AUTOMATED SCREENING TOOL FOR STABILITY OF HIGHWAY BRIDGES

SUBJECT TO SCOUR

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AUTOMATED SCREENING TOOL FOR STABILITY OF HIGHWAY BRIDGES

SUBJECT TO SCOUR

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THESIS ABSTRACT

AUTOMATED SCREENING TOOL FOR STABILITY OF HIGHWAY BRIDGES

SUBJECT TO SCOUR

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Most bridges in Alabama that are over shallow bodies of water, including small creeks, wetlands, and marshes, were designed so that the bridge superstructure is supported on pile bents. During major flood events, excessive scour can occur at these bridge bent sites. Scour is the washing away of streambed material by the water channel flow. Hundreds of Alabama's bridges were designed and constructed without recognizing the impact of scour events on the bridge piers. In lieu of this problem, the Alabama Department of Transportation (ALDOT) is currently assessing the scour susceptibility of its bridges, including an evaluation of the structural stability of these bridges for an estimated flood/scour event.

Phase I research work determined that the development of a "screening tool" was technically feasible, the primary parameters that scour susceptibility depends on were

identified, and it was verified that these parameters were in ALDOT's databases, or could be estimated reasonably. In Phase II, a "screening tool" was developed to assess the adequacy of bridge pile bents for an estimated flood/scour event, and a user's guide that explained the proper use of the tool when evaluating the structural stability of the pile bents was created. The objective of the Phase III work was to expand, refine, and automate the "screening tool" developed in the previous phases.

This report focuses on the automation of the screening tool. Visual Basic Studio 2005 was the software package (chosen in agreement with ALDOT engineers) used to automate the ST. The ST is a stand-alone computer program in which ALDOT engineers input bridge/site parameter values, and the program evaluates the stability of a critical pile or bent, or a set of bents, and outputs results regarding the adequacy of the bridge's stability. The ST evaluates the four most critical failure modes, which were identified in Phases I and II as plunging, kick-out, buckling, and pushover failures. Tier-2 screening refinements and expansions, introduced in a sister Phase III report, were also included in the automation of the ST.

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Style used: Chicago Manual Style

Computer software used: Microsoft Word, Microsoft Excel, Visual Basic Studio 2005,

Microsoft Paint, Microsoft Access

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CHAPTER 1: INTRODUCTION

1.1   Statement of Problem

Prior to 1990, Alabama's bridges were designed and constructed without

recognizing the impact of scour events on the bridge piers. There were also hundreds of

county bridges constructed using standardized designs, which did not include scour

analysis in the design of their foundations. To correct this oversight, the Alabama

Department of Transportation (ALDOT) is currently assessing the scour susceptibility of

its bridges, including an evaluation of the structural stability of these bridges for an

estimated flood/scour event. A simple "screening tool" (ST) was developed that can

efficiently and quickly access the susceptibility of these bridges to scour. Along with

scour analyses, the screening tool will be used to identify bridges that are most likely to

be deficient, and that should be prioritized for more a detailed study.

Phases I and II of this research project have already been completed. In the Phase I

work, it was determined that the development of a "screening tool" was technically

feasible, the primary parameters that scour susceptibility depends on were identified, and

it was verified that these parameters were in ALDOT's databases, or could be estimated

reasonably. In Phase II, a "screening tool" was developed to assess the adequacy of

bridge pile bents for an estimated flood/scour event.

1.2 Objectives

The objective of this Phase III work are to refine, simplify, and expand the scope of applicability, as well as to automate the "screening tool" (ST) developed in Phase II. Specifically, the objectives of Phase III are stated below:

1. Identify how the ST can be simplified and expanded in scope of applicability in order to make it more user-friendly and helpful by working with ALDOT maintenance engineers who perform bridge pile bent evaluations for adequacy during estimated extreme flood/scour events.

2. Identify commonly used bridge bent configurations for which the "screening tool" is not presently applicable. Determine if these commonly used bents can be effectively evaluated with the ST when using appropriate limiting conditions. Determine if expansion in the scope of the ST is possible if minimal changes are made.

3. Determine follow-up assessment procedures for those bents that do not pass the initial evaluation of the ST (i.e., those that generate an indication that one should check more closely for possible plunging [kick-out, buckling, pushover] failure).

4. Automate the ST and incorporate simplifications, refinements, and expansions as they are identified and prepared.

1.3   Work Plan

The work plan used to accomplish the above objectives is outlined below.

1. Work with ALDOT engineers to identify problem areas with the ST, areas where the tool is difficult to apply, and/or where parameters needed by the ST are not readily available. Make modifications in the ST to correct these problems and make the ST more user-friendly and productive.

2. Work with ALDOT engineers to identify the bridge bents that are commonly used, but that fall outside the current scope of the ST. Determine the changes or additional analyses for these bents necessary to incorporate them into the ST analyses.

3. Identify what additional checking, analyses, and input data are needed for bents for which the ST indicates "check more closely for possible pile/bent plunging (kick-out, buckling, pushover) failure."

4. Develop a second-tier "screening tool" which includes the checks identified in (3) above.

5. Work with ALDOT engineers to automate the ST for simple computer evaluation of the adequacy of bridge pile bents for estimated extreme flood/scour events. Create an *Automated Screening Tool User's Guide* to be used with the ST, including application examples.

6. Prepare and conduct a training program on the automated ST developed in (5) above.

7. Prepare Phase III Final Report.

1.4   Scope

The part of Phase III research described in this thesis was limited to the automation of the ST. Visual Studio 2005 was the software package (chosen in agreement with ALDOT engineers) used to automate the ST. The ST is a stand-alone computer program in which ALDOT engineers input bridge/site parameter values, and the program evaluates the stability of a critical pile or bent, or a set of bents, and outputs results regarding the adequacy/inadequacy of the bridge's stability. The ST evaluates the four most critical failure modes, which are plunging, kick-out, buckling, and pushover failures. Tier 2 screening refinements and expansions were included in the automation of the ST. Numerical examples were also created to help with the understanding of the ST's implementation and to ensure that the program is user-friendly.

1.5   Thesis Organization

An overview of the project that includes the objectives, work plan, and scope of the Phase III project is presented in Chapter 1. A brief explanation of the background of the project is contained in Chapter 2, followed by a literature review on the relevant topics. The failure mode calculations are presented and described in Chapter 3. In Chapter 4, assumptions used in the development of the Screening Tool are detailed. Chapter 5 contains the Screening Tool User's Guide, which was developed to be used alongside the ST. Chapter 6 provides examples used to illustrate how the ST operates and to show the types of output information that could be generated. Conclusions drawn from the work and recommendations for future study are presented in Chapter 7. Finally,

appendices are attached that include the actual program code, and the relevant bridge

parameter tables and figures.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 Background

Most bridges in Alabama that are over shallow bodies of water, including small creeks, wetlands, and marshes, were designed so that the bridge superstructure is supported on pile bents. Common bridge pile bents contain 3, 4, 5, or 6 steel HP piles in a row, with the two end piles battered. The piles are most commonly oriented so that their weak axis is perpendicular to the longitudinal direction of the bridge. Generally, for these types of bridges, girders are placed directly above the piles, and this was implicitly assumed in the development of the screening tool. These piles are driven to a firm stratum with a length above ground/water up to the level of a concrete bent cap, which supports the superstructure. A photograph of a typical bridge bent is shown in Figure 2.1.

Figure 2.1 Typical Bridge Bent Configuration

During major flood events, excessive scour can occur at these bent sites. Scour is the washing away of streambed material by the water channel flow. Scour usually occurs when the streambed becomes constricted or narrowed with debris. When the channel becomes constricted significantly, the increased velocity of the stream can cause the substructure footings or piles to become undermined and unstable (Tonias and Zhao 2007). There is a significant need to develop an efficient and simple screening tool that ALDOT maintenance engineers can use to quickly assess the hundreds of Alabama bridge bents that may be susceptible to failure during an extreme scour event. The screening tool addresses a broad range of typical bridge layouts, substructure designs,

pile bent foundations, geotechnical conditions, and scour events typically seen in Alabama.

2.1.1 Past Research (Phase I and Phase II)

In the Phase I work associated with this project, the following goals were attained: 1) it was determined that the development of a "screening tool" was technically feasible; 2) the primary parameters upon which scour susceptibility depends were identified; and 3) it was verified that data for these parameters were contained in ALDOT's databases, or that they could be estimated reasonably. In Phase II, a "screening tool" was developed to assess the adequacy of bridge pile bents for an estimated flood/scour event, and a User's Guide was produced, which explained the proper use of the tool.

After completion of Phases I and II, possible failure modes that could be experienced by bridge pile bents during extreme scour events were determined:

1. Flexural Buckling of bent piles in longitudinal direction of the bridge

2. Flexural Buckling of bent piles in transverse direction of the bridge

3. Crushing or reaching the yield load, P_y, of piles

4. Plunging failure of piles (soil failure)

5. Local yielding of piles

6. Flexural failure of bent cap

7. Bent pushover failure from combined superstructure gravity load and transverse flood water load on pile bent

8. Bent failure from piles tips being "kicked" out due to zero or almost zero embedment after scour.

Some of these eight modes were disregarded because they were not of greatest concern, or were not likely to occur. The Phase I report (Ramey and Brown 2004) indicates that flexural failure of the bent cap can only occur if the maximum load on a girder is greater than the load required to cause buckling, or the load necessary to cause plunging (i.e., $P_{girder\ max} > P_{pile\ buckling}$ or $P_{pile\ plunging}$). Additionally, flexural failure of the cap must be prevented for a pile to gain lean-on support from the adjacent piles in the bent. If $P_{girder\ max} < P_{pile\ buckling}$ or $P_{pile\ plunging}$, then the flexural failure of the bent cap will not occur. In every practical situation, the maximum girder load will indeed be less than that required to cause buckling or plunging of the weakest pile in a bent.

Local yielding of a bent pile only results in local permanent deformations in the pile, and is normally not a tragic situation. In Phase I, it was determined that the piles may reach a fully plastic moment state at the pile ground line, at the section of maximum moment, M_{max}. If this occurs, the pile would continue to function in a stable and effective manner. Therefore, this failure condition is not of concern.

An extreme scour event would not change the maximum vertical load applied to a pile, $P_{max\ applied}$, or the vertical load required to cause yielding, P_y, thus, crushing or yielding of the bent piles will not occur as a result of an extreme scour event. However, the crushing of the pile (or the pile reaching P_y), is checked in the screening tool when inelastic buckling of the pile is considered.

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Consequently, the only four catastrophic failure modes remaining, which are included in the screening tool, are the 1) buckling of the bent piles (either elastic or inelastic buckling), 2) plunging of the piles (soil failure), 3) bent pushover failure from combined superstructure gravity and flood water lateral loads, and 4) bent failure from the pile tips "kicking-out" due to zero, or almost zero, embedment after scour (Ramey et. al 2006). These four failure modes are the only ones that are checked by the "screening tool" and they will be discussed at length in Chapter 5.

2.1.2   Phase III Automation

The "screening tool," developed in Phases I and II of this project, was automated using Microsoft Visual Studio 2005 software. Visual Studio 2005 is a development tool in which applications can be created for the Windows operating system, the World Wide Web, and other environments and settings. The Visual Basic program was written in the Visual Studio 2005 Integrated Development Environment (IDE). Visual Studio is a "powerful and customizable programming workshop that contains all the tools you need to build robust programs for Windows and the Web quickly and efficiently" (Halvorson 2006). Forms containing textboxes, labels, and other useful tools are created within the IDE so that the user can easily input information needed for computations within the program. The functions, or calculations, are performed in Modules, which are also created within the IDE.

An additional advantage that prompted the use of Visual Studio software was its ability to "interact" with data contained in properly formatted databases. In several

instances, it was necessary that the automated screening tool be able to gather existing data for particular bridge pile bent configurations in order to proceed with a calculation. The Visual Basic program was able to "call" specific data from the proper table within a database, and return it to the main program for processing.

2.2 Literature Review

2.2.1 Stream Flow

Structures with supports in the course of water are at risk for having those supports slide or overturn due to stream flow forces. Excessive stream flow velocity can lead to scour conditions, which can undermine footings and threaten the integrity of the structure. The pressure due to stream flow is a result of the change in momentum of water as it impacts a pier and then travels away from it (Tonias and Zhao 2007).

According to the American Association of State Highway and Transportation Officials Load and Resistance Factor Design manual, *AASHTO LRFD Bridge Design Specifications* (AASHTO 2006), the equation for the pressure of flowing water acting in the longitudinal direction of the substructure is (AASHTO LRFD 3.7.3.1-1):

$$p = \frac{C_D V^2}{1000}$$

where p = pressure of flowing water (ksf)

V = design velocity of water (ft/s)

C_D = drag coefficient for piers.

The drag coefficient is a function of the shape of the piers, and can be found in Table 2.1.

Table 2.1 Drag Coefficients (AASHTO LRFD 3.7.3.1-1)

Type	C_D
semicircular-nosed pier	0.7
square-ended pier	1.4
debris lodged against the pier	1.4
wedged-nosed pier with nose angle 90° or less	0.8

The longitudinal drag force on a pile bent is the product of the longitudinal pressure times the projected area of the bent.

Bridge piers or bents are usually aligned so that their longitudinal axis is parallel to the direction of stream flow. In an extreme flood event, and with possible stream channel direction changes with time, the direction of stream flow will be at some angle, θ, with respect to the longitudinal bent axis, as illustrated in Figure 2.2.
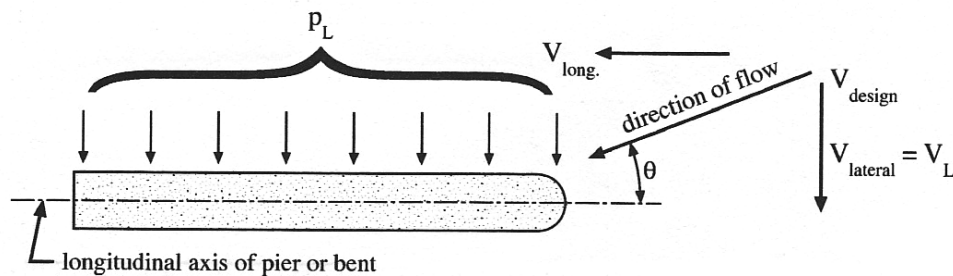
Figure 2.2 Stream Flow Forces on Pier/Bent (Ramey and Brown 2004)

In this case, the uniformly distributed lateral pressure on a pier, p_L, due to water flowing at an angle, θ, to the longitudinal axis of the pier is (AASHTO LRFD 3.7.3.1-1):

$$p_L = \frac{C_L V^2}{1000}$$

where p_L = lateral pressure of flowing water (ksf)

V = design velocity of water (ft/s)

C_L = lateral drag coefficient for piers

The coefficient C_L varies with the angle between the direction of flow and the longitudinal axis of the pier, as shown in Table 2.2.

Table 2.2 Lateral Drag Coefficient (AASHTO LRFD 3.7.3.2-1)

Angle, θ, between direction of flow and longitudinal axis of the pier	C_L
0°	0.0
5°	0.5
10°	0.7
20°	0.9
≥30°	1.0

The lateral drag force on a pile bent is the product of the lateral pressure times the projected area of the bent.

2.2.2   Effect of Surrounding Soil on Pile Capacity

For a pile having adequate structural strength to carry an intended bridge loading, the total downward load capacity on the pile, Q_{total}, will be controlled by the properties of the soil surrounding the pile. This ultimate pile capacity is the sum of the resistance along

the surface of the pile shaft, Q_{shaft}, and the end bearing capacity at the tip of the pile, Q_{tip}, (McCarthy 2007). Thus,

$$Q_{total} = Q_{shaft} + Q_{tip}.$$

The resistance along the surface of the shaft is also referred to as the side frictional force. This frictional force can be taken as

$$Q_{shaft} = f A_{\text{shaft surface}}$$

where $A_{\text{shaft surface}}$ = effective surface area of pile in contact with soil along the embedded shaft length, and

f = unit shearing strength of the interface soil zone immediately adjacent to the pile shaft; this unit shearing strength typically varies along the length of the pile.

Currently, there are two methods used to determine the load capacity developed along the length of the pile shaft: the effective stress analysis and the total stress analysis. The effective stress analysis applies to the post-construction conditions, whereas the total stress analysis applies to conditions existing during installation and shortly after installation (McCarthy 2007). The focus of this research is on existing bridges that are in service, and therefore the effective stress method is of primary interest; therefore, the total stress analysis technique was not examined.

According to the effective stress method, the unit resistance value, f_{soil}, developed along the surface of the pile shaft, for any depth in soil mass, theoretically becomes (McCarthy 2007):

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$$f_{soil} = \sigma_h \tan\delta = K\bar{\sigma}_v \tan\delta$$

where K= lateral earth pressure coefficient (ratio of σ_h / σ_v at the pile-soil layer

interface)

$\bar{\sigma}_v$ = effective vertical pressure (overburden) acting at depth Z within a soil mass

σ_h = effective horizontal soil pressure acting at any depth Z in a soil mass

$\tan\delta$ = the coefficient representing the ratio of the resistance to sliding movement

that develops along the pile shaft to the soil pressure acting normal to the

shaft surface

The value of the interface coefficient, $\tan\delta$, is influenced by the pile shaft material as

well as the type and condition of the soil. For conventional pile materials, values for

δ can be expressed as:

$$\delta = \left(\frac{\delta}{\phi'}\right)\phi'$$

where $\left(\dfrac{\delta}{\phi'}\right)$ = a ratio based on properties of the soil and the pile shaft material (a table of

these ratio values can be found in McCarthy 2007), and

ϕ' = angle of friction for the soil (drained shear strength or effective stress

condition).

After substituting, the total shaft resistance (capacity) developed along the embedded

length of pile is:

$$Q_{shaft} = (K\bar{\sigma}_v)\tan\left(\left(\frac{\delta}{\phi'}\right)\phi'\right)A_{shaft\ surface}$$

For most practical applications, the total end bearing capacity is as follows (McCarthy 2007):

$$Q_{tip} = q_{tip} A_{tip}$$

where q_{tip} = end bearing pressure of soil at pile tip, and

A_{tip} = pile tip bearing area.

A generalized equation for the end bearing pressure that is applicable for all soil types is (McCarthy 2007):

$$q_{tip} = \bar{\sigma}_v N_{tip}$$

Where, $\bar{\sigma}_v$ = the effective vertical soil pressure acting at pile tip depth (psf, kN/m^2)

N_{tip} = tip bearing capacity coefficient related to the drained shear strength (for all

soil types, also found in McCarthy 2007).

The total end bearing for the pile becomes:

$$Q_{tip} = (\bar{\sigma}_v N_{tip}) A_{tip}$$

If all of the information detailed above is known for a pile at a specific site, then the pile capacity could be easily calculated. However, information on soil properties at each specific bent is often inadequate or incomplete. Alternatively, pile capacity can be determined by the driving resistance of the pile at time of construction. Driving resistance is referred to as the number of blows per foot of penetration during pile driving, and it provides a reasonable indication of the amount of soil resistance that the pile has sustained (Ramey et. al 2006). Also, information regarding the driving resistance of the

pile is often the most commonly available information that can be used to indicate pile capacity.

The axial resistance of a pile after scour is mainly a function of

1. The driving resistance at the end of pile driving, indicated as blows per inch (bpi) or blows per foot (bpf) of penetration.

2. Hammer driving energy (kip-feet) used to drive the pile. The energy of the hammer is calculated by multiplying the weight of the ram (kips) by the height of the drop from the driver to the top of the pile (feet).

3. The type of soil that provides the resistance.

4. The amount of scour that occurred and the nature of the scour event.

The wave equation modeling technique provides the most appropriate model for comparing driving resistance to axial static capacity, and this technique is required by ALDOT to establish pile driving criteria for new projects. This model requires more information about the pile driving system than can often be obtained from records of older projects. When there is insufficient information available to utilize such a model, AASHTO specifications allow the use of the Modified Gates equation. The Modified Gates formula is a simple pile driving formula that develops correlations of pile capacity with hammer driving energy and driving resistance at the end of driving (EOD) for a range of pile hammer energies. The formula is as follows:

$$P = 0.875 \ E^{0.5} \ \text{Log} \ (10N_b) - 50$$

where P = nominal resistance in tons,

E = energy produced by the hammer per blow in foot-pounds, and

N_b = the blow count in blows per inch (bpi).

For the interested reader, results from this static pile capacity equation are compared with actual pile-driving data in the report by Ramey and Hudgins (1975).

2.2.3   Column/Pile Buckling

Bridge piles are considered to be slender columns and are subject to a type of behavior known as buckling. If the load on the member remains relatively small, increases in the load result only in a relatively small axial shortening of the member. However, once a critical load is reached, the member will suddenly bend, or buckle. In turn, the member will fail once it experiences large lateral deformations caused by the bending.

The critical buckling load is also referred to as the Euler buckling load. When deriving an equation to represent this load the following is assumed: 1) the member is perfectly straight; 2) the loading is concentric at every cross section; 3) the member has a constant cross-sectional area and is made of a homogeneous material; 4) the material obeys Hooke's law; and 5) the ends of the member are simply supported. The Euler load is the smallest load at which a state of neutral equilibrium is possible, just after the column ceases to be in stable equilibrium (Chajes 1974). The equation for the Euler buckling load, P_{CR} (modified to include the effects of end conditions other than pinned) is shown below,

$$P_{CR} = \frac{\pi^2 EI}{(kl)^2}$$

where E = the modulus of elasticity of the pile material,

I = the moment of inertia of the pile cross section,

k = the effective length factor, determined from the pile's end support conditions,

l = the unsupported length of the column, and

$(kl)^2$ = the square of the "effective" length.

Perfect column/pile load-deflection (P-Δ) and load-to-failure ($P_{failure}$) versus effective

length curves are shown in Figure 2.3 and Figure 2.4, respectively.
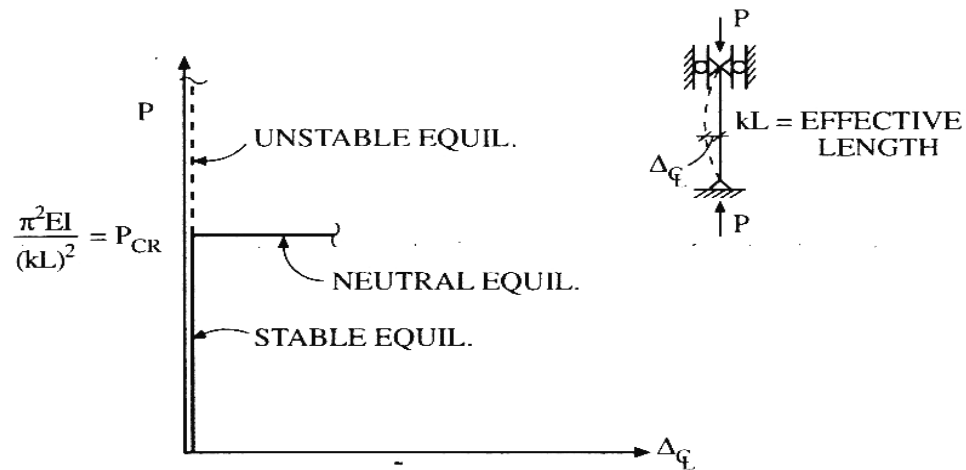
Figure 2.3 Perfect Pile P-Δ Curve (Ramey and Brown 2004)

The figure shows a plot with P_f on the vertical axis and kL on the horizontal axis. Labels include:

$P_Y = \sigma_Y A$

P_Y

FAILURE CURVES

EULER BUCKLING LOAD

$$P_{CR} = \frac{\pi^2 EI}{(kL)^2}$$

STABILITY FAILURE

STRENGTH OF MATERIAL FAILURE
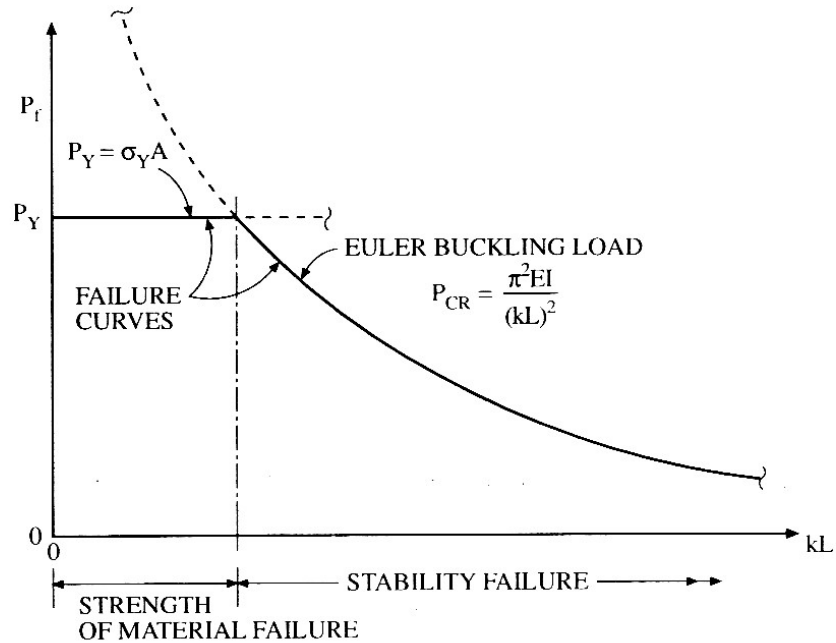
Figure 2.4 Perfect Pile Pf vs. kL Failure Curves (Ramey 2004)

Figure 2.3 represents graphically the behavior of a perfect column. It indicates that the column will remain perfectly straight until the buckling load, P_{CR}, is reached, after which the pile will begin to significantly deform laterally. Figure 2.4 sheds light on the fact, that though a perfect pile may fail either due to insufficient yield strength (P_y) or due to buckling (reaching P_{CR}), the mode of failure depends on the pile's effective length. The smallest effective length for an unbraced bent pile is the pile length from the bent cap to the ground line (i.e., the entire pile length) (Ramey and Brown 2004).

Because bent piles are never perfectly straight or subject to perfect concentric loading, and because they only obey Hooke's Law at stresses less than the yield stress, it is important to review the behavior of imperfect columns. Imperfect columns are

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considered to be members whose centroidal axis is initially bent, or those in which the load is applied with some eccentricity. Consider the hinged column shown in Figure 2.5, which is initially bent.
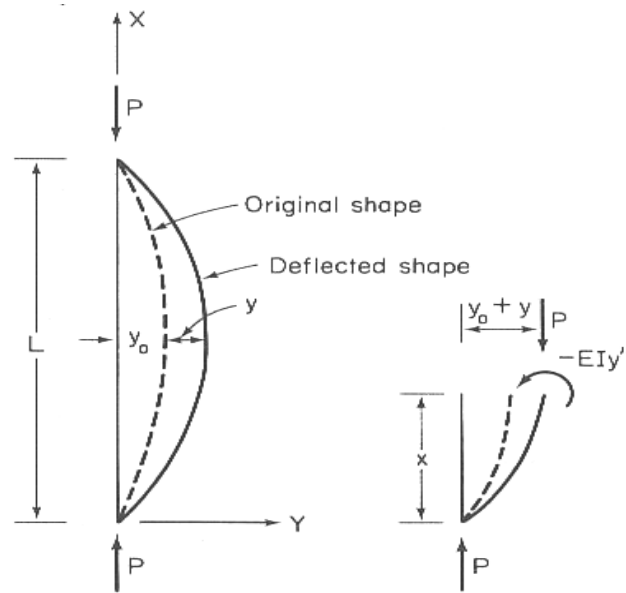
Figure 2.5 Buckling Behavior of an Initially Bent Column (Chajes 1974)

In this figure, the initial deformation of the member is represented by y_o and the corresponding additional deformation due to bending is represented by y, as shown. The initial deformation is assumed to be of the form

$$y_o = a \sin \frac{\pi x}{L}$$

where a = an arbitrary constant representing the magnitude of the initial deflection,

x = the position coordinate along the length of the column, as shown, and

L = the vertical height of the column, as indicated in the figure.

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The change in curvature, y'', causes the bending strains in the column, as opposed to the total curvature, $y_o'' + y''$. Therefore, the internal resisting moment at any position x along the column height is

$$M_x = -EIy''.$$

Equating this moment to bending moment due to the applied load, $P(y + y_o)$, gives

$$EIy'' + P(y + y_o) = 0$$

Substituting the initial deformation equation for y_o in the equation above, and using the notation $k^2 = P / EI$, one obtains

$$y'' + k^2 y = -k^2 a \sin\frac{\pi x}{L}$$

as the governing differential equation of equilibrium for the problem. After solving the differential equation by standard methods, and after solving for the arbitrary constants of differentiation by evaluating the boundary conditions, the bending deflection becomes

$$y = \frac{\alpha}{1-\alpha} a \sin\frac{\pi x}{L}$$

The constant α can be defined as the ratio of the current axial load to the Euler buckling load for a pinned-pinned column (k = 1), i.e. $\alpha = P / P_e$ and $P_e = \pi^2 EI / L^2$. Therefore, the total deflection from the vertical, y_T, is obtained by adding this deflection, y, and the initial deflection, y_0. Thus

$$y_T = y_o + y = (1 + \frac{\alpha}{1-\alpha}) a \sin\frac{\pi x}{L}$$

which can be simplified as

$$y_T = \frac{a}{1-\alpha}\sin\frac{\pi x}{L}$$

The total deflection at midheight of the column, where $x = L/2$ and a = the size of initial imperfection at midheight, is

$$\delta = \frac{a}{1-\alpha} = \frac{a}{1-(P/P_e)}$$

Figure 2.6 gives a plot of midheight deflection, δ, as a function of α for two different values of initial imperfection, a (Chajes 1974). As can be seen, as the ratio of the current axial load to the Euler buckling load approaches 1.0, the midheight deflection increases dramatically.
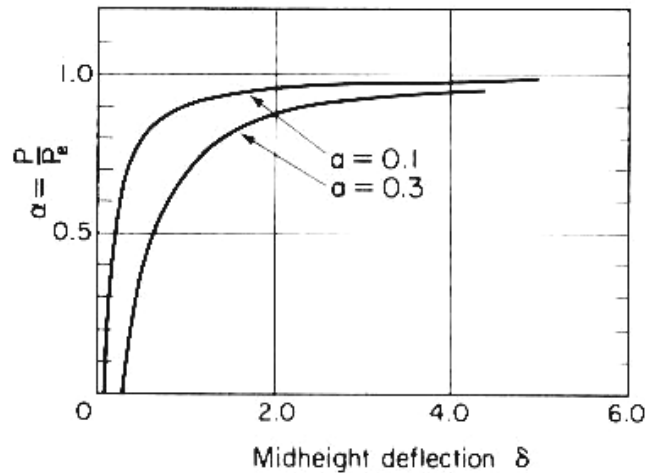
Figure 2.6 Load-Deflection Curves of Initially Bent Columns (Chajes 1974)

The effects of imperfections on column behavior can also be studied by considering a member that is initially straight but is eccentrically loaded, as shown in Figure 2.7.

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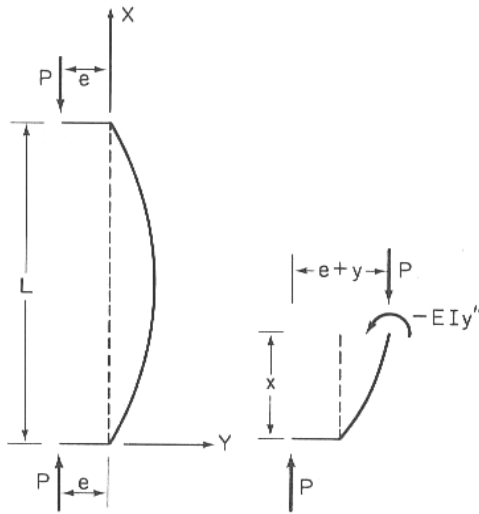
Figure 2.7 Eccentrically Loaded Column (Chajes 1974)

For this case, equating the internal resisting moment, $-EIy''$, at any section, to

the corresponding applied moment, $P(e+y)$, gives

$$EIy'' + P(e+y) = 0$$

Recall that $k^2 = P/EI$. Therefore, the equation above becomes

$$y'' + k^2 y = -k^2 e$$

After satisfying the boundary conditions, the solution to the differential equation becomes

$$y = e\left(\cos kx + \frac{1-\cos kL}{\sin kL}\sin kx - 1 \right).$$

The expression for the midheight deflection, y=δ, is obtained by substituting $x = L/2$ into

the above equation, yielding

$$\delta = e\left(\cos\frac{kL}{2} + \frac{1-\cos kL}{\sin kL}\sin\frac{kL}{2} - 1 \right).$$

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Simplification of this equation gives

$$\delta = e\left(\sec\frac{kL}{2} - 1\right)$$

which can be rewritten as

$$\delta = \left[\sec\left(\frac{\pi}{2}\sqrt{\frac{P}{P_e}}\right) - 1\right]$$

where $P_e = \pi^2 EI / L^2$, as before. A plot illustrating the relationship between the midheight deflection δ and the ratio of P/P_e for two different values of load eccentricity or load imperfection, e, is shown in Figure 2.8.
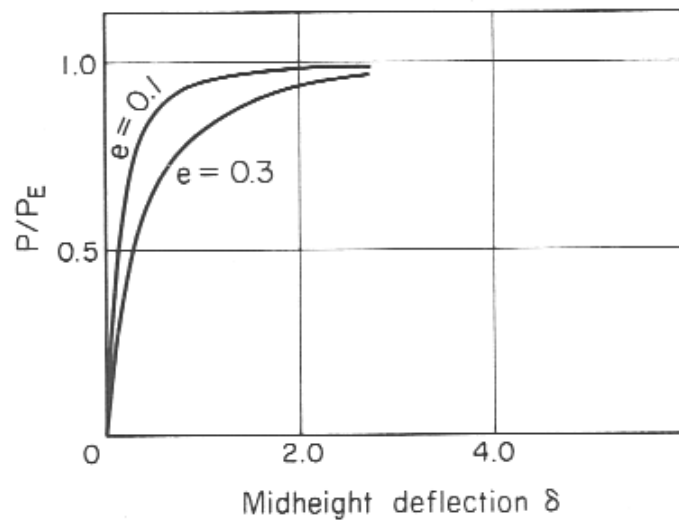
Figure 2.8 Load-Deflection Curves for Eccentrically Loaded Columns with Two Initial Eccentricities (Chajes 1974)

Comparing Figure 2.6 with Figure 2.8, one can see that the columns that are initially curved exhibit essentially the same behavior as the columns that are initially straight and loaded eccentrically. In both cases, bending begins as soon as the column is loaded. The deflection increases slowly at first and then more rapidly as P approaches P_e (Chajes 1974).

In summary, several important conclusions about the behavior of imperfect columns can be reached from observing Figure 2.6 and Figure 2.8:

1. Imperfect columns start to bend and deflect as soon as any axial load is applied.

2. The fact that the curves in each figure exhibit asymptotic behavior approaching a P/P_e value of 1 indicates that, for small values of a or e, the Euler load is a good approximation of the maximum load that a "real," imperfect column can support without bending excessively, and that the intensity of the load does not cause yielding of the material.

3. The behavior of imperfect columns provides a useful method of stability analysis, as stated by Chajes (1974): "The critical load is the load at which the deformations of a slightly imperfect system increase without bound. To apply this criterion, one gives the structural member or system to be investigated a small initial deformation and then determines the load at which this deformation becomes unbounded." This concept is appropriate because it is quite likely that a majority of the in-service bridge piles have some degree of initial imperfection.

4. The behavior of an imperfect system can be replicated either by giving the system some initial crookedness or by applying an eccentric loading.

2.2.4 Pile Bracing

The design of columns in braced frames is based on the effective length of the column. Bracing is used to reduce the effective length of a column, which increases its critical buckling load, and therefore, its stability. Figure 2.9 shows a typical ALDOT bridge bent with bracing.
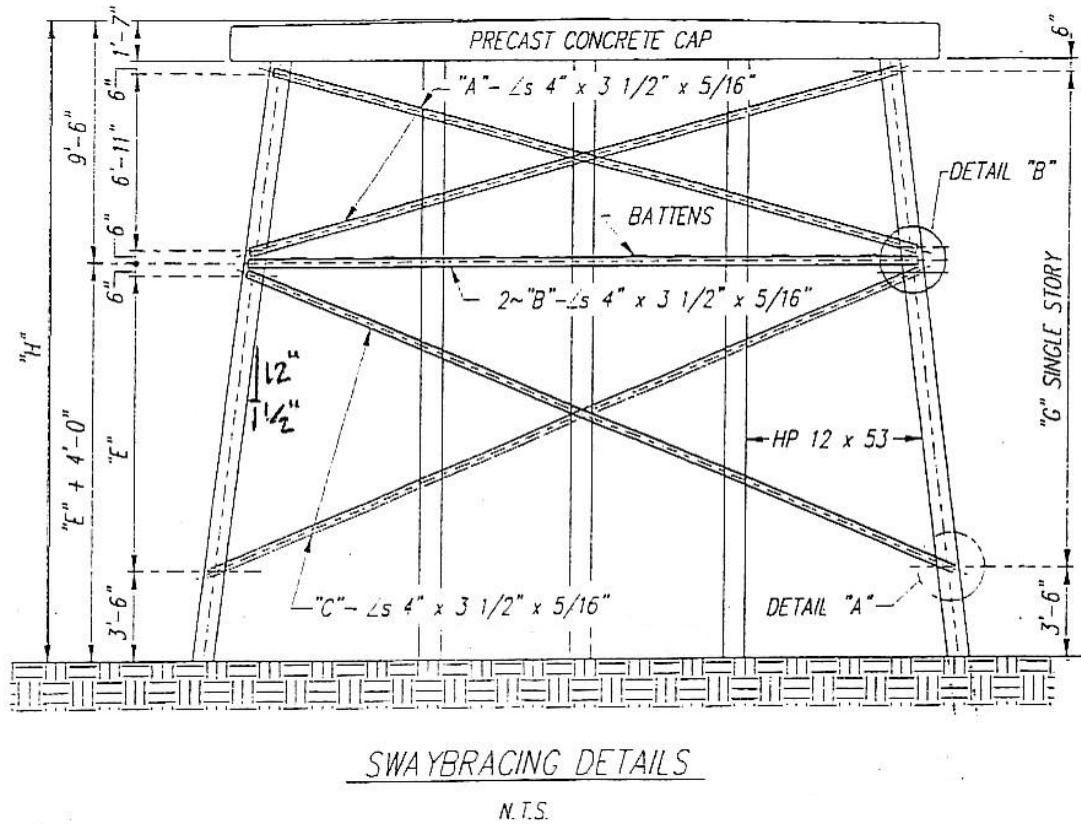
Figure 2.9 Typical ALDOT Bridge Pile Bent (Ramey and Brown 2004)

Braces must have adequate stiffness and strength in order to achieve a reduction in effective column length. General guidelines and comments regarding design of braces are as follows (Ramey and Brown 2004):

- Stiffness

  - Use brace system stiffness at least twice the ideal value, as depicted in Figure 2.10, which is described below.

  - Poor connection details can be detrimental.

- Strength

  - Brace forces are directly related to the magnitude of initial out-of-straightness of the braced pile.

  - Design the brace and its connections for 0.4%-1% of the compressive force in the braced pile.

In Figure 2.10, computation of a system's ideal bracing stiffness is illustrated with a rigid bar stability problem. The stability of the rigid bar is directly related to the bracing conditions at the top of the bar, i.e., the stiffness and strength of the top spring. If a column is initially straight and concentrically loaded, the bracing only needs stiffness because there is no force developed in the brace. If the column conditions are not ideal (initially crooked and/or eccentrically loaded) the brace needs both stiffness and strength (Ramey and Brown 2004).

$F_s = k\Delta$

RIGID
BAR

$P_{CR} = kL$

$k = \dfrac{P_{CR}}{L}$

Note, $k_{IDEAL} = \dfrac{P_E}{L} = \dfrac{\pi^2 EI/L^2}{L}$

$k_{IDEAL} = \dfrac{\pi^2 EI}{L^3}$

$P_E = \dfrac{\pi^2 EI}{L^2}$

$P_{CR} = kL$

If $k > k_{IDEAL}$

If $0 < k < k_{IDEAL}$

If $k = k_{IDEAL}$
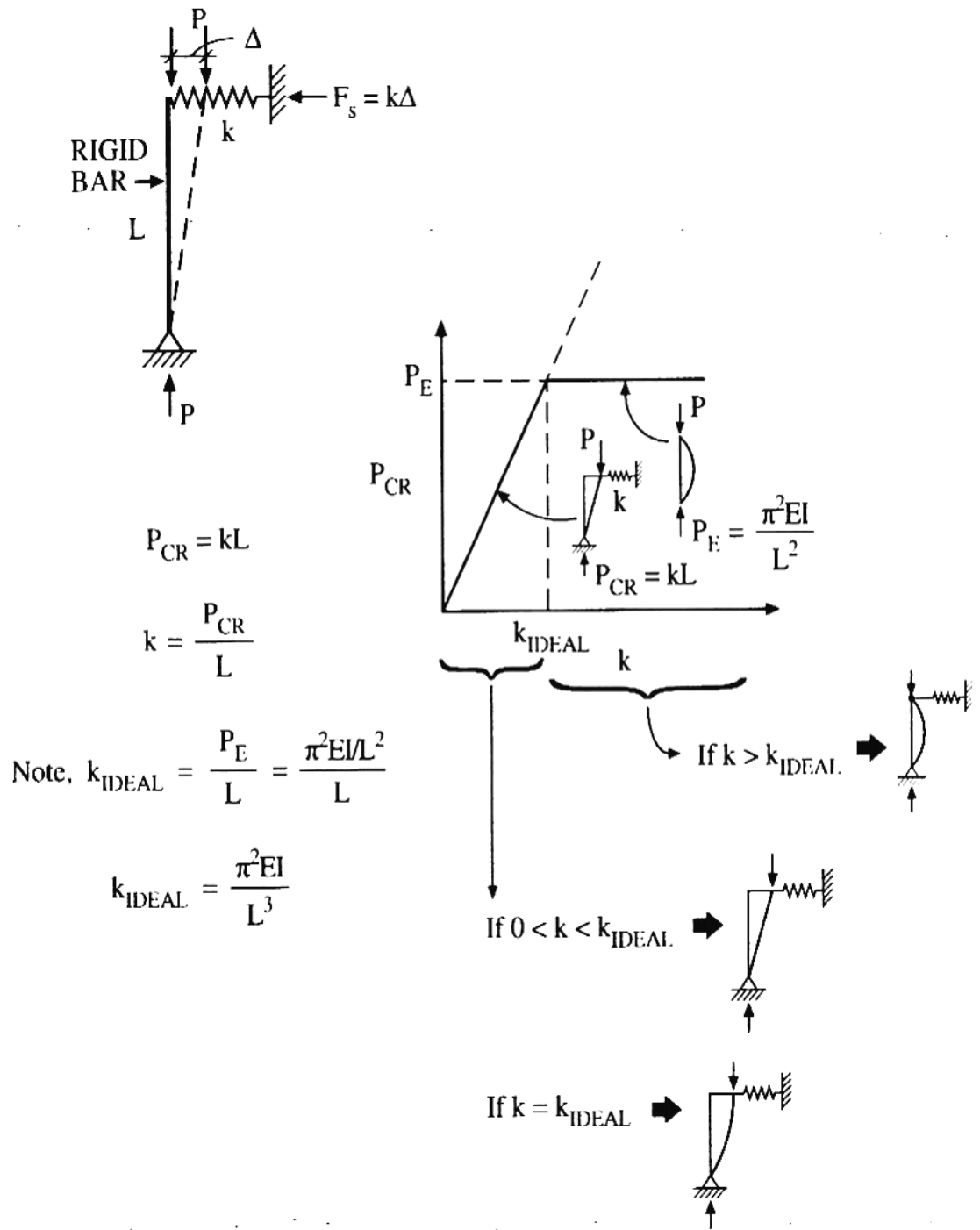
Figure 2.10 Ideal Bracing for a Rigid Bar Stability Case (Ramey and Brown 2004)

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There are four main categories of lateral bracing components and systems used to increase the stability of a frame (or of a pile bent). These include relative, discrete, continuous, and lean-on bracing systems. Figure 2.11 illustrates the four bracing systems

.
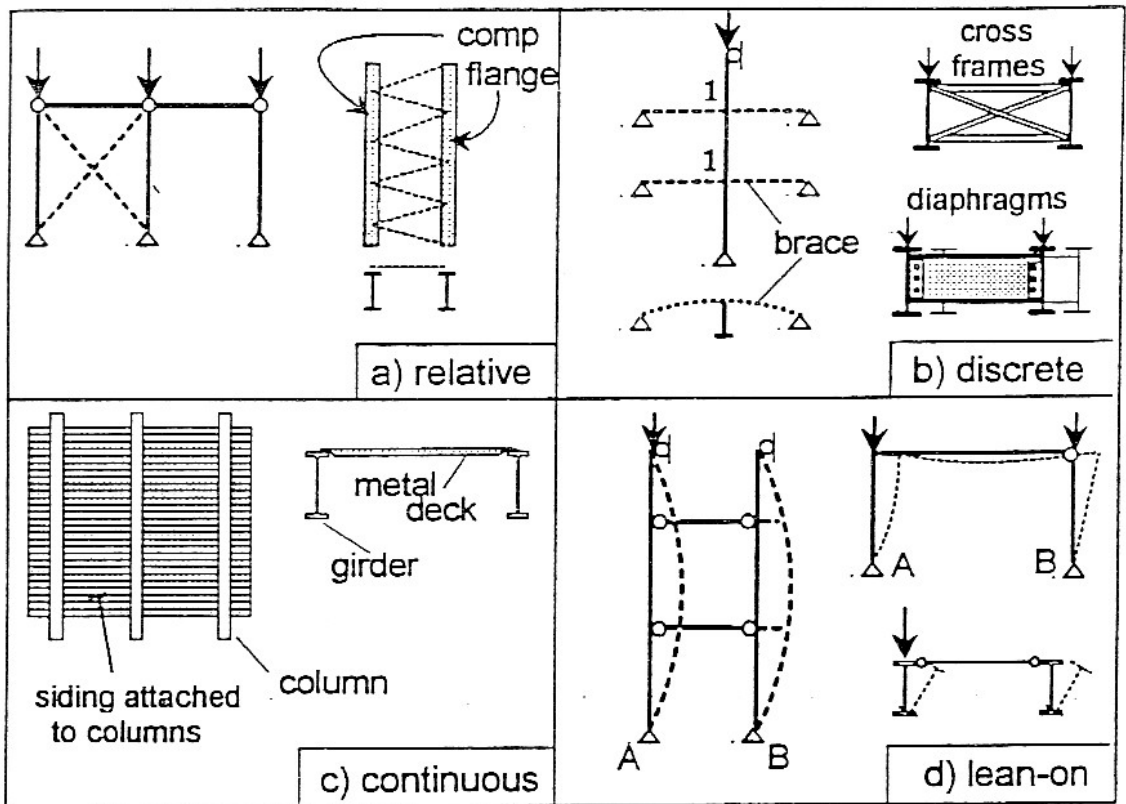
Figure 2.11 Types of Bracing Systems (Yura and Helwig 1997)

Lean-on bracing systems are the most unfamiliar of all the bracing systems. A "leaning" column is a pin-ended column that has no lateral stability of its own, and therefore must rely on other parts of the structure to provide for its lateral stability and for the lateral resistance for the entire frame (Geschwindner 1995). A lean-on system relies

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on the lateral buckling strength of a lightly-loaded adjacent column to laterally support a

column that is loaded more heavily, when all the columns are horizontally tied together.

An important characteristic of a lean-on system, as it pertains to a bridge pile bent

system, is that all columns must buckle simultaneously in a sidesway mode (Ramey and

Brown 2004). This phenomenon is referred to as the ΣP concept (or lean-on concept), and

can be used to design the members of a lean-on bracing system.

According to Yura (2006), the "design strength" obtained for each column of a

story (or of a pile bent) should be viewed only as a contribution to the total sway

buckling strength of the story (or bent). The structure will sway buckle when the total

load on the story exceeds the sum of the individual column contributions ($\Sigma P_{cr} > \Sigma P$). The

elastic buckling load is not significantly affected by the actual load distribution on each

column. However, the load on any individual column in the story cannot exceed the no-

sway capacity of the column. This concept is illustrated in Figure 2.12, where α is the

ratio of the loads on the two columns. As can be seen in the figure, the sum of the

individual column contributions to the critical load is practically constant, no matter what

the value of α is.
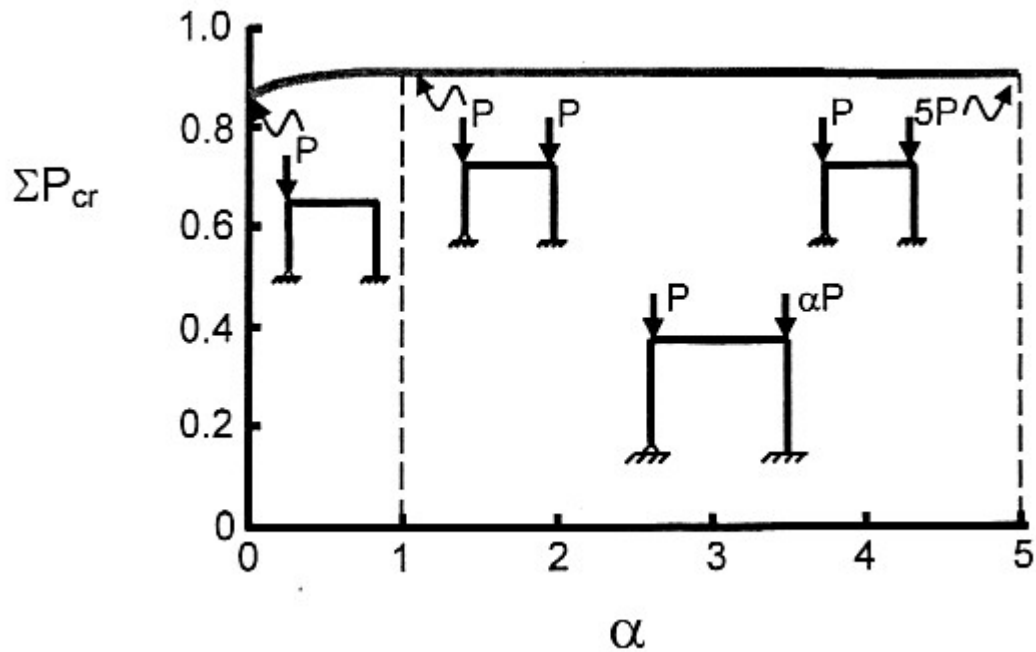
Figure 2.12 Effect of Load Distribution on the Elastic Buckling Load (Yura 2006)

The ΣP concept also shows that lateral loading does not affect the axial buckling load significantly because the sum of the vertical forces (ΣP) does not change with lateral loading (Yura 2006). Lateral loading does, however, influence the pushover failure mode for bent piles, as will be described in the next section. Additionally, high values of $\dfrac{\Sigma P}{\Sigma P_{cr}}$ can reduce pushover capacity by increasing moments at the ends of the piles due to sway forces.

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2.2.5 Pushover Analysis

Possible bent pushover failure may occur from a combination of bent gravity loads acting on the bent cap above each pile, and a flood water loading lateral to the bridge or in the plane of the bent applied near the top of the bent. In order to prevent this failure it is necessary to perform a pushover analysis.

Pushover analysis, as included in the GTSTRUDL (2002) structural analysis software package, is an automated nonlinear incremental load analysis which contains a procedure that automatically searches for the load at which structural instability or collapse occurs. A pushover analysis can be performed for any combination of nonlinear effects including nonlinear geometry, elements supporting tension/compression only, plastic hinges, nonlinear member end connections, friction dampers, nonlinear spring elements, and cable elements (GTSTRUDL 2002).

GTSTRUDL uses a Newton-Raphson solution technique based on the tangent stiffness method to solve the nonlinear equations resulting from the geometric and material nonlinearities. The solution technique is shown in Figure 2.13.
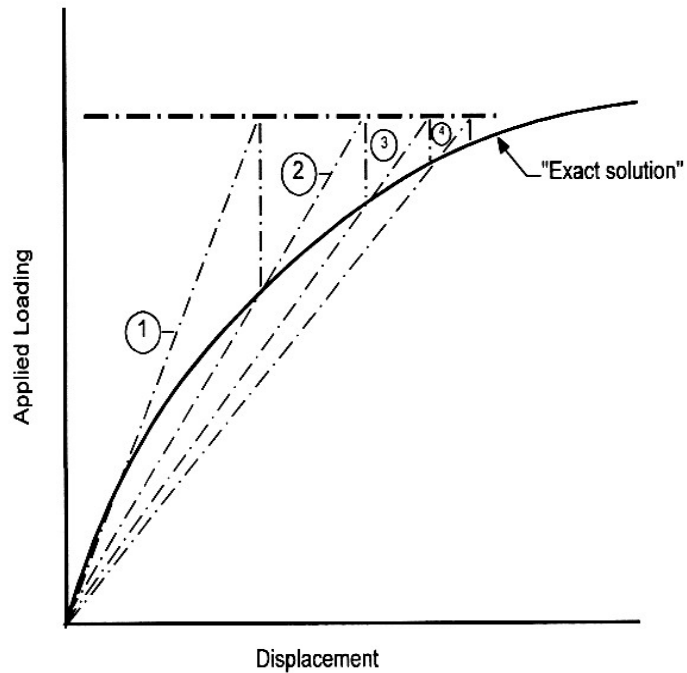
Numbers in circles indicate cycle of nonlinear solution.

Figure 2.13 Direct Iteration Solution Procedure (GTSTRUDL 2002)

As described in the GTSTRUDL Reference Manual (2002), "In the figure, the

'exact' response is illustrated by the solid line and each iteration or cycle of the nonlinear

solution is indicated by the dashed line with a circled number representing the cycle of

the solution. The nonlinear iterations continue until convergence is achieved or a limit on

the number of cycles is reached." It is necessary to control either or both of the number of

cycles of iteration and the convergence tolerance when performing a nonlinear analysis.

GTSTRUDL provides for both of these control procedures (GTSTRUDL 2002).

Load incrementation is very important for the nonlinear analysis of structures that

display dramatic changes in stiffness during the course of load application. Stress-

stiffening behavior is characterized by rapidly increasing stiffness for small changes in

strain, typically during the early stages of loading. Cable structures typically display

stress-stiffening behavior; this type of load-displacement response is illustrated in Figure

2.14.
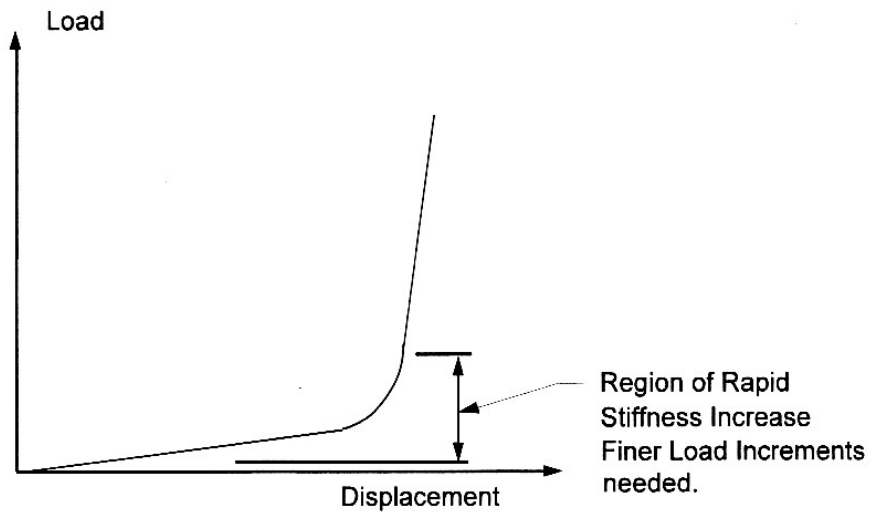
Figure 2.14 Typical Stress-Stiffening Response (GTSTRUDL 2002).

Frame structure instability is characterized by rapidly decreasing stiffness for

small changes in deformation during the late stages of loading when the collapse load is

approached, i.e. buckling. Figure 2.15 illustrates the response for this type of stiffness

change.
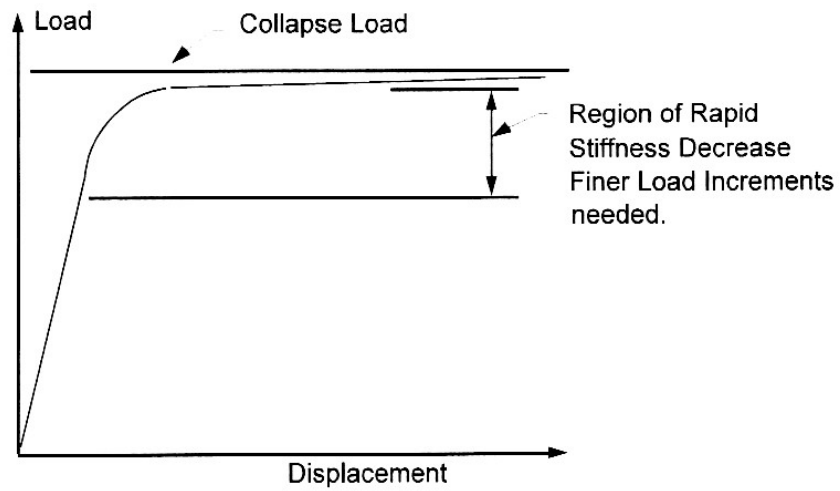
Figure 2.15 Typical Instability Response (GTSTRUDL 2002)

In the cases described above, GTSTRUDL's nonlinear analysis may not converge if the total loading is applied as a single increment of sufficient magnitude to include the regions where the load-displacement response demonstrates rapid stiffness change. By breaking the total loading into smaller increments, especially in the regions of rapid stiffness change, the success rate of the convergence and subsequent analysis is greatly improved (GTSTRUDL 2002).

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CHAPTER 3: DETERMINING MAXIMUM APPLIED PILE AND BENT LOADS

The maximum loads applied to a bridge bent, and to an individual pile in a bent, must be determined so that the adequacy of the bridge bents during an extreme flood/scour event can be evaluated. The applied loads include the dead loads (DL) and live loads (LL) for the various pertinent structural support systems, including simple span, continuous, and continuous for live load support systems. The maximum applied pile and bent gravity loads are primarily a function of the type of loading, the span length, the bridge width and girder spacing, and the superstructure support conditions mentioned above.

3.1 Maximum Applied Pile and Bent Dead Load (DL)

In order to determine the maximum applied pile and bent DL to be used in the "Screening Tool", it was necessary to gather bridge superstructure information common to the majority of "typical" ALDOT bridges. This information, along with several "rules-of-thumb" and some assumptions made for the practical development of the screening tool, are listed below:

- Round deck thickness up to nearest ½".

- Calculate the deck thickness outboard of exterior girders as the deck thickness + 2 inches

- Assume that the deck overhang beyond the center of exterior girders = 4' – 0" each side.

- Assume barrier rails are Jersey barriers with a distributed dead load weight of w_{DL} = 390 lb/ft each.

- Diaphragms:

  Steel girders: Neglect diaphragm weight.

  Concrete girders: Assume diaphragm thickness is 9 inches.

  For $\ell \leq 30'$: ℓ = span length

  Assume 1 diaphragm each end of span

  (2 Diaph.Wts. per bent = No. Diaph per span)

  $30' < \ell \leq 60'$: Assume 1 diaphragm each end of span and one at midspan.

  (3 Diaph. Wts. per bent = No. Diaph per span)

  $60' < \ell \leq 100'$: Assume 1 diaphragm each end of span and one each at ⅓ points of span

  (4 Diaph. Wts. per bent = No. Diaph per span)

- Calculate deck width as the out-to-out width of superstructure or roadway width + 3 feet.

- Take the deck length equal to the span length.

- Include the deck support girders in the load calculation according to their number, spacing, and type/size/weight per ft.

- Classify the girder support arrangement as either simply supported or continuous for "xx" number of spans.

- Calculate the bent cap length = girder/pile spacing x (no. piles -1) + 4ft.

- Assume a bent pile cap cross-sectional size of 2.5' x 2.5' if it is unknown.

- Use the maximum girder reactions due to a uniform DL, as described below.

The maximum girder reactions due to a uniform DL are determined by analyzing the girder support conditions for the pertinent number of uniformly loaded spans. Figure 3.1 shows the reactions for two, three, and four equal span continuous bridges under uniform loading.

