Load and Resistance Factor Design (LRFD) for Analysis/Design of Piles Axial Capacity

By

M. S. Rahman, Ph.D., P.E., Professor

M. A. Gabr, Ph.D., P.E., Professor

R. Z. Sarica, Graduate Assistant

M. S. Hossain, Graduate Assistant

Department of Civil, Construction and Environmental Engineering

North Carolina State University

In Cooperation with

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16. Abstract

Resistance factors were developed for use as a part of the implementation of the Load and Resistance Factor Design (LRFD) method of driven piles' axial capacity. Resistance factors were calibrated in the framework of reliability theory utilizing pile load test data available from North Carolina Department of Transportation (NCDOT). Resistance statistics were evaluated for each data case in terms of bias factors. Reliability analyses on the current practice of pile foundation design by the Vesic, Meyerhof, and Nordlund methods were performed to evaluate the level of safety and to select target reliability indexes. Two types of First Order Reliability Method, Mean Value First Order Second Moment method and Advanced First Order Second Moment method, were employed for the reliability analysis and the calibration of the resistance factors. Recommended resistance factors for the three design methods (Vesic, Meyerhof, and Nordlund) are presented for the target reliability indexes of 2.0 and 2.5. Seven design categories for which the resistance factors are recommended are coastal concrete square pile with N@Toe<=40, coastal concrete square pile with N@Toe>40, coastal steel HP pile, coastal steel pipe pile, coastal concrete cylinder pile, piedmont concrete square pile, and piedmont steel HP pile. The resistance factors were calibrated separately for total, skin and toe capacities in an attempt to develop a correlation between the three resistance factors for each design category. In many cases, however, the resistance factor for total capacity is larger than both the skin and toe resistance factors and only total capacity factors are recommended. The resistance factors developed and recommended from this research are specific for the distinct soil types of North Carolina and for the unique practice of pile foundation design in the NCDOT.

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Executive Summary

Resistance factors were developed in the framework of reliability theory for axial capacity of driven piles in two North Carolina geologic provinces. The development of resistance factors utilized 140 Pile Driving Analyzer (PDA) data and 35 static load test data available from the North Carolina Department of Transportation. Pile records were compiled and grouped into different design categories encopmassing four pile types and two geologic regions. Resistance statistics were evaluated for each category in terms of bias factors. Bayesian updating was employed in an attempt to improve the statistics of the resistance bias factors, given the limited number of pile load test data. Load statistics presented in the current AASHTO LRFD bridge design specifications were used in the reliability analysis and the calibration of the resistance factors.

Resistance factor calibration was performed for the three methods of static pile capacity analysis commonly used in the NCDOT: Vesic, Nordlund, and Meyerhof methods. Two types of First Order Reliability Methods, Mean Value First Order Second Moment method and Advanced First Order Second Moment method, were employed for the reliability analysis and the calibration of the resistance factors. Recommended resistance factors are presented for the three methods of static pile capacity analysis and for seven different design categories of pile type and region. These are coastal concrete square pile with <u>N@Toe<=40</u>, coastal concrete square pile with <u>N@Toe>40</u>, coastal steel HP pile, coastal steel pipe pile, coastal concrete cylinder pile, piedmont concrete square pile, and piedmont steel HP pile.

For the coastal concrete square piles, the pile capacities measured in the PDA restrikes (BOR) appear to represent the ultimate pile capacity more accurately than those measured in the PDA initial driving (EOD), and the resistance factors calibrated using the PDA BOR databases are given more weight than those based on the PDA EOD. For the coastal steel HP piles, the increase in the calibrated resistance factors from PDA EOD to PDA BOR due to the capacity gain with time (setup) is significant. The setup effects for the coastal steel pipe piles are also significant. All but one PDA data for the coastal steel pipe piles are from the same project site, and this probably contributed to the resistance statistics for all the three static capacity analysis methods. More variation in the resistance bias factors maybe expected if the PDA data were from more diverse project sites, which would result in smaller resistance factors. Recommended resistance factors for reliability levels of 2.0 and 2.5 are as follows:

Recommended Resistance Factors

Pile Type and Region (Design Category)	Vesic		Nordlund		Meyerhof	
	$\beta_T = 2.0$	$\beta_T = 2.5$	$\beta_T = 2.0$	$\beta_T = 2.5$	$\beta_T = 2.0$	$\beta_T = 2.5$
Coastal Concrete Square Pile N@Toe<=40	0.60	0.50	0.55	0.45	0.90	0.70
Coastal Concrete Square Pile N@Toe>40	0.50	0.40	0.40	0.35	0.80	0.60
Coastal Steel HP Pile	0.75	0.65	0.80	0.70	0.65	0.55
Coastal Steel Pipe Pile	0.90	0.75	0.70	0.60	0.95	0.80
Coastal Concrete Cylinder Pile	0.50	0.45	0.15*	0.10*	0.90	0.75
Piedmont Concrete Square Pile	0.75	0.65	0.90	0.75	0.45	0.35
Piedmont Steel HP Pile	0.90	0.75	0.50	0.40	0.85	0.70

*=not recommended for practice

Limitations to the values presented in this report include the resistance factors for the coastal concrete cylinder piles are based on the least amount of the pile load test data, and therefore are considered least reliable. The resistance factors calibrated for the Nordlund method are extremely small and are not recommended for practical use. The static load test data are considered more reliable than the PDA EOD data, and therefore recommended resistance factors for the Vesic and Meyerhof methods are selected based on the static load test data.

Conservatism is applied in the selection of the recommended resistance factors due to the limited number of the data points. The resistance factors developed and recommended from this research are specific for the distinct soil types of the geologic regions of North Carolina and for the unique practice of pile foundation design at NCDOT. The approach of the resistance factor calibration developed from this research can be applied to the resistance factor calibration for other foundation types.

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Driven piles are one of the main elements of bridge foundations. Currently, North Carolina Department of Transportation (NCDOT) uses static methods of design of the foundation piles with the conventional factor of safety (referred to as Allowable Strength Design). In addition Wave Equation Analysis is used to provide the pile driving criteria, which show the required hammer blow counts for achieving the pile design capacity. Static load tests and Pile Driving Analyzer (PDA) are sometimes used to verify the design. The American Association of State Highway and Transportation Officials (AASHTO) has called for the implementation of Load and Resistance Factor Design (LRFD) for bridges including their foundations. Presently, virtually all reinforced concrete superstructures are designed using LRFD method, and steel design is in the process of transition from the Allowable Strength Design (ASD) code to the newer LRFD code.

Over the past 18 years there has been a general move toward the increased use of LRFD in structural and geotechnical design. In order to adopt a consistent design for both the superstructures and the foundations, many state DOT's are now moving to the implementation of the AASHTO LRFD Specifications (Passe, 1997). In LRFD approach, load and resistance factors need to be defined. For the geotechnical design of driven piles, AASHTO guidelines provide these factors for general soil conditions. However, the AASHTO factors are not appropriate for specific local conditions. The available literature indicates that several users found the AASHTO-recommended factors lead to inappropriate design conflicting with their experiences (Goble, 1999). A recent study team organized by the Federal Highway Administration (FHWA) reviewed the developments in load and resistance factor design methods in Canada, Germany, France, Denmark, Norway, and Sweden (DiMaggio et al, 1999). The main recommendation of the team was the need for calibration of geotechnical load and resistance factors for different geotechnical applications utilizing existing databases.

1.2 A BRIEF HISTORY OF LRFD FOR STRUCTURE DESIGN

The earliest use of LRFD was in the American Concrete Institute (ACI) "Building Code Requirements for Reinforced Concrete", adopted in 1956 by ACI Committee 318 (ACI 1956). The document was brief, and the design method was called "Ultimate Strength Design". In this code, resistance factor concept was not introduced, so all of the safety factors were embedded in the load factors. However, the load factors were different for different load types and also for different load combinations. In the next version of the ACI 318 Code (ACI 1963), a complete LRFD format was used including resistance factors. The design method was still known as Ultimate Strength Design, but it was identical in format with LRFD concept. However, both the load and resistance factors in the ACI Codes were not selected based on a rational analysis, but by the intuition and judgment of the committee members.

Cornell (1969) presented a paper "A Probability Based Structural Code" in the ACI journal proposing probability based design codes. Cornell outlined the framework of probability-based structural design codes and discussed the detailed procedures to develop the resistance and load factors. Ellingwood et al. (1980) presented in the National Bureau of Standard (NBS) Report #577 the development of load factors for design of buildings based on a probabilistic analysis. The basic concepts of probability theory application for load factor calibration were presented in the paper. The American Institute of Steel Construction (AISC) did extensive calibration study to develop resistance factors for the various steel structural elements. AISC adopted the load factors presented in NBS Report #577 when they published the LRFD Specification in 1986 (AISC 1986).

The bridge design code adopted by AASHTO in 1977 contained a design procedure called Load Factor Design (LFD) along with the conventional ASD procedure. Both working loads and factored loads were included, and either method could be used in design. In 1994 AASHTO adopted a LRFD code developed from National Cooperative Highway Research Program (NCHRP) Project 12-33 (Nowak, 1992). Interim specifications have been adopted and the new design procedure is now being implemented into practice. Most government agencies as well as private firms are now using LRFD procedures for the bridge superstructure design, and they are in the process of adopting the LRFD procedures for the substructure elements.

1.3 A BRIEF HISTORY OF LRFD FOR GEOTECHNICAL DESIGN

In 1950's the Danish Geotechnical Institute investigated a limit state design method for geotechnical applications. Hansen (1966) presented a limit state code for foundation engineering, which was adopted by the Danish Engineering Association. This code used factors on both the load and the resistance and appears to be the first attempt of

LRFD for geotechnical design. These factors were derived from previous Danish experience, and the resistance factors were applied to the soil properties rather than directly to the resistance. The Danish Code published by the Danish Geotechnical Institute (1985) is the successor of the original limit state code developed by Hansen. It dealt with the design of both shallow and deep foundations, and specific procedures for earth pressure calculations were included.

The province of Ontario in Canada adopted LRFD for bridge design in 1979 with the publication of Ontario Highway Bridge Design Code and Commentary. In 1983, the second edition of the LRFD Code with Commentary was adopted in Ontario and its use became mandatory. This code was developed based on a reliability index of 3.5 for superstructure elements. The corresponding results of using similar reliability index in geotechnical engineering were not encouraging since the foundation elements generally became larger and the design became more conservative. The third edition of the Ontario Bridge Code with Commentary was adopted in 1992, and its use yields more reasonable design of foundations but still more conservative than the previous AASHTO-based designs using ASD method.

When the LRFD method was adopted for the new AASHTO bridge design specification in 1994, it was necessary to include LRFD version for foundation design. Goble (1980) investigated the LRFD concept for pile foundation design. Barker et al. (1991) presented an extensive research effort for the development of LRFD for bridge foundation design. Their research led to NCHRP Report 343, which became the basis for the 1994 AASHTO bridge design specification. The research made the rational probabilistic approach on the model variability and the inherent spatial variability of soil properties. However it did not include the site variability. Goble (1999) presented his findings of the survey on the state DOT's practice of LRFD for geotechnical design. Several users of the AASHTO specifications reported that the resistance factors for the foundation design did not fit in their design practice and resulted in an over-conservative design. Withiam et al. (1998) authored a manual titled 'LRFD for Highway Bridge Substructures' published by the Federal Highway Administration (FHWA). Using this manual, FHWA offered a National Highway Institute (NHI) training course to many of the state DOT's in an effort to implement LRFD for foundation design.

In 1997 the Florida Department of Transportation (FDOT) developed LRFD Code for their bridge design (Passe, 1997). The Code was developed using the AASHTO-recommended load combinations and load factors. The reliability index was calculated for the safety factor used in their ASD practice, and a target reliability index was chosen. The resistance factors were then calibrated for the target reliability index. Though no probabilistic analysis was performed in the calibration process, FDOT was a pioneer among the state DOT's in implementing the LRFD for geotechnical applications.

1.4 PROBLEM STATEMENT

NCDOT is currently using static design methods for estimating the axial capacity of pile foundations based on the allowable strength design (ASD) principles with a predetermined factor of safety. The factor of safety used in the axial pile capacity analysis is the same for all pile types, soil conditions and the static design methods. This practice does not consider any variation in uncertainties regarding the pile types, the subsurface conditions, or the design methods.

AASHTO has mandated the implementation of LRFD for all bridge structures including foundations beginning year 2007. FHWA also has called for LRFD in all federally-funded projects from year 2007. NCDOT's transition from ASD to LRFD is inevitable in order to meet the mandates of AASHTO and FHWA and to provide geotechnical design measures, which are more consistent with the bridge superstructure design.

NCDOT has been using the Vesic method (Vesic, 1977) as the main tool for the static analysis of pile's capacities, supplemented by other methods such as the Nordlund method and the Standard Penetration Test (SPT) method. The Vesic method has been proven effective based on the many years of experience and a previous study (Keane, 1990). However, this method was not included in any of the previous studies conducted to develop the resistance factors for driven piles' axial capacity, and the resistance factor for this method is not available in literature including the AASHTO LRFD Bridge Design Specifications. In addition, the factor of safety used in the NCDOT practice, based on many years of the pile foundation design and construction experience, is different from the factor of safety used in the calibration of the resistance factors recommended in the current AASHTO LRFD Specifications.

There are several factors that can influence the prediction of a pile's capacity. Among them are the static analysis model, the site geology, the in-situ and laboratory tests for estimating soil strength parameters, and the designer's judgment and experience. Therefore, it is important to consider all these design aspects in the development of resistance factors. The resistance factors in the AASHTO LRFD Specifications are based on nationwide general geologic conditions and do not address local specific conditions.

It has been proven that the AASHTO resistance factors do not provide a reasonable foundation design that conforms to the local experiences (Goble, 1999).

It is necessary and urgent to develop the resistance factors for the axial capacity of driven piles in North Carolina. These factors must be developed for the unique soil types for the region, in which the piles are used, incorporating the many years of pile design and construction experience.

1.5 RESEARCH SCOPE AND OBJECTIVES

The main objective of this research is to develop the resistance factors for the design of driven piles in North Carolina. The resistance factors are developed for the different types of the static pile capacity analysis methods, for different pile types, and for the unique geologic coastal and piedmont regions of the state. These factors are developed in the framework of 'reliability analysis' using the Pile Driving Analyzer (PDA) test and static load test data embodying the uncertainties associated with the capacity prediction model, the pile type and geometry, and the soil parameters. The form of probability distribution function describing the pile capacity is studied, and the associated parameters are quantified. The first-order reliability method (FORM) is used to evaluate the reliability index of the current design methods and to select the target reliability index, which is used to develop the resistance factors for the design of the axial capacity of the driven piles in North Carolina. Specifically, the following objectives are achieved:

i. Review the NCDOT's current design practice for the bearing capacity of the driven piles along with the geologic characteristics of the different regions of the state,

ii. Review and compile the PDA and static load test data maintained by NCDOT, and do the static analysis of the pile's bearing capacity for each test data with the different methods of the static analysis,

iii. Perform the statistical analysis of the pile's predicted and measured bearing capacities and establish the resistance statistics including the probability distribution and the parameters,

iv. Perform the reliability analysis of the current design methods using the First Order Reliability Methods (both MVFOSM and AFOSM) and select the target reliability index,

v. Calibrate the resistance factors for the different static analysis methods, for the different pile types (concrete, steel HP and pipe piles) and geometry, and for the different geologic regions (coastal and piedmont) of North Carolina,

vi. Perform parametric and comparative studies to evaluate the influence of the pile length over diameter ratio, the effect of jetting, and the set-up or relaxation effect on the resistance factors, and

vii. Develop detailed LRFD procedures for the axial capacity of driven piles in North Carolina and compare the design by the LRFD procedures with the design by the current ASD methods.

CHAPTER 2.

STATIC ANALYSIS OF AXIAL CAPACITY OF DRIVEN PILES

2.1 INTRODUCTION

There are many static analysis methods available to estimate the required pile lengths and the number of piles for a given set of applied loads to the substructure. Some of them such as the Meyerhof method, the α-method and the CPT method are mainly empirical, and others such as the Nordlund method, the β-method, and the Vesic method are semi-empirical. There are some advantages and disadvantages in each method, and the selection of the most appropriate method depends on the site geology, pile type, availability of soil parameters, and the designer's experience. NCDOT has traditionally been using the Vesic method as the main model for the driven pile's axial capacity analysis, supplemented by the Nordlund method and the Meyerhof method. Each of the three methods has a provision in its algorithm that employs the Tomlinson method for the section of the pile in a soft to medium dense clay layer. The resistance factors developed in this study are for these three models.

The ultimate capacity of a single pile is the sum of skin and toe resistance ($R_U = R_S + R_T$). The calculation assumes that the skin and toe resistances can be determined separately and these two values do not affect each other. The ultimate load on a pile is the load that can cause failure of either the pile or the soil. The pile failure condition may govern the design where pile points penetrate dense sand or rock, but in most situations, ultimate load is determined by the soil failure. Axial capacity of piles is greatly affected by the assumed distribution of the soil parameters and the soil-pile interaction. Gabr (1993) listed the uncertainties in parameters affecting the axial capacity including physical soil properties, the characterization of the interface side friction, and the pile material and loading conditions. Sensitivity study of the cyclic axial capacity of a single pile also indicated the variation in the level of contribution of these parameters as a function of pile deformation (Nadim et al., 1989).

In broad terms, there are two methods of design in current use: the working stress design, referred to by AISC as Allowable Strength Design (ASD) and limit state design, referred to as Load and Resistance Factor Design (LRFD). ASD has been the principal method of design used during the past 100 years. During the past 20 years or so, design has been moving toward more rational approach of LRFD, in which the reliability of the design is ensured in a rational framework. In the following, these two types of design methods and the four static analysis methods are presented.

2.2 ALLOWABLE STRENGTH DESIGN (ASD)

Considering R to represent the capacity or resistance of a system and Q ($=\Sigma Q_i$) the demand or load acting on it, safety is ensured in the design by use of a factor of safety (F) in the following equation:

$$R/F = Q \tag{2-1}$$

The reason for using a factor of safety to reduce the nominal resistance is the uncertainty associated with the evaluation of both R and Q (even though we are applying F to the resistance only). Meyerhof (1970) presented a very good discussion of safety factors in geotechnical engineering. The following should provide an insight into the way in which a value for safety factor is arrived at. Suppose the actual pile load is expected to exceed the service load by an amount ΔQ, and the actual resistance is less than the evaluated resistance by an amount ΔR. A pile that is just adequate would have

$$R - \Delta R = Q + \Delta Q$$

or,
$$R(1 - \Delta R/R) = Q(1 + \Delta Q/Q) \qquad (2\text{-}2)$$

The safety factor, F as defined above, can be written as

$$F = R/Q = (1 + \Delta Q/Q)/(1 - \Delta R/R) \qquad (2\text{-}3)$$

The above equation illustrates the effect of over-load ($\Delta Q/Q$) and under-strength ($\Delta R/R$) on the safety factor without identifying the factors contributing to either. In order to arrive at a numerical value of safety factor, numerical estimates of over-load and under-strength have to be made according to judgment and prior experience. For example, if one assumes that the occasional over-load may be 20% and that the occasional under-strength may be 30%, the safety factor will then be given as:

$$F = (1+0.2) / (1-0.3) = 1.72 \qquad (2\text{-}4)$$

The advantage of ASD is its simplicity; however, the shortcomings of this approach are:

- The degree of uncertainty associated with R and Q is not incorporated in a systematic way. The factor of safety as used here is not a good measure of reliability. For a system designed by this method, different probabilities of failure may correspond to the same factor of safety.
- The factor of safety is selected on the basis of experience and judgment, and therefore tends to be subjective and arbitrary (Tang et al, 1976).

- Additional information through intensive soil exploration, improved testing techniques, or better correlation studies cannot be incorporated in the evaluation of the uncertainty and subsequent reduction of the required factor of safety for design.

2.3 Load and Resistance Factor Design (LRFD)

In the LRFD procedure, margins for safety are incorporated through load factors and resistance factors. Goble (1996) illustrated the load and resistance factor design (LRFD) bridge specification that was accepted by the AASHTO Bridge Committee. He tested the design procedure for driven pile foundations using a hypothetical example and concluded that the AASHTO LRFD specification would work effectively, but the resistance factors should be modified to be more effective through further research. Green (1994) identified several technical problems in using the LRFD specification with issues relating to earth pressures, shallow and deep foundations.

The basic requirements for LRFD-based design can be expressed as:

$$\phi R = \Sigma \gamma_i Q_i \tag{2-5}$$

where ϕ is a resistance factor and γ_i are load factors. The idea here is to reduce the resistance and increase the load in order to account for the uncertainty associated with both of them. However, in this method, these factors can be systematically developed in the framework of reliability theory. The uncertainties associated with both the resistance and the load may be fully defined through their probability distributions. The probability of failure may be considered through the extent of overlap (Figure 2-1) between the distributions of the resistance and the load. This area of overlap depends on three factors:

(i) the relative position of two curves, represented by the means (μ_R, μ_Q) of the two variables, (ii) the dispersion of the two curves, represented by the standard deviations (σ_R, σ_Q) of the two variables, and (iii) the shapes of the two curves, represented by their probability density functions $f_R(r)$ and $f_Q(q)$.

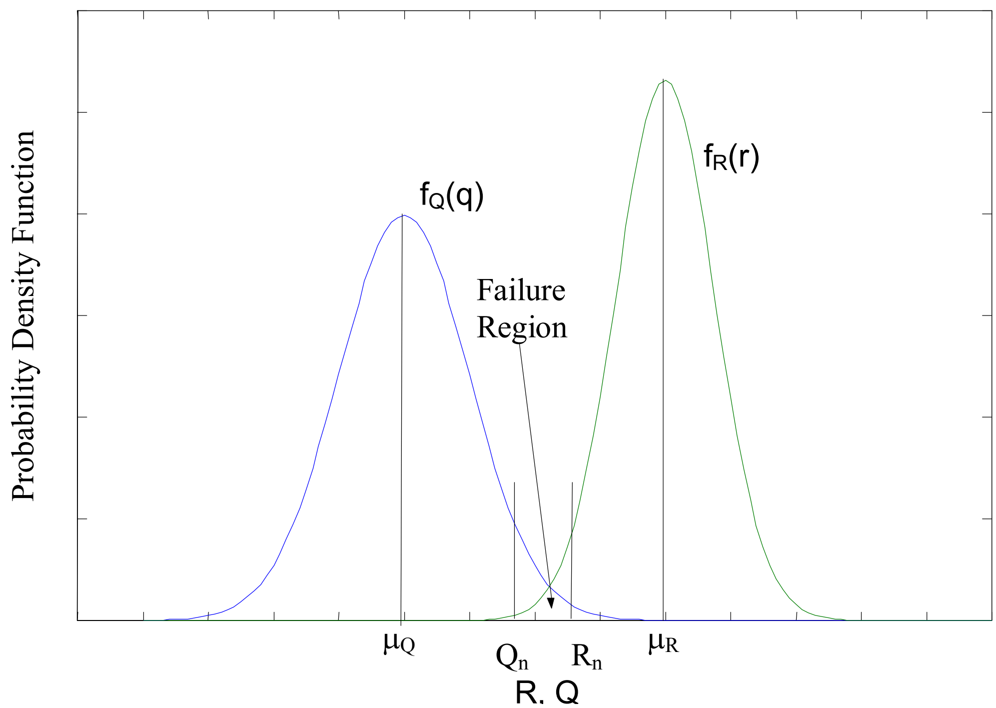

Figure2-1. Distribution of Load and Resistance (Haldar, 2000)

The objective of safe design can be achieved by selecting the design variables in such a way that the area of overlap is as small as possible, so that the underlying risk is not compromised within the constraints of economy. In ASD method, this objective is achieved by shifting the positions of the curves through the use of safety factors. A more rational approach would be to compute the risk by accounting for all three factors of the overlap and to select the design variables so that an acceptable risk of failure is achieved. This is the basis of risk-based design concept.

The advantages of this approach are:

- The uncertainties associated with the soil properties are handled in a rational framework of the theory of probability.
- The reliability, or risk, is quantified through a consistent measure, and a consistent level of safety can be assured.
- Additional information can be incorporated in the evaluation of uncertainty and subsequent updating of the load and resistance factors.
- LRFD is being widely adopted in practice, and the adoption of this approach for pile design will be consistent with the design of other components of a civil engineering system.
- The rationality of LRFD is attractive, and it will also lead to a safer and more economical design.
- LRFD provides the framework to handle unusual loads that may not be covered by the specifications. The design may have uncertainty relating to the resistance of a pile, in which case the resistance factors may be modified.
- Future adjustments in the calibration of the method can be made without much complication. Calibration of LRFD is usually done for an average situation, but it might need to be adjusted in the future.
- Design practice is still at the beginning stage with regard to the serviceability limit states; however, at least the LRFD provides the approach.

The disadvantages of the LRFD are:

- The reliability analysis to develop and adjust resistance factors for individual situations requires considerable amounts of statistical data and probabilistic design algorithms.
- The quality of data can influence the resistance factors significantly.
- Implementation requires some degree of training and understanding of the LRFD methodologies and a change in design procedures.

2.4 VESIC METHOD

Vesic (1977) presented his design method for pile foundations in the NCHRP Synthesis #42. This is a semi-empirical method based on a number of field test data from several different locations of the U.S. and the abroad. The Vesic method has been used most widely in NCDOT to predict a driven pile's bearing capacity for a long period of time. Keane (1990) reported that the Vesic method predicted the pile's bearing capacity most closely to the measured values from the 13 static load tests performed in the past by NCDOT. In the early 1990, NCDOT coded a computer program 'PILECAP' following the general algorithm of the Vesic method. PILECAP calculates a pile's bearing capacities and pile toe settlements at predetermined depth intervals. An example PILECAP output is included in Appendix A.

The Vesic method equates the ultimate bearing capacity to the sum of the total skin resistance and the total toe resistance. The unit skin resistance, f_s, consists of two parts as shown in the following equation.

$$f_s = c_a + q_s \tan\delta \qquad (2\text{-}6)$$

In the equation $\tan\delta$ represents the coefficient of friction between the soil and the pile, which can be taken equal to $\tan\phi$, the coefficient of friction of the remolded soil in terms of effective stresses. The pile-soil cohesion (c_a) is normally small for granular soils and is neglected in the design. The normal stress on the skin (q_s) is related to the effective vertical stress (q_v) at the point of interest and the coefficient of lateral earth pressure (K), and the Equation 2-6 can be rewritten as follows.

$$f_s = K \tan\phi \; q_v = N_s \, q_v \qquad (2\text{-}7)$$

Vesic reported the measured N_s values for driven piles in very dense sand varying from about 2 for very short piles to about 0.4 for very long piles. In loose sand N_s can be as low as 0.1 with no obvious decrease with increasing pile length. Vesic also reported that for piles in medium to dense sand, f_s reaches a quasi-constant limit value after some penetration into the sand stratum, which is a function of only the initial sand density and the overconsolidation ratio of the deposit. He proposed the following simple formula for the unit skin resistance of piles in a granular soil deposit in terms of the soil's relative density (Dr) in each layer.

$$f_s = (1.5)\,(0.08)\,(10)^{1.5Dr^{\wedge}4} \quad \text{tsf} \quad \text{for driven piles} \qquad (2\text{-}8)$$

$$f_s = (1.5)\,(0.025)\,(10)^{1.5Dr^{\wedge}4} \quad \text{tsf} \quad \text{for bored or jacked piles} \qquad (2\text{-}9)$$

The relative density can be represented as a function of the effective overburden pressure (q_v) and the soil's strength parameters. Figure 2-2 shows the relationship between the relative density, the effective overburden pressure, and the standard penetration test (SPT) blow counts (N). This is the figure NCDOT uses along with the Equations 2-8 and 2-9 to compute the unit skin resistance. NCDOT limits the maximum

f_s to 1 tsf and the minimum to 0.126 tsf. The total skin resistance is simply the summation of the unit skin resistance multiplied by the surface area of the pile from all of the soil layers.

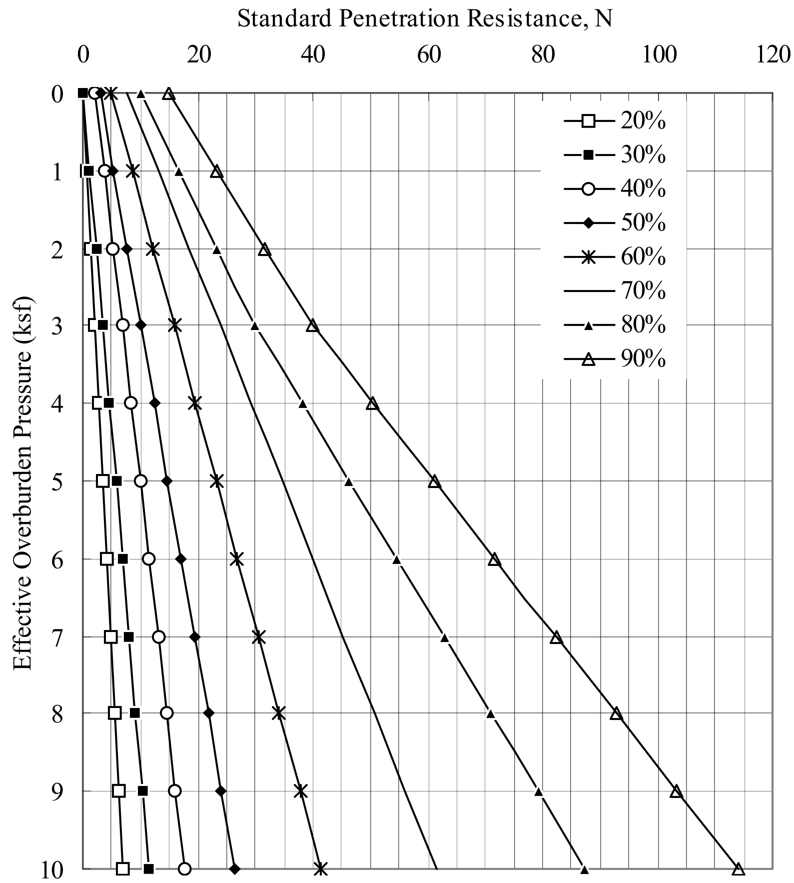

Figure 2-2. Relationship between Standard Penetration Resistance, Relative Density, And Effective Overburden Pressure (Schultze, 1965)

Vesic proposed another equation to predict the unit skin resistance of a pile in a soft to medium stiff clay layer.

$$f_s = \alpha\, S_u \tag{2-10}$$

This is identical to the Tomlinson's equation for the unit skin resistance, in which α is an empirical adhesion factor. However, the adhesion factor in the Vesic method, which varies from 0.2 to 1.5 for different pile types and soil conditions, is different from that in the Tomlinson method. The experience within NCDOT has found that this equation does not predict the skin resistance adequately for the clay soils in North Carolina. Instead of using this equation, NCDOT has a provision in the Vesic method that uses the Tomlinson's α method for the skin resistance in a soft to medium stiff clay layer. Many researchers including Vesic (1977) found that the behavior of piles in stiff clay is frictional in nature and fundamentally similar to that of piles in dense sand. In NCDOT's practice, a clay soil with the SPT N value over 20 is treated as a granular soil in the bearing capacity predictions.

The unit toe resistance is represented by the following equation based on nonlinear elasto-plastic theories.

$$q_t = c\,N_c + q_v N_q \qquad (2\text{-}11)$$

in which c represents the strength intercept (cohesion) of the assumed straight line Mohr envelope and q_v, the effective vertical stress in the ground at the depth of consideration. N_c and N_q are dimensionless bearing capacity factors, related to each other by the equation

$$N_c = (N_q - 1)\cot\phi \qquad (2\text{-}12)$$

where ϕ is the soil's angle of frictional resistance. Vesic confirmed that the toe resistance is governed not by the vertical effective stress (q_v) but by the mean normal ground stress (σ_o), which is related to q_v by the expression

$$\sigma_o = [(1 + 2\,K_o) / 3]\,q_v \qquad (2\text{-}13)$$

in which K_o represents the coefficient of at-rest lateral earth pressure. Thus, Equation 2-11 can be revised to the following form.

$$q_t = c\, N_c + \sigma_o\, N_\sigma \qquad (2\text{-}14)$$

in which N_σ is a bearing capacity factor and is a function of the soil's angle of frictional resistance and the rigidity index (I_r). The rigidity index is determined by the mean normal ground stress and the soil's relative density using Figure 2-3. The bearing capacity factors (N_c and N_σ) can be obtained from Table 2-1 for ranges of ϕ and I_r values.

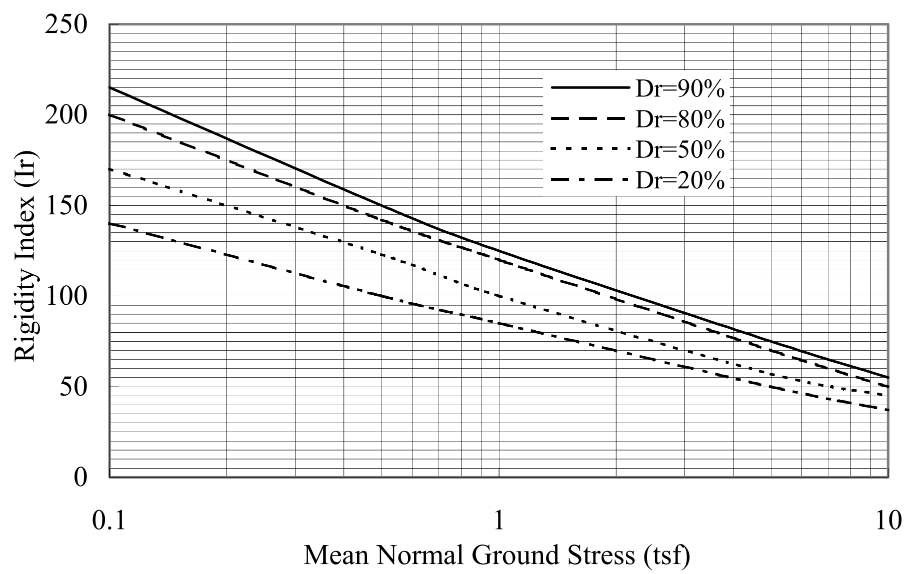

Figure 2-3. Relationship between Mean Normal Ground Stress, Relative Density, and Rigidity Index (Schultze, 1965)

NCDOT uses SPT blow counts (N values) as the standard in-situ test data to obtain the soil's strength parameters, the cohesion (c) and the angle of frictional resistance (ϕ). The N values collected from the field tests are converted to N' (corrected blow counts) to account for the effects of the overburden pressure at the depth of each layer using the following equation.

$$N' = 0.77 \log (20/ q_v)\, N \qquad (2\text{-}15)$$

in which q_v is the effective overburden pressure in tsf. N' is limited to two times N regardless of q_v. When there is no laboratory test data available for the angle of frictional resistance, which is the case most of the time, ϕ is estimated using N' in the equation.

$$\phi = 0.3\, (N' + 90) \text{ degrees} \qquad (2\text{-}16)$$

The N value used here is the average N value for each layer. When jetting or predrilling is used to install the piles to a required depth, the soil is severely disturbed and loses its strengths considerably. To account for the effect of jetting or predrilling, the N value of one was used in this study regardless of the original SPT blow counts for the soil layers where jetting or predrilling was used.

When the pile toe is in a soft to medium stiff clay layer, the Tomlinson method is used to predict the toe resistance in the same way as for the skin resistance. It is important to note that the toe resistance is influenced by the soil within a certain distance from the toe. This influence zone depends on several factors including the pile type, the soil type near the toe and the capacity prediction model. No documented information on the influence zone is available for the Vesic method, and the influence zone is assumed in this study to be 3D above the toe to 3D below the toe, where D is the pile diameter or width.

Table 2-1. Bearing Capacity Factors (N_c and N_σ) for Vesic Method (Vesic, 1977)

ϕ (deg)	I_r	10	20	40	60	80	100	200	300
26	Nc	24.98	33.77	45.42	53.93	60.87	66.84	89.25	105.61
	Nσ	13.18	17.47	23.15	27.30	30.69	33.60	44.53	52.51
27		26.16	35.57	48.13	57.34	64.88	71.39	95.02	113.92
		14.33	19.12	25.52	30.21	34.06	37.37	49.88	59.05
28		27.40	37.45	50.96	60.93	69.12	76.20	103.01	122.79
		15.57	20.91	28.10	33.40	37.75	41.51	55.77	66.29
29		28.69	39.42	53.95	64.71	73.58	81.28	110.54	132.23
		16.90	22.85	30.90	36.87	41.79	46.05	62.27	74.30
30		30.03	41.49	57.08	68.69	78.30	86.64	118.53	142.27
		18.24	24.95	33.95	40.66	46.21	51.02	69.43	83.14
31		31.43	43.64	60.37	72.88	83.27	92.31	126.99	152.95
		19.88	27.22	37.27	44.79	51.03	56.46	77.31	92.90
32		32.89	45.90	63.82	77.29	88.50	98.28	135.96	164.29
		21.55	29.68	40.88	49.30	56.30	62.41	85.96	103.66
33		34.41	48.26	67.44	81.92	94.01	104.58	145.46	176.33
		23.34	32.34	44.80	54.20	62.05	68.92	95.46	115.51
34		35.99	50.72	71.24	86.80	99.82	111.22	155.51	189.11
		25.28	35.21	49.05	59.54	68.33	78.02	105.90	128.55
35		37.65	53.30	75.22	91.91	105.92	118.22	166.14	202.64
		27.36	38.32	53.67	65.36	75.17	83.78	117.33	142.89
36		39.37	55.99	79.39	97.29	112.34	125.59	177.38	216.98
		29.60	41.68	58.68	71.69	82.62	92.24	129.87	158.65
37		41.17	58.81	83.77	102.94	119.10	133.34	189.25	232.17
		32.02	45.31	64.13	78.57	90.75	101.48	143.61	175.95
38		43.04	61.75	88.36	108.86	126.20	141.50	201.78	248.23
		34.63	49.24	70.03	86.05	99.60	111.56	158.65	194.94
39		44.99	61.83	93.17	115.09	133.66	150.00	215.01	265.23
		37.44	53.50	76.45	94.20	109.24	122.54	175.11	215.78
40		47.03	68.04	98.21	121.62	141.51	159.13	228.97	283.19
		40.47	58.10	83.40	103.05	119.74	134.52	193.13	238.62
41		49.16	71.41	103.49	128.48	149.75	168.63	243.69	302.17
		43.74	63.07	90.96	112.68	131.18	147.59	212.74	263.67
42		51.38	74.92	109.02	135.68	158.41	178.62	259.22	322.22
		47.27	68.46	99.16	123.16	143.64	161.83	234.40	291.13
43		53.70	78.60	114.82	143.23	167.51	189.13	279.59	343.40
		51.08	74.30	108.08	134.56	157.21	177.36	257.59	321.22
44		56.13	82.45	120.91	151.16	177.07	200.17	292.15	365.75
		55.20	80.62	117.76	146.97	172.00	194.34	283.50	354.20

2.5 TOMLINSON METHOD

For piles in a soft to medium stiff clay, a total stress analysis is more appropriate due to the fact that the soil is in an undrained condition with excess pore water pressure developed by the pile driving. In this case, the skin resistance is independent of the effective overburden pressure and the unit skin resistance can be expressed as Equation 2-10 and is repeated here.

$$f_s = \alpha\, S_u$$

S_u is the undrained shear strength of the soil and can be estimated from SPT N values as follows.

$$S_u = 100\ N\ \text{psf} \qquad (2\text{-}17)$$

N value is limited to 20, and the values α decrease with increasing undrained shear strength as shown in Table 2-2.

