Report No. K-TRAN: KU-13-4 ▪ FINAL REPORT ▪ February 2014

Load and Resistance Factor Design Calibration to Determine a Resistance Factor for the Modification of the Kansas Department of Transportation-Engineering News Record Formula

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A cooperative transportation research program between
Kansas Department of Transportation,
Kansas State University Transportation Center, and
The University of Kansas

Kansas Department of Transportation

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1 Report No. K-TRAN: KU-13-4	**2 Government Accession No.**	**3 Recipient Catalog No.**

4 Title and Subtitle
Load and Resistance Factor Design Calibration to Determine a Resistance Factor for the Modification of the Kansas Department of Transportation-Engineering News Record Formula

5 Report Date
February 2014

6 Performing Organization Code

7 Author(s)
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8 Performing Organization Report No.

9 Performing Organization Name and Address
The University of Kansas
Civil, Environmental & Architectural Engineering Department
1530 West 15th Street
Lawrence, Kansas 66045-7609

10 Work Unit No. (TRAIS)

11 Contract or Grant No.
C1927

12 Sponsoring Agency Name and Address
Kansas Department of Transportation
Bureau of Research
2300 SW Van Buren Street
Topeka, Kansas 66611-1195

13 Type of Report and Period Covered
Final Report
May 2012–February 2014

14 Sponsoring Agency Code
RE-0603-01

15 Supplementary Notes
For more information, write to address in block 9.

16 Abstract
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17 Key Words LRFD, Load and Resistance Factor Design, Resistance Factor, Pile PDA, Pile Driving Analyzer, Pile Driving	**18 Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19 Security Classification (of this report) Unclassified	**20 Security Classification (of this page)** Unclassified	**21 No. of pages** 71	**22 Price**

Form DOT F 1700.7 (8-72)

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A Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

THE UNIVERSITY OF KANSAS
LAWRENCE, KANSAS

February 2014

PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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Abstract

This report contains the results of a study describing the development of resistance factors for use with the Kansas Department of Transportation (KDOT) Engineering News Record (ENR) formula for driven piles. KDOT has verified driven pile resistance for many years using a version of the ENR formula. This formula yields estimates of nominal resistance values that are much lower than the actual resistance, based on department experience and comparisons with other resistance measurement methods. For this study actual ENR resistance estimates were compared with estimates obtained using a pile driving analyzer (PDA) system. The PDA values were taken as the true capacity. There were 175 end-of-drive data points and 189 restrike data points available for statistical analysis. A set of correction (resistance) factors to be used with the ENR formula was developed, with individual factors based on given probabilities of pile failure (capacity being exceeded).

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Chapter 1: Introduction

The Kansas Department of Transportation (KDOT) has, in recent years, used a variation of the Engineering News Record (ENR) formula to determine the capacity of piles in the field. It was a concern that the KDOT-ENR formula was under-predicting actual pile capacity.

KDOT has used the Pile Driving Analyzer (PDA) in the field since 1986 for at least 246 pile-driving operations. It was consistently noted that the PDA- and Case Pile Wave Analysis Program- (CAPWAP) predicted capacity was significantly greater than KDOT-ENR-predicted capacity. Therefore, the objective of this analysis was to compare available KDOT-ENR data to PDA and CAPWAP data in order to arrive at a revised version of the KDOT-ENR formula. This formula should more closely approach the PDA- and/or CAPWAP-predicted capacity, which is considered more indicative of the true capacity of the pile (Likins 2004). The objective was to arrive at a resistance factor that is a multiplier coefficient added to the existing KDOT-ENR formula.

This research involved statistical analysis of KDOT-ENR, PDA, and CAPWAP data using the Monte Carlo Method, as described in the Transportation Research Board's Transportation Research Circular by Allen et al. (2005).

A revised KDOT-ENR formula could provide a significant reduction in the cost of pile installation. If the current KDOT-ENR formula consistently under-predicts pile capacity in the field, piles are being driven to a capacity that is overly conservative. By applying a calibrated factor to the existing formula, piles will be credited with reaching the design resistance at shallower depths, resulting in savings on materials and labor.

KDOT provided pile data to researchers at the University of Kansas in May of 2012. These data were collected by KDOT from 1986-2012 from 54 bridge sites around the state of Kansas. The information provided by KDOT consisted of Bridge Foundation Geology Reports, PDA Reports, CAPWAP files, PDA files, and other related documentation.

Information was available for end-of-drive piles and restrikes. Some piles did not require a restrike if capacity was gained at the end of the initial drive. In cases where the pile did not gain the necessary capacity, a restrike test was usually performed 15 minutes or more after the initial drive. In most cases, the restrike drive resulted in a higher predicted capacity due to the effects of soil setup.

End-of-drive capacity was determined by the movement (set) in the last 20 blows of driving. The restrike capacity was determined by the movement of the pile in the first five blows of driving. In some cases, the first five blows did not provide a reliable estimate, so the first 20 blows were used to determine restrike capacity.

All relevant information was entered into a Microsoft Access database. The piles that had a KDOT-ENR-reported capacity and a PDA- and/or CAPWAP-reported capacity were analyzed. Ultimately, there were 175 end-of-drive data points and 189 restrike data points available for statistical analysis. This resulted in 364 sets of data points, or biases, available for analysis.

Of the 246 piles entered into the database, 223 were H-piles, 13 were pipe piles, and 10 were concrete piles.

Two different types of pile-driving hammers were used by KDOT in the majority of the cases: Delmag/APE (diesel) hammers and gravity hammers. Piles driven with other types of hammers were excluded from this analysis because there were not enough data. KDOT utilizes a different pile-driving formula for diesel and gravity hammers.

For the end-of-drive piles, there were 164 data points for Delmag/APE hammers and 11 data points for gravity hammers. For the restrike analysis, data points for the 189 Delmag/APE hammers were analyzed. There were only six data points for the gravity hammer restrikes, so these data points were eliminated from analysis.

The cases that did not have a reported KDOT-ENR capacity were excluded. For both end-of-drive and restrike piles, there were 106 cases that did not include the KDOT-ENR formula's predicted capacity. Likewise, there were 24 cases that did not include PDA- or CAPWAP-predicted capacity, and there was not enough information available to accurately estimate it.

Performing the back-calculation for KDOT-ENR formula may have introduced an element of error, so it was decided to exclude those cases from the study. Since the KDOT-ENR was normally calculated in the field, generally by the same two or three investigators, it was decided that performing a back-calculation was not acceptable and may not produce consistent results.

A detailed list of all the pile cases is shown in Appendix A.

Chapter 2: Literature Review

Other states that have performed related research include Wisconsin, Nebraska, Florida, and Washington. This section summarizes the research done by these states.

2.1 Wisconsin Highway Research Program

This study was conducted by researchers at the University of Illinois at Urbana-Champaign for the Wisconsin Department of Transportation (WisDOT). The analysis consisted of comparing five different widely used methods for determining pile-bearing capacity. The methods analyzed were the Wisconsin ENR (used at the time by WisDOT), the FHWA-Gates formula, the Pile-Driving Analyzer, and a formula developed by the Washington State Department of Transportation (WSDOT). The study concluded that a “corrected” version of the FHWA-Gates formula and the WSDOT formula predicted capacity most accurately.

The study had the advantage of having static-load test data available for a large number of cases so that a comparison could be made to predicted capacities. Major emphasis was given to the cases with static-load results. In their nationwide database there were 156 static-load tests.

The variable Q_P represents the predicted capacity for each method, whereas Q_M represents the measured capacity by the static-load test. A ratio of Q_P/Q_M was determined, which indicates how accurately a method was able to predict capacity relative to the static-load test. The following statistics were determined for each method’s Q_P/Q_M ratio (Long 2009).

TABLE 2.1
Statistics for Select Methods Examined in Wisconsin Study

Mean	COV	Method
0.43	0.47	Wisc-EN
1.11	0.39	WSDOT
1.13	0.42	FHWA-Gates
0.73	0.40	PDA
1.20	0.40	FHWA-Gates for piles < 750 kips
1.02	0.36	“Corrected” FHWA-Gates for piles > 750 kips

Pile-driving formulas analyzed in the Wisconsin study include:

2.1.1 Wisc-EN Formula

$$Q_{\text{all}} = \frac{2WH}{(s+c)}$$

where Q_{all} = the allowable pile load (safe bearing load in kips), W = weight of hammer (kips), H= drop of hammer (feet), s = pile penetration for the last blow (inches) and c is a constant equal to 0.2 for air/steam and diesel hammers. This formula is the basic ENR formula with an implicit factor of safety of 6.0 and a c value of 0.2 instead of 0.1.

2.1.2 Washington State Department of Transportation (WSDOT) Equation

The original intention of the Washington DOT was to improve the Gates Formula, but significant changes were made. The WSDOT method is given as:

$$R_n = 6.6\, F_{\text{eff}} WH \ln(10N)$$

where R_n = ultimate axial pile capacity (kips), F_{eff} = a hammer efficiency factor based on hammer and pile type, W = weight of hammer (kips), H = drop of hammer (feet), and N=average penetration resistance in blows/inch at the end of driving.

2.1.3 FHWA-Modified Gates Equation (USDOT)

$$R_u = 1.75 \sqrt{eE_r} \log (10N_b) - 100$$

where R_u = ultimate pile capacity (kips), e = hammer efficiency, E_r = energy of the pile-driving hammer (ft-lb), and N_b = the number of blows required to penetrate the pile one inch.

2.2 Nebraska Department of Roads

In 2007, researchers at the University of Nebraska-Lincoln analyzed data from static-load tests, CAPWAP, Wave equation, Gates formula, and the Nebraska modified ENR formula. According to the published report, an LRFD calibration was performed, and a formula was proposed that was in agreement with CAPWAP results. The proposed formula was a variation of the ENR formula and is as follows:

$$P = \frac{6E}{(S+0.5)}$$

Where P is the nominal pile capacity in kips, S is the average penetration in inches of the pile per blow for the last ten blows for steam or diesel hammers, and E is the energy per blow in foot-kips. This formula applies to both concrete and steel piles and does not depend on the type of soil. The researchers found that the results based on the proposed formula are closer to CAPWAP than the Nebraska Department of Roads (NDOR) equation (Nowak 2007).

2.3 Florida Department of Transportation

The University of Florida-Gainesville performed an analysis delivered in August 2002 to the Florida Department of Transportation (FDOT). Many available dynamic and static pile-prediction formulas and methods were evaluated in this study. The database contained 175 Florida-driven piles and 53 non-Florida-driven piles. The type of piles used were concrete and H-piles. In contrast to KDOT, which used a majority of H-piles, FDOT had a majority of concrete piles. For the Florida-driven piles, 162 of the 175 piles were concrete and 13 were pipe piles.

For the LRFD calibration, the Davisson capacity was taken as the measured capacity. This capacity was used as the measure of true capacity to which to compare the dynamic methods. The dynamic methods analyzed were ENR, modified ENR, the Paikowsky method, CAPWAP, PDA, Gates, FDOT, and the Japanese energy method.

It was concluded that ENR and modified ENR significantly under-predict capacity compared to the Davisson method. On the other hand, the Paikowsky method had an excellent correlation with the Davisson method (ratio close to one), but had a larger standard deviation, indicating that the scatter of the data is larger. The CAPWAP prediction was found to under-predict capacity at end-of-drive and is more accurate for beginning-of-restrike conditions.

The Florida study, as well as the Wisconsin study documented previously, made a distinction between accuracy of various equations or methods based on an upper limit of capacity. For the Florida study, it was noted that ENR, modified ENR, Gates, and FDOT correlated closely with the Davisson capacity if the capacity was less than 200 tons (400 kips). In the past, loading demand on piles rarely exceeded 200 tons, so this finding is understandable, considering that the four methods mentioned are older methods (McVay 2002).

2.4 Washington State Department of Transportation

The Washington Department of Transportation (WSDOT) published a report in 2005 summarizing its research on driven piles and exploration into a new formula. Prior to 1997, WSDOT used the ENR formula for driving piling to the design capacity. It was their original intention to develop a formula similar to the Gates formula, but the recommended formula had significant differences.

A Monte Carlo simulation was performed to determine resistance factors.

Once the WSDOT driving formula had been developed, statistical parameters were established to be used in reliability analyses to determine resistance factors for LRFD. The Monte Carlo method was used to perform the reliability analyses. The study analyzed other driving methods, and it was determined that the WSDOT formula produced the most efficient result, with a resistance factor of 0.55 to 0.60. The research also determined that dynamic measurement during pile driving using the PDA and CAPWAP produced the most efficient result of all the pile resistance prediction methods, with a resistance factor of 0.70 to 0.80 (Allen 2005).

The WSDOT equation is restated as follows:

$$R_n = 6.6\, F_{eff} W H \ln(10N)$$

where R_n = ultimate axial pile capacity (kips), F_{eff} = a hammer efficiency factor based on hammer and pile type, W = weight of hammer (kips), H = drop of hammer (feet), and N = average penetration resistance in blows/inch at the end of driving.

Chapter 3: KDOT's Bearing Capacity Formula

KDOT's dynamic pile-driving formula for Delmag and APE diesel hammers is given by:

$$P_u = \frac{1.6WH}{(s+0.1\left(\frac{X}{W}\right))}$$

- P_u = formerly pile capacity and currently the target nominal capacity (R_n, see page 11)
- W = Weight of the piston, given in the hammer specifications (kips)
- H = Maximum hammer drop (in feet)
- s = Set per hammer blow, for last 20 blows for EOD and first five blows for restrike (inches)
- X = Weight of pile + weight of pile cap and/or anvil (kips)
- Note that the units of H (height of stroke) and s (set, per hammer blow) are entered into the formula in different units. H is entered in feet, and s is entered in inches.
- A factor of safety of 7.5 is built into this formula. Since the units of the numerator are ft-kips, and the units of the denominator are inches, the factor of safety is determined as 12/1.6 = 7.5.

The ENR formula, which was proposed by A.M. Wellington in 1888 (Coduto 2001 after Wellington), is given by:

$$P_u = \frac{W_r H}{F(s+c)}$$

- W_r = weight of the hammer ram
- H = distance of the hammer stroke
- F = a factor of safety, which is commonly taken as 6.0
- s = pile set (penetration) in inches
- H and S are required to be in identical units
- c = a constant, often taken as 0.1 for single acting hammers (Coduto, 2001)

Chapter 4: Pile-Driving Analyzer (PDA)

The Pile-Driving Analyzer (PDA) has been widely used around the world for nearly 30 years. Accelerometers and strain transducers are attached to the pile before driving. The PDA gathers force and velocity data in the pile from the blow and generates a pile capacity from the field. The system is also capable of monitoring shaft integrity and investigating driving stresses and hammer energy during driving (Soil Dynamics 2008).

KDOT has used the PDA in at least 246 pile tests since 1986. In earlier cases, PDA capacity was reported without a later CAPWAP software analysis. For this study, the KDOT-ENR-predicted capacity was compared to the PDA-predicted capacity if the CAPWAP-predicted capacity was not available.

4.1 Case Pile Wave Analysis Program (CAPWAP)

CAPWAP (**Ca**se **P**ile **W**ave **A**nalysis **P**rogram) software (Version 2006) is used by KDOT to analyze pile capacity in the office after pile installation. The PDA gathers force and velocity data, which are provided as inputs for the CAPWAP analysis. It involves applying the measured pile top force and velocity-time as a boundary condition to a wave-equation model of the pile. The program generates estimates for total pile bearing capacity, resistance distribution along the pile, and more (Soil Dynamics 2008).

For this study, in cases where necessary information was not provided in KDOT's PDA report, CAPWAP software was utilized to determine information such as ultimate PDA capacity, match quality (MQ), damping factors, toe capacity, and side capacity.

4.2 Load and Resistance Factor Design (LRFD)

For KDOT's pile-design practice, the Geology unit recommends a pile-tip elevation and calculates a nominal pile resistance. The nominal resistance is estimated using static pile-capacity resistance formulas. The nominal resistance incorporates only field investigation data and not test-pile data. At this stage, neither KDOT-ENR nor PDA data is used. Geology determines the appropriate resistance factor and applies it to the nominal resistance, and the factored resistance is then provided to Design.

Bridge Design then divides the factored load ($\gamma_Q Q_n$), which it has calculated, by the factored pile resistance provided by Geology. Design rounds this value up to the nearest whole number to determine the minimum number of piles required for the project. Design divides the factored load by the actual number of piles to determine the minimum factored resistance required for each pile (R_f). Design specifies pile locations and calculates pile lengths based on the embedded pile length between the cutoff elevations and the tip elevations. These pile lengths and the required factored pile resistances are provided to Construction.

Construction supervises pile installation and monitors nominal (actual) resistance of each pile using the Pile Driving Analyzer (PDA) in select cases and the KDOT-ENR formula in all cases. Driving is halted when the target nominal resistance is achieved (R_n). The target nominal resistance is determined from the factored resistance (R_f), which was provided by Design, using one of the following equations:

PDA: $R_n = \frac{R_f}{\emptyset_R}$ **KDOT-ENR*:** $\frac{1.6WH}{(s+0.1\left(\frac{X}{W}\right))}$ **KDOT-ENR**:** $\frac{3*W*H}{s+0.35}\left(\frac{W}{(W+X)}\right)$

$\Phi_R \leq 0.65$

* This version is used for diesel hammers, such as Delmag and APE.

** This version is used for gravity hammers.

4.3 The KDOT Database

All relevant data that were available were entered into the Microsoft Access database. KDOT provided geology reports (BFGRs), PDA reports, CAPWAP files, and other relevant information.

The database contained four main tables, with each table's fields shown below.

1. Project Information:
    a. Project number;

b. County where the pile was driven;
c. Route (or the nearest major roadway, highway or interstate);
d. Units of measurement (English or Metric);
e. Bridge Design Engineer; and
f. Field Geologist

2. Structure:
   a. Bridge Serial Number;
   b. Date of the Bridge Foundation Geology Report;
   c. Mile Post;
   d. Crossing Type (whether the pile was driven into water or grade);
   e. Groundwater elevation;
   f. Phi factors (φ) used for the abutment and/or pier;
   g. Contractor;
   h. Checkboxes for types of geotechnical testing performed;
   i. Checkboxes for types of bedrock encountered (Shale, Ogallala, Chalk);
   j. Toe material; and
   k. Checkboxes for types of soil encountered (sand, clay, silt, cemented soils, gravel).

3. Test Pile:
   a. Time and date the pile was driven;
   b. Element type and number (such as Pier 1 or Abutment 2);
   c. Bent/group (one is selected);
   d. Pile type (Pipe, H-Pile, or Concrete);
   e. Pile size;
   f. Cutoff elevation;
   g. Plan-tip elevation;
   h. Mantle bedrock elevation;
   i. Ground elevation;

j. Scour elevation;
k. Factored/allowable Load;
l. Factored/design Load;
m. Bearing formula EOD (the KDOT-ENR capacity determined in the field, entered in tons or kN);
n. PDA-predicted capacity determined in the field (entered in kips or kN);
o. PDA-predicted toe capacity (entered in kips or kN);
p. Friction/end bearing;
q. PDA geologist;
r. Movement in last 20 blows (entered in inches or mm);
s. Stroke of hammer (in feet or mm);
t. Pile penetration;
u. Recommended length of pile;
v. Hammer type and size;
w. Average ETR (Energy-Transfer Ratio);
x. Dampening factor; and
y. CAPWAP Match Quality.

4. Restrike:
    a. Restrike date and time;
    b. Restrike Bearing Formula (KDOT-ENR);
    c. Pile movement in last 5 blows;
    d. Pile movement in last 20 blows;
    e. Stroke of hammer (in feet or meters);
    f. Average ETR (Energy-Transfer Ratio);
    g. PDA-predicted capacity;
    h. Restrike toe capacity;
    i. Restrike dampening factor; and
    j. CAPWAP Match Quality.

Chapter 5: Data Analysis

There were 246 end-of-drive cases. Of these, 175 were able to be used for this study. There were 68 cases that were excluded due to missing KDOT-ENR-predicted capacity, PDA/CAPWAP-predicted capacity, or a hammer type other than diesel/gravity. There were an additional five cases performed by a Vulcan or Conmaco hammer. These were excluded because there were not enough cases to perform statistical analysis. Of the 175 pile cases, 164 were performed with a Delmag/APE diesel hammer, and 11 were performed with a Gravity hammer. These were analyzed separately because the KDOT formula is different depending on the type of hammer.

The data were grouped in two subsets according to whether the reported capacity was given by the PDA or determined by CAPWAP software. The PDA- or CAPWAP-predicted capacity was divided by the KDOT-ENR-predicted capacity to result in a bias value.

Figure 5.1 shows the distribution of the bias values (PDA/KDOT-ENR and CAPWAP/KDOT-ENR), which closely resembles a lognormal distribution. Figure 5.2 is a histogram showing the biases of only the PDA cases, and Figure 5.3 is a histogram showing the biases of only the CAPWAP cases.

