TABLE OF CONTENTS ~ BRIDGE SUBSTRUCTURE DESIGN

6 Bridge Substructure Design
6.1 General
6.1.1 Policy overview
6.1.2 Design information
6.1.3 Definitions
6.1.4 Abbreviations and notation
6.1.5 References

6 Bridge Substructure Design

6.1 General

The series of articles under Section 6, Bridge Substructure Design, is intended to fit together as a unit. As much as possible, cross references are used to avoid duplication.

In a following article [BDM 6.1.5], several references are listed for soils, driven piles, and integral abutments. Although the soils reference, *Foundation Soils Information Chart, Pile Foundation*, (a.k.a.Blue Book) has not been updated for LRFD, it provides some of the background on which the recent Iowa State University LRFD calibration for driven piles was based.

For driven pile design, in 2007 the office moved to an interim LRFD procedure with a single resistance factor of 0.725 fitted to the Blue Book and to an approximate average load factor of 1.45. Since the LRFD statistical calibration to static pile load tests was completed by Iowa State University (ISU) in 2012, the pile section [BDM 6.2] of the LRFD Bridge Design Manual has been rewritten to adopt geotechnical and target driving resistance factors from the research discussed in *Volume IV of Development of LRFD Procedures for Bridge Pile Foundations in Iowa* and from subsequent discussions with the researchers regarding setup in cohesive soil. More basic information about the ISU research is available in earlier Volumes I - III [BDM 6.1.5].

In the past designers were encouraged to obtain and use the 1987 integral abutment reference, *Final Report, Pile Design and Tests for Integral Abutment Bridges, HR-273, and Addendum*, for relatively long bridges. However, the office no longer encourages use of the reference because the bridge length policy recently has been revised to allow longer bridges, and the 2005 reference, *Field Testing of Integral Abutments, Final Report HR-399*, has modified the older recommended design procedures [BDM Table 6.5.1.1.1]. The two integral abutment references generally substantiate the present policy, and the designer may find them useful in understanding the various rules associated with the policy.

6.1.1 Policy overview

In the Office of Bridges and Structures, the design of typical highway bridge substructures proceeds from preliminary to final design sections. The preliminary design section selects the abutment, pier, and foundation type based on bridge site information and criteria stated in *Bridge Design Manual* Section 3, Preliminary Design. In some cases the preliminary design section also considers aesthetic criteria in Section 4, Aesthetic Design (in process). Final design sections then complete the structural design and detailing following policies in Section 5, Bridge Superstructure Design, and Section 6, Bridge Substructure Design.

For a bridge over a waterway a Corps of Engineers 404 permit is required, but there no longer is a need for a note on the bridge plans. For typical bridge projects the Office of Design will provide notes and details for the 404 permit. If special permit conditions are identified in the submittal letter from the Office of Location and Environment (Green Sheet), the Office of Bridges and Structures will work with the Office of Design to provide appropriate notes and details in the project plans.

In the past the office has followed the AASHTO Standard Specifications but now has transitioned to the AASHTO LRFD Specifications. The office interprets the basic LRFD specifications when designing foundations, abutments, and piers and specifies rules for detailing of those substructure components. This series of articles on substructure components covers most typical designs but does not cover special designs for signature bridges and long-span bridges.

In all cases substructure components need to be designed for vertical and lateral loads, settlement, stability, and economy considering the complete bridge structure. Pile, drilled shaft, footing, abutment, and pier design is affected by the choice of bearings [BDM 5.7] because bearings transmit loads from the superstructure. Abutment and pier design also is affected by the choice of foundations because foundations provide support and either partial or complete fixity.

For highway bridge foundations, the office generally selects among three types: piles, drilled shafts, and spread footings. Because most Iowa bridge sites are in rural areas and because bedrock seldom is near the surface, site conditions and economy usually favor the use of piles for the support of substructure components. In cases where pile driving would disturb adjacent structures and where site conditions permit, substructure components may be supported on drilled shafts. In cases where bedrock is close to the planned bottom elevation of a substructure component, the component should be placed on a spread footing notched into the rock.

In order to eliminate expansion joints, wherever practical the office selects integral abutments instead of other abutment types. Based on research and testing for bridges without skew, the office generally orients integral abutment steel H-piles for weak axis bending with respect to longitudinal expansion or contraction of the superstructure. For bridges with skews of 30 degrees or less, H-piles are rotated to align the pile webs with the centerline of abutment bearings. However, at skews above 30 degrees, piles shall be aligned with pile webs perpendicular to centerline of roadway.

