Development of LRFD Procedures for Bridge Pile Foundations in Iowa

Volume IV: Design Guide and Track Examples

tech transfer summary

This project has developed regional LRFD recommendations for driven piles so that bridge foundations can be designed and constructed with uniform reliability and cost effectiveness.

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RESEARCH PROJECT TITLE
Development of LRFD Procedures for Bridge Pile Foundations in Iowa Volume IV: Design Guide and Track Examples

SPONSORS
Iowa Highway Research Board
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Iowa Department of Transportation
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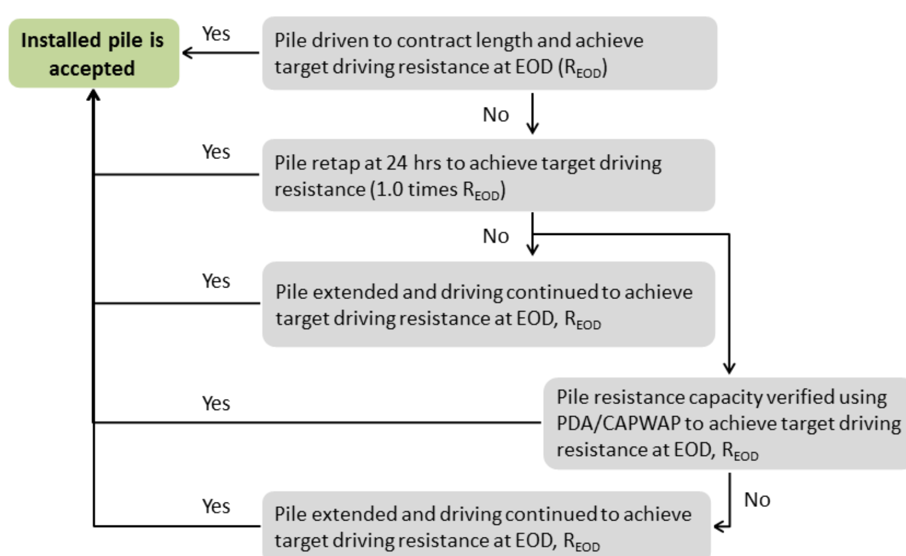
Background

The outcomes of three research projects sponsored by the Iowa Highway Research Board (IHRB) led to the development of the regional Load and Resistance Factor Design (LRFD) method for driven pile foundations in Iowa. The project findings are presented in three volumes:

I: An Electronic Database for PIle LOad Tests in Iowa (PILOT)
II: Field Testing of Steel Piles in Clay, Sand, and Mixed Soils and Data Analysis
III: Recommended Resistance Factors with Consideration of Construction Control and Setup

Methodology

The Iowa Department of Transportation's (DOT's) LRFD design procedures for driven piles presented in the fourth volume were developed by incorporating the regional LRFD recommendations from the completed research and adopting the American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Specifications (2010).



Construction control flow chart for end bearing piles in all soil types and friction piles embedded in non-cohesive and mixed soil types

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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Institute for Transportation

Summary of pile design and construction steps

Design	Task
Step 1	Develop bridge situation plan (or TS&L, Type, Size, and Location)*
Step 2	Develop soils package, including soil borings and foundation recommendations*
Step 3	Determine pile arrangement, pile loads, and other design requirements*
Step 4	Estimate the nominal geotechnical resistance per foot of pile embedment**
Step 5	Select resistance factor(s) to estimate pile length based on the soil profile and construction control**
Step 6	Calculate the required nominal pile resistance, R_n**
Step 7	Estimate contract pile length, L**
Step 8	Estimate target nominal pile driving resistance, R_{ndr-T}**
Step 9	Prepare CADD notes for bridge plans
Step 10	Check the design, depending on bridge project and office practice
Construction	**Task(s)**
Step 11	Prepare bearing graph
Step 12	Observe construction, record driven resistance, and resolve any construction issues

*These steps determine the basic information for geotechnical pile design and will vary depending on bridge project and office practice.
**These steps are modified in Track 1 Example 5 for piles that are end bearing in bedrock.

