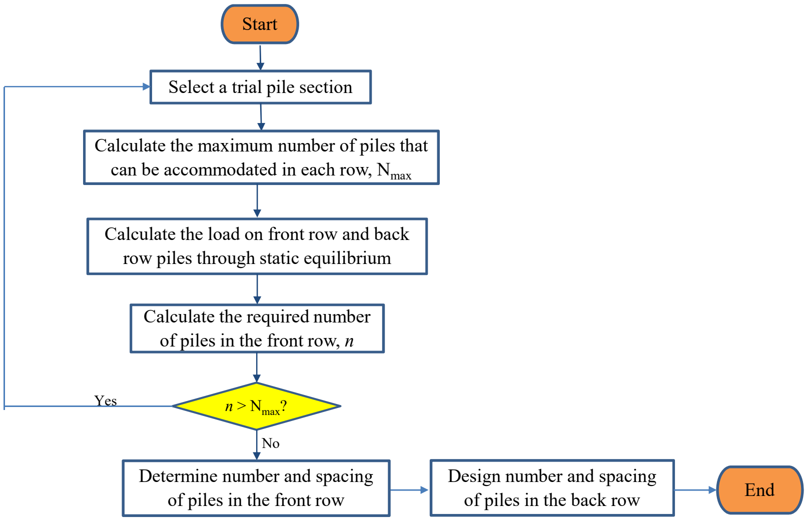
Design Pile Size and Layout

Page 164

- H-piles most commonly used by MDOT
- Embedment depth into the footing: 6 in. without tremie and 12 in. with a tremie **BDM 7.03.09.A5**
- Pile spacing: The minimum pile spacing is controlled by the greater of 30 in. or 2.5 times the pile diameter. MDOT practice is to use 3 times the pile diameter. **LRFD 10.7.1.2**
- Edge distance: Minimum edge distance 18 in. **BDM 7.03.09A**
- Battered front row piles: Generally, piles are to be battered no flatter than 3V:1H. **BDM 7.03.09.A9**

DESIGN OF ABUTMENT WITH PILES

Design Pile Size and Layout



Start

Select a trial pile section

Calculate the maximum number of piles that can be accommodated in each row, N_{max}

Calculate the load on front row and back row piles through static equilibrium

Calculate the required number of piles in the front row, n

$n > N_{max}$?

Yes

No

Determine number and spacing of piles in the front row

Design number and spacing of piles in the back row

End

DESIGN OF ABUTMENT WITH PILES

Select a trial pile section

- Start with an initial pile nominal resistance. As an example, 350 kips

BDM 7.03.09.B

HP 10X42	275 kips
HP 10X57	350 kips
HP 12X53	350 kips
HP 12X74	500 kips
HP 12X84	600 kips
HP 14X73	500 kips
HP 14X89	600 kips

- $R_R = \varphi_{dyn} \times R_n$

  φ_{dyn} Resistance Factor
  R_n Nominal Pile Resistance
  R_R Factored Nominal Resistance

DESIGN OF ABUTMENT WITH PILES

Select a trial pile section

- φ_{dyn} Resistance Factor

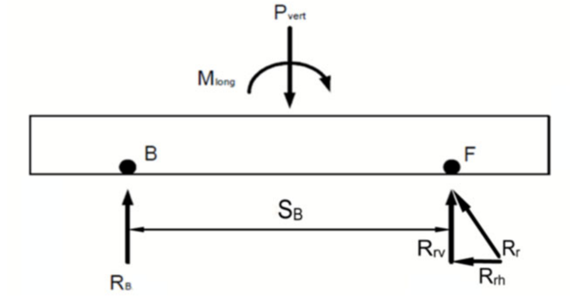
In general, the Resistance Factor for Driven Piles (φ_{dyn}) = 0.50 assuming that the Nominal Pile Driving Resistance (R_{ndr}) is verified using the FHWA-modified Gates Dynamic Formula. The Resistance Factor (φ_{dyn}) = 0.65 when dynamic testing with signal matching (P.D.A. testing) is used and (φ_{dyn}) = 0.80 with static load tests.

BDM 7.03.09.B

DESIGN OF ABUTMENT WITH PILES

Page 164

Calculate the load on front row and back row piles through static equilibrium



$$R_{rv} := \frac{\left(M_{long} + P_{vert}\cdot\frac{S_B}{2}\right)}{S_B}$$

$$R_B := P_{vert} - R_{rv}$$

R_{rv} - Vertical component of axial force in the front row piles

R_B - Axial force in the back row piles

DESIGN OF ABUTMENT WITH PILES

Page 164

- Calculate the maximum number of piles that can be accommodated

$Spacing_{min} := 36in$ $PileEdgeDist := 18in$

Use two rows of piles.

