Low-Volume Road Abutment Design Standards

V.W. Robbins
HNTB Corporation
7450 W. 130th St., Suite 400
Overland Park, KS 66213
vrobbins@hntb.com

F. Wayne Klaiber
Bridge Engineering Center
418 Town Engineering Building.
Iowa State University
Ames, IA 50011
klaiber@iastate.edu

David J. White
Department of Civil, Construction and Environmental Engineering
Iowa State University
476 Town Engineering Building
Ames, IA 50011
djwhite@iastate.edu

Brent M. Phares, Terry J. Wipf
Bridge Engineering Center
Center for Transportation Research and Education
2901 South Loop Drive, Suite 3100
Ames, IA 50010
bphares@iastate.edu, tjwipf@iastate.edu

ABSTRACT

Although several superstructure design methodologies have been developed for low-volume road bridges by the Iowa State University Bridge Engineering Center, no standard abutment designs had been developed. Thus, there was need for an easy-to-use design methodology, generic abutment construction drawings, and other design aids for the more common substructure systems used in Iowa.

A survey of the Iowa county engineers determined that while most counties use similar types of abutments, only 17% use some type of standard abutment designs or plans. In consultation with the Project Advisory Committee, a design methodology was developed for single-span stub abutments supported on steel or timber piles for bridge spans ranging from 20 to 90 ft and roadway widths of 24 and 30 ft. Using the foundation design template provided, other roadway widths can also be designed. The backwall height was limited to between 6 and 12 ft, while both cohesive and cohesionless soil types were considered. Depending upon the combination of variables for a specific site, tiebacks may be required; the design of tiebacks is also included.

Various design aids, for example charts for determining dead and live gravity loads based on the roadway width, span length, and superstructure type, were developed for the design of the stub abutments. A foundation design template was developed in which the engineer can check a substructure design by inputting basic bridge site information. Information for estimating pile friction and end bearing for different combinations of soils and pile types published by the Iowa DOT were also included. Generic

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Proceedings of the 2005 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2005.

standard abutment plans were developed to enable engineers to detail county bridge substructures more efficiently.

In addition to briefly describing the substructure design methodology developed in this project, two example problems with different combinations of soil type, backwall height, and pile type, plus a construction drawing example, will be presented to show the versatility and applicability of the materials developed.

Key words: abutment standards—bridge abutments—low-volume bridges

INTRODUCTION

Various superstructure design methodologies have been developed by the Iowa State University Bridge Engineering Center. However, to date no standard abutment designs or design methodologies have been developed. Obviously, with a set of abutment standards and the various superstructures previously developed, 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 in addition to generating generic abutment standards for the more common systems used in Iowa counties.

OBJECTIVE AND SCOPE

The objective of this project was to develop a series of standard abutment designs, a simple design methodology, and a series of design aids for the more commonly used substructure systems. Based on the results of a survey of Iowa counties and the recommendations of the Project Advisory Committee (PAC), a simple design methodology and a series of standard abutment design aids were developed. The design aids include the following: (1) graphs for estimating dead and live load abutment reactions, (2) a summary of estimated allowable pile end and friction bearing values based on the Iowa DOT Foundation Soil Information Chart (Iowa DOT FSIC 1994), (3) a generic foundation design template (FDT), and (4) a set of generic standard abutment plans. When used correctly, these tools will assist 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). 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 the only superstructure system included in the LVR bridge abutment design aids. However, the general design methodology can be applied to the design of substructures for other superstructure systems.

INPUT FROM IOWA ENGINEERS

Local engineers were actively involved in the development stage (i.e., providing information, guidelines, and recommendations to the research team) to assist in meeting the project objectives. This included information on the design of the most common abutment systems, construction practices, and county capabilities. This information was collected through a survey sent to the Iowa counties, from the recommendations of the PAC, and from personal contacts with county engineers.

Based on the collected information, it was decided that standard abutment designs should include roadway widths of 24 and 30 ft with span lengths ranging from 20 to 90 ft. It was also decided that the standard abutment designs should accommodate different superstructure types, such as the RRFC, BISB, PCDT, PSC, quad tees, glulam timber girders, and slab bridges. Additionally, since 6 to 12 ft is a common range for abutment backwall heights in Iowa, designs were limited to this range. Since most Iowa counties primarily use steel and timber piles, only these two materials were investigated for use in the abutment designs.