Table 2-2. Coefficient of Adhesion for Tomlinson's Method (NCDOT, 1995)

Value of S_u (psf)	α for Non-Displace Piles	α for Displacement Piles
$0 \le S_u \le 250$	1.00	1.00
$250 \le S_u \le 500$	0.95	0.95
$500 \le S_u \le 1000$	0.75	0.80
$1000 \le S_u \le 2000$	0.45	0.55

The unit toe resistance is expressed as

$$q_t = S_u\, N_c \qquad (2\text{-}18)$$

in which N_c is usually taken as 9. When a steel pipe pile or HP pile is driven into soils, especially into a clay soil, the effects of soil plugging must be considered. However, it is very difficult to quantify the amount of plugging without a load test. Also it should be noted that the movement required to mobilize the toe resistance is several times greater than that required to mobilize the skin resistance. Therefore, the toe resistance contribution to the ultimate pile capacity of a steel pipe pile or HP pile is usually very small.

2.6 NORDLUND METHOD

Nordlund (1963) presented his method for computing the ultimate bearing capacity of a pile and the results of the field test programs, in which several pile types including timber, steel HP, closed-end pipe, monotubes, and Raymond step taper piles were used. The Nordlund method (1963, 1979) is a semi-empirical model based on the field load tests in cohesionless soils and considers the shape of pile taper and the soil displacement in calculating the skin resistance. Blue-Six Software, Inc. coded the computer program 'DRIVEN' in 1997 under a contract with FHWA, which follows the methods and equations of Nordlund (1963, 1979), Thurman (1964), Meyerhof (1976), and Tomlinson (1980, 1985). DRIVEN Version 1.1 was used in this study to predict the pile bearing capacity by the Nordlund method. The program has a provision to use the Tomlinson method for a total stress analysis, and this method is applied to the sections of the piles embedded in a soft to medium stiff clay layer with the average N value not more than 20.

Nordlund proposed the following equation for calculating total skin resistance.

$$Q_s = \sum_{d=0}^{d=L} K_\delta \, C_F \, P_d \sin(\delta+\omega) \sec(\omega) \, C_d \, \Delta d \qquad (2\text{-}19)$$

in which, d: depth

L: embedded pile length

K_δ: coefficient of lateral earth pressure

C_F: correction factor for K_δ when $\delta \neq \phi$

P_d: effective overburden pressure at center of depth increment d

δ: friction angle between pile and soil

ω: angle of pile taper from vertical

ϕ: soil friction angle

C_d: pile perimeter at depth d

Δd: length of pile segment

For a pile with a uniform cross section ($\omega = 0$), the equation simplifies as follows.

$$Q_s = \sum_{d=0}^{d=L} K_\delta \, C_F \, P_d \sin(\delta) \, C_d \, \Delta d \qquad (2\text{-}20)$$

The soil friction angle ϕ influences most the bearing capacity in the Nordlund method. In the absence of laboratory test data, ϕ is estimated from corrected SPT blow counts (N') in a similar way as in the Vesic method. The estimated ϕ values from the Nordlund method are very much identical to those from Vesic method, except that the Nordlund method gives slightly lower values than the Vesic method for N' over 35. The ratio δ/ϕ depends on the amount of soil displaced by pile driving and the type of pile. It increases as the displaced soil volume increases, but it is always less than one for timber piles, precast concrete piles, steel HP piles, and closed-end and open-end steel pipe piles. Coefficient of lateral earth pressure (K_δ) is determined for a given ϕ value, the displaced soil volume, and the pile taper angle. When δ and ϕ are different, a correction factor (C_F) needs to be applied to K_δ.

The Nordlund method computes the total toe resistance in the following form.

$$Q_t = \alpha\ N_q\ A_t\ q_t \qquad (2\text{-}21)$$

in which, α: dimensionless factor dependent on ϕ and pile embedment depth over width ratio

N_q: bearing capacity factor, which is a function of ϕ

q_t: effective overburden pressure at pile toe

A_t: pile cross sectional area at toe

Both α and N_q are determined for ϕ at the pile toe, which can be estimated from the corrected SPT N' values. As mentioned in the Vesic method, the N' value is selected as the average value within the toe influence zone that is from 3 pile width/diameter above the toe to 3 pile width/diameter below the toe. If DRIVEN computes a pile toe resistance exceeding the limiting value suggested by Meyerhof (1976), then the program gives the limiting value as the output value. Figure 2-4 shows the Meyerhof's limiting unit toe resistance for range of ϕ values. Also, the program has an option to account for the soil plugging effects. An example output of DRIVEN is included in Appendix A.

2.7 MEYERHOF METHOD

Meyerhof (1976) made empirical correlations between SPT results and static pile load tests performed in a variety of cohesionless soil deposits. He reported that the unit skin resistance, f_s, of driven displacement piles such as precast concrete piles and closed-end steel pipe piles is:

$$f_s = 0.02\ N'\ \text{tsf}\ \leq 1\ \text{tsf} \qquad (2\text{-}22)$$

The unit skin resistance of driven non-displacement piles such as steel HP piles is:

$$f_s = 0.01\ N'\ \text{tsf}\ \leq 1\ \text{tsf} \qquad (2\text{-}23)$$

N' is the corrected N value using Equation 2-15. The total skin resistance is f_s multiplied by the total pile skin surface area. Soil plugging needs to be considered in the skin surface calculation for non-displacement piles.

The unit toe resistance, q_t, is computed in the following equations.

$$q_t = 0.4\ N_t'\ L / D \leq 4\ N_t'\ \text{tsf}\ \text{ for sand and gravel} \qquad (2\text{-}24)$$

$$q_t = 0.3\ N_t'\ L / D \leq 3\ N_t'\ \text{tsf}\ \text{ for non-plastic silts} \qquad (2\text{-}25)$$

in which, L is the pile embedment depth to the toe and D is the pile diameter or width. N_t' is the average corrected SPT blow count within the toe influence zone. Meyerhof (1976) suggested the toe influence zone to be from 4D above the toe to 1D below the toe, which was used in this study with the Meyerhof method.

In this study, the above procedures of computing the bearing capacity by the Meyerhof method have been coded in a spreadsheet format using the computer program Excel to accelerate the calculation process. As in the case of the other two methods described above, the spreadsheet includes the Tomlinson method to compute the bearing capacity of the sections of a pile in a soft to medium stiff clay layer with the average N value not more than 20. The computed unit toe resistance is limited to the maximum value for the soil friction angle as shown in Figure 2-4, in the same way as in the Nordlund method. To estimate the limiting unit toe resistance, the corrected N value from the toe influence zone (N_t') is converted to the friction angle ϕ using Equation 2-16. An example spread sheet for the Meyerhof method is included in Appendix A.

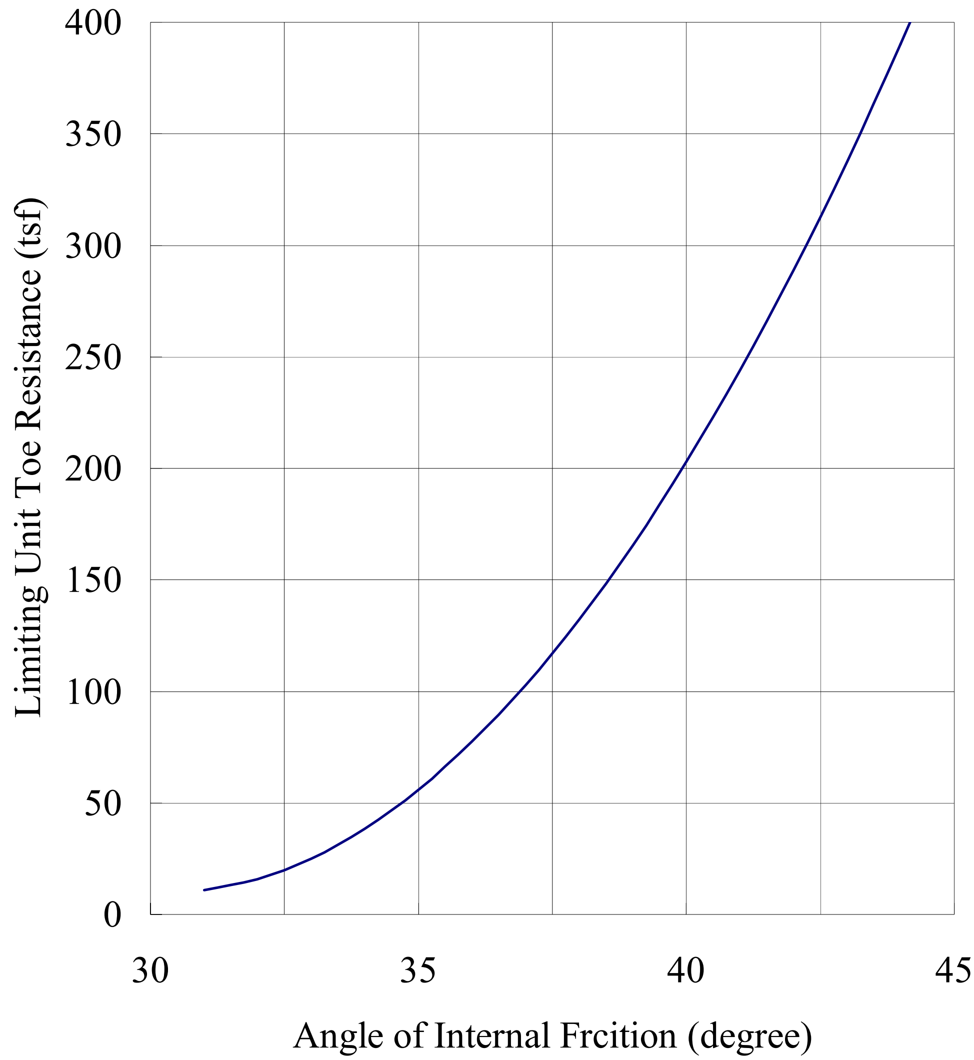

Figure 2-4. Relationship between Maximum Unit Toe Resistance and Friction Angle (Meyerhof, 1976)

CHAPTER 3. PILE LOAD TEST DATA

3.1 GENERAL DESCRIPTION OF NORTH CAROLINA GEOLOGY

North Carolina is divided into three distinct geologic regions: mountain, piedmont and coastal. Soil types are quite distinctive between these regions, and it is logical to compile and evaluate the pile load test data separately for each geologic region. A North Carolina geologic map and a brief description of the general geology in each region are presented below (NCGS, 1988).

Figure 3-1. North Carolina Geologic Map (NCGS, 1985)

3.1.1 Coastal Region

This region is characterized by low relief and large formations of shallow sea depositional units of sand, sandstone, silty/sandy clay and clay. The southeast coastal margin has a few units of limestones and indurated shell deposits, and there are several areas of phosphate deposition. Along the coastal margin, sounds and tidewaters may contain high organic levels. The extreme east and northeast parts of the region contain large swamps, sounds and estuary areas, which have deposited surficial unconsolidated sands, silts, clays, peat and muck. The vertical soil profile in this region is generally mixed soils with more granular soil deposits than fine grained soils. Four distinct geologic sub-formations within this region are Black Creek, Peedee, Yorktown, and Undifferentiated formations.

The Black Creek Formation consists typically of sands and clays that vary abruptly with sand predominating in some places and clay in others. Soils in this formation were laid down either in shallow sea water as in bays or estuaries or in deeper marine waters. The Peedee Formation crops out in a belt east of the Black Creek formation with a width ranging from 3 to 25 miles. The thickness of this formation varies from 220 to 700 feet in Craven and Dare counties and to 900 feet near Wilmington. The Peedee was laid down in shallow open marine waters and consists of sands and impure limestone. Dark marine clay layers are found amongst the sand deposits. The Yorktown Formation was deposited in the Miocene age and is exposed over most of the western half of the coastal region north of the Neuse River. The formation was laid down in shallow marine waters with its typical thickness of 200 feet. It consists of clay, sand and shell marl. A blue clay that varies from arenaceous to calcareous is the dominant feature in this formation. The clay contains lenses of sand and shell marl. The Undifferentiated Formation encompasses all sediments in the coastal region younger than the Miocene age. The deposits consist of fine to coarse sand, silty sand, sandy silt and interbedded clay. The deposits are usually less than 30 feet thick, but some deposits are much thicker.

3.1.2 Piedmont Region

This region encompasses rock types from plutonic granite intrusions and gneisses to high metamorphic grade slates, mudstones and volcanic rocks. Outcrops are most common in stream bottoms and on the steeper slopes, and conversely deep weathering is most common on the uplands. In many locales, the thickness of weathered material can vary greatly over a few tens of feet. Some rock types such as argillite in the Carolina Slate belt are not deeply weathered, which results in shallow soil and saprolite layers. This central region is also defined by the Durham Triassic basins. Soils in this region are deeply weathered into sandy silts, silty clays and clays. The vertical soil profile in this region is generally mixed soils with more fine grained soils than granular soils.

3.1.3 Mountain Region

The vast majority of rock cuts in North Carolina is in this region and involves rock types consisting of gneisses, schists and metamorphosed sand, silt and mudstones. Discontinuity orientations are rarely orthogonal or predictable because of the tectonic history. Faster erosion rates limit deep weathering of the rock. Residual soils are generally silty sands and clays are very limited, usually forming along narrow alluvial floodplains. Many rocks weather into saprolite, which is usually a 20 to 100 SPT blow count soil material and retains its rock structure. This allows it to fail in planar fashion like rock or circular like a soil, or a combination of both. A distinct feature of this region are colluvium deposits, which are usually wet deposits of landslide obviously jumbled into a mass of unconsolidated material consisting of everything from sand to car-sized rock blocks. Few pile load tests have been done by NCDOT in this region due to the fact that piles are usually driven into shallow depths of dense soil or rock layers without a significant concern of the bearing capacity.

3.2 PILE DRIVING ANALYZER (PDA) DATA

NCDOT has performed many pile driving analyzer (PDA) tests over the past 16 years to measure the actual performance of pile driving. PDA is a computerized system that applies Case Method (Goble, et al., 1975) equations on measured pile dynamic data in order to determine, among other quantities, the pile's ultimate bearing capacity. The wave propagation data are received from piezoelectric accelerometers and strain transducers attached near the top of the pile. The most useful and convenient quantities for measurement are force and acceleration at the pile top. Forces are measured from the strain transducers. As the transducer is deformed by the passing stress wave, signals proportional to the strain magnitude are generated. Acceleration measurements can be made using any of a number of commercially available accelerometers modified to be attached to the pile. The result of the measurement activity is matching records of force and velocity along the pile in the ground. These two quantities are particularly useful in the application of one-dimensional wave mechanics to the analysis of pile driving. In addition, since force and velocity are known to be proportional as long as wave propagation is in one direction only, a check of this proportionality provides a verification of the correctness of the two independent measurements.

When a pile is driven into the soil, the soil is greatly disturbed. As the soil surrounding the pile recovers from the driving disturbance, a time dependent change in pile capacity often occurs. The pile capacity may increase with time due to soil setup effects or decrease due to soil relaxation. Therefore, the actual pile capacity should be measured a sufficient time after pile driving to account for soil setup or relaxation effects. For this reason, PDA tests are often performed with restrike of the piles that have already been installed. However, this is not always the case due to the practical restrictions of the construction schedule or cost considerations.

All of the NCDOT bridge construction projects, in which a PDA test was performed, were reviewed. One hundred and forth (140) PDA/CAPWAP cases were found to be usable in this study. The summary of PDA/CAPWAP data is included in Appendix B. One hundred twenty nine (129) of the case studies are from the coastal area and the remaining eleven (11) are from the piedmont area. There are no PDA data available for the mountain area, and therefore the mountain area is not considered in this study. The majority of the PDA were performed on prestressed concrete square piles in the coastal area. The sizes of the concrete piles ranged from 12” square to 30” square. Details of the data for each region and pile type are described in the following sections of this chapter.

3.2.1 Case Pile Wave Analysis Program (CAPWAP)

The PDA data are further evaluated by the rigorous numerical analysis program CAPWAP (Hannigan, 1990) to determine static bearing capacity, and to distinguish between the toe resistance and the distribution of the skin resistance along the pile. In the analysis of pile driving, there are three unknowns: pile forces, pile motion and boundary conditions. If two of the three are known, the third can be calculated. It is not possible to determine the soil response from the measured force and velocity records. However, it is possible to analyze a pile under the action of either the force or the velocity record, with an assumed soil model. The other unused record is then plotted and compared against an equivalent computed plot. Differences between the measured and the computed curves lead an experienced engineer to conclusions regarding the differences between the actual soil behavior and the assumed set of soil parameters. He may then modify these parameters to obtain a better match in a second iteration. CAPWAP was written to facilitate this type of analysis.

Soil reaction forces can be accurately expressed as a function of pile motion only. It is generally assumed that the soil reaction consists of elasto-plastic, and linear viscous components. In this way, the soil model has at each point three unknowns: the ultimate static resistance, the quake or elastic soil deformation, and a damping constant. An error minimization procedure is used to assess the differences between the measured and computed curves, and quantify the sum of these differences with the so-called Match Quality Number (MQN). MQN = SUM (ABS (f_{jc} – f_{jm}) / Fi) where, f_{jc} and f_{jm} are the computed and the measured pile top variables at time step j, respectively. SUM stands for a summation over a time period and Fi is the pile top force at the time of the maximum pile top velocity. Reducing the MQN to a minimum value subject to several constraints will result in a unique solution.

3.2.2 Coastal Area Concrete Square Piles

There are 85 end of driving (EOD) and 26 beginning of restrike (BOR) PDA data available under this category from 32 different project sites. The summary of EOD and BOR data is shown in Table 3-1 and Table 3-2, respectively. Twenty of the PDA files have both EOD and BOR data for the same pile, and they are marked by an asterisk (*) after the file number (Tables 3-1 and 3-2). The size of pile ranges from 12” to 30”

Table 3-1. PDA EOD Coastal Concrete Square Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Shaft (Ton)	PDA Toe (Ton)
85*	250	D30	4	227	114	113
98	200	D30	8	519	308	211
56*	80	D20	12	142	81	61
105	45	D12	12	85	4	81
4C*	100	D20	13	220	157	63
86*	250	D30	13	135	48	87
94*	237	D30	13	315	135	180
70	250	D30	14	890	235	655
92*	200	D30	14	392	110	282
122	100	D20	14	297	108	189
4B	100	D24	15	417	128	289
39	70	D16	15	144	50	94
60B*	250	D30	16	797	212	585
90	200	D30	16	302	65	237
69	250	D30	17	502	339	163
89*	237	D30	17	355	55	300
60A*	250	D30	18	683	462	221
45	30	D12	19	75	28	47
61	250	D30	19	553	443	110
74*	250	D30	19	565	241	324
141	100	D24	19	378	165	213
93*	200	D30	20	177	111	66
66	250	D30	21	574	455	119
99	200	D30	21	603	145	458
101	45	D12	21	75	13	62
115	100	D24	21	316	51	265
4A*	100	D24	22	107	30	77
46	60	D20	22	155	9	146
91*	100	D20	22	213	81	132
1*	100	D20	23	116	35	81
11	85	D20	23	91	22	69
54	70	D20	23	143	25	118
37B	100	D24	24	270	88	182
52	60	D20	25	211	36	175
55	60	D20	25	238	15	223
114	100	D24	26	223	127	96
19	80	D24	27	285	46	239
62	250	D30	27	505	312	193
107A*	100	D20	27	222	26	196
96*	200	D30	28	575	179	396
117	200	D30	28	461	153	308
3	55	D20	29	156	117	39
5	50	D12	29	117	24.5	92.5

Table 3-1. PDA EOD Coastal Concrete Square Piles (Continued)

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Shaft (Ton)	PDA Toe (Ton)
6	100	D24	29	210	18	192
28	100	D20	29	187	112	75
118	200	D30	30	416	210	206
31	100	D20	32	167	40	127
77	250	D30	32	458	52	406
82	250	D30	32	533	406	127
22	85	D20	33	215	51	164
36	100	D20	33	255	63	192
95	200	D30	34	697	127	570
48	50	D12	35	156	46	110
53	110	D24	38	405	52	353
87*	250	D30	38	392	117	275
108	100	D20	38	230	61	169
21	45	D12	39	100	44	56
30	100	D20	39	241	60	181
32*	100	D20	39	169	26	143
33*	100	D20	39	196	90	106
35	100	D20	39	209	55	154
68	250	D30	39	502	273	229
75	250	D30	39	659	122	537
17	60	D20	40	285	112	173
18	60	D20	40	270	85	185
67	250	D30	40	648	305	343
12	60	D20	41	188	29	159
7	100	D24	43	425	102	323
76	250	D30	44	529	135	394
14	80	D20	45	138	95	43
13	80	D20	50	127	46	81
51	60	D20	50	162	23	139
58*	253	D30	50	681	78	603
24	75	D20	51	240	29	211
78	250	D30	54	529	96	433
64	250	D30	55	648	289	359
37A	100	D24	60	499	137	362
107B	100	D20	60	274	26	248
23	85	D20	62	389	72	317
80	250	D30	62	815	673	142
140	100	D24	62	377	28	349
59	250	D30	70	645	275	370
8	100	D24	75	218	20	198
9	100	D24	100	216	51	165
71	250	D30	100	832	197	635

Table 3-2. PDA BOR Coastal Concrete Square Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
85*	250	D30	4	262	120	142
56*	80	D20	12	247	209	38
4C*	100	D20	13	226	161	65
86*	250	D30	13	525	392	133
94*	237	D30	13	629	360	269
65	250	D30	14	955	655	300
92*	200	D30	14	719	374	345
63	250	D30	17	662	183	479
89*	237	D30	17	701	378	323
60A*	250	D30	18	1128	897	231
74*	250	D30	19	950	759	191
79	250	D30	20	877	766	111
93*	200	D30	20	712	301	411
4A*	100	D24	22	218	106	112
91*	100	D20	22	288	85	203
1*	100	D20	23	206	125	81
11*	85	D20	23	91	22	69
107A*	100	D20	27	265	96	169
96*	200	D30	28	650	183	467
81	250	D30	35	812	561	251
87*	250	D30	38	540	249	291
32*	100	D20	39	265	53	212
33*	100	D20	39	266	108	158
58*	250	D30	50	765	141	624
83	250	D30	53	825	670	155
84	250	D30	56	900	553	347

square, and the embedded pile lengths range from 11 feet to 125 feet. This results in a pile length over width ratio (L/D) from 6.6 to 61. The SPT blow count (N) at the pile toe varies from 4 to 100. The toe blow count may affect the pile capacity evaluation significantly because mobilization of the toe resistance is greatly influenced by the stiffness of the soil near the pile toe. The effect of N value at the pile toe, on both the measured and predicted pile capacities, was investigated in this study. Accordingly the

PDA data were sub-grouped for N-value less than or equal to 40 and for N-value more than 40.

The comparison of the pile capacities from the 20 EOD and BOR data indicates a significant increase in the capacity with time (setup) as shown in Table 3-3. The setup effects were further evaluated by regression analyses as shown in Figures 3-2, 3-3 and 3-4 for the total, skin, and toe capacities, respectively. The setup effect on the skin

Table 3-3. Coastal Concrete Square Piles
PDA BOR / PDA EOD (Set-Up)

File No.	Design Load (Ton)	Pile Type & Size	PDA Total BOR (Ton)	PDA Total EOD (Ton)	PDA Total BOR/EOD	PDA Skin BOR (Ton)	PDA Skin EOD (Ton)	PDA Skin BOR/EOD	PDA Toe BOR (Ton)	PDA Toe EOD (Ton)	PDA Toe BOR/EOD
1*	100	D20	206	116	1.78	125	35	3.57	81	81	1.00
4A*	100	D24	218	107	2.04	106	30	3.53	112	77	1.45
4C*	100	D20	226	220	1.03	161	157	1.03	65	63	1.03
11*	85	D20	167	91	1.84	23	22	1.05	144	69	2.09
32*	100	D20	265	169	1.57	53	26	2.04	212	143	1.48
33*	100	D20	266	196	1.36	108	90	1.20	158	106	1.49
56*	80	D20	247	142	1.74	209	81	2.58	38	61	0.62
58*	253	D30	765	681	1.12	141	78	1.81	624	603	1.03
60A*	250	D30	1128	683	1.65	897	462	1.94	231	221	1.05
74*	250	D30	950	565	1.68	759	241	3.15	191	324	0.59
85*	250	D30	262	227	1.15	120	114	1.05	142	113	1.26
86*	250	D30	525	135	3.89	392	48	8.17	133	87	1.53
87*	250	D30	540	392	1.38	249	117	2.13	291	275	1.06
89*	237	D30	701	355	1.97	378	55	6.87	323	300	1.08
91*	100	D20	288	213	1.35	85	81	1.05	203	132	1.54
92*	200	D30	719	392	1.83	374	110	3.40	345	282	1.22
93*	200	D30	712	177	4.02	301	111	2.71	411	66	6.23
94*	237	D30	629	315	2.00	360	135	2.67	269	180	1.49
96*	200	D30	650	575	1.13	183	179	1.02	467	396	1.18
107A*	100	D20	265	222	1.19	96	26	3.69	169	196	0.86
				Mean	1.79		Mean	2.73		Mean	1.46
				S.Dev.	0.81		S.Dev.	1.90		S.Dev.	1.17
				COV	0.45		COV	0.70		COV	0.80

resistance is more significant than that on the toe resistance. This is probably due to the fact that a larger soil displacement was needed to mobilize the toe resistance, and the hammer impact energy was not sufficient to activate full toe resistance during the restrike.

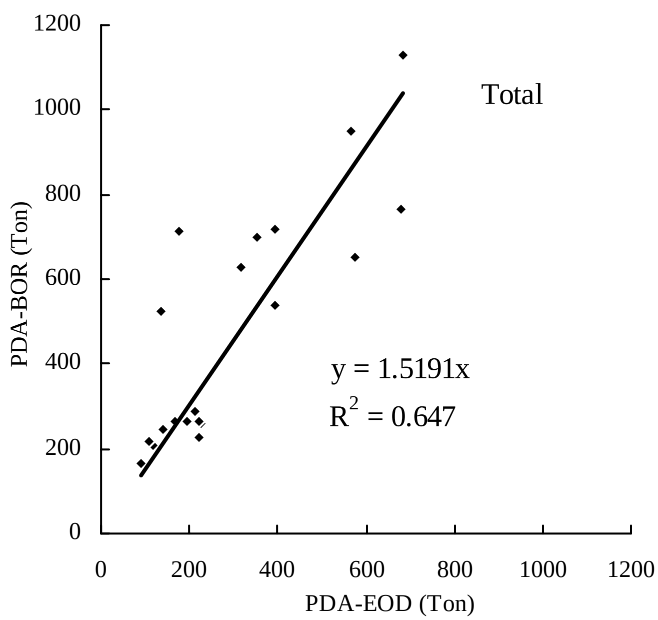

Figure 3-2. Coastal Concrete Square Piles – Setup Effect (Total Capacity)

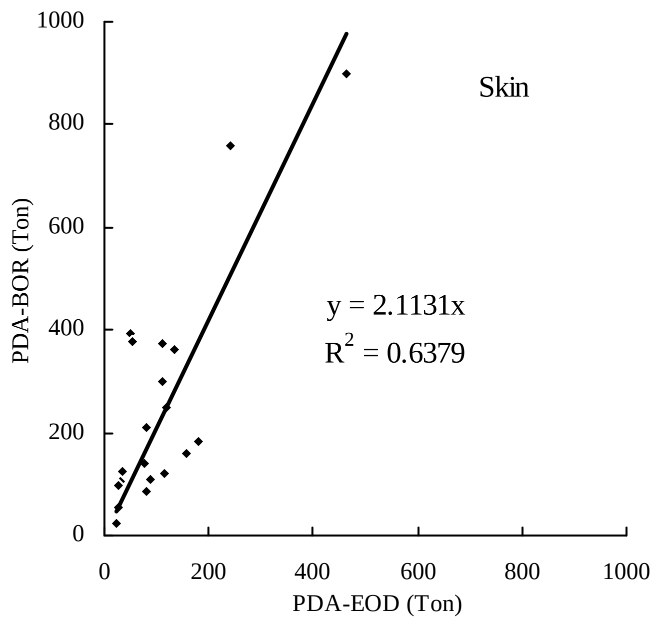

Figure 3-3. Coastal Concrete Square Piles – Setup Effect (Skin Capacity)

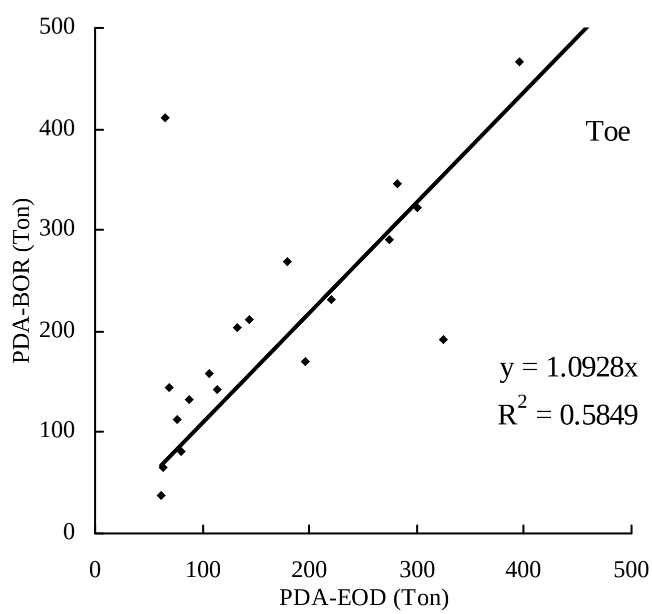

Figure 3-4. Coastal Concrete Square Piles – Setup Effect (Toe Capacity)

3.2.3 Jetting Effects

Piles are sometimes jetted to a prescribed depth in order to attain the pile penetration depths required for the lateral stability of the structure. The use of jetting results in a severe soil disturbance, and its effect on both the measured and predicted pile capacities should be considered. However, there is no rational means to quantify the percentage of the pile capacity reduction due to jetting, other than a pile load test. For this reason, the PDA data were sub-grouped for the piles driven with jetting and those without jetting in order to consider the jetting effects on the ratio of the measured capacity over the predicted capacity. In the pile capacity prediction using the static analysis methods, the SPT N value of one (1) was assumed for the soil layers where the pile penetration was performed by jetting. Actual SPT blow count of the soil disturbed by jetting may be more than one. But it would not be much larger than one, because piles penetrate into the disturbed ground by their own weights when jetting is used. This assumption is justified for the Vesic method, in which a minimum unit skin resistance of 0.126 ton per square foot (tsf) is used regardless of the SPT blow counts or the relative density of the soil. This assumption is also justified for the Nordlund method because the low range N-values (say, less than 5) would make little difference in the correlation of the N-values with the soil friction angle (ϕ). This assumption may underpredict the pile skin capacity in the Meyerhof method; however, this will be accounted for in the bias factors and in the process of the resistance factor calibration. Of the 85 EOD PDA data, 50 piles were initially installed with jetting, and 15 piles, out of the 26 PDA restrike data, were initially installed with jetting.

3.2.4 Coastal Area Steel HP Piles

Seventeen PDA EOD and only three restrike (BOR) PDA data are available for this category. The summary of EOD and BOR data is shown in Table 3-4 and Table 3-5, respectively. Two of the data files marked by an asterisk (*) in Tables 3-4 and 3-5 have both EOD and BOR data for the same pile. Most of the HP piles in this category are HP 12X53, and the other four are HP 14X73 piles. The embedded length of these HP piles ranges from 19 feet to 76 feet. The SPT blow count (N) at the pile toe varies from 12 to 100. As in the case of the coastal area concrete square piles, the effect of N value at the pile toe, on both measured and predicted pile capacities, was investigated in this study, and the PDA data were sub-grouped for N less than or equal to 40 and for N more than 40.

Table 3-4. PDA EOD Coastal Steel HP Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
10*	40	HP 12 X 53	12	87	62	25
106*	45	HP 12 X 53	14	110	89	21
49	45	HP 12 X 53	17	107	85	22
100	30	HP 14 X 73	23	63	50	13
50	45	HP 12 X 53	25	102	99	3
102	45	HP 12 X 53	26	96	88	8
104	45	HP 12 X 53	32	98	12	86
16	50	HP 12 X 53	34	94	80	14
110	60	HP 12 X 53	35	192	158	34
103	45	HP 12 X 53	38	72	45	27
121	70	HP 14 X 73	45	202	180	22
43	50	HP 14 X 73	55	111	91	20
44	50	HP 14 X 73	70	151	139	12
57	45	HP 12 X 53	100	68	44	24
111	50	HP 12 X 53	100	103	36	67
112	50	HP 12 X 53	100	169	91	78
113	50	HP 12 X 53	100	159	150	9

Table 3-5. PDA BOR Coastal Steel HP Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
10*	40	HP 12 X 53	12	134	108	26
106*	45	HP 12 X 53	14	122	99	23
25	45	HP 12 X 53	35	212	183	29

3.2.5 Coastal Area Steel Pipe Piles

Seven PDA EOD and 15 BOR data are available for this category. The pile restrike was performed about 24 hours after the end of initial driving for the most BOR data. All but one of these piles was driven as open-ended. All of the piles had 24" outside diameter, except one that was 18" diameter pile. The 24" and 18" pipe piles had a wall thickness of 0.625 and 0.5 inches, respectively. The summary of EOD and BOR data is shown in Table 3-6 and Table 3-7, respectively. The PDA EOD data files that also have BOR data are marked by an asterisk (*) in Tables 3-6 and 3-7. All but two of the data points are from the same project site with the pile embedment lengths of 52 feet to 78 feet. The SPT blow count (N) at the pile toe varies from 12 to 65, and all but two are less than 40.

Table 3-6. PDA EOD Coastal Steel Pipe Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
125*	100	S- D24 Pipe (OE)	12	155	99	56
124*	100	S- D24 Pipe (OE)	14	304	250	54
128	100	S- D24 Pipe (OE)	19	298	139	159
139*	60	S- D18 Pipe (OE)	21	138	118	20
127*	100	S- D24 Pipe (OE)	25	264	104	160
42	100	S- D24 Pipe (CE)	31	373	73	300
126*	100	S- D24 Pipe (OE)	35	324	196	128

Table 3-7. PDA BOR Coastal Steel Pipe Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
125*	100	S-D24 Pipe (OE)	12	333	296	37
124*	100	S-D24 Pipe (OE)	14	351	304	54
134	100	S-D24 Pipe (OE)	16	263	188	75
130	100	S-D24 Pipe (OE)	18	326	284	42
138	100	S-D24 Pipe (OE)	20	254	205	49
139*	100	S-D24 Pipe (OE)	21	200	190	10
127*	100	S-D24 Pipe (OE)	25	383	333	50
132	100	S-D24 Pipe (OE)	25	355	318	37
137	100	S-D24 Pipe (OE)	25	305	253	52
131	100	S-D24 Pipe (OE)	28	380	269	111
126*	100	S-D24 Pipe (OE)	35	434	401	33
133	100	S-D24 Pipe (OE)	35	312	263	49
135	100	S-D24 Pipe (OE)	35	390	271	119
129	100	S-D24 Pipe (OE)	56	482	389	93
136	100	S-D24 Pipe (OE)	65	447	288	159

3.2.6 Coastal Area Concrete Cylinder Piles

There are only three PDA/CAPWAP cases available for this category, which is not sufficient for a statistical evaluation of the pile capacity predictions and the resistance factor development. However, five static load test data are available for the same category, which may be combined with the PDA/CAPWAP data for the calibration of the resistance factors. Table 3-8 shows the three PDA data points: two 54" diameter cylinder piles with the wall thickness of 5 inches, and a 66" diameter cylinder pile with 6 inch thick wall. The 54" diameter piles were driven 75 and 87 feet into the ground, and the 66" one was embedded 105 feet.

Table 3-8. PDA EOD Coastal Concrete Cylinder Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
27	350	D54	24	359	272	87
123	450	D66	46	639	411	228
26	350	D54	50	640	342	298

3.2.7 Piedmont Area Concrete Square Piles

Six PDA EOD data are available for this category as shown in Table 3-9. There is no PDA restrike data for this category. The size of pile ranges from 12" to 20" square, and the embedded pile lengths are from 12 feet to 45 feet. This results in the pile length over width ratio (L/D) that ranges from 7.2 to 45. The SPT blow count (N) at the pile toe varies from 16 to 34. The pile sizes, lengths, and the site soil profiles for this category are in a relatively uniform range.

Table 3-9. PDA EOD Piedmont Concrete Square Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
47	50	D12	16	105	69	36
20	60	D20	18	122	22	100
2	30	D12	21	66	37	29
38	60	D18	27	154	51	103
15	65	D20	28	241	152	89
116	50	D12	34	211	171	40

3.2.8 Piedmont Area Steel HP Piles

Five PDA EOD data, with no restrike, are available for this category as shown in Table 3-10. All of them are HP 12X53 piles with the embedded lengths that range from 25 to 68 feet. The SPT blow count (N) at the pile toe varies from 13 to 100. It should be noted that the database size is not large enough to represent the actual variation of the measured or predicted pile capacities.

Table 3-10. PDA EOD Piedmont Steel HP Piles

File Number	Design Load (Ton)	Pile Type & Size	SPT N at Toe	PDA Total (Ton)	PDA Skin (Ton)	PDA Toe (Ton)
34	45	HP 12 X 53	13	93	73	20
41	40	HP 12 X 53	40	85	77	8
40A	40	HP 12 X 53	62	106	41	65
40B	40	HP 12 X 53	100	103	45	58
109	60	HP 12 X 53	100	151	132	19

3.3 STATIC LOAD TEST DATA

NCDOT has performed static load tests on driven piles in selected bridge construction projects to verify the piles' bearing capacity. Due to its high cost, this type of test is warranted only for large bridge projects, in which pile foundations are subjected to unusually high loads or when the pile foundation cost is significant. In this study, 35 static load test data were synthesized from the NCDOT project files. The data set are summarized in Table 3-11. Thirty-one of the load test cases are from the coastal region, and only four static load test data, on three steel HP piles and a prestressed concrete pile, are available in the piedmont area. Twenty-two of the coastal region tests were performed on prestressed concrete piles, whose width ranges from 12 inches to 30 inches. Five concrete cylinder piles, two steel HP piles, a steel pipe pile with tip, and a timber pile are included in the coastal region data. All of the static load tests were performed in accordance with ASTM D1143 “Piles Under Static Axial Compressive Load” using the quick load test method.

