F. W. Klaiber, D. J. White, T. J. Wipf, B. M. Phares, V. W. Robbins

Development of Abutment Design Standards for Local Bridge Designs
Volume 2 of 3

Design Manual

August 2004

Sponsored by the
Iowa Department of Transportation
Highway Division and the
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Iowa DOT Project TR - 486

Final

REPORT

Iowa State University
of Science and Technology

Department of Civil and Construction Engineering

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ABSTRACT

Several superstructure design methodologies have been developed for low volume road bridges by the Iowa State University Bridge Engineering Center. However, to date no standard abutment designs have been developed. Thus, there was a need to establish an easy to use design methodology in addition to generating generic abutment standards and other design aids for the more common substructure systems used in Iowa.

The final report for this project consists of three volumes. The first volume summarizes the research completed in this project. A survey of the Iowa County Engineers was conducted from which it was determined that while most counties use similar types of abutments, only 17 percent use some type of standard abutment designs or plans. A literature review revealed several possible alternative abutment systems for future use on low volume road bridges in addition to two separate substructure lateral load analysis methods. These consisted of a linear and a non-linear method. The linear analysis method was used for this project due to its relative simplicity and the relative accuracy of the maximum pile moment when compared to values obtained from the more complex non-linear analysis method. The resulting design methodology was developed for single span stub abutments supported on steel or timber piles with a bridge span length ranging from 20 to 90 ft and roadway widths of 24 and 30 ft. However, other roadway widths can be designed using the foundation design template provided. The backwall height is limited to a range of 6 to 12 ft, and the soil type is classified as cohesive or cohesionless. The design methodology was developed using the guidelines specified by the American Association of State Highway Transportation Officials Standard Specifications, the Iowa Department of Transportation Bridge Design Manual, and the National Design Specifications for Wood Construction.

The second volume (this volume) introduces and outlines the use of the various design aids developed for this project. Charts for determining dead and live gravity loads based on the roadway width, span length, and superstructure type are provided. A foundation design template was developed in which the engineer can check a substructure design by inputting basic bridge site information. Tables published by the Iowa Department of Transportation that provide values for estimating pile friction and end bearing for different combinations of soils and pile types are also included. Generic standard abutment plans were developed for which the engineer can provide necessary bridge site information in the spaces provided. These tools enable engineers to design and detail county bridge substructures more efficiently.

The third volume provides two sets of calculations that demonstrate the application of the substructure design methodology developed in this project. These calculations also verify the accuracy of the foundation design template. The printouts from the foundation design template are provided at the end of each example. Also several tables provide various foundation details for a pre-cast double tee superstructure with different combinations of soil type, backwall height, and pile type.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Various superstructure design methodologies have been developed by the Iowa State University (ISU) Bridge Engineering Center (BEC). However, to date no standard abutment designs or design methodologies have been developed. Obviously, with a design methodology and a set of standard abutment plans for the various superstructures systems, a County Engineer could design a complete bridge for a given site. Thus, there was a need to establish an easy-to-use design methodology and standard abutment plans for the more common substructure systems used in Iowa.

1.1. OBJECTIVE AND SCOPE OF ABUTMENT DESIGN AIDS

The objective of this project was to develop a simple design methodology, a series of standard abutment plans, and a series of design aids for the more commonly used substructure systems in Iowa counties. The design aids include: 1.) graphs for estimating dead and live load abutment reactions, 2.) a summary table of estimated allowable pile end and friction bearing values based on the Iowa Department of Transportation Foundation Soil Information Chart (Iowa DOT FSIC) [1], 3.) a generic foundation design template (FDT), and 4.) generic standard abutment plans. When used correctly, these tools will assist the Iowa County Engineers in the design and construction of low-volume road (LVR) bridge abutments.

The assumptions incorporated in the developed design methodology and corresponding design aids are similar to those made for a stub abutment system. The applicability of the design aids are limited to span lengths ranging from 20 to 90 ft and are intended for roadway widths of 24 and 30 ft (however, abutments for other roadway widths can be designed with the FDT). Also, the soil profile must be relatively uniform and mostly consist of a cohesive or cohesionless soil. Superstructure systems other than the beam-in-slab bridge (BISB), railroad flat car (RRFC), pre-cast double tee (PCDT), glued-laminated girders (glulam), prestressed concrete (PSC), quad-tee, and slab bridge systems are not incorporated in the LVR bridge abutment design aids. However, the general design methodology can, in theory, be applied to the design of substructures for a variety of other superstructure systems.

1.2. REPORT SUMMARY

This volume is the second of three comprising this final report. Volume 1: *Development of Design Methodology* provides a summary of the tasks completed in the project. This includes a survey of the Iowa County Engineers, the collection of input from a Project Advisory Committee (PAC), the development of a LVR bridge abutment design methodology, and a summary of research required to increase the types of abutments that could be used on LVR bridges.

Volume 2: *Design Manual* provides instructions for using the previously mentioned design aids. This includes a detailed description of all required input parameters for the FDT, a description of the design requirements, and recommendations for optimizing the pile and anchor system to effectively meet these requirements. Instructions for using the estimated gravity load charts, estimated pile bearing tables, and standard abutment plans are also included in this volume.

Volume 3: *Verification of Design Methodology* provides two sets of calculations that demonstrate the application of the substructure design methodology developed in this project. These calculations also verify the accuracy of the FDT. The printouts from the FDT are provided at the end of each example. Additionally, several tables present various foundation details for a pre-cast double tee superstructure (PCDT) with different combinations of soil type, backwall height, and pile type.

2. DESIGN METHODOLOGY SUMMARY

A brief summary of the design methodology developed for LVR bridge abutments is presented in this chapter. This includes the determination of the substructure loads, the structural analysis, foundation capacity calculations, and checking design requirements for the pile and anchor systems. Additional substructure elements such as the pile cap, abutment wale, and backwall also need to be investigated; however, a design methodology for these elements was beyond the scope of this project. A graphical flowchart of the design methodology summarized herein is presented in Figure 2.1 (same as Figure 4.1 in Volume 1).

2.1. DESIGN LOADS

The first step in designing a foundation is the determination of loads. Gravity loads include the bridge self-weight in addition to bridge live loads. Lateral loadings are imparted to the bridge substructure by active and passive soil pressures in addition to lateral forces transmitted from the superstructure to the substructure through the bridge bearings.

2.1.1. Gravity Loads

Conservative total dead load abutment reactions for various superstructure systems are given in Figures A.1 and A.2 of Appendix A for 24 and 30 ft roadway widths, respectively. These estimates are based on published standard bridge designs for the respective superstructure systems. More accurate, and potentially smaller, dead load abutment reactions can be determined using site-specific bridge information. The live load abutment reaction is computed using the American Association of State Highway Transportation Officials (AASHTO) Standard Specifications for Highway Bridges, Sixteenth Edition [2] HS20-44 design truck. The maximum simple span abutment reaction occurs when the back axle is placed directly over the centerline of the piles with the front and middle axles on the bridge. The live load abutment reactions for two, 10 ft wide design traffic lanes without impact are provided in Figure A.3 of Appendix A.

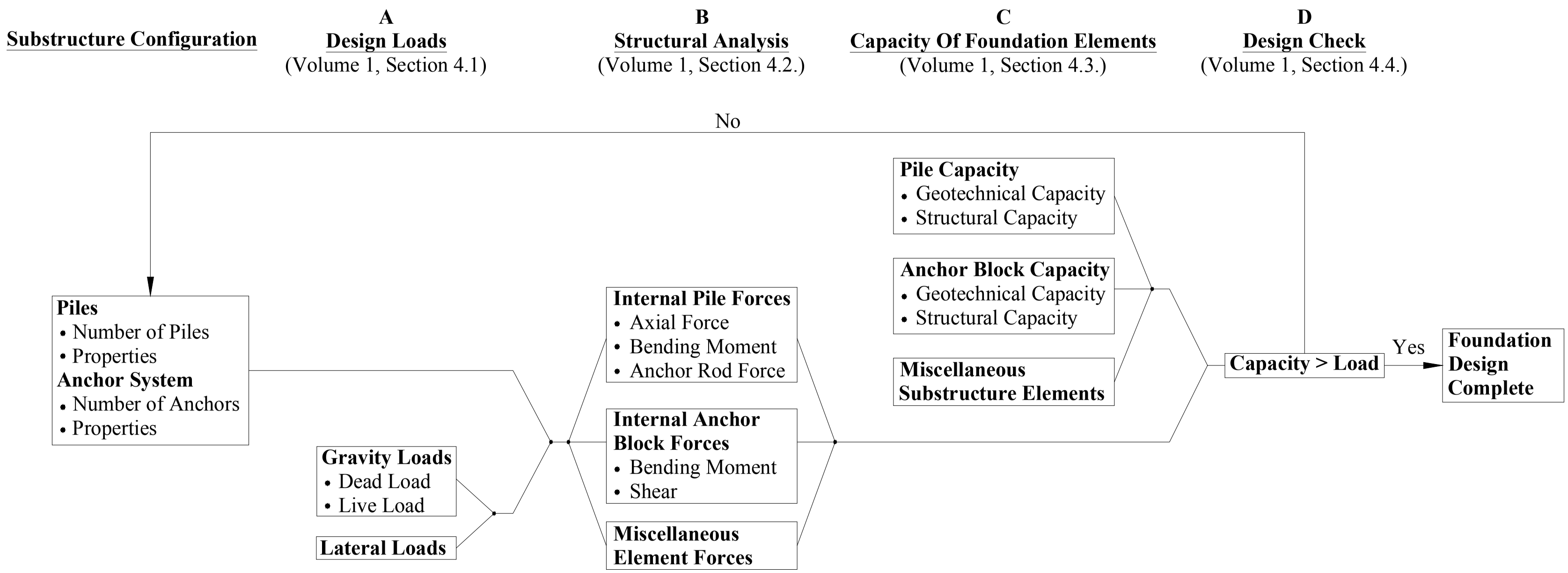
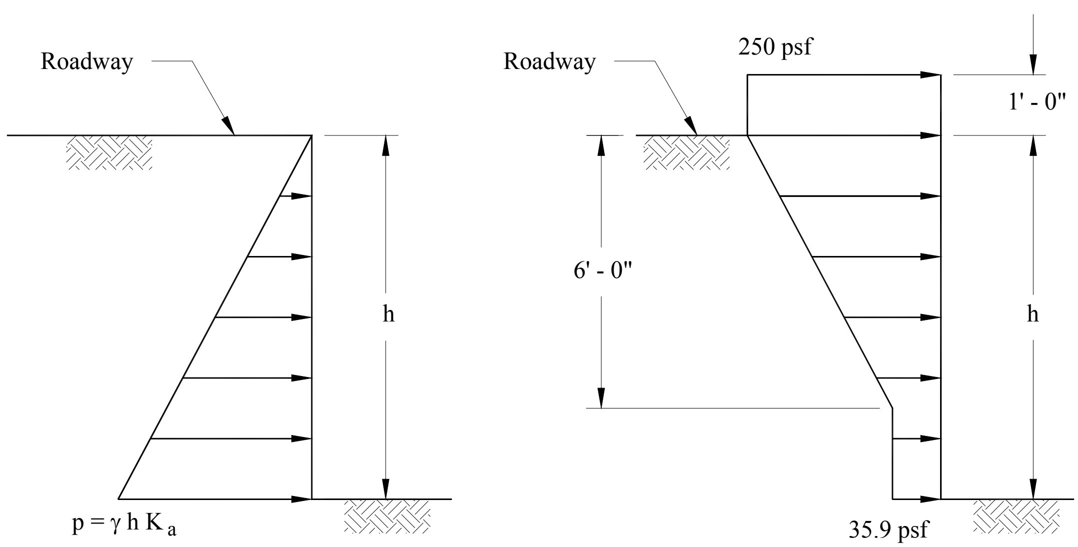


Figure 2.1. Graphical representation of the design methodology for a LVR bridge abutment [Figure 4.1 of Volume 1].

2.1.2. Lateral Loads

The substructure systems commonly used by Iowa counties require the piles to resist lateral loads in addition to gravity loads. The Iowa Department of Transportation Bridge Design Manual (Iowa DOT BDM) [3] specifies two different horizontal soil pressures for bridge substructures as shown in Figure 2.2. The first pressure distribution (Figure 2.2a) represents the active soil pressure attributed to the permanent loading of the backfill soil. The second pressure distribution (Figure 2.2b) represents a gravity live load on the approach roadway. This live load is modeled as an equivalent soil surcharge equal to two feet of soil above the approach roadway thus resulting in the pressure distribution shown. Both lateral soil pressure distributions are included in the design methodology for this project.

Other lateral bridge loadings such as longitudinal wind forces, transverse wind forces, and a longitudinal braking force are also listed in the Iowa DOT BDM [3]. Longitudinal wind forces were investigated and found to be negligible for LVR bridge abutments and therefore were not included in the design methodology for this project. The longitudinal braking force is equal to five percent of the total gravity component for the AASHTO [2] lane loading multiplied by the number of 10 ft design lanes and does not include the multilane reduction factor. One type of transverse wind load consists of a 50 psf pressure that acts on the elevation surface area of the superstructure, roadway and barrier rail. This transverse loading acts perpendicular to the flow of traffic. A second transverse wind load,



a) Active soil pressure distribution.

b) Equivalent live load surcharge.

Figure 2.2. Lateral soil pressure distributions [adapted from the Iowa DOT BDM, 2004; Figure 4.5 of Volume 1].

also perpendicular to the flow of traffic, consists of a 100 plf line load that represents wind acting on the bridge live load. Both transverse wind loads and the longitudinal braking force were included in the design methodology for this project. The load groups cited in Section 6.6 of the Iowa DOT BDM [3] are used to determine the maximum loading effects for the various combinations of gravity and lateral loadings previously discussed.

2.2. STRUCTURAL ANALYSIS

Once the substructure loads have been determined, a structural analysis of the foundation system can be performed to determine the internal forces. This includes the pile axial force and bending moment, anchor rod axial force, and the internal anchor block shears and bending moments. Sample calculations for the analysis methods summarized herein are provided in Volume 3 of this final report.

2.2.1. Internal Pile Loads

The total abutment reaction, which is the sum of the dead and live load abutment reactions, is used to determine the individual axial pile forces. The axial pile loads (i.e., the load each pile must resist) are a function of the total number of piles and their spacing along with the superstructure reaction applied at bearing locations. Different combinations of pile and superstructure bearings point configurations will produce various maximum axial pile forces within a given pile group. Therefore, a nominal axial pile factor was developed using structural analysis software for all superstructure systems included in this design methodology to account for the different axial forces that can develop. The design axial pile force is equal to the total abutment reaction divided by the number of piles times the nominal axial pile factor provided in Table 2.1. As previously discussed, the total abutment reaction is the sum of the dead and live load reactions which are used to determine the individual axial pile load.

Table 2.1. Nominal axial pile factors for various superstructure systems [Table 4.1 of Volume 1].

Superstructure System	Nominal Axial Pile Factor
PCDT	1.40
BISB	1.35
RRFC (Type 1)	1.20
RRFC (Type 2)	1.40
Prestressed girder	1.30
Slab bridge	1.00
Quad-tee	1.50
Glulam girder	1.40

The lateral load analysis technique used in this design methodology is reported by Broms [4, 5]. Specifically, the pile is considered fixed at a calculated depth below ground and is analyzed as a cantilever structure. The depth to fixity is a function of different parameters such as the pile width and the above ground lateral pile loads. The undrained shear strength and friction angle of the soil are also required for cohesive and cohesionless soils, respectively.

A lateral restraint system can be used to reduce the lateral loading effects on the piles. The lateral restraint systems incorporated into the design methodology were a buried reinforced concrete anchor block connected to the substructure with tension rods, and a positive connection between the superstructure and substructure.

If a lateral restraint system is not utilized, the system is statically determinant and the maximum pile bending moment and deflection are easily determined using statics. Superposition can be used to determine the combined effects of all the lateral pile loadings.

The incorporation of a lateral restraint system creates a statically indeterminate system. The structural analysis methodology for this project uses an iterative, consistent deformation approach in which the displacement of the lateral restraint system is equal to the displacement of the pile at the connection point; elongation of the anchor rods is also included. An example of this analysis procedure is provided in Volume 3 of this final report.

2.2.2. Internal Anchor Block Forces

Once the anchor rod force per pile has been determined, the internal anchor block bending moment and shear loads can be calculated. The anchor force per pile, in addition to other parameters such as the elevation of the anchor, anchor rod properties, and pile spacing required for the structural analysis of the pile system are also used in the structural analysis of the anchor block.

The anchor block is analyzed as a continuous beam with simple supports that correspond to the locations of the anchor rods. The net soil reaction imparted on the anchor block to resist the lateral substructure loads is represented by a uniformly distributed load equal to the anchor rod force per pile, multiplied by the number of piles, and divided by the total length of the anchor block. The internal anchor block shears and bending moments can be determined using a number of indeterminate structural analysis techniques.

2.3. CAPACITY OF FOUNDATION ELEMENTS

The guidelines specified in the Iowa DOT BDM [3], AASHTO [2], and the National Design Specification Manual for Wood Construction (NDS Manual) [6] were used to determine the capacities of the various foundation elements.

2.3.1. Pile Capacity

For this project, a foundation pile is classified as one of three different groups; end bearing piles, friction bearing piles, or combined friction and end bearing piles. The bearing capacity of an end bearing pile is attributed to the bearing of the pile tip on a relatively hard foundation material. Estimated end bearing values for various H-pile sizes and foundation materials as cited by the Iowa DOT FSIC [1] are presented in Appendix B. The bearing capacity of friction piles is attributed to the shear forces developed between the embedded pile surface and the surrounding soil. The magnitude of this resistance varies significantly with both the pile and soil type. Appendix B also contains estimated friction bearing values for various pile and soil type combinations. The bearing capacity of a combined friction and end bearing pile is equal to the sum of the end bearing and friction bearing resistances previously described.

The Iowa DOT BDM [3] states that piles are to be designed using allowable stress design methods. All equations used for the design methodology of steel piles in this section are taken from Part C (Service Load Design Method) of AASHTO Section 10 [2]; these are also provided in Appendix E. As previously noted, the piles for typical LVR bridge abutments used by Iowa counties are required to resist both axial and bending forces. Therefore, interaction equations for steel piles subjected to combined loads are used.

The design capacity of timber piles are determined using the guidelines specified by AASHTO [2] and the NDS Manual [6] as summarized in Appendix E. The timber material properties vary significantly with the species type, member size and shape, loading conditions and surrounding environmental conditions. Therefore, timber modification factors are used to account for these variables. All modification factors used in the design methodology for timber piles are taken from AAHSTO, Section 13 [2]. As recommended by AASHTO [2], the interaction equation defined by the NDS Manual is used to verify the structural adequacy of timber piles subjected to combined axial and bending forces.

2.3.2. Anchor Block Capacity

The structural capacity and passive resistance of the surrounding soil must also be determined. The lateral capacity of the anchor system is related to the mobilized soil pressure that acts on the vertical faces on the anchor block. The magnitude of the soil pressure is a function of the surrounding soil properties and the depth of the anchor block with respect to the roadway surface. The maximum lateral capacity of the anchor block (per pile) is determined by multiplying the passive soil resistance per foot by the pile spacing. The information used to determine the lateral capacity of the anchor system is cited in Bowles [7] and is provided in Appendix E. Bowles [7] also states that the maximum anchor efficiency is achieved when the anchor block is positioned beyond the passive and active soil failure planes behind the backwall face as shown in Figure 2.3.

Once the lateral capacity of the anchor system has been calculated, the structural capacity of the anchor block must be determined. The anchor block capacity is determined using reinforced concrete design specifications presented in Section 8 of AASHTO [2]. This includes the design of the flexural and shear reinforcement in addition to checking the flexural reinforcement development length, the ductility, and the minimum reinforcement requirements.

2.4. PILE AND ANCHOR SYSTEM DESIGN REQUIREMENTS

Once the internal forces and capacities have been determined, one must check the adequacy of the foundation system. In general, this consists of verifying that the individual elements are adequate to support the applied loads. For design bearing requirements, the capacity must be greater than the axial pile load. Additional requirements are cited by AASHTO [2] and the Iowa DOT BDM [3]. Due to the presence of combined bending and axial loads, the structural capacity of the pile is not directly determined. Rather, interaction requirements previously described are used to compare the ratios of applied to allowable stresses for combined bending and axial loadings. If the interaction equations yield a value less than 1.0, the pile is structurally adequate. However, if this requirement is not satisfied, an alternative pile configuration and corresponding loads must be used.

The capacity of the anchor system must also be verified. The applied anchor rod stress must be less than the allowable anchor rod stress defined by AASHTO [2]. The maximum lateral capacity

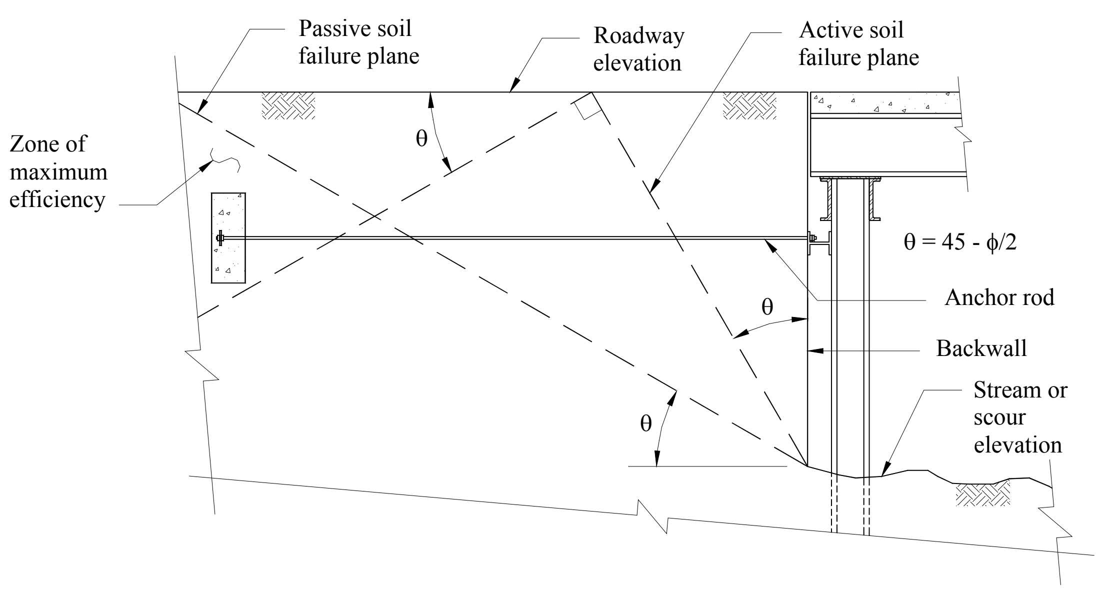


Figure 2.3. Location of anchor block for maximum efficiency [adapted from Bowles, 1996; Figure 4.6 of Volume 1].

of the soil surrounding the anchor block (per pile) must be greater than the required anchor force per pile. In order to satisfy the structural design requirements, the internal anchor block shear forces and bending moments determined using AASHTO [2] reinforced concrete design guidelines must be greater than the effects of the internal loads.

3. DESIGN AID INSTRUCTIONS

This chapter provides the instructions for using the various low-volume road (LVR) bridge abutments design aids developed in this project. These design aids include: 1.) graphs for estimating dead and live load abutment reactions 2.) estimated pile end bearing and friction bearing values, 3.) the FDT, and 4.) generic standard abutment plans.

3.1. ESTIMATED GRAVITY LOADS

The estimation of both dead and live load abutment reactions based on various superstructure systems, span lengths, and roadway widths are presented in Appendix A. Conservative dead load abutment reactions for PCDT, PSC, quad tee, glulam, and slab bridge systems are shown in Figures A.1 and A.2 for 24 and 30 ft roadway widths, respectively. More accurate and potentially smaller dead load abutment reactions can be determined using site-specific bridge information. The live load abutment reactions without impact for two AASHTO [2] HS20-44 design trucks are shown in Figure A.3. Data from Figure A.3 can be proportioned for a different number of design traffic lanes as needed. However if more than two traffic lanes are considered, the lane reduction factor specified in Section 3 of AASHTO [2] (i.e., 0.90 and 0.75 for three and four or more traffic lanes, respectively) needs to be included.

To obtain the dead load abutment reaction, select the bridge superstructure being used in either Figure A.1 or A.2 and the bridge span length. The live load abutment reaction is determined in the same manner using Figure A.3.

3.2. FOUNDATION DESIGN TEMPLATE

The FDT is used to verify the design of a given foundation system. At most, there are two worksheets that the engineer will be required to use. These include the Pile Design and Anchor Design worksheets (PDW and ADW, respectively). The use of the ADW may not be necessary depending on the bridge site. In the complete FDT, there are four different PDW, one for each combination of pile type (steel or timber) and soil type (cohesive or cohesionless). The engineer is automatically directed to the appropriate PDW by the clicking the associated appropriate button on the Start worksheet of the FDT (see Figure 3.1). It should be noted that the BEC logo in Figure 3.1 and applicable subsequent figures can be replaced with the logo of a given county or consulting firm.

A numbering system is used to correlate the input values in the FDT with the descriptions provided in this chapter. Many input values, such as the roadway width, number of piles and lateral restraint details are required for both steel and timber piles. Therefore, the instructions for using the FDT for steel and timber piles are separated into three sections: 1.) steel piles in a cohesive or

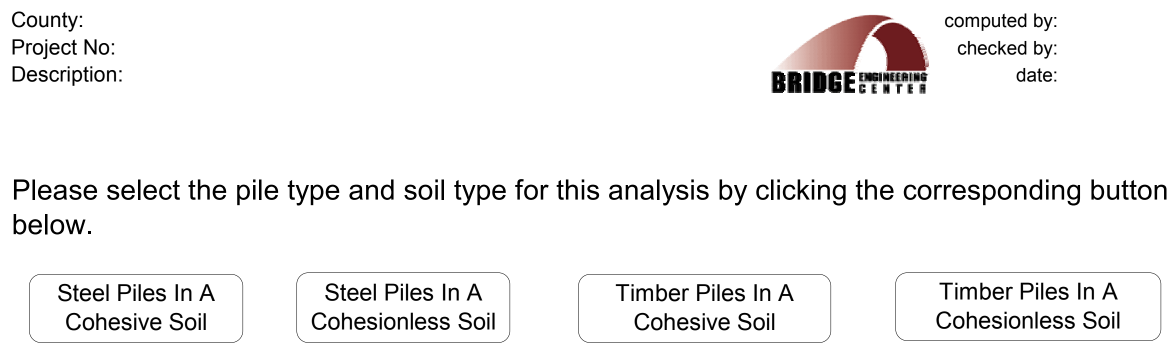


Figure 3.1. View of the Start worksheet for the FDT.

cohesionless soil, 2.) timber piles in a cohesive or cohesionless soil, and 3.) anchor block design. The instructions for using the ADW are applicable to all combinations of piles and soil types. Printouts of all worksheets produced by the FDT for each combination of pile and soil type are presented in Appendix C. In the case where a subsurface bridge site investigation reveals a non-uniform soil profile consisting of both cohesive and cohesionless soils, the properties of the upper level soil should be used to determine which PDW should be used.

3.2.1. Steel Piles in a Cohesive or Cohesionless Soil

3.2.1.1. INSTRUCTION WORKSHEET

The Instruction Worksheet (IW) provides a brief description of the input quantities required for the PDW. A portion of the IW for steel piles is shown in Figure 3.2. Also, the IW contains a figure of an abutment cross section and roadway cross section near the abutment which is reproduced in Figure 3.3. This figure provides a graphical representation of some of the required input values. Each circled number in Figure 3.3 corresponds to an input cell number on the IW and PDW for steel piles (Figures 3.2 and 3.4, respectively). Once the IW has been reviewed, the engineer may proceed by clicking the 'PDW' button (in the upper left corner as shown in Figure 3.2).

3.2.1.2. REQUIRED INPUT

This section provides a detailed explanation of the input values required for the PDW for a steel pile. As shown in Figure 3.4, each input cell is highlighted; quantities shown in the highlighted input cells of Figure 3.4 are shown for demonstration purposes only. The only difference between the PDW for steel piles in a cohesive or cohesionless soil is the required soil input parameter (undrained shear strength and soil friction angle, respectively).

County: computed by:
Project No: checked by:
Description: date:

The calculations performed in the Pile Design Worksheet are based on the guidelines of the AASHTO Standard Specifications and the Iowa DOT Bridge Design Manual (Iowa DOT BDM).

Once the instructions in this worksheet have been reviewed, proceed to the Pile Design Worksheet or return to the pile and soil selection worksheet by clicking the icons below.

Pile Design Worksheet

Return to Pile and Soil Selection Worksheet

Data required is to be entered in the highlighted cells of the Pile Design Worksheet.

The stream elevation is the datum for all elevations.

The following numbers and explanations correspond the highlighted cells on the Pile Design Worksheet; all circled numbers are shown on the figure provided.

Cell No.	Description
1	Enter the span length between the centerline of the abutment bearings.
2	Enter the roadway width of the bridge.
③	Enter the distance between the centerline of the exterior pile and the edge of the roadway. This value is positive for situations when the exterior pile is within the limits of the roadway width as shown above.
4	Enter the number of piles per abutment. This value must be within the range given in the cells directly above this input cell.
⑤	Enter the vertical distance between the roadway grade and the stream elevation.
⑥	Enter the vertical distance from the stream elevation to the estimated depth of scour. This value is based on stream hydraulics, geological information, and engineering judgment.
7	Use the pull-down menu provided to select the type of superstructure system for this analysis.
8	Enter the dead load abutment reaction for this analysis. A default value may be provided in the cell directly above this input cell.
9	Enter the live load abutment reaction for this analysis. A default value is provided directly above this input cell.
10	Enter the average standard penetration test (SPT) blow count (N-value) for the upper level soil.
11	Enter the undrained shear strength of the soil for this analysis. A default value based on the SPT N-value is provided in the cell directly above this input cell.
12	Use the pull-down menu provided to select the type of pile bearing resistance for gravity loads. NOTE: End bearing is only allowed in bed rock for this spreadsheet.
13	If applicable, enter the friction bearing resistance per foot of pile, for the soil *within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
14	If applicable, enter the friction bearing resistance per foot of pile, for the soil *not within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
⑮	If applicable, enter the estimated depth to adequate end bearing foundation material.
16	If applicable, use the pull-down menu provided to select the SPT N-value for the end bearing foundation material.
17	Use the pull-down menu provided to select the pile yield stress.
18	Use the pull-down menu provided to select an H-pile shape. If a standard shape is selected, input values for cell 19 through 25 will not be required from the engineer.
19	If applicable, enter the cross-sectional area of the pile.
20	If applicable, enter the total depth of the pile.

Figure 3.2. Selected portion of the FDT IW for a steel pile.

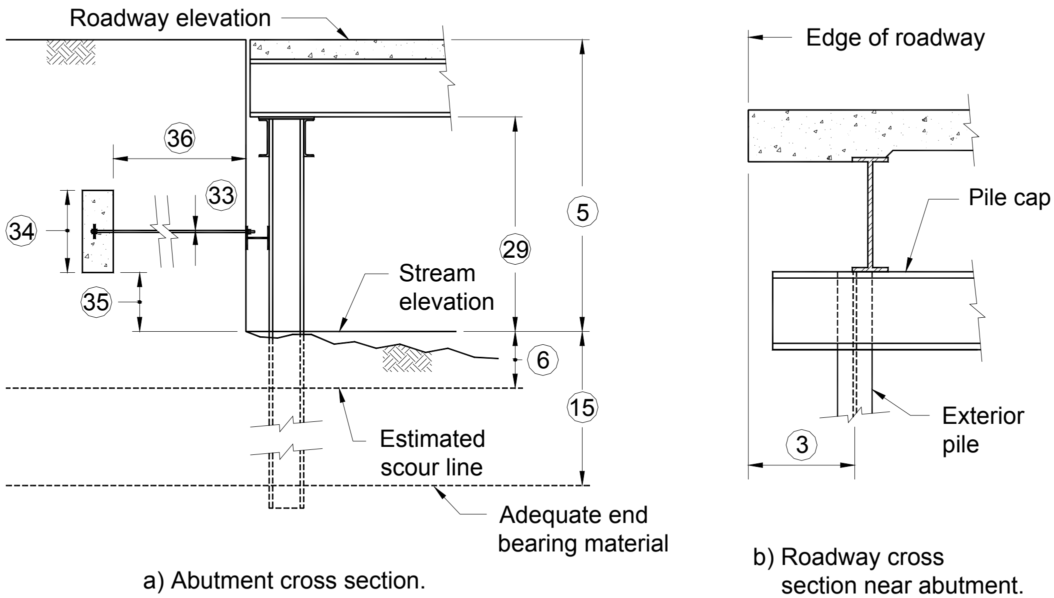


Figure 3.3. Graphical representation of selected input variables for steel piles.

1. Span length (ft) – Enter the bridge span length as measured from the centerlines of the bridge abutments. This input value is limited to a value between 20 and 90 ft.
2. Roadway width (ft) – Enter the bridge roadway width. This input value must be greater than or equal to 24 ft.
3. Location of the exterior pile relative to the edge of the roadway (ft) – Enter the horizontal distance,(3), between the centerline of the exterior pile and the roadway edge as shown in Figure 3.3b. This value, limited to plus or minus 5 ft, is positive if all piles are located within the exterior limits of the roadway as shown in Figure 3.3b.
4. Number of piles (no units) – Enter the number of piles. This value must be a whole number that falls within the ranged specified in the two cells located directly above this input cell. The range of piles provided is based on the roadway width, location of the exterior pile relative to the edge of the roadway (input Cells 2 and 3, respectively), and spacing limitations cited in Section 6.2.4 of the Iowa DOT BDM [3].
5. Backwall height (ft) – Enter the vertical distance,(5), between the stream elevation and roadway elevation as shown in Figure 3.3a.
6. Estimated scour depth (ft) – Enter the estimated depth of soil,(6), that could potentially be eroded away due to scour as shown in Figure 3.3a. This value should be based on hydraulic and geological information as well as sound engineering judgment.

County: computed by:

Project No: checked by:

Description: date:

BRIDGE ENGINEERING CENTER

Instructions Worksheet

Go to Pile and Soil Selection Worksheet

General Bridge Input	1	Span length	60.00	ft		
	2	Roadway width	24.00	ft		
	3	Location of exterior pile relative to the edge of the roadway	0.75	ft		
		Maximum number of piles	10	piles on	2.50	ft centers
		Minimum number of piles	4	piles on	7.50	ft centers
	4	Number of piles	6			
	5	Backwall height	8.00	ft		
	6	Estimated scour depth	2.00	ft		
	7	Superstructure system	PCDT			
		Estimated dead load abutment reaction	180.9	kip per abutment (default value)		
	8	Dead load abutment reaction for this analysis	180.9	kip per abutment		
		Estimated live load abutment reaction	121.5	kip per abutment (default value)		
	9	Live load abutment reaction for this analysis	121.5	kip per abutment		
Foundation Material Input	10	Soil SPT blow count (N)	10			
		Correlated soil un-drained shear strength (C_u)	1,270	psf		
	11	Soil undrained shear strength for this analysis	1,270	psf		
	12	Type of vertical pile bearing resistance	friction & end bearing			
	13	Estimated friction bearing values for depths < 30 ft	0.7	tons per ft		
	14	Estimated friction bearing values for depths < 30 ft	0.8	tons per ft		
	15	Depth to adequate end bearing foundation material	40	ft		
	16	SPT blow count for end bearing foundation material	100 < N < 200			
Pile Input	17	Pile steel yield stress	36	ksi		
	18	Select pile type	HP10x42			
	19	Pile cross sectional area	12.4	in^2		
	20	Pile depth	9.70	in.		
	21	Pile web thickness	0.415	in.		
	22	Pile flange width	10.1	in.		
	23	Pile flange thickness	0.420	in.		
	24	Pile moment of inertia (strong axis)	210	in^4		
	25	Pile section modulus (strong axis)	43.4	in^3		
	26	Pile section modulus (weak axis)	14.2	in^3		
	27	Pile radius of gyration (strong axis)	4.13	in.		
	28	Pile radius of gyration (weak axis)	2.41	in.		
Lateral Restraint Input	29	Superstructure bearing elevation	5.00	ft		
	30	Type of lateral restraint system	buried concrete anchor block			
	31	Anchor rod steel yield stress	60	ksi		
	32	Total number of anchor rods per abutment	6	per abutment		
	33	Anchor rod diameter	0.88	in.		
	34	Height of anchor block	2.50	ft		
	35	Bottom elevation of anchor block	3.00	ft		
		Anchor block lateral capacity	10.8	kip per pile		
		Computed anchor force per pile	9.7	kip per pile		
		Minimum anchor rod length	14.69	ft		
	36	Anchor rod length	16.00	ft		

Check Pile Design

Figure 3.4. Input section of the FDT PDW for steel piles.

7. Superstructure system (no units) – Use the provided pull-down menu to select the appropriate superstructure being used.
8. Dead load abutment reaction for this analysis (kips per abutment) – Enter the dead load abutment reaction for this analysis. If a 24 or 30 ft roadway width and a superstructure system other than a BISB and RRFC are used, a conservative value will be shown in the cell located directly above this input cell as shown in Figure 3.4. This default value is based on span length, roadway width, and the superstructure used (input Cells 1, 2, and 7, respectively).
9. Live load abutment reaction for this analysis (kips per abutment) – Enter the live load abutment reaction for this analysis. A conservative value is provided in the cell directly above this input cell as shown in Figure 3.4. This default value is based on the span length and roadway width (input Cells 1 and 2, respectively).
10. Soil SPT blow count (N) – Enter the SPT blow count for the soil in the immediate vicinity of the foundation piles. If a non-uniform soil profile is present, use the average blow count for the upper level soil. This input value must be a whole number between 1 and 50.
11. Soil undrained shear strength for this analysis, **for steel piles in cohesive soil only** (psf) Enter the undrained shear strength (c_U); a default value based on a commonly used correlation of the SPT blow count and undrained shear strength as reported by Terzaghi and Peck [8] is provided in the cell directly above this input cell as shown in Figure 3.4. This relationship is provided as Equation 3.1. Since this correlation can be unreliable for some in-situ conditions, it is recommended that, whenever possible, the undrained shear strength be determined by testing soil samples from the bridge site. This input value is used to calculate the depth of pile fixity for piles in cohesive soils, the equations for which are presented in Appendix E.

$$c_u = 0.06 * N * P_{ATM} \qquad (3.1)$$

where:

c_u = Soil undrained shear strength.

N = SPT blow count.

P_{ATM} = Atmospheric pressure.

11. Soil friction angle for this analysis, **for steel piles in cohesionless soil only** (degrees)

Enter the soil friction angle (ϕ); a default value based on a correlation of the SPT blow count and the soil friction angle as reported by Peck [9] is provided in the cell directly above this input cell. This input value is not shown in Figure 3.4 in lieu of the undrained shear strength. This relationship is provided as Equation 3.2. Due to uncertainties in empirical relationships, it is recommended that the soil friction angle be verified from laboratory tests (e.g., direct shear test) on soil samples from the bridge site. This input value is used to calculate the depth of pile fixity for piles in cohesionless soils, the equations for which are presented in Appendix E.

$$\phi = 53.881 - \left(27.6034 * e^{-0.0147\ N}\right) \quad (3.2)$$

where:

N = SPT blow count.

ϕ = Soil friction angle.

12. Type of vertical pile bearing resistance (no units) – Use the provided pull-down menu to select an appropriate type of vertical bearing resistance.
13. Estimated friction bearing value for depths less than 30 ft (tons per ft) – If applicable, enter an estimated friction bearing resistance for the soil *within* 30 ft of the natural ground line. Estimated values for this input parameter can be obtained from Appendix B or the Iowa DOT FSIC [1]. This input value must be between 0.1 and 2.0 tons per foot.
14. Estimated friction bearing value for depths greater than 30 ft (tons per ft) – If applicable, enter an estimated friction bearing resistance for soils *not within* 30 ft of the natural ground line. Estimated values for this input parameter can be obtained from Appendix B or the Iowa DOT FSIC [1]. This input value must be between 0.1 and 2.0 tons per foot.
15. Depth to adequate end bearing foundation material (ft) – If applicable, enter the estimated depth below stream elevation to adequate end bearing foundation material, (15), as shown in Figure 3.3a. This input value must be greater than 10 ft as cited by the Iowa DOT BDM [3].
16. SPT blow count for end bearing foundation material (N-value) – If applicable, use the provided pull-down menu to select an estimated SPT blow count range for the end bearing foundation material.
17. Pile steel yield stress (ksi) – Use the provided pull-down menu to select the yield stress of the steel in the pile.

18. Select pile type (no units) – Use the provided pull-down menu to either select a standard H-Pile shape or the option to manually input the pile properties defined below for input Cells 19 through 28.
19. Pile cross sectional area (in^2) – If applicable, enter the cross sectional area of the pile.
20. Pile depth (in.) – If applicable, enter the total depth of the pile.
21. Pile web thickness (in.) – If applicable, enter the width of the pile web.
22. Pile flange width (in.) – If applicable, enter the pile width measured parallel to the backwall face.
23. Pile flange thickness (in.) – If applicable, enter the thickness of the pile flange.
24. Pile moment of inertia (in^4) – If applicable, enter the strong axis moment of inertia. For this analysis, it is assumed that the strong pile axis is parallel to the backwall face.
25. Pile section modulus (in^3) - If applicable, enter the *strong* axis section modulus. For this analysis, it is assumed that the *strong* pile axis is *parallel* to the backwall face.
26. Pile section modulus (in^3) – If applicable, enter the *weak* axis section modulus. For this analysis, it is assumed that the *weak* pile axis is *perpendicular* to the backwall face.
27. Pile radius of gyration (in.) - If applicable, enter the *strong* axis radius of gyration. For this analysis, it is assumed that the *strong* pile axis is *parallel* to the backwall face.
28. Pile radius of gyration (in.) - If applicable, enter the *weak* axis radius of gyration. For this analysis, it is assumed that the *weak* pile axis is *perpendicular* to the backwall face.
29. Superstructure bearing elevation (ft) – Enter the vertical distance between the stream elevation and superstructure bearings,(29), as shown in Figure 3.3a. This input value must be between 0 ft and the backwall height (input Cell 5).
30. Type of lateral restraint system (no units) – Use the provided pull-down menu to select the lateral restraint system for this analysis.
31. Anchor rod steel yield stress (ksi) – If applicable, use the pull down menu provided to select the yield stress of the anchor rod steel.
32. Total number of anchor rods per abutment (no units) – If applicable, enter the total number of anchor rods per abutment. This input value must be a whole number between 1 and 16.
33. Anchor rod diameter (in.) – If applicable, enter the anchor rod diameter,(33), as shown in Figure 3.3a.
34. Height of anchor block (ft) – If applicable, enter the height of the anchor block,(34), as shown in Figure 3.3a.

35. Bottom elevation of anchor block (ft) – If applicable, enter the vertical distance between the stream elevation and bottom of the anchor block,(35), as shown in Figure 3.3a. This input value is limited such that the bottom and top anchor block faces must be between the stream and roadway elevations, respectively.
36. Anchor rod length (ft) – If applicable, enter the anchor rod length,(36), as shown in Figure 3.3a. This value must be greater than or equal to the minimum anchor rod length provided in the cell directly above this input cell. This minimum value is determined by the FDT and ensures that the buried concrete anchor block is beyond the passive and active soil failure planes as shown in Figure 2.3.

Once the required input values have been entered in the highlighted cells, and if no red text warning messages appear, the adequacy of the pile system can be verified. This is accomplished by clicking the 'Check Pile Design' button located below the last input cell as shown in Figure 3.4. The engineer must click this button each time changes are made to any of the input values previously designated.

3.2.1.3. DESIGN CHECKS

The next section of the PDW displays the various design requirements for steel piles in a cohesive or cohesionless soil. A brief explanation of the various strength and serviceability requirements is also presented. Additionally, suggestions for adjusting the previously described input values to satisfy these design requirements are also included in this section. As shown in Figure 3.5, each design requirement is assigned a number that corresponds to the description provided in this section.

1. Axial pile stress (ksi) – The total axial pile stress must be less than the allowable stress limits cited in Section 6.2.6.1 of the Iowa DOT BDM [3]. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use a pile with a larger cross sectional area (input Cell 18 or 19).
   - Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).