It was also evident that integral abutment systems used in Iowa counties are based on the standard designs available through the Iowa DOT (1987). Thus, it was decided that the focus of this research project would be non-integral or stub abutments. As shown in Figure 1, a typical Iowa county stub abutment consists of a single vertical row of either steel or timber piles. The pile cap typically consists of either steel channels connected to the piles or a cast-in-place reinforced concrete cap (not shown). Also shown in this figure is a tie back system, which will not be required in numerous abutment systems.

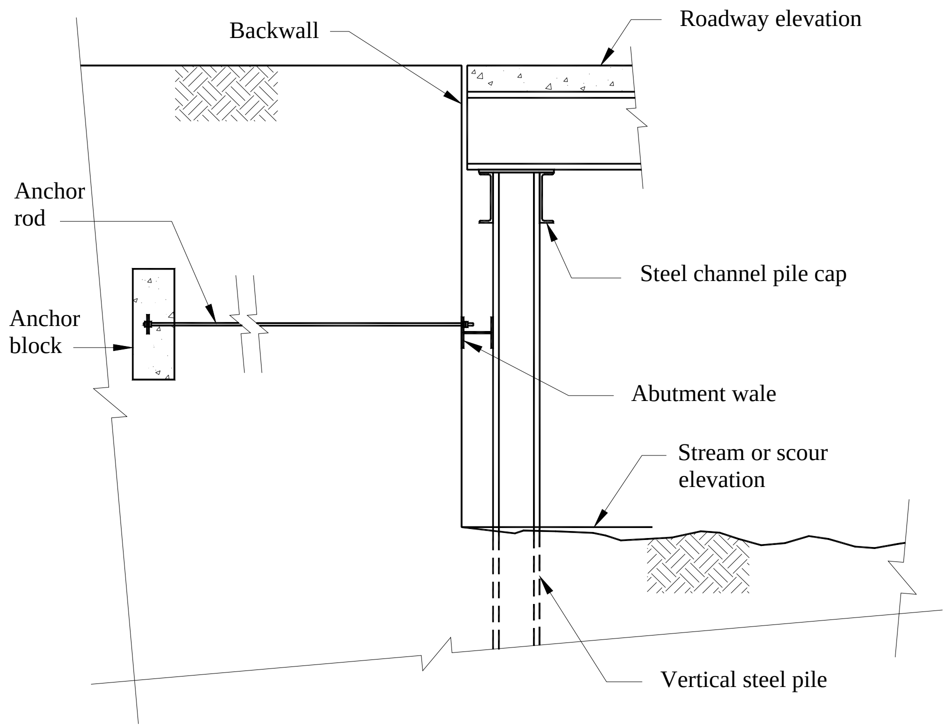

Figure 1. Typical Iowa county stub abutment with a steel channel pile cap

LATERAL LOAD ANALYSIS

Two different lateral load analysis methods were investigated in this project. The first lateral load analysis method, commonly known as the p-y method, utilizes a series of non-linear, horizontal springs to represent the soil reaction imparted on the pile when subjected to lateral loads. The springs have non-linear stiffness properties similar to the surrounding soil, which creates a statically indeterminate, non-linear system (Bowles 1996).

The second lateral load analysis method, developed by Broms (1964), considers a sufficiently long pile, fixed at a calculated depth below ground. By assuming a point of fixity, the pile can be analyzed as a cantilever structure with external loadings and appropriate boundary conditions. The calculated depth to fixity is a function of soil properties, pile width, lateral loadings and pile head boundary conditions. The pile moment and deflection can be determined using basic structural analysis techniques.

A comparison of the two lateral load analysis techniques revealed advantages for both methods. The non-linear method can be used for more complex soil conditions such as a non-homogenous soil profile and more accurate soil reaction distribution. However, advanced geotechnical software is needed to perform this analysis. In the linear method, the assumed soil pressure distributions used to determine the depth to fixity and soil reactions were developed in the 1960s. Also, the linear method does not account for the redistribution of pile loads below the assumed point of fixity. However, once the shape of the soil reaction is established, pile deflection and moment along the length of the pile above the point of fixity can easily be determined and incorporated into commonly available spreadsheet software.