Maximum number of piles in each row the footing can accommodate

$$N_{MaxPiles} := \frac{L_{footing} - 2\cdot PileEdgeDist}{Spacing_{min}} = 20.917$$

- Start with nominal pile resistance 350 kips $R_n := 350kip$

- Factored nominal pile resistance $\varphi_{dyn} := 0.5$

$$R_R := \varphi_{dyn}\cdot R_n = 175\cdot kip$$

DESIGN OF ABUTMENT WITH PILES

Page 165

- Calculate required number of front piles

Required number of piles in the front row $n_{front\_required} := \frac{R_r}{R_R} = 21.462$

$n_{front\_required} > N_{MaxPiles}$

Consider a larger pile section. HP 14X73

$R_n := 500kip$ **BDM 7.03.09.B**

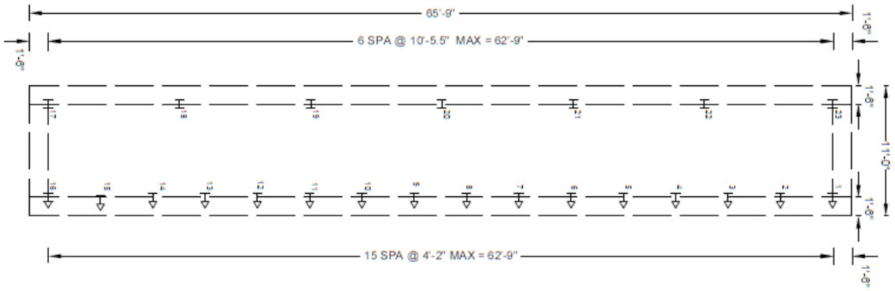
$R_R := \varphi_{dyn} \cdot R_n = 250 \cdot kip$

$n_{front} := \frac{R_r}{R_R} = 15.023$ Use 16 piles in the front row

Use 7 piles in the back row

DESIGN OF ABUTMENT WITH PILES

Page 166



AASHTO LRFD 10.7.5

The effects of corrosion and deterioration from environmental conditions shall be considered in the selection of the pile type and cross-section.

Consult the Geotechnical Services Section to determine a suitable pile type and cross-section for the selected site.

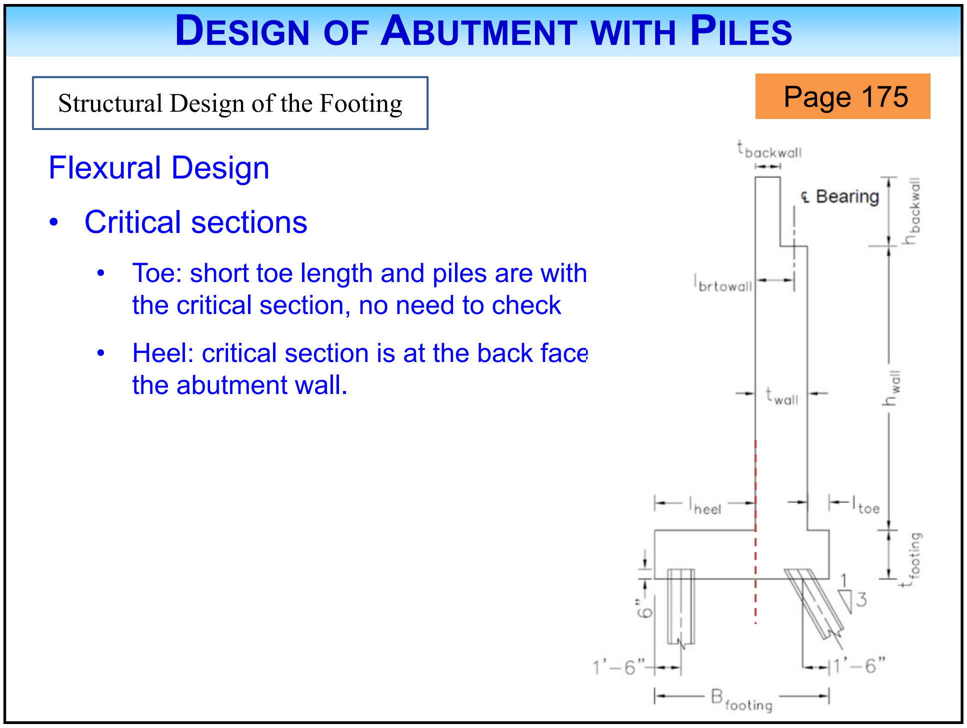
DESIGN OF ABUTMENT WITH PILES

Check Pile Capacity

Page 168

- After pile layout has been determined, check the axial forces on piles in the front and back rows, and the required lateral load resistance on each pile.