Design Checks					
	1	Axial pile stress	$P/A \le \sigma_{ALL}$	5.83 ksi	OK
	2	Pile bearing capacity	$\text{Axial Pile Load} \le \text{Capacity}$	727.6 kip	OK
	3	Interaction equation validation	$\frac{1}{(1 - f_a/F'_e)} > 1.0$	1.04	OK
	4	Combined loading interaction requirement # 1 $\frac{f_a}{F_a} + \frac{C_{mx}\, f_{bx}}{\left(1 - \frac{f_a}{F'_{ex}}\right) F_b} + \frac{C_{my}\, f_{by}}{\left(1 - \frac{f_a}{F'_{ey}}\right) F_b} \le 1.0$		0.70	OK
	5	Combined loading interaction requirement # 2 $\frac{f_a}{0.472\, F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \le 1.0$		0.75	OK
	6	Buried anchor block location	$\text{Anchor rod length} \ge \text{minimum}$	16.00 ft	OK
	7	Anchor rod stress	$\sigma \le 0.55\ F_Y$	16.1 ksi	OK
	8	Anchor block capacity	$\text{Total Anchor Force} \le \text{Capacity}$	10.8 kip per pile	OK
	9	Maximum displacement	$\delta_{MAX} \le 1.5\ \text{in.}$	0.21 in.	OK

Anchor Design Worksheet

Foundation Summary			
	1	Roadway width	24.00 ft
	2	Span length	60.00 ft
	3	Distance between superstructure bearings and roadway grade	3.00 ft
	4	Backwall height	8.00 ft
	5	Dead load abutment reaction	180.9 kip per abutment
	6	Live load abutment reaction	121.5 kip per abutment
	7	Number of piles	6
	8	Total axial pile load	36.1 tons
	9	Pile spacing	4.50 ft
	10	Pile size	HP10x42
	11	Pile steel yield stress	36 ksi
	12	Minimum total pile length	47 ft

Figure 3.5. Design Checks and Foundation Summary section of the FDT PDW for steel piles.

2. Pile bearing capacity (kips) – The total axial pile load must be less than the bearing capacity. The bearing capacity of a friction pile will be sufficient if the embedded length is greater than or equal to the minimum length specified in the Foundation Summary section (Cell 13) of the PDW (discussed later in this chapter). If this requirement is not satisfied for end bearing and combination end and friction bearing piles, the engineer could:
   - Increase the number of piles (input Cell 4).
   - If applicable, use an alternative pile size that provides a larger friction bearing resistance per foot (input Cells 13, 14, and 18 through 28).

- If applicable, use an alternative pile size with a larger end bearing area (input Cell 18 or 19).
- Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).

3. <u>Interaction equation validation (non-dimensional)</u> – The secondary pile moment factor must be greater than or equal to one. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use an alternative pile size with a larger axial capacity (input Cell 18 or 19 through 28).
   - Use an alternative lateral restraint system or configuration (input Cells 30 through 36).
   - Use a pile with a higher steel yield stress (input Cell 17).
   - Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).
4. <u>Combined loading interaction requirement # 1 (non-dimensional)</u> – This is the first of two AASHTO [2] interaction equations. This equation (Equation E.1 of Appendix E) must yield a value less than or equal to one. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use an alternative pile size with a larger axial and flexural capacity (input Cell 18 or 19 through 28).
   - Use an alternative lateral restraint system or configuration (input Cells 30 through 36).
   - Use a pile with a higher steel yield stress (input Cell 17).
   - Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).
5. <u>Combined loading interaction requirement # 2 (non-dimensional)</u> – This is the second of two AASTHO [2] interaction equations (Equation E.6 of Appendix E). This interaction equation must yield a value less than or equal to one. If this requirement is not satisfied, the engineer could use the recommendations provided for the previous pile interaction requirement (design check Cell 4).

6. Buried anchor block location (ft) – The length of the anchor rod must be long enough to ensure the failure planes of the anchor block and backwall do not intersect as shown in Figure 2.3. If this requirement is not satisfied, the engineer could:
   - Increase the anchor rod length (input Cell 36).
   - Adjust the distance between the bottom face of the anchor block and the stream elevation (input Cell 35).
7. Anchor rod stress (ksi) – The applied anchor rod stress must be less than or equal to 55 percent the yield stress as specified by AASHTO [2]. If this requirement is not satisfied, the engineer could:
   - Increase the number of anchor rods per abutment (input Cell 32).
   - Increase the anchor rod diameter (input Cell 33).
   - Use an anchor rod with a higher steel yield stress (input Cell 31).
   - Increase the number of piles to reduce the required anchor rod force (input Cell 4).
   - Use an alternative pile size with an increased flexural capacity to reduce the required anchor rod force (input cell 18 or 19 through 28).
8. Anchor block capacity (kip per pile) – The lateral anchor force per pile must be less than the maximum passive resistance of the soil surrounding the anchor block. The maximum lateral capacity per pile and computed anchor force per pile are provided directly below input Cell 35 as shown in Figure 3.4. The anchor capacity per pile is based on the soil pressure distribution of Figure E.1 and Equation E.15 in Appendix E. The computed anchor force per pile is determined by the FDT using indeterminate structural analysis as described in Chapter 2. If this requirement is not satisfied, the engineer could:
   - Increase the height of the anchor block (input Cell 34).
   - Decrease the distance between the bottom face of the anchor block and the stream elevation (input Cell 35).
   - Use an alternative pile size with a larger flexural capacity to reduce the required anchor force per pile (input Cell 18 or 19 through 28).
9. Maximum displacement (in.) – AASHTO, Section 4 [2] defines the maximum allowable longitudinal substructure displacement as 1.5 in. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use an alternative pile size with a larger flexural rigidity (input Cell 18 or 19 through 28).

- Use an alternative lateral restraint system or configuration (input Cells 30 through 36).

3.2.1.4. INFORMATION SUMMARY

As shown in Figure 3.5 the PDW also contains a Foundation Summary section. Each summary cell is assigned a number that corresponds to the description provided in this section. Items 1, 2, 4 through 7, 10, and 11 are provided by the engineer.

1. <u>Roadway width (ft)</u>
2. <u>Span length (ft)</u>
3. <u>Distance between superstructure bearings and roadway grade (ft)</u> – This cell contains the combined depth of the superstructure plus roadway as determined by the FDT.
4. <u>Backwall height (ft)</u>
5. <u>Dead load abutment reaction (kips per abutment)</u>
6. <u>Live load abutment reaction (kips per abutment)</u>
7. <u>Number of piles (no units)</u>
8. <u>Total axial pile load (tons)</u> – This cell contains the total axial pile load as determined by the FDT. This value includes the sum of the dead and live load axial pile loads (both multiplied by the nominal axial pile factor as described in Chapter 2) and the pile self-weight.
9. <u>Pile spacing (ft)</u> – This cell contains the pile spacing as determined by the FDT.
10. <u>Pile size (no units)</u> – This cell contains the standard pile shape for this analysis as indicated by the engineer. If a non-standard pile shape size was used, this summary cell indicates a reference to the pile property input cells.
11. <u>Pile steel yield stress (ksi)</u>
12. <u>Minimum total pile length (ft)</u> – This cell contains the minimum total pile length as determined by the FDT. For end bearing and combination bearing piles, the minimum total pile length is equal the vertical distance between the superstructure bearings and the location of adequate end bearing material. For friction bearing piles, the minimum required pile length is equal to the vertical distance between the stream elevation and the superstructure bearings plus the depth required for adequate bearing capacity.
13. <u>Minimum embedded pile length (ft)</u> – If the pile is designed as a friction pile, this cell contains the minimum required embedded pile length for friction pile as determined by the FDT.

3.2.2. Timber Piles in a Cohesive or Cohesionless Soil

3.2.2.1. INSTRUCTION WORKSHEET

The IW provides a brief description of the input quantities required for the PDW. A portion of the IW for timber piles is shown in Figure 3.6. Also, the IW contains a figure of an abutment cross section and roadway cross section near the abutment which is reproduced in Figure 3.7. This figure provides a graphical representation of some of the required input parameters. Each circled number in Figure 3.7 corresponds to an input cell number on the IW and PDW for timber piles (Figures 3.6 and 3.8, respectively). Once the IW has been reviewed, the engineer may proceed by clicking the 'Pile Design Worksheet' button (in the upper left corner as shown in Figure 3.6).

3.2.2.2. REQUIRED INPUT

This section provides a detailed explanation of the input values required for the PDW for a timber pile. As shown in Figure 3.8, each input cell is highlighted. The quantities shown in the highlighted input cells of Figure 3.8 are not applicable for all bridge sites and are shown for demonstration purposes only. The only difference between the PDW for timber piles in a cohesive or cohesionless soil is the required soil input parameter (undrained shear strength and soil friction angle, respectively).

1. Span length (ft) – Enter the bridge span length as measured from the centerlines of the bridge abutments. This input value is limited to a value between 20 and 90 ft.
2. Roadway width (ft) – Enter the bridge roadway width. This input value must be greater than or equal to 24 ft.
3. Location of the exterior pile relative to the edge of the roadway (ft) – Enter the horizontal distance, (3), between the centerline of the exterior pile and the roadway edge as shown in Figure 3.7b. This value, limited to plus or minus 5 ft, is positive if all piles are located within the exterior limits of the roadway as shown in Figure 3.7b.
4. Number of piles (no units) – Enter the number of piles. This value must be a whole number that falls within the range specified in the two cells located directly above this input cell. The range of piles provided is based on the roadway width, location of the exterior pile relative to the edge of the roadway (input Cells 2 and 3, respectively), and spacing limitations cited in section 6.2.4 of the Iowa DOT BDM [3].
5. Backwall height (ft) – Enter the vertical distance, (5), between the stream elevation and roadway elevation as shown in Figure 3.7a.

County:
Project No:
Description:

computed by:
checked by:
date:

The calculations performed in the Pile Design Worksheet are based on the guidelines of the AASHTO Standard Specifications, the Iowa DOT Bridge Design Manual (Iowa DOT BDM), and the National Design Specifications Manual for Wood Construction (NDS Manual).

Once the instructions on this worksheet have been reviewed, proceed to the Pile Design Worksheet or return to the pile and soil selection worksheet by clicking the icons below.

Pile Design Worksheet

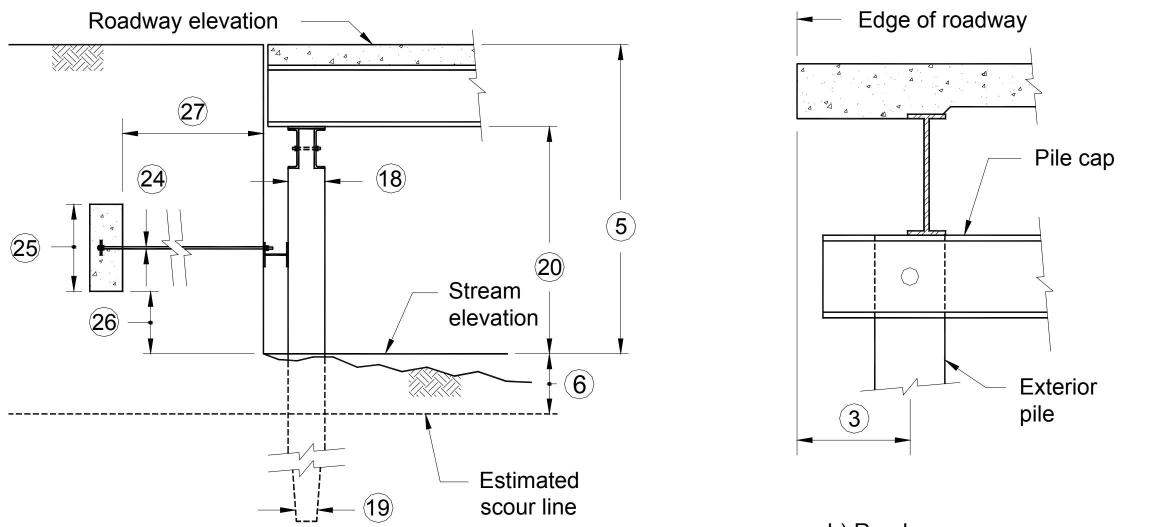
Return to Pile and Soil Selection Worksheet

Data required is to be entered in the highlighted cells of the Pile Design Worksheet.

The following numbers and explanations correspond the highlighted cells on the Pile Design Worksheet; all circled numbers are shown on the figure provided.

Cell No.	Description
1	Enter the span length between the centerline of the abutment bearings.
2	Enter the roadway width of the bridge.
(3)	Enter the distance between the centerline of the exterior pile and the edge of the roadway. This value is positive for situations when the exterior pile is within the limits of the roadway width as shown above.
4	Enter the number of piles per abutment. This value must be within the range given in the cells directly above this input cell.
(5)	Enter the vertical distance between the roadway grade and the stream elevation.
(6)	Enter the vertical distance from the stream elevation to the estimated depth of scour. This value is based on stream hydraulics, geological information, and engineering judgment.
7	Use the pull-down menu provided to select the superstructure system for this analysis
8	Enter the dead load abutment reaction for this analysis. A default value maybe provided in the cell directly above this input cell.
9	Enter the live load abutment reaction for this analysis. A default value is provided in the cell directly above this input cell.
10	Enter the average standard penetration test (SPT) blow count (N-value) for the upper level soil.
11	Enter the undrained shear strength of the soil for this analysis. A default value base of the SPT N-value is provided in the cell located directly above this input cell.
12	Enter the friction bearing resistance per foot of pile for soils *within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
13	Enter the friction bearing resistance per foot of pile for soils *not within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
14	Use the pull-down menu provided to select the timber species for this analysis.
15	Enter the tabulated timber bending stress.
16	Enter the tabulated timber compressive stress (parallel to the grain).
17	Enter the tabulated modulus of elasticity.
(18)	Enter the pile butt diameter (i.e., the driving end).
(19)	Enter the pile tip diameter (i.e., the embedded end).
(20)	Enter the vertical distance between the stream elevation and the superstructure bearing points.
21	Use the pull-down menu provided to select the type of lateral restraint system (if any) for this analysis.
22	If applicable, use the pull-down menu provided to select the anchor rod yield stress.
23	If applicable, enter the total number of anchor rods for one abutment.
(24)	If applicable, enter the anchor rod diameter.

Figure 3.6. Selected portion of the FDT IW for timber piles.



a) Abutment cross section.

b) Roadway cross section near abutment.

Figure 3.7. Graphical representation of various input requirements for timber piles.

6. Estimated scour depth (ft) – Enter the estimated depth of soil, (6), that could potentially be eroded away due to scour as shown in Figure 3.7a. This value should be based on hydraulic and geological information as well as sound engineering judgment.
7. Superstructure system (no units) – Use the pull-down menu provided to select the appropriate superstructure being used.
8. Dead load abutment reaction for this analysis (kips per abutment) – Enter the dead load abutment reaction for this analysis. If a 24 or 30 ft roadway width and a superstructure system other than a BISB and RRFC are used, a conservative value will be shown in the cell located directly above this input cell as shown in Figure 3.8. This default value is based on span length, roadway width, and the superstructure used (input Cells 1, 2, and 7, respectively).
9. Live load abutment reaction for this analysis (kips per abutment) – Enter the live load abutment reaction for this analysis. A conservative value is provided in the cell directly above this input cell as shown in Figure 3.8. This default value is based on the span length and roadway width (input Cells 1 and 2, respectively).
10. Soil SPT blow count (N) – Enter the SPT blow count for the soil in the immediate vicinity of the foundation piles. If a non-uniform soil profile is present, use the average blow count for the upper level soil. This input value must be a whole number between 1 and 50.

County:
Project No:
Description:

computed by:
checked by:
date:

Instructions Worksheet

Return to Pile and Soil Selection Worksheet

General Bridge Input	1	Span length	40.00	ft	
	2	Roadway width	24.00	ft	
	3	Location of exterior pile relative to the edge of the roadway	0.92	ft	
		Maximum number of piles	9	piles on	2.77 ft centers
		Minimum number of piles	4	piles on	7.39 ft centers
	4	Number of piles	8		
	5	Backwall height	6.00	ft	
	6	Estimated scour depth	2.00	ft	
	7	Superstructure system	PCDT		
		Estimated dead load abutment reaction	128.6	kip per abutment (default value)	
	8	Dead load abutment reaction for this analysis	128.6	kip per abutment	
		Estimated live load abutment reaction	110.0	kip per abutment (default value)	
	9	Live load abutment reaction for this analysis	110.0	kip per abutment	
Foundation Material Input	10	Soil SPT blow count (N)	20		
		Correlated soil friction angle (ϕ)	33.3	degrees	
	11	Soil friction angle for this analysis	33.3	degrees	
	12	Estimated friction bearing value for depths less than 30 ft	0.7	tons per ft	
	13	Estimated friction bearing value for depths greater than 30 ft	0.7	tons per ft	
Pile Input	14	Timber species	southern pine		
	15	Tabulated timber bending stress	1,750	psi	
	16	Tabulated timber compressive stress	1,100	psi	
	17	Tabulated timber modulus of elasticity	1,600,000	psi	
	18	Pile butt diameter	13.0	in.	
	19	Pile tip diameter	10.0	in.	
Lateral Restraint Input	20	Superstructure bearing elevation	3.58	ft	
	21	Type of lateral restraint system	buried concrete anchor block		
	22	Anchor rod steel yield stress	60	ksi	
	23	Total number of anchor rods per abutment	5	per abutment	
	24	Anchor rod diameter	0.75	in.	
	25	Height of anchor block	3.00	ft	
	26	Bottom elevation of anchor block	1.08	ft	
		Anchor block lateral capacity	8.3	kip per pile	
		Computed anchor force per pile	6.3	kip per pile	
		Minimum anchor rod length	13.47	ft	
	27	Anchor rod length	15.00	ft	

Check Pile Design

Figure 3.8. Input section of the FDT PDW for timber piles.

11. <u>Soil undrained shear strength for this analysis, **for timber piles in a cohesive soil only** (psf)</u>

Enter the undrained shear strength (c_U); a default value based on a commonly used correlation of the SPT blow count and undrained shear strength as reported by Terzaghi and Peck [8] is provided in the cell directly above this input cell. This input cell is not shown in Figure 3.8 in lieu of the soil friction angle. This relationship is provided as

Equation 3.1. Since this correlation can be unreliable for some in-situ conditions, it is recommended that, whenever possible, the undrained shear strength be determined by testing soil samples from the bridge site. This input value is used to calculate the depth of pile fixity for piles in cohesive soils, the equations for which are presented in Appendix E.

11. Soil friction angle for this analysis, **for timber piles in a cohesionless soil only** (degrees)
    Enter the soil friction angle (ϕ); a default value, based on the correlation of the SPT blow count and the soil friction angle as reported by Peck [9] is provided in the cell directly above this input cell as shown in Figure 3.8. This relationship is provided as Equation 3.2. Due to uncertainties in empirical relationships, it is recommended that the soil friction angle be verified from laboratory tests (e.g., direct shear test) on soil samples from the bridge site. This input value is used to calculate the depth of pile fixity for piles in cohesionless soils, the equations for which are presented in Appendix E.
12. Estimated friction bearing value for depths less than 30 ft (tons per ft) – Enter an estimated friction bearing resistance for the soil *within* 30 ft of the natural ground line. Estimated values for this input parameter can be obtained from Appendix B or the Iowa DOT FSIC [1]. This input value must be between 0.1 and 2.0 tons per foot.
13. Estimated friction bearing value for depths greater than 30 ft (tons per ft) – Enter an estimated friction bearing resistance for soils *not within* 30 ft of the natural ground line. Estimated values for this input parameter can be obtained from Appendix B or the Iowa DOT FSIC [1]. This input value must be between 0.1 and 2.0 tons per foot.
14. Timber species (no units) – Use the provided pull-down menu to select the timber species for this analysis.
15. Tabulated timber bending stress (psi) – Enter the tabulated timber bending stress. AASHTO Table 13.5.1A. [2] recommends a tabulated timber bending stress of 1,750 psi for both southern pine and douglas fir timber species (structural grade lumber).
16. Tabulated timber compressive stress (psi) – Enter the tabulated timber compressive stress (parallel to the grain). AASHTO Table 13.5.1A. [2] recommends tabulated compressive stress values of 1,100 and 1,350 psi for southern pine and douglas fir timber species, respectively (structural grade lumber).
17. Tabulated timber modulus of elasticity (psi) – Enter the tabulated timber modulus of elasticity. AASHTO Table 13.5.1A. [2] recommends tabulated timber modulus of

elasticity values of 1,600,000 and 1,700,000 psi for southern pine and douglas fir timber species, respectively (structural grade lumber).

18. Pile butt diameter (in.) – Enter the diameter of the pile as measured at the butt or pile driving end,(18), as shown in Figure 3.7a. This input value must be greater than or equal to 10 in. as required by the Iowa DOT Standard Specifications [10].
19. Pile tip diameter (in.) – Enter the diameter of the pile as measured at the tip or embedded end,(19), as shown in Figure 3.7a. This input value must be greater than or equal to 6 in. as required by the Iowa DOT Standard Specifications [10].
20. Superstructure bearing elevation (ft) – Enter the vertical distance between the stream elevation and superstructure bearings,(20), as shown in Figure 3.7a. This input value must be between 0 ft and the backwall height (input Cell 5).
21. Type of lateral restraint system (no units) – Use the provided pull-down menu to select the lateral restraint system for this analysis.
22. Anchor rod steel yield stress (ksi) – If applicable, use the pull down menu provided to select the anchor rod steel yield stress.
23. Total number of anchor rods per abutment (no units) – If applicable, enter the total number of anchor rods per abutment. This input value must be a whole number between 1 and 16.
24. Anchor rod diameter (in.) – If applicable, enter the anchor rod diameter,(24), as shown in Figure 3.7a.
25. Height of anchor block (ft) – If applicable, enter the height of the anchor block,(25), as shown in Figure 3.7a.
26. Bottom elevation of anchor block (ft) – If applicable, enter the vertical distance between the stream elevation and bottom of the anchor block,(26) , as shown in Figure 3.7a. This input value is limited such that the bottom and top anchor block faces must be between the stream and roadway elevations, respectively.
27. Anchor rod length (ft) – If applicable, enter the anchor rod length,(27), as shown in Figure 3.7a. This value must be greater than or equal to the minimum anchor rod length provided in the cell directly above this input cell. This minimum value is determined by the FDT and ensures that the buried concrete anchor block is beyond the passive and active soil failure planes as shown in Figure 2.3.

Once the required input values have been entered in the highlighted cells, and if no red text warning messages appear, the adequacy of the pile system can be verified. This is accomplished by clicking the 'Check Pile Design' button located below the last input cell as shown in Figure 3.8. The engineer must click this button each time changes are made to any of the input values previously designated.

3.2.2.3. DESIGN CHECKS

The next section of the PDW displays the various design requirements for timber piles in a cohesive or cohesionless soil. A brief explanation of the various strength and serviceability requirements is also presented. Additionally, suggestions for adjusting the previously described input values to satisfy these design requirements are also included in this section. As shown in Figure 3.9, each design requirement is assigned a number that corresponds to the description provided in this section.

1. Axial pile load (kips) – The total axial pile load for a timber pile must be less than the allowable limit cited in Section 6.2.6.3 of the Iowa DOT BDM [3]. The maximum axial load for a timber pile with a length between 20 and 30 ft is 20 tons. However, this allowable load can be increased to 25 tons per pile if the pile length is greater than 30 ft. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).
2. Pile length(ft) – The length of a timber pile must be between 20 and 55 ft as cited by Section 6.2.6.3 of the Iowa DOT BDM [3]. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use a larger diameter pile to increase the friction bearing resistance per foot of pile thus reducing the required pile length (input cells 18 and 19).
   - Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).
3. Pile bearing capacity (kips) – The total axial pile load must be less than the bearing capacity. The bearing capacity of a friction pile will be sufficient if the embedded length is greater than or equal to the minimum length provided for this design requirement as shown in Figure 3.9.

Design Checks					
	1	Axial pile load	$P \le P_{ALLOWABLE}$	42.1 kip	OK
	2	Pile length	$\text{Length} \le 55\text{ ft}$	33 ft	OK
	3	Pile bearing capacity	$\text{Axial Pile Load} \le \text{Capacity}$	sufficient if pile is embedded at least	30 ft
	4	Interaction equation validation	$\frac{1}{(1 - f_C/F'_e)} > 1.0$	1.04	OK
	5	Combined loading interaction requirement $\left(\frac{f_C}{F'_C}\right)^2 + \frac{f_{bx}}{F'_b\left(1-\frac{f_C}{F'_{ex}}\right)} + \frac{f_{by}}{F'_b\left(1-\frac{f_C}{F'_{ey}}-\left(\frac{f_{bx}}{F'_{bE}}\right)^2\right)} \le 1.0$		0.61	OK
	6	Buried anchor block location	$\text{Anchor rod length} \ge \text{minimum}$	15.00 ksi	OK
	7	Anchor rod stress	$\sigma \le 0.55\ F_Y$	22.9 ksi	OK
	8	Anchor block capacity	$\text{Total Anchor Force} \le \text{Capacity}$	8.3 kip per pile	OK
	9	Maximum displacement	$\delta_{MAX} \le 1.5\text{ in.}$	0.35 in.	OK

Anchor Design Worksheet

Foundation Summary			
	1	Roadway width	24.00 ft
	2	Span length	40.00 ft
	3	Distance between superstructure bearings and roadway grade	2.42 ft
	4	Backwall height	6.00 ft
	5	Dead load abutment reaction	128.6 kip per abutment
	6	Live load abutment reaction	110.0 kip per abutment
	7	Number of piles	8
	8	Total axial pile load	21.0 tons
	9	Pile spacing	3.17 ft
	10	Pile size	
		Butt diameter	13.0 in.
		Tip diameter	10.0 in.
	11	Pile material properties	
		Timber species	southern pine
		Tabulated timber compressive stress	1,100 psi
		Tabulated timber bending stress	1,750 psi
		Tabulated timber modulus of elasticity	1,600,000 psi
	12	Minimum total pile length	33 ft

Figure 3.9. Design Checks and Foundation Summary sections of the FDT PDW for timber piles.

4. Interaction equation validation (non-dimensional) – The secondary pile moment factor must be greater than or equal to one. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use a larger pile diameter to increase the axial capacity (input Cells 18 and 19).
   - Use an alternative lateral restraint system or configuration (input Cells 21 through 27).

- Use a timber species with a higher tabulated compressive stress (input Cells 14 and 16).
- Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).

5. <u>Combined loading interaction requirement (non-dimensional)</u> – The NDS Manual [6] interaction equation (Equation E.8 in Appendix E) must yield a value less than or equal to one. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use a larger pile diameter which increases the axial and flexural capacity of the pile (input Cells 18 and 19).
   - Use a timber species with a higher tabulated timber bending and axial stress (input Cells 14 through 16).
   - Use an alternate lateral restraint system or configuration (input Cells 21 through 27).
   - Use a less conservative (i.e., calculate a more accurate value) dead load and/or live load abutment reaction (input Cells 8 and 9, respectively).
6. <u>Buried anchor block location (ft)</u> – The length of the anchor rod must be long enough to ensure the failure planes of the anchor block and backwall do not intersect as shown in Figure 2.3. If this requirement is not satisfied, the engineer could:
   - Increase the anchor rod length (input Cell 27).
   - Adjust the distance between the bottom face of the anchor block and the stream elevation (input Cell 26).
7. <u>Anchor rod stress (ksi)</u> – The applied anchor rod stress must be less than 55 percent the yield stress as specified by AASHTO [2]. If this requirement is not satisfied, the engineer could:
   - Increase the number of anchor rods per abutment (input Cell 23).
   - Increase the diameter of the anchor rods (input Cell 24).
   - Use an anchor rod with a higher steel yield stress (input Cell 22).
   - Use a larger pile diameter which increases the flexural capacity and reduces the required anchor rod force (input Cells 18 and 19).
   - Increase the number of piles to reduce the required anchor rod force (input Cell 4).

8. Anchor block capacity (kips per pile) – The lateral anchor force per pile must be less than the maximum passive resistance of the soil surrounding the anchor block. The maximum lateral capacity per pile and computed anchor force per pile are provided below input Cell 26 as shown in Figure 3.8. The anchor capacity per pile is based on the soil pressure distribution of Figure E.1 and Equation E.15 in Appendix E. The computed anchor force per pile is determined by the FDT using indeterminate structural analysis as described in Chapter 2. If this requirement is not satisfied, the engineer could:
   - Increase the height of the anchor block (input Cell 25).
   - Decrease the distance between the bottom face of the anchor and the stream elevation (input Cell 26).
   - Use a larger diameter pile which will increase the pile flexural capacity and reduce the required anchor force per pile (input Cells 18 and 19).
9. Maximum displacement (in.) – AASHTO, Section 4 [2] defines in the maximum allowable longitudinal substructure displacement as 1.5 in. If this requirement is not satisfied, the engineer could:
   - Increase the number of piles (input Cell 4).
   - Use a larger diameter pile which increases the flexural rigidity of the pile (input Cells 18 and 19).
   - Use an alternative lateral restraint system or configuration (input Cells 21 through 27).

3.2.2.4. INFORMATION SUMMARY

As shown in Figure 3.9, the PDW also contains a Foundation Summary section. Each summary value is assigned a number that corresponds to the description provided in this section. Items 1, 2, 4 through 7, 10, and 11 are provided by the engineer.

1. Roadway width (ft)
2. Span length (ft)
3. Distance between superstructure bearings and roadway grade (ft) – This cell contains the combined depth of the superstructure plus roadway as determined by the FDT.
4. Backwall height (ft)
5. Dead load abutment reaction (kip per abutment)
6. Live load abutment reaction (kip per abutment)
7. Number of piles (no units)

8. <u>Total axial pile load (tons)</u> – This cell contains the total axial pile load as determined by the FDT. This value includes the sum of the dead and live load axial pile loads (both multiplied by the nominal axial pile factor as described in Chapter 2), and the pile self-weight.
9. <u>Pile spacing (ft)</u> – This cell contains the pile spacing as determined by the FDT.
10. <u>Pile size (in.)</u> – These cells provide the pile butt and tip diameters.
11. <u>Pile material properties (psi)</u> – These cells provide the timber species, tabulated compressive stress, tabulated bending stress, and elastic modulus.
12. <u>Minimum total pile length (ft)</u> – This cell contains the minimum total pile length required as determined by the FDT. The minimum required pile length is equal to the vertical distance between the stream elevation and the superstructure bearings plus the depth required for bearing capacity.

3.2.3. Anchor Design Worksheet

The Anchor Design Worksheet (ADW) is only required if the buried concrete anchor block option is selected in the PDW (input Cells 30 and 21 for steel and timber piles, respectively). The ADW provided is applicable to all combinations of piles and soil types. If applicable, the engineer may proceed by clicking the 'ADW' button shown in Figures 3.5 and 3.9 (for steel and timber piles, respectively) once all the design requirements have been satisfied in the PDW. In the ADW, additional input information such as the anchor material properties, size of reinforcement, etc. need to be provided by the engineer. This input information, which is briefly described in the Instructions section of the ADW, is used to calculate the internal anchor block shears and moments, determine the structural capacity, and check a series of design requirements. Other information required for the design of the reinforced concrete anchor block (e.g., the anchor height, anchor rod force, etc.) are entered or determined by the PDW. A summary of the anchor system details is also provided in the ADW.

3.2.3.1. INSTRUCTIONS

The Instructions section of the ADW provides a brief description of the input required as shown in Figure 3.10. Additionally, the Instructions section also contains a figure of an anchor cross section and plan view of the reinforced concrete anchor block which is reproduced in Figure 3.11. This figure provides a graphical representation of some anchor block quantities required from the engineer. Each circled number in Figure 3.11 corresponds to cell number in the Instructions and Input section of the ADW (Figures 3.10 and 3.12, respectively). The height of the reinforced

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY TO BE USED AFTER THE PILE SYSTEM HAS BEEN DESIGNED AND ALL DESIGN REQUIREMENTS HAVE BEEN SATISFIED.

Return to Pile Design Worksheet

Go to Pile and Soil Selection Worksheet

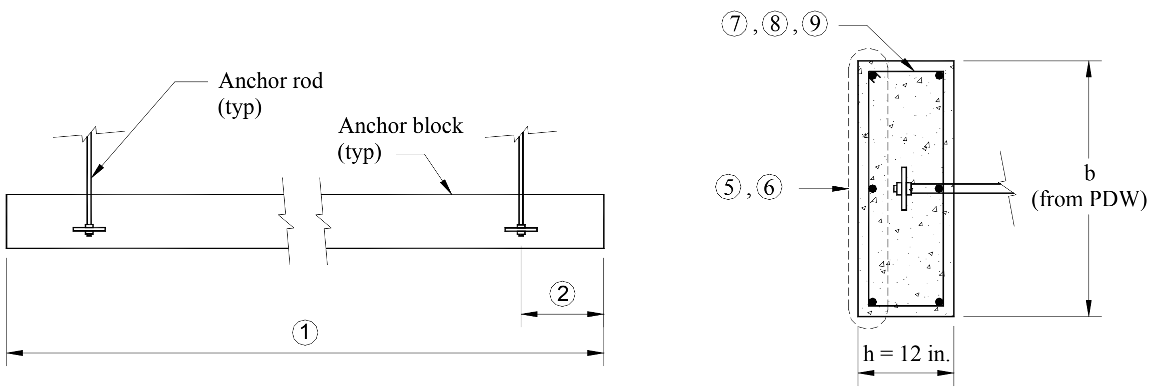
The design in this worksheet is based on Section 8 of the AASHTO Standard Specifications.

Once the instructions on this sheet have been reviewed, proceed to the input section of this worksheet below.

Data required is to be entered in the highlighted cells of the Input Information section; all circled numbers are shown on the figure provided.

Instructions	Cell No.	Description
	①	Enter the total length of the anchor block.
	②	Enter the distance between the end of the anchor block and the exterior anchor rod.
	3	Enter the anchor block concrete compressive strength.
	4	Use the pull-down menu provided to select the yield strength of the reinforcing steel.
	⑤	Enter the number of tension steel reinforcing bars on one vertical anchor block face.
	⑥	Use the pull-down menu provided to select the tension steel bar size.
	⑦	If applicable, use the pull-down menu provided to select the stirrup bar size.
	⑧	If applicable, enter the number of stirrup legs per section.
	⑨	If applicable, enter the stirrup spacing for this analysis. This value must be less than the value in the cell directly above this input cell.

Figure 3.10. Selected portion of the FDT ADW Instructions.



a) Anchor block plan view.

b) Anchor block cross section.

Figure 3.11. Graphical representation of selected input values for the ADW.

concrete anchor block, denoted as ‘b’ in Figure E.1 of Appendix E, is not a required input value for the ADW. This PDW input value is shown as (34) and (25) in Figures 3.3 and 3.7, respectively. The width of the anchor block, which is used to calculate the effective depth of the concrete, is set at 12 in. for this analysis. An anchor block with a different width can be designed using the design methodology summarized in Chapter 2.

3.2.3.2. REQUIRED INPUT

A brief explanation of the input information required from the engineer for the ADW, shown in Figure 3.12, is presented in this section. Each input cell is highlighted and assigned a number that corresponds to the description provided in this section. The quantities shown in the highlighted input cells of Figure 3.12 are shown for clarity and obviously are not applicable to all bridge sites.

Input Information	No.	Item	Value	Unit
	1	Anchor block length	28.00	ft
	2	Distance from end of anchor block to exterior anchor rod	2.00	ft
	3	Concrete compressive strength	3.0	ksi
	4	Yield strength of reinforcing steel	60	ksi
		Tension steel area required	0.24	in^2
	5	Number of reinforcing bars on one vertical anchor block face	3	bars
	6	Tension steel bar size	5	#
		Minimum tension steel area	0.93	in^2
		Are stirrups required?	Yes	
	7	Shear stirrup bar size number	3	#
	8	Number of stirrup legs per section	2	
		Maximum stirrup spacing	4.66	in.
	9	Stirrup spacing for this analysis	4.50	in.

Design Checks	No.	Check	Criterion	Value	Unit	Status	Reference
	1	Design flexural capacity	$M_U < \phi M_N$	37.70	ft-kips	OK	{AASHTO 8.16.3.2}
	2	Reinforcement ratio	$\rho < 0.75\rho_b$	0.0028		OK	{AASHTO 8.16.3.2.2}
	3	Minimum reinforcement				OK	{AASHTO 8.17}
	4	Design shear capacity	$V_U < \phi V_N$	54.4	kip	OK	{AASHTO 8.16.6.1.1}

Anchor System Summary	No.	Item	Value	Unit			
	1	Number of anchor rods	5				
	2	Anchor rod steel yield stress	60	ksi			
	3	Anchor rod diameter	0.750	in.			
	4	Anchor rod length	15.00	ft			
	5	Anchor rod spacing	6.00	ft			
	6	Vertical distance between bottom of anchor block and roadway grade	4.92	ft			
	7	Anchor block length	28.00	ft			
	8	Anchor block height	3.0	ft			
	9	Anchor block width	12.0	in.			
	10	Concrete compressive strength	3.0	ksi			
	11	Details of reinforcement on one vertical anchor block face	3		# 5 bars		
	12	Details for stirrups	# 3	bars on		4.50	in. centers

Figure 3.12. Input Information, Design Checks, and Anchor System Summary sections of the FDT ADW.

1. Anchor block length (ft) – Enter the total length of the anchor block,(1), as shown in Figure 3.11a. This input value must be greater than or equal to the product of the pile spacing and number of piles which accounts for an additional one-half pile space for each exterior pile.
2. Distance from the end of the anchor block to exterior anchor rod (ft) – Enter the distance between the end of the anchor block and the exterior anchor rod,(2), as shown in Figure 3.11a. This input value must be greater than or equal to 1 ft.
3. Concrete compressive strength (ksi) – Enter the compressive strength of the concrete to be used in the anchor block. As a minimum, 3 ksi was selected for this input value, however a higher concrete compressive strength can be used.
4. Yield strength of reinforcing steel (ksi) – Use the provided pull-down menu to select the steel reinforcement yield stress.
5. Number of reinforcing bars on one vertical anchor block face (no units) – Enter the number of tension steel bars located on one vertical anchor block face,(5), shown in Figure 3.11b. This input cell, in addition to Input Cell 6, determines the tension steel area provided for one vertical anchor block face. The provided tension steel area must be greater than the area of steel required to obtain the necessary flexural capacity that is given directly above this input cell as shown in Figure 3.12. The required steel area is determined by reinforced concrete design equations, the anchor block dimensions, material properties entered, and the maximum factored moment as determined by the FDT using the moment distribution method and AASHTO [2] load combinations. This input value must be a whole number that, when evenly spaced, provides a spacing of less than 18 in. as required by Section 8.21.6 of AASHTO [2].
6. Tension steel bar size (no units) – Use the provided pull-down menu to select the tension steel bar size,(6), as shown in Figure 3.11b. As previously discussed, this input cell in addition to input Cell 5, is used to determine the area of steel provided which must be greater than the required steel area which is provided directly above input Cell 5 as shown in Figure 3.12.
7. Shear stirrup bar size (no units) – If shear stirrups are required as indicated by cell located directly above this input cell (shown in Figure 3.12), use the pull-down menu provided to select the shear stirrup bar size,(7).

8. Number of stirrup legs per section (no units) – If shear stirrups are required, enter the number of stirrup legs per section, (8). This input value must be a whole number that is greater than or equal to one.
9. Stirrup spacing for this analysis (in.) – If shear stirrups are required, enter the stirrup center-to-center spacing, (9). This input value must be less than the value provided directly above this input cell as shown in Figure 3.12. The maximum stirrup spacing is the minimum of: 1.) the maximum spacing allowed to obtain the necessary shear design capacity, 2.) the maximum spacing allowed if only minimum stirrups are required, 3.) one-half the effective depth of the concrete, and 4.) 24 in. In the ADW, it is assumed that the shear strength provided by the stirrups (V_s) is less than twice the shear strength provided by the concrete (V_c). Therefore, the last two maximum stirrup spacings do not need to be reduced by half.

3.2.3.3. DESIGN CHECKS

The next section of the ADW displays the various design requirements for the reinforced concrete anchor block. A brief explanation of the structural and serviceability requirements follows. Additionally, suggestions for adjusting the previously described input values to satisfy these design requirements are also included in this section. As shown in Figure 3.12, each design requirement is assigned a number that corresponds to the description provided in this section.

1. Design flexural capacity (ft-kips) – The maximum factored bending moment, which is determined by the ADW using the moment distribution method and AASHTO [2] load combinations, must be less than the design flexural capacity of the anchor block as specified by AASHTO, Section 8 [2]. If this requirement is not satisfied, the engineer could:
   - Redesign the anchor block section.
   - Use an alternate pile and anchor rod configuration to possibly reduce the required anchor rod force and corresponding internal anchor block bending loads (input cells located in the PDW).
2. Reinforcement ratio (non-dimensional) – The reinforcement ratio of the anchor block must be less than 75 percent of the balanced reinforcement ratio, both of which are defined in AASHTO, Section 8 [2]. If this requirement is not satisfied, the engineer could:
   - Increase the width of the concrete compression block by increasing the height of the anchor block (input cell located in the PDW).

- Increase the concrete compressive strength (input Cell 3).
- Redesign the anchor block section.

3. Minimum reinforcement (no units) – The cracking moment, multiplied by a factor of 1.2, must be less than the design flexural capacity of the anchor block. Alternatively, this requirement can be waived if the area of tension steel provided (input Cells 5 and 6) is at least four-thirds the minimum steel area required. If this requirement is not satisfied, the engineer could:
   - Use a smaller anchor block height to reduce the gross moment of inertia (input cell in the PDW).
   - Increase the design flexural capacity of the anchor block as previously described.
4. Design shear capacity (kips) – The maximum factored shear force must be less than the design shear capacity of the anchor block as specified by AASHTO, Section 8 [2]. The design shear capacity is the sum of the concrete shear strength and the additional capacity provided by the stirrups. If this requirement is not satisfied, the engineer could:
   - Increase the compressive strength of the concrete (input Cell 3).
   - Decrease the stirrup spacing (input Cell 9).
   - Use a larger stirrup bar size (input Cell 7).
   - Increase the number of stirrup legs per section (input Cell 8).
   - Increase the height of the anchor block thus increasing the concrete shear strength (input cell in the PDW).

3.2.3.4. INFORMATION SUMMARY

As shown in Figure 3.12, the ADW also contains an Anchor System Summary section. Each summary value has been assigned a number that corresponds to the brief description that follows. Note that quantities 1 through 4, 7, 8, and 10 through 12 have been entered by the engineer.

1. Number of anchor rods (no units)
2. Anchor rod steel yield stress (ksi)
3. Anchor rod diameter (in.)
4. Anchor rod length (ft)
5. Anchor rod spacing (ft) – This cell contains the anchor rod spacing as determined by the FDT.

6. Vertical distance between bottom of anchor block and roadway grade (ft) – This cell contains the vertical distance between the bottom of the anchor block and roadway elevation as determined by the FDT.
7. Anchor block length (ft)
8. Anchor block height (ft)
9. Anchor block width (in.) – This cell contains the width of the concrete anchor block which is set to 12 in. for all designs in the ADW.
10. Concrete compressive strength (ksi)
11. Details of reinforcement on one vertical anchor block face (various units) – This cell contains the tensile reinforcement details. This includes the number of reinforcement bars on each vertical anchor block face in addition to the bar size.
12. Details for stirrups (various units) – If applicable, this cell contains the shear stirrup reinforcement details. This includes the bar size in addition to the stirrup spacing.

3.3. STANDARD ABUTMENT PLANS

A complete set of generic standard abutment plans that were developed for this project are presented in Appendix D. The AutoCAD computer files that are also included as a CD with Appendix D will produce full size (11 in. by 17 in.) sheets. Additionally, the full size sheets can be easily modified to produce larger construction sheets.

The standard abutment plans can be used by Iowa County Engineers to produce the necessary drawings for the more common LVR bridge abutments systems. Using the various superstructures and the associated standard plans previously developed by the BEC, the engineer can generate a complete set of bridge plans. It should be noted that by modifying the bearing surface of the standard abutment systems provided, essentially any type of bridge superstructure system can be supported.

In order for the engineer to produce a finished set of abutment plans, the necessary details such as the bridge geometry, member size designations (i.e., W, C, and HP shapes), and material properties must be inserted in the spaces provided. The FDT provides many of the necessary details for the generic standard abutment plans.

