Development of LRFD Procedures for Bridge Pile Foundations in Iowa

Volume I: An Electronic Database for Pile Load Tests (PILOT)

Final Report
June 2010

Database for Pile Load Tests in Iowa (PILOT)

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### 16. Abstract
For well over 100 years, the Working Stress Design (WSD) approach has been the traditional basis for geotechnical design with regard to settlements or failure conditions. However, considerable effort has been put forth over the past couple of decades in relation to the adoption of the Load and Resistance Factor Design (LRFD) approach into geotechnical design. With the goal of producing engineered designs with consistent levels of reliability, the Federal Highway Administration (FHWA) issued a policy memorandum on June 28, 2000, requiring all new bridges initiated after October 1, 2007, to be designed according to the LRFD approach. Likewise, regionally calibrated LRFD resistance factors were permitted by the American Association of State Highway and Transportation Officials (AASHTO) to improve the economy of bridge foundation elements. Thus, projects TR-573, TR-583 and TR-584 were undertaken by a research team at Iowa State University’s Bridge Engineering Center with the goal of developing resistance factors for pile design using available pile static load test data.

To accomplish this goal, the available data were first analyzed for reliability and then placed in a newly designed relational database management system termed Pile LOad Tests (PILOT), to which this first volume of the final report for project TR-573 is dedicated. PILOT is an amalgamated, electronic source of information consisting of both static and dynamic data for pile load tests conducted in the State of Iowa. The database, which includes historical data on pile load tests dating back to 1966, is intended for use in the establishment of LRFD resistance factors for design and construction control of driven pile foundations in Iowa. Although a considerable amount of geotechnical and pile load test data is available in literature as well as in various State Department of Transportation files, PILOT is one of the first regional databases to be exclusively used in the development of LRFD resistance factors for the design and construction control of driven pile foundations. Currently providing an electronically organized assimilation of geotechnical and pile load test data for 274 piles of various types (e.g., steel H-shaped, timber, pipe, Monotube, and concrete), PILOT ([http://srg.cce.iastate.edu/lrfd/](http://srg.cce.iastate.edu/lrfd/)) is on par with such familiar national databases used in the calibration of LRFD resistance factors for pile foundations as the FHWA’s Deep Foundation Load Test Database. By narrowing geographical boundaries while maintaining a high number of pile load tests, PILOT exemplifies a model for effective regional LRFD calibration procedures.

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1. INTRODUCTION

Over a twenty-four year period defined by the years from 1966 to 1989, information concerning 264 pile static load tests (SLTs) conducted in the State of Iowa on steel H-shaped, timber, pipe, Monotube, and concrete piles (Figure 1.1) was collected by the Iowa Department of Transportation (Iowa DOT). During this time period, the entirety of the aforementioned collected information, although not always wholly available, included details concerning the site location, subsurface conditions, pile type, hammer characteristics, end-of-driving (EOD) blow count, and static load test results. All of this information was stored by the Iowa DOT in hardcopy format, making its usage for the Load and Resistance Factor Design (LRFD) resistance factor calibration process cumbersome and almost impractical. As a part of research project TR-573: Development of LRFD Design Procedures for Bridge Piles in Iowa, which is directed at the development of LRFD procedures for bridge piles in the State of Iowa, the electronic database for PIle LOad Tests (PILOT) was developed using Microsoft Office Access™ and in conjunction with the Iowa DOT to allow for the efficient performance of reference and/or analysis procedures on the amassed dataset.

![Pie chart showing the distribution of historical pile SLTs by pile type](image)

**Figure 1.1: Distribution of Historical Pile SLTs by Pile Type**

Even though an abundance of geotechnical and deep foundation load test data is currently available in literature as well as in various State DOT files, the electronic assimilation of such data has been sparsely documented. In fact, the Federal Highway Administration’s (FHWA’s) Deep Foundation Load Test Database (DFLTD) is the lone electronic database that has been encountered to date (Kalavar & Early, 2000). Consisting of more than 1500 deep foundation load test records from nearly 850 sites from various parts of the world, the DFLTD provides an economical source of information for feasibility studies, foundation design, as well as research and development activities. However, it is important to note that the DFLTD, like all of the databases summarized by Roling (2010), lacks a distinct system by which the quality of a given deep foundation load test may be assessed.
In an effort to match the comprehensiveness of the DFLTD while still maintaining the desired regional characteristics and for verification of the regionally calibrated LRFD resistance factors recommended by AbdelSalam et al. (2010), PILOT was extended to include ten additional load tests on steel H-shaped piles, the most commonly used pile type within the State of Iowa (AbdelSalam et al., 2010). In addition to simply driving and statically load testing the piles to failure, most of the test piles were instrumented with strain gauges and dynamically monitored during driving and restrikes using the Pile Driving Analyzer (PDA) device. Moreover, the subsurface conditions at the location of each of the test piles were characterized using various laboratory tests (e.g., moisture content, grain-size distribution, Atterberg limits, consolidation, and Triaxial Consolidated-Undrained compression tests) and in-situ tests (e.g., Standard Penetration Test (SPT), Cone Penetration Test (CPT), and Borehole Shear Test (BST)). In some cases, ground instrumentation (i.e., push-in pressure cells) was used to capture horizontal stress and porewater pressure data near the test pile during driving and static load testing. The reader is referred to Ng et al. (2010) for more detailed information concerning these ten additional pile load tests.

With the inclusion of this additional information, PILOT contains adequate data for the development of regionally calibrated LRFD resistance factors for the following three different sources of estimates for pile resistance: static analysis methods (e.g., α-Tomlinson, Nordlund and Thurman, Meyerhof SPT, Schmertmann CPT, etc.), dynamic analysis methods (e.g., Wave Equation Analysis Approach (WEAP), PDA, CAse Pile Wave Analysis Program (CAPWAP)), and dynamic pile driving formulas (e.g., Engineering News Record (ENR), Gates, FHWA Modified Gates, Janbu, etc.). Furthermore, as more pile load test data are regularly collected in the future and added to the database, PILOT can only become invaluable on account of the high quality assurance provisions and its ability to continue to improve foundation design and construction practices.

In the following sections of this report, the importance of PILOT will be detailed together with a brief description of the structure and key parameters used in the development of this database. A detailed description of the historical dataset upon which the database was originally fashioned will also be provided, before a comprehensive review of all fields contained within the database is given. Therefore, this report serves as a user guide for PILOT, which is available to any user via the project web site (http://srg.cce.iastate.edu/lrdf/).
2. BACKGROUND

To determine friction pile lengths and end-bearing capacities, Iowa DOT bridge designers have used a simple methodology based on tables found in *Foundation Soils Information Chart: Pile Foundation* (Dirks & Kam, 1989; revised 1994) and corresponding soil information. Wave equation concepts were used to develop the end bearing chart, while the skin friction chart was adopted from G. Meyerhoff’s semi-empirical relationship and M. J. Tomlinson’s 1979 research. Meyerhoff’s semi-empirical relationship, which was established in 1976, elucidates the fact that the unit skin friction varies linearly with the SPT N-value number up to a value of 50 blows per foot, at which point the unit skin friction becomes a constant 1 ton per square foot value. Tomlinson’s 1979 research correlated adhesion and cohesion values for different pile materials and pile embedment. Using these techniques as a basis, adjustments were ultimately made via SLT data collected from pile SLTs conducted during the time period spanning 1965 to 1987 before the final version of the charts, which underwent a relatively minor update in 1994, was released.

This approach for designing piles was simple, efficient, and compatible with working stress design (WSD) procedures. However, it has long been recognized that standard bridge design specifications based on WSD cannot ensure the consistent, reliable performance of structures. Since the foundation is a critical element of any bridge system, ensuring the system’s uniform performance requires a consistent and reliable design of the foundation, including footings supported by piles. The LRFD method has been progressively developed since the mid-1980s with this sole purpose of ensuring the uniform reliability of bridge systems throughout the United States by unifying the design of superstructure and foundation elements.