TWO EQUAL SPANS—UNIFORM LOADED

$\frac{3}{8}wl=R_1$ $R_2=\frac{10}{8}wl=1.25wl$

One span loaded

$\frac{7}{16}wl=R_1$
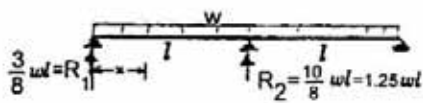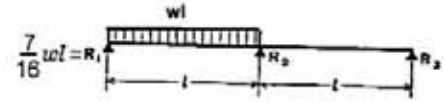
CONTINUOUS BEAM—THREE EQUAL SPANS—ONE END SPAN UNLOADED

$R_A = 0.383\,wl$ $R_B = 1.20\,wl$ $R_C = 0.450\,wl$ $R_D = -0.033\,wl$
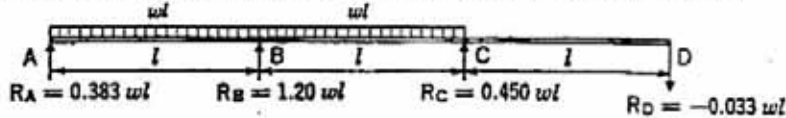
CONTINUOUS BEAM—THREE EQUAL SPANS—END SPANS LOADED

$R_A = 0.450\,wl$ $R_B = 0.550\,wl$ $R_C = 0.550\,wl$ $R_D = 0.450\,wl$

CONTINUOUS BEAM—THREE EQUAL SPANS—ALL SPANS LOADED

$R_A = 0.400\,wl$ $R_B = 1.10\,wl$ $R_C = 1.10\,wl$ $R_D = 0.400\,wl$
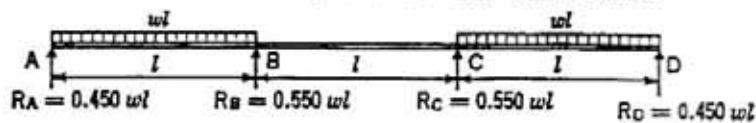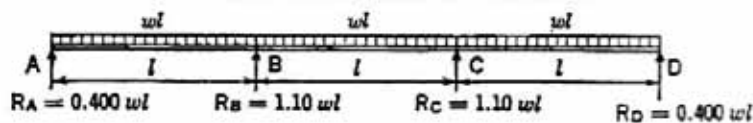
CONTINUOUS BEAM—FOUR EQUAL SPANS—THIRD SPAN UNLOADED

$R_A = 0.380\,wl$ $R_B = 1.223\,wl$ $R_C = 0.357\,wl$ $R_D = 0.598\,wl$ $R_E = 0.442\,wl$
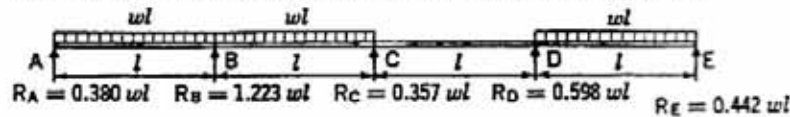
CONTINUOUS BEAM—FOUR EQUAL SPANS—LOAD FIRST AND THIRD SPANS

$R_A = 0.446\,wl$ $R_B = 0.572\,wl$ $R_C = 0.464\,wl$ $R_D = 0.572\,wl$ $R_E = -0.054\,wl$

CONTINUOUS BEAM—FOUR EQUAL SPANS—ALL SPANS LOADED

$R_A = 0.393\,wl$ $R_B = 1.143\,wl$ $R_C = 0.928\,wl$ $R_D = 1.143\,wl$ $R_E = 0.393\,wl$
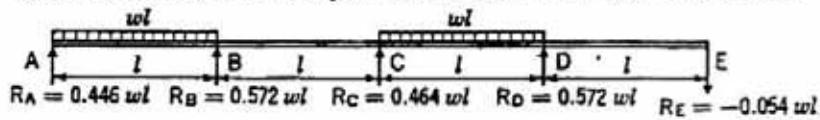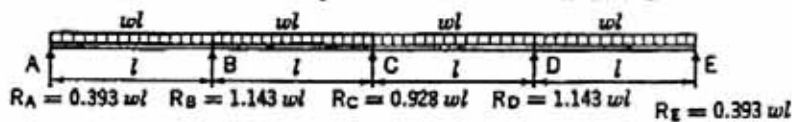
Figure 3.1 Girder/Beam Reactions for Two, Three, and Four Equal Span Continuous Bridges under Uniform Loading (Ramey et. al. 2006, after AISC 2003)

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The bridge girder maximum DL reactions, R_{max}^{DL}, for various girder support

conditions are summarized in Table 3.1 for a uniform dead load, w_{DL}.

Table 3.1 Maximum Girder Reactions for Various Bridge/Girder Support Conditions

Bridge/Girder Support Condition	R_{Max}^{DL}
SS	$1.0w_{DL}\ell$
2-Span Continuous	$1.25w_{DL}\ell$
3-Span Continuous	$1.10w_{DL}\ell$
4-Span Continuous	$1.15w_{DL}\ell$
5-Span Continuous (or larger)	$1.15w_{DL}\ell$

The tributary weight of the bent cap and the girder must be added to the

appropriate girder reaction to determine the pile and bent design DL forces (where girder

weight is calculated as the girder weight per foot times the span length). If the bent cap

size is unknown, as stated previously, a 2.5' x 2.5' cross-sectional area is assumed.

Therefore, the bent cap weight (load) is calculated assuming the following to estimate its

size and weight.

Bent cap weight = 2.5' x 2.5' x cap length x 0.150 k/ ft³.

The cap weight is assumed to be equally distributed to the piles. Therefore, the load on

and individual pile due to the bent cap weight, P_{Pile}^{Cap}, is

$$P_{Pile}^{Cap} = \text{Cap Weight / No. Bent Piles}$$

Examples illustrating the complete calculation of the maximum applied pile and bent

DL's, as performed in the automated screening tool, are shown in section 3.3.

3.2 Maximum Applied Pile and Bent Live Loads

The information needed regarding the bridge superstructure to determine the maximum applied pile and bent live loads are as follows:

- Girder support arrangement, i.e., simply supported, or continuous for what number of spans

- Girder spacing

- Span length

- Roadway width (taken as the curb-to-curb width)

- Number of traffic lanes

- Design live load, as per AASHTO LRFD Section 3.6

The impact factor is assumed to be 1.1 when determining maximum applied pile and bent live loads. Because the failure of the bridge pile/bents will be a considerable distance away from the truck impact loadings, this impact factor seemed reasonable for this investigation. Also, a more sustained load will cause pile/bent buckling and plunging failure, as opposed to an impact loading.

The majority of ALDOT's bridge superstructures and pile bents were designed for HS20 or H20 truck and lane loads. Dimensions and weights for the standard AASHTO design trucks, including HS20, H20, HS15 and H15 trucks, and lane loadings, are shown in Figure 3.2 and Figure 3.3, respectively.
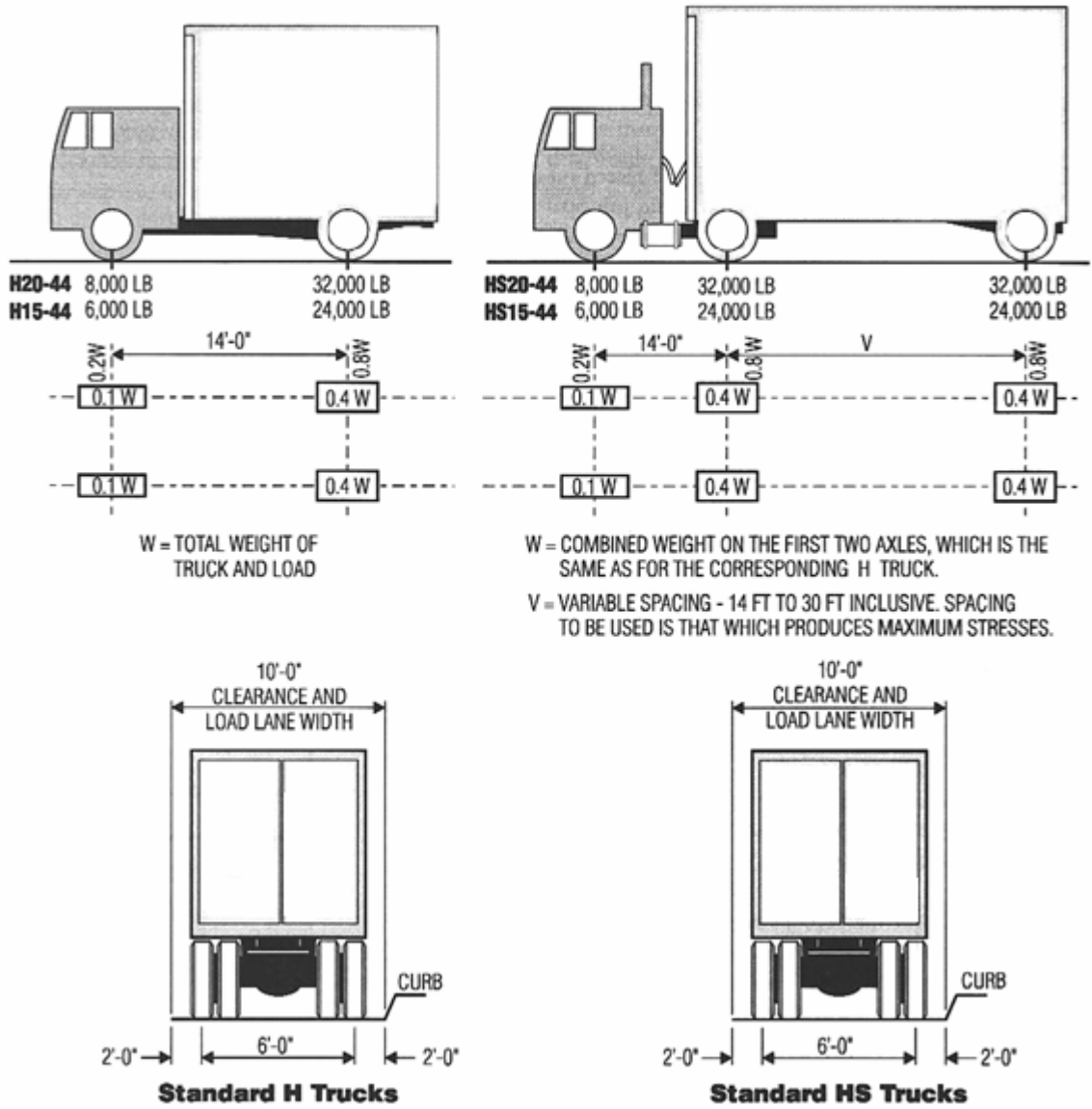
Figure 3.2 AASHTO Standard H and HS Design Trucks (AASHTO LRFD 2006)

CONCENTRATED LOAD— 18,000 LBS. FOR MOMENT*
26,000 LBS. FOR SHEAR

UNIFORM LOAD 640 LBS. PER LINEAR FOOT OF LOAD LANE
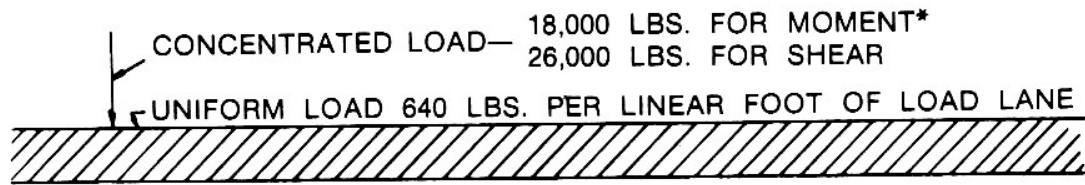
H20-44 LOADING
HS20-44 LOADING

CONCENTRATED LOAD— 13,500 LBS. FOR MOMENT*
19,500 LBS. FOR SHEAR

UNIFORM LOAD 480 LBS. PER LINEAR FOOT OF LOAD LANE
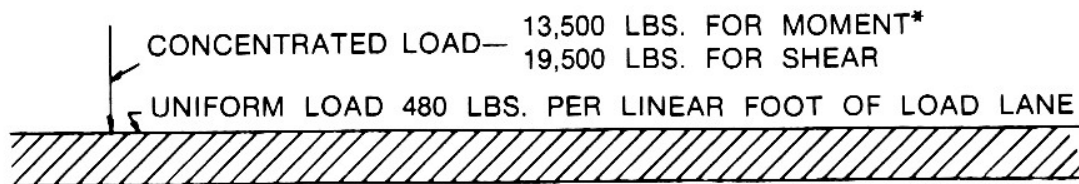
H15-44 LOADING
HS15-44 LOADING

Figure 3.3 AASHTO H and HS Lane Loadings (AASHTO 2002)

According to AASHTO LRFD, the design truck and lane loadings are assumed to be distributed over a 10-ft. width in the transverse direction (AASHTO 3.6.1.2.4). Additionally, the number of design lanes should be determined by taking the integer part of the clear roadway width (curb-to-curb) in feet, divided by 12 ft. When traffic lanes are less than 12.0 ft. wide, the number of design lanes is equal to the number of traffic lanes, and the width of the design lane is equal to the width of the traffic lane. Roadway widths from 20.0 to 24.0 ft. are specified to have two design lanes, each equal to one-half the

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roadway width (AASHTO 3.6.1.1.1). Table 3.2 below shows the number of design traffic

lanes based on a bridge's curb-to-curb width.

Table 3.2 Design Traffic Lanes

Curb to Curb Width	No. of Design Lanes
20 to 30 ft.	2
30 to 42 ft.	3
42 to 54 ft.	4
54 to 66 ft.	5
66 to 78 ft.	6
78 to 90 ft.	7
90 to 102 ft.	8
102 to 114 ft.	9
114 to 126 ft.	10

A truck wheel loading distribution must be taken into account when calculating

the maximum vehicular live load (LL) on a bent pile. As shown in Figure 3.2, the

distance between the wheels is 6 feet. If the girder spacing is not equal to 6 feet, an

adjustment must be made to the axial load applied to the pile to account for the truck's

transverse position on the bridge. Figure 3.4 illustrates three different wheel load

distributions, where P represents the wheel loads. Assuming that the slab spans between

girders are simply supported, the adjustment factor (known as a wheel load distribution

factor) is calculated by adding the contributions of each concentrated P-load to the center

girder (the critical girder supporting the maximum load). Because the wheel load

distribution can be computed as a factor of girder spacing, a generalized equation for

determining the wheel load distribution factor is as follows:

$$\text{Wheel Load Distribution Factor} = \left[1 + \left(\frac{\text{Girder Spacing} - 6\,ft.}{\text{Girder Spacing}}\right)\right]P$$

where P = weight of one wheel loading (as prescribed in Figure 3.2).

If the girder spacing is exactly 6 feet, then the wheel load distribution factor is calculated

to be 1, when only one lane is loaded. (It should be noted that the axial load applied to an

exterior girder is conservatively taken to be equal to that applied to an interior girder.)
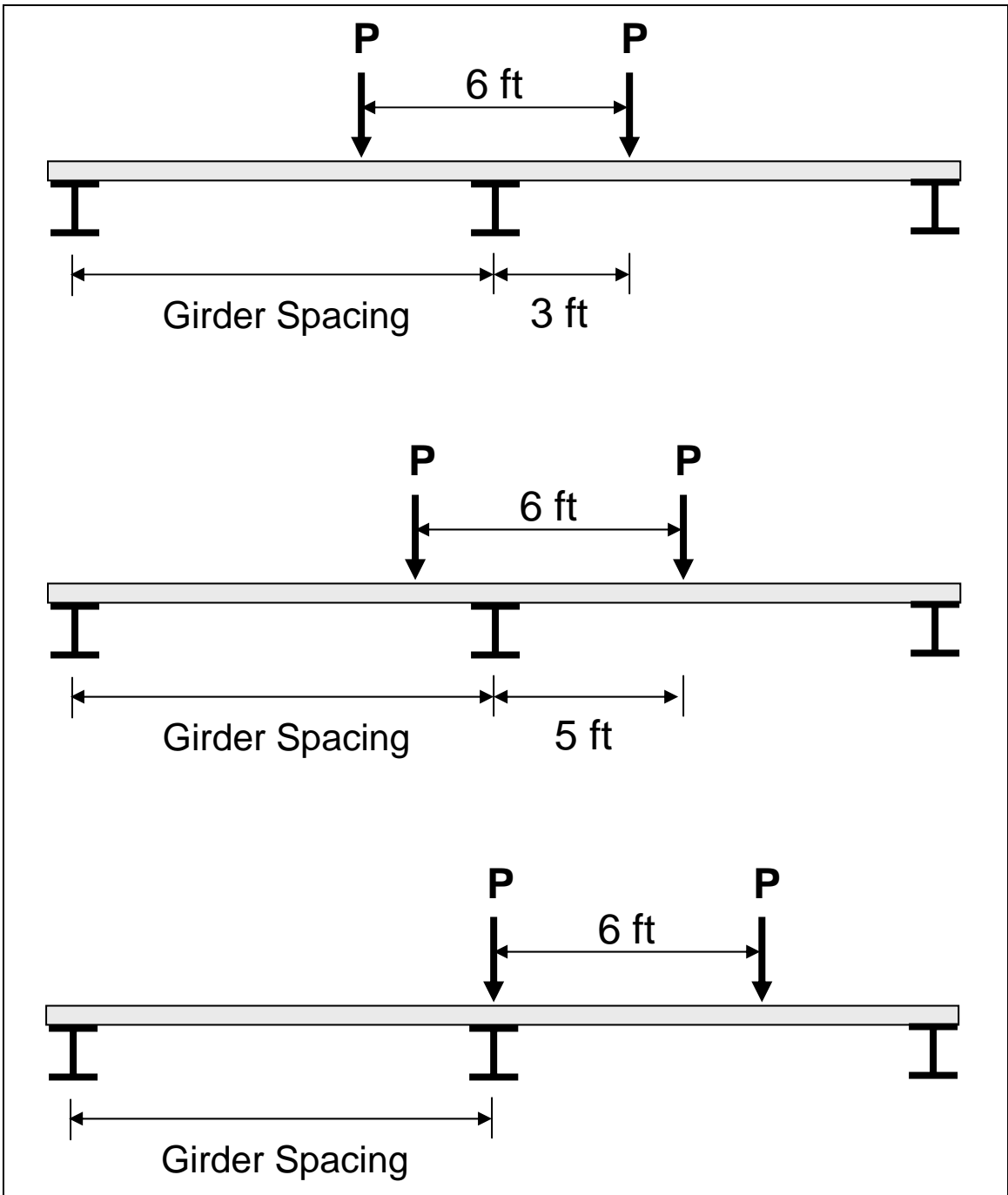
Figure 3.4 Possible Transverse Position of Truck for Wheel Load Distribution Computation

In order to estimate the maximum vehicular LL (including impact) on a bent pile,

a girder-line approach was taken. An example of this approach to determine LL is

illustrated in Figure 3.5 for a bridge with two span lengths of 34' and a girder spacing of 6'. The loads shown in Figure 3.5 apply to an HS20 loading, while the loads shown in parenthesis are applicable to an HS15 loading.

For a continuous beam span having a constant moment of inertia, the three-moment equation (as described in Hibbeler 2002), which "relates the internal moments in a continuous beam at three points of support to the loads acting between the supports," was used to determine the applicable load for the truck line load case. Accordingly, the numbers shown for the truck line load, two-span continuous case in the example were determined according to this three-moment equation.
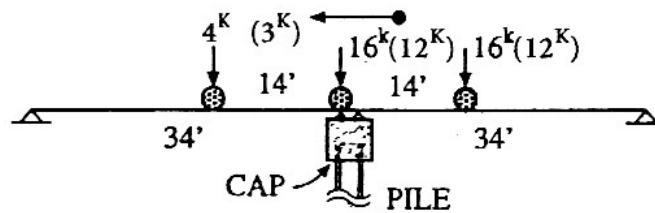
a. Truck Line Load
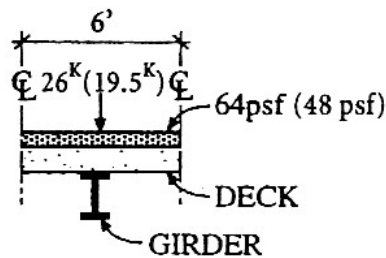
b. Design Lane Loading

Figure 3.5 Girder Lane Loading to Determine $P^{LL}_{\text{PileMax Applied}}$ (Ramey et. al. 2006)

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The maximum applied live load assigned to a pile, $P^{LL}_{\text{PileMax Applied}}$, is specified to be the larger of that determined from the truck lane loading or the design lane loading. Calculation of $P^{LL}_{\text{PileMax Applied}}$, considering two simply supported spans, and a 2-span continuous condition, is determined using Figure 3.2 through Figure 3.5 as follows:

<div align="center">

SS Spans   2-Span Continuous

</div>

a. Truck Line Load: $\quad P^{LL}_{\text{Pile}} = \left[16^k + 16^k\left(\dfrac{20}{34}\right) + 4^k\left(\dfrac{20}{34}\right)\right]1.1 \qquad \left[2(3.12) + 16 + 9.36\right]1.1$

$$= \left[16 + 9.41 + 2.35\right]1.1 = 30.5^k \qquad\qquad = 34.5^k$$

b. Design Lane Load: $\quad P^{LL}_{\text{Pile}} = \left[0.64\dfrac{k}{ft^2}\times 6'\times 34' + 26^k\right]1.1 \qquad \left[(0.64\times 6\times 34)1.25 + 26\right]1.1$

$$= \left[13.1 + 26\right]1.1 = 43.0^k \qquad \left[16.32 + 26\right]1.1 = 46.6^k$$

Note, the wheel distribution factor for the above example is equal to 1 because the girder spacing is exactly 6 feet.

For both the simply supported and the continuous span cases, the pile LL determined from the design lane load is larger than that calculated for the truck line load. Therefore, this load governs for both cases, and

$P^{LL}_{\text{Pile Max Applied}} = 43.0^k$ for a simply supported bridge

$P^{LL}_{\text{Pile Max Applied}} = 46.6^k$ for a 2-Span continuous or continuous for LL bridge

$P^{LL}_{\text{Pile Max Applied}} = 46.6^k$ for 3-or-more-span continuous or continuous for LL bridge

The latter value is deemed appropriate because, for purposes of estimating the maximum $P^{LL}_{\text{Pile Max Applied}}$ to a bent cap and pile, conservatively using an upper bound value

of live load, then applying the largest live load value in Table 3.3 of $P_{\text{Max}}^{\text{LL}} = 1.25 w_{LL} \ell$

would be conservative and appropriate for the "screening tool" for equal span continuous

bridges of any number of continuous spans.

Table 3.3 Maximum Girder Reactions for Various Bridge/Girder Support Conditions

Bridge/Girder Support Condition	R_{Max}^{LL}
SS	$1.0 w_{LL} \ell$
2-Span Continuous	$1.25 w_{LL} \ell$
3-Span Continuous	$1.20 w_{LL} \ell$
4-Span Continuous	$1.22 w_{LL} \ell$
5-Span Continuous (or larger)	$1.22 w_{LL} \ell$

More detailed examples illustrating the calculation of the maximum applied pile

and bent LL's are presented in section 3.3.

3.3   Example Calculations of Maximum Applied Load (Including DL and LL),

$P_{Max\ Applied}^{Pile}$ **and** $P_{Max\ Applied}^{Bent}$ **, for a Typical Bridge Superstructure**

A cross-section of a typical ALDOT simply supported (SS) bridge with a span

length of 34 ft. is shown in Figure 3.6 below. The superstructure includes a 7 inches thick

concrete deck, Jersey Barriers, and AASHTO Type II Girders (5 girders with 8 ft.

spacing). It also includes 5-Pile bents with concrete caps having 2.5 ft. x 2.5 ft. cross-

sectional dimensions. Though not explicitly shown in the figure, a typical diaphragm

thickness of 9 inches is assumed, and it is assumed that there are 3 diaphragms per span,

based on the fact that the span length is between 30 ft. and 60ft., as described in Section

3.1.
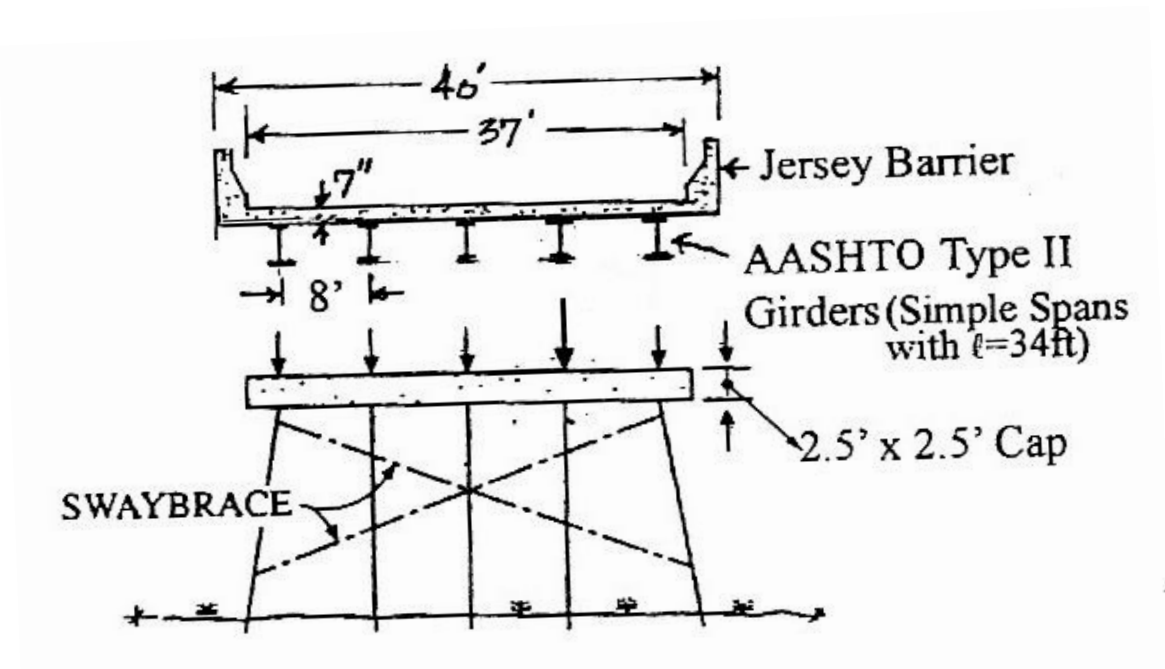
Figure 3.6 Typical Pile Bent and Superstructure (Ramey et al. 2006)

Calculations for the determination of $P^{Pile}_{Max\ Applied}$ and $P^{Bent}_{Max\ Applied}$ by girder line

analysis are given in sections 3.3.1 and 3.3.2 , respectively.

3.3.1 Determination of $P^{Pile}_{Max\ Applied}$

P_{DL}: Deck: *Deck Thickness x Gir. Spac. x Span Length x $0.150^k/ft^3$.*

$$\frac{7"}{12} \text{ x 8' x 34' x } 0.15^k/ft^3 \qquad\qquad = 23.8^k$$

Diaphragm: *Diaph. Thickness x Gir. Depth x Gir. Spac. x $0.150^k/ft^3$ x No.*

Diaph. Per Span

$$\frac{9"}{12} \text{ x 3.0' x 8' x } 0.150^k/ft^3 \text{ x 3} \qquad\qquad = 8.1^k$$

Girder: *Girder Wt./ ft. x Span Length*

$$0.384^k/ft \text{ x 34'} \qquad\qquad = 13.1^k$$

Bent Cap: *Cap Width x Cap Depth x Gir. Spac. x $0.150^k/ft^3$*

$$2.5' \text{ x 2.5' x 8' x } 0.150^k/ft^3 \qquad\qquad = 7.5^k$$

Barrier Rail: *(Jersey Barrier Wt./ft x Span Length x 2)/ No. Piles*

$$(0.390^k/ft \text{ x 34' x 2) / 5} \qquad\qquad = \underline{5.3^k}$$

$$P_{DL} \quad = 57.8^k$$

P_{LL}: Design Lane Load: *$[0.64^k/ft^2$ x Gir. Spac. x Span Length + 26^k] IF*

$$\left[0.064^k/ft^2 \text{ x 8' x 34' } + 26^k \right] 1.1 \qquad = 47.7^k$$

Truck Lane Load: $$\left[16^k + 16^k \left(\frac{20}{34}\right) + 4^k \left(\frac{20}{34}\right) \right] 1.25 \text{ x } 1.1 \qquad = 38.2^k$$

(where the wheel load distribution factor = 1.25 for 8 ft. girder spacing)

Design lane load is greater, therefore $\qquad\qquad P_{LL} \quad = 47.7^k$

The sum of the dead load and live load values gives the maximum load applied to the

pile, therefore $P^{Pile}_{Max\ Applied} = P_{DL} + P_{LL} = 57.8^k + 47.7^k = 105.5^k$.

3.3.2 Determination of $P^{Bent}_{Max\ Applied}$

P_{DL}: Deck: *Deck Thickness x Out-to-Out Deck Width. x Span Length x 0.150^k/ft^3.*

$$\frac{7"}{12} \text{ x 40' x 34' x } 0.15^k/\text{ft}^3 \qquad\qquad = 119.0^k$$

Thickened Deck Overhang:

ΔOverhang Thickness x Overhang Width x Span Length x 0.150^k/ft^3 x 2.

$$\frac{2"}{12} \text{ x 4' x 34' x } 0.15^k/\text{ft}^3 \text{ x 2} \qquad\qquad = 6.8^k$$

Diaphragm: $\dfrac{9"}{12}$ *x Gir. Width x Distance Between Exterior Girders x 0.150^k/ft^3 x*

No. Diaph. Per Span

$$\frac{9"}{12} \text{ x 3.0' x 32' x } 0.150^k/\text{ft}^3 \text{ x 3} \qquad\qquad = 32.4^k$$

Girder: *Girder Wt./ ft x Span Length x No. Girders per Span*

$$0.384^k/\text{ft x 34' x 5} \qquad\qquad = 65.3^k$$

Barrier Rail: Jersey Barrier Wt./ft x Span Length x 2

$$0.390^k/\text{ft x 34' x 2} \qquad\qquad = 26.5^k$$

Bent Cap: *Cap Width x Cap Depth x Cap Length* x 0.150^k/ft^3*

$$2.5' \text{ x 2.5' x 36' x } 0.150^k/\text{ft}^3 \qquad\qquad = \underline{33.8^k}$$

*If Cap Length is unavailable use the distance between exterior girders plus 4'.

$$P_{DL} \quad = 283.8^k$$

P_{LL}: Design Lane Load: $\left[0.064^k / ft^2 \ x \ 10' \ x \ 34' \ + 26^k \right] 3 \ x \ 1.1 \quad = 157.6^k$

Truck Lane Load: $\left[32^k + 32^k \left(\dfrac{20}{34} \right) + 8^k \left(\dfrac{20}{34} \right) \right] 3 \ x \ 1.1 \quad = 183.3^k$

The truck lane load is greater, therefore $\qquad\qquad\qquad\qquad P_{LL} \quad = 183.3^k$

The sum of the dead load and live load values gives the maximum load applied to the bent, therefore, $P^{Bent}_{Max\ Applied} = P_{DL} + P_{LL} = 283.8^k + 183.3^k = 467.1^k$.

For calculations included in the pushover analysis, the P-load to be used above each pile was taken as the bent maximum applied force divided by the number of piles. This technique was used to so that a uniform gravity load could be input for the GTSTRUDL pushover analysis calculations. Thus, the P-load for pushover analysis for the example bridge above would be $\dfrac{P^{Bent}_{Max\ Applied}}{No.\ of\ Piles} = \dfrac{467.1^k}{5\ piles} = \underline{93.4^k}$ per pile. (For calculations in all other failure mode conditions, the maximum force applied to the pile, $P^{Pile}_{Max\ Applied}$, as determined by the method illustrated above, was used.)

CHAPTER 4: SCREENING TOOL ASSUMPTIONS

The screening tool is meant to serve as a quick check to determine whether or not a bridge needs to undergo a further, more thorough investigation for scour susceptibility (or, conversely, to quickly deem that a bridge is not at risk for damage due to scour). For this purpose, several generalizing assumptions have been included in the screening tool package. A list of those assumptions inherent to the screening tool for checking the adequacy of bridge pile bents during an extreme flood/scour event follows (Ramey et. al. 2006).

1. For a given pile bent, if the pile subjected to $P^{Pile}_{Max\ Applied}$ (assumed to be the critical pile) is safe from pile "kick-out", plunging, or buckling failures, then it is assumed that the bent is also safe regarding these failure modes.

2. A pile and/or bent is considered safe from failure in the pile "kick-out", plunging, buckling, and pushover failure modes if the calculated failure load, $P_{Failure}$, is greater than 1.25 (the applied factor of safety) times the calculated maximum applied load for that pile, $P_{Max\ Applied}$, i.e., if $P_{Failure} > 1.25 P_{Max\ Applied}$. The procedure to determine $P_{Failure}$ for the various failure modes is given in later section.

3. The bridge bents are limited to single-row pile bents having 3, 4, 5, or 6 steel HP10-series or HP12-series piles, and possessing either an unbraced or X-braced configuration. These bent configurations are the most common for the ALDOT bridges requiring inspection for possible damage due to scour susceptibility (Ramey et. al. 2006).

4. For bents with concrete-encased HP10- or HP12-series piles, the contribution of the concrete encasement is conservatively neglected, and the bent is treated as an uncased and unbraced steel pile bent.

5. The pile tops have an attached end plate that is embedded 1 ft. into the bent cap, or are welded to steel plates that are embedded into the bent cap so that the pile-to-cap connection is considered a rigid connection in the plane of the bent.

6. All pile caps have adequate strength and stiffness, and therefore will not be the cause of a bent failure.

7. The girder loads are distributed to the piles as follows: 1) the superstructure girders are placed on the bent cap directly above each pile, and/or 2) the bent cap is sufficiently strong and stiff to effectively distribute the girder loads evenly.

8. The design live load for the bridge is known, or can be calculated, and is based on either AASHTO HS15 or HS20 truck loadings.

9. The type of soil layer at the pile tips, and the original depth of embedment of the pile tips at that layer, is known.

10. The determination of $P^{Pile}_{Max\ Applied}$ and $P^{Bent}_{Max\ Applied}$ are based on bridges with equal span lengths, which may include simply supported spans or continuous (or made continuous for LL) spans. If the bridge under investigation has span lengths that vary significantly, then the procedures for calculating $P^{Pile}_{Max\ Applied}$ and $P^{Bent}_{Max\ Applied}$, described in Chapter 3 should be modified.

11. Scour and/or flood water loading does not change the gravity loading on a pile or bent, i.e., does not change P^{Pile}_{DL+LL} or P^{Bent}_{DL+LL}.

12. Curves showing the theoretical load that causes failure, $P_{Failure}$, versus the pile length, ℓ, (i.e., $P_{failure}$ vs. ℓ curves) for the bent piles are assumed to correspond to those shown in Figure 4.1, and it is assumed that the bent piles were designed with a factor of safety greater than two against compressive yielding. Therefore, a maximum applied load less than half the yield load ($P_{Max\ Applied} < P_y / 2$) will be assumed, and so if a pile or bent buckles, it will experience an elastic buckling behavior, as indicated in Figure 4.1.
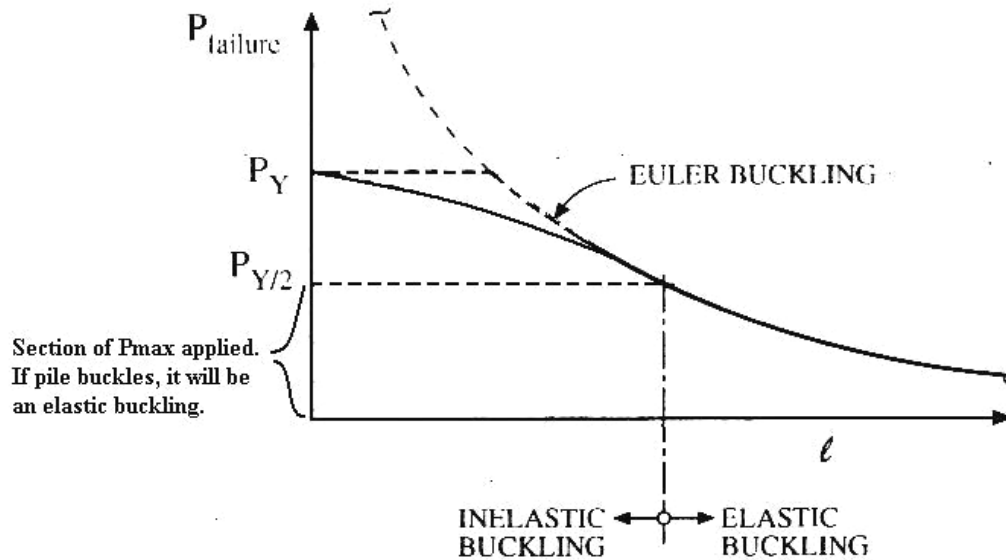
Figure 4.1 P$_{Failure}$ vs. ℓ Curve (Ramey et. al. 2006)

13. Sidesway buckling and pushover failure in the longitudinal direction of the bridge is assumed not to be possible because the bridge superstructure is positively connected to the bent caps and to the abutments that allow only small longitudinal movements due to thermal expansion/contraction. Therefore, sway buckling and/or pushover failures of the piles/bent are limited to failures in the transverse direction, i.e., in the plane of the bent.

14. Weak-axis buckling of the piles/bents will govern the buckling failure mode for the following reasons: 1) bridge superstructures have very little movement in the longitudinal direction; 2) bent piles have a rather large ratio of strong-to-weak-axis moments of inertia, I_{strong} / I_{weak}, and 3) the bent boundary conditions are configured such that weak-axis buckling is more likely to occur

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than strong-axis buckling. For weak-axis buckling, the boundary conditions are assumed to be partially fixed (50% fixity) at the top due to the bent cap and at the bottom due to the stiffness of the ground. Additionally, it is conservatively assumed that for the nonsway mode of buckling, the bracing effect is discounted, and the pile length, for buckling calculations, is taken as the length from the bottom of the bent cap to the ground line.

15. In the transverse direction, prior to any scour (i.e., under normal service conditions for the bridge), the bent X-bracing will prevent sidesway displacement and occurrence of the buckling failure mode. This bracing will also increase the bent load required to produce transverse pushover.

16. In the transverse direction, when there is a large amount of scour, sidesway pile buckling can occur from the position of the lowest horizontal compression strut in the X-bracing system to the new ground line.

4.1   Tier-1 Screening Tool Module Assumptions

The following assumptions were made specifically within the modules of the Tier-1 screening tool (the first stage of the screening tool development):

1. The screening tool will only evaluate bents with steel HP10- or 12-series piles.

2. The maximum estimated scour, S_{max}, that will occur at a bent/pile is 25 feet.

3. The pile/bent is safe when the critical scour, S_{cr}, calculated in the plunging, buckling, and pushover modules, is greater than the known maximum estimated scour, i.e. $S_{cr} > S_{max}$.

4. In the Preliminary Evaluation module, the most critical pile of the most critical bent will be evaluated for scour failure.

5. If the bent piles have lost more than 25% of their original area in the splash zone or at the ground line due to corrosion, immediate corrective action must be taken to build-up the pile section back to its original, or greater, dimensions.

6. In order to assess the plunging failure mode, the following information is known, or can be estimated by the user, about the particular bent piles in question: 1) driving resistance (blows/inch) at end of driving, 2) type of driving hammer, 3) hammer driving energy, 4) pile type, 5) pile embedment length before scour, and 6) maximum estimated scour.

7. The flood water debris raft elevation dimensions and design floodwater velocity values were assumed to be 6 ft. by 30 ft. and 6 mph. Using these dimensions and floodwater velocity value, along with an assumed factor of safety (F.S.) of 1.25, the maximum design horizontal force, $F_t^{max\ applied}$, was determined to be 12.15 kips. Details of this calculation are given later in Chapter 5, Section 5.5. The screening tool will indicate that the bent should be checked more closely for possible pushover failure when the calculated

pushover capacity of the bent, F_t, is less than the maximum applied lateral force of 12.15 kips, i.e. when $F_t < F_t^{\text{max applied}} = 12.15$ kips.

8. When there is no history of stream flood debris from which a bent debris raft can be built, the design horizontal force is reduced to 2.5 kips (includes a F.S = 1.25). Therefore, when $F_t < F_t^{\text{max applied}} = 2.5$ kips, the screening tool will indicate that the bent should be checked more closely for possible pushover failure.

9. For pushover evaluation, a uniform and symmetric P-load distribution across the bent cap is assumed. The P-load is determined by dividing the maximum applied bent load, $P_{\text{max applied}}^{\text{bent}}$, by the number of piles in the bent.

4.2 Tier-2 Screening Tool Module Assumptions

Tier-2 screenings were developed to guide the inspecting engineer through a further series of checks for bents that do not pass the Tier-1 criteria, i.e. for bents in which the critical scour value is calculated to be less than the maximum estimated scour value ($S_{cr} < S_{max}$). Tier-2 screenings assess the bent more carefully by checking the bents against new criteria. In some instances a bent can not pass the Tier-1 ST checks, but after closer examination in Tier-2 screening, can be found to be adequate and safe. The following assumptions were made specifically within the modules of the Tier-2 "screening tool". These assumptions can also be found in the Phase III, Part I report (Ramey et. al. 2008).

1. In the pile plunging evaluation, when the bents are found to have a maximum estimated scour that exceeds the calculated critical scour value (i.e., the bents do not pass the $S_{cr} > S_{max}$ check), the maximum applied bent load, $P_{Max\ Applied}^{Bent}$, should be redetermined, with the assumption that each bridge span supported by the bent under investigation is a simply supported span loaded with live load applied only to the bridge actual traffic lanes, rather than applied to the design traffic lanes.

2. Pile plunging adequacy should be reassessed, including a new assumption that

$$P_{Max\ Applied}^{Pile} = P_{Max\ Applied}^{Bent} / \text{Number of Piles in Bent}$$

   (in contrast to calculating the specific $P_{Max\ Applied}^{Pile}$ as detailed in Chapter 3). This assumption is validated after recognizing the following facts (Ramey et. al. 2008): 1) the most heavily loaded pile in a bent will get "lean-on" support for plunging from the adjacent piles in the bent; 2) for continuous span bridges, the most heavily loaded bent will get "lean-on" support from the adjacent bents/supports; and 3) it is unreasonable to think that all possible design traffic lanes will be fully loaded with live load during an extreme flood/scour event, especially when a bridge only has two actual traffic lanes.

3. Bents with more than six HP piles of any size in a row, whether braced or unbraced, have adequate pushover capacity for maximum scour levels estimated for Alabama, and therefore are safe from failure due to pushover.

4. For any bent with HP10- or 12-series piles, the bent pushover adequacy will be checked assuming that the piles are the smallest size of the series, HP10x42

or HP12x53. This will give the most critical (and therefore most conservative)

pushover force used to check against the maximum applied pushover force,

$F_t^{max\ applied}$, to determine if the bent is safe from pushover.

CHAPTER 5: SCREENING TOOL FAILURE MODE CHECKS

The Alabama Department of Transportation (ALDOT) is currently assessing the scour susceptibility of its bridges, to include an evaluation of the adequacy (or inadequacy) of the structural stability of these bridges when subjected to an estimated flood/scour event. A simple "screening tool" (ST) was developed that can efficiently and quickly access the susceptibility of these bridges to scour. The screening tool facilitates an automated bridge scour analysis, and is intended to be used to identify bridges that are most likely to be deficient, and that should be prioritized for more a detailed study.

The major modes of failure identified to be the primary causes for possible bridge collapse due to scour susceptibility were narrowed to four. These include 1) bent pile tip "kick-out" failure, 2) bent pile plunging failure, 3) bent pile buckling, and 4) bent pushover failure. Flowcharts that illustrate the logical sequence of calculation steps included in the ST, used to assess a bridge's stability related to these four failure modes, are presented and described in the following sections.

5.1 Description of Screening Tool Flowcharts

In Phase II of the ALDOT project for which the scour screening tool was developed, the logic of the "screening tool" was mapped, and a User's Guide was created

which explained the proper use of the tool. The User's Guide was presented in the form of a series of flowcharts illustrating the "micro-plan" for checking the adequacy of ALDOT bridge pile bents after an extreme flood/scour event.

The ST flowchart is broken into five modules: the first contains a preliminary evaluation to collect general bridge information; the second maps the evaluation for the pile kick-out and plunging failure modes; the third module involves steps for a pile buckling evaluation; the fourth module includes calculations required for a bent pushover evaluation, and the fifth involves steps to evaluate the upstream pile for beam-column failure. The first four modules are the primary focus of this report. The fifth module is still in development and will be detailed further in a future report. The ST flowchart is shown in its entirety in Figure 5.1.
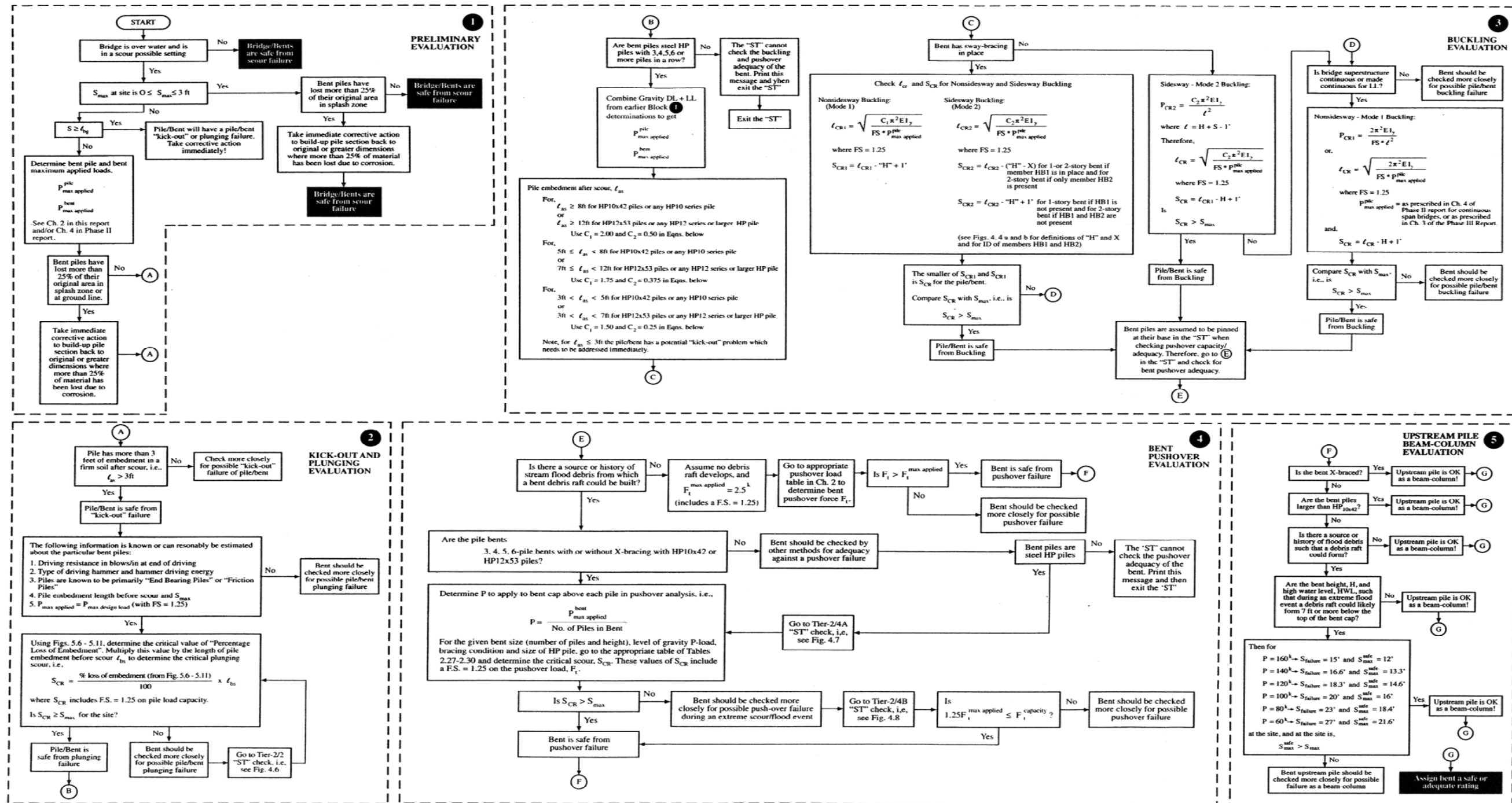
Figure 5.1 ST Flowchart for Assessing Pile Bent Adequacy During an Extreme Flood/Scour Event (Ramey et. al. 2008)

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In this section, general descriptions of the flowcharts for the particular screening tool modules will be given. Afterwards, in the following section, pertinent features of the checks and calculations contained in the second, third, and fourth modules will be described in more detail.

The main purpose for including the preliminary evaluation module is to check for material deterioration of the pile, primarily due to corrosion. The ST checks the most critical pile of the most critical bent for deterioration. The most critical pile will be determined by the engineers running the inspection. Most likely, the "critical" pile will be the pile with the heaviest load (an interior pile), that has lost much of its support from the surrounding soil because a high amount of scour has occurred at the pile site. If the pile is determined to be significantly corroded (lost more than 25% of its original area in splash zone or at ground line), then corrective action must be taken to build-up the pile section back to its former dimensions or greater. The preliminary evaluation (Module 1) flowchart is shown in Figure 5.2.

The "kick-out" and plunging evaluation module (Module 2) contains several geotechnical failure checks. First, a typical bridge bent pile is checked for possible kick-out failure due to scour and lateral floodwater loading (lateral to the bent's longitudinal axis). The pile is then checked for possible pile plunging failure due to inadequate soil support capacity after scour. The Module 2 flowchart is illustrated in Figure 5.3.

The first of the structural checks is contained in the buckling evaluation (Module 3) flowchart. The most heavily loaded bent pile is checked for a possible axial buckling failure. To maintain simplicity in the screening tool, it is assumed that if this pile buckles,

then the whole bent will buckle. The steps included in the Module 3 buckling flowchart are presented in Figure 5.4.

The pushover evaluation (Module 4) is also a structural check. In order to determine the adequacy of the bent to resist a pushover failure, the maximum gravity load applied to the bent must first be determined. Again, for simplicity in the screening-tool environment, this load is assumed to be equally distributed to the bent piles. With these gravity loads held constant, a horizontal load (parallel to the longitudinal axis of the bent) is applied to the bent at a position two feet below the top of the bent cap in the plane of the bent, and is increased incrementally until the bent achieves a pushover failure.

The pushover failure load is calculated using GTSTRUDL structural analysis software. As the lateral load is incremented, the deflection is recorded that corresponds to each lateral load increment. At a certain level of deflection, the load-deflection curve begins to "lean over," and the deflection increases significantly, with very little increase in lateral load. The maximum load value achieved is determined to be the load that will cause a pushover failure, i.e., the calculated pushover capacity. This failure horizontal load is then compared with the maximum lateral flood water loading deemed to be possible for the bridge in question to check for pushover failure. If the calculated pushover capacity is greater than the maximum possible floodwater load, then the pile is designated to be safe from failure by pushover. Conversely, if the maximum practical horizontal floodwater load the bridge may encounter is greater than the calculated pushover capacity the screening tool indicates that the bridge is susceptible to failure in

this mode. The flowchart showing the progression of steps included in the pushover

evaluation (Module 4) is given in Figure 5.5.

Figure 5.2 Enlargement of Preliminary Evaluation Module (Ramey et. al. 2008)

A

Pile has more than 3 feet of embedment in a firm soil after scour, i.e.. $\ell_{as} > 3 ft$ ——No—→ Check more closely for possible "kick-out" failure of pile/bent

Yes

Pile/Bent is safe from "kick-out" failure

The following information is known or can reasonably be estimated about the particular bent piles:

1. Driving resistance in blows/in at end of driving
2. Type of driving hammer and hammer driving energy
3. Piles are known to be primarily "End Bearing Piles" or "Friction Piles"
4. Pile embedment length before scour and S_{max}
5. $P_{max\ applied} = P_{max\ design\ load}$ (with FS = 1.25)

——No—→ Bent should be checked more closely for possible pile/bent plunging failure

Yes

Using Figs. 5.6 - 5.11, determine the critical value of "Percentage Loss of Embedment". Multiply this value by the length of pile embedment before scour ℓ_{bs} to determine the critical plunging scour, i.e.,

$$S_{CR} = \frac{\%\ loss\ of\ embedment\ (from\ Fig.\ 5.6 - 5.11)}{100} \times \ell_{bs}$$

where S_{CR} includes F.S. = 1.25 on pile load capacity.

Is $S_{CR} \geq S_{max}$ for the site?

Yes — No

Pile/Bent is safe from plunging failure

Bent should be checked more closely for possible pile/bent plunging failure ——→ Go to Tier-2/2 "ST" check, i.e., see Fig. 4.6

B

2

KICK-OUT AND PLUNGING EVALUATION

Figure 5.3 Enlargement of Kick-Out and Plunging Evaluation Module (Ramey et. al. 2008)

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BUCKLING EVALUATION

B

Are bent piles steel HP piles with 3,4,5,6 or more piles in a row? — No → The "ST" cannot check the buckling and pushover adequacy of the bent. Print this message and yhen exit the "ST"

↓ Exit the "ST"

Yes ↓

Combine Gravity DL + LL from earlier Block ① determinations to get

$P_{max\ applied}^{pile}$

$P_{max\ applied}^{bem}$

Pile embedment after scour, ℓ_{as}

For,
$\ell_{as} \geq$ 8ft for HP10x42 piles or any HP10 series pile
or
$\ell_{as} \geq$ 12ft for HP12x53 piles or any HP12 series or larger HP pile
Use $C_1 = 2.00$ and $C_2 = 0.50$ in Eqns. below

For,
5ft $\leq \ell_{as} <$ 8ft for HP10x42 piles or any HP10 series pile
or
7ft $\leq \ell_{as} <$ 12ft for HP12x53 piles or any HP12 series or larger HP pile
Use $C_1 = 1.75$ and $C_2 = 0.375$ in Eqns. below

For,
3ft $< \ell_{as} <$ 5ft for HP10x42 piles or any HP10 series pile
or
3ft $< \ell_{as} <$ 7ft for HP12x53 piles or any HP12 series or larger HP pile
Use $C_1 = 1.50$ and $C_2 = 0.25$ in Eqns. below

Note, for $\ell_{as} \leq$ 3ft the pile/bent has a potential "kick-out" problem which needs to be addressed immediately.

C

C

Bent has sway-bracing in place — No →

Yes ↓

Check ℓ_{cr} and S_{CR} for Nonsidesway and Sidesway Buckling

Nonsidesway Buckling: (Mode 1)

$\ell_{CR1} = \sqrt{\dfrac{C_1 \pi^2 EI_y}{FS \cdot P_{max\ applied}^{pile}}}$

where FS = 1.25

$S_{CR1} = \ell_{CR1} - "H" + 1'$

Sidesway Buckling: (Mode 2)

$\ell_{CR2} = \sqrt{\dfrac{C_2 \pi^2 EI_y}{FS \cdot P_{max\ applied}^{pile}}}$

where FS = 1.25

$S_{CR2} = \ell_{CR2} - ("H" - X)$ for 1-or 2-story bent if member HB1 is in place and for 2-story bent if only member HB2 is present

$S_{CR2} = \ell_{CR2} - "H" + 1'$ for 1-story bent if HB1 is not present and for 2-story bent if HB1 and HB2 are not present

(see Figs. 4.4 a and b for definitions of "H" and X and for ID of members HB1 and HB2)

↓

The smaller of S_{CR1} and S_{CR1} is S_{CR} for the pile/bent.

Compare S_{CR} with S_{max}. i.e., is

$S_{CR} > S_{max}$ — No → D

Yes ↓

Pile/Bent is safe from Buckling →

Sidesway - Mode 2 Buckling:

$P_{CR2} = \dfrac{C_2 \pi^2 EI_y}{\ell^2}$

where $\ell = H + S - 1'$

Therefore,

$\ell_{CR} = \sqrt{\dfrac{C_2 \pi^2 EI_y}{FS \cdot P_{max\ applied}^{pile}}}$

where FS = 1.25

$S_{CR} = \ell_{CR1} - H + 1'$

Is

$S_{CR} > S_{max}$

Yes ↓   No →

Pile/Bent is safe from Buckling →

Bent piles are assumed to be pinned at their base in the "ST" when checking pushover capacity/adequacy. Therefore, go to Ⓔ in the "ST" and check for bent pushover adequacy.

E

D

Is bridge superstructure continuous or made continuous for LL? — No → Bent should be checked more closely for possible pile/bent buckling failure

Yes ↓

Nonsidesway - Mode 1 Buckling:

$P_{CR1} = \dfrac{2\pi^2 EI_y}{FS \cdot \ell^2}$

or,

$\ell_{CR} = \sqrt{\dfrac{2\pi^2 EI_y}{FS \cdot P_{max\ applied}^{pile}}}$

where FS = 1.25

$P_{max\ applied}^{pile}$ = as prescribed in Ch. 4 of Phase II report for continuous span bridges, or as prescribed in Ch. 3 of the Phase III Report.

and,

$S_{CR} = \ell_{CR} - H + 1'$

↓

Compare S_{CR} with S_{max}. i.e., is

$S_{CR} > S_{max}$ — No → Bent should be checked more closely for possible pile/bent buckling failure

Yes ↓

Pile/Bent is safe from Buckling

Figure 5.4 Enlargement of Buckling Evaluation Mode (Ramey et. al. 2008)

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Figure 5.5 Enlargement of Pushover Evaluation Module (Ramey et. al. 2008)

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5.2 "Kick-Out" Failure Check (Module 2) Details

When water flows against driven piles, forces are created that act transversely to the plane of the pile bent, i.e., parallel to the centerline of the bridge. A "kick-out" failure may occur if the force exerted at the lower tip of the pile, F_{tip}, exceeds the passive earth pressure at the tip of the driven pile (Ramey et. al. 2006). An illustration of the kick-out phenomenon is presented in Figure 5.6.
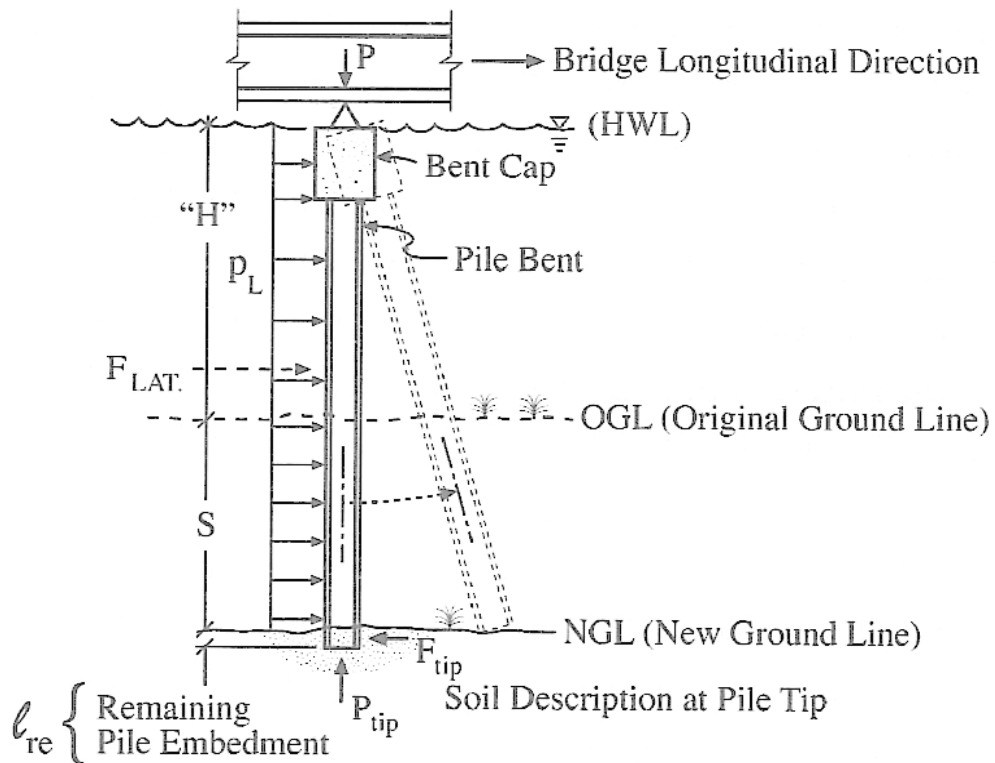
Figure 5.6 Side Elevation View of Bent Pile "Kick-Out" Failure Due to Extreme Flood/Scour Event (Ramey et. al. 2006)

In order to determine the force exerted on the pile tip, the pressure on a substructure due to the water flow must first be determined. Bridge piers or bents are

usually aligned so that their longitudinal axis is parallel to the direction of stream flow.