As shown in Appendix D, the standard abutment plans provided consist of three different types of sheets. The first type consists of two general sheets that will be used for all bridge abutments and are both included in the final set of construction documents. These include the cover sheet (Sheet A1) and a general bridge plan and elevation layout sheet (Sheet A2). The second sheet type (Sheet D1) provides general information and instructions relating to the scope and use of the standard abutment plans. Sheet D1 also includes a feasibility flow chart (shown as Figure D.1 in Appendix D) to help the engineer determine if the standard abutment plans and FDT are appropriate for a given bridge site. Additionally, Sheet D1 includes a detail for an alternate steel channel pile cap (also provided as Figure D.2 in Appendix D). The flat steel bearing plate shown on the steel channel pile cap details of some U-series sheets (described below) can be replaced with a third c-channel. Sheet D1 is not to be included in the final set of construction documents. The third type of sheet consists of 16 construction sheets (Sheets U1 through U16) with different combinations of pile caps, backwall systems, anchor systems, and pile types. For example, if the bridge site requires steel H-piles with an anchor system, a concrete pile cap, and a sheet pile backwall, Sheet U7 should be used. At most, two of these construction sheets will be required for a particular bridge site (i.e., a different construction sheet for each bridge abutment). If the two bridge abutments use the same combination of previously mentioned substructure variables, the same sheet can be used twice with different dimensions, if necessary.

4. VERIFICATION OF THE FOUDATION DESIGN TEMPLATE

The use of the FDT for foundation systems is presented in Volume 3 of this final report. These include the use of the FDT for two foundation systems. These calculations demonstrate the application of the design methodology developed for this project and also verify the accuracy of the FDT. Also included with the design verification examples is a table that presents the various foundation details for different combinations of soil type, backwall height, and pile type. A general description of the design examples presented in Volume 3 follows.

Example 1: The first set of calculations demonstrates the design methodology for timber piles with a reinforced concrete anchor block connected with tension rods. An abutment is designed for a PCDT superstructure with a span length and roadway width of 40 and 24 ft, respectively. The timber piles are embedded in a soil that is described in the Iowa DOT FSIC [1] as gravelly sand with an average SPT blow count of 21. The backwall height and estimated depth of scour are equal to six and two feet, respectively.

Example 2: The second set of calculations demonstrates the design methodology for steel piles without an anchor system. An abutment is designed for a PSC superstructure with a span length and roadway width of 60 and 24 ft, respectively. The steel piles are embedded in soil that is described in the Iowa DOT FSIC [1] as a firm, glacial clay with an average SPT blow count of 11. The backwall height and estimated depth of scour are equal to six and two feet, respectively.

Several computer models were also developed using structural analysis software for the previously described lateral substructure loadings to verify the internal forces and deflections computed by the FDT for the various foundation elements. These computer models consisted of both determinate (i.e., without an anchor) and indeterminate (i.e., with an anchor) systems. Additionally, computer models were developed to verify the internal pile forces and deflections computed by the FDT if a positive connection between the superstructure and substructure is used.

5. SUMMARY OF USERS MANUAL

This research project consisted of three major phases: the collection of information for LVR bridge abutments, the development of an easy-to-use design methodology, and the creation of several substructure design aids for the Iowa County Engineers. In the first phase, a literature review and survey of the Iowa County Engineers was completed. The literature review focused on locating LVR bridge abutment information and standard abutment plans. A survey of the Iowa counties was used to determine the use of standard abutment plans by the counties and the identification of common construction methods and trends. In this phase of the project, several LVR bridge abutment systems commonly used by the Iowa counties, a series of possible alternative abutment systems, and two different pile analysis methodologies that could be used to investigate the influence of the lateral and vertical loadings on the piles were identified.

The second phase of this project involved investigating different analysis methodologies and the development of a design methodology for the different foundation elements. Two lateral load analysis methods were investigated including a linear and non-linear method. It was found that each method has certain advantages such as the ability to model complex soil conditions and profiles, accurately representing the actual soil and pile interaction, and the ease of incorporating the analysis method into a complete design methodology. It was decided that the linear analysis procedure presented by Broms [4, 5] would be the most suitable for this project based on its relative simplicity and correlation of the calculated maximum pile moment when compared to the values obtained in the non-linear analysis method. This method considers the pile fixed at a calculated depth below ground level based on soil and pile properties in addition to lateral loading conditions. A design methodology used to determine the structural capacity of the steel and timber piles was developed using the recommendations of the Iowa DOT BDM [3], AASHTO [2], and the NDS Manual [6].

An analysis and design methodology was also developed for a lateral restraint system that can potentially be used to resist the lateral substructure loads. Two lateral restraint systems are presented including a positive connection between the superstructure and substructure, and a buried anchor block connected to the substructure with the use of anchor rods. If a positive connection is used, the longitudinal stiffness of the superstructure is assumed to transfer lateral loads between the substructure units. The lateral restraint provided by an anchor system is a result of the passive soil pressure that acts on the vertical anchor block face. This passive soil resistance force is transferred to the substructure through anchor rods and an abutment wale. A procedure for determining the structural capacity of the anchor block was developed using the reinforced concrete design specifications in AASHTO [2].

The third and final phase of this project involved the development of LVR bridge abutment design aids. These design aids include the FDT and a series of generic standard abutment plans. The FDT is used to verify the adequacy of a pile and anchor system for a particular bridge and site. Information such as the bridge geometry, soil conditions, pile information, and lateral restraint details are provided by the engineer. This information is used to determine the substructure loads, perform a structural analysis of the foundation elements, determine the respective capacities, and perform a series of design checks. The various generic standard abutment plans include general information and instruction sheets in addition to construction sheets with different combinations of substructure details. Additionally, a series of calculations that demonstrates the application of the LVR bridge abutment design methodology and the FDT are provided in Volume 3 of this final report. Also included with the design verification examples is a table that presents the various foundation details for different combinations of soil type, backwall height, and pile type.

6. AKNOWLEDGEMENTS

The research presented in this report was conducted by the Bridge Engineering Center under the auspices of the Engineering Research Institute of Iowa State University. The research was sponsored by the Highway Division of the Iowa Department of Transportation and the Iowa Highway Research Board under Research Project TR-486.

The authors wish to thank the various Iowa DOT Engineers and Iowa County Engineers who provided their input and support. In particular, we wish to thank the Project Advisory Committee:

Dean G. Bierwagen: Methods Engineer, Office of Bridges and Structures, Iowa DOT.

Brian Keierleber: County Engineer, Buchanan County.

Mark J. Nahra: County Engineer, Delaware County.

Tom P. Schoellen: Assistant County Engineer, Black Hawk County.

Special thanks are accorded to the following Iowa State University undergraduate civil engineering students for their assistance in various aspects of the project: Toshia Akers, Jonathan Greenlee, and Katie Hagen.

7. REFERENCES

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Additional related references are provided in Volume 1 of this final report.

APPENDIX A

ESTIMATED GRAVITY LOADS

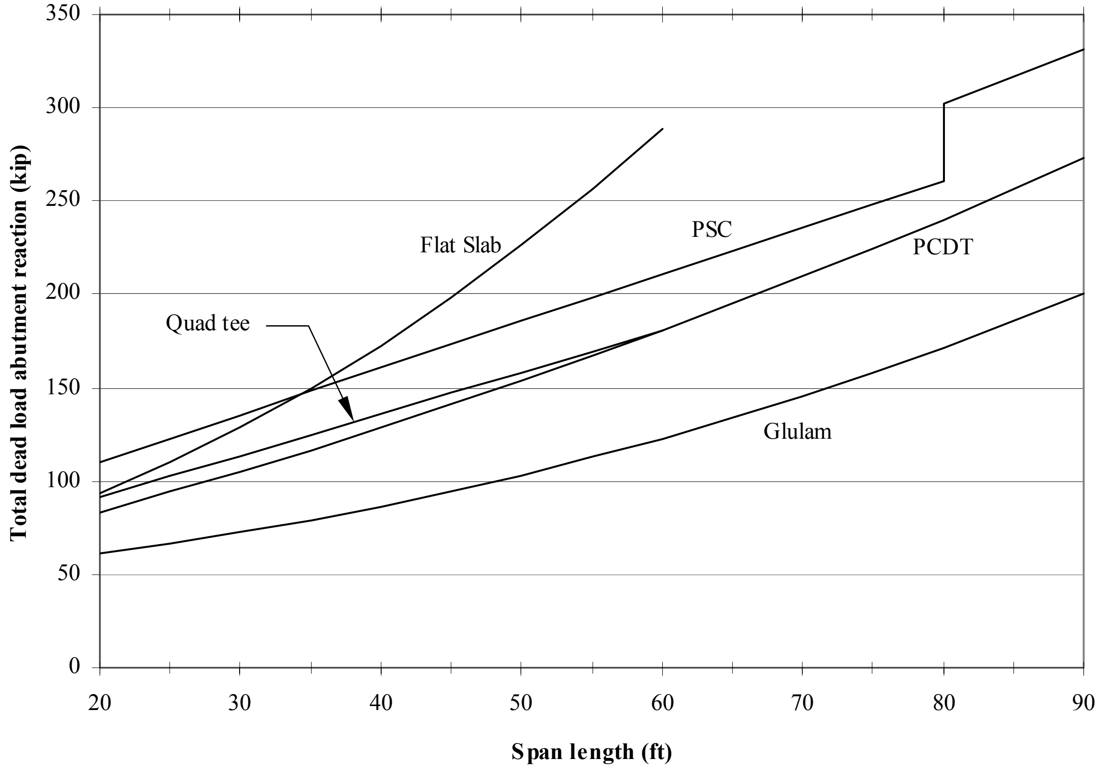


Figure A.1. Estimated dead load abutment reaction for a 24 ft roadway width.

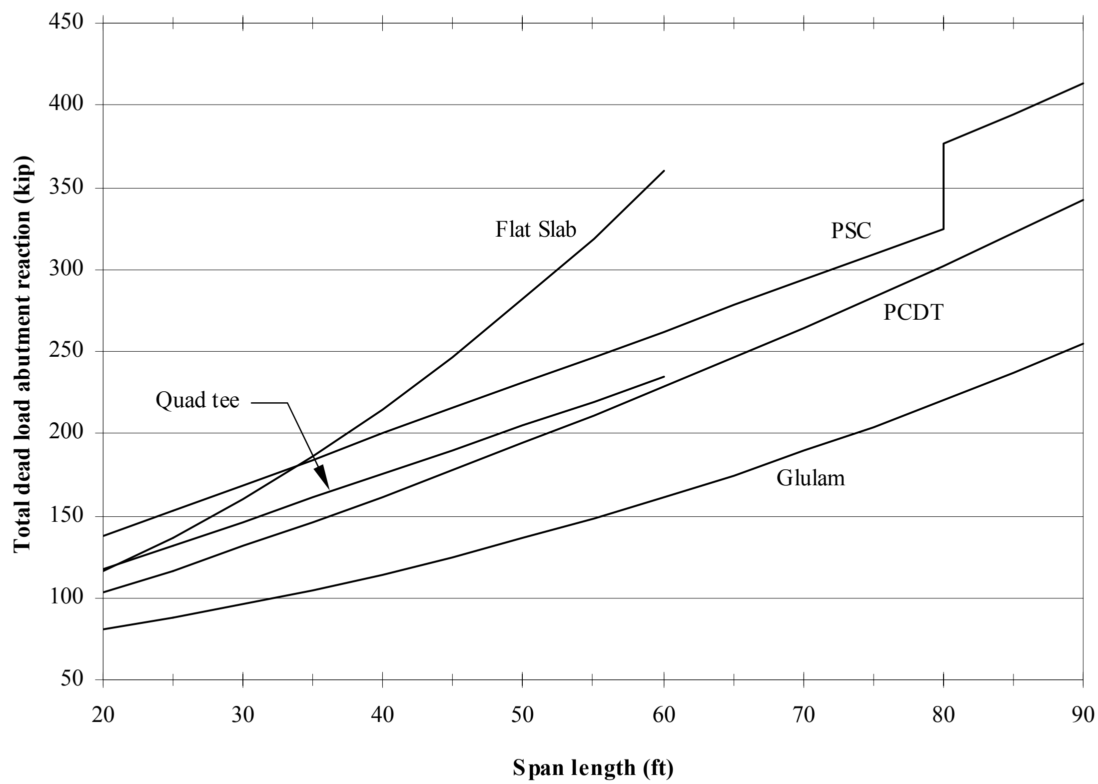


Figure A.2. Estimated dead load abutment reaction for a 30 ft roadway width.

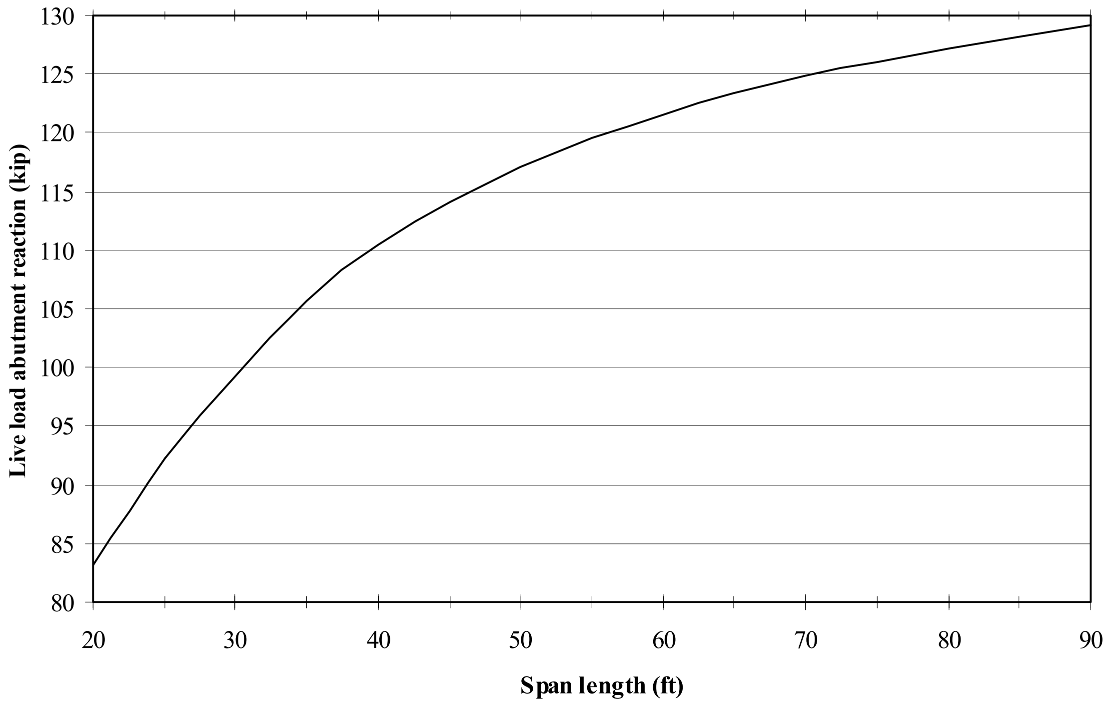


Figure A.3. Estimated live load abutment reaction without impact for two 10 ft design traffic lanes.

APPENDIX B

DRIVEN PILE FOUNDATION SOILS INFORMATION CHART

Table B.1. Estimated end bearing values for steel H-piles.

Soil Description	SPT Blow Count (N) Mean	SPT Blow Count (N) Range	* Estimated End Bearing Values for Steel H-Piles (psi)
Granular Material	-	0 - 25	0
	-	25 - 50	1,000 - 2,000
	-	50 - 100	2,000 - 4,000
	-	100 - 300	4,000 - 8,000
Bedrock	-	> 300	9,000
	-	100 - 200	6,000
	-	> 200	9,000
Cohesive Material	12	10 - 50	0
	20	-	500
	25	-	1,000
	50	-	2,000
	100	-	3,500

* End bearing values include a factor of safety equal to 2.0.

NOTE: Table B.1 is adapted from the Iowa DOT Foundation Soils Information Chart (1994), Table 1.1

Table B.2. Estimated friction bearing values for steel H-piles and 10 in. diameter timber piles.

Soil Description	SPT Blow Count (N) Mean	SPT Blow Count (N) Range	* Estimated Friction Bearing Values (tons / ft) Timber ** 10 in. η	Steel H-Piles HP 10	Steel H-Piles HP 12	Steel H-Piles HP 14
Alluvium or Loess						
Very Soft Silty Clay	1	0 - 1	0.2	0.1	0.2	0.2
Soft Silty Clay	3	2 - 4	0.3	0.2	0.3	0.3
Stiff Silty Clay	6	4 - 8	0.4	0.3	0.4	0.5
Firm Silty Clay	11	7 - 15	0.6	0.5	0.6	0.7
Stiff Silt	6	3 - 7	0.4	0.3	0.4	0.4
Stiff Sandy Silt	6	4 - 8	0.4	0.3	0.4	0.4
Stiff Sandy Clay	6	4 - 8	0.4	0.3	0.4	0.5
Silty Sand	8	3 - 13	0.3	0.3	0.3	0.4
Clayey Sand	13	6 - 20	0.5	0.4	0.5	0.7
Fine Sand	15	8 - 22	0.6	0.5	0.6	0.7
Coarse Sand	20	12 - 28	0.8	0.7	0.8	0.9
Gravelly Sand	21	11 - 31	0.8	0.7	0.8	0.9
Granular Material	> 40	-	1.0	1.0	1.2	1.4
Glacial Clay						
Firm Silty Glacial Clay	11	7 - 15	0.7	0.6	0.7	0.8
Firm Clay (Gumbotil)	12	9 - 15	0.7	0.6	0.7	0.8
Firm Glacial Clay (depths > 30 ft)	11	7 - 15	0.6 (0.8)	0.7 (0.8)	0.8 (1.0)	0.9 (1.1)
Firm Sandy Glacial Clay (depths > 30 ft)	13	9 - 15	0.6 (0.8)	0.7 (0.8)	0.8 (1.0)	0.9 (1.1)
Firm - Very Firm Glacial Clay (depths > 30 ft)	14	11 - 17	0.7 (0.9)	0.7 (1.0)	0.8 (1.2)	0.9 (1.4)
Very Firm Glacial Clay (depths > 30 ft)	24	17 - 30	0.7 (0.9)	0.7 (1.0)	0.8 (1.2)	0.9 (1.4)
Very Firm Sandy Glacial Clay (depths > 30 ft)	25	15 - 30	0.8 (1.0)	0.7 (1.0)	0.8 (1.2)	0.9 (1.4)
Cohesive of Glacial Material (depths > 30 ft)	> 35	-	0.8 (1.0)	0.7 (1.0)	0.8 (1.2)	0.9 (1.4)

* Friction bearing values include a factor of safety equal to 2.0.

** Friction bearing values for other than a 10 in. diameter pile = chart value * pile diameter / 10.

NOTE: Table B.2 is adapted from the Iowa DOT Foundation Soils Information Chart (1994), Table 1.1.

APPENDIX C

PRINTOUTS FROM THE FOUNDATION DESIGN TEMPLATE

START UP WORKSHEET

County:
Project No:
Description:

computed by:
checked by:
date:

Please select the pile type and soil type for this analysis by clicking the corresponding button below.

Steel Piles In A Cohesive Soil	Steel Piles In A Cohesionless Soil	Timber Piles In A Cohesive Soil	Timber Piles In A Cohesionless Soil

STEEL PILES IN A COHESIVE SOIL
INSTRUCTIONS AND PILE DESIGN WORKSHEET

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIVE SOIL.

The calculations performed in the Pile Design Worksheet are based on the guidelines of the AASHTO Standard Specifications and the Iowa DOT Bridge Design Manual (Iowa DOT BDM).

Once the instructions in this worksheet have been reviewed, proceed to the Pile Design Worksheet or return to the pile and soil selection worksheet by clicking the icons below.

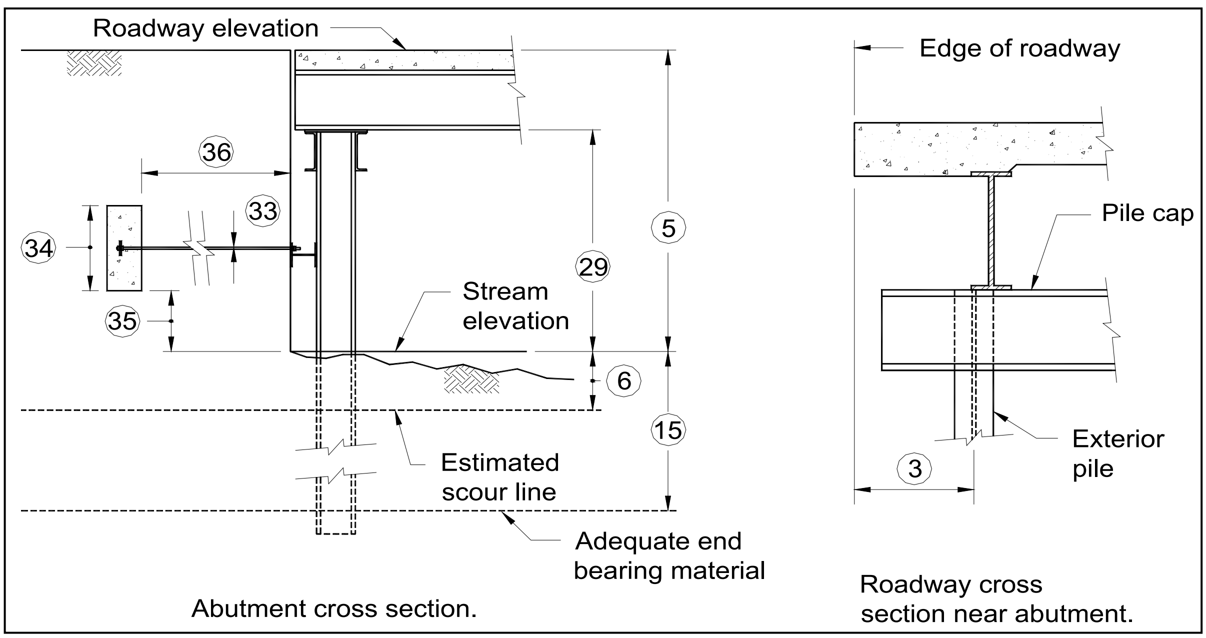
Pile Design Worksheet

Return to Pile and Soil Selection Worksheet

Data required is to be entered in the highlighted cells of the Pile Design Worksheet.

The figure below is to be used as a reference for the various input dimensions.

The stream elevation is the datum for all elevations.



County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIVE SOIL.

The following numbers and explanations correspond the highlighted cells on the Pile Design Worksheet; all circled numbers are shown on the figure above.

Cell No.	Description
1	Enter the span length between the centerline of the abutment bearings.
2	Enter the roadway width of the bridge.
(3)	Enter the distance between the centerline of the exterior pile and the edge of the roadway. This value is positive for situations when the exterior pile is within the limits of the roadway width as shown above.
4	Enter the number of piles per abutment. This value must be within the range given in the cells directly above this input cell.
(5)	Enter the vertical distance between the roadway grade and the stream elevation.
(6)	Enter the vertical distance from the stream elevation to the estimated depth of scour. This value is based on stream hydraulics, geological information, and engineering judgment.
7	Use the pull-down menu provided to select the type of superstructure system for this analysis.
8	Enter the dead load abutment reaction for this analysis. A default value may be provided in the cell directly above this input cell.
9	Enter the live load abutment reaction for this analysis. A default value is provided directly above this input cell.
10	Enter the average standard penetration test (SPT) blow count (N-value) for the upper level soil.
11	Enter the undrained shear strength of the soil for this analysis. A default value based on the SPT N-value is provided in the cell directly above this input cell.
12	Use the pull-down menu provided to select the type of pile bearing resistance for gravity loads. NOTE: End bearing is only allowed in bed rock for this spreadsheet.
13	If applicable, enter the friction bearing resistance per foot of pile, for the soil *within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
14	If applicable, enter the friction bearing resistance per foot of pile, for the soil *not within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
(15)	If applicable, enter the estimated depth to adequate end bearing foundation material.
16	If applicable, use the pull-down menu provided to select the SPT N-value for the end bearing foundation material.
17	Use the pull-down menu provided to select the pile yield stress.
18	Use the pull-down menu provided to select an H-pile shape. If a standard shape is selected, input values for cell 19 through 25 will not be required from the engineer.
19	If applicable, enter the cross-sectional area of the pile.
20	If applicable, enter the total pile depth.
21	If applicable, enter the pile web thickness.
22	If applicable, enter the pile width measured parallel to the backwall.
23	If applicable, enter the pile flange thickness.
24	If applicable, enter the strong axis moment of inertia (the strong axis is assumed parallel to the backwall).
25	If applicable, enter the strong axis section modulus (the strong axis is assumed parallel to the backwall).

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIVE SOIL.

26	If applicable, enter the weak axis section modulus (the weak axis is assumed perpendicular to the backwall).
27	If applicable, enter the strong axis radius of gyration (the strong axis is assumed parallel to the backwall.)
28	If applicable, enter the weak axis radius of gyration (the weak axis is assumed perpendicular to the backwall.)
(29)	Enter the vertical distance between the stream elevation and the superstructure bearing points.
30	Use the pull-down menu provided to select the type of lateral restraint system (if any) for this analysis.
31	If applicable, use the pull-down menu provided to select the anchor rod yield stress.
32	If applicable, enter the total number of anchor rods for one abutment.
(33)	If applicable, enter the anchor rod diameter.
(34)	If applicable, enter the height of the anchor block .
(35)	If applicable, enter the vertical distance between the stream elevation and the bottom of the anchor block.
(36)	If applicable, enter the anchor rod length for this analysis. This value must be greater than or equal to the value given directly above this input cell.

County:
Project No:
Description:

BRIDGE ENGINEERING CENTER

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIVE SOIL.

Instructions Worksheet

Go to Pile and Soil Selection Worksheet

General Bridge Input	1	Span length	60.00	ft
	2	Roadway width	24.00	ft
	3	Location of exterior pile relative to the edge of the roadway	0.75	ft
		Maximum number of piles	10	piles on 2.50 ft centers
		Minimum number of piles	4	piles on 7.50 ft centers
	4	Number of piles	6	
	5	Backwall height	8.00	ft
	6	Estimated scour depth	2.00	ft
	7	Superstructure system	PCDT	
		Estimated dead load abutment reaction	180.9	kip per abutment (default value)
	8	Dead load abutment reaction for this analysis	180.9	kip per abutment
		Estimated live load abutment reaction	121.5	kip per abutment (default value)
	9	Live load abutment reaction for this analysis	121.5	kip per abutment
Foundation Material Input	10	Soil SPT blow count (N)	10	
		Correlated soil un-drained shear strength (C_u)	1,270	psf
	11	Soil undrained shear strength for this analysis	1,270	psf
	12	Type of vertical pile bearing resistance	friction & end bearing	
	13	Estimated friction bearing value for depths < 30 ft	0.7	tons per ft
	14	Estimated friction bearing value for depths > 30 ft	0.8	tons per ft
	15	Depth to adequate end bearing foundation material	40	ft
	16	SPT blow count for end bearing foundation material	100 < N < 200	
Pile Input	17	Pile steel yield stress	36	ksi
	18	Select pile type	HP10x42	
	19	Pile cross sectional area	12.4	in^2
	20	Pile depth	9.70	in.
	21	Pile web thickness	0.415	in.
	22	Pile flange width	10.1	in.
	23	Pile flange thickness	0.420	in.
	24	Pile moment of inertia (strong axis)	210	in^4
	25	Pile section modulus (strong axis)	43.4	in^3
	26	Pile section modulus (weak axis)	14.2	in^3
	27	Pile radius of gyration (strong axis)	4.13	in.
	28	Pile radius of gyration (weak axis)	2.41	in.
Lateral Restraint Input	29	Superstructure bearing elevation	5.58	ft
	30	Type of lateral restraint system	buried concrete anchor block	
	31	Anchor rod steel yield stress	60	ksi
	32	Total number of anchor rods per abutment	5	per abutment
	33	Anchor rod diameter	0.75	in.
	34	Height of anchor block	3.00	ft
	35	Bottom elevation of anchor block	3.08	ft
		Anchor block lateral capacity	12.3	kip per pile
		Computed anchor force per pile	8.4	kip per pile
		Minimum anchor rod length	15.10	ft
	36	Anchor rod length	17.00	ft

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIVE SOIL.

Check Pile Design

Geotechnical, Structural and Serviceability Requirements

Design Checks					
	1	Axial pile stress	$P/A \le \sigma_{ALL}$	5.85 ksi	OK
	2	Pile bearing capacity	Axial Pile Load ≤ Capacity	111.6 kip	OK
	3	Interaction equation validation	$\frac{1}{(1 - f_a/F'_e)} > 1.0$	1.05	OK
	4	Combined loading interaction requirement # 1	$\frac{f_a}{F_a} + \frac{C_{mx}\, f_{bx}}{\left(1-\frac{f_a}{F'_{ex}}\right)F_b} + \frac{C_{my}\, f_{by}}{\left(1-\frac{f_a}{F'_{ey}}\right)F_b} \le 1.0$	0.78	OK
	5	Combined loading interaction requirement # 2	$\frac{f_a}{0.472\, F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \le 1.0$	0.84	OK
	6	Buried anchor block location	Anchor rod length ≥ minimum	17.00 ft	OK
	7	Anchor rod stress	$\sigma \le 0.55\ F_Y$	22.9 ksi	OK
	8	Anchor block capacity	Total Anchor Force ≤ Capacity	12.3 kip per pile	OK
	9	Maximum displacement	$d_{MAX} \le 1.5\,\text{in.}$	0.278 in.	OK

Anchor Design Worksheet

Foundation Summary			
	1	Roadway width	24.00 ft
	2	Span length	60.00 ft
	3	Distance between superstructure bearings and roadway grade	2.42 ft
	4	Backwall height	8.00 ft
	5	Dead load abutment reaction	180.9 kip per abutment
	6	Live load abutment reaction	121.5 kip per abutment
	7	Number of piles	6
	8	Total axial pile load	36.2 tons
	9	Pile spacing	4.50 ft
	10	Pile size	HP10x42
	11	Pile steel yield stress	36 ksi
	12	Minimum total pile length	46 ft

STEEL PILES IN COHESIONLESS SOIL
INSTRUCTIONS AND PILE DESIGN WORKSHEET

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIONLESS SOIL.

The calculations performed in the Pile Design Worksheet are based on the guidelines of the AASHTO Standard Specifications and the Iowa DOT Bridge Design Manual (BDM).

Once the instructions in this worksheet have been reviewed, proceed to the Pile Design Worksheet or return to the pile and soil selection worksheet by clicking the icons below.

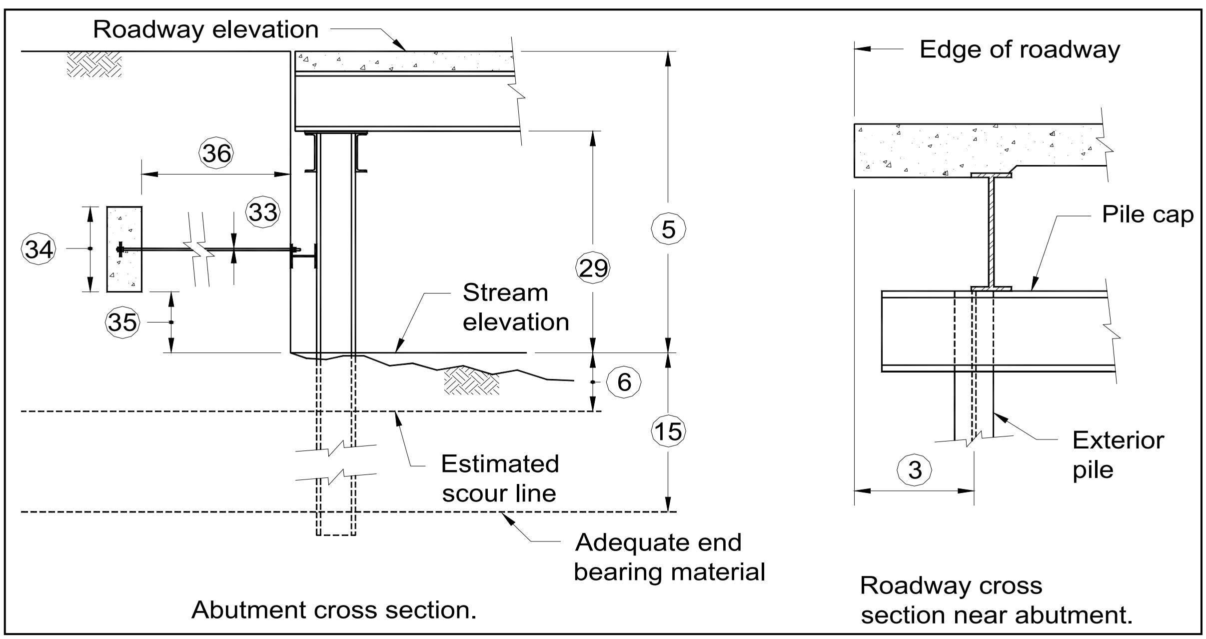
Pile Design Worksheet

Return to Pile and Soil Selection Worksheet

Data required is to be entered in the highlighted cells of the Pile Design Worksheet.

The stream elevation is the datum for all elevations.

The figure below is to be used as a reference for the various input dimensions.



County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIONLESS SOIL.

The following numbers and explanations correspond the highlighted cells on the Pile Design Worksheet; all circled numbers are shown on the figure above.

Cell No.	Description
1	Enter the span length between the centerline of the abutment bearings.
2	Enter the roadway width of the bridge.
③	Enter the distance between the centerline of the exterior pile and the edge of the roadway. This value is positive for situations when the exterior pile is within the limits of the roadway width as shown above.
4	Enter the number of piles per abutment. This value must be within the range given in the cells directly above this input cell.
⑤	Enter the vertical distance between the roadway grade and the stream elevation.
⑥	Enter the vertical distance from the stream elevation to the estimated depth of scour. This value is based on stream hydraulics, geological information, and engineering judgment.
7	Use the pull-down menu provided to select the type of superstructure system for this analysis.
8	Enter the dead load abutment reaction for this analysis. A default value may be provided in the cell directly above this input cell.
9	Enter the live load abutment reaction for this analysis. A default value is provided directly above this input cell.
10	Enter the average standard penetration test (SPT) blow count (N-value) for the upper level soil.
11	The soil friction angle to be used for this analysis. The engineer can either use the default value given directly above this input cell or a value based of bridge site soil tests.
12	Use the pull-down menu provided to select the type of pile bearing resistance for gravity loads. NOTE: End bearing is only allowed in bed rock for this spreadsheet.
13	If applicable, enter the friction bearing resistance per foot of pile, for the soil *within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
14	If applicable, enter the friction bearing resistance per foot of pile, for the soil *not within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
⑮	If applicable, enter the estimated depth to adequate end bearing foundation material.
16	If applicable, use the pull-down menu provided to select the SPT N-value for the end bearing foundation material.
17	Use the pull-down menu provided to select the pile yield stress.
18	Use the pull-down menu provided to select an H-pile shape. If a standard shape is selected, input values for cell 19 through 25 will not be required from the engineer.
19	If applicable, enter the cross-sectional area of the pile.
20	If applicable, enter the total pile depth.
21	If applicable, enter the pile web thickness.
22	If applicable, enter the pile width measured parallel to the backwall.
23	If applicable, enter the pile flange thickness.
24	If applicable, enter the strong axis moment of inertia (the strong axis is assumed parallel to the backwall).
25	If applicable, enter the strong axis section modulus (the strong axis is assumed parallel to the backwall).

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIONLESS SOIL.

26	If applicable, enter the weak axis section modulus (the weak axis is assumed perpendicular to the backwall).
27	If applicable, enter the strong axis radius of gyration (the strong axis is assumed parallel to the backwall.)
28	If applicable, enter the weak axis radius of gyration (the weak axis is assumed perpendicular to the backwall.)
(29)	Enter the vertical distance between the stream elevation and the superstructure bearing points.
30	Use the pull-down menu provided to select the type of lateral restraint system (if any) for this analysis.
31	If applicable, use the pull-down menu provided to select the anchor rod yield stress.
32	If applicable, enter the total number of anchor rods for one abutment.
(33)	If applicable, enter the anchor rod diameter.
(34)	If applicable, enter the height of the anchor block .
(35)	If applicable, enter the vertical distance between the stream elevation and the bottom of the anchor block.
(36)	If applicable, enter the anchor rod length for this analysis. This value must be greater than or equal to the value given directly above this input cell.

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIONLESS SOIL.

Instructions Worksheet

Go to Pile and Soil Selection Worksheet

General Bridge Input	1	Span length	60.00	ft	
	2	Roadway width	24.00	ft	
	3	Location of exterior pile relative to the edge of the roadway	0.75	ft	
		Maximum number of piles	10	piles on	2.50 ft centers
		Minimum number of piles	4	piles on	7.50 ft centers
	4	Number of piles	6		
	5	Backwall height	8.00	ft	
	6	Estimated scour depth	2.00	ft	
	7	Superstructure system	PCDT		
		Estimated dead load abutment reaction	180.9	kip per abutment (default value)	
	8	Dead load abutment reaction for this analysis	180.9	kip per abutment	
		Estimated live load abutment reaction	121.5	kip per abutment (default value)	
	9	Live load abutment reaction for this analysis	121.5	kip per abutment	
Foundation Material Input	10	Soil SPT blow count (N)	20		
		Correlated soil friction angle (ϕ)	33.3	degrees	
	11	Soil friction angle for this analysis	33.3	degrees	
	12	Type of vertical pile bearing resistance	friction & end bearing		
	13	Estimated friction bearing value for depths < 30 ft	0.7	tons per ft	
	14	Estimated friction bearing value for depths > 30 ft	0.8	tons per ft	
	15	Depth to adequate end bearing foundation material	40	ft	
	16	SPT blow count for end bearing foundation material	100 < N < 200		
Pile Input	17	Pile steel yield stress	36	ksi	
	18	Select pile type	HP10x42		
	19	Pile cross sectional area	12.4	in^2	
	20	Pile depth	9.70	in.	
	21	Pile web thickness	0.415	in.	
	20	Pile flange width	10.1	in.	
	21	Pile flange thickness	0.420	in.	
	21	Pile moment of inertia (strong axis)	210	in^4	
	22	Pile section modulus (strong axis)	43.4	in^3	
	23	Pile section modulus (weak axis)	14.2	in^3	
	24	Pile radius of gyration (strong axis)	4.13	in.	
	25	Pile radius of gyration (weak axis)	2.41	in.	
Lateral Restraint Input	26	Superstructure bearing elevation	5.58	ft	
	27	Type of lateral restraint system	buried concrete anchor block		
	28	Anchor rod steel yield stress	60	ksi	
	29	Total number of anchor rods per abutment	5	per abutment	
	30	Anchor rod diameter	0.75	in.	
	31	Height of anchor block	3.00	ft	
	32	Bottom elevation of anchor block	3.08	ft	
		Anchor block lateral capacity	12.32	kip per pile	
		Computed anchor force per pile	9.27	kip per pile	
		Minimum anchor rod length	15.10	ft	
	33	Anchor rod length	17.00	ft	

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR STEEL PILES IN A COHESIONLESS SOIL.

Check Pile Design

Geotechnical, Structural and Serviceability Requirements

Design Check	1	Axial pile stress	$P/A \le \sigma_{ALL}$	5.85 ksi	OK
	2	Pile bearing capacity	$\text{Axial Pile Load} \le \text{Capacity}$	111.6 kip	OK
	3	Interaction equation validation	$\frac{1}{(1 - f_a/F'_e)} > 1.0$	1.06	OK
	4	Combined loading interaction requirement # 1 $\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F'_{ex}}\right) F_b} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F'_{ey}}\right) F_b} \le 1.0$		0.77	OK
	5	Combined loading interaction requirement # 2 $\frac{f_a}{0.472\,F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \le 1.0$		0.82	OK
	6	Anchor rod stress	$\sigma \le 0.55\ F_Y$	25.2 ksi	OK
	7	Buried anchor block location	$\text{Anchor rod length} \ge \text{minimum}$	17.00 ft	OK
	8	Anchor block capacity	$\text{Total Anchor Force} \le \text{Capacity}$	12.3 kip per pile	OK
	9	Maximum displacement	$d_{MAX} \le 1.5\,\text{in.}$	0.29 in.	OK

Anchor Design Worksheet

Foundation Summary	1	Roadway width	24.00 ft
	2	Span length	60.00 ft
	3	Distance between superstructure bearings and roadway grade	2.42 ft
	4	Backwall height	8.00 ft
	5	Dead load abutment reaction	180.9 kip per abutment
	6	Live load abutment reaction	121.5 kip per abutment
	7	Number of piles	6
	8	Total axial pile load	36.2 tons
	9	Pile spacing	4.50 ft
	10	Pile size	HP10x42
	11	Pile steel yield stress	36 ksi
	12	Minimum total pile length	46 ft

TIMBER PILES IN A COHESIVE SOIL
INSTRUCTIONS AND PILE DESIGN WORKSHEET

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIVE SOIL.

The calculations performed in the Pile Design Worksheet are based on the guidelines of the AASHTO Standard Specifications, the Iowa DOT Bridge Design Manual (Iowa DOT BDM), and the National Design Specifications Manual for Wood Construction (NDS Manual).

Once the instructions on this worksheet have been reviewed, proceed to the Pile Design Worksheet or return to the pile and soil selection worksheet by clicking the icons below.

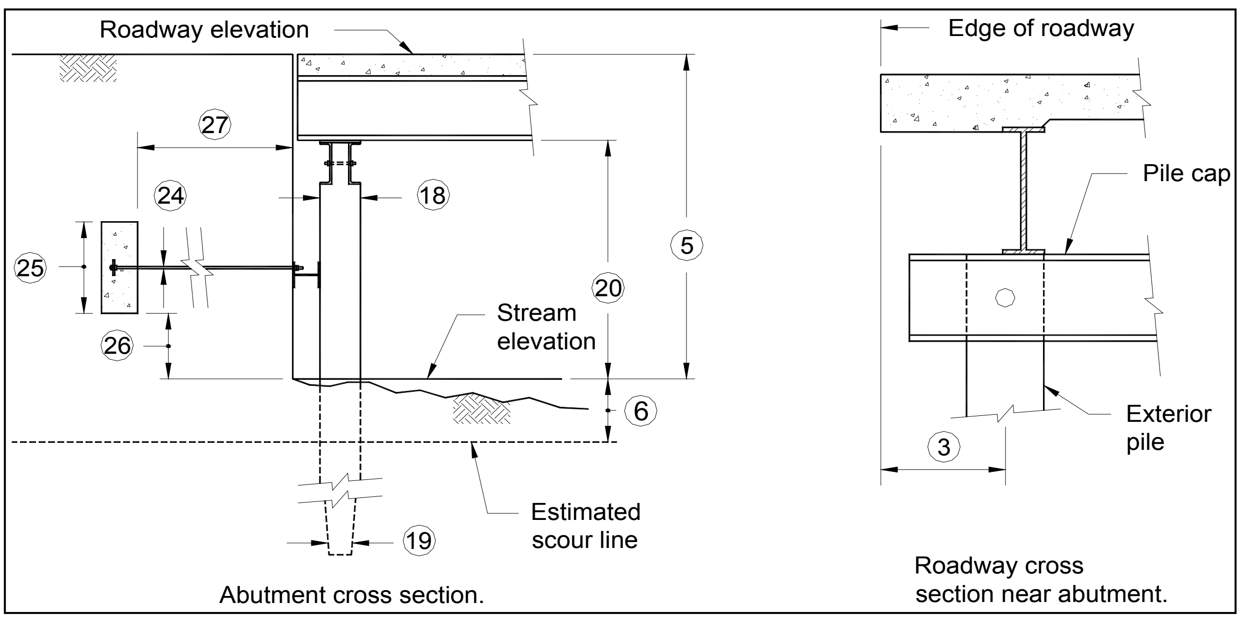
Pile Design Worksheet

Return to Pile and Soil Selection Worksheet

Data required is to be entered in the highlighted cells of the Pile Design Worksheet.

The stream elevation is the datum for all elevations.

The figure below is to be used as a reference for the vertical input dimensions.



County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIVE SOIL.

The following numbers and explanations correspond the highlighted cells on the Pile Design Worksheet; all circled numbers are shown on the figure above.