In a response to this documented reliability of the LRFD approach over the more traditional WSD approach, the FHWA issued a policy memorandum on June 28, 2000, requiring all new bridges initiated after October 1, 2007, to be designed according to the LRFD approach. This approach for designing foundation elements has substantially more challenges associated with it than, for example, the design of superstructure elements following the same design approach. These challenges develop mainly from the inherently high variability of soil properties across, as well as within, regions and the ability to predict the realistic pile resistance and driving stresses. Since the foundation is a critical element of the bridge system, conservative LRFD resistance factors have been recommended for their design (AASHTO, 2007) to ensure safe foundation design practices. In this process, soil variability expected at the national level was given consideration, contributing to the conservativeness of the recommended LRFD resistance factors. However, for economical reasons, an unnecessarily conservative design method should not be adopted since foundation systems typically account for as much as thirty percent of the total bridge cost. Consequently, regionally calibrated LRFD resistance factors have been permitted by the American Association of State Highway and Transportation Officials (AASHTO) in order to improve the economy of the bridge foundation elements.
3. SIGNIFICANCE OF PILOT

In response to AASHTO’s permittance of regionally calibrated LRFD resistance factors for the design of driven pile foundations, many states across the nation have made an effort to develop regionally calibrated LRFD resistance factors for the design and construction control of driven pile foundations. More specifically, Florida (McVay et al., 2000), Illinois (Long et al., 2009), Washington (Allen, 2005), and Wisconsin (Long et al., 2009) have all published studies recommending LRFD resistance factors for the design of driven pile foundations by means of static analysis methods and the construction control of driven pile foundations by means of dynamic analysis methods and dynamic pile driving formulas. While these studies provide valuable information including the identification of available regional pile load test data, in all cases, except for the State of Florida study, the reported LRFD resistance factor calibrations were accomplished through the use of national databases such as the DFLTD. Such procedures were adopted due to the absence of quality assurance provisions and required geotechnical and load test data for the regionally reported static pile load tests.

According to McVay et al. (2000), the University of Florida has been collecting pile load test data for the Florida DOT since 1989. The resultant database, termed PILEUF, contains data for 247 piles of various types (e.g., square concrete, round concrete, pipe, and steel H-shaped), with 180 of those piles being located in the State of Florida. Although it is unknown as to whether PILEUF exists in an electronic form, its general characteristics resemble those of PILOT. With the goal of becoming a model database for an effective regional LRFD calibration process that can be refined as more data becomes available, PILOT is based on a well-defined hierarchical classification scheme, in addition to an appealing user-friendly interface, that has not yet been seen with other databases such as DFLTD and PILEUF. Furthermore, imposition of a strict acceptance criterion for each of the three hierarchical pile load test dependability classifications, expounded in the subsequent section, ensures that the resulting data available in PILOT for LRFD regional calibration is of superior quality and consistency. These aforementioned qualities delineate the importance of establishing databases such as PILOT at the state and national levels.
4. KEY TERMINOLOGY USED FOR DATA QUALITY ASSURANCE

As mentioned previously, an estimate of a pile's resistance can be achieved through the use of static and/or dynamic methods. Employing a static method requires a detailed site investigation for the evaluation of soil parameters, while for a dynamic method driving record information and reported pile driving equipment characteristics are typically required. Consequently, it was determined during the formulation of PILOT that a well-defined hierarchical classification scheme would be required to clearly identify those pile load tests containing sufficient information for the estimation of pile resistance by means of both static and dynamic methods. Furthermore, based upon the reality that not every pile load test yielded dependable results, an additional level in the hierarchical classification scheme was deemed necessary for initial separation of the reliable pile load tests from the entirety of the PILOT database.

The unique classification system developed for PILOT catalogs pile load tests as “reliable,” “usable-static,” and “usable-dynamic.” The first tier of the hierarchical system, which was originally termed by Dirks and Kam (1989; revised 1994), assigns the reliable classification to a pile static load test that has achieved the displacement based criteria for pile resistance, as defined by Davisson (1972), prior to the pull-out of any anchor piles. The second tier assigns the usable-static classification, which identifies those pile load tests possessing sufficient information for the prediction of pile resistance by means of static methods, to a reliable pile static load test that has soil boring information and SPT data within one hundred feet of the test pile. Furthermore, the third tier assigns the usable-dynamic classification, which identifies those pile load tests containing sufficient information for the prediction of pile resistance by means of dynamic methods, to a usable-static pile load test that has complete driving records and information concerning characteristics of the pile driving equipment for the test pile under consideration.

As a final means of ensuring data quality and consistency within PILOT, distinct classification rules, which were missing from the numerous databases presented by Roling (2010) were established for generalization of the soil profile located along the test pile embedded length. In other words, a test pile is classified as being embedded in a sand soil profile when at least 70% of the soil located along the shaft of the pile is classified as a sand or non-cohesive material according to the Unified Soil Classification System (USCS). Likewise, a test pile is classified as being embedded in a clay soil profile when at least 70 percent of the soil located along the shaft of the pile is classified as a clay or cohesive material according to the USCS. However, when neither of the aforementioned classifications is achieved, the test pile is classified as being embedded in a mixed soil profile. In light of the key terminology defined in this subsection, a descriptive summary of the historical data subset upon which PILOT was originally fashioned is presented below.
5. DESCRIPTIVE SUMMARY OF PILOT HISTORICAL DATA SUBSET

A descriptive summary of the 264 pile SLTs conducted in the State of Iowa on steel H-shaped, timber, pipe, Monotube, and concrete piles is provided as a function of pile type in the following subsections.

5.1 Steel H-Pile SLTs

Of the 264 pile SLTs conducted by the Iowa DOT, 164 were performed on H-shaped steel piles. A distribution of the number of static pile load tests conducted on the various sizes of steel H-shaped piles has been provided in Figure 5.1. Likewise, a distribution indicating the various embedded lengths for the 164 steel H-shaped test piles is depicted in Figure 5.2, for which the mean and standard deviation are 53.20 and 18.56 feet, respectively.

Of considerable interest and value to the objectives of this research project is the fact that a total of 139 steel H-pile load tests were classified in PILOT as reliable, with 80 of those being classified as usable-static and 32 of those 80 being grouped as usable-dynamic. For the 80 usable-static steel H-pile load tests, distributions amongst Iowa’s five predominant soil regions, the predominant soil medium encountered along the shaft of the pile, and Iowa’s 99 counties have been provided in Figure 5.3, Figure 5.4, and Figure 5.5, respectively. Likewise, for the 32 usable-dynamic steel H-pile load tests, distributions amongst Iowa’s five predominant soil regions, the predominant soil medium encountered along the shaft of the pile, and Iowa’s 99 counties have been provided in Figure 5.6, Figure 5.7, and Figure 5.8, respectively.

Lastly, to assist with future investigations concerning the effect of soil setup on pile resistance, the time interval between the EOD condition and the actual SLT was established for each of the 80 usable-static steel H-pile load tests. With this information, distributions for both the usable-static and usable-dynamic data subsets were generated and have been provided in Figure 5.9 and Figure 5.10, respectively. More specifically, the usable-static distribution of Figure 5.9 possesses a mean of 4.9 days and a standard deviation of 2.2 days, whereas the usable-dynamic distribution of Figure 5.10 possesses a mean of 4.6 days and a standard deviation of 1.7 days. When considering only those steel H-piles embedded in a clay soil profile, for which the influence of soil setup is greatest on account of a characteristically slow time rate of consolidation, the mean and standard deviation for the distribution of the time interval between the EOD condition and the actual SLT become 4.4 days and 1.9 days, respectively, for the usable-static records and 3.7 days and 1.3 days, respectively, for the usable-dynamic records.
Figure 5.1: Distribution of Historical Steel H-Pile SLTs by Pile Size

Figure 5.2: Distribution of Embedded Pile Lengths for Historical Steel H-Pile Dataset
Figure 5.3: Distribution of Historical Usable-Static Steel H-Pile SLTs amongst Iowa’s Predominant Soil Regions

Figure 5.4: Distribution of Historical Usable-Static Steel H-Pile SLTs by Test Site Soil Classification
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Figure 5.10: Distribution of Time Interval between EOD and SLT for Historical Usable-Dynamic Steel H-Pile SLTs
5.2 Timber Pile SLTs

Of the 264 pile SLTs conducted by the Iowa DOT, 75 were performed on timber piles. For the entirety of this timber pile load test data subset, it was presumed that all test piles were 10 inches in diameter as a consequence of inadequate size classification information. This assumption follows that made by Dirks and Kam (1989; revised 1994) in their derivation of the skin friction and end bearing design charts found in *Foundation Soils Information Chart: Pile Foundation*. The various embedded lengths for these 75 timber piles have been provided in the distribution presented in Figure 5.11, for which the mean and standard deviation are 29.00 and 10.68 feet.