In an extreme flood event, and with possible stream channel direction changes with time,

the direction of stream flow will be at some angle θ with respect to the bent axis, as

illustrated in Figure 5.7.
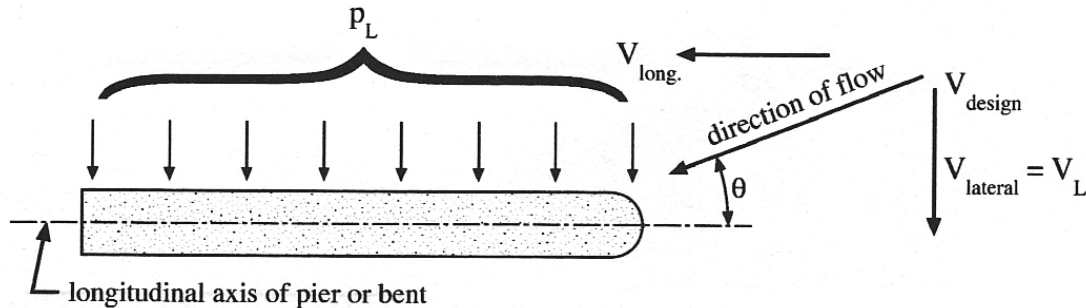
Figure 5.7 Stream Flow Forces on Pier/Bent (Ramey and Brown 2004)

The lateral, uniformly distributed pressure, p_L , due to water flowing at an angle,

θ, to the longitudinal axis of the pier can be determined as described previously in

Section 2.2.1.

In the Phase I report (Ramey and Brown 2004), it was determined that the most

probable maximum value of θ that may occur is 20°. Additionally, from Table 2.2, it can

be seen that for values of $\theta \geq 30°$, the lateral drag effects will remain essentially constant.

The flood water lateral pressures, p_L, on the pile bent were determined using these values

of θ, and assuming a design flood water velocity, V_{Design}, of 10km/h (or 6mph = 8.80 fps).

C_{DL} represents the lateral drag coefficient and is assumed (from fluid mechanics) to be

approximately 2.0 (Ramey et. al. 2006). These values are shown in Table 5.1.

Table 5.1 Estimates of Maximum Flood Water Lateral Pressures on Pile Bent for
v_{Design} = 10 km/h (6mi/h)

Parameter	Maximum probable angle, $\theta = 20°$	Estimated upper bound angle, $\theta = 30°$
V_{Design}	10 km/h=2.7 m/s (6mi/h=8.80 fps)	10 km/h=2.7 m/s (6mi/h=8.80 fps)
C_{DL}	2.0	2.0
$V_L = V_{Design} \sin\Theta$	0.92 m/s (3.01 fps)	1.34 m/s (4.40 fps)
$p_L = C_{DL}V_L^2$	0.87 kPa (18.12 psf)	1.85 kPa (38.72 psf)

The lateral drag force exerted on a pile bent will equal the lateral pressure, p_L, times the projected area of the bent on the vertical plane perpendicular to the lateral velocity, V_L. The equations for the approximate lateral drag force, F_{LAT}, on HP10x42 and HP12x53 piles (whose flange widths are nominally 10" and 12", respectively), and the equation for the approximate load exerted on the pile tip, F_{tip}, are as follows:

$$F_{LAT}^{HP10x42} \approx p_L \times \frac{10in}{12\,in/ft} \times ("H"+S)$$

$$F_{LAT}^{HP12x53} \approx p_L \times \frac{12in}{12\,in/ft} \times ("H"+S)$$

$$F_{tip} \approx \frac{1}{2}F_{LAT}$$

where "H" and S are the dimensions shown in Figure 5.6, measured in feet. Using the lateral pressure values given in Table 5.1, the resulting maximum flood water values of the applied tip force, $F_{tip}^{applied}$, per pile, for various "H"+S bent heights, are shown in Table 5.2.

Table 5.2 $F_{tip}^{applied}$ Values for HP $_{10x42}$ and HP$_{12x53}$ Piles for θ Values of 20° and 30° for a Range of "H"+S Values for V$_{Design}$ of 10 km/h (6 mi/h)

"H"+S Value [m (ft)]	$F_{tip}^{applied}$, [kN (lb) per pile]			
	θ = 20°		θ = 30°	
	HP10x42 $_{pile}$	HP12x53$_{pile}$	HP10x42 $_{pile}$	HP12x53$_{pile}$
4.6 (15)	0.50 (133)	0.60 (136)	1.08 (242)	1.29 (290)
6.1 (20)	0.67 (151)	0.81 (181)	1.44 (323)	1.72 (387)
7.6 (25)	0.84 (189)	1.01 (227)	1.79 (403)	2.15 (484)
9.1 (30)	1.01 (227)	1.21 (272)	2.15 (484)	2.58 (581)
10.7 (35)	1.17 (264)	1.41 (317)	2.51 (565)	3.02 (678)
12.2 (40)	1.34 (302)	1.61 (362)	2.87 (645)	3.44 (774)
13.7 (45)	1.51 (340)	1.81 (408)	3.23 (726)	3.87 (871)
15.2 (50)	1.68 (378)	2.01 (453)	3.59 (807)	4.31 (968)

The required pile embedment depth to provide adequate resistance for these forces was determined using the fact that the soil will resist these forces through passive earth pressures. The equation for passive earth pressure, P_P, is as follows:

$$(FS) \times P_P = \frac{1}{2} \gamma H^2 K_P$$

where FS = applied factor of safety

γ = buoyant weight of the soil

H = distance from top of bent cap to old ground line, ft, and

K_P = coefficient of passive lateral earth pressure.

A factor of safety, FS, of 1.5 is used for this equation. A value of 60lb/ft³ is used in the screening tool to represent the buoyant weight of soil, γ, and a conservative value

for the coefficient of passive lateral earth pressure, $K_P = 3$, was chosen (Ramey et. al 2006).

Using the highest loading shown in Table 5.2, corresponding to $\theta = 20°$, along with the equation for passive earth pressure above, the largest value of required embedment length to prevent a "kick-out" failure was determined to be 2.5 feet. To be conservative, it was established that a pile should have an embedment depth of at least 3 feet to avoid a "kick-out" failure. Any pile that has less than 3 feet of embedment after scour should be checked more closely for "kick-out" failure (Ramey et. al. 2006), and this is indicated by the output from the screening tool.

5.3   Bent Pile Plunging Check (Module 2) Details

A bent pile plunging failure may occur when a pile has inadequate axial resistance during an extreme flood/scour event to support the axial pile loads. When the axial resistance, or pile bearing capacity, is exceeded, the pile will fail by "plunging." To analyze plunging failure for this project, the maximum applied axial load, $P^{Pile}_{Max\ Applied}$ (determined as described in Chapter 3), is applied to the individual pile under investigation. The bridge bent is considered safe when it is determined that all the individual piles are safe from plunging failure.

The axial resistance is derived from a combination of pile tip bearing capacity and side frictional forces, as illustrated in Figure 5.8.
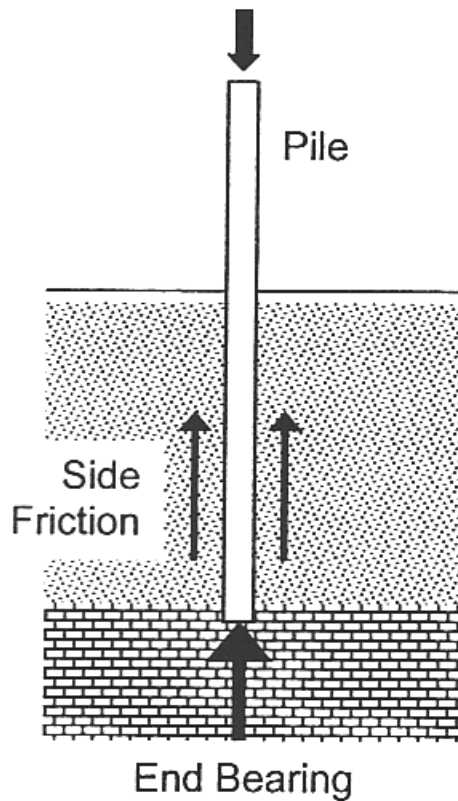
Figure 5.8 Pile Plunging Forces (Ramey et. al. 2006)

The magnitude of these resisting forces is a function of the surrounding soil properties. Although information on specific bent soil properties is often hard to obtain, the driving resistance of a pile at time of construction provides a reasonable indication of the amount of soil resistance that the pile has sustained (Ramey et. al. 2006). Driving resistance is referred to as the number of blows per foot (or blows per inch) of penetration achieved during pile driving, and is information that is generally available in the bridge construction records.

As indicated by the driving resistance during pile driving, the main variables affecting the axial resistance of a pile (after scour) are:

1. The driving resistance at the end of pile driving, indicated as blows per inch (bpi) or blows per foot (bpf) of penetration.

2. Hammer driving energy (kip-feet) used to drive the pile. The energy of the hammer is calculated by multiplying the weight of the ram (kips) by the height of the drop from the driver to the top of the pile (feet).

3. The type of soil that provides the resistance.

4. The amount of scour that occurred and the nature of the scour event.

The contribution of the pile end bearing resistance as a proportion of the total resistance is particularly important, because the greater this proportion, the less loss of resistance for a given amount of scour. This is because local scour, which is the type of scour that will reduce the amount of soil in contact with the sides of the pile and will thus reduce the side friction, is confined to a small area around the pile. Local scour does not, however, reduce the end bearing resistance in proportion to the amount of soil removed along the side of the pile because it does not have a large effect on the magnitude of the confining pressures on the soil at the tip. General scour, though, along the entire streambed around the bent would most likely reduce the confining pressures in the ground at the pile tip. Therefore, the end bearing resistance and the side shearing resistance may be reduced as a result of general scour (Ramey et. al 2006).

As mentioned in Chapter 2, the Modified Gates formula can be used to estimate the pile capacity when there is insufficient information available to perform a wave

equation model. For this project, the method used to relate axial static resistance to scour is as follows:

1. The Modified Gates formula was used to develop correlations of pile capacity with hammer driving energy and driving resistance at the end of driving (EOD) for a range of pile hammer energies (Ramey et. al. 2006). The formula used to perform this calculation is described in Chapter 2, in Section 2.2.2. For purposes of the screening tool, it was assumed that 8 bpi was the maximum blow count that could be encountered.

2. The axial resistance before scour is assumed to divide piles into one of two categories: 1) an "end bearing pile," in which 75% of the axial resistance is provided by end bearing and only 25% is provided by side shear, or 2) a "friction pile," in which 75% of the axial resistance is provided by side shear, and 25% is provided by end bearing. A friction pile is more susceptible to scour because the removal of the soil against the pile would have more of an impact on side shear than on end bearing.

3. Scour is represented as a percentage loss of embedment. After scour, it is assumed that the axial resistance in side shear is reduced by a percentage of the total side shearing resistance, which is proportional to the percentage loss of embedment due to scour.

Ramey et. al.(2006) describes the loss in resistance due to scour in this manner:

> In a homogeneous soil profile with general scour of the streambed instead of localized scour, it is conceivable that the reduction could be greater than the proportional percentage due to the reduction in

confining stress associated with scour. However, it is anticipated that a significant proportion of the scour loss will usually be due to localized scour which will not have a significant effect of confining pressure. It is also expected that the more common situation is one in which side shearing resistance increases with increasing depth, and so a proportional reduction in side shear is thought to be conservative.

4. The end bearing resistance is reduced by an amount equal to half of the proportional loss of embedment due to scour, in order to account for the reduction in confining stresses at the pile tip associated with scour. This reduction is believed to be realistic for piles bearing in cohesionless sand and for cemented bearing strata which have significant cohesion (Ramey et.al. 2006).

In order to clarify the method described above, a numerical example for determining the pile capacity of an end bearing and friction pile, having 20% loss of embedment, is given below. Assume the hammer energy is 12000 ft-lbs and the final driving resistance is 5 blows/inch.

Modified Gates Formula (nominal resistance):

$$P = 0.875E^{0.5}Log(10N_b) - 50 = (0.875 \times (12000\,ft - lbs)^{0.5} \times Log(10 \times 5bpi)) - 50$$
$$P = 112.9 tons$$

where N_b = driving resistance in number of blows per inch at end of driving, and

  E = energy produced by the hammer per blow in foot-pounds.

The nominal resistance is reduced by a factor of safety, F.S=1.25, to obtain allowable resistance.

  Allowable Resistance = $P / FS = 112.9 tons / 1.25 = 90.3 tons$

The Allowable Resistance is the same for both the end bearing and friction pile. As stated in item (2) above, if a pile is considered an end bearing pile 75% of its axial resistance is at the tip, the other 25% is assumed to be shear resistance. The percentages are vice versa for friction piles. Additionally, the end bearing resistance is reduced by an amount equal to half of the proportional loss of embedment due to sour, item (4) above. Given that the loss of embedment due to scour is 20%, the pile capacity equations for end bearing and friction piles are given below.

End Bearing Pile:

Pile Capacity for 20% loss of embedment =

$$\text{Allowable Resistance} - \left(\left(\left(\left(\frac{75\%}{100\%} \right) \times \left(\frac{10\%}{100\%} \right) \times \text{Allowable Resistance} \right) + \left(\left(\frac{25\%}{100\%} \right) \times \left(\frac{20\%}{100\%} \right) \times \text{Allowable Resistance} \right) \right) \right)$$

where 75% = the assumed tip resistance for end bearing piles

25% = the assumed shear resistance for end bearing piles

10% = half of the 20% loss of embedment due to scour

Therefore, the end bearing pile capacity for 20% loss of embedment becomes:

$$90.2 tons - ((0.75 \times 0.1 \times 90.2 tons) + (0.25 \times 0.2 \times 90.2 tons)) = \underline{78.9 \text{ tons}}$$

Friction Pile:

Pile Capacity for 20% loss of embedment =

$$\text{Allowable Resistance} - \left(\begin{array}{l} \left(\left(\dfrac{75\%}{100\%} \right) \times \left(\dfrac{20\%}{100\%} \right) \times \text{Allowable Resistance} \right) + \\ \left(\left(\dfrac{25\%}{100\%} \right) \times \left(\dfrac{10\%}{100\%} \right) \times \text{Allowable Resistance} \right) \end{array} \right)$$

where 75% = the assumed shear resistance for friction piles

25% = the assumed tip resistance for friction piles

10% = half of the 20% loss of embedment due to scour

Therefore, the friction pile capacity for 20% loss of embedment becomes:

$90.2 tons - ((0.75 \times 0.2 \times 90.2 tons) + (0.25 \times 0.1 \times 90.2 tons)) = \underline{74.4 \text{ tons}}$

The tabular results of the analyses described above, for several values of hammer driving energies, for three driving resistance values (3 bpi, 5 bpi, and 8 bpi), for the two pile categories (end bearing piles and friction piles), and for several values of percent loss of embedment are shown below in Table 5.3. Examples of graphical results generated using data from this table for end bearing piles and friction piles, specifically for a driving resistance of 3 bpi, are shown in Figure 5.9 and Figure 5.10, respectively.

Table 5.3 Pile Capacity in Tons with FS = 1.25 (Based on Modified Gates Formula)

Hammer Energy (ft-lb)	Final Driving Resistance (blows/inch)	Allowable Resistance (tons)	End Bearing Pile Load Capacity (tons) (assume 75% tip resistance) % loss of embedment					Friction Pile Load Capacity (tons) (assume 25% tip resistance) % loss of embedment				
			0	20	40	60	80	0	20	40	60	80
4000	3	25	25	22	19	16	13	25	21	16	12	8
6000	3	40	40	35	30	25	20	40	33	26	19	12
8000	3	52	52	46	39	33	26	52	43	34	25	16
10000	3	63	63	55	47	39	32	63	52	41	30	19
12000	3	73	73	64	55	46	37	73	60	47	35	22
15000	3	87	87	76	65	54	44	87	72	57	41	26
20000	3	106	106	93	80	66	53	106	87	69	50	32
4000	5	35	35	31	26	22	18	35	29	23	17	11
6000	5	52	52	46	39	33	26	52	43	34	25	16
8000	5	66	66	58	50	41	33	66	54	43	31	20
10000	5	79	79	69	59	49	40	79	65	51	38	24
12000	5	90	90	79	68	56	45	90	74	59	43	27
15000	5	106	106	93	80	66	53	106	87	69	50	32
20000	5	128	128	112	96	80	64	128	106	83	61	38
4000	8	44	44	39	33	28	22	44	36	29	21	13
6000	8	63	63	55	47	39	32	63	52	41	30	19
8000	8	79	79	69	59	49	40	79	65	51	38	24
10000	8	93	93	81	70	58	47	93	77	60	44	28
12000	8	106	106	93	80	66	53	106	87	69	50	32
15000	8	123	123	108	92	77	62	123	101	80	58	37
20000	8	148	148	130	111	93	74	148	122	96	70	44

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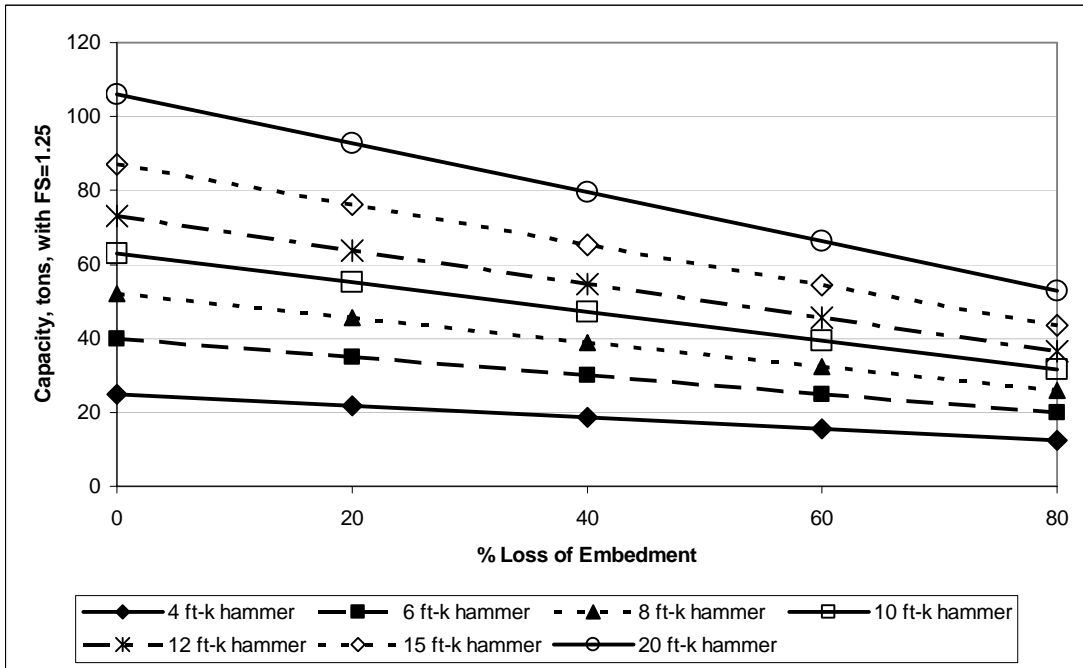
Figure 5.9 End Bearing Pile Capacities, 3 blows/inch Driving Resistance at End of Driving
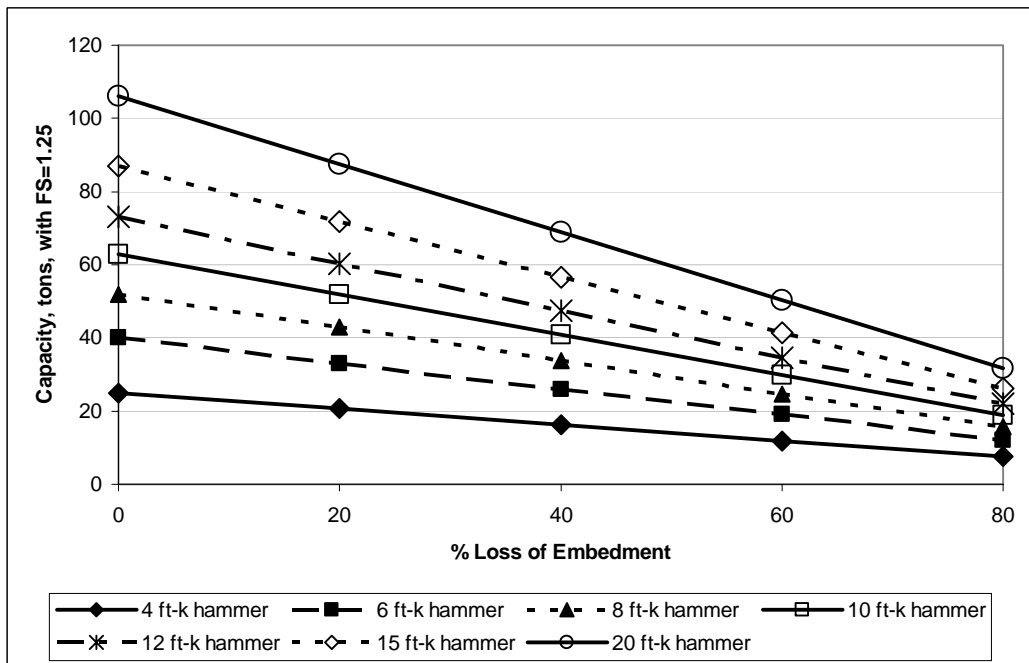
Figure 5.10 Friction Pile Capacities, 3 blows/inch Driving Resistance at End of Driving

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These figures (Figure 5.9 and Figure 5.10) are used to determine the critical plunging scour (the scour amount, in feet, that is determined to just bring the pile to the point of a plunging failure) and the estimated pile capacity, based on soil resistance, for a particular pile. To make these determinations, the following information must be known, or must be reasonably estimated (Ramey et. al. 2006):

1. Hammer type and driving energy: The hammer used to install the pile and its corresponding driving energy must be known or estimated. The driving energy is most often given as a "rated energy" which refers to the weight of the ram times the drop height for a simple single-acting hammer. Because the hammers are not always efficient, the "rated energy" must be reduced to reflect the actual energy delivered. Common types of hammers used throughout Alabama, with their estimated efficiency, are as follows:

Table 5.4 Hammer Type and Estimated Driving Efficiency

Hammer Type	Estimated Efficiency (%)
Single-acting air/stream	67
Double-acting air/stream	50
Diesel	80
Drop hammers	50*

*Note: Drop hammers are not currently used on ALDOT projects, but may have been used on older bridges. With relatively high drop heights (more than 3-5 feet) and low ram weights, the energy losses can result in efficiency less than 50%.

2. Driving resistance, measured in blows per inch (bpi): The driving resistance at the end of driving must be obtained from the pile driving records for the job. If these records cannot be located, then the driving resistance must be reasonably estimated.

3. Pile type: A pile must be classified as an end bearing or a friction pile. Determination of pile type comes from some knowledge of the soil conditions, indicated either by borings or from the driving records (Ramey et. al. 2006). Locations that have dense sand strata, hard clays, or rocks underlying soft alluvial soil are representative of a case in which end bearing controls. Also, pile driving records that indicate a low blow count, followed by a striking increase in the driving resistance at a depth just before the end of driving, suggest a strong bearing layer. Where there are deep clay strata with no hard bearing layer, and embedment lengths are large, friction piles are usually specified.

4. Pile embedment length and scour: The original embedment length of the pile and the amount of scour relative to its length must be known in order to assess the effect of scour on the stability of the pile.

A numerical example illustrating the process for determining the critical scour and pile capacity as describe above is given below.

Example Problem 1: A friction pile that was driven to an estimated final driving resistance of 3 blows/inch is considered. The pile was driven to an embedment of 30 feet with a single-acting air hammer having a rated energy of 15 ft-k. The

estimated axial applied load was determined to be 60 kips, i.e. $P^{Pile}_{Max\ Applied} = 30$ tons.

It was determined that a scour of 8 feet is possible at the bent location.

Solution 1: A single-acting air hammer has an efficiency of 67%, making the estimated driving energy 10 ft-k. From Figure 5.10, for a friction pile with 3 bpi driving resistance, a 10 ft-k hammer, and assuming that the needed pile capacity is 38 tons, the corresponding percent loss of embedment is determined to be approximately 44%. The needed pile capacity is determined by multiplying the applied axial load of 30 tons by the factor of safety of 1.25. Using the equation given in Module 2 for determining the critical scour, S_{CR} (the scour that would produce that percentage loss of embedment for the 38 ton load), the critical scour for this example, with a length before scour, $\ell_{bs} = 30$ ft., becomes:

$$S_{CR} = \frac{\%\ \text{loss of embedment}}{100} \times \ell_{bs} = \frac{44\%}{100} \times 30\,ft$$

$$S_{CR} = 13.2\,ft$$

$$S_{CR} = 13.2\,ft > S_{Max} = 8\,ft$$

Since the critical scour required to produce a plunging failure with the given parameters is determined to be 13.2 ft, and the estimated maximum scour that will realistically be possible at the pile site is only 8 ft, the pile is deemed to be safe from a plunging failure.

Another related technique for determining plunging adequacy is to determine the actual pile capacity, considering the % loss of embedment corresponding to the maximum estimated scour at the bent site, $S_{Max} = 8\,ft$, and

the embedment length before scour, $\ell_{bs} = 30\,ft$. For this case, the percent loss of

embedment becomes:

$$\text{\% loss of embedment} = \frac{S_{CR}}{\ell_{bs}} \times 100\% = \frac{8'}{30'} \times 100\% = 27\%$$

Using Figure 5.10 again for friction piles with 3 bpi final driving resistance, a

27% loss of embedment, and a 10 ft-k driving hammer, the indicated capacity of

the pile is slightly less than 50 tons (including a FS=1.25). The estimated capacity

of 50 tons is greater than the 38 ton demand, and thus the pile again deemed safe

from plunging failure.

The ST minimizes the work load of the engineer responsible for the bridge

assessment by automating the calculation of the critical plunging scour of a pile, S_{CR}, so

that he/she does not need to "eyeball" an interpolation from the given figures. After

consulting with ALDOT engineers, it was decided that the ST should calculate and

display these S_{CR} values for both end bearing and friction piles since, often, they cannot

easily determine what type of pile is under investigation. The example problem below

illustrates the method by which the ST calculates the pile capacity and critical scour for

the plunging evaluation directly, using the Modified Gates equation, rather than using

interpolation among the previous figures. (The allowable resistance values, and the pile

capacities given in Figure 5.9 and Figure 5.10 were generated using the Modified Gates

Equation, and the data from Table 5.3 are the basis for the figures, so this direct

technique gives the same results as the graphical technique.)   For simplicity, the given

information of Example Problem 1 will be used.

Example Problem 2: $P^{Pile}_{Max\ Applied} = 30$ tons, $S_{Max} = 8\,ft$, $\ell_{bs} = 30\,ft$,

Driving resistance = 3 bpi, Driving energy = 10 ft-k hammer, FS = 1.25.

Solution 2: The Modified Gates formula is used to find the nominal axial pile resistance, P:

$$P = 0.875E^{0.5}Log(10N_b) - 50 = (0.875\times(10000\,ft-lbs)^{0.5}\times Log(10\times3bpi)) - 50$$
$$P = 79.25tons$$

where N_b = driving resistance in number of blows per inch at end of driving, and

E = energy produced by the hammer per blow in foot-pounds.

Then, the determination of the allowable resistance becomes:

Allowable Resistance = $P / FS = 79.25tons / 1.25 = 63.4tons$

Scour is expressed in terms of percent loss of embedment. In order to find the percent loss of embedment to be used for the critical scour calculation, one must determine the linear relationship, or slope, relating the percent loss of embedment to the pile capacity. This is accomplished by calculating the pile capacity for 80% loss of embedment and 0% loss of embedment, which is the allowable resistance.

To calculate the pile's capacity, the percent loss of embedment is found using the maximum estimated scour at the site and the original embedment length. The pile capacity is then determined using the equation of a line with the same slope determined as described above.

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Example calculations for determining the critical scour and the pile capacity are shown below, first for a friction pile, followed by the calculations for an end bearing pile.

Friction Pile:

Critical Scour, S_{CR}, for a Friction Pile:

Pile Capacity for 80% loss of embedment =

$$\text{Allowable Resistance} - \left(\begin{array}{l} \left(\left(\left(\frac{75\%}{100\%} \right) \times \left(\frac{80\%}{100\%} \right) \times \text{Allowable Resistance} \right) + \\ \left(\left(\left(\frac{25\%}{100\%} \right) \times \left(\frac{40\%}{100\%} \right) \times \text{Allowable Resistance} \right) \end{array} \right)$$

Substituting the allowable resistance value calculated earlier, the pile capacity for an 80% loss of embedment becomes

Pile Capacity for 80% loss of embedment =

$$63.4 tons - ((0.75 \times 0.8 \times 63.4 tons) + (0.25 \times 0.4 \times 63.4 tons)) = 19.02 \text{ tons}$$

Slope = (19.02-63.4) / 80 = -0.55

% loss of embedment =

$$\frac{(1.25 \times P_{\text{Max Applied}}^{\text{Pile}}) - \text{Allowable Resistance}}{\text{Slope}} = \frac{(38 - 63.4)}{-0.55} = 46.2\%$$

where F.S.=1.25.

$$S_{CR} = \frac{\% \text{ loss of embedment}}{100} \times \ell_{bs} = \frac{46.2\%}{100} \times 30\,ft$$

$$\underline{S_{CR} = 13.9\,ft} \text{ for a friction pile.}$$

Capacity for a Friction Pile:

$$\text{\% loss of embedment} = \frac{S_{Max}}{\ell_{bs}} \times 100\% = \frac{8}{30} \times 100\% = 27\%$$

Friction Pile Capacity = (Slope x % loss of embedment) + Allowable
Resistance

Friction Pile Capacity = (-0.55 x 27) + 63.4 tons

➔ Friction Pile Capacity = 48.6 tons

End Bearing Pile:

Critical Scour, S_{CR}, for an End Bearing Pile:

Pile Capacity for 80% loss of embedment =

$$\text{Allowable Resistance} - \left(\begin{array}{c} \left(\left(\frac{25\%}{100\%} \right) \times \left(\frac{80\%}{100\%} \right) \times \text{Allowable Resistance} \right) + \\ \left(\left(\frac{75\%}{100\%} \right) \times \left(\frac{40\%}{100\%} \right) \times \text{Allowable Resistance} \right) \end{array} \right)$$

Substituting the allowable resistance value calculated earlier, the pile capacity

for an 80% loss of embedment becomes

Pile Capacity for 80% loss of embedment =

$$63.4 tons - ((0.25 \times 0.8 \times 63.4 tons) + (0.75 \times 0.4 \times 63.4 tons)) = 31.7 \text{ tons}$$

Slope = (31.7-63.4) / 80 = -0.40

% loss of embedment =

$$\frac{(1.25 \times P_{\text{Max Applied}}^{\text{Pile}}) - \text{Allowable Resistance}}{\text{Slope}} = \frac{(38 - 63.4)}{-0.40} = 63.5\%$$

where F.S.=1.25.

$$S_{CR} = \frac{\% \text{ loss of embedment}}{100} \times \ell_{bs} = \frac{63.5\%}{100} \times 30\,ft$$

$\underline{S_{CR} = 19.1\,ft}$ for an end bearing pile.

Capacity for an <u>End Bearing Pile</u>:

$$\% \text{ loss of embedment} = \frac{S_{Max}}{\ell_{bs}} \times 100\% = \frac{8}{30} \times 100\% = 27\%$$

End Bearing Pile Capacity = (Slope x % loss of embedment) + Allowable Resistance

End Bearing Pile Capacity = (-0.4 x 27) + 63.4 tons

➔ <u>End Bearing Pile Capacity = 52.6 tons</u>

In summary, the critical scour values and pile capacity values computed for the given conditions are:

Pile Type	S_{CR} (ft)	Pile Capacity (tons)
Friction	13.9	48.6
End Bearing	19.1	52.6

The estimated capacity of 48.6 tons and 52.6 tons for the friction and end bearing piles, respectively, is greater than the 38 ton demand (applied axial load with F.S. =1.25). Also, the critical scour value for both piles is greater than the maximum estimated scour value of 8 ft. Therefore, both piles are safe from plunging failure.

All of the calculations detailed above are included in the Tier-1 plunging evaluation of the automated screening tool. If it turns out that the critical scour is less than the maximum estimated scour at the site, i.e., $S_{CR} < S_{max}$, then the ST would check more closely for a possible pile/bent plunging failure by going into the Tier-2 ST check. If this occurs, the calculations above would be executed again using a new $P_{Max\ Applied}^{Pile}$. In order to obtain this new value, it is assumed that each bridge span supported by the bent in question is a simply supported span loaded, and that live load is applied only to the bridge actual traffic lanes (rather than the design traffic lanes, as is the assumption for the Tier 1 screening); a new maximum applied bent loading, $P_{Max\ Applied}^{Bent}$, is then determined based on this assumption. Once $P_{Max\ Applied}^{Bent}$ has been redetermined, a new maximum applied pile loading, $P_{Max\ Applied}^{Pile}$, is found by dividing the maximum applied axial load on the bent, $P_{Max\ Applied}^{Bent}$, by the number of piles contained in the bent. Recall, these assumptions were outlined in Section 4.3.

5.4   Bent Pile Buckling Check (Module 3) Details

If a bridge bent buckles, it will only do so in the transverse direction of the bridge (perpendicular to the longitudinal centerline of the bridge). Bridge bent piles will not buckle in a sidesway mode in the longitudinal direction of the bridge because the bridge abutments and the connection of the abutments and bent caps to the bridge superstructure prevent movement of the bent in the longitudinal direction of the bridge. The bent piles will also not buckle in a nonsidesway mode in the longitudinal direction of the bridge

because of the piles' orientation on the bridge superstructure. For a nonsidesway mode of buckling in the longitudinal direction, the bent piles would have to buckle about their strong-axis, which has a moment of inertia three times greater than the moment of inertia of the weak-axis. The piles will not buckle about their strong-axes; therefore, buckling will only occur in the transverse direction of the bridge about the weak-axis of the bent pile. For the purposes of the screening tool, if the most heavily loaded pile in a bent is safe from buckling failure, then it is assumed that the whole bent will be safe from buckling failure.

5.4.1   X-Braced Bent Pile Buckling About the Weak-Axis

There are two possible modes of transverse buckling that a bridge bent can experience: the nonsidesway mode (Mode 1) and the sidesway mode (Mode 2). Figure 5.11 illustrates these transverse buckling modes.
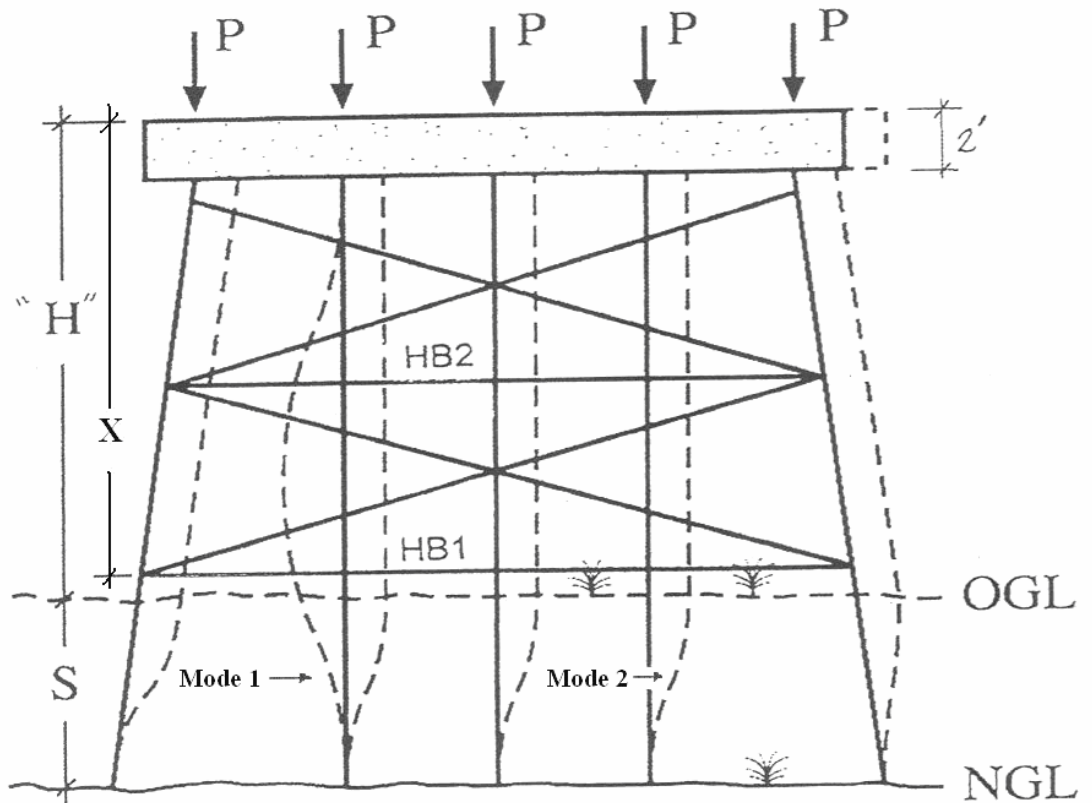
Figure 5.11 Transverse Buckling Modes for X-Braced Bents (Ramey et. al. 2008)

Bents with heights ranging from 13 to 25 feet generally have some configuration of X-bracing. For an X-braced bent, such as that shown above, with no scour or with a small amount of scour, S, the bracing will prevent sidesway buckling in the transverse direction. Thus, Mode 1 (Nonsidesway) buckling will control. Mode 1 buckling has an assumed buckled shape ranging from the bottom of the bent cap down to the new ground line (NGL), as shown in Figure 5.11. To achieve this buckled shape, it is assumed that the diagonal X-braces will buckle and that the horizontal braces (HB1 and HB2) will remain rigid as all the piles in the bent buckle. When this occurs, the horizontal braces will no longer provide bracing points for the piles.

When there is significant scour, S, the X-braced bent could buckle in a transverse sidesway mode (Mode 2), with the buckled length ranging from the bottom of the lowest horizontal brace to the new ground line after the scour event. If the X-braced bent does not have a horizontal brace, then sidesway buckling would occur from the bottom of the bent cap down to the new ground line after scour. Without a horizontal brace, it is assumed that the X-braced bent will buckle like an unbraced bent. Mode 2 buckling is represented in Figure 5.11.

When comparing the maximum vertical load applied to a pile, $P_{\text{Max Applied}}^{\text{Pile}}$, for continuous span and simple span bridges with the same span lengths, the continuous span bridges will have larger $P_{\text{Max Applied}}^{\text{Pile}}$ loads at intermediate supports/bents (Ramey et. al. 2006). However, continuous span bridges will gain extra support for the intermediate bents in the transverse direction because of the bridge superstructure. This will prevent sidesway buckling in the transverse direction and will increase the critical buckling load, P_{CR}, for continuous span bridges by a factor of approximately four (Ramey et. al. 2006), i.e. from $P_{CR} \approx \dfrac{1}{2}\dfrac{\pi^2 EI_y}{\ell^2}$ to approximately $P_{CR} \approx 2\dfrac{\pi^2 EI_y}{\ell^2}$ (assuming bracing members and piles have a 50% fixity at the cap and groundline). Therefore, for X-braced bents, as a conservative approximation in the ST, it is assumed that $P_{\text{Max Applied}}$ values are equal to those for simple spans for any superstructure support system and that P_{CR}^{Pile} values are equal to those applicable for simply supported spans, where sidesway in the lower regions of the bent is possible, as shown by the Mode 2 buckled shape in Figure 5.11.

The Mode 1 and Mode 2 equations for determining the critical buckling loads for X-braced bents are shown below:

Buckling Mode 1 (Nonsidesway):

$$P_{CR1} = \frac{C_1 \pi^2 EI_y}{\ell^2_{CR1}}$$

Buckling Mode 2 (Sidesway):

$$P_{CR2} = \frac{C_2 \pi^2 EI_y}{\ell^2_{CR2}}$$

where C_1 and C_2 = fixity coefficients related to the pile embedment length after scour,

ℓ_{as} (C_1 and C_2 are discussed more fully below),

E = the pile modulus of elasticity,

I_y = the area moment of inertia about the pile's weak axis,

$\ell_{CR1} = S + ("H" - 1')$,

$\ell_{CR2} = S + ("H" - X)$ for a 1 or 2-story bent if member HB1 is present

and for a 2-story bent if only member HB2 is present

$\ell_{CR2} = S + ("H" - 1')$ for 1-story bent if HB1 is not present and for a 2-story bent if

HB1 and HB2 are not present,

S = the amount of scour, in feet,

"H" = the vertical distance between the top of the bent cap and the new ground

line, in feet,

X = the vertical distance between the top of the bent cap and the lowest horizontal

brace, HB1.

In the equations for critical lengths, the 1' dimension is included because the piles are assumed to be embedded into the bent cap 1' from the top of the bent cap.

The distances S, "H", and X are illustrated in Figure 5.11. C_1 and C_2 are fixity coefficients related to the pile embedment length after scour, ℓ_{as}. As the depth of embedment is reduced, the fixity of the pile at the ground level is reduced, as well as the estimated pile buckling capacity. These constants are given for HP10 and 12 series piles for different ranges of pile embedment lengths after scour in Table 5.5 and Table 5.6, respectively (Ramey et. al. 2008).

Table 5.5 C_1 and C_2 values for HP10 series pile

Pile embedment after scour, ℓ_{as} (ft)	C_1	C_2
≥ 8 ft	2.00	0.50
5 ft $\leq \ell_{as} < 8$ ft	1.75	0.375
3 ft $< \ell_{as} < 5$ ft	1.50	0.25

Table 5.6 C_1 and C_2 values for HP12 series pile

Pile embedment after scour, ℓ_{as} (ft)	C_1	C_2
≥ 12 ft	2.00	0.50
7 ft $\leq \ell_{as} < 12$ ft	1.75	0.375
3 ft $< \ell_{as} < 7$ ft	1.50	0.25

Note, for $\ell_{as} \leq 3$ ft the pile/bent has a potential "kick-out" problem which needs to be addressed immediately, so fixity coefficients are not listed for these lengths.

Knowing the $P_{\text{Max Applied}}^{\text{Pile}}$ for the particular bridge/bent under investigation (and setting this value times a factor of safety equal to the critical buckling load), and knowing

the correct fixity constants, the levels of scour necessary to reach Mode 1 and Mode 2 buckling can be determined by rearranging the equations above, as follows:

For Mode 1 (Nonsidesway) buckling, as illustrated in Figure 5.11, the critical pile length that will produce this buckling configuration is found to be

$$\ell_{CR1} = \sqrt{\frac{C_1 \pi^2 EI_y}{FS \times P_{Max\ Applied}^{Pile}}}$$

where FS = 1.25.

The corresponding critical scour value is:

$$S_{CR1} = \ell_{CR1} - ("H" - 1') .$$

For Mode 2 (Sidesway) buckling, as illustrated in Figure 5.11, the critical pile length that will produce this buckling configuration is found to be

$$\ell_{CR2} = \sqrt{\frac{C_2 \pi^2 EI_y}{FS \times P_{Max\ Applied}^{Pile}}}$$

where FS = 1.25.

The corresponding critical scour value is:

$$S_{CR2} = \ell_{CR2} - ("H" - X) \text{ for 1 or 2-story bent if member HB1 is present}$$

and for 2-story bent if only member HB2 is present, and

$$S_{CR2} = \ell_{CR2} - ("H" - 1') \text{ for 1-story bent if HB1 is not present and for 2-story bent}$$

if HB1 and HB2 are not present.

The critical scour, S_{CR}, for the pile/bent will be the smaller of S_{CR1} and S_{CR2}. If $S_{CR} \geq S_{Max}$ (the maximum value of scour estimated to be possible at the bridge site), then the bent is safe from buckling failure.

If $S_{CR} < S_{Max}$ and the bridge superstructure is continuous or made continuous for live load, nonsidesway buckling is checked for the bent using the following equation,

$$\ell_{CR} = \sqrt{\frac{2\pi^2 EI_y}{FS \times P_{Max\ Applied}^{Pile}}}$$

where FS = 1.25, and

$$S_{CR} = \ell_{CR} - ("H"-1') .$$

This assumes the bracing members and piles have a 50% fixity at the cap and ground, making the fixity coefficient equal to 2.

This new value of S_{CR} is compared with S_{Max}, and if $S_{CR} > S_{Max}$ then the bent is safe from buckling failure. If not, the screening tool indicates that the bent should be checked more closely by the inspecting engineers for possible pile/bent pushover failure.

5.4.2 Unbraced Bent Pile Buckling About Weak-Axis

If both HB1 and HB2 members are not present, the bent should be considered unbraced (Ramey et. al. 2006). If this true, then the bent can either be checked using the procedure above or the procedure given in this section.

The equations for unbraced bent pile buckling are similar to the equations for sidesway buckling for X-braced bents. The fixity constant, C_2, can be found in Table 5.5 or Table 5.6 (presented in Section 5.4.1 above) for HP10- or 12-series piles, respectively.

The equations for calculating the critical buckling load and the associated value of critical scour for unbraced bents are as follows:

For Sidesway (Mode 2) buckling,

$$P_{CR2} = \frac{C_2 \pi^2 EI_y}{\ell^2}$$

where $\ell = ("H" - 1') + S$

Therefore,

$$\ell_{CR} = \sqrt{\frac{C_2 \pi^2 EI_y}{FS \times P_{Max\ Applied}^{Pile}}}$$

where FS = 1.25, and

$$S_{CR} = \ell_{CR} - ("H" - 1').$$

There are existing bridges in Alabama in which the bent height, "H" is less than or equal to 13 ft, and the bent piles are encased in concrete from the bottom of the bent cap to a point 3 ft below the original ground line. Sway-bracing for these types of bents is typically omitted. A drawing of a bent with this configuration is illustrated in Figure 5.12.
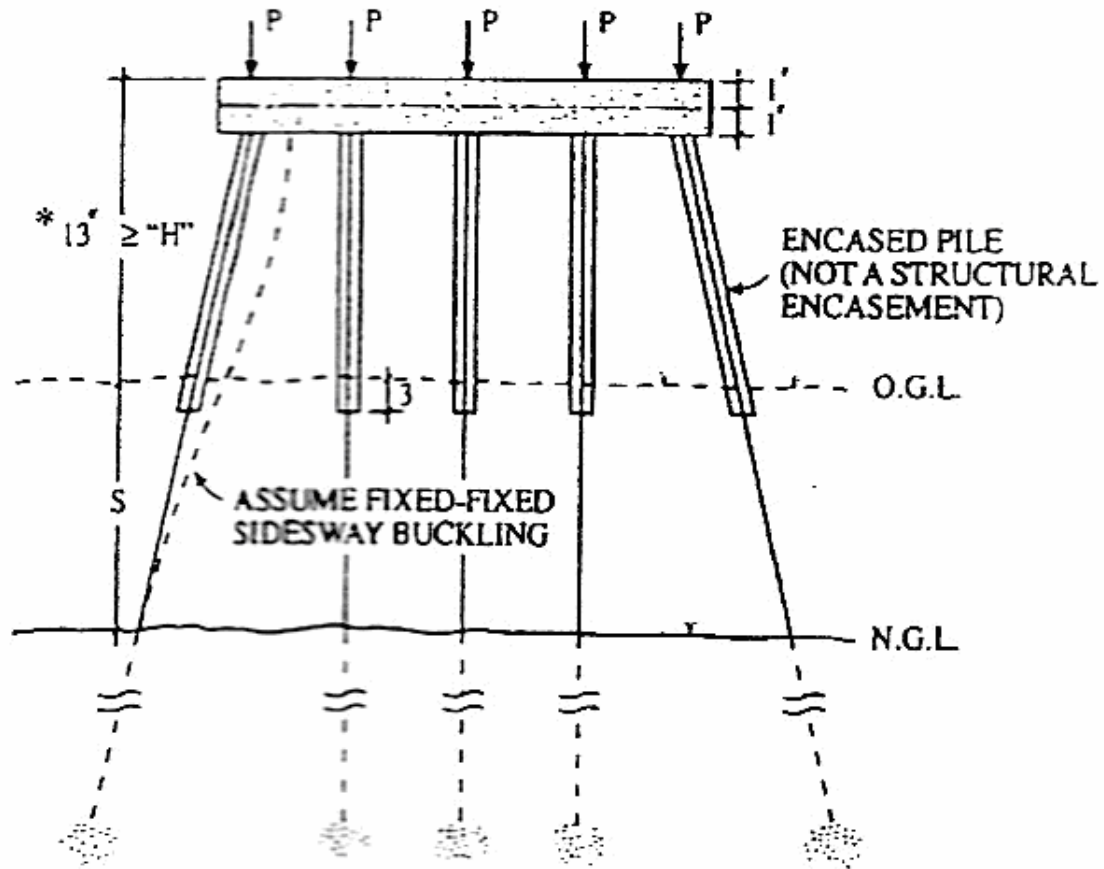
Figure 5.12 Bent with Encased Piles and No Sway-Bracing (Ramey et. al. 2006)

Sometimes ALDOT engineers encounter unbraced pile bents where "H" > 13 ft. If so, the procedure for determining P_{CR} and S_{CR} is the same as the procedure for "H" $\leq$ 13 ft. Even if the piles are encased in concrete, it is conservatively assumed for the screening tool that the encasement has spalled off. This is conservative considering that the encasement would increase the pile stiffness and buckling capacity.

The computed value of S_{CR} is compared with S_{Max}, and if $S_{CR} > S_{Max}$ then the bent is safe from buckling failure. If $S_{CR} < S_{Max}$ and the bridge superstructure is

continuous or made continuous for live load, the bent should then be checked in the

nonsidesway mode using the same equation as for an X-braced bent:

$$\ell_{CR} = \sqrt{\frac{2\pi^2 EI_y}{FS \times P_{\text{Max Applied}}^{\text{Pile}}}}$$

where FS = 1.25, and

$$S_{CR} = \ell_{CR} - (\text{"H"} - 1').$$

This new value of S_{CR} is compared with S_{Max}, and if $S_{CR} > S_{\text{Max}}$ then the bent is

safe from buckling failure. If not, the screening tool indicates that the bent should be

checked more closely by the inspecting engineers for possible pile/bent pushover failure.

5.5   Bent Pushover Failure Check (Module 4)

Another failure mode that could be experienced is a bent pushover failure. This

situation may occur as a result of the combination of the bent gravity loads (P_{DL+LL}) with

a flood water loading acting lateral to the bridge, in the plane of the bent, applied near the

top of the bent. The bent is modeled as pictured in Figure 5.13a, with a gravity load

positioned above each pile, and the horizontal floodwater load acting in the horizontal

direction. The analysis can be run by either holding the horizontal load, F_t fixed and

incrementing the gravity P-loads until a pushover failure occurs, or vice versa. For the

development of the screening tool, the P-loads were fixed, and the F_t load was

incremented until failure.

The pushover curve is generated as the plot of the bent pushover load, F_t, versus

the horizontal displacement, Δ, for a given bent and a given P-load level. As can be seen

in Figure 5.13b, a pushover failure is indicated when the horizontal deflection, Δ, increases significantly with very little change in the incremented force (i.e., when the curve reaches an asymptotic value of the incremented force).
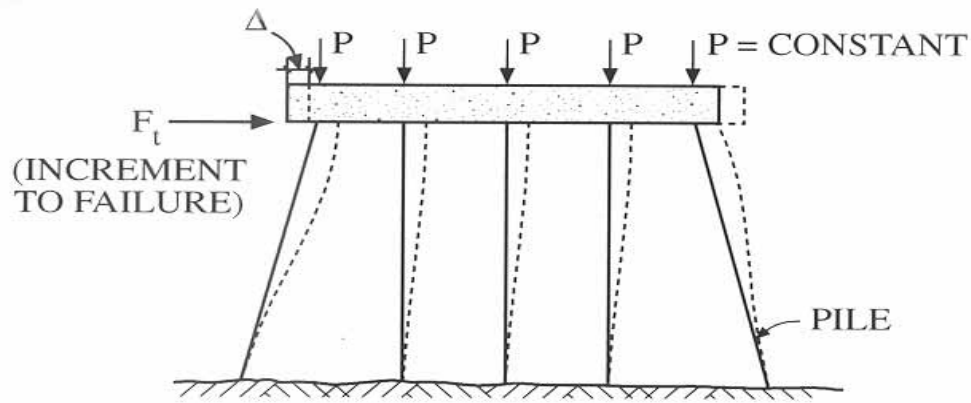
a. Gravity + Flood Water Loaded Pile Bent
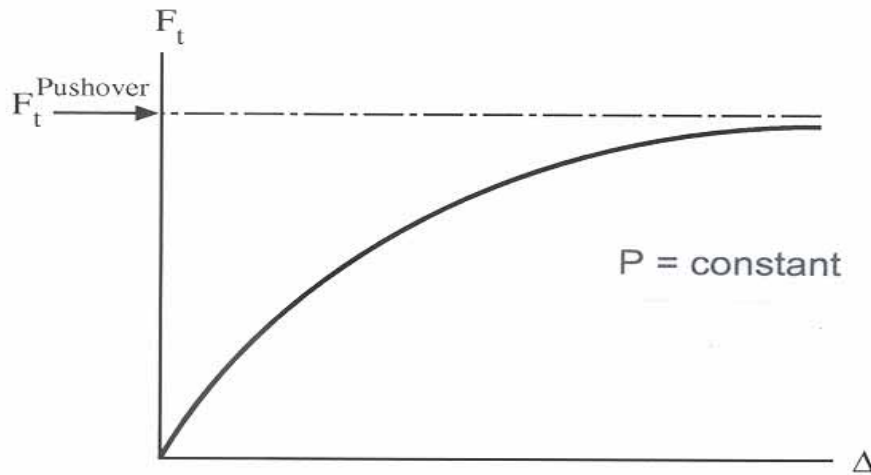
b. Bent Pushover Curve

Figure 5.13 Typical Nonlinear Pile Bent Pushover Modeling Scenario and P-Δ Curve (Ramey et. al. 2006)

The pushover analysis subprogram in GTSTRUDL was used to perform the nonlinear analysis, which considers both geometric and material nonlinearity of the bent. In the program, the bent's stiffness matrix is modified after each load increment by considering the deformed geometry and the member stress-strain relation (E values) for each load increment (Ramey et. al. 2006). The vertical P-load level is determined for the screening tool by simply dividing the maximum applied bent load, $P_{max\ applied}^{bent}$, by the number of piles in the bent. Two typical GTSTRUDL bent pushover curves (for two different bent configurations and zero feet of scour) are illustrated in Figure 5.14.
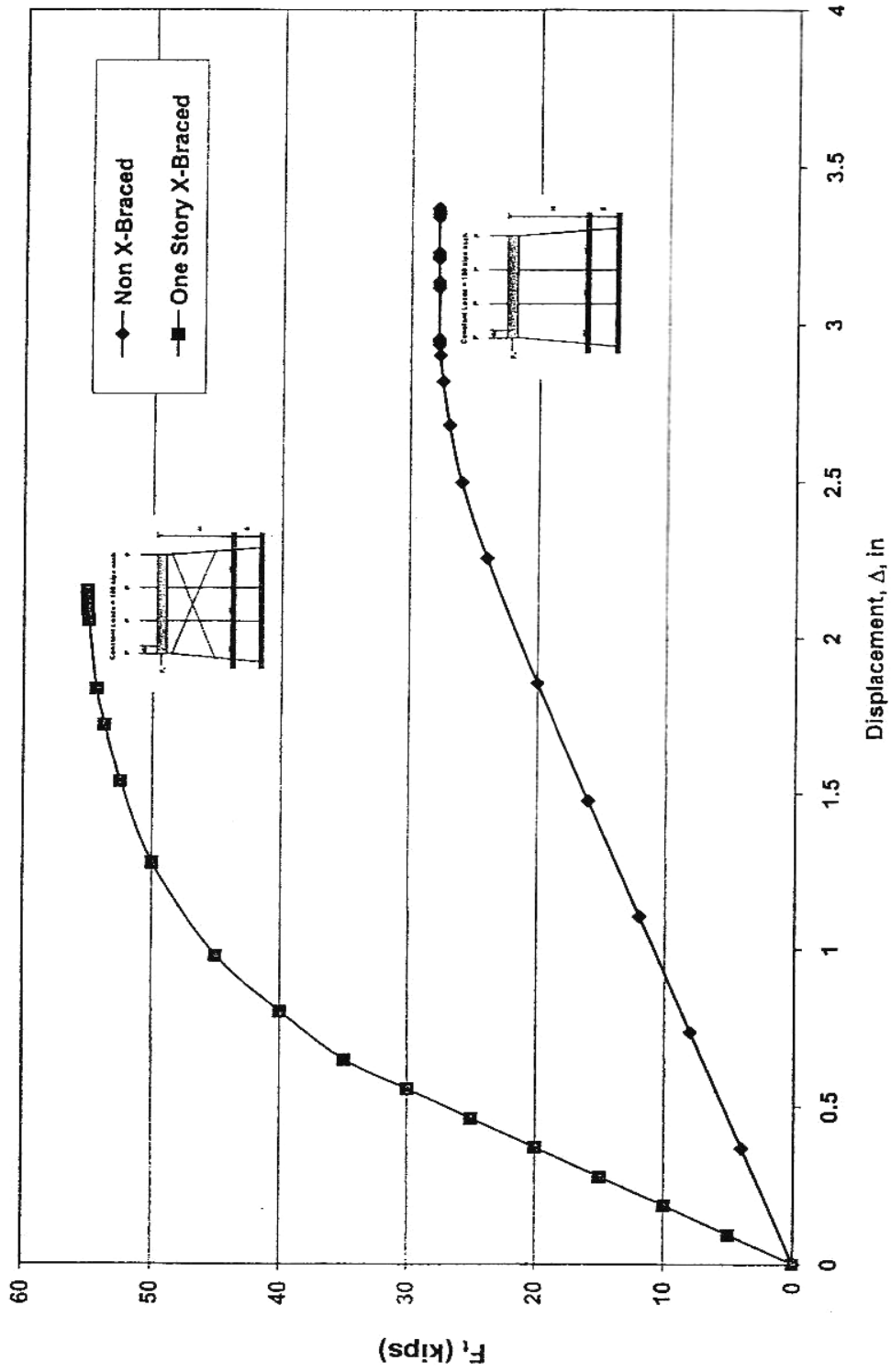
Figure 5.14 GTSTRUDL Pushover Analysis for HP$_{10x42}$ 4-Pile Bents, Bents Pinned at Ground, H=13 ft, S=0 ft, P=100k   (Ramey et. al. 2006)

The bent pushover loads, $F_t^{Pushover}$, for each bent configuration considered, were determined from bent pushover curves of F_t vs. Δ generated for each case in GTSTRUDL (like those curves seen in Figure 5.14). The bent pushover load is the maximum load that the bent can withstand before failure, represented by the last point on the pushover curve (the asymptotic value). A complete set of bent pushover curves for all bent configurations considered for the screening tool is contained in the Phase II Report (Ramey et. al. 2006) in Appendices A and B. The pushover load values for the various bent sizes and number of piles, bent heights, levels of P-load, levels of scour, and X-braced and unbraced conditions, are presented in tables in Appendix A (for HP10x42) and B (for HP12x53) of this thesis. A sample of the tables contained in Appendices A and B is shown in Table 5.7, which summarizes the pushover capacities of HP10x42 pile bents with X-bracing for 3 and 4-pile bents, where the pushover load, F_t, is assumed to be applied at the bottom of the pile cap.