Cell No.	Description
1	Enter the span length between the centerline of the abutment bearings.
2	Enter the roadway width of the bridge.
③	Enter the distance between the centerline of the exterior pile and the edge of the roadway. This value is positive for situations when the exterior pile is within the limits of the roadway width as shown above.
4	Enter the number of piles per abutment. This value must be within the range given in the cells directly above this input cell.
⑤	Enter the vertical distance between the roadway grade and the stream elevation.
⑥	Enter the vertical distance from the stream elevation to the estimated depth of scour. This value is based on stream hydraulics, geological information, and engineering judgment.
7	Use the pull-down menu provided to select the superstructure system for this analysis
8	Enter the dead load abutment reaction for this analysis. A default value maybe provided in the cell directly above this input cell.
9	Enter the live load abutment reaction for this analysis. A default value is provided in the cell directly above this input cell.
10	Enter the average standard penetration test (SPT) blow count (N-value) for the upper level soil.
11	Enter the undrained shear strength of the soil for this analysis. A default value base of the SPT N-value is provided in the cell located directly above this input cell.
12	Enter the friction bearing resistance per foot of pile for soils *within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
13	Enter the friction bearing resistance per foot of pile for soils *not within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
14	Use the pull-down menu provided to select the timber species for this analysis.
15	Enter the tabulated timber bending stress.
16	Enter the tabulated timber compressive stress (parallel to the grain).
17	Enter the tabulated modulus of elasticity.
⑱	Enter the pile butt diameter (i.e., the driving end).
⑲	Enter the pile tip diameter (i.e., the embedded end).
⑳	Enter the vertical distance between the stream elevation and the superstructure bearing points.
21	Use the pull-down menu provided to select the type of lateral restraint system (if any) for this analysis.
22	If applicable, use the pull-down menu provided to select the anchor rod yield stress.
23	If applicable, enter the total number of anchor rods for one abutment.
㉔	If applicable, enter the anchor rod diameter.
㉕	If applicable, enter the height of the anchor block.
㉖	If applicable, enter the vertical distance between the stream elevation and the bottom of the anchor block.
㉗	If applicable, enter the anchor rod length. This value must be greater than or equal the value given directly above this input cell.

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIVE SOIL.

Instructions Worksheet

Return to Pile and Soil Selection Worksheet

General Bridge Input	1	Span length	40.00	ft	
	2	Roadway width	24.00	ft	
	3	Location of exterior pile relative to the edge of the roadway	0.50	ft	
		Maximum number of piles	10	piles on	2.56 ft centers
		Minimum number of piles	4	piles on	7.67 ft centers
	4	Number of piles	7		
	5	Backwall height	6.00	ft	
	6	Estimated scour depth	2.00	ft	
	7	Superstructure system	PCDT		
		Estimated dead load abutment reaction	128.6	kip per abutment (default value)	
	8	Dead load abutment reaction for this analysis	128.6	kip per abutment	
		Estimated live load abutment reaction	110.0	kip per abutment (default value)	
	9	Live load abutment reaction for this analysis	110.0	kip per abutment	
Foundation Material Input	10	Soil SPT blow count (N)	10		
		Correlated soil un-drained shear strength (C_U)	1,270	psf	
	11	Soil undrained shear strength for this analysis	1,270	psf	
	12	Estimated friction bearing value for depths less than 30 ft	0.7	tons per ft	
	13	Estimated friction bearing value for depths greater than 30 ft	0.7	tons per ft	
Pile Input	14	Timber species	southern pine		
	15	Tabulated timber bending stress	1,750	psi	
	16	Tabulated timber compressive stress	1,100	psi	
	17	Tabulated timber modulus of elasticity	1,600,000	psi	
	18	Pile butt diameter	13.0	in.	
	19	Pile tip diameter	10.0	in.	
Lateral Restraint Input	20	Superstructure bearing elevation	3.58	ft	
	21	Type of lateral restraint system	buried concrete anchor block		
	22	Anchor rod steel yield stress	60	ksi	
	23	Total number of anchor rods per abutment	5	per abutment	
	24	Anchor rod diameter	0.75	in.	
	25	Height of anchor block	2.50	ft	
	26	Bottom elevation of anchor block	1.33	ft	
		Anchor block lateral capacity	8.7	kip per pile	
		Computed anchor force per pile	7.8	kip per pile	
		Minimum anchor rod length	13.00	ft	
	27	Anchor rod length	15.00	ft	

Check Pile Design

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIVE SOIL.

Design Checks					
	1	Axial pile load	$P \le P_{ALLOWABLE}$	48.0 kip	OK
	2	Pile length	$Length \le 55\ ft$	37 ft	OK
	3	Pile bearing capacity	$Axial\ Pile\ Load \le Capacity$	sufficient if pile is embedded at least	34 ft
	4	Interaction equation validation	$\frac{1}{(1 - f_C/F'_e)} > 1.0$	1.04	OK
	5	Combined loading interaction requirement	$\left(\frac{f_C}{F'_C}\right)^2 + \frac{f_{bx}}{F'_b\left(1 - \frac{f_C}{F'_{ex}}\right)} + \frac{f_{by}}{F'_b\left(1 - \frac{f_C}{F'_{ey}} - \left(\frac{f_{bx}}{F'_{bE}}\right)^2\right)} \le 1.0$	0.76	OK
	6	Buried anchor block location	$Anchor\ rod\ length \ge minimum$	15.00 ft	OK
	7	Anchor rod stress	$\sigma \le 0.55\ F_Y$	24.7 ksi	OK
	8	Anchor block capacity	$Total\ Anchor\ Force \le Capacity$	8.7 kip per pile	OK
	9	Maximum displacement	$d_{MAX} \le 1.5\ in.$	0.38 in.	OK

Anchor Design Worksheet

Foundation Summary				
	1	Roadway width		24.00 ft
	2	Span length		40.00 ft
	3	Distance between superstructure bearings and roadway grade		2.42 ft
	4	Backwall height		6.00 ft
	5	Dead load abutment reaction		128.6 kip per abutment
	6	Live load abutment reaction		110.0 kip per abutment
	7	Number of piles		7
	8	Total axial pile load		24.0 tons
	9	Pile spacing		3.83 ft
	10	Pile size		
			Butt diameter	13.0 in.
			Tip diameter	10.0 in.
	11	Pile material properties		
			Timber species	southern pine
			Tabulated timber compressive stress	1,100 psi
			Tabulated timber bending stress	1,750 psi
			Tabulated timber modulus of elasticity	1,600,000 psi
	12	Minimum total pile length		37 ft

TIMBER PILES IN A COHESIONLESS SOIL
INSTRUCTIONS AND PILE DESIGN WORKSHEET

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIONLESS SOIL.

The calculations performed in the Pile Design Worksheet are based on the guidelines of the AASHTO Standard Specifications, the Iowa DOT Bridge Design Manual (Iowa DOT BDM), and the National Design Specifications Manual for Wood Construction (NDS Manual).

Once the instructions on this worksheet have been reviewed, proceed to the Pile Design Worksheet or return to the pile and soil selection worksheet by clicking the icons below.

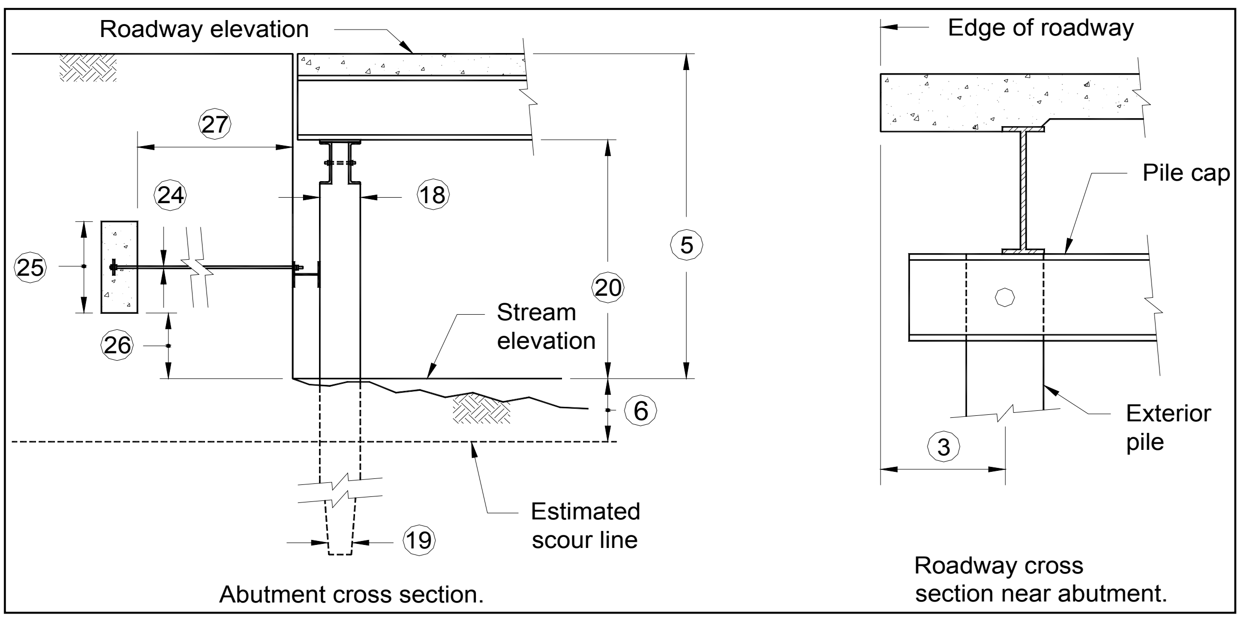
Pile Design Worksheet

Return to Pile and Soil Selection Worksheet

Data required is to be entered in the highlighted cells of the Pile Design Worksheet.

The stream elevation is the datum for all elevations.

The figure below is to be used as a reference for the vertical input dimensions.



County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIONLESS SOIL.

The following numbers and explanations correspond the highlighted cells on the Pile Design Worksheet; all circled numbers are shown on the figure above.

Cell No.	Description
1	Enter the span length between the centerline of the abutment bearings.
2	Enter the roadway width of the bridge.
③	Enter the distance between the centerline of the exterior pile and the edge of the roadway. This value is positive for situations when the exterior pile is within the limits of the roadway width as shown above.
4	Enter the number of piles per abutment. This value must be within the range given in the cells directly above this input cell.
⑤	Enter the vertical distance between the roadway grade and the stream elevation.
⑥	Enter the vertical distance from the stream elevation to the estimated depth of scour. This value is based on stream hydraulics, geological information, and engineering judgment.
7	Use the pull-down menu provided to select the superstructure system for this analysis
8	Enter the dead load abutment reaction for this analysis. A default value maybe provided in the cell directly above this input cell.
9	Enter the live load abutment reaction for this analysis. A default value is provided in the cell directly above this input cell.
10	Enter the average standard penetration test (SPT) blow count (N-value) for the upper level soil.
11	The soil friction angle for this analysis. A default value is provided in the cell located directly above this input cell.
12	Enter the friction bearing resistance per foot of pile for soils *within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
13	Enter the friction bearing resistance per foot of pile for soils *not within* 30 ft of the natural ground line. Appendix C of Volume I provides friction bearing values based on the SPT N-value.
14	Use the pull-down menu provided to select the timber species for this analysis.
15	Enter the tabulated timber bending stress.
16	Enter the tabulated timber compressive stress (parallel to the grain).
17	Enter the tabulated modulus of elasticity.
⑱	Enter the pile butt diameter (i.e., the driving end).
⑲	Enter the pile tip diameter (i.e., the embedded end).
⑳	Enter the vertical distance between the stream elevation and the superstructure bearing points.
21	Use the pull-down menu provided to select the type of lateral restraint system (if any) for this analysis.
22	If applicable, use the pull-down menu provided to select the anchor rod yield stress.
23	If applicable, enter the total number of anchor rods for one abutment.
㉔	If applicable, enter the anchor rod diameter.
㉕	If applicable, enter the height of the anchor block.
㉖	If applicable, enter the vertical distance between the stream elevation and the bottom of the anchor block.
㉗	If applicable, enter the anchor rod length. This value must be greater than or equal the value given directly above this input cell.

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIONLESS SOIL.

Instructions Worksheet

Return to Pile and Soil Selection Worksheet

General Bridge Input	1	Span length	40.00	ft
	2	Roadway width	24.00	ft
	3	Location of exterior pile relative to the edge of the roadway	0.50	ft
		Maximum number of piles	10	piles on 2.56 ft centers
		Minimum number of piles	4	piles on 7.67 ft centers
	4	Number of piles	7	
	5	Backwall height	6.00	ft
	6	Estimated scour depth	2.00	ft
	7	Superstructure system	PCDT	
		Estimated dead load abutment reaction	128.6	kip per abutment (default value)
	8	Dead load abutment reaction for this analysis	128.6	kip per abutment
		Estimated live load abutment reaction	110.0	kip per abutment (default value)
	9	Live load abutment reaction for this analysis	110.0	kip per abutment
Foundation Material Input	10	Soil SPT blow count (N)	20	
		Correlated soil friction angle (ϕ)	33.3	degrees
	11	Soil friction angle for this analysis	33.3	degrees
	12	Estimated friction bearing value for depths less than 30 ft	0.7	tons per ft
	13	Estimated friction bearing value for depths greater than 30 ft	0.7	tons per ft
Pile Input	14	Timber species	southern pine	
	15	Tabulated timber bending stress	1,750	psi
	16	Tabulated timber compressive stress	1,100	psi
	17	Tabulated timber modulus of elasticity	1,600,000	psi
	18	Pile butt diameter	13.0	in.
	19	Pile tip diameter	10.0	in.
Lateral Restraint Input	20	Superstructure bearing elevation	3.58	ft
	21	Type of lateral restraint system	buried concrete anchor block	
	22	Anchor rod steel yield stress	60	ksi
	23	Total number of anchor rods per abutment	5	per abutment
	24	Anchor rod diameter	0.75	in.
	25	Height of anchor block	2.50	ft
	26	Bottom elevation of anchor block	1.33	ft
		Anchor block lateral capacity	8.7	kip per pile
		Computed anchor force per pile	7.8	kip per pile
		Minimum anchor rod length	13.00	ft
	27	Anchor rod length	15.00	ft

Check Pile Design

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY FOR TIMBER PILES IN A COHESIONLESS SOIL.

Design Checks	1	Axial pile load	$P \le P_{ALLOWABLE}$	48.0 kip	OK
	2	Pile length	$\text{Length} \le 55\ \text{ft}$	37 ft	OK
	3	Pile bearing capacity	$\text{Axial Pile Load} \le \text{Capacity}$	sufficient if pile is embedded at least	34 ft
	4	Interaction equation validation	$\dfrac{1}{(1 - f_C/F'_e)} > 1.0$	1.04	OK
	5	Combined loading interaction requirment $\left(\dfrac{f_C}{F'_C}\right)^2 + \dfrac{f_{bx}}{F'_b\left(1 - \dfrac{f_C}{F'_{ex}}\right)} + \dfrac{f_{by}}{F'_b\left(1 - \dfrac{f_C}{F'_{ey}} - \left(\dfrac{f_{bx}}{F'_{bE}}\right)^2\right)} \le 1.0$		0.76	OK
	6	Buried anchor block location	$\text{Anchor rod length} \ge \text{minimum}$	15.00 ft	OK
	7	Anchor rod stress	$\sigma \le 0.55\ F_Y$	24.7 ksi	OK
	8	Anchor block capacity	$\text{Total Anchor Force} \le \text{Capacity}$	8.7 kip per pile	OK
	9	Maximum displacement	$d_{MAX} \le 1.5\ \text{in.}$	0.38 in.	OK

Anchor Design Worksheet

Foundation Summary	1	Roadway width	24.00 ft
	2	Span length	40.00 ft
	3	Distance between superstructure bearings and roadway grade	2.42 ft
	4	Backwall height	6.00 ft
	5	Dead load abutment reaction	128.6 kip per abutment
	6	Live load abutment reaction	110.0 kip per abutment
	7	Number of piles	7
	8	Total axial pile load	24.0 tons
	9	Pile spacing	3.83 ft
	10	Pile size	
		Butt diameter	13.0 in.
		Tip diameter	10.0 in.
	11	Pile material properties	
		Timber species	southern pine
		Tabulated timber compressive stress	1,100 psi
		Tabulated timber bending stress	1,750 psi
		Tabulated timber modulus of elasticity	1,600,000 psi
	12	Minimum total pile length	37 ft

ANCHOR DESIGN WORKSHEET

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY TO BE USED AFTER THE PILE SYSTEM HAS BEEN DESIGNED AND ALL DESIGN REQUIREMENTS HAVE BEEN SATISFIED.

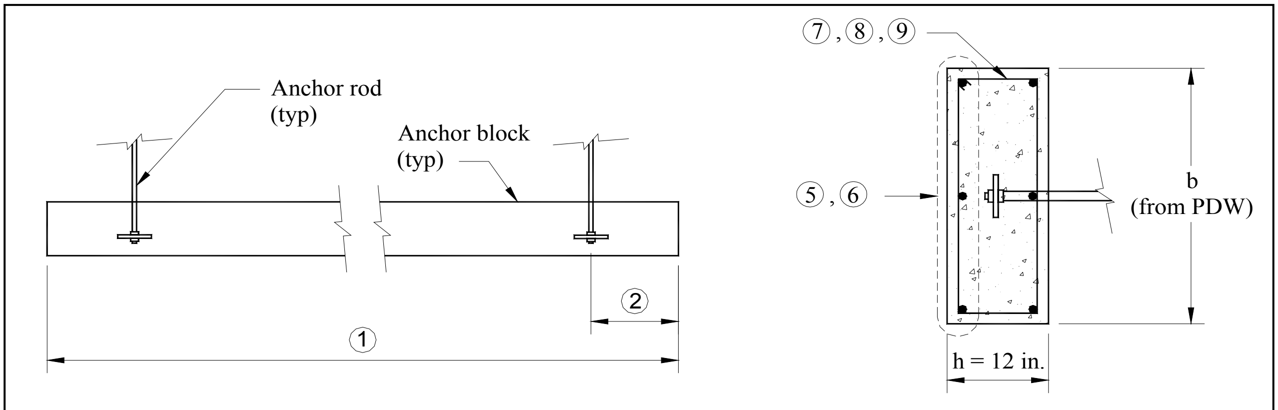
Return to Pile Design Worksheet

Go to Pile and Soil Selection Worksheet

The design in this worksheet is based on Section 8 of the AASHTO Standard Specifications.

Once the instructions on this sheet have been reviewed, proceed to the input section of this worksheet below.

Data required is to be entered in the highlighted cells of the Input Information section; all circled numbers are shown on the figure below.



Anchor block plan view.

Anchor block cross section.

Instructions	Cell No.	Description
	①	Enter the total length of the anchor block.
	②	Enter the distance between the end of the anchor block and the exterior anchor rod.
	3	Enter the anchor block concrete compressive strength.
	4	Use the pull-down menu provided to select the yield strength of the reinforcing steel.
	⑤	Enter the number of tension steel reinforcing bars on one vertical anchor block face.
	⑥	Use the pull-down menu provided to select the tension steel bar size.
	⑦	If applicable, use the pull-down menu provided to select the stirrup bar size.
	⑧	If applicable, enter the number of stirrup legs per section.
	⑨	If applicable, enter the stirrup spacing for this analysis. This value must be less than the value in the cell directly above this input cell.

County:
Project No:
Description:

computed by:
checked by:
date:

THIS WORKSHEET IS ONLY TO BE USED AFTER THE PILE SYSTEM HAS BEEN DESIGNED AND ALL DESIGN REQUIREMENTS HAVE BEEN SATISFIED.

Input Information	1	Anchor block length	28.00	ft
	2	Distance from end of anchor block to exterior anchor rod	1.50	ft
	3	Concrete compressive strength	3.0	ksi
	4	Yield strength of reinforcing steel	60	ksi
		Tension steel area required	0.28	in^2
	5	Number of reinforcing bars per vertical anchor block face	3	bars
	6	Tension steel bar size	4	#
		Tension steel area provided	0.60	in^2
		Are stirrups required?	Yes	
	7	Stirrup bar size number	3	#
	8	Number of stirrup legs per section	2	
		Maximum stirrup spacing	4.69	in.
	9	Stirrup spacing for this analysis	4.50	in.

Design Checks	1	Design flexural capacity	$M_U < \phi M_N$	24.78	ft-kips	OK	{AASHTO 8.16.3.2}
	2	Reinforcement ratio	$\rho < 0.75\rho_b$	0.0018		OK	{AASHTO 8.16.3.2.2}
	3	Minimum reinforcement				OK	{AASHTO 8.17}
	4	Design shear capacity	$V_U < \phi V_N$	54.8	kip	OK	{AASHTO 8.16.6.1.1}

Anchor System Summary	1	Number of anchor rods	5				
	2	Anchor rod steel yield stress	60	ksi			
	3	Anchor rod diameter	0.750	in.			
	4	Anchor rod length	17.00	ft			
	5	Anchor rod spacing	6.25	ft			
	6	Vertical distance between bottom of anchor block and roadway grade	4.92	ft			
	7	Anchor block length	28.00	ft			
	8	Anchor block height	3.0	ft			
	9	Anchor block width	12.0	in.			
	10	Concrete compressive strength	3.0	ksi			
	11	Details of reinforcement on one vertical anchor block face	3		# 4	bars	
	12	Details for stirrups	# 3	bars on		4.50	in. centers

APPENDIX D

GENERIC STANDARD ABUTMENT PLANS

APPENDIX D TABLE OF CONTENTS

D.1. GENERAL INFORMATION

These generic standard abutment design sheets were developed to provide the user with a means of producing a set of drawings for a single span stub abutment for bridges with spans in the 20 to 90 ft range with no or small skew angles. By using the FDT and inserting basic geometry and bridge site information, the designer can generate a complete set of abutment construction drawings.

Although an effort has been made to give sufficiently complete information and to allow for adaptation to specific sites, requirements imposed by site conditions may necessitate modification of these drawings.

The completed set of abutment drawings assembled from these templates shall be reviewed and approved by a Registered Professional Engineer prior to the beginning of construction. It is important that a subsurface soil investigation be performed prior to completion of the foundation design and drawings. It is recommended that a SPT be performed. However, a more accurate foundation design can be completed if the soil undrained shear strength or friction angle is determined for cohesive and cohesionless soils, respectively. These parameters can then be used in the FDT.

The concepts, designs, details, and notes shown in these standard plans for the piles and anchor system have been developed by the BEC of Iowa State University using the guidelines specified in the AASHTO Standard Specifications [2], the NDS Manual [6], the Iowa DOT BDM [3] and proven design practices. While the bridge system shown has been carefully designed, detailed, and checked, any user should independently determine the appropriateness, and potential adaptability of this abutment design methodology for specific bridge sites.

D.2. INSTRUCTIONS FOR USING CONSTRUCTION DRAWINGS

Prior to utilizing these drawings, the designer must obtain basic survey and geometric data for the proposed construction site. Information concerning the foundation material and the elevation of the potential foundation bearing areas must also be obtained.

The feasibility of the FDT and standard abutment plans for a specific bridge site shall be determined using the flowchart provided as Figure D.1. Once the design has been completed and all necessary geometry, bearing elevations, finished ground elevations, etc. have been determined, the designer can produce the final construction drawings. Completed drawings should be included with the final set of construction documents. The following steps should be followed in the preparation process:

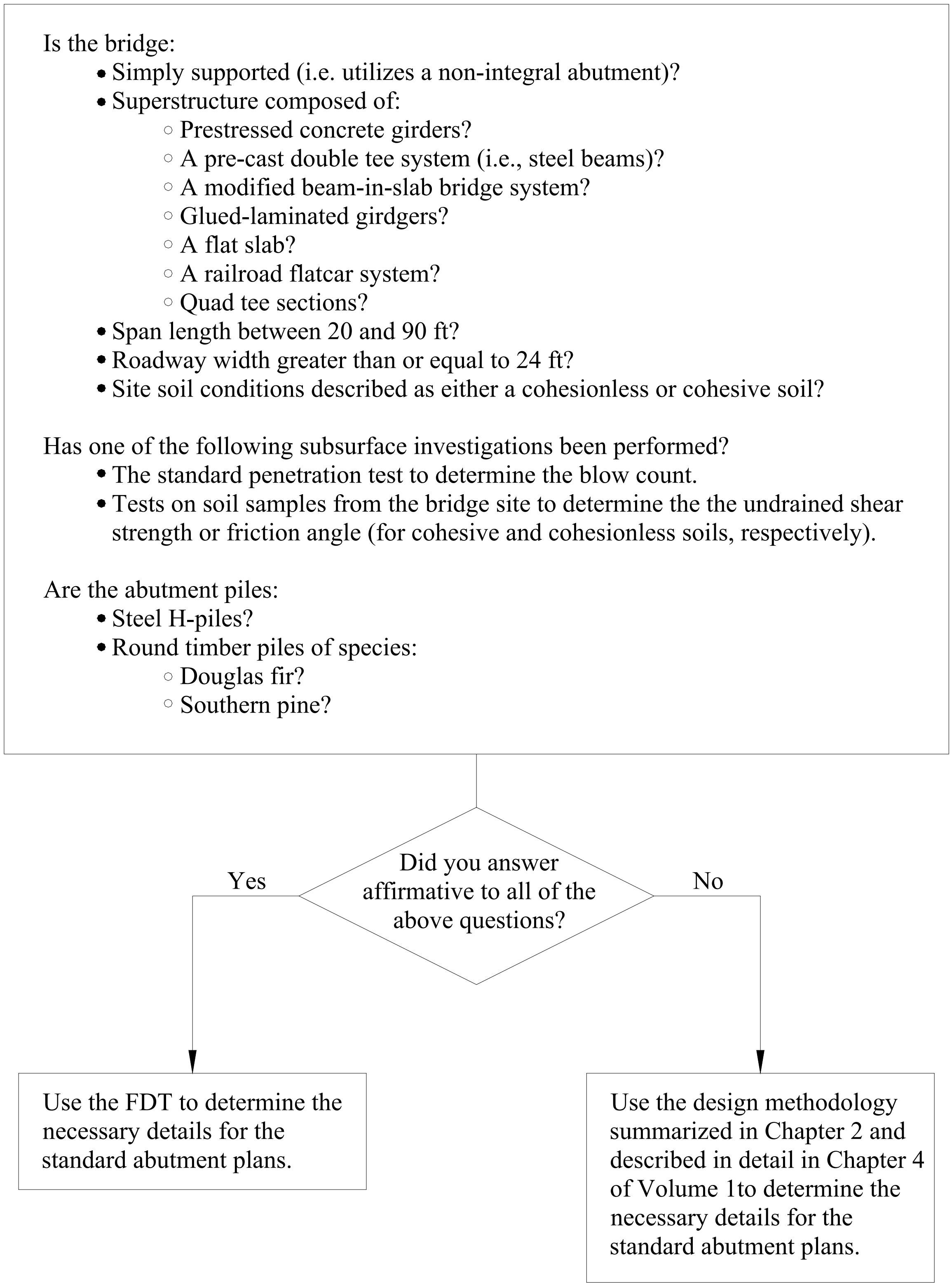


Figure D.1. FDT feasibility flowchart.

1. Complete the superstructure design.
2. Fill in all information pertinent to the bridge and construction site in indicated locations (i.e., fill in all boxes) including:
   - Basic survey information
   - Design details provided by the FDT.
3. Add drawing titles and add miscellaneous information including:
   - Customizing the standard drawings by adding necessary location and route information to the title block of each sheet.
   - Add necessary information pertaining to utilities, hydraulic data, etc.
   - Add subsurface exploration data

The standard abutment plans consist of three different types of sheets. The first type consists of two general sheets that will be used for all bridge abutments and are both included in the final set of construction sheets. These include a cover sheet (Sheet A1) and a general bridge plan and elevation layout sheet (Sheet A2). The second type of sheet (Sheet D1) provides general information and instructions relating to the usage of the construction sheets. Sheet D1 also includes Figures D.1 and D.2. Figure D.1 has been previously introduced and Figure D.2 is a detail for an alternate steel channel pile cap. The flat steel bearing plate shown on the steel channel pile cap details of some U-series sheets (described below) can be replaced with a third c-channel as shown in Figure D.2. Sheet D1 is not to be included in the final set of construction documents. The final type of sheet consists of 16 abutment construction sheets (Sheets U1 through U16) with different combinations of pile caps, backwall systems, anchor systems, and pile types. For example, if the bridge site requires steel H-piles with an anchor system, a concrete pile cap, and a sheet pile backwall, Sheet U7 should be used. At most, two of these abutment construction sheets will be required for a particular bridge site (i.e., a different construction sheet for each bridge abutment). If the two bridge abutments use the same combination of previously mentioned substructure variables, the same sheet can be used twice with different dimensions, if necessary.

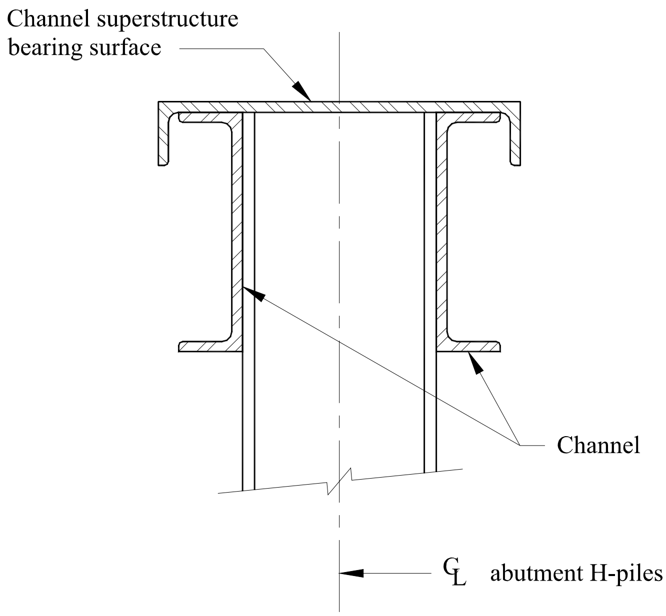


Figure D.2. Alternate steel channel pile cap detail for a steel H-pile abutment.

GENERIC STANDARD ABUTMENT PLANS

IOWA
DEPARTMENT OF TRANSPORTATION

Project Development Division
PLANS OF PROPOSED IMPROVEMENT ON THE

SECONDARY ROAD SYSTEM
COUNTY
BRIDGE

The Standard Specifications, Series of 2002, of the Iowa Department of Transportation Shall Apply to Construction Work on this Project
Plus Current Special Provisions and Supplemental Specifications

Scales: As Noted

N

SITE

MAP

AADT V.P.D.

Project No.

- roadway width
- piles
- backwall
- pile cap
- superstructure

APPROVED

County Engineer

Date __/__/__

Approved: County

Board of Supervisors

INDEX OF SHEETS

No.	Description

MILEAGE SUMMARY

Div.	Location	Lin. Ft.	Miles

ROAD STANDARD PLANS

The following Standard Plans shall be considered applicable to construction work on this project.

Identification	Date	Identification	Date	Identification	Date

BRIDGE STANDARDS

The following Bridge Standards shall be be considered applicable

Standard	Date Issued	Latest Revision	Standard	Date Issued	Latest Revision

Designed by: __________ Design checked by: __________
Drawn by: __________ Drawings checked by: __________

I hereby certify that this engineering document was prepared by me or under my direct personal supervision and that I am a duly licensed professional Engineer under the laws of the State of Iowa

Iowa Registration # Date __/__/__
Registration Subject to Renewal __/__/__

REVISIONS

Cover sheet

DATE:
DRAWN BY:
CHECKED BY:
SCALE:
PROJECT NO:
SHEET NO:

A1

INSERT PLAN VIEW

PLAN

INSERT ELEVATION VIEW

ELEVATION

GENERAL NOTES

- Materials and workmanship shall be in accordance with all applicable Iowa Department of Transportation standards.
- Structural timber shall conform to ASTM designation as noted.
- Structural steel shall conform to ASTM designation as noted.
- Exposed steel and or timber shall be painted as noted and conform to .
- Structural steel and hardware shall be galvanized and shall conform to ASTM designation as noted.
- Concrete cover on reinforcement shall be as noted.
- Concrete shall be class .
- All reinforcement steel shall meet applicable requirements for ASTM Grade .
- Reinforcement shall be expoxy coated as noted and shall conform to ASTM .
- All dimensions are horizontal and shall be accurate at a temperature of degrees.
- The shall notify all involved utility companies a minimum of 7 days prior to starting work. Utilities shall not be disturbed or endangered during construction operations.

SUMMARY OF ESTIMATED QUANTITIES FOR ABUTMENT

ITEM NO.	ITEM	QTY.	UNIT	TOTAL

SUMMARY OF ESTIMATED QUANTITIES FOR ABUTMENT

ITEM NO.	ITEM	QTY.	UNIT	TOTAL

REVISIONS

General bridge plan and elevation layout

Table of quantities

DATE:

DRAWN BY:

CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

A2

GENERAL PLAN

PILE STUB ABUTMENT

LOCATION:

Table of Contents

Sheet	Pile type	Pile cap	Backwall	Anchor Included
U1	Steel	Steel channel	Sheet pile	No
U2	Steel	Steel channel	Timber plank	No
U3	Steel	Concrete	Sheet pile	No
U4	Steel	Concrete	Timber plank	No
U5	Steel	Steel channel	Sheet pile	Yes
U6	Steel	Steel channel	Timber plank	Yes
U7	Steel	Concrete	Sheet pile	Yes
U8	Steel	Concrete	Timber plank	Yes
U9	Timber	Steel channel	Sheet pile	No
U10	Timber	Steel channel	Timber plank	No
U11	Timber	Concrete	Sheet pile	No
U12	Timber	Concrete	Timber plank	No
U13	Timber	Steel channel	Sheet pile	Yes
U14	Timber	Steel channel	Timber plank	Yes
U15	Timber	Concrete	Sheet pile	Yes
U16	Timber	Concrete	Timber plank	Yes

General Information

These generic standard abutment design sheets were developed to provide the user with a means of producing a set of drawings for a single span stub abutment for bridges in the 20 to 90 ft range with no or small skew angles. By first using the foundation design template (FDT) to determine the number of piles required, their length, etc., and inserting basic geometry and job information, the designer can generate a complete set of abutment construction drawings.

Although an effort has been made to provide sufficiently complete information and to allow for adaptation to a specific site, requirements imposed by site conditions may necessitate modification of these drawings.

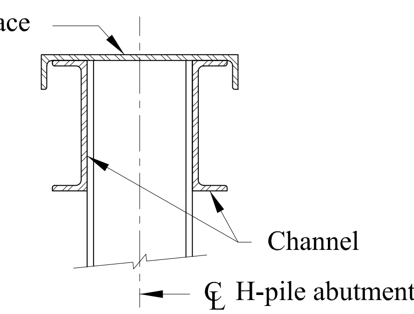
The completed set of abutment drawings assembled from these templates shall be reviewed and sealed by a Registered Professional Engineer prior to the beginning of construction. It is important that a subsurface soil investigation be performed prior to completion of the foundation design and its drawings. It is recommended, wherever possible, that a standard penetration test (SPT) be performed. However, a more accurate foundation design can be completed if the soil undrained shear strength or friction angle is determined for cohesive and cohesionless soil, respectively. These parameters can then be used in the FDT.

The concepts, designs, details, and notes shown in these standard plans for the piles and anchor system have been developed by the Bridge Engineering Center (BEC) of Iowa State University using the guidelines specified in the AASHTO Standard Specifications, the National Design Specifications (NDS), the Iowa DOT Bridge Design Manual, and proven design practices. While the bridge system shown has been carefully designed, detailed, and checked, any user should independently determine the appropriateness, and potential adaptability of this abutment design methodology and drawings for specific bridge sites.

Instructions for Using Construction Drawings

These standard abutment plans consist of three different types of sheets. The first type (A-series) consists of two general sheets that will be used for all bridge abutments, both need to be included in the final set of construction sheets. This sheet (Sheet D1), provides general information and instructions relating to the usage of the construction sheets and is not to be included in the final set of construction documents. The final type of sheet consists of 16 abutment construction sheets (U-series) with different combinations of pile caps, backwall systems, anchor systems, and pile types. For example, if the bridge site requires steel H-piles with an anchor system, a concrete pile cap, and a sheet pile backwall, Sheet U7 should be used.

It should be noted that the flat steel bearing plate shown on the steel channel pile cap details on some standard abutment drawings can be replaced with a third channel as shown below.



Prior to using these design drawings, the designer must obtain basic survey and geometric data of the bridge site. Information concerning the foundation material and the elevation of the potential foundation bearing surface must also be obtained.

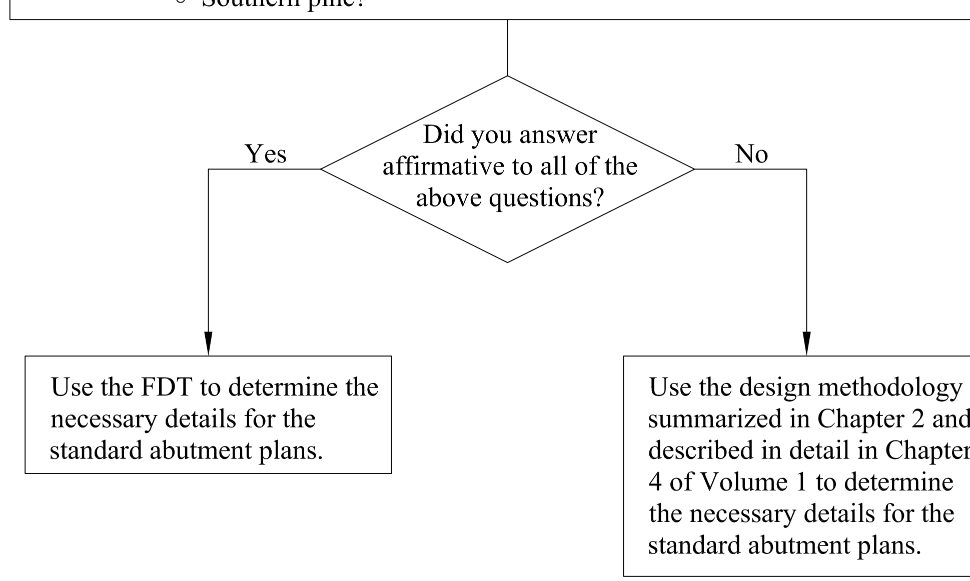
The design of the substructure shall be completed following the flowchart shown on this sheet. Once the design has been completed and all necessary geometry, bearing elevations, finished ground elevations, etc. have been determined, the designer can produce the final construction drawings. Completed drawings should be included with the final set of construction documents. The following steps should be followed in the preparation process:

1. Complete the superstructure design.
2. Fill in all information pertinent to the bridge and construction site in indicated locations (i.e., fill in all of the blank boxes) including:
   - Basic survey information.
   - Design details provided by the FDT.
3. Add drawing titles and add miscellaneous information including:
   - Customizing the standard drawings by adding necessary location and route information to the title block of each sheet.
   - Add necessary information pertaining to utilities, hydraulic data.
   - Add subsurface exploration data.

Is the bridge:
- Simply supported (i.e. utilizes a non-integral abutment)?
- Superstructure composed of:
  - Prestressed concrete girders?
  - A pre-cast double tee system (i.e., steel beams)?
  - A modified beam-in-slab bridge system?
  - Glued-laminated girdgers?
  - A flat slab?
  - A railroad flatcar system?
  - Quad tee sections?
- Span length between 20 and 90 ft?
- Roadway width greater than or equal to 24 ft?
- Site soil conditions described as either a cohesionless or cohesive soil?

Has one of the following subsurface investigations been performed?
- The standard penetration test to determine the blow count.
- Tests on soil samples from the bridge site to determine the the undrained shear strength or friction angle (for cohesive and cohesionless soils, respectively).

Are the abutment piles:
- Steel H-piles?
- Round timber piles of species:
  - Douglas fir?
  - Southern pine?



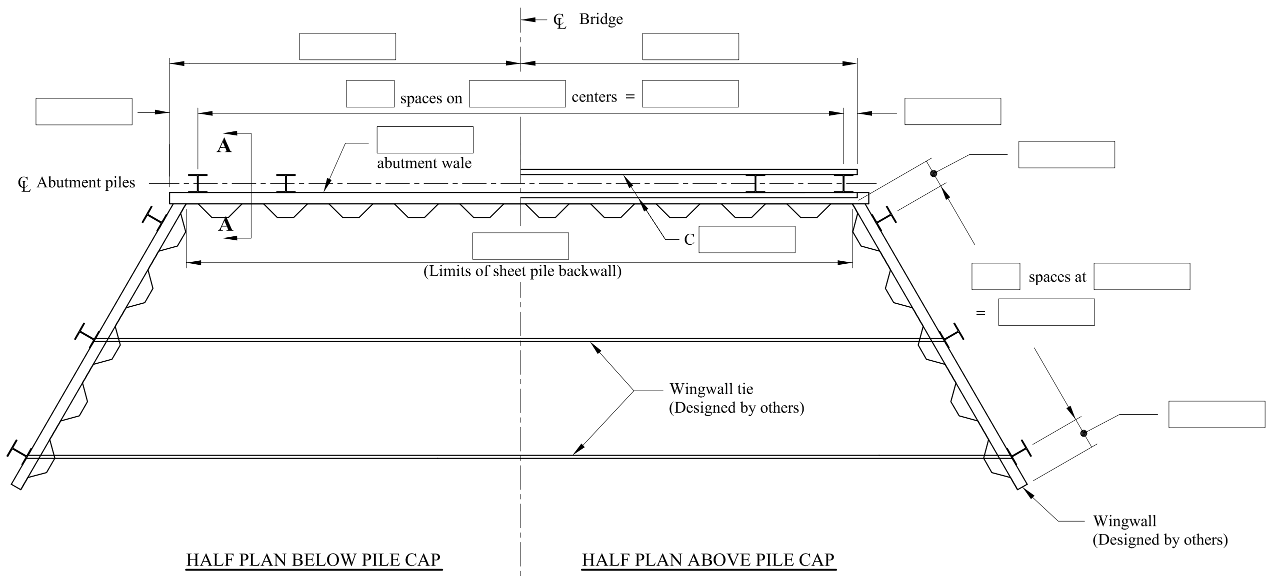
REVISIONS

General information and notes

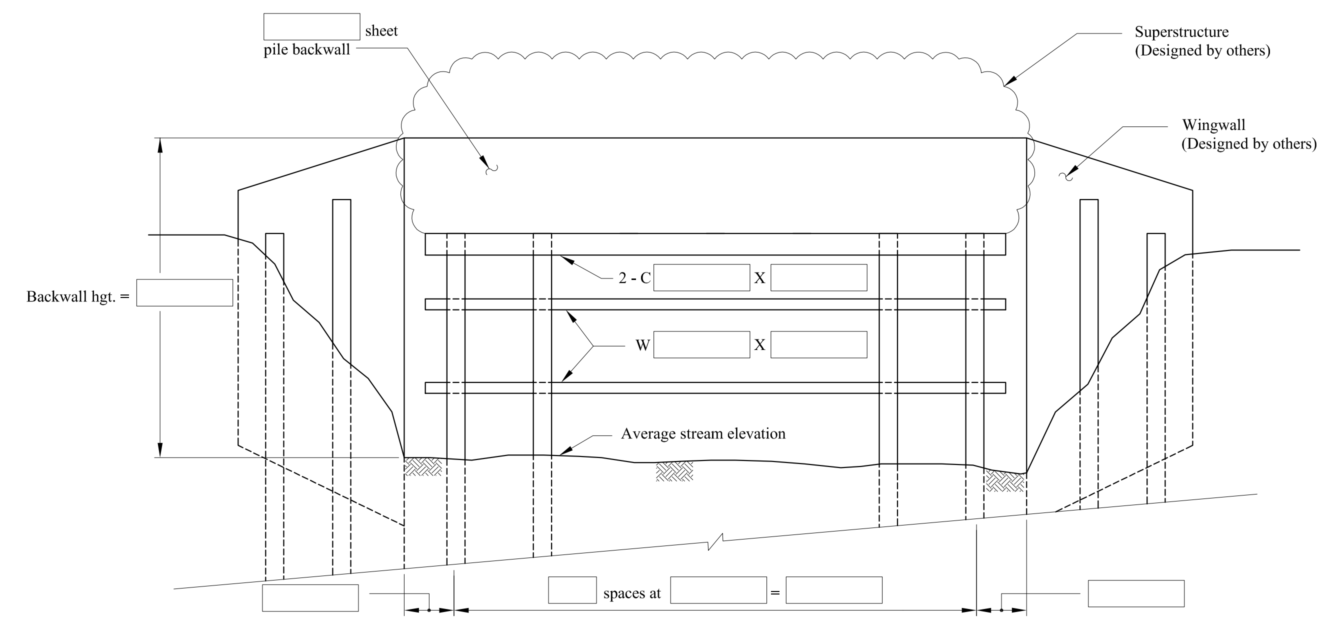
DATE:
DRAWN BY:
CHECKED BY:
SCALE:
PROJECT NO:
SHEET NO:

D1

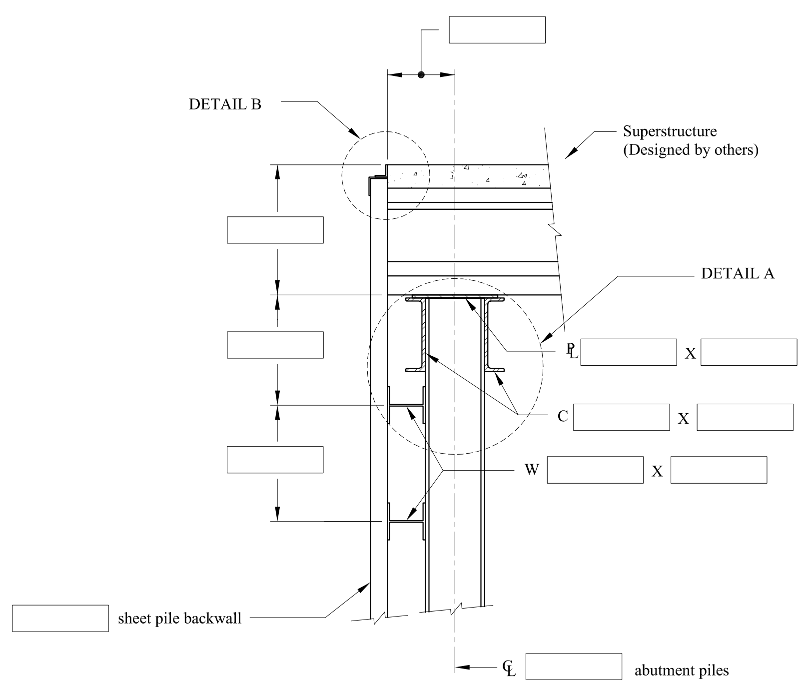
INSTRUCTIONS
PILE STUB ABUTMENT
LOCATION:



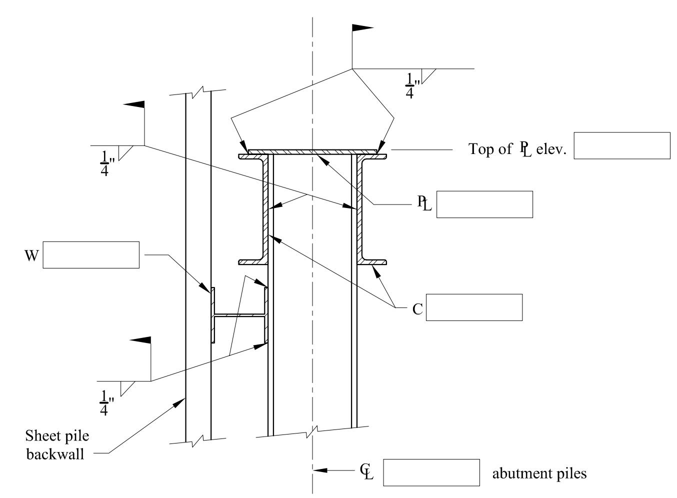
PLAN VIEW



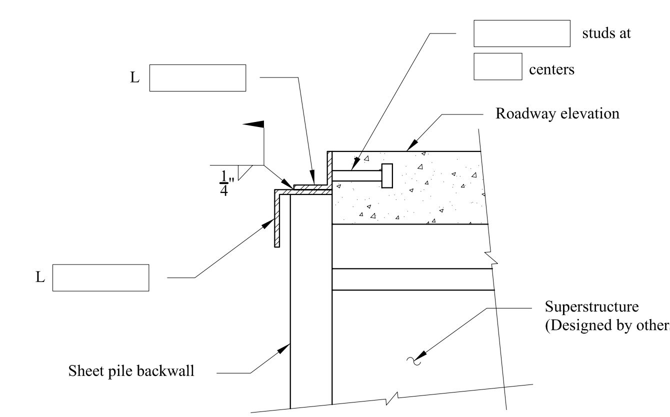
CROSS SECTION NEAR ABUTMENT



Section A-A: ABUTMENT SECTION



DETAIL A: PILE CAP AND WALE WELDING DETAILS



DETAIL B: SHEET PILE BACKWALL CAP AND CONNECTION DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ____ and ____ abutments.