  Required lateral load resistance on each pile =
  (Total shear force acting on the footing – total horizontal components of the battered piles) / number of piles
- The axial force can not exceed $\varphi_{dyn} \times R_n$
- The lateral force on each pile can not exceed the later load capacity determined by the geotechnical engineer.
  - MDOT practice is to use 12 kips as the typical lateral resistance of a vertical pile.
  - *p-y* analysis may be performed by incorporating soil-pile interaction to determine a more accurate lateral load resistance of the piles.



DESIGN OF ABUTMENT WITH PILES

Structural Design of the Footing

Page 175

Flexural Design

- Critical sections
  - Toe: short toe length and piles are with the critical section, no need to check
  - Heel: critical section is at the back face the abutment wall.

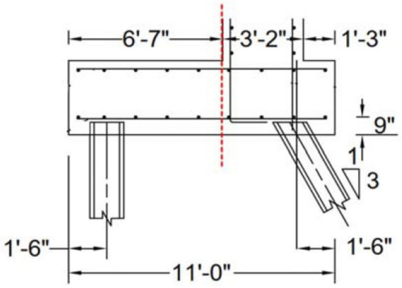
DESIGN OF ABUTMENT WITH PILES

Structural Design of the Footing

Page 175

Flexural design at the critical section of the heel

- Consider two cases: bottom in tension and top in tension



- Bottom in tension: use maximum axial loads in the back row piles and minimum load factors for the resisting force, excluding live load surcharge.
- Top in tension: use minimum axial loads in the back row piles, and maximum load factors for the resisting force, including live load surcharge.

DESIGN OF ABUTMENT WITH PILES

Structural Design of the Footing

Page 175

- Bottom in tension: use maximum axial loads in the back row piles and minimum load factors for the resisting force, excluding live load surcharge – Load Case III

$$M_{rb} := \frac{R_{backMax} \cdot d_{arm}}{L_{footing}} - 0.9W_c \cdot t_{footing} \cdot \frac{l_{heel}^2}{2} - EV_{earthBk} \cdot \frac{l_{heel}}{2} = -36.942 \cdot \frac{kip \cdot ft}{ft}$$

No need to check

- Top in tension: use minimum axial loads in the back row piles, and maximum load factors for the resisting force, including live load surcharge

$$M_{rt} := 1.25W_c \cdot t_{footing} \cdot \frac{l_{heel}^2}{2} + 1.35EV_{earthBk} \cdot \frac{l_{heel}}{2} + 1.75V_{LSFooting} \cdot \frac{l_{heel}}{2} - \frac{R_{backMin} \cdot d_{arm}}{L_{footing}} = 88.333 \cdot \frac{kip \cdot ft}{ft}$$

DESIGN OF ABUTMENT WITH PILES

Structural Design of the Footing

Page 179

Shear Design

- Toe: short toe length and piles are within the critical section, no need to check.
- One-way shear (beam action shear) and two-way shear (punching shear)
- Simplified procedure can be applied in the design for the one-way shear in the footing.

DESIGN OF ABUTMENT WITH PILES

Structural Design of the Footing

Page 180

- Shear Design – two-way shear

LRFD 5.12.8.6.3

For two-way action, the pile critical perimeter, b_o, is located a minimum of $0.5d_v$ from the perimeter of the pile. If portions of the critical perimeter are located off the footing, that portion of the critical perimeter is limited by the footing edge.

$$V_n = \left(0.063 + \frac{0.126}{\beta_c}\right)\lambda\sqrt{f'_c}\,b_o d_v \le 0.126\lambda\sqrt{f'_c}\,b_o d_v \qquad (5.12.8.6.3\text{-}1)$$

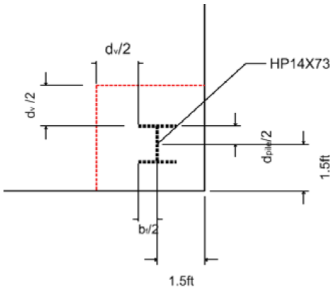
where:

β_c = ratio of long side to short side of the rectangle through which the concentrated load or reaction force is transmitted

λ = concrete density modification factor as specified in Article 5.4.2.8

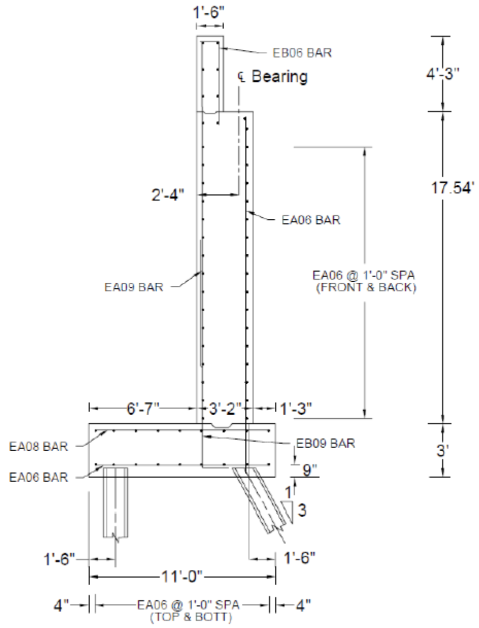
b_o = the perimeter of the critical section for shear (in.)

d_v = effective shear depth (in.)



DESIGN OF ABUTMENT WITH PILES

Page 183



Note: Refer to MDOT Bridge Design Guides for additional bars, laps, embedment, keyway dimensions, and drainage details. They are not shown in this drawing for clarity of main reinforcement.

TREMIE SEAL DESIGN

Appendix 4.A

BDM 7.03.06

Page 184

- Tremie seals should be called for on all structures where it is expected that difficulty will be encountered in pumping the water down below the bottom of footing.
- The tremie seal shall be designed to resist the hydrostatic pressure at the bottom of the tremie by a combination of
  - Its weight
  - the bond on the cofferdam and piles
- The allowable bond stress is 10 psi on the piles and 5 psi on the cofferdam.
- The allowable tension in bending on the tremie seal is 30 psi.
- Hydrostatic head should be figured from bottom of tremie seal to ordinary water surface elevation.

TREMIE SEAL DESIGN

Appendix 4.A

Page 184

- Assumptions
  - Consider 1-ft width of tremie seal.
  - Tremie seal is simply supported on both ends by the cofferdam.
  - MDOT practice is to neglect the bonding between tremie seal and piles.
- Two checks
  - Flexural stress in the tremie seal
  - Resistance to the hydrostatic pressure

TREMIE SEAL DESIGN

Appendix 4.A

Page 185

- Flexural stress in the tremie seal

Tremie is assumed to be simply-supported on the ends by the cofferdams.

The pile resistance is not considered.

$$S_{tremie} := \frac{1}{6} \cdot h_{tremie}^{2}$$

$$M_{tremie} := \frac{1}{8}\left[\gamma_{water} \cdot \left(H_{water} + t_{footing}\right) - \gamma_{tremie} \cdot t_{footing}\right] \cdot l_{tremie}^{2}$$

$$F_c := \frac{M_{tremie}}{S_{tremie}} \quad < 30 \text{ psi}$$

TREMIE SEAL DESIGN

Appendix 4.A

Page 186

Resistance to the hydrostatic pressure

- Resistance by the bond between cofferdam and tremie seal

  = 5 psi × contact area between cofferdam and tremie seal
- Resistance by the bond between piles and tremie seal

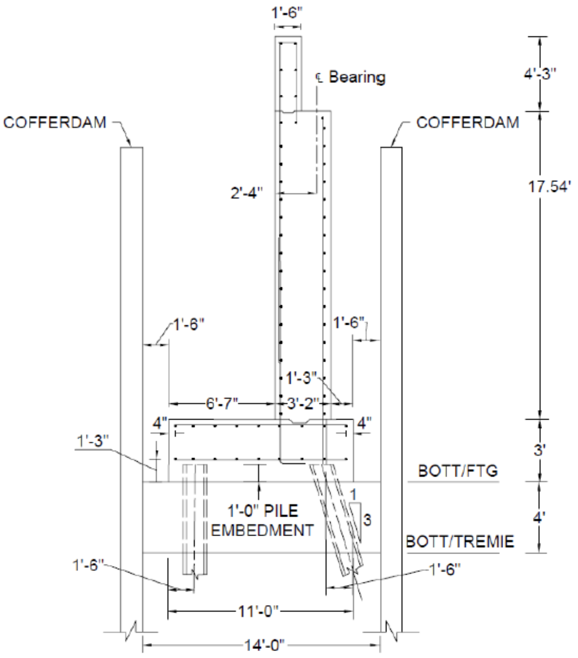
  = 10 psi × contact area between piles and tremie seal