Although the non-linear and linear methods use different assumptions and modeling techniques, they produce comparable maximum pile bending moments for different soil types and practical lateral load cases for LVR bridge abutments. The linear method is more conservative for stiff cohesive soils and cohesionless soils by up to 15% depending on soil type and lateral load magnitude. However, the linear method is less conservative for soft cohesive soils by approximately 3% to 20% depending on the magnitude of the lateral load. Given the assumptions used for the development of this design methodology, general similarity in results when compared to the non-linear method, and reduced computational requirements, the linear method, presented by Broms (1964), was used in this investigation for the development of LVR bridge abutment design methodology.

SUMMARY OF DESIGN METHODOLOGY

Once a lateral load analysis method was selected, a design methodology was developed for LVR bridge abutments. This included determination of substructure loads, performing of the structural analysis, foundation capacity calculations, and checking of design requirements for the pile and anchor systems. Additional miscellaneous substructure elements such as the pile cap, abutment wall, and backwall also need to be investigated; however, designing these elements was beyond the scope of this project. A graphical representation of the design methodology summarized herein is shown in Figure 2.

Design Loads

The first step in the design methodology is determining the substructure configuration such as number of piles, pile section properties, and general bridge geometry. This permits the calculation of bridge gravity and lateral loads. Lateral loadings are imparted to the bridge substructure by active and passive soil pressures on the backwall in addition to superstructure lateral forces transmitted through bridge bearings.

Conservative dead load abutment reactions for the PCDT, PSC, quad-tee, glulam, and slab bridge systems are shown in Figure 3 for a 24-ft roadway width. Similarly, charts for conservative dead load reactions for a 30-ft roadway and gravity live loads for two traffic lanes were also developed, but are not included in this paper. These estimates are based on published standard bridge designs for the respective superstructure systems and include the self-weight of both the superstructure and substructure. The maximum simple-span live load abutment reaction for one traffic lane occurs when the back axle of an American Association of State Highway and Transportation Officials (AASHTO 1996) HS20-44 design truck is placed directly over the centerline of the piles, with the front and middle axles on the bridge.

Substructure systems commonly used by Iowa counties require the piles to resist lateral loads in addition to gravity loads. The Iowa DOT Bridge Design Manual (Iowa DOT BDM 2004) provides guidance for the soil pressure distributions to be used in the design of bridge substructures. Other lateral bridge loadings, such as longitudinal wind forces, transverse wind forces, and a longitudinal braking force, are also included in the Iowa DOT BDM. The longitudinal braking force, transverse wind load on the superstructure, and transverse wind load on the bridge live load are included in the design methodology for this project. Longitudinal wind forces were investigated and found to be negligible for LVR bridge abutments and are therefore not included. Load groups cited in the Iowa DOT BDM are used to determine maximum loading effects for various combinations of gravity and lateral loadings.