Table 3-11. Static Pile Load Test Data

Static File No.	PDA File No.	TIP No.	Region	County	Pile Type	Pile Length (ft)	Design Load (Ton)	Failure Load (Ton)+	Vesic Ult. (Ton)	Nordlund Ult. (Ton)	Meyerhof Ult. (Ton)
S1	116	NCSU	P	Wake	12" PCP	45	50	205	161	168	82
S2	4A	B-1098	C	Carteret	24" PCP	73	100	193	404	370	85
S3	4C	B-1098	C	Carteret	20" PCP	41	100	156	179	118	51
S4	26	B-2060	C	Onslow	54" CCP	87	350	765	1114	2734	601
S5		B-1098	C	Carteret	24" PCP	42	100	200	462	457	610
S6	1	B-900	C	Martin	20" PCP	57	100	200	300	276	140
S7	107A	B-2023	C	Dare	20" PCP	54	100	195	269	234	61
S8		B-2531A	C	Craven	20" PCP	20	60	204	215	92	224
S9		B-2023	C	Dare	20" PCP	56	100	332	282	244	103
S10		B-2023	C	Dare	20" PCP	47	100	295	432	624	397
S11		B-2023	C	Dare	20" PCP	38	100	230	206	157	184
S12		B-646	C	Chowan	20" PCP	52	100	320	460	569	347
S13		B-646	C	Chowan	24" PCP	75	135	300	358	316	78
S14		B-646	C	Chowan	24" PCP	72	135	315	400	362	172
S15		B-646	C	Chowan	24" PCP	56	100	350	380	201	162
S16		B-646	C	Chowan	24" PCP	64	100	200	315	112	94
S17	19	B-1310	C	Onslow	24" PCP	35	80	400	363	300	311
S18		B-626	C	Brunswick	20" PCP	34	90	258	255	170	97
S19	42	M-103	C	Craven	24" SPP	32	100	270	303	244	311

\+ Failure Load: Davisson Failure Criteria
++ Test Method: ASTM Quick Load Test

Table 3-11. Static Pile Load Test Data (Continued)

Static File No.	PDA File No.	TIP No.	Region	County	Pile Type	Pile Length (ft)	Design Load (Ton)	Failure Load (Ton)+	Vesic Ult. (Ton)	Nordlund Ult. (Ton)	Meyerhof Ult. (Ton)
S20		R-2551	C	Dare	54" CCP	121	1000	2000	2330	3195	345
S21		R-538	C	Bladen	HP 14x73	40	65	245	97	148	96
S22		B-627	C	Brunswick	20" PCP	35	100	220	445	593	450
S23		B-41	C	Carteret	54" CCP	38	350	691	543	445	255
S24		8.24327	P	Wake	HP 12x53	37	45	193	62	102	56
S25		8.14753	P	Wake	HP 12x53	54	45	91	90	179	89
S26		8.122332	C	Duplin	Timber	16	30	80	46	23	25
S27		R-2551	C	Dare	30" PCP	89	253	625	1195	905	239
S28		B-824	C	Tyrrell	20" PCP	84	50	217	271	352	84
S29	106	X-3BA	C	Sampson	HP 12x53	51	45	160	77	109	157
S30	85	R-2551	C	Dare	30" PCP	70	253	325	526	445	222
S31	41	I-900AA	P	Forsyth	HP 12x53	57	40	175	77	123	89
S32	123	B-2500	C	Dare	66" CCP	105	450	990+	1555	3174	552
S33	91	R-2512A	C	Chowan	20" PCP	32	100	255+	217	158	241
S34	89	R-2512A	C	Chowan	30" PCP	66	237	930	676	609	271
S35		R-2512A	C	Chowan	66" CCP	105	425	850+	1244	2287	352

\+ Failure Load: Davisson Failure Criteria
++ Test Method: ASTM Quick Load Test

The failure load for each static load test pile was determined by the Davisson Method (1972). The Davisson failure load is defined as the load corresponding to the pile's axial displacement that exceeds the elastic compression of the pile by 0.15 inches plus the pile diameter or width in inches divided by 120. During the load test, relative displacement of the pile was measured and recorded with each successive load increment until the pile failed or the practical limit of the loading system was reached. The failure load is then determined by using the following procedure: A graph is constructed with the movement of the pile in inches on the x-axis and the load in tons on the y-axis. The elastic compression line is drawn as a straight line for a linear equation P = A*E*δ/L, in which P is the load applied on the pile, A is the cross-sectional area of the pile, E is the pile's modulus of elasticity, δ is the axial compression of the pile, and L is the length of the pile. A line is drawn parallel to the elastic compression line at an offset of 0.15 + D/120, where D is the pile diameter or width in inches. The movements corresponding the loads recorded from the load test are then plotted on the graph, and the data points are connected with a smooth line. The intersection of the offset line with the load-movement curve is defined as the failure load as shown in Figure 3-5.

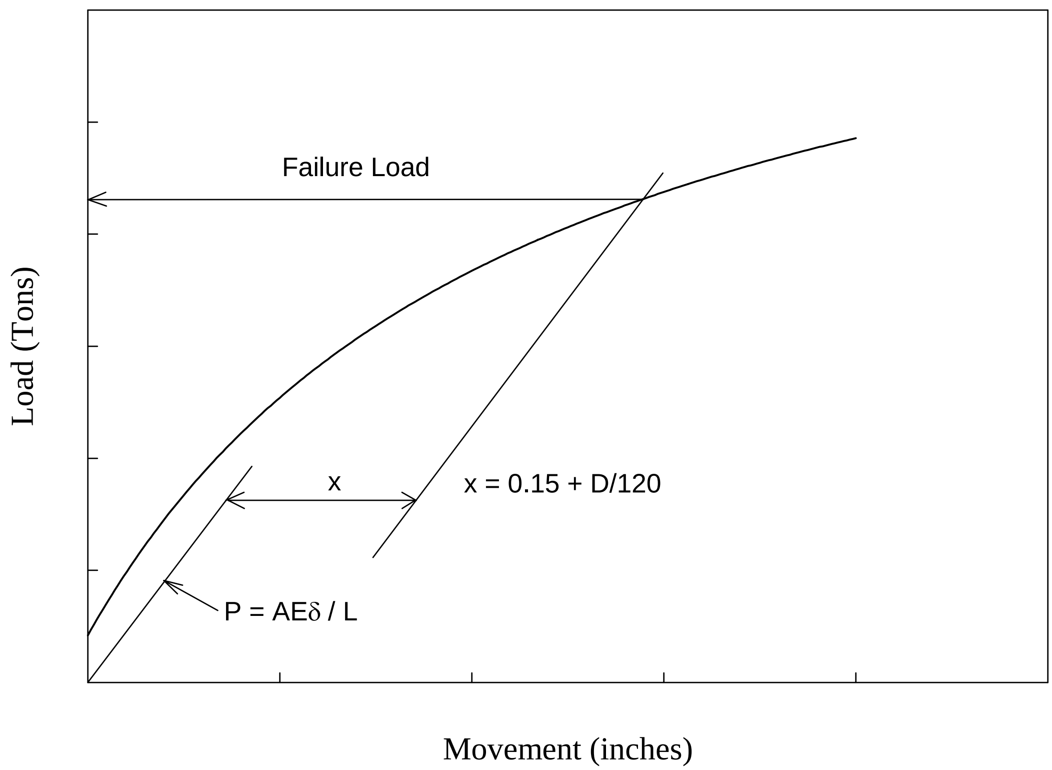

Figure 3-5. Davisson's Failure Criteria (Davisson, 1972)

Information on the pile, soil profiles and the load test data were reviewed for the purpose of extracting information to be used in the reliability analysis. The soils at each test site were characterized based on the available geotechnical reports. The static analysis of the pile bearing capacity was performed using the three methods (Vesic, Nordlund, and Meyerhof) presented in Chapter 2. The predicted static pile capacities were then compared with the load test results, and a bias factor, which is the ratio of the measured capacity over the predicted capacity, was computed for each data case. Bayesian updating technique was utilized to improve the statistics of the bias factors, where appropriate. The statistical parameters of the bias factors were incorporated in the calibration of the resistance factors. Details of the bias factors and the Bayesian updating will be presented in the following chapter.

CHAPTER 4. RELIABILITY ANALYSIS

4.1 INTRODUCTION

The first step in evaluating the reliability or probability of failure of a pile foundation is to decide on specific performance criteria in terms of a limit state function and the relevant load and resistance parameters. Assume that there are two basic random variables, the load (Q) and the resistance (R). The limit state function can be defined as g(R, Q) = 0, which can be a linear or nonlinear function of R and Q. Failure occurs when g(R, Q) < 0 and the probability of failure, P_f, is expressed by the integral (Haldar, et al., 2000)

$$P_f = \iint_{g<0} f_{R,Q}(r,q)\,dr\,dq \qquad (4.1)$$

in which, $f_{R,Q}(r,q)$ is the joint probability density function for the basic random variables R and Q, and the integration is performed over the failure region, that is, $g < 0$. If the random variables are statistically independent, then the joint probability density function may be replaced by the product of the individual probability density functions (PDF) in the integral.

Equation 4.1 is considered to be the basic equation of reliability analysis, and the computation of P_f by the integration is called the full distributional approach. In general, the joint probability density function of random variables is practically not possible to obtain, and the PDF of individual random variables may not always be available in explicit form. Even if this information is available, evaluating the multiple integral is very difficult. Therefore, analytical approximations of this integral are employed to simplify the computation of the reliability or the probability of failure. These methods of approximations are First-Order Reliability Methods (FORM) and Second-Order Reliability Methods (SORM). In this study, two types of FORM, Mean Value First-Order Second Moment (MVFOSM) method and Advanced First-Order Second Moment (AFOSM) method, are used to evaluate the reliability of the current design methods for axial capacity of driven piles. In the FORM, the reliability or the probability of failure is expressed in terms of reliability index (β), which can be computed using the statistics of the loads and resistance.

4.2 LOAD STATISTICS

This study employed the load statistics and the load factors from the current AASHTO LRFD Specifications (1998) to make the pile foundation design consistent with the bridge superstructure design. The load combination of dead load (Q_D) and live load (Q_L) for the Strength Case I (AASHTO, 1998) was chosen for the reliability analysis because this combination is considered the most conservative for the calibration of the resistance factors. The load factors used in the reliability analysis are 1.25 for dead load and 1.75 for live load. The load statistics are presented in terms of mean and coefficient of variation (COV) of the bias factors. The bias factor is defined as the ratio of the observed actual load over the nominal load. Nowak (1992) presented the results of statistical analysis of highway dead and live loads, as summarized in Table 4.1. The largest variation is the weight of the asphalt wearing surface placed on the bridge deck. However, this is a very small percent of the total bridge dead load and can be ignored in the calculation of the mean and COV of the overall bias factor of the dead load.

Table 4-1. Statistics of Bridge Load Components

Load Component	Bias Factor Mean	Bias Factor COV
Dead Load		
Factory Made	1.03	0.08
Cast-In-Place	1.05	0.10
Asphalt Wearing Surface	1.00	0.25
Live Load	1.10 - 1.20	0.18

Thus, the mean and the coefficient of variation of bias factor for the dead load are:

$$\lambda_{QD} = 1.03 \text{ x } 1.05 = 1.08$$

$$COV_{QD} = (0.08^2 + 0.10^2)^{0.5} = 0.13$$

The mean bias factor and COV for the live load are taken as 1.15 and 0.18, respectively. The distribution of the bias factors of both dead and live loads is assumed to be lognormal considering that all of these values are positive. Lognormal distribution of the loads was also assumed by Barker, et al (1991b) in the calibration of the resistance factors for bridge foundations adopted by AASHTO (1994).

4.3 RESISTANCE STATISTICS

4.3.1 Bias Factor

The resistance statistics were represented in terms of the bias factors. The bias factor is defined as the ratio of the measured pile capacity over the predicted pile capacity. Once the measured pile capacities from the PDA/CAPWAP and the static load test data were compiled, as presented in Chapter 3, the predicted pile capacities were evaluated for the same pile type, length, soil condition and the installation methods using the three static analysis methods presented in Chapter 2. The computer program PILECAP was used for the Vesic method, the program DRIVEN was used for the Nordlund method, and an Excel spreadsheet was utilized to speed up the calculation process of the Meyerhof method. The bias factor was computed for each data set, and the statistics of the bias factors were evaluated. An example of the bias factor statistics is shown in Table 4-2.

Table 4-2. Bias Factor Statistics for Coastal Steel HP Piles – Vesic Method

Proj. No.	Pile Type	Total			Skin			Toe		
		PDA	Vesic	λ	PDA	Vesic	λ	PDA	Vesic	λ
10*	HP 12 X 53	87	76	1.14	62	75	0.83	25	1	
106*	HP 12 X 53	110	77	1.43	89	71	1.25	21	6	3.50
49	HP 12 X 53	107	150	0.71	85	142	0.60	22	8	2.75
100	HP 14 X 73	63	168	0.38	50	154	0.32	13	14	0.93
50	HP 12 X 53	102	75	1.36	99	67	1.48	3	8	0.38
102	HP 12 X 53	96	212	0.45	88	204	0.43	8	8	1.00
104	HP 12 X 53	98	47	2.09	12	5	2.40	86	42	2.05
16	HP 12 X 53	94	115	0.82	80	104	0.77	14	11	1.27
110	HP 12 X 53	192	112	1.71	158	99	1.60	34	13	2.62
103	HP 12 X 53	72	89	0.81	45	82	0.55	27	7	3.86
121	HP 14 X 73	202	107	1.89	180	92	1.96	22	15	1.47
43	HP 14 X 73	111	176	0.63	91	157	0.58	20	19	1.05
44	HP 14 X 73	151	213	0.71	139	184	0.76	12	29	0.41
57	HP 12 X 53	68	126	0.54	44	86	0.51	24	40	0.60
111	HP 12 X 53	103	160	0.64	36	119	0.30	67	41	1.63
112	HP 12 X 53	169	158	1.07	91	117	0.78	78	41	1.90
113	HP 12 X 53	159	155	1.03	150	115	1.30	9	40	0.23
			Mean	1.02		Mean	0.97		Mean	1.60
			Stdev.	0.51		Stdev.	0.60		Stdev.	1.11
			COV	0.50		COV	0.63		COV	0.69

In Table 4-2, the bias factor (λ) is the ratio of the PDA (measured capacity from PDA/CAPWAP) over Vesic (predicted capacity by the Vesic method). This bias factor accounts for all of the uncertainties from various sources of errors such as model uncertainty, SPT blow count error, spatial variability of the SPT measurement, load test error, errors in the strength parameter correlations with the SPT blow counts, and so on. There is a basic assumption in this study that the statistics of the bias factors will represent all the sources of errors including SPT testing, pile load tests, and the static pile capacity prediction models. The bias factor statistics were evaluated separately for the total, shaft and toe pile capacities from the PDA/CAPWAP data. For the static load test data, the bias factor statistics for total capacity only were calculated since there is no separation of skin and toe resistance components from the static load tests. The bias factor statistics for all other categories of the data for the reliability analysis and the resistance factor calibration are tabulated and included in Appendix C. Summaries of the bias factor statistics for the six categories (coastal concrete square pile, coastal steel HP pile, coastal steel pipe pile, coastal concrete cylinder pile, piedmont concrete square pile, and piedmont steel HP pile) are presented in Tables 4-3 through 4-8.

The distribution of the bias factors for each category was examined by Kolmogorov-Smirnov test (Ang, et al., 1975) using the computer program MATLAB. Lognormal distribution was found to represent the bias factor distributions most closely for all the categories. Accordingly, lognormal distribution was assumed in the reliability analysis and the resistance factor calibrations. The bias factor statistics are influenced by the size of the data set for each category and the variation in the bias factors. Extremely outlying data points may not be representative of the resistance due to the large error in either the measured capacity or the predicted capacity. Therefore, it is reasonable to remove the far-outlying data points from the bias factor statistics. The bias factor values outside the boundaries defined by the mean plus or minus two times the standard deviation were discarded.

The statistical parameters were evaluated for every available database corresponding to the study categories. The concrete square piles and the steel HP piles in the coastal region have the database for both the PDA initial driving (EOD) and the PDA restrike (BOR) as well as the static load tests.

Table 4-3. Summary of Bias Factor Statistics – Coastal Concrete Square Pile

Coastal Region Concrete Square Pile		Vesic		Nordlund		Meyerhof	
		λ–Mean	λ–COV	λ–Mean	λ–COV	λ–Mean	λ–COV
N@Toe<=40 PDA EOD	Total	0.76	0.39	0.83	0.51	1.68	0.54
	Skin	1.03	0.62	0.59	0.70	1.67	0.73
	Toe	0.73	0.49	2.19	0.79	2.00	0.64
N@Toe>40 PDA EOD	Total	0.53	0.41	0.39	0.34	0.71	0.44
	Skin	0.87	0.54	0.57	0.84	1.48	0.54
	Toe	0.50	0.51	0.51	0.34	0.57	0.46
Total PDA EOD	Total	0.73	0.42	0.71	0.54	1.43	0.56
	Skin	0.95	0.59	0.59	0.72	1.77	0.76
	Toe	0.69	0.54	1.79	0.84	1.70	0.71
N@Toe<=40 PDA BOR	Total	0.97	0.29	1.05	0.37	2.90	0.52
	Skin	2.20	0.55	0.78	0.39	3.81	0.82
	Toe	0.56	0.49	3.36	0.74	2.46	0.58
N@Toe>40 PDA BOR	Total	0.76	0.29	0.94	0.45		
	Skin	3.04	0.57	0.64	0.63		
	Toe	0.47	0.99	4.92	0.76		
Total PDA BOR	Total	0.94	0.29	1.01	0.35	2.96	0.51
	Skin	2.30	0.56	0.82	0.34	4.00	0.80
	Toe	0.64	0.49	3.54	0.74	2.46	0.56
Static Load Test		0.80	0.29	1.02	0.46	1.95	0.53

The coastal steel pipe piles have the database for both the PDA EOD and BOR, but no static load tests. The coastal concrete cylinder piles and the piedmont steel HP piles have the database for the PDA EOD and the static load tests. The piedmont concrete square piles have the database for the PDA EOD only.

Table 4-4. Summary of Bias Factor Statistics – Coastal Steel HP Pile

Coastal Region Steel HP Pile		Vesic		Nordlund		Meyerhof	
		λ–Mean	λ–COV	λ–Mean	λ–COV	λ–Mean	λ–COV
N@Toe<=40 PDA EOD	Total	1.09	0.51	1.07	0.53	1.28	0.50
	Shaft	1.02	0.64	0.76	0.37	0.87	0.56
	Toe	2.04	0.60	7.95	1.15	7.37	1.21
N@Toe>40 PDA EOD	Total	0.77	0.29	1.16	0.42	0.85	0.28
	Shaft	0.88	0.64	1.19	0.54	0.59	0.28
	Toe	1.04	0.62	1.03	0.72	1.48	0.71
Total PDA EOD	Total	1.02	0.50	1.11	0.47	1.03	0.46
	Shaft	0.97	0.63	0.92	0.48	0.81	0.54
	Toe	1.60	0.69	5.10	1.51	2.47	0.94
Total PDA BOR	Total	1.47	0.25	1.76	0.33	1.29	0.38
	Shaft	1.27	0.20	1.59	0.37	1.12	0.37
	Toe	10.75	1.23	10.22	1.34	10.59	1.26

Table 4-5. Summary of Bias Factor Statistics – Coastal Steel Pipe Pile

Coastal Region Steel Pipe Pile		Vesic		Nordlund		Meyerhof	
		λ–Mean	λ–COV	λ–Mean	λ–COV	λ–Mean	λ–COV
Total PDA EOD	Total	1.43	0.46	1.05	0.47	1.21	0.36
	Shaft	1.00	0.47	0.79	0.45	0.89	0.53
	Toe	3.51	0.66	2.12	0.67	11.44	0.82
Total PDA BOR	Total	1.64	0.19	1.07	0.29	1.83	0.23
	Shaft	1.65	0.32	1.27	0.24	1.56	0.20
	Toe	2.29	0.62	0.84	0.70	9.87	0.76

Table 4-6. Summary of Bias Factor Statistics – Coastal Concrete Cylinder Pile

Coastal Region Concrete Cylinder Pile		Vesic		Nordlund		Meyerhof	
		λ–Mean	λ–COV	λ–Mean	λ–COV	λ–Mean	λ–COV
Total PDA EOD	Total	0.51	0.17	0.26	0.28	1.02	0.16
	Shaft	1.80	0.08	0.29	0.20	7.10	0.99
	Toe	0.22	0.40	0.21	0.32	0.85	0.73
Static Load Test		0.83	0.32	0.63	0.85	2.80	0.63

Table 4-7. Summary of Bias Factor Statistics – Piedmont Concrete Square Pile

Piedmont Region Concrete Square Pile		Vesic		Nordlund		Meyerhof	
		λ–Mean	λ–COV	λ–Mean	λ–COV	λ–Mean	λ–COV
Total PDA EOD	Total	1.10	0.19	1.57	0.28	1.40	0.63
	Shaft	1.94	0.77	1.71	0.41	1.84	0.57
	Toe	0.86	0.61	1.83	0.68	1.23	0.87

Table 4-8. Summary of Bias Factor Statistics – Piedmont Steel HP Pile

Piedmont Region Steel HP Pile		Vesic		Nordlund		Meyerhof	
		λ–Mean	λ–COV	λ–Mean	λ–COV	λ–Mean	λ–COV
Total PDA EOD	Total	1.17	0.15	0.92	0.41	1.24	0.28
	Shaft	1.14	0.08	0.74	0.39	0.97	0.13
	Toe	1.21	0.54	5.00	1.68	5.61	1.44
Static Load Test		2.13	0.50	1.27	0.55	2.15	0.57

4.3.2 Bayesian Updating of the Bias Factors

The resistance statistics used in the reliability analysis and the calibration of the resistance factors must be based on the measured pile capacities that are ‘ultimate’ in nature. It is known that the pile bearing capacity measured from the PDA EOD very often does not represent the actual ultimate capacity because the bearing capacity is not fully mobilized at the time of the initial driving of the pile. Many researchers including Svinkin, et al. (1994) reported that the pile capacity changes with time. This was verified in this study as presented in Figures 3-5 to 3-7. Also, Likins, et al. (1996) reported that the pile capacities from PDA restrike showed an excellent correlation with the static pile load test data. Therefore, PDA restrike data and the static load test data should be used, wherever available, for verification of ultimate pile capacity estimates.

However, the databases for the PDA restrike (BOR) and the static load tests are not large enough to represent the resistance statistics, except for the coastal region concrete square piles. To supplement the limited sizes of the databases, Bayesian updating was employed using the available pile load test data for each category. To apply Bayesian updating in this study, the bias factor distribution for the PDA EOD data was treated as the prior distribution, and the bias factor distribution for the PDA BOR or static load test data was treated as the likelihood distribution. As mentioned earlier, the resistance statistics were found to follow a lognormal distribution. To facilitate Bayesian updating, the lognormal distributions were converted to normal distributions using a natural logarithmic transformation before conducting the updating. Based on the converted normal distributions of the prior information (PDA EOD data) and the likelihood information (PDA BOR or static load test data), Bayesian updating yields the mean and the variance of the updated (posterior) distribution as the following formula.

$$\mu_u = \frac{\mu_p . \sigma_l^2 + \mu_l . \sigma_p^2}{\sigma_p^2 + \sigma_l^2} \qquad (4\text{-}2)$$

$$\sigma_u^2 = \frac{\sigma_p^2 . \sigma_l^2}{\sigma_p^2 + \sigma_l^2} \qquad (4\text{-}3)$$

where, μ stands for mean and σ for standard deviation. Subscripts p, l and u stand for prior, likelihood and updated (posterior) estimate, respectively. After the updated mean and variance of the converted normal distributions are obtained, they can be converted back to the mean and variance of the updated statistics of the bias factors using the following equations.

$$\mu_\lambda = \exp(\mu_u + 0.5 * \sigma_u^2) \qquad (4\text{-}4)$$

$$\sigma_\lambda^2 = \mu_\lambda^2 (\exp(\sigma_u^2) - 1) \qquad (4\text{-}5)$$

The updated statistics of the bias factors for the pile total capacities are summarized in Tables 4-9 through 4-12.

Table 4-9. Bayesian Updating: C-C-SQ, Total Capacity

Coastal Region Concrete Square Pile		Vesic		Nordlund		Meyerhof	
		Mean	COV	Mean	COV	Mean	COV
N@Toe<=40	Prior	0.76	0.39	0.83	0.51	1.68	0.54
Prior: PDA EOD	Likelihood	0.97	0.29	1.05	0.37	2.90	0.52
Likelihood: PDA BOR	Updated	0.85	0.26	0.93	0.29	1.96	0.42
N@Toe>40	Prior	0.53	0.41	0.39	0.34	0.71	0.44
Prior: PDA EOD	Likelihood	0.76	0.29	0.94	0.45	Not Available	
Likelihood: PDA BOR	Updated	0.67	0.23	0.47	0.26		
PDA Total	Prior	0.73	0.42	0.71	0.54	1.43	0.56
Prior: PDA EOD	Likelihood	0.94	0.29	1.01	0.35	2.96	0.51
Likelihood: PDA BOR	Updated	0.83	0.26	0.86	0.30	1.86	0.44

Table 4-10. Bayesian Updating: C-S-HP, Total Capacity

Coastal Region Steel HP Pile		Vesic		Nordlund		Meyerhof	
		Mean	COV	Mean	COV	Mean	COV
N@Toe<=40	Prior	1.09	0.51	1.07	0.53	1.28	0.50
Prior: PDA EOD	Likelihood	1.47	0.25	1.76	0.33	1.29	0.38
Likelihood: PDA BOR	Updated	1.37	0.25	1.44	0.30	1.26	0.34
N@Toe>40	Prior	0.77	0.29	1.16	0.42	0.85	0.28
Prior: PDA EOD	Likelihood	1.47	0.25	1.76	0.33	1.29	0.38
Likelihood: PDA BOR	Updated	1.07	0.20	1.41	0.27	0.94	0.22
PDA Total	Prior	1.02	0.50	1.11	0.47	1.03	0.46
Prior: PDA EOD	Likelihood	1.47	0.25	1.76	0.33	1.29	0.38
Likelihood: PDA BOR	Updated	1.33	0.24	1.42	0.29	1.13	0.30

Table 4-11. Bayesian Updating: C-S-PP, Total Capacity

Coastal Region Steel Pipe Pile		Vesic		Nordlund		Meyerhof	
		Mean	COV	Mean	COV	Mean	COV
PDA Total	Prior	1.43	0.46	1.05	0.47	1.21	0.36
Prior: PDA EOD	Likelihood	1.64	0.19	1.07	0.29	1.83	0.23
Likelihood: PDA BOR	Updated	1.59	0.18	1.04	0.27	1.58	0.19

Table 4-12. Bayesian Updating: C-C-CL, Total Capacity

Coastal Region Concrete Cylinder Pile		Vesic		Nordlund		Meyerhof	
		Mean	COV	Mean	COV	Mean	COV
PDA Total	Prior	0.51	0.17	0.26	0.28	1.02	0.16
Prior: PDA EOD	Likelihood	0.83	0.32	0.63	0.85	2.80	0.63
Likelihood: Static Load Test	Updated	0.59	0.16	0.28	0.26	1.10	0.16

4.4 FIRST ORDER SECOND MOMENT (FOSM) ANALYSIS

The FOSM analysis is also referred to as the Mean Value First Order Second Moment (MVFOSM) analysis in the literature. The MVFOSM analysis derives its name from the fact that it is based on a first-order Taylor series approximation of the limit state function linearized at the mean values of the random variables, and it uses only second-moment statistics (means and standard deviations) of the random variables. In this study, two random variables, the load (Q) and the resistance (R), are considered and they are assumed to be lognormally distributed. The limit state function in this case is defined as:

$$g\,(R, Q) = \ln (R) - \ln (Q) = \ln (R/Q) \qquad (4\text{-}6)$$

It is logical to assume that R and Q are mutually independent, and the mean value of g (R, Q) is expressed as:

$$\overline{g} = \ln\left[\frac{\overline{R}}{\overline{Q}}\sqrt{\frac{1+COV_Q^{\ 2}}{1+COV_R^{\ 2}}}\right] \qquad (4\text{-}7)$$

and its standard deviation is:

$$\zeta_g = \sqrt{\ln\left[(1+COV_R^{\ 2})(1+COV_Q^{\ 2})\right]} \qquad (4\text{-}8)$$

where, $\overline{R}$, $\overline{Q}$: mean values of the resistance and load

COV_R, COV_Q : coefficients of variation of R and Q

By definition, the reliability index (β) is the ratio of $\overline{g}$ over ζ_g (Haldar, et al., 2000), and it can be expressed in the following equation.

$$\beta = \frac{\ln\left[(\overline{R}/\overline{Q})\sqrt{(1+COV_Q^{\,2})/(1+COV_R^{\,2})}\right]}{\sqrt{\ln[(1+COV_R^{\,2})(1+COV_Q^{\,2})]}} \qquad (4\text{-}9)$$

The mean values of the load and resistance can be expressed in terms of nominal load and resistance and their respective bias factors such that:

$$\overline{Q} = \lambda_Q Q_n \quad \text{and} \quad \overline{R} = \lambda_R R_n$$

And Equation (4-9) can be rewritten as:

$$\beta = \frac{\ln\left[(\lambda_R R_n / \lambda_Q Q_n)\sqrt{(1+COV_Q^{\,2})/(1+COV_R^{\,2})}\right]}{\sqrt{\ln[(1+COV_R^{\,2})(1+COV_Q^{\,2})]}} \qquad (4\text{-}10)$$

R_n and Q_n can be expressed in terms of factor of safety (FS) such that R_n = FS * Q_n. Consider the load combination of dead load (QD) and live load (QL) for AASHTO Strength I case. Then, $\lambda_Q Q_n = \lambda_{QD}$ QD + λ_{QL} QL and R_n = FS (QD + QL). Also, QD and QL are assumed to be mutually independent and $COV_Q^2 = COV_{QD}^2 + COV_{QL}^2$. Therefore, Equation (4-10) can be rewritten in the following form.

$$\beta = \frac{\ln\left[\frac{\lambda_R FS(QD+QL)}{\lambda_{QD}QD+\lambda_{QL}QL}\sqrt{(1+COV_{QD}^{\,2}+COV_{QL}^{\,2})/(1+COV_R^{\,2})}\right]}{\sqrt{\ln[(1+COV_R^{\,2})(1+COV_{QD}^{\,2}+COV_{QL}^{\,2})]}} \qquad (4\text{-}11)$$

or, $$\beta = \frac{\ln\left[\frac{\lambda_R FS(QD/QL+1)}{\lambda_{QD} QD/QL + \lambda_{QL}}\sqrt{(1+COV_{QD}^{\ 2}+COV_{QL}^{\ 2})/(1+COV_R^{\ 2})}\right]}{\sqrt{\ln[(1+COV_R^{\ 2})(1+COV_{QD}^{\ 2}+COV_{QL}^{\ 2})]}} \qquad (4\text{-}12)$$

It is seen from this equation that the reliability index is a function of FS, QD/QL, the load statistics (λ_{QD}, λ_{QL}, COV_{QD}, COV_{QL}) and the resistance statistics (λ_R, COV_R). The ratio of dead load over live load (QD/QL) is a function of the bridge span length. Withiam, et al. (1998) tabulated the relationship between QD/QL ratio and bridge span length using Hansell and Viest (1971)'s empirical formula. This study adopted the relationship for the reliability analysis and the resistance factor calibrations.

In the MVFOSM analysis, the limit state function (g) is linearized at the mean values of the random variables rather than at a point on the failure surface. When g is non-linear, as in the case of g = ln (R/Q), a significant error may be introduced by neglecting higher order terms. Also, the reliability index may not be constant for different but mechanically equivalent formulations of the same limit state function. To overcome these deficiencies of the MVFOSM approach, the Advanced First Order Second Moment (AFOSM) analysis is carried out in this study.

4.5 ADVANCED FIRST ORDER SECOND MOMENT (AFOSM) ANALYSIS

The basic concepts and analytical procedures of the AFOSM methods were developed by Ditlevsen (1974), Ellingwood, et al. (1980), Hasofer and Lind (1974), and Rackwitz and Fiessler (1978) to improve the mean value methods. In the AFOSM analysis, the limit state function is linearized at a point on the failure surface. If the limit state function is linear and if all of the random variables are mutually independent and normally distributed, then the AFOSM methods give an identical reliability index as the

MVFOSM methods. But this may not be true for all other cases. This study employed the iteration algorithm of the Rackwitz and Fiessler's AFOSM method considering that the random variables in this study follow a lognormal distribution and the limit state function is non-linear. A computer program 'AdvRel' was coded in the MATLAB environment to facilitate the iteration processes. The following is the step-by-step procedure of the AFOSM analysis written into the computer program to compute the reliability index.

- Step 1. Define the Limit State Function g in terms of the random variables λ_R, λ_{QD} and λ_{QL}.

$$g = \ln\left(\frac{FS * \lambda_R * (QD/QL + 1)}{\lambda_{QD} * QD/QL + \lambda_{QL}}\right)$$

- Step 2. Assume an initial value of the Reliability Index β. Any value of β can be assumed.
- Step 3. Assume the initial values of the design points (dp). The initial design points can be assumed to be at the mean values of the random variables.
- Step 4. Compute the mean and standard deviation at the design point of the equivalent normal distribution for the random variables that are lognormal.

lognormal standard deviation: $\xi = \sqrt{\ln(1 + COV^2)}$

mean: $\lambda = \ln(\mu) - 0.5 * \xi^2$

equivalent normal standard deviation: $\sigma_x^N = \xi * dp$

mean: $\mu_x^N = dp * (1 - \ln(dp) + \lambda)$

- Step 5. Compute the partial derivatives evaluated at the design points.

$$pder = \left(\frac{\partial g}{\partial x}\right)_{x=dp}$$

- Step 6. Compute the direction cosines α at the design points.

$$\alpha = \left[\frac{\frac{\partial g}{\partial x} * \sigma_x^N}{\sqrt{\sum_i^n \left(\frac{\partial g}{\partial x} * \sigma_x^N\right)^2}}\right]_{x=dp}$$

- Step 7**.** Compute the new values for the design points as:

$$\mathrm{dp} = \mu_x^N - \alpha * \beta * \sigma_x^N$$

  Repeat the steps 4 through 7 until the direction cosines (α) converge to a specified tolerance value of 0.005.

- Step 8. Once α's converge, the new design points can be expressed in terms of β as the unknown parameter. These new design points must satisfy the limit state function. Substitute the random variables in the limit state function with these new design points and solve g for β.
- Step 9. Repeat the steps 3 through 8 until β converges to a tolerance value of 0.001.

4.6 RELIABILITY ESTIMATE OF THE CURRENT DESIGN PRACTICE

4.6.1 Introduction

Reliability indexes of the NCDOT's current allowable strength design practice on the pile foundation design were evaluated using the two reliability analysis methods described above. The reliability analysis was performed on all the compiled database of the resistance statistics for the six different categories of the pile type and region combinations: (i) coastal area concrete square pile, (ii) coastal area steel HP pile, (iii) coastal area steel pipe pile, (iv) coastal area concrete cylinder pile, (v) piedmont area concrete square pile, and (vi) piedmont area steel HP pile. Also, the three static pile capacity analysis methods (Vesic, Nordlund, Meyerhof) were evaluated for each category. In the NCDOT practice, a minimum factor of safety (FS) of two (2) is used for the design bearing capacity of pile foundations. Therefore, the reliability analysis was performed for FS of 2, 2.5 and 3. The results of the reliability analyses are summarized in Tables 4-13 through 4-18 for the Vesic method, Tables 4-19 through 4-24 for the Nordlund method, and Tables 4-25 through 4-30 for the Meyerhof method.

4.6.2 Vesic Method

Coastal Concrete Square Piles:

Table 4-13 shows the reliability indexes computed for the seven different databases available for this category. There are large variations in the reliability indexes between the PDA EOD and the PDA BOR and between the skin and toe resistance components. Clearly the PDA restrike (BOR) data show a higher reliability than the PDA initial driving (EOD) data, except for the toe capacities. This can be explained by the fact that the PDA restrike mobilized a much larger set-up in the skin resistance than in the toe resistance, as shown in Figures 3-1 through 3-3 of Chapter 3. Reliability indexes from the static load test data are between those from the PDA EOD and those from the PDA BOR. As expected, the reliability indexes reflect the bias factor statistics shown in Table 4-3. On the average, AFOSM resulted in a higher reliability index than MVFOSM by approximately 10% for the total capacity, 4% for the skin capacity, and 32% for the toe capacity. The reliability indexes for the toe capacity are not realistic and should not be considered for the resistance factor calibration. The reliability indexes for the total capacity range from –0.2 to 1.6 for FS of 2, 0.3 to 2.4 for FS of 2.5, and 0.7 to 3.1 for FS of 3.

Table 4-13. Summary of Reliability Analyses: C-C-SQ, Vesic

Vesic Method		Total		Shaft		Toe	
Coastal Concrete Square Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	0.66	0.62	0.81	0.79	0.38	0.38
EOD	2.5	1.23	1.14	1.20	1.16	0.85	0.82
N@Toe<=40	3.0	1.71	1.56	1.52	1.46	1.23	1.17
PDA	2.0	-0.27	-0.22	0.65	0.63	-0.42	-0.36
EOD	2.5	0.27	0.27	1.07	1.04	0.04	0.06
N@Toe>40	3.0	0.72	0.68	1.41	1.37	0.41	0.41
PDA	2.0	0.50	0.48	0.71	0.69	0.21	0.22
EOD	2.5	1.03	0.96	1.11	1.07	0.64	0.62
All	3.0	1.46	1.36	1.43	1.38	0.99	0.96
PDA	2.0	1.76	1.52	2.37	2.25	-0.20	-0.16
BOR	2.5	2.50	2.14	2.80	2.65	0.27	0.28
N@Toe<=40	3.0	3.10	2.65	3.12	2.97	0.65	0.63
PDA	2.0	0.95	0.84	2.89	2.75	-0.15	-0.55
BOR	2.5	1.69	1.46	3.30	3.14	0.08	-0.28
N@Toe>40	3.0	2.30	1.97	3.64	3.45	0.24	-0.07
PDA	2.0	1.63	1.43	2.46	2.33	0.09	0.10
BOR	2.5	2.37	2.04	2.88	2.73	0.56	0.54
All	3.0	2.96	2.55	3.22	3.05	0.94	0.90
Static Load Tests	2.0	1.08	0.95				
	2.5	1.81	1.57				
	3.0	2.40	2.07				

Coastal Steel HP Piles:

Table 4-14 shows the reliability indexes computed for the four different databases available for this category. There is a large increase in the reliability indexes between the PDA EOD and the PDA BOR, especially for the skin resistance component. This is probably due to a larger set-up in the shaft resistance than in the toe resistance from the PDA restrike. As expected, the reliability indexes reflect the bias factor statistics shown in Table 4-4. Also it is reasonable to observe that the difference in the computed reliability indexes between N@Toe<=40 database and N@Toe>40 database is greater for the toe resistance component than for the skin resistance component. On the average, AFOSM resulted in a higher reliability index than MVFOSM by about 12% for the total capacity, 10% for the shaft capacity, and 3% for the toe capacity. The reliability indexes for the total capacity range from 0.9 to 3.6 for FS of 2, 1.4 to 4.4 for FS of 2.5, and 1.8 to 5.1 for FS of 3.