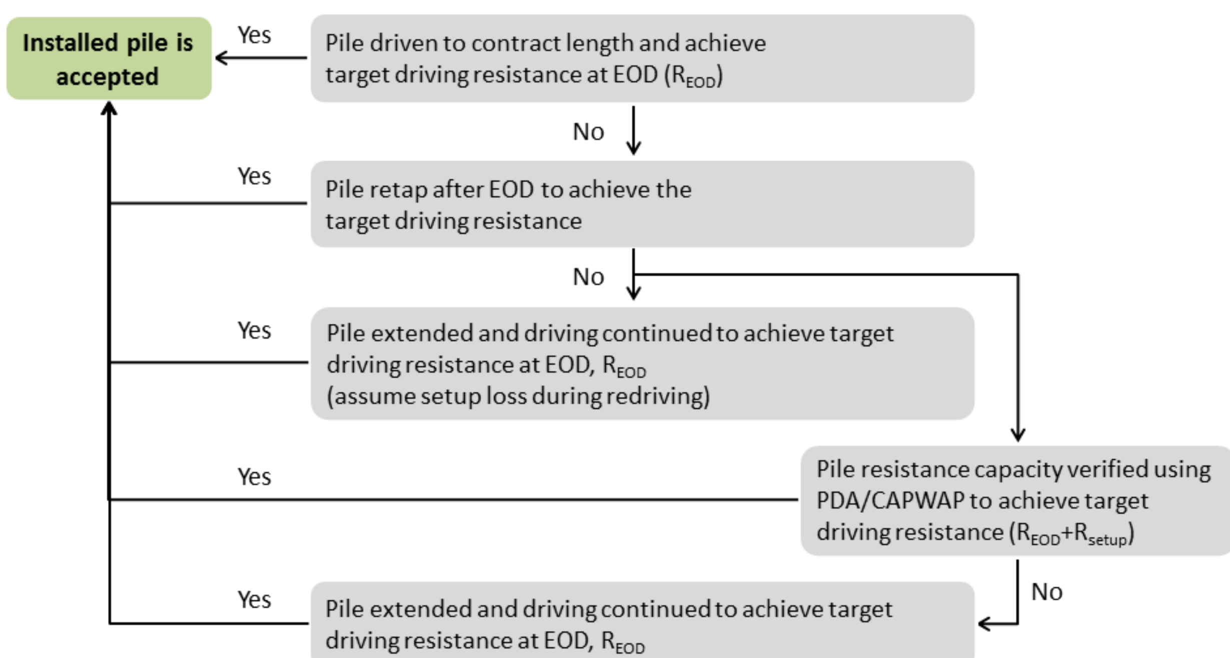
Using the PILOT database and 10 field test results, resistance factors were calibrated for various static analysis methods. Among the various methods, the in-house Iowa "Blue Book" method (based on its Geotechnical Resistance Charts) was recommended for design of steel H-piles. Similarly, resistance factors were calibrated for various pile construction control methods.

Following the examination of efficiencies of different methods and current construction practices in Iowa, the modified Iowa Engineering News Record (ENR) formula, Wave Equation Analysis Program (WEAP), and CAse Pile Wave Analysis Program (CAPWAP) are recommended for the construction control of steel H-piles, while the modified Iowa ENR formula is recommended for the construction control of timber piles.

In addition, LRFD recommendations with consideration of pile setup and construction control were developed.

Results

This volume outlines the concept of three tracks, which highlight options that were identified as acceptable construction control methods (i.e., modified Iowa ENR formula, WEAP, and CAPWAP) from the completed LRFD research project. This volume illustrates the pile design procedures, provides the computer-aided design and drafting (CADD) design notes, and presents the driving notes for the construction of abutment piles and pier piles.