Table 5.7 Pushover Load, F_t, for Single Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP_{10x42} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470 \text{ in}^4$ for Symmetric Distribution of Varying Values of P-Load, H, and S.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	13	0	46.7	44.5	42.5	41.5	39.7	38.3
		5	19.1	17.1	15.5	14.4	12.8	11.2
		10	10.6	8.5	6.3	4.0	2.8	unstable
		15	5.9	3.3	unstable	unstable	unstable	unstable
		20	unstable	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
	17	0	44.9	42.9	41.2	39.9	38.3	36.8
		5	17.8	15.9	13.9	12.6	10.6	8.7
		10	9.6	7.1	4.8	2.9	1.0	unstable
		15	4.9	2.0	unstable	unstable	unstable	unstable
		20	unstable	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
4	13	0	62.8	58.6	55.1	51.2	48.2	45.3
		5	35.1	31.4	28.1	24.7	22.0	19.3
		10	28.7	24.6	21.0	17.3	14.0	10.9
		15	25.9	21.7	17.4	13.1	9.4	5.8
		20	19.7	15.4	11.3	8.0	5.0	1.8
		25	13.3	10.0	7.0	4.1	2.0	unstable
	17	0	58.4	53.7	49.8	45.5	42.6	40.2
		5	32.7	28.7	25.1	21.4	18.3	15.5
		10	27.0	22.4	18.2	14.3	10.7	7.4
		15	23.3	18.6	14.0	9.7	5.8	2.1
		20	17.0	12.4	9.0	5.0	2.1	unstable
		25	11.0	8.0	5.0	3.0	unstable	unstable

The floodwater force exerted on the pile is a function of the size of the debris raft and the design floodwater pressure. A schematic of the debris raft is shown in Figure 5.15.
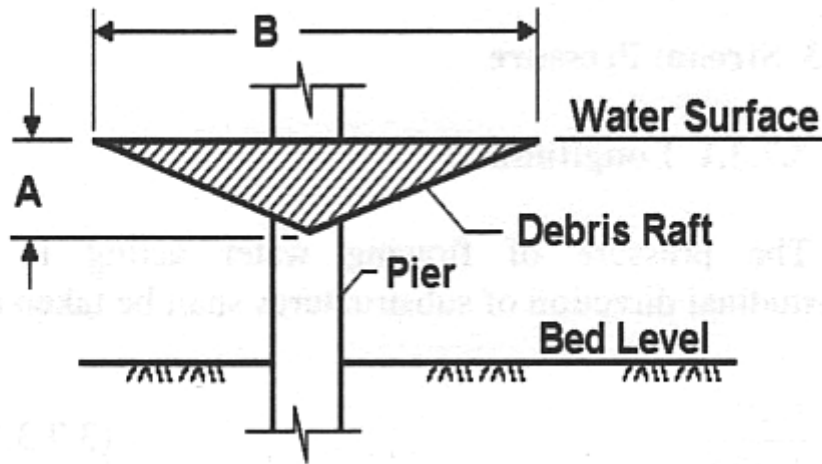
Figure 5.15 Debris Raft for Pier Design (AASHTO LRFD 2005)

According to AASHTO LRFD (2005), the size of the debris raft is a matter of judgment, but dimension A should be half the water depth, but no larger than 10 feet, and dimension B should be half the sum of adjacent span lengths, but no larger than 45 feet. As stated in Section 4.1, for this project the flood water debris raft is assumed to have dimensions of A= 6' and B= 30', with a design floodwater velocity of V= 6 mph. The design flood water pressure is determined using the equation in Section 2.2.1 as:

$$p = C_D V^2$$

where V= design floodwater velocity = 6mph = 8.80 fps

C_D=1.4 (from Table 2.1)

Therefore,

$$p = 1.4(8.80\text{fps})^2 = 108 \text{ psf}$$

The design lateral force, F_t, on the bent is calculated using the following equation,

$$F_t = p \times \text{Debris Raft Area}$$

$$F_t = 108\,psf\left[\frac{1}{2}\text{A} \times \text{B}\right] = 54\,psf \times 6' \times 30' = 9.72 \text{ kips}$$

Therefore, the maximum applied horizontal force (i.e., the maximum practical value of the lateral floodwater force) becomes $F_{t\,max\,applied} = 9.72kips$. Assuming a factor of safety of 1.25 leads to a maximum design horizontal force of,

$$F_{t\,max\,design} = 9.72kips \times 1.25 = 12.15kips\,.$$

If a pushover load calculate from the GTSTRUDL analysis for a particular bent is greater than the maximum design horizontal force, $F_t > F_{t\,max\,design} = 12.15kips$, then the bent is safe from pushover failure (because the factored maximum practical floodwater load will never reach that magnitude). If there is not a source of stream flood debris from which a debris raft could be generated, or a history of debris, the design horizontal force is reduced to 2.5 kips (which includes a F.S.=1.25) (Ramey et. al. 2008). Therefore, for a bent with no debris raft present, if the load calculated to cause a pushover failure, F_t, is less than the design horizontal force of 2.5 kips, (i.e., $F_t < F_t^{max\,applied} = 2.5$ kips), the screening tool will recommend that the bent should be checked more closely by the inspecting engineers for possible indications of pushover failure.

Linear interpolation may be used to determine the pushover force of a bent if the P-load level, scour level, and/or bent height fall between those values specifically listed

in Appendices A-H. However, extrapolation is not permitted outside of the minimum and maximum values given for a particular field.

For the automated screening tool, linear interpolation between values given in the pushover tables was used to determine the values of critical scour, S_{CR}, corresponding to $F_{t\,max\,design}=12.15^k$ for each bent geometry configuration, height, and P-load level. If the resulting $S_{CR} > S_{Max}$ at the site, then the screening tool states that the bent is safe from pushover failure. The entire set of tables in which this critical scour value is calculated, for each bent configuration (each P-load level, scour level, and/or bent height investigated for the screening tool) can be found in Appendices E and F. An example a scour table is shown below in Table 5.8

Table 5.8 Critical Scour, S_{CR}, of HP_{10x42} 3 and 4-Pile Bents with X-Bracing to Resist $F_{t\,max\,design}$ =12.15^k (includes a FS=1.25)

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	Single-X Per Story	1	13	9.1	7.9	6.8	6.1	5.3	4.8
			17	8.4	7.1	6.0	5.2	4.7	4.4
		2	21	8.9	8.1	7.3	6.4	5.5	4.9
			25	7.5	6.9	6.4	5.3	4.8	4.4
4	Single-X Per Story	1	13	>25.0	23.0	19.3	15.9	12.0	9.3
			17	24.0	20.3	16.9	12.3	9.0	7.1
		2	21	24.2	19.8	15.0	11.0	8.8	7.3
			25	22.6	17.0	11.9	8.8	6.9	5.3

In order for the automated screening tool (coded with Visual Studio 2005) to access the data quickly from the pushover force and critical scour tables, a database was created within Microsoft Access that contains both sets of tables. During the execution of the automated screening tool, the particular applicable values of pushover force, F_t , and critical scour, S_{CR}, for a particular bent in question are retrieved from the Access database based on the following user input: 1) the bent size (number of piles and height), 2) level of gravity P-load as determined above, 3) bracing condition, and 4) size of HP pile. (Interpolation for values between tables is automated in the Visual Studio program code to obtain the proper, interpolated values of F_t and S_{CR}.) Once the specific values are retrieved from the database, they are compared to the appropriate $F_{t\ max\ design}$ and S_{Max} values at the site. If $F_t > F_{t\ max\ design} = 12.15 kips$, when a debris raft may develop, the bent is safe from pushover. When a debris raft will most likely not develop and

$F_t > F_{t\ max\ design} = 2.5 kips$, then the bent is safe from pushover. Additionally, if the critical scour found in the database is greater than the maximum estimated scour, $S_{CR} > S_{Max}$, then the bent is safe from pushover failure.

All the checks described above are included in the Tier-1 portion of the screening tool. However, an additional level of screening was developed in the recent months, so that if $S_{CR} < S_{Max}$, the screening tool will indicate that the bent should be checked more closely for possible pushover failure and, to do so, the program will automatically proceed to a Tier-2 screening. However if $F_t < F_{t\ max\ design} = 2.5 kips$ when no debris raft can develop, the screening tool will indicate that the bent should be checked more closely

for possible pushover failure, but will not move into Tier-2 screening (i.e., there is no Tier-2 screening evaluation for a condition with no debris raft).

For the Tier-1 level of screening, it is assumed that a uniform level of scour exists along the profile of the bent. However, in reality, localized scour at the base of the bent piles will most likely vary from a maximum level at the upstream pile to a minimum level at the downstream pile. An illustration of this scour profile is shown in Figure 5.16. The structure shown in the middle represents a bridge bent.
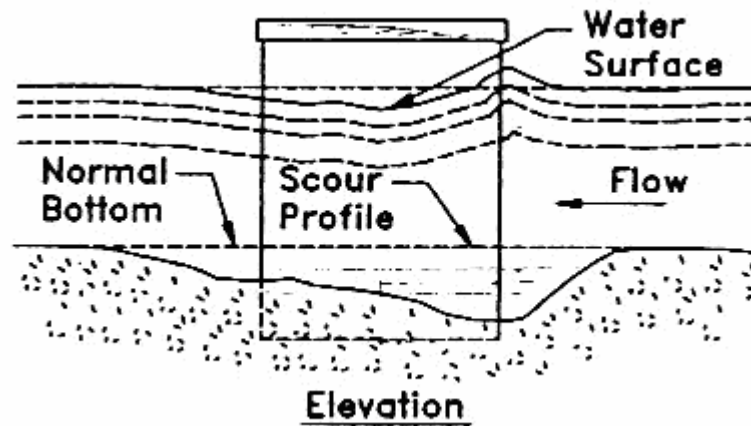
Figure 5.16 Elevation View of a Possible Scour Profile (Ramey et. al. 2008).

Once the bent under investigation moves into the Tier-2 screening, it is analyzed as having a variable scour distribution. As discussed in the Phase III Part I ALDOT report (Ramey et. al. 2008), the pushover capacities for bents with a variable scour distribution (for which some piles will have less scour than the estimated maximum, S_{Max}) will be

greater than those bents for which all the piles in the bent experience a uniform maximum

level of scour, S_{Max}.

Pushover force and critical scour tables have also been developed for HP_{10x42} and

HP_{12x53} piles for 3 and 4-pile bents, with and without X-bracing, for various heights,

levels of P-load, and variable levels of scour for the Tier-2 screenings. The assumed

scour distribution profile is illustrated in Figure 5.17.
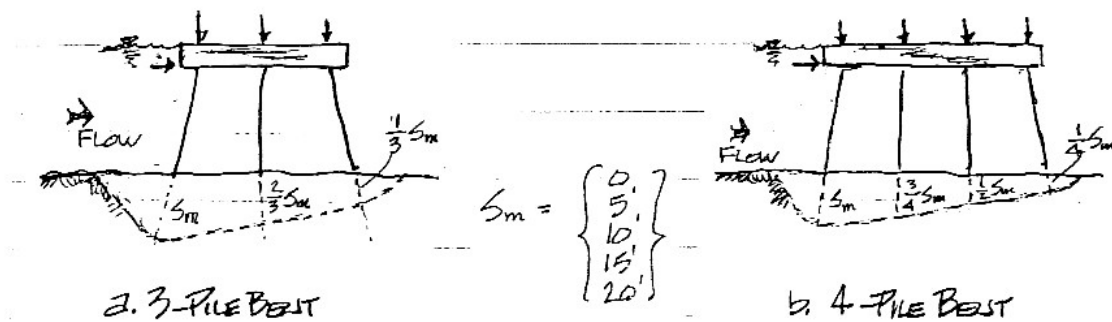
Figure 5.17 Assumed Scour Distribution Profile (Ramey et. al. 2008).

Table 5.9 summarizes the pushover capacities of HP_{10x42} pile bents with X-

bracing for 3 and 4-pile bents having variable scour distributions, where the pushover

load, F_t , is assumed to be applied at the bottom of the pile cap. Appendices C and D

contain pushover tables for all other bent configurations investigated for the Tier-2 ST.

An example of a Tier-2 table of critical scour values is presented in Table 5.10.

Appendices G and H contain critical scour tables for all other bent configurations

investigated for the Tier-2 ST.

Table 5.9 Pushover Load, F_t, for Single Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP_{10x42} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4 for Symmetric Distribution of Varying Values of P-Load, H, and S for Variable Scour Distributions.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	13	0	NN	NN	NN	NN	NN	NN
		5	24.7	22.7	20.6	18.7	16.8	15.0
		10	15.4	13.0	11.0	9.8	8.6	7.3
		15	9.9	8.3	7.1	5.7	4.5	3.4
		20	7.1	5.8	4.4	3.2	unstable	unstable
		25	5.3	3.9	2.5	unstable	unstable	unstable
	17	0	NN	NN	NN	NN	NN	NN
		5	23.1	20.8	18.6	16.5	14.6	13.1
		10	13.9	11.6	10.1	8.7	7.2	5.8
		15	9.2	7.7	6.2	4.7	3.3	unstable
		20	6.7	5.1	3.6	2.1	unstable	unstable
		25	4.9	3.2	unstable	unstable	unstable	unstable
4	13	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	NN
		10	32.1	28.1	24.5	21.1	18.1	15.2
		15	27.6	23.3	19.4	16.0	13.0	10.3
		20	24.9	20.4	16.3	12.9	9.9	7.5
		25	22.0	17.8	14.1	10.7	7.9	5.5
	17	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	22.3
		10	29.0	24.8	20.9	17.4	14.1	11.5
		15	25.1	20.1	16.1	12.6	9.7	7.4
		20	21.8	17.1	13.1	9.7	7.1	4.8
		25	19.2	14.8	11.0	7.8	5.2	2.9

Table 5.10 Critical Scour, S_{CR}, of HP_{10x42} 3 and 4-Pile Bents with X-Bracing to Resist $F_{t\ max\ design}$ =12.15^k (includes a FS=1.25), Unsymmetric Scour

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	Single-X	1	13	13.0	10.9	9.4	8.7	7.8	6.9
	Per Story		17	11.9	9.7	8.8	7.8	6.7	5.7
		2	21	13.5	11.5	9.8	9.0	8.1	7.2
			25	12.3	10.1	9.1	8.0	6.9	5.8
4	Single-X	1	13	>25.0	>25.0	>25.0	21.7	16.4	13.1
	Per Story		17	>25.0	>25.0	22.3	15.8	12.2	9.7
		2	21	>25.0	>25.0	19.9	15.2	12.6	10.2
			25	>25.0	22.6	15.7	12.3	9.7	8.4

The pushover failure check for the Tier-2 screening is identical to that for the Tier-1 screening. The pushover force and capacity tables for the variable scour configurations are also contained in the Access database, and the values for a particular bent are retrieved with the same user input described earlier. As before, if $F_t > F_{t\,max\,design} = 12.15kips$, then the bent is safe from pushover. If the critical scour found in the database is greater than the maximum estimated scour, $S_{CR} > S_{Max}$, then the bent is safe from pushover failure. If either check results in an unsafe condition, then the screening tool will finally recommend that the bent be checked more closely by the inspecting engineers for additional conditions that could lead to a possible bent pushover failure.

CHAPTER 6: AUTOMATED SCREENING TOOL USER'S GUIDE

6.1   General

A simple screening tool (ST) was developed in cooperation with ALDOT to quickly and efficiently check the adequacy of bridge bent/piles after a scour event. The effort reported herein constituted the Phase III, Part II portion of the ALDOT-sponsored project, and included the automation of the screening tool using Visual Studio 2005 software. A list of information the user of the automated screening tool must know, or must be able to reasonably estimate, in order to run the ST program is contained in this chapter. Also, a step-by-step guide detailing the steps in completing a scour analysis using the program is given.

6.2   Bridge/Site Information Needed to Run ST Program

Information necessary for performing the ST "checks" detailed in Chapter 5, which enable an inspecting engineer to evaluate the adequacy of ALDOT bridge pile bents for extreme scour events, is listed below. Most of the information will be available to the engineer from the bridge construction records and/or via a visual inspection of the bridge. In some instances, however, reasonable estimations for unknown values must be made using engineering judgment.

In particular, for a case in which the inspecting engineer either knows, or can accurately estimate, the actual maximum vertical load applied to the bent and its piles, $P_{\text{Max Applied}}^{\text{Pile}}$ and $P_{\text{Max Applied}}^{\text{Bent}}$, it is not necessary to supply the bridge superstructure information listed below in category (4) that is used to calculate an estimate of these loads.

Information that Must be Supplied:

1. General Scour and Stream Information

    a. Is the bridge over water, supported by steel pile bents, and in a scour possible setting?

    b. Is the formation of a debris raft at this bridge site possible?

    c. What is the maximum estimated scour at the bridge site, S_{max}?

2. Pile Bent Geometry and Design Information

    a. Original and new (after scour) cross-sectional area of pile in splash zone

    b. Approximate size of bent cap cross-section (depth and width)

    c. Bent height from top of cap to original ground line, i.e., "H", as depicted in Figure 5.11.

    d. The distance from the top of the bent cap to the lowest horizontal brace, if bracing is included, i.e., "X", as depicted in Figure 5.11.

    e. Type, size (HP10- and 12-series only), spacing, and number of piles per bent

    f. Configuration of bent's steel angle iron sway bracing

g. Number of bent stories

h. Existence or non-existence of horizontal bracing members

i. Live load to be estimated using AASHTO HS20-44 or HS15-44 loading configuration

3. Pile Driving Information

a. Original length/depth of pile embedment in soil before scour

b. Length of pile embedment in soil after scour

c. Pile driving resistance at end of driving

d. Pile driving hammer type and hammer energy

4. Bridge Superstructure Information

a. Span support conditions, i.e., spans are simply supported or continuous spans, or are made continuous for live load. If continuous, number of continuous spans

b. Number of bents or spans

c. Span length(s)

d. Girder type, size, number per span, and spacing

e. Deck and diaphragm thickness

f. Outside-to-outside deck width

g. Curb-to-curb deck width and number of actual traffic lanes loaded.

h. Overhang thickness and width

i. Existence or non-existence of a Jersey barrier rail on the bridge

6.3 Automated Screening Tool

The automated screening tool was developed in Visual Studio 2005 using the Visual Basic programming language. It was created to be a user-friendly program designed to enable ALDOT engineers to quickly and easily assess the sufficiency of bridge bents subjected to scour events. The program has six main windows (in which the user inputs bridge/bent information and results are shown), nine modules (in which all major calculations are performed), and approximately 4,200 lines of code. The six main windows seen by the user are: 1) Introduction, 2) Preliminary Evaluation, 3) Determination of $P_{max\ applied}$ for Pile and Bent, 4) Kick-out and Plunging Evaluation, 5) Buckling Evaluation, and 6) Pushover Evaluation. Note that windows 4 through 6 correspond with the failure modules 2 through 4 in the ST flowchart, shown in Figure 5.1.

The primary focus of this section (Section 6.3) is to familiarize the user with the automated screening tool's screens and progression. A comprehensive example problem using the screening tool is given in the following section.

6.3.1 Computer Set-Up and Download

There are a few steps the user must follow first in order to properly set up and run the screening tool program. Listed below are the appropriate steps the user must take in order to successfully download the screening tool and to prepare it for use.

1. Obtain the automated screening tool installation CD. The installation CD will contain two files: 1) Bridge Scour.exe and 2) Critical Scour.mdb.

2. Copy both files to a folder of your choosing on a local hard drive. It is very important that both files are copied to the same folder and that the folder is saved on a local hard drive. If either of these things is not done, the program will not work.

3. Double click the Bridge Scour.exe file to begin to run the automated screening tool program.

The computer on which the automated screening tool will run must have Microsoft .NET Framework 2.0 software. If the computer does not have .NET Framework 2.0, then the computer must be updated. To automatically update the computer, follow the directions listed below:

1. Click on the green "START" button at the bottom of the computer screen.

2. Click "All Programs" and select Microsoft (or may be called Windows) Update.

3. Select the 'Custom' option.

4. Choose to install .NET framework 2.0 and complete the installation directions.

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After this installation is complete, the automated screening tool should run properly.

6.3.2 Automated Screening Tool Procedure

After proper download and set-up of the automated screening tool, the procedure for analyzing the stability of the bridge/bent in question after an extreme scour event is as follows:

6.3.2.1 Introduction Window

The first window seen by the user is the *Introduction* window, Figure 6.1. General information is listed in the window, such as the project name, the authors and sponsors of the tool, and general directions for beginning to run the program. The execution of the ST can be halted at anytime by pressing the "End Program" option on any of the windows.
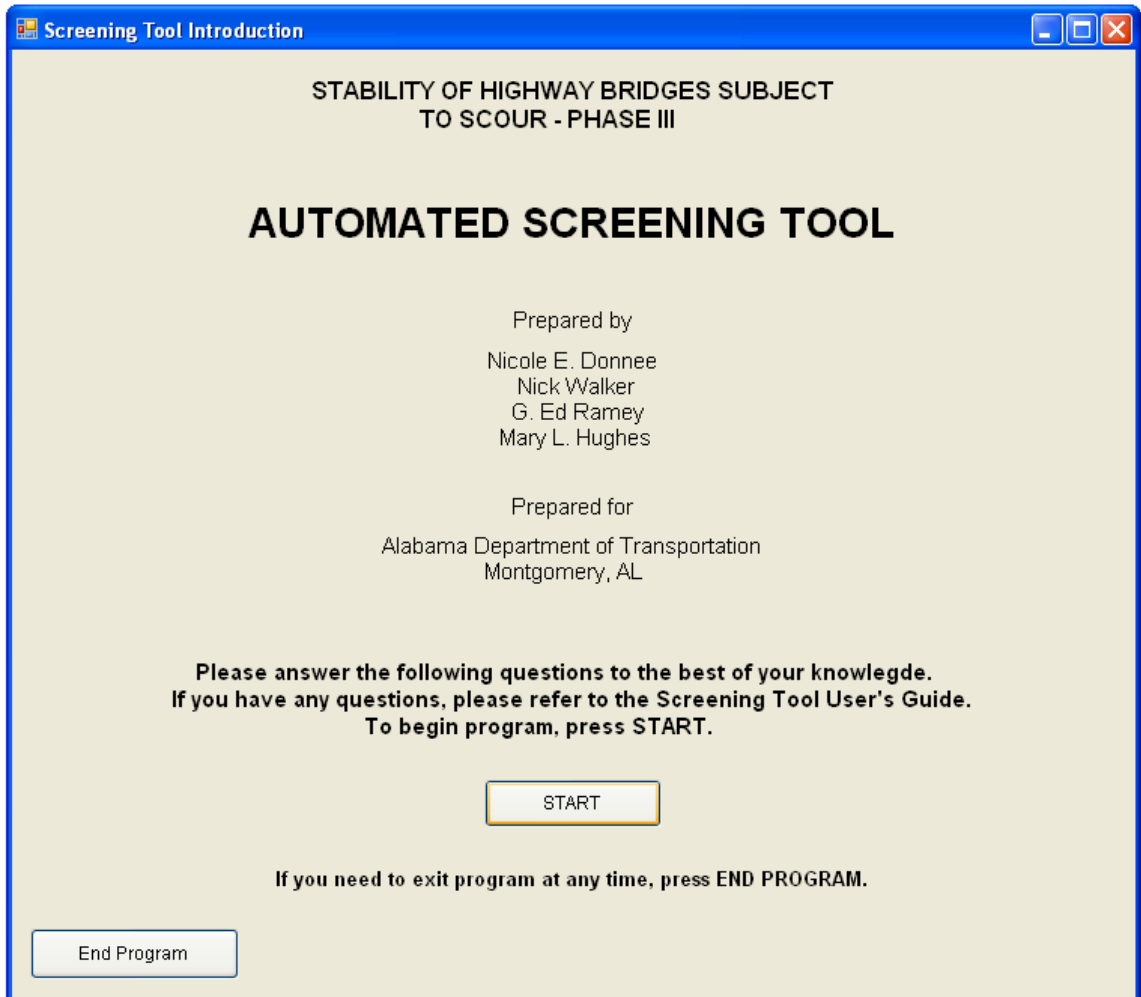
Figure 6.1 Introduction Window of Automated Screening Tool

Press the "Start" button to begin the Automated Screening Tool program.

6.3.2.2 Preliminary Evaluation

The second screen viewed is the *Preliminary Evaluation* window, shown in

Figure 6.2. The main purpose of the *Preliminary Evaluation* window is to check for an

unacceptable reduction in cross-sectional area of the most critical pile of the most critical

bent due to corrosion. Also, the "Maximum Estimated Scour" and "Length of pile

embedment before scour" values entered here will be used throughout the program,

unless otherwise specified.

Figure 6.2 Preliminary Evaluation Window of Automated Screening Tool

Begin answering the questions as requested on the *Preliminary Evaluation*

window. After entering values in each textbox, press "Enter." Examples of some possible

warnings that may be encountered when entering the requested values are listed below.

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1. If the bridge is not over water or is not in a scour-possible setting and "No" is selected, the bridge is safe from scour failure and the message shown in Figure 6.3 is displayed. The screening tool program is only applicable to bridges that are over water and are exposed to scour-possible settings.
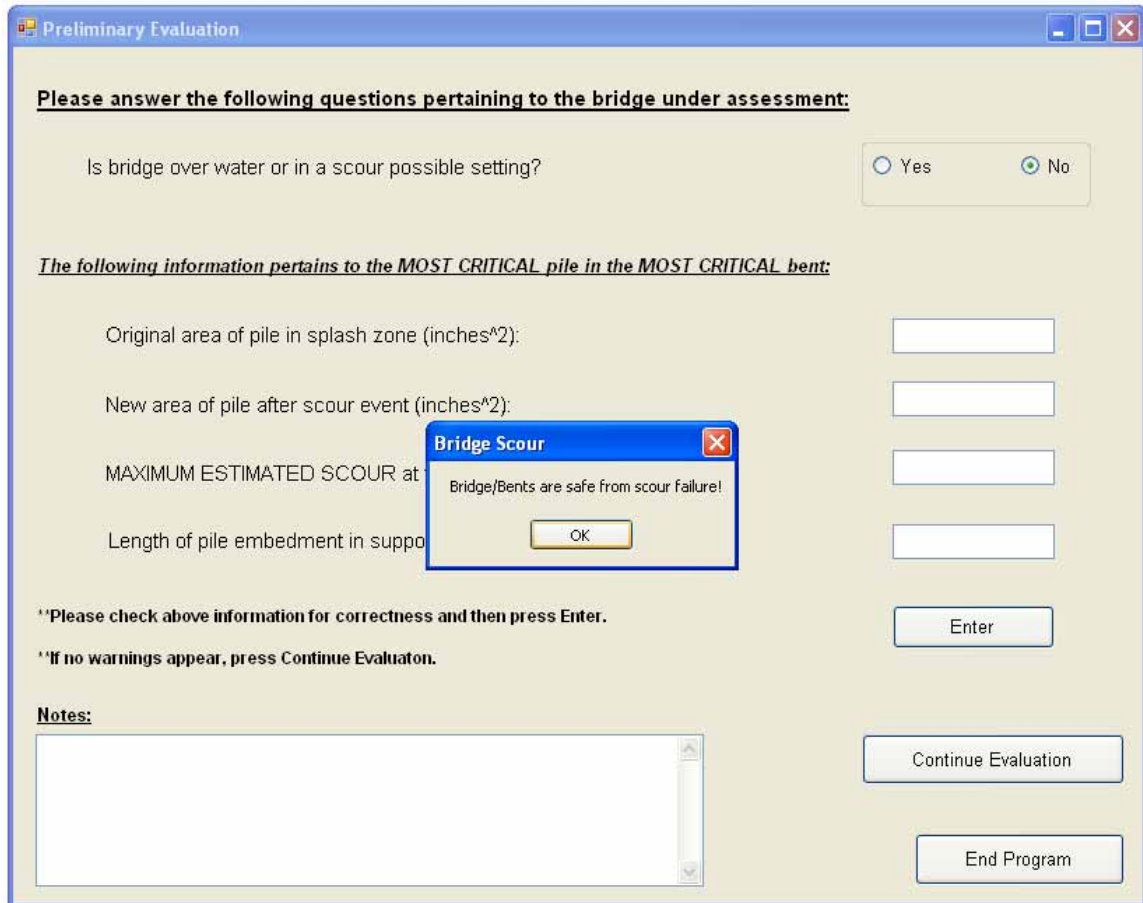
Figure 6.3 Warning that Appears in the Preliminary Evaluation Window when Bridge Is Not in a Scour Possible Setting

2. The screening tool will only evaluate bents that may have scour levels up to 25 feet. If the maximum estimated scour at the bent site is more than 25 feet,

the bridge's stability must be checked by other means. If a number greater than 25 is entered in the "Maximum Estimated Scour at bridge/bent site" textbox, the following message in Figure 6.4 is displayed:
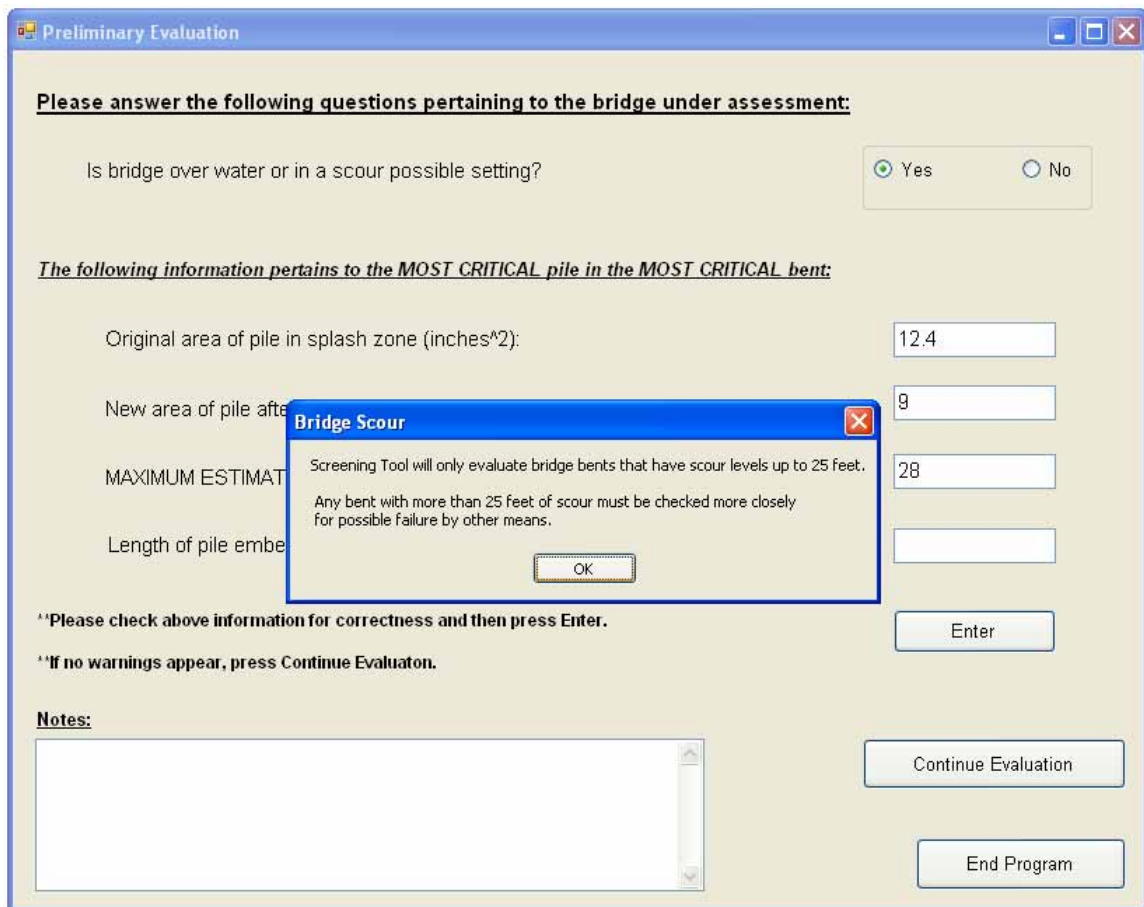
Figure 6.4 Warning that Appears in the Preliminary Evaluation Window when a "Maximum Estimated Scour" Value Greater than 25 Feet is Entered.

3. After all the values in the textboxes have been entered and after the "Enter" button has been pressed, a warning may appear if the new area of the bent is less than 75% of the original area. The screening tool issues a warning to take

corrective action to build the section back to its original or greater dimensions. This warning is shown in Figure 6.5.
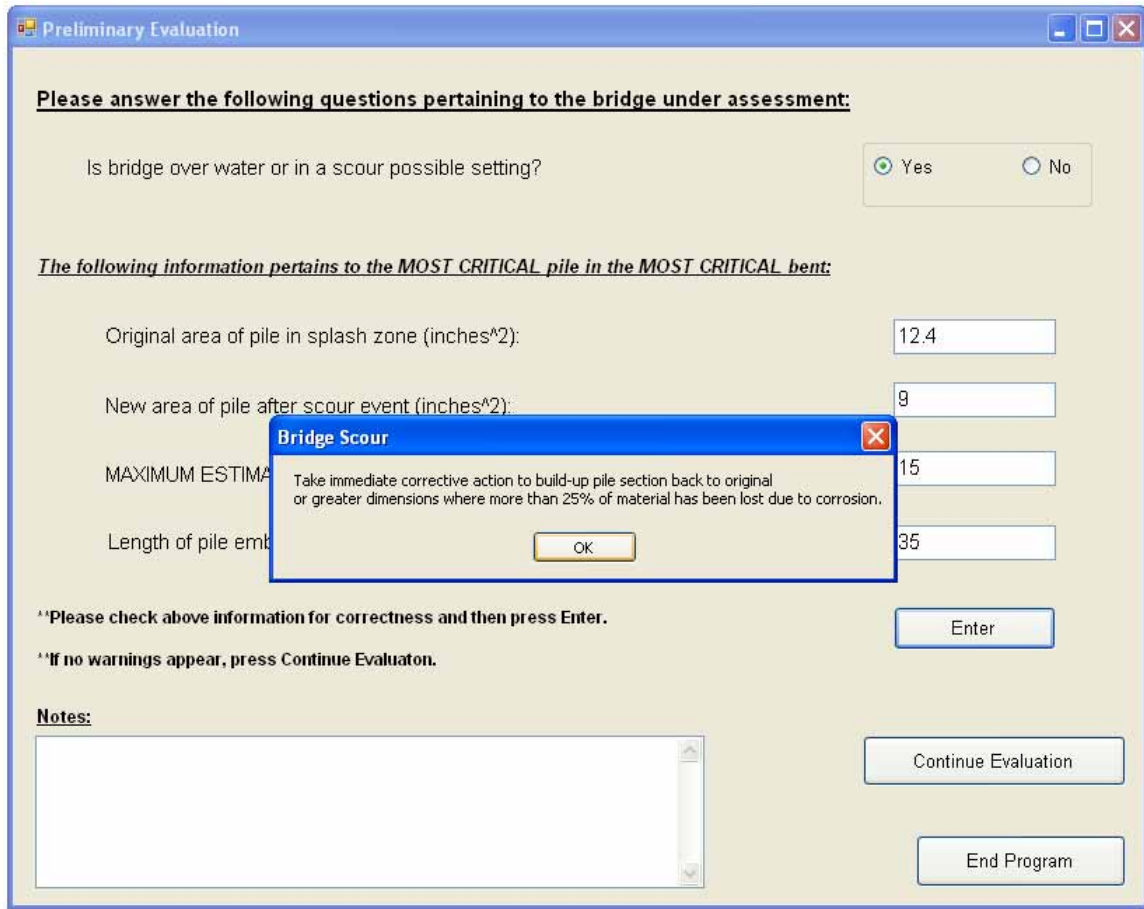
Figure 6.5 Warning that Appears in the Preliminary Evaluation Window when Significant Corrosive Deterioration is Detected.

Once all the requested information has been entered and no warnings appear, such as shown in Figure 6.6, the "Continue Evaluation" button may then be pressed to move on to the next window.

Figure 6.6. Successful Entry of All Preliminary Window Input Boxes.

6.3.2.3   Determination of $P_{max\ applied}$ for Pile and Bent

The third window is the window in which information is gathered for determining

the maximum applied axial loads for the pile and bent. Figure 6.7 illustrates what the

window looks like when it first appears.

Figure 6.7 Determining Pmax_Applied for Pile and Bent Window for the Automated Screening Tool

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The user must first select what type of superstructure support system is applicable to the bridge under investigation. Then, there are two ways of determining the maximum applied pile and bent axial loads to be used for later calculations. These load values may either be entered directly by the user, or they can be determined from the given bridge/bent geometry and superstructure information, as described in Chapter 3. For the first option, the user can click on the radio-button next to "Enter Pmax values for Pile and Bent." Once that option is chosen, the load values may be entered directly into the corresponding textboxes near the top of the window, and the textboxes in the bottom section are "grayed out" and are unavailable for input, so that no conflicting duplicate information can be given. The user should press "Enter" at the bottom of the window once the values are entered. An illustration of this option is shown in Figure 6.8.

Figure 6.8 Illustration of Entering the Maximum Applied Axial Loads for Pile and Bent Directly Option

If the maximum applied pile and bent axial loads are not already know, they can be calculated based on the bridge/bent geometry and superstructure information provided by the user in the lower section of the window. The radio-button next to "Calculate Pmax values by supplying ALL information below" should be clicked to enable this option. Once this button is clicked, all the textboxes in the lower section of the window are enabled and ready for input, while the textboxes pertaining to direct input of the loads in the top portion of the window are inactivated. After completing all the textboxes with proper values, the user presses "Enter" at the bottom of the window. Figure 6.9 shows a representation of this option.

Figure 6.9 Illustration of "Calculating Pmax Values" Option when Entering All Bridge Superstructure and Geometry Information

Notice that once "Enter" is pressed, for both options, the values for the maximum applied loads for the pile and bent are shown in the boxes marked "Max Applied Load, Pile (kips)" and "Max Applied Load, Bent (kips)," respectively. In general, for the screening tool program, textboxes that are not the color white (i.e., those that resemble the background color), and have blue writing next to them, are output boxes. These are not meant for inputting values, but are for displaying results. The "Max Applied Load, Pile (kips)" value will be used in the kick-out, plunging, and buckling evaluations. The value calculated in the "Max Applied Load, Bent (kips)" textbox, divided by the number of piles in the bent, is used in the pushover evaluation calculations, as mentioned in Chapter 5. To continue to the next evaluation, the user then presses "Continue Evaluation."

6.3.2.4 Kick-Out and Plunging Evaluation

The window used for the kick-out and plunging evaluation is shown below in Figure 6.10. Notice that the last six rows of boxes are the same color as the background, with corresponding blue labels. Once again, these boxes represent output boxes, in which the results of the evaluation will be displayed. The user should not try to write in them. Also, one may notice how the border around the "Max Applied Load, Pile (tons)" label is three-dimensional. This means that the value found in the corresponding textbox, which is usually the background color, is imported from another window. For example, since the maximum applied axial load for a pile, determined in the *Determination P*$_{max\ applied}$*for Pile and Bent* window, will be used in the *Kick-out and Plunging Evaluation* and in the

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Buckling Evaluation calculations, the "Max Applied Load, Pile," value will be shown in each evaluation window using the three-dimensional border. Its appearance in these windows is used to remind the user what axial load has been used in a particular calculation.

Figure 6.10 Kick-Out and Plunging Evaluation Window for Automated Screening Tool

The first question on the form pertains to the kick-out evaluation. If the piles are embedded in more than 3 feet of firm soil after scour has occurred (and therefore "Yes" is

checked), a message appears stating that the pile/bent is safe from kick-out failure, as

illustrated in Figure 6.11.
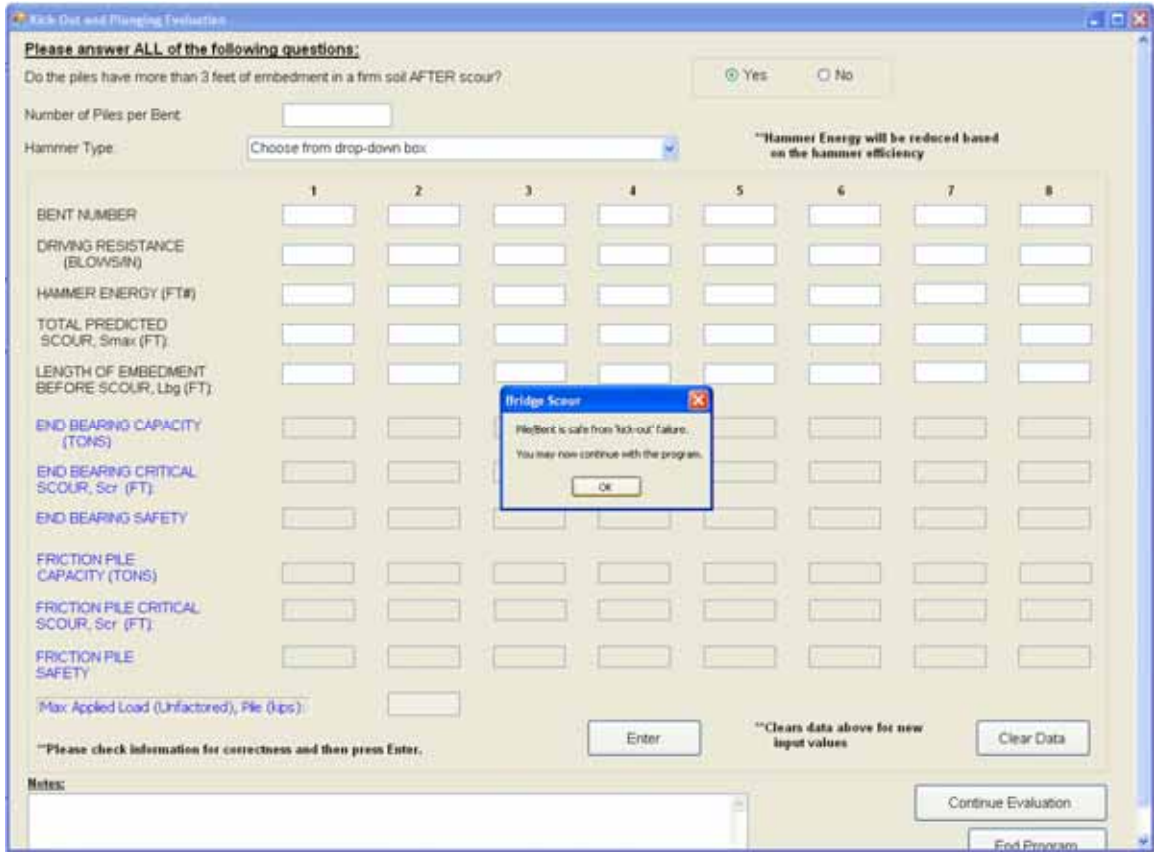
Figure 6.11 Kick-Out and Plunging Evaluation Message when there is More than 3 Feet
of Embedment After Scour.

If the pile does not have more than 3 feet of embedment after scour, and "No" is

therefore checked, then the pile should be checked more closely for other possible

sources of kick-out failure. A message, like the one shown in Figure 6.12, will appear.

Figure 6.12 Kick-Out and Plunging Evaluation Message when there is Less than 3 Feet of Embedment After Scour

The user should continue to answer the remaining questions for the plunging evaluation. Notice that, in order to analyze several bents of interest at once, it is possible to enter information for eight bents in this window. Figure 6.13 shows input for four bridge bents. The user presses "Enter" to evaluate the bents. If the bridge in question has more than eight bents, after the initial evaluation is completed, the "Clear Data" button may be pressed to clear the input values of the first evaluation so additional information can be entered.

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Figure 6.13 Example of Input Values in the Kick-Out and Plunging Evaluation Window

Because it is often difficult to know if a pile is an end bearing or a friction pile,

the program contains calculations for the analyses of each pile type. Based on the input of

the user, the program outputs the end bearing and friction pile capacities (in tons), and a

safety message. This safety message is a result of a comparison between the total

predicted scour, entered in this window, with the critical scour calculated for each pile

type. This calculation is described in Chapter 5. An illustration of these outputs is shown

in Figure 6.14.

Kick Out and Plunging Evaluation

Please answer ALL of the following questions:

Do the piles have more than 3 feet of embedment in a firm soil AFTER scour?   ○ Yes   ○ No

Number of Piles per Bent: 4

Hammer Type: Double acting air/steam (Assumed 50% Efficient)

Hammer Energy will be reduced based on the hammer efficiency

	1	2	3	4	5	6	7	8
BENT NUMBER	1	2	3	4				
DRIVING RESISTANCE (BLOWS/IN)	3	3	3	3				
HAMMER ENERGY (FT#)	24000	20000	20000	24000				
TOTAL PREDICTED SCOUR, Smax (FT)	8.5	12	15	10.5				
LENGTH OF EMBEDMENT BEFORE SCOUR, Lbg (FT)	30	32	25	30				
END BEARING CAPACITY (TONS)	60.29	48.54	39.62	57.24				
END BEARING CRITICAL SCOUR, Scr (FT)	11.82	6.60	5.16	11.82				
END BEARING SAFETY	SAFE	UNSAFE	UNSAFE	SAFE				
FRICTION PILE CAPACITY (TONS)	55.10	42.60	30.11	60.83				
FRICTION PILE CRITICAL SCOUR, Scr (FT)	8.44	4.71	3.68	8.44				
FRICTION PILE SAFETY	UNSAFE	UNSAFE	UNSAFE	UNSAFE				

Max Applied Load (Unfactored), Pile (kips): 53.42

Please check information for correctness and then press Enter.   [Enter]

Clears data above for new input values   [Clear Data]

Notes:

[Continue Evaluation]

[Exit Program]

Figure 6.14 Example of Input and Output Values in the Kick-Out and Plunging
Evaluation Window

If the critical scour value calculated by the Tier-1 ST plunging checks is determined to be less than the total predicted scour, then the ST automatically goes into the Tier-2 screening checks, described in Chapter 5. However, if the maximum applied axial loads for the pile and bent were entered by the user directly in the top portion of the *Determination $P_{max\ applied}$ for Pile and Bent* window, as discussed in Section 6.3.2.3, the ST does not have the bridge bent geometry and superstructure information need to calculate the Tier-2 plunging checks. If this occurs, the following message in Figure 6.15

is seen by the user for every case in which the pile is rendered "UNSAFE" (if the applied

loads were entered directly).
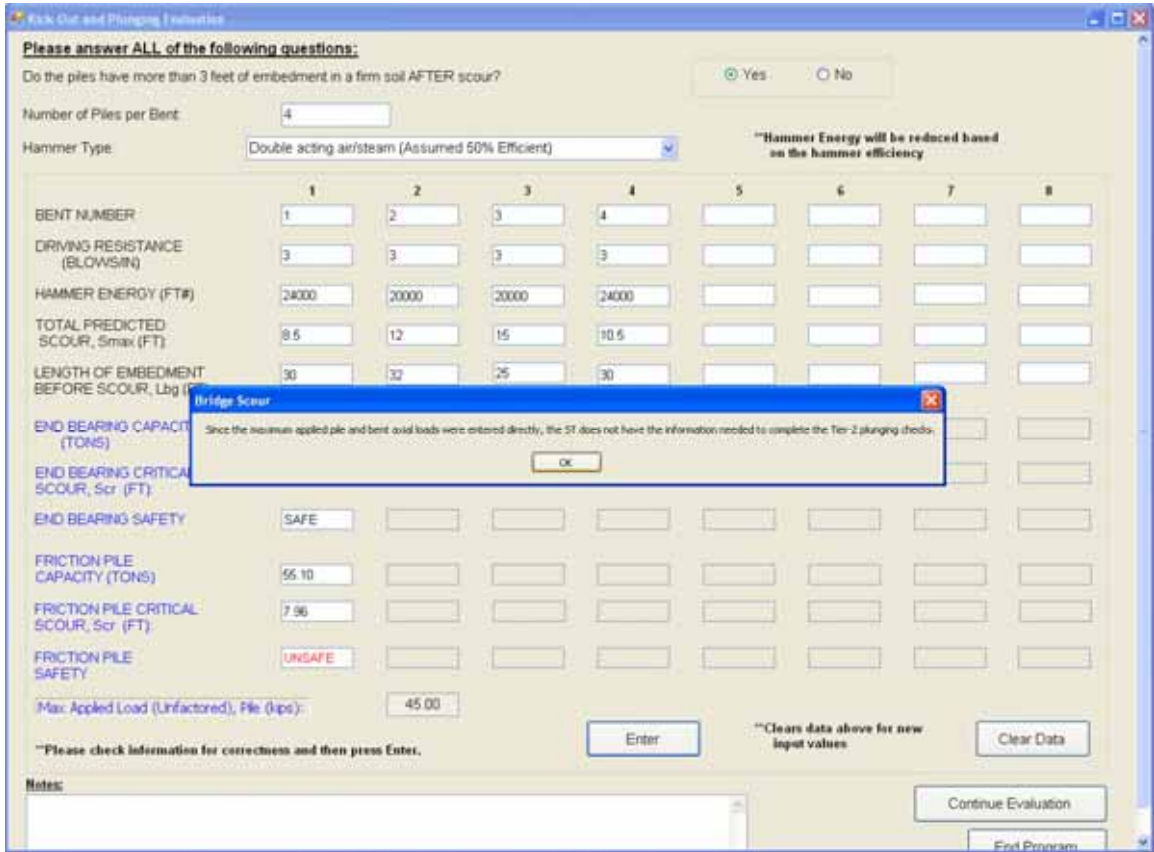
Figure 6.15 Message for Kick-Out and Plunging Window when Not Enough Information
Is Known to Complete the Tier-2 Screening Checks

If the user encounters this message, if desired, he/she may reopen the

Determination $P_{max\ applied}$ for Pile and Bent window and input the required bent/pile

geometry and bridge superstructure information necessary to calculate the applied loads.

An example of the output from a new evaluation in which the maximum applied axial load to the pile was directly entered as 90 kips, is shown below in Figure 6.16.

Figure 6.16 Example of Input and Output Values in the Kick-Out and Plunging Evaluation Window

Note, if "UNSAFE" appears in the safety boxes, the corresponding pile/bent should be checked more closely by the inspecting engineer for the possibility of a plunging failure. The user then presses the "Continue Evaluation" button to move to the next failure evaluation.

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6.3.2.5 Buckling Evaluation

The buckling evaluation is the third failure evaluation of the program. The *Buckling Evaluation* window is illustrated in Figure 6.17.

Figure 6.17 Buckling Evaluation Window for the Automated Screening Tool

The ST was constructed only to evaluate the stability of bridges with steel HP piles. If the bent piles are not steel and there are not 3 or more piles in a row, then the ST cannot be used to check the adequacy of that particular bridge bent. If this is the case and,

therefore, "No" is selected as the answer to the first question, the warning shown in

Figure 6.18 appears. If this is not the case, the user will continue answering the questions

presented in the *Buckling Evaluation*.
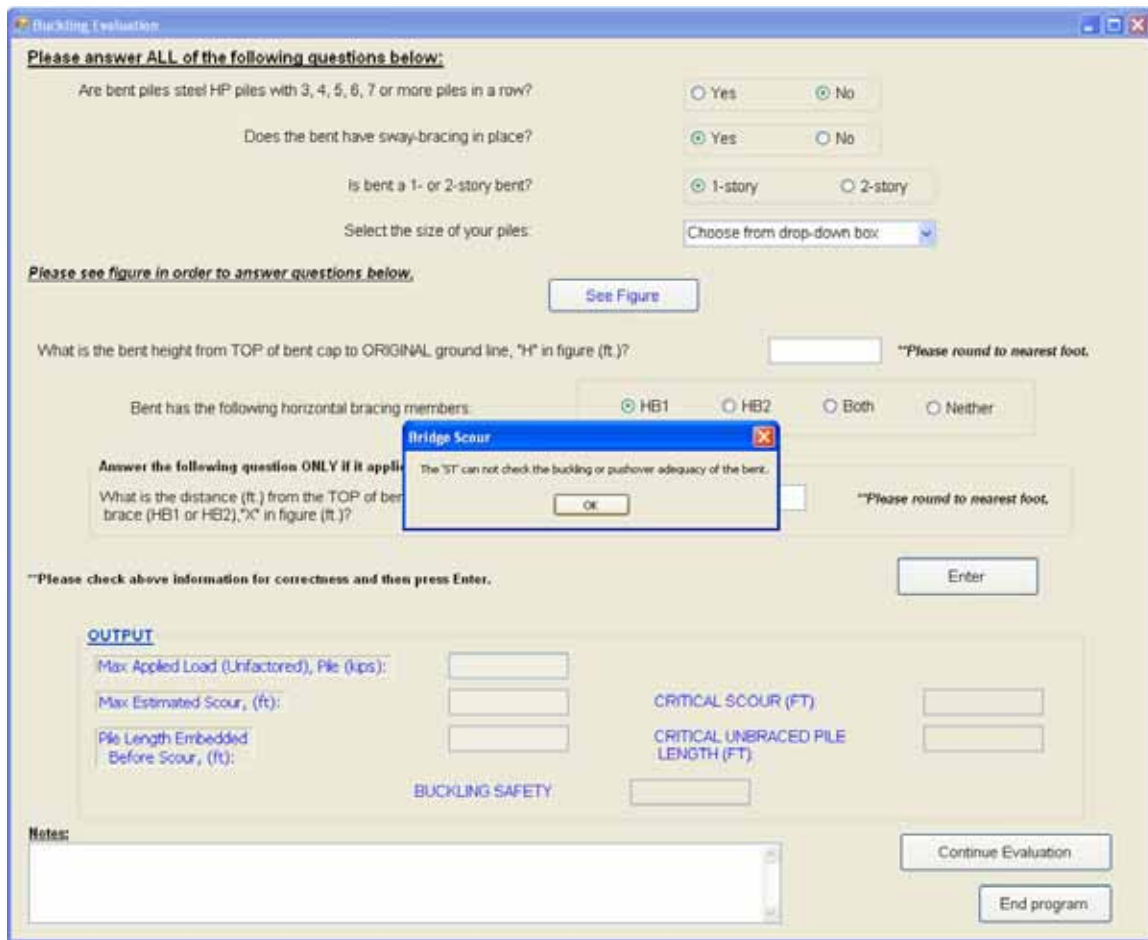
Figure 6.18 Message in Buckling Evaluation when Piles under Investigation are Not Steel
HP Piles with 3, 4, 5, 6, 7 or More Piles in a Row

Many of the questions asked on the *Buckling Evaluation* window may require the

user to refer to a figure. When the "See Figure" button is selected, a picture of a typical

bridge bent is shown in a separate window in order to help the user identify various variables, such as "H", X, and HB1or HB2. The typical bridge bent window is illustrated in Figure 6.19. The user may press "OK" to return to the *Buckling Evaluation* window when finished referring to the figure.
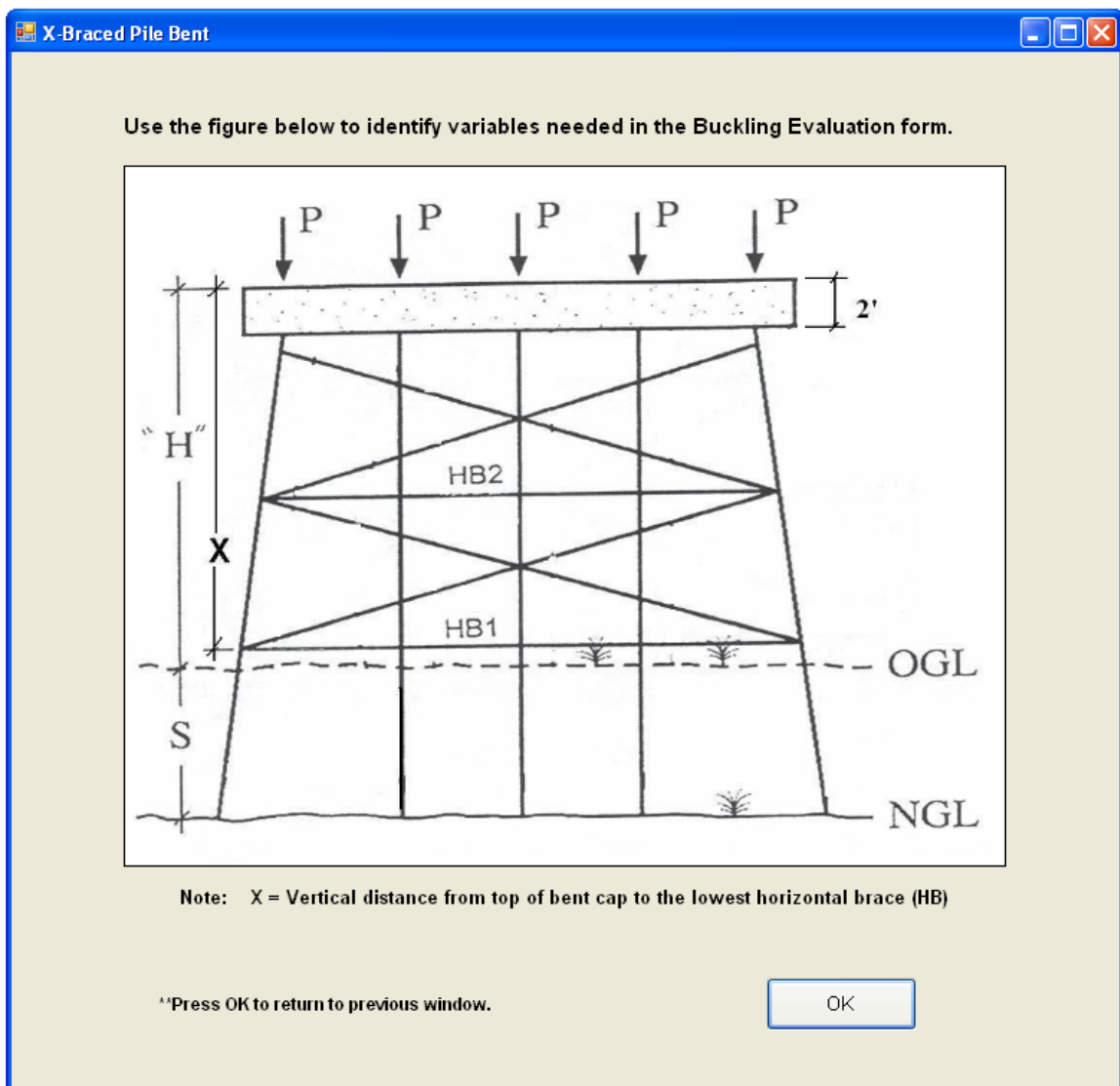
Figure 6.19 X-Braced Pile Bent Figure in Automated Screening Tool

After completing all of the questions on the *Buckling Evaluation* window, the user

presses the "Enter" button to display the results. Figure 6.20 is an example of user input,

and Figure 6.21 is an example of the results that are displayed.

Figure 6.20 Example of User Input into the Buckling Evaluation Window

Figure 6.21 Example of User Input and Output in the Buckling Evaluation Window

As shown in Figure 6.21, the results are displayed in the "OUTPUT" box. The first output box on the left-hand side displays the maximum axial load applied to the pile, as determined in the *Determination $P_{max\ applied}$ for Pile and Bent* window and imported to this window. The other two output boxes on the left correspond with values the user had previously input on the *Preliminary Evaluation* window. The bridge bent pile is considered "SAFE" when the critical scour calculated is greater than the "Max Estimated Scour" value. If this is untrue, the "BUCKLING SAFETY" textbox will read "UNSAFE"

in red type. The user then presses "Continue" to move to the last failure evaluation,

Pushover Evaluation.

6.3.2.6   Pushover Evaluation

The *Pushover Evaluation* window appears as shown in Figure 6.22.