All piling shall be driven to practical refusal but not less than ____ ton bearing.

The piling shall be cut off at an elevation of ____.

The superstructure bearings are located at an elevation of ____.

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ____.

REVISIONS

ABUTMENT DETAILS

STEEL PILES WITH STEEL CHANNEL PILE CAP AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

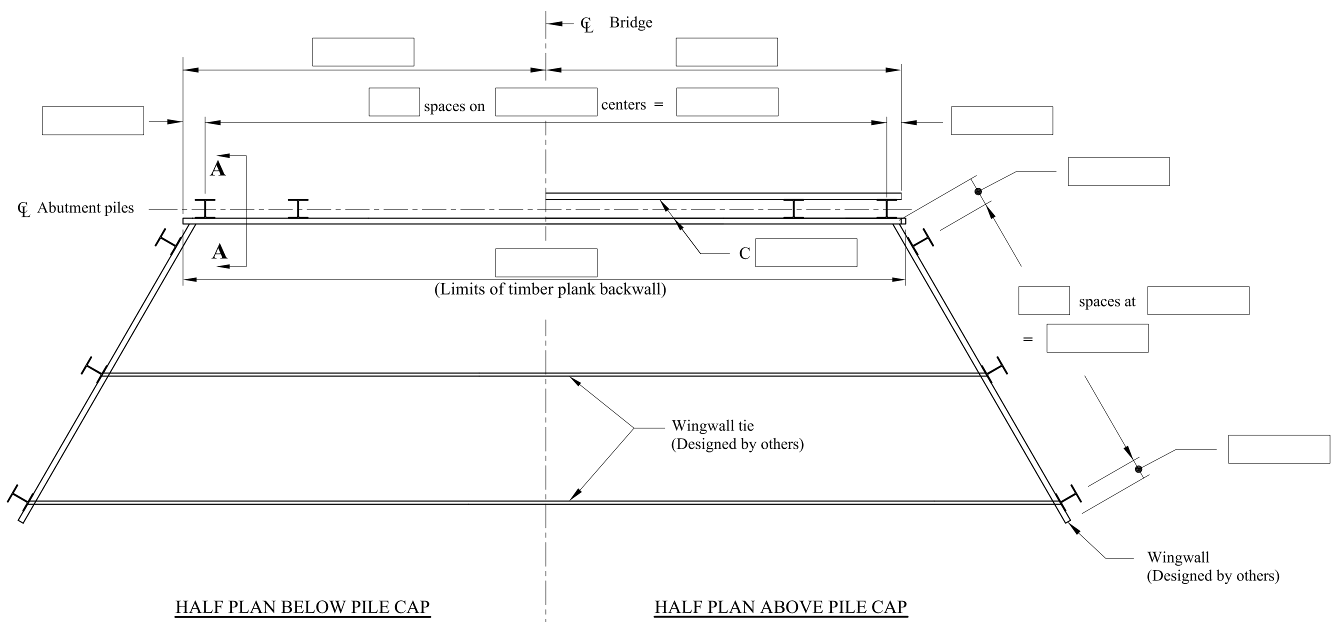
CHECKED BY:

SCALE:

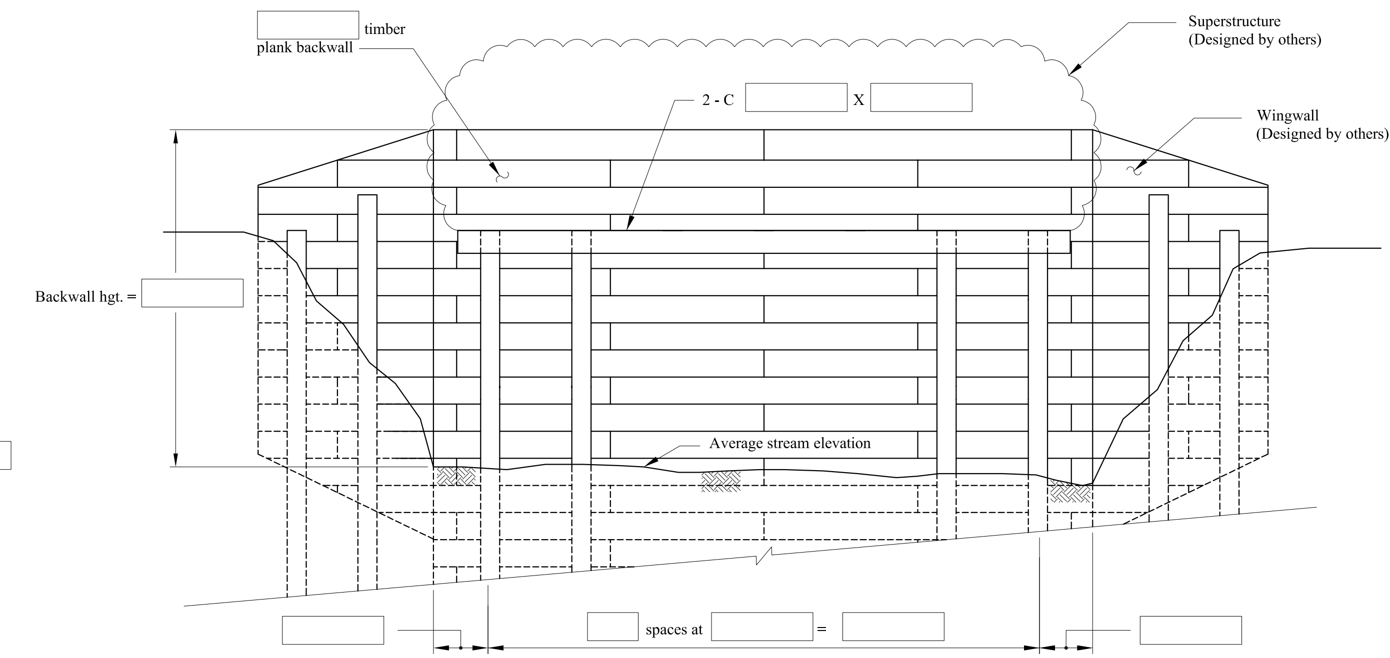
PROJECT NO:

SHEET NO:

U1



PLAN VIEW



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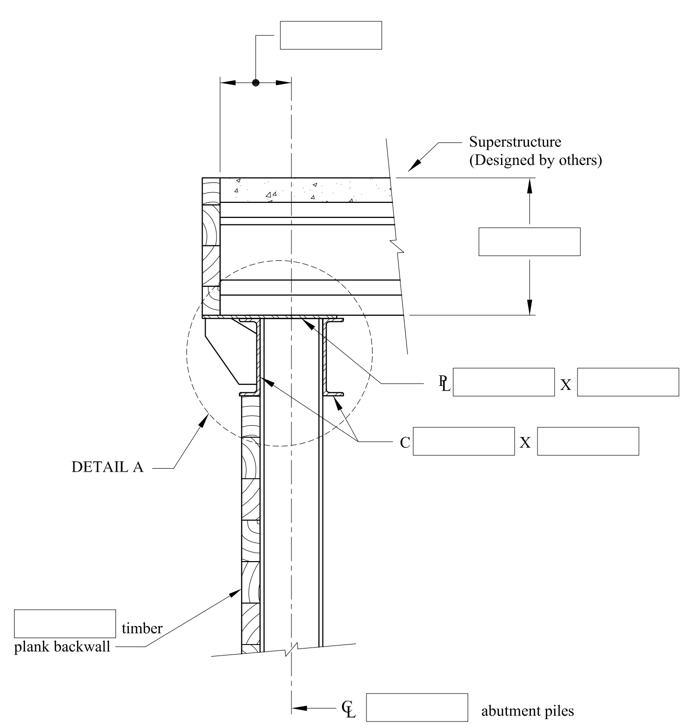
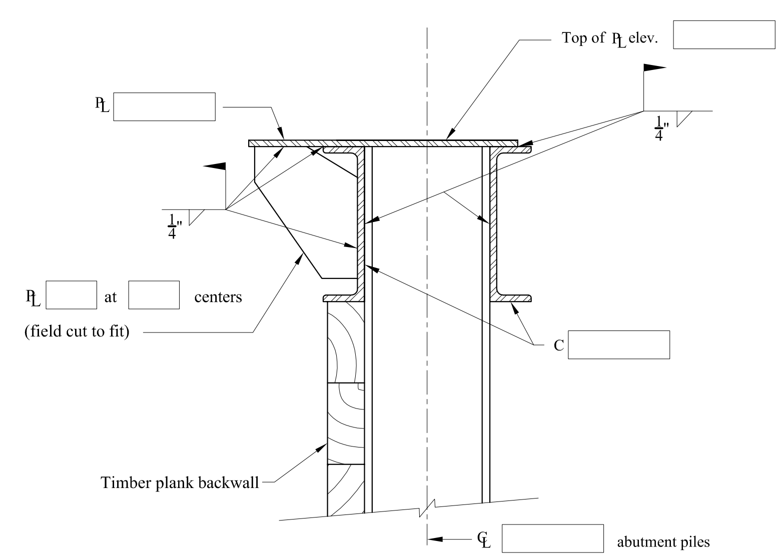


Section A-A: ABUTMENT SECTION



DETAIL A: PILE CAP WELDING DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

All timber shall be creosote treated.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

REVISIONS

ABUTMENT DETAILS

STEEL PILES WITH STEEL CHANNEL PILE CAP AND TIMBER PLANK BACKWALL

DATE:

DRAWN BY:

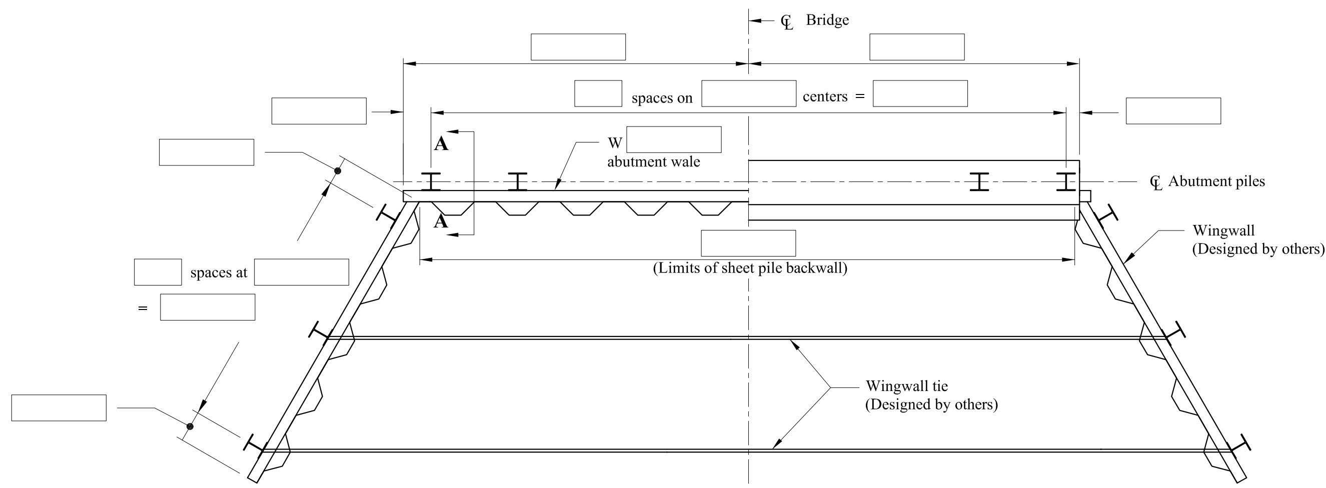
CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

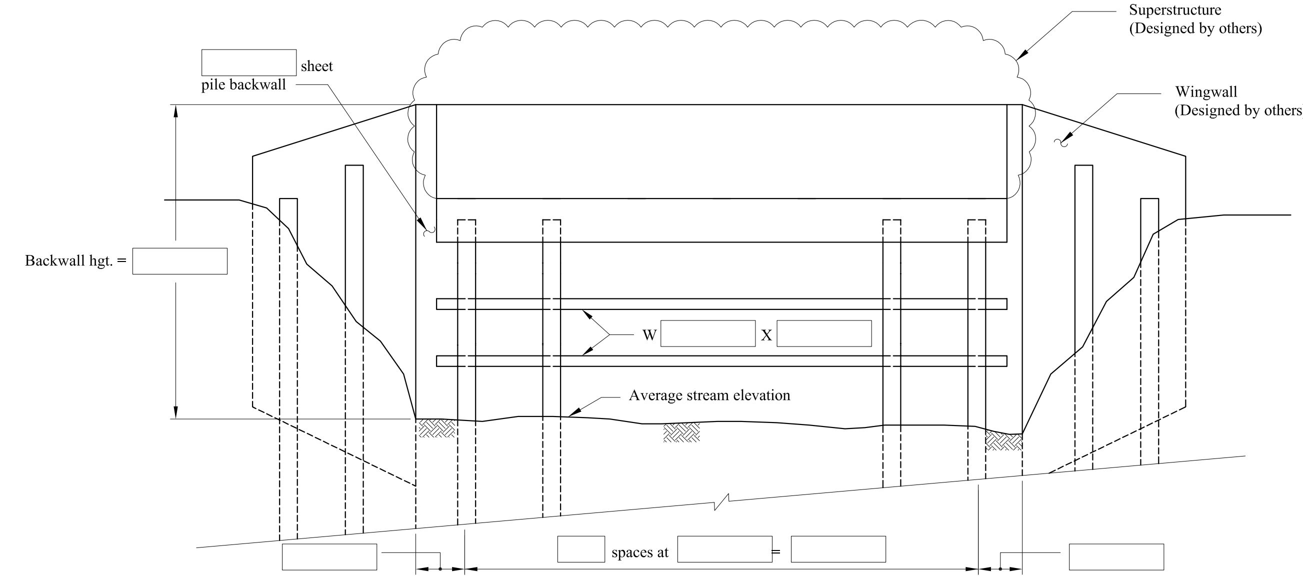
U2



HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

PLAN VIEW



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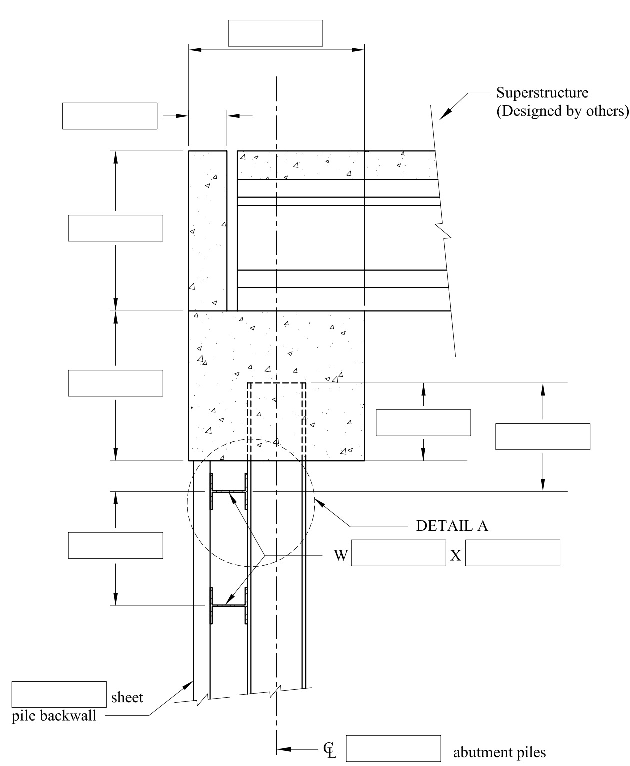
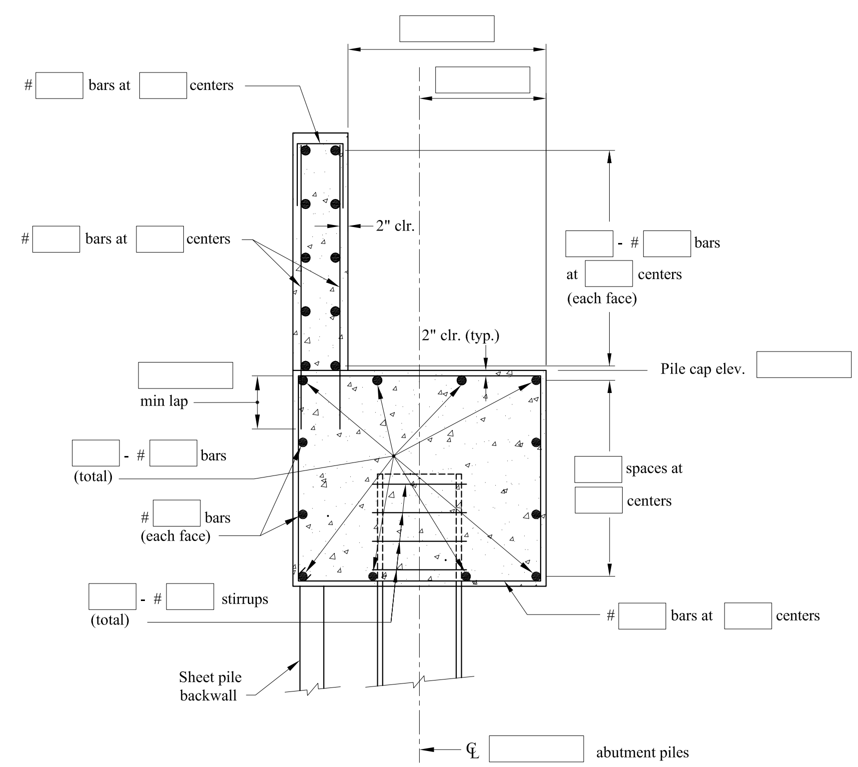
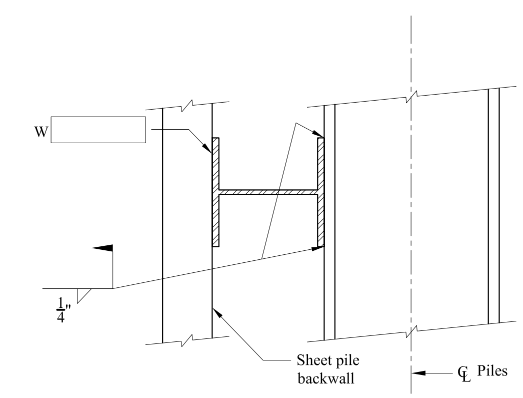


Section A-A: ABUTMENT SECTION



PILE CAP DETAILS



DETAIL A: WALE WELDING DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the and abutments.

All piling shall be driven to practical refusal but not less than ton bearing.

The piling shall be cut off at an elevation of .

The superstructure bearings are located at an elevation of .

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

STEEL PILES WITH CONCRETE PILE CAP AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

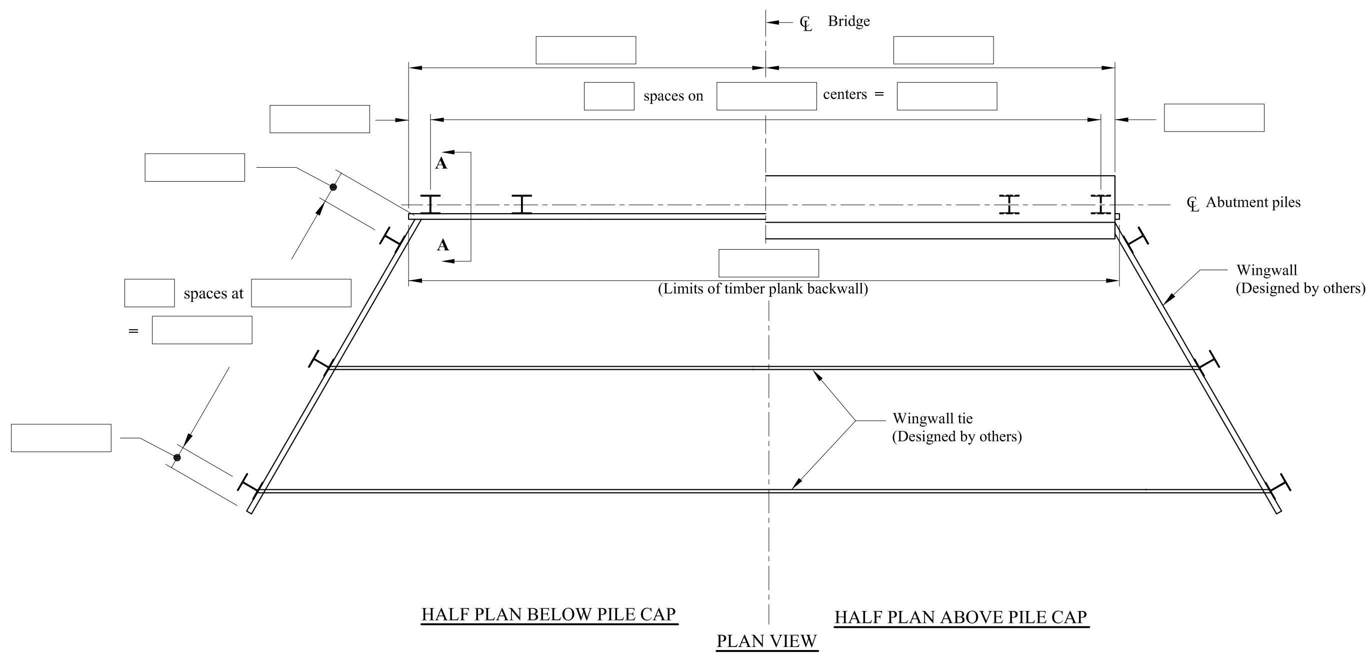
CHECKED BY:

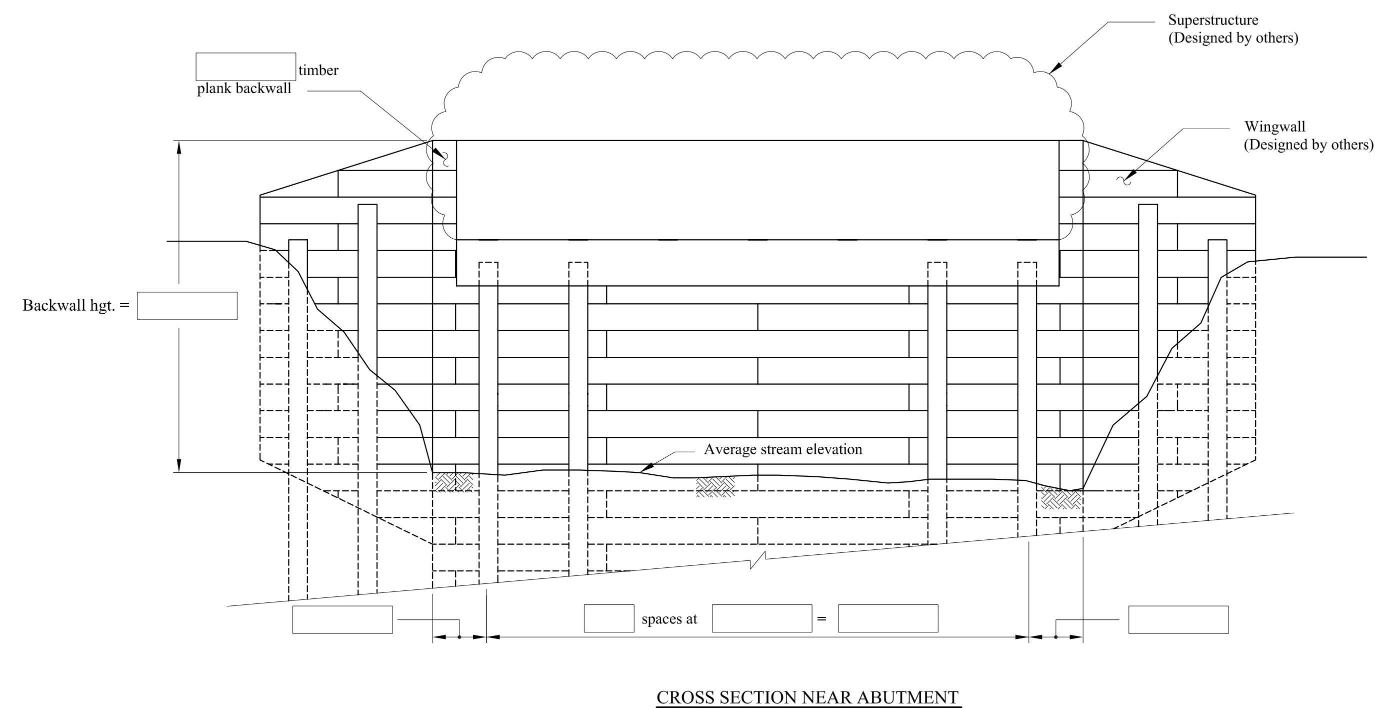
SCALE:

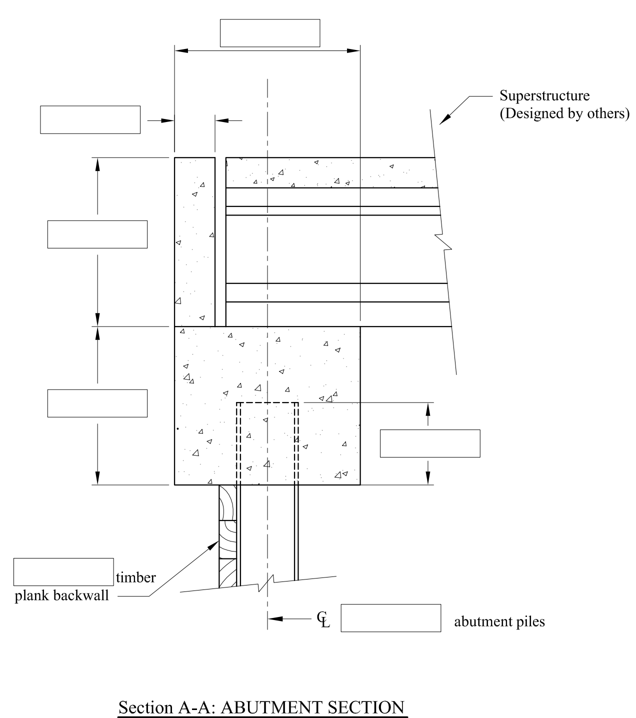
PROJECT NO:

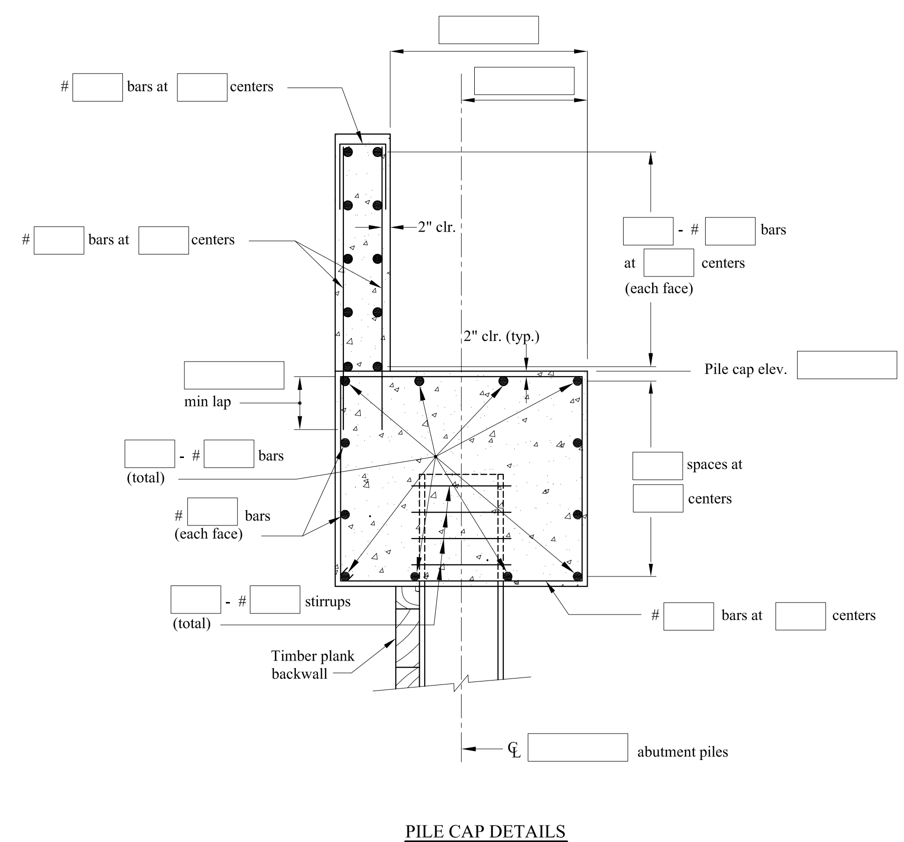
SHEET NO:

U3









In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

All timber shall be creosote treated.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

STEEL PILES WITH CONCRETE PILE CAP AND TIMBER PLANK BACKWALL

DATE:

DRAWN BY:

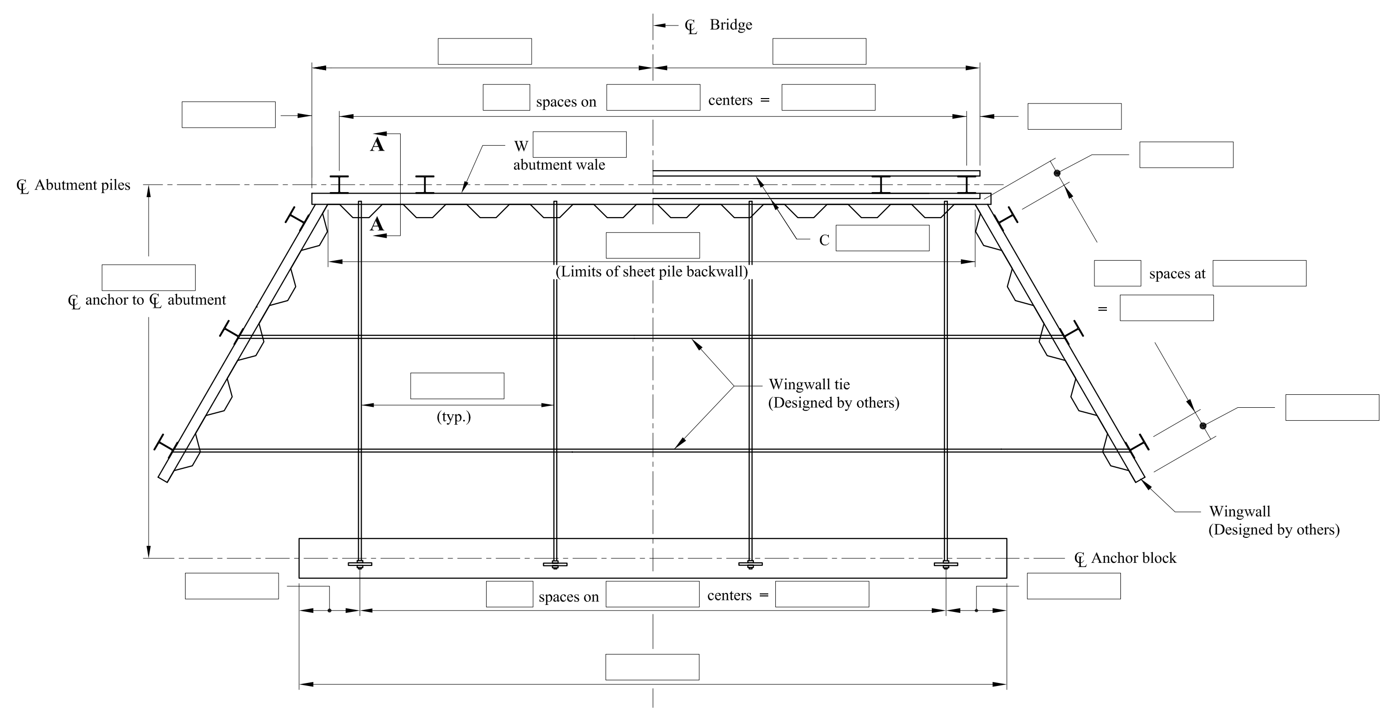
CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

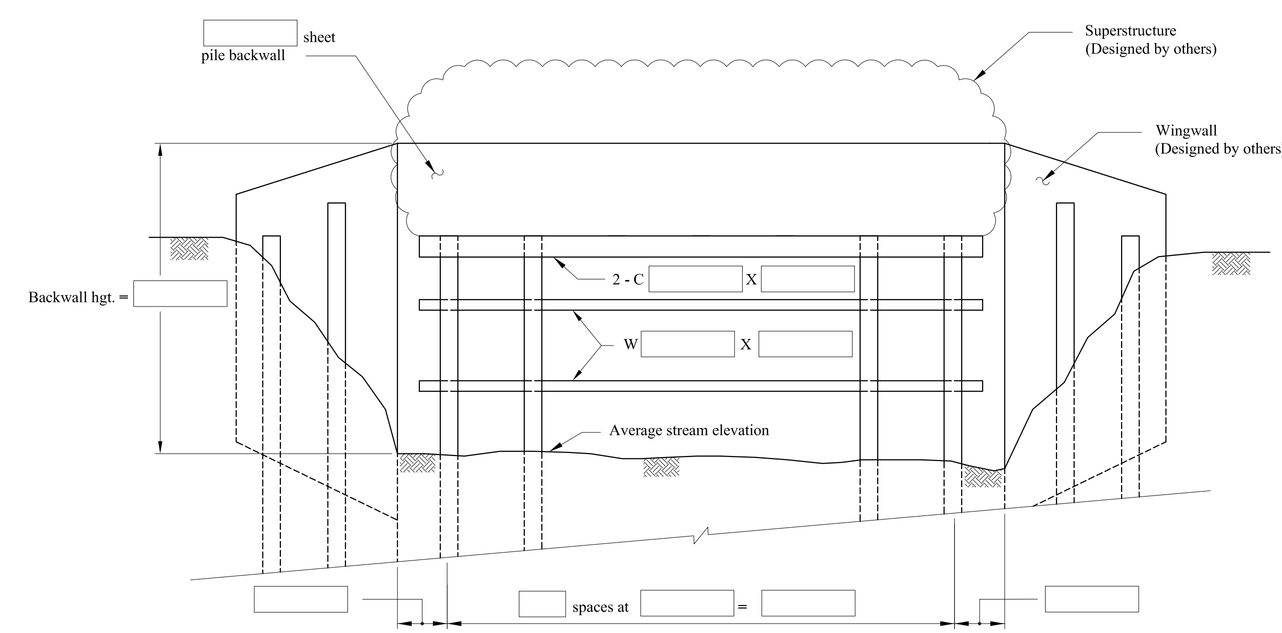
U4



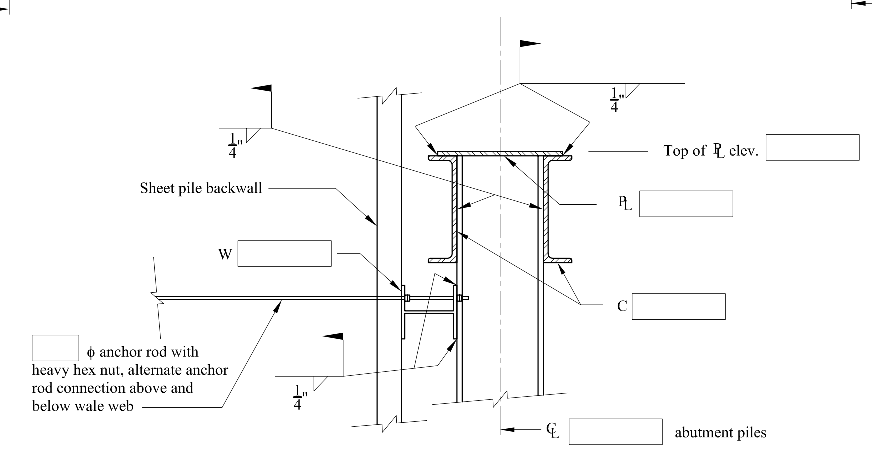
HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

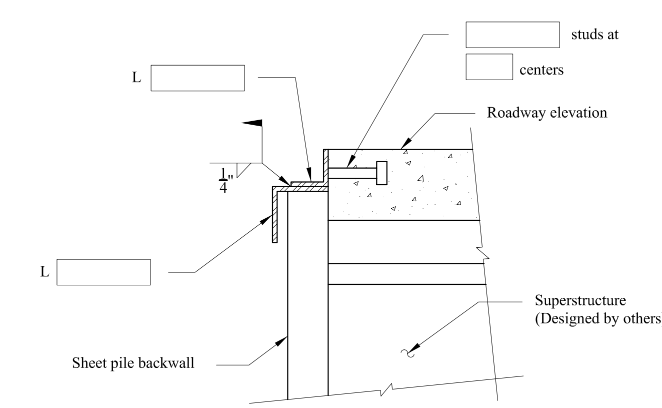
PLAN VIEW



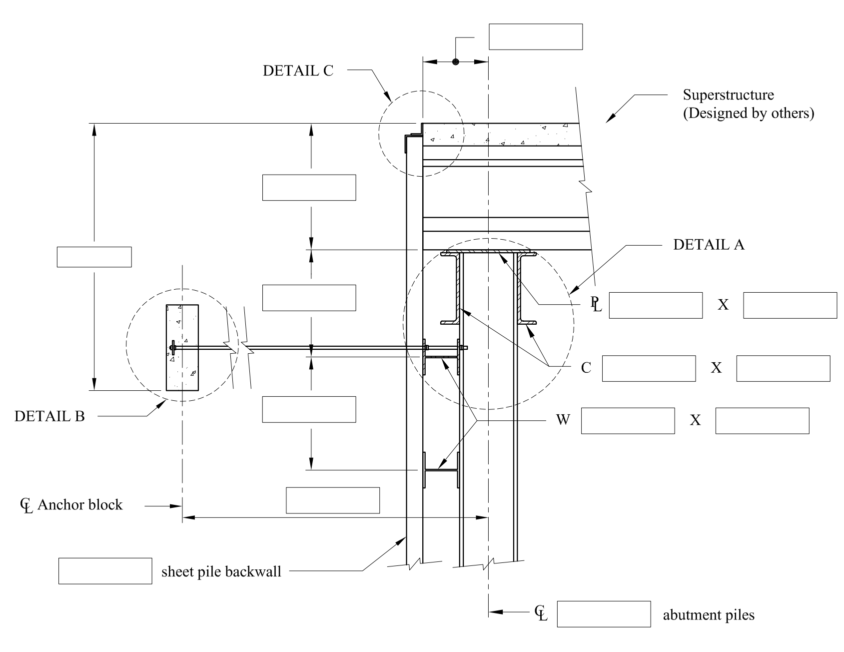
CROSS SECTION NEAR ABUTMENT



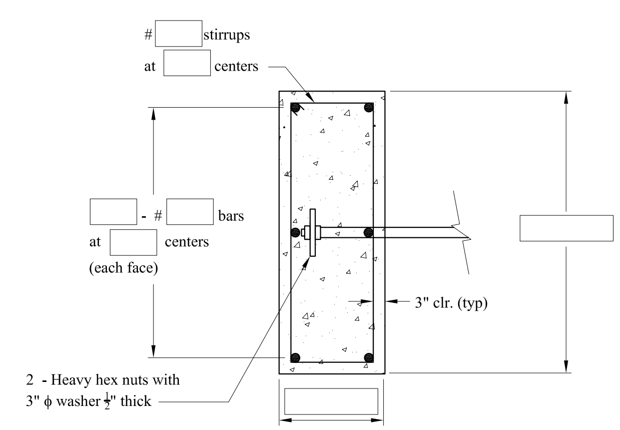
DETAIL A: PILE CAP AND WALE WELDING DETAILS



DETAIL C: SHEET PILE BACKWALL CAP AND CONNECTION DETAILS



Section A-A: ABUTMENT SECTION



DETAIL B: ANCHOR BLOCK DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______.

The superstructure bearings are located at an elevation of ______.

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______.