Table 4-14. Summary of Reliability Analyses: C-S-HP, Vesic

Vesic Method		Total		Shaft		Toe	
Coastal Steel HP Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA EOD N@Toe<=40	2.0	1.15	1.11	0.76	0.75	2.06	1.97
	2.5	1.62	1.53	1.14	1.10	2.45	2.35
	3.0	1.98	1.87	1.45	1.40	2.78	2.65
PDA EOD N@Toe>40	2.0	0.99	0.87	0.51	0.51	0.82	0.80
	2.5	1.72	1.49	0.89	0.87	1.21	1.17
	3.0	2.32	2.00	1.19	1.16	1.52	1.46
PDA EOD All	2.0	1.05	1.01	0.69	0.67	1.39	1.35
	2.5	1.52	1.44	1.07	1.04	1.74	1.68
	3.0	1.89	1.79	1.38	1.33	2.03	1.96
PDA BOR All	2.0	3.59	2.95	3.68	2.83	2.61	2.57
	2.5	4.43	3.63	4.67	3.59	2.84	2.79
	3.0	5.11	4.18	5.49	4.21	3.02	2.98

Coastal Steel Pipe Piles:

Table 4-15 shows the reliability indexes computed for the two databases available for this category. There is a large increase in the reliability indexes between the PDA EOD and the PDA BOR for the total and shaft capacities, which reflects the set-up effects. But the reliability indexes for the toe capacity are less for the BOR than for the EOD. This probably implies that the toe capacity was not fully mobilized during the PDA restrikes. On the average, AFOSM resulted in a higher reliability index than MVFOSM by about 18% for the total capacity, 10% for the shaft capacity, and 4% for the toe capacity. The reliability indexes for the total capacity range from 1.8 to 4.9 for FS of 2, 2.3 to 6.0 for FS of 2.5, and 2.6 to 6.8 for FS of 3. These relatively high reliability indexes reflect the fact that most of the piles for this category were from the same project site, thus there are small variations in the bias factor statistics as shown in Table 4-5.

Table 4-15. Summary of Reliability Analyses: C-S-PP, Vesic

Vesic Method		Total		Shaft		Toe	
Coastal Steel Pipe Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	1.92	1.79	1.09	1.03	2.75	2.64
EOD	2.5	2.36	2.25	1.57	1.48	3.11	2.99
All	3.0	2.66	2.62	1.97	1.84	3.41	3.27
PDA	2.0	4.94	3.75	3.18	2.78	2.20	2.11
BOR	2.5	5.96	4.52	3.85	3.37	2.58	2.47
All	3.0	6.79	5.15	4.40	3.84	2.90	2.77

Coastal Concrete Cylinder Piles:

Table 4-16 shows the reliability indexes computed for the two databases available for this category. The reliability indexes for the toe capacity from the PDA EOD database are not realistic, probably because the toe capacities measured from the PDA are not reliable. Also, the PDA database size is not large enough to provide reliable resistance statistics. The very large reliability indexes for the shaft resistance suggest that the Vesic method for the concrete cylinder pile's shaft capacity is very conservative and

may need to be revised. The static load test data are more reliable than the PDA data. On the average, AFOSM shows about 7% higher reliability index than MVFOSM for the static load test database.

Table 4-16. Summary of Reliability Analyses: C-C-CL, Vesic

Vesic Method		Total		Shaft		Toe	
Coastal Concrete Cylinder Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA EOD All	2.0	-0.32	-0.24	7.83	5.13	-3.04	-2.12
	2.5	0.75	0.56	8.73	6.08	-2.10	-1.63
	3.0	1.51	1.21	9.33	6.86	-1.42	-1.23
Static Load Tests	2.0	1.12	1.00				
	2.5	1.73	1.59				
	3.0	2.14	2.07				

<u>Piedmont Concrete Square Piles:</u>

There is only one database available for this category's reliability analysis as shown in Table 4-17. The computed reliability indexes reflect the bias factor statistics shown in Table 4-7; the reliability indexes for the total capacity are much larger than those for the shaft and toe capacities. This is probably due to the averaging effects in the total capacity variations by combining the variations of the shaft and toe capacities. The difference in the computed reliability indexes between AFOSM and MVFOSM is also much more significant for the total capacity than for the shaft or toe capacity. On the average, AFOSM resulted in a higher reliability index than MVFOSM by 34% for the total capacity, 2% for the shaft capacity, and 0% for the toe capacity.

Table 4-17. Summary of Reliability Analyses: P-C-SQ, Vesic

Vesic Method		Total		Shaft		Toe	
Piedmont Concrete Square Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	3.20	2.42	1.48	1.47	0.48	0.49
EOD	2.5	4.28	3.20	1.81	1.78	0.87	0.86
All	3.0	5.17	3.83	2.08	2.04	1.18	1.16

Piedmont Steel HP Piles:

Two databases are available for this category's reliability analysis as shown in Table 4-18. The computed reliability indexes reflect the bias factor statistics shown in Table 4-8. The reliability indexes for the shaft capacity are much larger than those for the toe capacities because of the much less COV of the shaft capacity than COV of the toe capacity.

Table 4-18. Summary of Reliability Analyses: P-S-HP, Vesic

Vesic Method		Total		Shaft		Toe	
Piedmont Steel HP Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	4.22	2.89	5.88	3.15	1.25	1.23
EOD	2.5	5.53	3.74	7.91	4.11	1.69	1.63
All	3.0	6.61	4.43	9.61	4.88	2.05	1.96
Static Load Tests	2.0	2.60	2.43				
	2.5	3.06	2.87				
	3.0	3.44	3.22				

The difference in the computed reliability indexes between AFOSM and MVFOSM is also much more significant for the shaft capacity than for the toe capacity. On the average, AFOSM resulted in a higher reliability index than MVFOSM by 27% for the total capacity, 92% for the shaft capacity, and 3% for the toe capacity.

4.6.3 Nordlund Method

Coastal Concrete Square Piles:

Table 4-19 shows the reliability indexes computed for the seven different databases available for this category.

Table 4-19. Summary of Reliability Analyses: C-C-SQ, Nordlund

Nordlund Method		Total		Shaft		Toe	
Coastal Concrete Square Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	0.62	0.60	-0.18	-0.16	1.62	1.59
EOD	2.5	1.06	1.02	0.10	0.18	1.93	1.89
N@Toe<=40	3.0	1.44	1.36	0.45	0.45	2.20	2.14
PDA	2.0	-1.12	-0.94	-0.31	-0.28	-0.36	-0.28
EOD	2.5	-0.47	-0.38	0.00	0.01	0.29	0.29
N@Toe>40	3.0	0.05	0.08	0.24	0.25	0.82	0.75
PDA	2.0	0.26	0.27	-0.20	-0.18	1.24	1.21
EOD	2.5	0.70	0.68	0.14	0.15	1.54	1.51
All	3.0	1.04	1.01	0.42	0.42	1.79	1.75
PDA	2.0	1.58	1.44	0.72	0.68	2.38	2.31
BOR	2.5	2.17	1.97	1.29	1.19	2.71	2.63
N@Toe<=40	3.0	2.66	2.40	1.75	1.60	2.98	2.89
PDA	2.0	0.91	0.94	0.23	0.01	2.89	2.80
BOR	2.5	1.17	1.40	0.50	0.37	3.22	3.11
N@Toe>40	3.0	1.34	1.78	0.68	0.66	3.48	3.37
PDA	2.0	1.55	1.39	1.01	0.91	2.47	2.39
BOR	2.5	2.18	1.95	1.66	1.48	2.81	2.71
All	3.0	2.69	2.40	2.19	1.94	3.08	2.98
Static Load Tests	2.0	1.15	1.09				
	2.5	1.65	1.54				
	3.0	2.05	1.91				

As for the Vesic method, there are large variations in the reliability indexes between the PDA EOD and the PDA BOR and between the shaft and toe resistances. Clearly the PDA restrike (BOR) data show a much higher reliability than the PDA initial driving (EOD) data. The reliability indexes from the static load test data are about 1.1 for FS of 2, 1.5 for FS of 2.5, and 1.9 for FS of 3; which are a little less than those from the PDA BOR data. As expected, the reliability indexes reflect the bias factor statistics shown in Table 4-3. The reliability indexes from the PDA EOD N@Toe>40 database are unrealistically low, reflecting the extremely low means and the large COV's of the bias factors in Table 4-3. The reliability indexes for the shaft capacity are all very low, which implies that the Nordlund method overpredicts the shaft resistance of coastal concrete square piles. The difference in the computed reliability indexes between AFOSM and MVFOSM is relatively small in this category. On the average, AFOSM shows 3%, 0%, and 2% higher than MVFOSM for the total, shaft, and toe capacity, respectively.

<u>Coastal Steel HP Piles:</u>

Table 4-20 shows the reliability indexes computed for the four different databases available for this category. There is a large increase in the reliability indexes between the PDA EOD and the PDA BOR, especially for the shaft resistance. This is probably due to a much larger set-up in the shaft resistance than in the toe resistance from the PDA restrike. The reliability indexes for the shaft and toe resistances are quite different between N@Toe<=40 and N@toe>40 of the PDA EOD databases: the reliability indexes from the N@Toe<=40 database show larger values for the toe than the shaft, whereas, the N@Toe>40 database resulted in larger reliability indexes for the shaft than for the toe.

This is consistent with the bias factor statistics shown in Table 4-4. On the average, AFOSM resulted in a higher reliability index than MVFOSM by about 8% for the total capacity, 8% for the shaft, and 1% for the toe capacity. The reliability indexes for the total capacity range from 1.0 to 3.3 for FS of 2, 1.4 to 3.9 for FS of 2.5, and 1.8 to 4.5 for FS of 3.

Table 4-20. Summary of Reliability Analyses: C-S-HP, Nordlund

Nordlund Method		Total		Shaft		Toe	
Coastal Steel HP Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	1.06	1.02	0.69	0.64	2.45	2.41
EOD	2.5	1.51	1.43	1.27	1.17	2.69	2.65
N@Toe<=40	3.0	1.86	1.77	1.76	1.60	2.89	2.84
PDA	2.0	1.61	1.49	1.26	1.21	0.66	0.65
EOD	2.5	2.15	1.98	1.71	1.62	1.00	0.98
N@Toe>40	3.0	2.59	2.38	2.06	1.95	1.28	1.25
PDA	2.0	1.31	1.25	0.90	0.86	1.50	1.49
EOD	2.5	1.82	1.70	1.38	1.30	1.70	1.69
All	3.0	2.21	2.07	1.78	1.67	1.87	1.85
PDA	2.0	3.27	2.88	2.69	2.42	2.37	2.34
BOR	2.5	3.92	3.45	3.29	2.95	2.59	2.56
All	3.0	4.46	3.92	3.77	3.39	2.77	2.73

Coastal Steel Pipe Piles:

Table 4-21 shows the reliability indexes computed for the two databases available for this category. There is a large increase in the reliability indexes between the PDA EOD and the PDA BOR for the shaft capacities, which reflects the set-up effects. But the PDA BOR database gives much lower reliability indexes for the toe capacity than the PDA EOD. This probably implies that the toe capacity was not fully mobilized during the PDA restrikes. On the average, AFOSM resulted in a higher reliability index than

MVFOSM by about 11% for the total capacity, 14% for the shaft capacity, and 2% for the toe capacity. The reliability indexes for the total capacity range from 1.1 to 2.1 for FS of 2, 1.6 to 2.8 for FS of 2.5, and 2.0 to 3.4 for FS of 3. These reliability indexes are generally lower than those for the Vesic method by a considerable margin.

Table 4-21. Summary of Reliability Analyses: C-S-PP, Nordlund

Nordlund		Total		Shaft		Toe	
Coastal Steel Pipe Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	1.20	1.14	0.62	0.59	1.87	1.81
EOD	2.5	1.70	1.59	1.11	1.05	2.23	2.16
All	3.0	2.10	1.96	1.53	1.43	2.53	2.44
PDA	2.0	2.08	1.80	3.08	2.53	0.37	0.37
BOR	2.5	2.82	2.42	3.93	3.21	0.72	0.71
All	3.0	3.42	2.92	4.62	3.77	1.00	0.98

Coastal Concrete Cylinder Piles:

Table 4-22 shows the reliability indexes computed for the two databases available for this category. All of the reliability indexes computed for this category are extremely low and unrealistic, reflecting the extremely low mean values and the variances of the bias factors shown in Table 4-6. Also, the PDA database size is not large enough to provide reliable resistance statistics. The reliability indexes presented in Table 4-22 suggest that the Nordlund method should not be used for the static capacity estimate of the concrete cylinder piles, unless a significant modification is made in the method.

Table 4-22. Summary of Reliability Analyses: C-C-CL, Nordlund

Nordlund Method		Total		Shaft		Toe	
Coastal Concrete Cylinder Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	-3.21	-2.20	-3.26	-2.13	-4.06	-2.64
EOD	2.5	-2.12	-1.57	-1.98	-1.36	-2.92	-2.05
All	3.0	-1.31	-1.06	-1.00	-0.73	-2.06	-1.56
Static Load Tests	2.0	-0.18	-0.16				
	2.5	0.12	0.13				
	3.0	0.36	0.37				

Piedmont Concrete Square Piles:

There is only one database available for this category's reliability analysis as shown in Table 4-23. The computed reliability indexes reflect the bias factor statistics shown in Table 4-7; the reliability indexes for the total capacity are larger than those for the shaft and toe capacities. This is probably due to the averaging effects in the total capacity variations by combining the variations of the shaft and toe capacities. The difference in the computed reliability indexes between AFOSM and MVFOSM is also much more significant for the total capacity than for the shaft or toe capacity.

Table 4-23. Summary of Reliability Analyses: P-C-SQ, Nordlund

Nordlund Method		Total		Shaft		Toe	
Piedmont Concrete Square Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	3.45	2.93	2.56	2.37	1.62	1.59
EOD	2.5	4.22	3.57	3.11	2.86	1.98	1.93
All	3.0	4.85	4.09	3.56	3.27	2.28	2.21

On the average, AFOSM resulted in a higher reliability index than MVFOSM by 18% for the total capacity, 9% for the shaft capacity, and 3% for the toe capacity.

Piedmont Steel HP Piles:

Two databases are available for this category's reliability analysis as shown in Table 4-24. The computed reliability indexes reflect the bias factor statistics shown in Table 4-8. Contrary to the Vesic method, the reliability indexes for the toe capacity are much larger than those for the shaft capacities because of the much less COV of the shaft capacity than COV of the toe capacity. The difference in the computed reliability indexes between AFOSM and MVFOSM is also much more significant for the shaft capacity than for the toe capacity. The reliability indexes for the total capacity range from 1.0 to 1.3 for FS of 2, 1.2 to 1.7 for FS of 2.5, and 1.3 to 2.1 for FS of 3.

Table 4-24. Summary of Reliability Analyses: P-S-HP, Nordlund

Nordlund Method		Total		Shaft		Toe	
Piedmont Steel HP Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA EOD All	2.0	1.05	1.01	0.55	0.55	1.32	1.32
	2.5	1.60	1.50	1.11	1.06	1.52	1.51
	3.0	2.05	1.91	1.58	1.47	1.67	1.66
Static Load Tests	2.0	1.03	1.29				
	2.5	1.19	1.69				
	3.0	1.29	2.02				

4.6.4 Meyerhof Method

Coastal Concrete Square Piles:

Table 4-25 shows the reliability indexes computed for the six different databases available for this category. Overall, the Meyerhof method gives the largest reliability indexes for this category, followed by the Vesic method. Clearly the PDA restrike (BOR) data show a much higher reliability than the PDA initial driving (EOD) data. The reliability indexes from the static load test data are about 2.2 for FS of 2, 2.6 for FS of 2.5, and 2.9 for FS of 3; which are between those from the PDA EOD data and those from the PDA BOR data. As expected, the reliability indexes reflect the bias factor statistics shown in Table 4-3. The reliability indexes for the toe capacity from the PDA EOD N@Toe>40 database are very low, and it is probably because only a small percentage of the ultimate toe resistance was mobilized during the initial PDA operation of the many test piles.

Table 4-25. Summary of Reliability Analyses: C-C-SQ, Meyerhof

Meyerhof Method		Total		Shaft		Toe	
Coastal Concrete Square Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA EOD N@Toe<=40	2.0	1.92	1.83	1.36	1.32	1.80	1.83
	2.5	2.35	2.23	1.69	1.65	2.28	2.19
	3.0	2.71	2.56	1.97	1.91	2.59	2.48
PDA EOD N@Toe>40	2.0	0.41	0.40	1.69	1.60	-0.11	-0.07
	2.5	0.93	0.88	2.12	2.01	0.39	0.38
	3.0	1.36	1.26	2.47	2.34	0.80	0.76
PDA EOD All	2.0	1.53	1.46	1.38	1.34	1.43	1.39
	2.5	1.94	1.85	1.70	1.66	1.77	1.72
	3.0	2.29	2.17	1.96	1.91	2.05	1.99
PDA BOR N@Toe<=40	2.0	3.06	2.89	2.32	2.26	2.49	2.37
	2.5	3.51	3.30	2.63	2.56	2.90	2.76
	3.0	3.87	3.64	2.88	2.80	3.24	3.07
PDA BOR All	2.0	3.17	2.98	2.44	2.38	2.54	2.42
	2.5	3.63	3.40	2.76	2.68	2.96	2.81
	3.0	3.95	3.75	3.01	2.93	3.30	3.13
Static Load Tests	2.0	2.26	2.13				
	2.5	2.66	2.55				
	3.0	2.92	2.88				

The difference in the computed reliability indexes between AFOSM and MVFOSM is relatively small in this category. On the average, AFOSM shows 5%, 3%, and 1% higher than MVFOSM for the total, shaft, and toe capacity, respectively.

Coastal Steel HP Piles:

Table 4-26 shows the reliability indexes computed for the four different databases available for this category. As in the cases of both the Vesic method and the Nordlund method, there is a large increase in the reliability indexes between the PDA EOD and the PDA BOR, especially for the shaft resistance. This is probably due to a much larger set-up in the shaft resistance than in the toe resistance from the PDA restrike. As expected, the reliability indexes reflect the bias factor statistics shown in Table 4-4.

Table 4-26. Summary of Reliability Analyses: C-S-HP, Meyerhof

Meyerhof Method		Total		Shaft		Toe	
Coastal Steel HP Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	1.52	1.44	0.63	0.61	2.26	2.23
EOD	2.5	1.98	1.87	1.05	1.01	2.49	2.46
N@Toe<=40	3.0	2.35	2.22	1.37	1.33	2.68	2.64
PDA	2.0	1.36	1.17	0.15	0.16	1.21	1.18
EOD	2.5	2.13	1.81	0.89	0.79	1.55	1.51
N@Toe>40	3.0	2.75	2.33	1.50	1.30	1.83	1.78
PDA	2.0	1.19	1.12	0.51	0.50	1.48	1.46
EOD	2.5	1.68	1.58	0.94	0.91	1.76	1.73
All	3.0	2.09	1.95	1.29	1.24	1.99	1.95
PDA	2.0	2.07	1.88	1.78	1.61	2.53	2.49
BOR	2.5	2.65	2.40	2.38	2.15	2.75	2.72
All	3.0	3.13	2.83	2.88	2.58	2.94	2.90

The computed reliability indexes for the shaft capacity are relatively low, and it implies that the Meyerhof method overpredicts the shaft resistance. On the average, AFOSM resulted in a higher reliability index than MVFOSM by about 10% for the total capacity, 6% for the shaft, and 2% for the toe capacity. The reliability indexes for the total capacity range from 1.1 to 2.1 for FS of 2, 1.6 to 2.7 for FS of 2.5, and 2.0 to 3.1 for FS of 3.

<u>Coastal Steel Pipe Piles:</u>

Table 4-27 shows the reliability indexes computed for the two databases available for this category. There is a large increase in the reliability indexes between the PDA EOD and the PDA BOR for the total and shaft capacities, which reflects the large set-up effects. But the reliability indexes for the toe capacity are not much different between the EOD and the BOR. This probably implies that the toe capacity was not fully mobilized during the PDA restrikes. On the average, AFOSM resulted in a higher reliability index than MVFOSM by about 17% for the total capacity, 17% for the shaft capacity, and 3% for the toe capacity.

Table 4-27. Summary of Reliability Analyses: C-S-PP, Meyerhof

Meyerhof Method		Total		Shaft		Toe	
Coastal Steel Pipe Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	1.98	1.80	0.69	0.67	3.83	3.73
EOD	2.5	2.57	2.35	1.12	1.08	4.13	4.03
All	3.0	3.10	2.79	1.48	1.41	4.38	4.27
PDA	2.0	4.72	3.78	4.60	3.53	3.92	3.79
BOR	2.5	5.61	4.49	5.60	4.29	4.25	4.11
All	3.0	6.33	5.07	6.41	4.91	4.52	4.36

The reliability indexes for the total capacity range from 1.8 to 4.7 for FS of 2, 2.4 to 5.6 for FS of 2.5, and 2.8 to 6.3 for FS of 3. These reliability indexes are generally higher than those for the Nordlund method by a considerable margin, but similar to those for the Vesic method.

Coastal Concrete Cylinder Piles:

Table 4-28 shows the reliability indexes computed for the two databases available for this category. The reliability indexes for the toe capacity from the PDA EOD database are very low, as expected by the low mean and the large COV values of this database shown in Table 4-6. Also, the PDA database size is not large enough to provide reliable resistance statistics. The reliability indexes from the static load test data are 2.5 for FS of 2, 2.9 for FS of 2.5, and 3.2 for FS of 3, and these are more reliable than those from the PDA data. On the average, AFOSM shows about 4% higher reliability indexes than MVFOSM for the static load test database.

Table 4-28. Summary of Reliability Analyses: C-C-CL, Meyerhof

Meyerhof Method		Total		Shaft		Toe	
Coastal Concrete Cylinder Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA EOD All	2.0 2.5 3.0	3.08 4.21 5.14	2.25 3.06 3.72	2.66 2.93 3.14	2.61 2.87 3.08	0.49 0.67 0.79	0.35 0.67 0.94
Static Load Tests	2.0 2.5 3.0	2.48 2.86 3.17	2.38 2.74 3.03				

Piedmont Concrete Square Piles:

There is only one database available for this category's reliability analysis as shown in Table 4-29. The computed reliability indexes reflect the bias factor statistics shown in Table 4-7; the reliability indexes for the shaft capacity are larger than those for the toe capacity, and the reliability indexes for the total capacity are between the shaft and the toe. On the average, AFOSM resulted in a higher reliability index than MVFOSM by 3% for the total capacity, 4% for the shaft capacity, and 1% for the toe capacity.

Table 4-29. Summary of Reliability Analyses: P-C-SQ, Meyerhof

Meyerhof Method		Total		Shaft		Toe	
Piedmont Concrete Square Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	1.31	1.28	1.95	1.89	0.69	0.69
EOD	2.5	1.69	1.65	2.37	2.27	0.99	0.98
All	3.0	2.00	1.94	2.71	2.59	1.23	1.21

<u>Piedmont Steel HP Piles:</u>

Two databases are available for this category's reliability analysis as shown in Table 4-30. The computed reliability indexes reflect the bias factor statistics shown in Table 4-8. The reliability indexes for the shaft capacity are much larger than those for the toe capacities because of the much less COV of the shaft capacity than COV of the toe capacity. The difference in the computed reliability indexes between AFOSM and MVFOSM is also much more significant for the shaft capacity than for the toe capacity. On the average, AFOSM resulted in a higher reliability index than MVFOSM by 10% for the total capacity, 52% for the shaft capacity, and 1% for the toe capacity.

Table 4-30. Summary of Reliability Analyses: P-S-HP, Meyerhof

Meyerhof Method		Total		Shaft		Toe	
Piedmont Steel HP Piles	FS	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM	Reliability Index from AFOSM	Reliability Index from MVFOSM
PDA	2.0	2.66	2.28	3.32	2.23	1.65	1.64
EOD	2.5	3.43	2.92	4.74	3.10	1.86	1.85
All	3.0	4.07	3.44	5.91	3.81	2.03	2.02
Static Load Tests	2.0	2.26	2.16				
	2.5	2.64	2.54				
	3.0	2.89	2.86				

4.7 TARGET RELIABILITY INDEX (β_T)

The reliability analysis on the current design practice shows a large variation in the reliability index among the three different analysis methods and for the different pile types and regions. This indicates that the NCDOT's current practice of pile foundation design applies different levels of safety to the different design method, pile type, or region. The level of safety should be consistent in the LRFD-based pile foundation design, and a constant target reliability index should be used in the calibration of the resistance factors. Barker, el al. (1991b) selected β_T of 2.0 to 2.5 in their resistance factor calibration for driven piles, and Withiam, el al. (1998) confirmed that this range of target reliability index is reasonable for a single pile design considering that piles are usually used in groups. β_T of 2.0 to 2.5 is within a reasonable conformity with the reliability indexes evaluated for the current design practice. The reliability index of 2.0 to 2.5 corresponds to the probability of failure of approximately 0.1 (10%) to 0.01 (1%). This range of failure probability is acceptable for piles that are used in groups due to the redundancy in each pile's probability of failure. Thus, the target reliability indexes of 2.0 and 2.5 are selected for the calibration of the resistance factors in this study.

CHAPTER 5. CALIBRATION OF RESISTANCE FACTORS

5.1 INTRODUCTION

Information from load statistics, resistance statistics, and the reliability analysis are used for calibration process of resistance factors. Calibration is the process of assigning values to the resistance factors or the load factors. In this study, calibration was performed only for the resistance factors since predetermined load factors in the current AASHTO LRFD specifications will be used. This research was focused on developing the resistance factors in the LRFD approach of the axial capacity of driven piles. Calibration was performed based on the three static pile capacity analysis methods (Vesic, Nordlund, and Meyerhof) for each of the six categories of the resistance statistics: coastal concrete square pile, coastal steel HP pile, coastal steel pipe pile, coastal concrete cylinder pile, piedmont concrete square pile, and piedmont steel HP pile. The resistance factors for total, skin, and toe capacities were calibrated separately. Also, calibration was performed on every available database of the resistance statistics from the PDA initial driving (EOD), the PDA restrike (BOR), the static load test, and the Bayesian updating.

In chapter 4, two types of the first order reliability methods were utilized for the reliability analysis: MVFOSM and AFOSM. Results show some difference in the computed reliability indexes between the two methods. This warrants that the two methods be used for the calibration of the resistance factors. Calibration of the resistance factors was performed for two target reliability indexes of 2.0 and 2.5, using the two reliability methods. A brief description of each of the reliability method is presented below, followed by the results of the resistance factor calibration for the three pile bearing capacity analysis methods.

5.2 MVFOSM METHOD

The basic equation for LRFD was expressed as Equation 2-5 in Chapter 2 and is rewritten here in the following format.

$$\phi = \Sigma \gamma_i Q_i / R \tag{5-1}$$

The nominal resistance R can be replaced by the mean value ($\bar{R}$) and the resistance bias factor (λ_R). Then,

$$\phi = \frac{\lambda_R (\Sigma \gamma_i Q_i)}{\bar{R}} \tag{5-2}$$

From Equation 4-9, $\bar{R}$ can be replaced by the following equation.

$$\bar{R} = \frac{\bar{Q} \exp(\beta \sqrt{\ln[(1+COV_R^2)(1+COV_Q^2)]})}{\sqrt{(1+COV_Q^2)/(1+COV_R^2)}} \tag{5-3}$$

And Equation 5-2 can be rewritten in the following form.

$$\phi = \frac{\lambda_R (\Sigma \gamma_i Q_i) \sqrt{(1+COV_Q^2)/(1+COV_R^2)}}{\bar{Q} \exp(\beta \sqrt{\ln[(1+COV_R^2)(1+COV_Q^2)]})} \tag{5-4}$$

$\bar{Q}$ can be expressed in terms of nominal load (Q) and its bias factor (λ_Q), such that,

$\bar{Q} = \lambda_Q * Q$. We consider only the dead load and live load combination (Strength I case), and Equation 5-4 can be rewritten as:

$$\phi = \frac{\lambda_R (\gamma_{QD} QD + \gamma_{QL} QL) \sqrt{(1+COV_{QD}^2 + COV_{QL}^2)/(1+COV_R^2)}}{(\lambda_{QD} QD + \lambda_{QL} QL) \exp(\beta \sqrt{\ln[(1+COV_R^2)(1+COV_{QD}^2 + COV_{QL}^2)]})} \tag{5-5}$$

Dividing the numerator and the denominator by QL, and replacing β with the target reliability index β_T, Equation 5-5 becomes:

$$\phi = \frac{\lambda_R (\gamma_{QD} \frac{QD}{QL} + \gamma_{QL}) \sqrt{\frac{1 + COV_{QD}^2 + COV_{QL}^2}{1 + COV_R^2}}}{(\lambda_{QD} \frac{QD}{QL} + \lambda_{QL}) \exp\{\beta_T \sqrt{\ln[(1 + COV_R^2)(1 + COV_{QD}^2 + COV_{QL}^2)]}\}} \quad (5\text{-}6)$$

Equation 5-6 is then used for calibration of the resistance factors. It can be seen from this equation that the resistance factor is a function of the load statistics, the load factors, the resistance statistics, the dead load over live load ratio, and the target reliability index. All the elements of the information required for the resistance factor calibration are as presented in Chapter 4. Table 5-1 shows an example Excel spreadsheet that was used in the calculation of ϕ using Equation 5-6. The ratio of dead load over live load (QD/QL) varies with bridge span length as presented in the publication by Withiam, et al. (1998).

Table 5-1. MVFOSM Calibration for PDA BOR C-C-SQ, Vesic

Span (ft)	QD/QL	γ_D	γ_L	λ_{QD}	λ_{QL}	COV_{QD}	COV_{QL}	λ_R	COV_R	β_T	ϕ
30	0.5	1.25	1.75	1.08	1.15	0.13	0.18	0.94	0.29	2.00	0.634
60	1.0	1.25	1.75	1.08	1.15	0.13	0.18	0.94	0.29	2.00	0.607
90	1.5	1.25	1.75	1.08	1.15	0.13	0.18	0.94	0.29	2.00	0.590
120	2.0	1.25	1.75	1.08	1.15	0.13	0.18	0.94	0.29	2.00	0.579
150	2.5	1.25	1.75	1.08	1.15	0.13	0.18	0.94	0.29	2.00	0.571
200	3.5	1.25	1.75	1.08	1.15	0.13	0.18	0.94	0.29	2.00	0.560
250	4.3	1.25	1.75	1.08	1.15	0.13	0.18	0.94	0.29	2.00	0.555

5.3 AFOSM METHOD

The basic algorithm of the AFOSM for the resistance factor calibration is similar to that of the AFOSM reliability analysis presented in Chapter 4. The limit state function is defined as:

$$g = \ln R - \ln(\Sigma Q_i) = \ln \frac{R}{\Sigma Q_i} \tag{5-7}$$

If we consider only the dead and live loads, the limit state function can be rewritten in terms of the bias factors of the load and the resistance as follows:

$$g = \ln \frac{\lambda_R R}{\lambda_{QD} QD + \lambda_{QL} QL} \tag{5-8}$$

Equation 2-5 can be rewritten as follow in terms of the dead and live loads.

$$\phi\ R = \gamma_{QD}\ QD + \gamma_{QL}\ QL \tag{5-9}$$

Substituting R from Equation 5-9 into Equation 5-8 yields the following limit state function.

$$g = \ln \frac{\lambda_R (\gamma_{QD} QD + \gamma_{QL} QL)}{\phi(\lambda_{QD} QD + \lambda_{QL} QL)} \tag{5-10}$$

Divide the numerator and the denominator by QL and the Equation 5-10 becomes:

$$g = \ln \frac{\lambda_R (\gamma_{QD} QD / QL + \gamma_{QL})}{\phi(\lambda_{QD} QD / QL + \lambda_{QL})} \tag{5-11}$$

This is the limit state function used in the AFOSM calibration of the resistance factors. A computer program was developed on the MATLAB environment to facilitate the iteration process for the calculation of the resistance factors. The program output provides graphical data showing the relationship between the reliability indexes and the calibrated resistance factors. Three examples of AFOSM calibration output graphs are shown in Figures 5-1. The resistance factors corresponding to the target reliability indexes of 2.0 and 2.5 can be found by using the spline interpolant fitting method available in the EXCEL program. As shown in Table 5-1, the resistance factors do not vary significantly for the different bridge span lengths, and applying a different resistance factor for the different span length will be cumbersome in the pile foundation design practice. It was found that the bridge span lengths in the range of 90 feet are most frequently used in the NCDOT practice. The span length of 90 feet corresponds to the QD/QL ratio of 1.5. Therefore, it was determined that a single resistance factor based on QD/QL ratio of 1.5 will be recommended for all span lengths. The AFOSM calibration was carried out for QD/QL ratio of 1.5 only.

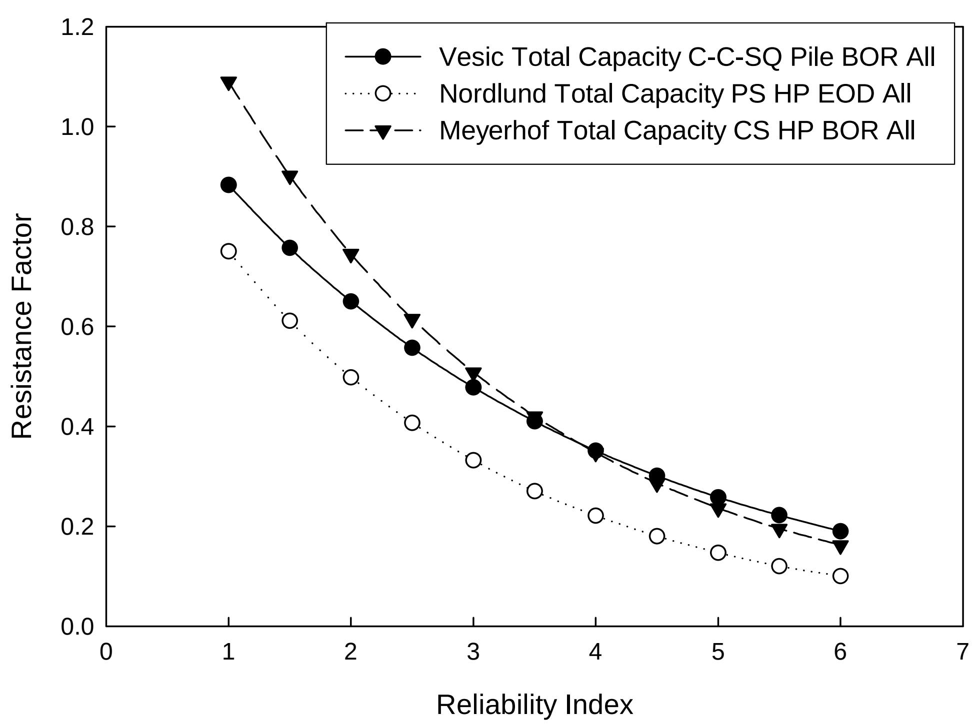

Figure 5-1. AFOSM Calibration Graphical Output

5.4 RESISTANCE FACTORS FOR THE VESIC METHOD

Coastal Concrete Square Piles:

Calibration was performed on the 10 cases of the resistance statistics for this category and the results are summarized in Table 5-2. The resistance statistics for this category are from 85 PDA EOD, 26 PDA BOR, and 22 static load test data. The PDA data were divided into N@Toe<=40 and N@Toe>40, as presented in Chapter 3. The resistance factors calibrated on the N@Toe<=40 data are somewhat larger than those calibrated on the N@Toe>40 data. Bayesian updating on the resistance statistics was also performed, as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-2. There is a significant difference in the resistance factors between the PDA EOD and the PDA BOR, which is consistent with the reliability analysis results presented in Chapter 4. As the PDA restrike (BOR) data are believed to represent the actual pile capacity more accurately than the PDA EOD data, and the database size (total 26) is large enough to draw a reliable statistics on the resistance, it is reasonable to select the resistance factors for this category based on the PDA BOR rather than the PDA EOD. The resistance factors for pile skin capacity are consistently larger than those for toe capacity. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 4% to 13%, except the small resistance factors for the toe capacity based on the PDA BOR N@Toe>40 data. The resistance factors for pile total capacity are in the range of 0.27 to 0.67 for β_T of 2.0, and 0.21 to 0.58 for β_T of 2.5.

Table 5-2. Resistance Factors for Coastal Concrete Square Piles (QD/QL = 1.5)

Vesic Method		Total		Skin		Toe	
Coastal Concrete Square Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD N@Toe<=40	2.0	0.43	0.40	0.37	0.35	0.34	0.32
	2.5	0.36	0.32	0.27	0.26	0.27	0.24
PDA EOD N@Toe>40	2.0	0.29	0.27	0.36	0.34	0.22	0.21
	2.5	0.23	0.21	0.28	0.26	0.18	0.16
PDA EOD ALL	2.0	0.39	0.36	0.37	0.34	0.29	0.27
	2.5	0.31	0.29	0.27	0.25	0.22	0.21
PDA BOR N@Toe<=40	2.0	0.67	0.61	0.90	0.85	0.25	0.24
	2.5	0.58	0.51	0.68	0.64	0.20	0.19
PDA BOR N@Toe>40	2.0	0.53	0.48	1.22	1.12	-0.06	0.08
	2.5	0.45	0.40	0.92	0.84	-0.09	0.05
PDA BOR ALL	2.0	0.65	0.59	0.92	0.87	0.29	0.28
	2.5	0.56	0.49	0.69	0.65	0.23	0.21
Bayesian N@Toe<=40	2.0	0.62	0.57				
	2.5	0.52	0.48				
Bayesian N@Toe>40	2.0	0.50	0.46				
	2.5	0.45	0.41				
Bayesian All	2.0	0.60	0.55				
	2.5	0.52	0.47				
Static Load Tests	2.0	0.55	0.50				
	2.5	0.47	0.42				

Coastal Steel HP Piles:

Calibration was performed on the seven cases of the resistance statistics for this category and the results are summarized in Table 5-3. The resistance statistics for this category are from 17 PDA EOD and 3 PDA BOR data. The PDA EOD data were divided into N@Toe<=40 and N@Toe>40 as presented in Chapter 3. The difference in the resistance factors between the N@Toe<=40 data and the N@Toe>40 data is not significant in this category. However, there is a significant difference in the resistance factors between the PDA EOD and the PDA BOR, which is consistent with the reliability analysis results presented in Chapter 4. Bayesian updating on the resistance statistics was also performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-3. The resistance factors calibrated on the updated resistance statistics are much closer to the factors from the PDA BOR data than those from the PDA EOD data. As the size of the PDA BOR database (total 3) is not large enough to draw a reliable statistics on the resistance, it is reasonable to combine the PDA EOD and BOR in the selection of the resistance factors for this category. The resistance factors for pile toe capacity are consistently larger than those for skin capacity. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 4% to 15%. The resistance factors for pile total capacity are in the range of 0.43 to 1.06 for β_T of 2.0, and 0.33 to 0.91 for β_T of 2.5.