The mean bias for end-of-drive piles using the PDA-predicted capacity was found to be 2.49 with a COV of 0.328. The mean bias for end-of-drive piles using the CAPWAP-predicted capacity was found to be 2.38 with a COV of 0.256. When PDA-predicted and CAPWAP-predicted biases were combined, the mean bias was found to be 2.41 with a COV of 0.285.

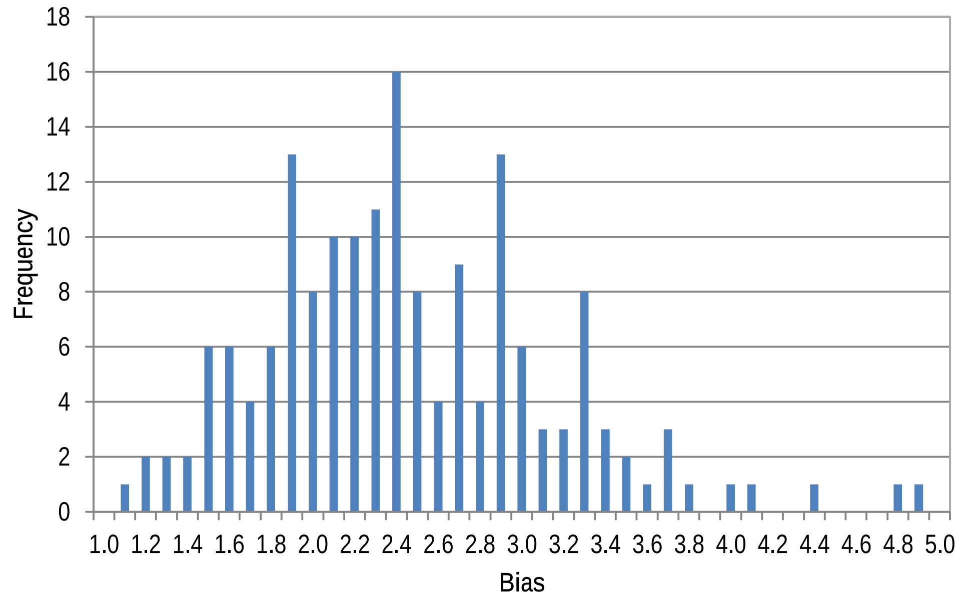

FIGURE 5.1
(CAPWAP or PDA)/KDOT-ENR Bias Distribution for 164 End-of-Drive Piles Driven by Diesel Hammers

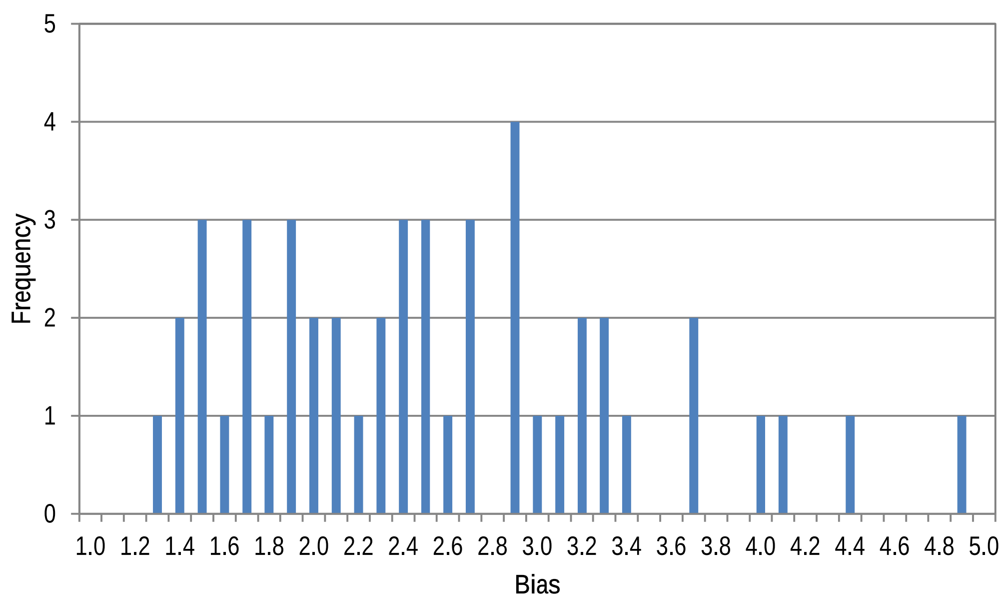

FIGURE 5.2
PDA/KDOT-ENR Bias Distribution for 48 End-of-Drive Piles Driven by Diesel Hammers

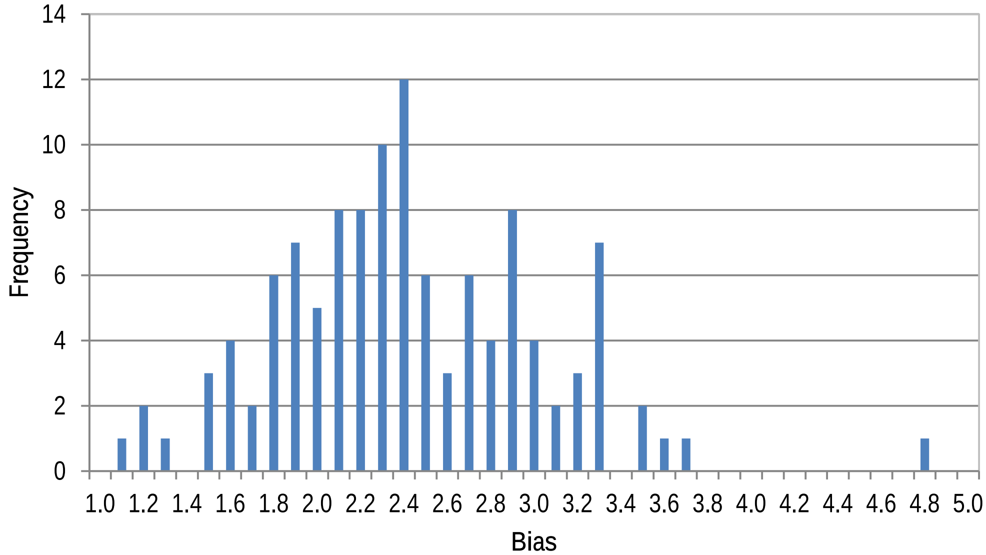

FIGURE 5.3
CAPWAP/KDOT-ENR Bias Distribution for 116 End-of-Drive Piles Driven by Diesel Hammers

Figure 5.4 shows the data points of CAPWAP and PDA versus KDOT-ENR with a trendline and a 1:1 line, for which the PDA/CAPWAP capacity would be equivalent to the KDOT-ENR capacity. Figures 5.5 and 5.6 show the data points of the PDA versus KDOT-ENR and CAPWAP versus KDOT-ENR, respectively.

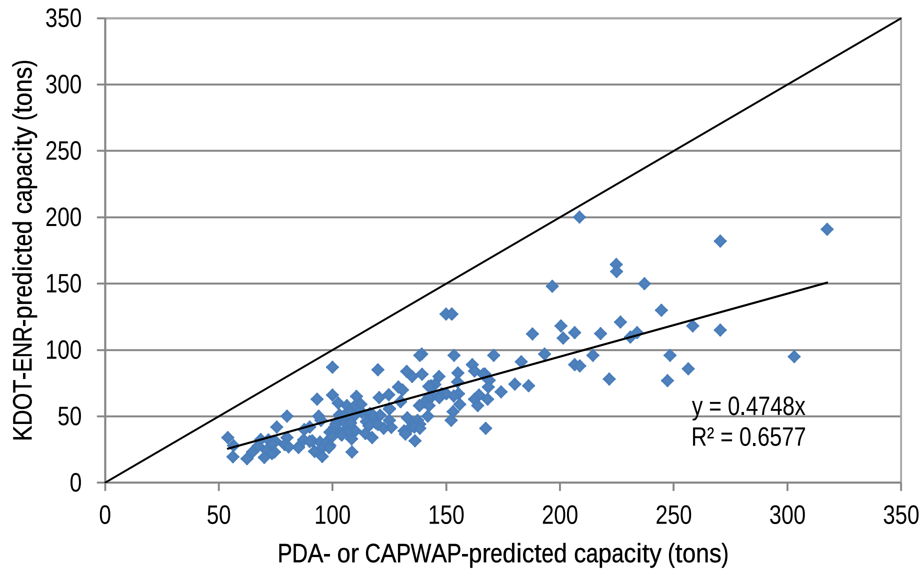

FIGURE 5.4
End-of-Drive Data for 164 Piles Driven by Diesel Hammers

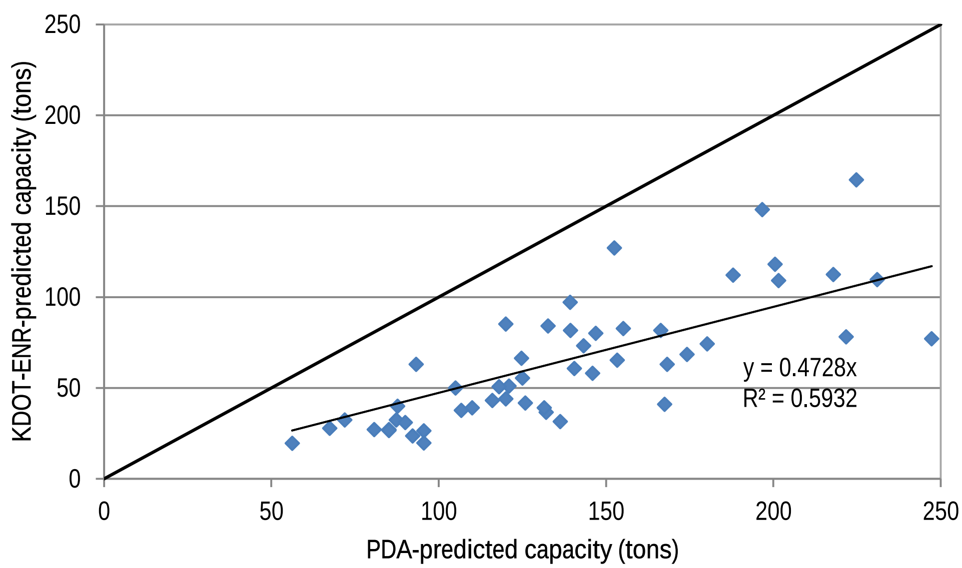

FIGURE 5.5
End-of-Drive Data for 48 Piles Driven by Diesel Hammers

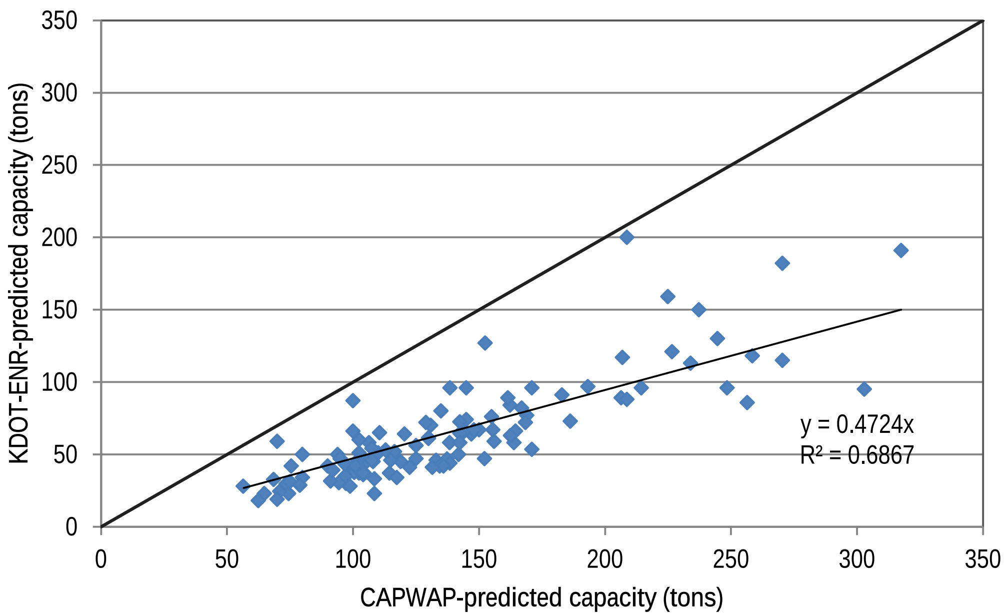

FIGURE 5.6
End-of-Drive Data for 116 Piles Driven by Diesel Hammers

The standard normal variable plot for end-of-drive piles driven with a diesel hammer is shown in Figure 5.7. Figures 5.8 and 5.9 show the standard normal variable plot for the PDA biases and the CAPWAP biases, respectively.

The predicted lognormal and normal distributions are shown on this plot for comparison. By visual inspection of Figure 5.7, the biases in the tail region align more closely with the lognormal distribution.

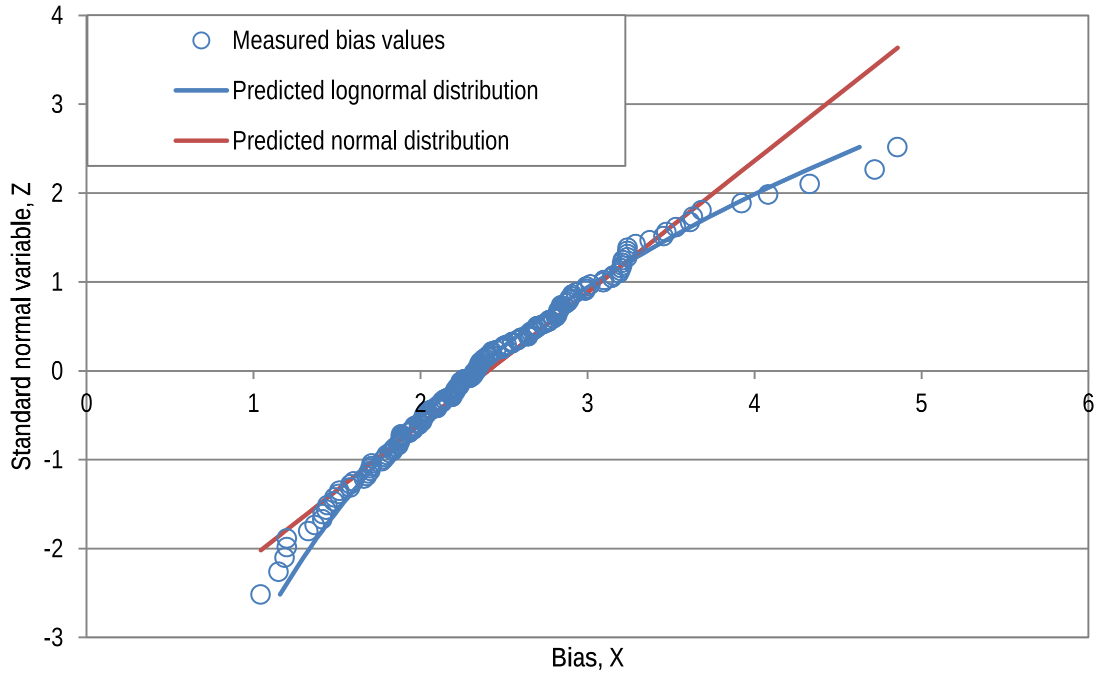

FIGURE 5.7
Standard Normal Variable for 164 End-of-Drive Biases (PDA and CAPWAP), Driven by Diesel Hammers

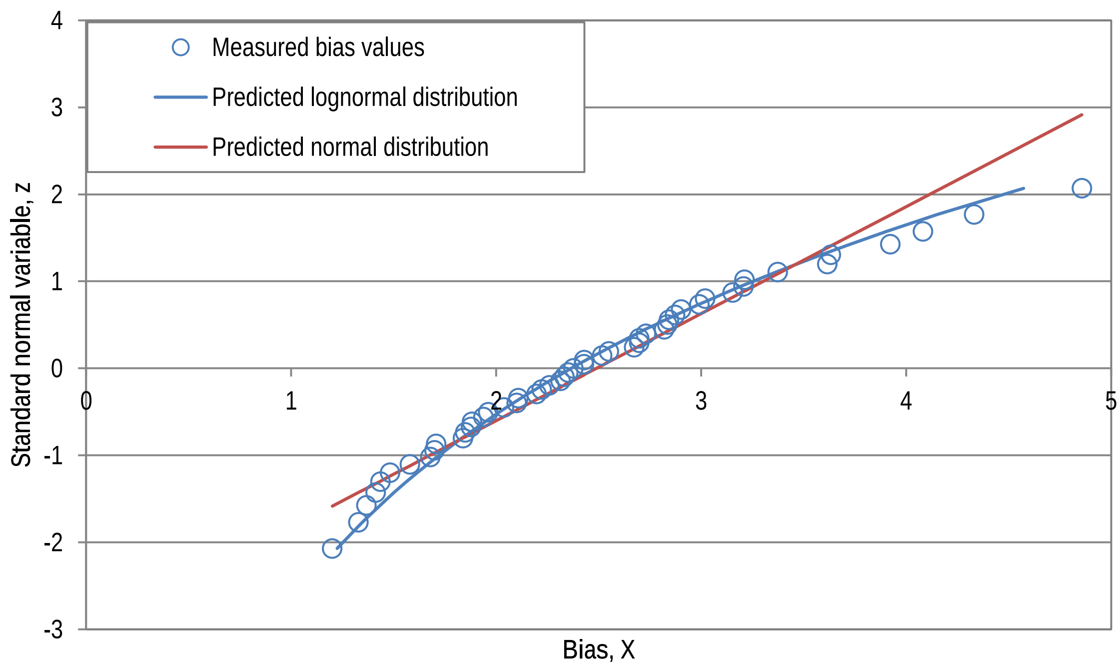

FIGURE 5.8
Standard Normal Variable for 48 End-of-Drive PDA/KDOT-ENR Biases, Driven by Diesel Hammers

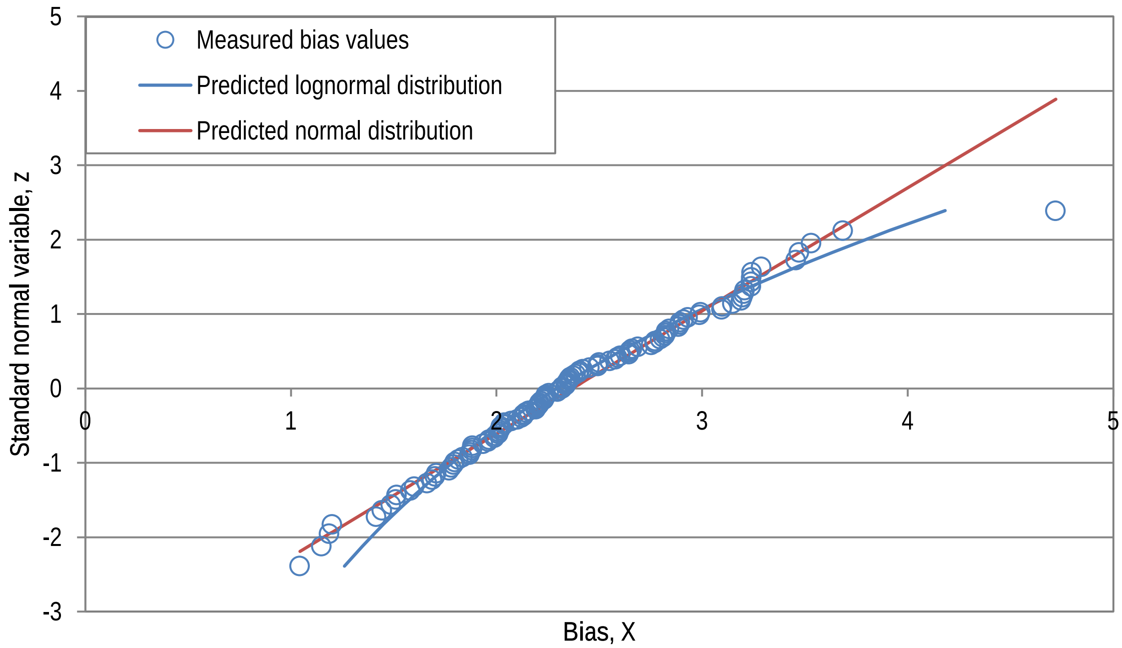

FIGURE 5.9
Standard Normal Variable for 116 End-of-Drive CAPWAP/KDOT-ENR Biases, Driven by Diesel Hammers

The equations for calculating the lognormal mean μ_{ln} and lognormal standard deviation σ_{ln}, which were used to produce the predicted lognormal distribution curve, can be found in the Transportation Research Circular E-C079 (Allen et al. 2005). They are reproduced here as follows:

$$\mu_{ln} = LN(\mu_s) - 0.5\sigma_{ln}^2$$

$$\sigma_{ln} = (LN((\sigma/\mu_s)^2 + 1))^{0.5}$$

where μ_s is the normal mean, σ is the normal standard deviation, and LN is the natural logarithm (base e).