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

STEEL PILES WITH ANCHORS, STEEL CHANNEL PILE CAP, AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

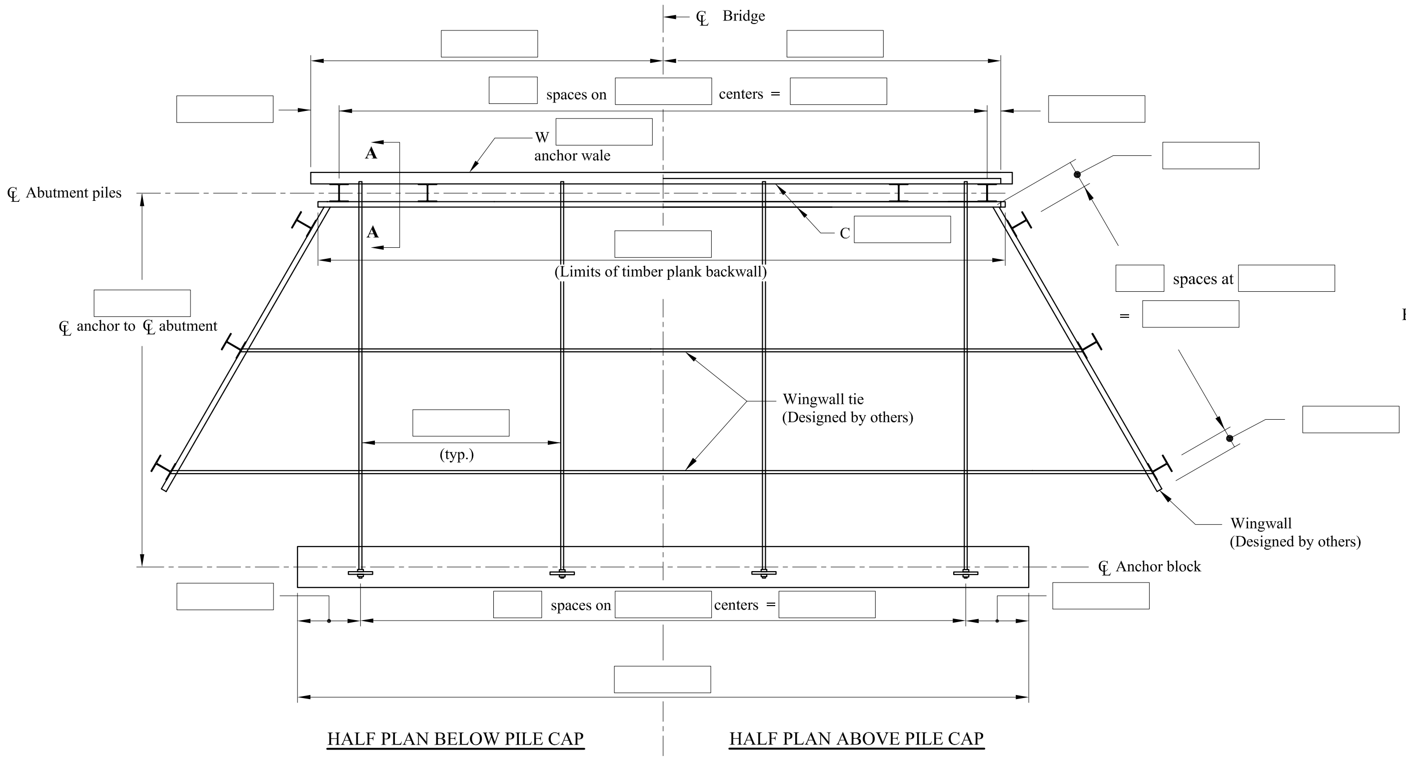
CHECKED BY:

SCALE:

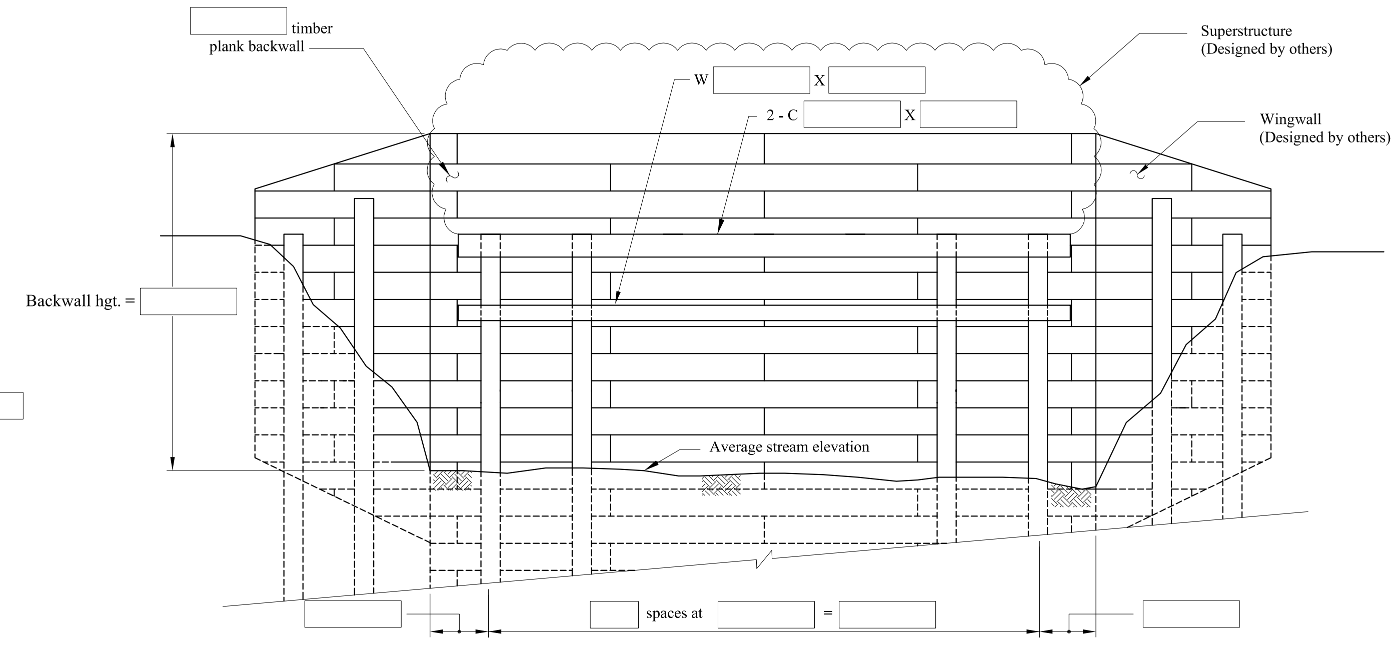
PROJECT NO:

SHEET NO:

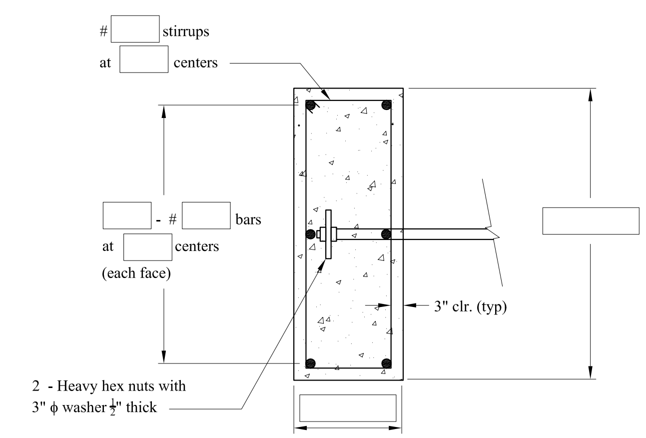
U5



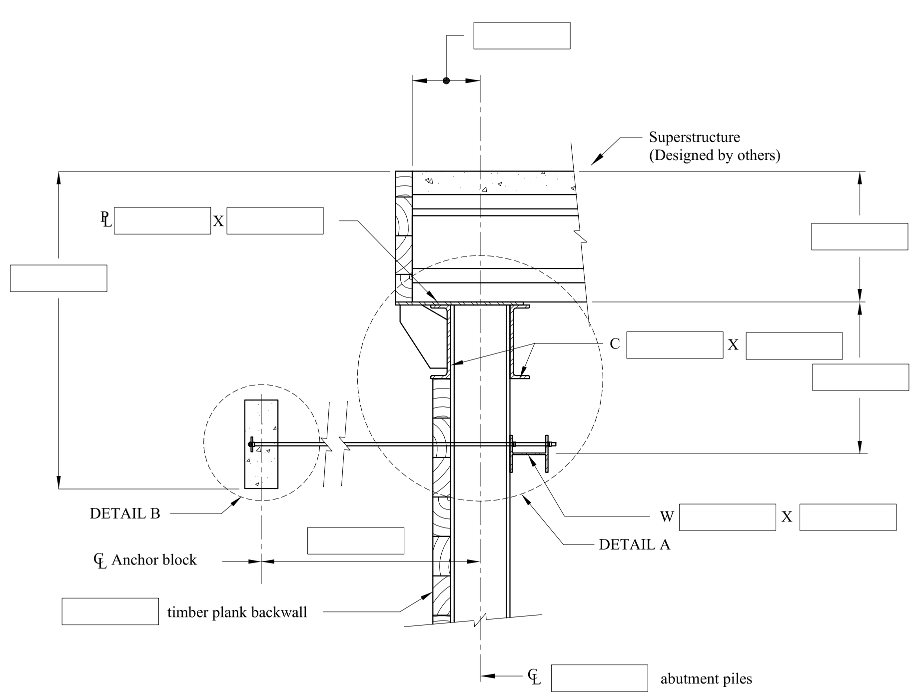
PLAN VIEW



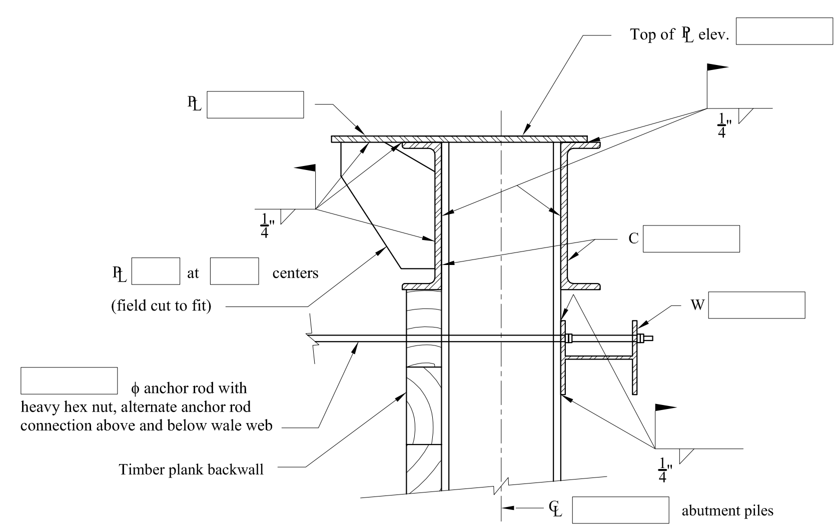
CROSS SECTION NEAR ABUTMENT



DETAIL B: CONCRETE ANCHOR DETAILS



Section A-A: ABUTMENT SECTION



DETAIL A: PILE CAP AND WALE WELDING DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

All timber shall be creosote treated.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

STEEL PILES WITH ANCHORS, STEEL CHANNEL PILE CAP, AND TIMBER PLANK BACKWALL

DATE:

DRAWN BY:

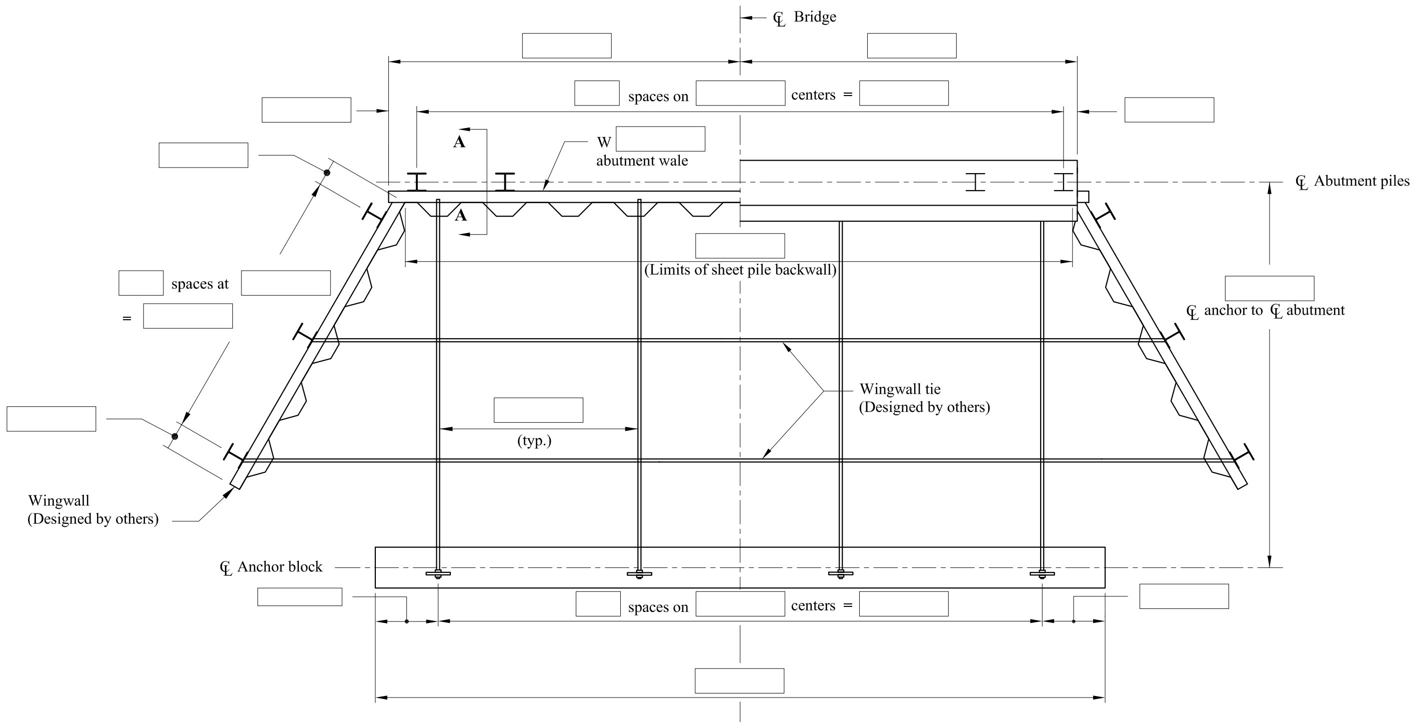
CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

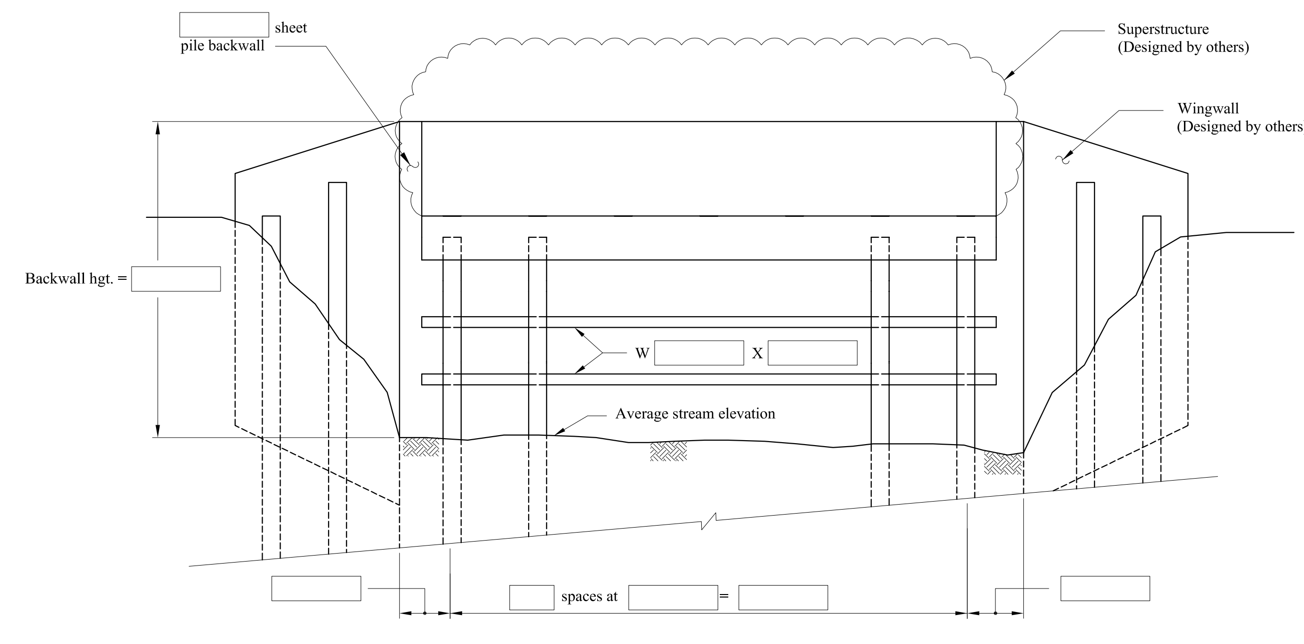
U6



HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

PLAN VIEW



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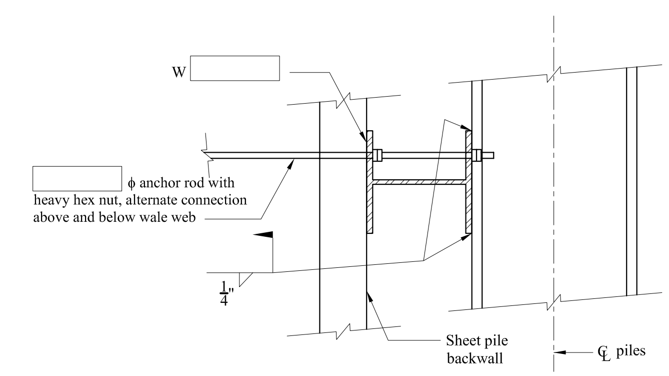
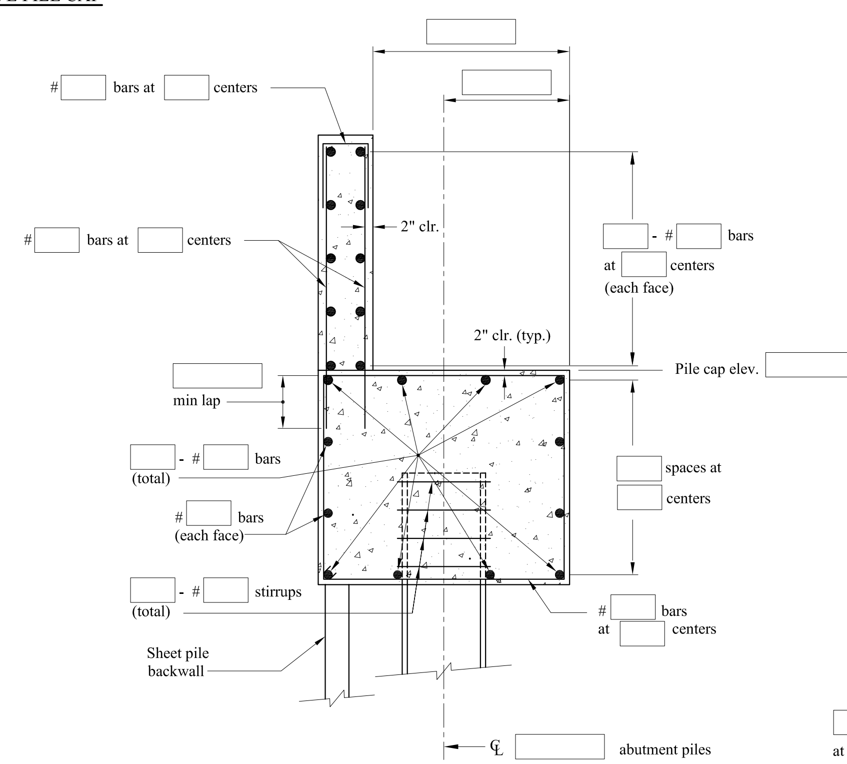
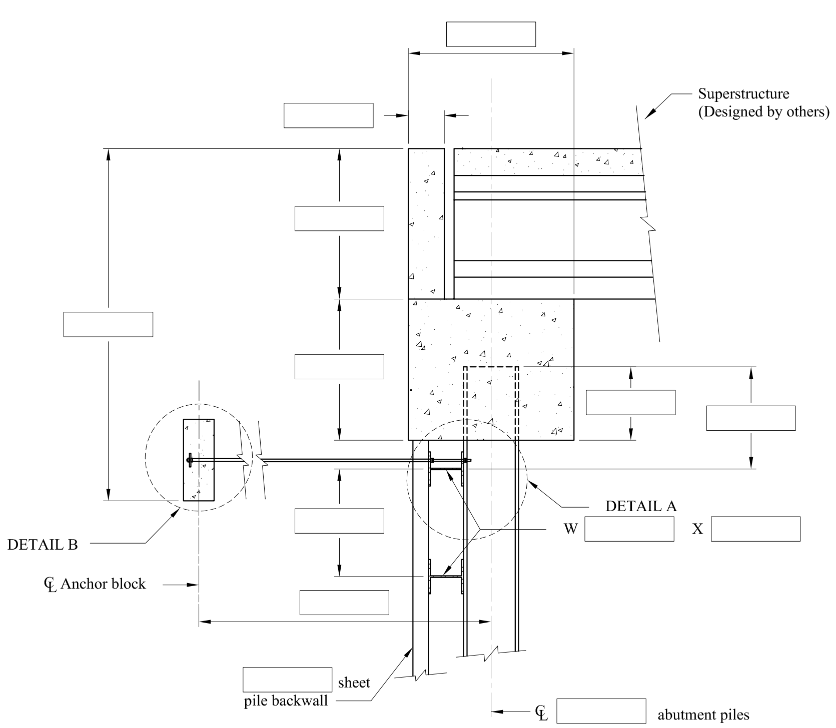


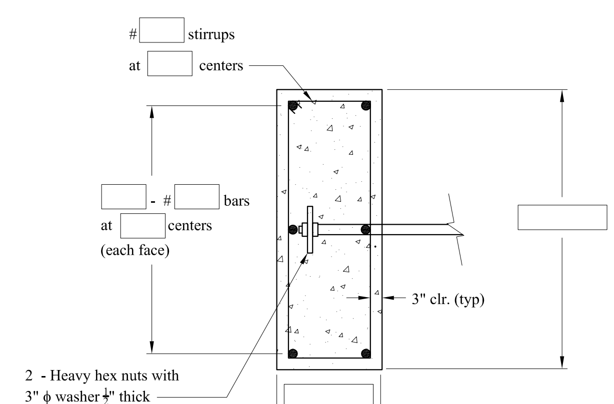
DETAIL A: WALE WELDING DETAILS



PILE CAP DETAILS



Section A-A: ABUTMENT SECTION



DETAIL B: ANCHOR BLOCK DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ____ and ____ abutments.

All piling shall be driven to practical refusal but not less than ____ ton bearing.

The piling shall be cut off at an elevation of ____ .

The superstructure bearings are located at an elevation of ____ .

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ____ .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

STEEL PILES WITH ANCHORS, CONCRETE PILE CAP, AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

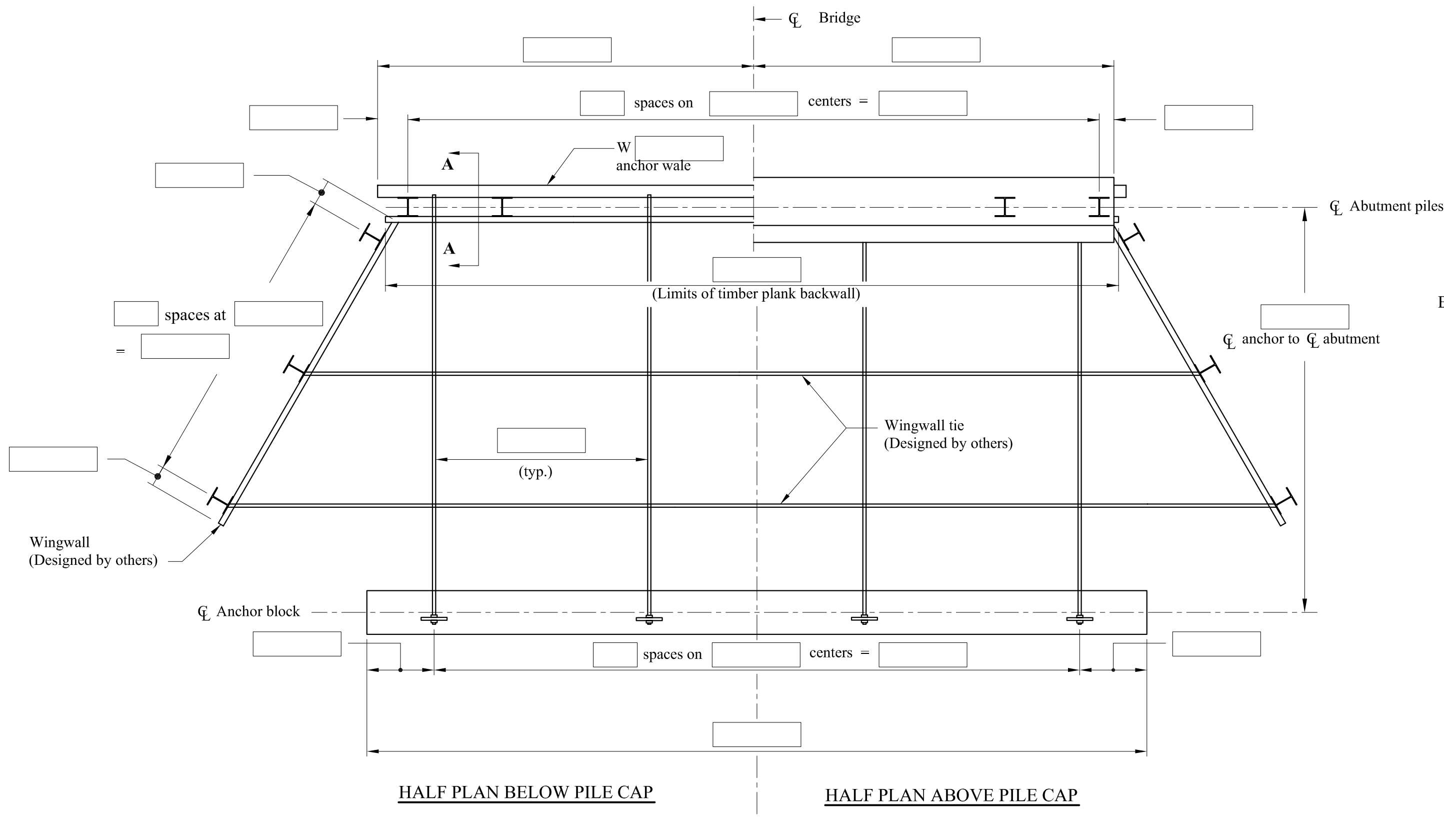
CHECKED BY:

SCALE:

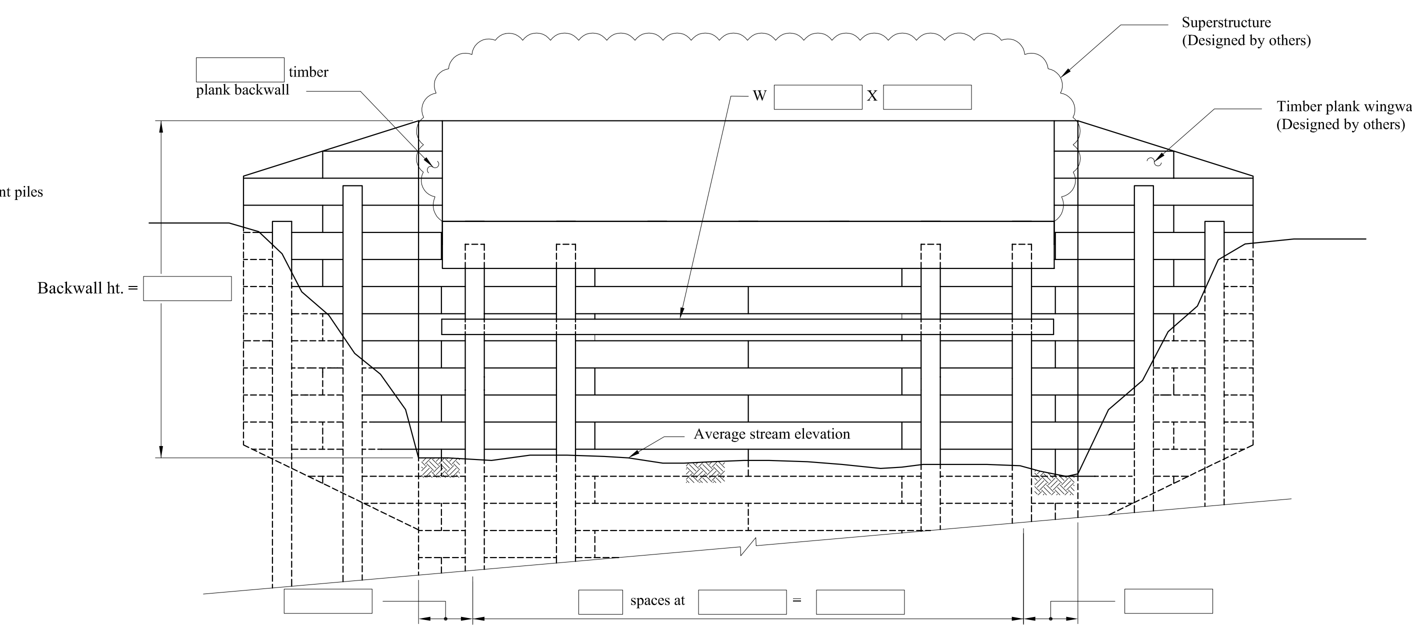
PROJECT NO:

SHEET NO:

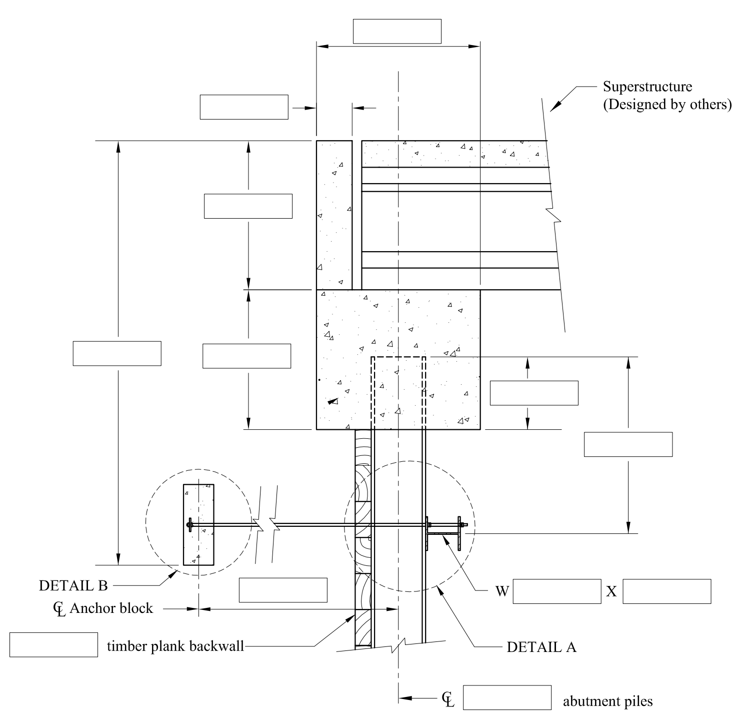
U7



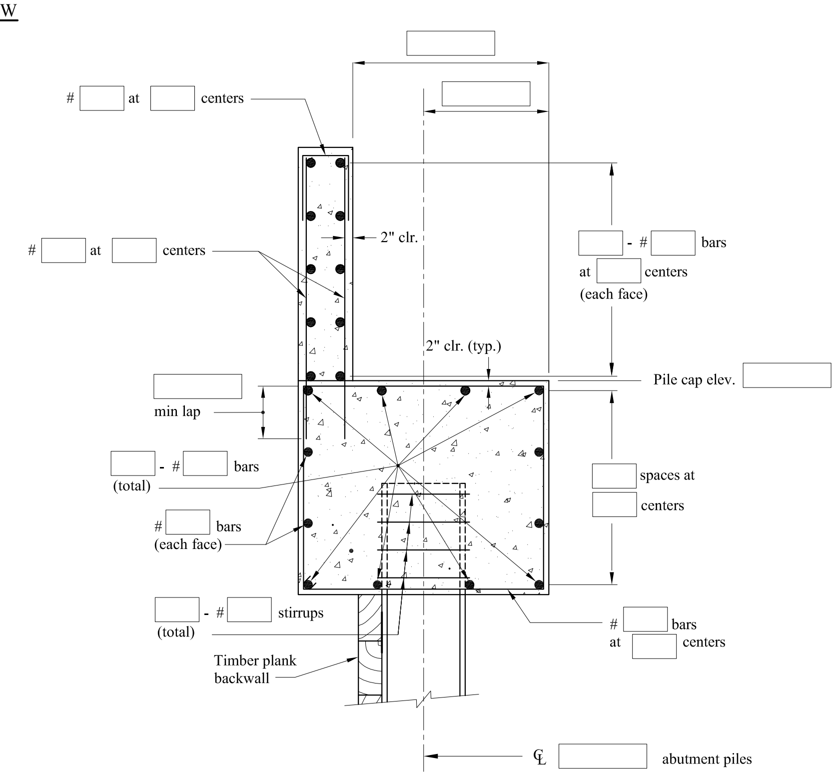
PLAN VIEW



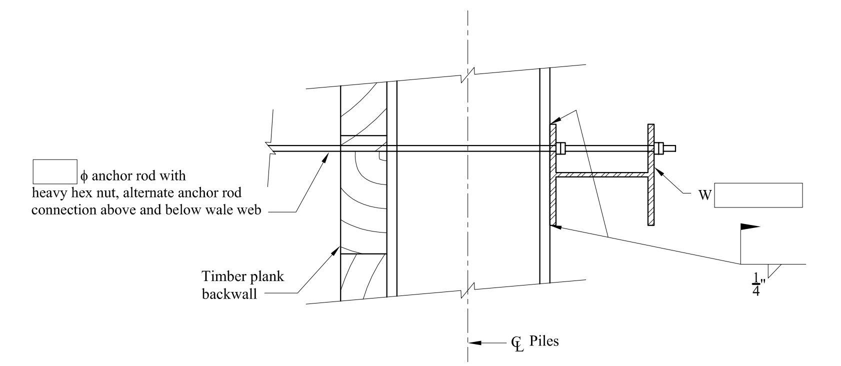
CROSS SECTION NEAR ABUTMENT



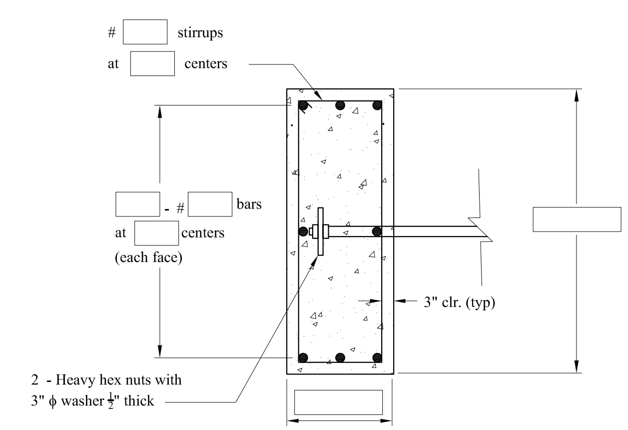
Section A-A
ABUTMENT SECTION



PILE CAP DETAILS



DETAIL A: WALE WELDING DETAILS



DETAIL B: ANCHOR BLOCK DETAILS

In this abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

All timber shall be creosote treated.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______.

The superstructure bearings are located at an elevation of ______.

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______.

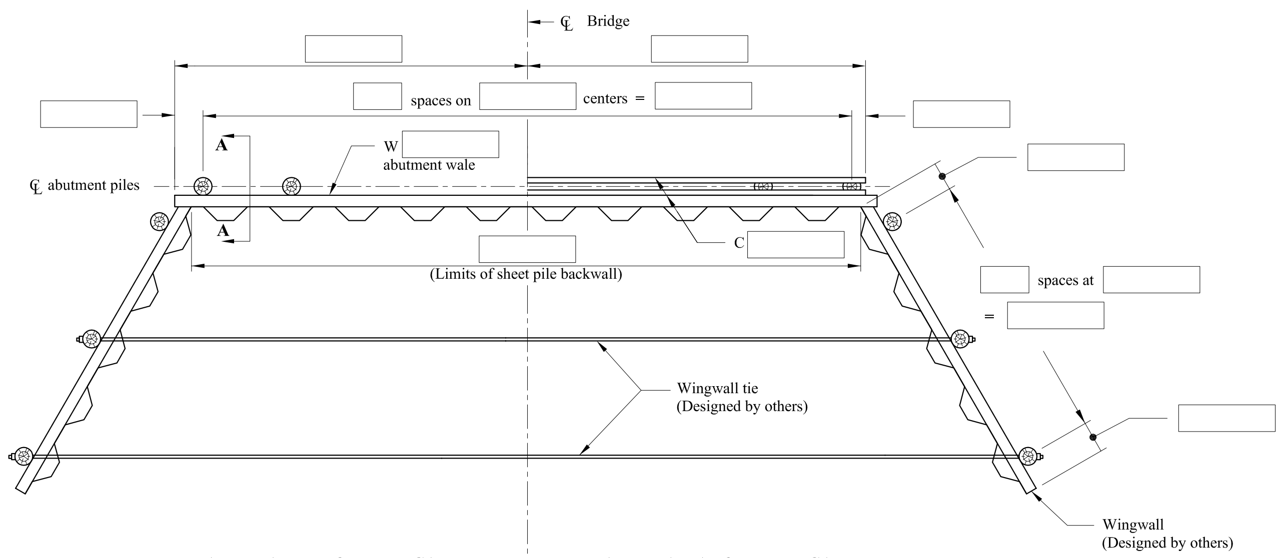
Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS
STEEL PILES WITH ANCHORS, CONCRETE PILE CAP, AND TIMBER PLANK BACKWALL

DATE:
DRAWN BY:
CHECKED BY:
SCALE:
PROJECT NO:
SHEET NO:

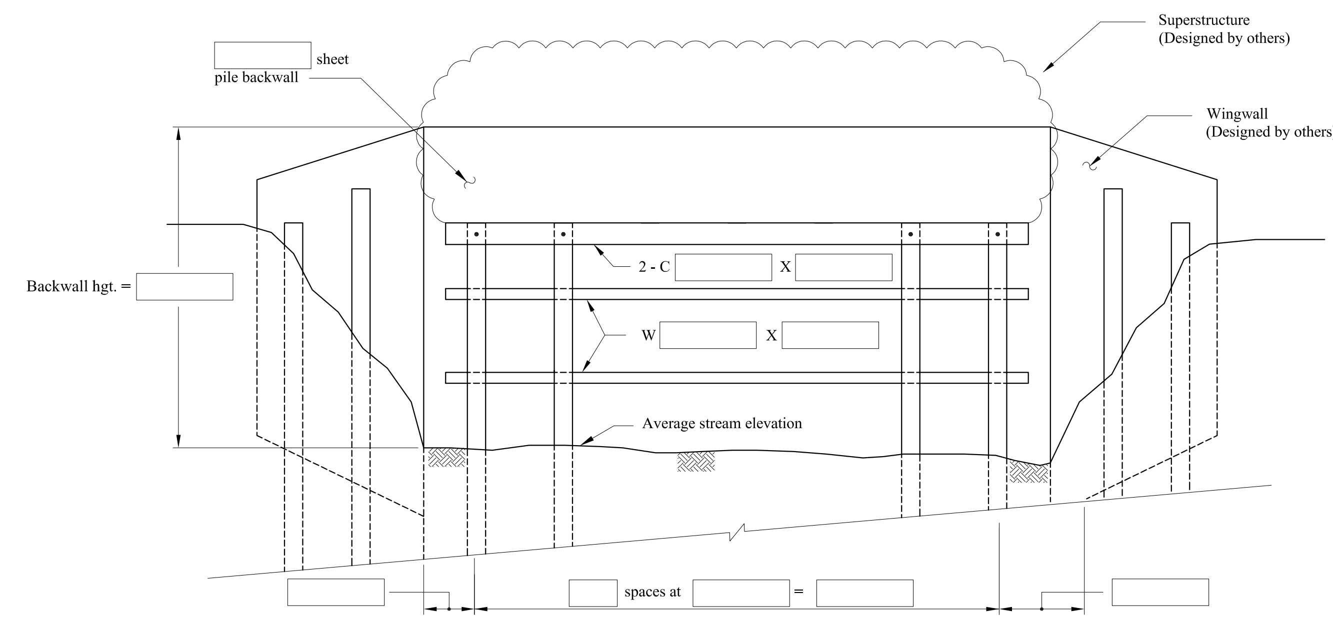
U8



HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

PLAN VIEW



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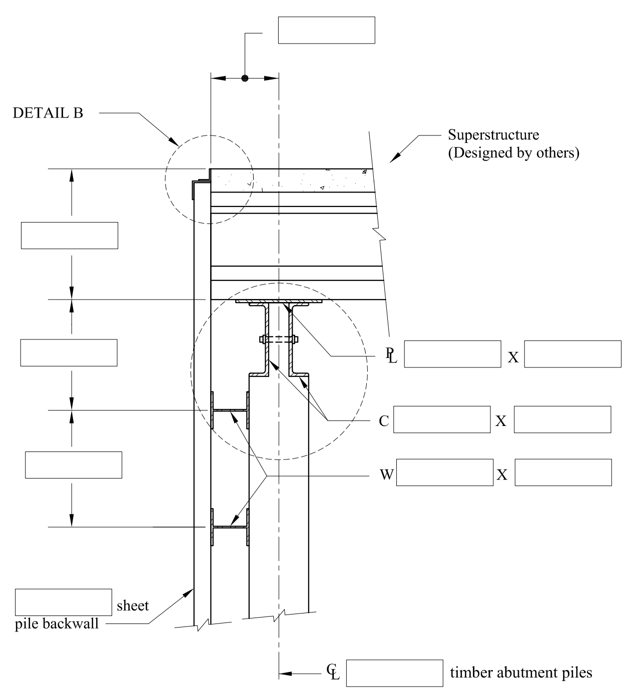
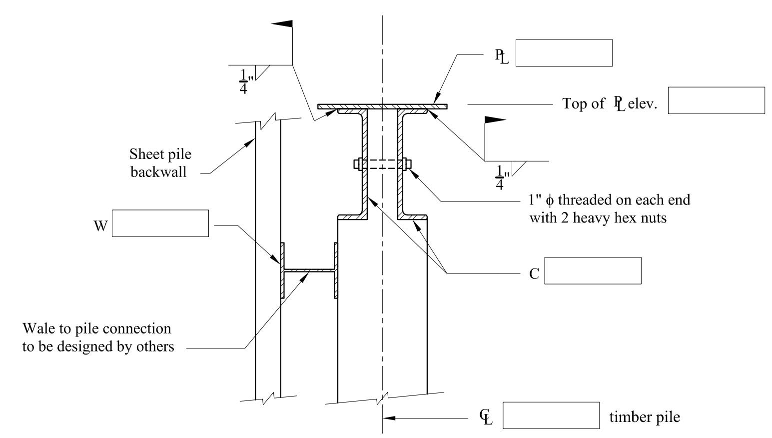
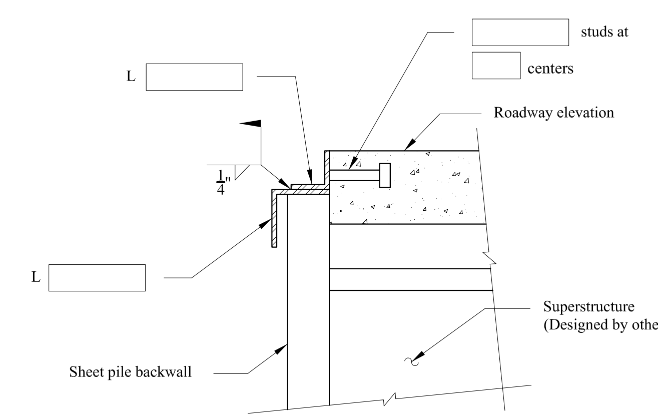


Section A-A: ABUTMENT SECTION



DETAIL A: PILE CAP AND WALE CONNECTION DETAILS



DETAIL B: SHEET PILE BACKWALL CAP AND CONNECTION DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH STEEL CHANNEL PILE CAP AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