Figure 6.22. Bent Pushover Evaluation Window in Automated Screening Tool

For pushover failure evaluation, the ST was only designed to check bridge bents that have three to six steel HP piles. Bridge bents with more than six steel HP piles in a row, whether braced or unbraced, have been determined by the authors of the screening tool, in collaboration with ALDOT engineers, to have adequate pushover capacity for the maximum estimated scour levels anticipated anywhere in Alabama. Bridge bents with this configuration are therefore deemed safe from pushover failure. If "More than 6 piles" is selected from the drop down menu, a message with the statement above is displayed, as shown in Figure 6.23.
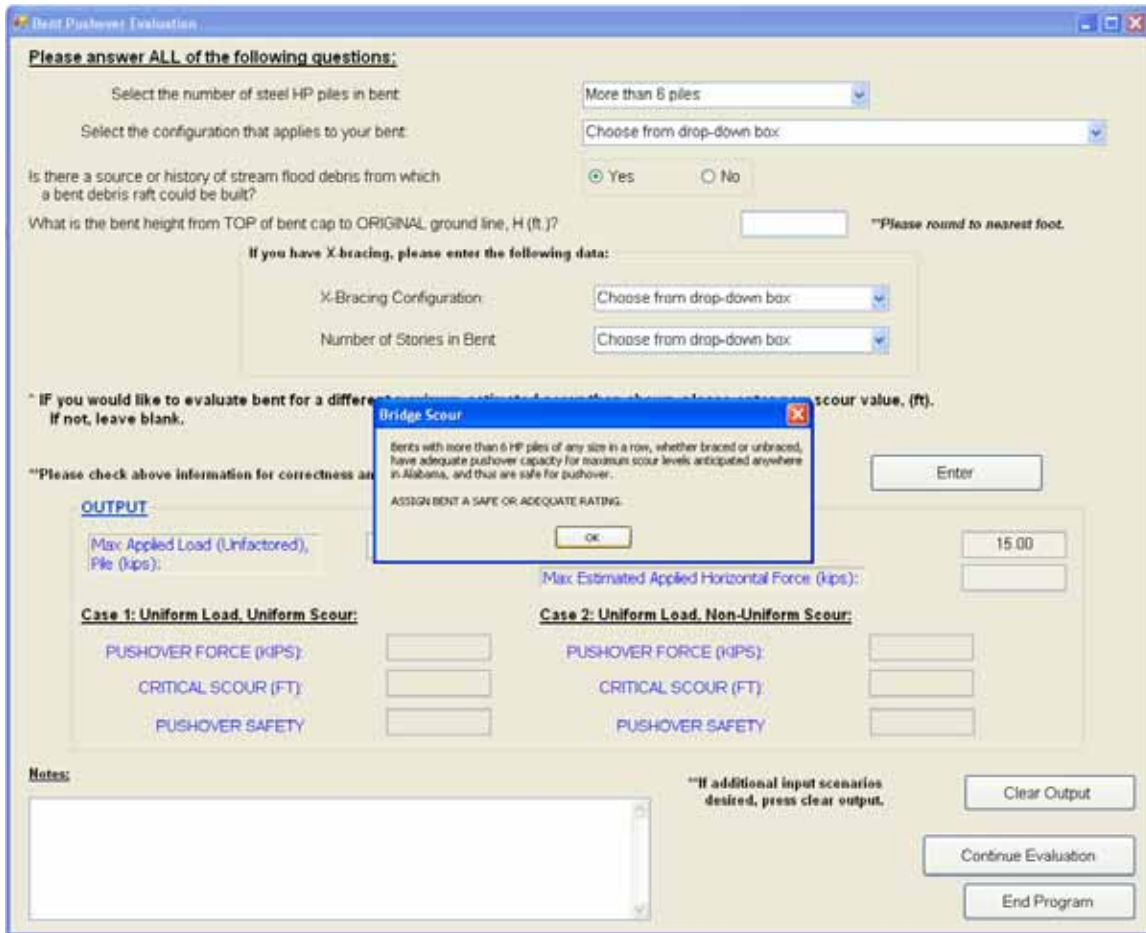
Figure 6.23. Message that Appears when "More than 6 Piles" is Selected From the "Number of Steel HP Piles in Bent" Drop-Box

The user should continue to answer the questions regarding the configuration, location, and geometry of the bridge bent. An example of user input is shown in Figure 6.24. The user then press "Enter" to display the results.

Figure 6.24 Example of User Input into the Bent Pushover Evaluation Window

Notice in Figure 6.24 that if there is a possibility that a debris raft could be formed (and therefore the "Yes" button is clicked in answer to the form's question, "Is there a source or history of stream flood debris from which a bent debris raft could be built?"), the maximum practical estimated horizontal force that will be applied to a bent is 12.15 kips, as described in Chapter 5. If this is the situation, there are two cases that are automatically analyzed in the automated screening tool for pushover failure. Case 1 is the case in which the pushover failure loads calculated using GTSTRUDL are obtained by

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distributing a uniform P-load on the top of the bridge bent (placing one instance of P above each pile) and by modeling a uniform scour distribution at the bottom of the piles. This configuration is considered the worst case scenario, of the two, because the depth of the uniform scour distribution is the total maximum estimated scour. However, in Case 2, there is also a uniformly distributed P-load placed on the top of the bridge bent, but the scour varies from a depth corresponding to the maximum estimated scour at the front (upstream) pile to a depth of 1/3 the maximum estimated scour at the downstream pile. The pushover failure force and critical scour output values determined by the automated screening tool are drawn from the corresponding Access database tables (tables of pushover failure loads calculated using GTSTRUDL); this data can also be found in Appendices A-H of this report. A more in-depth description of this failure mode and it calculations can be found in Chapter 5.

Figure 6.25 below shows the output from a screening tool pushover analysis.

Figure 6.25 Example of User Output in the Bent Pushover Evaluation Window

There is an option on the *Bent Pushover Evaluation* window to change the value of the maximum estimated scour displayed in the output box (which was input previously on the *Preliminary Evaluation* window). To change this estimated scour value, the user types the new value into the white "Max Estimated Scour" box and presses "Enter." Notice in Figure 6.26 below, after doing so, the maximum estimated scour in the output box, as well as the other output values, will change accordingly. If the user chooses not to change the value, he/she should leave the white "Max Estimated Scour" box blank.

Figure 6.26. Example of How to Change the "Max. Estimated Scour" Value in the Bent
Pushover Evaluation Window

The "Clear Output" button can be used to clear the output from the first pushover

evaluation if additional input scenarios are to be checked. For example, if there is no

possibility for a formation of a debris raft, the "Clear Output" button must first be pressed

in order to enable the user to check the "No" button at the top of the window, and for the

correct values to be displayed in the output box. After selecting "No" from the debris raft

formation question, and then pressing "Enter," as can be seen in Figure 6.27, the new

maximum estimated horizontal force is 2.5 kips, as described in Chapter 5 for the case in

which no debris raft can be formed, and the "Pushover Safety" for Case 1 now reads

"SAFE."

Figure 6.27 Example of User Output in the Bent Pushover Evaluation Window when the
Formation of a Debris Raft is Not Possible

Finally, the user should press the "End Program" button to close the automated

screening tool program.

CHAPTER 7: AUTOMATED SCREENING TOOL EXAMPLE PROBLEMS

7.1 General

The screening tool was developed so that the stability of highway bridges in an extreme flood/scour event could be assessed quickly and efficiently by ALDOT personnel. To accomplish this goal, an automated version of the screening tool was created that significantly reduces the amount of work it takes to analyze a bridge bent. In Chapter 6, the setup of the automated ST was discussed, and the step-by-step procedure for completing a bridge pile/bent evaluation using the automated ST, including Tier-1 and Tier-2 checks, was described. Two comprehensive example applications illustrating the procedure by which the automated screening tool checks a bridge bent for the four failure modes discussed in Chapter 5 (kick-out, plunging, buckling, and pushover failures) are presented below. The first example applies to a 3-pile, unbraced bent and the second example illustrates the procedure for a 4-pile, X-braced bent.

7.2 Example Application: 3-Pile, Unbraced Bent

A schematic of a simply supported bridge with a single 34 foot span is presented in Figure 7.1. The bridge contains a 7" thick deck, 3 AASHTO Type II concrete girders with 8' spacing, and Jersey Barriers on each side. The bent considered is a 3-pile bent

with 2.5' x 2.5' cap cross-sectional dimensions. The diaphragms are 9 inches thick. The overhang thickness (not including the deck thickness) is 2 inches, and the overhang width is 5.5 feet on each side. An HS20 design truck loading is assumed.

The three piles are HP_{10x57} piles driven to an embedment length of 30 feet with a single-acting air hammer having a rated energy of 20 ft-kips. The pile was driven to an estimated final driving resistance of 8 blows/inch. An estimate of the maximum possible scour value is 10 feet. The current cross-sectional area of the pile is 16 square inches, and the development of a debris raft is not possible.
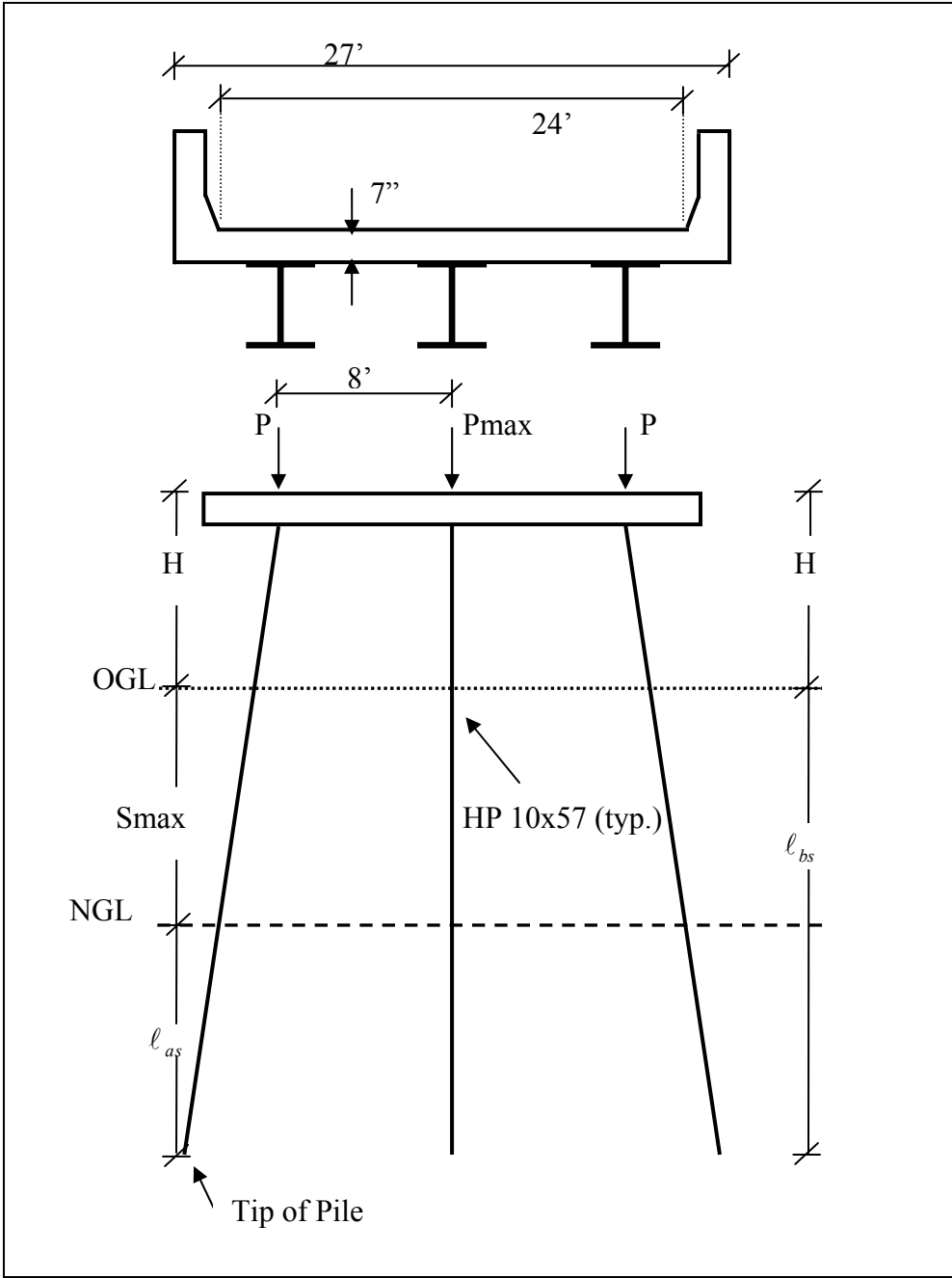
Figure 7.1 Schematic of a 3-Pile Simply Supported, Unbraced Bridge with a Single 34 Foot Span

The automated ST program is begun by pressing "Start" on the *Introduction* window, Figure 7.2.
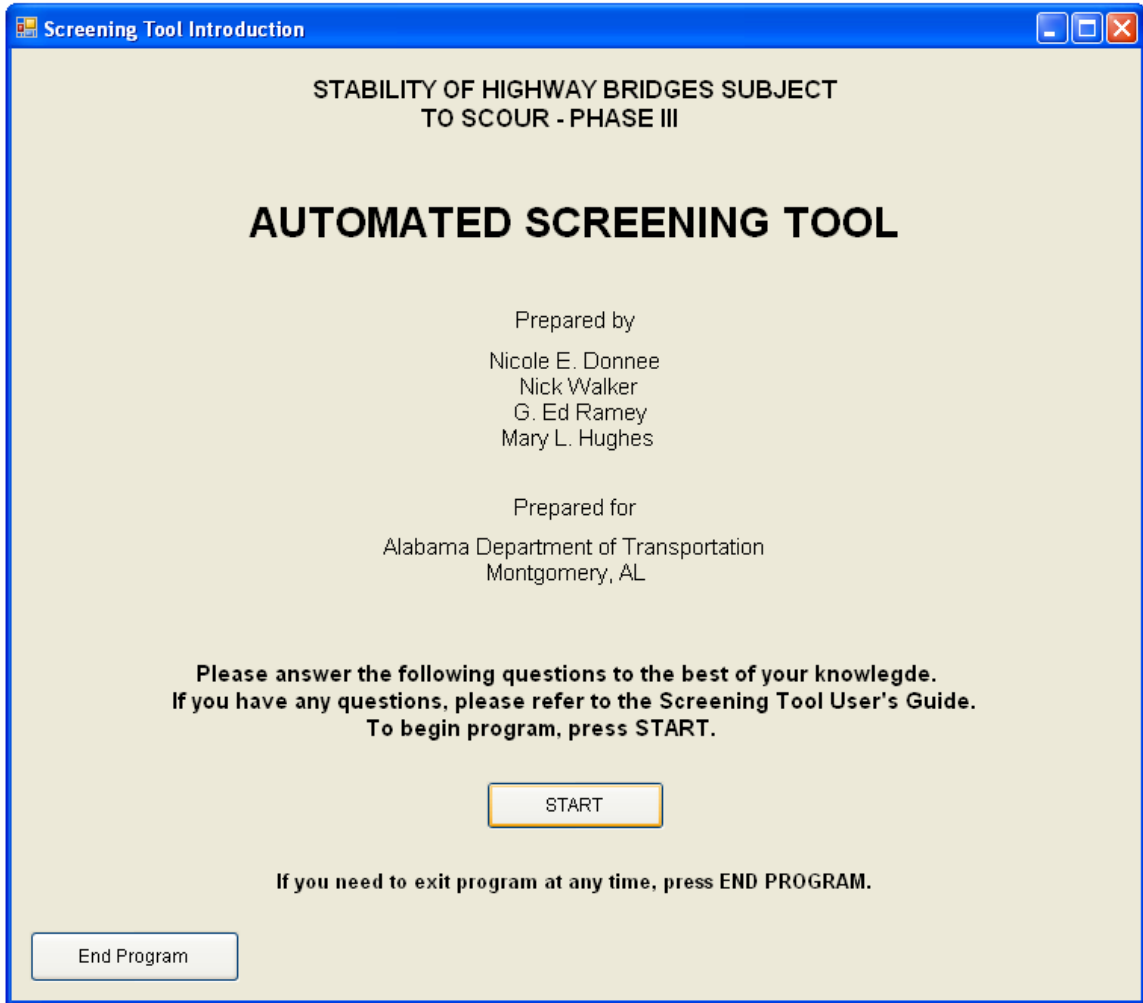
Figure 7.2. Introduction Window for Automated Screening Tool

To complete the *Preliminary Evaluation,* the following information must be entered into the ST, obtained from the problem statement above.

Original Area of an HP_{10x57} pile = 16.8 in²

New Area of the HP_{10x57} pile = 16 in²

S_{max} = 10'

ℓ_{bs} = 30'

After inputting the *Preliminary Evaluation* information, the window should look like the one illustrated in Figure 7.3.

Figure 7.3 Example of User Input into the Preliminary Evaluation Window

The user should recall that, once "Enter" is pressed and no warnings appear, he/she should press "Continue Evaluation" to advance to the next window of the program.

The first question of the *Determining Pmax Applied for Pile and Bent* window pertains to the bridge superstructure support system. It was stated above that the bridge is a SS bridge, therefore select "Simply Supported Bridge" from the drop-box menu.

All the bridge geometry and superstructure information was given in the problem statement. The "Calculate Pmax" radio-button is clicked, and the user begins entering the following information:

Span length = 34 ft.

Bent cap dimensions = 2.5' by 2.5'

Number of girders per span = 3

Girder spacing = 8 ft.

Girder type = Concrete, AASHTO Type II

Deck thickness = 7"

Diaphragm thickness = 9"

Out-to-out deck width = 27'

Curb-to-curb width = 24'

Overhang thickness = 2"

Overhang width = 5.5'

Barrier Rails = Jersey

Design Truck Loading = HS20

The *Determining Pmax Applied for Pile and Bent* window should resemble the one shown in Figure 7.4.

Determining Pmax_Applied for Pile and Bent

What type of superstructure support system is used?

Simply Supported Bridge

○ **Enter Pmax values for Pile and Bent, then press Enter:**

Max Applied Load (Unfactored), Pile (kips):

Max Applied Load (Unfactored), Bent (kips):

◉ **Calculate Pmax values by supplying ALL information below, then press Enter:**

General and Bent Information

Input spanlength, ft.: 34

Input bent cap width, ft.: 2.5

Input bent cap depth, ft.: 2.5

Input cap length, ft., if known (if not known, input "-1"): -1

Girder Information

Input number of girders per span: 3

Input girder spacing, ft.: 8

What type of girders are used?

◉ **Concrete:** Concrete, AASHTO Type II

○ **RCDG Concrete:** Height _____ Width: _____

○ **Steel, W-Shape:** _____ × _____ (ex. 44 X 335)

○ **Steel, Plate Girder:**

Top Flange: _____ × _____ (ex. Width x Thickness)

Web: _____ × _____ (ex. Width x Depth)

Bottom Flange: _____ × _____ (ex. Width x Thickness)

Diaphram and Deck Information

Input deck thickness, in.: 7

Input diaphragm thickness, in.: 9

Input number of traffic lanes: 2

Input out-to-out deck width, ft.: 27

Input curb-to-curb width, ft.: 24

Input overhang thickness (not including deck thickness), in.: _____

Input overhang width (one side only), ft.: _____

Are Jersey barrier rails included? ◉ Yes ○ No

Designed for HS20-44 or HS15-44 loading? ◉ HS-20 ○ HS-15

Enter

** Please check information above for correctness then press Enter.

Maximum Applied Loads for Pile and Bent are as follows:

Max Applied Load (Unfactored), Pile (kips): 109.04

Max Applied Load (Unfactored), Bent (kips): 309.93

** You may now proceed with the evaluation.

Continue Evaluation

Figure 7.4 Example of User Input and Output into the Determining Pmax_Applied for Pile and Bent Window

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The "Continue Evaluation" button is pressed to move to the next evaluation. The following information is entered into the *Kick-Out and Plunging Evaluation* window:

$\ell_{as} = \ell_{bs} - S_{max} = 30' - 10' = 20'$

Number of Piles = 3

Hammer Type = Single-acting air hammer

Driving Resistance = 8 blows/inch

Hammer Energy = 20 ft-kips

$S_{max} = 10'$

$\ell_{bs} = 30'$

Notice that the length of embedment after scour is found to be 20'. The only failure criterion for preventing a "kick-out" failure is that the length of embedment after scour is greater than 3 feet. Thus, the pile/bent is safe from "kick-out" failure for this example. A message box will appear stating that the pile/bent is safe from "kick-out" failure after answering the first question on the *Kick-Out and Plunging Evaluation* window.

When finished entering all above information, the user presses "Enter" and the resulting window should look like the one shown in Figure 7.5.

Figure 7.5 Example of User Input and Output for the Kick-Out and Plunging Evaluation Window

As can be determined from Figure 7.5, comparison of the calculated critical scour and pile capacity values with the total predicted scour and maximum applied pile load values, respectively, leads to a "SAFE" output for both friction and end bearing piles. Therefore, the pile/bent is adequate, indicating that it is safe from a plunging failure. The "Continue Evaluation" button is pressed to continue to the next window.

Using the information provided in the problem statement, along with Figure 7.1, the user then completes the *Buckling Evaluation* window. After pressing "Enter," the output should be the same as the output shown in Figure 7.6.

Figure 7.6 Example of User Input and Output for Buckling Evaluation Window

Based on the output of Figure 7.6, the pile/bent under consideration is deemed to be adequate to withstand a buckling failure. The user presses the "Continue Evaluation" button to move on to the last evaluation window.

The user then selects the answers that are appropriate for this example from the drop-down menus on the *Bent Pushover Evaluation* window. After answering all the questions pertaining to this example, "Enter" is pressed The output box, illustrated in

Figure 7.7, shows the pushover evaluation results for Cases 1 and 2 (uniform and non-uniform scour conditions), detailed in Chapters 5 and 6.

Figure 7.7 Example of User Input and Output for Bent Pushover Evaluation Window

In both cases, it is determined that, for the conditions given in this example, the bent is safe from a pushover failure. To end the program, or to start an evaluation for a different bridge, the "End Program" button is pressed.

7.3   Example Application: 4-Pile, 2-Story, X-Braced Bent

A schematic of a simply supported bridge with a single 34 foot span is presented in Figure X. The estimated axial load for an extreme scour event on a pile is 110 kips and for the bent is 460 kips. The four piles are HP_{12x63} piles driven to an embedment length of 22 feet with a diesel hammer having a rated energy of 20 ft-kips. The pile was driven to an estimated final driving resistance of 6 blows/inch. An estimate of the maximum possible scour value for the bridge site is 12 feet. The current cross-sectional area of the pile is 18 square inches, and the development of a debris raft is possible.
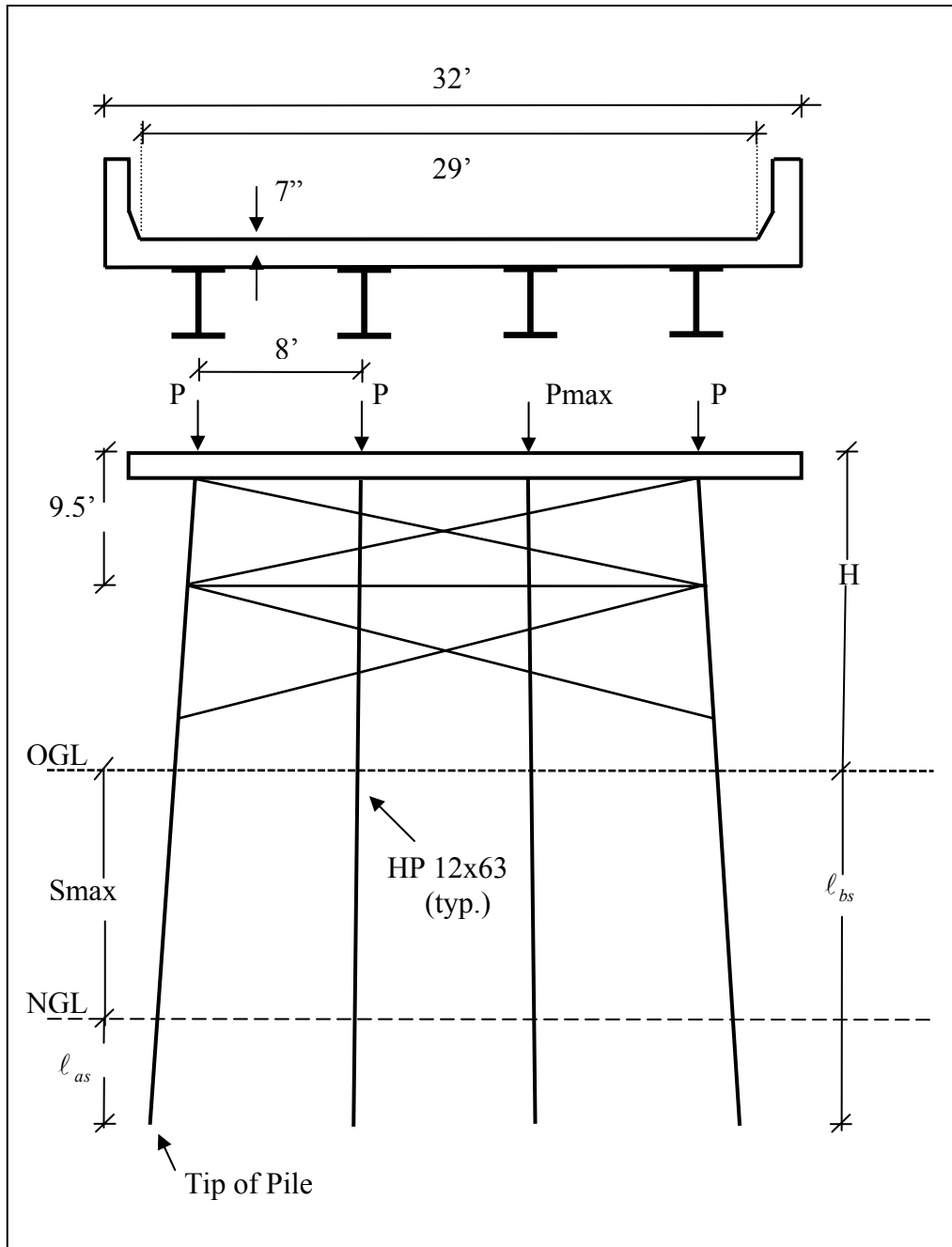
Figure 7.8 Schematic of a 4-Pile Simply Supported, X-Braced Bridge with a Single 34 Foot Span

The automated ST program is begun by pressing "Start" on the *Introduction* window.
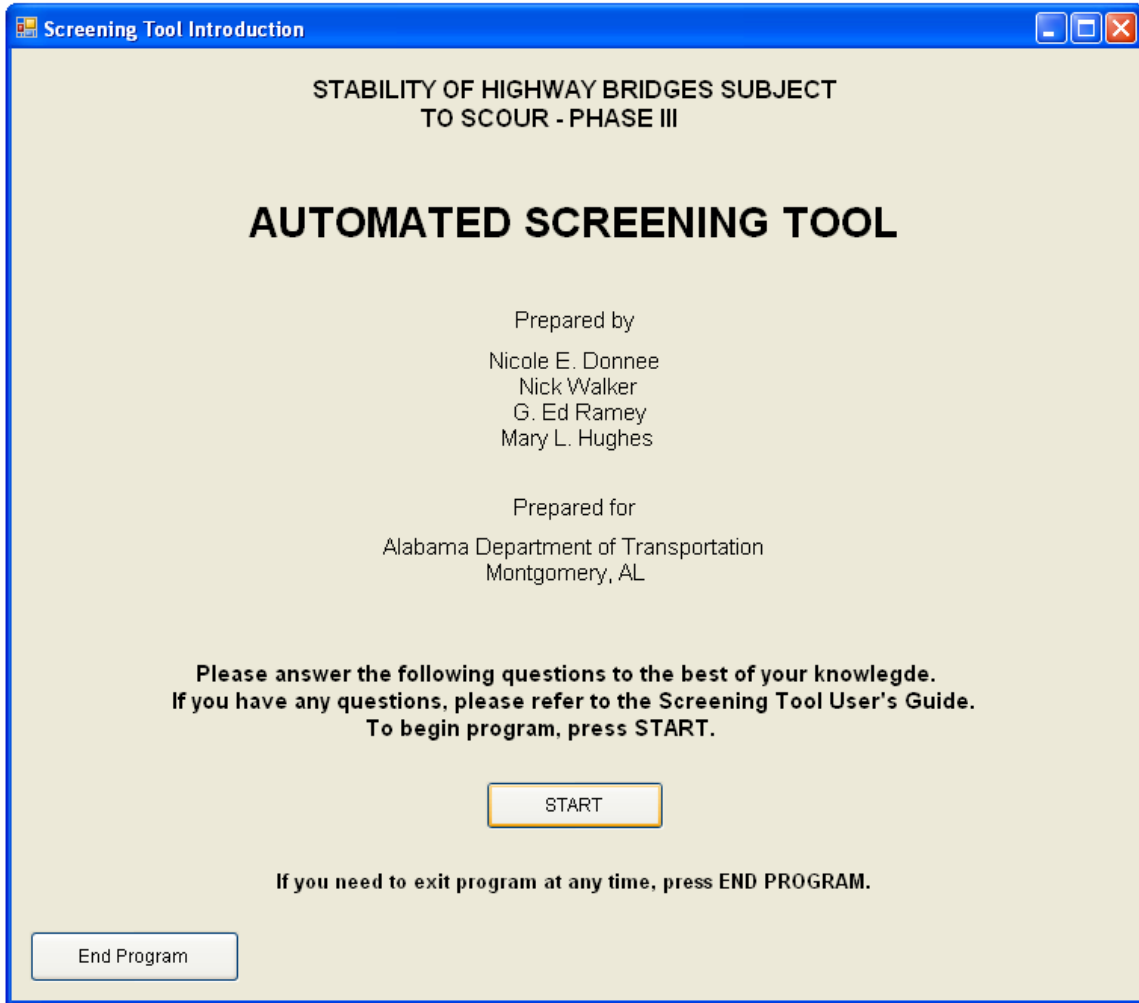
Figure 7.9 Introduction Window for Automated Screening Tool

To complete the *Preliminary Evaluation*, the following information must be entered into the ST, obtained from the problem statement above:

Original Area of the HP_{12x63} pile = 18.4 in²

New Area of the HP_{12x63} pile = 18.0 in²

S_{max} = 10'

ℓ_{bs} = 30'

After inputting the *Preliminary Evaluation* information, the window should look like the one illustrated in Figure 7.10.

Figure 7.10 Example of User Input into the Preliminary Evaluation Window

Recall that, once "Enter" is pressed and no warnings appear, the user should press "Continue Evaluation" to advance to the next window of the program.

Once the *Determining Pmax Applied for Pile and Bent* window appears, the user answers the question pertaining to the bridge superstructure support system. It was stated above that the bridge is a SS bridge, therefore the "Simply Supported Bridge" option is selected from the drop-box menu.

In this example, the estimated axial loads applied to the pile and bent were given as 110 kips and 460 kips, respectively. Since these values were given directly, the user can click on the "Enter Pmax values" radio-button and then fill in the textboxes accordingly. The *Determining Pmax Applied for Pile and Bent* window should resemble the example shown in Figure 7.11.

Determining Pmax_Applied for Pile and Bent

What type of superstructure support system is used? [Simply Supported Bridge ▼]

◉ **Enter Pmax values for Pile and Bent, then press Enter:**

Max Applied Load (Unfactored), Pile (kips): [110]

Max Applied Load (Unfactored), Bent (kips): [460]

○ **Calculate Pmax values by supplying ALL information below, then press Enter:**

General and Bent Information

Input spanlength, ft:

Input bent cap width, ft:

Input bent cap depth, ft:

Input cap length, ft, if known (if not known, input "-1"):

Girder Information

Input number of girders per span:

Input girder spacing, ft:

What type of girders are used?

◉ **Concrete:** [Choose a type from the drop-down box ▼]

○ **RCDG Concrete:** Height: Width:

○ **Steel, W-Shape:** [ ] X [ ] (ex. 44 X 335)

○ **Steel, Plate Girder:**

Top Flange: [ ] X [ ] (ex. Width x Thickness)

Web: [ ] X [ ] (ex. Width x Depth)

Bottom Flange: [ ] X [ ] (ex. Width x Thickness)

Diaphragm and Deck Information

Input deck thickness, in:

Input diaphragm thickness, in:

Input number of traffic lanes:

Input out-to-out deck width, ft:

Input curb-to-curb width, ft:

Input overhang thickness (not including deck thickness), in:

Input overhang width (one side only), ft:

Are Jersey barrier rails included?   ◉ Yes   ○ No

Designed for HS20-44 or HS15-44 loading?   ◉ HS-20   ○ HS-15

[Enter]

** Please check information above for correctness then press Enter.

Maximum Applied Loads for Pile and Bent are as follows:

Max Applied Load (Unfactored), Pile (kips): [110.00]

Max Applied Load (Unfactored), Bent (kips): [460.00]

[Continue Evaluation]

** You may now proceed with the evaluation.

Figure 7.11 Example of User Input and Output into the Determining Pmax_Applied for Pile and Bent Window

The "Continue Evaluation" button is pressed to move to the next window. The following information is entered into the *Kick-Out and Plunging Evaluation* window:

$\ell_{as} = \ell_{bs} - S_{max} = 22' - 12' = 10'$

Number of Piles = 4

Hammer Type = Diesel hammer

Driving Resistance = 6 blows/inch

Hammer Energy = 20 ft-kips

$S_{max} = 12'$

$\ell_{bs} = 22'$

Notice that the length of embedment after scour is found to be 10'. Again, the only failure criterion for preventing a "kick-out" failure is that the length of embedment after scour is greater than 3 feet. Thus, the pile/bent is safe from "kick-out" failure for this example. A message box will appear stating that the pile/bent is safe from "kick-out" failure after answering the first question on the *Kick-Out and Plunging Evaluation* window.

When finished entering all above information, the user presses "Enter" and the resulting window should look like the one shown in Figure 7.12.
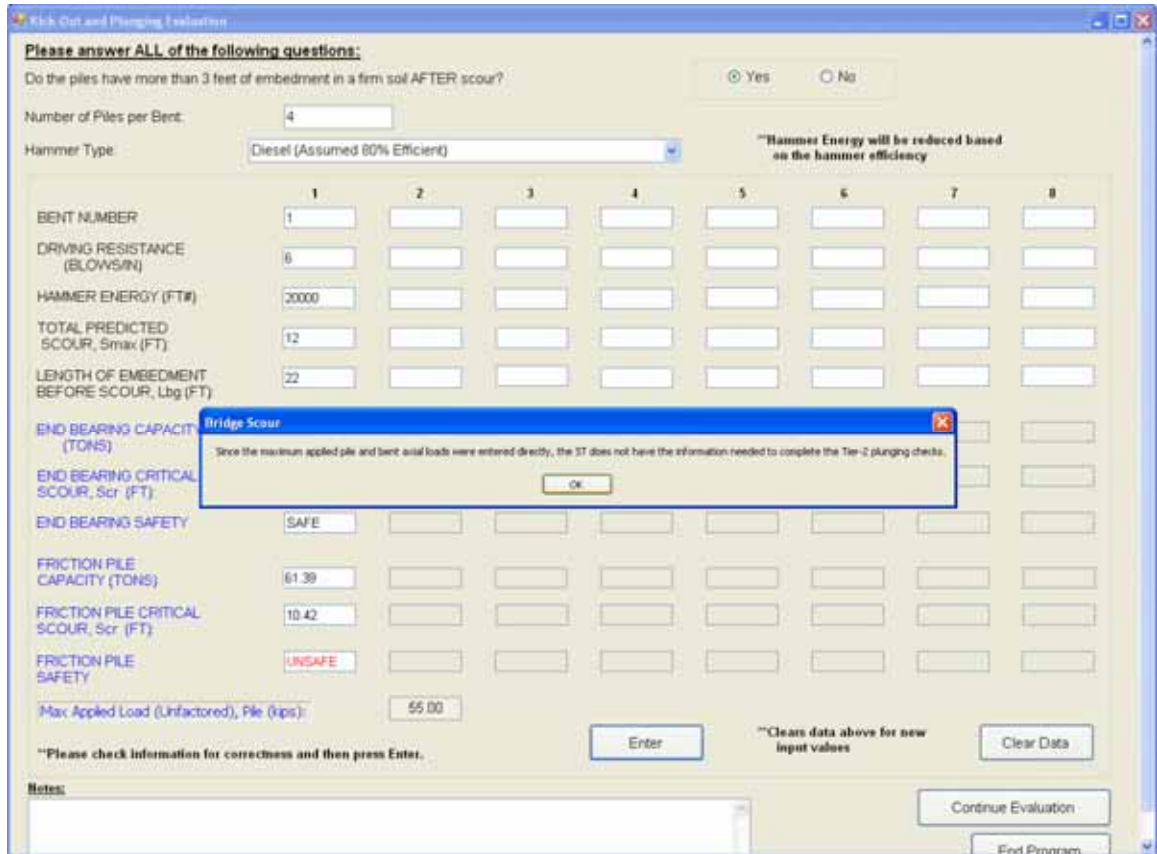
Figure 7.12 Kick-Out and Plunging Evaluation Warning as a Result of Insufficient Information to Proceed with Tier-2 ST Checks

The user should recall that if the maximum applied loads are entered directly, and the bent piles do not pass the Tier-1 screenings, the ST does not have the bridge superstructure and bent geometry information needed to complete the Tier-2 screenings. Thus, a message like the one seen in Figure 7.12 will appear each time this condition arises.

Once the user presses "OK" the final kick-out results for this example are shown in Figure 7.13.

Figure 7.13 Example of User Input and Output for the Kick-Out and Plunging Evaluation
Window

As can be determined from Figure 7.13, comparison of the calculated critical

scour and pile capacity values with the total predicted scour and maximum applied pile

load values, respectively, leads to a "SAFE" output for end bearing piles and an

"UNSAFE" output for the friction piles. Therefore, the pile/bent is adequate, and safe,

from a plunging failure only if the piles are considered to be end bearing piles. The

"Continue Evaluation" button is pressed to continue to the next window.

Using the information provided in the problem statement, along with Figure 7.8, the user then completes the *Buckling Evaluation* window. After pressing "Enter," the output should be the same as the output shown in Figure 7.14.

Figure 7.14 Example of User Input and Output in the Buckling Evaluation Window

Based on the output of Figure 7.14, the pile/bent under consideration is deemed to be adequate to withstand a buckling failure. The user presses the "Continue Evaluation" button to move on to the last evaluation window.

The user then selects the answers that are appropriate for this example from the drop-down menus on the *Bent Pushover Evaluation* window. After answering all the questions pertaining to this example, "Enter" is pressed. The output box, illustrated in Figure 7.15, shows the pushover evaluation results for Cases 1 and 2 (uniform and non-uniform scour conditions), detailed in Chapters 5 and 6.

Figure 7.15 Example of User Input and Output in the Bent Pushover Evaluation Window

In both cases, it is determined that, for the conditions given in this example, the bent is safe from a pushover failure. To end the program, or to start an evaluation for a different bridge, the "End Program" button is pressed.

CHAPTER 8:   CONCLUSIONS AND RECOMMENDATONS

Most of Alabama's bridges span shallow bodies of water where significant scour events may likely occur. The bridge bents typically consist of 3, 4, 5, or 6 steel HP piles in a row, with the two end piles battered. When scour events do occur, some of the streambed material is washed away by the channel flow. If the scour becomes excessive at the bent piles, the stability of these piles, and of the bridge itself, is questionable. A "screening tool" (ST) was developed to quickly and efficiently check the adequacy of the bent piles in question after scour events have occurred. Phases I and II of the development project have been completed, and the objectives of the Phase III portion were to refine, simplify, and expand the scope of application of the screening tool, and to automate its use via a user-friendly software application. The primary focus of the work reported herein was the automation of the screening tool.

8.1   Conclusions

The automated version of the ST was completed using Visual Studio 2005. Five forms were created with which the user can input bridge/bent variables, such as geometry, size, and geotechnical information specific to the particular bridge and failure

mode in question. Using this input, the automated ST checks for possible HP pile/bent failure for the following four failure modes:

- Pile "kick-out" failure due to insufficient pile embedment after scour.

- Pile plunging failure due to insufficient soil end bearing and side friction capacity.

- Pile buckling failure due to applied axial load.

- Pile pushover failure due to the combination of axial load and floodwater lateral loading.

Calculations applicable to checks for each of these failure modes are presented in detail in Chapter 5. During the execution of the screening tool program, if the bridge bent under investigation does not satisfy the first set of safety criteria (Tier-1 screening) for each failure mode, it is subsequently checked more closely by a Tier-2 screening process. Based on the results of the Tier-2 screening, the bridge bent is either deemed safe and structurally adequate, or unsafe. If it is determined to be unsafe, the output of the screening tool recommends that ALDOT engineers check the bridge bent more closely for conditions that may lead to a possible failure.

ALDOT personnel who intend to use the ST should attend a training seminar on the procedures for using the ST properly. All personnel should have an understanding of the principles underlying the ST program, and should be familiar with the calculations and assumptions used in the screening tool to check for possible HP pile/bent failure.

8.2　Recommendations

Based on the experience gained by the programmer of the automated screening tool, and on conversations with the ALDOT engineers that will be the primary users, the following improvements and additions to the screening tool are recommended:

- Create an output page that succinctly displays all the results for a particular run of the screening tool.

- Create an option to save the input information for a particular bent evaluation entered by the user, so that the user can quickly open an existing file, change a few inputs to represent a "what-if" scenario for a particular bent, and run the program again, instead of re-entering all the necessary input information.

- Create an online User's Help Guide.

- Create an option to run another pushover configuration (with, perhaps, another P-load), so two or more configuration outputs can be compared without starting an entirely new evaluation.

- Configure the screening tool to check the upstream bent pile for possible beam-column failure due to debris raft loading.

With the completion of the automated screening tool, ALDOT engineers can now evaluate the stability of Alabama's highway bridges after extreme scour events at a more rapid rate. The automated ST allows for effective and quick checking of bridge bents/piles for the four main causes of bridge scour-related failure, as identified in this report. An additional failure mode, beam-column failure of the up-stream pile, is

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currently being evaluated for inclusion in the ST. Once the evaluation is completed and

the appropriate checks and calculations are developed, the automated ST will allow

inspecting engineers to screen the bridges for this type of failure also.

REFERENCES

AASHTO. 2006. *AASHTO LRFD Bridge Design Specifications: Customary U.S. Units*. 3rd ed. Washington D.C.: American Association of State Highway and Transportation Officials (AASHTO).

AASHTO. 2004. *AASHTO LRFD Bridge Design Specifications: Customary U.S. Units*. 3rd ed. Washington D.C.: American Association of State Highway and Transportation Officials (AASHTO).

AASHTO. 2002. *Standard Specifications for Highway Bridges*. 17th ed. Washington D.C.: American Association of State Highway and Transportation Officials (AASHTO).

AISC Manual of Steel Construction. 2001. *Load and Resistance Factor Design*. 3rd ed. American Institute of Steel Construction, Inc (AISC).

Chajes, A. 1974. *Principles of Structural Stability Theory*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

Georgia Tech Research Corporation. 2002. GTSTRUDL reference manual, v 3. Atlanta, Georgia.

Geschwindner, L.F. 1995. A Practical Approach to the "Leaning" Column. *Engineering Journal* 32, 2nd Quarter, no. 2: 63-72.

Halvorson, M. 2006. Microsoft Visual Basic 2005: Step by Step. 2005 ed. Microsoft

Press. Redmond, Washington.

Hibbeler, R.C. 2002. *Structural Analysis*. 5th ed. Prentice Hall. Upper Saddle River, New

Jersey.

McCarthy, D.F. 2007. Essentials of Soil Mechanics and Foundations: Basic Geotechnics.

7th ed. Pearson Prentice Hall. Upper Saddle River, New Jersey.

Ramey, G.E. and D.A. Brown. 2004. "Stability of Highway Bridges Subject to Scour –

Phase I." *Alabama Department of Transportation Project No. 930-585, Final Report.*

Highway Research Center, Auburn University, Auburn, Alabama.

Ramey, G.E., D.A. Brown, D. Hughes, J. Daniels, and L. Agnew. 2006. "Stability of

Highway Bridges Subject to Scour – Phase II." *Alabama Department of*

Transportation Project No. 930-608, Final Report. Highway Research Center,

Auburn University, Auburn, Alabama.

Ramey, G.E, D.A. Brown, M.L. Hughes, D. Hughes, and J. Daniels. 2007. Screening

Tool to Access Adequacy of Bridge Pile Bents during Extreme Flood/Scour Events.

ASCE: Practice Periodical on Structural Design and Construction 12, no. 2:109-121.

Ramey, G.E., D.A. Brown, M.L. Hughes, N. Donnee, and N. Walker. 2008. "Stability of

Highway Bridges Subject to Scour – Phase III." *Alabama Department of*

Transportation Project No. 930-674, to be published. Highway Research Center,

Auburn University, Auburn, Alabama.

Ramey, G.E. and A.P. Hudgins. 1975. "Modification of Pile Capacity and Length

    Prediction Equations Based on Historical Alabama Pile Test Data." *Alabama*

    Department of Transportation Project No. 75

Tonias, D.E. and J.J. Zhao. 2007. *Bridge Engineering: Design, Rehabilitation, and*

    Maintenance of Modern Highway Bridges. 2nd ed. McGraw-Hill. New York, New

    York.

Yura, J. A. and T. A. Helwig. 1997. "Bracing for Stability." *Notes from Seminar*

    Sponsored by Stability Research Council and AISC.

Yura, J.A. 2006. "Five Useful Stability Concepts." *Proceedings of the 2006 Structural*

    Stability Research Council Annual Stability Conference. San Antonio, Texas.

APPENDIX A: PUSHOVER TABLES FOR UNBRACED AND X-BRACED

STEEL HP$_{10x42}$ BENT PILES FOR SYMMETRIC DISTRIBUTION OF

VARYING VALUES OF P-LOAD

Table A.1 Pushover Load, F_t, for Unbraced 3-Pile and 4-Pile Bridge Bents with HP$_{10x42}$ Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4 for Varying Values of P-Load, H, and S.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	10	0	21.6	20.6	19.6	20.0	18.8	17.6
		5	12.9	11.5	10.1	8.9	7.3	5.6
		10	8.2	6.3	4.3	2.3	unstable	unstable
		15	4.9	2.3	unstable	unstable	unstable	unstable
		20	2.0	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
	13	0	15.6	14.4	13.2	12.4	11.0	9.5
		5	9.8	8.2	6.4	4.7	2.8	unstable
		10	6.1	3.9	1.5	unstable	unstable	unstable
		15	3.1	unstable	unstable	unstable	unstable	unstable
		20	unstable	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
4	10	0	38.3	35.7	33.5	34.8	32.3	29.9
		5	31.8	28.9	26.1	24.8	21.8	18.9
		10	30.8	27.2	24.3	22.0	18.5	15.1
		15	24.8	21.6	18.2	14.8	11.6	8.4
		20	19.0	15.5	12.3	9.0	6.3	3.8
		25	13.6	10.5	7.8	5.3	3.3	1.8
	13	0	33.6	30.6	27.9	27.5	24.8	22.0
		5	30.7	27.6	24.6	22.7	19.3	16.0
		10	27.8	23.8	20.8	17.8	14.3	10.9
		15	21.3	17.8	14.5	11.1	8.0	5.3
		20	15.6	12.3	9.3	6.5	4.1	2.5
		25	11.0	8.3	6.0	4.0	2.5	unstable

Table A.2 Pushover Load, F_t, for Single Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP_{10x42} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4 for Symmetric Distribution of Varying Values of P-Load, H, and S.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	13	0	46.7	44.5	42.5	41.5	39.7	38.3
		5	19.1	17.1	15.5	14.4	12.8	11.2
		10	10.6	8.5	6.3	4.0	2.8	unstable
		15	5.9	3.3	unstable	unstable	unstable	unstable
		20	unstable	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
	17	0	44.9	42.9	41.2	39.9	38.3	36.8
		5	17.8	15.9	13.9	12.6	10.6	8.7
		10	9.6	7.1	4.8	2.9	1.0	unstable
		15	4.9	2.0	unstable	unstable	unstable	unstable
		20	unstable	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
4	13	0	62.8	58.6	55.1	51.2	48.2	45.3
		5	35.1	31.4	28.1	24.7	22.0	19.3
		10	28.7	24.6	21.0	17.3	14.0	10.9
		15	25.9	21.7	17.4	13.1	9.4	5.8
		20	19.7	15.4	11.3	8.0	5.0	1.8
		25	13.3	10.0	7.0	4.1	2.0	unstable
	17	0	58.4	53.7	49.8	45.5	42.6	40.2
		5	32.7	28.7	25.1	21.4	18.3	15.5
		10	27.0	22.4	18.2	14.3	10.7	7.4
		15	23.3	18.6	14.0	9.7	5.8	2.1
		20	17.0	12.4	9.0	5.0	2.1	unstable
		25	11.0	8.0	5.0	3.0	unstable	unstable

Table A.3 Pushover Load, F_t, for 2- Story X-Braced 3-Pile and 4-Pile Bridge Bents
with HP_{10x42} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4
for Symmetric Distribution of Varying Values of P-Load, H, and S.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	21	0	51.3	48.9	46.7	44.7	43.2	41.3
		5	20.6	18.4	16.5	14.5	12.3	10.4
		10	11.1	8.6	6.1	3.8	unstable	unstable
		15	5.8	2.8	unstable	unstable	unstable	unstable
		20	unstable	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
	25	0	49.1	46.9	45.0	43.2	41.3	39.1
		5	19.1	16.8	14.5	12.1	9.8	7.6
		10	9.9	7.0	4.3	unstable	unstable	unstable
		15	4.6	unstable	unstable	unstable	unstable	unstable
		20	unstable	unstable	unstable	unstable	unstable	unstable
		25	unstable	unstable	unstable	unstable	unstable	unstable
4	21	0	63.3	58.9	55.1	51.6	48.5	45.6
		5	32.8	28.9	25.5	22.3	19.6	16.9
		10	25.0	20.6	16.8	13.2	9.7	6.4
		15	21.7	16.7	12.2	8.0	4.0	unstable
		20	16.8	12.0	7.4	4.0	unstable	unstable
		25	11.3	8.0	4.1	unstable	unstable	unstable
	25	0	58.3	53.5	49.7	46.6	44.1	41.7
		5	30.1	26.1	22.3	18.9	15.8	12.8
		10	23.2	18.1	13.9	10.0	6.4	2.8
		15	19.2	14.1	9.3	4.9	unstable	unstable
		20	14.4	9.4	5.0	unstable	unstable	unstable
		25	10.0	6.0	3.0	unstable	unstable	unstable

APPENDIX B: PUSHOVER TABLES FOR UNBRACED AND X-BRACED STEEL HP$_{12x53}$ BENT PILES FOR SYMMETRIC DISTRIBUTION OF VARYING VALUES OF P-LOAD

Table B.1 Pushover Load, F_t, for Unbraced 3-Pile and 4-Pile Bridge Bents with
HP_{12x53} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4
for Varying Values of P-Load, H, and S.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	10	0	33.8	32.8	32.0	34.2	33.1	32.0
		5	21.6	20.4	19.3	18.9	17.6	16.3
		10	15.4	14.0	12.5	11.2	9.6	7.8
		15	11.5	9.7	7.7	5.8	3.6	1.4
		20	8.5	6.3	3.8	1.1	unstable	unstable
		25	6.1	3.2	unstable	unstable	unstable	unstable
	13	0	25.3	24.3	23.3	23.5	22.2	21.1
		5	17.5	16.2	14.9	13.9	12.4	10.9
		10	12.9	11.2	9.5	7.8	5.9	3.8
		15	9.6	7.5	5.3	2.9	unstable	unstable
		20	7.0	4.4	unstable	unstable	unstable	unstable
		25	4.7	unstable	unstable	unstable	unstable	unstable
4	10	0	56.6	53.4	50.7	54.4	52.3	50.1
		5	45.4	41.6	38.8	38.7	36.2	33.7
		10	41.1	37.8	35.0	34.0	31.0	27.8
		15	40.7	37.4	33.8	31.4	28.1	24.4
		20	33.3	29.6	26.6	23.4	19.9	16.5
		25	27.3	23.8	20.4	17.0	13.6	10.5
	13	0	47.3	44.3	41.7	42.8	40.5	38.1
		5	42.4	39.0	36.1	35.3	32.4	29.6
		10	41.0	37.4	35.0	33.1	29.6	26.3
		15	36.7	32.6	29.0	26.9	23.1	19.5
		20	29.2	26.2	22.7	19.3	16.0	12.8
		25	23.5	20.3	16.8	13.5	10.5	7.8

Table B.2 Pushover Load, F_t, for Single Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP_{12x53} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4 for Symmetric Distribution of Varying Values of P-Load, H, and S.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	13	0	67.7	65.9	64.0	64.8	63.1	61.4
		5	32.0	30.0	28.0	26.9	25.2	23.8
		10	19.8	17.7	15.9	14.5	12.8	11.1
		15	13.5	11.3	9.1	7.5	5.3	3.1
		20	9.5	6.9	4.3	2.1	unstable	unstable
		25	6.4	unstable	unstable	unstable	unstable	unstable
	17	0	66.8	64.9	62.9	61.3	59.2	57.2
		5	30.6	28.4	26.5	25.1	23.5	22.0
		10	18.8	16.6	14.6	13.0	11.1	9.1
		15	12.7	10.2	7.8	5.8	3.4	1.1
		20	8.6	5.8	2.9	unstable	unstable	unstable
		25	5.5	2.2	unstable	unstable	unstable	unstable
4	13	0	91.9	88.3	84.5	80.0	76.7	73.7
		5	53.3	49.3	45.7	41.9	38.8	35.9
		10	42.5	38.4	34.8	31.0	27.8	24.7
		15	38.9	34.9	30.9	26.6	22.9	19.4
		20	35.4	30.8	26.7	22.2	18.2	14.4
		25	28.2	24.1	19.9	15.6	12.0	9.0
	17	0	85.1	82.3	79.4	76.3	72.7	69.0
		5	50.9	46.4	42.4	38.2	34.9	31.8
		10	40.8	36.4	32.3	28.1	24.6	21.3
		15	37.4	32.8	28.1	23.5	19.7	15.9
		20	32.5	27.9	23.3	18.7	14.6	10.7
		25	25.6	21.1	16.6	12.5	9.0	6.0

Table B.3 Pushover Load, F_t, for 2- Story X-Braced 3-Pile and 4-Pile Bridge Bents
with HP_{12x53} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4
for Symmetric Distribution of Varying Values of P-Load, H, and S.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	21	0	76.0	73.8	71.6	69.4	67.1	64.9
		5	34.7	32.5	30.2	28.3	26.6	24.9
		10	21.2	18.9	16.7	14.6	12.4	10.2
		15	14.2	11.6	9.1	6.5	4.0	unstable
		20	9.6	6.6	3.6	unstable	unstable	unstable
		25	6.1	2.6	unstable	unstable	unstable	unstable
	25	0	73.4	71.4	69.3	67.1	64.9	62.6
		5	33.1	30.6	28.5	26.5	24.5	22.5
		10	19.9	17.4	15.1	12.7	10.2	7.8
		15	13.1	10.3	7.4	4.6	unstable	unstable
		20	8.6	5.2	unstable	unstable	unstable	unstable
		25	5.0	unstable	unstable	unstable	unstable	unstable
4	21	0	95.9	92.2	88.0	84.0	80.0	76.2
		5	51.6	47.5	43.8	40.3	37.0	33.9
		10	39.6	35.2	31.3	27.6	24.1	20.8
		15	35.4	30.6	25.8	21.6	17.8	14.1
		20	31.3	26.2	21.4	16.8	12.6	8.6
		25	25.4	20.6	16.1	11.6	7.5	4.0
	25	0	89.6	86.4	83.1	79.7	75.8	71.7
		5	48.8	44.3	40.2	36.3	32.9	29.8
		10	37.6	32.8	28.5	24.4	20.8	17.5
		15	34.0	27.9	22.7	18.5	14.4	10.5
		20	28.8	23.5	18.5	13.8	9.4	5.1
		25	23.1	18.0	13.3	8.8	5.0	unstable

APPENDIX C: PUSHOVER LOAD TABLES FOR UNBRACED AND X-BRACED STEEL HP$_{10X42}$ PILES FOR SYMMETRIC DISTRIBUTION OF VARYING VALUES OF P-LOAD AND FOR VARIABLE SCOUR DISTRIBUTIONS

Table C.1 Pushover Load, F_t, for Unbraced 3-Pile and 4-Pile Bridge Bents with
HP$_{10x42}$ Piles and Reinforced Concrete Bent Cap with I$_{gross}$ = 41,470 in^4
for Varying Values of P-Load, H, and S for Variable Scour Distributions.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	10	0	NN	NN	NN	NN	NN	NN
		5	14.8	13.4	12.0	10.7	9.3	8.0
		10	10.3	8.7	7.2	5.7	4.5	3.3
		15	7.3	5.6	4.3	3.0	unstable	unstable
		20	5.1	3.7	2.3	unstable	unstable	unstable
		25	3.8	2.3	unstable	unstable	unstable	unstable
	13	0	NN	NN	NN	NN	11.0	9.5
		5	11.1	9.5	7.9	6.3	4.9	3.3
		10	7.8	6.0	4.3	2.8	unstable	unstable
		15	5.3	3.6	2.0	unstable	unstable	unstable
		20	3.7	2.0	unstable	unstable	unstable	unstable
		25	2.5	unstable	unstable	unstable	unstable	unstable
4	10	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	NN
		10	NN	NN	NN	NN	NN	NN
		15	30.3	26.9	24.1	20.0	16.9	13.8
		20	26.2	23.6	20.9	17.4	14.3	11.6
		25	23.9	21.0	17.9	15.0	12.2	9.4
	13	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	NN
		10	NN	NN	NN	NN	NN	14.5
		15	28.1	24.3	21.5	18.0	15.0	12.0
		20	24.2	21.4	18.1	14.9	11.9	8.9
		25	21.1	17.8	14.6	11.5	8.5	5.8

Table C.2 Pushover Load, F_t, for Single Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP_{10x42} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4 for Symmetric Distribution of Varying Values of P-Load, H, and S for Variable Scour Distributions.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	13	0	NN	NN	NN	NN	NN	NN
		5	24.7	22.7	20.6	18.7	16.8	15.0
		10	15.4	13.0	11.0	9.8	8.6	7.3
		15	9.9	8.3	7.1	5.7	4.5	3.4
		20	7.1	5.8	4.4	3.2	unstable	unstable
		25	5.3	3.9	2.5	unstable	unstable	unstable
	17	0	NN	NN	NN	NN	NN	NN
		5	23.1	20.8	18.6	16.5	14.6	13.1
		10	13.9	11.6	10.1	8.7	7.2	5.8
		15	9.2	7.7	6.2	4.7	3.3	unstable
		20	6.7	5.1	3.6	2.1	unstable	unstable
		25	4.9	3.2	unstable	unstable	unstable	unstable
4	13	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	NN
		10	32.1	28.1	24.5	21.1	18.1	15.2
		15	27.6	23.3	19.4	16.0	13.0	10.3
		20	24.9	20.4	16.3	12.9	9.9	7.5
		25	22.0	17.8	14.1	10.7	7.9	5.5
	17	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	22.3
		10	29.0	24.8	20.9	17.4	14.1	11.5
		15	25.1	20.1	16.1	12.6	9.7	7.4
		20	21.8	17.1	13.1	9.7	7.1	4.8
		25	19.2	14.8	11.0	7.8	5.2	2.9

Table C.3 Pushover Load, F_t, for 2-Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP$_{10x42}$ Piles and Reinforced Concrete Bent Cap with I$_{gross}$ = 41,470 in^4 for Symmetric Distribution of Varying Values of P-Load, H, and S for Variable Scour Distributions.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	21	0	NN	NN	NN	NN	NN	NN
		5	26.7	24.4	22.1	19.9	17.7	15.9
		10	16.3	13.6	11.7	10.3	8.8	7.3
		15	10.4	8.7	7.3	5.7	4.4	3.0
		20	7.4	5.9	4.3	2.9	unstable	unstable
		25	5.5	3.8	2.3	unstable	unstable	unstable
	25	0	NN	NN	NN	NN	NN	NN
		5	24.6	22.0	19.6	17.1	15.3	13.5
		10	14.4	12.1	10.5	8.8	7.1	5.5
		15	9.6	7.9	6.1	4.5	2.9	unstable
		20	6.8	5.0	3.3	unstable	unstable	unstable
		25	4.9	3.0	unstable	unstable	unstable	unstable
4	21	0	NN	NN	NN	NN	NN	NN
		5	38.8	35.2	31.7	28.5	25.4	22.5
		10	29.1	25.1	21.4	18.0	15.0	12.3
		15	24.1	19.3	15.6	12.3	9.6	7.4
		20	20.8	15.8	12.1	8.9	6.5	4.4
		25	18.0	13.5	9.8	6.8	4.4	2.2
	25	0	NN	NN	NN	NN	NN	NN
		5	35.1	31.4	27.9	24.6	21.3	18.1
		10	26.0	21.8	18.0	14.4	11.5	9.3
		15	21.0	16.4	12.6	9.4	7.1	4.9
		20	17.7	13.3	9.5	6.7	4.3	2.1
		25	15.3	11.1	7.4	4.8	2.3	unstable

APPENDIX D: PUSHOVER LOAD TABLES FOR UNBRACED AND X-BRACED STEEL HP$_{12x53}$ PILES FOR SYMMETRIC DISTRIBUTION OF VARYING VALUES OF P-LOAD AND FOR VARIABLE SCOUR DISTRIBUTIONS

Table D.1 Pushover Load, F_t, for Unbraced 3-Pile and 4-Pile Bridge Bents with
HP$_{12x53}$ Piles and Reinforced Concrete Bent Cap with I$_{gross}$ = 41,470 in^4
for Varying Values of P-Load, H, and S for Variable Scour Distributions.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	10	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	18.5
		10	18.5	17.0	15.6	14.3	13.0	11.7
		15	14.4	12.8	11.3	9.8	8.4	7.2
		20	11.5	9.7	8.0	6.7	5.6	4.4
		25	9.2	7.3	5.9	4.8	3.5	2.3
	13	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	16.7	15.3	14.0	12.7
		10	15.1	13.4	11.9	10.4	8.9	7.4
		15	11.9	10.2	8.4	6.8	5.5	4.1
		20	9.5	7.6	5.9	4.5	3.1	unstable
		25	7.6	5.7	4.2	unstable	unstable	unstable
4	10	0	NN					
		5						
		10						
		15						
		20						
		25						NN
	13	0	NN					
		5						
		10						
		15						
		20						
		25						NN

Table D.2 Pushover Load, F_t, for Single Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP_{12x53} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4 for Varying Values of P-Load, H, and S for Variable Scour Distributions.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	13	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	NN
		10	27.4	25.2	23.0	20.9	18.9	17.2
		15	19.7	17.3	15.0	13.3	12.2	11.1
		20	14.6	12.2	10.8	9.6	8.5	7.2
		25	10.9	9.4	8.2	7.0	5.7	4.5
	17	0	NN	NN	NN	NN	NN	NN
		5	NN	NN	NN	NN	NN	NN
		10	26.1	23.6	21.1	18.8	17.0	15.7
		15	18.6	15.8	13.8	12.6	11.3	10.0
		20	13.4	11.5	10.2	8.9	7.5	6.2
		25	10.5	9.0	7.6	6.2	4.8	3.5
4	13	0	NN					
		5						
		10						
		15						
		20						
		25						NN
	17	0	NN					
		5						
		10						
		15						
		20						
		25						NN

Table D.3 Pushover Load, F_t, for 2-Story X-Braced 3-Pile and 4-Pile Bridge Bents with HP_{12x53} Piles and Reinforced Concrete Bent Cap with $I_{gross} = 41,470$ in^4 for Symmetric Distribution of Varying Values of P-Load, H, and S for Variable Scour Distributions.