Total resistance = Bond forces + weight of tremie seal

Hydrostatic buoyancy force

$= \gamma_{water}$ *× tremie seal bottom area × hydrostatic head*

Page 187



Break

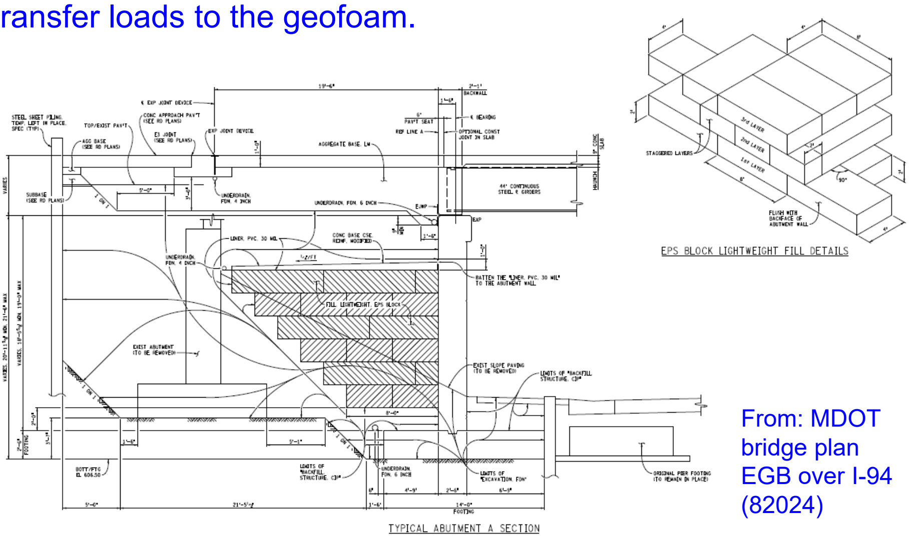
DESIGN OF ABUTMENT BACKFILLED WITH EPS

Geofoam made with EPS is effective at reducing lateral forces or settlement potential for bridge abutments.

Photos from:
EPS Geofoam Applications and Technical Data, by the EPS Industry Alliance

DESIGN OF ABUTMENT BACKFILLED WITH EPS

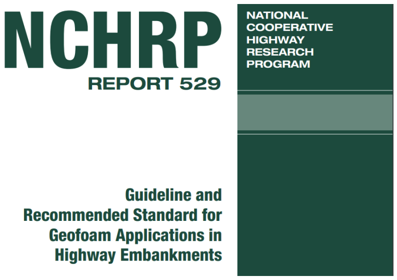
Typical geofoam embankments consist of the foundation soils, the geofoam fill, and a load dissipater slab designed to transfer loads to the geofoam.



From: MDOT bridge plan EGB over I-94 (82024)

DESIGN OF ABUTMENT BACKFILLED WITH EPS

Design guidelines for geofoam embankments are provided in NCHRP Report 529 and NCHRP web document 65, *Geofoam Applications in the Design and Construction of Highway Embankments* (Stark et al., 2004)

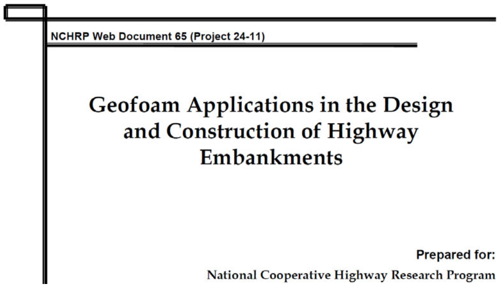


NCHRP

REPORT 529

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Guideline and Recommended Standard for Geofoam Applications in Highway Embankments



NCHRP Web Document **65** (Project 24-11)

Geofoam Applications in the Design and Construction of Highway Embankments

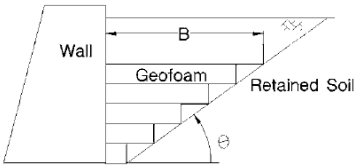
Prepared for:
National Cooperative Highway Research Program