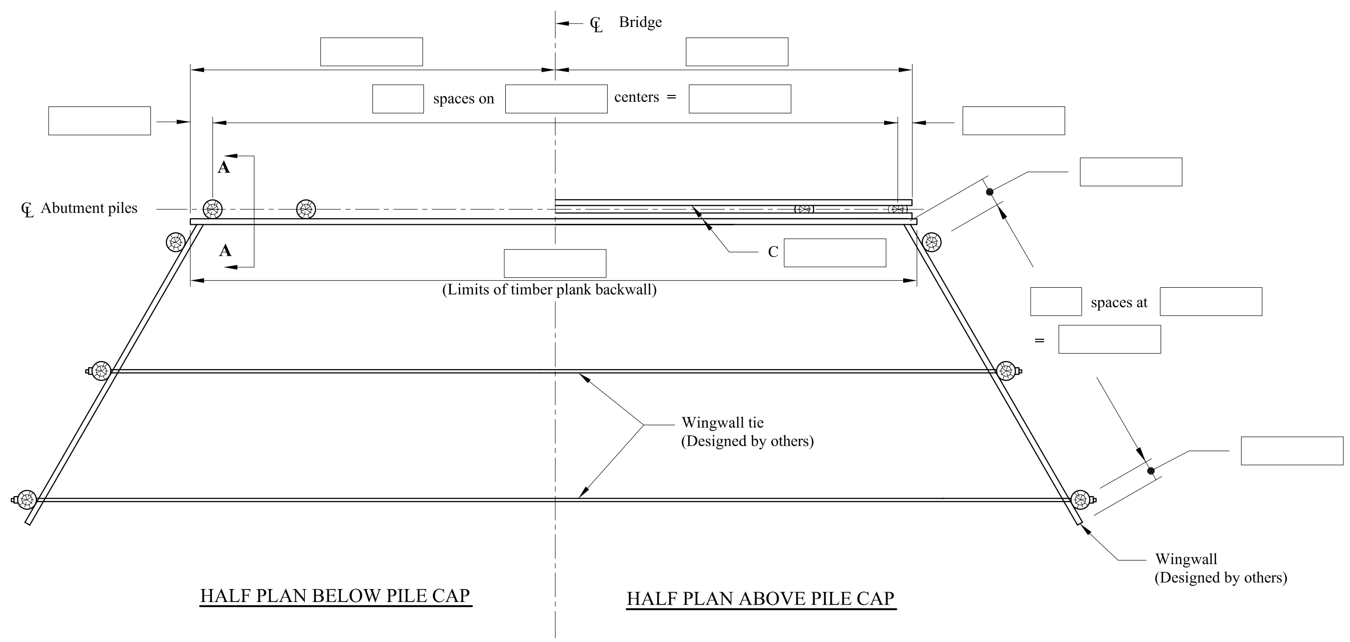
CHECKED BY:

SCALE:

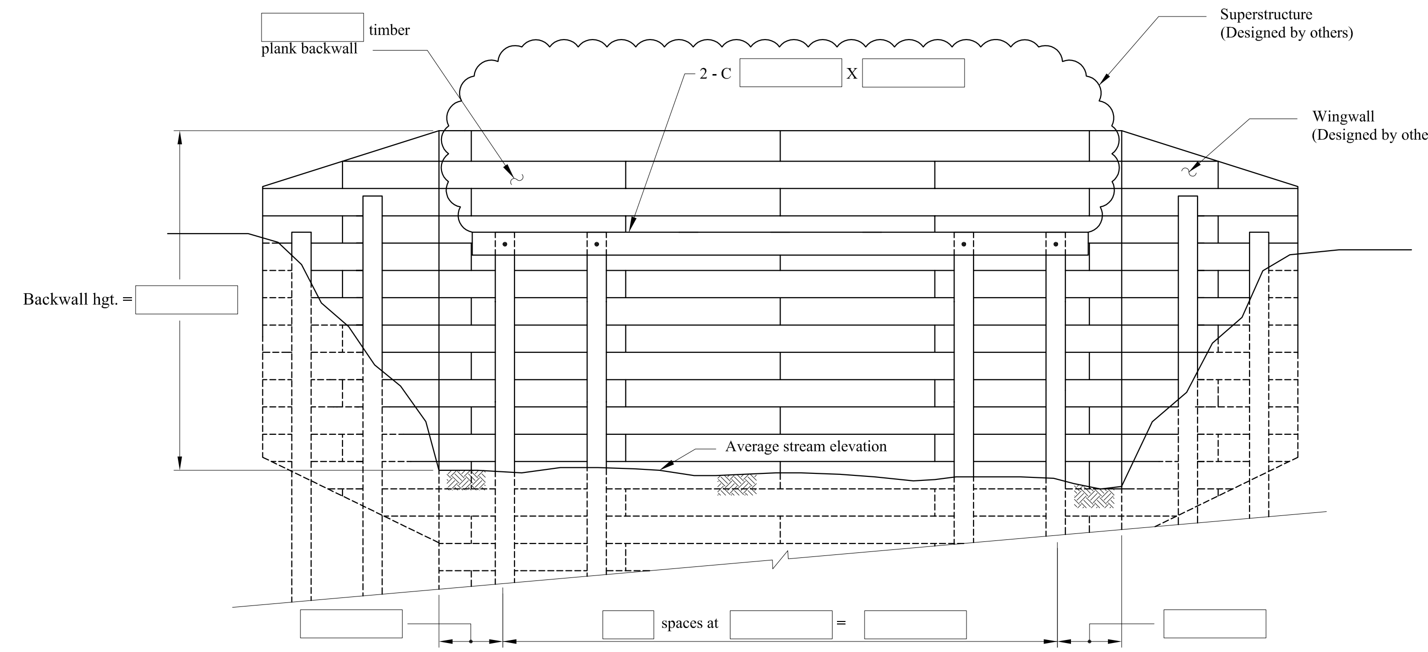
PROJECT NO:

SHEET NO:

U9



PLAN VIEW



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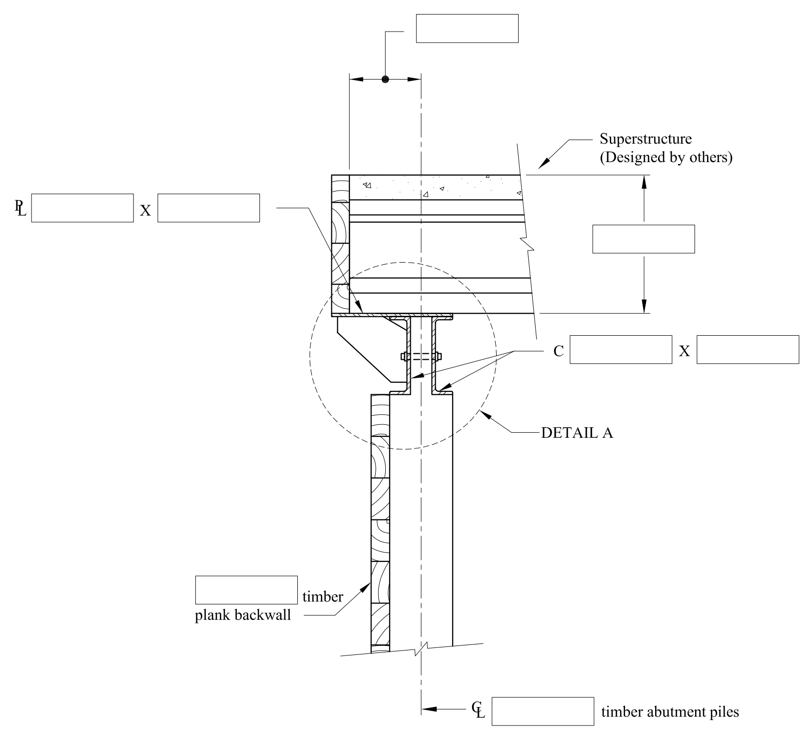
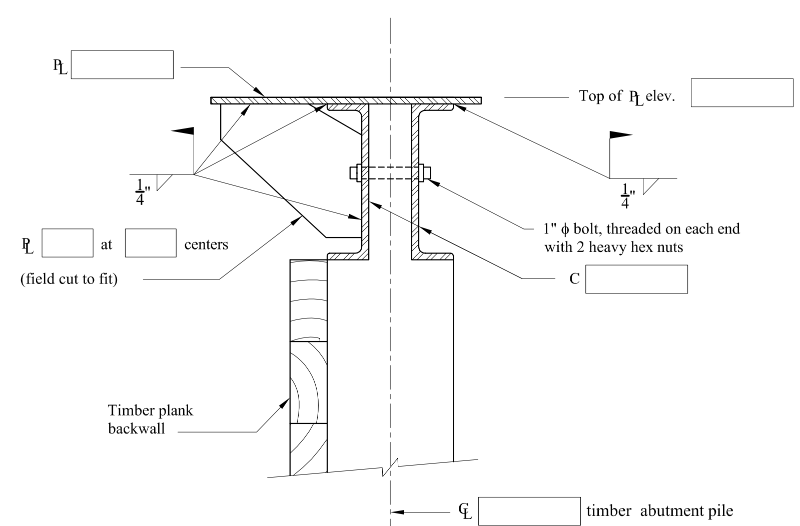


Section A-A: ABUTMENT SECTION



DETAIL A: PILE CAP CONNECTION DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH STEEL CHANNEL PILE CAP AND TIMBER PLANK BACKWALL

DATE:

DRAWN BY:

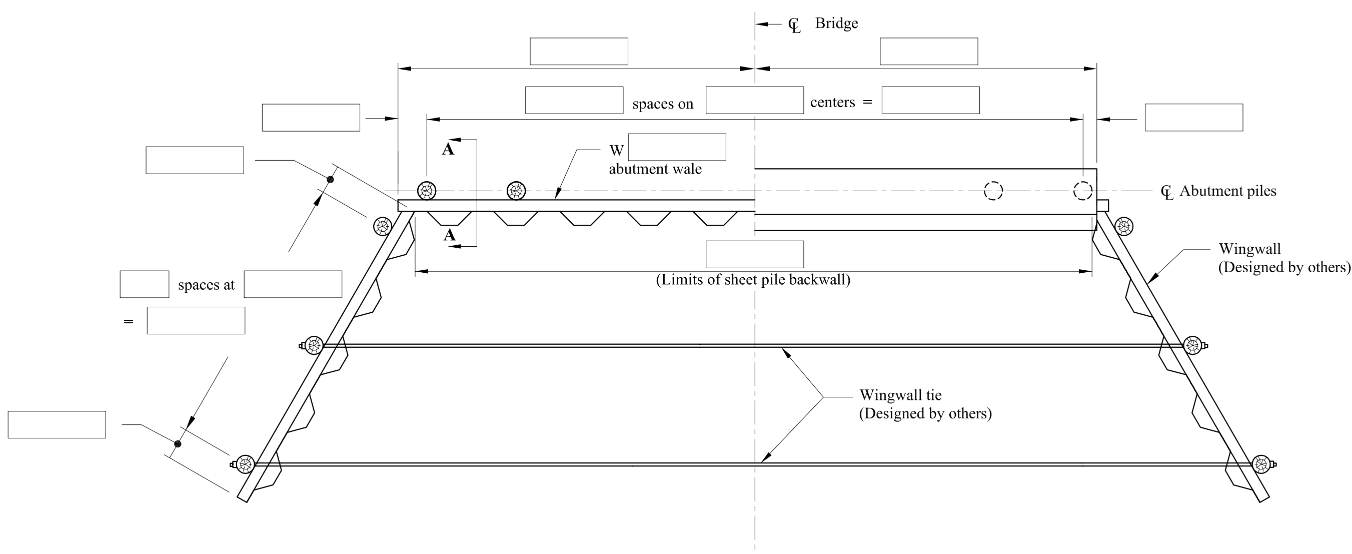
CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

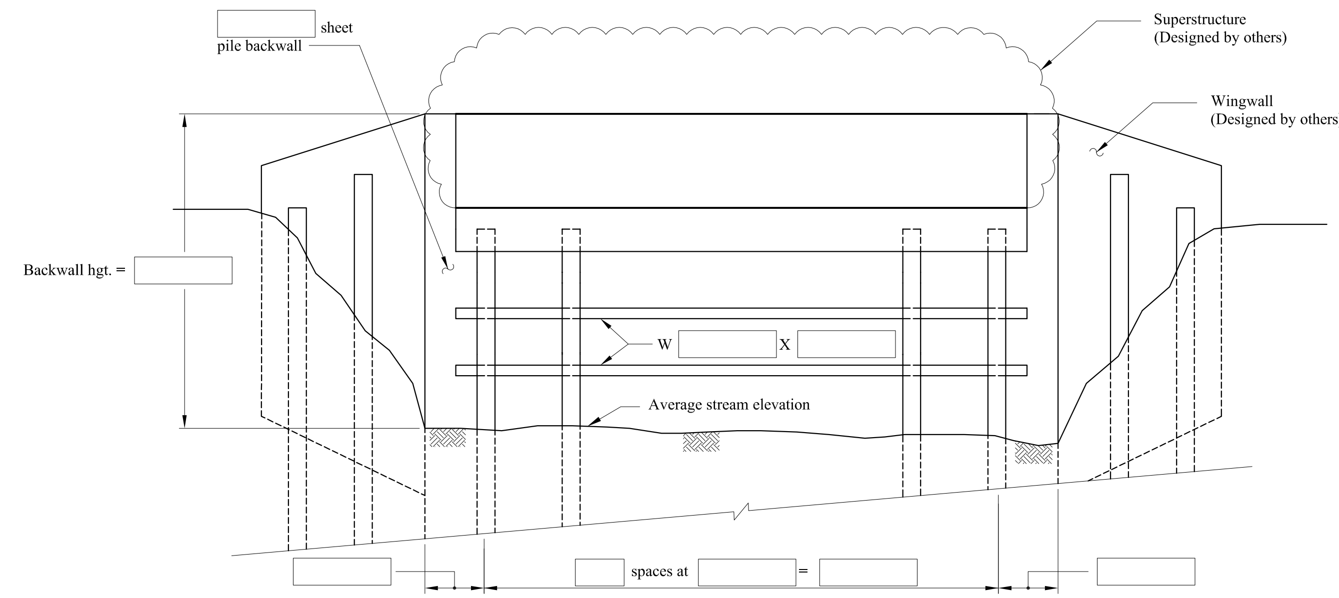
U10



HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

PLAN VIEW



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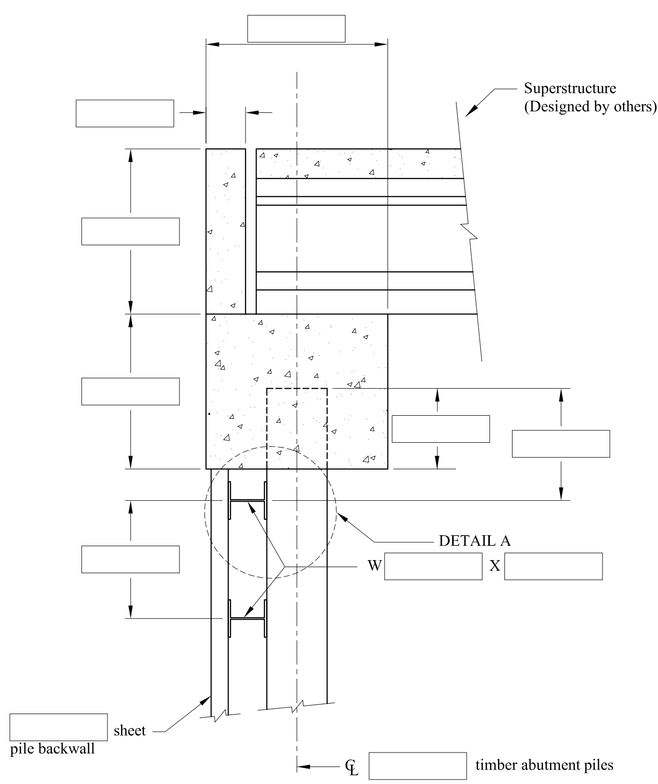
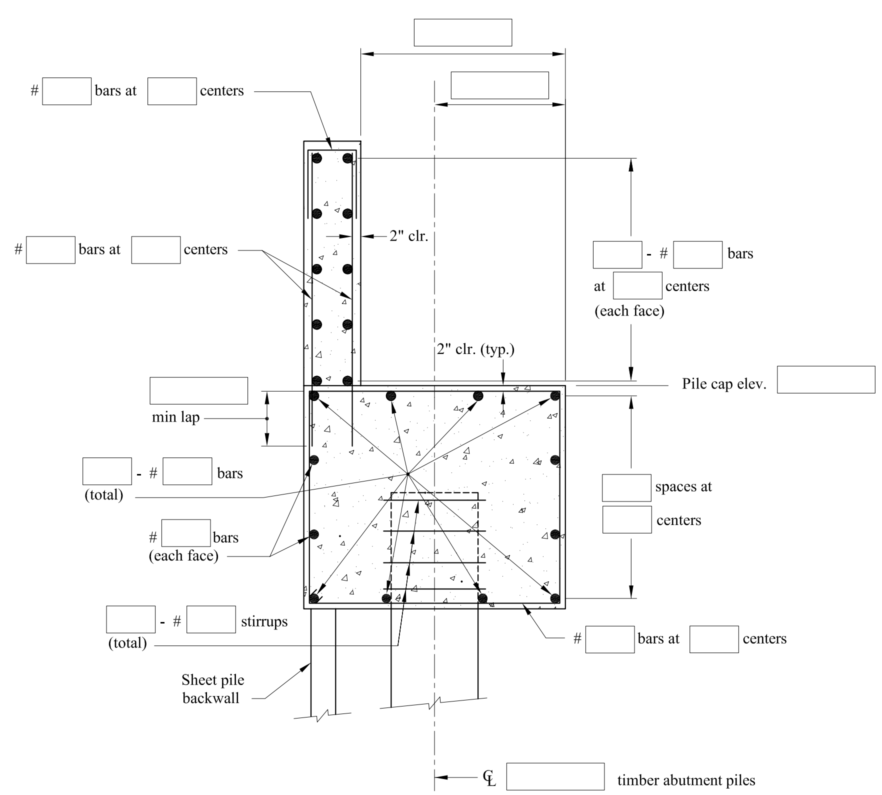
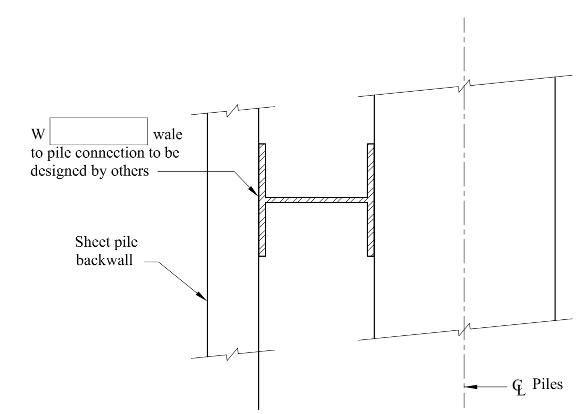


Section A-A: ABUTMENT SECTION



PILE CAP DETAILS



DETAIL A: WALE DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH CONCRETE PILE CAP AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

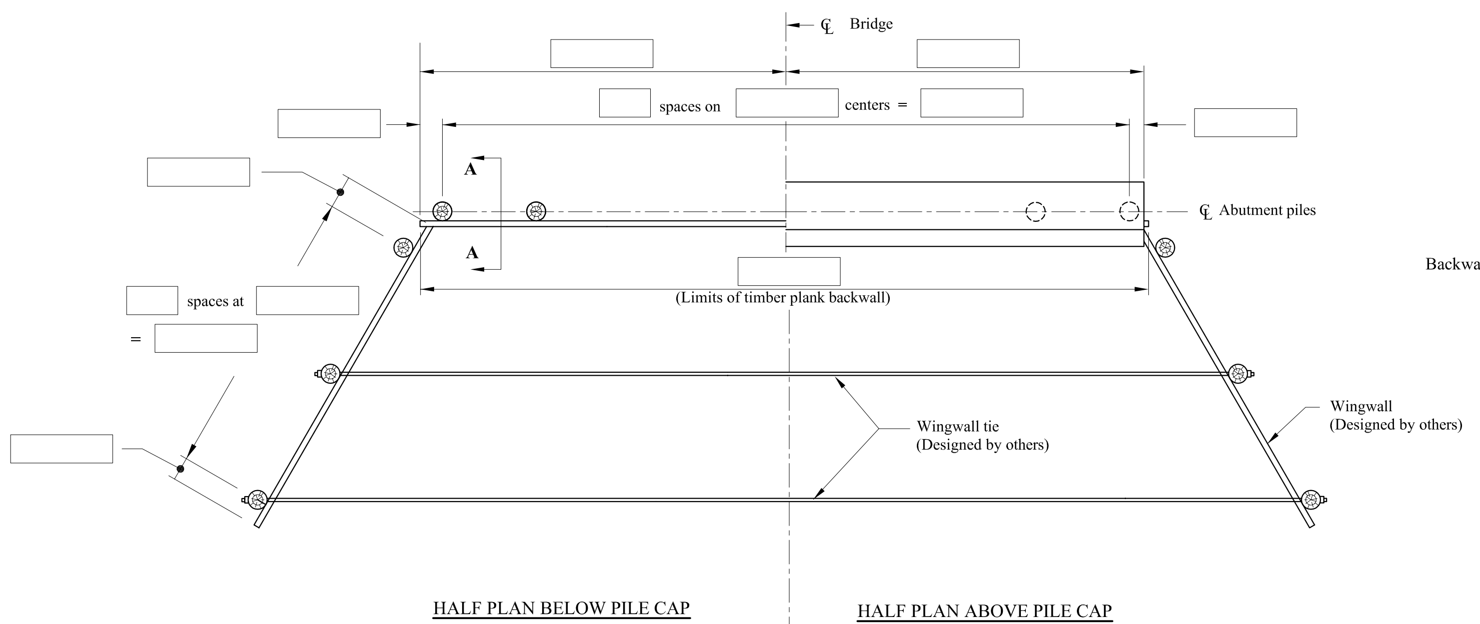
CHECKED BY:

SCALE:

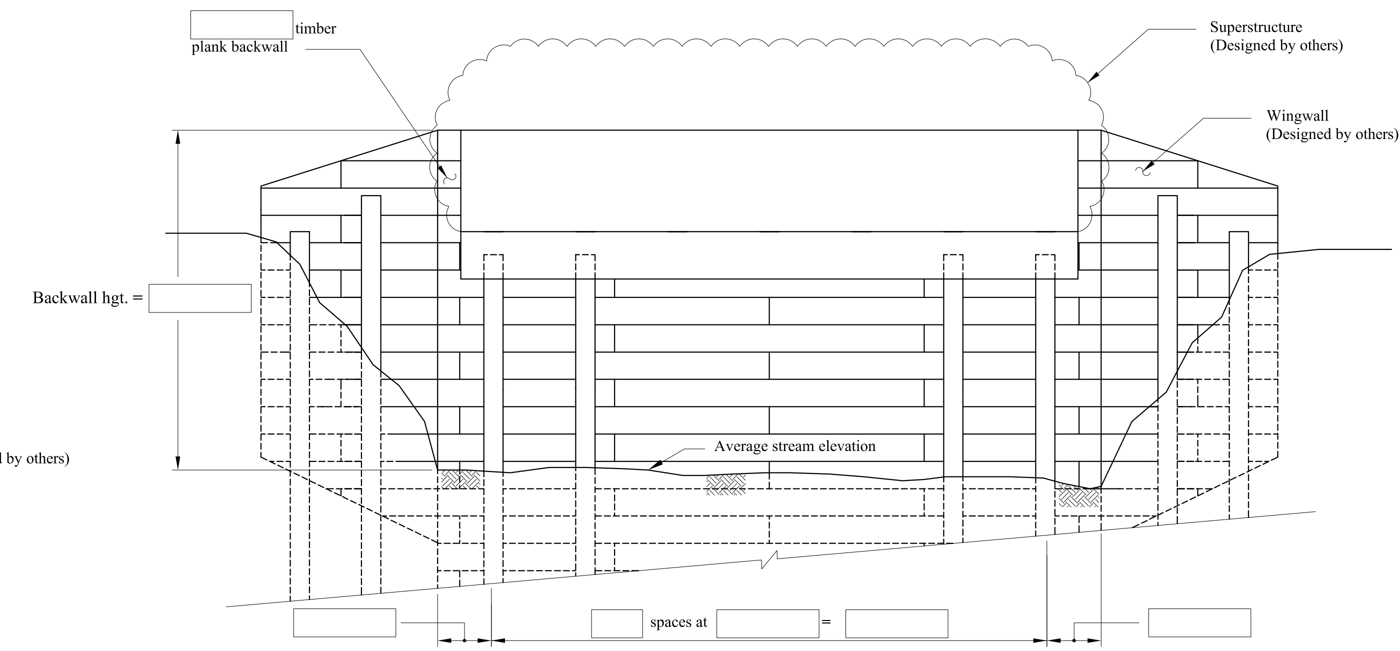
PROJECT NO:

SHEET NO:

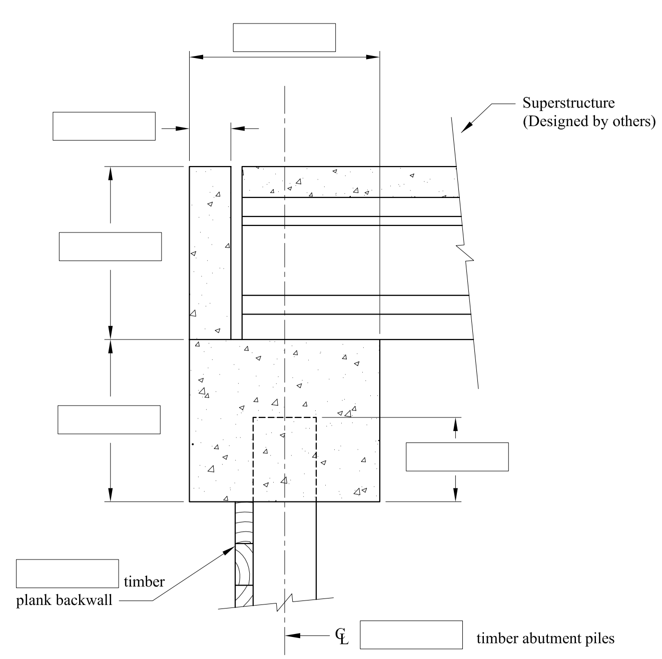
U11



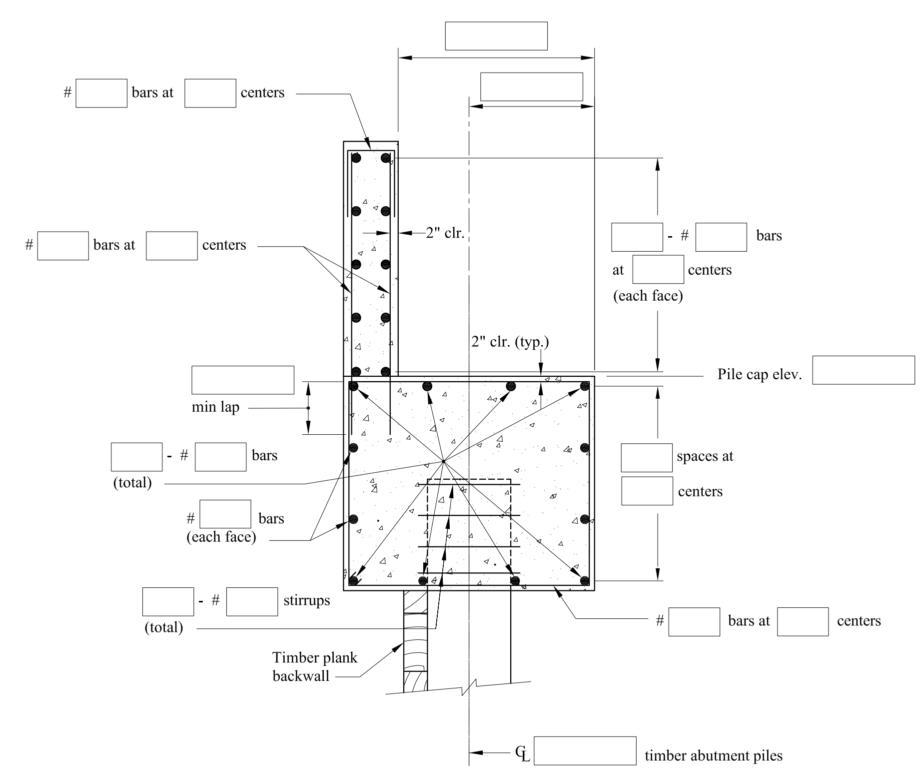
PLAN VIEW



CROSS SECTION NEAR ABUTMENT



Section A-A: ABUTMENT SECTION



PILE CAP DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH CONCRETE PILE CAP AND TIMBER PLANK BACKWALL

DATE:

DRAWN BY:

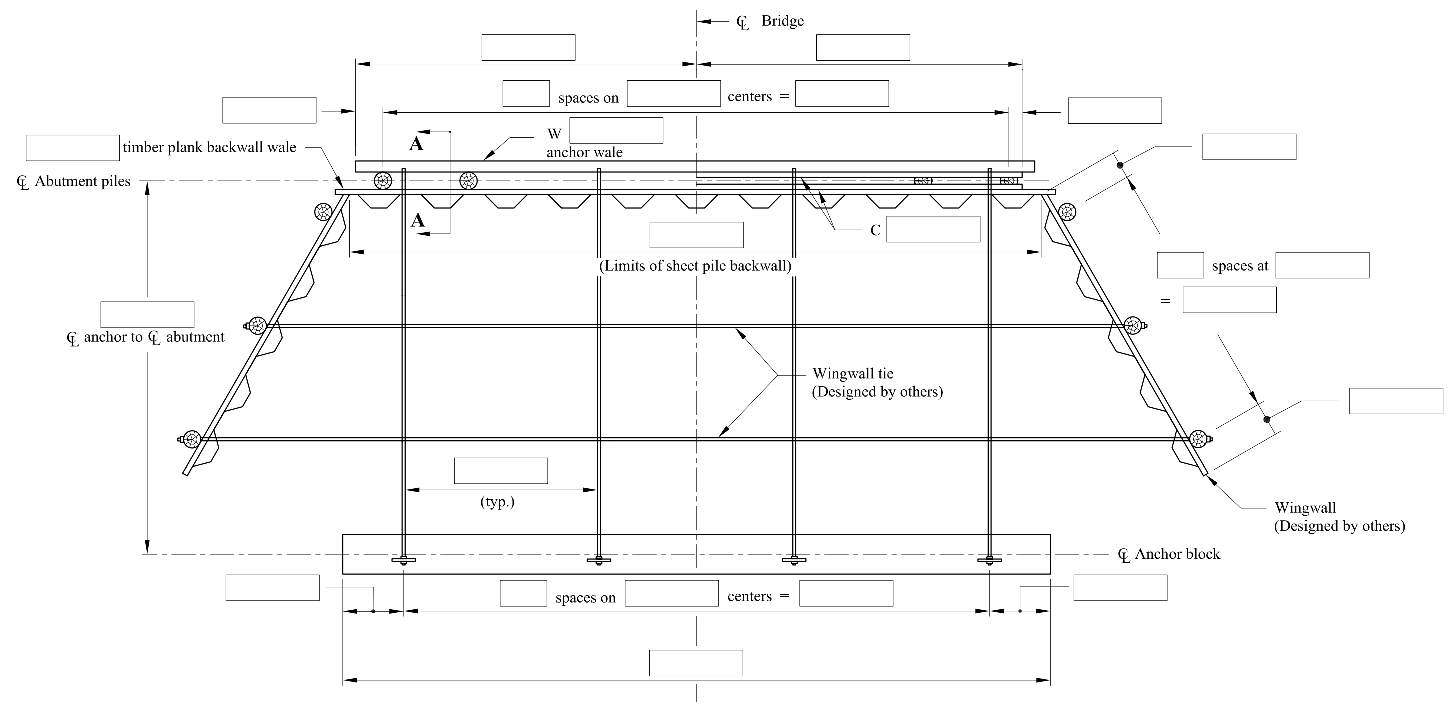
CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

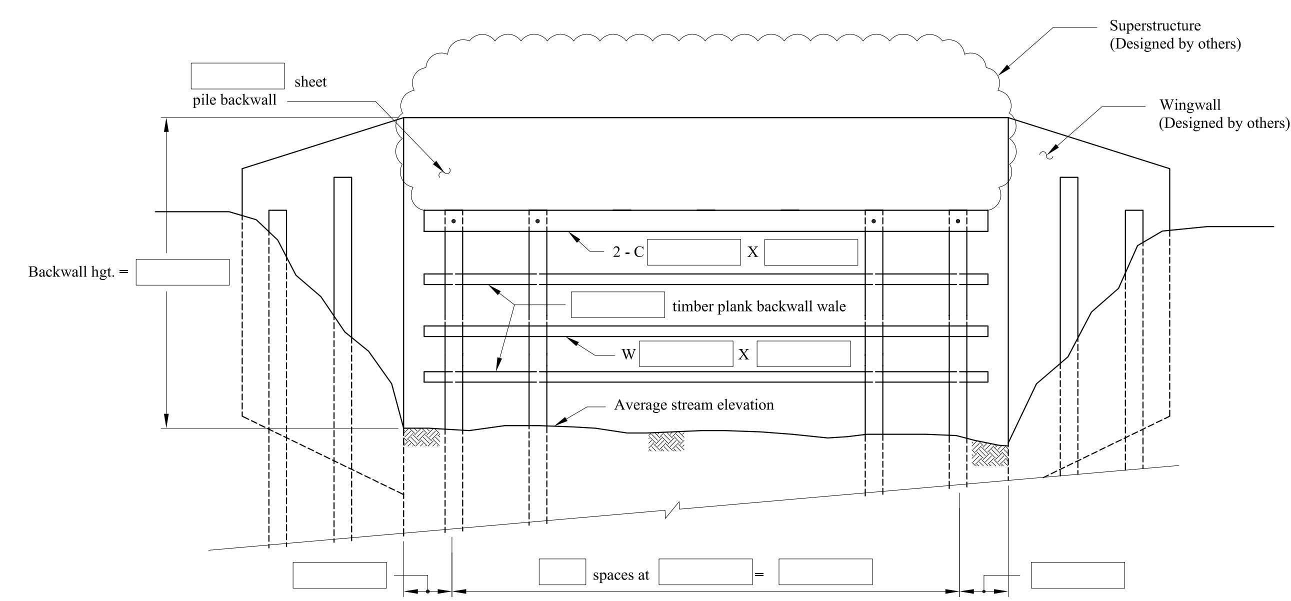
U12



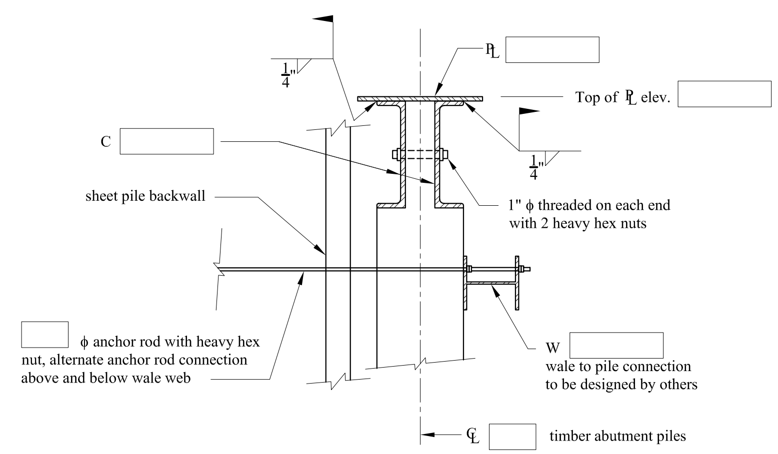
HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

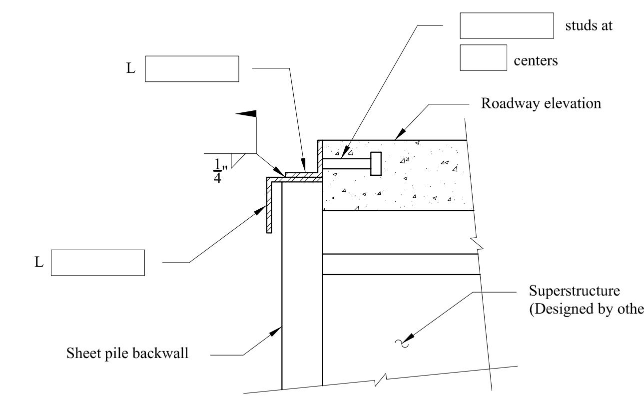
PLAN VIEW



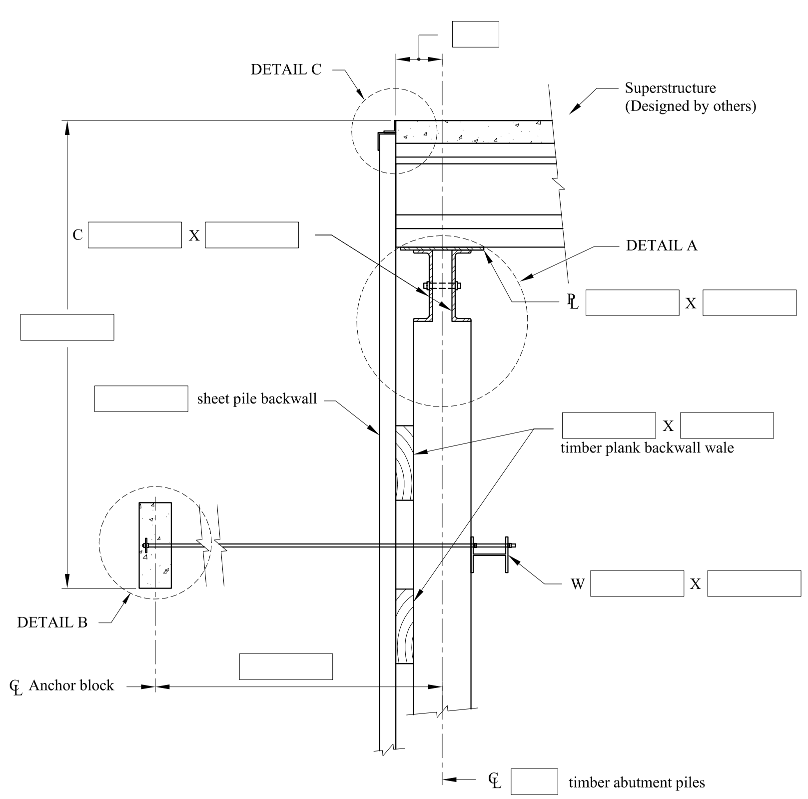
CROSS SECTION NEAR ABUTMENT



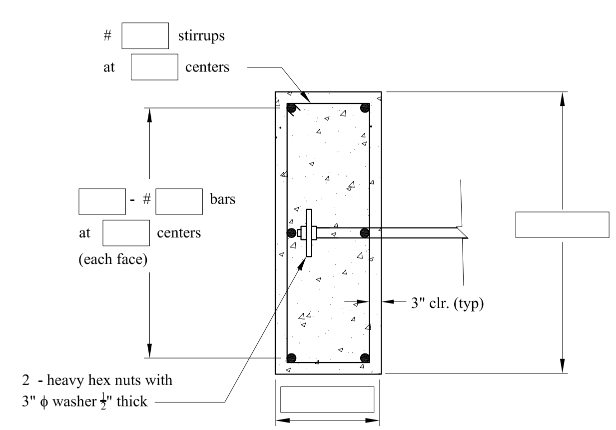
DETAIL A: PILE CAP AND WALE CONNECTION DETAILS



DETAIL C: SHEET PILE BACKWALL CAP AND CONNECTION DETAILS



Section A-A: ABUTMENT SECTION



DETAIL B: ANCHOR BLOCK DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______.

The superstructure bearings are located at an elevation of ______.

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______.