No. Bent Piles	H (ft)	S (ft)	Pushover Force, F_t (kips)					
			P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
3	21	0	NN	NN	NN	NN	NN	NN
		5	44.5	41.9	39.5	37.1	35.0	32.7
		10	29.3	26.8	24.4	22.1	19.9	18.0
		15	20.8	18.1	15.7	14.1	12.8	11.5
		20	15.1	12.8	11.3	10.0	8.6	7.2
		25	11.4	9.8	8.4	7.0	5.5	4.2
	25	0	NN	NN	NN	NN	NN	NN
		5	41.2	38.9	36.6	34.4	32.3	29.9
		10	27.7	24.8	22.0	19.7	17.9	16.4
		15	19.3	16.3	14.5	13.1	11.6	10.1
		20	13.9	12.1	10.5	9.0	7.4	5.9
		25	10.9	9.2	7.6	6.0	4.4	2.4
4	21	0	NN	NN	NN	NN	NN	NN
		5	59.6	56.1	52.8	49.3	46.0	42.9
		10	46.8	42.9	39.2	35.6	32.2	28.7
		15	39.2	35.0	30.7	26.8	23.3	20.0
		20	34.9	30.4	25.3	21.3	17.9	14.9
		25	32.1	26.5	21.5	17.8	14.5	11.5
	25	0	NN	NN	NN	NN	NN	NN
		5	55.9	51.7	47.8	44.1	40.6	37.6
		10	43.3	39.1	35.4	31.4	27.7	24.2
		15	36.1	31.5	27.4	23.2	19.5	16.5
		20	31.6	26.7	22.0	18.2	14.7	11.9
		25	28.2	23.1	18.6	14.8	11.5	9.1

APPENDIX E: CRITICAL SCOUR TABLES FOR UNBRACED AND X-BRACED STEEL HP$_{10x42}$ BENT PILES FOR SYMMETRIC DISTRIBUTION OF VARYING VALUES OF P-LOAD

Table E.1 Critical Scour, S_{CR}, of HP_{10x42} 3, 4, 5, 6-Pile Bents without X-Bracing to Resist $F_{t\ max\ design}$ =12.15k (includes a FS=1.25)

No.of Piles in Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
		$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	10	5.8	4.6	3.9	3.5	2.9	2.3
	13	3.0	1.8	0.8	0.2	unstable	unstable
4	10	>25	23.4	20.2	17.3	14.6	12.2
	13	23.8	20.2	17.3	14.2	11.7	8.8
5	10	>25.0	>25.0	>25.0	>25.0	19.3	16.4
	13	>25.0	>25.0	>25.0	19.9	16.4	13.3
6	10	>25.0	>25.0	>25.0	>25.0	18.9	14.9
	13	>25.0	>25.0	>25.0	19.9	15.8	12.1

Table E.2 Critical Scour, S_{CR}, of HP_{10x42} 3 and 4-Pile Bents with X-Bracing to Resist $F_{t\ max\ design}$ =12.15k (includes a FS=1.25)

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	Single-X	1	13	9.1	7.9	6.8	6.1	5.3	4.8
	Per Story		17	8.4	7.1	6.0	5.2	4.7	4.4
		2	21	8.9	8.1	7.3	6.4	5.5	4.9
			25	7.5	6.9	6.4	5.3	4.8	4.4
4	Single-X	1	13	>25.0	23.0	19.3	15.9	12.0	9.3
	Per Story		17	24.0	20.3	16.9	12.3	9.0	7.1
		2	21	24.2	19.8	15.0	11.0	8.8	7.3
			25	22.6	17.0	11.9	8.8	6.9	5.3

Table E.3 Critical Scour, S_{CR}, of HP$_{10x42}$ 5 and 6-Pile Bents with X-Bracing to Resist F$_{t\ max\ design}$ =12.15k (includes a FS=1.25)

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				P=60^k	P=80^k	P=100^k	P=120^k	P=140^k	P=160^k
5	Single-X Per Story	1	13	>25.0	>25.0	>25.0	25.0	18.6	14.2
			17	>25.0	>25.0	>25.0	19.8	15.4	9.5
		2	21	>25.0	>25.0	>25.0	18.4	12.7	9.1
			25	>25.0	>25.0	>25.0	14.9	9.3	6.9
6	Single-X Per Story	1	13	>25.0	>25.0	>25.0	>25.0	18.5	12.1
			17	>25.0	>25.0	>25.0	>25.0	14.6	8.8
		2	21	>25.0	>25.0	>25.0	19.7	12.6	9.0
			25	>25.0	>25.0	>25.0	15.7	9.4	7.0
6	Double-X Per Story	1	13	>25.0	>25.0	>25.0	>25.0	19.1	13.9
			17	>25.0	>25.0	>25.0	>25.0	16.7	10.1
		2	21	>25.0	>25.0	>25.0	>25.0	16.9	11.5
			25	>25.0	>25.0	>25.0	>25.0	14.0	9.3

APPENDIX F: CRITICAL SCOUR TABLES FOR UNBRACED AND X-BRACED STEEL HP$_{12x53}$ BENT PILES FOR SYMMETRIC DISTRIBUTION OF VARYING VALUES OF P-LOAD

Table F.1 Critical Scour, S_{CR}, of HP_{12x53} 3, 4, 5, 6-Pile Bents without X-Bracing to Resist $F_{t\ max\ design}$ =12.15k (includes a FS=1.25)

No.of Piles in Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
		$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	10	14.2	12.2	10.4	9.4	8.4	7.4
	13	11.1	9.1	7.5	6.4	5.2	4.4
4	10	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
	13	>25.0	>25.0	>25.0	>25.0	23.5	20.7
5	10	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
	13	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
6	10	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
	13	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0

Table F.2 Critical Scour, S_{CR}, of HP_{12x53} 3 and 4-Pile Bents with X-Bracing to Resist $F_{t\,max\,design}$ =12.15k (includes a FS=1.25)

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	Single-X	1	13	16.7	14.3	12.8	11.7	10.4	9.6
	Per Story		17	15.7	13.5	11.8	10.6	9.6	8.8
		2	21	15.5	14.3	13.2	11.8	10.5	9.6
			25	14.3	13.2	12.2	10.7	9.6	8.8
4	Single-X	1	13	>25.0	>25.0	>25.0	>25.0	24.9	22.0
	Per Story		17	>25.0	>25.0	>25.0	>25.0	22.2	18.6
		2	21	>25.0	>25.0	>25.0	24.5	20.4	16.8
			25	>25.0	>25.0	>25.0	21.7	17.3	13.8

Table F.3 Critical Scour, S_{CR}, of HP_{12x53} 5 and 6-Pile Bents with X-Bracing to Resist $F_{t\ max\ design}$ =12.15k (includes a FS=1.25)

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
5	Single-X Per Story	1	13	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
			17	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
		2	21	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
			25	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
6	Single-X Per Story	1	13	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
			17	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
		2	21	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
			25	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
6	Double-X Per Story	1	13	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
			17	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
		2	21	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
			25	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0

APPENDIX G: CRITICAL SCOUR TABLES FOR UNBRACED AND X-BRACED STEEL HP$_{10X42}$ PILES FOR SYMMETRIC DISTRIBUTION OF VARYING VALUES OF P-LOAD AND FOR VARIABLE SCOUR DISTRIBUTIONS

Table G.1 Critical Scour, S_{CR}, of HP_{10x42} 3and 4-Pile Bents without X-Bracing to Resist $F_{t\ max\ design}$ =12.15k (includes a FS=1.25), Unsymmetric Scour

No.of Piles in Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
		$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	10	7.9	6.3	4.9	4.2	3.5	2.8
	13	3.8	2.3	1.0	unstable	unstable	unstable
4	10	>25.0	>25.0	>25.0	>25.0	>25.0	18.8
	13	>25.0	>25.0	>25.0	>25.0	24.0	19.6

Table G.2 Critical Scour, S_{CR}, of HP_{10x42} 3 and 4-Pile Bents with X-Bracing to Resist $F_{t\,max\,design}$=12.15k (includes a FS=1.25), Unsymmetric Scour

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	Single-X	1	13	13.0	10.9	9.4	8.7	7.8	6.9
	Per Story		17	11.9	9.7	8.8	7.8	6.7	5.7
		2	21	13.5	11.5	9.8	9.0	8.1	7.2
			25	12.3	10.1	9.1	8.0	6.9	5.8
4	Single-X	1	13	>25.0	>25.0	>25.0	21.7	16.4	13.1
	Per Story		17	>25.0	>25.0	22.3	15.8	12.2	9.7
		2	21	>25.0	>25.0	19.9	15.2	12.6	10.2
			25	>25.0	22.6	15.7	12.3	9.7	8.4

APPENDIX H: **CRITICAL SCOUR TABLES FOR UNBRACED AND X-BRACED STEEL HP$_{12x53}$ PILES FOR SYMMETRIC DISTRIBUTION OF VARYING VALUES OF P-LOAD AND FOR VARIABLE SCOUR DISTRIBUTIONS**

Table H.1 Critical Scour, S_{CR}, of HP_{12x53} 3 and 4-Pile Bents without X-Bracing to Resist $F_{t\,max\,design}$=12.15k (includes a FS=1.25), Unsymmetric Scour

No.of Piles in Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
		$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	10	18.9	16.0	14.0	12.4	10.9	9.7
	13	14.6	12.0	9.7	8.2	6.8	5.5
4	10	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
	13	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0

Table H.2 Critical Scour, S_{CR}, of HP_{12x53} 3 and 4-Pile Bents with X-Bracing to Resist $F_{t\ max\ design}$ =12.15k (includes a FS=1.25), Unsymmetric Scour

No.of Piles in Bent	X-Bracing Configuration	No. of Stories In Bent	Bent Height (ft)	Critical Scour, S_{CR} (ft)					
				$P=60^k$	$P=80^k$	$P=100^k$	$P=120^k$	$P=140^k$	$P=160^k$
3	Single-X	1	13	23.3	20.1	18.4	16.6	15.1	14.1
	Per Story		17	22.2	19.2	17.3	15.6	14.3	13.1
		2	21	24.0	21.0	19.0	17.4	15.8	14.5
			25	22.9	19.9	17.9	16.2	14.6	13.4
4	Single-X	1	13	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
	Per Story		17	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
		2	21	>25.0	>25.0	>25.0	>25.0	>25.0	>25.0
			25	>25.0	>25.0	>25.0	>25.0	24.0	19.7

APPENDIX I: **CODE FOR AUTOMATED SCREENING TOOL**

INTRODUCTION FORM

```
Public Class Intro

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
        End 'ends program when prompted
    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        My.Forms.Prelim.Show()
        WindowState = FormWindowState.Minimized
    End Sub
End Class
```

APPENDIX J: **CODE FOR AUTOMATED SCREENING TOOL**

PRELIMINARY EVALUATION FORM

```vb
Public Class Prelim

    Public Area, NewArea, A As Single
    Public Lbg, Smax As Single

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnEnter1.Click

        Area = Val(txtArea.Text) 'Original Area
        NewArea = Val(txtNewArea.Text)

        Lbg = Val(txtLbg.Text)
        Smax = Val(txtSmax.Text)

        'Calculates 75% of area in order to see if piles have lost more
than 25% of their original area
        A = Area - (Area * 0.25)

        'Creates a loop to check if Smax is between 0 and 3ft.
        If Smax >= 0 And Smax <= 3 Then
            If NewArea >= A Then 'Checks if piles have lost more than
25% of original area
                MsgBox("Bridge/Bents are safe from scour failure!")
            Else
                MsgBox("Take immediate corrective action to build-up
pile section back to original" _
                & Chr(10) & "or greater dimensions where more than 25%
of material has been lost due to corrosion." _
                & Chr(13) & Chr(13) & "If you do so, then bridge/bents
are safe from scour failure.")
            End If
        Else 'If scour is > than 3ft.
            If Smax >= Lbg Then
                MsgBox("Pile/Bent will have a pile/bent 'kick-out' or
plunging failure." _
                & Chr(13) & Chr(13) & "Take corrective action
immediately!")
            Else
                If NewArea <= A Then 'Checks if piles have lost more
than 25% of original area
                    MsgBox("Take immediate corrective action to build-
up pile section back to original" _
                    & Chr(10) & "or greater dimensions where more than
25% of material has been lost due to corrosion.")
                End If
            End If
        End If
    End Sub

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnEnd1.Click
        End 'Ends program when prompted
    End Sub
```

```vb
    Private Sub RadioButton2_CheckedChanged(ByVal sender As
System.Object, _
        ByVal e As System.EventArgs) Handles radbtnNo.CheckedChanged

        'Creates message if the No is checked when answering if the
bridge is over water and subjected to scour
        If radbtnNo.Checked = True Then
            MsgBox("Bridge/Bents are safe from scour failure!")
        End If
    End Sub

    Private Sub Prelim_Load(ByVal sender As Object, ByVal e As
System.EventArgs) Handles Me.Load
        Dim s As String = Application.ExecutablePath
        Dim sDir As String = s.Substring(0, s.LastIndexOfAny("\") + 1)
        Call IO_Scr.SetConnection(sDir & "Critical Scour.mdb")
        Call IO_Ft_III.SetConnection(sDir & "Critical Scour.mdb")
    End Sub

    Private Sub txtSmax_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles txtSmax.TextChanged
        Smax = Val(txtSmax.Text)
        'Sets upper-bound limit on Smax values to be evaluated.
        If Smax > 25 Then
            MsgBox("Screening Tool will only evaluate bridge bents that
have scour levels up to 25 feet." _
            & Chr(13) & Chr(13) & " Any bent with more than 25 feet of
scour must be checked more closely" _
            & Chr(10) & " for possible failure by other means.")
        End If
    End Sub

    Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button4.Click
        My.Forms.Pmax.Show()
        WindowState = FormWindowState.Minimized
    End Sub
End Class
```

APPENDIX K: CODE FOR AUTOMATED SCREENING TOOL

DETERMINATING PMAX_APPLIED FOR PILE AND BENT FORM AND

RELATED MODULES

```vb
Public Class Pmax
    Public Spanlength, GirderSpacing, DeckThick, DiaphThick, _
        CapWidth, CapDepth, CapLength, OutOutDeckWidth, CurbCurbWidth, _
        GirderWeightPerFoot, GirderDepth, GirderDensity, OverhangThick, OverhangWidth, _
        JerseyBarrierWtPerFt, LaneLoad, ConcLoadforLaneLoading, SteelDepth, SteelWt, _
        TFlangeWidth, TFlangeThick, WebWidth, WebDepth, BFlangeWidth, BFlangeThick, GirdArea As Single
    Public PmaxApplPile, PmaxApplBent, RCDGheight, RCDGwidth, DstrbFact As Single
    Public NoGirdersPerSpan, NoDiaphPerSpan, NoLanesLoaded As Integer
    Public DesignTruck, Support, GirderMaterial As String

    Private Sub Pmax_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles MyBase.Load
        comboGirderType.Items.Add("Concrete, AASHTO Type I")
        comboGirderType.Items.Add("Concrete, AASHTO Type II")
        comboGirderType.Items.Add("Concrete, AASHTO Type III")
        comboGirderType.Items.Add("Concrete, AASHTO Type IV")

        comboSupportType.Items.Add("Simply Supported Bridge")
        comboSupportType.Items.Add("Two equal spans made continuous for live load")
        comboSupportType.Items.Add("Three equal spans made continuous for live load")
        comboSupportType.Items.Add("Four or more equal spans made continuous for live load")
        comboSupportType.Items.Add("Two equal spans continuous")
        comboSupportType.Items.Add("Three equal spans continuous")
        comboSupportType.Items.Add("Four or more equal spans continuous")

    End Sub


    Private Sub btnStartCalculations_Click(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles btnStartCalculations.Click

        If radbtnPmaxValues.Checked Then    'if Pmax values are entered directly from user
            PmaxApplPile = Val(txtPmaxPileEntered.Text)
            PmaxApplBent = Val(txtPmaxBentEntered.Text)

            txtPmaxApplPile.Enabled = True
            txtPmaxApplPile.Text = PmaxApplPile.ToString("###0.00")
            txtPmaxApplBent.Enabled = True
            txtPmaxApplBent.Text = PmaxApplBent.ToString("###0.00")

        Else    'Calculates Pmax values from user input

            'Apply text box values to variables
```

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```vb
            Spanlength = txtSpanlength.Text
            NoGirdersPerSpan = txtNoGirdersPerSpan.Text
            GirderSpacing = txtGirderSpacing.Text
            DeckThick = txtDeckThick.Text
            DiaphThick = txtDiaphThick.Text
            CapWidth = txtCapWidth.Text
            CapDepth = txtCapDepth.Text
            If txtCapLength.Text <> "-1" Then
                CapLength = txtCapLength.Text
            Else : CapLength = (GirderSpacing * (NoGirdersPerSpan - 1))
+ 4
            End If
            OutOutDeckWidth = txtOutOutDeckWidth.Text
            CurbCurbWidth = txtCurbCurbWidth.Text
            OverhangThick = txtOverhangThick.Text
            OverhangWidth = txtOverhangWidth.Text

            'Distribution factor for Pmax-pile-LL, for truck lane
loading
            DstrbFact = 1 + ((GirderSpacing - 6) / GirderSpacing)


            ' Determine number of diagphragms per span, based on
spanlength
            If Spanlength <= 30 Then
                NoDiaphPerSpan = 2
            ElseIf Spanlength <= 60 Then
                NoDiaphPerSpan = 3
            Else
                NoDiaphPerSpan = 4
            End If

            'Make names for support cases
            Select Case comboSupportType.SelectedIndex
                Case 0 'Simply supported
                    Support = "SS"
                Case 1 '2 equal spans made continuous for live load
                    Support = "2-contforlive"
                Case 2 '3 equal spans made continuous for live load
                    Support = "3-contforlive"
                Case 3 '4 or more equal spans made continuous for live
load
                    Support = "4ormore-contforlive"
                Case 4 '2 equal spans continuous
                    Support = "2-cont"
                Case 5 '3 equal spans continuous
                    Support = "3-cont"
                Case 5 '3 equal spans continuous
                    Support = "3-cont"
                Case 6 '4 or more equal spans continuous
                    Support = "4ormore-cont"
            End Select

            ' Calculate number of lanes loaded
```

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```
            If CurbCurbWidth < 20 Then
                NoLanesLoaded = 1
            ElseIf CurbCurbWidth < 30 Then
                NoLanesLoaded = 2
            ElseIf CurbCurbWidth < 42 Then
                NoLanesLoaded = 3
            ElseIf CurbCurbWidth < 54 Then
                NoLanesLoaded = 4
            ElseIf CurbCurbWidth < 66 Then
                NoLanesLoaded = 5
            ElseIf CurbCurbWidth < 78 Then
                NoLanesLoaded = 6
            ElseIf CurbCurbWidth < 90 Then
                NoLanesLoaded = 7
            ElseIf CurbCurbWidth < 102 Then
                NoLanesLoaded = 8
            ElseIf CurbCurbWidth < 114 Then
                NoLanesLoaded = 9
            ElseIf CurbCurbWidth < 126 Then
                NoLanesLoaded = 10
            Else : NoLanesLoaded = 11
                MsgBox("For curb-to-curb widths > 126 ft, 11 lanes
loaded are assumed.")
            End If


            'Apply text box values to variables
            SteelDepth = Val(txtSteelDepth.Text)
            SteelWt = Val(txtSteelWt.Text)
            TFlangeWidth = Val(txtTFlanWidth.Text)
            TFlangeThick = Val(txtTFlanThick.Text)
            WebWidth = Val(txtWebWidth.Text)
            WebDepth = Val(txtWebDepth.Text)
            BFlangeWidth = Val(txtBFlanWidth.Text)
            BFlangeThick = Val(txtBFlanThick.Text)
            RCDGheight = Val(txtRCDGheight.Text)
            RCDGwidth = Val(txtRCDGwidth.Text)

            'Girder Material info
            If radbtnSteelW.Checked = True Then
                GirderMaterial = "Steel"
                GirderWeightPerFoot = (SteelWt / 1000) 'k/ft
                GirderDepth = (SteelDepth / 12) 'in converted to ft
                GirderDensity = 0.49 'k/ft^3

            ElseIf radbtnSteelPlate.Checked = True Then
                GirderMaterial = "Steel"
                GirderDensity = 0.49 'k/ft^3
                GirderDepth = (TFlangeThick + WebDepth + BFlangeThick)
/ 12   'in converted to ft.
                GirdArea = (TFlangeWidth * TFlangeThick) + (WebWidth *
WebDepth) + (BFlangeWidth * BFlangeThick) 'in^2
                GirderWeightPerFoot = (GirdArea / 144) * GirderDensity
'Converts in^2 to ft^2 in order to get k/ft
```

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```vb
            ElseIf radbtnRCDG.Checked = True Then
                GirderDensity = 0.15 'k/ft^3
                GirderWeightPerFoot = (RCDGheight * RCDGwidth) *
GirderDensity
                GirderDepth = RCDGheight
            Else
                'Determine girder weight/ft, girder depth, and girder
mass density
                Select Case comboGirderType.SelectedIndex
                    Case 0 'Concrete, AASHTO Type I
                        GirderWeightPerFoot = 0.287 'k/ft
                        GirderDepth = (28 / 12) 'in converted to ft
                        GirderDensity = 0.15 'k/ft^3
                    Case 1 'Concrete, AASHTO Type II
                        GirderWeightPerFoot = 0.384 'k/ft
                        GirderDepth = 3.0 'ft
                        GirderDensity = 0.15 'k/ft^3
                    Case 2 'Concrete, AASHTO Type III
                        GirderWeightPerFoot = 0.583 'k/ft
                        GirderDepth = (45 / 12) 'in converted to ft
                        GirderDensity = 0.15 'k/ft^3
                    Case 3 'Concrete, AASHTO Type III
                        GirderWeightPerFoot = 0.822 'k/ft
                        GirderDepth = (54 / 12) 'in converted to ft
                        GirderDensity = 0.15 'k/ft^3
                End Select
            End If


            txtPmaxApplPile.Enabled = True

            PmaxApplPile = PmaxAppl_Pile(Spanlength, GirderSpacing,
DeckThick, _
            DiaphThick, CapWidth, CapDepth, GirderWeightPerFoot,
GirderDepth, GirderDensity, _
            LaneLoad, ConcLoadforLaneLoading, NoGirdersPerSpan,
NoDiaphPerSpan, DesignTruck, _
            Support, GirderMaterial, DstrbFact, JerseyBarrierWtPerFt)

            txtPmaxApplPile.Text = PmaxApplPile.ToString("###0.00")

            txtPmaxApplBent.Enabled = True

            PmaxApplBent = PMaxAppl_Bent(DeckThick, OutOutDeckWidth,
Spanlength, _
            OverhangThick, OverhangWidth, DiaphThick, GirderDepth,
GirderSpacing, GirderDensity, _
            NoDiaphPerSpan, GirderWeightPerFoot, NoGirdersPerSpan,
JerseyBarrierWtPerFt, _
            CapWidth, CapDepth, CapLength, DesignTruck, LaneLoad,
ConcLoadforLaneLoading, _
            NoLanesLoaded, Support, GirderMaterial)
```

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```vb
            txtPmaxApplBent.Text = PmaxApplBent.ToString("##0.00")
        End If

    End Sub

    Private Sub radiobutYes_CheckedChanged(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles radbutYes.CheckedChanged

        If radbutYes.Checked = True Then
            JerseyBarrierWtPerFt = 0.39 'k/ft
        Else : JerseyBarrierWtPerFt = 0.0 'k/ft
        End If
    End Sub


    Private Sub radbutHS20_CheckedChanged(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles radbutHS20.CheckedChanged

        If radbutHS20.Checked = True Then
            DesignTruck = "HS20"
            LaneLoad = 0.064 'k/ft^2
            ConcLoadforLaneLoading = 26.0 'k
        Else
            DesignTruck = "HS15"
            LaneLoad = 0.048 'k/ft^2
            ConcLoadforLaneLoading = 19.5 'k
        End If
    End Sub

    Private Sub btnContinue_Click(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles btnContinue.Click
        'Continues evaluation and brings up kickoutplunging form
        My.Forms.KickOutPlunging.Show()
        WindowState = FormWindowState.Minimized
    End Sub

    Private Sub radbtnConcrete_CheckedChanged(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles radbtnConcrete.CheckedChanged
        'Changes form settings when options are selected
        If radbtnConcrete.Checked = True Then
            comboGirderType.Enabled = True
            txtSteelDepth.Enabled = False
            txtSteelWt.Enabled = False
            txtTFlanWidth.Enabled = False
            txtTFlanThick.Enabled = False
            txtWebWidth.Enabled = False
            txtWebDepth.Enabled = False
            txtBFlanWidth.Enabled = False
            txtBFlanThick.Enabled = False
            txtRCDGheight.Enabled = False
```

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```vb
            txtRCDGwidth.Enabled = False
        End If
    End Sub

    Private Sub radbtnPmaxValues_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
radbtnPmaxValues.CheckedChanged
        'Changes form settings when options are selected
        If radbtnPmaxValues.Checked Then
            txtPmaxPileEntered.Enabled = True
            txtPmaxBentEntered.Enabled = True
            GroupBox2.Enabled = False
            GroupBox3.Enabled = False
            GroupBox4.Enabled = False

            ' Sets Pmax values equal to those entered
            PmaxApplPile = Val(txtPmaxPileEntered.Text)
            PmaxApplBent = Val(txtPmaxBentEntered.Text)

            txtPmaxApplPile.Enabled = True
            txtPmaxApplPile.Text = PmaxApplPile.ToString("###0.00")
            txtPmaxApplBent.Enabled = True
            txtPmaxApplBent.Text = PmaxApplBent.ToString("###0.00")
        End If

    End Sub

    Private Sub radbtnRCDG_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
radbtnRCDG.CheckedChanged
        'Changes form settings when options are selected
        If radbtnRCDG.Checked = True Then
            txtRCDGheight.Enabled = True
            txtRCDGwidth.Enabled = True
            txtSteelDepth.Enabled = False
            txtSteelWt.Enabled = False
            txtTFlanWidth.Enabled = False
            txtTFlanThick.Enabled = False
            txtWebWidth.Enabled = False
            txtWebDepth.Enabled = False
            txtBFlanWidth.Enabled = False
            txtBFlanThick.Enabled = False
            comboGirderType.Enabled = False

        End If
    End Sub

    Private Sub radbtnSteelW_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
radbtnSteelW.CheckedChanged
        'Changes form settings when options are selected
        If radbtnSteelW.Checked = True Then
            txtSteelDepth.Enabled = True
            txtSteelWt.Enabled = True
```

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```vb
            txtTFlanWidth.Enabled = False
            txtTFlanThick.Enabled = False
            txtWebWidth.Enabled = False
            txtWebDepth.Enabled = False
            txtBFlanWidth.Enabled = False
            txtBFlanThick.Enabled = False
            comboGirderType.Enabled = False
            txtRCDGheight.Enabled = False
            txtRCDGwidth.Enabled = False
        End If
    End Sub
    Private Sub radbtnSteelPlate_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
radbtnSteelPlate.CheckedChanged
        'Changes form settings when options are selected
        If radbtnSteelPlate.Checked = True Then
            txtTFlanWidth.Enabled = True
            txtTFlanThick.Enabled = True
            txtWebWidth.Enabled = True
            txtWebDepth.Enabled = True
            txtBFlanWidth.Enabled = True
            txtBFlanThick.Enabled = True
            txtSteelDepth.Enabled = False
            txtSteelWt.Enabled = False
            comboGirderType.Enabled = False
            txtRCDGheight.Enabled = False
            txtRCDGwidth.Enabled = False
        End If
    End Sub

    Private Sub radbtnCalculatePmax_CheckedChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
radbtnCalculatePmax.CheckedChanged
        'Changes form settings when options are selected
        If radbtnCalculatePmax.Checked Then
            txtPmaxPileEntered.Enabled = False
            txtPmaxBentEntered.Enabled = False
            GroupBox2.Enabled = True
            GroupBox3.Enabled = True
            GroupBox4.Enabled = True
        End If
    End Sub
End Class
```

```vb
Module MaxLoadAppl_Pile
    Public Spanlength, GirderSpacing, DeckThick, DiaphThick, _
        CapWidth, CapDepth, GirderWeightPerFoot, GirderDepth,
GirderDensity, _
        LaneLoad, ConcLoadforLaneLoading, DstrbFact As Single
    Public NoGirdersPerSpan, NoDiaphPerSpan As Integer
    Public DesignTruck, Support, GirderMaterial As String


    Public Const ConcreteDens As Single = 0.15 'k/ft^3

    Function PmaxAppl_Pile(ByVal Span As Single, ByVal GirdSpace As
Single, _
    ByVal DeckThickness As Single, ByVal DiaphThickness As Single, _
    ByVal BentCapWidth As Single, ByVal BentCapDepth As Single, _
    ByVal GirderWtPerFt As Single, ByVal GirdDepth As Single, _
    ByVal GirdDens As Single, ByVal LaneLd As Single, _
    ByVal ConcLoadforLaneLdg As Single, _
    ByVal NoGirders As Integer, ByVal NoDiaph As Integer, _
    ByVal Truck As String, ByVal SupportType As String, ByVal GirdMat
As String, _
    ByVal DistrbFact As Single, ByVal BarrierWtPerFt As Single)


        ' Calculating Max Applied Dead Load for Pile
        Dim DeckDeadLoad, DiaphDeadLoad, GirderDeadLoad,
BentCapDeadLoad, _
          PmaxApplDead_Pile, PPile_LL_TruckLineLoad, k, _
          PPile_LL_DesignLaneLoad, PmaxApplLive_Pile,
BarrierRailDeadLoad_Pile As Single


        DeckDeadLoad = (DeckThickness / 12) * GirdSpace * Span *
ConcreteDens
        If GirdMat = "Steel" Then
            DiaphDeadLoad = 0    'If steel girders are used then neglect
diaphram wt. in dead load calc.
        Else : DiaphDeadLoad = (DiaphThickness / 12) * GirdDepth *
GirdSpace * GirdDens * NoDiaph
        End If
        GirderDeadLoad = GirderWtPerFt * Span
        BentCapDeadLoad = BentCapWidth * BentCapDepth * GirdSpace *
ConcreteDens
        BarrierRailDeadLoad_Pile = (BarrierWtPerFt * Span * 2) /
NoGirders

        PmaxApplDead_Pile = DeckDeadLoad + DiaphDeadLoad +
GirderDeadLoad + BentCapDeadLoad + BarrierRailDeadLoad_Pile

        ' Calculating Max Applied Live Load for Pile

        ' Truck Line Load (see equations Phase II report p. 4-9)
        If Truck = "HS20" Then
            If SupportType = "SS" Then
```

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```vb
                        PPile_LL_TruckLineLoad = (16 + (16 * (Span - 14) /
Span) + (4 * (Span - 14) / Span)) * DistrbFact * 1.1
                        'Assumes an impact factor of 1.1
                    Else
                        k = (Span - 14) / Span
                        PPile_LL_TruckLineLoad = (2 * ((-56 / Span) + 2 * (k -
k ^ 3) + 4) + 16 + (6 * (k - k ^ 3) - (168 / Span) + 12)) * DistrbFact
* 1.1
                        ' Assumes an impact factor of 1.1
                    End If
                Else 'Truck = HS15
                    If SupportType = "SS" Then
                        PPile_LL_TruckLineLoad = (12 + (12 * (Span - 14) /
Span) + (3 * (Span - 14) / Span)) * DistrbFact * 1.1
                        'Assumes an impact factor of 1.1
                    Else
                        k = (Span - 14) / Span
                        PPile_LL_TruckLineLoad = (2 * ((-42 / Span) + 1.5 * (k
- k ^ 3) + 3) + 12 + (4.5 * (k - k ^ 3) - (126 / Span) + 9)) *
DistrbFact * 1.1
                        ' Assumes an impact factor of 1.1
                    End If
                End If


                ' Design Lane Load (conservatively assumes max design lane load
of 64 psf for HS20 _
                ' and 48 psf for HS15; see Phase II report Fig. 4.6
                If Truck = "HS20" Then
                    If SupportType = "SS" Then
                        PPile_LL_DesignLaneLoad = (LaneLd * GirdSpace * Span +
ConcLoadforLaneLdg) * 1.1
                        ' Assumes an impact factor of 1.1
                    Else
                        PPile_LL_DesignLaneLoad = (1.25 * (10 * LaneLd) *
(GirdSpace / 10) * Span + ConcLoadforLaneLdg) * 1.1
                        ' Assumes impact factor = 1.1 and conservatively
assumes 1.25 factor for 2 or more continuous spans
                    End If
                Else ' Truck = HS15
                    If SupportType = "SS" Then
                        PPile_LL_DesignLaneLoad = (LaneLd * GirdSpace * Span +
ConcLoadforLaneLdg) * 1.1
                        ' Assumes an impact factor of 1.1
                    Else
                        PPile_LL_DesignLaneLoad = (1.25 * (10 * LaneLd) *
(GirdSpace / 10) * Span + ConcLoadforLaneLdg) * 1.1
                        ' Assumes impact factor = 1.1 and conservatively
assumes 1.25 factor for 2 or more continuous spans
                    End If
                End If


                PmaxApplLive_Pile = Math.Max(PPile_LL_TruckLineLoad,
PPile_LL_DesignLaneLoad)
```

```
        PmaxAppl_Pile = PmaxApplDead_Pile + PmaxApplLive_Pile

    End Function
End Module
```

```vb
Module MaxLoadAppl_Bent

    Function PMaxAppl_Bent(ByVal DeckThickness As Single, ByVal
OuttoOutDeckWidth _
    As Single, ByVal Span As Single, ByVal OverhangThickness As Single,
ByVal OverhangWid _
    As Single, ByVal DiaphThickness As Single, ByVal GirdDepth As
Single, ByVal GirdSpace _
    As Single, ByVal GirderDens As Single, ByVal NoDiaph As Single,
ByVal GirderWtPerFt _
    As Single, ByVal NoGirders As Integer, ByVal BarrierWtPerFt As
Single, _
    ByVal BentCapWidth As Single, ByVal BentCapDepth As Single, ByVal
BentCapLength _
    As Single, ByVal Truck As String, ByVal LaneLd As Single, ByVal
ConcLoadforLaneLdg _
    As Single, ByVal NumberLanesLoaded As Integer, ByVal SupportType As
String, _
    ByVal GirdMat As String)

        'Calculating Max Applied Dead Load for Bent
        Dim DeckDeadLoad_Bent, OverhangDeadLoad_Bent,
DiaphDeadLoad_Bent, _
        GirderDeadLoad_Bent, BarrierRailDeadLoad_Bent,
BentCapDeadLoad_Bent, _
        PmaxApplDead_Bent, PBent_LL_TruckLaneLoad,
PBent_LL_DesignLaneLoad, _
        PmaxApplLive_Bent, k As Single

        DeckDeadLoad_Bent = (DeckThickness / 12) * OuttoOutDeckWidth *
Span * ConcreteDens
        OverhangDeadLoad_Bent = (OverhangThickness / 12) * OverhangWid
* Span * ConcreteDens * 2

        If GirdMat = "Steel" Then
            DiaphDeadLoad_Bent = 0  'If Steel girders are used neglect
diaphram wt.
        Else : DiaphDeadLoad_Bent = (DiaphThickness / 12) * GirdDepth *
((NoGirders - 1) * GirdSpace) _
        * GirderDens * NoDiaph
        End If

        GirderDeadLoad_Bent = GirderWtPerFt * Span * NoGirders
        BarrierRailDeadLoad_Bent = BarrierWtPerFt * Span * 2
        BentCapDeadLoad_Bent = BentCapWidth * BentCapDepth *
BentCapLength * ConcreteDens

        PmaxApplDead_Bent = DeckDeadLoad_Bent + OverhangDeadLoad_Bent +
DiaphDeadLoad_Bent _
        + GirderDeadLoad_Bent + BarrierRailDeadLoad_Bent +
BentCapDeadLoad_Bent

        ' Calculating Max Applied Live Load for Bent
        ' Truck Line Load
```

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```
        If Truck = "HS20" Then
            If SupportType = "SS" Then
                PBent_LL_TruckLaneLoad = (32 + (32 * (Span - 14) /
Span) + (8 * (Span - 14) / Span)) * NumberLanesLoaded * 1.1
                'Assumes an impact factor of 1.1
            Else
                k = (Span - 14) / Span
                PBent_LL_TruckLaneLoad = (2 * (2 * ((-56 / Span) + 2 *
(k - k ^ 3) + 4)) + 32 + (2 * (6 * (k - k ^ 3) - (168 / Span) + 12))) *
3 * 1.1
                ' Assumes an impact factor of 1.1
            End If
        Else 'Truck = HS15
            If SupportType = "SS" Then
                PBent_LL_TruckLaneLoad = (24 + (24 * (Span - 14) /
Span) + (6 * (Span - 14) / Span)) * NumberLanesLoaded * 1.1
                'Assumes an impact factor of 1.1
            Else
                k = (Span - 14) / Span
                PBent_LL_TruckLaneLoad = (2 * (2 * ((-42 / Span) + 1.5
* (k - k ^ 3) + 3)) + 24 + (2 * (4.5 * (k - k ^ 3) - (126 / Span) +
9))) * 3 * 1.1
                ' Assumes an impact factor of 1.1
            End If
        End If


        ' Design Lane Load (conservatively assumes max design lane load
of 64 psf for HS20 _
        ' and 48 psf for HS15; see Phase II report Fig. 4.6
        If Truck = "HS20" Then
            If SupportType = "SS" Then
                PBent_LL_DesignLaneLoad = (LaneLd * 10 * Span +
ConcLoadforLaneLdg) * NumberLanesLoaded * 1.1
                ' Assumes an impact factor of 1.1
            Else
                PBent_LL_DesignLaneLoad = (1.25 * LaneLd * 10 * Span +
ConcLoadforLaneLdg) * NumberLanesLoaded * 1.1
                ' Assumes impact factor = 1.1 and conservatively
assumes 1.25 factor for 2 or more continuous spans
                ' Also assumes 10' lane load width
            End If
        Else ' Truck = HS15
            If SupportType = "SS" Then
                PBent_LL_DesignLaneLoad = (LaneLd * 10 * Span +
ConcLoadforLaneLdg) * NumberLanesLoaded * 1.1
                ' Assumes an impact factor of 1.1
            Else
                PBent_LL_DesignLaneLoad = (1.25 * LaneLd * 10 * Span +
ConcLoadforLaneLdg) * NumberLanesLoaded * 1.1
                ' Assumes impact factor = 1.1 and conservatively
assumes 1.25 factor for 2 or more continuous spans
                ' Also assumes 10' lane load width
            End If
        End If
```

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```vbnet
        PmaxApplLive_Bent = Math.Max(PBent_LL_TruckLaneLoad,
PBent_LL_DesignLaneLoad)
        PMaxAppl_Bent = PmaxApplDead_Bent + PmaxApplLive_Bent
    End Function
End Module
```

```vb
Module MaxLoadAppl_Bent_LL

    Function PMaxAppl_Bent_LL(ByVal DeckThickness As Single, ByVal
OuttoOutDeckWidth _
        As Single, ByVal Span As Single, ByVal OverhangThickness As
Single, ByVal OverhangWid _
        As Single, ByVal DiaphThickness As Single, ByVal GirdDepth As
Single, ByVal GirdSpace _
        As Single, ByVal GirderDens As Single, ByVal NoDiaph As Single,
ByVal GirderWtPerFt _
        As Single, ByVal NoGirders As Integer, ByVal BarrierWtPerFt As
Single, _
        ByVal BentCapWidth As Single, ByVal BentCapDepth As Single,
ByVal BentCapLength _
        As Single, ByVal Truck As String, ByVal LaneLd As Single, ByVal
ConcLoadforLaneLdg _
        As Single, ByVal NumberLanesLoaded As Integer, ByVal
SupportType As String, _
        ByVal GirdMat As String)

        'Calculating Max Applied Dead Load for Bent
        Dim DeckDeadLoad_Bent, OverhangDeadLoad_Bent,
DiaphDeadLoad_Bent, _
        GirderDeadLoad_Bent, BarrierRailDeadLoad_Bent,
BentCapDeadLoad_Bent, _
        PmaxApplDead_Bent, PBent_LL_TruckLaneLoad,
PBent_LL_DesignLaneLoad, _
        PmaxApplLive_Bent As Single

        DeckDeadLoad_Bent = (DeckThickness / 12) * OuttoOutDeckWidth *
Span * ConcreteDens
        OverhangDeadLoad_Bent = (OverhangThickness / 12) * OverhangWid
* Span * ConcreteDens * 2

        If GirdMat = "Steel" Then
            DiaphDeadLoad_Bent = 0  'If Steel girders are used neglect
diaphram wt.
        Else : DiaphDeadLoad_Bent = (DiaphThickness / 12) * GirdDepth *
((NoGirders - 1) * GirdSpace) _
        * GirderDens * NoDiaph
        End If

        GirderDeadLoad_Bent = GirderWtPerFt * Span * NoGirders
        BarrierRailDeadLoad_Bent = BarrierWtPerFt * Span * 2
        BentCapDeadLoad_Bent = BentCapWidth * BentCapDepth *
BentCapLength * ConcreteDens

        PmaxApplDead_Bent = DeckDeadLoad_Bent + OverhangDeadLoad_Bent +
DiaphDeadLoad_Bent _
        + GirderDeadLoad_Bent + BarrierRailDeadLoad_Bent +
BentCapDeadLoad_Bent

        ' Calculating Max Applied Live Load for Bent According to Tier-
2/2B (Fig. 4.8)
```

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```vb
        'Assumes each bridge span is a SS span loaded with LL on only
the bridge actual traffic lanes

        ' Truck Line Load
        If Truck = "HS20" Then
            SupportType = "SS"
            PBent_LL_TruckLaneLoad = (32 + (32 * (Span - 14) / Span) +
(8 * (Span - 14) / Span)) * NumberLanesLoaded * 1.1
            'Assumes an impact factor of 1.1

        Else 'Truck = HS15
            SupportType = "SS"
            PBent_LL_TruckLaneLoad = (24 + (24 * (Span - 14) / Span) +
(6 * (Span - 14) / Span)) * NumberLanesLoaded * 1.1
            'Assumes an impact factor of 1.1

        End If

        ' Design Lane Load (conservatively assumes max design lane load
of 64 psf for HS20 _
        ' and 48 psf for HS15; see Phase II report Fig. 4.6
        If Truck = "HS20" Then
            SupportType = "SS"
            PBent_LL_DesignLaneLoad = (LaneLd * 10 * Span +
ConcLoadforLaneLdg) * NumberLanesLoaded * 1.1
            ' Assumes an impact factor of 1.1

        Else ' Truck = HS15
            SupportType = "SS"
            PBent_LL_DesignLaneLoad = (LaneLd * 10 * Span +
ConcLoadforLaneLdg) * NumberLanesLoaded * 1.1
            ' Assumes an impact factor of 1.1

        End If

        PmaxApplLive_Bent = Math.Max(PBent_LL_TruckLaneLoad,
PBent_LL_DesignLaneLoad)

        PMaxAppl_Bent_LL = PmaxApplDead_Bent + PmaxApplLive_Bent
    End Function
End Module
```

APPENDIX L: CODE FOR AUTOMATED SCREENING TOOL KICK-OUT

AND PLUNGING FORM AND RELATED MODULES

```vb
Public Class KickOutPlunging

    Public DrivingResist, DrivingEnergy, BearingCap, PmaxDesign, _
FrictionCap As Single
    Public HammerType, PileType, HammEngy, DrivingEng As String
    Public Lbg, Smax, PmaxApplPile, ScrEndBear, ScrFriction As Single
    Public NoLanesLoaded, PileNo, BentNum1, BentNum2, BentNum3, _
    BentNum4, BentNum5, BentNum6, BentNum7, BentNum8 As Integer

    Public Spanlength, GirderSpacing, DeckThick, DiaphThick, _
            CapWidth, CapDepth, CapLength, OutOutDeckWidth, _
CurbCurbWidth, _
            GirderWeightPerFoot, GirderDepth, GirderDensity, _
OverhangThick, OverhangWidth, _
            JerseyBarrierWtPerFt, LaneLoad, ConcLoadforLaneLoading, _
SteelDepth, SteelWt, _
            TFlangeWidth, TFlangeThick, WebWidth, WebDepth, _
BFlangeWidth, BFlangeThick, GirdArea As Single
    Public PmaxApplBent As Single

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As _
System.EventArgs) Handles Button2.Click
        End 'Ends program when prompted
    End Sub

    Private Sub KickOutPlunging_Load(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles MyBase.Load

        'Adds options to the hammer type combo box
        comboHammerTyp.Items.Add("Single acting air/steam (Assumed 67% _
Efficient)")
        comboHammerTyp.Items.Add("Double acting air/steam (Assumed 50% _
Efficient)")
        comboHammerTyp.Items.Add("Diesel (Assumed 80% Efficient)")
        comboHammerTyp.Items.Add("Drop Hammers (Assumed 50% _
Efficient)")

    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As _
System.EventArgs) Handles Button1.Click
        'Apply text box values to variables
        HammerType = comboHammerTyp.SelectedItem
        PmaxDesign = (Pmax.txtPmaxApplPile.Text) / 2 'tons
        PileNo = Val(txtNumPiles.Text)

        'Displays the Max Applied Pile load on form so the capacity can _
be compared.
        txtPmaxPileDesign.Enabled = True
        txtPmaxPileDesign.Text = PmaxDesign.ToString("###0.00")

        'Info from Pmax module to calculate Pmax applied bent
        DeckThick = Pmax.DeckThick
        OutOutDeckWidth = Pmax.OutOutDeckWidth
```

```vb
        Spanlength = Pmax.Spanlength
        OverhangThick = Pmax.OverhangThick
        OverhangWidth = Pmax.OverhangWidth
        DiaphThick = Pmax.DiaphThick
        GirderDepth = Pmax.GirderDepth
        GirderSpacing = Pmax.GirderSpacing
        GirderDensity = Pmax.GirderDensity
        NoDiaphPerSpan = Pmax.NoDiaphPerSpan
        GirderWeightPerFoot = Pmax.GirderWeightPerFoot
        NoGirdersPerSpan = Pmax.NoGirdersPerSpan
        JerseyBarrierWtPerFt = Pmax.JerseyBarrierWtPerFt
        CapWidth = Pmax.CapWidth
        CapDepth = Pmax.CapDepth
        CapLength = Pmax.CapLength
        DesignTruck = Pmax.DesignTruck
        LaneLoad = Pmax.LaneLoad
        ConcLoadforLaneLoading = Pmax.ConcLoadforLaneLoading
        Support = Pmax.Support
        GirderMaterial = Pmax.GirderMaterial

        BentNum1 = Val(txtBent1.Text)
        If BentNum1 <> "0" Then
            Lbg = Val(txtLbg1.Text)
            Smax = Val(txtSmax1.Text)
            DrivingResist = Val(txtDriveResist1.Text)   'blows/inch
            If DrivingResist > 8 Then
                MsgBox("Maximum driving resistance evaluated is 8
blows/inch." _
                    & " End the program or re-evaluate bridge" _
                    & " bent at a lower driving resistance.")
            End If

            DrivingEnergy = Val(txtHamEngy1.Text) 'ft-lb
            If HammerType = "Single acting air/steam (Assumed 67%
Efficient)" Then  'Reduces Drivng Energy based on hammer efficiency
                HammEngy = DrivingEnergy * 0.67
            ElseIf HammerType = "Double acting air/steam (Assumed 50%
Efficient)" Then
                HammEngy = DrivingEnergy * 0.5
            ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
                HammEngy = DrivingEnergy * 0.8
            ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)"
Then
                HammEngy = DrivingEnergy * 0.5
            End If

            BearingCap = ScrPlunging_EndBearingCap(HammEngy,
DrivingResist, Smax, Lbg)
            txtEndCap1.Enabled = True
            txtEndCap1.Text = BearingCap.ToString("##0.00")

            ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
            If ScrEndBear < 0 Then
```

```vb
                    MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                    & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrEndBear >= Smax Then
                txtEbScr1.Enabled = True
                txtEbScr1.Text = ScrEndBear.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtEndSafe1.Enabled = True
                txtEndSafe1.ForeColor = Color.Black
                txtEndSafe1.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtEbScr1.Enabled = True
                    txtEbScr1.Text = ScrEndBear.ToString("##0.00")
                    txtEndSafe1.Enabled = True
                    txtEndSafe1.ForeColor = Color.Red
                    txtEndSafe1.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2   'tons

                    ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                    If ScrEndBear >= Smax Then
                        txtEbScr1.Enabled = True
                        txtEbScr1.Text = ScrEndBear.ToString("##0.00")
                        txtEndSafe1.Enabled = True
                        txtEndSafe1.ForeColor = Color.Black
                        txtEndSafe1.Text = "SAFE"
                    Else
                        txtEbScr1.Enabled = True
                        txtEbScr1.Text = ScrEndBear.ToString("##0.00")
                        txtEndSafe1.Enabled = True
                        txtEndSafe1.ForeColor = Color.Red
                        txtEndSafe1.Text = "UNSAFE"
                    End If
                End If
            End If
```

```vbnet
                FrictionCap = ScrPlunging_FrictionCap(HammEngy,
DrivingResist, Smax, Lbg)
                txtFricCap1.Enabled = True
                txtFricCap1.Text = FrictionCap.ToString("###0.00")

                ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist,
PmaxDesign, Lbg)
                If ScrFriction < 0 Then
                    MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                    & Chr(13) & "Therefore, the bent pile is unsafe.")
                End If

                If ScrFriction >= Smax Then
                    txtFpScr1.Enabled = True
                    txtFpScr1.Text = ScrFriction.ToString("##0.00")
                    'Displays following message if Scr is greater than Smax
                    txtFricSafe1.Enabled = True
                    txtFricSafe1.ForeColor = Color.Black
                    txtFricSafe1.Text = "SAFE"
                Else 'Checks more closely for possible plunging failure
                    If Pmax.radbtnPmaxValues.Checked = True Then
                        txtFpScr1.Enabled = True
                        txtFpScr1.Text = ScrFriction.ToString("##0.00")
                        txtFricSafe1.Enabled = True
                        txtFricSafe1.ForeColor = Color.Red
                        txtFricSafe1.Text = "UNSAFE"
                        MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                        & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                    Else
                        NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                        PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
                        PmaxDesign = (PmaxApplBent / PileNo) / 2   'tons

                        ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                        If ScrFriction >= Smax Then
                            txtFpScr1.Enabled = True
                            txtFpScr1.Text = ScrFriction.ToString("##0.00")
                            'Displays following message if Scr is greater
than Smax
                            txtFricSafe1.Enabled = True
```

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```vbnet
                            txtFricSafe1.ForeColor = Color.Black
                            txtFricSafe1.Text = "SAFE"
                        Else
                            txtFpScr1.Enabled = True
                            txtFpScr1.Text = ScrFriction.ToString("##0.00")
                            txtFricSafe1.Enabled = True
                            txtFricSafe1.ForeColor = Color.Red
                            txtFricSafe1.Text = "UNSAFE"
                        End If
                    End If
                End If
            End If
            BentNum2 = Val(txtBent2.Text)
            If BentNum2 <> "0" Then
                Lbg = Val(txtLbg2.Text)
                Smax = Val(txtSmax2.Text)
                DrivingResist = Val(txtDriveResist2.Text)  'blows/inch
                If DrivingResist > 8 Then
                    MsgBox("Maximum driving resistance evaluated is 8 _
blows/inch." _
                        & " End the program or re-evaluate bridge" _
                        & " bent at a lower driving resistance.")
                End If

                DrivingEnergy = Val(txtHamEngy2.Text) 'ft-lb
                If HammerType = "Single acting air/steam (Assumed 67%
Efficient)" Then  'Reduces Drivng Energy based on hammer efficiency
                    HammEngy = DrivingEnergy * 0.67
                ElseIf HammerType = "Double acting air/steam (Assumed 50%
Efficient)" Then
                    HammEngy = DrivingEnergy * 0.5
                ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
                    HammEngy = DrivingEnergy * 0.8
                ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)"
Then
                    HammEngy = DrivingEnergy * 0.5
                End If

                BearingCap = ScrPlunging_EndBearingCap(HammEngy,
DrivingResist, Smax, Lbg)
                txtEndCap2.Enabled = True
                txtEndCap2.Text = BearingCap.ToString("###0.00")

                ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                If ScrEndBear < 0 Then
                    MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                        & Chr(13) & "Therefore, the bent pile is unsafe.")
                End If

                If ScrEndBear >= Smax Then
                    txtEbScr2.Enabled = True
```

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```vb
                    txtEbScr2.Text = ScrEndBear.ToString("##0.00")
                    'Displays following message if Scr is greater than Smax
                    txtEndSafe2.Enabled = True
                    txtEndSafe2.ForeColor = Color.Black
                    txtEndSafe2.Text = "SAFE"
                Else 'Checks more closely for possible plunging failure
                    If Pmax.radbtnPmaxValues.Checked = True Then
                        txtEbScr2.Enabled = True
                        txtEbScr2.Text = ScrEndBear.ToString("##0.00")
                        txtEndSafe2.Enabled = True
                        txtEndSafe2.ForeColor = Color.Red
                        txtEndSafe2.Text = "UNSAFE"
                        MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                        & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                    Else
                        NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                        PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                                OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                                NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                                CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                                NoLanesLoaded, Support, GirderMaterial)
                        PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                        ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                        If ScrEndBear >= Smax Then
                            txtEbScr2.Enabled = True
                            txtEbScr2.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe2.Enabled = True
                            txtEndSafe2.ForeColor = Color.Black
                            txtEndSafe2.Text = "SAFE"
                        Else
                            txtEbScr2.Enabled = True
                            txtEbScr2.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe2.Enabled = True
                            txtEndSafe2.ForeColor = Color.Red
                            txtEndSafe2.Text = "UNSAFE"
                        End If
                    End If
                End If

                FrictionCap = ScrPlunging_FrictionCap(HammEngy,
DrivingResist, Smax, Lbg)
                txtFricCap2.Enabled = True
                txtFricCap2.Text = FrictionCap.ToString("###0.00")

                ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist,
PmaxDesign, Lbg)
```

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            If ScrFriction < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrFriction >= Smax Then
                txtFpScr2.Enabled = True
                txtFpScr2.Text = ScrFriction.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtFricSafe2.Enabled = True
                txtFricSafe2.ForeColor = Color.Black
                txtFricSafe2.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtFpScr2.Enabled = True
                    txtFpScr2.Text = ScrFriction.ToString("##0.00")
                    txtFricSafe2.Enabled = True
                    txtFricSafe2.ForeColor = Color.Red
                    txtFricSafe2.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                    ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                    If ScrFriction >= Smax Then
                        txtFpScr2.Enabled = True
                        txtFpScr2.Text = ScrFriction.ToString("##0.00")
                        'Displays following message if Scr is greater
than Smax
                        txtFricSafe2.Enabled = True
                        txtFricSafe2.ForeColor = Color.Black
                        txtFricSafe2.Text = "SAFE"
                    Else
                        txtFpScr2.Enabled = True
                        txtFpScr2.Text = ScrFriction.ToString("##0.00")
                        txtFricSafe2.Enabled = True
                        txtFricSafe2.ForeColor = Color.Red
                        txtFricSafe2.Text = "UNSAFE"
```

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                End If
            End If
        End If
    End If

    BentNum3 = Val(txtBent3.Text)
    If BentNum3 <> "0" Then
        Lbg = Val(txtLbg3.Text)
        Smax = Val(txtSmax3.Text)
        DrivingResist = Val(txtDriveResist3.Text)   'blows/inch
        If DrivingResist > 8 Then
            MsgBox("Maximum driving resistance evaluated is 8 blows/inch." _
                & " End the program or re-evaluate bridge" _
                & " bent at a lower driving resistance.")
        End If

        DrivingEnergy = Val(txtHamEngy3.Text) 'ft-lb
        If HammerType = "Single acting air/steam (Assumed 67% Efficient)" Then  'Reduces Drivng Energy based on hammer efficiency
            HammEngy = DrivingEnergy * 0.67
        ElseIf HammerType = "Double acting air/steam (Assumed 50% Efficient)" Then
            HammEngy = DrivingEnergy * 0.5
        ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
            HammEngy = DrivingEnergy * 0.8
        ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)" Then
            HammEngy = DrivingEnergy * 0.5
        End If

        BearingCap = ScrPlunging_EndBearingCap(HammEngy, DrivingResist, Smax, Lbg)
        txtEndCap3.Enabled = True
        txtEndCap3.Text = BearingCap.ToString("###0.00")

        ScrEndBear = ScrPlunging_EndBearing(HammEngy, DrivingResist, PmaxDesign, Lbg)
        If ScrEndBear < 0 Then
            MsgBox("Projected critical scour value for pile capacity calculated is negative because the pile capacity is less than maximum applied axial load." _
                & Chr(13) & "Therefore, the bent pile is unsafe.")
        End If

        If ScrEndBear >= Smax Then
            txtEbScr3.Enabled = True
            txtEbScr3.Text = ScrEndBear.ToString("##0.00")
            'Displays following message if Scr is greater than Smax
            txtEndSafe3.Enabled = True
            txtEndSafe3.ForeColor = Color.Black
            txtEndSafe3.Text = "SAFE"
        Else 'Checks more closely for possible plunging failure
            If Pmax.radbtnPmaxValues.Checked = True Then
```

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                    txtEbScr3.Enabled = True
                    txtEbScr3.Text = ScrEndBear.ToString("##0.00")
                    txtEndSafe3.Enabled = True
                    txtEndSafe3.ForeColor = Color.Red
                    txtEndSafe3.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                    ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                        If ScrEndBear >= Smax Then
                            txtEbScr3.Enabled = True
                            txtEbScr3.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe3.Enabled = True
                            txtEndSafe3.ForeColor = Color.Black
                            txtEndSafe3.Text = "SAFE"
                        Else
                            txtEbScr3.Enabled = True
                            txtEbScr3.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe3.Enabled = True
                            txtEndSafe3.ForeColor = Color.Red
                            txtEndSafe3.Text = "UNSAFE"
                        End If
                    End If
            End If