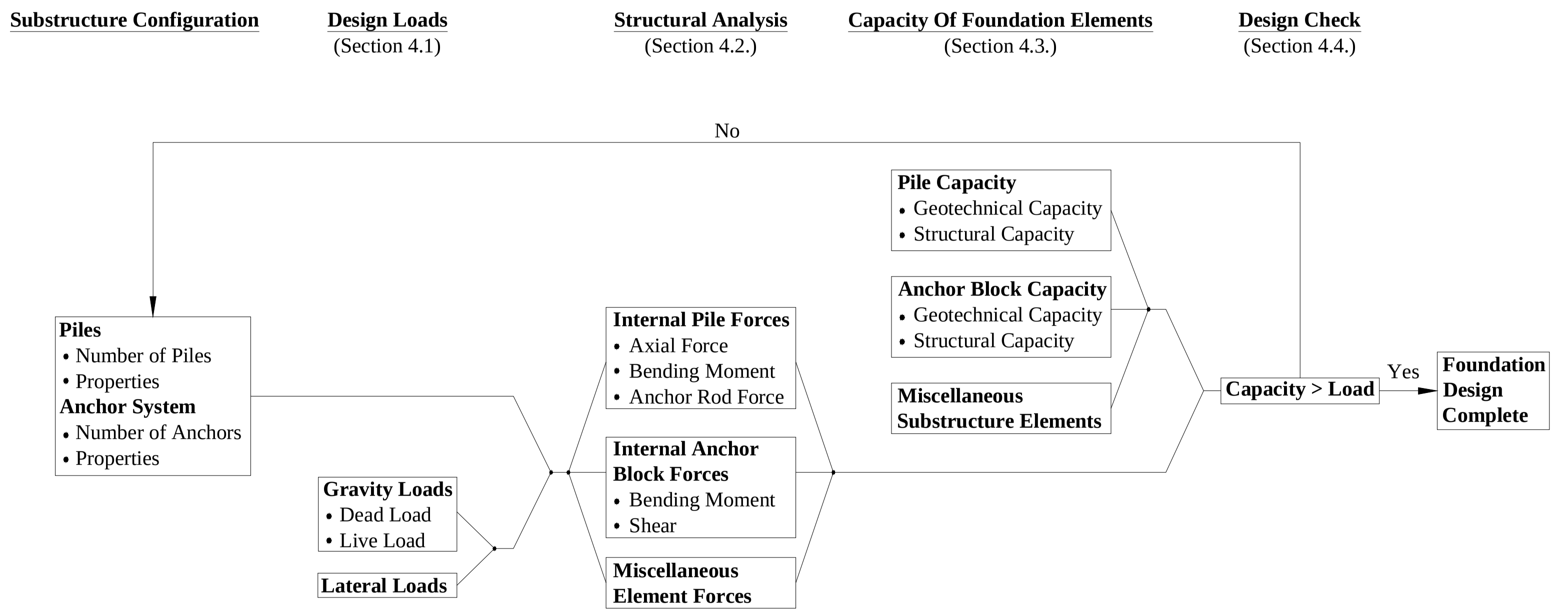

Figure 2. Graphical representation of the design methodology for a LVR bridge abutment

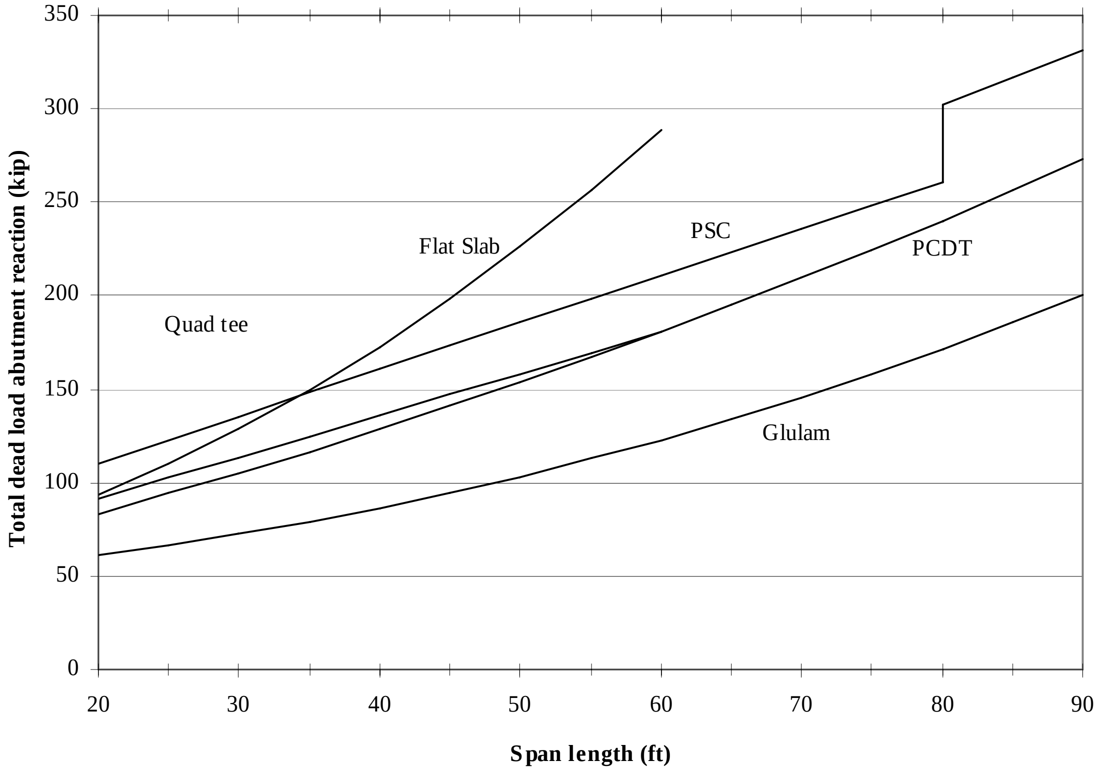

Figure 3. Estimated dead load abutment reactions for a 24-ft roadway width

Structural Analysis

Once the substructure loads have been determined, the structural analysis of the foundation system can be performed to determine internal pile forces. This includes pile axial force and bending moment, anchor rod axial force, and internal anchor block shears and bending moments.