![Figure 5.11: Distribution of Embedded Pile Lengths for Historical Timber Pile Dataset](image)

Out of the 75 total timber pile SLTs conducted by the Iowa DOT, 47 were classified in PILOT as reliable, with 24 of those being classified as usable-static and 9 of those 24 being grouped as usable-dynamic. For the 24 usable-static timber pile load tests, distributions amongst Iowa’s five predominant soil regions, the predominant soil medium encountered along the shaft of the pile, and Iowa’s 99 counties have been provided in Figure 5.12, Figure 5.13, and Figure 5.14, respectively. Similarly, for the 9 usable-dynamic timber pile load tests, distributions amongst Iowa’s five predominant soil regions, the predominant soil medium encountered along the shaft of the pile, and Iowa’s 99 counties have been provided in Figure 5.15, Figure 5.16, and Figure 5.17, respectively.

To finish, distributions of the time interval between the EOD condition and the actual SLT for both the usable-static and usable-dynamic timber pile data subsets have been provided in Figure 5.18 and Figure 5.19, respectively. More specifically, the usable-static distribution of Figure 5.18 possesses a mean of 5.8 days and a standard deviation of 2.7 days, whereas the usable-dynamic distribution of Figure 5.19 possesses a mean of 5.0 days and a standard deviation of 3.2 days.
Figure 5.12: Distribution of Historical Usable-Static Timber Pile SLTs amongst Iowa’s Predominant Soil Regions

Figure 5.13: Distribution of Historical Usable-Static Timber Pile SLTs by Test Site Soil Classification
Figure 5.14: Distribution of Historical Usable-Static Timber Pile SLTs amongst Iowa's Predominant Soil Regions and 99 Counties
Figure 5.15: Distribution of Historical Usable-Dynamic Timber Pile SLTs amongst Iowa’s Predominant Soil Regions

Figure 5.16: Distribution of Historical Usable-Dynamic Timber Pile SLTs by Test Site Soil Classification
Figure 5.17: Distribution of Historical Usable-Dynamic Timber Pile SLTs amongst Iowa's Predominant Soil Regions and 99 Counties
Figure 5.18: Distribution of Time Interval between EOD and SLT for Historical Usable-Static Timber Pile SLTs

Figure 5.19: Distribution of Time Interval between EOD and SLT for Historical Usable-Dynamic Timber Pile SLTs
5.3 Pipe, Monotube, and Concrete Pile SLTs

Finally, the 25 remaining pile SLTs conducted by the Iowa DOT were performed on steel pipe, Monotube, and prestressed concrete piles. More specifically, sixteen pile SLTs were performed on steel pipe piles, seven were performed on Monotube piles, which are essentially steel pipe piles with fluted walls and a tapered cross-section, and two were performed on prestressed concrete piles. A distribution showing the number of pile SLTs conducted on the various types and sizes of steel pipe, Monotube, and prestressed concrete piles has been provided in Figure 5.20. In addition, the various embedded lengths for these 25 steel pipe, Monotube, and prestressed concrete piles have been provided in the distribution presented in Figure 5.21, for which the mean and standard deviation are 41.47 feet and 16.21 feet, respectively.

Of the 25 total pile SLTs conducted on steel pipe, Monotube, and prestressed concrete piles, 21 were classified in PILOT as reliable (i.e., 15 steel pipe, 5 Monotube, and 1 prestressed concrete pile SLT), with 17 of those being classified as usable-static (i.e., 14 steel pipe and 3 Monotube pile SLTs) and 2 of those 17 being grouped as usable-dynamic (i.e., 2 steel pipe SLTs). For the 17 usable-static steel pipe and Monotube pile load tests, distributions amongst Iowa’s five predominant soil regions, the predominant soil medium encountered along the shaft of the pile, and Iowa’s 99 counties have been provided in Figure 5.22, Figure 5.23, and Figure 5.24, respectively. As for the two usable-dynamic steel pipe pile load tests, one was performed in Iowa’s loess on top of glacial soil region, while the other was performed in the loess soil region. Additionally, one of the two usable-dynamic steel pipe pile load tests was performed in Shelby County, while the other was performed in Woodbury County. Finally, a mixed soil medium was encountered along the shaft of both usable-dynamic steel pipe piles.

To conclude, a distribution of the time interval between the EOD condition and the actual SLT for the usable-static steel pipe and Monotube pile data subset has been provided in Figure 5.25, where the mean and standard deviation are 10.4 and 11.2 days, respectively. As for the two usable-dynamic steel pipe pile load tests, the one driven in Shelby County was statically load tested to failure seven days after the EOD, while the one driven in Woodbury County was statically loaded to failure fourteen days after the EOD.
Figure 5.20: Distribution of Historical Steel Pipe, Monotube, and Prestressed Concrete Pile SLTs by Type and Size

Figure 5.21: Distribution of Embedded Pile Lengths for Historical Steel Pipe, Monotube, and Prestressed Concrete Piles
Figure 5.22: Distribution of Historical Usable-Static Steel Pipe, Monotube, and Prestressed Concrete Pile SLTs amongst Iowa’s Predominant Soil Regions

Figure 5.23: Distribution of Historical Usable-Static Steel Pipe and Monotube Pile SLTs by Test Site Soil Classification
Figure 5.24: Distribution of Historical Usable-Static Steel Pipe and Monotube Pile SLTs amongst Iowa's Predominant Soil Regions and 99 Counties
Figure 5.25: Distribution of Time Interval between EOD and SLT for Historical Usable-Static Steel Pipe and Monotube Pile SLTs
6. PILOT USER MANUAL

As alluded to previously, PILOT was developed to provide a means for all past, present, and future Iowa DOT bridge pile load test data to be stored in electronic form for subsequent reference and/or analysis. The purpose of the following user manual is to provide a comprehensive explanation of the many features incorporated into PILOT, the details of how the quality of data was ensured, as well as information on how to add new SLT data and the minimum required extent of details for these new tests.

6.1 Accessing PILOT

To download and save a copy of the most recent version of PILOT, follow the steps listed below:

1) Open the My Computer system folder on a computer to which PILOT will be installed.
2) Insert the PILOT CD-ROM into the computer’s CD-ROM drive. Once the PILOT CD-ROM has been placed in the computer’s CD-ROM drive, the CD drive found in the My Computer system folder will display the name PILOT.
3) Open the PILOT CD-ROM by double-clicking with the mouse on the CD drive icon found in the My Computer system folder.
4) Drag the PILOT folder found on the PILOT CD-ROM to the Local Disk (C:) drive. The computer will now begin copying the PILOT folder to the Local Disk (C:) drive; note that this process may take a few minutes. (Should one wish to save the PILOT folder to a location other than the Local Disk (C:) drive, simply drag the PILOT folder found on the PILOT CD-ROM to the desired location.)
5) Once the PILOT folder has been successfully copied to the desired location, PILOT can be opened by first double-clicking with the mouse on the recently copied PILOT folder.
6) Upon opening the PILOT folder, locate and open the Database folder by double-clicking with the mouse.
7) Once the Database folder has been successfully opened, locate and open the Microsoft Office Access™ 2007 file named “PILOT.accdb” by double-clicking with the mouse. (Note that PILOT is best viewed at a screen resolution of 1600 by 1200 pixels.)