From these equations, the lognormal distribution of the bias as a function of z can be calculated as follows:

$$\text{Bias} = X = EXP(\mu_{ln} + \sigma_{ln} z)$$

The variable z is the standard normal variable and is calculated using the CDF (cumulative distribution function). Each data point was sorted in increasing order, with rank i, and z was found for each data point using an Excel function, as follows:

$$z = \Theta^{-1}(p) = \mathrm{NORMSINV}(i/(n+1))$$

where n is the number of data points in the set.

The predicted normal distribution curve was produced by graphing bias values on the x-axis and z values on the y-axis, with z determined as follows:

$$z = \frac{X - \mu}{\sigma}$$

where X is each bias value, μ is the mean, and σ is the standard deviation.

Figure 5.10 shows the bias distribution for the 11 end-of-drive piles driven with a gravity hammer. Figure 5.11 shows the data distribution (PDA- or CAPWAP-predicted capacity versus KDOT-ENR-predicted capacity) for the EOD gravity piles. The mean bias value for gravity hammers was 2.57 and the COV was 0.133.

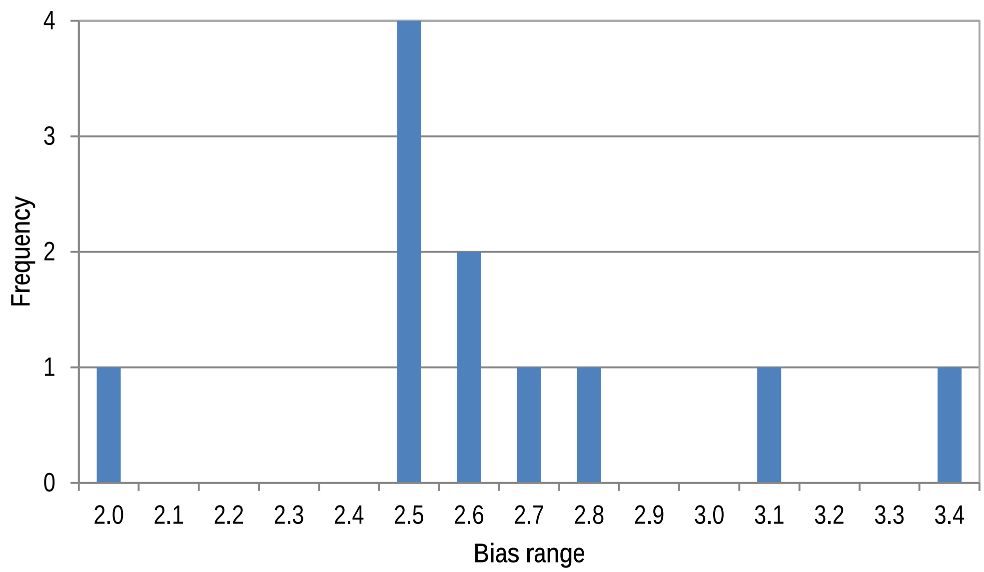

FIGURE 5.10
Bias Distribution for 11 End-of-Drive Piles Driven by Gravity Hammers

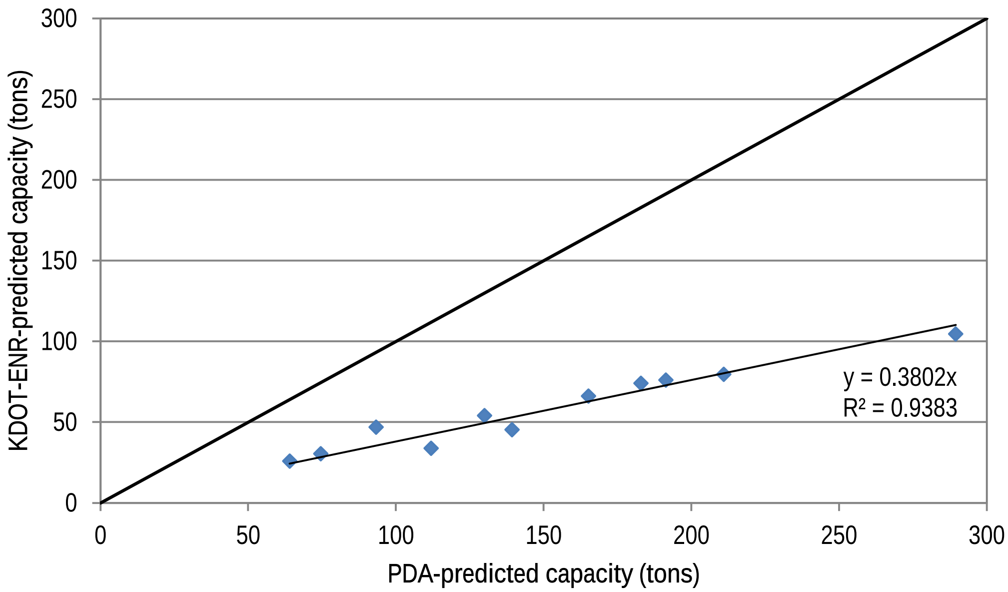

FIGURE 5.11
Data Points for 11 End-of-Drive Piles Driven by Gravity Hammers

Figure 5.12 is a graph of the standard normal variable for the gravity hammers. It can be seen that the data for the gravity piles do not align with either the normal or lognormal distribution lines shown in the graph, but this is not unusual given the relatively small number of data points available.

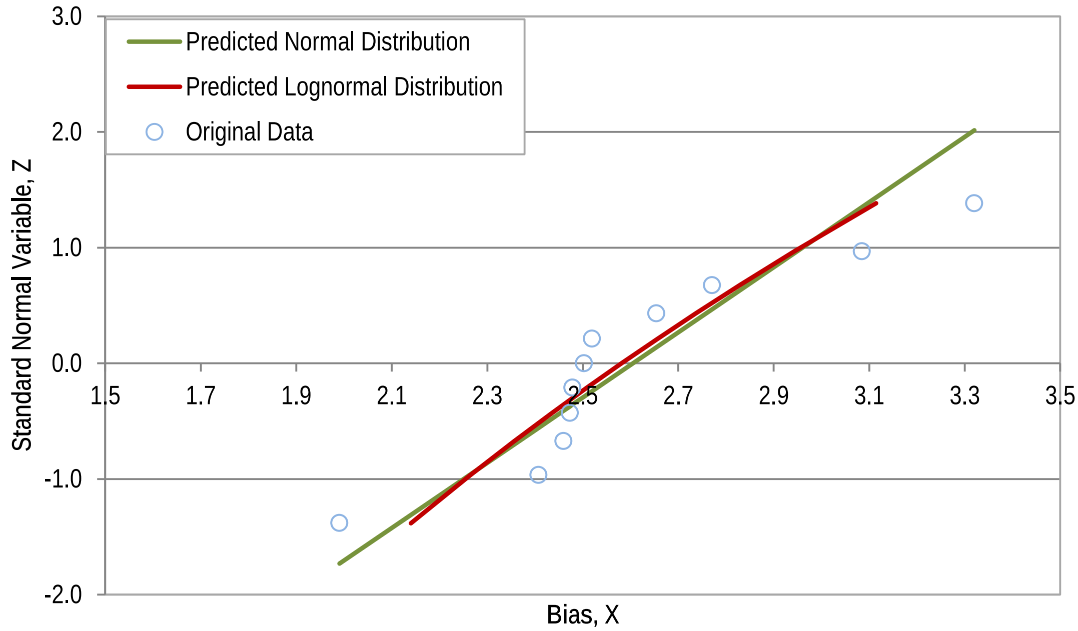

FIGURE 5.12
Standard Normal Variable for 11 End-of-Drive Piles Driven by Gravity Hammers

Figure 5.13 is a histogram of the biases of all the restrike piles. There were a total of 189 restrikes driven by diesel hammers. Of these, 29 yielded a PDA-predicted capacity and 160 yielded a CAPWAP-predicted capacity. Only diesel hammers were analyzed for restrikes since there were not enough data points for the other hammer types. Figures 14 a nd 15 di vide the restrike data into biases for the PDA-predicted/KDOT-ENR-predicted capacity and CAPWAP-predicted/KDOT-ENR-predicted capacity. The histograms all appear to display lognormal behavior.

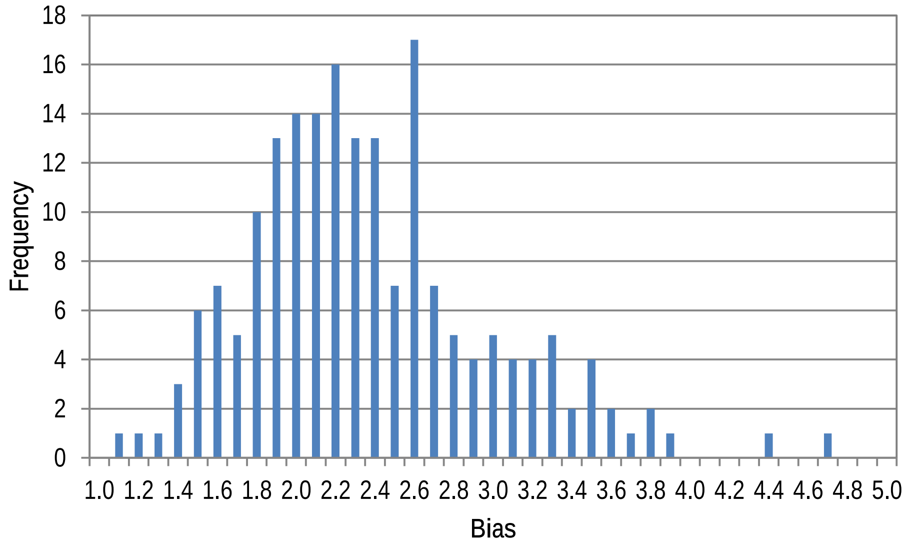

FIGURE 5.13
(CAPWAP or PDA)/KDOT-ENR Bias Distribution for 189 Restrikes Driven by Diesel Hammers

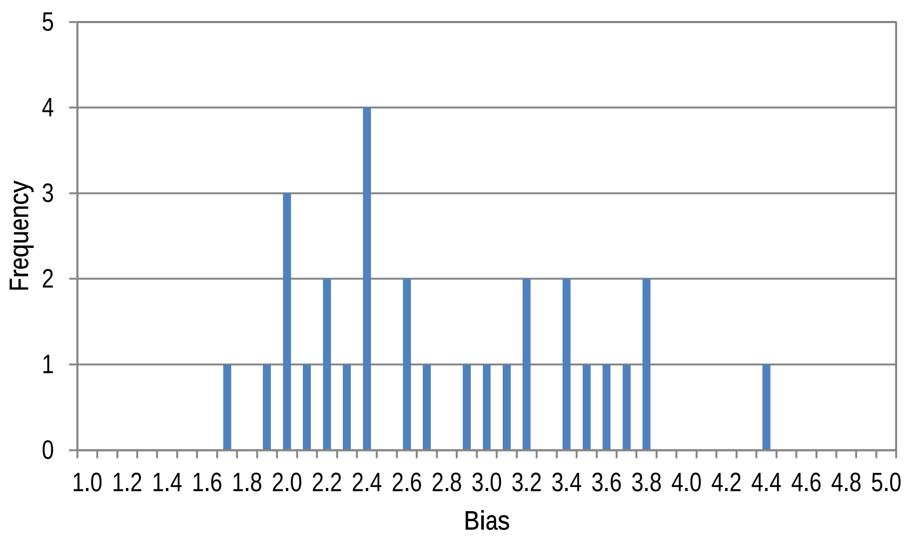

FIGURE 5.14
PDA/KDOT-ENR Bias Distribution for 29 Restrikes Driven by Diesel Hammers

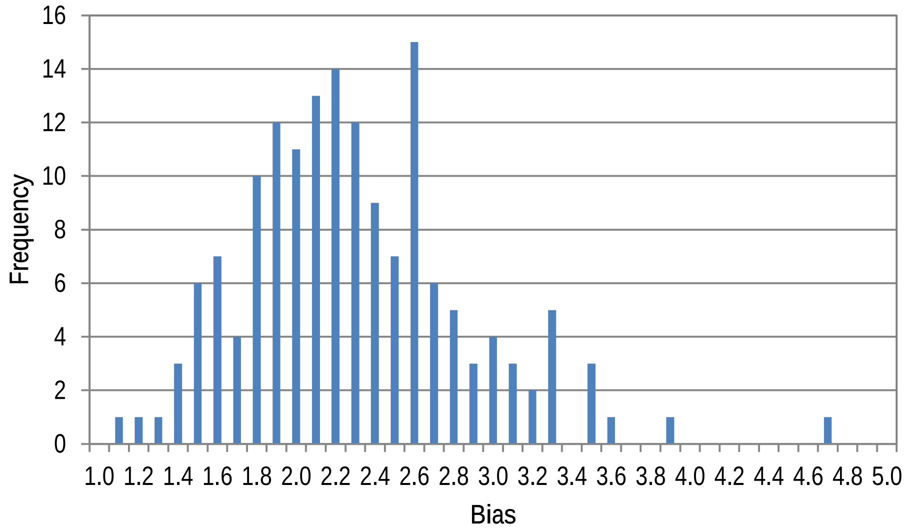

FIGURE 5.15
CAPWAP/KDOT-ENR Bias Distribution for 160 Restrikes Driven by Diesel Hammers

The mean bias for restrike piles using the PDA-predicted capacity was found to be 2.74 with a COV of 0.254. The mean bias for restrike piles using the CAPWAP-predicted capacity was found to be 2.24 with a COV of 0.251. When PDA-predicted and CAPWAP-predicted restrike biases were combined, the mean bias was found to be 2.31 with a COV of 0.272.

Figures 5.16 to 5.18 show the data points for restrikes for CAPWAP/PDA combined, PDA only, and CAPWAP only. These data are graphed versus the KDOT-ENR. A 1:1 line is shown in these charts to show a theoretical 1:1 correlation.

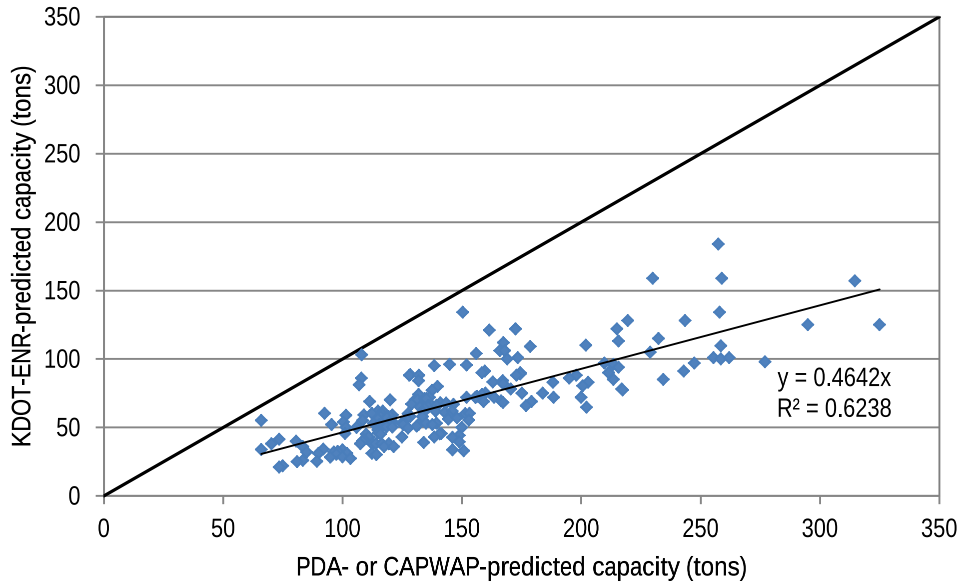

FIGURE 5.16
Restrike Data for 189 Piles Driven by Diesel Hammers

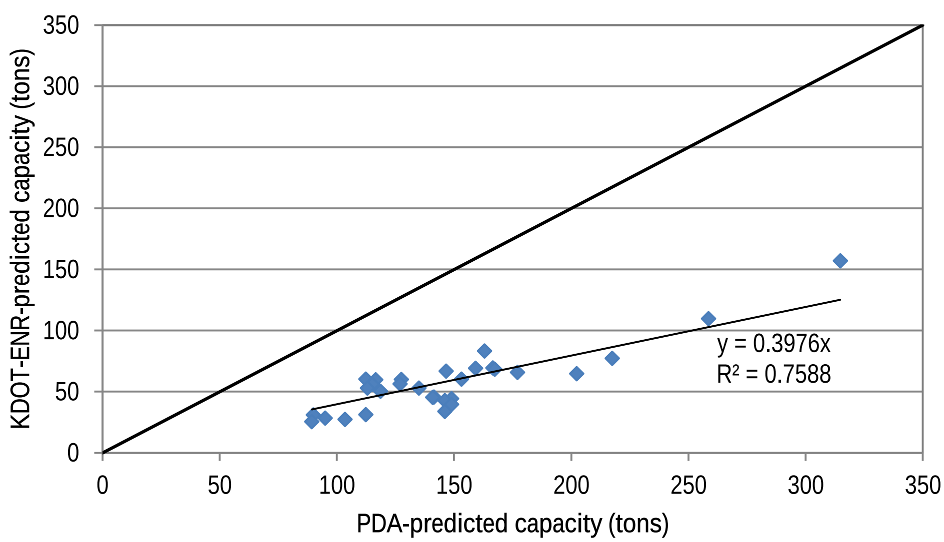

FIGURE 5.17
PDA Restrike Data for 29 Piles Driven by Diesel Hammers

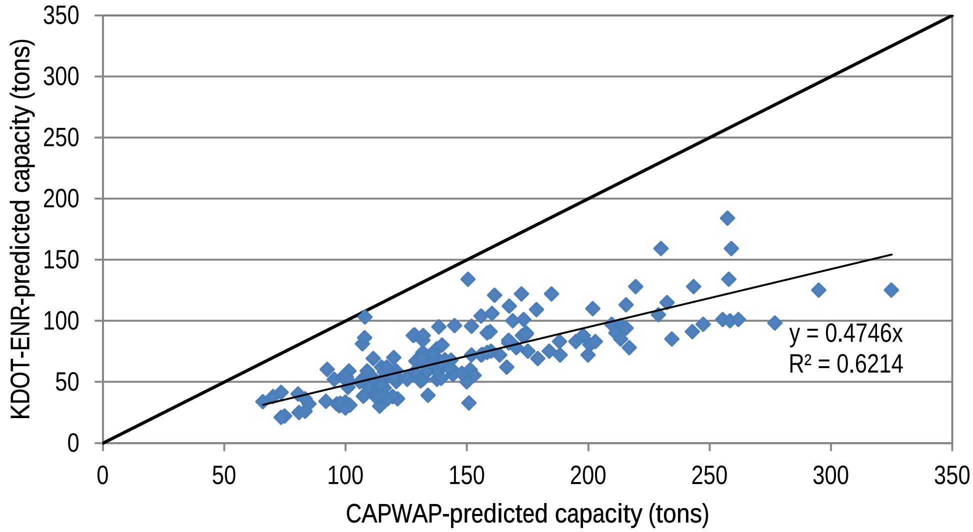

FIGURE 5.18
CAPWAP Restrike Data for 160 Piles Driven by Diesel Hammers

Figures 5.19 to 5.21 are the standard normal variable plots for restrikes. Generally these data appear to fit the lognormal distribution. Some of the data points at the tail do not perfectly fit either the lognormal or the normal distribution. The distributions were analyzed as lognormal.