The total abutment reaction, which is the sum of dead and live load abutment reactions, is used to determine individual axial pile forces. The axial pile loads (i.e., the load each pile much resist) are a function of the total number of piles and their spacing plus the superstructure bearing points. 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 for all superstructure systems and 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.

As previously described, the lateral load analysis technique used in this design methodology considers the pile fixed at a calculated depth below ground. After the depth of fixity is determined, the pile is analyzed as a cantilever structure. A lateral restraint system can be used to reduce lateral loading on the piles. The lateral restraint system incorporated in the design methodology was 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. Incorporation of a lateral restraint system creates a statically indeterminate system. The structural analysis methodology in this project used 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. Once the anchor rod force per pile has been determined, internal anchor block bending moments and shear forces can also be calculated.

The anchor block is analyzed as a continuous beam with simple supports that correspond to the anchor rod locations. The net soil reaction imparted on the anchor block to resist 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.

Capacity of Foundation Elements

Guidelines specified in the Iowa DOT BDM, AASHTO, and the National Design Specification Manual for Wood Construction (NDS Manua1 2001) were all used to determine the capacities of various foundation elements. For this design methodology, foundation piles are classified as end bearing piles, friction bearing piles, or combined friction and end bearing piles. The Iowa DOT FSIC provides estimated end bearing and friction bearing values for various pile types, sizes, and foundation materials and soil types. The Iowa DOT BDM states that piles are to be designed using allowable stress design methods. All equations used for determining the design capacity of steel piles are from Part C (Service Load Design Method) of AASHTO, Section 10. Piles for typical Iowa county LVR bridge abutments are required to resist both axial and bending forces. Therefore, interaction equations for steel piles subjected to combined loading are used.

The design capacity of a timber pile is determined using the guidelines specified by AASHTO and the NDS Manual. The timber material properties vary significantly with the species type, member size and shape, loading conditions, and surrounding environmental conditions. Therefore, timber modification factors taken from AASHTO Section 13 are used to account for these variables. As recommended by AASHTO, the interaction equation defined by the NDS Manual is used to verify the structural adequacy of timber piles subjected to combined axial and bending loads.

The structural capacity of the anchor system 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 of the anchor block. The magnitude of the soil pressure is a function of surrounding soil properties and the depth of the anchor block with respect to the roadway surface (Bowles 1996). Once the lateral capacity of the anchor system has been calculated, the structural capacity of the anchor block must be determined using reinforced concrete design practices as described in Section 8 of AASHTO.

Design Requirements

Once the foundation systems' capacities have been determined, the foundation system's adequacy must be verified. In general, this consists of verifying that capacities of the individual elements are greater than the effects of the applied loads. For design bearing requirements in general, the capacity must be greater than the axial pile load. Due to the presence of combined bending and axial loads, the structural capacity of a pile cannot be determined directly. Rather, interaction requirements are used to compare ratios of applied to allowable stresses due to combined bending and axial loads. Other design requirements include pile deflection, axial piles stress, anchor rod stress, maximum pile length (timber piles only), etc.

The capacity of the anchor system must also be verified. The maximum lateral capacity of soil surrounding the anchor block (per pile) must be greater than the required anchor force per pile. To satisfy structural design requirements, the internal anchor block shear and bending forces must be less than the structural capacity of the anchor block determined from AASHTO reinforced concrete design guidelines.

DESIGN AIDS

In addition to the development of a design methodology, several design aids were also created, including (1) graphs for estimating dead and live load abutment reactions, (2) estimated pile end bearing and friction bearing values, (3) a FDT, and (4) a set of generic standard abutment plans.

Foundation Design Template

The FDT is an Excel spreadsheet that is used to verify the design of a foundation system. At most for a given site, the engineer will need two worksheets. These include pile design and anchor design worksheets (PDW and ADW, respectively). Use of the ADW may not be necessary depending on the bridge site. The engineer has the option to use a unique PDW for each combination of pile type (steel or timber) and soil type (cohesive or cohesionless). In the case where a subsurface bridge site investigation reveals a non-uniform soil profile consisting of both cohesive and cohesionless soils, properties of the upper-level soil should be used to determine which PDW should be used. Examples of the PDW are presented in Figures 4 and 5, and the ADW can be seen in Figure 6.