DESIGN OF ABUTMENT BACKFILLED WITH EPS

NCHRP method to calculate the lateral force on the abutment backfilled with EPS

- Lateral earth pressure generated by the soil behind the EPS/soil interface is conservatively assumed to be transmitted without dissipation through the geofoam.
- The active earth pressure acting along this interface is calculated using a coefficient of active earth pressure, K_A.

$$K_A = \left[\frac{\sin(\theta-\varphi)\left(\frac{1}{\sin\theta}\right)}{\sqrt{\sin(\theta+\delta)} + \sqrt{\frac{\sin(\varphi+\delta)\sin(\varphi)}{\sin(\theta)}}} \right]^2$$



Where δ is the friction angle of the EPS/soil interface. The value of δ can be assumed to be equal to the friction angle of the soil, φ.

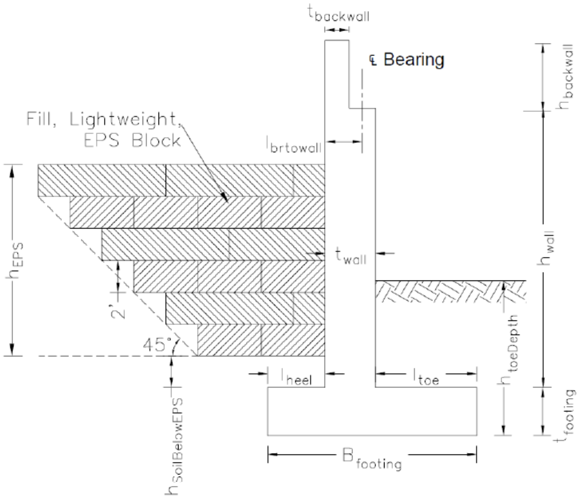
DESIGN OF ABUTMENT BACKFILLED WITH EPS

- NCHRP method to calculate the lateral force on the abutment backfilled with EPS
  - In addition, NCHRP method assumes that the lateral pressure imposed by the live load surcharge is equal to 1/10 times the vertical stress.
- MDOT practice: Neglect the lateral load from EPS.
- In this example, the NCHRP method is followed, and the results are compared with MDOT practice.

DESIGN OF ABUTMENT BACKFILLED WITH EPS

- Preliminary abutment dimension

Page 89



$l_{toe} := 6ft + 4in = 6.333\ ft$

$l_{heel} := 4ft$

$B_{footing} := l_{toe} + l_{heel} + t_{wall} = 13.5\ ft$

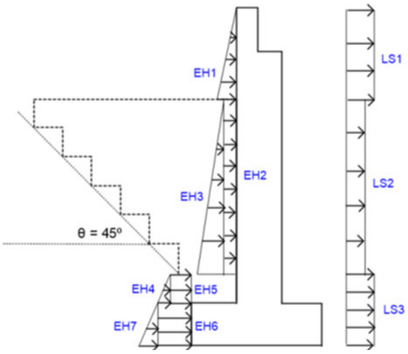
Compared with the spread footing in Section 2, $B_{footing} = 17$ ft

---

DESIGN OF ABUTMENT BACKFILLED WITH EPS

- The design procedure is very similar with spread footing, except the calculation of the lateral earth load
- NCHRP method is followed

Page 96



EH 1: the lateral pressure from the soil above the EPS blocks
EH 2: the lateral pressure due to the vertical load at the top of the EPS blocks
EH 3: the lateral pressure from the soil behind the EPS blocks
EH 4: the lateral pressure from the soil located below the EPS blocks and above the top of the footing
EH 5: the lateral pressure due to the vertical load at the bottom of the EPS blocks
EH 6: the lateral pressure due to the vertical load at the top of the footing
EH 7: the lateral pressure from the soil located along the depth (thickness) of the footing.

DESIGN OF ABUTMENT BACKFILLED WITH EPS

- NCHRP method and MDOT practice comparison

Page 105

NCHRP method

	Vu (kip/ft) Strength I	Vu (kip/ft) Service I	Mu (kip·ft/ft) Strength I	Mu (kip·ft/ft) Service I
LC I	4.69	3.13	43.28	28.53
LC III	4.69	3.13	56.97	37.66
LC IV	6.68	4.62	75.76	54.58

MDOT

	Vu (kip/ft) Strength I	Vu (kip/ft) Service I	Mu (kip·ft/ft) Strength I	Mu (kip·ft/ft) Service I
LC I	4.29	2.86	40.87	26.93
LC III	4.29	2.86	54.56	36.06
LC IV	6.31	4.41	73.89	54.06

Page 148