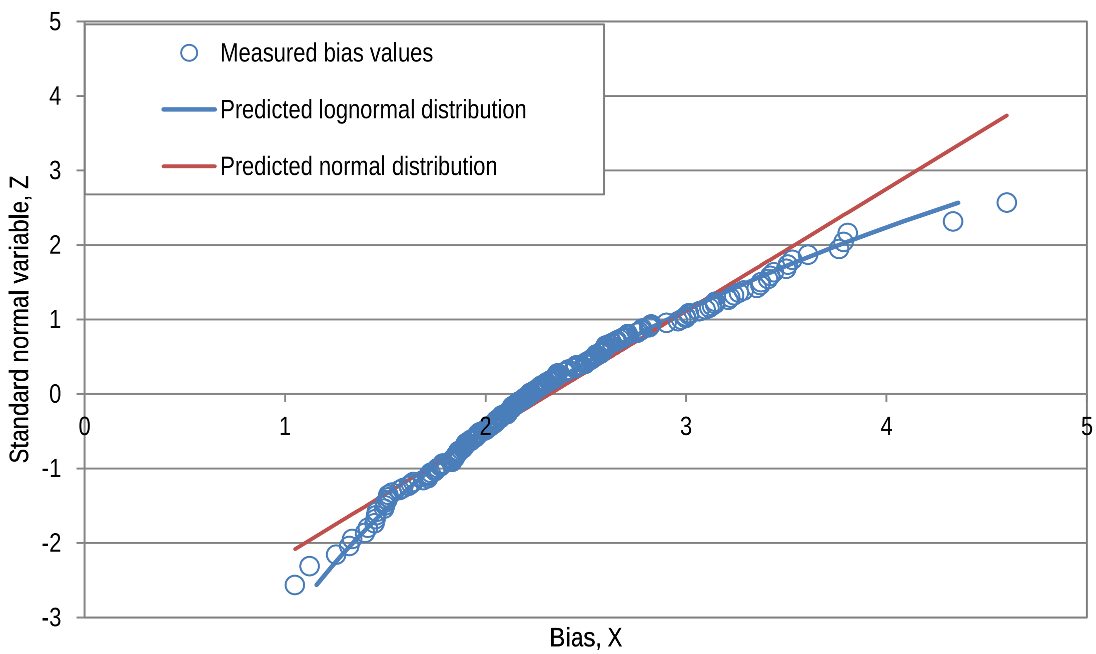

FIGURE 5.19
Standard Normal Variable for 189 Restrike Biases (PDA and CAPWAP), Driven by Diesel Hammers

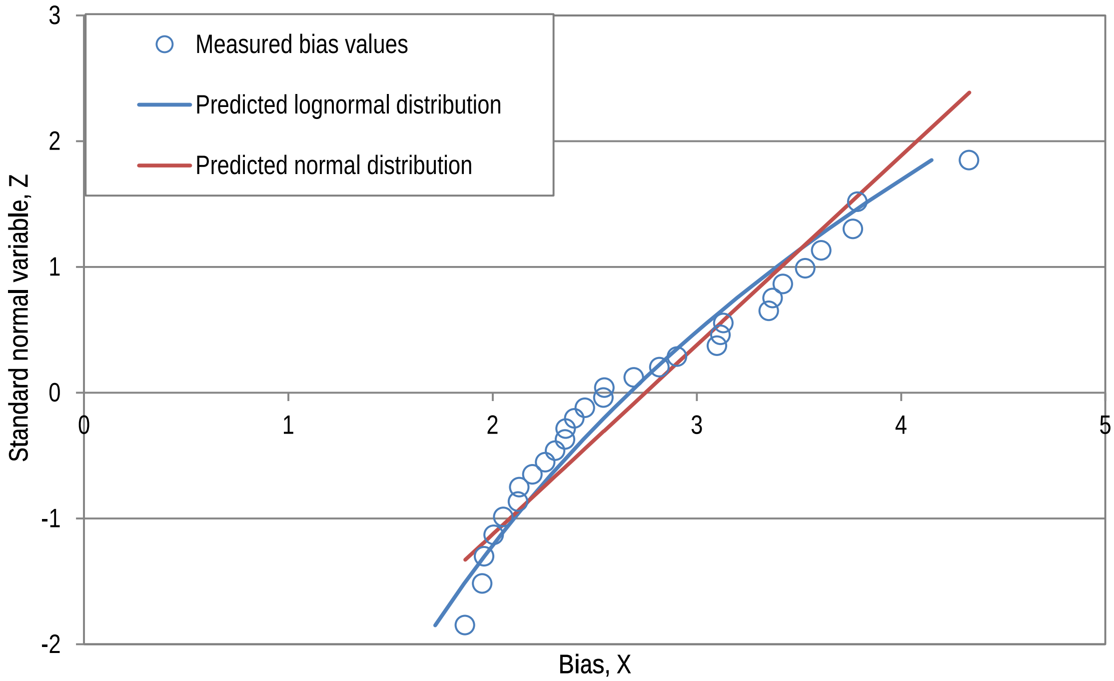

FIGURE 5.20
Standard Normal Variable for 29 Restrike Biases (PDA Only), Driven by Diesel Hammers

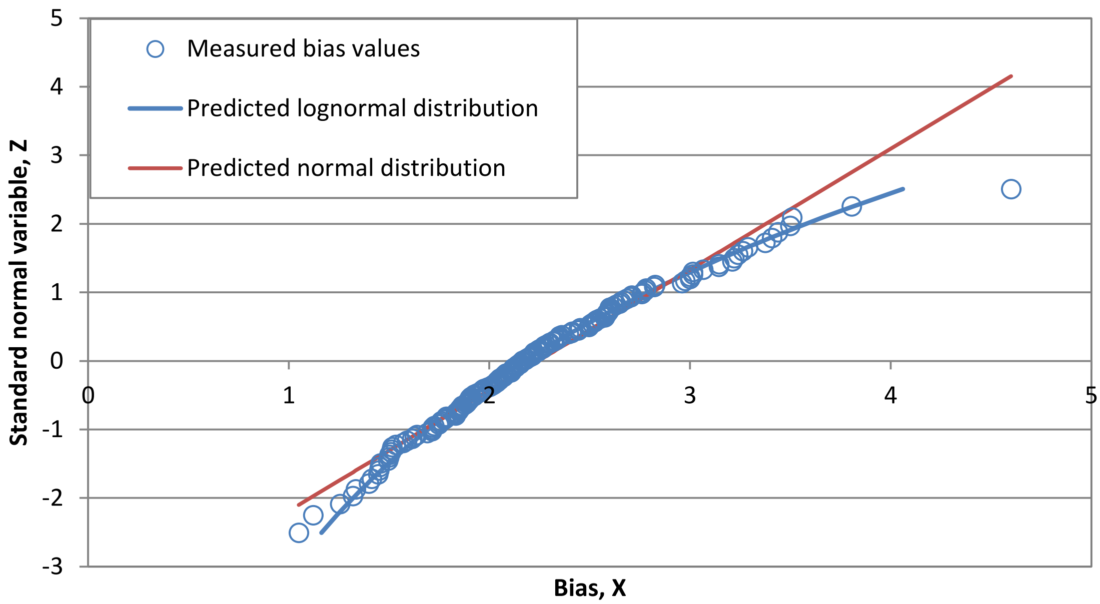

FIGURE 5.21
Standard Normal Variable for 160 Restrike Biases (CAPWAP Only), Driven by Diesel Hammers

Figure 5.22 is a chart of the end of drive (EOD) and restrike piles grounded in bedrock. This chart compares PDA- or CAPWAP-predicted capacity to the KDOT-ENR capacity. Figure 5.23 is a chart of EOD and restrike piles grounded in non-bedrock soils. It can be observed from Figures 5.22 and 5.23 that the bias of (PDA or CAPWAP)/KDOT-ENR did not appear to depend on the toe material.

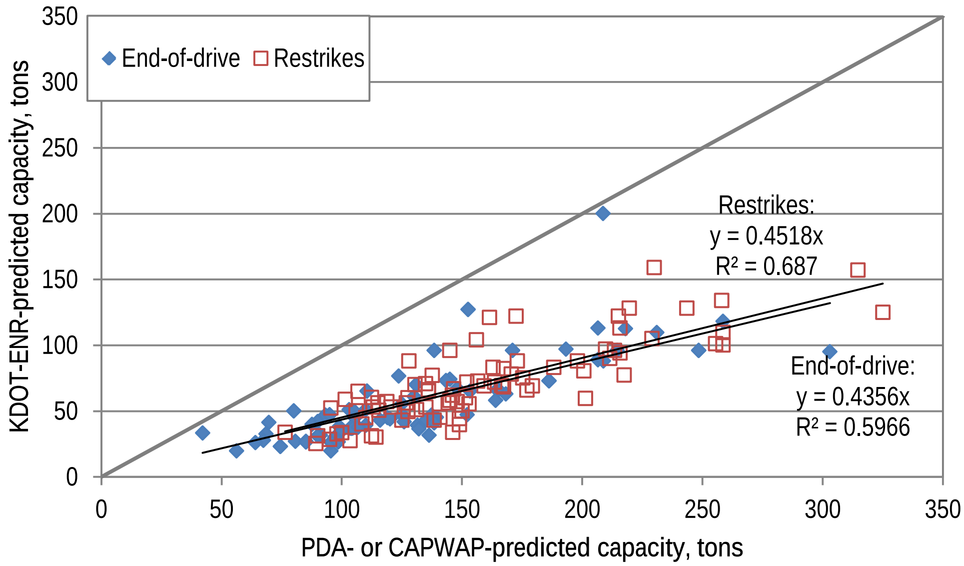

FIGURE 5.22
Data Points for 106 Piles Grounded in Bedrock

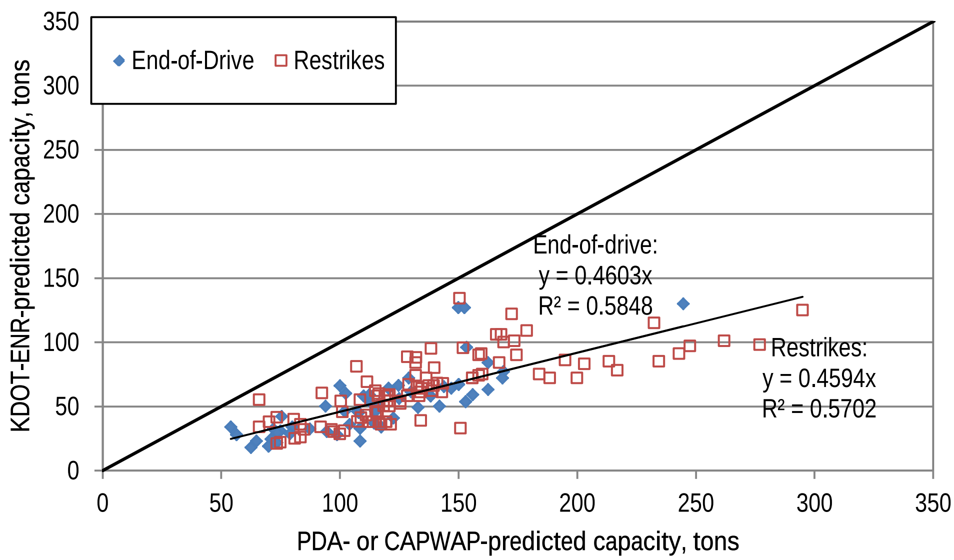

FIGURE 5.23
Data Points for 114 Piles Grounded in Non-Bedrock Soils

Figure 5.24 shows the data points for capacity at the end of drive and at beginning of restrike for 160 piles. As expected, capacity for both PDA and CAPWAP increased from end-of-drive to restrike. For the entire data set (both PDA and CAPWAP), the average increase in pile capacity was found to be 29%.

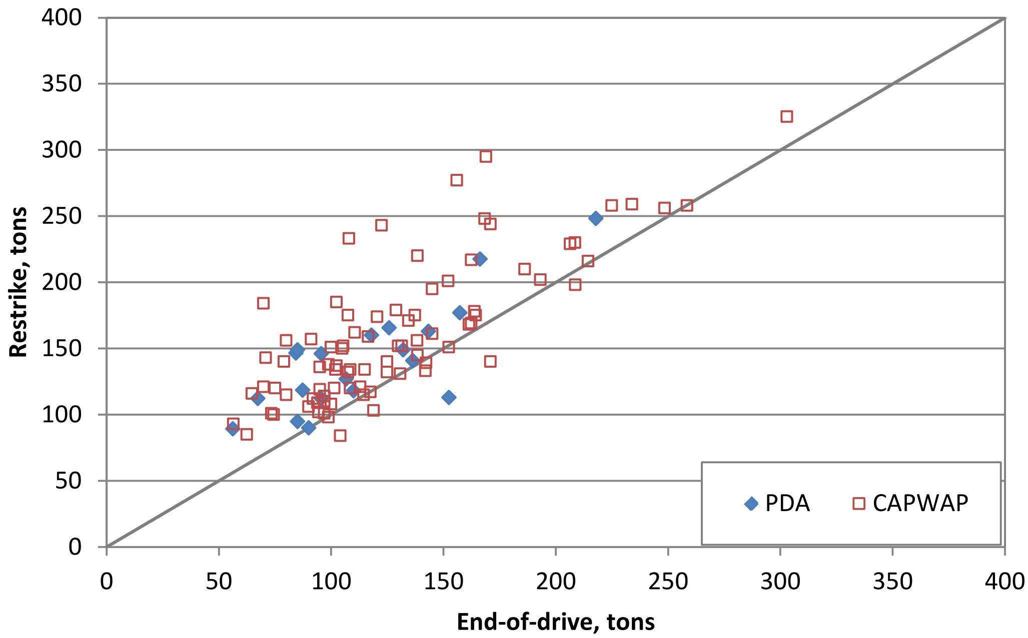

FIGURE 5.24
Comparison of End-of-Drive and Restrike Data for 160 Piles

Chapter 6: LRFD Calibration and Determination of the Resistance Factor

After predicted capacities for KDOT-ENR and PDA or CAPWAP were gathered, biases were determined as measured-to-predicted values, where the measured value was the pile-bearing capacity given by the PDA or CAPWAP, and the predicted pile-bearing capacity was given by the KDOT-ENR formula. Statistical analysis was performed using the Monte Carlo method, following the method in the Transportation Research Circular E-C079 (Allen et al. 2005). The statistical parameters used in the Monte Carlo simulation are shown in Tables 6.1 and 6.2 for end-of-drive blows and restrikes. The terms "μ_R" and "COV_R" represent the mean and coefficient-of-variation of the biases.

TABLE 6.1
Parameters for End-of-Drive Pile Blows Used in Monte Carlo Simulation

	No. of Cases	μ_R	COV_R
PDA	48	2.49	0.328
CAPWAP	116	2.38	0.256
Combined PDA/CAPWAP	164	2.41	0.285
Gravity (PDA and CAPWAP)	11	2.57	0.133

TABLE 6.2
Parameters for Restrikes Used in Monte Carlo Simulation

	No. of Cases	μ_R	COV_R
PDA	29	2.74	0.254
CAPWAP	160	2.24	0.251
Combined PDA/CAPWAP	189	2.31	0.272

For end-of-drive and restrike piles, there were 364 biases available for analysis (175 end-of-drive and 189 restrikes).

The limit-state function is written as:

$g = [\varphi R - (\gamma_{LL}LL + \gamma_{DL}DL)] \geq 0$ Note: if $\gamma_{LL} = \gamma_{DL}$ then LL and DL may be combined where g = safety margin; LL, DL = nominal live and dead loads; γ_{LL}, γ_{DL} = live and dead load factors; R = nominal resistance; and φ = resistance factor.

Figure 6.1a shows the generic load and resistance distribution curves, Q and R. The region of overlap in these distributions represents failure. The safety margin, g, shown in Figure 6.1b, is represented by g = R-Q. To avoid failure, the value of g must be greater than or equal to zero. As the distance βσ from the mean increases, the probability of failure decreases.

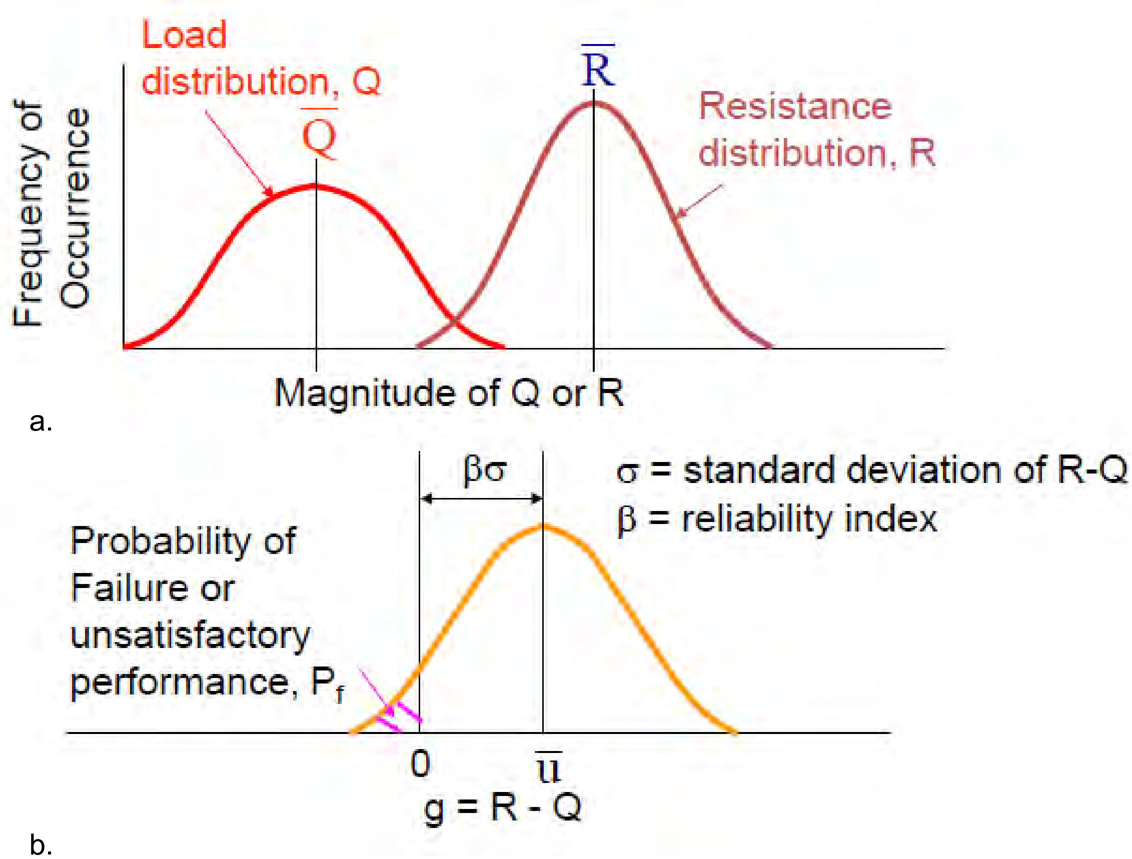

FIGURE 6.1
Load and Resistance Curves and Failure Region

For calibration, statistical characteristics and load factors were adopted from the Transportation Research Circular E-C079 and are shown in Table 6.3. Both dead and live loads are assumed to be normally distributed.

TABLE 6.3
Statistical Characteristics and Load Factors

	Bias	COV	Load factor
Live load	$\lambda_{LL} = 1.15$	$COV_{LL} = 0.2$	$\gamma_{LL} = 1.75$
Dead load	$\lambda_{DL} = 1.05$	$COV_{DL} = 0.1$	$\gamma_{DL} = 1.25$

NOTE: Bias is the mean value of the measured/predicted load. COV is the coefficient of variation, which is the standard deviation divided by the mean.

In this study, five target reliability indices β_T were examined: 1.5, 2.0, 2.5, 3.0, and 3.5. Table 6.4 relates each target reliability index to a probability of failure, p_f, and Figure 6.2 shows a distribution of probability of failure corresponding to $\boldsymbol{\beta}$ values on a log scale.

TABLE 6.4
Target Reliability Index and Probability of Failure

$\boldsymbol{\beta_T}$	$\mathbf{p_f}$
1.5	1/15
2.0	1/44
2.5	1/161
3.0	1/743
3.5	1/4298

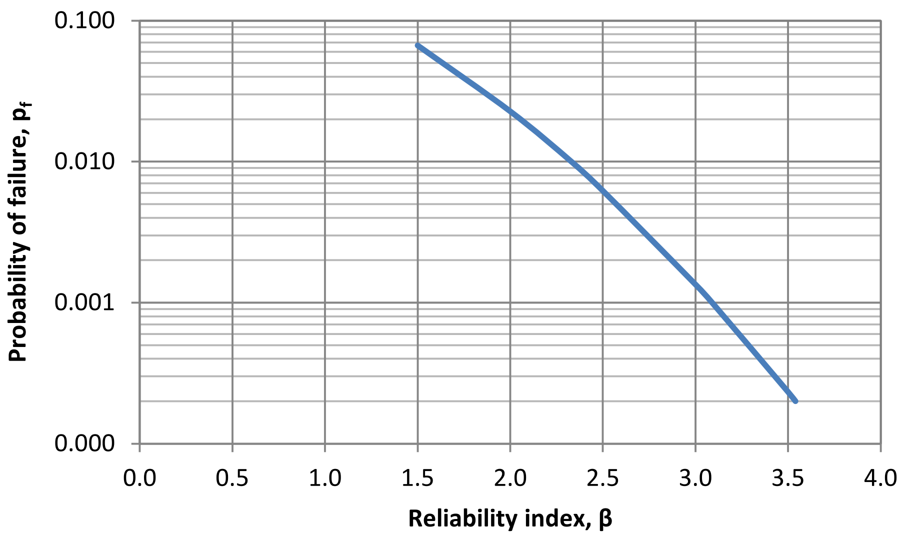

FIGURE 6.2
Probability of Failure Corresponding to a Range of β Values

For the Monte Carlo simulation, 50,000 load cases were generated in a spreadsheet based on coefficients a, b, and c, which were random numbers between 0 and 1. The spreadsheet generated a random live load (LL_{rnd}), a random dead load (DL_{rnd}), and a random resistance (R_{rnd}) using the following equations:

$$LL_{rnd} = LL \cdot \lambda_{LL} \cdot (1 + a \cdot COV_{LL})$$
$$DL_{rnd} = DL \cdot \lambda_{DL} = LL \cdot \frac{DL}{LL} \cdot \lambda_{DL} \cdot (1 + b \cdot COV_{DL})$$
$$R_{rnd} = \exp(\mu_{ln} + c \cdot \sigma_{ln})$$

where

$$\mu_{ln} = \ln\left(\mu_R \cdot \frac{LL \cdot \gamma_{LL} + DL \cdot \gamma_{DL}}{\varphi}\right) - 0.5\sigma_{ln}$$
$$\sigma_{ln} = \{\ln[(COV_R)^2 + 1]\}^{0.5}$$

The preceding equations were taken from the Transportation Research Circular E-C079. In the formula for μ_{ln}, above, φ is a trial resistance factor. A DL/LL ratio of 2.0 was chosen.