6.2 Description of PILOT Database Fields

The architecture of PILOT was developed through the use of Microsoft Office Access™ with the goal of delivering an organized storage facility shrouded beneath an appealing user-friendly interface. It was designed to perform efficient filtering, sorting, and querying procedures on the amassed dataset. Consisting of only two main forms, navigation within PILOT is straightforward. The first of these two forms is the PILOT Display Form shown in Figure 6.1. This main form contains a datasheet view of all available records presented in datasheet view and two quick access buttons for the insertion of new pile load tests records. The acquisition of additional details concerning PILOT, along with a drop-down menu featuring a variety of
filtering options are also made available on this form. All of these functions for the PILOT Form allow it to successfully function as the nucleus for the entire database.

The second of the two main forms, Pile Load Test Record Form (PLTRF), can be accessed via unique hyperlinked identification numbers, or the “New Pile Load Test” quick-access button located on the PILOT Display Form. Containing detailed information organized into ten groupings for each pile load test, PLTRF functions as a user-friendly complement to the PILOT Display Form. As illustrated in Figure 6.2, the PLTRF consists of a series of nine tabbed subforms located in the lower left-hand quadrant. The remaining form space is accompanied by a multitude of informative database fields. These database fields are described in detail in the following subsections.

6.2.1 General Pile Load Test Record Form Information

Described below are various fields included in the general Pile Load Test Record Form (PLTRF) with reference to labels included in Figure 6.2.

A. **ID:** A unique cataloging number automatically assigned by Microsoft Office Access™ to each record within PILOT.

B. **Data Folder Location:** A database field that specifies the location of the pile load test records for each load test contained within the database. The directory housing these various pile load test records, the Pile Load Tests Records Directory, is organized by three volumes. Volume 1 consists of pile load test records for steel H-piles, Volume 2 consists of pile load test records for prestressed concrete, Monotube, and steel pipe piles, Volume 3 consists of pile load test records for timber piles, and Volume 4 consists of pile load test records for those piles tested as a part of IHRB Project TR-583 (Ng et al., 2010). Therefore, the possible entries into this database field are as follows: Volume 1, Volume 2, Volume 3, or Volume 4.

C. **Lab Number:** The identification number used by the Iowa DOT to distinguish between the various test piles (e.g., AXP0-1, AXP1-9, etc.).

D. **Contractor:** The name of the contracting company responsible for the construction of the specified bridge project including driving of the test pile.

E. **Project Number:** The unique Iowa DOT cataloging number assigned to each construction project.

F. **Design Number:** This database field goes hand in hand with the previously described field E (i.e., Project Number). For every construction project in the State of Iowa, in addition to assigning a unique project number, each bridge project within the construction project is assigned a unique design number. The bridge design number corresponding to a specified pile load test is entered into this database field.
Figure 6.1: PILOT Display Form (Microsoft Office Access™ 2007)
Figure 6.2: Pile Load Test Record Form (PLTRF)

Use these controls to navigate amongst the various records in PILOT
G. **County:** This database field utilizes a drop-down menu for simple selection of the Iowa County in which the specified bridge construction project is located.

H. **Township:** This field allows one to manually enter the name of the township corresponding to the location of the specified Iowa bridge construction project.

I. **Section:** This numerical database field allows one to manually enter the section number in which the specified Iowa bridge construction project is located.

J. **Pile Location:** This text database field allows one to manually enter a short description of the test pile location in relation to the features of the bridge under construction. For instance, a typical description will specify if the test pile was located near an abutment or a pier. Furthermore, either the pile number or a detailed narrative identifying the exact location of the pile within the abutment or pier is usually provided.

K. **Tested By:** This text database field allows one to manually enter the names of those people who were responsible for carrying out the pile load test on the specified pile.

L. **Date Tested:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year (e.g., 3/8/1984), the date on which the pile static load test was conducted on the specified pile is specified.

M. **Date Reported:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year (e.g., 3/8/1984), the date on which the pile load test results for the specified pile were reported to the Iowa DOT is specified.

N. **1. Pile Size:** This database field utilizes a drop-down menu for simple selection of the test pile type and size. The options available for selection in this database field are as follows: Steel H-Piles (10×42, 10×57, 12×53, 12×74, 14×73, 14×89, and Steel H – a generic option that may be utilized for instances where the exact Steel H pile size is unknown), Monotube Piles, Steel Pipe Piles (10”, 12”, 16”, and 18” outside diameter), and Timber Piles (18’, 20’, 25’, 30’, 34’, 35’, 40’, 45’, 50’, 55’, and 60’ length or Timber – a generic option that may be utilized for instances where the exact timber pile length is unknown).

O. **2. Date Driven:** In this database field, which has been formatted to accept dated entries of the form Month/Day/Year (e.g., 3/8/1984), the date on which the specified test pile was driven is included.

P. **3. Design Load (Tons):** This database field specifies the total sum of all design loads for which any given pile in the structure is anticipated to support based on the superstructure loading evaluation accomplished using either WSD or LRFD principles. In other words, the given pile must possess a bearing resistance equal to or greater than this value to ensure the safety of the structure. For all piles driven prior to October 1, 2007, the reported value in this field corresponds to the WSD design load while LRFD design load is included for all piles driven after this date, since it corresponds to the FHWA's mandate on the use of LRFD for all new bridge construction.
Q. **4. Bearing by Formula (Tons):** This database field specifies the anticipated bearing resistance for a given pile as determined through the use of the Iowa DOT Modified ENR dynamic pile driving formula, which is supplied in Article 2501.13 of the Iowa Department of Transportation Standard Specifications, Series 2008 (Iowa DOT, 2008) and is discussed in more detail in Chapter 3 of AbdelSalam et al. (2010).

R. **5. Type of Hammer Used:** This database field contains information about the type of hammer used for driving the test pile. Examples of possible entries into this database field include: Gravity, Kobe K-13, and Delmag D-12; the last two examples specify both a brand and series number.

S. **6. Depth of Hole Bored before Driving Pile (ft):** The depth, in feet, of the hole bored to initiate pile driving of the specified test pile. (A value of zero in this field indicates that no hole was bored prior to driving.)

T. **7. Length of Test Pile in Contact with the Soil (ft):** The length, in feet, of the test pile in direct contact with the soil.

U. **8. Elevation at the Bottom Tip of the Test Pile (ft):** The elevation, in feet, at which the toe of the driven test pile resides with reference to the mean sea level datum.

V & W. **9. Highest Gauge Reading Under ### Ton Load (in):** Based upon the SLT results for the specified pile (the location of the SLT results for each record in the database is shown in Figure 6.3), the maximum load experienced by the pile is recorded where the number signs (i.e., ###) appear in the above statement and the displacement gauge reading, in inches, corresponding to this maximum applied load is included in database field W.

X & Y. **10. Gauge Reading after Load Released for ### Minutes (in):** The final entry into each record’s static load test table shows a load of zero tons and a corresponding non-zero gauge reading. This gauge reading represents the rebound of the specified pile after the release of the maximum applied vertical load for a given period of time. The time between the release of the maximum applied load to the pile and the subsequent recording of the final gauge reading is added where the number signs (i.e., ###) appear in the above statement. The final gauge reading, in inches, is then specified in database field Y.

Z. **Record Comments:** Any pertinent additional information regarding the record as a whole is included in this text database field.

AA - FF. **Attachments (1) – (6):** These six hyperlink database fields were created so that important information related to each pile load test could be easily accessed from the PLTRF. The hyperlinked text descriptions found within these database fields maintain a direct path to the file of interest.

To add a new hyperlink to the PLTRF, follow the steps outlined below:

1) Open the desired PLTRF to which a new hyperlink will be added.
2) Position the cursor over the preferred location, Attachments (1) – (6), for the new hyperlink.