Except for integral abutments, wherever practical the office batters some of the foundation piles for a substructure component. Typically the inner line of stub abutment piles, stub abutment wing wall piles, and the perimeter piles for pier foundations are battered at a 1 horizontal to 4 vertical slope. The end piles for pile bents are battered at a 1 horizontal to 12 vertical slope.

6.1.2 Design information

For each bridge site the Soils Design Section in the Office of Design provides to the Office of Bridges and Structures a bridge soils package that typically includes three primary items: the boring logs, the soil profile sheet, and the supplemental. There may be other items or attachments as needed based on site conditions and other factors.

The supplemental is organized to provide the N-values for the standard penetration test, but the document typically provides additional information, requirements, and recommendations for three design factors: slope stability, settlement, and foundation. These three items can vary from very short to complex, can discuss work to be done by a grading contractor, and can discuss further coordination between design offices.

For the foundation part of the supplemental, the Soils Design Section typically recommends a foundation type, usually one of the following:

- Point-bearing piles driven to a rock formation,
- Friction or friction plus bearing piles driven to a specified load capacity, below any expected scour elevation,
- Drilled shafts, or
- Spread footings founded directly on a rock formation.

The Soils Design Section does not necessarily make more specific recommendations, such as a pile type. If applicable, the section discusses downdrag and relates downdrag to design requirements and

delay period. The settlement information on the supplemental includes consolidation time rate information.

The Soils Design Section typically recommends pile driving points if soil conditions warrant, but the designer may discuss the need with the section if it appears that points are advisable.

The majority of Iowa bridge foundations are placed on piles that derive support from shear strength of surrounding soil and end bearing. Based on approximately 280 pile load tests in Iowa soils and experience with previous charts the Soils Design Section prepared *Foundation Soils Information Chart, Pile Foundation* in 1989, updated the chart in 1994, and accepted charts updated to LRFD geotechnical resistance for trial use in 2006. The revised 2007 LRFD geotechnical resistance charts [BDM 6.2.7] shall be used for design of pile foundations for Iowa bridges.

6.1.3 Definitions

Substructure is any construction below the bearing seats or, in the absence of bearings, below the soffit of the superstructure.

6.1.4 Abbreviations and notation

N or N-value, standard penetration test number of blows per foot (300 mm). N also may be given as **SPT NO**, the Standard Penetration Test Number, in the soils information chart reference.

6.1.5 References

AbdelSalam, S.S.,K.W. Ng, S. Sritharan, M.T. Suleiman, and M. Roling. *Development of LRFD Procedures for Bridge Pile Foundations in Iowa – Volume III: Recommended Resistance Factors with Consideration of Construction Control and Setup.* Ames: Institute for Transportation, Iowa State University, 2012. (Available on the Internet at: http://www.intrans.iastate.edu/research/documents/research-reports/lrfd_vol_iv_final_w_cvr.pdf)

Abendroth, R.E. and L.F. Greimann. *Field Testing of Integral Abutments, Final Report HR-399.* Ames: Center for Transportation Research and Education, Iowa State University, 2005. (Available on the Internet at http://www.iowadot.gov/operationsresearch/reports/reports_pdf/hr_and_tr/reports/hr399.pdf)

Dirks, Kermit and Patrick Kam. *Foundation Soils Information Chart, Pile Foundation*. Ames: Iowa Department of Transportation, Office of Road Design, January 1989/September 1994. (a.k.a. **Blue Book**) Generally with the move to LRFD, the ASD-based Blue Book is out-of-date, and its contents have been revised and moved to the BDM. The Blue Book is available from the Soils Design Section in the Office of Design.

Green, D., K.W. Ng, K.F. Dunker, S. Sritharan, and M. Nop. *Development of LRFD Procedures for Bridge Pile Foundations in Iowa – Volume IV: Design Guide and Track Examples.* Ames: Institute for Transportation, Iowa State University, 2012. (Available on the Internet at: http://www.intrans.iastate.edu/research/projects/detail/?projectID=-700958271)

Greimann, L.F., R.E. Abendroth, D.E. Johnson, and P.B. Ebner. *Final Report, Pile Design and Tests for Integral Abutment Bridges, HR-273, and Addendum.* Ames: Iowa Department of Transportation and College of Engineering, Iowa State University, 1987. (Available on the Internet athttp://www.iowadot.gov/operationsresearch/reports/reports_pdf/hr_and_tr/reports/hr273.pdf)

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Roling, M., S. Sritharan, and M. Suleiman. *Development of LRFD Procedures for Bridge Pile Foundations in Iowa – Volume I: An Electronic Database for Pile Load Tests in Iowa (PILOT-IA).* Ames: Institute for Transportation, Iowa State University, 2010. (Available on the Internet at: http://publications.iowa.gov/13624/)