For each generated group of random loads, the safety margin, g, was calculated using the following equation:

$$g = R_{rnd} - LL_{rnd} - DL_{rnd}$$

The probability of failure is determined by dividing the number of randomly generated cases in which g < 0 by 50,000.

$$P_f = \frac{N_{g<0}}{50{,}000}$$

The Monte Carlo simulation was run in Excel using a trial-and-error process. Values of the resistance factor, φ, were entered to arrive at a value for the reliability index. The reliability index, β, was estimated in Excel as:

$$\beta = \text{-NORMSINV}(p_f)$$

The details of this mathematical function are complex and are omitted here. Trial resistance factors were entered until the target reliability index was achieved, where $\beta = \beta_T$. Table 6.5 shows the resistance factors that were determined for various reliability indices.

TABLE 6.5
KDOT-ENR Resistance Factors from Monte Carlo Simulation

	β = 1.5	β = 2.0	β = 2.5	β = 3.0	β = 3.5
End-of-Drive					
PDA	1.88	1.59	1.35	1.16	0.95
CAPWAP	2.02	1.76	1.53	1.35	1.17
Combined	1.95	1.68	1.45	1.25	1.07
Restrikes					
PDA	2.38	2.09	1.85	1.63	1.45
CAPWAP	1.91	1.68	1.47	1.28	1.13
Combined	1.90	1.65	1.43	1.24	1.09
EOD Gravity	2.64	2.43	2.25	2.07	1.94

The resistance factors in Table 6.5 represent a combination of the bias resulting from the underprediction of resistance and the uncertainty resulting from using the KDOT-ENR method, where the nominal PDA value was assumed to be the true value. The underprediction of the resistance is the more dominant of the two factors and is the reason the resistance factors are greater than 1.0. The new KDOT-ENR factored resistance becomes:

$$P_u = \varphi_{ENR}\left[\frac{1.6WH}{\left(s+0.1\left(\frac{X}{W}\right)\right)}\right]$$

Where φ_{ENR} is selected from Table 6.5.

Chapter 7: Recommendations

Resistance factors (φ_{ENR}) for five reliability index values were determined and are shown in Table 6.5. To use these resistance factors, the user must select the desired resistance factor from Table 6.5 and multiply it by the KDOT-ENR nominal resistance to get the factored resistance as shown in the equation below. These resistance factors are greater than one, which is unusual, but is true for this case because the factors take into account not only the uncertainty of the KDOT-ENR method but also the significant underprediction of pile resistance that comes from using the KDOT-ENR method.

$$P_u = \varphi_{ENR}\left[\frac{1.6WH}{(s+0.1\left(\frac{X}{W}\right))}\right]$$

The upper limit for resistance factor based on the combined data set should be no more than 1.55. This value was arrived at as follows. Consider a pile with an EOD actual capacity of 100 kips. The CAPWAP value is assumed to measure it accurately and measures 100 kips. A resistance factor (φ_{dyn}) of 0.65 is applied and a CAPWAP factored resistance of 65 kips is calculated. Based on a mean bias of 2.38 (Table 6.1), the KDOT-ENR nominal resistance is expected to be 42 kips for this pile (100 kips/2.38). A resistance value (φ_{ENR}) of 1.55 applied to the KDOT-ENR value yields a factored resistance of 65 kips, the same as would be calculated using the CAPWAP value. Use of a resistance factor higher than 1.55 would, on average, result in a more aggressive value for factored resistance using the KDOT-ENR method than would be determined using CAPWAP, which is the better method. It is recommended that a resistance factor lower than 1.55 be used in practice given the additional uncertainty introduced by the use of the KDOT-ENR method. For this example, use of a resistance factor of 1.35 (β = 3.0) would result in a factored KDOT-ENR capacity of 56.7 kips and corresponds to a probability of failure of 1/743 or 0.13%, where in this case failure represents a KDOT-ENR value in excess of the nominal CAPWAP value.

If the CAPWAP resistance factor (φ_{dyn}) is lower than 0.65, then the value of φ_{ENR} should also be reduced so the factored resistance using the KDOT-ENR method is not higher than it would be if the CAPWAP method were used. For example, if the EOD actual capacity is 100 kips and φ_{dyn} = 0.50, then the CAPWAP factored resistance is 50 kips. The KDOT-ENR nominal resistance is still expected to be 42 kips for this pile (100 kips/2.38). The maximum value of φ_{ENR} then is 50kip/42kip = 1.19. For φ_{ENR} =1.19, The KDOT-ENR factored resistance becomes (42kips)(1.19) = 50 kips, the same as for the CAPWAP method with the lower resistance factor.

Resistance factors for gravity hammers were calculated and are presented in Table 6.5 but their use is not recommended, due to the small size of the data set and the high values obtained. Furthermore, until additional data is obtained, it is recommended that only the smaller resistance factors from diesel hammer driven piles be used.

References

Allen, T.M., A.S. Nowak, and R.J. Bathurst. 2005. *Calibration to Determine Load and Resistance Factors for Geotechnical and Structural Design.* Transportation Research Circular E-C079. Transportation Research Board of the National Academies, Washington, D.C.

Allen, T.M. March, 2005. *Development of the WSDOT Pile Driving Formula and Its Calibration for Load and Resistance Factor Design (LRFD). WA-RD 610.1*. Washington State Department of Transportation.

Coduto, Donald P. 2001. *Foundation Design Principles and Practices. 2nd ed*. Prentice Hall Inc., Englewood Cliffs, N.J., 883p.

Dynamics, Inc. 2004. "PDA-W Manual of Operation." (Corresponds to PDA-W version 95.) Cleveland, Ohio.

Likins, G.E., and F. Rausche. 2004. "Correlation of CAPWAP with Static Load Tests." In *Proceedings of the Seventh International Conference on the Application of the Stresswave Theory to Piles*, pp. 153–165.

Long, J.H., J. Hendrix, and D. Jaromin. 2009. "Comparison of Five Different Methods for Determining Pile Bearing Capacities." Wisconsin Highway Research Program #0092-07-04. Submitted to the Wisconsin Department of Transportation.

McVay, M.C., V. Alvarez, L. Zhang, A. Perez, and A. Gibsen. 2002. *Estimating Driven Pile Capacities during Construction*. University of Florida-Gainesville final report (FDOT No.: 99700-3600-119) submitted to the Florida Department of Transportation.

Nowak, A.S., M. Kozikowski, J. Larsen, T. Lutomirski, and P. Paczkowski. 2007. *Implementation of the AASHTO LRFD Code in Geotechnical Design—Piles*. Project SPR-1(07) P595. UNL No. 26-1107-013001. Nebraska Department of Roads and the University of Nebraska-Lincoln.

Paikowsky, S.G. 2004. NCHRP Report 507: *Load and Resistance Factor Design (LRFD) for Deep Foundations*. Transportation Research Board of the National Academies, Washington, D.C.

Soil Dynamics. 2008. *Case Pile Wave Analysis Program*. Retrieved March 5, 2013, f rom http://www.pile.com.my/case.htm

Withiam, J. L., E.P. Voytko, R.M. Barker, J.M. Duncan, B.C. Kelly, S.C. Musser, and V. Elias, 1998, *Load and Resistance Factor Design (LRFD) for Highway Bridge Substructures*, FHWA HI-98-032.

Yang, X., J. Han, R.L. Parsons, and R.W. Henthorne. 2008. *Resistance Factors for Drilled Shafts in Weak Rock Based on O-Cell Test Data*. Transportation Research Board Record No. 2045. Transportation Research Board of the National Academies, Washington, D.C., pp. 62–67. DOI: 10.3141/2045-07.

Appendix A

TABLE A1
PDA End-of-Drive Data for 51 Piles

Project	Bridge No.	Element	No.	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	PDA (tons)	Bias	Hammer Type	Hammer Size
K-3386-01	077	Abut	1	Harvey	US-50	May-94	C,M,S	Silty clay	51	121	2.38	Delmag	D 12-32
K-5046-03	112	Pier	1	Reno	K-96	Oct-98	C,M,S	Alluvium	32	72	2.22	Delmag	D 16-32
K-5046-03	112	Pier	5	Reno	K-96	Oct-98	C,M,S	Alluvium	23	92	3.92	Delmag	D 16-32
K-5046-03	112	Pier	11	Reno	K-96	Oct-98	C,M,S	Alluvium	63	93	1.48	Delmag	D 16-32
K-5046-03	113	Pier	1	Reno	K-96	Oct-98	C,M,S	Alluvium	83	155	1.88	Delmag	D 16-32
K-5046-03	114	Pier	1	Reno	K-96	Oct-98	S	Alluvium	66	125	1.88	Delmag	D 16-32
K-5046-03	114	Pier	2	Reno	K-96	Oct-98	S	Alluvium	82	139	1.71	Delmag	D 16-32
K-5046-03	114	Pier	3	Reno	K-96	Oct-98	S	Alluvium	84	133	1.58	Delmag	D 16-32
K-6373-01	074	Abut	2	Norton	US-36	May-06	C,M,S,G	Ogallala	77	247	3.21	Delmag	D 12-32
K-6373-01	083	Abut	2	Norton	US-36	Jan-06	C,S,M,glacial	Ogallala	31	136	4.33	Delmag	D 12-32
K-6373-01	083	Pier	1	Norton	US-36	Jan-06	C,S,M,glacial	Ogallala	20	96	4.86	Delmag	D 12-32
K-6373-01	084	Pier	1	Norton	US-36	Feb-06	C,S,glacial	Ogallala	37	132	3.62	Delmag	D 12-32
K-6373-01	084	Abut	2	Norton	US-36	Feb-06	C,S,glacial	Ogallala	26	96	3.63	Delmag	D 12-32
K-6373-01	085	Abut	1	Norton	US-36	May-06	M,S	Ogallala	41	167	4.08	Delmag	D 12-32
K-6410-01	040	Abut	1	Nemaha	K-9	Mar-05	C,M,G,glacial	Glacial till	32	87	2.70	Delmag	D 12-42
K-6803-01	049	Abut	2	Trego	US-283	Mar-06	C,M,S	Shale/chalk	82	166	2.04	Delmag	D 19-32
K-6803-01	049	Pier	1	Trego	US-283	Mar-06	C,M,S	Shale/chalk	78	222	2.84	Delmag	D 19-32
K-6809-02	047	Pier	2	Sherman	K-27	Mar-05	C,M,S,G	Shale	112	218	1.94	Delmag	D22
K-6809-02	047	Pier	5	Sherman	K-27	Mar-05	C,M,S,G	Shale	110	225	2.05	Delmag	D22
K-7341-01	008	Pier	1a	Stanton	K-27	Aug-06	C,M,S,glacial	Ogallala	65	157	2.41	Delmag	D 12-42
K-7341-01	008	Pier	1b	Stanton	K-27	Aug-06	C,M,S,glacial	Ogallala	68	174	2.55	Delmag	D 12-42
K-7341-01	008	Pier	2	Stanton	K-27	Aug-06	C,M,S,glacial	Ogallala	63	166	2.64	Delmag	D 12-42
K-7387-01	034	Abut	1	Meade	K-23	Oct-05	S	Siltstone	51	118	2.33	Delmag	D 15
K-7387-01	034	Abut	2	Meade	K-23	Oct-05	S	Siltstone	73	143	1.96	Delmag	D 15

Project	Bridge No.	Element	No.	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	PDA (tons)	Bias	Hammer Type	Hammer Size
K-7387-01	034	Pier	4	Meade	K-23	Oct-05	S	Siltstone	61	141	2.31	Delmag	D 15
K-7387-01	035	Abut	1	Meade	K-23	Oct-05	C,M,S	Nippewalla	28	67	2.43	Delmag	D 15
K-7392-01	019	Pier	1	Comanche	US-160	Dec-06	C,M,S	Mantle	42	126	3.02	Delmag	D 12-42
K-7392-01	019	Pier	5	Comanche	US-160	Dec-06	C,M,S	Mantle	27	84	3.13	Delmag	D 12-42
K-7393-01	042	Pier	1	Mitchell	K-181	Jul-06	C,M,S,G	Chalk	112	188	1.68	Delmag	D 12-42
K-7393-01	042	Pier	2	Mitchell	K-181	Jul-06	C,M,S,G	Chalk	118	201	1.70	Delmag	D 12-42
K-7402-01	161	Abut	1	Saline	K-4	Jan-07	C,M,S	Shale	44	118	2.69	Delmag	D 16-32
K-7407-01	041	Pier	1	Jewell	US-36	Mar-07	C,M,S,G	Shale	80	128	1.60	Delmag	D 19-32
K-7409-01	120	Pier	1	Reno	US-50	Jan-07	M,S	Shale	27	85	3.15	Delmag	D 12-42
K-7409-01	121	Pier	2	Reno	US-50	Jan-07	M,S	Shale	27	85	3.21	Delmag	D 12-42
K-7409-01	124	Pier	5	Reno	US-50	Dec-06	M,S	Shale	74	180	2.42	Delmag	D 19-32
K-7409-02	145	Abut	2	Reno	US-50	Oct-11	C,M,S,G	Shale	39	132	3.37	Delmag	D 16-32
K-7409-02	145	Pier	1	Reno	US-50	Oct-11	C,M,S,G	Shale	55	125	2.26	Delmag	D 16-32
K-7409-02	146	Pier	2	Reno	US-50	Jan-12	C,M,S,G	Shale	127	153	1.20	Delmag	D 16-32
K-7432-01	009	Abut	1	Wichita	K-25	Nov-06	M,S,glacial	Ogallala	39	110	2.82	Delmag	D 15
K-7432-01	009	Pier	3a	Wichita	K-25	Nov-06	M,S,glacial	Ogallala	31	90	2.90	Delmag	D 15
K-7441-01	058	Abut	2	Riley	US-77	Sep-07	C,M	Shale	164	225	1.37	Delmag	D 19-42
K-7441-01	058	Pier	4	Riley	US-77	Sep-07	C,M	Shale	148	197	1.33	Delmag	D 19-42
K-7888-01	120	Abut	1	Douglas	US-59	Oct-10	C,M,S	Shale	85	120	1.41	Delmag	D 12-42
K-7889-01	112	Abut	2	Franklin	US-59	Oct-07	C,M	Unknown	97	139	1.44	Delmag	D 19-42
K-7889-01	114	Pier	3	Franklin	US-59	Dec-07	C,M,S	Bedrock	109	202	1.85	Delmag	D 19-42
K-8213-01	011	Abut	1a	Cheyenne	K-161	Jun-04	C,M,S	Shale	20	56	2.87	Delmag	D 12
K-8213-01	011	Abut	1b	Cheyenne	K-161	Jun-04	C,M,S	Shale	40	88	2.20	Delmag	D 12
K-8213-01	011	Pier	2	Cheyenne	K-161	Jun-04	C,M,S	Shale	38	107	2.84	Delmag	D 12
KA-0710-01	298	Abut	2	Shawnee	US-24	Apr-12	C,S,G	Unknown	54	130	2.41	Gravity	---
KA-0710-01	298	Pier	2	Shawnee	US-24	Apr-12	C,S,G	Unknown	74	183	2.47	Gravity	---
KA-0711-01	299	Abut	1	Shawnee	US-24	May-12	C,M,S	Shale	80	211	2.65	Gravity	---

TABLE A2
CAPWAP End-of-Drive Data for 124 Piles

Project	Bridge No.	Element	No.	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-7387-01	035	Pier	2	Meade	K-23	Jan-06	C,M,S	Nippewalla	47	93	1.99	Gravity	---
K-7409-02	139	Abut	1	Reno	US-50	Feb-12	C,M,S,G	Shale	37	105	2.82	Delmag	D 16-32
K-7409-02	139	Pier	3	Reno	US-50	Feb-12	C,M,S,G	Shale	73	186	2.55	Delmag	D 16-32
K-7409-02	140	Abut	2	Reno	US-50	Feb-12	C,M,S,G	Shale	30	97	3.23	Delmag	D 16-32
K-7409-02	140	Pier	1	Reno	US-50	Feb-12	C,M,S,G	Shale	58	164	2.83	Delmag	D 16-32
K-7409-02	141	Abut	1	Reno	US-50	Feb-12	C,M,S	Shale	47	152	3.24	Delmag	D 16-32
K-7409-02	141	Pier	3	Reno	US-50	Feb-12	C,M,S	Shale	47	137	2.93	Delmag	D 16-32
K-7409-02	146	Abut	1	Reno	US-50	Feb-12	C,M,S,G	Shale	44	139	3.15	Delmag	D 16-32
K-7427-01	058	Pier	2	Marshall	K-9	Jul-06	C,M,S,G	Unknown	30	74	2.44	Gravity	---
K-7427-01	059	Abut	1	Marshall	K-9	Jul-06	C,M,S,G,glacial	Mantle	26	64	2.48	Gravity	---
K-7427-01	059	Abut	1a	Marshall	K-9	Aug-06	C,M,S,G,glacial	Mantle	34	110	3.25	Gravity	---
K-7427-01	059	Pier	2	Marshall	K-9	Aug-06	C,M,S,G,glacial	Mantle	45	139	3.08	Gravity	---
K-7888-01	117	Abut	2	Douglas	US-59	Oct-09	C,M	Shale	91	183	2.01	Delmag	D 19-42
K-7888-01	117	Pier	2	Douglas	US-59	Oct-09	C,M	Shale	200	209	1.04	Delmag	D 19-42
K-7888-01	120	Abut	2	Douglas	US-59	Oct-09	C,S,M,G	Shale	70	131	1.87	Delmag	D 12
K-7889-01	114	Abut	1	Franklin	US-59	Nov-07	C,S,M,G	Bedrock	150	237	1.58	Delmag	D 19-42
K-7889-01	117	Abut	2	Franklin	US-59	Feb-08	C,M	Shale	66	170	2.58	Gravity	---
K-7889-01	117	Pier	1	Franklin	US-59	Jun-08	C,M	Shale	76	191	2.52	Gravity	---
K-8237-01	075	Pier	1	Ford	US-400	Nov-08	C,S,M	Alluvium	50	94	1.88	APE	D 19-42
K-8237-01	075	Pier	2	Ford	US-400	Nov-08	C,S,M	Alluvium	80	135	1.69	Delmag	D 19-42
K-8237-01	075	Pier	3	Ford	US-400	Nov-08	C,S,M	Alluvium	58	146	2.52	Delmag	D 19-42
K-8237-01	075	Abut	1	Ford	US-400	Nov-08	C,S,M	Alluvium	46	133	2.89	APE	D 19-42
K-8237-01	076	Pier	12	Ford	US-400	Oct-08	M,S	Ogallala	50	80	1.60	Delmag	D 19-32
K-8237-01	076	Abut	1	Ford	US-400	Oct-08	M,S	Ogallala	51	103	2.01	APE	D 19-42
K-8237-01	076	Abut	2	Ford	US-400	Oct-08	M,S	Ogallala	65	111	1.70	APE	D 19-42
K-8237-01	076	Pier	3	Ford	US-400	Oct-08	M,S	Ogallala	42	90	2.14	Delmag	D 19-32
K-8237-01	076	Pier	4	Ford	US-400	Oct-08	M,S	Ogallala	38	101	2.65	Delmag	D 19-32