3) Right click with the mouse and select Hyperlink-Edit Hyperlink…

4) Locate the file to which the hyperlink will be tied and provide a concise but meaningful description of the file in the “Text to display:” option.

GG. **All Record Data Entered?:** This yes/no database field was created mostly for the one(s) responsible for the data entry procedures, so that an easy distinction could be made between those records still requiring data to be entered and those that had been termed complete. When all available information has been entered for a specific record, this field receives a check mark.

### 6.2.2 Static Load Test Results Tab of PLTRF

As illustrated in Figure 6.3, the first of nine tabs encountered on the PLTRF (i.e., Static Load Test Results) houses those results related to a pile static load test. Most importantly, this tab contains a table which displays the load versus displacement results obtained during static load testing of the pile. The remaining fields contained within this tab are elucidated below.

**A. 11. Davisson Pile Capacity (Tons):** Utilizing the static load test results supplied for each pile, shown in Figure 6.3, the Davisson failure criterion was utilized to determine the ultimate pile capacity (i.e., the dependable pile resistance). The Davisson failure criterion states that the ultimate load of a pile subjected to a vertical load test is the load which the displacement of the pile exceeds the elastic compression of the pile by $0.15 + D/120$ inches, where $D$ is the pile depth or diameter (Davisson, 1972). The elastic compression of the pile is simply the length of the pile divided by its elastic modulus and cross-sectional area (i.e., the pile stiffness), then multiplied by the applied load. The Davisson pile capacity established for each pile SLT is provided in this numerical database field.

**B. Static Load Test Remarks:** Any additional comments or information relating to the pile SLT results are supplied in this text database field. Examples of information presented in this database field include the time duration step used for each load increment and pertinent test reliability information such as observed pile punching, pulling out of anchor piles, or no observed yielding of the test pile.

**C. Reliable Static Load Test?:** This yes/no database field receives a checkmark if the SLT data for the specified pile is considered reliable. A reliable test is one in which the test pile reached its displacement-based capacity (i.e., the Davisson pile capacity) with no anchor piles being pulled out prior to its achievement. If the SLT data for a specified test pile does not meet this criterion, then the test is considered unreliable and this database field is left unchecked.

### 6.2.3 Dynamic Load Test Results Tab of PLTRF

As illustrated in Figure 6.4, the second of nine tabs included on the PLTRF (i.e., Dynamic Load
Test Results) houses those results obtained from a dynamic pile load test using PDA. The fifteen fields contained within this tab are described below.

<table>
<thead>
<tr>
<th>Load (Tons)</th>
<th>Gauge Reading (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.3: Static Load Test Results Tab of PLTRF**
Figure 6.4: Dynamic Load Test Results Tab of PLTRF
A. **12. Was PDA used to monitor the pile during driving or restrike?** This yes/no database field receives a checkmark when the PDA device is used to monitor the installation of the test pile, which must be instrumented with accelerometers and strain transducers near the pile head, and assess its bearing resistance at either the EOD or BOR conditions; otherwise, this database field is left unchecked.

B. **13. EOD Date/Time:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year Time-of-Day (e.g., 3/8/1984 10:12:55 AM), the date and time at which the EOD condition was achieved is input.

C. **14. EOD Capacity (kips):** The maximum static pile resistance estimate, in units of kips, provided by PDA at the EOD (i.e., RMX).

D. **15. First Restrike Date/Time:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year Time-of-Day (e.g., 3/8/1984 10:12:55 AM), the date and time corresponding to the beginning of the first restrike are added.

E. **16. First Restrike Capacity (kips):** This field represents the maximum static pile resistance estimate, in units of kips, provided by PDA at the beginning of the first restrike (i.e., RMX).

F. **17. Second Restrike Date/Time:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year Time-of-Day (e.g., 3/8/1984 10:12:55 AM), the date and time corresponding to the beginning of the second restrike are inserted.

G. **18. Second Restrike Capacity (kips):** This field represents the maximum static pile resistance estimate, in units of kips, provided by PDA at the beginning of the second restrike (i.e., RMX).

H. **19. Third Restrike Date/Time:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year Time-of-Day (e.g., 3/8/1984 10:12:55 AM), the date and time corresponding to the beginning of the third restrike are input.

I. **20. Third Restrike Capacity (kips):** This field represents the maximum static pile resistance estimate, in units of kips, provided by PDA at the beginning of the third restrike (i.e., RMX).

J. **21. Fourth Restrike Date/Time:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year Time-of-Day (e.g., 3/8/1984 10:12:55 AM), the date and time corresponding to the fourth restrike are added.

K. **22. Fourth Restrike Capacity (kips):** This field represents the maximum static pile resistance estimate, in units of kips, provided by PDA at the beginning of the fourth restrike (i.e., RMX).

L. **23. Fifth Restrike Date/Time:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year Time-of-Day (e.g., 3/8/1984 10:12:55 AM), the date and time corresponding to the fifth restrike are inserted.
M. **Fifth Restrike Capacity (kips):** This field represents the maximum static pile resistance estimate, in units of kips, provided by PDA at the beginning of the fifth restrike (i.e., RMX).

N. **Sixth Restrike Date/Time:** In this database field, which has been formatted to accept dated entries of the form: Month/Day/Year Time-of-Day (e.g., 3/8/1984 10:12:55 AM), the date and time corresponding to the sixth restrike are input.

O. **Sixth Restrike Capacity (kips):** This field represents the maximum static pile resistance estimate, in units of kips, provided by PDA at the beginning of the sixth restrike (i.e., RMX).

### 6.2.4 Average Soil Profile Tab of PLTRF

As illustrated in Figure 6.5, the third of nine tabs included on the PLTRF (i.e., Average Soil Profile) houses information concerning various soil parameters characteristic of the average soil profile found at the location of the test pile. The various soil parameters included in the table provided in this tab include thickness, an average SPT blow count (NAVG), and a nominal unit skin friction value specified by the design chart found in the *Iowa LRFD Bridge Design Manual* (Iowa DOT, 2010) for each soil layer, as well as a total soil layer nominal skin friction value resulting from the multiplication of the soil layer thickness by the nominal unit skin friction value.

A. **Total Sum of Soil Layer Thicknesses (ft):** This database field refers to the average soil profile table illustrated in Figure 6.5. Based upon the average soil layer data found in this table, the sum of the thicknesses of the various soil strata identified in the table is reported in this field.

B. **Calculated Total Skin Friction Using Design Charts (Tons):** This field refers to the average soil profile table illustrated in Figure 6.5. Based upon the average soil layer data found in this table, the sum of the total skin friction values listed for each of the various soil strata identified in the table is reported in this database field.

C. **Calculated End Bearing Using Design Charts (Tons):** The value input into this field is determined through the use of the average soil profile table illustrated in Figure 6.5 and the design chart found in the *Iowa LRFD Bridge Design Manual* (Iowa DOT, 2010). Based upon the average blow count (i.e., NAVG) value obtained for the soil layer in which the test pile toe resides and the aforementioned design chart, a nominal end bearing value is established and recorded into this database field.

D. **Total Pile Capacity Using Design Charts (Tons):** The value input into this database field is the result of the addition of the value found in the database field marked with a number 28 (i.e., Calculated Total Skin Friction Using Design Charts) and the value found in the database field marked with a number 29 (i.e., Calculated End Bearing Using Design Charts).
E. **Capacity Ratio:** The value entered into this database field is the result of dividing the value found in the database field marked with a number 11 (i.e., Davisson Pile Capacity) by the value found in the database field marked with a number 3 (i.e., Design Load).

F. **Test Site Soil Classification:** This database field utilizes a drop-down menu for simple selection of the predominant soil medium (i.e., sand, clay, or, mixed) encountered along the shaft of the test pile. When at least two soil types are present along the shaft of the test pile and none account for 70 percent or more of the soil profile encountered along the shaft of the test pile, then a mixed soil classification is used to describe the predominant soil medium.