            FrictionCap = ScrPlunging_FrictionCap(HammEngy,
DrivingResist, Smax, Lbg)
            txtFricCap3.Enabled = True
            txtFricCap3.Text = FrictionCap.ToString("###0.00")

            ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist,
PmaxDesign, Lbg)
            If ScrFriction < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If
```

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            If ScrFriction >= Smax Then
                txtFpScr3.Enabled = True
                txtFpScr3.Text = ScrFriction.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtFricSafe3.Enabled = True
                txtFricSafe3.ForeColor = Color.Black
                txtFricSafe3.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtFpScr3.Enabled = True
                    txtFpScr3.Text = ScrFriction.ToString("##0.00")
                    txtFricSafe3.Enabled = True
                    txtFricSafe3.ForeColor = Color.Red
                    txtFricSafe3.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                    ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                    If ScrFriction >= Smax Then
                        txtFpScr3.Enabled = True
                        txtFpScr3.Text = ScrFriction.ToString("##0.00")
                        'Displays following message if Scr is greater
than Smax
                        txtFricSafe3.Enabled = True
                        txtFricSafe3.ForeColor = Color.Black
                        txtFricSafe3.Text = "SAFE"
                    Else
                        txtFpScr3.Enabled = True
                        txtFpScr3.Text = ScrFriction.ToString("##0.00")
                        txtFricSafe3.Enabled = True
                        txtFricSafe3.ForeColor = Color.Red
                        txtFricSafe3.Text = "UNSAFE"
                    End If
                End If
            End If
        End If

        BentNum4 = Val(txtBent4.Text)
        If BentNum4 <> "0" Then
```

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            Lbg = Val(txtLbg4.Text)
            Smax = Val(txtSmax4.Text)
            DrivingResist = Val(txtDriveResist4.Text)  'blows/inch
            If DrivingResist > 8 Then
                MsgBox("Maximum driving resistance evaluated is 8
blows/inch." _
                    & " End the program or re-evaluate bridge" _
                    & " bent at a lower driving resistance.")
            End If

            DrivingEnergy = Val(txtHamEngy4.Text) 'ft-lb
            If HammerType = "Single acting air/steam (Assumed 67%
Efficient)" Then  'Reduces Drivng Energy based on hammer efficiency
                HammEngy = DrivingEnergy * 0.67
            ElseIf HammerType = "Double acting air/steam (Assumed 50%
Efficient)" Then
                HammEngy = DrivingEnergy * 0.5
            ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
                HammEngy = DrivingEnergy * 0.8
            ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)"
Then
                HammEngy = DrivingEnergy * 0.5
            End If

            BearingCap = ScrPlunging_EndBearingCap(HammEngy,
DrivingResist, Smax, Lbg)
            txtEndCap4.Enabled = True
            txtEndCap4.Text = BearingCap.ToString("###0.00")

            ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
            If ScrEndBear < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                    & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrEndBear >= Smax Then
                txtEbScr4.Enabled = True
                txtEbScr4.Text = ScrEndBear.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtEndSafe4.Enabled = True
                txtEndSafe4.ForeColor = Color.Black
                txtEndSafe4.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtEbScr4.Enabled = True
                    txtEbScr4.Text = ScrEndBear.ToString("##0.00")
                    txtEndSafe4.Enabled = True
                    txtEndSafe4.ForeColor = Color.Red
                    txtEndSafe4.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
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                        & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                    Else
                        NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                        PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                                OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                                NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                                CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                                NoLanesLoaded, Support, GirderMaterial)
                        PmaxDesign = (PmaxApplBent / PileNo) / 2   'tons

                        ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                        If ScrEndBear >= Smax Then
                            txtEbScr4.Enabled = True
                            txtEbScr4.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe4.Enabled = True
                            txtEndSafe4.ForeColor = Color.Black
                            txtEndSafe4.Text = "SAFE"
                        Else
                            txtEbScr4.Enabled = True
                            txtEbScr4.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe4.Enabled = True
                            txtEndSafe4.ForeColor = Color.Red
                            txtEndSafe4.Text = "UNSAFE"
                        End If
                    End If
                End If

                FrictionCap = ScrPlunging_FrictionCap(HammEngy,
DrivingResist, Smax, Lbg)
                txtFricCap4.Enabled = True
                txtFricCap4.Text = FrictionCap.ToString("###0.00")

                ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist,
PmaxDesign, Lbg)
                If ScrFriction < 0 Then
                    MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                    & Chr(13) & "Therefore, the bent pile is unsafe.")
                End If

                If ScrFriction >= Smax Then
                    txtFpScr4.Enabled = True
                    txtFpScr4.Text = ScrFriction.ToString("##0.00")
                    'Displays following message if Scr is greater than Smax
                    txtFricSafe4.Enabled = True
                    txtFricSafe4.ForeColor = Color.Black
                    txtFricSafe4.Text = "SAFE"
```

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```vb
                    MsgBox("Since the maximum applied pile and bent axial
loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else 'Checks more closely for possible plunging failure
                    If Pmax.radbtnPmaxValues.Checked = True Then
                        txtFpScr4.Enabled = True
                        txtFpScr4.Text = ScrFriction.ToString("##0.00")
                        txtFricSafe4.Enabled = True
                        txtFricSafe4.ForeColor = Color.Red
                        txtFricSafe4.Text = "UNSAFE"
                    Else
                        NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                        PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                                OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                                NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                                CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                                NoLanesLoaded, Support, GirderMaterial)
                        PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                        ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                        If ScrFriction >= Smax Then
                            txtFpScr4.Enabled = True
                            txtFpScr4.Text = ScrFriction.ToString("##0.00")
                            'Displays following message if Scr is greater
than Smax
                            txtFricSafe4.Enabled = True
                            txtFricSafe4.ForeColor = Color.Black
                            txtFricSafe4.Text = "SAFE"
                        Else
                            txtFpScr4.Enabled = True
                            txtFpScr4.Text = ScrFriction.ToString("##0.00")
                            txtFricSafe4.Enabled = True
                            txtFricSafe4.ForeColor = Color.Red
                            txtFricSafe4.Text = "UNSAFE"
                        End If
                    End If
                End If
            End If

        BentNum5 = Val(txtBent5.Text)
        If BentNum5 <> "0" Then
            Lbg = Val(txtLbg5.Text)
            Smax = Val(txtSmax5.Text)
            DrivingResist = Val(txtDriveResist5.Text)  'blows/inch
            If DrivingResist > 8 Then
                MsgBox("Maximum driving resistance evaluated is 8
blows/inch." _
                    & " End the program or re-evaluate bridge" _
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                                & " bent at a lower driving resistance.")
                End If

                DrivingEnergy = Val(txtHamEngy5.Text) 'ft-lb
                If HammerType = "Single acting air/steam (Assumed 67%
    Efficient)" Then   'Reduces Drivng Energy based on hammer efficiency
                    HammEngy = DrivingEnergy * 0.67
                ElseIf HammerType = "Double acting air/steam (Assumed 50%
    Efficient)" Then
                    HammEngy = DrivingEnergy * 0.5
                ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
                    HammEngy = DrivingEnergy * 0.8
                ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)"
    Then
                    HammEngy = DrivingEnergy * 0.5
                End If

                BearingCap = ScrPlunging_EndBearingCap(HammEngy,
    DrivingResist, Smax, Lbg)
                txtEndCap5.Enabled = True
                txtEndCap5.Text = BearingCap.ToString("###0.00")

                ScrEndBear = ScrPlunging_EndBearing(HammEngy,
    DrivingResist, PmaxDesign, Lbg)
                If ScrEndBear < 0 Then
                    MsgBox("Projected critical scour value for pile
    capacity calculated is negative because the pile capacity is less than
    maximum applied axial load." _
                    & Chr(13) & "Therefore, the bent pile is unsafe.")
                End If

                If ScrEndBear >= Smax Then
                    txtEbScr5.Enabled = True
                    txtEbScr5.Text = ScrEndBear.ToString("##0.00")
                    'Displays following message if Scr is greater than Smax
                    txtEndSafe5.Enabled = True
                    txtEndSafe5.ForeColor = Color.Black
                    txtEndSafe5.Text = "SAFE"
                Else 'Checks more closely for possible plunging failure
                    If Pmax.radbtnPmaxValues.Checked = True Then
                        txtEbScr5.Enabled = True
                        txtEbScr5.Text = ScrEndBear.ToString("##0.00")
                        txtEndSafe5.Enabled = True
                        txtEndSafe5.ForeColor = Color.Red
                        txtEndSafe5.Text = "UNSAFE"
                        MsgBox("Since the maximum applied pile and bent
    axial loads were entered directly," _
                        & " the ST does not have the information needed to
    complete the Tier-2 plunging checks.")
                    Else
                        NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                        PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
    OutOutDeckWidth, Spanlength, _
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                                OverhangThick, OverhangWidth, DiaphThick, _
GirderDepth, GirderSpacing, GirderDensity, _
                                NoDiaphPerSpan, GirderWeightPerFoot, _
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                                CapWidth, CapDepth, CapLength, DesignTruck, _
LaneLoad, ConcLoadforLaneLoading, _
                                NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                    ScrEndBear = ScrPlunging_EndBearing(HammEngy, _
DrivingResist, PmaxDesign, Lbg)
                        If ScrEndBear >= Smax Then
                            txtEbScr5.Enabled = True
                            txtEbScr5.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe5.Enabled = True
                            txtEndSafe5.ForeColor = Color.Black
                            txtEndSafe5.Text = "SAFE"
                        Else
                            txtEbScr5.Enabled = True
                            txtEbScr5.Text = ScrEndBear.ToString("##0.00")
                            txtEndSafe5.Enabled = True
                            txtEndSafe5.ForeColor = Color.Red
                            txtEndSafe5.Text = "UNSAFE"
                        End If
                    End If
                End If

                FrictionCap = ScrPlunging_FrictionCap(HammEngy, _
DrivingResist, Smax, Lbg)
                txtFricCap5.Enabled = True
                txtFricCap5.Text = FrictionCap.ToString("###0.00")

                ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist, _
PmaxDesign, Lbg)
                If ScrFriction < 0 Then
                    MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                    & Chr(13) & "Therefore, the bent pile is unsafe.")
                End If

                If ScrFriction >= Smax Then
                    txtFpScr5.Enabled = True
                    txtFpScr5.Text = ScrFriction.ToString("##0.00")
                    'Displays following message if Scr is greater than Smax
                    txtFricSafe5.Enabled = True
                    txtFricSafe5.ForeColor = Color.Black
                    txtFricSafe5.Text = "SAFE"
                Else 'Checks more closely for possible plunging failure
                    If Pmax.radbtnPmaxValues.Checked = True Then
                        txtFpScr5.Enabled = True
                        txtFpScr5.Text = ScrFriction.ToString("##0.00")
                        txtFricSafe5.Enabled = True
                        txtFricSafe5.ForeColor = Color.Red
```

```vb
                            txtFricSafe5.Text = "UNSAFE"
                            MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                            & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                    Else
                            NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                            PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                                    OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                                    NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                                    CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                                    NoLanesLoaded, Support, GirderMaterial)
                            PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                            ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                            If ScrFriction >= Smax Then
                                txtFpScr5.Enabled = True
                                txtFpScr5.Text = ScrFriction.ToString("##0.00")
                                'Displays following message if Scr is greater
than Smax
                                txtFricSafe5.Enabled = True
                                txtFricSafe5.ForeColor = Color.Black
                                txtFricSafe5.Text = "SAFE"
                            Else
                                txtFpScr5.Enabled = True
                                txtFpScr5.Text = ScrFriction.ToString("##0.00")
                                txtFricSafe5.Enabled = True
                                txtFricSafe5.ForeColor = Color.Red
                                txtFricSafe5.Text = "UNSAFE"
                            End If
                    End If
                End If
            End If

        BentNum6 = Val(txtBent6.Text)
        If BentNum6 <> "0" Then
            Lbg = Val(txtLbg6.Text)
            Smax = Val(txtSmax6.Text)
            DrivingResist = Val(txtDriveResist6.Text)   'blows/inch
            If DrivingResist > 8 Then
                MsgBox("Maximum driving resistance evaluated is 8
blows/inch." _
                    & " End the program or re-evaluate bridge" _
                    & " bent at a lower driving resistance.")
            End If

            DrivingEnergy = Val(txtHamEngy6.Text) 'ft-lb
            If HammerType = "Single acting air/steam (Assumed 67%
Efficient)" Then  'Reduces Drivng Energy based on hammer efficiency
```

```vb
                HammEngy = DrivingEnergy * 0.67
            ElseIf HammerType = "Double acting air/steam (Assumed 50%
Efficient)" Then
                HammEngy = DrivingEnergy * 0.5
            ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
                HammEngy = DrivingEnergy * 0.8
            ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)"
Then
                HammEngy = DrivingEnergy * 0.5
            End If

            BearingCap = ScrPlunging_EndBearingCap(HammEngy,
DrivingResist, Smax, Lbg)
            txtEndCap6.Enabled = True
            txtEndCap6.Text = BearingCap.ToString("###0.00")

            ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
            If ScrEndBear < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrEndBear >= Smax Then
                txtEbScr6.Enabled = True
                txtEbScr6.Text = ScrEndBear.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtEndSafe6.Enabled = True
                txtEndSafe6.ForeColor = Color.Black
                txtEndSafe6.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtEbScr6.Enabled = True
                    txtEbScr6.Text = ScrEndBear.ToString("##0.00")
                    txtEndSafe6.Enabled = True
                    txtEndSafe6.ForeColor = Color.Red
                    txtEndSafe6.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
```

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```vbnet
                        PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                        ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                            If ScrEndBear >= Smax Then
                                txtEbScr6.Enabled = True
                                txtEbScr6.Text = ScrEndBear.ToString("##0.00")
                                txtEndSafe6.Enabled = True
                                txtEndSafe6.ForeColor = Color.Black
                                txtEndSafe6.Text = "SAFE"
                            Else
                                txtEbScr6.Enabled = True
                                txtEbScr6.Text = ScrEndBear.ToString("##0.00")
                                txtEndSafe6.Enabled = True
                                txtEndSafe6.ForeColor = Color.Red
                                txtEndSafe6.Text = "UNSAFE"
                            End If
                    End If
                End If


            FrictionCap = ScrPlunging_FrictionCap(HammEngy,
DrivingResist, Smax, Lbg)
            txtFricCap6.Enabled = True
            txtFricCap6.Text = FrictionCap.ToString("###0.00")

            ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist,
PmaxDesign, Lbg)
            If ScrFriction < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                    & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrFriction >= Smax Then
                txtFpScr6.Enabled = True
                txtFpScr6.Text = ScrFriction.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtFricSafe6.Enabled = True
                txtFricSafe6.ForeColor = Color.Black
                txtFricSafe6.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtFpScr6.Enabled = True
                    txtFpScr6.Text = ScrFriction.ToString("##0.00")
                    txtFricSafe6.Enabled = True
                    txtFricSafe6.ForeColor = Color.Red
                    txtFricSafe6.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                        & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
```

```vb
                        NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                        PmaxApplBent = PMaxAppl_Bent_LL(DeckThick, _
OutOutDeckWidth, Spanlength, _
                                OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                                NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                                CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                                NoLanesLoaded, Support, GirderMaterial)
                        PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                        ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                        If ScrFriction >= Smax Then
                            txtFpScr6.Enabled = True
                            txtFpScr6.Text = ScrFriction.ToString("##0.00")
                            'Displays following message if Scr is greater
than Smax
                            txtFricSafe6.Enabled = True
                            txtFricSafe6.ForeColor = Color.Black
                            txtFricSafe6.Text = "SAFE"
                        Else
                            txtFpScr6.Enabled = True
                            txtFpScr6.Text = ScrFriction.ToString("##0.00")
                            txtFricSafe6.Enabled = True
                            txtFricSafe6.ForeColor = Color.Red
                            txtFricSafe6.Text = "UNSAFE"
                        End If
                    End If
                End If
            End If

        BentNum7 = Val(txtBent7.Text)
        If BentNum7 <> "0" Then
            Lbg = Val(txtLbg7.Text)
            Smax = Val(txtSmax7.Text)
            DrivingResist = Val(txtDriveResist7.Text)   'blows/inch
            If DrivingResist > 8 Then
                MsgBox("Maximum driving resistance evaluated is 8
blows/inch." _
                    & " End the program or re-evaluate bridge" _
                    & " bent at a lower driving resistance.")
            End If

            DrivingEnergy = Val(txtHamEngy7.Text) 'ft-lb
            If HammerType = "Single acting air/steam (Assumed 67%
Efficient)" Then   'Reduces Drivng Energy based on hammer efficiency
                HammEngy = DrivingEnergy * 0.67
            ElseIf HammerType = "Double acting air/steam (Assumed 50%
Efficient)" Then
                HammEngy = DrivingEnergy * 0.5
            ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
                HammEngy = DrivingEnergy * 0.8
```

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```vb
            ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)"
Then
                HammEngy = DrivingEnergy * 0.5
            End If

            BearingCap = ScrPlunging_EndBearingCap(HammEngy,
DrivingResist, Smax, Lbg)
            txtEndCap7.Enabled = True
            txtEndCap7.Text = BearingCap.ToString("###0.00")

            ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
            If ScrEndBear < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrEndBear >= Smax Then
                txtEbScr7.Enabled = True
                txtEbScr7.Text = ScrEndBear.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtEndSafe7.Enabled = True
                txtEndSafe7.ForeColor = Color.Black
                txtEndSafe7.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtEbScr7.Enabled = True
                    txtEbScr7.Text = ScrEndBear.ToString("##0.00")
                    txtEndSafe7.Enabled = True
                    txtEndSafe7.ForeColor = Color.Red
                    txtEndSafe7.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                                OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                                NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                                CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                                NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2   'tons

                    ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                    If ScrEndBear >= Smax Then
                        txtEbScr7.Enabled = True
```

```vb
                                    txtEbScr7.Text = ScrEndBear.ToString("##0.00")
                                    txtEndSafe7.Enabled = True
                                    txtEndSafe7.ForeColor = Color.Black
                                    txtEndSafe7.Text = "SAFE"
                               Else
                                    txtEbScr7.Enabled = True
                                    txtEbScr7.Text = ScrEndBear.ToString("##0.00")
                                    txtEndSafe7.Enabled = True
                                    txtEndSafe7.ForeColor = Color.Red
                                    txtEndSafe7.Text = "UNSAFE"
                               End If
                          End If
                     End If

                     FrictionCap = ScrPlunging_FrictionCap(HammEngy,
DrivingResist, Smax, Lbg)
                     txtFricCap7.Enabled = True
                     txtFricCap7.Text = FrictionCap.ToString("###0.00")

                     ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist,
PmaxDesign, Lbg)
                     If ScrFriction < 0 Then
                          MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                               & Chr(13) & "Therefore, the bent pile is unsafe.")
                     End If

                     If ScrFriction >= Smax Then
                          txtFpScr7.Enabled = True
                          txtFpScr7.Text = ScrFriction.ToString("##0.00")
                          'Displays following message if Scr is greater than Smax
                          txtFricSafe7.Enabled = True
                          txtFricSafe7.ForeColor = Color.Black
                          txtFricSafe7.Text = "SAFE"
                     Else 'Checks more closely for possible plunging failure
                          If Pmax.radbtnPmaxValues.Checked = True Then
                               txtFpScr7.Enabled = True
                               txtFpScr7.Text = ScrFriction.ToString("##0.00")
                               txtFricSafe7.Enabled = True
                               txtFricSafe7.ForeColor = Color.Red
                               txtFricSafe7.Text = "UNSAFE"
                               MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                               & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                          Else
                               NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                               PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                                    OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                                    NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
```

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```vbnet
                                    CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                                NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                    ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                        If ScrFriction >= Smax Then
                            txtFpScr7.Enabled = True
                            txtFpScr7.Text = ScrFriction.ToString("##0.00")
                            'Displays following message if Scr is greater
than Smax
                            txtFricSafe7.Enabled = True
                            txtFricSafe7.ForeColor = Color.Black
                            txtFricSafe7.Text = "SAFE"
                        Else
                            txtFpScr7.Enabled = True
                            txtFpScr7.Text = ScrFriction.ToString("##0.00")
                            txtFricSafe7.Enabled = True
                            txtFricSafe7.ForeColor = Color.Red
                            txtFricSafe7.Text = "UNSAFE"
                        End If
                    End If
                End If
        End If

        BentNum8 = Val(txtBent8.Text)
        If BentNum8 <> "0" Then
            Lbg = Val(txtLbg8.Text)
            Smax = Val(txtSmax8.Text)
            DrivingResist = Val(txtDriveResist8.Text)  'blows/inch
            If DrivingResist > 8 Then
                MsgBox("Maximum driving resistance evaluated is 8
blows/inch." _
                    & " End the program or re-evaluate bridge" _
                    & " bent at a lower driving resistance.")
            End If

            DrivingEnergy = Val(txtHamEngy8.Text) 'ft-lb
            If HammerType = "Single acting air/steam (Assumed 67%
Efficient)" Then  'Reduces Drivng Energy based on hammer efficiency
                HammEngy = DrivingEnergy * 0.67
            ElseIf HammerType = "Double acting air/steam (Assumed 50%
Efficient)" Then
                HammEngy = DrivingEnergy * 0.5
            ElseIf HammerType = "Diesel (Assumed 80% Efficient)" Then
                HammEngy = DrivingEnergy * 0.8
            ElseIf HammerType = "Drop Hammers (Assumed 50% Efficient)"
Then
                HammEngy = DrivingEnergy * 0.5
            End If

            BearingCap = ScrPlunging_EndBearingCap(HammEngy,
DrivingResist, Smax, Lbg)
```

```vb
            txtEndCap8.Enabled = True
            txtEndCap8.Text = BearingCap.ToString("###0.00")

            ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
            If ScrEndBear < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrEndBear >= Smax Then
                txtEbScr8.Enabled = True
                txtEbScr8.Text = ScrEndBear.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtEndSafe8.Enabled = True
                txtEndSafe8.ForeColor = Color.Black
                txtEndSafe8.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtEbScr8.Enabled = True
                    txtEbScr8.Text = ScrEndBear.ToString("##0.00")
                    txtEndSafe8.Enabled = True
                    txtEndSafe8.ForeColor = Color.Red
                    txtEndSafe8.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                    ScrEndBear = ScrPlunging_EndBearing(HammEngy,
DrivingResist, PmaxDesign, Lbg)
                    If ScrEndBear >= Smax Then
                        txtEbScr8.Enabled = True
                        txtEbScr8.Text = ScrEndBear.ToString("##0.00")
                        txtEndSafe8.Enabled = True
                        txtEndSafe8.ForeColor = Color.Black
                        txtEndSafe8.Text = "SAFE"
                    Else
                        txtEbScr8.Enabled = True
                        txtEbScr8.Text = ScrEndBear.ToString("##0.00")
```

```vb
                        txtEndSafe8.Enabled = True
                        txtEndSafe8.ForeColor = Color.Red
                        txtEndSafe8.Text = "UNSAFE"
                    End If
                End If
            End If

            FrictionCap = ScrPlunging_FrictionCap(HammEngy,
DrivingResist, Smax, Lbg)
            txtFricCap8.Enabled = True
            txtFricCap8.Text = FrictionCap.ToString("###0.00")

            ScrFriction = ScrPlunging_Friction(HammEngy, DrivingResist,
PmaxDesign, Lbg)
            If ScrFriction < 0 Then
                MsgBox("Projected critical scour value for pile
capacity calculated is negative because the pile capacity is less than
maximum applied axial load." _
                & Chr(13) & "Therefore, the bent pile is unsafe.")
            End If

            If ScrFriction >= Smax Then
                txtFpScr8.Enabled = True
                txtFpScr8.Text = ScrFriction.ToString("##0.00")
                'Displays following message if Scr is greater than Smax
                txtFricSafe8.Enabled = True
                txtFricSafe8.ForeColor = Color.Black
                txtFricSafe8.Text = "SAFE"
            Else 'Checks more closely for possible plunging failure
                If Pmax.radbtnPmaxValues.Checked = True Then
                    txtFpScr8.Enabled = True
                    txtFpScr8.Text = ScrFriction.ToString("##0.00")
                    txtFricSafe8.Enabled = True
                    txtFricSafe8.ForeColor = Color.Red
                    txtFricSafe8.Text = "UNSAFE"
                    MsgBox("Since the maximum applied pile and bent
axial loads were entered directly," _
                    & " the ST does not have the information needed to
complete the Tier-2 plunging checks.")
                Else
                    NoLanesLoaded = Val(Pmax.txtNumLanes.Text)
                    PmaxApplBent = PMaxAppl_Bent_LL(DeckThick,
OutOutDeckWidth, Spanlength, _
                            OverhangThick, OverhangWidth, DiaphThick,
GirderDepth, GirderSpacing, GirderDensity, _
                            NoDiaphPerSpan, GirderWeightPerFoot,
NoGirdersPerSpan, JerseyBarrierWtPerFt, _
                            CapWidth, CapDepth, CapLength, DesignTruck,
LaneLoad, ConcLoadforLaneLoading, _
                            NoLanesLoaded, Support, GirderMaterial)
                    PmaxDesign = (PmaxApplBent / PileNo) / 2    'tons

                    ScrFriction = ScrPlunging_Friction(HammEngy,
DrivingResist, PmaxDesign, Lbg)
```

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```vb
                        If ScrFriction >= Smax Then
                            txtFpScr8.Enabled = True
                            txtFpScr8.Text = ScrFriction.ToString("##0.00")
                            'Displays following message if Scr is greater
than Smax
                            txtFricSafe8.Enabled = True
                            txtFricSafe8.ForeColor = Color.Black
                            txtFricSafe8.Text = "SAFE"
                        Else
                            txtFpScr8.Enabled = True
                            txtFpScr8.Text = ScrFriction.ToString("##0.00")
                            txtFricSafe8.Enabled = True
                            txtFricSafe8.ForeColor = Color.Red
                            txtFricSafe8.Text = "UNSAFE"
                        End If
                    End If
                End If
            End If
        End Sub

    Private Sub radbtnNo2_CheckedChanged(ByVal sender As System.Object,
_
        ByVal e As System.EventArgs) Handles radbtnNo2.CheckedChanged

        'Creates message if the No is checked when answering if the
pile has
        'more than 3 feet of embedment after scour.
        If radbtnNo2.Checked = True Then
            MsgBox("Check more closely for possible 'kick-out' failure
of pile/bent.")

        End If

    End Sub

    Private Sub radbtnNo1_CheckedChanged_1(ByVal sender As
System.Object, _
        ByVal e As System.EventArgs) Handles radbtnNo1.CheckedChanged

        If radbtnNo1.Checked = True Then
            MsgBox("Pile/Bent is safe from 'kick-out' failure." _
            & Chr(13) & Chr(13) & "You may now continue with the
program.")
        End If
    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
        My.Forms.Buckling.Show()                    'Moves to next form
        WindowState = FormWindowState.Minimized  'Minimizes current
form
    End Sub
```

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```vb
    Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button4.Click
        'Erases values in the text boxes in case more runs or new runs
need to be done
        txtBent1.Text = " "
        txtLbg1.Text = " "
        txtSmax1.Text = " "
        txtDriveResist1.Text = " "
        txtHamEngy1.Text = " "
        txtEndCap1.Text = " "
        txtFricCap1.Text = " "
        txtEndSafe1.Text = " "
        txtFricSafe1.Text = " "
        txtFpScr1.Text = " "
        txtEbScr1.Text = " "

        txtBent2.Text = " "
        txtLbg2.Text = " "
        txtSmax2.Text = " "
        txtDriveResist2.Text = " "
        txtHamEngy2.Text = " "
        txtEndCap2.Text = " "
        txtFricCap2.Text = " "
        txtEndSafe2.Text = " "
        txtFricSafe2.Text = " "
        txtFpScr2.Text = " "
        txtEbScr2.Text = " "

        txtBent3.Text = " "
        txtLbg3.Text = " "
        txtSmax3.Text = " "
        txtDriveResist3.Text = " "
        txtHamEngy3.Text = " "
        txtEndCap3.Text = " "
        txtFricCap3.Text = " "
        txtEndSafe3.Text = " "
        txtFricSafe3.Text = " "
        txtFpScr3.Text = " "
        txtEbScr3.Text = " "

        txtBent4.Text = " "
        txtLbg4.Text = " "
        txtSmax4.Text = " "
        txtDriveResist4.Text = " "
        txtHamEngy4.Text = " "
        txtEndCap4.Text = " "
        txtFricCap4.Text = " "
        txtEndSafe4.Text = " "
        txtFricSafe4.Text = " "
        txtFpScr4.Text = " "
        txtEbScr4.Text = " "

        txtBent5.Text = " "
        txtLbg5.Text = " "
```

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```
        txtSmax5.Text = " "
        txtDriveResist5.Text = " "
        txtHamEngy5.Text = " "
        txtEndCap5.Text = " "
        txtFricCap5.Text = " "
        txtEndSafe5.Text = " "
        txtFricSafe5.Text = " "
        txtFpScr5.Text = " "
        txtEbScr5.Text = " "

        txtBent6.Text = " "
        txtLbg6.Text = " "
        txtSmax6.Text = " "
        txtDriveResist6.Text = " "
        txtHamEngy6.Text = " "
        txtEndCap6.Text = " "
        txtFricCap6.Text = " "
        txtEndSafe6.Text = " "
        txtFricSafe6.Text = " "
        txtFpScr6.Text = " "
        txtEbScr6.Text = " "

        txtBent7.Text = " "
        txtLbg7.Text = " "
        txtSmax7.Text = " "
        txtDriveResist7.Text = " "
        txtHamEngy7.Text = " "
        txtEndCap7.Text = " "
        txtFricCap7.Text = " "
        txtEndSafe7.Text = " "
        txtFricSafe7.Text = " "
        txtFpScr7.Text = " "
        txtEbScr7.Text = " "

        txtBent8.Text = " "
        txtLbg8.Text = " "
        txtSmax8.Text = " "
        txtDriveResist8.Text = " "
        txtHamEngy8.Text = " "
        txtEndCap8.Text = " "
        txtFricCap8.Text = " "
        txtEndSafe8.Text = " "
        txtFricSafe8.Text = " "
        txtFpScr8.Text = " "
        txtEbScr8.Text = " "
    End Sub
End Class
```

```vb
Module Scr_Plunging

    Public bc As Double
    Public AllowResist, Capacity80Loss, Slope, PercLoss, _
EndBearCapacity, FrictionCapacity As Single
    Function ScrPlunging_EndBearing(ByVal HammEnergy As Single, ByVal _
BlowCnt As Double, _
        ByVal PmaxDesign As Single, ByVal Lbg As Single) As Double

        'Uses Gates formula to calc allowable resistance (tons).
        bc = Math.Log10(10 * BlowCnt)
        AllowResist = ((0.875 * (HammEnergy ^ 0.5) * bc) - 50) / 1.25
'Allowable resistance = Nominal resistance/ F.S.

        'Calcs 80% Loss to find slope
        Capacity80Loss = AllowResist - ((0.75 * 0.4 * AllowResist) +
(0.25 * 0.8 * AllowResist))

        'Calcs Slope
        Slope = (Capacity80Loss - AllowResist) / 80

        'Calcs % loss of embedment
        PercLoss = ((PmaxDesign * 1.25) - AllowResist) / Slope

        'Calcs S critical
        ScrPlunging_EndBearing = (PercLoss / 100) * Lbg
    End Function

    Function ScrPlunging_EndBearingCap(ByVal HammEnergy As Single, _
ByVal BlowCnt As Double, _
    ByVal Smax As Single, ByVal Lbg As Single) As Double

        'Uses Gates formula to calc allowable resistance (tons).
        bc = Math.Log10(10 * BlowCnt)
        AllowResist = ((0.875 * (HammEnergy ^ 0.5) * bc) - 50) / 1.25
'Allowable resistance = Nominal resistance/ F.S.

        'Calcs 80% Loss to find slope
        Capacity80Loss = AllowResist - ((0.75 * 0.4 * AllowResist) +
(0.25 * 0.8 * AllowResist))

        'Calcs Slope
        Slope = (Capacity80Loss - AllowResist) / 80

        'Calcs % loss of embedment
        PercLoss = (Smax / Lbg) * 100

        'Calcs End Bearing Capacity (tons)
        EndBearCapacity = (Slope * PercLoss) + AllowResist

        'Calcs S critical
        ScrPlunging_EndBearingCap = EndBearCapacity
    End Function
```

```vb
    Function ScrPlunging_Friction(ByVal HammEnergy As Single, ByVal
BlowCnt As Double, _
            ByVal PmaxDesign As Single, ByVal Lbg As Single) As Double

        'Uses Gates formula to calc allowable resistance (tons).
        bc = Math.Log10(10 * BlowCnt)
        AllowResist = ((0.875 * (HammEnergy ^ 0.5) * bc) - 50) / 1.25
'Allowable resistance = Nominal resistance/ F.S.

        'Calcs 80% Loss to find slope
        Capacity80Loss = AllowResist - ((0.25 * 0.4 * AllowResist) +
(0.75 * 0.8 * AllowResist))

        'Calcs Slope
        Slope = (Capacity80Loss - AllowResist) / 80

        'Calcs % loss of embedment
        PercLoss = ((PmaxDesign * 1.25) - AllowResist) / Slope

        'Calcs S critical
        ScrPlunging_Friction = (PercLoss / 100) * Lbg
    End Function

    Function ScrPlunging_FrictionCap(ByVal HammEnergy As Single, ByVal
BlowCnt As Double, _
    ByVal Smax As Single, ByVal Lbg As Single) As Double

        'Uses Gates formula to calc allowable resistance (tons)
        bc = Math.Log10(10 * BlowCnt)
        AllowResist = ((0.875 * (HammEnergy ^ 0.5) * bc) - 50) / 1.25
'Allowable resistance = Nominal resistance/ F.S.

        'Calcs 80% Loss to find slope
        Capacity80Loss = AllowResist - ((0.25 * 0.4 * AllowResist) +
(0.75 * 0.8 * AllowResist))

        'Calcs Slope
        Slope = (Capacity80Loss - AllowResist) / 80

        'Calcs % loss of embedment
        PercLoss = (Smax / Lbg) * 100

        'Calcs Friction Capacity (tons)
        FrictionCapacity = (Slope * PercLoss) + AllowResist

        'Calcs S critical
        ScrPlunging_FrictionCap = FrictionCapacity
    End Function
End Module
```

APPENDIX M: **CODE FOR AUTOMATED SCREENING TOOL**

BUCKLING EVALUATION AND RELATED MODULES

```vb
Public Class Buckling

    Public S, Lbg, OGL, NGL, Las, Smax, H, InertiaY, _
        ScrMode1, ScrMode2, ScrNoBrace, ScrBuckling, Lcr, _
        Story, ScrLL, CapToStrutHt, Lcr1, Lcr2, LcrLL, LcrNoBrace As
Single
    Public PmaxApplPile, PmaxDesign, C1, C2, Series As Single
    Public HorizBrace, PileSize, SupportTyp, LLcont As String

    Private Sub radbtnNo_CheckedChanged(ByVal sender As System.Object,
_
        ByVal e As System.EventArgs) Handles radbtnNo.CheckedChanged

        'Creates message if No is checked when asked if bent piles are
        'steel HP piles with 3-7 or more piles in a row.

        If radbtnNo.Checked = True Then
            MsgBox("The 'ST' can not check the buckling or pushover
adequacy of the bent.")
        End If
    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles Button1.Click
        End 'Ends program when prompted
    End Sub

    Private Sub Button2_Click(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles Button2.Click

        'Apply text box values to variables
        Lbg = Val(Prelim.txtLbg.Text)
        H = Val(txtHeight.Text)
        PmaxDesign = Val(Pmax.txtPmaxApplPile.Text)
        Smax = Val(Prelim.txtSmax.Text)
        Las = Lbg - Smax
        CapToStrutHt = Val(txtCapToStrut.Text)

        'Displays the Max Applied Pile load on form so the capacity can
be compared.
        'Also displays Smax and Lbg values
        txtPmaxDesignBuckl.Enabled = True
        txtPmaxDesignBuckl.Text = PmaxDesign.ToString("###0.00")

        txtSmaxBuckl.Enabled = True
        txtSmaxBuckl.Text = Smax.ToString("###0.00")

        txtLbgBuckl.Enabled = True
        txtLbgBuckl.Text = Lbg.ToString("###0.00")

        'So it will recognize if the support type chosen on the Pmax
form is
        'made continuous for LL for the Buckling check.
        SupportTyp = Pmax.Support
```

```vb
        If SupportTyp = "2-contforlive" Then
            LLcont = "Yes"
        ElseIf SupportTyp = "3-contforlive" Then
            LLcont = "Yes"
        ElseIf SupportTyp = "3-contforlive" Then
            LLcont = "Yes"
        Else
            LLcont = "No"
        End If

        If radbtnHB1.Checked = True Then
            HorizBrace = "HB1"
        ElseIf radbtnHB2.Checked = True Then
            HorizBrace = "HB2"
        ElseIf radbtnBoth.Checked = True Then
            HorizBrace = "Both"
        ElseIf radbtnNeither.Checked = True Then
            HorizBrace = "Neither"
        End If

        If radbtnStory1.Checked = True Then
            Story = "1"
        ElseIf radbtnStory2.Checked = True Then
            Story = "2"
        End If

        'Gets the Inertia for the selected member size and categorizes
    member
        'either as a HP10 or 12 series
        PileSize = cmboxSize.SelectedItem

        If PileSize = "HP12x84" Then
            InertiaY = 213 'in^4
            Series = "12"
        ElseIf PileSize = "HP12x74" Then
            InertiaY = 186 'in^4
            Series = "12"
        ElseIf PileSize = "HP12x63" Then
            InertiaY = 153 'in^4
            Series = "12"
        ElseIf PileSize = "HP12x53" Then
            InertiaY = 127 'in^4
            Series = "12"
        ElseIf PileSize = "HP10x57" Then
            InertiaY = 101 'in^4
            Series = "10"
        ElseIf PileSize = "HP10x42" Then
            InertiaY = 71.7 'in^4
            Series = "10"
        End If

        'Check for adequate pile embedment for fixity after scour
        If Series = "10" Then
```

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```vbnet
                If Las >= 8 Then        'Makes sure that pile's Las is
greater than 8 ft. for HP10 series pile.
                    C1 = 2.0
                    C2 = 0.5
                    If radbtnYes2.Checked = True Then   'Bent has sway-
bracing in place
                        'Evaluates Nonsidesway - Mode 1 Buckling
                        Lcr1 = Lcr_Mode1(PmaxDesign, InertiaY, C1)
                        ScrMode1 = Lcr1 - (H - 1)

                        'Evaluates Sidesway - Mode 2 Buckling
                        Lcr2 = Lcr_Mode2(PmaxDesign, InertiaY, C2)
                        If HorizBrace = "HB1" Or HorizBrace = "Both" Then
                            If Story = "1" Or Story = "2" Then
                                ScrMode2 = Lcr2 - (H - CapToStrutHt)
                            End If
                        ElseIf HorizBrace = "HB2" And Story = "2" Then
                            ScrMode2 = Lcr2 - (H - CapToStrutHt)
                        ElseIf HorizBrace = "Neither" Then
                            If Story = "1" Or Story = "2" Then
                                ScrMode2 = Lcr2 - (H - 1)
                            End If
                        End If

                        'Assigns critical length to mode
                        If ScrMode1 < ScrMode2 Then
                            ScrBuckling = ScrMode1
                            Lcr = Lcr1
                        Else
                            ScrBuckling = ScrMode2
                            Lcr = Lcr2
                        End If

                        If ScrBuckling > Smax Then
                            'Displays following message if Scr is greater
than Smax
                            txtScrBuckling.Enabled = True
                            txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                            txtLcr.Enabled = True
                            txtLcr.Text = Lcr.ToString("###0.00")
                            txtBucklingSafety.Enabled = True
                            txtBucklingSafety.ForeColor = Color.Black
                            txtBucklingSafety.Text = "SAFE"

                        Else 'If bridge superstructure is continuous or
made continuous for LL
                            'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1

                                If ScrLL > Smax Then
```

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```vb
                                                'Displays following message if Scr is
greater than Smax
                                                txtScrBuckling.Enabled = True
                                                txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                                txtLcr.Enabled = True
                                                txtLcr.Text = LcrLL.ToString("###0.00")
                                                txtBucklingSafety.Enabled = True
                                                txtBucklingSafety.ForeColor =
Color.Black

                                                txtBucklingSafety.Text = "SAFE"
                                                'Displays following message if Scr is
less than Smax
                                            Else
                                                txtScrBuckling.Enabled = True
                                                txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                                txtLcr.Enabled = True
                                                txtLcr.Text = LcrLL.ToString("###0.00")
                                                txtBucklingSafety.Enabled = True
                                                txtBucklingSafety.ForeColor = Color.Red
                                                txtBucklingSafety.Text = "UNSAFE"
                                            End If
                                        Else 'If superstructure is not continuous or
made continuous for LL and Scr < Smax
                                            txtScrBuckling.Enabled = True
                                            txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                            txtLcr.Enabled = True
                                            txtLcr.Text = Lcr.ToString("###0.00")
                                            txtBucklingSafety.Enabled = True
                                            txtBucklingSafety.ForeColor = Color.Red
                                            txtBucklingSafety.Text = "UNSAFE"
                                        End If
                                    End If

                    Else 'Bent has sway-bracing omitted

                            'For partial fixed-fixed transverse side-sway
buckling mode.
                            LcrNoBrace = Lcr_NoBrace(PmaxDesign, InertiaY, C2)
                            ScrNoBrace = LcrNoBrace - H + 1
                            If ScrNoBrace > Smax Then
                                'Displays following message if Scr is greater
than Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = LcrNoBrace.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Black
                                txtBucklingSafety.Text = "SAFE"
```

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```vbnet
                        Else 'If bridge superstructure is continuous or
made continuous for LL
                            'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" = True Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1
                                If ScrLL > Smax Then
                                        'Displays following message if Scr is
greater than Smax
                                        txtScrBuckling.Enabled = True
                                        txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                        txtLcr.Enabled = True
                                        txtLcr.Text = LcrLL.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor =
Color.Black
                                        txtBucklingSafety.Text = "SAFE"
                                        'Displays following message if Scr is
less than Smax
                                    Else
                                        txtScrBuckling.Enabled = True
                                        txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                        txtLcr.Enabled = True
                                        txtLcr.Text = LcrLL.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor = Color.Red
                                        txtBucklingSafety.Text = "UNSAFE"
                                End If
                            Else 'If superstructure is not continuous or
made continuous for LL
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text =
LcrNoBrace.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                            End If
                        End If
                    End If


            ElseIf Las >= 5 And Las < 8 Then
                C1 = 1.75
                C2 = 0.375
                If radbtnYes2.Checked = True Then  'Bent has sway-
bracing in place
                    'Evaluates Nonsidesway - Mode 1 Buckling
                    Lcr1 = Lcr_Mode1(PmaxDesign, InertiaY, C1)
                    ScrMode1 = Lcr1 - H + 1
```

```vbnet
                        'Evaluates Sidesway - Mode 2 Buckling
                        Lcr2 = Lcr_Mode2(PmaxDesign, InertiaY, C2)
                        If HorizBrace = "HB1" Or HorizBrace = "Both" Then
                            If Story = "1" Or Story = "2" Then
                                ScrMode2 = Lcr2 - (H - CapToStrutHt)
                            End If
                        ElseIf HorizBrace = "HB2" And HorizBrace = "2" Then
                            ScrMode2 = Lcr2 - (H - CapToStrutHt)
                        ElseIf HorizBrace = "Neither" Then
                            If Story = "1" Or Story = "2" Then
                                ScrMode2 = Lcr2 - H + 1
                            End If
                        End If

                        'Assigns critical length to mode
                        If ScrMode1 < ScrMode2 Then
                            ScrBuckling = ScrMode1
                            Lcr = Lcr1
                        Else
                            ScrBuckling = ScrMode2
                            Lcr = Lcr2
                        End If

                        If ScrBuckling > Smax Then
                            'Displays following message if Scr is greater
than Smax
                            txtScrBuckling.Enabled = True
                            txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                            txtLcr.Enabled = True
                            txtLcr.Text = Lcr.ToString("###0.00")
                            txtBucklingSafety.Enabled = True
                            txtBucklingSafety.ForeColor = Color.Black
                            txtBucklingSafety.Text = "SAFE"

                        Else 'If bridge superstructure is continuous or
made continuous for LL
                            'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1

                                If ScrLL > Smax Then
                                    'Displays following message if Scr is
greater than Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor =
Color.Black
```

```vbnet
                                            txtBucklingSafety.Text = "SAFE"
                                            'Displays following message if Scr is
less than Smax
                                    Else
                                        txtScrBuckling.Enabled = True
                                        txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                        txtLcr.Enabled = True
                                        txtLcr.Text = LcrLL.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor = Color.Red
                                        txtBucklingSafety.Text = "UNSAFE"
                                    End If
                            Else 'If superstructure is not continuous or
made continuous for LL and Scr < Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = Lcr.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                                End If
                        End If

                Else 'Bent has sway-bracing omitted

                        'For partial fixed-fixed transverse side-sway
buckling mode.
                        LcrNoBrace = Lcr_NoBrace(PmaxDesign, InertiaY, C2)
                        ScrNoBrace = LcrNoBrace - H + 1
                        If ScrNoBrace > Smax Then
                                'Displays following message if Scr is greater
than Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = LcrNoBrace.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Black
                                txtBucklingSafety.Text = "SAFE"

                        Else 'If bridge superstructure is continuous or
made continuous for LL
                                'then checks Nonsidesway-Mode 1 Buckling
                                If LLcont = "Yes" = True Then
                                    LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                    ScrLL = LcrLL - H + 1
                                    If ScrLL > Smax Then
                                            'Displays following message if Scr is
greater than Smax

                                            txtScrBuckling.Enabled = True
```

```vb
                                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                                    txtLcr.Enabled = True
                                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                                    txtBucklingSafety.Enabled = True
                                                    txtBucklingSafety.ForeColor =
Color.Black

                                                    txtBucklingSafety.Text = "SAFE"
                                                    'Displays following message if Scr is
less than Smax
                                                Else
                                                    txtScrBuckling.Enabled = True
                                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                                    txtLcr.Enabled = True
                                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                                    txtBucklingSafety.Enabled = True
                                                    txtBucklingSafety.ForeColor = Color.Red
                                                    txtBucklingSafety.Text = "UNSAFE"
                                                End If
                                            Else 'If superstructure is not continuous or
made continuous for LL
                                                txtScrBuckling.Enabled = True
                                                txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")

                                                txtLcr.Enabled = True
                                                txtLcr.Text =
LcrNoBrace.ToString("###0.00")

                                                txtBucklingSafety.Enabled = True
                                                txtBucklingSafety.ForeColor = Color.Red
                                                txtBucklingSafety.Text = "UNSAFE"
                                            End If
                                        End If
                                    End If


                        ElseIf Las > 3 And Las < 5 Then
                            C1 = 1.5
                            C2 = 0.25
                            If radbtnYes2.Checked = True Then  'Bent has sway-
bracing in place
                                'Evaluates Nonsidesway - Mode 1 Buckling
                                Lcr1 = Lcr_Mode1(PmaxDesign, InertiaY, C1)
                                ScrMode1 = Lcr1 - H + 1

                                'Evaluates Sidesway - Mode 2 Buckling
                                Lcr2 = Lcr_Mode2(PmaxDesign, InertiaY, C2)
                                If HorizBrace = "HB1" Or HorizBrace = "Both" Then
                                    If Story = "1" Or Story = "2" Then
                                        ScrMode2 = Lcr2 - (H - CapToStrutHt)
                                    End If
                                ElseIf HorizBrace = "HB2" And HorizBrace = "2" Then
                                    ScrMode2 = Lcr2 - (H - CapToStrutHt)
                                ElseIf HorizBrace = "Neither" Then
```

```vb
                            If Story = "1" Or Story = "2" Then
                                ScrMode2 = Lcr2 - H + 1
                            End If
                        End If

                        'Assigns critical length to mode
                        If ScrMode1 < ScrMode2 Then
                            ScrBuckling = ScrMode1
                            Lcr = Lcr1
                        Else
                            ScrBuckling = ScrMode2
                            Lcr = Lcr2
                        End If

                        If ScrBuckling > Smax Then
                            'Displays following message if Scr is greater
than Smax
                            txtScrBuckling.Enabled = True
                            txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                            txtLcr.Enabled = True
                            txtLcr.Text = Lcr.ToString("###0.00")
                            txtBucklingSafety.Enabled = True
                            txtBucklingSafety.ForeColor = Color.Black
                            txtBucklingSafety.Text = "SAFE"

                        Else 'If bridge superstructure is continuous or
made continuous for LL
                            'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1

                                If ScrLL > Smax Then
                                    'Displays following message if Scr is
greater than Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor =
Color.Black
                                    txtBucklingSafety.Text = "SAFE"
                                    'Displays following message if Scr is
less than Smax
                                Else
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
```

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```vb
                                        txtBucklingSafety.ForeColor = Color.Red
                                        txtBucklingSafety.Text = "UNSAFE"
                                    End If
                                Else 'If superstructure is not continuous or
made continuous for LL and Scr < Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = Lcr.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                                End If
                            End If

                    Else 'Bent has sway-bracing omitted

                            'For partial fixed-fixed transverse side-sway
buckling mode.
                            LcrNoBrace = Lcr_NoBrace(PmaxDesign, InertiaY, C2)
                            ScrNoBrace = LcrNoBrace - H + 1
                            If ScrNoBrace > Smax Then
                                    'Displays following message if Scr is greater
than Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = LcrNoBrace.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Black
                                txtBucklingSafety.Text = "SAFE"

                            Else 'If bridge superstructure is continuous or
made continuous for LL
                                'then checks Nonsidesway-Mode 1 Buckling
                                If LLcont = "Yes" = True Then
                                    LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                    ScrLL = LcrLL - H + 1
                                    If ScrLL > Smax Then
                                            'Displays following message if Scr is
greater than Smax
                                        txtScrBuckling.Enabled = True
                                        txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                        txtLcr.Enabled = True
                                        txtLcr.Text = LcrLL.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor =
Color.Black
                                        txtBucklingSafety.Text = "SAFE"
                                        'Displays following message if Scr is
less than Smax
```

281

```vb
                                    Else
                                        txtScrBuckling.Enabled = True
                                        txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                        txtLcr.Enabled = True
                                        txtLcr.Text = LcrLL.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor = Color.Red
                                        txtBucklingSafety.Text = "UNSAFE"
                                    End If
                                Else 'If superstructure is not continuous or
made continuous for LL
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text =
LcrNoBrace.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                                End If
                            End If
                    End If
                End If

            ' If have HP12 series piles
        ElseIf Series = "12" Then

            If Las >= 12 Then 'Makes sure that pile's Las is greater
than 12 ft. for HP12 series pile.
                C1 = 2.0
                C2 = 0.5
                If radbtnYes2.Checked = True Then  'Bent has sway-
bracing in place
                    'Evaluates Nonsidesway - Mode 1 Buckling
                    Lcr1 = Lcr_Mode1(PmaxDesign, InertiaY, C1)
                    ScrMode1 = Lcr1 - H + 1

                    'Evaluates Sidesway - Mode 2 Buckling
                    Lcr2 = Lcr_Mode2(PmaxDesign, InertiaY, C2)
                    If HorizBrace = "HB1" Or HorizBrace = "Both" Then
                        If Story = "1" Or Story = "2" Then
                            ScrMode2 = Lcr2 - (H - CapToStrutHt)
                        End If
                    ElseIf HorizBrace = "HB2" And HorizBrace = "2" Then
                        ScrMode2 = Lcr2 - (H - CapToStrutHt)
                    ElseIf HorizBrace = "Neither" Then
                        If Story = "1" Or Story = "2" Then
                            ScrMode2 = Lcr2 - H + 1
                        End If
                    End If
```

```vb
                                'Assigns critical length to mode
                                If ScrMode1 < ScrMode2 Then
                                    ScrBuckling = ScrMode1
                                    Lcr = Lcr1
                                Else
                                    ScrBuckling = ScrMode2
                                    Lcr = Lcr2
                                End If

                                If ScrBuckling > Smax Then
                                        'Displays following message if Scr is greater
than Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = Lcr.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Black
                                    txtBucklingSafety.Text = "SAFE"

                                Else 'If bridge superstructure is continuous or
made continuous for LL
                                        'then checks Nonsidesway-Mode 1 Buckling
                                    If LLcont = "Yes" Then
                                        LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                        ScrLL = LcrLL - H + 1

                                        If ScrLL > Smax Then
                                                'Displays following message if Scr is
greater than Smax
                                            txtScrBuckling.Enabled = True
                                            txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                            txtLcr.Enabled = True
                                            txtLcr.Text = LcrLL.ToString("###0.00")
                                            txtBucklingSafety.Enabled = True
                                            txtBucklingSafety.ForeColor =
Color.Black
                                            txtBucklingSafety.Text = "SAFE"
                                                'Displays following message if Scr is
less than Smax
                                        Else
                                            txtScrBuckling.Enabled = True
                                            txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                            txtLcr.Enabled = True
                                            txtLcr.Text = LcrLL.ToString("###0.00")
                                            txtBucklingSafety.Enabled = True
                                            txtBucklingSafety.ForeColor = Color.Red
                                            txtBucklingSafety.Text = "UNSAFE"
                                        End If
                                    Else 'If superstructure is not continuous or
made continuous for LL and Scr < Smax
```

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```vb
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                        txtLcr.Enabled = True
                                        txtLcr.Text = Lcr.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor = Color.Red
                                        txtBucklingSafety.Text = "UNSAFE"
                                End If
                            End If

                    Else 'Bent has sway-bracing omitted

                        'For partial fixed-fixed transverse side-sway
buckling mode.
                        LcrNoBrace = Lcr_NoBrace(PmaxDesign, InertiaY, C2)
                        ScrNoBrace = LcrNoBrace - H + 1
                        If ScrNoBrace > Smax Then
                            'Displays following message if Scr is greater
than Smax
                            txtScrBuckling.Enabled = True
                            txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                            txtLcr.Enabled = True
                            txtLcr.Text = LcrNoBrace.ToString("###0.00")
                            txtBucklingSafety.Enabled = True
                            txtBucklingSafety.ForeColor = Color.Black
                            txtBucklingSafety.Text = "SAFE"

                        Else 'If bridge superstructure is continuous or
made continuous for LL
                            'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" = True Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1
                                If ScrLL > Smax Then
                                    'Displays following message if Scr is
greater than Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor =
Color.Black
                                    txtBucklingSafety.Text = "SAFE"
                                    'Displays following message if Scr is
less than Smax
                                Else
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                    txtLcr.Enabled = True
```

```vb
                                txtLcr.Text = LcrLL.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Red
                                txtBucklingSafety.Text = "UNSAFE"
                            End If
                        Else 'If superstructure is not continuous or
made continuous for LL
                            txtScrBuckling.Enabled = True
                            txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                            txtLcr.Enabled = True
                            txtLcr.Text =
LcrNoBrace.ToString("###0.00")
                            txtBucklingSafety.Enabled = True
                            txtBucklingSafety.ForeColor = Color.Red
                            txtBucklingSafety.Text = "UNSAFE"
                        End If
                    End If
                End If


            ElseIf Las >= 7 And Las < 12 Then
                C1 = 1.75
                C2 = 0.375
                If radbtnYes2.Checked = True Then   'Bent has sway-
bracing in place
                    'Evaluates Nonsidesway - Mode 1 Buckling
                    Lcr1 = Lcr_Mode1(PmaxDesign, InertiaY, C1)
                    ScrMode1 = Lcr1 - H + 1

                    'Evaluates Sidesway - Mode 2 Buckling
                    Lcr2 = Lcr_Mode2(PmaxDesign, InertiaY, C2)
                    If HorizBrace = "HB1" Or HorizBrace = "Both" Then
                        If Story = "1" Or Story = "2" Then
                            ScrMode2 = Lcr2 - (H - CapToStrutHt)
                        End If
                    ElseIf HorizBrace = "HB2" And HorizBrace = "2" Then
                        ScrMode2 = Lcr2 - (H - CapToStrutHt)
                    ElseIf HorizBrace = "Neither" Then
                        If Story = "1" Or Story = "2" Then
                            ScrMode2 = Lcr2 - H + 1
                        End If
                    End If

                    'Assigns critical length to mode
                    If ScrMode1 < ScrMode2 Then
                        ScrBuckling = ScrMode1
                        Lcr = Lcr1
                    Else
                        ScrBuckling = ScrMode2
                        Lcr = Lcr2
                    End If

                    If ScrBuckling > Smax Then
```

```vbnet
                                'Displays following message if Scr is greater
than Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = Lcr.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Black
                                txtBucklingSafety.Text = "SAFE"

                    Else 'If bridge superstructure is continuous or
made continuous for LL
                                'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1

                                If ScrLL > Smax Then
                                    'Displays following message if Scr is
greater than Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor =
Color.Black
                                    txtBucklingSafety.Text = "SAFE"
                                    'Displays following message if Scr is
less than Smax
                                Else
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                                End If
                            Else 'If superstructure is not continuous or
made continuous for LL and Scr < Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = Lcr.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Red
                                txtBucklingSafety.Text = "UNSAFE"
                            End If
                    End If
```

```vb
                Else 'Bent has sway-bracing omitted

                    'For partial fixed-fixed transverse side-sway
buckling mode.
                    LcrNoBrace = Lcr_NoBrace(PmaxDesign, InertiaY, C2)
                    ScrNoBrace = LcrNoBrace - H + 1
                    If ScrNoBrace > Smax Then
                        'Displays following message if Scr is greater
than Smax
                        txtScrBuckling.Enabled = True
                        txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                        txtLcr.Enabled = True
                        txtLcr.Text = LcrNoBrace.ToString("###0.00")
                        txtBucklingSafety.Enabled = True
                        txtBucklingSafety.ForeColor = Color.Black
                        txtBucklingSafety.Text = "SAFE"

                    Else 'If bridge superstructure is continuous or
made continuous for LL
                        'then checks Nonsidesway-Mode 1 Buckling
                        If LLcont = "Yes" = True Then
                            LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                            ScrLL = LcrLL - H + 1
                            If ScrLL > Smax Then
                                'Displays following message if Scr is
greater than Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = LcrLL.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor =
Color.Black
                                txtBucklingSafety.Text = "SAFE"
                                'Displays following message if Scr is
less than Smax
                            Else
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = LcrLL.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Red
                                txtBucklingSafety.Text = "UNSAFE"
                            End If
                        Else 'If superstructure is not continuous or
made continuous for LL
                            txtScrBuckling.Enabled = True
                            txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
```

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```vbnet
                                txtLcr.Enabled = True
                                txtLcr.Text =
LcrNoBrace.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                                End If
                            End If
                    End If

                ElseIf Las > 3 And Las < 7 Then
                        C1 = 1.5
                        C2 = 0.25
                        If radbtnYes2.Checked = True Then  'Bent has sway-
bracing in place
                            'Evaluates Nonsidesway - Mode 1 Buckling
                            Lcr1 = Lcr_Mode1(PmaxDesign, InertiaY, C1)
                            ScrMode1 = Lcr1 - H + 1

                            'Evaluates Sidesway - Mode 2 Buckling
                            Lcr2 = Lcr_Mode2(PmaxDesign, InertiaY, C2)
                            If HorizBrace = "HB1" Or HorizBrace = "Both" Then
                                If Story = "1" Or Story = "2" Then
                                    ScrMode2 = Lcr2 - (H - CapToStrutHt)
                                End If
                            ElseIf HorizBrace = "HB2" And Story = "2" Then
                                ScrMode2 = Lcr2 - (H - CapToStrutHt)
                            ElseIf HorizBrace = "Neither" Then
                                If Story = "1" Or Story = "2" Then
                                    ScrMode2 = Lcr2 - H + 1
                                End If
                            End If

                            'Assigns critical length to mode
                            If ScrMode1 < ScrMode2 Then
                                ScrBuckling = ScrMode1
                                Lcr = Lcr1
                            Else
                                ScrBuckling = ScrMode2
                                Lcr = Lcr2
                            End If

                            If ScrBuckling > Smax Then
                                'Displays following message if Scr is greater
than Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = Lcr.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Black
                                txtBucklingSafety.Text = "SAFE"
```