Construction control flow chart for friction piles embedded in cohesive soil and retap performed after end of driving (EOD)

Summary of track examples

Track	Pile Type	Example	Sub-Structure Type	Soil Type	Special Considerations	Construction Controls: Driving Criteria Basis	Construction Controls: Planned Retap 3 Days after EOD
1	H-Pile	1	Integral Abutment	Cohesive	---	Wave Equation	No
		2	Pier	Mixed	Scour		
		3	Integral Abutment	Cohesive	Downdrag		
		4	Pier	Non-Cohesive	Uplift		
		5	Integral Abutment	Cohesive	End Bearing in Bedrock		
	Pipe Pile	6	Pile Bent	Non-Cohesive	Scour		
	Prestressed Concrete Pile	7	Pile Bent	Non-Cohesive	Scour		
2	H-Pile	1	Integral Abutment	Cohesive	---	Modified Iowa ENR Formula	
	Timber	2	Integral Abutment	Non-Cohesive	---		
3	H-Pile	1	Integral Abutment	Cohesive	---	PDA/CAPWAP and Wave Equation	
		2	Integral Abutment	Cohesive	---	Wave Equation	Yes

The application of the LRFD approach is demonstrated using several pile design examples in the three different tracks, depending on the construction control method selected to verify pile resistance in the field. In all cases, piles are designed using the Iowa Blue Book method as recommended in Volume III.

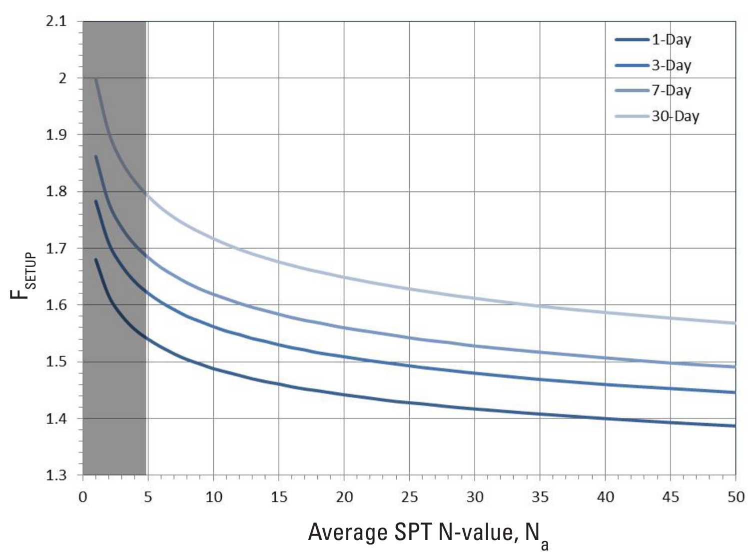
The different track examples cover various pile types, three different soil profiles (cohesive, non-cohesive, and mixed) and special design considerations (piles on rock, scouring, downdrag, and uplift). In each case, all steps required to complete the design and construction control are presented.

Track 1 consists of seven design examples that use WEAP as the construction control method to define the pile driving criteria. The applications of LRFD in the three different soil categories are illustrated in Track 1.

Track 2 consists of two examples that use the modified Iowa ENR formula as the construction control method to define pile driving criteria. The LRFD application to timber piles is also demonstrated in this track.

Track 3 demonstrates two design examples for projects that require special construction control procedures using the Pile Driving Analyzer (PDA)/CAPWAP, WEAP, and/or planned retaps.

Finally, supplementary materials, design formulation, resistance factors, and other recommendations are included in the appendices.



Pile setup factor chart for WEAP as a construction control method

Implementation Benefits

The research outcomes presented in the first three volumes, which culminated in the development of this fourth volume, support the goals in Iowa to produce engineered foundation designs with consistent levels of reliability and to meet the Federal Highway Administration (FHWA) mandate that all new bridges be designed according to the LRFD approach.

Recommended H-pile penetration into bedrock

Rock Classification	Recommended Penetration (ft)
Broken Limestone	8 – 12 (where practical)
Shale or Firm Shale	8 – 12
Medium Hard Shale, Hard Shale, or Siltstone	4 – 8
Sandstone, Siltstone, or Shale (N ≥ 200)	3
Solid Limestone	1 – 3

Resistance factors for design of single pile in axial compression for redundant pile groups (contract length)