![Figure 6.5: Average Soil Profile Tab of PLTRF](image)

6.2.5 **Borehole/SPT Information Tab of PLTRF**

As illustrated in Figure 6.6, the fourth of nine tabs included on the PLTRF (i.e., Borehole/SPT Information) houses information concerning the availability of borehole and SPT data at the location of the test pile. Most importantly, this tab possesses a table that displays the available borehole and SPT data at the test pile location. The remaining fields contained within this tab are described below.

A. **Total Number of Boreholes:** The total number of boreholes drilled for the corresponding construction project. This information is taken from the relevant project Situation Plan Sheet.
B. **33. Total Number of Borehole with SPT Data:** The total number of boreholes possessing soil penetration data or SPT N-values. This information is taken from the relevant project Sounding Data Plan Sheet.

C. **34. Borehole(s) near Test Pile Location:** This yes/no database field receives a checkmark if a borehole is located within 100 feet of the specified test pile location. If no borehole is located within 100 feet of the test pile location, the field is left without a checkmark.

D. **35. Borehole Number(s) near Test Pile Location:** When the Borehole(s) at Test Pile Location database field is checked, the identification number associated with each of the boreholes located within 100 feet of the test pile location is reported in this text database field. Otherwise, if no boreholes are located within 100 feet the test pile location, the word “None” is entered into this database field. When a borehole or boreholes are located within 100 feet of the location of the test pile, the resulting soil profiles are displayed in the table identified in Figure 6.6.

E. **36. SPT Data Available near Test Pile Location:** When any of the boreholes listed in the Borehole(s) at Test Pile Location database field possess SPT data, then the identification number of such boreholes is repeated in this database field, and the resulting data, soil profile and SPT values are entered into the table identified in Figure 6.6. If none of the boreholes listed in the Borehole(s) at Test Pile Location database field have SPT data, then the word “None” appears in this database field. Although, if the soil profile at the test pile location matches that of any of the boreholes with SPT data, even though these boreholes are not located at or within 100 feet of the test pile location, the resulting information for such boreholes is also provided in the table identified in Figure 6.6.

F. **Usable-Static Test?** This yes/no database field receives a checkmark if a checkmark already exists in the Reliable Load Test? database field and if there is acceptable SPT data available at or within 100 feet of the test pile location.

6.2.6 **Advanced In-Situ Soil Tests Tab of PLTRF**

As illustrated in Figure 6.7, the fifth of nine tabs included on the PLTRF (i.e., Advanced In-Situ Soil Tests) houses those results obtained from advanced in-situ soil tests such as the CPT and the BST, as well as horizontal stress and porewater pressure data collected from push-in pressure cells. The twelve fields contained within this tab are described below.

A. **37. Were Push-In Pressure Cells used to monitor lateral earth and porewater pressure?** This yes/no database field receives a checkmark if one or more push-in pressure cells were installed near the location of the test pile for acquisition of horizontal stress and porewater pressure data; otherwise, this database field is left unchecked.
B. **38. Number of Pressure Cells Used:** When the database field marked with a number 37 (i.e., Were Push-In Pressure Cells used to monitor lateral earth and porewater pressure?) is checked, the total number of push-in pressure cells installed near the location of the test pile is reported in this text database field.

C. **39. Depth of Pressure Cells:** When the database field marked with a number 37 (i.e.,Were Push-In Pressure Cells used to monitor lateral earth and porewater pressure?) is checked, the depths to which each of the push-in pressure cells identified in the database field marked with a number 38 (i.e., Number of Pressure Cells Used) were installed are reported in this text database field.

D. **40. Complete Pressure Cell Data:** This hyperlink database field allows for the establishment of a direct path to the file(s) holding all data acquired from the installed push-in pressure cells. The reader is referred to Section 6.2.1 for instructions on how to add a new hyperlink to the PLTRF.

E. **41. Was a Cone Penetration Test (CPT) Performed?:** This yes/no database field receives a checkmark if one or more CPTs were performed near the location of the test pile; otherwise, this database field is left unchecked.

F. **42. Number of CPT Soundings:** When the database field marked with a number 41 (i.e., Was a Cone Penetration Test (CPT) Performed?) is checked, the total number of
soundings performed near the location of the test pile is reported in this text database field.

G. **43. Number of Pore Pressure Dissipation Tests:** When the database field marked with a number 41 (i.e., Was a Cone Penetration Test (CPT) Performed?) is checked, the number of pore pressure dissipation tests conducted in conjunction with each of the CPT soundings identified in the database field marked with a number 42 (i.e., Number of CPT Soundings) is reported in this text database field.

H. **44. Complete CPT Data:** This hyperlink database field allows for the establishment of a direct path to the file(s) holding all data acquired from the various CPTs performed near the location of the test pile. The reader is referred to Section 6.2.1 for instructions on how to add a new hyperlink to the PLTRF.

I. **45. Was a Borehole Shear Test (BST) Performed?:** This yes/no database field receives a checkmark if one or more BSTs were performed near the location of the test pile; otherwise, this database field is left unchecked.

J. **46. Number of BSTs Performed:** When the database field marked with a number 45 (i.e., Was a Borehole Shear Test (BST) Performed?) is checked, the total number of BSTs performed near the location of the test pile is reported in this text database field.

K. **47. Depths of BSTs:** When the database field marked with a number 45 (i.e., Was a Borehole Shear Test (BST) Performed?) is checked, the depths at which each of the BSTs identified in the database field marked with a number 46 (i.e., Number of BSTs Performed) were performed are reported in this text database field.

L. **48. Complete BST Data:** This hyperlink database field allows for the establishment of a direct path to the file(s) holding all data acquired from the various BSTs performed near the location of the test pile. The reader is referred to Section 6.2.1 for instructions on how to add a new hyperlink to the PLTRF.

6.2.7 *Dynamic Analysis Parameters Tab of PLTRF*

As illustrated in Figure 6.8, the sixth of nine tabs included on the PLTRF (i.e., Dynamic Analysis Parameters) houses information necessary for the prediction of pile resistance by means of dynamic methods (e.g., WEAP, PDA, CAPWAP, and dynamic pile driving formulas). The eleven fields contained within this tab are described below.

A. **49. Water Table Location:** The elevation at which the groundwater table is encountered at the site of the test pile is included in this database field. Such information is taken from the relevant Sounding Data Plan Sheet.

B. **50. Driven Pile Length (ft):** The total length of pile, in units of feet, placed in the leads of the pile driving rig is inserted into this database field.
C. **51. Pile Cross-Sectional Area (square inches):** The total cross-sectional area, in units of square inches, of the pile driven for load testing purposes is inserted into this database field.

D. **52. Pile Weight (lb):** The total weight, in units of pounds, of the pile driven for load testing purposes is inserted into this database field. This pile weight should be in agreement with the length of pile specified in the database field marked with the number 50 (i.e., Driven Pile Length).

E. **53. Hammer (Ram) Weight (lb):** This numerical database field presents the total dynamic weight, in units of pounds, of the hammer used for driving the test pile. The dynamic weight of the hammer is determined by taking the total static weight of the hammer less such deductions resulting from air resistance, lead friction, etc.

F. **54. Cap Weight (lb):** The total weight of the cap, in units of pounds, used while driving the test pile is inserted into this database field.

G. **55. Anvil Weight (lb):** The total weight of the anvil, in units of pounds, used while driving the test pile is inserted into this database field.

H. **56. Hammer Stroke (ft):** The average height above the pile head, in units of feet, from which the hammer is dropped during the final five to ten blows of driving is recorded in this database field.
I. **Developed Hammer Energy (ft-tons):** The total developed energy, in units of foot-pounds, imparted by the hammer to the test pile is recorded in this database field. Simply put, the total developed energy is determined by multiplying the hammer (ram) weight with the hammer stroke.

J. **Average Number of Blows per Foot of Pile Penetration (blows/ft):** The average number of blows needed to advance the test pile tip one foot near the end of driving is recorded in this database field. This value is determined from the average penetration of the test pile over the last five to ten blows (i.e., five blows for gravity hammers and 10 blows for steam or diesel hammers) as recorded on the “Log of Piling Driven” record.