Table 5-3. Resistance Factors for Coastal Steel HP Piles (QD/QL = 1.5)

Vesic Method		Total		Skin		Toe	
Coastal Steel HP Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD N@Toe<=40	2.0 2.5	0.48 0.38	0.45 0.35	0.35 0.26	0.33 0.24	0.75 0.56	0.71 0.53
PDA EOD N@Toe>40	2.0 2.5	0.53 0.46	0.48 0.40	0.30 0.22	0.28 0.21	0.37 0.27	0.35 0.26
PDA EOD ALL	2.0 2.5	0.46 0.36	0.43 0.33	0.34 0.25	0.32 0.23	0.50 0.36	0.47 0.34
PDA BOR ALL	2.0 2.5	1.06 0.91	0.99 0.84	0.99 0.87	0.92 0.80	1.33 0.82	1.27 0.78
Bayesian N@Toe<=40	2.0 2.5	1.01 0.86	0.93 0.79				
Bayesian N@Toe>40	2.0 2.5	0.86 0.78	0.78 0.68				
Bayesian All	2.0 2.5	0.97 0.85	0.91 0.78				

Coastal Steel Pipe Piles:

Calibration was performed on the three cases of the resistance statistics for this category and the results are summarized in Table 5-4. The resistance statistics for this category are from 7 PDA EOD and 15 PDA BOR data. Bayesian updating on the resistance statistics was also performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for the pile total capacity are included in Table 5-4. There is a significant difference in the resistance factors between the PDA EOD and the PDA BOR. However, there is no consistency in the change of the resistance factors for skin and toe capacities between the PDA EOD and BOR. The resistance factors calibrated on the Bayesian updated data are very close to those calibrated on the PDA BOR data. The calibrated resistance factors are relatively large, probably because of the fact that most of the PDA data were collected from the same project site and this resulted in relatively low variation in the resistance bias factors. The AFOSM analysis gave larger resistance factors than the MVFOSM analysis by about 5% to 12%. The resistance factors for pile total capacity are in the range of 0.65 to 1.33 for β_T of 2.0, and 0.51 to 1.16 for β_T of 2.5.

Table 5-4. Resistance Factors for Coastal Steel Pipe Piles (QD/QL = 1.5)

Vesic Method		Total		Skin		Toe	
Coastal Steel Pipe Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0	0.70	0.65	0.48	0.45	1.14	1.09
	2.5	0.55	0.51	0.38	0.35	0.83	0.79
PDA BOR ALL	2.0	1.33	1.21	1.07	0.98	0.81	0.77
	2.5	1.16	1.05	0.91	0.81	0.60	0.57
Bayesian All	2.0	1.31	1.20				
	2.5	0.87	0.79				

Coastal Concrete Cylinder Piles:

Calibration was performed on the three cases of the resistance statistics for this category and the results are summarized in Table 5-5. The resistance statistics for this category are from 3 PDA EOD and 5 static load test data. Bayesian updating on the resistance statistics was also performed, as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-5. The resistance factors calibrated on the Bayesian updated data appear to represent reasonably the resistance statistics of both the PDA data and the static load test data. The resistance factors for skin capacity are very large, while the resistance factors for toe capacity are extremely small. This implies that the Vesic method underestimates skin capacity and overestimates toe capacity of coastal concrete cylinder piles to a great degree. It is noted that the database of the resistance statistics for this category is relatively small. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 8% to 12%, except for toe capacity. The resistance factors for pile total capacity are in the range of 0.65 to 1.33 for β_T of 2.0, and 0.51 to 1.16 for β_T of 2.5.

Table 5-5. Resistance Factors for Coastal Concrete Cylinder Piles (QD/QL = 1.5)

Vesic Method		Total		Skin		Toe	
Coastal Conc Cylinder Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0	0.42	0.39	1.68	1.51	0.05	0.11
	2.5	0.37	0.34	1.50	1.34	-0.10	0.09
Static Load Tests	2.0	0.55	0.49				
	2.5	0.46	0.41				
Bayesian All	2.0	0.51	0.46				
	2.5	0.44	0.40				

Piedmont Concrete Square Piles:

There is only one case of the resistance statistics for this category, which was derived from six PDA EOD data. The calibrated resistance factors are shown in Table 5-6. The resistance factors for both skin and toe capacities are smaller than those for total capacity, which means that a reasonable combination of skin and toe resistance factors that is equivalent to a resistance factor for total capacity is not possible. It appears that the calibrated resistance factors are relatively large for the PDA EOD data. This is probably due to the small number of the data points for this category, which resulted in the low COV of the bias factors as shown in Table 4-7. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 5% to 11%. The resistance factors for pile total capacity are in the range of 0.81 to 0.89 for β_T of 2.0, and 0.70 to 0.78 for β_T of 2.5.

Table 5-6. Resistance Factors for Piedmont Concrete Square Piles (QD/QL = 1.5)

Vesic Method		Total		Skin		Toe	
Piedmont Concrete Square Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	0.89 0.78	0.81 0.70	0.52 0.37	0.49 0.34	0.31 0.23	0.29 0.22

Piedmont Steel HP Piles:

Calibration was performed on the two cases of the resistance statistics for this category and the results are summarized in Table 5-7. The resistance statistics for this category are from 5 PDA EOD and 3 static load test data. The resistance factors calibrated on the PDA data are very close to those calibrated on the static load test data, which eliminated the need for the Bayesian updating. It appears that the calibrated resistance factors are quite large for the PDA EOD data. This is probably due to the relatively small number of the data points for this category and the low COV of the bias factors as shown in Table 4-8. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 6% to 11%. The resistance factors for pile total capacity are in the range of 0.90 to 0.99 for β_T of 2.0, and 0.70 to 0.87 for β_T of 2.5.

Table 5-7. Resistance Factors for Piedmont Steel HP Piles (QD/QL = 1.5)

Vesic Method		Total		Skin		Toe	
Piedmont Steel HP Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	0.98 0.87	0.91 0.80	1.06 0.94	0.96 0.85	0.50 0.39	0.47 0.36
Static Load Tests	2.0 2.5	0.99 0.78	0.90 0.70				

5.5 RESISTANCE FACTORS FOR THE NORDLUND METHOD

Coastal Concrete Square Piles:

Calibration was performed on the 10 cases of the resistance statistics for this category and the results are summarized in Table 5-8. The resistance statistics for this category are from 85 PDA EOD, 26 PDA BOR, and 22 static load test data. The PDA data were divided into N@Toe<=40 and N@Toe>40, as presented in Chapter 3. The resistance factors calibrated on the N@Toe<=40 data are somewhat larger than those calibrated on the N@Toe>40 data. Bayesian updating on the resistance statistics was also performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-8. There is a significant difference in the resistance factors between the PDA EOD and the PDA BOR, which is consistent with the reliability analysis results presented in Chapter 4. As the PDA restrike (BOR) data are believed to represent the actual pile capacity more accurately than the PDA EOD data and the database size (total 26) is large enough to draw a reliable statistics on the resistance, it is reasonable to select the resistance factors for this category based on the PDA BOR rather than the PDA EOD. The resistance factors for pile toe capacity are consistently much larger than those for skin capacity. The AFOSM analysis gave larger resistance factors than the MVFOSM, but the percentage of increase varies from 0% to 11%. The resistance factors for pile total capacity are in the range of 0.22 to 0.64 for β_T of 2.0, and 0.18 to 0.54 for β_T of 2.5.

Table 5-8. Resistance Factors for Coastal Concrete Square Piles (QD/QL = 1.5)

Nordlund Method		Total		Skin		Toe	
Coastal Concrete Square Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD N@Toe<=40	2.0 2.5	0.37 0.29	0.34 0.26	0.18 0.12	0.17 0.12	0.57 0.40	0.54 0.37
PDA EOD N@Toe>40	2.0 2.5	0.24 0.20	0.22 0.18	0.14 0.10	0.13 0.09	0.32 0.27	0.29 0.24
PDA EOD ALL	2.0 2.5	0.30 0.23	0.28 0.21	0.17 0.12	0.16 0.12	0.43 0.29	0.40 0.27
PDA BOR N@Toe<=40	2.0 2.5	0.62 0.51	0.57 0.46	0.44 0.36	0.41 0.33	0.95 0.68	0.90 0.64
PDA BOR N@Toe>40	2.0 2.5	0.47 0.37	0.44 0.34	0.22 0.17	0.21 0.16	1.33 0.94	1.27 0.89
PDA BOR ALL	2.0 2.5	0.62 0.52	0.57 0.47	0.52 0.43	0.47 0.39	1.00 0.71	0.95 0.67
Bayesian N@Toe<=40	2.0 2.5	0.64 0.54	0.59 0.49				
Bayesian N@Toe>40	2.0 2.5	0.42 0.36	0.39 0.33				
Bayesian All	2.0 2.5	0.58 0.48	0.54 0.45				
Static Load Tests	2.0 2.5	0.49 0.39	0.47 0.37				

Coastal Steel HP Piles:

Calibration was performed on the seven cases of the resistance statistics for this category and the results are summarized in Table 5-9. The resistance statistics for this category are from 17 PDA EOD and 3 PDA BOR data. The PDA EOD data were divided into N@Toe<=40 and N@Toe>40, as presented in Chapter 3. The resistance factors from the PDA EOD N@Toe>40 data are larger than those from the N@Toe<=40 data for total and skin capacities for this category. Toe capacity has much smaller resistance factors from the N@Toe>40 data than from the N@Toe<=40 data. The resistance factors increase significantly from the PDA EOD data to the PDA BOR data. Bayesian updating on the resistance statistics was performed as presented in Chapter 4,

Table 5-9. Resistance Factors for Coastal Steel HP Piles (QD/QL = 1.5)

Nordlund Method		Total		Skin		Toe	
Coastal Steel HP Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD N@Toe<=40	2.0	0.45	0.43	0.44	0.41	1.10	1.06
	2.5	0.35	0.33	0.37	0.33	0.69	0.66
PDA EOD N@Toe>40	2.0	0.62	0.57	0.50	0.47	0.30	0.29
	2.5	0.50	0.46	0.39	0.35	0.21	0.20
PDA EOD ALL	2.0	0.53	0.50	0.44	0.41	0.44	0.41
	2.5	0.42	0.39	0.35	0.31	0.25	0.23
PDA BOR ALL	2.0	1.12	1.03	0.94	0.86	1.08	1.03
	2.5	0.94	0.85	0.78	0.70	0.64	0.61
Bayesian N@Toe<=40	2.0	0.93	0.89				
	2.5	0.78	0.74				
Bayesian N@Toe>40	2.0	0.99	0.92				
	2.5	0.84	0.78				
Bayesian All	2.0	0.97	0.90				
	2.5	0.83	0.75				

and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-9. The resistance factors calibrated on the updated resistance statistics are much closer to the factors from the PDA BOR data than those from the PDA EOD data. As the size of the PDA BOR database (total 3) is not large enough to draw a reliable statistics on the resistance, it is reasonable to combine the PDA EOD and BOR in the selection of the resistance factors for this category. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 3% to 13%. The resistance factors for pile total capacity are in the range of 0.43 to 1.12 for β_T of 2.0, and 0.33 to 0.94 for β_T of 2.5.

<u>Coastal Steel Pipe Piles:</u>

Calibration was performed on the three cases of the resistance statistics for this category and the results are summarized in Table 5-10. The resistance statistics for this category are from 7 PDA EOD and 15 PDA BOR data. Bayesian updating on the resistance statistics was performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-10. The resistance factors from the PDA BOR data are larger than those from the PDA EOD data for total and skin capacities for this category. However, toe capacity has much smaller resistance factors from the restrike data than from the PDA EOD data. The resistance factors calibrated on the Bayesian updated data are almost identical to those calibrated on the PDA BOR data. It is noted that most of the PDA data for this category were collected from the same project site and this resulted in relatively low variation in the resistance bias factors. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 5% to 14%. The resistance factors for pile total capacity are in the range of 0.47 to 0.75 for β_T of 2.0, and 0.37 to 0.65 for β_T of 2.5.

Table 5-10. Resistance Factors for Coastal Steel Pipe Piles (QD/QL = 1.5)

Nordlund Method		Total		Skin		Toe	
Coastal Steel Pipe Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0	0.51	0.47	0.39	0.37	0.69	0.65
	2.5	0.40	0.37	0.31	0.29	0.50	0.47
PDA BOR ALL	2.0	0.74	0.67	0.97	0.87	0.26	0.24
	2.5	0.64	0.56	0.83	0.74	0.19	0.17
Bayesian All	2.0	0.75	0.68				
	2.5	0.65	0.57				

Coastal Concrete Cylinder Piles:

Calibration was performed on the three cases of the resistance statistics for this category and the results are summarized in Table 5-11. The resistance statistics for this category are from 3 PDA EOD and 5 static load test data. Bayesian updating on the resistance statistics was performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-11. The resistance factors calibrated on the Bayesian updated data are slightly larger than those from both the PDA data and the static load test data. However, all of the resistance factors presented in Table 5-11 are very small, and the validity of the calibrated resistance factors for this category is questionable. Also, it is noted that the database of the resistance statistics for this category is relatively small. Comparison of the resistance factors between AFOSM and MVFOSM shows an interesting trend to note: The ϕ values from the AFOSM method are larger than those from the MVFOSM method for the MVFOSM ϕ values greater than or equal to 0.18. But, for the MVFOSM ϕ values less than 0.18, the AFOSM method gave a resistance factor smaller than or equal to that from the MVFOSM method. The resistance factors for pile total capacity are in the range of 0.14 to 0.20 for β_T of 2.0, and 0.09 to 0.16 for β_T of 2.5.

Table 5-11. Resistance Factors for Coastal Concrete Cylinder Piles (QD/QL = 1.5)

Nordlund Method		Total		Skin		Toe	
Coastal Conc Cylinder Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0	0.14	0.17	0.23	0.21	0.10	0.13
	2.5	0.10	0.14	0.20	0.18	0.06	0.10
Static Load Tests	2.0	0.14	0.14				
	2.5	0.09	0.09				
Bayesian All	2.0	0.20	0.19				
	2.5	0.16	0.16				

Piedmont Concrete Square Piles:

There is only one case of the resistance statistics for this category, which was derived from six PDA EOD data. The calibrated resistance factors are shown in Table 5-12. The resistance factors for both skin and toe capacities are smaller than those for total capacity, which means that a reasonable combination of skin and toe resistance factors that is equivalent to a resistance factor for total capacity is not possible. The calibrated resistance factors are very large considering that the calibration was based on the PDA EOD data. This implies that the Nordlund method underestimates the capacity of piedmont concrete square piles. The AFOSM analysis gave larger resistance factors than the MVFOSM analysis by about 5% to 14%. The resistance factors for pile total capacity are in the range of 1.00 to 1.11 for β_T of 2.0, and 0.84 to 0.96 for β_T of 2.5.

Table 5-12. Resistance Factors for Piedmont Concrete Square Piles (QD/QL = 1.5)

Nordlund Method		Total		Skin		Toe	
Piedmont Concrete Square Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	1.11 0.96	1.00 0.84	0.92 0.75	0.86 0.69	0.58 0.42	0.55 0.40

Piedmont Steel HP Piles:

Calibration was performed on the two cases of the resistance statistics for this category and the results are summarized in Table 5-13. The resistance statistics for this category are from 5 PDA EOD and 3 static load test data. The resistance factors calibrated on the PDA data are very close to those calibrated on the static load test data, which eliminated the need for the Bayesian updating. The resistance factors for both skin and toe capacities are smaller than those for total capacity, which means that a reasonable combination of skin and toe resistance factors that is equivalent to a resistance factor for total capacity is not possible. The AFOSM analysis resulted in larger resistance factors than the MVFOSM analysis by about 3% to 11%. The resistance factors for pile total capacity are in the range of 0.46 to 0.52 for β_T of 2.0, and 0.37 to 0.41 for β_T of 2.5.

Table 5-13. Resistance Factors for Piedmont Steel HP Piles (QD/QL = 1.5)

Nordlund Method		Total		Skin		Toe	
Piedmont Steel HP Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	0.50 0.41	0.46 0.37	0.41 0.34	0.39 0.31	0.34 0.19	0.33 0.18
Static Load Tests	2.0 2.5	0.52 0.40	0.49 0.37				

5.6 RESISTANCE FACTORS FOR THE MEYERHOF METHOD

Coastal Concrete Square Piles:

Calibration was performed on the 8 cases of the resistance statistics for this category and the results are summarized in Table 5-14. The resistance statistics for this category are from 85 PDA EOD, 26 PDA BOR, and 22 static load test data. The PDA EOD data were divided into N@Toe<=40 and N@Toe>40, as presented in Chapter 3. There is no N@Toe>40 case of the PDA BOR data for the Meyerhof method due to the insufficient amount of data points. The resistance factors calibrated on the PDA EOD N@Toe<=40 data case are larger than those calibrated on the N@Toe>40 data case for total and toe capacities. But, N@Toe<=40 data case resulted in smaller resistance factors than N@Toe>40 data case for skin capacity. Bayesian updating on the resistance statistics was also performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-14. There is a significant difference in the resistance factors between the PDA EOD and the PDA BOR, which is consistent with the reliability analysis results presented in Chapter 4. As the PDA restrike (BOR) data are believed to represent the actual pile capacity more accurately than the PDA EOD data and the data size (total 26) is large enough to draw a reliable statistics on the resistance, it is reasonable to select the resistance factors for this category based on the PDA BOR rather than the PDA EOD. The resistance factors calibrated on the static load test data case are a little larger than those from the PDA EOD data case, but much smaller than those from the PDA BOR data case. The AFOSM analysis resulted in larger resistance factors than the MVFOSM, with the percentage of increase varying from 4% to 15%. The resistance factors for pile total capacity are in the range of 0.34 to 1.28 for β_T of 2.0, and 0.27 to 0.98 for β_T of 2.5.

Table 5-14. Resistance Factors for Coastal Concrete Square Piles (QD/QL = 1.5)

Meyerhof Method		Total		Skin		Toe	
Coastal Concrete Square Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD N@Toe<=40	2.0 2.5	0.70 0.53	0.66 0.50	0.49 0.34	0.46 0.32	0.68 0.50	0.65 0.47
PDA EOD N@Toe>40	2.0 2.5	0.37 0.30	0.34 0.27	0.62 0.48	0.58 0.44	0.28 0.23	0.26 0.20
PDA EOD ALL	2.0 2.5	0.57 0.43	0.54 0.41	0.49 0.34	0.46 0.32	0.51 0.36	0.48 0.34
PDA BOR N@Toe<=40	2.0 2.5	1.24 0.96	1.18 0.90	0.93 0.65	0.88 0.61	0.95 0.72	0.89 0.67
PDA BOR ALL	2.0 2.5	1.28 0.98	1.23 0.94	1.01 0.69	0.96 0.66	0.98 0.74	0.93 0.70
Bayesian N@Toe<=40	2.0 2.5	1.02 0.82	0.97 0.77				
Bayesian All	2.0 2.5	0.92 0.72	0.88 0.69				
Static Load Tests	2.0 2.5	0.83 0.64	0.78 0.59				

Coastal Steel HP Piles:

Calibration was performed on the seven cases of the resistance statistics for this category and the results are summarized in Table 5-15. The resistance statistics for this category are from 17 PDA EOD and 3 PDA BOR data. The PDA EOD data were divided into N@Toe<=40 and N@Toe>40, as presented in Chapter 3. The resistance factors from the PDA EOD N@Toe>40 data case are close to those from the N@Toe<=40 data case for total and skin capacities for this category. Toe capacity has much smaller resistance factors from the N@Toe>40 data case than from the

N@Toe<=40 data case. The PDA BOR show larger resistance factors than the PDA EOD, most significantly for toe capacity. Bayesian updating on the resistance statistics was also performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-15. The resistance factors calibrated on the updated resistance statistics are almost identical to the factors from the PDA BOR data case. As the size of the PDA BOR data (total 3) is not large enough to draw a reliable statistics on the resistance, it is reasonable to combine the PDA EOD and BOR in the selection of the resistance factors for this category. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 4% to 13%. The resistance factors for pile total capacity are in the range of 0.47 to 0.78 for β_T of 2.0, and 0.37 to 0.64 for β_T of 2.5.

Table 5-15. Resistance Factors for Coastal Steel HP Piles (QD/QL = 1.5)

Meyerhof Method		Total		Skin		Toe	
Coastal Steel HP Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD N@Toe<=40	2.0	0.59	0.54	0.35	0.33	0.95	0.90
	2.5	0.45	0.42	0.27	0.25	0.58	0.55
PDA EOD N@Toe>40	2.0	0.60	0.54	0.42	0.38	0.45	0.42
	2.5	0.52	0.46	0.36	0.32	0.32	0.30
PDA EOD ALL	2.0	0.50	0.47	0.34	0.32	0.50	0.46
	2.5	0.40	0.37	0.26	0.24	0.34	0.31
PDA BOR ALL	2.0	0.75	0.69	0.67	0.61	1.25	1.20
	2.5	0.62	0.56	0.56	0.49	0.77	0.73
Bayesian N@Toe<=40	2.0	0.78	0.72				
	2.5	0.63	0.59				
Bayesian N@Toe>40	2.0	0.73	0.66				
	2.5	0.64	0.57				
Bayesian All	2.0	0.74	0.69				
	2.5	0.63	0.57				

Coastal Steel Pipe Piles:

Calibration was performed on the three cases of the resistance statistics for this category and the results are summarized in Table 5-16. The resistance statistics for this category are from 7 PDA EOD and 15 PDA BOR data. Bayesian updating on the resistance statistics was also performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-16. There is a significant increase in the resistance factors for total and skin capacities from the PDA EOD data to the PDA BOR data. However, there is little difference in the resistance factors for toe capacity between the PDA EOD and BOR. The resistance factors calibrated on the Bayesian updated data are very close to those calibrated on the PDA BOR data. As in the Vesic method, the calibrated resistance factors are very large, which indicates that both the Vesic and the Meyerhof methods underestimate the capacity of coastal steel pipe piles. It is noted that the skin capacity was estimated based on only the outside surface area of the steel pipe piles and the toe capacity was predicted without considering the effect of pile plugging for all the three static analysis methods used in this study. The large resistance factors are also due to the fact that most of the PDA data were collected from the same project site, and this resulted in relatively low variation in the resistance bias factors. The AFOSM analysis gave larger resistance factors than the MVFOSM analysis by about 3% to 13%. The resistance factors for pile total capacity are in the range of 0.67 to 1.38 for β_T of 2.0, and 0.54 to 1.19 for β_T of 2.5.

Table 5-16. Resistance Factors for Coastal Steel Pipe Piles (QD/QL = 1.5)

Meyerhof Method		Total		Skin		Toe	
Coastal Steel Pipe Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	0.73 0.61	0.67 0.54	0.37 0.29	0.36 0.27	2.85 1.97	2.65 1.82
PDA BOR ALL	2.0 2.5	1.38 1.19	1.27 1.09	1.25 1.08	1.14 0.98	2.72 1.92	2.55 1.79
Bayesian All	2.0 2.5	1.27 1.12	1.17 1.01				

Coastal Concrete Cylinder Piles:

Calibration was performed on the three cases of the resistance statistics for this category and the results are summarized in Table 5-17. The resistance statistics for this category are from 3 PDA EOD and 5 static load test data. Bayesian updating on the resistance statistics was also performed as presented in Chapter 4, and the resistance factors calibrated on the updated statistics for pile total capacity are included in Table 5-17. There is not much difference in the resistance factors calibrated from all the three cases. The resistance factors for skin capacity are very large, while the resistance factors for toe capacity are very small. This implies that the Meyerhof method underestimates skin capacity and overestimates toe capacity of coastal concrete cylinder piles to a great degree. It is noted that the database of the resistance statistics for this category is relatively small. The AFOSM analysis gave larger resistance factors than the MVFOSM by about 4% to 10%. The resistance factors for pile total capacity are in the range of 0.79 to 0.98 for β_T of 2.0, and 0.68 to 0.81 for β_T of 2.5.

Table 5-17. Resistance Factors for Coastal Concrete Cylinder Piles (QD/QL = 1.5)

Meyerhof Method		Total		Skin		Toe	
Coastal Conc Cylinder Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	0.86 0.76	0.79 0.69	1.29 0.85	1.22 0.80	0.24 0.17	0.23 0.16
Static Load Tests	2.0 2.5	0.98 0.72	0.92 0.68				
Bayesian All	2.0 2.5	0.91 0.81	0.84 0.74				

<u>Piedmont Concrete Square Piles:</u>

There is only one case of the resistance statistics for this category, which was derived from six PDA EOD data. The calibrated resistance factors are shown in Table 5-18. The resistance factors in this table are relatively small compare to the resistance factors calibrated for the Vesic and the Nordlund methods. This implies that the Meyerhof method overpredicts pile capacity to some degree, especially toe capacity. The AFOSM analysis gave larger resistance factors than the MVFOSM analysis by about 4% to 9%. The resistance factors for pile total capacity are in the range of 0.46 to 0.49 for β_T of 2.0, and 0.34 to 0.37 for β_T of 2.5.

Table 5-18. Resistance Factors for Piedmont Concrete Square Piles (QD/QL = 1.5)

Meyerhof Method		Total		Skin		Toe	
Piedmont Concrete Square Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	0.49 0.37	0.46 0.34	0.72 0.55	0.68 0.51	0.27 0.19	0.26 0.18

Piedmont Steel HP Piles:

Calibration was performed on the two cases of the resistance statistics for this category and the results are summarized in Table 5-19. The resistance statistics for this category are from 5 PDA EOD and 3 static load test data. The resistance factors calibrated with the PDA data are very close to those calibrated with the static load test data, which eliminated the need for the Bayesian updating. The resistance factors for both skin and toe capacities are smaller than those for total capacity, which means that a reasonable combination of skin and toe resistance factors that is equivalent to a resistance factor for total capacity is not possible. The AFOSM analysis gave larger resistance factors than the MVFOSM analysis by about 7% to 15%. The resistance factors for pile total capacity are in the range of 0.79 to 0.89 for β_T of 2.0, and 0.60 to 0.77 for β_T of 2.5.

Table 5-19. Resistance Factors for Piedmont Steel HP Piles (QD/QL = 1.5)

Meyerhof Method		Total		Skin		Toe	
Piedmont Steel HP Piles	β_T	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM	ϕ from AFOSM	ϕ from MVFOSM
PDA EOD ALL	2.0 2.5	0.89 0.77	0.79 0.67	0.87 0.76	0.78 0.68	0.53 0.31	0.49 0.29
Static Load Tests	2.0 2.5	0.86 0.68	0.79 0.60				

5.7 EFFECTS OF JETTING ON THE RESISTANCE FACTORS

As mentioned in Chapter 3, SPT N-value of one was assumed for the prediction of skin resistance for the section of piles installed with jetting. To evaluate the effects of jetting on the resistance factors for the coastal concrete square piles, the PDA/CAPWAP data were sub-grouped to piles driven with jetting and those driven without jetting. Statistical evaluation of the resistance bias factors for each subgroup was performed and the resistance factors were computed separately for the two subgroups using the MVFOSM method. Table 5-20 shows the effects of jetting on the calibrated resistance factors. In the table, ‘All’ means all the PDA/CAPWAP data points without consideration of jetting effects. ‘Jetting’ means the subgroup of the piles driven with jetting, and ‘No Jetting’ means the subgroup of the piles driven without jetting.

Generally the effect of jetting is not consistent for the three static pile capacity analysis methods, or for total, skin and toe capacities. For the Vesic method, the jetting effect on toe resistance is more significant than on skin resistance. The resistance factors for total capacity of the Vesic method show somewhat lower values for the jetting subgroup than for the no-jetting subgroup. One possible reason for the lower resistance factors for the jetting subgroup is higher model uncertainty and higher variation in the PDA capacity measurements due to inconsistent jetting operations. There has been no specific guidance for the jetting procedures in NCDOT, and the degree of disturbance of the surrounding soil by jetting varies widely from project to project depending on the individual contractor’s operation. The resistance factors for both skin and toe capacities of the Nordlund method show somewhat lower values for the jetting subgroup than for the no-jetting subgroup, except for toe capacity of the PDA BOR case. But the resistance factors for total capacity of the jetting subgroup are very close to those for ‘All’ data case. The Meyerhof method shows more inconsistency in the jetting effects on the resistance factors. For the two PDA EOD cases, the resistance factors for the jetting subgroup are lower than for the no-jetting subgroup. However, the opposite is true for the PDA BOR case.

Table 5-20. Jetting Effects on Resistance Factor

Resistance Factors are from MVFOSM Method for QD/QL = 1.5

Coastal Concrete Square Piles		Vesic			Nordlund			Meyerhof		
		Total	Skin	Toe	Total	Skin	Toe	Total	Skin	Toe
PDA EOD N@Toe<=40	All	0.40	0.35	0.32	0.34	0.17	0.54	0.66	0.46	0.65
	Jetting	0.35	0.31	0.17	0.33	0.09	0.47	0.68	0.50	0.63
	No Jetting	0.41	0.36	0.40	0.37	0.13	0.55	0.77	0.38	0.74
PDA EOD N@Toe>40	All	0.27	0.34	0.21	0.22	0.13	0.29	0.34	0.58	0.26
	Jetting	0.24	0.35	0.14	0.19	0.08	0.15	0.32	0.57	0.21
	No Jetting	0.36	0.17	0.40	0.30	0.16	0.36	0.52	0.98	0.44
PDA BOR ALL	All	0.59	0.87	0.28	0.57	0.47	0.95	1.23	0.96	0.93
	Jetting	0.52	1.04	0.17	0.55	0.31	0.95	1.61	1.49	1.05
	No Jetting	0.78	0.95	0.60	0.74	0.55	0.90	0.92	0.71	0.86

From the observations discussed above, it is concluded that the jetting effects on the resistance factors are not clear enough to warrant any adjustments in the calibrated resistance factors. More study on the effects of jetting on the pile bearing capacity and the resistance factors is recommended.

CHAPTER 6. COMPARISON OF ASD AND LRFD - EXAMPLES

Three design cases are selected to illustrate the Load and Resistance Factor Design (LRFD) procedure to determine the pile length for the required axial pile capacity in comparison with the Allowable Strength Design (ASD) procedure. All the three design cases are from the PDA data files complied for this study. A coastal concrete square pile for the Vesic method is presented below as Example 1. A piedmont concrete square pile for the Nordlund method is presented below as Example 2. And a coastal steel HP pile for the Meyerhof method is presented below as Example 3.

Example 1:

20” square concrete piles were designed to support the interior bents of the bridge in Dare County. The bridge span length was 90 feet, which corresponds to the dead load over live load ratio (QD/QL) of 1.5. The program PILECAP was used for the Vesic method to compute the bearing capacity of the pile for each pile length increment. The computer program output is included in Appendix A.

In ASD, assume FS = 2. The unfactored design load is given as 85 tons per pile. Then, the required ultimate pile capacity is 170 tons ($Q_{ULT} = Q_{DESIGN} \times FS$). From the PILECAP output in Appendix A, the required pile length is estimated as 29 feet.

In LRFD, assume $\beta_T = 2.0$. The recommended resistance factor is 0.6 for coastal concrete square piles with SPT N-value at toe of 23. The basic LRFD equation can be written as:

$$0.6\ R = 1.25\ QD + 1.75\ QL \qquad (6\text{-}1)$$

Since QD/QL = 1.5, QD = 1.5 QL, or QD = 0.6 Q and QL = 0.4 Q, where Q = QD + QL. Equation (6-1) can be rewritten as:

$$0.6\ R = 1.25\ (0.6\ Q) + 1.75\ (0.4\ Q) = 1.45\ Q$$

From this, R = $\frac{1.45Q}{0.6} = \frac{1.45*85}{0.6}$ = 205 tons. From the PILECAP output in Appendix A, the required pile length is estimated as 32 feet. The required pile length from LRFD is longer than that from ASD by three feet.

Example 2:

12" square concrete piles were designed to support the end bents of the bridge in Polk County (R-99BA). The bridge span length was 50 feet, which corresponds to the dead load over live load ratio (QD/QL) of 1.0. The program DRIVEN was used for the Nordlund method to compute the bearing capacity of the pile for each pile length increment. The computer program output is included in Appendix A.

In ASD, assume FS = 2. The unfactored design load is given as 50 tons per pile. Then, the required ultimate pile capacity is 100 tons ($Q_{ULT} = Q_{DESIGN}$ x FS). From the DRIVEN output in Appendix A, the required pile length is estimated as 28 feet.

In LRFD, assume $\beta_T = 2.0$. The recommended resistance factor is 0.9 for piedmont concrete square piles. The basic LRFD equation can be written as:

$$0.9\ R = 1.25\ QD + 1.75\ QL \qquad (6\text{-}2)$$

Since QD/QL = 1.0, QD = QL, or QD = 0.5 Q and QL = 0.5 Q, where Q = QD + QL. Equation (6-2) can be rewritten as:

$$0.6\ R = 1.25\ (0.5\ Q) + 1.75\ (0.5\ Q) = 1.5\ Q$$

From this, R = $\frac{1.5Q}{0.6}$ = $\frac{1.5*50}{0.6}$ = 83 tons. From the DRIVEN output in Appendix A, the required pile length is estimated as 28 feet. In this case, the estimated pile lengths by LRFD and ASD are the same.

Example 3:

HP 12x53 steel piles were designed to support the interior bent footings of the bridge in Onslow County. The bridge span length was 60 feet, which corresponds to the dead load over live load ratio (QD/QL) of 1.0. The Excel spreadsheet program was used for the Meyerhof method to compute the bearing capacity of the pile. The Excel spreadsheet output is included in Appendix A.

In ASD, assume FS = 2. The unfactored design load is given as 50 tons per pile. Then, the required ultimate pile capacity is 100 tons ($Q_{ULT} = Q_{DESIGN}$ x FS). From the Excel spreadsheet output in Appendix A, the required pile length is estimated as 60 feet.

In LRFD, assume β_T = 2.0. The recommended resistance factor is 0.65 for coastal steel HP piles. The basic LRFD equation can be written as:

$$0.65 \text{ R} = 1.25 \text{ QD} + 1.75 \text{ QL} \qquad (6\text{-}3)$$

Since QD/QL = 1.0, QD = QL, or QD = 0.5 Q and QL = 0.5 Q, where Q = QD + QL. Equation (6-3) can be rewritten as:

$$0.65 \text{ R} = 1.25 (0.5 \text{ Q}) + 1.75 (0.5 \text{ Q}) = 1.5 \text{ Q}$$

From this, R = $\frac{1.5Q}{0.65}$ = $\frac{1.5*50}{0.65}$ = 115 tons. The required pile length is estimated as 62 feet. The required pile length from LRFD is longer than that from ASD by two feet.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

Resistance factors for driven piles were developed using available databases of the resistance bias. For the categories of coastal concrete square piles and coastal steel HP piles, the resistance factors were evaluated separately for the two different subgroups based on the SPT N-value at the pile toe: N@Toe<=40 and N@Toe>40. For coastal steel HP piles, the difference in the calibrated resistance factors between the two subgroups is insignificant. Thus, only one set of the resistance factors is recommended for this category. For "coastal" concrete square piles, it is warranted to recommend a separate set of resistance factors for each N-value category. The effect of Jetting on coastal concrete square piles are not conclusive, thus at this time they are not considered in the selection of the recommended resistance factors.

The resistance factors were calibrated separately for total, skin and toe capacities in an attempt to develop a correlation between the three resistance factors for each design category. In many cases, however, the resistance factor for total capacity is larger than both the skin and toe resistance factors. Thus, the combination of the skin and toe resistance factors cannot produce the factored resistance equivalent to that by the total capacity resistance factor. One probable reason is the averaging effect of the variations in skin and toe capacities when they are combined for total pile capacity. Also, most of the driven piles develop both skin and toe resistances, but the percentage of skin or toe capacity to total capacity is not constant. For these reasons, the resistance factors for only total capacity are recommended.

This study considered seven design categories for which the resistance factors are recommended for each of the three static pile capacity analysis methods. These are coastal concrete square pile with N@Toe<=40, coastal concrete square pile with N@Toe>40, coastal steel HP pile, coastal steel pipe pile, coastal concrete cylinder pile, piedmont concrete square pile, and piedmont steel HP pile. The resistance factors calibrated in Chapter 5 are based on many different sizes of pile load test databases with different degrees of variety in pile sizes and lengths, test locations, and soil types. This variation in the databases is considered and some degree of judgment is exercised in the selection of the recommended resistance factors from the calibrated resistance factors for each design category. Calibration was performed using both the PDA EOD databases and the PDA BOR databases as well as the Bayesian updated databases, whenever the databases are available. The resistance factors calibrated using the static load test databases are compared with those calibrated using the PDA databases. All calibrated resistance factors are then considered in the selection of the recommended resistance factors for each design category.

For the coastal concrete square piles, the pile capacities measured in the PDA restrikes (BOR) appear to represent the ultimate pile capacity more accurately than those measured in the PDA initial driving (EOD) or even the static load tests (given that the static load tests were not normally carried to failure). In this case, the resistance factors calibrated using the PDA BOR databases are given more weight than those based on the PDA EOD or static load test databases. For the coastal steel HP piles, the increase in the calibrated resistance factors from PDA EOD to PDA BOR due to the capacity gain with time (setup) is significant. However, the PDA EOD databases are rather small and considered less reliable than the PDA EOD databases. The recommended resistance factors are selected by weighing the calibrated resistance factors from the two databases equally, though the resistance factors calibrated using the Bayesian updated databases are closer to those calibrated using the PDA BOR databases.

The setup effects for the coastal steel pipe piles are also significant. All but one PDA data for the coastal steel pipe piles are from the same project site, and this probably contributed to the resistance statistics for all the three static capacity analysis methods. More variation in the resistance bias factors is expected if the PDA data were from more diverse project sites, which would result in smaller resistance factors. The recommended resistance factors are selected conservatively considering this fact. The resistance factors for the coastal concrete cylinder piles are based on the least amount of the pile load test data, and therefore least reliable. The resistance factors calibrated for the Nordlund method are extremely small and are not recommended for practical use. The static load test data are considered more reliable than the PDA EOD data, and the recommended resistance factors for the Vesic and Meyerhof methods are selected based on the static load test data.

It is interesting to note that the calibrated resistance factors for the piedmont concrete square piles are quite small compared to those for other categories of the Meyerhof method or those for the same category of the Vesic and Nordlund methods. It is probably because of the large COV of the resistance bias factors as shown in Table 4-7.

AFOSM resulted in larger resistance factors than MVFOSM (by 4 to 15 percent for the total capacity.) Since AFOSM method is more accurate than MVFOSM method, the results from AFOSM are used in the selection of the recommended resistance factors. The resistance factors are recommended for the target reliability index (β_T) of 2.0 and

2.5, which corresponds to the approximate probability of failure of 10% and 1%, respectively.

Implementation

All the recommended resistance factors are rounded to the nearest 0.05 and summarized in Table 7-1. The implementation of the resistance factor should be at the discretion of NCDOT's engineers. It is advisable that during a transition phase, the design be conducted on the basis of, both, factor of safety determination and resistance factor implementation. The obtained pile length using each approach should be compared and extent of difference in results explained. Periodic updating of the resistance factors presented in Table 7-1 is recommended when more pile load test data become available. It is recommended that NCDOT engineers attend FHWA training courses on using LRFD for substructures/foundations and superstructures. The substructure course is available through FHWA's National Highway Institute (NHI).