Project	Bridge No.	Element	No.	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-8237-01	076	Pier	6	Ford	US-400	Oct-08	M,S	Ogallala	38	99	2.60	Delmag	D 19-32
K-8237-01	076	Pier	9	Ford	US-400	Oct-08	M,S	Ogallala	47	95	2.02	Delmag	D 19-32
K-8237-01	076	Pier	15	Ford	US-400	Oct-08	M,S	Ogallala	47	95	2.02	Delmag	D 19-32
K-8237-01	076	Pier	17	Ford	US-400	Oct-08	M,S	Ogallala	45	106	2.34	Delmag	D 19-32
K-8237-01	077	Abut	1	Ford	US-400	Feb-09	M,S	Ogallala	51	105	2.06	APE	D 19-42
K-8237-01	077	Pier	2	Ford	US-400	Jan-09	M,S	Ogallala	43	116	2.70	APE	D 19-42
K-8237-01	078	Pier	1	Ford	US-400	Oct-08	M,S,G	Alluvium	74	145	1.96	APE	D 19-42
K-8237-01	078	Pier	2	Ford	US-400	Oct-08	M,S,G	Alluvium	37	103	2.77	Delmag	D 19-32
K-8237-01	078	Pier	2b	Ford	US-400	Oct-08	M,S,G	Alluvium	37	101	2.69	APE	D 19-42
K-8237-01	078	Pier	4	Ford	US-400	Oct-08	M,S,G	Alluvium	61	130	2.12	Delmag	D 19-42
K-8238-02	055	Abut	2	Atchison	US-59	Aug-09	C,M,G	Shale	121	227	1.87	Delmag	D30-32
K-8243-03	039	Abut	2	Pratt	US-54	Feb-09	C,M,S,G	Sand	54	171	3.20	Delmag	D 16-32
K-8243-03	039	Pier	1	Pratt	US-54	Feb-09	C,M,S,G	Sand	30	74	2.49	Delmag	D 16-32
K-8243-03	042	Pier	1	Pratt	US-54	Apr-10	C,M,S,G	Sand	31	95	3.10	Delmag	D 16-32
K-8243-03	042	Abut	2a	Pratt	US-54	Apr-10	C,M,S,G	Sand	23	109	4.72	Delmag	D 16-32
K-8243-03	042	Abut	2b	Pratt	US-54	Apr-10	C,M,S,G	Sand	28	99	3.53	Delmag	D 16-32
K-8243-03	042	Abut	2c	Pratt	US-54	Apr-10	C,M,S,G	Sand	33	109	3.29	Delmag	D 16-32
K-8243-03	042	Abut	2d	Pratt	US-54	Apr-10	C,M,S,G	Sand	36	104	2.89	Delmag	D 16-32
K-8243-03	043	Abut	1	Pratt	US-54	Apr-10	C,M,S,G	Sand	37	115	3.09	Delmag	D 16-32
K-8243-03	043	Pier	2b	Pratt	US-54	Apr-10	C,M,S,G	Sand	34	118	3.46	Delmag	D 16-32
K-8244-01	082	Pier	2	Kingman	US-54	Jun-09	C,M,S	Caliche	42	135	3.20	Delmag	D 16-32
K-8244-01	083	Pier	1	Kingman	US-54	Nov-08	C,M,S	Caliche	42	136	3.24	Delmag	D 16-32
K-8244-01	087	Abut	1	Kingman	US-54	May-11	C,M,S	Caliche	32	91	2.88	Delmag	D 16-32
K-8244-01	087	Pier	1	Kingman	US-54	May-11	C,M,S	Caliche	23	75	3.24	Delmag	D 12-32
K-8246-01	026	Abut	1	Finney	US-50	Jan-10	M,S	Mantle	64	121	1.88	Delmag	D 19-32
K-8246-01	026	Pier	2a	Finney	US-50	Nov-09	M,S	Mantle	59	70	1.19	Delmag	D 19-32
K-8246-01	027	Abut	1	Finney	US-50	Apr-10	M,S,G	Mantle	35	97	2.77	Delmag	D 19-42
K-8246-01	027	Pier	2a	Finney	US-50	Jul-09	M,S,G	Mantle	37	105	2.84	Delmag	D 12-42

Project	Bridge No.	Element	No.	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-8246-01	027	Pier	2b	Finney	US-50	Jul-09	M,S,G	Mantle	33	69	2.10	Delmag	D 12-42
K-8246-01	028	Pier	1	Finney	US-50	Sep-09	M,S,G	Mantle	41	132	3.21	Delmag	D 12-42
K-8246-01	028	Abut	2	Finney	US-50	Dec-09	M,S,G	Mantle	45	119	2.64	Delmag	D 12-42
K-8246-01	029	Abut	1	Finney	US-50	Oct-09	C,M,S	Sand	34	80	2.35	Delmag	D 19-32
K-8246-01	029	Pier	2	Finney	US-50	Jul-09	C,M,S	Sand	45	108	2.40	Delmag	D 19-32
K-8246-01	030	Abut	1	Finney	US-50	Oct-09	C,M,S	Sand	39	92	2.36	Delmag	D 19-32
K-8246-01	030	Pier	1	Finney	US-50	Jun-09	C,M,S	Sand	28	57	2.02	Delmag	D 19-32
K-8251-08	406	Abut	2	Johnson	I-435	Mar-12	C,M	Shale	117	207	1.77	Delmag	D 19-42
K-8251-08	496	Abut	1	Johnson	I-435	Aug-12	C,M	Shale	182	271	1.49	Delmag	D 19-42
K-8252-01	129	Abut	2	Reno	K-61	Jul-10	C,M,S	Alluvium	46	102	2.22	Delmag	D 16-32
K-8252-01	129	Pier	1	Reno	K-61	Jul-10	C,M,S	Alluvium	52	117	2.24	Delmag	D 16-32
K-8252-01	130	Abut	1	Reno	K-61	Jul-10	C,M,S	Alluvium	60	103	1.71	Delmag	D 16-32
K-8252-01	130	Pier	2	Reno	K-61	Jul-10	C,M,S	Alluvium	46	108	2.34	Delmag	D 16-32
K-8252-01	131	Abut	2	Reno	K-61	Nov-10	C,M,S,glacial	Sand	65	143	2.21	Delmag	D 16-32
K-8252-01	131	Pier	1	Reno	K-61	Jul-09	C,M,S,glacial	Sand	65	144	2.20	Delmag	D 16-32
K-8252-01	132	Abut	1	Reno	K-61	Nov-10	C,M,S,glacial	Sand	73	142	1.96	Delmag	D 16-32
K-8252-01	132	Pier	2	Reno	K-61	Jul-09	C,M,S,glacial	Sand	67	150	2.24	Delmag	D 16-32
K-8253-02	132	Pier	2a	McPherson	K-61	Oct-09	C,M,S	Sand	43	97	2.26	Delmag	D 30
K-8253-02	132	Pier	2b	McPherson	K-61	Oct-09	C,M,S	Sand	53	113	2.13	Delmag	D 16-32
K-8253-02	132	Pier	2c	McPherson	K-61	Oct-09	C,M,S	Sand	127	153	1.20	Delmag	D30
K-8253-02	133	Pier	1	McPherson	K-61	Nov-09	C,M,S,G	Sand	96	145	1.51	Delmag	D 30
K-8253-02	135	Abut	2	McPherson	K-61	Dec-10	C,M,S,G	Sand	84	162	1.93	Delmag	D 16-32
K-8253-02	135	Pier	1	McPherson	K-61	Jul-09	C,M,S,G	Sand	56	125	2.23	Delmag	D 16-32
K-8253-02	136	Pier	2b	McPherson	K-61	Aug-09	C,M,S,G	Sand	72	129	1.79	Delmag	D 16-32
K-8253-02	136	Pier	3b	McPherson	K-61	Dec-10	C,M,S,G	Sand	58	138	2.39	Delmag	D 16-32
K-8260-01	033	Pier	1	Jackson	US-75	Feb-06	C,M,G,glacial	Silty clay	130	245	1.88	Delmag	D 19-32
K-9439-01	105	Abut	1	Harvey	US-50	Jul-12	C,M	Shale	58	143	2.45	Delmag	D 16-32
K-9439-01	105	Abut	1b	Harvey	US-50	Jul-12	C,M	Shale	97	193	1.99	Delmag	D 16-32

Project	Bridge No.	Element	No.	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-9657-01	042	Pier	1	Clark	US-183	Sep-10	M,S,G	Shale	66	165	2.49	Delmag	D 19-42
K-9657-01	042	Abut	2	Clark	US-183	Sep-10	M,S,G	Shale	47	125	2.66	Delmag	D 19-42
K-9661-01	034	Abut	1	Pawnee	K-156	Nov-07	C,M,S,G	Sand	42	76	1.80	Delmag	D 15
K-9661-01	034	Pier	2	Pawnee	K-156	Nov-07	C,M,S,G	Sand	66	100	1.52	Delmag	D 15
K-9661-01	035	Abut	2	Pawnee	K-156	Nov-07	C,M,S,G	Sand	31	75	2.42	Delmag	D 12-32
KA-0387-01	043	Abut	2	Clark	US-183	Oct-10	C,S,G	Shale	67	148	2.21	Delmag	D 19-42
KA-0387-01	043	Pier	1	Clark	US-183	Oct-10	C,S,G	Shale	76	155	2.04	Delmag	D 19-42
KA-0387-01	043	Pier	3a	Clark	US-183	Oct-10	C,S,G	Shale	67	156	2.32	Delmag	D 19-42
KA-0387-01	043	Pier	3b	Clark	US-183	Oct-10	C,S,G	Shale	82	167	2.04	APE	D 19-42
KA-0387-01	043	Pier	3c	Clark	US-183	Oct-10	C,S,G	Shale	88	209	2.37	APE	D 19-42
KA-0387-01	044	Abut	1	Clark	US-183	Sep-10	C,S	Shale	89	207	2.32	APE	D 19-42
KA-0387-01	044	Pier	2	Clark	US-183	Jul-10	C,S	Shale	96	249	2.59	Delmag	D 19-42
KA-0387-01	044	Pier	4a	Clark	US-183	Jul-10	C,S	Shale	96	139	1.44	Delmag	D 19-42
KA-0387-01	044	Pier	4b	Clark	US-183	Jul-10	C,S	Shale	96	171	1.78	APE	D 19-42
KA-0387-01	044	Pier	7	Clark	US-183	Jul-10	C,S	Shale	96	215	2.23	APE	D 19-42
KA-0410-03	067	Abut	1	Riley	K-18	Nov-10	C,M,S,G	Shale	118	259	2.19	Delmag	D 30-32
KA-0410-03	071	Pier	3	Riley	K-18	Jul-10	S,G	Limestone	191	318	1.66	Delmag	D 30-32
KA-0410-04	075	Abut	1	Riley	K-18	Oct-11	C,M	Limestone	95	303	3.19	APE	D 19-42
KA-0688-01	045	Abut	1	Rice	K-14	Jul-11	C,M,S,G	Alluvium	18	63	3.47	Delmag	D 12-42
KA-0688-01	045	Pier	2	Rice	K-14	May-11	C,M,S,G	Alluvium	29	79	2.75	Delmag	D 12-42
KA-0688-01	045	Pier	4	Rice	K-14	May-11	C,M,S,G	Alluvium	23	65	2.82	Delmag	D 12-42
KA-0688-01	045	Pier	4b	Rice	K-14	May-11	C,M,S,G	Alluvium	24	71	2.91	Delmag	D 12-42
KA-0688-01	045	Pier	6	Rice	K-14	May-11	C,M,S,G	Alluvium	19	70	3.68	Delmag	D 12-42
KA-0688-01	046	Abut	2	Rice	K-14	Mar-11	M,S,G	Alluvium	46	115	2.50	Delmag	D 12-32
KA-0688-01	046	Pier	3	Rice	K-14	Mar-11	M,S,G	Alluvium	50	142	2.84	Delmag	D 12-32
KA-0691-01	038	Abut	1	Meade	K-23	Mar-11	C,M,S,G	Sandy Clay	63	163	2.58	Delmag	D 19-32
KA-0691-01	038	Pier	2	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	41	123	2.99	Delmag	D 19-32
KA-0691-01	038	Pier	5	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	59	156	2.64	Delmag	D 19-32

Project	Bridge No.	Element	No.	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
KA-0691-01	038	Pier	6	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	77	169	2.19	Delmag	D 19-32
KA-0691-01	038	Pier	10	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	72	169	2.34	Delmag	D 19-32
KA-0693-01	052	Abut	1	Thomas	K-25	Mar-12	M,S,G	unknown	44	102	2.31	Delmag	D 12-42
KA-0693-01	052	Pier	2	Thomas	K-25	Mar-12	M,S,G	unknown	54	108	1.99	Delmag	D 12-42
KA-0708-01	039	Abut	1	Clay	US-24	Feb-12	C,S	Shale	87	100	1.15	Delmag	D 19-42
KA-0708-01	039	Pier	2	Clay	US-24	Feb-12	C,S	Shale	159	225	1.42	Delmag	D 19-42
KA-0711-01	299	Pier	2	Shawnee	US-24	May-12	C,M,S	Shale	105	290	2.76	Gravity	---
KA-0715-01	013	Pier	3	Edwards	US-50	Dec-11	Sand	Dakota Fm	86	257	2.99	Delmag	D 16-32
KA-0715-01	013	Pier	5	Edwards	US-50	Nov-11	Sand	Dakota Fm	115	271	2.35	Delmag	D 16-32
KA-0715-01	013	Pier	7	Edwards	US-50	Nov-11	Sand	Dakota Fm	113	234	2.07	Delmag	D 16-32
KA-0717-01	148	Abut	1	Sumner	US-81	Oct-11	C,M,S	unknown	42	101	2.40	Delmag	D 19-32
KA-0717-01	148	Pier	2	Sumner	US-81	Nov-11	C,M,S	unknown	89	162	1.81	Delmag	D 16-32

TABLE A3
PDA Restrike Data for 29 Piles

Project	Bridge No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	PDA (tons)	Bias	Hammer Type	Hammer Size
K-6373-01	074	Pier	1	1	0.25	Norton	US-36	May-06	C,M,S,G	Ogallala	43	146	3.4	Delmag	D 12-32
K-6373-01	083	Abut	2	1	46	Norton	US-36	Jan-06	C,M,S,glacial	Ogallala	45	141	3.1	Delmag	D 12-32
K-6373-01	083	Pier	1	1	16	Norton	US-36	Jan-06	C,M,S,glacial	Ogallala	34	146	4.3	Delmag	D 12-32
K-6373-01	084	Abut	2	1	22	Norton	US-36	Feb-06	C,S,glacial	Ogallala	31	112	3.6	Delmag	D 12-32
K-6373-01	084	Pier	1	1	26	Norton	US-36	Feb-06	C,S,glacial	Ogallala	44	149	3.4	Delmag	D 12-32
K-6373-01	085	Pier	2	1	0.25	Norton	US-36	May-06	M,S	Ogallala	65	202	3.1	Delmag	D 12-32
K-6410-01	040	Abut	1	1	20	Nemaha	K-9	Mar-05	C,M,G,glacial	Glacial	50	119	2.4	Delmag	D 12-42
K-6410-01	040	Pier	2a	2	120	Nemaha	K-9	Apr-05	C,M,G,glacial	Glacial	60	117	1.9	Delmag	D 12-42
K-6809-02	047	Pier	2	1	2	Sherman	K-27	Mar-05	C,M,S,G	Shale	147	248	1.7	Delmag	D22
K-7341-01	008	Pier	1a	1	22	Stanton	K-27	Aug-06	C,M,S,glacial	Ogallala	66	177	2.7	Delmag	D 12-42

Project	Bridge No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	PDA (tons)	Bias	Hammer Type	Hammer Size
K-7341-01	008	Pier	2	1	19	Stanton	K-27	Aug-06	C,M,S,glacial	Ogallala	77	217	2.8	Delmag	D 12-42
K-7387-01	034	Abut	2	1	21	Meade	K-23	Oct-05	S	Siltstone	83	163	2.0	Delmag	D 15
K-7387-01	035	Abut	1	1	20	Meade	K-23	Oct-05	C,M,S	Nippewalla	60	112	1.9	Delmag	D15
K-7392-01	019	Pier	1	1	20	Comanche	US-160	Dec-06	C,M,S	Mantle	69	166	2.4	Delmag	D 12-42
K-7392-01	019	Pier	5	1	17	Comanche	US-160	Dec-06	C,M,S	Mantle	67	147	2.2	Delmag	D 12-42
K-7402-01	161	Abut	1	1	18	Saline	K-4	Jan-07	C,M,S	Shale	68	160	2.3	Delmag	D 16-32
K-7409-01	119	Abut	1	1	88	Reno	US-50	Mar-07	M,S	Shale	60	153	2.5	Delmag	D 19-32
K-7409-01	120	Abut	2	1	48	Reno	US-50	May-07	M,S	Shale	46	141	3.1	Delmag	D12-42
K-7409-01	120	Pier	1	1	18	Reno	US-50	Jan-07	M,S	Shale	28	95	3.4	Delmag	D 12-42
K-7409-01	121	Pier	2	1	121	Reno	US-50	Feb-07	M,S	Shale	27	103	3.8	Delmag	D 12-42
K-7409-01	121	Pier	2	2	1129	Reno	US-50	Mar-07	M,S	Shale	40	149	3.8	Delmag	D 12-42
K-7409-02	139	Abut	1	1	0.3	Reno	US-50	Feb-12	C,M,S,G	Shale	53	135	2.5	Delmag	D 16-32
K-7409-02	146	Pier	2	1	0.25	Reno	US-50	Jan-12	C,M,S,G	Sand	53	113	2.1	Delmag	D 16-32
K-7432-01	009	Abut	1	1	5	Wichita	K-25	Nov-06	M,S,glacial	Ogallala	60	118	2.0	Delmag	D 15
K-7432-01	009	Pier	3a	1	4.5	Wichita	K-25	Nov-06	M,S,glacial	Ogallala	31	90	2.9	Delmag	D 15
K-8213-01	011	Abut	1a	1	2.5	Cheyenne	K-161	Jun-04	C,M,S	Shale	25	89	3.5	Delmag	D 12
K-8213-01	011	Pier	2	1	2	Cheyenne	K-161	Jun-04	C,M,S	Shale	56	127	2.3	Delmag	D 12
K-8237-01	076	Abut	1	1	23	Ford	US-400	Oct-08	M,S	Ogallala	69	159	2.3	APE	D 19-42
K-8237-01	077	Abut	1	1	17	Ford	US-400	Feb-09	M,S	Ogallala	56	115	2.1	Delmag	D 12-42

TABLE A4
CAPWAP Restrike Data for 160 Piles

Project	Brg No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-7409-02	139	Pier	3	3	18	Reno	US-50	Oct-11	C,M,S,G	Shale	97	210	2.2	Delmag	D 16-32
K-7409-02	140	Abut	2	1	0.25	Reno	US-50	Jan-12	C,M,S,G	Shale	30	114	3.8	Delmag	D 16-32
K-7409-02	140	Abut	2	2	2	Reno	US-50	Jan-12	C,M,S,G	Shale	40	114	2.9	Delmag	D 16-32
K-7409-02	140	Pier	1	1	0.3	Reno	US-50	Oct-11	C,M,S,G	Shale	69	178	2.6	Delmag	D 16-32
K-7409-02	141	Abut	1	1	0.25	Reno	US-50	Nov-11	C,M,S	Shale	80	201	2.5	Delmag	D 16-32
K-7409-02	141	Pier	3	1	0.25	Reno	US-50	Nov-11	C,M,S	Shale	82	167	2.0	Delmag	D 16-32
K-7409-02	141	Pier	3	2	2.50	Reno	US-50	Nov-11	C,M,S	Shale	75	175	2.3	Delmag	D 16-32
K-7409-02	145	Abut	2	1	0.25	Reno	US-50	Oct-11	C,M,S,G	Shale	51	131	2.6	Delmag	D 16-32
K-7409-02	145	Abut	2	2	1.50	Reno	US-50	Oct-11	C,M,S,G	Shale	62	167	2.7	Delmag	D 16-32
K-7409-02	145	Abut	2	3	19	Reno	US-50	Oct-11	C,M,S,G	Shale	88	173	2.0	Delmag	D 16-32
K-7409-02	145	Pier	1	1	0.25	Reno	US-50	Oct-11	C,M,S,G	Shale	72	164	2.3	Delmag	D 16-32
K-7409-02	146	Abut	1	1	0.25	Reno	US-50	Jan-12	C,M,S,G	Shale	58	145	2.5	Delmag	D 16-32
K-7409-02	146	Pier	2	1	1.00	Reno	US-50	Jan-12	C,M,S,G	Shale	56	145	2.6	Delmag	D 16-32
K-7888-01	117	Pier	2	1	0.5	Douglas	US-59	Apr-09	C,M,G	Limestone	159	230	1.4	Delmag	D 19-42
K-7888-01	120	Abut	2	1	2	Douglas	US-59	Oct-10	C,M,S	Shale	70	131	1.9	Delmag	D 12
K-8237-01	075	Pier	1	1	618	Ford	US-400	Jun-08	C,M,S	Alluvium	55	109	2.0	APE	D 19-42
K-8237-01	076	Abut	2	1	16	Ford	US-400	Nov-08	M,S	Ogallala	88	128	1.5	APE	D 19-42
K-8237-01	076	Abut	2	2	283	Ford	US-400	Nov-08	M,S	Ogallala	121	162	1.3	APE	D 19-42
K-8237-01	076	Pier	3	1	19	Ford	US-400	Apr-08	M,S	Ogallala	50	106	2.1	Delmag	D 19-32
K-8237-01	076	Pier	6	1	118	Ford	US-400	Apr-08	M,S	Ogallala	77	138	1.8	Delmag	D 19-32
K-8237-01	076	Pier	9	1	39	Ford	US-400	Apr-08	M,S	Ogallala	57	119	2.1	Delmag	D 19-32
K-8237-01	076	Pier	12	1	28	Ford	US-400	Apr-08	M,S	Ogallala	59	102	1.7	Delmag	D 19-32
K-8237-01	076	Pier	12	2	338	Ford	US-400	May-08	M,S	Ogallala	104	156	1.5	Delmag	D 19-32
K-8237-01	076	Pier	15	1	25	Ford	US-400	Apr-08	M,S	Ogallala	66	136	2.1	Delmag	D 19-32
K-8237-01	076	Pier	17	1	24	Ford	US-400	Apr-08	M,S	Ogallala	52	96	1.8	Delmag	D 19-32
K-8237-01	076	Pier	17	2	332	Ford	US-400	May-08	M,S	Ogallala	60	152	2.5	Delmag	D 19-32
K-8237-01	078	Pier	1	1	12	Ford	US-400	Oct-08	M,S,G	Alluvium	83	195	2.3	APE	D 19-42