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	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 (□)	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	9.7	kip per pile		
		Computed anchor force per pile	7.5	kip per pile		
		Minimum anchor rod length	13.47	ft		
	27	Anchor rod length	15.00	ft		

Figure 4. Input section of PDW

Design Checks	1	Axial pile load	$\boxed{P \le P_{ALLOWABLE}}$	48.0	kip	OK
	2	Pile length	$\boxed{\text{Length} \le 55 \text{ ft}}$	37	ft	OK
	3	Pile bearing capacity	$\boxed{\text{Axial Pile Load} \le \text{Capacity}}$	sufficient if pile is embedded at least		34 ft
	4	Interaction equation validation	$\boxed{\frac{1}{(1 - f_C / F'_e)} > 1.0}$	1.04		OK
	5	Combined loading interaction requirement $\boxed{\left(\frac{f_C}{F'_C}\right)^2 + \frac{f_{bx}}{F'_b\left(1 - \frac{f_C}{F'_{ex}}\right)} + \frac{f_{by}}{F'_b\left(1 - \frac{f_C}{F'_{ey}} - \left(\frac{f_{bx}}{F'_{bE}}\right)^2\right)} \le 1.0}$		0.75		OK
	6	Buried anchor block location	$\boxed{\text{Anchor rod length} \ge \text{minimum}}$	15.00	ksi	OK
	7	Anchor rod stress	$\boxed{\sigma \le 0.55\ F_Y}$	23.9	ksi	OK
	8	Anchor block capacity	$\boxed{\text{Total Anchor Force} \le \text{Capacity}}$	9.7	kip per pile	OK
	9	Maximum displacement	$\boxed{\delta_{MAX} \le 1.5 \text{ in.}}$	0.37	in.	OK

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		3.69	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

Figure 5. The Design checks and foundation summary sections of the PDW

Input Information	1	Anchor block length	27.00	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 on one vertical anchor block face	3	bars
	6	Tension steel bar size	4	#
		Minimum tension steel area	0.60	in^2
		Are stirrups required?	Yes	
	7	Shear stirrup bar size number	3	#
	8	Number of stirrup legs per section	2	
		Maximum stirrup spacing	4.69	in.
	9	Stirrup spacing for this analysis	4.50	in.

Design Checks	1	Design flexural capacity	$\boxed{M_U < \phi M_N}$	24.78	ft-kips	OK	{AASHTO 8.16.3.2}
	2	Reinforcement ratio	$\boxed{\rho < 0.75\rho_b}$	0.0018		OK	{AASHTO 8.16.3.2.2}
	3	Minimum reinforcement				OK	{AASHTO 8.17}
	4	Design shear capacity	$\boxed{V_U < \phi V_N}$	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	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	27.00	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

Figure 6. The input, design checks, and summary sections of the ADW

In the PDW, the engineer will input basic bridge parameters such as span length, roadway width, backwall height, the number of piles, pile section and material properties, the soil standard penetration test (SPT) blow count, and lateral restraint usage. These values are used in the structural analysis of the system; several design checks required by the Iowa DOT BDM, NDS Manual, and AASHTO are completed in the PDW.

Also included in the PDW are various design checks for the given foundation system. This includes but is not limited to the allowable axial pile stress, bearing capacity, combined loading interaction equations, and anchor block capacity. Finally, the PDW provides a summary of the overall bridge geometry and foundation configuration as entered by the engineer.

The ADW is only required if a buried concrete anchor is selected in the PDW. The ADW is the same for all combinations of piles and soil types. If applicable, the ADW is used only after all design requirements have been satisfied in the PDW. Additional information, such as the reinforced concrete anchor block material properties and anchor rod details, are also required. This additional information is used to calculate internal anchor block shears and moments, determine the structural capacity, and check anchorage system design requirements.

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

Standard Abutment Plans

In addition to the FDT, a complete set of generic standard abutment plans were developed. 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 various superstructures and associated standard plans previously developed by the BEC, the engineer can generate a complete set of bridge plans. Note 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, necessary details such as bridge geometry, member size designations (i.e., W, C, and HP shapes), and material properties must be inserted in spaces provided. The FDT provides many necessary details for the standard abutment sheets in the summary sections shown in Figures 5 and 6.