K. **Usable-Dynamic Test?:** This yes/no database field receives a checkmark if a checkmark already exists in the Usable-Static Test? database field and if complete driving records and information concerning characteristics of the pile driving equipment are available for the test pile.

![Figure 6.8: Dynamic Analysis Parameters Tab of PLTRF](image)

**Figure 6.8: Dynamic Analysis Parameters Tab of PLTRF**

### 6.2.8 Static Analysis Results Tab of PLTRF

As illustrated in Figure 6.9, the seventh of nine tabs included on the PLTRF (i.e., Static Analysis Results) displays the results obtained from the application of five static analysis methods upon the given test pile. The five static analysis methods displayed on this tab were chosen by AbdelSalam (2010) in response to an in-depth literature review of the most common and well-performing methods. The five fields contained within this tab are described below.
A. **59. Pile Capacity by Iowa Blue Book Method (Tons):** The nominal pile capacity, in tons, predicted by the Iowa Blue Book static analysis method (Dirks and Kam 1989, revised 1994; AbdelSalam et al. 2010) is placed in this field.

B. **60. Pile Capacity by SPT Method (Tons):** The nominal pile capacity, in tons, predicted by the SPT-Meyerhof static analysis method (Meyerhof, 1976) is placed in this field.

C. **61. Pile Capacity by Alpha-API Method (Tons):** The nominal pile capacity, in tons, predicted by the α-API (American Petroleum Institute) static analysis method (API, 1984) is placed in this field.

D. **62. Pile Capacity by Beta Method (Tons):** The nominal pile capacity, in tons, predicted by the β static analysis method (Burland, 1973) is placed in this field.

E. **63. Pile Capacity by Nordlund Method (Tons):** The nominal pile capacity, in tons, predicted by the Nordlund static analysis method (Nordlund, 1963) is placed in this field.

![Figure 6.9: Static Analysis Results Tab of PLTRF](image)

**Figure 6.9: Static Analysis Results Tab of PLTRF**

### 6.2.9 Dynamic Analysis Results Tab of PLTRF

As illustrated in Figure 6.10, the eighth of nine tabs included on the PLTRF (i.e., Dynamic Analysis Results) displays the results obtained from the application of three dynamic analysis methods upon the given test pile. The three dynamic analysis methods displayed on this tab
were chosen by Ng (2011) in response to an in-depth literature review of the most common and well-performing methods. The fields contained within this tab are described below.

A. 64. Pile Capacity by WEAP (Tons): The nominal pile capacity, in tons, as predicted by the Wave Equation Analysis Program (Pile Dynamics, Inc., 2005) is placed in this field.

B. 65. Shaft Quake used in WEAP Analysis: The elastic compression limit or quake, in units of inches, for soil located along the shaft of the test pile that was used to determine the WEAP pile capacity is placed in this field.

C. 66. Toe Quake used in WEAP Analysis: The elastic compression limit or quake, in units of inches, for soil located at the toe of the test pile that was used to determine the WEAP pile resistance is placed in this field.

D. 67. Shaft Damping Factor used in WEAP Analysis: The damping factor for soil located along the shaft of the test pile that was used to determine the WEAP pile resistance is placed in this field.

E. 68. Toe Damping Factor used in WEAP Analysis: The damping factor for soil located at the toe of the test pile that was used to determine the WEAP pile capacity is placed in this field.

F. 69. Pile Capacity from PDA (Tons): The nominal pile capacity, in tons, as predicted by PDA (Pile Dynamics, Inc., 1992) is placed in this field.

G. 70. Case Damping Factor used by PDA: The Case damping factor utilized by PDA to predict the ultimate capacity of the test pile is reported in this field.

H. 71. Pile Capacity from CAPWAP (Tons): The nominal pile capacity, in tons, as predicted by the CAse Pile Wave Analysis Program (Pile Dynamics, Inc., 2000) is placed in this field.

I. 72. Smith Shaft Damping Factor Calculated by CAPWAP: The damping factor for soil located along the shaft of the test pile that was calculated by CAPWAP in predicting the pile capacity is placed in this field.

J. 73. Smith Toe Damping Factor Calculated by CAPWAP: The damping factor for soil located at the toe of the test pile that was calculated by CAPWAP in predicting the pile capacity is placed in this field.

K. 74. Shaft Quake Calculated by CAPWAP: The elastic compression limit or quake, in units of inches, for soil located along the shaft of the test pile that was calculated by CAPWAP in predicting the pile capacity is placed in this field.

L. 75. Toe Quake Calculated by CAPWAP: The elastic compression limit or quake, in units of inches, for soil located at the toe of the test pile that was calculated by CAPWAP in predicting the pile capacity is placed in this field.
M. 76. **Case Shaft Damping Factor Calculated by CAPWAP:** The Case damping factor for soil located along the shaft of the test pile that was calculated by CAPWAP in predicting the pile capacity is reported in this field.

N. 77. **Case Toe Damping Factor Calculated by CAPWAP:** The Case damping factor for soil located at the toe of the test pile that was calculated by CAPWAP in predicting the pile capacity is reported in this field.

Figure 6.10: Dynamic Analysis Results Tab of PLTRF

### 6.2.10 Dynamic Formula Results Tab of PLTRF

As illustrated in Figure 6.11, the final tab included on the PLTRF (i.e., Dynamic Formula Results) displays the results obtained from the application of seven dynamic pile driving formulas upon the given test pile. The seven dynamic pile driving formulas displayed on this tab were chosen as a consequence of the results obtained from the in-depth literature review of the most common and well-performing formulas presented by Roling (2010). The fields contained within this tab are described below.

A. **78. Pile Capacity by ENR Formula (Tons):** The nominal pile capacity, in tons, as predicted by the Engineering News Record formula (Wellington, 1893) is reported in this field.
B. **79. Pile Capacity by Iowa DOT Modified ENR Formula (Tons):** The nominal pile capacity, in tons, as predicted by the Iowa DOT Modified Engineering News Record formula (Iowa DOT, 2008) is reported in this field.

C. **80. Pile Capacity by Gates Formula (Tons):** The nominal pile capacity, in tons, as predicted by the Gates formula (Gates, 1957) is reported in this field.

D. **81. Pile Capacity by FHWA Modified Gates Formula (Tons):** The nominal pile capacity, in tons, as predicted by the FHWA Modified Gates formula (AASHTO, 2007) is reported in this field.

E. **82. Pile Capacity by Janbu Formula (Tons):** The nominal pile capacity, in tons, as predicted by the Janbu formula (Bowles, 1996) is reported in this field.

F. **83. Pile Capacity by Pacific Coast Uniform Building Code Formula (Tons):** The nominal pile capacity, in tons, as predicted by the Pacific Coast Uniform Building Code formula (Bowles, 1996) is reported in this field.

G. **84. Pile Capacity by Washington Department of Transportation Formula (Tons):** The nominal pile capacity, in tons, as predicted by the Washington State Department of Transportation formula (Allen, 2005) is reported in this field.