Table 7-1. Recommended Resistance Factors

Pile Type and Region (Design Category)	Vesic		Nordlund		Meyerhof	
	$\beta_T = 2.0$	$\beta_T = 2.5$	$\beta_T = 2.0$	$\beta_T = 2.5$	$\beta_T = 2.0$	$\beta_T = 2.5$
Coastal Concrete Square Pile N@Toe<=40	0.60	0.50	0.55	0.45	0.90	0.70
Coastal Concrete Square Pile N@Toe>40	0.50	0.40	0.40	0.35	0.80	0.60
Coastal Steel HP Pile	0.75	0.65	0.80	0.70	0.65	0.55
Coastal Steel Pipe Pile	0.90	0.75	0.70	0.60	0.95	0.80
Coastal Concrete Cylinder Pile	0.50	0.45	0.15*	0.10*	0.90	0.75
Piedmont Concrete Square Pile	0.75	0.65	0.90	0.75	0.45	0.35
Piedmont Steel HP Pile	0.90	0.75	0.50	0.40	0.85	0.70

* These resistance factors are displayed for future reference only and are not recommended for practical use.

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APPENDIX A

Static Pile Capacity Analysis Example

The Vesic Method

The Nordlund Method

The Meyerhof Method

North Carolina Department of Transportation
Soils & Foundation Unit
Pile Bearing Capacity and Settlement Report
Project 8.2050301 (TIP No. B2024-B4) Dare County

Prepared By: Md. Sahadat Hossain **Station: 23+32.5** **09/10/2001**

Bridge over Colington Cut on SR 1217(b2024b4.pcd)

Input Data

Natural Ground:	1.000 ft	Cap Elevation:	1.000 ft	Water Table:	1.000 ft	Analysis Increment:	1.000 ft
No Cut/Fill/Scour adjustments				Design Load:	85.000 Tons		

Pile Data

Pile Type: 20" Square Concrete -- Square Concrete Pile

Perimeter:	6.667 ft	Area:	2.778 ft^2	Unit Weight:	0.150 K/ft^3
Moment of Inertia:	13333.000 in^4	Modulus of Elasticity:		4000.000 K/in^2	

Soil Data

Layer #	Top Elevation	Bottom Elevation	Soil Type	Analysis Method	Total Unit Weight	Av. BPF	Tip BPF	Pile Coeff.	Unit Shaft Resistance	Coeff. of Adhesion	Jetted or Driven
1	1.000 ft	-25.000 ft	Cohesionless	Vesic	0.120 K/ft^3	1 BPF	1 BPF	0.000	0.000 T/ft^2	0.000 T/ft^2	Jetted
2	-25.000 ft	-30.000 ft	Cohesionless	Vesic	0.120 K/ft^3	23 BPF	23 BPF	0.030	0.000 T/ft^2	0.000 T/ft^2	Driven
3	-30.000 ft	-35.000 ft	Cohesionless	Vesic	0.120 K/ft^3	33 BPF	33 BPF	0.030	0.000 T/ft^2	0.000 T/ft^2	Driven
4	-35.000 ft	-45.000 ft	Cohesionless	Vesic	0.120 K/ft^3	33 BPF	34 BPF	0.030	0.000 T/ft^2	0.000 T/ft^2	Driven

North Carolina Department of Transportation
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Pile Bearing Capacity and Settlement Report
Project 8.2050301 (TIP No. B2024-B4) Dare County

Prepared By: Md. Sahadat Hossain | Station: 23+32.5 | 09/10/2001

Tip Elevation	Shaft Length	Unit Shaft Resistance	Coefficient of Adhesion	Shaft Resistance	Total Shaft Resistance	Mean Normal Ground Stress	Bearing Factor	Tip Resistance	Total Resistance	Total Settlement
0.000 ft	1.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	0.840 T	0.022 T/ft²	48.897	3.006 T	3.846 T	N/A
-1.000 ft	2.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	1.680 T	0.044 T/ft²	46.913	5.767 T	7.447 T	N/A
-2.000 ft	3.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	2.520 T	0.066 T/ft²	45.697	8.426 T	10.947 T	N/A
-3.000 ft	4.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	3.360 T	0.089 T/ft²	44.806	11.016 T	14.376 T	N/A
-4.000 ft	5.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	4.200 T	0.111 T/ft²	44.098	13.553 T	17.753 T	N/A
-5.000 ft	6.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	5.040 T	0.133 T/ft²	43.507	16.045 T	21.086 T	N/A
-6.000 ft	7.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	5.880 T	0.155 T/ft²	42.999	18.501 T	24.381 T	N/A
-7.000 ft	8.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	6.720 T	0.177 T/ft²	42.552	20.924 T	27.644 T	N/A
-8.000 ft	9.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	7.560 T	0.199 T/ft²	42.152	23.318 T	30.879 T	N/A
-9.000 ft	10.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	8.400 T	0.221 T/ft²	41.790	25.687 T	34.087 T	N/A
-10.000 ft	11.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	9.240 T	0.243 T/ft²	41.459	28.031 T	37.272 T	N/A
-11.000 ft	12.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	10.081 T	0.266 T/ft²	41.153	30.354 T	40.435 T	N/A
-12.000 ft	13.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	10.921 T	0.288 T/ft²	40.869	32.657 T	43.577 T	N/A
-13.000 ft	14.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	11.761 T	0.310 T/ft²	40.603	34.940 T	46.701 T	N/A
-14.000 ft	15.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	12.601 T	0.332 T/ft²	40.354	37.206 T	49.807 T	N/A
-15.000 ft	16.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	13.441 T	0.354 T/ft²	40.119	39.455 T	52.896 T	N/A
-16.000 ft	17.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	14.281 T	0.376 T/ft²	39.896	41.689 T	55.969 T	N/A
-17.000 ft	18.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	15.121 T	0.398 T/ft²	39.111	43.273 T	58.393 T	N/A
-18.000 ft	19.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	15.961 T	0.420 T/ft²	38.914	45.446 T	61.407 T	N/A
-19.000 ft	20.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	16.801 T	0.443 T/ft²	38.726	47.607 T	64.407 T	N/A
-20.000 ft	21.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	17.641 T	0.465 T/ft²	37.973	49.015 T	66.656 T	N/A

North Carolina Department of Transportation
Soils & Foundation Unit
Pile Bearing Capacity and Settlement Report
Project 8.2050301 (TIP No. B2024-B4) Dare County

Prepared By: Md. Sahadat Hossain | Station: 23+32.5 | 09/10/2001

Tip Elevation	Shaft Length	Unit Shaft Resistance	Coefficient of Adhesion	Shaft Resistance	Total Shaft Resistance	Mean Normal Ground Stress	Bearing Factor	Tip Resistance	Total Resistance	Total Settlement
-21.000 ft	22.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	18.481 T	0.487 T/ft²	37.804	51.121 T	69.601 T	N/A
-22.000 ft	23.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	19.321 T	0.509 T/ft²	37.641	53.214 T	72.535 T	N/A
-23.000 ft	24.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	20.161 T	0.531 T/ft²	37.485	55.297 T	75.458 T	N/A
-24.000 ft	25.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	21.001 T	0.553 T/ft²	37.333	57.369 T	78.370 T	N/A
-25.000 ft	26.000 ft	0.126 T/ft²	0.000 T/ft²	0.840 T	21.841 T	0.575 T/ft²	37.187	59.430 T	81.271 T	N/A
-26.000 ft	27.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	26.695 T	0.532 T/ft²	89.557	132.257 T	158.952 T	0.305 in
-27.000 ft	28.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	31.550 T	0.551 T/ft²	89.161	136.548 T	168.098 T	0.277 in
-28.000 ft	29.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	36.404 T	0.571 T/ft²	88.777	140.815 T	177.219 T	0.250 in
-29.000 ft	30.000 ft	0.494 T/ft²	0.000 T/ft²	3.292 T	39.696 T	0.591 T/ft²	87.414	143.434 T	183.130 T	0.234 in
-30.000 ft	31.000 ft	0.494 T/ft²	0.000 T/ft²	3.292 T	42.989 T	0.610 T/ft²	87.056	147.610 T	190.598 T	0.215 in
-31.000 ft	32.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	49.656 T	0.596 T/ft²	120.189	198.994 T	248.650 T	0.148 in
-32.000 ft	33.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	56.323 T	0.615 T/ft²	119.702	204.381 T	260.704 T	0.126 in
-33.000 ft	34.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	62.990 T	0.633 T/ft²	119.228	209.740 T	272.729 T	0.105 in
-34.000 ft	35.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	69.657 T	0.652 T/ft²	118.663	214.920 T	284.576 T	0.085 in
-35.000 ft	36.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	76.324 T	0.672 T/ft²	117.114	218.555 T	294.879 T	0.065 in
-36.000 ft	37.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	82.991 T	0.688 T/ft²	119.076	227.523 T	310.514 T	0.046 in
-37.000 ft	38.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	89.658 T	0.708 T/ft²	117.567	231.105 T	320.762 T	0.043 in
-38.000 ft	39.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	96.325 T	0.727 T/ft²	116.113	234.641 T	330.965 T	0.046 in
-39.000 ft	40.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	102.992 T	0.747 T/ft²	113.411	235.436 T	338.427 T	0.050 in
-40.000 ft	41.000 ft	1.000 T/ft²	0.000 T/ft²	6.667 T	109.659 T	0.767 T/ft²	112.075	238.853 T	348.512 T	0.053 in
-41.000 ft	42.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	114.513 T	0.787 T/ft²	110.784	242.231 T	356.744 T	0.056 in

North Carolina Department of Transportation
Soils & Foundation Unit
Pile Bearing Capacity and Settlement Report
Project 8.2050301 (TIP No. B2024-B4) Dare County

Prepared By: Md. Sahadat Hossain **Station: 23+32.5** **09/10/2001**

Tip Elevation	Shaft Length	Unit Shaft Resistance	Coefficient of Adhesion	Shaft Resistance	Total Shaft Resistance	Mean Normal Ground Stress	Bearing Factor	Tip Resistance	Total Resistance	Total Settlement
-42.000 ft	43.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	119.367 T	0.807 T/ft²	109.535	245.569 T	364.936 T	0.058 in
-43.000 ft	44.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	124.221 T	0.827 T/ft²	108.326	248.870 T	373.091 T	0.061 in
-44.000 ft	45.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	129.076 T	0.847 T/ft²	107.154	252.134 T	381.210 T	0.064 in
-45.000 ft	46.000 ft	0.728 T/ft²	0.000 T/ft²	4.854 T	133.930 T	0.867 T/ft²	104.807	252.443 T	386.373 T	0.067 in

DRIVEN 1.0

GENERAL PROJECT INFORMATION

Filename: C:\DRIVEN1.1\R99BA.DVN
Project Name: R99 BA   Project Date: 09/25/2001
Project Client: NCDOT
Computed By: Md. Sahadat Hossain
Project Manager: KJK

PILE INFORMATION

Pile Type: Concrete Pile
Top of Pile: 0.00 ft
Length of Square Side: 12.00 in

ULTIMATE CONSIDERATIONS

Water Table Depth At Time Of:	- Drilling:	36.00 ft
	- Driving/Restrike	36.00 ft
	- Ultimate:	36.00 ft
Ultimate Considerations:	- Local Scour:	0.00 ft
	- Long Term Scour:	0.00 ft
	- Soft Soil:	0.00 ft

ULTIMATE PROFILE

Layer	Type	Thickness	Driving Loss	Unit Weight	Strength	Ultimate Curve
1	Cohesionless	11.00 ft	10.00%	120.00 pcf	29.4/28.8	Nordlund
2	Cohesionless	17.00 ft	10.00%	120.00 pcf	31.1/30.4	Nordlund
3	Cohesionless	10.00 ft	10.00%	120.00 pcf	30.5/30.3	Nordlund
4	Cohesionless	6.00 ft	10.00%	120.00 pcf	30.7/30.9	Nordlund
5	Cohesionless	4.00 ft	10.00%	120.00 pcf	30.2/30.1	Nordlund

ULTIMATE - SKIN FRICTION

Depth	Soil Type	Effective Stress At Midpoint	Sliding Friction Angle	Adhesion	Skin Friction
0.01 ft	Cohesionless	0.60 psf	22.57	N/A	0.00 Kips
9.01 ft	Cohesionless	540.60 psf	22.57	N/A	7.69 Kips
10.99 ft	Cohesionless	659.40 psf	22.57	N/A	11.45 Kips
11.01 ft	Cohesionless	1320.60 psf	23.82	N/A	11.49 Kips
20.01 ft	Cohesionless	1860.60 psf	23.82	N/A	43.07 Kips
27.99 ft	Cohesionless	2339.40 psf	23.82	N/A	86.39 Kips
28.01 ft	Cohesionless	3360.60 psf	23.37	N/A	86.51 Kips
35.99 ft	Cohesionless	3839.40 psf	23.37	N/A	140.35 Kips
36.01 ft	Cohesionless	4320.29 psf	23.37	N/A	140.50 Kips
37.99 ft	Cohesionless	4377.31 psf	23.37	N/A	155.73 Kips
38.01 ft	Cohesionless	4435.49 psf	23.57	N/A	155.89 Kips
43.99 ft	Cohesionless	4607.71 psf	23.57	N/A	205.84 Kips
44.01 ft	Cohesionless	4781.09 psf	23.15	N/A	206.01 Kips
47.99 ft	Cohesionless	4895.71 psf	23.15	N/A	239.03 Kips

ULTIMATE - END BEARING

Depth	Soil Type	Effective Stress At Tip	Bearing Cap. Factor	Limiting End Bearing	End Bearing
0.01 ft	Cohesionless	1.20 psf	25.54	13.32 Kips	0.02 Kips
9.01 ft	Cohesionless	1081.20 psf	25.54	13.32 Kips	13.32 Kips
10.99 ft	Cohesionless	1318.80 psf	25.54	13.32 Kips	13.32 Kips
11.01 ft	Cohesionless	1321.20 psf	32.33	16.61 Kips	16.61 Kips
20.01 ft	Cohesionless	2401.20 psf	32.33	16.61 Kips	16.61 Kips
27.99 ft	Cohesionless	3358.80 psf	32.33	16.61 Kips	16.61 Kips
28.01 ft	Cohesionless	3361.20 psf	31.81	15.87 Kips	15.87 Kips
35.99 ft	Cohesionless	4318.80 psf	31.81	15.87 Kips	15.87 Kips
36.01 ft	Cohesionless	4320.58 psf	31.81	15.87 Kips	15.87 Kips
37.99 ft	Cohesionless	4434.62 psf	31.81	15.87 Kips	15.87 Kips
38.01 ft	Cohesionless	4435.78 psf	34.55	19.74 Kips	19.74 Kips
43.99 ft	Cohesionless	4780.22 psf	34.55	19.74 Kips	19.74 Kips
44.01 ft	Cohesionless	4781.38 psf	30.76	14.39 Kips	14.39 Kips
47.99 ft	Cohesionless	5010.62 psf	30.76	14.39 Kips	14.39 Kips

ULTIMATE - SUMMARY OF CAPACITIES

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 Kips	0.02 Kips	0.02 Kips
9.01 ft	7.69 Kips	13.32 Kips	21.01 Kips
10.99 ft	11.45 Kips	13.32 Kips	24.77 Kips
11.01 ft	11.49 Kips	16.61 Kips	28.10 Kips
20.01 ft	43.07 Kips	16.61 Kips	59.68 Kips
27.99 ft	86.39 Kips	16.61 Kips	103.00 Kips
28.01 ft	86.51 Kips	15.87 Kips	102.38 Kips
35.99 ft	140.35 Kips	15.87 Kips	156.22 Kips
36.01 ft	140.50 Kips	15.87 Kips	156.38 Kips
37.99 ft	155.73 Kips	15.87 Kips	171.61 Kips
38.01 ft	155.89 Kips	19.74 Kips	175.64 Kips
43.99 ft	205.84 Kips	19.74 Kips	225.58 Kips
44.01 ft	206.01 Kips	14.39 Kips	220.40 Kips
47.99 ft	239.03 Kips	14.39 Kips	253.42 Kips

SPT (MEYERHOF) DESIGN METHODOLOGY

Soils&Foundation Unit

Pile Bearing Capacity Data (To be used with Meyerhof Method)

57_Project 6.269002T (TIP No. R2406B) Onslow County

Station 609+23

i=layer #	1	2	3	4	5	6	7	8			Tip
Pile Installation Type*	1	1	1	1	1	1	1	1			1
γ(i), unit weight, kcf	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06			0.06
d(i), depth of each layer, ft	1	3.5	7.5	5	4	10	31	2.5			10
N(i), uncorrected SPT blow count in the layer	4	4	10	11	5	17	1	100			75
P(i), perimeter of pile, ft	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8			
L(i), length of the pile segment in the layer, ft	0	0	7.5	5	4	10	31	2.5			
Type of Soil**	1	1	2	1	2	1	2	1			1
Type of Pile Material (For Cohesive Soils)***			3		3		3				
Po(i), effective overburden in the middle of each layer, Tsf	0.03	0.11	0.28	0.47	0.60	0.81	1.43	1.93	1.97	1.97	1.97
N(i), uncorrected SPT blow count in the layer	4	4	10	11	5	17	1	100	1	1	
N'(i), average corrected SPT blow count in the layer	8	7	14	14	6	18	1	78	1	1	58
fs, Average unit skin friction in a particaler layer, tsf	0.16	0.14	0.29	0.28	0.12	0.36	0.02	1.00	0.01	0.01	
Qs, the skin friction in a particular layer, tons, (If Cohesionless)	0.00	0.00	0.00	8.03	0.00	21.14	0.00	14.50	0.00	0.00	
c, Cohesion, psf	400	400	1000	1100	500	0	100	0	0	0	
Qs, the skin friction in a particular layer, tons, (If Cohesive)	0.00	0.00	16.31	0.00	5.51	0.00	8.99	0.00	0.00	0.00	
TOTAL SKIN RESISTANCE, tons	74.48										

Effective Overburden Pressure Calculation : If depth of water table is more than the depth of a certain layer, Normal unit weight of that layer will be used in calculation. Otherwise, Effective unit weight will be used.

***** *1=Driven Displacement, 2=Driven Non-Displacement*

*** 1=Cohesionless or Stiff Clay, 2=Soft Clay*

**** 3=Steel Piles, 4=Timber and Concrete Piles*

TIP RESISTANCE CALCULATION

Ap, Area of Pile Tip, ft^2	0.1076365
Type of Soil****	2
ϕ, Angle of Internal Friction, degree	44.46
ql, Ultimate Tip Resistance, tsf	232.8
qpl, Limiting Unit Point Resistance, tsf	415.5
Qtip, Ultimate Tip Capacity, tons	25.05

*****1= Non-plastic Silts, 2=Sands or Gravels*

SUMMARY	
Qskin, tons	74
Qtip, tons	25
Qultimate, tons	100

APPENDIX B

PDA/CAPWAP Data Summary Sheets

TOTAL PDA/CAPWAP DATA SUMMARY

File No.	TIP NO.	Project No.	Bridge	County	Bent / Pile	Pile Type	Pile Length	Hammer	Test Date	Design	Total Ru	Skin Rs	Toe Rt	Comments
			Station				feet			Load (Ton)	Ton	Ton	Ton	
1 (S6)	B-900	8.1090201	46+92 -L-	Martin	Bent-8, Pile #8	20" PCP	62(57)	Kobe K-22	1988-7-28	100	116	35	81	Initial
				/Bertie					1988-8-2		206	125	81	Restrike
2	B-910	8.2830201	5+17.63 -L-	Lincoln	Bent-2	12" PCP	30(19)	Delmag D-12	1988-6-16	30	66	37	29	
3	B-1097	8.1161403	327+65 -L-	Carteret	Bent 2	20" PCP	65(46)	Delmag D46-23	1991-12-19	55	156	117	39	
4A (S2)	B-1098	8.1161601	34+00 -L-	Carteret		24" PCP	80(73)	Conmaco 160	1992-11-24	100	107	30	77	Initial
									1992-12-7		218	106	112	Restrike
4B	B-1098	8.1161601	21+94	Carteret	Bent-4	24" PCP	85(70)	Conmaco 160	1993-6-9	100	417	128	289	
4C (S3)	B-1098	8.1161601	40+15	Carteret	TP #1	20" PCP	65(41)	Conmaco 160	1992-12-28	100	220	157	63	Initial
									1993-1-13		226	161	65	Restrike
5	B-1098	8.1161601	19+84.96	Carteret	EB-1	12" PCP	35(35)	Conmaco 160	1994-3-7	50	117	25	92	

6	B-1098	8.1161601	27+36	Carteret	Bent-12	24" PCP	80(57)	Conmaco 160	1993-4-8	100	210	18	192	
7	B-1098	8.1161601	35+90	Carteret	Bent-20	24" PCP	80(57)	Conmaco 160	1993-8-17	100	425	102	323	
8	B-1098	8.1161601	43+98	Carteret	Bent-28	24" PCP	80(60)	Conmaco 160	1993-10-14	100	218	20	198	
9	B-1098	8.1161601	48+41	Carteret	Bent-35	24" PCP	65(50)	Conmaco 160	1993-10-13	100	216	51	165	
10	B-1200	8.1060101	13+21.92	Gates	EB-2	HP 12x53	40(36)	Delmag D-22	1992-10-16	40	87	62	25	Initial
									1992-10-19		134	108	26	Restrike
11	B-1231	8.1070401	23+45.48	Hertford	Bent-1, Pile #9	20" PCP	75(34)	Mitsubishi	1998-12-2	85	91	22	69	Initial
								M-33	1998-12-9		167	23	144	Restrike
12	B-1258	8.1190201	17+50.5 -L-	Jones	Bent-1	20" PCP	45(11)	DE-70/50B	1993-2-10	60	188	29	159	
13	B-1260	8.2190201	34+68.5	Jones	Bent-2, Pile #3	20" PCP	51(36)	MKT DE-70B	1993-5-17	80	127	46	81	
14	B-1260	8.2190201	34+68.5	Jones	Bent-2, Pile #2	20" PCP	51(30)	MKT DE-70B	1993-5-12	80	138	95	43	
15	B-1286	8.2560301	18+07	Moore	Bent-2	20" PCP	40(24)	FEC	1993-4-20	65	241	152	89	
16	B-1293	8.1320401	39+65 L	Nash/	EB-2	HP 12x53	100(70)	Delmag D-8/22	1992-2-28	50	94	80	14	
				Edgecombe										
17	B-1296	8.1250201	40+52	New	Bent-2	20" PCP	55(45)	Kobe K-22	1988-8-11	60	286	113	173	

18	B-1296	8.1250201	40+52	Hanover	Bent-6	20" PCP	49(25)	Kobe K-22	1988-8-12	60	271	86	185	
19 (S17)	B-1310	8.2260101	21+90	Onslow		24" PCP	65(35)	Delmag D-22	1988-3-14	80	285	46	239	
20	B-1343	8.1461201	17+74	Robeson	Bent-1, Pile #3	20" PCP	35(12)	MKT	1993-1-19	60	122	22	100	
21	B-1380	8.1280501	15+42 -L-	Sampson	EB-1, Pile #1	12" PCP	30(18)	MKT-30B	1987-7-21	45	100	44	56	
22	B-2024	8.2050301	23+32.5	Dare	BR #5, Bent-4	20" PCP	48(30)	Mitsubishi	1994-3-16	85	215	52	163	
23	B-2024	8.2050301	61+60	Dare	BR #6	20" PCP	80(50)	M-33	1993-1-12	85	389	72	317	
24	B-2054	8.2190301	17+31	Jones	Bent-1	20" PCP	50(36)	MKT	1993-8-13	75	240	29	211	
				/Carteret				DE-50B						
25	B-2059	8.2250202	16+79.25	New	Bent-1	HP 14x73	50(35)	Kobe	1993-11-16	45	212	183	29	Restrike
				Hanover				K-13						
26 (S4)	B-2060	8.1260601	41+75	Onslow	Between	54" CCP	116(87)	Conmaco	1991-7-22	350	640	342	298	
					B-10 & B-11			C-300						
27	B-2060	8.1260601	43+26	Onslow	Bent-12	54" CCP	108(75)	Conmaco 300	1991-9-18	350	359	272	87	
28	B-2060	8.1260601	47+12	Onslow	Bent-16	20" PCP	62(53)	ICE 70S	1991-8-29	100	187	112	75	
29	Data Discarded													
30	B-2060	8.1260601	53+03.92	Onslow	Bent-23	20" PCP	57	ICE 70S	1991-9-12	100	241	60	181	
31	B-2060	8.1260601	54+72.92	Onslow	Bent-25	20" PCP	40(37)	ICE 70S	1991-9-12	100	167	40	127	
32	B-2142	6.503224	16 + 65 -L-	Harnett/	Bent 2, Pile #1	20" PCP	40(26)	MKT	1993-5-24	100	169	26	143	Initial
				Sampson				DE-70B	1993-6-1		265	53	212	Restrike

33	B-2142	6.503224	16 + 65 -L-	Harnett	Bent 2, Pile #3	20" PCP	40(26)	MKT	1993-5-24	100	196	90	106	Initial
								DE-70B	1993-6-1		266	108	158	Restrike
34	B-2222	6.503201	22+23.6-L-	Wake	End Bent 1	HP 12x53	60(50)	FEC-1500	1990-2-21	45	93	73	20	
35	B-2301	8T051301	168+94.50	Dare	Bent 5, Pile #7	20" PCP	90(62)	Delmag	1993-1-7	100	209	56	153	
								D 30-32						
36	B-2301	8T051301	167+44.50	Dare	Bent1, Pile #7	20" PCP	90(75)	Delmag	1993-1-7	100	255	63	192	
								D 30-32						
37A	B-2531A	8.1170803	2+360.3	Craven	35 EBL	24" PCP	30(21)	Delmag	1996-4-26	100	499	137	362	
								D 46-23						
37B	B-2531A	8.1170803	131+66.3	Craven	22 EBL	24" PCP	30(24)	Del 46-23	1996-4-1	100	270	88	182	
38	B-2991	8.2311901	14+07.00 -L-	Johnston	Bent 2	18" PCP	35(15)	Kobe	2000-2-17	60	154	51	103	
								K-22						
39	B-3028	8.1462601	17+86.5-L-	Bladen/	Bent 2	16" PCP	55(35)	Delmag	2000-2-17	70	144	50	94	
				Robeson				D 19-32						
40A	I-900AD	8.1620419	409+65 -L-	Forsyth	EB1	HP 12x53	45(25)	FEC 1500	1991-8-28	40	106	41	65	
40B	I-900AD	8.1620419	18+36 -L-	Forsyth	EB1	HP 12x53	50(32)	FEC 1500	1990-9-26	40	103	45	58	
41 (S31)	I-900AA	8.1620414	59+07	Forsyth	Bent 3	HP 12x53	80(57)	MKT	1988-4-1	40	85	77	8	
								DA-35B						
42 (S19)	M-103	9.90898	13+97	Craven	Bent 3	24" SPP(C)	80(32)	Conmaco 125	1991-11-5	100	373	73	300	
43	M-103	9.90898	13+43.9	Craven	Bent 2	HP 14x73	120(36)	Conmaco 125	1991-10-25	50	111	91	20	

44	M-103	9.90898	13+63	Craven	Bent 2	HP 14x73	100(41)	Conmaco 125	1991-10-25	50	151	139	12	
45	M-137	6.121002		Perquimans		12" PCP	50(35)	MKT 30B	1989-4-10	30	75	28	47	
46	R-83	8.1230303		Brunswick	bent 2	20" PCP	43(29)	Kobe K-22	1990-6-7	60	156	9	147	
47	R-99BA	6.989001T	397+28	Polk	EB 2	12" PCP	45(40)	Berminghahm	1992-8-27	50	105	69	36	
								B-225						
48	R-525	8.1230105	479+80	Pitt	EB-1	12" PCP	65(61)	Kobe K-22	1990-7-11	50	156	46	110	
49	R-606	8.1223353	20+16	Sampson	Bent 2	HP 12x53	80(64.5)	MKT	1989-5-25	45	107	85	22	
								DE-30B						
50	R-606	8.1223353	20+16	Sampson	Bent 1	HP 12x53	80(48)	MKT	1989-6-19	45	102	99	3	
								DE-30B						
51	R-606A	8.1240604	253+74.75	Duplin	WBL Bent 3	20" PCP	51(44)	FEC 3000	1992-5-18	60	162	23	139	TP-2
52	R-606A	8.1240604	253+74.75	Duplin	EBL Bent 3	20" PCP	52(16)	FEC 3000	1992-6-11	60	211	36	175	TP-1
53	R-1022	6.229001T	196+84	Pitt	Bent 12	24" PCP	65(42)	MKT	1990-9-24	110	405	52	353	
								DE-70B						
54	R-1022B	6.229001T	55+50	Pitt	B-2	20" PCP	70(55)	MKT	1991-11-25	70	143	25	118	
								DE-70B						
55	R-2021	9.8024837	70+41.50	Beaufort	Bent 1	20" PCP	75(55)	MKT	1994-1-26	60	238	15	223	
								DE-70B						
56	R-2404C	6.019003T	78+47 -L-	Bertie	Bent 1	20" PCP	105(90)	FEL 3000	1998-9-29	80	142	81	61	Initial
									1998-9-30		247	209	38	Restrike
57	R-2406B	6.269002T	609+23 -L-	Onslow	Bent 2	HP 12x53	60(60)	MKT	1997-10-30	45	68	44	24	
								DE 42/35						
58	R-2551A	8.T051403	41+38.85	Dare	Non-prodct	30" PCP	110(98)	Delmag	1998-10-26	250	681	78	603	Initial

								D-100-13	1998-10-27		765	141	624	Restrike
59	R-2551A	8.T051403	43+54.86	Dare	B-12	30" PCP	110(99)	Delmag	1999-3-4	250	645	275	370	
								D-100-13						
60A	R-2551A	8.T051403	46+36	Dare	B-21	30" PCP	125(111)	Delmag	1998-11-16	250	683	462	221	Initial
								D-100-13	1998-11-17		1128	897	231	Restrike
60B	R-2551A	8.T051403	46+36	Dare	B-21	30" PCP	125(111)	Delmag	1998-11-16	250	797	212	585	Initial
								D-100-13						
61	R-2551A	8.T051403	49+46.86	Dare	B-32	30" PCP	125(99)	Delmag	1998-12-7	250	553	443	110	
								D-100-13						
62	R-2551A	8.T051403	51+83.66	Dare	B-40	30" PCP	128(102)	Delmag	1998-12-7	250	505	312	193	
								D-100-13						
63	R-2551A	8.T051403	57+19.00	Dare	B-58	30" PCP	135(111)	Delmag	1999-1-4	250	662	183	479	Restrike
								D-100-13						
64	R-2551A	8.T051403	60+16.5	Dare	B-68	30" PCP	138(103)	Delmag	1998-12-17	250	648	289	359	
								D-100-13						
65	R-2551A	8.T051403	65+52.01	Dare	B-86	30" PCP	135(99)	Delmag	1999-8-13	250	955	655	300	Restrike
								D-100-13						
66	R-2551A	8.T051403	67+00	Dare	B-91	30" PCP	135(112)	Delmag	1998-11-23	250	574	455	119	
								D-100-13						
67	R-2551A	8.T051403	69+09.01	Dare	B-98	30" PCP	135(98)	Delmag	1998-11-25	250	648	305	343	
								D-100-13						
68	R-2551A	8.T051403	72+18.76	Dare	B-108	30" PCP	138(99)	Delmag	1999-8-13	250	502	273	229	
								D-100-13						
69	R-2551A	8.T051403	75+96.26	Dare	B-117	30" PCP	135(107)	Delmag	1999-11-10	250	502	339	163	
								D-100-13						

70	R-2551A	8.T051403	78+87.76	Dare	B-124	30" PCP	145(117)	Delmag	1998-12-3	250	890	235	655	
								D-100-13						
71	R-2551A	8.T051403	81+22.76	Dare	B-129	30" PCP	145(125)	Delmag	1998-12-4	250	832	197	635	
								D-100-13						
72	Data Discarded													
73	Data Discarded													
74	R-2551A	8.T051403	85+00.76	Dare	B-138	30" PCP	145(105)	Delmag	1999-12-28	250	565	241	324	Initial
								D-100-13	1999-12-29		950	759	191	Restrike
75	R-2551A	8.T051403	91+15.01	Dare	B-157	30" PCP	135(80)	Comaco	2000-3-8	250	659	122	537	
								3.00E+05						
76	R-2551A	8.T051403	94+12.51	Dare	B-167	30" PCP	118(73)	Comaco	2000-3-9	250	529	135	394	
								3.00E+05						
77	R-2551A	8.T051403	97+10.01	Dare	B-177	30" PCP	121(82)	Comaco	2000-3-10	250	458	52	406	
								3.00E+05						
78	R-2551A	8.T051403	103+05.01	Dare	B-197	30" PCP	121(86)	Comaco	2000-3-13	250	529	96	433	
								3.00E+05						
79	R-2551A	8.T051403	107+21.51	Dare	B-211	30" PCP	135(109)	Delmag	1999-1-4	250	877	766	111	Restrike
								D-100-13						
80	R-2551A	8.T051403	111+95.86	Dare	B-227	30" PCP	141(110)	Delmag	1999-1-19	250	815	673	142	
								D-100-13						
81	R-2551A	8.T051403	115+21.46	Dare	B-238	30" PCP	118(90)	Delmag	1999-1-19	250	812	561	251	Restrike
								D-100-13						
82	R-2551A	8.T051403	117+87.86	Dare	B-247	30" PCP	125(104)	Delmag	1999-1-19	250	533	406	127	

								D-100-13						
83	R-2551A	8.T051403	122+02.26	Dare	B-261	30" PCP	118(110)	ICE 205 S	2000-7-5	250	825	670	155	Restrike
84	R-2551A	8.T051403	42+06.86	Dare	B-7	30" PCP	114(94)	Delmag	1999-4-7	250	900	553	347	Restrike
								D-100-13						
85 (S30)	R-2551A	8.T051403	106+00	Dare	Predesign Static	30" PCP	95(70)	Delmag	1997-5-5	250	227	114	113	Initial
					Load Test #1			D-100-13	1997-5-7		262	120	142	Restrike
86	R-2551A	8.T051403	106+00	Dare	Predesign Static	30" PCP	125(100)	Delmag	1997-5-2	250	135	48	87	Initial
					Load Test #2			D-100-13	1997-5-3		525	392	133	Restrike
87	R-2512A	8.T010604	2+02.1	Bertie/	Bent 7	30" PCP	103(58)	Cinmaco 300	1997-8-1	200	392	117	275	Initial
				Chowan					1997-8-4		540	249	291	Restrike
88	Data Discarded													
89 (S34)	R-2512A	8.T010604	3+115.00	Bertie/	Static Load	30" PCP	119(66)	Raymond 60x	1997-4-4	237	355	55	300	Initial
				Chowan	Test #2				1998-4-7		701	378	323	Restrike
90	R-2512A	8.T010604	2+125	Bertie/	B-11	30" PCP	100(73)	Raymond 60x	1997-9-19	200	302	66	236	
				Chowan										
91 (S33)	R-2512A	8.T010604	4+340	Bertie/	Static Load	20" PCP	46(32)	Conmaco 300	1997-1-2	100	213	81	132	Initial
				Chowan	Test #1				1997-1-13		288	85	203	Restrike
92	R-2512A	8.T010604	2+248	Bertie/	B-14 (DTP2)	30" PCP	102(63)	Raymond	1997-7-9	200	392	110	182	Initial

								60x						
				Chowan					1997-7-10		719	374	345	Restrike
93	R-2512A	8.T010604	2+658	Bertie/	B-24 (DTP3)	30" PCP	102(70)	Raymond 60x	1997-7-14	200	177	111	66	Initial
				Chowan					1997-7-15		712	301	411	Restrike
94	R-2512A	8.T010604	2+882	Bertie/	B-29 (DTP4)	30" PCP	99(64)	Raymond 60x	1997-8-22	237	315	135	180	Initial
				Chowan					1997-8-25		629	360	269	Restrike
95	R-2512A	8.T010604	3+695.7	Bertie/	B-51 (DTP5)	30" PCP	72(41)	Raymond 60x	1997-7-17	200	697	128	569	
				Chowan										
96	R-2512A	8.T010604	4+78.88	Bertie/	B-65 (DTP6)	30" PCP	72(40)	Raymond 60x	1997-5-8	200	575	179	396	Initial
				Chowan					1997-5-9		650	183	467	Restrike
97	Data discarded													
98	R-2512A	8.T010604	2+084	Bertie/	B-10	30" PCP	100(93)	Conmaco 300	1997-9-5	200	519	308	211	
				Chowan										
99	R-2512A	8.T010604	4+297.75	Bertie/	B-73	30" PCP	69(55)	ICE 80 S	1997-6-27	200	603	145	458	
				Chowan										
100	U-1452E	9.8922824	23+46	Carteret	EB-2	HP 14x73	80(76)	Vulcan	1991-2-5	30	63	50	13	
								No. 1						
101	U-2103D	8.2440703	117+44	Cumberland	EB-1	12" PCP	45(34)	Berm	1992-7-22	45	75	13	62	
								B-300						

102	U-2107B	8.T261301	31+54.84	Onslow	B-2	HP 12x53	50(49)	ICE 40S	1998-9-21	45	96	88	8	
103	X-3AE	8.1223341	20+65.47	Sampson	B-1	HP 12x53	35(26)	MKT	1988-6-1	45	72	45	27	
								DA-35						
104	X-3AE	8.1223341	20+65.47	Sampson	B-1	HP 12x53	36(19)	MKT	1988-6-1	45	98	12	86	
						w/ Plate Tip		DA-35						
105	X-3AE	8.1223341	20+65.47	Sampson	B-1	12" PCP	25(15)	MKT	1988-6-1	45	85	4	81	
								DA-35						
106 (S29)	X-3BA	8.1223310		Sampson	B-2	HP 12x53	55(51)	MKT	1987-10-20	45	110	89	21	Initial
								DE-30B	1987-10-22		122	99	23	Restrike
107A(S 7)	B-2023	8.1050702	143+35	Dare	B-48	20" PCP	66(54)	Vulcan 512	1988-3-31	100	222	26	196	Initial
					Static Load Test				1988-4-5		265	96	169	Restrike
107B	B-2023	8.1050702	131+66.32	Dare	B-49	20" PCP	58(40)	Vulcan 512	1988-7-14	100	274	123	151	
108	B-2023	8.1050702	135+2.88	Dare	B-54	20" PCP	58(37)	Vulcan 512	1988-6-28	100	230	61	169	
109	S&ME	Zebulon		Wake	Water Tank	HP 12x53	72(68)	Conmaco 565	1998-6-18	60	151	132	19	Initial
									1998-6-19		168	141	27	Restrike
110	S&ME	Fremont		Wayne	Water Tank	HP 12x53	65(63)	Conmaco 65E	1999-8-9	60	192	158	34	
111	S&ME	Newport	2B	Carteret	Water Tank	HP 12x53	50(50)	Del D12	1999-12-22	50	103	36	67	
112	S&ME	Newport	3E	Carteret	Water Tank	HP 12x53	50(50)	Del D12	1999-12-22	50	169	91	78	
113	S&ME	Newport	5F	Carteret	Water Tank	HP 12x53	50(50)	Del D12	1999-12-22	50	159	150	9	