Project	Brg No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-8237-01	078	Pier	2	1	100	Ford	US-400	Jun-08	M,S,G	Alluvium	95	139	1.5	Delmag	D 19-32
K-8237-01	078	Pier	2	2	3020	Ford	US-400	Oct-08	M,S,G	Alluvium	122	185	1.5	APE	D 19-42
K-8237-01	078	Pier	4	1	120	Ford	US-400	Jun-08	M,S,G	Alluvium	96	152	1.6	Delmag	D 19-42
K-8243-03	039	Abut	2	1	0.25	Pratt	US-54	Feb-09	C,M,S,G	Sand	75	160	2.1	Delmag	D 16-32
K-8243-03	039	Abut	2	2	2.5	Pratt	US-54	Feb-09	C,M,S,G	Sand	80	140	1.7	Delmag	D 16-32
K-8243-03	039	Pier	1	1	0.25	Pratt	US-54	Feb-09	C,M,S,G	Sand	38	70	1.9	Delmag	D 16-32
K-8243-03	039	Pier	1	2	1	Pratt	US-54	Feb-09	C,M,S,G	Sand	40	81	2.0	Delmag	D 16-32
K-8243-03	039	Pier	1	3	27	Pratt	US-54	Feb-09	C,M,S,G	Sand	46	101	2.2	Delmag	D 16-32
K-8243-03	042	Abut	2a	1	0.30	Pratt	US-54	Jun-10	C,M,S	Sand	25	81	3.2	Delmag	D 16-32
K-8243-03	042	Abut	2a	2	17.5	Pratt	US-54	Jun-10	C,M,S	Sand	38	120	3.1	Delmag	D 16-32
K-8243-03	042	Abut	2b	1	0.25	Pratt	US-54	Jun-10	C,M,S	Sand	30	98	3.2	Delmag	D 16-32
K-8243-03	042	Abut	2c	1	0.25	Pratt	US-54	Jun-10	C,M,S	Sand	38	113	3.0	Delmag	D 16-32
K-8243-03	042	Abut	2c	2	2	Pratt	US-54	Jun-10	C,M,S	Sand	38	120	3.1	Delmag	D 16-32
K-8243-03	042	Abut	2c	3	5	Pratt	US-54	Jun-10	C,M,S	Sand	39	134	3.4	Delmag	D 16-32
K-8243-03	042	Abut	2d	1	1	Pratt	US-54	Jun-10	C,M,S	Sand	36	84	2.3	Delmag	D 16-32
K-8243-03	042	Pier	1	1	0.25	Pratt	US-54	Apr-10	C,M,S	Sand	32	97	3.0	Delmag	D 16-32
K-8243-03	042	Pier	1	2	2	Pratt	US-54	Apr-10	C,M,S	Sand	31	102	3.3	Delmag	D 16-32
K-8243-03	043	Abut	1	1	0.25	Pratt	US-54	Jun-10	C,M,S	Sand	43	111	2.6	Delmag	D 16-32
K-8243-03	043	Abut	1	2	16.75	Pratt	US-54	Jun-10	C,M,S	Sand	46	115	2.5	Delmag	D 16-32
K-8243-03	043	Pier	2b	1	0.3	Pratt	US-54	Apr-10	C,M,S	Sand	36	118	3.3	Delmag	D 16-32
K-8243-03	043	Pier	2b	2	2	Pratt	US-54	Apr-10	C,M,S	Sand	38	117	3.1	Delmag	D 16-32
K-8244-01	082	Abut	1	1	24	Kingman	US-54	Jun-09	C,M,S	Caliche	52	138	2.6	Delmag	D 16-32
K-8244-01	082	Abut	1	2	168	Kingman	US-54	Jun-09	C,M,S	Caliche	71	134	1.9	Delmag	D 16-32
K-8244-01	082	Pier	2	1	21	Kingman	US-54	Oct-08	C,M,S	Caliche	78	171	2.2	Delmag	D 16-32
K-8244-01	083	Abut	2	1	40	Kingman	US-54	Jun-09	C,M,S	Caliche	71	135	1.9	Delmag	D 16-32
K-8244-01	087	Abut	1	1	0.3	Kingman	US-54	May-11	C,M,S	Caliche	51	116	2.3	Delmag	D 16-32
K-8244-01	087	Abut	1	2	3.5	Kingman	US-54	May-11	C,M,S	Caliche	73	157	2.2	Delmag	D 16-32
K-8244-01	087	Pier	1	1	0.25	Kingman	US-54	Apr-11	C,M,S	Caliche	33	98	3.0	Delmag	D 12-32

Project	Brg No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-8244-01	087	Pier	1	2	2.25	Kingman	US-54	Apr-11	C,M,S	Caliche	34	100	3.0	Delmag	D 12-32
K-8246-01	026	Abut	1	1	0.25	Finney	US-50	Jan-10	M,S	Sand	84	132	1.6	Delmag	D 19-32
K-8246-01	026	Abut	1	2	1.75	Finney	US-50	Jan-10	M,S	Sand	89	129	1.5	Delmag	D 19-32
K-8246-01	026	Abut	1	3	17500	Finney	US-50	Jan-10	M,S	Sand	101	174	1.7	Delmag	D 19-32
K-8246-01	026	Pier	2a	1	0.25	Finney	US-50	Nov-09	M,S	Mantle	59	121	2.1	Delmag	D 19-32
K-8246-01	027	Abut	1	1	1	Finney	US-50	Apr-10	M,S,G	Mantle	45	110	2.4	Delmag	D 19-42
K-8246-01	027	Pier	2a	1	17.5	Finney	US-50	Jul-09	M,S,G	Mantle	50	150	3.0	Delmag	D 12-42
K-8246-01	028	Abut	2	1	1.5	Finney	US-50	Dec-09	M,S,G	Mantle	53	121	2.3	Delmag	D 12-42
K-8246-01	028	Pier	1	1	0.25	Finney	US-50	Sep-09	M,S,G	Mantle	57	148	2.6	Delmag	D 12-42
K-8246-01	028	Pier	1	2	1	Finney	US-50	Sep-09	M,S,G	Mantle	55	153	2.8	Delmag	D 12-42
K-8246-01	028	Pier	1	3	16.25	Finney	US-50	Sep-09	M,S,G	Mantle	72	152	2.1	Delmag	D 12-42
K-8246-01	029	Abut	1	1	16.5	Finney	US-50	Oct-09	C,M,S	Sand	62	115	1.9	Delmag	D 19-32
K-8246-01	029	Pier	2	1	0.25	Finney	US-50	Jun-09	C,M,S	Sand	50	121	2.4	Delmag	D 19-32
K-8246-01	029	Pier	2	2	1	Finney	US-50	Jun-09	C,M,S	Sand	68	144	2.1	Delmag	D 19-32
K-8246-01	029	Pier	2	3	15.5	Finney	US-50	Jun-09	C,M,S	Sand	115	233	2.0	Delmag	D 19-32
K-8246-01	030	Abut	1	1	18.5	Finney	US-50	Oct-09	C,M,S	Sand	52	112	2.2	Delmag	D 19-32
K-8246-01	030	Pier	1	1	0.25	Finney	US-50	Jun-09	C,M,S	Sand	34	66	2.0	Delmag	D 19-32
K-8246-01	030	Pier	1	2	1	Finney	US-50	Jun-09	C,M,S	Sand	41	74	1.8	Delmag	D 19-32
K-8246-01	030	Pier	1	3	19	Finney	US-50	Jun-09	C,M,S	Sand	60	93	1.5	Delmag	D 19-32
K-8252-01	127	Pier	2	1	48	Reno	K-61	Oct-09	C,S	Sand	84	167	2.0	Delmag	D 16-32
K-8252-01	128	Abut	1	1	24	Reno	K-61	Nov-09	C,S	Sand	91	160	1.8	Delmag	D 16-32
K-8252-01	129	Abut	2	1	0.25	Reno	K-61	Jul-10	C,M,S	Alluvium	54	126	2.3	Delmag	D 16-32
K-8252-01	129	Abut	2	2	1.25	Reno	K-61	Jul-10	C,M,S	Alluvium	61	134	2.2	Delmag	D 16-32
K-8252-01	129	Pier	1	1	0.25	Reno	K-61	Jul-10	C,M,S	Alluvium	58	129	2.2	Delmag	D 16-32
K-8252-01	129	Pier	1	2	19	Reno	K-61	Jul-10	C,M,S	Alluvium	90	159	1.8	Delmag	D 16-32
K-8252-01	130	Abut	1	1	0.25	Reno	K-61	Jul-10	C,M,S	Alluvium	67	129	1.9	Delmag	D 16-32
K-8252-01	130	Abut	1	2	1	Reno	K-61	Jul-10	C,M,S	Alluvium	72	137	1.9	Delmag	D 16-32
K-8252-01	130	Pier	2	1	0.25	Reno	K-61	Jul-10	C,M,S	Alluvium	58	119	2.1	Delmag	D 16-32

Project	Brg No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
K-8252-01	130	Pier	2	2	1.25	Reno	K-61	Jul-10	C,M,S	Alluvium	66	138	2.1	Delmag	D 16-32
K-8252-01	130	Pier	2	3	5.5	Reno	K-61	Jul-10	C,M,S	Alluvium	68	141	2.1	Delmag	D 16-32
K-8252-01	130	Pier	2	4	29	Reno	K-61	Jul-10	C,M,S	Alluvium	90	175	1.9	Delmag	D 16-32
K-8253-02	132	Abut	1	1	1.5	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	62	139	2.2	Delmag	D 30
K-8253-02	132	Pier	2a	1	0.25	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	54	99	1.8	Delmag	D 30
K-8253-02	132	Pier	2a	2	16	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	54	101	1.9	Delmag	D 30
K-8253-02	132	Pier	2b	1	0.3	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	54	121	2.2	Delmag	D 16-32
K-8253-02	132	Pier	2b	2	1	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	58	116	2.0	Delmag	D 16-32
K-8253-02	132	Pier	2b	3	20	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	58	120	2.1	Delmag	D 16-32
K-8253-02	132	Pier	2c	2	1.5	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	134	151	1.1	Delmag	D30
K-8253-02	133	Abut	2	2	16	McPherson	K-61	Oct-09	C,M,S,G	Sand	81	107	1.3	Delmag	D 16-32
K-8253-02	133	Pier	1	1	1.5	McPherson	K-61	Nov-09	C,M,S,G	Sand	106	161	1.5	Delmag	D 30
K-8253-02	135	Abut	2	1	0.25	McPherson	K-61	Dec-10	C,M,S,G	Sand	100	169	1.7	Delmag	D 16-32
K-8253-02	135	Pier	1	1	0.8	McPherson	K-61	Jul-09	C,M,S,G	Sand	74	132	1.8	Delmag	D 16-32
K-8253-02	136	Pier	2a	1	1.75	McPherson	K-61	Aug-09	C,M,S,G	Sand	69	112	1.6	Delmag	D 16-32
K-8253-02	136	Pier	2a	2	15.75	McPherson	K-61	Aug-09	C,M,S,G	Sand	88	132	1.5	Delmag	D 16-32
K-8253-02	136	Pier	2b	1	15	McPherson	K-61	Aug-09	C,M,S,G	Sand	109	179	1.6	Delmag	D 16-32
K-8253-02	136	Pier	3b	1	2	McPherson	K-61	Dec-10	C,M,S,G	Sand	72	156	2.2	Delmag	D 16-32
K-9439-01	105	Abut	1b	1	1.25	Harvey	US-50	Jul-12	C,M	Shale	110	202	1.8	Delmag	D 16-32
K-9657-01	042	Abut	2	1	1.25	Clark	US-183	Sep-10	M,S,G	Shale	52	132	2.5	Delmag	D 19-42
K-9657-01	042	Abut	2	2	17	Clark	US-183	Sep-10	M,S,G	Shale	53	140	2.6	Delmag	D 19-42
K-9657-01	042	Pier	1	1	0.25	Clark	US-183	Sep-10	M,S,G	Shale	89	175	2.0	Delmag	D 19-42
K-9661-01	034	Pier	1	1	240	Pawnee	K-156	Nov-07	C,M,S,G	Sand	33	151	4.6	Delmag	D 15
K-9661-01	035	Abut	2	1	19	Pawnee	K-156	Nov-07	C,M,S,G	Sand	54	120	2.2	Delmag	D 12-32
K-9661-01	035	Pier	1	1	72	Pawnee	K-156	Nov-07	C,M,S,G	Sand	64	135	2.1	Delmag	D 12-32
KA-0387-01	043	Pier	3c	1	0.5	Clark	US-183	Oct-10	C,S,G	Shale	88	198	2.3	APE	D 19-42
KA-0387-01	044	Abut	1	1	0.5	Clark	US-183	Sep-10	C,S	Shale	90	212	2.4	APE	D 19-42
KA-0387-01	044	Abut	1	2	18	Clark	US-183	Sep-10	C,S	Shale	105	229	2.2	APE	D 19-42

Project	Brg No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
KA-0387-01	044	Pier	2	1	1	Clark	US-183	Jul-10	C,S	Shale	100	259	2.6	Delmag	D 19-42
KA-0387-01	044	Pier	2	2	121	Clark	US-183	Aug-10	C,S	Shale	101	256	2.5	Delmag	D 19-42
KA-0387-01	044	Pier	4a	1	1.5	Clark	US-183	Jul-10	C,S	Shale	96	145	1.5	Delmag	D 19-42
KA-0387-01	044	Pier	4a	2	118	Clark	US-183	Aug-10	C,S	Shale	128	220	1.7	Delmag	D 19-42
KA-0387-01	044	Pier	4b	1	13	Clark	US-183	Jul-10	C,S	Shale	96	214	2.2	APE	D 19-42
KA-0387-01	044	Pier	4b	2	116	Clark	US-183	Aug-10	C,S	Shale	128	244	1.9	APE	D 19-42
KA-0387-01	044	Pier	7	1	1	Clark	US-183	Jul-10	C,S	Shale	94	216	2.3	APE	D 19-42
KA-0387-01	044	Pier	7	2	97	Clark	US-183	Aug-10	C,S	Shale	113	216	1.9	APE	D 19-42
KA-0410-03	067	Abut	1	1	1	Riley	K-18	Nov-10	C,M,S,G	Shale	134	258	1.9	Delmag	D 30-32
KA-0410-04	075	Abut	1	1	1	Riley	K-18	Oct-11	C,M	Limestone	125	325	2.6	APE	D 19-42
KA-0688-01	045	Abut	1	1	0.25	Rice	K-14	Jun-11	C,M,S,G	Alluvium	21	74	3.5	Delmag	D 12-42
KA-0688-01	045	Abut	1	2	3.25	Rice	K-14	Jun-11	C,M,S,G	Alluvium	32	85	2.7	Delmag	D 12-42
KA-0688-01	045	Pier	2	1	0.40	Rice	K-14	May-11	C,M,S,G	Alluvium	34	92	2.7	Delmag	D 12-42
KA-0688-01	045	Pier	2	2	24	Rice	K-14	May-11	C,M,S,G	Alluvium	66	140	2.1	Delmag	D 12-42
KA-0688-01	045	Pier	4	1	0.30	Rice	K-14	May-11	C,M,S,G	Alluvium	26	84	3.2	Delmag	D 12-42
KA-0688-01	045	Pier	4	2	32	Rice	K-14	May-11	C,M,S,G	Alluvium	45	116	2.6	Delmag	D 12-42
KA-0688-01	045	Pier	4b	1	0.25	Rice	K-14	May-11	C,M,S,G	Alluvium	29	100	3.5	Delmag	D 12-42
KA-0688-01	045	Pier	4b	2	2.25	Rice	K-14	May-11	C,M,S,G	Alluvium	38	108	2.8	Delmag	D 12-42
KA-0688-01	045	Pier	4b	3	19	Rice	K-14	May-11	C,M,S,G	Alluvium	61	143	2.3	Delmag	D 12-42
KA-0688-01	045	Pier	6	1	0.25	Rice	K-14	May-11	C,M,S,G	Alluvium	22	75	3.4	Delmag	D 12-42
KA-0688-01	045	Pier	6	2	3	Rice	K-14	May-11	C,M,S,G	Alluvium	38	114	3.0	Delmag	D 12-42
KA-0688-01	045	Pier	6	3	34	Rice	K-14	May-11	C,M,S,G	Alluvium	75	184	2.5	Delmag	D 12-42
KA-0688-01	046	Abut	2	1	0.3	Rice	K-14	Mar-11	M,S,G	Alluvium	52	126	2.4	Delmag	D 12-32
KA-0688-01	046	Abut	2	2	15	Rice	K-14	Mar-11	M,S,G	Alluvium	58	134	2.3	Delmag	D 12-32
KA-0688-01	046	Pier	1	1	67	Rice	K-14	Feb-11	M,S,G	Alluvium	72	200	2.8	Delmag	D 12-32
KA-0688-01	046	Pier	3	1	0.25	Rice	K-14	Mar-11	M,S,G	Alluvium	72	189	2.6	Delmag	D 12-32
KA-0688-01	046	Pier	3	2	17.5	Rice	K-14	Mar-11	M,S,G	Alluvium	65	133	2.0	Delmag	D 12-32
KA-0691-01	038	Abut	1	1	0.5	Meade	K-23	Mar-11	C,M,S,G	Sandy Clay	78	217	2.8	Delmag	D 19-32

Project	Brg No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soils Present	Toe	KDOT-ENR (tons)	CAPWAP (tons)	Bias	Hammer Type	Hammer Size
KA-0691-01	038	Pier	2	1	0.5	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	74	159	2.1	Delmag	D 19-32
KA-0691-01	038	Pier	2	2	2.5	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	91	243	2.7	Delmag	D 19-32
KA-0691-01	038	Pier	5	1	0.25	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	83	203	2.4	Delmag	D 19-32
KA-0691-01	038	Pier	5	2	2.75	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	98	277	2.8	Delmag	D 19-32
KA-0691-01	038	Pier	6	1	0.3	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	85	235	2.8	Delmag	D 19-32
KA-0691-01	038	Pier	6	2	1	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	101	262	2.6	Delmag	D 19-32
KA-0691-01	038	Pier	6	3	17.5	Meade	K-23	Mar-11	C,M,S,G	Sandy Clay	125	295	2.4	Delmag	D 19-32
KA-0691-01	038	Pier	10	1	0.3	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	85	214	2.5	Delmag	D 19-32
KA-0691-01	038	Pier	10	2	1.5	Meade	K-23	Feb-11	C,M,S,G	Sandy Clay	97	248	2.6	Delmag	D 19-32
KA-0693-01	052	Abut	1	1	0.3	Thomas	K-25	Mar-12	M,S,G	unknown	50	102	2.0	Delmag	D 12-42
KA-0693-01	052	Abut	1	2	1.75	Thomas	K-25	Mar-12	M,S,G	unknown	59	109	1.8	Delmag	D 12-42
KA-0693-01	052	Abut	1	3	5	Thomas	K-25	Mar-12	M,S,G	unknown	62	117	1.9	Delmag	D 12-42
KA-0693-01	052	Abut	1	4	22	Thomas	K-25	Mar-12	M,S,G	unknown	70	120	1.7	Delmag	D 12-42
KA-0693-01	052	Pier	2	1	0.5	Thomas	K-25	Mar-12	M,S,G	unknown	48	115	2.4	Delmag	D 12-42
KA-0693-01	052	Pier	2	2	1.5	Thomas	K-25	Mar-12	M,S,G	unknown	52	116	2.2	Delmag	D 12-42
KA-0693-01	052	Pier	2	3	18.5	Thomas	K-25	Mar-12	M,S,G	unknown	70	132	1.9	Delmag	D 12-42
KA-0708-01	039	Abut	1	1	0.25	Clay	US-24	Feb-12	C,S	Shale	86	108	1.3	Delmag	D 19-42
KA-0708-01	039	Abut	1	2	3	Clay	US-24	Feb-12	C,S	Shale	103	108	1.1	Delmag	D 19-42
KA-0708-01	039	Pier	2	1	0.25	Clay	US-24	Feb-12	C,S	Shale	184	258	1.4	Delmag	D 19-42
KA-0715-01	013	Pier	7	1	1.25	Edwards	US-50	Nov-11	S	Dakota Fm	159	259	1.6	Delmag	D 16-32
KA-0717-01	148	Pier	2	1	26	Sumner	US-81	Nov-11	C,M,S	unknown	112	168	1.5	Delmag	D 16-32