The standard abutment plans are composed of three different types of sheets. The first type consists of two general sheets that will be used for all bridge abutments and that are both included in the final set of construction documents. These include a cover sheet and a general bridge plan and elevation layout sheet. The second type of sheet provides general information and instructions relating to the scope and use of the standard abutment plans and is not included in the final set of construction documents. This sheet also includes a feasibility flow chart to help the engineer determine whether the standard abutment plans and FDT are appropriate for a given bridge site. The third type of sheet consists of 16 construction sheets with different combinations of pile caps, backwall systems, anchor systems, and pile types. For example, if a bridge site requires steel H-piles with an anchor, a steel channel pile cap, and sheet pile backwall, the sheet shown in Figure 7 should be used. If both bridge abutments use the same combination substructure components, the same sheet can be used twice with different dimensions, if necessary.

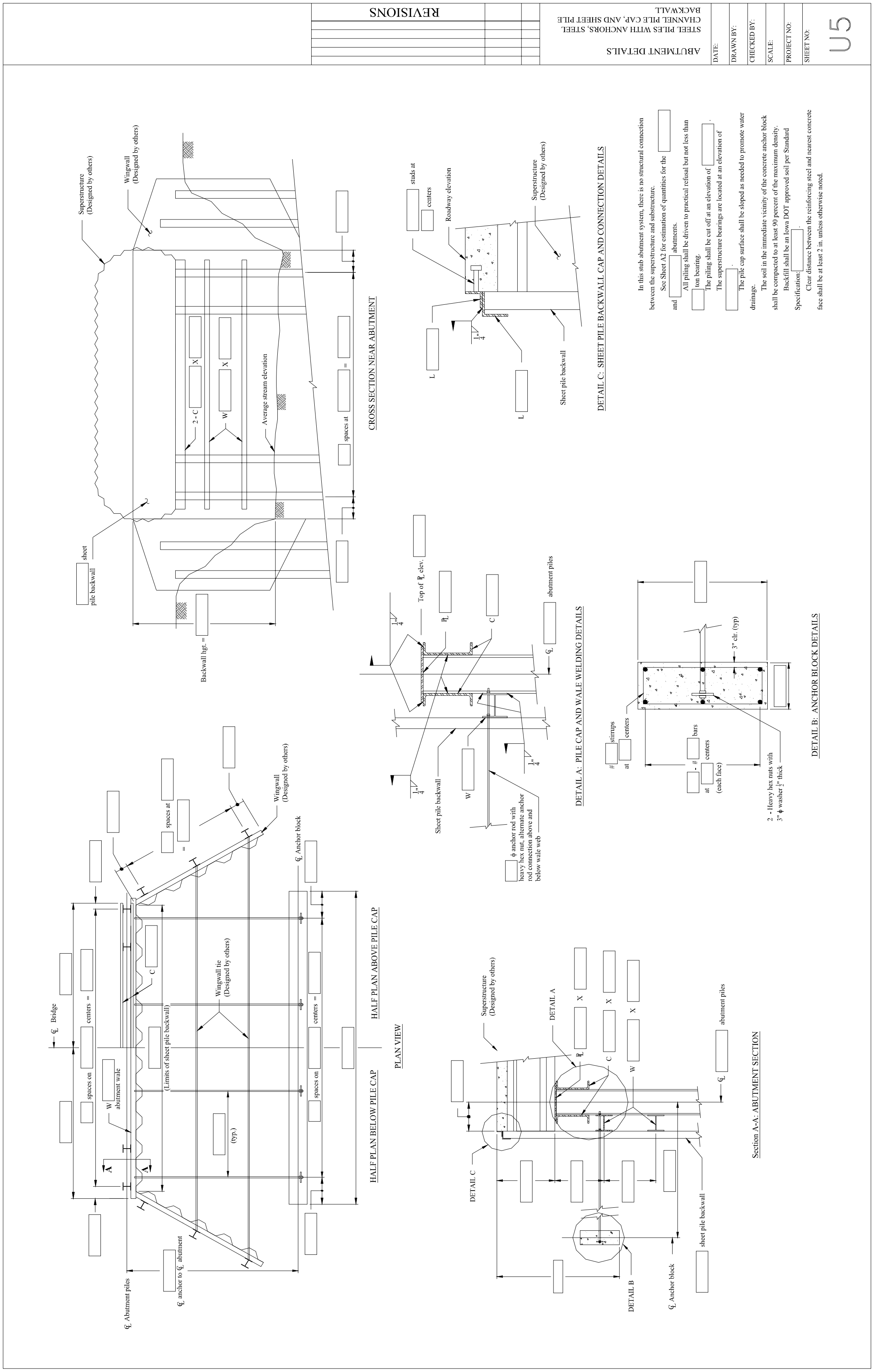

Figure 7. Standard abutment detail sheet for an anchored steel pile abutment with a steel channel pile cap and sheet pile backwall

VERIFICATION OF THE FOUDATION DESIGN TEMPLATE

Sample calculations for two examples were developed to verify and demonstrate the versatility of the FDT. These calculations are not provided here, but are available in Volume 3 of the final project report (2004). As mentioned, the FDT can be used for various roadway widths, pile types, soil types, and backwall heights. For both examples, the required input variables for the FDT are presented below. The PDW and ADW for the first example can be seen in Figures 4 through 6.

Example 1. In the first example, the FDT is used to verify the design of a timber pile abutment with a reinforced concrete anchor. The superstructure is a PCDT system with a span length and roadway width of 40 and 24 ft, respectively. In this case, bridge dead and live loads are provided by the FDT. Figure 3 can also be used to determine the gravity dead load manually. Seven timber piles with a 13-in. butt diameter are embedded in a soil best described in the Iowa DOT FSIC as gravelly sand with an average SPT blow count of 21. The backwall height and estimated depth of scour are 6 and 2 ft, respectively.

Example 2. In the second example, the FDT is used to verify design of a steel pile abutment. The superstructure is a PSC system with a span length and roadway width of 60 and 24 ft, respectively. Again, bridge dead load, provided by the FDT, can be obtained from Figure 3. Eight HP10 x 42 steel piles are embedded in soil best described in the Iowa DOT FSIC as a firm, glacial clay with an average SPT blow count of 11. The backwall height and estimated depth of scour, as in Example 1, are 6 and 2 ft, respectively.