288

```vbnet
                        Else 'If bridge superstructure is continuous or
made continuous for LL
                            'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1

                                If ScrLL > Smax Then
                                    'Displays following message if Scr is
greater than Smax
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor =
Color.Black

                                    txtBucklingSafety.Text = "SAFE"
                                    'Displays following message if Scr is
less than Smax
                                Else
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrLL.ToString("###0.00")

                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrLL.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                                End If
                            Else 'If superstructure is not continuous or
made continuous for LL and Scr < Smax
                                txtScrBuckling.Enabled = True
                                txtScrBuckling.Text =
ScrBuckling.ToString("###0.00")
                                txtLcr.Enabled = True
                                txtLcr.Text = Lcr.ToString("###0.00")
                                txtBucklingSafety.Enabled = True
                                txtBucklingSafety.ForeColor = Color.Red
                                txtBucklingSafety.Text = "UNSAFE"
                            End If
                        End If

                    Else 'Bent has sway-bracing omitted

                        'For partial fixed-fixed transverse side-sway
buckling mode.
                        LcrNoBrace = Lcr_NoBrace(PmaxDesign, InertiaY, C2)
                        ScrNoBrace = LcrNoBrace - H + 1
                        If ScrNoBrace > Smax Then
                            'Displays following message if Scr is greater
than Smax
                            txtScrBuckling.Enabled = True
```

```vb
                                    txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text = LcrNoBrace.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Black
                                    txtBucklingSafety.Text = "SAFE"

                            Else 'If bridge superstructure is continuous or
made continuous for LL
                                    'then checks Nonsidesway-Mode 1 Buckling
                            If LLcont = "Yes" = True Then
                                LcrLL = Lcr_LL(PmaxDesign, InertiaY)
                                ScrLL = LcrLL - H + 1
                                If ScrLL > Smax Then
                                        'Displays following message if Scr is
greater than Smax
                                        txtScrBuckling.Enabled = True
                                        txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                        txtLcr.Enabled = True
                                        txtLcr.Text = LcrLL.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor =
Color.Black
                                        txtBucklingSafety.Text = "SAFE"
                                        'Displays following message if Scr is
less than Smax
                                Else
                                        txtScrBuckling.Enabled = True
                                        txtScrBuckling.Text =
ScrLL.ToString("###0.00")
                                        txtLcr.Enabled = True
                                        txtLcr.Text = LcrLL.ToString("###0.00")
                                        txtBucklingSafety.Enabled = True
                                        txtBucklingSafety.ForeColor = Color.Red
                                        txtBucklingSafety.Text = "UNSAFE"
                                End If
                            Else 'If superstructure is not continuous or
made continuous for LL
                                    txtScrBuckling.Enabled = True
                                    txtScrBuckling.Text =
ScrNoBrace.ToString("###0.00")
                                    txtLcr.Enabled = True
                                    txtLcr.Text =
LcrNoBrace.ToString("###0.00")
                                    txtBucklingSafety.Enabled = True
                                    txtBucklingSafety.ForeColor = Color.Red
                                    txtBucklingSafety.Text = "UNSAFE"
                            End If
                        End If
                End If
            End If
        End If
```

```vb
    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
        My.Forms.HB1Picture.Show()
    End Sub

    Private Sub Buckling_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        'Adds options to the Number of Piles combo box
        cmboxSize.Items.Add("HP10x42")
        cmboxSize.Items.Add("HP10x57")
        cmboxSize.Items.Add("HP12x53")
        cmboxSize.Items.Add("HP12x63")
        cmboxSize.Items.Add("HP12x74")
        cmboxSize.Items.Add("HP12x84")
    End Sub

    Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button4.Click
        My.Forms.PushOver.Show()                    'Moves to next form
        WindowState = FormWindowState.Minimized  'Minimizes current
form
    End Sub
End Class
```

```vb
Module Mode1and2Buckling

    Public H, PmaxDesign, InertiaY, C1 As Single
    Public Const PI As Double = 3.1415926535
    Function Lcr_Mode1(ByVal PmaxPileApplied As Single, ByVal Iy As
Single, _
        ByVal Const1 As Single)

        Dim E, FS As Single
        E = 29000  'ksi
        FS = 1.25   'Factor of Safety is assumed to be 1.25

        Lcr_Mode1 = (((Const1 * (PI) ^ 2 * E * Iy) / (FS *
PmaxPileApplied)) ^ (1 / 2)) / 12    'feet

        'Scr_Mode1 = (Lcr1 / 12) - Ht + 1
    End Function
    Function Lcr_Mode2(ByVal PmaxPileAppl As Single, ByVal Iy As
Single, _
    ByVal Const2 As Single)

        Dim Elasticity, FS As Single
        Elasticity = 29000  'ksi
        FS = 1.25   'Factor of Safety is assumed to be 1.25

        Lcr_Mode2 = (((Const2 * (PI) ^ 2 * Elasticity * Iy) / (FS *
PmaxPileAppl)) ^ (1 / 2)) / 12    'feet

    End Function
End Module
```

```vb
Module Mode1ForLL

    Public PmaxDesign, InertiaY As Single
    Public Const PI As Double = 3.1415926535
    Function Lcr_LL(ByVal PmaxPileApplied As Single, ByVal Iy As
Single)

        Dim E, FS As Single
        E = 29000  'ksi
        FS = 1.25  'Factor of Safety is assumed to be 1.25

        Lcr_LL = (((2 * (PI) ^ 2 * E * Iy) / (FS * PmaxPileApplied)) ^
(1 / 2)) / 12  'feet

        'Scr_LL = Lcr_LL - Ht + 1
    End Function
End Module
```

```vb
Module TrnsvrsSideSwayBuckl

    Public PmaxDesign, InertiaY, C2 As Single
    Public Const PI As Double = 3.1415926535
    Function Lcr_NoBrace(ByVal PmaxPileAppl As Single, _
        ByVal Iy As Single, ByVal Const2 As Single)

        Dim E, FS As Single
        E = 29000  'ksi
        FS = 1.25  'Factor of Safety is assumed to be 1.25

        Lcr_NoBrace = (((Const2 * (PI) ^ 2 * E * Iy) / (FS *
PmaxPileAppl)) ^ (1 / 2)) / 12  'feet
        'Scr_NoBrace = Lcr - Ht + 1
    End Function
End Module
```

APPENDIX N: **CODE FOR AUTOMATED SCREENING TOOL**

PUSHOVER EVALUATION AND RELATED MODULES

```vb
Public Class PushOver

    Public AccessTables As String
    Public H, CriticalScour1, CriticalScour2, PApplied, Smax, Ft_max, Ft, _
        Ft1, Ft2, Series, AltSmax, ScrPO1 As Single
    Public NumOfPiles, NumOfStories, iPAppl As Integer
    Public XBracingConfig, XBraceConfig, PileNum As String

    Private Sub PushOver_Load(ByVal sender As System.Object, _
            ByVal e As System.EventArgs) Handles MyBase.Load

        'Adds options to the Number of Piles combo box
        cmboxNoOfPiles.Items.Add("3")
        cmboxNoOfPiles.Items.Add("4")
        cmboxNoOfPiles.Items.Add("5")
        cmboxNoOfPiles.Items.Add("6")
        cmboxNoOfPiles.Items.Add("More than 6 piles")

        'Adds options to the Configuraton combo box so that you can choose
        'what table to go to in Access
        cmbxAccessTable.Items.Add("HP10 Series; 3, 4, 5, 6-Pile Bents without X-bracing")
        cmbxAccessTable.Items.Add("HP10 Series; 3, 4, 5, 6-Pile Bents with X-bracing")
        cmbxAccessTable.Items.Add("HP12 Series; 3, 4, 5, 6-Pile Bents without X-bracing")
        cmbxAccessTable.Items.Add("HP12 Series; 3, 4, 5, 6-Pile Bents with X-bracing")
        cmbxAccessTable.Items.Add("None of the above")

        'Adds options to the X-Bracing combo box
        cmbxXBracing.Items.Add("Single-X per Story")
        cmbxXBracing.Items.Add("Double-X per Story")
        'Adds options to the Number of Stories in Bent combo box
        cmbxNoStories.Items.Add("1")
        cmbxNoStories.Items.Add("2")

        Smax = Val(Prelim.txtSmax.Text)

        'Displays Smax value in form
        txtSmaxPO.Enabled = True
        txtSmaxPO.Text = Smax.ToString("###0.00")
    End Sub

    Private Sub btnEnd_Click(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles btnEnd.Click
        End 'ends program when prompted
    End Sub

    Private Sub cmbxAccessTable_SelectedIndexChanged(ByVal sender As System.Object, _
```

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        ByVal e As System.EventArgs) Handles
cmbxAccessTable.SelectedIndexChanged
        'Apply text box values to variables
        AccessTables = cmbxAccessTable.SelectedItem

        If AccessTables = "None of the above" Then
            MsgBox("Bent should be checked by other methods for
adequacy" _
            & " against a pushover failure.")
        End If
    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, _
        ByVal e As System.EventArgs) Handles Button1.Click

        H = Val(txtHeightPO.Text)
        PileNum = Val(cmboxNoOfPiles.SelectedItem)
        AccessTables = cmbxAccessTable.SelectedItem

        'Converts PileNum (string) to NumOfPiles (Single)
        If PileNum = "3" Then
            NumOfPiles = 3
        ElseIf PileNum = "4" Then
            NumOfPiles = 4
        ElseIf PileNum = "5" Then
            NumOfPiles = 5
        ElseIf PileNum = "6" Then
            NumOfPiles = 6
        End If

        'Calculates Pmax applied to bent
        PApplied = (Pmax.txtPmaxApplBent.Text) / NumOfPiles

        'rounds Papplied to whole number and displays on form
        iPAppl = Int(PApplied)
        txtPmaxDesignPushOver.Enabled = True
        txtPmaxDesignPushOver.Text = iPAppl.ToString("###0.00")

        XBracingConfig = cmbxXBracing.SelectedItem
        'Renames so database will recognize it.
        If XBracingConfig = "Single-X per Story" Then
            XBraceConfig = "Single"
        Else : XBraceConfig = "Double"
        End If

        'Converts access tables (string) to Series (Single)
        If AccessTables = "HP12 Series; 3, 4, 5, 6-Pile Bents without
X-bracing" Then
            Series = "12"
        ElseIf AccessTables = "HP12 Series; 3, 4, 5, 6-Pile Bents with
X-bracing" Then
            Series = "12"
        Else
            Series = "10"
```

```vb
        End If

        'Changes default Smax value to value entered
        AltSmax = Val(txtSmaxPO2.Text)
        If AltSmax <> "0" Then
            Smax = AltSmax
            'Displays new Smax value in form
            txtSmaxPO.Enabled = True
            txtSmaxPO.Text = Smax.ToString("###0.00")

        Else : Smax = Val(Prelim.txtSmax.Text)
        End If

        'Sets upper-bound limit on Smax values to be evaluated by
database.
        If Smax > 25 Then
            MsgBox("Screening Tool will only evaluate possible
pushover" _
            & Chr(10) & " failure of bridge bents that have scour
levels up to 25 feet." _
            & Chr(13) & Chr(13) & " Any bent with more than 25 feet of
scour must be checked more closely" _
            & Chr(10) & " for possible pushover failure by other
means.")
        End If

        'If number of piles are more than 4 and the size is any HP12
series,
        'then bent is safe from pushover and program doesn't need
        'to go into the database. If the bent has 5 or more piles,
Pmax<100k, and is a HP10 series
        'then the bent is safe from pushover and program won't go into
database.
        If NumOfPiles > 4 Then
            If Series = "12" Then
                MsgBox("Bents with piles as large or larger than
HP12x53" _
                & " with 5 or more piles have adequate bent" _
                & Chr(10) & "pushover capacity for the maximum scour "
_
                & " levels anticipated anywhere in Alabama, and" _
                & Chr(10) & "thus are safe for pushover")
            ElseIf Series = "10" Then
                If iPAppl < 100 Then 'kips
                    MsgBox("Bents with  5 or 6 piles as large or larger
than HP10x42" _
                    & " with a Pmax < 100kips have adequate bent" _
                    & Chr(10) & " pushover capacity for the maximum
scour " _
                    & "levels anticipated anywhere in Alabama, and" _
                    & Chr(10) & " thus are safe for pushover.")
                End If
            End If
        End If
```

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```vb
            'Checks to make sure H values are within boundaries
            NumOfStories = cmbxNoStories.SelectedItem
            If NumOfStories = "1" Then
                If XBraceConfig = "Single" Then
                    If H > 17 Then      'Upperbound for 1-story X-braced
bent
                        MsgBox("The maximum H value evaluated for a 1-
Story, X-braced bent is 17 feet." _
                        & " Please re-evaluate or end program.")
                    ElseIf H < 13 Then  'Lowerbound for 1-story X-braced
bent
                        MsgBox("The minimum H value evaluated for a 1-
Story, X-braced bent is 13 feet." _
                        & " Please re-evaluate or end program.")
                    End If
                Else
                    If H > 13 Then      'Upperbound for 1-story unbraced
bent
                        MsgBox("The maximum H value evaluated for a 1-
Story, unbraced bent is 13 feet." _
                        & " Please re-evaluate or end program.")
                    ElseIf H < 10 Then  'Lowerbound for 1-story unbraced
bent
                        MsgBox("The minimum H value evaluated for a 1-
Story, unbraced bent is 10 feet." _
                        & " Please re-evaluate or end program.")
                    End If
                End If
            ElseIf NumOfStories = "2" Then
                If XBraceConfig = "Single" Then
                    If H > 25 Then      'Upperbound for 2-story X-braced
bent
                        MsgBox("The maximum H value evaluated for a 2-
Story, X-braced bent is 25 feet." _
                        & " Please re-evaluate or end program.")
                    ElseIf H < 21 Then  'Lowerbound for 2-story X-braced
bent
                        MsgBox("The minimum H value evaluated for a 2-
Story, X-braced bent is 21 feet." _
                        & " Please re-evaluate or end program.")
                    End If
                ElseIf XBraceConfig = "Double" Then
                    If H > 25 Then      'Upperbound for 2-story X-braced
bent
                        MsgBox("The maximum H value evaluated for a 2-
Story, X-braced bent is 25 feet." _
                        & " Please re-evaluate or end program.")
                    ElseIf H < 21 Then  'Lowerbound for 2-story X-braced
bent
                        MsgBox("The minimum H value evaluated for a 2-
Story, X-braced bent is 21 feet." _
                        & " Please re-evaluate or end program.")
                    End If
```

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                End If
            End If


        If radbtnNo.Checked = True Then
                'Assumes no debris raft develops
                Ft_max = 2.5 'Kips (includes a F.S.= 1.25)
                txtFtMax.Enabled = True
                txtFtMax.Text = Ft_max.ToString("###0.00")

                If AccessTables = "HP10 Series; 3, 4, 5, 6-Pile Bents with
X-bracing" Then
                    CriticalScour1 = Get_Scr_B("B10x42", NumOfPiles,
XBraceConfig, NumOfStories _
                                                    , H, iPAppl)
                    txtScrPOcase1.Enabled = True
                    txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")

                    Ft1 = Get_Ft_B_III("B10x42_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                    txtFtcase1.Enabled = True
                    txtFtcase1.Text = Ft1.ToString("###0.00")

                    If Ft1 > Ft_max Then
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Black
                        txtPOSafety1.Text = "SAFE"

                    Else
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Red
                        txtPOSafety1.Text = "UNSAFE"
                    End If

                    'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                    'Assumes FS = 1.25

                    CriticalScour2 = Get_Scr_B("B10x42unsyS", NumOfPiles,
XBraceConfig, NumOfStories _
                                        , H, iPAppl)
                    txtScrPOcase2.Enabled = True
                    txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                    Ft2 = Get_Ft_B_III("B10x42unsyS_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                    txtFtcase2.Enabled = True
                    txtFtcase2.Text = Ft2.ToString("###0.00")

                    If Ft2 > Ft_max Then
                        'Displays following message if Ft> Ft_max
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Black
                        txtPOSafety2.Text = "SAFE"
```

```vb
                Else
                    txtPOSafety2.Enabled = True
                    txtPOSafety2.ForeColor = Color.Red
                    txtPOSafety2.Text = "UNSAFE"
                End If

            ElseIf AccessTables = "HP10 Series; 3, 4, 5, 6-Pile Bents
without X-bracing" Then
                CriticalScour1 = Get_Scr_UB("UB10x42", NumOfPiles, H,
iPAppl)
                txtScrPOcase1.Enabled = True
                txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")

                Ft1 = Get_Ft_UB_III("UB10x42_Ft", NumOfPiles, H, Smax,
iPAppl)
                txtFtcase1.Enabled = True
                txtFtcase1.Text = Ft1.ToString("###0.00")

                If Ft1 > Ft_max Then
                    txtPOSafety1.Enabled = True
                    txtPOSafety1.ForeColor = Color.Black
                    txtPOSafety1.Text = "SAFE"
                Else
                    txtPOSafety1.Enabled = True
                    txtPOSafety1.ForeColor = Color.Red
                    txtPOSafety1.Text = "UNSAFE"
                End If

                'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                'Assumes FS = 1.25

                CriticalScour2 = Get_Scr_UB("UB10x42unsyS", NumOfPiles,
H, iPAppl)
                txtScrPOcase2.Enabled = True
                txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                Ft2 = Get_Ft_UB_III("UB10x42unsyS_Ft", NumOfPiles, H,
Smax, iPAppl)
                txtFtcase2.Enabled = True
                txtFtcase2.Text = Ft2.ToString("###0.00")

                If Ft2 > Ft_max Then
                    'Displays following message if Ft> Ft_max
                    txtPOSafety2.Enabled = True
                    txtPOSafety2.ForeColor = Color.Black
                    txtPOSafety2.Text = "SAFE"

                Else
                    txtPOSafety2.Enabled = True
                    txtPOSafety2.ForeColor = Color.Red
                    txtPOSafety2.Text = "UNSAFE"
                End If
```

```vb
            ElseIf AccessTables = "HP12 Series; 3, 4, 5, 6-Pile Bents
with X-bracing" Then
                CriticalScour1 = Get_Scr_B("B12x53", NumOfPiles,
XBraceConfig, NumOfStories _
                                            , H, iPAppl)
                txtScrPOcase1.Enabled = True
                txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")

                Ft1 = Get_Ft_B_III("B12x53_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                txtFtcase1.Enabled = True
                txtFtcase1.Text = Ft1.ToString("###0.00")

                If Ft1 >= Ft_max Then
                    txtPOSafety1.Enabled = True
                    txtPOSafety1.ForeColor = Color.Black
                    txtPOSafety1.Text = "SAFE"
                Else
                    txtPOSafety1.Enabled = True
                    txtPOSafety1.ForeColor = Color.Red
                    txtPOSafety1.Text = "UNSAFE"
                End If
                'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                'Assumes FS = 1.25

                CriticalScour2 = Get_Scr_B("B12x53unsyS", NumOfPiles,
XBraceConfig, NumOfStories _
                                , H, iPAppl)
                txtScrPOcase2.Enabled = True
                txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                Ft2 = Get_Ft_B_III("B12x53unsyS_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                txtFtcase2.Enabled = True
                txtFtcase2.Text = Ft2.ToString("###0.00")

                If Ft2 > Ft_max Then
                    'Displays following message if Ft> Ft_max
                    txtPOSafety2.Enabled = True
                    txtPOSafety2.ForeColor = Color.Black
                    txtPOSafety2.Text = "SAFE"

                Else

                    txtPOSafety2.Enabled = True
                    txtPOSafety2.ForeColor = Color.Red
                    txtPOSafety2.Text = "UNSAFE"
                End If

            ElseIf AccessTables = "HP12 Series; 3, 4, 5, 6-Pile Bents
without X-bracing" Then
                CriticalScour1 = Get_Scr_UB("UB12x53", NumOfPiles, H,
iPAppl)
                txtScrPOcase1.Enabled = True
```

```vb
                    txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")

                    Ft1 = Get_Ft_UB_III("UB12x53_Ft", NumOfPiles, H, Smax,
iPAppl)

                    txtFtcase1.Enabled = True
                    txtFtcase1.Text = Ft1.ToString("###0.00")

                    If Ft1 > Ft_max Then
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Black
                        txtPOSafety1.Text = "SAFE"
                    Else
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Red
                        txtPOSafety1.Text = "UNSAFE"
                    End If

                    'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                    'Assumes FS = 1.25

                    CriticalScour2 = Get_Scr_UB("UB12x53unsyS", NumOfPiles,
H, iPAppl)

                    txtScrPOcase2.Enabled = True
                    txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                    Ft2 = Get_Ft_UB_III("UB12x53unsyS_Ft", NumOfPiles, H,
Smax, iPAppl)

                    txtFtcase2.Enabled = True
                    txtFtcase2.Text = Ft2.ToString("###0.00")

                    If Ft2 > Ft_max Then
                        'Displays following message if Ft> Ft_max
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Black
                        txtPOSafety2.Text = "SAFE"

                    Else
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Red
                        txtPOSafety2.Text = "UNSAFE"
                    End If
                End If

            Else

                'Connects to database in order to determine if Scr > Smax
                'for given geometry
                Ft_max = 12.15 'Kips
                txtFtMax.Enabled = True
                txtFtMax.Text = Ft_max.ToString("###0.00")

                If AccessTables = "HP10 Series; 3, 4, 5, 6-Pile Bents
without X-bracing" Then
```

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```vbnet
                CriticalScour1 = Get_Scr_UB("UB10x42", NumOfPiles, H,
iPAppl)

                txtScrPOcase1.Enabled = True
                txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")

                Ft1 = Get_Ft_UB_III("UB10x42_Ft", NumOfPiles, H, Smax,
iPAppl)

                txtFtcase1.Enabled = True
                txtFtcase1.Text = Ft1.ToString("###0.00")

                If CriticalScour1 > Smax Then
                    'Displays following message if Scr is greater than
Smax
                    txtPOSafety1.Enabled = True
                    txtPOSafety1.ForeColor = Color.Black
                    txtPOSafety1.Text = "SAFE"

                Else

                    txtPOSafety1.Enabled = True
                    txtPOSafety1.ForeColor = Color.Red
                    txtPOSafety1.Text = "UNSAFE"
                End If

                'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                'Assumes FS = 1.25

                CriticalScour2 = Get_Scr_UB("UB10x42unsyS", NumOfPiles,
H, iPAppl)

                txtScrPOcase2.Enabled = True
                txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                Ft2 = Get_Ft_UB_III("UB10x42unsyS_Ft", NumOfPiles, H,
Smax, iPAppl)

                txtFtcase2.Enabled = True
                txtFtcase2.Text = Ft2.ToString("###0.00")

                If Ft2 > Ft_max Then
                    'Displays following message if Ft> Ft_max
                    txtPOSafety2.Enabled = True
                    txtPOSafety2.ForeColor = Color.Black
                    txtPOSafety2.Text = "SAFE"

                Else
                    txtPOSafety2.Enabled = True
                    txtPOSafety2.ForeColor = Color.Red
                    txtPOSafety2.Text = "UNSAFE"
                End If

            ElseIf AccessTables = "HP12 Series; 3, 4, 5, 6-Pile Bents
without X-bracing" Then
                CriticalScour1 = Get_Scr_UB("UB12x53", NumOfPiles, H,
iPAppl)
                txtScrPOcase1.Enabled = True
```

```vbnet
                    txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")

                    Ft1 = Get_Ft_UB_III("UB12x53_Ft", NumOfPiles, H, Smax, _
        iPAppl)

                    txtFtcase1.Enabled = True
                    txtFtcase1.Text = Ft1.ToString("###0.00")

                    If CriticalScour1 > Smax Then
                        'Displays following message if Scr is greater than
        Smax

                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Black
                        txtPOSafety1.Text = "SAFE"

                    Else
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Red
                        txtPOSafety1.Text = "UNSAFE"
                    End If

                    'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                    'Assumes FS = 1.25

                    CriticalScour2 = Get_Scr_UB("UB12x53unsyS", NumOfPiles, _
        H, iPAppl)

                    txtScrPOcase2.Enabled = True
                    txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                    Ft2 = Get_Ft_UB_III("UB12x53unsyS_Ft", NumOfPiles, H, _
        Smax, iPAppl)

                    txtFtcase2.Enabled = True
                    txtFtcase2.Text = Ft2.ToString("###0.00")

                    If Ft2 > Ft_max Then
                        'Displays following message if Ft> Ft_max
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Black
                        txtPOSafety2.Text = "SAFE"

                    Else
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Red
                        txtPOSafety2.Text = "UNSAFE"
                    End If

                ElseIf AccessTables = "HP10 Series; 3, 4, 5, 6-Pile Bents
        with X-bracing" Then
                    CriticalScour1 = Get_Scr_B("B10x42", NumOfPiles, _
        XBraceConfig, NumOfStories _
                            , H, iPAppl)
                    txtScrPOcase1.Enabled = True
                    txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")
```

```vb
                    Ft1 = Get_Ft_B_III("B10x42_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                    txtFtcase1.Enabled = True
                    txtFtcase1.Text = Ft1.ToString("###0.00")

                    If CriticalScour1 > Smax Then
                        'Displays following message if Scr is greater than
Smax
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Black
                        txtPOSafety1.Text = "SAFE"

                    Else
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Red
                        txtPOSafety1.Text = "UNSAFE"
                    End If

                    'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                    'Assumes FS = 1.25

                    CriticalScour2 = Get_Scr_B("B10x42unsyS", NumOfPiles,
XBraceConfig, NumOfStories _
                                    , H, iPAppl)
                    txtScrPOcase2.Enabled = True
                    txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                    Ft2 = Get_Ft_B_III("B10x42unsyS_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                    txtFtcase2.Enabled = True
                    txtFtcase2.Text = Ft2.ToString("###0.00")

                    If Ft2 > Ft_max Then
                        'Displays following message if Ft> Ft_max
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Black
                        txtPOSafety2.Text = "SAFE"

                    Else
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Red
                        txtPOSafety2.Text = "UNSAFE"
                    End If


                Else : AccessTables = "HP12 Series; 3, 4, 5, 6-Pile Bents
with X-bracing"
                    CriticalScour1 = Get_Scr_B("B12x53", NumOfPiles,
XBraceConfig, NumOfStories _
                                    , H, iPAppl)
                    txtScrPOcase1.Enabled = True
                    txtScrPOcase1.Text = CriticalScour1.ToString("###0.00")
```

```vbnet
                    Ft1 = Get_Ft_B_III("B12x53_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                    txtFtcase1.Enabled = True
                    txtFtcase1.Text = Ft1.ToString("###0.00")

                    If CriticalScour1 > Smax Then
                        'Displays following message if Scr is greater than
Smax
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Black
                        txtPOSafety1.Text = "SAFE"

                    Else
                        txtPOSafety1.Enabled = True
                        txtPOSafety1.ForeColor = Color.Red
                        txtPOSafety1.Text = "UNSAFE"
                    End If

                    'Checks Case 2 (Tier-2/2B, Fig. 4-12)
                    'Assumes FS = 1.25

                    CriticalScour2 = Get_Scr_B("B12x53unsyS", NumOfPiles,
XBraceConfig, NumOfStories _
                                , H, iPAppl)
                    txtScrPOcase2.Enabled = True
                    txtScrPOcase2.Text = CriticalScour2.ToString("###0.00")

                    Ft2 = Get_Ft_B_III("B12x53unsyS_Ft", NumOfPiles,
XBraceConfig, NumOfStories, H, Smax, iPAppl)
                    txtFtcase2.Enabled = True
                    txtFtcase2.Text = Ft2.ToString("###0.00")

                    If Ft2 > Ft_max Then
                        'Displays following message if Ft> Ft_max
                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Black
                        txtPOSafety2.Text = "SAFE"

                    Else

                        txtPOSafety2.Enabled = True
                        txtPOSafety2.ForeColor = Color.Red
                        txtPOSafety2.Text = "UNSAFE"
                    End If

                End If
            End If
        End Sub

    Private Sub cmboxNoOfPiles_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
cmboxNoOfPiles.SelectedIndexChanged
            PileNum = cmboxNoOfPiles.SelectedItem
            If PileNum = "More than 6 piles" Then
```

```vbnet
            MsgBox("Bents with more than 6 HP piles of any size in a
row, whether braced or unbraced," _
            & Chr(10) & "have adequate pushover capacity for maximum
scour levels anticipated anywhere" _
            & Chr(10) & "in Alabama, and thus are safe for pushover." _
            & Chr(13) & Chr(13) & "ASSIGN BENT A SAFE OR ADEQUATE
RATING.")
        End If
    End Sub

    Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button4.Click
        'Clears output box if new run is clicked
        txtPOSafety1.Text = " "
        txtFtcase1.Text = " "
        txtScrPOcase1.Text = " "

        txtPOSafety2.Text = " "
        txtFtcase2.Text = " "
        txtScrPOcase2.Text = " "
    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
        'My.Forms.BeamColumn.Show()
        'WindowState = FormWindowState.Minimized
    End Sub
End Class
```

```vb
Imports System
Imports System.Data
Imports System.Data.OleDb
Imports System.Text
Module IO_Ft_III 'Triple Integrations

    Dim gdcCriticalScour As OleDbConnection
    Public Sub SetConnection(ByVal sFileName As String)
        ' Call once on application load
        Dim sConn As String
        sConn = "Provider=Microsoft.Jet.OLEDB.4.0"
        sConn = sConn & ";Data Source=" & sFileName
        sConn = sConn & ";Mode=Share Deny None"
        gdcCriticalScour = New OleDbConnection(sConn)

    End Sub
    Function Get_Ft_B_III(ByVal TableName As String, ByVal rnNoPiles As _
Integer, ByVal rsBracing As String, _
    ByVal rnStories As Integer, ByVal rnBentHeight As Single, ByVal _
rfScour As Single, ByVal rfVForce As Single) As Single

        Dim dcmd As OleDbCommand
        Dim SQL As String
        Dim dr As OleDbDataReader
        Dim bFirst As Boolean = True
        Dim nHighBh As Single
        Dim fHighVf As Single
        Dim fHighS As Single
        Dim fLowBhLowSLowVf As Single
        Dim fLowBhLowSHighVf As Single
        Dim fLowBhHighSLowVf As Single
        Dim fLowBhHighSHighVf As Single
        Dim fHighBhLowSLowVf As Single
        Dim fHighBhLowSHighVf As Single
        Dim fHighBhHighSLowVf As Single
        Dim fHighBhHighSHighVf As Single
        Dim nBentHeightSQL As Single
        Dim nBentHeight As Single
        Dim fVerticalForce As Single
        Dim fMidBhLowVf As Single
        Dim fMidBhHighVf As Single
        Dim fMidSLowVf As Single
        Dim fMidSHighVf As Single
        Dim fMidSLowBh As Single
        Dim fMidSHighBh As Single
        Dim fLowBhMidSLowVf As Single
        Dim fLowBhMidSHighVf As Single
        Dim fLowBhMidSMidVf As Single
        Dim fHighBhMidSLowVf As Single
        Dim fHighBhMidSHighVf As Single
        Dim fHighBhMidSMidVf As Single
        Dim fScour As Single
        Dim PushOver As Single
        gdcCriticalScour.Open()
```

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```vb
SQL = "SELECT  Ht, S, VertForce, Ft "
SQL = SQL & " FROM " & TableName
SQL = SQL & " WHERE PileNum =" & rnNoPiles.ToString
SQL = SQL & " AND NumStories =" & rnStories.ToString
SQL = SQL & " AND BraceConfig =" & SQ(rsBracing)

If rnStories = 1 Then
    If rnBentHeight <= 13 Then
        nBentHeightSQL = 13
    ElseIf rnBentHeight > 13 And rnBentHeight < 17 Then
        'Both
        nBentHeightSQL = 0
    Else
        nBentHeightSQL = 17
    End If
Else
    If rnBentHeight <= 21 Then
        nBentHeightSQL = 21
    ElseIf rnBentHeight > 21 And rnBentHeight < 25 Then
        'Both
        nBentHeightSQL = 0
    Else
        nBentHeightSQL = 25
    End If
End If
If nBentHeightSQL > 0 Then
    SQL = SQL & " AND Ht =" & nBentHeightSQL.ToString
End If

Select Case rfScour
    Case Is <= 0
        SQL = SQL & " AND S = 0.0"
    Case 0.1 To 4.9
        SQL = SQL & " AND S >= 0.0"
        SQL = SQL & " AND S <= 5.0"
    Case Is = 5.0
        SQL = SQL & " AND S = 5.0"
    Case 5.1 To 9.9
        SQL = SQL & " AND S >= 5.0"
        SQL = SQL & " AND S <= 10.0"
    Case Is = 10.0
        SQL = SQL & " AND S = 10.0"
    Case 10.1 To 14.9
        SQL = SQL & " AND S >= 10.0"
        SQL = SQL & " AND S <= 15.0"
    Case Is = 15
        SQL = SQL & " AND S = 15.0"
    Case 15.1 To 19.9
        SQL = SQL & " AND S >= 15.0"
        SQL = SQL & " AND S <= 20.0"
    Case Else
        SQL = SQL & " AND S = 20.0"
End Select
```

```vb
Select Case rfVForce
    Case Is <= 60.0
        SQL = SQL & " AND VertForce =60.0"
    Case 60.1 To 79.9
        SQL = SQL & " AND VertForce >=60.0"
        SQL = SQL & " AND VertForce <=80.0"
    Case Is = 80.0
        SQL = SQL & " AND VertForce =80.0"
    Case 80.1 To 99.9
        SQL = SQL & " AND VertForce >=80.0"
        SQL = SQL & " AND VertForce <=100.0"
    Case Is = 100.0
        SQL = SQL & " AND VertForce =100.0"
    Case 100.1 To 119.9
        SQL = SQL & " AND VertForce >=100.0"
        SQL = SQL & " AND VertForce <=120.0"
    Case Is = 120
        SQL = SQL & " AND VertForce =120.0"
    Case 120.1 To 139.9
        SQL = SQL & " AND VertForce >=120.0"
        SQL = SQL & " AND VertForce <=140.0"
    Case Is = 140
        SQL = SQL & " AND VertForce =140.0"
    Case 140.1 To 159.9
        SQL = SQL & " AND VertForce >=140.0"
        SQL = SQL & " AND VertForce <=160.0"
    Case Else
        SQL = SQL & " AND VertForce >=160.0"
End Select
SQL = SQL & " Order By Ht , S , VertForce "
dcmd = New OleDbCommand(SQL)
dcmd.Connection = gdcCriticalScour
dr = dcmd.ExecuteReader
Do While dr.Read
    Dim fPushOverF As Single
    nBentHeight = dr.Item("Ht")
    fScour = dr.Item("S")
    fVerticalForce = dr.Item("VertForce")
    fPushOverF = dr.Item("Ft")
    If bFirst = True Then
        nHighBh = nBentHeight
        fHighS = fScour
        fHighVf = fVerticalForce
        fLowBhLowSLowVf = fPushOverF
        fLowBhLowSHighVf = fPushOverF
        fLowBhHighSLowVf = fPushOverF
        fLowBhHighSHighVf = fPushOverF
        fHighBhLowSLowVf = fPushOverF
        fHighBhLowSHighVf = fPushOverF
        fHighBhHighSLowVf = fPushOverF
        fHighBhHighSHighVf = fPushOverF
        bFirst = False
    Else
```

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```vba
                        If nBentHeight > nHighBh And fScour > fHighS And
fVerticalForce > fHighVf Then
                            fHighBhHighSHighVf = fPushOverF

                        ElseIf nBentHeight > nHighBh And fScour > fHighS And
fVerticalForce <= fHighVf Then
                            fHighBhHighSLowVf = fPushOverF

                        ElseIf nBentHeight > nHighBh And fScour <= fHighS And
fVerticalForce > fHighVf Then
                            fHighBhLowSHighVf = fPushOverF

                        ElseIf nBentHeight > nHighBh And fScour <= fHighS And
fVerticalForce <= fHighVf Then
                            fHighBhLowSLowVf = fPushOverF

                        ElseIf nBentHeight <= nHighBh And fScour > fHighS And
fVerticalForce > fHighVf Then
                            fLowBhHighSHighVf = fPushOverF

                        ElseIf nBentHeight <= nHighBh And fScour > fHighS And
fVerticalForce <= fHighVf Then
                            fLowBhHighSLowVf = fPushOverF

                        ElseIf nBentHeight <= nHighBh And fScour <= fHighS And
fVerticalForce > fHighVf Then
                            fLowBhLowSHighVf = fPushOverF

                        End If
                    End If

            Loop
            If nBentHeight = nHighBh And fScour = fHighS And rfVForce =
fVerticalForce Then  'Pushover Force if H, S, and V are exact
                    PushOver = fLowBhLowSLowVf
            ElseIf nBentHeight = nHighBh And fScour = fHighS Then
'Pushover Force if H and S are exact
                    PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fLowBhLowSHighVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf

            ElseIf rfVForce = fVerticalForce And fScour = fHighS Then
'Pushover Force if V and S are exact
                    PushOver = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf

            ElseIf nBentHeight = nHighBh And rfVForce = fVerticalForce Then
'Pushover Force if H and V are exact
                    PushOver = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf

            ElseIf nBentHeight = nHighBh Then    'Pushover Force if H is
exact; S and V vary
                    fMidSLowVf = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
```

```vb
            fMidSHighVf = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSHighVf - fLowBhLowSHighVf)) + fLowBhLowSHighVf
            PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidSHighVf - fMidSLowVf)) + fMidSLowVf

        ElseIf fScour = fHighS Then      'Pushover Force if S is exact;
H and V vary
            fMidBhLowVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
            fMidBhHighVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowSHighVf - fLowBhLowSHighVf)) + fLowBhLowSHighVf
            PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidBhHighVf - fMidBhLowVf)) + fMidBhLowVf

        ElseIf fScour = fHighS Then      'Pushover Force if V is exact;
S and H vary
            fMidSLowBh = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
            fMidSHighBh = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhHighSLowVf - fHighBhLowSLowVf)) + fHighBhLowSLowVf
            PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidBhHighVf - fMidBhLowVf)) + fMidBhLowVf

        Else     'Pushover Force if H, S, and V vary
            'Uses triple interpolation to get pushover value
            fLowBhMidSLowVf = (((rfScour - fHighS) / (fScour - fHighS))
* (fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
            fLowBhMidSHighVf = (((rfScour - fHighS) / (fScour -
fHighS)) * (fLowBhHighSHighVf - fLowBhLowSHighVf)) + fLowBhLowSHighVf
            fLowBhMidSMidVf = (((rfVForce - fHighVf) / (fVerticalForce
- fHighVf)) * (fLowBhMidSHighVf - fLowBhMidSLowVf)) + fLowBhMidSLowVf

            fHighBhMidSLowVf = (((rfScour - fHighS) / (fScour -
fHighS)) * (fHighBhHighSLowVf - fHighBhLowSLowVf)) + fHighBhLowSLowVf
            fHighBhMidSHighVf = (((rfScour - fHighS) / (fScour -
fHighS)) * (fHighBhHighSHighVf - fHighBhLowSHighVf)) +
fHighBhLowSHighVf
            fHighBhMidSMidVf = (((rfVForce - fHighVf) / (fVerticalForce
- fHighVf)) * (fHighBhMidSHighVf - fHighBhMidSLowVf)) +
fHighBhMidSLowVf

            PushOver = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhMidSMidVf - fLowBhMidSMidVf)) + fLowBhMidSMidVf

        End If
        Get_Ft_B_III = PushOver
        dr.Close()
        gdcCriticalScour.Close()
        dr = Nothing
        dcmd = Nothing
    End Function

    Function SQ(ByVal s As String) As String
        Dim w As New StringBuilder
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```

```vbnet
        Dim c As Char
        w.Append("'")
        For Each c In s
            If c <> "'" And c <> Chr(34) Then w.Append(c)
        Next
        w.Append("'")
        Return w.ToString
    End Function

 Function Get_Ft_UB_III(ByVal TableName As String, ByVal rnNoPiles As
Integer, ByVal rnBentHeight As Single, _
                   ByVal rfScour As Single, ByVal rfVForce As Single)
As Single
        Dim dcmd As OleDbCommand
        Dim SQL As String
        Dim dr As OleDbDataReader
        Dim bFirst As Boolean = True
        Dim nHighBh As Single
        Dim fHighVf As Single
        Dim fHighS As Single
        Dim fLowBhLowSLowVf As Single
        Dim fLowBhLowSHighVf As Single
        Dim fLowBhHighSLowVf As Single
        Dim fLowBhHighSHighVf As Single
        Dim fHighBhLowSLowVf As Single
        Dim fHighBhLowSHighVf As Single
        Dim fHighBhHighSLowVf As Single
        Dim fHighBhHighSHighVf As Single
        Dim nBentHeightSQL As Single
        Dim nBentHeight As Single
        Dim fVerticalForce As Single
        Dim fMidBhLowVf As Single
        Dim fMidBhHighVf As Single
        Dim fMidSLowVf As Single
        Dim fMidSHighVf As Single
        Dim fMidSLowBh As Single
        Dim fMidSHighBh As Single
        Dim fLowBhMidSLowVf As Single
        Dim fLowBhMidSHighVf As Single
        Dim fLowBhMidSMidVf As Single
        Dim fHighBhMidSLowVf As Single
        Dim fHighBhMidSHighVf As Single
        Dim fHighBhMidSMidVf As Single
        Dim fScour As Single
        Dim PushOver As Single
        gdcCriticalScour.Open()
        SQL = "SELECT  Ht, S, VertForce, Ft "
        SQL = SQL & " FROM " & TableName
        SQL = SQL & " WHERE PileNum =" & rnNoPiles.ToString

        If rnBentHeight <= 10 Then
            nBentHeightSQL = 10
        ElseIf rnBentHeight > 10 And rnBentHeight < 13 Then
            'Both
```

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```vb
        nBentHeightSQL = 0
Else
        nBentHeightSQL = 13
End If

If nBentHeightSQL > 0 Then
        SQL = SQL & " AND Ht =" & nBentHeightSQL.ToString
End If

Select Case rfScour
    Case Is <= 0
            SQL = SQL & " AND S = 0.0"
    Case 0.1 To 4.9
            SQL = SQL & " AND S >= 0.0"
            SQL = SQL & " AND S <= 5.0"
    Case Is = 5.0
            SQL = SQL & " AND S = 5.0"
    Case 5.1 To 9.9
            SQL = SQL & " AND S >= 5.0"
            SQL = SQL & " AND S <= 10.0"
    Case Is = 10.0
            SQL = SQL & " AND S = 10.0"
    Case 10.1 To 14.9
            SQL = SQL & " AND S >= 10.0"
            SQL = SQL & " AND S <= 15.0"
    Case Is = 15
            SQL = SQL & " AND S = 15.0"
    Case 15.1 To 19.9
            SQL = SQL & " AND S >= 15.0"
            SQL = SQL & " AND S <= 20.0"
    Case Else
            SQL = SQL & " AND S = 20.0"
End Select

Select Case rfVForce
    Case Is <= 60.0
            SQL = SQL & " AND VertForce =60.0"
    Case 60.1 To 79.9
            SQL = SQL & " AND VertForce >=60.0"
            SQL = SQL & " AND VertForce <=80.0"
    Case Is = 80.0
            SQL = SQL & " AND VertForce =80.0"
    Case 80.1 To 99.9
            SQL = SQL & " AND VertForce >=80.0"
            SQL = SQL & " AND VertForce <=100.0"
    Case Is = 100.0
            SQL = SQL & " AND VertForce =100.0"
    Case 100.1 To 119.9
            SQL = SQL & " AND VertForce >=100.0"
            SQL = SQL & " AND VertForce <=120.0"
    Case Is = 120
            SQL = SQL & " AND VertForce =120.0"
    Case 120.1 To 139.9
            SQL = SQL & " AND VertForce >=120.0"
```

```vb
                SQL = SQL & " AND VertForce <=140.0"
            Case Is = 140
                SQL = SQL & " AND VertForce =140.0"
            Case 140.1 To 159.9
                SQL = SQL & " AND VertForce >=140.0"
                SQL = SQL & " AND VertForce <=160.0"
            Case Else
                SQL = SQL & " AND VertForce >=160.0"
        End Select
        SQL = SQL & " Order By Ht , S , VertForce "
        dcmd = New OleDbCommand(SQL)
        dcmd.Connection = gdcCriticalScour
        dr = dcmd.ExecuteReader
        Do While dr.Read
            Dim fPushOverF As Single
            nBentHeight = dr.Item("Ht")
            fScour = dr.Item("S")
            fVerticalForce = dr.Item("VertForce")
            fPushOverF = dr.Item("Ft")
            If bFirst = True Then
                nHighBh = nBentHeight
                fHighS = fScour
                fHighVf = fVerticalForce
                fLowBhLowSLowVf = fPushOverF
                fLowBhLowSHighVf = fPushOverF
                fLowBhHighSLowVf = fPushOverF
                fLowBhHighSHighVf = fPushOverF
                fHighBhLowSLowVf = fPushOverF
                fHighBhLowSHighVf = fPushOverF
                fHighBhHighSLowVf = fPushOverF
                fHighBhHighSHighVf = fPushOverF
                bFirst = False
            Else
                If nBentHeight > nHighBh And fScour > fHighS And
fVerticalForce > fHighVf Then
                    fHighBhHighSHighVf = fPushOverF

                ElseIf nBentHeight > nHighBh And fScour > fHighS And
fVerticalForce <= fHighVf Then
                    fHighBhHighSLowVf = fPushOverF

                ElseIf nBentHeight > nHighBh And fScour <= fHighS And
fVerticalForce > fHighVf Then
                    fHighBhLowSHighVf = fPushOverF

                ElseIf nBentHeight > nHighBh And fScour <= fHighS And
fVerticalForce <= fHighVf Then
                    fHighBhLowSLowVf = fPushOverF

                ElseIf nBentHeight <= nHighBh And fScour > fHighS And
fVerticalForce > fHighVf Then
                    fLowBhHighSHighVf = fPushOverF
```

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```vb
                    ElseIf nBentHeight <= nHighBh And fScour > fHighS And
fVerticalForce <= fHighVf Then
                        fLowBhHighSLowVf = fPushOverF

                    ElseIf nBentHeight <= nHighBh And fScour <= fHighS And
fVerticalForce > fHighVf Then
                        fLowBhLowSHighVf = fPushOverF

                    End If
                End If

        Loop
        If nBentHeight = nHighBh And fScour = fHighS And rfVForce =
fVerticalForce Then   'Pushover Force if H, S, and V are exact
            PushOver = fLowBhLowSLowVf
        ElseIf nBentHeight = nHighBh And fScour = fHighS Then
'Pushover Force if H and S are exact
            PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fLowBhLowSHighVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf

        ElseIf rfVForce = fVerticalForce And fScour = fHighS Then
'Pushover Force if V and S are exact
            PushOver = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf

        ElseIf nBentHeight = nHighBh And rfVForce = fVerticalForce Then
'Pushover Force if H and V are exact
            PushOver = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf

        ElseIf nBentHeight = nHighBh Then   'Pushover Force if H is
exact; S and V vary
            fMidSLowVf = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
            fMidSHighVf = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSHighVf - fLowBhLowSHighVf)) + fLowBhLowSHighVf
            PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidSHighVf - fMidSLowVf)) + fMidSLowVf

        ElseIf fScour = fHighS Then     'Pushover Force if S is exact;
H and V vary
            fMidBhLowVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
            fMidBhHighVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowSHighVf - fLowBhLowSHighVf)) + fLowBhLowSHighVf
            PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidBhHighVf - fMidBhLowVf)) + fMidBhLowVf

        ElseIf fScour = fHighS Then     'Pushover Force if V is exact;
S and H vary
            fMidSLowBh = (((rfScour - fHighS) / (fScour - fHighS)) *
(fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
            fMidSHighBh = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhHighSLowVf - fHighBhLowSLowVf)) + fHighBhLowSLowVf
```

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```vbnet
            PushOver = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidBhHighVf - fMidBhLowVf)) + fMidBhLowVf

        Else    'Pushover Force if H, S, and V vary
            'Uses triple interpolation to get pushover value
            fLowBhMidSLowVf = (((rfScour - fHighS) / (fScour - fHighS))
* (fLowBhHighSLowVf - fLowBhLowSLowVf)) + fLowBhLowSLowVf
            fLowBhMidSHighVf = (((rfScour - fHighS) / (fScour -
fHighS)) * (fLowBhHighSHighVf - fLowBhLowSHighVf)) + fLowBhLowSHighVf
            fLowBhMidSMidVf = (((rfVForce - fHighVf) / (fVerticalForce
- fHighVf)) * (fLowBhMidSHighVf - fLowBhMidSLowVf)) + fLowBhMidSLowVf

            fHighBhMidSLowVf = (((rfScour - fHighS) / (fScour -
fHighS)) * (fHighBhHighSLowVf - fHighBhLowSLowVf)) + fHighBhLowSLowVf
            fHighBhMidSHighVf = (((rfScour - fHighS) / (fScour -
fHighS)) * (fHighBhHighSHighVf - fHighBhLowSHighVf)) +
fHighBhLowSHighVf
            fHighBhMidSMidVf = (((rfVForce - fHighVf) / (fVerticalForce
- fHighVf)) * (fHighBhMidSHighVf - fHighBhMidSLowVf)) +
fHighBhMidSLowVf

            PushOver = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhMidSMidVf - fLowBhMidSMidVf)) + fLowBhMidSMidVf

        End If
        Get_Ft_UB_III = PushOver
        dr.Close()
        gdcCriticalScour.Close()
        dr = Nothing
        dcmd = Nothing
    End Function
End Module
```

```vb
Imports System
Imports System.Data
Imports System.Data.OleDb
Imports System.Text
Module IO_Scr
    Dim gdcCriticalScour As OleDbConnection
    Public Sub SetConnection(ByVal sFileName As String)
        ' Call once on application load
        Dim sConn As String
        sConn = "Provider=Microsoft.Jet.OLEDB.4.0"
        sConn = sConn & ";Data Source=" & sFileName
        sConn = sConn & ";Mode=Share Deny None"
        gdcCriticalScour = New OleDbConnection(sConn)

    End Sub
    Function Get_Scr_B(ByVal TableName As String, ByVal rnNoPiles As Integer, ByVal rsBracing As String, _
    ByVal rnStories As Integer, ByVal rnBentHeight As Single, ByVal rfVForce As Single) As Single
        Dim dcmd As OleDbCommand
        Dim SQL As String
        Dim dr As OleDbDataReader
        Dim bFirst As Boolean = True
        Dim nHighBh As Single
        Dim fHighVf As Single
        Dim fLowBhLowVf As Single
        Dim fLowBhHighVf As Single
        Dim fHighBhLowVf As Single
        Dim fHighBhHighVf As Single
        Dim nBentHeightSQL As Single
        Dim nBentHeight As Single
        Dim fVerticalForce As Single
        Dim fMidBhLowVf As Single
        Dim fMidBhHighVf As Single
        Dim Scour As Single
        gdcCriticalScour.Open()
        SQL = "SELECT  BntHt, VertForce, CritScour "
        SQL = SQL & " FROM " & TableName
        SQL = SQL & " WHERE PileNum =" & rnNoPiles.ToString
        SQL = SQL & " AND NumStories =" & rnStories.ToString
        SQL = SQL & " AND BraceConfig =" & SQ(rsBracing)

        If rnStories = 1 Then
            If rnBentHeight <= 13 Then
                nBentHeightSQL = 13
            ElseIf rnBentHeight > 13 And rnBentHeight < 17 Then
                'Both
                nBentHeightSQL = 0
            Else
                nBentHeightSQL = 17
            End If
        Else
            If rnBentHeight <= 21 Then
                nBentHeightSQL = 21
```
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```vb
        ElseIf rnBentHeight > 21 And rnBentHeight < 25 Then
            'Both
            nBentHeightSQL = 0
        Else
            nBentHeightSQL = 25
        End If
    End If
    If nBentHeightSQL > 0 Then
        SQL = SQL & " AND BntHt =" & nBentHeightSQL.ToString
    End If
    Select Case rfVForce
        Case Is <= 60.0
            SQL = SQL & " AND VertForce =60.0"
        Case 60.1 To 79.9
            SQL = SQL & " AND VertForce >=60.0"
            SQL = SQL & " AND VertForce <=80.0"
        Case Is = 80.0
            SQL = SQL & " AND VertForce =80.0"
        Case 80.1 To 99.9
            SQL = SQL & " AND VertForce >=80.0"
            SQL = SQL & " AND VertForce <=100.0"
        Case Is = 100.0
            SQL = SQL & " AND VertForce =100.0"
        Case 100.1 To 119.9
            SQL = SQL & " AND VertForce >=100.0"
            SQL = SQL & " AND VertForce <=120.0"
        Case Is = 120
            SQL = SQL & " AND VertForce =120.0"
        Case 120.1 To 139.9
            SQL = SQL & " AND VertForce >=120.0"
            SQL = SQL & " AND VertForce <=140.0"
        Case Is = 140
            SQL = SQL & " AND VertForce =140.0"
        Case 140.1 To 159.9
            SQL = SQL & " AND VertForce >=140.0"
            SQL = SQL & " AND VertForce <=160.0"
        Case Else
            SQL = SQL & " AND VertForce >=160.0"
    End Select
    SQL = SQL & " Order By BntHt , VertForce "
    dcmd = New OleDbCommand(SQL)
    dcmd.Connection = gdcCriticalScour
    dr = dcmd.ExecuteReader
    Do While dr.Read
        Dim fCriticalScour As Single
        nBentHeight = dr.Item("BntHt")
        fVerticalForce = dr.Item("VertForce")
        fCriticalScour = dr.Item("CritScour")
        If bFirst = True Then
            nHighBh = nBentHeight
            fHighVf = fVerticalForce
            fLowBhLowVf = fCriticalScour
            fLowBhHighVf = fCriticalScour
            fHighBhLowVf = fCriticalScour
```

```vbnet
                    fHighBhHighVf = fCriticalScour
                    bFirst = False
                Else
                    If nBentHeight > nHighBh And fVerticalForce > fHighVf
Then
                        fHighBhHighVf = fCriticalScour

                    ElseIf nBentHeight > nHighBh And fVerticalForce <=
fHighVf Then
                        fHighBhLowVf = fCriticalScour

                    ElseIf nBentHeight <= nHighBh And fVerticalForce >
fHighVf Then
                        fLowBhHighVf = fCriticalScour

                    End If
                End If

        Loop
        If nBentHeight = nHighBh And rfVForce = fVerticalForce Then
'if H and V values are exact
            Scour = fLowBhLowVf
        ElseIf nBentHeight = nHighBh Then                'If H is exact
            Scour = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fLowBhHighVf - fLowBhLowVf)) + fLowBhLowVf
        ElseIf rfVForce = fVerticalForce Then        'If V is exact
            Scour = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowVf - fLowBhLowVf)) + fLowBhLowVf
        Else                                            'If H and V vary
            fMidBhLowVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowVf - fLowBhLowVf)) + fLowBhLowVf
            fMidBhHighVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhHighVf - fLowBhHighVf)) + fLowBhHighVf
            Scour = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidBhHighVf - fMidBhLowVf)) + fMidBhLowVf
        End If
        Get_Scr_B = Scour
        dr.Close()
        gdcCriticalScour.Close()
        dr = Nothing
        dcmd = Nothing
    End Function

    Function SQ(ByVal s As String) As String
        Dim w As New StringBuilder
        Dim c As Char
        w.Append("'")
        For Each c In s
            If c <> "'" And c <> Chr(34) Then w.Append(c)
        Next
        w.Append("'")
        Return w.ToString
    End Function
```

```vb
    Function Get_Scr_UB(ByVal TableName As String, ByVal rnNoPiles As
Integer, ByVal rnBentHeight As Single, _
                                  ByVal rfVForce As Single) As Single
        Dim dcmd As OleDbCommand
        Dim SQL As String
        Dim dr As OleDbDataReader
        Dim bFirst As Boolean = True
        Dim nHighBh As Single
        Dim fHighVf As Single
        Dim fLowBhLowVf As Single
        Dim fLowBhHighVf As Single
        Dim fHighBhLowVf As Single
        Dim fHighBhHighVf As Single
        Dim nBentHeightSQL As Single
        Dim nBentHeight As Single
        Dim fVerticalForce As Single
        Dim fMidBhLowVf As Single
        Dim fMidBhHighVf As Single
        Dim Scour As Single
        gdcCriticalScour.Open()
        SQL = "SELECT  BntHt, VertForce, CritScour "
        SQL = SQL & " FROM " & TableName
        SQL = SQL & " WHERE PileNum =" & rnNoPiles.ToString

        If rnBentHeight <= 10 Then
            nBentHeightSQL = 10
        ElseIf rnBentHeight > 10 And rnBentHeight < 13 Then
            'Both
            nBentHeightSQL = 0
        Else
            nBentHeightSQL = 13
        End If
        If nBentHeightSQL > 0 Then
            SQL = SQL & " AND BntHt =" & nBentHeightSQL.ToString
        End If
        Select Case rfVForce
            Case Is <= 60.0
                SQL = SQL & " AND VertForce =60.0"
            Case 60.1 To 79.9
                SQL = SQL & " AND VertForce >=60.0"
                SQL = SQL & " AND VertForce <=80.0"
            Case Is = 80.0
                SQL = SQL & " AND VertForce =80.0"
            Case 80.1 To 99.9
                SQL = SQL & " AND VertForce >=80.0"
                SQL = SQL & " AND VertForce <=100.0"
            Case Is = 100.0
                SQL = SQL & " AND VertForce =100.0"
            Case 100.1 To 119.9
                SQL = SQL & " AND VertForce >=100.0"
                SQL = SQL & " AND VertForce <=120.0"
            Case Is = 120
                SQL = SQL & " AND VertForce =120.0"
            Case 120.1 To 139.9
```

```vb
                    SQL = SQL & " AND VertForce >=120.0"
                    SQL = SQL & " AND VertForce <=140.0"
                Case Is = 140
                    SQL = SQL & " AND VertForce =140.0"
                Case 140.1 To 159.9
                    SQL = SQL & " AND VertForce >=140.0"
                    SQL = SQL & " AND VertForce <=160.0"
                Case Else
                    SQL = SQL & " AND VertForce >=160.0"
            End Select
            SQL = SQL & " Order By BntHt , VertForce "
            dcmd = New OleDbCommand(SQL)
            dcmd.Connection = gdcCriticalScour
            dr = dcmd.ExecuteReader
            Do While dr.Read
                Dim fCriticalScour As Single
                nBentHeight = dr.Item("BntHt")
                fVerticalForce = dr.Item("VertForce")
                fCriticalScour = dr.Item("CritScour")
                If bFirst = True Then
                    nHighBh = nBentHeight
                    fHighVf = fVerticalForce
                    fLowBhLowVf = fCriticalScour
                    fLowBhHighVf = fCriticalScour
                    fHighBhLowVf = fCriticalScour
                    fHighBhHighVf = fCriticalScour
                    bFirst = False
                Else
                    If nBentHeight > nHighBh And fVerticalForce > fHighVf
Then
                        fHighBhHighVf = fCriticalScour

                    ElseIf nBentHeight > nHighBh And fVerticalForce <=
fHighVf Then
                        fHighBhLowVf = fCriticalScour

                    ElseIf nBentHeight <= nHighBh And fVerticalForce >
fHighVf Then
                        fLowBhHighVf = fCriticalScour

                    End If
                End If

            Loop
            If nBentHeight = nHighBh And rfVForce = fVerticalForce Then
'if H and V values are exact
                Scour = fLowBhLowVf
            ElseIf nBentHeight = nHighBh Then           'If H is exact
                Scour = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fLowBhHighVf - fLowBhLowVf)) + fLowBhLowVf
            ElseIf rfVForce = fVerticalForce Then       'If V is exact
                Scour = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowVf - fLowBhLowVf)) + fLowBhLowVf
            Else                                        'If H and V vary
```

```
            fMidBhLowVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhLowVf - fLowBhLowVf)) + fLowBhLowVf
            fMidBhHighVf = (((rnBentHeight - nHighBh) / (nBentHeight -
nHighBh)) * (fHighBhHighVf - fLowBhHighVf)) + fLowBhHighVf
            Scour = (((rfVForce - fHighVf) / (fVerticalForce -
fHighVf)) * (fMidBhHighVf - fMidBhLowVf)) + fMidBhLowVf
        End If
          Get_Scr_UB = Scour
        dr.Close()
        gdcCriticalScour.Close()
        dr = Nothing
        dcmd = Nothing
    End Function
End Module
```