114	R-2105A	6.169001T	34+37.5	Onslow	B-11	24" PCP	56(24)	Mitsub M-33	2000-9-26	100	223	127	96	
115	R-2105A	6.169001T	34+61	Onslow	B-2	24" PCP	53(27)	Mitsub M-33	2000-9-20	100	316	51	265	
116 (S1)	NCSU	DFI		Wake	Parking Deck	12" PCP	54(45)	Conmaco 65	1988-3-7	50	211	171	40	
					Static Load Test									
117	R-2551A	8.T051403	95+1.76	Dare	B-170	30" PCP	98(74)	Del D100	2001-9-27	200	461	153	308	
118	R-2551A	8.T051403	95+31.51	Dare	B-171	30" PCP	105(81)	Del D100	2001-8-8	200	416	210	206	
119	Data Discarded													
120	Data Discarded													
121	B2959	8.2241601	13+78	Duplin	Bent-3 (P2)	HP 14x73	60(33)	Del D19-42	2001-12-12	70	202	180	22	
122	B3215	8.2260701	27+97	Onslow	Bent-1 (P4)	20" PCP	35(18.5)	Mitsub M-33	2001-7-12	60	297	108	189	
123(S32)	B2500	8.1051203	315+35.5	Dare	Predesign	66" CCP	130(105)	HPSI 3505	1996-8-22	450	639	411	228	
124	P-3100	9.9080131	18+00	Careteret	TP-1RR	24" OESP	117(78)	Del D46-32	1997-12-4	100	304	250	54	Initial
									1997-12-5		351	304	47	Restrike
125	P-3100	9.9080131	25+00	Careteret	TP-2RR	24" OESP	98.5(62)	Del D46-32	1997-12-8	100	155	99	56	Initial
									1997-12-9		333	296	37	Restrike
126	P-3100	9.9080131	29+50	Careteret	TP-3RR	24" OESP	94.4(54)	Del D46-32	1997-12-8	100	324	196	128	Initial
									1997-12-9		434	401	33	Restrike
127	P-3100	9.9080131	34+00	Careteret	TP-4RR	24" OESP	98.6(70)	Del D46-32	1997-12-8	100	264	104	160	Initial

									1997-12-9		383	333	50	Restrike
128	P-3100	9.9080131	31+50	Careteret	TP-5RR	24" OESP	98.6(68)	Del D46-32	1997-12-8	100	298	139	159	
129	P-3100	9.9080131	20+10	Careteret	TP-6RR	24" OESP	105(72.5)	Del D46-32	1998-6-22	100	482	389	93	Restrike
130	P-3100	9.9080131	16+95	Careteret	TP-7RR	24" OESP	100(67)	Del D46-32	1998-6-23	100	326	284	42	Restrike
131	P-3100	9.9080131	21+75	Careteret	TP-8RR	24" OESP	100(66)	Del D46-32	1998-6-23	100	380	269	111	Restrike
132	P-3100	9.9080131	24+68	Careteret	TP-9RR	24" OESP	105(55)	Del D46-32	1998-6-23	100	355	318	37	Restrike
133	P-3100	9.9080131	27+98	Careteret	TP-10RR	24" OESP	105(58)	Del D46-32	1998-6-24	100	312	263	49	Restrike
134	P-3100	9.9080131	28+31	Careteret	TP-11RR	24" OESP	100(52)	Del D46-32	1998-6-24	100	263	188	75	Restrike
135	P-3100	9.9080131	30+95	Careteret	TP-12RR	24" OESP	105(53)	Del D46-32	1998-6-25	100	390	271	119	Restrike
136	P-3100	9.9080131	31+28	Careteret	TP-13RR	24" OESP	100(62)	Del D46-32	1998-6-25	100	447	288	159	Restrike
137	P-3100	9.9080131	34+94	Careteret	TP-14RR	24" OESP	100(59)	Del D46-32	1998-6-29	100	305	253	52	Restrike
138	P-3100	9.9080131	36+56	Careteret	TP-15RR	24" OESP	85(63)	Del D46-32	1998-6-30	100	254	205	49	Restrike
139	B-3152	8.1442701	23+91	Sampson	B-1	18" OESP	70(65)	Kobe K-25	2002-3-13	80	138	118	20	Initial
									2002-3-15		200	190	10	Restrike
140	U-92A	8.2250101	2+28.78	New Hanover	B-1	24" PCP	40(36)	Del 46-32	2001-10-19	100	377	28	349	Initial
141	U-92A	8.2250101	24+91	New Hanover	B-6	24" PCP	30(26)	Del 46-32	2001-10-19	100	378	165	213	Initial

APPENDIX C

Resistance Bias Factor Statistics

N < 40 PDA EOD Coastal Concrete Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N @toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
85*	250	D30	4	227	526	0.43	114	183	0.62	113	343	0.33
98	200	D30	8	519	612	0.85	308	152	2.03	211	460	0.46
56*	80	D20	12	142	386	0.37	81	158	0.51	61	228	0.27
105	45	D12	12	85	20	4.25	4	15	0.27	81	5	16.20
4C*	100	D20	13	220	179	1.23	157	42	3.74	63	137	0.46
86*	250	D30	13	135	689	0.20	48	130	0.37	87	559	0.16
94*	237	D30	13	315	639	0.49	135	225	0.60	180	414	0.43
70	250	D30	14	890	922	0.97	235	283	0.83	655	639	1.03
92*	200	D30	14	392	533	0.74	110	111	0.99	282	422	0.67
122	100	D20	14	297	151	1.97	108	45	2.40	189	106	1.78
4B	100	D24	15	417	403	1.03	128	102	1.25	289	301	0.96
39	70	D16	15	144	142	1.01	50	60	0.83	94	82	1.15
60B*	250	D30	16	797	680	1.17	212	117	1.81	585	563	1.04
90	200	D30	16	302	615	0.49	65	123	0.53	237	492	0.48
69	250	D30	17	502	922	0.54	339	276	1.23	163	646	0.25
89*	237	D30	17	355	676	0.53	55	209	0.26	300	467	0.64
60A*	250	D30	18	683	817	0.84	462	154	3.00	221	663	0.33
45	30	D12	19	75	85	0.88	28	32	0.88	47	53	0.89
61	250	D30	19	553	757	0.73	443	126	3.52	110	631	0.17
74*	250	D30	19	565	870	0.65	241	215	1.12	324	655	0.49
141	100	D24	19	378	222	1.70	165	74	2.23	213	148	1.44

93*	200	D30	20	177	646	0.27	111	122	0.91	66	524	0.13
66	250	D30	21	574	807	0.71	455	163	2.79	119	644	0.18
99	200	D30	21	603	646	0.93	145	186	0.78	458	460	1.00
101	45	D12	21	75	95	0.79	13	31	0.42	62	64	0.97
115	100	D24	21	316	215	1.47	51	36	1.42	265	179	1.48
4A*	100	D24	22	107	404	0.26	30	68	0.44	77	336	0.23
46	60	D20	22	155	164	0.95	9	28	0.32	146	136	1.07
91*	100	D20	22	213	217	0.98	81	70	1.16	132	147	0.90
1*	100	D20	23	116	300	0.39	35	79	0.44	81	221	0.37
11	85	D20	23	91	207	0.44	22	47	0.47	69	160	0.43
54	70	D20	23	143	282	0.51	25	67	0.37	118	215	0.55
37B	100	D24	24	270	268	1.01	88	86	1.02	182	182	1.00
52	60	D20	25	211	167	1.26	36	32	1.13	175	135	1.30
55	60	D20	25	238	339	0.70	15	115	0.13	223	224	1.00
114	100	D24	26	223	210	1.06	127	27	4.70	96	183	0.52
19	80	D24	27	285	363	0.79	46	100	0.46	239	263	0.91
62	250	D30	27	505	935	0.54	312	185	1.69	193	750	0.26
107A*	100	D20	27	222	269	0.83	26	44	0.59	196	225	0.87
96*	200	D30	28	575	694	0.83	179	243	0.74	396	451	0.88
117	200	D30	28	461	764	0.60	153	127	1.20	308	637	0.48
3	55	D20	29	156	292	0.53	117	67	1.75	39	225	0.17
5	50	D12	29	117	121	0.97	24.5	60	0.41	92.5	61	1.52
6	100	D24	29	210	436	0.48	18	72	0.25	192	364	0.53
28	100	D20	29	187	361	0.52	112	120	0.93	75	241	0.31
118	200	D30	30	416	857	0.49	210	152	1.38	206	705	0.29

31	100	D20	32	167	299	0.56	40	81	0.49	127	218	0.58
77	250	D30	32	458	838	0.55	52	107	0.49	406	731	0.56
82	250	D30	32	533	966	0.55	406	131	3.10	127	835	0.15
22	85	D20	33	215	295	0.73	51	76	0.67	164	219	0.75
36	100	D20	33	255	407	0.63	63	88	0.72	192	319	0.60
95	200	D30	34	697	715	0.97	127	233	0.55	570	482	1.18
48	50	D12	35	156	136	1.15	46	31	1.48	110	105	1.05
53	110	D24	38	405	440	0.92	52	53	0.98	353	387	0.91
87*	250	D30	38	392	459	0.85	117	101	1.16	275	358	0.77
108	100	D20	38	230	334	0.69	61	83	0.73	169	251	0.67
21	45	D12	39	100	76	1.32	44	18	2.44	56	58	0.97
30	100	D20	39	241	409	0.59	60	101	0.59	181	308	0.59
32*	100	D20	39	169	220	0.77	26	28	0.93	143	192	0.74
33*	100	D20	39	196	290	0.68	90	98	0.92	106	192	0.55
35	100	D20	39	209	513	0.41	55	185	0.30	154	328	0.47
68	250	D30	39	502	1176	0.43	273	258	1.06	229	918	0.25
75	250	D30	39	659	981	0.67	122	153	0.80	537	828	0.65
17	60	D20	40	285	398	0.72	112	107	1.05	173	291	0.59
18	60	D20	40	270	252	1.07	85	62	1.37	185	190	0.97
67	250	D30	40	648	1107	0.59	305	183	1.67	343	924	0.37

Mean	0.82	Mean	1.16	Mean	0.91
Stand.Dev	0.54	Stand.Dev	0.92	Stand.Dev	1.95
Coeff.Variation	0.66	Coeff.Variation	0.80	Coeff.Variation	2.13

N < 40 PDA EOD Coastal Concrete Nordlund

				Total			Skin			Toe		
File No.	D L(Ton)	Pile Type	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nord
85*	250	D30	4	227	445	0.51	114	403	0.28	113	42	2.69
98	200	D30	8	519	822	0.63	308	718	0.43	211	104	2.03
56*	80	D20	12	142	166	0.86	81	160	0.51	61	6	10.17
105	45	D12	12	85	18	4.72	4	13	0.31	81	5	16.20
4C*	100	D20	13	220	118	1.86	157	92	1.71	63	26	2.42
86*	250	D30	13	135	599	0.23	48	583	0.08	87	16	5.44
94*	237	D30	13	315	617	0.51	135	574	0.24	180	43	4.19
70	250	D30	14	890	1805	0.49	235	1765	0.13	655	40	16.38
92*	200	D30	14	392	424	0.92	110	378	0.29	282	46	6.13
122	100	D20	14	297	117	2.54	108	29	3.72	189	88	2.15
4B	100	D24	15	417	425	0.98	128	392	0.33	289	33	8.76
39	70	D16	15	144	83	1.73	50	60	0.83	94	23	4.09
60B*	250	D30	16	797	727	1.10	212	679	0.31	585	48	12.19
90	200	D30	16	302	536	0.56	65	479	0.14	237	57	4.16
69	250	D30	17	502	1348	0.37	339	1303	0.26	163	45	3.62
89*	237	D30	17	355	585	0.61	55	521	0.11	300	64	4.69
60A*	250	D30	18	683	1011	0.68	462	963	0.48	221	48	4.60
45	30	D12	19	75	46	1.63	28	24	1.17	47	22	2.14
61	250	D30	19	553	816	0.68	443	759	0.58	110	57	1.93
74*	250	D30	19	565	1028	0.55	241	967	0.25	324	61	5.31
141	100	D24	19	378	94	4.02	165	37	4.46	213	57	3.74

93*	200	D30	20	177	482	0.37	111	396	0.28	66	86	0.77
66	250	D30	21	574	657	0.87	455	623	0.73	119	34	3.50
99	200	D30	21	603	521	1.16	145	401	0.36	458	120	3.82
101	45	D12	21	75	59	1.27	13	48	0.27	62	11	5.64
115	100	D24	21	316	133	2.38	51	37	1.38	87	16	5.44
4A*	100	D24	22	107	370	0.29	30	303	0.10	77	67	1.15
46	60	D20	22	155	128	1.21	9	43	0.21	146	85	1.72
91*	100	D20	22	213	158	1.35	81	81	1.00	132	77	1.71
1*	100	D20	23	116	276	0.42	35	221	0.16	81	55	1.47
11	85	D20	23	91	121	0.75	22	22	1.00	69	99	0.70
54	70	D20	23	143	195	0.73	25	168	0.15	118	27	4.37
37B	100	D24	24	270	183	1.48	88	61	1.44	182	122	1.49
52	60	D20	25	211	107	1.97	36	30	1.20	175	77	2.27
55	60	D20	25	238	308	0.77	15	228	0.07	223	80	2.79
114	100	D24	26	223	172	1.30	127	35	3.63	96	137	0.70
19	80	D24	27	285	300	0.95	46	121	0.38	239	179	1.34
62	250	D30	27	505	1246	0.41	312	1138	0.27	193	108	1.79
107A*	100	D20	27	222	234	0.95	26	125	0.21	196	109	1.80
96*	200	D30	28	575	574	1.00	179	256	0.70	396	318	1.25
117	200	D30	28	461	733	0.63	153	555	0.28	308	178	1.73
3	55	D20	29	156	219	0.71	117	71	1.65	39	148	0.26
5	50	D12	29	117	117	1.00	24.5	62	0.40	92.5	55	1.68
6	100	D24	29	210	389	0.54	18	226	0.08	192	163	1.18
28	100	D20	29	187	331	0.56	112	203	0.55	75	128	0.59
118	200	D30	30	416	840	0.50	210	651	0.32	206	189	1.09

31	100	D20	32	167	314	0.53	40	142	0.28	127	172	0.74
77	250	D30	32	458	766	0.60	52	541	0.10	406	225	1.80
82	250	D30	32	533	972	0.55	406	818	0.50	127	154	0.82
22	85	D20	33	215	283	0.76	51	103	0.50	164	180	0.91
36	100	D20	33	255	451	0.57	63	328	0.19	192	123	1.56
95	200	D30	34	697	715	0.97	127	259	0.49	570	456	1.25
48	50	D12	35	156	221	0.71	46	137	0.34	110	84	1.31
53	110	D24	38	405	487	0.83	52	122	0.43	353	365	0.97
87*	250	D30	38	392	1005	0.39	117	471	0.25	275	534	0.51
108	100	D20	38	230	371	0.62	61	128	0.48	169	243	0.70
21	45	D12	39	100	85	1.18	44	13	3.38	56	72	0.78
30	100	D20	39	241	542	0.44	60	262	0.23	181	280	0.65
32*	100	D20	39	169	258	0.66	26	38	0.68	143	220	0.65
33*	100	D20	39	196	308	0.64	90	88	1.02	106	220	0.48
35	100	D20	39	209	554	0.38	55	322	0.17	154	232	0.66
68	250	D30	39	502	1735	0.29	273	1449	0.19	229	286	0.80
75	250	D30	39	659	1100	0.60	122	687	0.18	537	413	1.30
17	60	D20	40	285	440	0.65	112	150	0.75	173	290	0.60
18	60	D20	40	270	293	0.92	85	57	1.49	185	236	0.78
67	250	D30	40	648	952	0.68	305	636	0.48	343	316	1.09

Mean	0.95	Mean	0.69	Mean	2.90
Stand.Dev	0.77	Stand.Dev	0.90	Stand.Dev	3.33
Coeff.Variation	0.81	Coeff.Variation	1.30	Coeff.Variation	1.15

N < 40   PDA EOD Coastal Concrete   Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
85*	250	D30	4	227	223	1.02	114	162	0.70	113	61	1.85
98	200	D30	9	519	257	2.02	308	151	2.04	211	106	1.99
56*	80	D20	11	142	188	0.76	81	149	0.54	61	39	1.56
115	100	D24	11	316	65	4.86	51	23	2.22	265	42	6.31
39	70	D16	12	144	70	2.06	50	52	0.96	94	18	5.22
4C*	100	D20	13	220	51	4.31	157	22	7.14	63	29	2.17
45	30	D12	13	75	37	2.03	28	26	1.08	47	11	4.27
94*	237	D30	13	315	217	1.45	135	151	0.89	180	66	2.73
92*	200	D30	14	392	192	2.04	110	128	0.86	282	64	4.41
60B*	250	D30	15	797	123	6.48	212	54	3.93	585	69	8.48
90	200	D30	15	302	201	1.50	65	137	0.47	237	64	3.70
93*	200	D30	15	177	193	0.92	111	128	0.87	66	65	1.02
60A*	250	D30	16	683	164	4.16	462	94	4.91	221	70	3.16
86*	250	D30	16	135	100	1.35	48	34	1.41	87	66	1.32
114	100	D24	16	223	105	2.12	127	14	9.07	61	39	1.56
89*	237	D30	17	355	271	1.31	55	203	0.27	300	68	4.41
101	45	D12	17	75	45	1.67	13	31	0.42	62	14	4.43
54	70	D20	18	143	100	1.43	25	64	0.39	118	36	3.28
61	250	D30	18	553	89	6.21	443	25	17.72	110	64	1.72
91*	100	D20	19	213	241	0.88	81	98	0.83	132	143	0.92
141	100	D24	19	378	201	1.88	165	54	3.06	213	147	1.45

32*	100	D20	20	169	97	1.74	26	10	2.60	143	87	1.64
107A*	100	D20	20	222	61	3.64	26	14	1.86	196	47	4.17
53	110	D24	21	405	118	3.43	52	26	2.00	353	92	3.84
105	45	D12	21	85	45	1.89	4	15	0.27	81	30	2.70
3	55	D20	22	156	113	1.38	117	47	2.49	39	66	0.59
4A*	100	D24	22	107	85	1.26	30	30	1.00	77	55	1.40
35	100	D20	22	209	193	1.08	55	144	0.38	154	49	3.14
46	60	D20	22	155	112	1.38	9	9	1.00	146	103	1.42
99	200	D30	22	603	316	1.91	145	190	0.76	458	126	3.63
11	85	D20	23	91	117	0.78	22	27	0.81	69	90	0.77
66	250	D30	23	574	174	3.30	455	92	4.95	119	82	1.45
122	100	D20	23	297	218	1.36	108	19	5.68	189	199	0.95
6	100	D24	24	210	137	1.53	18	32	0.56	192	105	1.83
36	100	D20	24	255	127	2.01	63	77	0.82	192	50	3.84
37B	100	D24	24	270	273	0.99	88	53	1.66	182	220	0.83
74*	250	D30	24	565	263.22	2.15	241	164.22	1.47	324	99	3.27
1*	100	D20	25	116	140	0.83	35	78	0.45	81	62	1.31
33*	100	D20	25	196	384	0.51	90	68	1.32	106	316	0.34
52	60	D20	25	211	201	1.05	36	44	0.82	175	157	1.11
140	100	D24	25	377	865	0.44	28	74	0.38	349	791	0.44
4B	100	D24	26	417	171	2.44	128	76	1.68	289	95	3.04
78	250	D30	26	529	167	3.17	96	51	1.88	433	116	3.73
82	250	D30	27	533	161	3.31	406	60	6.77	127	101	1.26
28	100	D20	26	187	187	1.00	112	96	1.17	75	91	0.82
19	80	D24	27	285	311	0.92	46	66	0.70	239	245	0.98

55	60	D20	28	238	169	1.41	15	62	0.24	223	107	2.08
77	250	D30	28	458	182	2.52	52	33	1.58	406	149	2.72
96*	200	D30	28	575	533	1.08	179	193	0.93	396	340	1.16
5	50	D12	30	117	99	1.18	24.5	37	0.66	92.5	62	1.49
37A	100	D24	30	499	531	0.94	137	109	1.26	362	422	0.86
58*	250	D30	30	681	208	3.27	78	69	1.13	603	139	4.34
62	250	D30	30	505	244	2.07	312	110	2.84	193	134	1.44
67	250	D30	30	648	215	3.01	305	73	4.18	343	142	2.42
117	200	D30	30	461	185	2.49	153	45	3.40	308	140	2.20
118	200	D30	30	416	330	1.26	210	73	2.88	206	257	0.80
31	100	D20	32	167	289	0.58	40	61	0.66	127	228	0.56
87*	250	D30	32	392	412	0.95	117	175	0.67	275	237	1.16
95	200	D30	32	697	548	1.27	127	72	1.76	570	476	1.20
22	85	D20	33	215	301	0.71	51	41	1.24	164	260	0.63
24	75	D20	33	240	264	0.91	29	10	2.90	211	254	0.83
48	50	D12	35	156	68	2.29	46	22	2.09	110	46	2.39
7	100	D24	38	425	386	1.10	102	40	2.55	323	346	0.93
23	85	D20	38	389	290	1.34	72	65	1.11	317	225	1.41
21	45	D12	39	100	64	1.56	44	16	2.75	56	48	1.17
108	100	D20	39	230	359	0.64	61	45	1.36	169	314	0.54
17	60	D20	40	285	238	1.20	112	77	1.45	173	161	1.07
18	60	D20	40	270	264	1.02	85	35	2.43	185	229	0.81
					Mean	1.86		Mean	2.11		Mean	2.16
					Stand.Dev	1.25		Stand.Dev	2.59		Stand.Dev	1.56
					Coeff.Variation	0.67		Coeff.Variation	1.23		Coeff.Variation	0.72

N > 40 PDA EOD Coastal Concrete Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
12	60	D20	41	188	108		29	18	1.61	159	90	
7	100	D24	43	425	586	0.73	102	92	1.11	323	494	0.65
76	250	D30	44	529	1055	0.50	135	169	0.80	394	886	0.44
14	80	D20	45	138	307	0.45	95	60	1.58	43	247	
13	80	D20	50	127	365	0.35	46	41	1.12	81	324	0.25
51	60	D20	50	162	432	0.38	23	66	0.35	139	366	0.38
58*	253	D30	50	681	755	0.90	78	137	0.57	603	618	0.98
24	75	D20	51	240	370	0.65	29	36	0.81	211	334	0.63
78	250	D30	54	529	1262	0.42	96	132	0.73	433	1130	0.38
64	250	D30	55	648	1401	0.46	289	192	1.51	359	1209	0.30
37A	100	D24	60	499	484	1.03	137	123	1.11	362	361	1.00
107B	100	D20	60	274	532	0.52	26	105	0.25	248	427	0.58
23	85	D20	62	389	580	0.67	72	94	0.77	317	486	0.65
140	100	D24	62	377	710	0.53	28	89	0.31	349	621	0.56
59	250	D30	70	645	1716	0.38	275	182	1.51	370	1534	0.24
8	100	D24	75	218	1029	0.21	20	74	0.27	198	955	0.21
9	100	D24	100	216	1609		51	93	0.55	165	1516	
71	250	D30	100	832	2753	0.30	197	312	0.63	635	2441	0.26
					Mean	0.53		Mean	0.87		Mean	0.50
					Stand.Dev	0.22		Stand.Dev	0.46		Stand.Dev	0.25
					Coeff.Variation	0.41		Coeff.Variation	0.54		Coeff.Variation	0.51

N > 40 PDA EOD Coastal Concrete Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
12	60	D20	41	188	189		29	10		159	179	0.89
7	100	D24	43	425	739	0.58	102	253	0.40	323	486	0.66
76	250	D30	44	529	1373	0.39	135	726		394	647	0.61
14	80	D20	45	138	403	0.34	95	86	1.10	43	317	
13	80	D20	50	127	512	0.25	46	80	0.58	81	432	
51	60	D20	50	162	634	0.26	23	167		139	467	0.30
58*	253	D30	50	681	1687	0.40	78	791		603	896	0.67
24	75	D20	51	240	535	0.45	29	75	0.39	211	460	0.46
78	250	D30	54	529	1516	0.35	96	618		433	898	0.48
64	250	D30	55	648	1934	0.34	289	1226	0.24	359	708	0.51
37A	100	D24	60	499	630	0.79	137	76	1.80	362	554	0.65
107B	100	D20	60	274	870	0.31	26	201		248	669	0.37
23	85	D20	62	389	941	0.41	72	180	0.40	317	761	0.42
80	250	D30	62	815	2091	0.39	673	1214	0.55	142	877	
140	100	D24	62	377	881	0.43	28	111	0.25	349	770	0.45
59	250	D30	70	645	2337	0.28	275	838	0.33	370	1499	0.25
8	100	D24	75	218	1601		20	246		198	1355	
9	100	D24	100	216	1581		51	226	0.23	165	1355	
71	250	D30	100	832	2703	0.31	197	1203		635	1500	0.42
					Mean	0.39		Mean	0.57		Mean	0.51
					Stand.Dev	0.13		Stand.Dev	0.48		Stand.Dev	0.17
					Coeff.Variation	0.34		Coeff.Variation	0.84		Coeff.Variation	0.34

N > 40 PDA EOD Coastal Concrete Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
8	100	D24	41	218	421	0.52	20	25	0.80	198	396	0.50
12	60	D20	41	188	140	1.34	29	11	2.64	159	129	
76	250	D30	44	529	703	0.75	135	96	1.41	394	607	0.65
14	80	D20	45	138	390	0.35	95	42	2.26	43	348	
64	250	D30	45	648	532	1.22	289	126	2.29	359	406	0.88
30	100	D20	47	241	383	0.58	60	54	2.88	81	204	0.40
13	80	D20	50	127	220	0.58	46	16	2.88	81	204	0.40
51	60	D20	50	162	409	0.40	23	36	0.64	139	373	0.37
69	250	D30	50	502	748	0.67	339	240	1.41	163	508	0.32
75	250	D30	51	659	769	0.86	122	94	1.30	537	675	0.80
59	250	D30	53	645	775	0.83	275	109	2.52	370	666	0.56
70	250	D30	55	890	800	1.11	235	224	1.05	655	576	1.14
68	250	D30	56	502	846	0.59	273	177.2	1.54	229	668.8	0.34
71	250	D30	60	832	966	0.86	197	289	0.68	635	677	0.94
107B	100	D20	65	274	594	0.46	26	84	0.31	248	510	0.49
80	250	D30	80	815	433		673	116		142	317	0.45
9	100	D24	100	216	848	0.25	51	57	0.89	165	791	0.21

Mean	0.71	Mean	1.59	Mean	0.56
Stand.Dev	0.31	Stand.Dev	0.86	Stand.Dev	0.26
Coeff.Variation	0.44	Coeff.Variation	0.54	Coeff.Variation	0.47

N<40 PDA EOD Coastal Steel HP VESIC

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
10*	40	HP 12 X 53	12	87	76	1.14	62	75	0.83	25	1	25
106*	45	HP 12 X 53	14	110	77	1.43	89	71	1.25	21	6	3.50
49	45	HP 12 X 53	17	107	150	0.71	85	142	0.60	22	8	2.75
100	30	HP 14 X 73	23	63	168	0.38	50	154	0.32	13	14	0.93
50	45	HP 12 X 53	25	102	75	1.36	99	67	1.48	3	8	0.38
102	45	HP 12 X 53	26	96	212	0.45	88	204	0.43	8	8	1.00
104	45	HP 12 X 53	32	98	47	2.09	12	5	2.40	86	42	2.05
16	50	HP 12 X 53	34	94	115	0.82	80	104	0.77	14	11	1.27
110	60	HP 12 X 53	35	192	112	1.71	158	99	1.60	34	13	2.62
103	45	HP 12 X 53	38	72	89	0.81	45	82	0.55	27	7	3.86

Mean	1.09	Mean	1.02	Mean	4.33
Stand.Dev	0.56	Stand.Dev	0.65	Stand.Dev	7.35
Coeff.Variation	0.51	Coeff.Variation	0.64	Coeff.Variation	1.70

N<40 PDA EOD Coastal Steel HP NORDLUND

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
10*	40	HP 12 X 53	12	87	71	1.23	62	70	0.89	25	1	25.00
106*	45	HP 12 X 53	14	110	109	1.01	89	96	0.93	21	13	1.62
49	45	HP 12 X 53	17	107	141	0.76	85	140	0.61	22	1	22.00
100	30	HP 14 X 73	23	63	151	0.42	50	127	0.39	13	24	0.54
50	45	HP 12 X 53	25	102	112	0.91	99	110	0.90	3	2	1.50
102	45	HP 12 X 53	26	96	130	0.74	88	127	0.69	8	3	2.67
104	45	HP 12 X 53	32	98	32	3.06	12	26	0.46	86	6	14.33
16	50	HP 12 X 53	34	94	133	0.71	80	128	0.63	14	5	2.80
110	60	HP 12 X 53	35	192	127	1.51	158	121	1.31	34	6	5.67
103	45	HP 12 X 53	38	72	31	2.32	45	23	1.96	27	8	3.38

Mean	1.27	Mean	0.88	Mean	7.95
Stand.Dev	0.83	Stand.Dev	0.46	Stand.Dev	9.10
Coeff.Variation	0.65	Coeff.Variation	0.53	Coeff.Variation	1.15

N<40 PDA EOD Coastal Steel HP Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
10*	40	HP 12 X 53	12	87	76	1.14	62	75	0.83	25	1	25.00
49	45	HP 12 X 53	17	107	130	0.82	85	129	0.66	22	1	22.00
50	45	HP 12 X 53	25	102	68	1.50	99	65	1.52	3	3	1.00
100	30	HP 14 X 73	25	63	135	0.47	50	108	0.46	13	27	0.48
102	45	HP 12 X 53	32	96	152	0.63	88	147	0.60	8	5	1.60
104	45	HP 12 X 53	33	98	48	2.04	12	38	0.32	86	10	8.60
106*	45	HP 12 X 53	33	110	157	0.70	89	151	0.59	21	6	3.50
16	50	HP 12 X 53	34	94	72	1.31	80	69	1.16	14	3	4.67
110	60	HP 12 X 53	35	192	99	1.94	158	93	1.70	34	6	5.67
121	70	HP 14 X 73	40	202	88	2.30	180	70	2.57	22	18	1.22

Mean	1.28	Mean	1.04	Mean	7.37
Stand.Dev	0.64	Stand.Dev	0.70	Stand.Dev	8.89
Coeff.Variation	0.50	Coeff.Variation	0.68	Coeff.Variation	1.21

N>40 Coastal Steel HP Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
121	70	HP 14 X 73	45	202	107	1.89	180	92	1.96	22	15	1.47
43	50	HP 14 X 73	55	111	176	0.63	91	157	0.58	20	19	1.05
44	50	HP 14 X 73	70	151	213	0.71	139	184	0.76	12	29	0.41
57	45	HP 12 X 53	100	68	126	0.54	44	86	0.51	24	40	0.60
111	50	HP 12 X 53	100	103	160	0.64	36	119	0.30	67	41	1.63
112	50	HP 12 X 53	100	169	158	1.07	91	117	0.78	78	41	1.90
113	50	HP 12 X 53	100	159	155	1.03	150	115	1.30	9	40	0.23

Mean	0.93	Mean	0.88	Mean	1.04
Stand.Dev	0.47	Stand.Dev	0.57	Stand.Dev	0.65
Coeff.Variation	0.50	Coeff.Variation	0.64	Coeff.Variation	0.62

N>40 Coastal Steel HP Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
121	70	HP 14 X 73	45	202	95	2.13	180	77	2.34	22	18	1.22
43	50	HP 14 X 73	55	111	123	0.90	91	94	0.97	20	29	0.69
44	50	HP 14 X 73	70	151	150	1.01	139	120	1.16	12	30	0.40
57	45	HP 12 X 53	100	68	87	0.78	44	50	0.88	24	37	0.65
111	50	HP 12 X 53	100	103	146	0.71	36	110	0.33	67	36	1.86
112	50	HP 12 X 53	100	169	125	1.35	91	89	1.02	78	36	2.17
113	50	HP 12 X 53	100	159	127	1.25	150	91	1.65	9	36	0.25

Mean	1.16	Mean	1.19	Mean	1.03
Stand.Dev	0.49	Stand.Dev	0.64	Stand.Dev	0.74
Coeff.Variation	0.42	Coeff.Variation	0.54	Coeff.Variation	0.72

N>40 Coastal Steel HP Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
43	50	HP 14 X 73	41	111	158	0.70	91	140	0.65	20	18	1.11
103	45	HP 12 X 53	42	72	105	0.69	45	93	0.48	27	12	2.25
44	50	HP 14 X 73	90	151	206	0.73	139	168	0.83	12	38	0.32
57	45	HP 12 X 53	100	68	100	0.68	44	75	0.59	24	25	0.96
111	50	HP 12 X 53	100	103	132	0.78	36	105	0.34	67	27	2.48
112	50	HP 12 X 53	100	169	161	1.05	91	134	0.68	78	27	2.89
113	50	HP 12 X 53	100	159	123	1.29	150	96	1.56	9	27	0.33

Mean	0.85	Mean	0.73	Mean	1.48
Stand.Dev	0.24	Stand.Dev	0.40	Stand.Dev	1.05
Coeff.Variation	0.28	Coeff.Variation	0.54	Coeff.Variation	0.71

Coastal Steel Pipe Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
125*		S- D24 Pipe (OE)	12	155	280	0.55	99	253	0.39	56	27	2.07
124*		S- D24 Pipe (OE)	14	304	194	1.57	250	166	1.51	54	28	1.93
128		S- D24 Pipe (OE)	19	298	137	2.18	139	111	1.25	159	26	6.12
139*	60	S- D18 Pipe (OE)	21	138	156	0.88	118	141	0.84	20	15	1.33
127*		S- D24 Pipe (OE)	25	264	214	1.23	104	184	0.57	160	30	5.33
42	100	S- D24 Pipe (CE)	31	373	303	1.23	73	89	0.82	300	214	1.40
126*		S- D24 Pipe (OE)	35	324	139	2.33	196	119	1.65	128	20	6.40

Mean	1.43	Mean	1.00	Mean	3.51
Stand.Dev	0.65	Stand.Dev	0.48	Stand.Dev	2.32
Coeff.Variation	0.46	Coeff.Variation	0.47	Coeff.Variation	0.66

Coastal Steel Pipe Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
125*		S- D24 Pipe (OE)	12	155	311	0.50	99	248	0.40	56	63	0.89
124*		S- D24 Pipe (OE)	14	304	316	0.96	250	284	0.88	54	32	1.69
128		S- D24 Pipe (OE)	19	298	242	1.23	139	203	0.68	159	39	4.08
139	60	S-D18 Pipe (OE)	21	138	200	0.69	118	128	0.92	20	72	0.28
127*		S- D24 Pipe (OE)	25	264	410	0.64	104	339	0.31	160	71	2.25
42	100	S- D24 Pipe (CE)	31	373	244	1.53	73	72	1.01	300	172	1.74
126*		S- D24 Pipe (OE)	35	324	179	1.81	196	146	1.34	128	33	3.88

Mean	1.05	Mean	0.79	Mean	2.12
Stand.Dev	0.49	Stand.Dev	0.36	Stand.Dev	1.42
Coeff.Variation	0.47	Coeff.Variation	0.45	Coeff.Variation	0.67

Coastal Steel Pipe Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
128		S- D24 Pipe (OE)	15	298	288	1.03	139	243	0.57	159	45	3.53
124*		S- D24 Pipe (OE)	16	304	148	2.05	250	145	1.72	54	3	18.00
126*		S- D24 Pipe (OE)	16	324	342	0.95	196	336	0.58	128	6	21.33
139*	60	S- D18 Pipe (OE)	21	138	123	1.12	118	113	1.04	20	10	2.00
125*		S- D24 Pipe (OE)	22	155	225	0.69	99	220	0.45	56	5	11.20
127*		S- D24 Pipe (OE)	25	264	188	1.40	104	181	0.57	160	7	22.86
42	100	S- D24 Pipe (CE)	30	373	311	1.20	73	58	1.26	300	253	1.19

Mean	1.21	Mean	0.89	Mean	11.44
Stand.Dev	0.43	Stand.Dev	0.47	Stand.Dev	9.38
Coeff.Variation	0.36	Coeff.Variation	0.53	Coeff.Variation	0.82

Piedmont Concrete Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
47	50	D12	16	105	109	0.96	69	28	2.46	36	81	0.44
20	60	D20	18	122	107	1.14	22	51	0.43	100	56	1.79
2	30	D12	21	66	49	1.35	37	18	2.06	29	31	0.94
38	60	D18	27	154	188	0.82	51	84	0.61	103	104	0.99
15	65	D20	28	241	233	1.03	152	96	1.58	89	137	0.65
116	50	D12	34	211	161	1.31	171	38	4.50	40	123	0.33

Mean	1.10	Mean	1.94	Mean	0.86
Stand.Dev	0.20	Stand.Dev	1.48	Stand.Dev	0.53
Coeff.Variation	0.19	Coeff.Variation	0.77	Coeff.Variation	0.61

Piedmont Concrete Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
47	50	D12	16	105	81	1.30	69	72	0.96	36	9	4.00
20	60	D20	18	122	52	2.35	22	14	1.57	100	38	2.63
2	30	D12	21	66	36	1.83	37	14	2.64	29	22	1.32
38	60	D18	27	154	124	1.24	51	42	1.21	103	82	1.26
15	65	D20	28	241	165	1.46	152	60	2.53	89	105	0.85
116	50	D12	34	211	168	1.26	171	126	1.36	40	42	0.95

Mean	1.57	Mean	1.71	Mean	1.83
Stand.Dev	0.44	Stand.Dev	0.71	Stand.Dev	1.24
Coeff.Variation	0.28	Coeff.Variation	0.41	Coeff.Variation	0.68

Piedmont Concrete Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
47	50	D12	16	105	44	2.39	69	33	2.09	36	11	3.27
20	60	D20	18	122	147	0.83	22	29	0.76	100	118	0.85
2	30	D12	22	66	48	1.38	37	25	1.48	29	23	1.26
38	60	D18	27	154	235	0.66	51	55	0.93	103	180	0.57
116	50	D12	32	211	82	2.57	171	47	3.64	40	35	1.14
15	65	D20	36	241	404	0.60	152	71	2.14	89	333	0.27

Mean	1.40	Mean	1.84	Mean	1.23
Stand.Dev	0.88	Stand.Dev	1.05	Stand.Dev	1.07
Coeff.Variation	0.63	Coeff.Variation	0.57	Coeff.Variation	0.87