TABLE A5
End-of-Drive Piles Excluded from Statistical Analysis (68 Piles)

Project	Bridge No.	Element	No.	County	Route	Date	Soil	Toe	KDOT-ENR (tons)	PDA/ CAPWAP (tons)	Hammer Type	Hammer Size
K-2030-01	020	Pier	1	Kiowa	US-54	May-86	C, S, M, G	Ogallala	---	110	Delmag	D 12
K-2054-01	1.80	Pier	1	Anderson	K-57	Oct-94	C,M,G	Shale	112	289	---	---
K-2355-01	006	Pier	5	Seward	US-54	Jul-86	M,S	Alluvium	---	---	---	---
K-2888-01	1.28	Pier	4-11	Wyandotte	I-673	Feb-87	C,M,S	Limestone	---	160	---	---
K-2888-01	1.28	Pier	4-13	Wyandotte	I-676	Feb-87	C,M,S	Limestone	---	168	---	---
K-2888-01	1.29	Pier	3-15	Wyandotte	I-674	Feb-88	Unknown	Unknown	---	160	---	---
K-2888-01	1.31	Pier	6-10	Wyandotte	I-675	Dec-87	C, S, glacial	Bedrock	142	165	---	---
K-2888-01	1.31	Pier	6-15	Wyandotte	I-670	Dec-87	C, S, glacial	Bedrock	131	120	---	---
K-2888-01	1.31	Pier	6-19	Wyandotte	I-679	Dec-87	C, S, glacial	Bedrock	122	179	---	---
K-2888-01	1.38	Pier	7-8	Wyandotte	I-671	Jan-88	M, S	Limestone	32	135	---	---
K-2888-01	1.38	Pier	7-14	Wyandotte	I-678	Jan-88	M, S	Limestone	140	175	---	---
K-2888-01	1.38	Pier	7-19	Wyandotte	I-672	Jan-88	M, S	Limestone	83	151	---	---
K-2888-01	1.38	Pier	7-23	Wyandotte	I-677	Jan-88	M, S	Limestone	111	170	---	---
K-3386-01	077	Abut	2	Harvey	US-50	May-94	C, M, S	Silty clay	---	115	Delmag	D 12-32
K-5046-03	109	Pier	1	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	114	Delmag	D 16-32
K-5046-03	109	Pier	5	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	110	Delmag	D 16-32
K-5046-03	109	Pier	7	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	109	Delmag	D 16-32
K-5046-03	109	Pier	11	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	101	Delmag	D 16-32
K-5046-03	110	Pier	1	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	111	Delmag	D 16-32
K-5046-03	110	Pier	2	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	88	Delmag	D 16-32
K-5046-03	111	Pier	1	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	96	Delmag	D 16-32
K-5046-03	111	Pier	2	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	33	Delmag	D 16-32
K-5766-01	058	Pier	1	Brown	US-75	Mar-04	C,M,S,G	Silty clay	---	101	Delmag	D 19-32
K-5766-01	059	Pier	1	Brown	US-75	Feb-04	C,M,S,G	Sand	---	139	Delmag	D 16-32
K-5766-01	059	Pier	3	Brown	US-75	Mar-04	C,M,S,G	Sand	---	159	Delmag	D 16-32
K-6373-01	074	Pier	1	Norton	US-36	May-06	C,M,S,G	Ogallala	---	118	Delmag	D 12-32

Project	Bridge No.	Element	No.	County	Route	Date	Soil	Toe	KDOT-ENR (tons)	PDA/ CAPWAP (tons)	Hammer Type	Hammer Size
K-6373-01	085	Pier	2	Norton	US-36	May-06	M,S	Ogallala	---	169	Delmag	D 12-32
K-6410-01	040	Pier	2a	Nemaha	K-9	Apr-05	C,M,G,glacial	Glacial till	23	---	Delmag	D 12-42
K-6410-01	040	Pier	2b	Nemaha	K-9	Apr-05	C,M,G,glacial	Glacial till	43	---	Delmag	D 12-42
K-7379-01	045	Abut	2	Rice	US-56	Oct-03	C,M	Silty clay	---	69	Delmag	D 19-42
K-7382-01	010	Abut	1	Meade	K-23	Aug-04	C,M,S,G	Ogallala	---	---	Kobe	K-22
K-7382-01	010	Pier	2	Meade	K-23	Aug-04	C,M,S,G	Ogallala	77	---	Kobe	K-22
K-7394-01	049	Abut	2	Doniphan	US-36	Oct-04	C,M,S,G	Shale	---	56	Delmag	D 19-32
K-7394-01	049	Pier	1	Doniphan	US-36	Oct-04	C,M,S,G	Shale	---	210	Delmag	D 19-32
K-7409-01	119	Abut	1	Reno	US-50	Mar-07	M,S	Shale	25	---	Delmag	D 19-32
K-7409-01	120	Abut	2	Reno	US-50	May-07	M,S	Shale	---	30	Delmag	D 19-32
K-7411-01	036	Abut	1	Meade	US-54	May-06	C,M,S	Ogallala	41	70	Conmaco	65
K-7411-01	036	Pier	2	Meade	US-54	May-06	C,M,S	Ogallala	33	42	Conmaco	65
K-7411-01	036	Pier	4a	Meade	US-54	May-06	C,M,S	Ogallala	---	51	Vulcan	1
K-7411-01	036	Pier	4b	Meade	US-54	May-06	C,M,S	Ogallala	77	124	Vulcan	1
K-7432-01	009	Pier	3b	Wichita	K-25	Nov-06	M,S,glacial	Ogallala	---	103	Delmag	D 15
K-7925-02	351	Abut	2	Johnson	K-7	Mar-10	C,M,S	Unknown	---	208	McK-Ter	D 30
K-8238-02	055	Pier	12	Atchison	US-59	Jul-09	C,M,G	Shale	---	---	Delmag	D 30-32
K-8238-02	055	Pier	14	Atchison	US-59	Jun-09	C,M,G	Shale	---	375	Delmag	D 30-32
K-8243-03	043	Pier	2a	Pratt	US-54	Apr-10	C,M,S	Sand	---	118	Delmag	D 16-32
K-8244-01	082	Abut	1	Kingman	US-54	Jun-09	C,M,S	Caliche	25	---	Delmag	D 16-32
K-8244-01	083	Abut	2	Kingman	US-54	Jun-09	C,M,S	Caliche	27	---	Delmag	D 16-32
K-8244-01	084	Abut	1	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	137	Delmag	D 16-32
K-8244-01	084	Abut	1b	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	122	---	---
K-8244-01	084	Pier	2	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	105	Delmag	D 16-32
K-8244-01	085	Abut	2	Kingman	US-54	Nov-09	C,M,S,G	Caliche	---	118	Delmag	D 16-32
K-8244-01	085	Pier	1	Kingman	US-54	Nov-09	C,M,S,G	Caliche	---	90	Delmag	D 16-32
K-8246-01	026	Pier	2b	Finney	US-50	Nov-09	M,S	Mantle	---	102	Delmag	D 19-32
K-8252-01	127	Abut	2	Reno	K-61	Oct-09	C,S	Sand	---	118	Delmag	D 16-32

Project	Bridge No.	Element	No.	County	Route	Date	Soil	Toe	KDOT-ENR (tons)	PDA/ CAPWAP (tons)	Hammer Type	Hammer Size
K-8252-01	127	Pier	2	Reno	K-61	Oct-09	C,S	Sand	40	---	Delmag	D 16-32
K-8252-01	128	Abut	1	Reno	K-61	Nov-09	C,S	Sand	46	---	Delmag	D 16-32
K-8252-01	128	Pier	2	Reno	K-61	Nov-09	C,S	Sand	40	---	Delmag	D 16-32
K-8253-02	132	Abut	1	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	50	---	Delmag	D 30
K-8253-02	133	Abut	2	McPherson	K-61	Oct-09	C,M,S,G	Sand	---	---	Delmag	D 16-32
K-8253-02	136	Pier	2a	McPherson	K-61	Aug-09	C,M,S,G	Sand	---	101	Delmag	D 16-32
K-8253-02	136	Pier	3a	McPherson	K-61	Dec-10	C,M,S,G	Sand	---	69	Delmag	D 16-32
K-8260-01	033	Abut	1	Jackson	US-75	Feb-06	C,M,G,glacial	Silty clay	---	130	Delmag	D 19-32
K-8260-01	033	Abut	2	Jackson	US-75	Feb-06	C,M,G,glacial	Silty clay	---	105	Delmag	D 19-32
K-9661-01	034	Pier	1	Pawnee	K-156	Nov-07	C,M,S,G	Sand	---	---	Delmag	D 15
K-9661-01	035	Pier	1	Pawnee	K-156	Nov-07	C,M,S,G	Sand	33	---	Delmag	D 12-32
KA-0688-01	046	Pier	1	Rice	K-14	Feb-11	M,S,G	Alluvium	35	---	Delmag	D 12-32
KA-0699-01	097	Abut	1	Neosho	K-47	Aug-12	C,M	Lenapah	160	249	Conmaco	65 air
KA-0699-01	097	Abut	2	Neosho	K-47	Aug-12	C,M	Lenapah	148	234	Conmaco	65 air

TABLE A6
Restrike Data Excluded from Statistical Analysis (79 Piles)

Project	Bridge No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soil	Toe	KDOT-ENR (tons)	PDA/ CAPWAP (tons)	Hammer Type	Hammer Size
K-5046-03	109	Pier	5	1	21	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	118	Delmag	D 16-32
K-5046-03	109	Pier	7	1	3	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	121	Delmag	D 16-32
K-5046-03	109	Pier	11	1	24	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	164	Delmag	D 16-32
K-5046-03	110	Pier	1	1	84	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	139	Delmag	D 16-32
K-5046-03	112	Pier	1	1	72	Reno	K-96	Oct-98	C,M,S,G	Alluvium	---	107	Delmag	D 16-32
K-5046-03	114	Pier	1	1	24	Reno	K-96	Oct-98	S	Alluvium	---	163	Delmag	D 16-32
K-5766-01	058	Pier	1	1	3	Brown	US-75	Mar-04	C,M,S,G	Silty clay	---	138	Delmag	D 19-32
K-5766-01	059	Pier	1	1	24	Brown	US-75	Jan-04	C,M,S,G	Sand	---	174	Delmag	D 16-32
K-5766-01	059	Pier	1	2	144	Brown	US-75	Feb-04	C,M,S,G	Sand	---	182	Delmag	D 16-32
K-5766-01	059	Pier	3	1	0.2	Brown	US-75	Jan-04	C,M,S,G	Sand	---	175	Delmag	D 16-32
K-6410-01	040	Pier	2a	1	24	Nemaha	K-96	Apr-05	C,M,G,glacial	Glacial till	34	---	Delmag	D 12-42
K-6410-01	040	Pier	2b	1	120	Nemaha	K-96	Apr-05	C,M,G,glacial	Glacial till	85	---	Delmag	D 12-42
K-7379-01	045	Abut	2	1	2.25	Rice	US-56	Oct-03	C,M	Silty clay	---	110	Delmag	D 19-42
K-7382-01	010	Abut	1	1	5	Meade	K-23	Aug-04	C,M,S,G,glacial	Ogallala	---	177	Kobe	K-22
K-7382-01	010	Pier	2	1	21	Meade	K-23	Aug-04	C,M,S,G,glacial	Ogallala	---	188	Kobe	K-22
K-7387-01	035	Abut	1	1	20	Meade	K-23	Oct-05	C,M,S	Nippewalla	60	112	Delmag	D15
K-7387-01	035	Pier	2	1	24	Meade	K-23	Jan-06	C,M,S	Nippewalla	71	135	Gravity	
K-7394-01	035	Abut	1	1	22	Meade	K-23	Oct-04	C,M,S	Nippewalla	---	58	Delmag	D 19-32
K-7394-01	035	Abut	1	2	328	Meade	K-23	Nov-04	C,M,S	Nippewalla	---	70	Delmag	D 19-32
K-7394-01	049	Pier	1	1	24	Doniphan	US-36	Oct-04	C,M,S,G	Shale	---	86	Delmag	D 19-32
K-7394-01	049	Pier	1	2	25	Doniphan	US-36	Oct-04	C,M,S,G	Shale	---	214	Delmag	D 19-32
K-7407-01	041	Pier	1	1	24	Jewell	US-36	Mar-07	C,M,S,G	Shale	118	---		
K-7409-02	139	Pier	3	1	0.25	Reno	US-50	Oct-11	C,M,S,G	Shale	---	197	Delmag	D 16-32
K-7409-02	139	Pier	3	2	1.5	Reno	US-50	Oct-11	C,M,S,G	Shale	---	210	Delmag	D 16-32
K-7411-01	036	Abut	1	1	4.25	Meade	US-54	Jun-06	C,M,S	Ogallala	65	107	Conmaco	65
K-7411-01	036	Pier	2	1	18.25	Meade	US-54	Jun-06	C,M,S	Ogallala	---	124	Conmaco	65
K-7427-01	058	Pier	2	1	18.25	Marshall	K-96	Jul-06	C,M,S,G	unknown	47	124	Gravity	---

Project	Bridge No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soil	Toe	KDOT-ENR (tons)	PDA/ CAPWAP (tons)	Hammer Type	Hammer Size
K-7427-01	059	Abut	1	1	22.75	Marshall	K-96	Aug-06	C,M,S,G,glacial	Mantle	34	76	Gravity	---
K-7427-01	059	Pier	2	1	19.75	Marshall	K-96	Aug-06	C,M,S,G,glacial	Mantle	60	190	Gravity	---
K-7432-01	009	Pier	3b	1	16	Wichita	K-25	Nov-06	M,S,glacial	Ogallala	---	105	Delmag	D 15
K-7889-01	117	Abut	2	1	4	Franklin	US-59	Feb-08	C,M	Shale	71	---	Gravity	---
K-8213-01	011	Abut	1b	1	24	Cheyenne	K-161	Jun-04	C,M,S	Shale	69	---	Delmag	D 12
K-8237-01	075	Abut	1	1	20	Ford	US-400	Nov-08	C,M,S	Alluvium	---	136	APE	D 19-42
K-8237-01	077	Pier	2	1	17.75	Ford	US-400	Jan-09	M,S	Ogallala	---	122	Delmag	D 12-42
K-8238-02	055	Pier	12	1	1	Atchison	US-59	Jul-09	C,M,G	Shale	---	257	Delmag	D 30-32
K-8238-02	055	Pier	14	1	0.25	Atchison	US-59	Jul-09	C,M,G	Shale	---	362	Delmag	D 30-32
K-8238-02	055	Pier	14	2	1	Atchison	US-59	Jul-09	C,M,G	Shale	---	367	Delmag	D 30-32
K-8238-02	055	Pier	14	3	4	Atchison	US-59	Jul-09	C,M,G	Shale	---	369	Delmag	D 30-32
K-8238-02	055	Pier	14	4	46.5	Atchison	US-59	Jul-09	C,M,G	Shale	---	373	Delmag	D 30-32
K-8243-03	042	Abut	2b	2	1	Pratt	US-54	Jun-10	C,M,S	Sand	---	94	Delmag	D 16-32
K-8243-03	043	Pier	2a	1	2	Pratt	US-54	Apr-10	C,M,S	Sand	---	118	Delmag	D 16-32
K-8243-03	039	Abut	2	3	19.5	Pratt	US-54	Feb-09	C,M,S,G	Sand	---	150	Delmag	D 16-32
K-8244-01	083	Abut	2	2	120	Kingman	US-54	Jun-09	C,M,S	Caliche	---	131	Delmag	D 16-32
K-8244-01	084	Pier	2	1	0.07	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	140	Delmag	D 16-32
K-8244-01	084	Pier	2	2	22.5	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	180	Delmag	D 16-32
K-8244-01	085	Abut	2	1	0.25	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	142	Delmag	D 16-32
K-8244-01	085	Abut	2	2	2.5	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	158	Delmag	D 16-32
K-8244-01	085	Pier	1	1	26	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	173	Delmag	D 16-32
K-8244-01	084	Abut	1	1	0.25	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	247	Delmag	D 16-32
K-8244-01	084	Abut	1	2	1	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	262	Delmag	D 16-32
K-8244-01	084	Abut	1	3	19	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	259	Delmag	D 16-32
K-8244-01	084	Abut	1b	1	1	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	203	---	---
K-8244-01	084	Abut	1b	2	23	Kingman	US-54	Feb-09	C,M,S,G	Caliche	---	307	---	---
K-8246-01	026	Pier	2a	2	2.50	Finney	US-50	Nov-09	M,S	Mantle	---	136	Delmag	D 19-32
K-8246-01	026	Pier	2a	3	16.50	Finney	US-50	Nov-09	M,S	Mantle	---	152	Delmag	D 19-32

Project	Bridge No.	Element	No.	Restrike No.	Restrike Time (hours)	County	Route	Date	Soil	Toe	KDOT-ENR (tons)	PDA/ CAPWAP (tons)	Hammer Type	Hammer Size
K-8246-01	026	Pier	2b	1	0.25	Finney	US-50	Nov-09	M,S	Mantle	---	111	Delmag	D 19-32
K-8246-01	026	Pier	2b	2	1	Finney	US-50	Nov-09	M,S	Mantle	---	110	Delmag	D 19-32
K-8246-01	027	Pier	2b	1	17	Finney	US-50	Jul-09	M,S,G	Mantle	35	---	Delmag	D 12-42
K-8251-08	406	Abut	2	1	1	Johnson	I-435	Mar-12	C,M	Shale	---	215	Delmag	D 19-42
K-8252-01	128	Pier	2	1	48	Reno	K-61	Oct-09	C,S	Sand	---	168	Delmag	D 16-32
K-8252-01	131	Pier	1	1	48	Reno	K-61	Jul-09	C,M,S,glacial	Sand	---	183	Delmag	D 16-32
K-8252-01	132	Pier	2	1	0.25	Reno	K-61	Oct-09	C,S	Sand	---	211	Delmag	D 16-32
K-8252-01	132	Pier	2	2	1	Reno	K-61	Oct-09	C,S	Sand	---	164	Delmag	D 16-32
K-8252-01	132	Pier	2	3	17	Reno	K-61	Oct-09	C,S	Sand	---	119	Delmag	D 16-32
K-8252-01	132	Pier	2	4	48	Reno	K-61	Oct-09	C,S	Sand	---	211	Delmag	D 16-32
K-8253-02	132	Pier	2c	1	0.25	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	---	154	Delmag	D30
K-8253-02	132	Pier	2c	3	23	McPherson	K-61	Oct-09	C,M,S,G,glacial	Sand	---	171	Delmag	D30
K-8253-02	133	Abut	2	1	4	McPherson	K-61	Oct-09	C,M,S,G	Sand	---	98	Delmag	D 16-32
K-8253-02	136	Pier	3a	1	2	McPherson	K-61	Dec-10	C,M,S,G	Sand	---	78	Delmag	D 16-32
K-8260-01	033	Pier	1	1	72	Jackson	US-75	Feb-06	C,M,G,glacial	Silty clay	---	291	Delmag	D 19-32
K-9661-01	034	Abut	1	1	18	Pawnee	K-156	Nov-07	C,M,S,G	Sand	---	126	Delmag	D 15
K-9661-01	034	Pier	2	1	19	Pawnee	K-156	Nov-07	C,M,S,G	Sand	---	100	Delmag	D 15
KA-0387-01	043	Abut	2	1	2.5	Clark	US-183	Oct-10	C,S,G	Shale	69	---	Delmag	D 19-42
KA-0699-01	097	Abut	2	1	2	Neosho	K-47	Aug-12	C,M	Lenapah	142	220	Conmanco	65 air
KA-0710-01	298	Abut	2	1	0.5	Shawnee	US-24	Apr-12	C,S,G	Unknown	59	139	Gravity	---
KA-0710-01	298	Pier	2	1	0.5	Shawnee	US-24	Apr-12	C,S,G	Unknown	76	202	Gravity	---
KA-0717-01	148	Abut	1	1	0.25	Sumner	US-81	Oct-11	C,M,S	Unknown	---	102	Delmag	D 19-32
KA-0717-01	148	Abut	1	2	2	Sumner	US-81	Oct-11	C,M,S	Unknown	---	126	Delmag	D 19-32
KA-0717-01	148	Abut	1	3	3	Sumner	US-81	Oct-11	C,M,S	Unknown	---	126	Delmag	D 19-32

Appendix B

Example of the procedure to calculate capacity using the resistance factor:

If a reliability index, β_T, of 3.0 is adopted, the resistance factor is 1.28. If the current KDOT-ENR formula yields a capacity of 50 tons, the capacity using the updated formula will be P_u = 50 x 1.28 = 64 tons.

$$P_u = 1.28\left[\frac{1.6WH}{s + 0.1\left(\frac{X}{W}\right)}\right] = 1.28(50\ tons) = 64\ tons.$$

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