SUMMARY

This research project consisted of the collection of LVR bridge abutment information, development of an abutment design methodology, and creation of design aids for Iowa county engineers, municipal engineers, etc. Information was primarily gathered by conducting a survey of the Iowa county engineers and through feedback of the PAC. The survey focused on the capabilities and practices of Iowa counties and the identification of common construction methods and trends. The PAC, composed Iowa county engineers and a representative from the Iowa DOT Office of Bridges and Structures, provided information about the scope of this project. This included roadway and span length limitations, common substructure configurations, and superstructures to be accommodated by the standard abutment designs. Additionally, members of the PAC suggested creating the flexible and easy-to-use design software.

Two different lateral load analysis methodologies were investigated before developing the foundation design methodology. This included a linear and a non-linear method. It was found that each method has certain advantages, such as the ability to model complex soil conditions and profiles, accurately represent actual interactions between the pile and surrounding soil, and ease of incorporating the analysis method into a complete design methodology. Based on relative simplicity and correlation of calculated maximum pile moments, it was decided that the linear analysis procedure presented by Broms (1964) would be most suitable for this project. The structural analysis procedure for the piles, both with and without lateral restraints, was developed using recommendations of the Iowa DOT BDM, AASTHO, and NDS Manual for steel and timber piles.

Finally, design aids that incorporate the design methodology were developed. These include gravity live and dead load charts for various span lengths and superstructure systems and the FDT and generic standard abutment plans. The FDT is used to verify the adequacy of a foundation system for a particular bridge site. The engineer inputs basic bridge and site data, and this information is used to determine the capacity of the foundation elements and to perform required design checks. The generic standard abutment plans include different standard sheets for each combination of pile type (steel or timber), anchor usage (with or without), pile cap (steel channel or concrete pile cap), and a backwall system (timber planks or vertically driven sheet piles). The standard abutment sheets can be used by engineers to produce necessary drawings for the more common LVR bridge abutments systems.

ACKNOWLEDGMENTS

The research presented in this report was conducted by the Bridge Engineering Center under the auspices of the Engineering Research Institute at 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.

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