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH ANCHORS, STEEL CHANNEL PILE CAP, AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

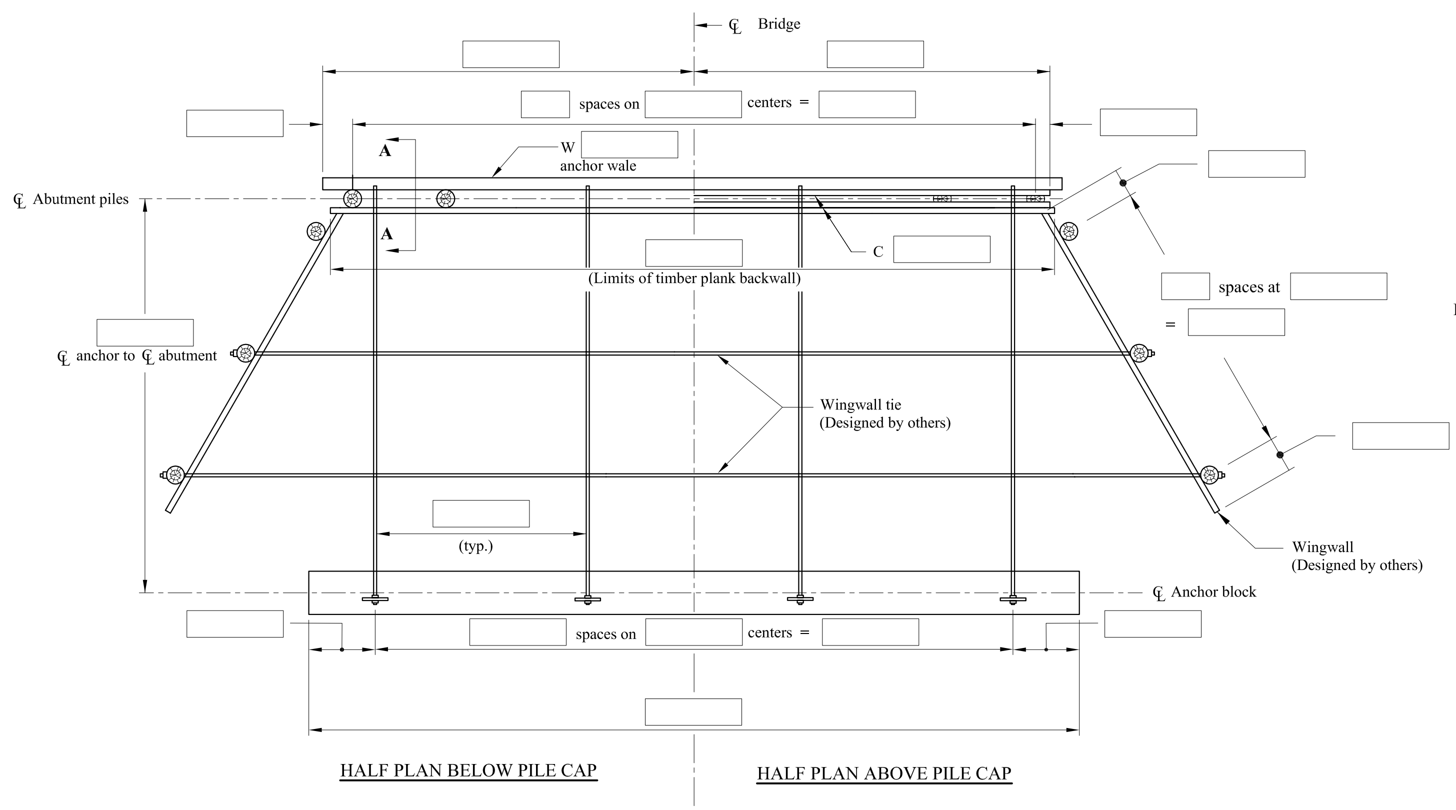
CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

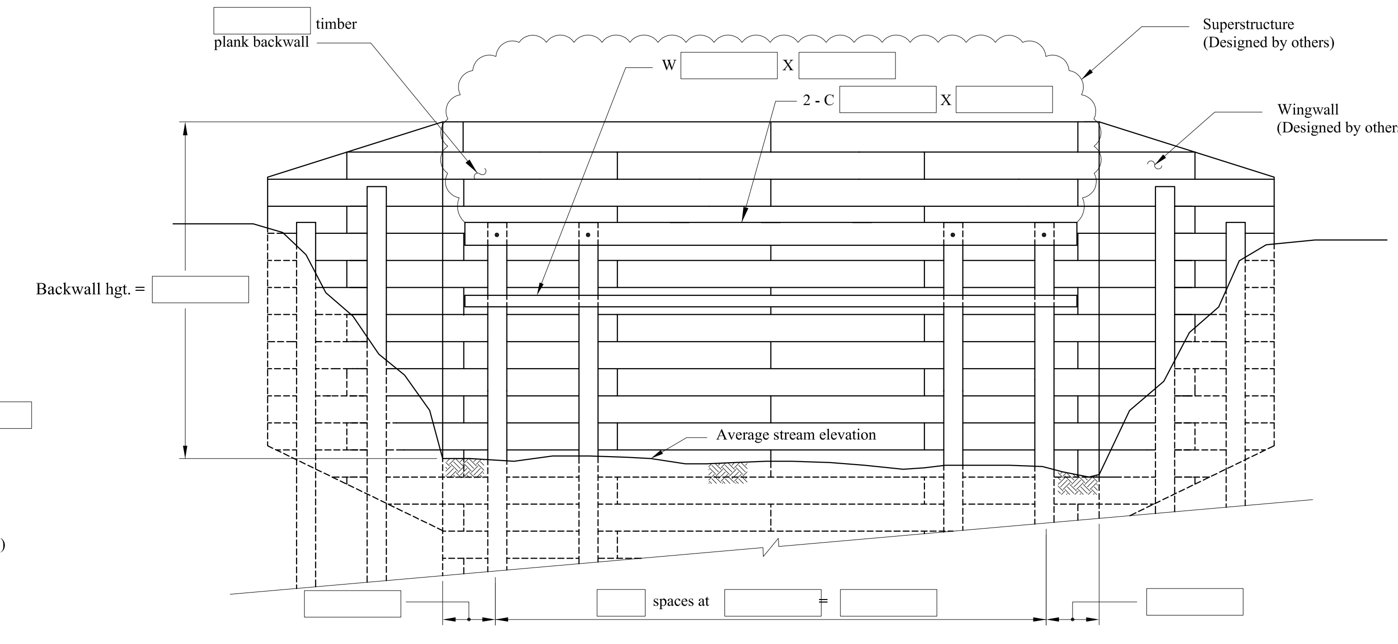
U13



HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

PLAN VIEW



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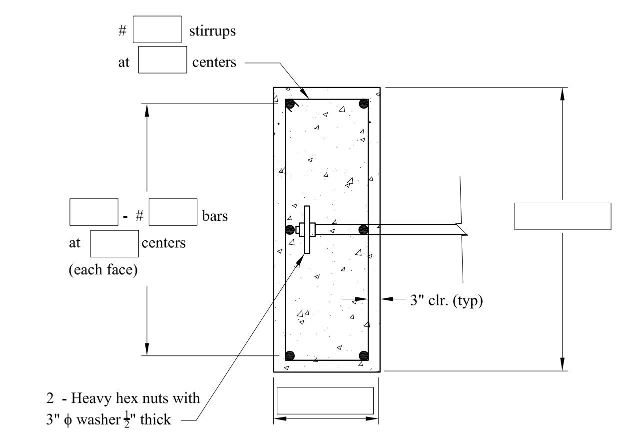
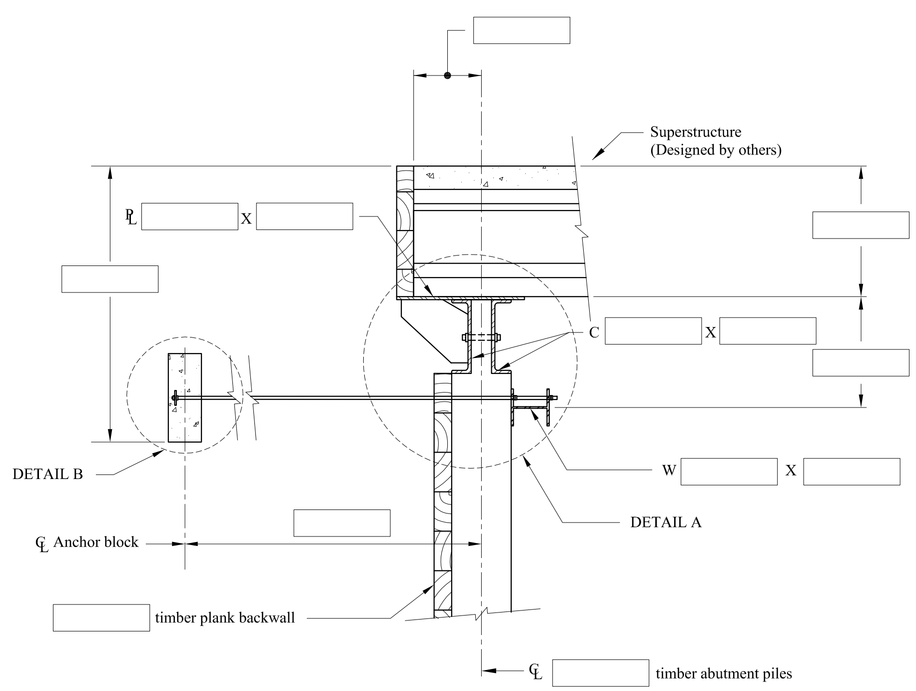
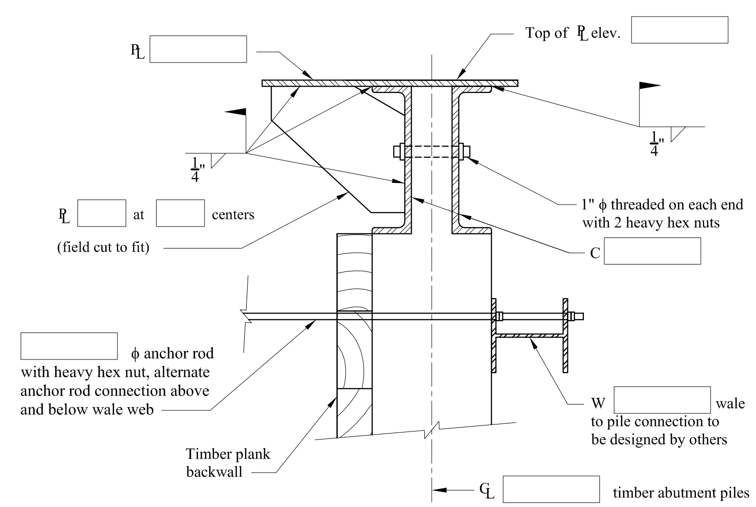


DETAIL B: ANCHOR BLOCK DETAILS



Section A-A: ABUTMENT SECTION



DETAIL A: PILE CAP AND WALE CONNECTION DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH ANCHORS, STEEL CHANNEL PILE CAP, AND TIMBER PLANK BACKWALL

DATE:

DRAWN BY:

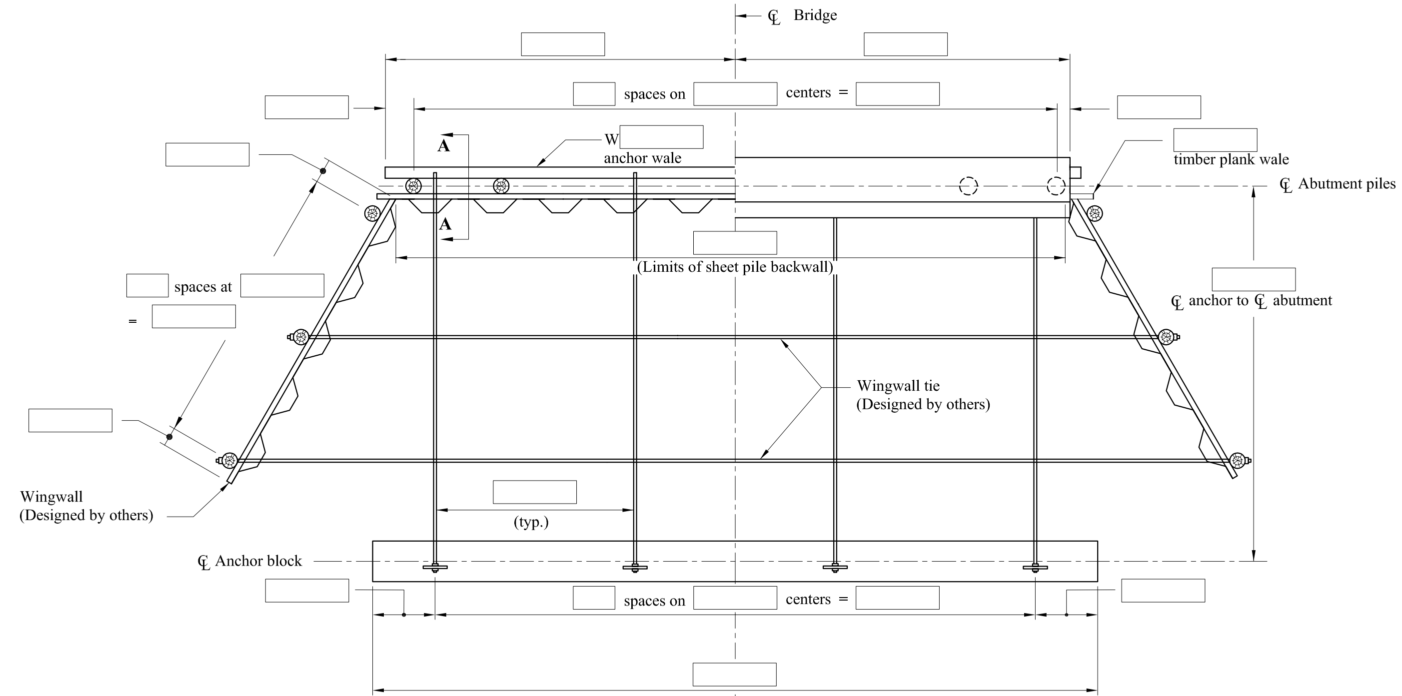
CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

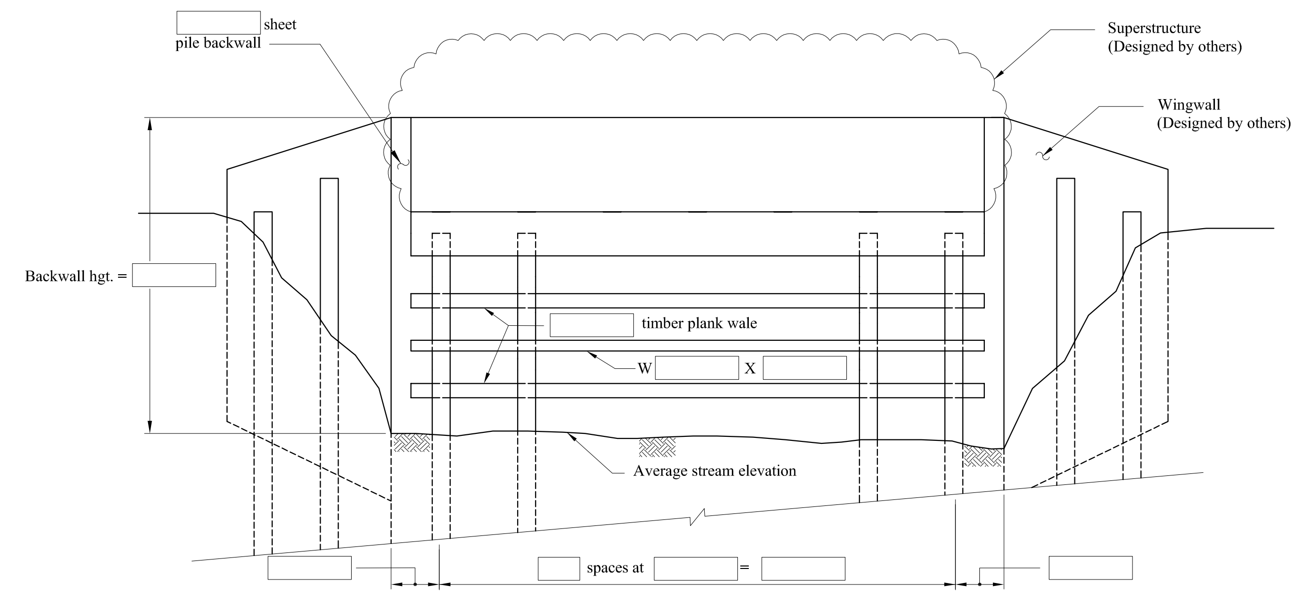
U14



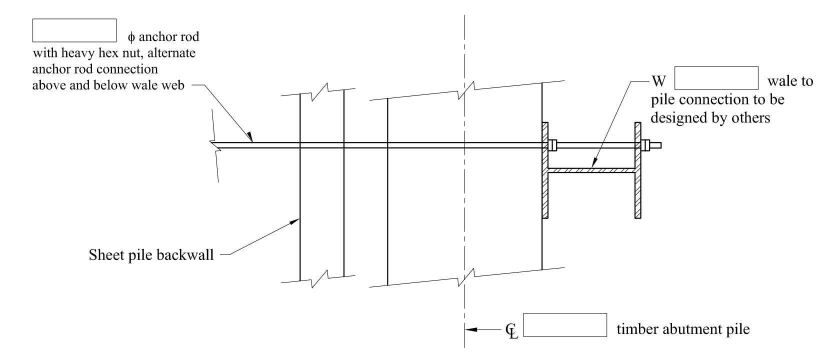
HALF PLAN BELOW PILE CAP

HALF PLAN ABOVE PILE CAP

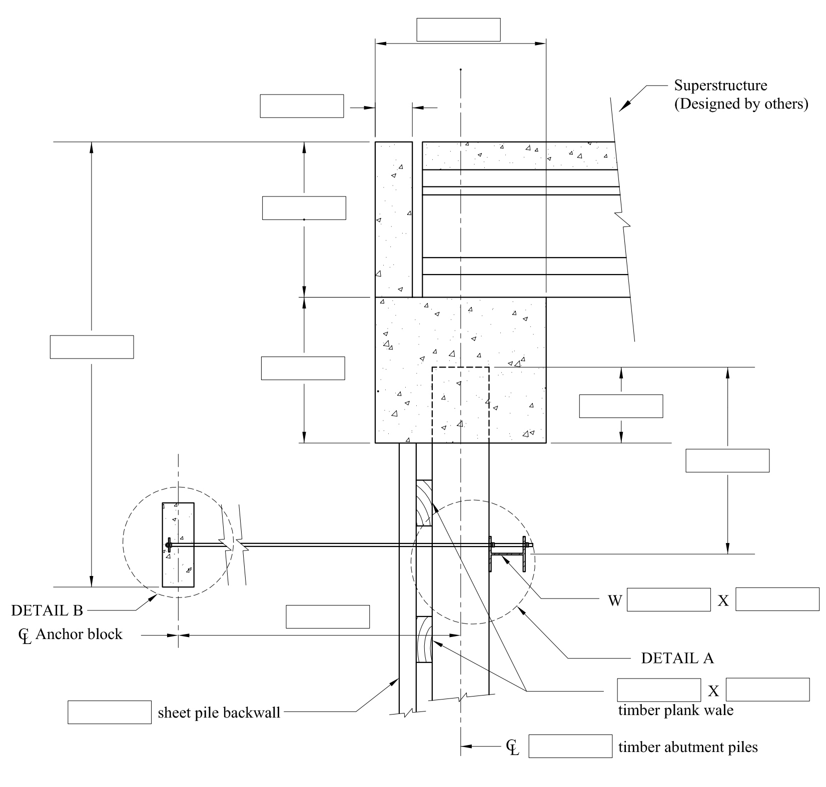
PLAN VIEW



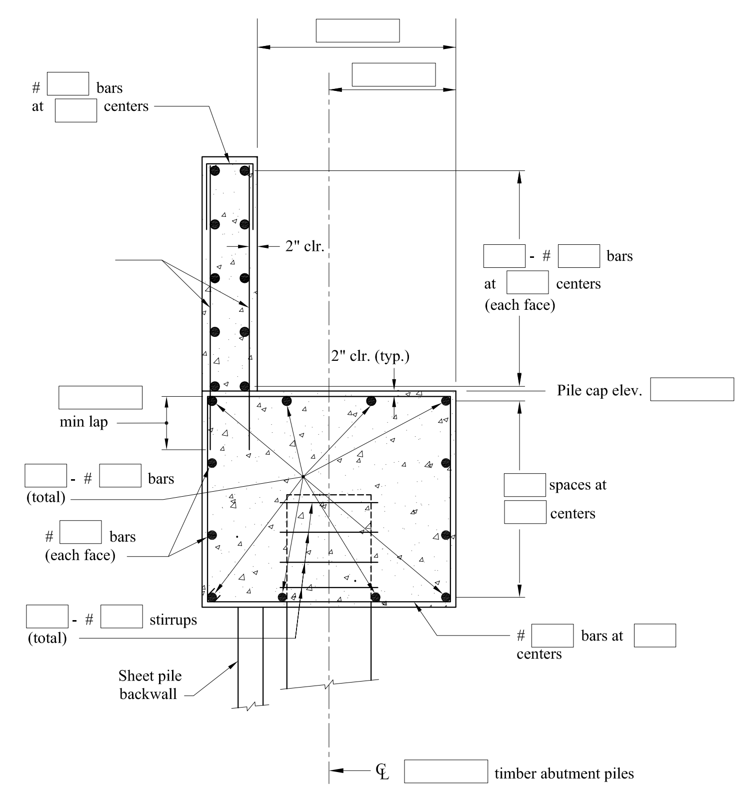
CROSS SECTION NEAR ABUTMENT



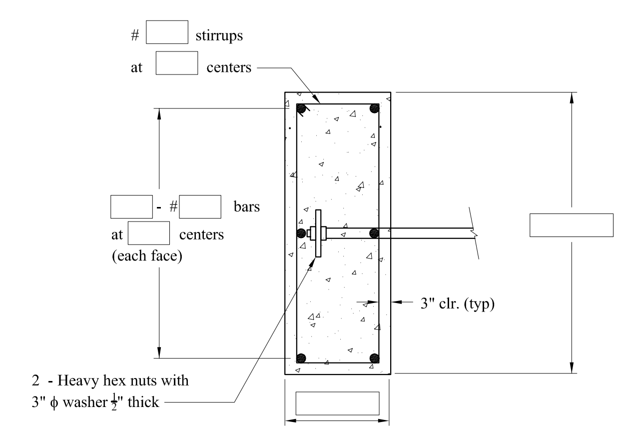
DETAIL A: WALE CONNECTION DETAILS



Section A-A: ABUTMENT SECTION



PILE CAP DETAILS



DETAIL B: ANCHOR BLOCK DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______.

The superstructure bearings are located at an elevation of ______.

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______.

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH ANCHORS, CONCRETE PILE CAP, AND SHEET PILE BACKWALL

DATE:

DRAWN BY:

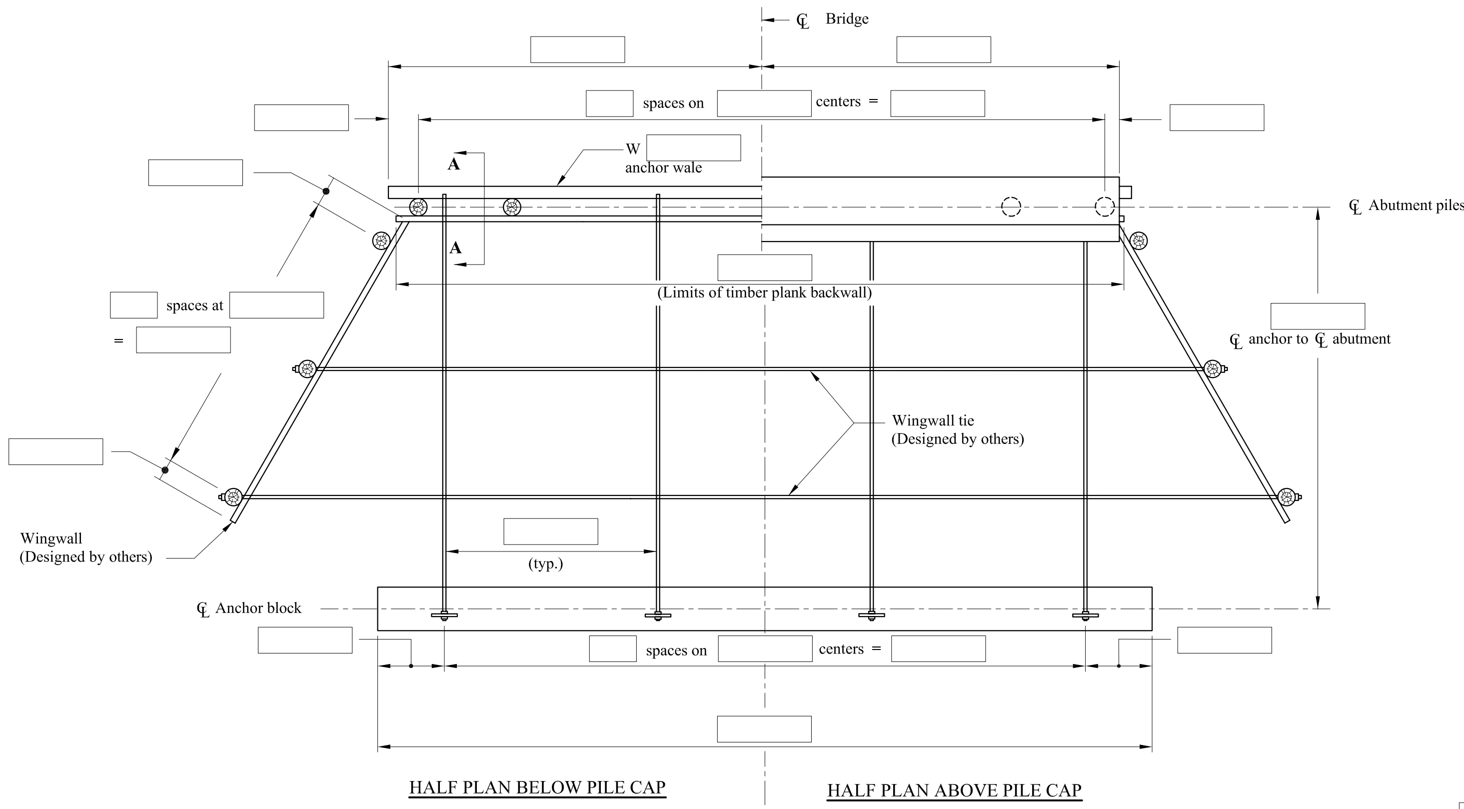
CHECKED BY:

SCALE:

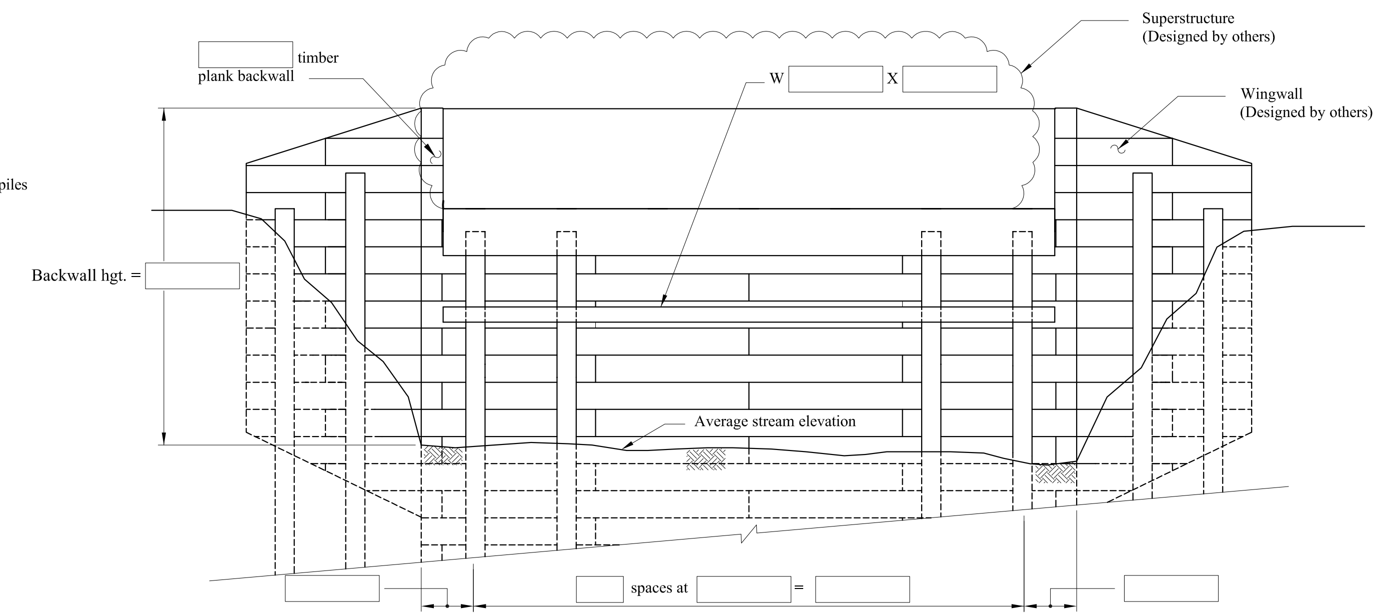
PROJECT NO:

SHEET NO:

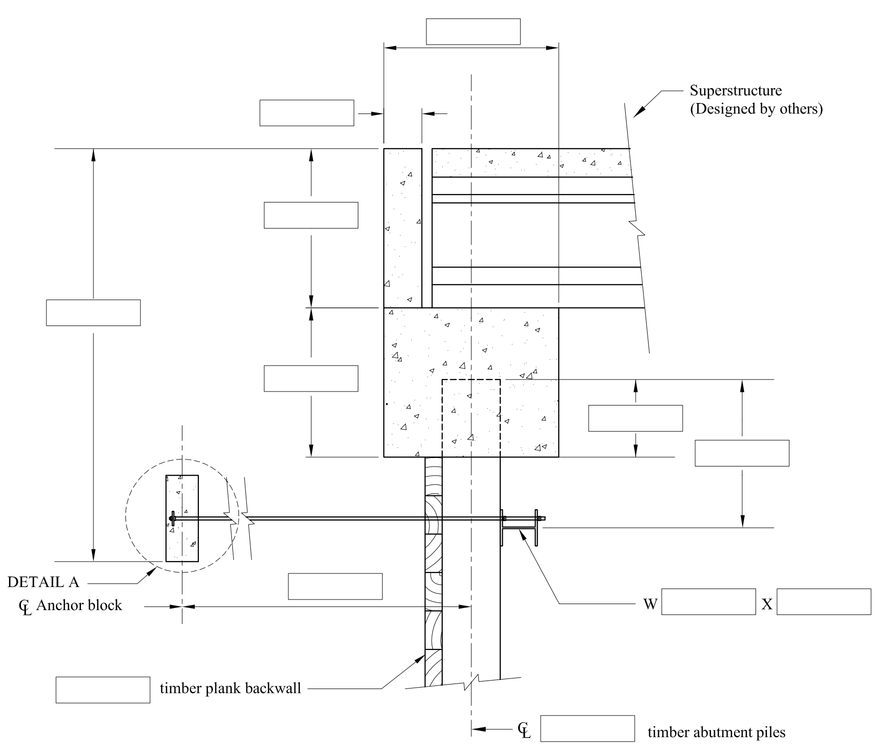
U15



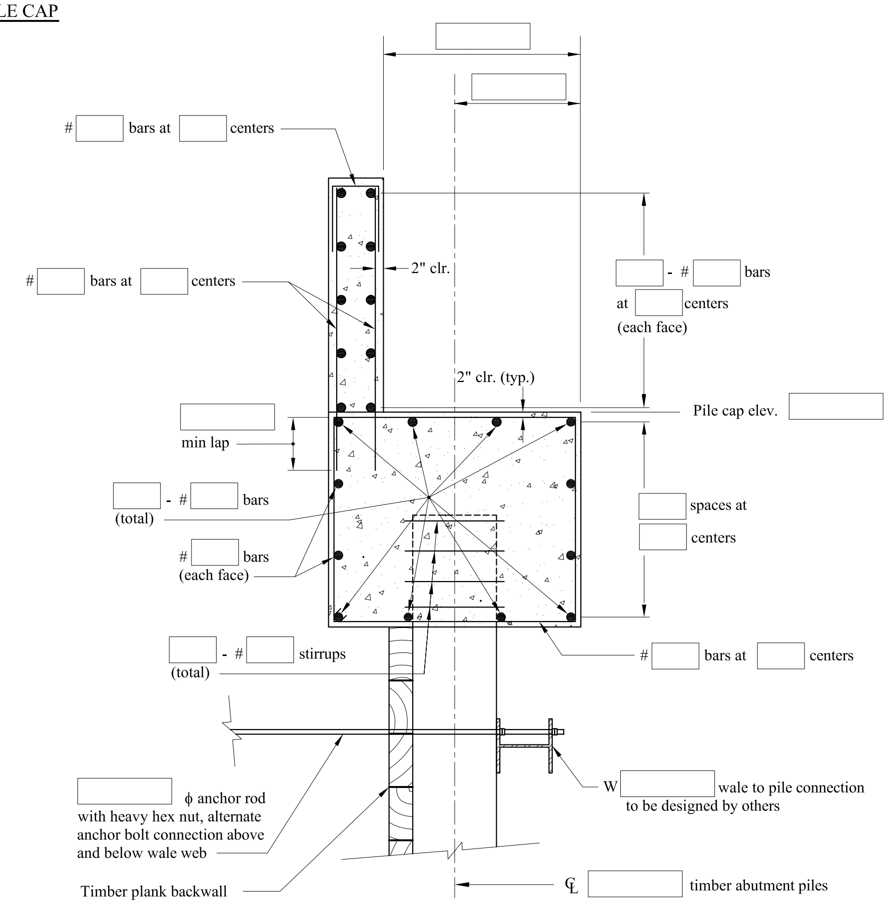
PLAN VIEW



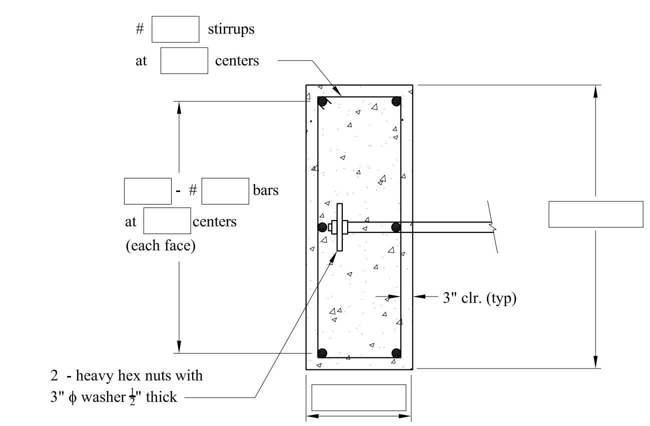
CROSS SECTION NEAR ABUTMENT



Section A-A: ABUTMENT SECTION



PILE CAP AND WALE DETAILS



DETAIL A: ANCHOR BLOCK DETAILS

In this stub abutment system, there is no structural connection between the superstructure and substructure.

See Sheet A2 for estimation of quantities for the ______ and ______ abutments.

Timber piles shall be a ______ species structural grade lumber

All timber shall be creosote treated. Timber piles shall meet the requirements for treated trestle piles.

All piling shall be driven to practical refusal but not less than ______ ton bearing.

The piling shall be cut off at an elevation of ______ .

The superstructure bearings are located at an elevation of ______ .

The pile cap surface shall be sloped as needed to promote water drainage.

The soil in the immediate vicinity of the concrete anchor block shall be compacted to at least 90 percent of the maximum density.

Backfill shall be an Iowa DOT approved soil per Standard Specification: ______ .

Clear distance between the reinforcing steel and nearest concrete face shall be at least 2 in. unless otherwise noted.

REVISIONS

ABUTMENT DETAILS

TIMBER PILES WITH ANCHORS, CONCRETE PILE CAP, AND TIMBER PLANK BACKWALL

DATE:

DRAWN BY:

CHECKED BY:

SCALE:

PROJECT NO:

SHEET NO:

U16

APPENDIX E
DESIGN METHODOLOGY EQUATIONS

E.1 STEEL PILE DESIGN EQUATIONS

The Iowa DOT BDM [3] states that piles are to be designed using allowable stress design methods. All equations used for the design methodology of steel piles in this section are taken from Part C (Service Load Design Method) of AASHTO Section 10 [2]. Additional details relating to these equations and their use are provided in Chapter 4 of Volume 1. Equation numbers in [ ] refer to their number in Volume 1.

$$\frac{f_a}{F_a} + \frac{C_{mx}\, f_{bx}}{F_b\left(1 - \frac{f_a}{F'_{ex}}\right)} + \frac{C_{my}\, f_{by}}{F_b\left(1 - \frac{f_a}{F'_{ey}}\right)} \leq 1.0 \qquad \text{(E.1) [4.2]}$$

where:

C_{mx} = Strong axis buckling coefficient.

C_{my} = Weak axis buckling coefficient.

F_a = Allowable axial stress.

f_a = Applied axial stress.

F_b = Allowable bending stress.

f_{bx} = Applied strong axis bending stress.

f_{by} = Applied weak axis bending stress.

F'_{ex} = Strong axis Euler buckling stress divided by a factor of safety.

F'_{ey} = Weak axis Euler buckling stress divided by a factor of safety.

$$F_b = \frac{50 \times 10^6\, C_b}{S_{xc}} \left(\frac{I_{yc}}{\varsigma}\right) \sqrt{0.772\left(\frac{J}{I_{yc}}\right) + 9.87\left(\frac{d}{\zeta}\right)^2} \leq 0.55F_y \qquad \text{(E.2) [4.3]}$$

where:

C_b = Bending coefficient (no units).

d = Pile depth (in.).

F_b = Allowable bending stress (psi).

F_y = Yield stress of steel in the pile (psi).

I_{yc} = Moment of inertia of the compression flange about the vertical axis in the plane of the web (in^4).

J = Torsional constant (in^4).

S_{xc} = Pile section modulus with respect to the compression flange (in^3).

ζ = Length of unsupported flange between lateral support locations (in.).

$$C_C = \sqrt{\frac{2\,\pi^2\,E}{F_y}} \tag{E.3}$$
[4.4]

where:

C_C = Column buckling coefficient.

E = Modulus of elasticity.

F_y = Yield stress of steel in pile.

If the largest slenderness ratio (defined below for both the strong and weak axis) is less than the column buckling coefficient given by Equation E.3, then Equation E.4 is used to determine the allowable axial pile stress. If the largest slenderness ratio is greater than the column buckling coefficient, then Equation E.5 is used with the appropriate slenderness ratio to determine the allowable axial pile stress.

$$F_a = \frac{F_y}{2.12}\left[1 - \frac{(K\,l/r)^2\,F_y}{4\,\pi^2\,E}\right] \tag{E.4}$$
[4.5]

where:

E = Modulus of elasticity.

F_a = Allowable axial stress.

F_y = Yield stress of steel in pile.

K = Effective length factor (see Table E.2).

Kl/r = Slenderness ratio.

l = Length between braced points (see Table E.2).

r = Radius of gyration.

Table E.1. Effective length factors and pile lengths between braced points [Table 4.2 of Volume 1].

	No Lateral Restraint System Used		Lateral Restraint System Used	
	Strong Axis	Weak Axis	Strong Axis	Weak Axis
K	2.0	0.7	0.7	0.7
Distance between braced points	Distance from point of fixity to roadway	Distance from point of fixity to bearings	Distance from point of fixity to lateral restraint location	Distance from point of fixity to bearings

$$F_a = \frac{\pi^2 E}{2.12(K l / r)^2}$$ (E.5) [4.6]

where:

- E = Modulus of elasticity.
- F_a = Allowable axial stress.
- K = Effective length factor (see Table E.1).
- Kl/r = Maximum slenderness ratio.
- l = Length between braced points (see Table E.1).
- r = Radius of gyration.

$$\frac{f_a}{0.472 F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0$$ (E.6) [4.7]

where:

- f_a = Applied axial stress.
- F_{bx} = Allowable strong axis bending stress.
- f_{bx} = Applied strong axis bending stress.
- F_{by} = Allowable strong axis bending stress.
- f_{by} = Applied weak axis bending stress.
- F_y = Yield stress of steel in pile.

E.2 TIMBER PILE DESIGN EQUATIONS

This section provides the structural capacity equations used to develop the design methodology for timber piles and are taken from Section 13 of the AASHTO Standard Specifications [2] and Chapter 3 of the NDS Manual [6]. Additional details relating to these equations and their use are provided in Chapter 4 of Volume 1.

$$d_{rep} = d_{min} + 0.33(d_{max} - d_{min})$$ (E.7) [4.8]

where:

- d_{max} = Maximum pile diameter (i.e., the pile butt).
- d_{min} = Minimum pile diameter (i.e., the pile tip).
- d_{rep} = Representative pile diameter.

$$\left(\frac{f_C}{F'_C}\right)^2 + \frac{f_{bx}}{F'_{bx}\left(1-\frac{f_C}{F'_{ex}}\right)} + \frac{f_{by}}{F'_{by}\left(1-\frac{f_C}{F'_{ey}}-\left(\frac{f_{bx}}{F_{bE}}\right)^2\right)} \le 1.0 \qquad \text{(E.8)} \; [4.9]$$

where:

F_{bE} = Bending buckling stress.

F'_{bx} = Allowable x-axis bending stress.

f_{bx} = Applied x-axis bending stress.

F'_{by} = Allowable y-axis bending stress.

f_{by} = Applied y-axis bending stress.

F'_C = Allowable compressive axial stress.

f_C = Applied compressive axial stress.

F'_{ex} = X-axis buckling stress.

F'_{ey} = Y-axis buckling stress.

$$F'_C = F_C\, C_M\, C_D\, C_P \qquad \text{(E.9)} \; [4.10]$$

where:

C_D = Load duration factor.

C_M = Wet service factor.

C_P = Controlling column stability factor.

F'_C = Allowable compressive stress parallel to the grain.

F_C = Tabulated compressive stress parallel to the grain.

$$C_P = \frac{1+F'_e/F_C^*}{2c} - \sqrt{\frac{\left(1+F'_e/F_C^*\right)^2}{(2c)^2} - \frac{F'_e/F_C^*}{c}} \qquad \text{(E.10)} \; [4.11]$$

where:

c = Member type adjustment factor.

C_P = Column stability factor.

F_C^* = Allowable compressive stress computed using Equation E.9 without the column stability factor.

$$F'_e = \frac{K_{cE}\,E'}{\left(l_e/d\right)^2}$$ (E.11)
[4.12]

where:

- d = Equivalent square dimension.
- E' = Tabulated modulus of elasticity multiplied by the wet service factor.
- F'_e = Buckling stress.
- K_{cE} = Timber grading factor.
- l_e = Effective column length.

$$F'_b = F_b\,C_M\,C_D\,C_L\,C_f$$ (E.12)
[4.13]

where:

- C_D = Load duration factor.
- C_f = Form factor.
- C_L = Beam stability factor.
- C_M = Wet service factor.
- F'_b = Allowable bending stress.
- F_b = Tabulated bending stress.

$$F_{bE} = \frac{K_{bE}\,E'}{{R_B}^2}$$ (E.13)
[4.14]

where:

- E' = Tabulated modulus of elasticity multiplied by the bending wet service factor.
- F_{bE} = Bending buckling stress.
- K_{bE} = Timber grading factor.
- R_B = Bending slenderness ratio.

$$R_B = \sqrt{\frac{l_e\,d}{b^2}}$$ (E.14)
[4.15]

where:

- b = Member width.
- d = Member depth.
- l_e = Effective pile length.
- R_B = Bending slenderness ratio.

E.3. ANCHOR BLOCK DESIGN EQUATIONS AND FIGURES

This section provides information for determining the lateral capacity of the soil surrounding the anchor block as cited by Bowles [7]. Additional details relating to these equations and their use are provided in Chapter 4 of Volume 1.

$$F_{max} = \frac{\gamma b}{2}(z_1+z_2)\left(K_p - K_a\right) \qquad \text{(E.15) [4.16]}$$

where:

- b = Anchor block height.
- F_{max} = Maximum lateral anchor block capacity (force per unit length).
- K_a = $\frac{1-\sin\phi}{1+\sin\phi}$ = Rankine active earth pressure coefficient.
- K_p = $\frac{1+\sin\phi}{1-\sin\phi}$ = Rankine passive earth pressure coefficient.
- z_1 = Distance from roadway grade to the top of anchor block.
- z_2 = Distance from roadway grade to the bottom of anchor block.
- ϕ = Soil friction angle.
- γ = Soil unit weight.

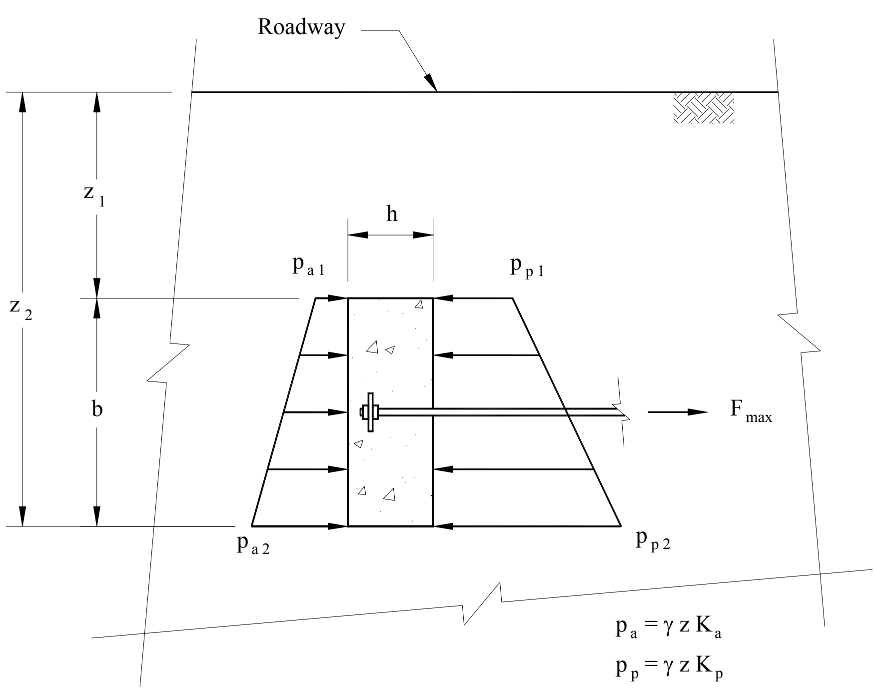


Figure E.1. Soil pressure distribution used to determine the lateral anchor block capacity [adapted from Bowles, 1996; Figure 4.7 of Volume 1].

E.4. LATERAL LOADING ANALYSIS EQUATIONS

This section provides the equations used to determine the depth to pile fixity for laterally loaded piles embedded in a cohesive or cohesionless soil. Additionally, equations for the pile moment at the point of fixity are also presented as cited in Broms [4, 5]. Additional details relating to these equations and their use are provided in Chapter 4 of Volume 1.

E.4.1. Piles Embedded in a Cohesive Soil

$$L = 1.5\,B + f \qquad \text{(E.16) [3.2]}$$

where:

- B = Pile width parallel to the plane of bending.
- f = Length of pile required to develop the passive soil reaction to oppose the above ground lateral pile loads (determined using Equation E.17).
- L = Depth to fixity below ground level.

$$f = \frac{H}{9\,c_u\,B} \qquad \text{(E.17) [3.3]}$$

where:

- B = Pile width parallel to the plane of bending.
- c_u = Undrained shear strength of the soil.
- f = Length of pile required to develop the passive soil reaction to oppose the above ground lateral pile loads.
- H = Total magnitude of the above ground lateral pile loads.

$$M = H\left(e + 1.5\,B + 0.5\,f\right) \qquad \text{(E.18) [3.4]}$$

where:

- B = Pile width parallel to the plane of bending.
- e = Distance above ground level to the centroid of the lateral pile loads.
- f = Length of pile required to develop the passive soil reaction to oppose the above ground lateral pile loads (determined using Equation E.17).
- H = Total magnitude of the above ground lateral pile loads.
- M = Pile moment at the point of fixity.

E.4.2. Piles Embedded in a Cohesionless Soil

$$f = 0.82\sqrt{\frac{H}{\gamma B K_p}}$$ (E.19)
[3.5]

where:

B = Pile width parallel to the plane of bending.

f = Depth to fixity below ground level and length of pile required to develop the passive soil reaction to oppose the above ground lateral loads.

H = Total magnitude of the above ground lateral pile loads.

$K_P = \frac{1+\sin\phi}{1-\sin\phi}$ = Rankine passive earth pressure coefficient.

γ = Soil unit weight.

ϕ = Soil friction angle.

$$M = H\left(e + 0.67\,f\right)$$ (E.20)
[3.6]

where:

e = Distance above ground level to the centroid of the lateral pile loads.

f = Depth to fixity below ground level (determined using Equation E.19).

H = Total magnitude of the above ground lateral pile loads.

M = Moment at the point of fixity.