![Figure 6.11: Dynamic Formula Results Tab of PLTRF](image-url)
6.3 Disclaimer Notice

PILOT was established as part of a research project (i.e., TR-573: Development of LRFD Design Procedures for Bridge Piles in Iowa) funded by the Iowa Highway Research Board (IHRB). Neither the IHRB nor the authors of this report make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information contained in PILOT. If a problem arises during the usage of PILOT or more knowledge is required, contact Iowa DOT or those currently maintaining the database via http://srg.cce.iastate.edu/lrfd/.
REFERENCES


APPENDIX A: SUMMARY OF PILOT HISTORICAL DATASET
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### Table A.1: PILOT Historical Steel H-Pile Dataset Summary (Records 1-18) – Continued

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Table A.1: PILOT Historical Steel H-Pile Dataset Summary (Records 1-18) – Continued

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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
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Table A.2: PILOT Historical Steel H-Pile Dataset Summary (Records 19-36) – Continued

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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
Table A.3: PILOT Historical Steel H-Pile Dataset Summary (Records 37-54)

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<th>Design #</th>
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<td>Pile Toe Elevation (ft)</td>
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<td>Ram Weight (lbs)</td>
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Table A.3: PILOT Historical Steel H-Pile Dataset Summary (Records 37-54) – Continued

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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
Table A.4: PILOT Historical Steel H-Pile Dataset Summary (Records 55-72)

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Table A.4: PILOT Historical Steel H-Pile Dataset Summary (Records 55-72) – Continued

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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
†From a back-calculated pile penetration value as shown in the example provided in Appendix B
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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
†From a back-calculated pile penetration value as shown in the example provided in Appendix B
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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
Table A.7: PILOT Historical Steel H-Pile Dataset Summary (Records 109-126)

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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
†From a back-calculated pile penetration value as shown in the example provided in Appendix B
Table A.8: PILOT Historical Steel H-Pile Dataset Summary (Records 127-144)

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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
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Table A.9: PILOT Historical Steel H-Pile Dataset Summary (Records 145-162) – Continued

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Table A.9: PILOT Historical Steel H-Pile Dataset Summary (Records 145-162) – Continued

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*Extrapolation of the load-displacement results according to the procedure outlined in the 1999 FHWA report by Paikowsky and Tolosko (1999)
### Table A.10: PILOT Historical Steel H-Pile Dataset Summary (Records 163-164)

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<thead>
<tr>
<th>ID #</th>
<th>County</th>
<th>Township</th>
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<th>Project #</th>
<th>Design #</th>
<th>Contractor</th>
<th>Pile Type</th>
<th>Design Load (tons)</th>
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<td>163</td>
<td>Woodbury</td>
<td>Sioux City</td>
<td>AXP9-7</td>
<td>IIG-F-29-7(13)150--0B-97</td>
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### Table A.10: PILOT Historical Steel H-Pile Dataset Summary (Records 163-164) – Continued

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<th>Soil Type</th>
<th>Bored Hole Depth (ft)</th>
<th>Embedded Pile Length (ft)</th>
<th>Pile Toe Elevation (ft)</th>
<th>Hammer Type</th>
<th>Ram Weight (lbs)</th>
<th>Cap Weight (lbs)</th>
<th>Anvil Weight (lbs)</th>
<th>Pile Weight (lbs)</th>
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### Table A.10: PILOT Historical Steel H-Pile Dataset Summary (Records 145-162) – Continued

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<th>Hammer Stroke (ft)</th>
<th>EOD Blow Count (blows/ft)</th>
<th>Davisson Pile Capacity (tons)</th>
<th>Reliable Static Pile Load Test</th>
<th>Usable-Static Pile Load Test</th>
<th>Usable-Dynamic Pile Load Test</th>
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<td>Township</td>
<td>Lab #</td>
<td>Project #</td>
<td>Design #</td>
<td>Contractor</td>
</tr>
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<td>0-750404-K</td>
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<td>United Contractors Inc.</td>
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<td>Pottawattamie</td>
<td>James</td>
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<td>FM-78(28)55-78</td>
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<td>Franklin &amp; Greenbrier</td>
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<td>L-12.0-4.05-70--73-37</td>
<td>None</td>
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<td>Burlington</td>
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<td>U-UG-534-9(12)--44-29</td>
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<td>Timber</td>
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<td>Scott</td>
<td>Sheridan</td>
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<td>FFD-561-1(2)--2N-82</td>
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<td>Timber</td>
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<td>AXP1-3</td>
<td>U-UG-534-9(12)--44-29</td>
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<td>Maple River</td>
<td>AXP1-10</td>
<td>RRS-30-2(37)--46-14</td>
<td>Cramer Brothers</td>
<td>Timber</td>
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<td>AXP2-7</td>
<td>F-30-7(64)--20-57</td>
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<td>Rapids</td>
<td>AXP2-15</td>
<td>I-380-6(40)260-01-57</td>
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<td>West Lucas</td>
<td>AXP3-1</td>
<td>FN-518-4(24)--21-52</td>
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<td>Pleasant Valley</td>
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<td>Troy</td>
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<td>BRF-149-2(34)--38-48</td>
<td>Grimshaw Construction Co.</td>
<td>Timber</td>
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<td>Hamilton</td>
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<td>DPF-250-4(13)39-40</td>
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<td>SN-3088(4)--51-13</td>
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<td>Timber</td>
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Table A.11: PILOT Historical Timber Pile Dataset Summary (Records 165-182) – Continued

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<th>Pile Toe Elevation (ft)</th>
<th>Hammer Type</th>
<th>Ram Weight (lbs)</th>
<th>Cap + Anvil + Pile Weight (lbs)</th>
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<td>12/16/1980</td>
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Table A.11: PILOT Historical Timber Pile Dataset Summary (Records 165-182) – Continued

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<th>Usable-Static Pile Load Test</th>
<th>Usable-Dynamic Pile Load Test</th>
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†From a back-calculated pile penetration value as shown in the example provided in Appendix B
Table A.12: PILOT Historical Timber Pile Dataset Summary (Records 183-200)

<table>
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<th>ID #</th>
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<th>Township</th>
<th>Lab #</th>
<th>Project #</th>
<th>Design #</th>
<th>Contractor</th>
<th>Pile Type</th>
<th>Design Load (tons)</th>
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<tbody>
<tr>
<td>183</td>
<td>Calhoun</td>
<td>Center</td>
<td>AXP3-7</td>
<td>SN-3088(4)--51-13</td>
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<td>Timber</td>
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<td>AXP3-8</td>
<td>FN-83-1(4)--21-78</td>
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<td>Freedom</td>
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<td>Jamestown</td>
<td>AXP3-13</td>
<td>SN-2923(7)--51-45</td>
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<td>Marion</td>
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†From a back-calculated pile penetration value as shown in the example provided in Appendix B
Table A.14: PILOT Historical Timber Pile Dataset Summary (Records 219-236)

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Table A.14: PILOT Historical Timber Pile Dataset Summary (Records 219-236) – Continued

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Table A.14: PILOT Historical Timber Pile Dataset Summary (Records 219-236) – Continued

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### Table A.15: PILOT Historical Timber Pile Dataset Summary (Records 237-239)

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### Table A.15: PILOT Historical Timber Pile Dataset Summary (Records 237-239) – Continued

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### Table A.15: PILOT Historical Timber Pile Dataset Summary (Records 237-239) – Continued

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Table A.17: PILOT Historical Pipe, Monotube, and Concrete Pile Dataset Summary (Records 258-264)

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Table A.17: PILOT Historical Pipe, Monotube, and Concrete Pile Dataset Summary (Records 258-264) – Continued

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APPENDIX B: BACK-CALCULATION OF PILE PENETRATION

Provided below is an example calculation showing how the pile penetration corresponding to the final 5 to 10 hammer blows was determined from available hammer data and the pile capacity as determined by the Iowa DOT Modified ENR formula.

Given: PILOT Record ID # 67

Pile Type = HP 10×42 \[\text{Pile Characteristics}\]

Pile Length = 35 ft

Hammer Weight = 2750 lb \[\text{Hammer Characteristics}\]

Cap Weight = 1980 lb

Anvil Weight = 810 lb

Hammer Energy = 20,000 ft-lb = 10 ft-ton

P = Bearing Capacity = 19.4 ton

Solution:

\[
P = \frac{3E}{S + 0.1} \times \frac{W}{W + M}
\]

\[M = (\text{Cap Weight}) + (\text{Anvil Weight}) + (\text{Pile Weight})\]

\[M = (1980 \text{ lb}) + (810 \text{ lb}) + (42 \text{ lb/ft})(35 \text{ ft}) = 4260 \text{ lb}\]

\[19.4 \text{ ton} = \frac{3(10 \text{ ft} - \text{ton})}{S + 0.1} \times \frac{2750 \text{ lb}}{2750 \text{ lb} + 4260 \text{ lb}}\]

\[S = 0.507 \text{ in/blow}\]