<table>
<tr><th rowspan="3">Theoretical Analysis [c]</th><th colspan="5">Construction Control (field verification) [a]</th><th colspan="5">Resistance Factor [b]</th></tr>
<tr><th colspan="2">Driving Criteria Basis</th><th rowspan="2">PDA/ CAPWAP</th><th rowspan="2">Retap Test 3-Days After EOD</th><th rowspan="2">Static Pile Load Test</th><th colspan="3">Cohesive</th><th>Mixed</th><th>Non-Cohesive</th></tr>
<tr><th>Iowa Modified ENR Formula</th><th>WEAP</th><th>φ</th><th>φ_{EOD}</th><th>φ_{setup}</th><th>φ</th><th>φ</th></tr>
<tr><td rowspan="5">Iowa Blue Book</td><td>Yes</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.60</td><td>-</td><td>-</td><td>0.60</td><td>0.50</td></tr>
<tr><td rowspan="4">-</td><td rowspan="4">Yes [d]</td><td>-</td><td>-</td><td>-</td><td>0.65</td><td>-</td><td>-</td><td>0.65</td><td>0.55</td></tr>
<tr><td rowspan="2">Yes</td><td>-</td><td>-</td><td>0.70 [e]</td><td>-</td><td>-</td><td>0.70</td><td>0.60</td></tr>
<tr><td>Yes</td><td>-</td><td>0.80</td><td>-</td><td>-</td><td>0.70</td><td>0.60</td></tr>
<tr><td>-</td><td>-</td><td>Yes</td><td>0.80</td><td>-</td><td>-</td><td>0.80</td><td>0.80</td></tr>
</table>

(a) Determine the construction control that will be specified on the Plans to achieve the Target Nominal Driving Resistance.
(b) Resistance factors are for redundant pile groups defined in Appendix H of the report. Refer to LRFD Report Volume III for resistance factors of non-redundant pile groups. A resistance factor of 1.0 shall be used for extreme event limit state.
(c) Use BDM Article 6.2.7 to estimate the theoretical nominal pile resistance, based on the Iowa Blue Book.
(d) Use the Iowa Blue Book soil input procedure to complete WEAP analyses.
(e) Setup effect has been included when WEAP is used to establish driving criteria and CAPWAP is used as a construction control.

Resistance factors for construction control for redundant pile groups

<table>
<tr><th rowspan="3">Theoretical Analysis [c]</th><th colspan="5">Construction Control (field verification) [a]</th><th colspan="5">Resistance Factor [b]</th></tr>
<tr><th colspan="2">Driving Criteria Basis</th><th rowspan="2">PDA/ CAPWAP</th><th rowspan="2">Retap Test 3-Days After EOD</th><th rowspan="2">Static Pile Load Test</th><th colspan="3">Cohesive</th><th>Mixed</th><th>Non-Cohesive</th></tr>
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<tr><td rowspan="6">Iowa Blue Book</td><td>Yes</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.55 [f]</td><td>-</td><td>-</td><td>0.55 [f]</td><td>0.50 [f]</td></tr>
<tr><td rowspan="5">-</td><td rowspan="5">Yes [d]</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.65</td><td>0.20</td><td rowspan="2">0.65</td><td rowspan="2">0.55</td></tr>
<tr><td rowspan="2">-</td><td>Yes</td><td>-</td><td>0.70</td><td>-</td><td>-</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>0.75</td><td>0.40</td><td rowspan="2">0.70</td><td rowspan="2">0.70</td></tr>
<tr><td>Yes [e]</td><td>Yes</td><td>-</td><td>0.80</td><td>-</td><td>-</td></tr>
<tr><td>-</td><td>-</td><td>Yes</td><td>0.80</td><td>-</td><td>-</td><td>0.80</td><td>0.80</td></tr>
</table>

(a) Refer to the Plans for the specified construction control that is required to achieve the Target Nominal Driving Resistance.
(b) Resistance factors are for redundant pile groups defined in Appendix H of the report. Refer to LRFD Report Volume III for resistance factors of non-redundant pile groups.
(c) Use BDM Article 6.2.7 to estimate the theoretical nominal pile resistance, based on the Iowa Blue Book.
(d) Use the Iowa Blue Book soil input procedure to complete WEAP analyses.
(e) Use signal matching to determine Nominal Driving Resistance.
(f) Reduce the resistance factor to 0.35 for redundant groups of driven timber pile, if the modified Iowa ENR formula is used for construction control. This is based on Iowa historic timber pile test data. For WEAP construction control to drive timber pile, the resistance factor may be taken as 0.40.