Piedmont Steel HP Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
34	45	HP 12 X 53	13	93	83	1.12	73	73	1.00	20	10	2.00
41	40	HP 12 X 53	40	85	77	1.10	77	64	1.20	8	13	0.62
40A	40	HP 12 X 53	62	106	78	1.36	41	37	1.11	65	41	1.59
40B	40	HP 12 X 53	100	103	77	1.34	45	36	1.25	58	41	1.41
109	60	HP 12 X 53	100	151	159	0.95	132	117	1.13	19	42	0.45

Mean	1.17	Mean	1.14	Mean	1.21
Stand.Dev	0.17	Stand.Dev	0.10	Stand.Dev	0.66
Coeff.Variation	0.15	Coeff.Variation	0.08	Coeff.Variation	0.54

Piedmont Steel HP Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
34	45	HP 12 X 53	13	93	78	1.19	73	77	0.95	20	1	20.00
41	40	HP 12 X 53	40	85	123	0.69	77	112	0.69	8	11	0.73
40A	40	HP 12 X 53	62	106	75	1.41	41	45	0.91	65	30	2.17
40B	40	HP 12 X 53	100	103	213	0.48	45	177	0.25	58	36	1.61
109*	60	HP 12 X 53	100	151	183	0.83	132	146	0.90	19	37	0.51

Mean	0.92	Mean	0.74	Mean	5.00
Stand.Dev	0.38	Stand.Dev	0.29	Stand.Dev	8.41
Coeff.Variation	0.41	Coeff.Variation	0.39	Coeff.Variation	1.68

Piedmont Steel HP Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
34	45	HP 12 X 53	18	93	84	1.11	73	83	0.88	20	1	20.00
41	40	HP 12 X 53	40	85	89	0.96	77	85	0.91	8	4	2.00
40A	40	HP 12 X 53	100	106	73	1.45	41	47	0.87	65	26	2.50
40B	40	HP 12 X 53	100	103	59	1.75	45	38	1.18	58	21	2.76
109*	60	HP 12 X 53	100	151	158	0.96	132	134	0.99	19	24	0.79

Mean	1.24	Mean	0.97	Mean	5.61
Stand.Dev	0.35	Stand.Dev	0.13	Stand.Dev	8.08
Coeff.Variation	0.28	Coeff.Variation	0.13	Coeff.Variation	1.44

Coastal Conc PDA Restrike N<=40, Vesic

				Total			Skin			Toe		
File No.	Design Load(Ton)	Pile	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
1*	100	D20	23	206	300	0.69	125	79	1.58	81	221	0.37
4A*	100	D24	22	218	404	0.54	106	68	1.56	112	336	0.33
4C*	100	D20	13	226	179	1.26	161	42	3.83	65	137	0.47
11*	85	D20	23	91	207	0.44	22	47	0.47	69	160	0.43
32*	100	D20	39	265	220	1.20	53	28	1.89	212	192	1.10
33*	100	D20	39	266	290	0.92	108	98	1.10	158	192	0.82
56*	80	D20	12	247	386	0.64	209	158	1.32	38	228	0.17
60A*	250	D30	18	1128	817	1.38	897	154	5.82	231	663	0.35
63	250	D30	17	662	816	0.81	183	163	1.12	479	653	0.73
65	250	D30	14	955	740	1.29	655	168	3.90	300	572	0.52
74*	250	D30	19	950	870	1.09	759	215	3.53	191	655	0.29
79	250	D30	20	877	887	0.99	766	199	3.85	111	688	0.16
81	250	D30	35	812	937	0.87	561	121	4.64	251	816	0.31
85*	250	D30	4	262	526	0.50	120	183	0.66	142	343	0.41
86*	250	D30	13	525	689	0.76	392	130	3.02	133	559	0.24
87*	250	D30	38	540	459	1.18	249	101	2.47	291	358	0.81
89*	237	D30	17	701	676	1.04	378	209	1.81	323	467	0.69
91*	100	D20	22	288	217	1.33	85	70	1.21	203	147	1.38
92*	200	D30	14	719	533	1.35	374	111	3.37	345	422	0.82
93*	200	D30	20	712	646	1.10	301	122	2.47	411	524	0.78
94*	237	D30	13	629	639	0.98	360	225	1.60	269	414	0.65

96*	200	D30	28	650	694	0.94	183	243	0.75	467	451	1.04
107A*	100	D20	27	265	269	0.99	96	44	2.18	169	225	0.75

Mean	0.97	Mean	2.35	Mean	0.59
Stand.Dev	0.28	Stand.Dev	1.41	Stand.Dev	0.32
Coeff.Variation	0.29	Coeff.Variation	0.60	Coeff.Variation	0.54

Coastal Concrete Restrike N<=40, Nordlund

				Total			Skin			Toe		
File No.	Design Load(Ton)	Pile	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
1*	100	D20	23	206	276	0.75	125	221	0.57	81	55	1.47
4A*	100	D24	22	218	370	0.59	106	303	0.35	112	67	1.67
4C*	100	D20	13	226	118	1.92	161	92	1.75	65	26	2.50
11*	85	D20	23	91	121	0.75	22	22	1.00	69	99	0.70
32*	100	D20	39	265	258	1.03	53	38	1.39	212	220	0.96
33*	100	D20	39	266	308	0.86	108	88	1.23	158	220	0.72
56*	80	D20	12	247	166	1.49	209	160	1.31	38	6	6.33
60A*	250	D30	18	1128	1011	1.12	897	963	0.93	231	48	4.81
63	250	D30	17	662	985	0.67	183	941	0.19	479	44	10.89
65	250	D30	14	955	1062	0.90	655	1020	0.64	300	42	7.14
74*	250	D30	19	950	1028	0.92	759	967	0.78	191	61	3.13
79	250	D30	20	877	1064	0.82	766	1007	0.76	111	57	1.95
81	250	D30	35	812	859	0.95	561	608	0.92	251	251	1.00
85*	250	D30	4	262	445	0.59	120	403	0.30	142	42	3.38
86*	250	D30	13	525	599	0.88	392	583	0.67	133	16	8.31
87*	250	D30	38	540	1005	0.54	249	471	0.53	291	534	0.54
89*	237	D30	17	701	585	1.20	378	521	0.73	323	64	5.05
91*	100	D20	22	288	158	1.82	85	81	1.05	203	77	2.64
92*	200	D30	14	719	424	1.70	374	378	0.99	345	46	7.50
93*	200	D30	20	712	482	1.48	301	396	0.76	411	86	4.78
94*	237	D30	13	629	617	1.02	360	574	0.63	269	43	6.26

96*	200	D30	28	650	574	1.13	183	256	0.71	467	318	1.47
107A*	100	D20	27	265	234	1.13	96	125	0.77	169	109	1.55

Mean	1.05	Mean	0.82	Mean	3.68
Stand.Dev	0.39	Stand.Dev	0.36	Stand.Dev	2.89
Coeff.Variation	0.37	Coeff.Variation	0.44	Coeff.Variation	0.79

Coastal Concrete Restrike N<=40, Meyerhof

				Total			Skin			Toe		
File No.	Design Load(Ton)	Pile	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
1*	100	D20	25	206	140	1.47	125	78	1.60	81	62	1.31
4A*	100	D24	22	218	85	2.56	106	30	3.53	112	55	2.04
4C*	100	D20	13	226	51	4.43	161	22	7.32	65	29	2.24
11*	85	D20	23	91	117	0.78	22	27	0.81	69	90	0.77
32*	100	D20	20	265	97	2.73	53	10	5.30	212	87	2.44
33*	100	D20	25	266	384	0.69	108	68	1.59	158	316	0.50
56*	80	D20	11	247	188	1.31	209	149	1.40	38	39	0.97
58*	250	D30	30	765	208	3.68	141	69	2.04	624	139	4.49
60A*	250	D30	16	1128	164	6.88	897	94	9.54	231	70	3.30
63	250	D30	32	662	246	2.69	183	106	1.73	479	140	3.42
65	250	D30	20	955	192	4.97	655	126	5.20	300	66	4.55
74*	250	D30	24	950	263	3.61	759	164	4.62	191	99	1.93
79	250	D30	16	877	206	4.25	766	137	5.59	111	69	1.60
81	250	D30	25	812	137	5.93	561	37	15.16	251	100	2.51
83	250	D30	35	825	268	3.08	670	73	9.18	155	195	0.79
85*	250	D30	4	262	223	1.17	120	162	0.74	142	61	2.33
86*	250	D30	16	525	100	5.25	392	34	11.53	133	66	2.02
87*	250	D30	32	540	412	1.31	249	175	1.42	291	237	1.23
89*	237	D30	17	701	271	2.59	378	203	1.86	323	68	4.75
91*	100	D20	19	288	241	1.20	85	98	0.87	203	143	1.42
92*	200	D30	14	719	192	3.74	374	128	2.92	345	64	5.39

93*	200	D30	15	712	193	3.69	301	128	2.35	411	65	6.32
94*	237	D30	13	629	217	2.90	360	151	2.38	269	66	4.08
96*	200	D30	28	650	533	1.22	183	193	0.95	467	340	1.37
107A*	100	D20	20	265	61	4.34	96	14	6.86	169	47	3.60

Mean	3.06	Mean	4.26	Mean	2.61
Stand.Dev	1.69	Stand.Dev	3.80	Stand.Dev	1.59
Coeff.Variation	0.55	Coeff.Variation	0.89	Coeff.Variation	0.61

PDA Restrike Coastal Conc N>40, Vesic

				Total			Skin			Toe		
File No.	Design Load(Ton)	Pile Type	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
58*	250	D30	50	765	755	1.01	141	137	1.03	624	618	1.01
83	250	D30	53	825	1375	0.60	670	163	4.11	155	1212	0.13
84	250	D30	56	900	1349	0.67	553	139	3.98	347	1210	0.29

Mean	0.76	Mean	3.04	Mean	0.47
Stand.Dev	0.22	Stand.Dev	1.74	Stand.Dev	0.47
Coeff.Variation	0.29	Coeff.Variation	0.57	Coeff.Variation	0.99

PDA Restrike Coastal Conc N>40, Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile	N@Toe	PDA	Nordlund	PDA/Nordl	PDA	Nordlund	PDA/Nordl	PDA	Nordlund	PDA/Nordlund
58*	250	D30	50	765	1687	0.45	141	791	0.18	624	896	0.70
83	250	D30	53	825	731	1.13	670	711	0.94	155	20	7.75
84	250	D30	56	900	735	1.22	553	680	0.81	347	55	6.31

Mean	0.94	Mean	0.64	Mean	4.92
Stand.Dev	0.42	Stand.Dev	0.41	Stand.Dev	3.73
Coeff.Variation	0.45	Coeff.Variation	0.63	Coeff.Variation	0.76

PDA Restrike Coastal Conc N>40, Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
84	250	D30	100	900	209	4.31	553	64	8.64	347	145	2.39

PDA Restrike Coastal Steel HP, Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
10*	40	HP 12 X 53	12	134	76	1.76	108	75	1.44	26	1	26.00
25	45	HP 12 X 53	35	211.5	199	1.06	182.5	187	0.98	29	12	2.42
106*	45	HP 12 X 53	14	122	77	1.58	99	71	1.39	23	6	3.83

Mean	1.47	Mean	1.27	Mean	10.75
Stand.Dev	0.36	Stand.Dev	0.26	Stand.Dev	13.23
Coeff.Variation	0.25	Coeff.Variation	0.20	Coeff.Variation	1.23

PDA Restrike Coastal Steel HP, Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
10*	40	HP 12 X 53	12	134	71	1.89	108	70	1.54	26	1	26.00
25	45	HP 14 X 73	35	211.5	93	2.27	182.5	83	2.20	29	10	2.90
106*	45	HP 12 X 53	14	122	109	1.12	99	96	1.03	23	13	1.77

Mean	1.76	Mean	1.59	Mean	10.22
Stand.Dev	0.59	Stand.Dev	0.59	Stand.Dev	13.67
Coeff.Variation	0.33	Coeff.Variation	0.37	Coeff.Variation	1.34

PDA Restrike Coastal Steel HP, Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
10*	40	HP 12 x 53	12	134	76	1.76	108	75	1.44	26	1	26.00
25	45	HP 14 x 73	35	211.5	158	1.34	182.5	143	1.28	29	15	1.93
106*	45	HP 12 X 53	33	122	157	0.78	99	151	0.66	23	6	3.83

Mean	1.29	Mean	1.12	Mean	10.59
Stand.Dev	0.49	Stand.Dev	0.41	Stand.Dev	13.38
Coeff.Variation	0.38	Coeff.Variation	0.37	Coeff.Variation	1.26

PDA Restrike Coastal Steel Pipe, Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
124*		S-D24 Pipe (OE)	14	351	194	1.57	304	166	1.51	54	28	1.93
125*		S-D24 Pipe (OE)	12	333	280	1.19	296	253	1.17	37	27	1.37
126*		S-D24 Pipe (OE)	35	434	139	3.12	401	119	3.37	33	20	1.65
127*		S-D24 Pipe (OE)	25	383	214	1.79	333	184	1.81	50	30	1.67
129		S-D24 Pipe (OE)	56	482	319	1.51	389	263	1.48	93	56	1.66
130		S-D24 Pipe (OE)	18	326	193	1.69	284	168	1.69	42	25	1.68
131		S-D24 Pipe (OE)	28	380	256	1.48	269	225	1.20	111	31	3.58
132		S-D24 Pipe (OE)	25	355	244	1.45	318	216	1.47	37	28	1.32
133		S-D24 Pipe (OE)	35	312	175	1.78	263	141	1.87	49	34	1.44
134		S-D24 Pipe (OE)	16	263	148	1.78	188	128	1.47	75	20	3.75
135		S-D24 Pipe (OE)	35	390	180	2.17	271	143	1.90	119	37	3.22
136		S-D24 Pipe (OE)	65	447	197	2.27	288	172	1.67	159	25	6.36
137		S-D24 Pipe (OE)	25	305	180	1.69	253	156	1.62	52	24	2.17
138		S-D24 Pipe (OE)	20	254	199	1.28	205	174	1.18	49	25	1.96
139*	60	S-D24 Pipe (OE)	21	200	156	1.28	190	141	1.35	10	15	0.67

Mean	1.74	Mean	1.65	Mean	2.29
Stand.Dev	0.49	Stand.Dev	0.53	Stand.Dev	1.42
Coeff.Variation	0.28	Coeff.Variation	0.32	Coeff.Variation	0.62

PDA Restrike Coastal Steel Pipe, Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
124*		S-D24 Pipe (OE)	14	351	316	1.11	304	284	1.07	54	32	1.69
125*		S-D24 Pipe (OE)	12	333	311	1.07	296	248	1.19	37	63	0.59
126*		S-D24 Pipe (OE)	35	434	179	2.42	401	146	2.75	33	33	1.00
127*		S-D24 Pipe (OE)	25	383	410	0.93	333	339	0.98	50	71	0.70
129		S-D24 Pipe (OE)	56	482	994	0.48	389	412	0.94	93	582	0.16
130		S-D24 Pipe (OE)	18	326	259	1.26	284	224	1.27	42	35	1.20
131		S-D24 Pipe (OE)	28	380	395	0.96	269	299	0.90	111	96	1.16
132		S-D24 Pipe (OE)	25	355	279	1.27	318	188	1.69	37	91	0.41
133		S-D24 Pipe (OE)	35	312	382	0.82	263	168	1.57	49	214	0.23
134		S-D24 Pipe (OE)	16	263	164	1.60	188	128	1.47	75	36	2.08
135		S-D24 Pipe (OE)	35	390	503	0.78	271	154	1.76	119	349	0.34
136		S-D24 Pipe (OE)	65	447	287	1.56	288	235	1.23	159	52	3.06
137		S-D24 Pipe (OE)	25	305	219	1.39	253	169	1.50	52	50	1.04
138		S-D24 Pipe (OE)	20	254	271	0.94	205	224	0.92	49	47	1.04
139*	60	S-D24 Pipe (OE)	21	200	200	1.00	190	128	1.48	10	72	0.14

	Total		Skin		Toe
Mean	1.17	Mean	1.38	Mean	0.99
Stand.Dev	0.46	Stand.Dev	0.47	Stand.Dev	0.80
Coeff.Variation	0.39	Coeff.Variation	0.34	Coeff.Variation	0.81

PDA Restrike Coastal Steel Pipe, Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
124*		S-D24 Pipe (OE)	16	351	148	2.05	304	145	1.72	54	3	18.00
125*		S-D24 Pipe (OE)	22	333	225	1.48	296	220	1.35	37	5	7.40
126*		S-D24 Pipe (OE)	16	434	342	1.27	401	336	1.19	33	6	5.50
127*		S-D24 Pipe (OE)	25	383	188	2.04	333	181	1.84	50	7	7.14
129		S-D24 Pipe (OE)	56	482	288	1.67	389	243	1.60	93	45	2.07
130		S-D24 Pipe (OE)	18	326	135	2.41	284	131	2.17	42	4	10.50
131		S-D24 Pipe (OE)	44	380	251	1.51	269	223	1.21	111	28	3.96
132		S-D24 Pipe (OE)	24	355	206	1.72	318	199	1.60	37	7	5.29
133		S-D24 Pipe (OE)	33	312	163	1.91	263	147	1.79	49	16	3.06
134		S-D24 Pipe (OE)	12	263	133	1.98	188	130	1.45	75	3	25.00
135		S-D24 Pipe (OE)	12	390	148	2.64	271	145	1.87	119	3	39.67
136		S-D24 Pipe (OE)	65	447	187	2.39	288	179	1.61	159	8	19.88
137		S-D24 Pipe (OE)	25	305	200	1.53	253	196	1.29	52	4	13.00
138		S-D24 Pipe (OE)	20	254	205	1.24	205	202	1.01	49	3	16.33
139*	60	S-D24 Pipe (OE)	21	200	123	1.63	190	113	1.68	10	10	1.00

Mean	1.83	Mean	1.56	Mean	11.85
Stand.Dev	0.42	Stand.Dev	0.31	Stand.Dev	10.52
Coeff.Variation	0.23	Coeff.Variation	0.20	Coeff.Variation	0.89

COASTAL CONCRETE CYLINDER PILE STATIC LOAD TEST DATA

Static File No	PDA File No	County	Pile Type	Static Load (Ton)	Vesic Ult (Ton)	Static/ Vesic	Nordlund Ult (ton)	Static/ Nordlund	SPT Ult (Ton)	Static/ SPT
S4	26	Onslow	54" CCP	765	1114	0.69	2734	0.28	601	1.27
S20		Dare	54" CCP	2000	2330	0.86	3195	0.63	345	5.80
S23	85	Carteret	54" CCP	691	543	1.27	445	1.55	255	2.71
S32	123	Dare	66" CCP	990	1555	0.64	3174	0.31	552	1.79
S35		Chowan	66" CCP	850	1244	0.68	2287	0.37	352	2.41

Mean	0.83	Mean	0.63	Mean	2.80
Stand.Dev	0.26	Stand.Dev	0.53	Stand.Dev	1.77
Coeff.Variation	0.32	Coeff.Variation	0.85	Coeff.Variation	0.63

COASTAL STEEL HP PILE STATIC LOAD TEST DATA

Static File No	PDA File No	County	Pile Type	Static Load (Ton)	Vesic Ult (Ton)	Static/ Vesic	Nordlund Ult (ton)	Static/ Nordlund	SPT Ult (Ton)	Static/ SPT
S21		Bladen	HP 14 X 73	245	97	2.53	148	1.66	96	2.55
S29	106	Sampson	HP 12 X 53	160	77	2.08	109	1.47	157	1.02

Mean	2.30	Mean	1.56	Mean	1.79
Stand.Dev	0.32	Stand.Dev	0.13	Stand.Dev	1.08
Coeff.Variation	0.14	Coeff.Variation	0.08	Coeff.Variation	0.61

PIEDMONT STEEL HP PILE STATIC LOAD TEST DATA

Static File No	PDA File No	County	Pile Type	Static Load (Ton)	Vesic Ult (Ton)	Static/ Vesic	Nordlund Ult (ton)	Static/ Nordlund	SPT Ult (Ton)	Static/ SPT
S24		Wake	HP 12 X 53	193	62	3.11	102	1.89	56	3.45
S25		Wake	HP 12 X 53	91	90	1.01	179	0.51	89	1.02
S31	41	Forsyth	HP 12 X 53	175	77	2.27	123	1.42	89	1.97

Mean	2.13	Mean	1.27	Mean	2.15
Stand.Dev	1.06	Stand.Dev	0.70	Stand.Dev	1.22
Coeff.Variation	0.50	Coeff.Variation	0.55	Coeff.Variation	0.57

COASTAL CONCRETE PILE STATIC LOAD TEST DATA

Static File No	PDA File No	County	Pile Type	Static Load (Ton)	Vesic Ult (Ton)	Static/ Vesic	Nordlund Ult (ton)	Static/ Nordlund	SPT Ult (Ton)	Static/ SPT
S2	4A	Carteret	24" PCP	193	404	0.48	370	0.52	85	2.27
S3	4C	Currituck/Dare	20" PCP	156	179	0.87	118	1.32	51	3.06
S5		Currituck/Dare	24" PCP	200	462	0.43	457	0.44	610	0.33
S6	1	Martin/Bertie	20" PCP	200	300	0.67	276	0.72	140	1.43
S7	107A	Dare	20" PCP	195	269	0.72	234	0.83	61	3.20
S8		Craven	20" PCP	204	215	0.95	92	2.22	224	0.91
S9		Dare	20" PCP	332	282	1.18	244	1.36	103	3.22
S10		Dare	20" PCP	295	432	0.68	624	0.47	397	0.74
S11		Dare	20" PCP	230	206	1.12	157	1.46	184	1.25
S12		Chowan/Wash	20" PCP	320	460	0.70	569	0.56	347	0.92
S13		Chowan/Wash	24" PCP	300	358	0.84	316	0.95	78	3.85
S14		Chowan/Wash	24" PCP	315	400	0.79	362	0.87	172	1.83
S15		Chowan/Wash	24" PCP	350	380	0.92	201	1.74	162	2.16
S16		Chowan/Wash	24" PCP	200	315	0.63	112	1.79	94	2.13
S17	19	Onslow	24" PCP	400	363	1.10	300	1.33	311	1.29
S18		Brunswick	20" PCP	258	255	1.01	170	1.52	97	2.66
S22		Brunswick	20" PCP	220	445	0.49	593	0.37	450	0.49

S27		Dare	30" PCP	625	1195	0.52	905	0.69	239	2.62
S28		Tyrrell	20" PCP	217	271	0.80	352	0.62	84	2.58
S30	85	Dare	30" PCP	325	526	0.62	445	0.73	222	1.46
S33	91	Chowan	20" PCP	255	217	1.18	158	1.61	241	1.06
S34	89	Chowan	30" PCP	930	676	1.38	609	1.53	271	3.43

Mean	0.82	Mean	1.08	Mean	1.95
Stand.Dev	0.26	Stand.Dev	0.53	Stand.Dev	1.03
Coeff.Variation	0.31	Coeff.Variation	0.49	Coeff.Variation	0.53

With Jetting N<40 PDA EOD Coastal Concrete Vesic

					Total			Shaft			Toe		
File No.	D. L. (Ton)	Jetting	Pile Type/Size	N @toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
3	55	y	D20	29	156	292	0.53	117	67	1.75	39	225	0.17
5	50	y	D12	29	117	121	0.97	24.5	60	0.41	92.5	61	1.52
6	100	y	D24	29	210	436	0.48	18	72	0.25	192	364	0.53
11	85	y	D20	23	91	207	0.44	22	47	0.47	69	160	0.43
22	85	y	D20	33	215	295	0.73	51	76	0.67	164	219	0.75
28	100	y	D20	29	187	361	0.52	112	120	0.93	75	241	0.31
31	100	y	D20	32	167	299	0.56	40	81	0.49	127	218	0.58
46	60	y	D20	22	155	164	0.95	9	28	0.32	146	136	1.07
52	60	y	D20	25	211	167	1.26	36	32	1.13	175	135	1.30
55	60	y	D20	25	238	339	0.70	15	115	0.13	223	224	1.00
61	250	y	D30	19	553	757	0.73	443	126	3.52	110	631	0.17
62	250	y	D30	27	505	935	0.54	312	185	1.69	193	750	0.26
66	250	y	D30	21	574	807	0.71	455	163	2.79	119	644	0.18
67	250	y	D30	40	648	1107	0.59	305	183	1.67	343	924	0.37
68	250	y	D30	39	502	1176	0.43	273	258	1.06	229	918	0.25
69	250	y	D30	17	502	922	0.54	339	276	1.23	163	646	0.25
70	250	y	D30	14	890	922	0.97	235	283	0.83	655	639	1.03
77	250	y	D30	32	458	838	0.55	52	107	0.49	406	731	0.56
82	250	y	D30	32	533	966	0.55	406	131	3.10	127	835	0.15
108	100	y	D20	38	230	334	0.69	61	83	0.73	169	251	0.67
114	100	y	D24	26	223	210	1.06	127	27	4.70	96	183	0.52

115	100	y	D24	21	316	215	1.47	51	36	1.42	265	179	1.48
117	200	y	D30	28	461	764	0.60	153	127	1.20	308	637	0.48
118	200	y	D30	30	416	857	0.49	210	152	1.38	206	705	0.29
1*	100	y	D20	23	116	300	0.39	35	79	0.44	81	221	0.37
4A*	100	y	D24	22	107	404	0.26	30	68	0.44	77	336	0.23
4B	100	y	D24	15	417	403	1.03	128	102	1.25	289	301	0.96
4C*	100	y	D20	13	220	179	1.23	157	42	3.74	63	137	0.46
60A*	250	y	D30	18	683	817	0.84	462	154	3.00	221	663	0.33
60B*	250	y	D30	16	797	680	1.17	212	117	1.81	585	563	1.04
74*	250	y	D30	19	565	870	0.65	241	215	1.12	324	655	0.49
85*	250	y	D30	4	227	526	0.43	114	183	0.62	113	343	0.33
86*	250	y	D30	13	135	689	0.20	48	130	0.37	87	559	0.16

Mean	0.70	Mean	1.37	Mean	0.57
Stand.Dev	0.30	Stand.Dev	1.14	Stand.Dev	0.39
Coeff.Variation	0.43	Coeff.Variation	0.83	Coeff.Variation	0.69

No Jetting N<40 PDA EOD Coastal Concrete Vesic

					Total			Shaft			Toe		
File No.	D. L. (Ton)	Jetting	Pile Type/Size	N @toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
17	60	n	D20	40	285	398	0.72	112	107	1.05	173	291	0.59
18	60	n	D20	40	270	252	1.07	85	62	1.37	185	190	0.97
19	80	n	D24	27	285	363	0.79	46	100	0.46	239	263	0.91
21	45	n	D12	39	100	76	1.32	44	18	2.44	56	58	0.97
30	100	n	D20	39	241	409	0.59	60	101	0.59	181	308	0.59
35	100	n	D20	39	209	513	0.41	55	185	0.30	154	328	0.47
36	100	n	D20	33	255	407	0.63	63	88	0.72	192	319	0.60
39	70	n	D16	15	144	142	1.01	50	60	0.83	94	82	1.15
45	30	n	D12	19	75	85	0.88	28	32	0.88	47	53	0.89
48	50	n	D12	35	156	136	1.15	46	31	1.48	110	105	1.05
53	110	n	D24	38	405	440	0.92	52	53	0.98	353	387	0.91
54	70	n	D20	23	143	282	0.51	25	67	0.37	118	215	0.55
75	250	n	D30	39	659	981	0.67	122	153	0.80	537	828	0.65
90	200	n	D30	16	302	615	0.49	65	123	0.53	237	492	0.48
95	200	n	D30	34	697	715	0.97	127	233	0.55	570	482	1.18
98	200	n	D30	8	519	612	0.85	308	152	2.03	211	460	0.46
99	200	n	D30	21	603	646	0.93	145	186	0.78	458	460	1.00
101	45	n	D12	21	75	95	0.79	13	31	0.42	62	64	0.97
105	45	n	D12	12	85	20	4.25	4	15	0.27	81	5	16.20
122	100	n	D20	14	297	151	1.97	108	45	2.40	189	106	1.78
141	100	n	D24	19	378	222	1.70	165	74	2.23	213	148	1.44

107A*	100	n	D20	27	222	269	0.83	26	44	0.59	196	225	0.87
32*	100	n	D20	39	169	220	0.77	26	28	0.93	143	192	0.74
33*	100	n	D20	39	196	290	0.68	90	98	0.92	106	192	0.55
37B	100	n	D24	24	270	268	1.01	88	86	1.02	182	182	1.00
56*	80	n	D20	12	142	386	0.37	81	158	0.51	61	228	0.27
87*	250	n	D30	38	392	459	0.85	117	101	1.16	275	358	0.77
89*	237	n	D30	17	355	676	0.53	55	209	0.26	300	467	0.64
91*	100	n	D20	22	213	217	0.98	81	70	1.16	132	147	0.90
92*	200	n	D30	14	392	533	0.74	110	111	0.99	282	422	0.67
93*	200	n	D30	20	177	646	0.27	111	122	0.91	66	524	0.13
94*	237	n	D30	13	315	639	0.49	135	225	0.60	180	414	0.43
96*	200	n	D30	28	575	694	0.83	179	243	0.74	396	451	0.88
						Mean	0.94		Mean	0.95		Mean	1.26
						Stand.Dev	0.69		Stand.Dev	0.59		Stand.Dev	2.70
						Coeff.Variation	0.73		Coeff.Variation	0.62		Coeff.Variation	2.14

With Jetting N<40 PDA EOD Coastal Concrete Nordlund

					Total			Shaft			Toe		
File No.	D.L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nord
3	55	y	D20	29	156	219	0.71	117	71	1.65	39	148	0.26
5	50	y	D12	29	117	117	1.00	24.5	62	0.40	92.5	55	1.68
6	100	y	D24	29	210	389	0.54	18	226	0.08	192	163	1.18
11	85	y	D20	23	91	121	0.75	22	22	1.00	69	99	0.70
22	85	y	D20	33	215	283	0.76	51	103	0.50	164	180	0.91
28	100	y	D20	29	187	331	0.56	112	203	0.55	75	128	0.59
31	100	y	D20	32	167	314	0.53	40	142	0.28	127	172	0.74
46	60	y	D20	22	155	128	1.21	9	43	0.21	146	85	1.72
52	60	y	D20	25	211	107	1.97	36	30	1.20	175	77	2.27
55	60	y	D20	25	238	308	0.77	15	228	0.07	223	80	2.79
61	250	y	D30	19	553	816	0.68	443	759	0.58	110	57	1.93
62	250	y	D30	27	505	1246	0.41	312	1138	0.27	193	108	1.79
66	250	y	D30	21	574	657	0.87	455	623	0.73	119	34	3.50
67	250	y	D30	40	648	952	0.68	305	636	0.48	343	316	1.09
68	250	y	D30	39	502	1735	0.29	273	1449	0.19	229	286	0.80
69	250	y	D30	17	502	1348	0.37	339	1303	0.26	163	45	3.62
70	250	y	D30	14	890	1805	0.49	235	1765	0.13	655	40	16.38
77	250	y	D30	32	458	766	0.60	52	541	0.10	406	225	1.80
82	250	y	D30	32	533	972	0.55	406	818	0.50	127	154	0.82
108	100	y	D20	38	230	371	0.62	61	128	0.48	169	243	0.70
114	100	y	D24	26	223	172	1.30	127	35	3.63	96	137	0.70

115	100	y	D24	21	316	133	2.38	51	37	1.38	265	96	2.76
117	200	y	D30	28	461	733	0.63	153	555	0.28	308	178	1.73
118	200	y	D30	30	416	840	0.50	210	651	0.32	206	189	1.09
1*	100	y	D20	23	116	276	0.42	35	221	0.16	81	55	1.47
4A*	100	y	D24	22	107	370	0.29	30	303	0.10	77	67	1.15
4B	100	y	D24	15	417	425	0.98	128	392	0.33	289	33	8.76
4C*	100	y	D20	13	220	118	1.86	157	92	1.71	63	26	2.42
60A*	250	y	D30	18	683	1011	0.68	462	963	0.48	221	48	4.60
60B*	250	y	D30	16	797	727	1.10	212	679	0.31	585	48	12.19
74*	250	y	D30	19	565	1028	0.55	241	967	0.25	324	61	5.31
85*	250	y	D30	4	227	445	0.51	114	403	0.28	113	42	2.69
86*	250	y	D30	13	135	599	0.23	48	583	0.08	87	16	5.44

Mean	0.78	Mean	0.57	Mean	2.90
Stand.Dev	0.49	Stand.Dev	0.70	Stand.Dev	3.47
Coeff.Variation	0.63	Coeff.Variation	1.22	Coeff.Variation	1.20

No Jetting N<40 PDA EOD Coastal Concrete Nordlund

					Total			Shaft			Toe		
File No.	D L(Ton)	jetting	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nord
17	60	n	D20	40	285	440	0.65	112	150	0.75	173	290	0.60
18	60	n	D20	40	270	293	0.92	85	57	1.49	185	236	0.78
19	80	n	D24	27	285	300	0.95	46	121	0.38	239	179	1.34
21	45	n	D12	39	100	85	1.18	44	13	3.38	56	72	0.78
30	100	n	D20	39	241	542	0.44	60	262	0.23	181	280	0.65
35	100	n	D20	39	209	554	0.38	55	322	0.17	154	232	0.66
36	100	n	D20	33	255	451	0.57	63	328	0.19	192	123	1.56
39	70	n	D16	15	144	83	1.73	50	60	0.83	94	23	4.09
45	30	n	D12	19	75	46	1.63	28	24	1.17	47	22	2.14
48	50	n	D12	35	156	221	0.71	46	137	0.34	110	84	1.31
53	110	n	D24	38	405	487	0.83	52	122	0.43	353	365	0.97
54	70	n	D20	23	143	195	0.73	25	168	0.15	118	27	4.37
75	250	n	D30	39	659	1100	0.60	122	687	0.18	537	413	1.30
90	200	n	D30	16	302	536	0.56	65	479	0.14	237	57	4.16
95	200	n	D30	34	697	715	0.97	127	259	0.49	570	456	1.25
98	200	n	D30	8	519	822	0.63	308	718	0.43	211	104	2.03
99	200	n	D30	21	603	521	1.16	145	401	0.36	458	120	3.82
101	45	n	D12	21	75	59	1.27	13	48	0.27	62	11	5.64
105	45	n	D12	12	85	18	4.72	4	13	0.31	81	5	16.20
122	100	n	D20	14	297	117	2.54	108	29	3.72	189	88	2.15
141	100	n	D24	19	378	94	4.02	165	37	4.46	213	57	3.74

107A*	100	n	D20	27	222	234	0.95	26	125	0.21	196	109	1.80
32*	100	n	D20	39	169	258	0.66	26	38	0.68	143	220	0.65
33*	100	n	D20	39	196	308	0.64	90	88	1.02	106	220	0.48
37B	100	n	D24	24	270	183	1.48	88	61	1.44	182	122	1.49
56*	80	n	D20	12	142	166	0.86	81	160	0.51	61	6	10.17
87*	250	n	D30	38	392	1005	0.39	117	471	0.25	275	534	0.51
89*	237	n	D30	17	355	585	0.61	55	521	0.11	300	64	4.69
91*	100	n	D20	22	213	158	1.35	81	81	1.00	132	77	1.71
92*	200	n	D30	14	392	424	0.92	110	378	0.29	282	46	6.13
93*	200	n	D30	20	177	482	0.37	111	396	0.28	66	86	0.77
94*	237	n	D30	13	315	617	0.51	135	574	0.24	180	43	4.19
96*	200	n	D30	28	575	574	1.00	179	256	0.70	396	318	1.25

Mean	1.12	Mean	0.81	Mean	2.83
Stand.Dev	0.96	Stand.Dev	1.06	Stand.Dev	3.21
Coeff.Variation	0.86	Coeff.Variation	1.31	Coeff.Variation	1.13

With Jetting N<40 PDA EOD Coastal Concrete Meyerhof

					Total			Shaft			Toe		
File No.	D.L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
3	55	y	D20	22	156	113	1.38	117	47	2.49	39	66	0.59
5	50	y	D12	30	117	99	1.18	24.5	37	0.66	92.5	62	1.49
6	100	y	D24	24	210	137	1.53	18	32	0.56	192	105	1.83
7	100	y	D24	38	425	386	1.10	102	40	2.55	323	346	0.93
11	85	y	D20	23	91	117	0.78	22	27	0.81	69	90	0.77
22	85	y	D20	33	215	301	0.71	51	41	1.24	164	260	0.63
23	85	y	D20	38	389	290	1.34	72	65	1.11	317	225	1.41
24	75	y	D20	33	240	264	0.91	29	10	2.90	211	254	0.83
28	100	y	D20	26	187	187	1.00	112	96	1.17	75	91	0.82
31	100	y	D20	32	167	289	0.58	40	61	0.66	127	228	0.56
46	60	y	D20	22	155	112	1.38	9	9	1.00	146	103	1.42
52	60	y	D20	25	211	201	1.05	36	44	0.82	175	157	1.11
55	60	y	D20	28	238	169	1.41	15	62	0.24	223	107	2.08
61	250	y	D30	18	553	89	6.21	443	25	17.72	110	64	1.72
62	250	y	D30	30	505	244	2.07	312	110	2.84	193	134	1.44
66	250	y	D30	23	574	174	3.30	455	92	4.95	119	82	1.45
67	250	y	D30	30	648	215	3.01	305	73	4.18	343	142	2.42
77	250	y	D30	28	458	182	2.52	52	33	1.58	406	149	2.72
78	250	y	D30	26	529	167	3.17	96	51	1.88	433	116	3.73
82	250	y	D30	27	533	161	3.31	406	60	6.77	127	101	1.26
108	100	y	D20	39	230	359	0.64	61	45	1.36	169	314	0.54

114	100	y	D24	16	223	105	2.12	127	14	9.07	119	82	1.45
115	100	y	D24	11	316	65	4.86	51	23	2.22	265	42	6.31
117	200	y	D30	30	461	185	2.49	153	45	3.40	308	140	2.20
118	200	y	D30	30	416	330	1.26	210	73	2.88	206	257	0.80
1*	100	y	D20	25	116	140	0.83	35	78	0.45	81	62	1.31
4A*	100	y	D24	22	107	85	1.26	30	30	1.00	77	55	1.40
4B	100	y	D24	26	417	171	2.44	128	76	1.68	289	95	3.04
4C*	100	y	D20	13	220	51	4.31	157	22	7.14	63	29	2.17
58*	250	y	D30	30	681	208	3.27	78	69	1.13	603	139	4.34
60A*	250	y	D30	16	683	164	4.16	462	94	4.91	221	70	3.16
60B*	250	y	D30	15	797	123	6.48	212	54	3.93	585	69	8.48
74*	250	y	D30	24	565	263.22	2.15	241	164.22	1.47	324	99	3.27
85*	250	y	D30	4	227	223	1.02	114	162	0.70	113	61	1.85
86*	250	y	D30	16	135	100	1.35	48	34	1.41	87	66	1.32

Mean	2.19	Mean	2.82	Mean	2.02
Stand.Dev	1.54	Stand.Dev	3.32	Stand.Dev	1.66
Coeff.Variation	0.70	Coeff.Variation	1.18	Coeff.Variation	0.82

No Jetting N<40 PDA EOD Coastal Concrete Meyerhof

					Total			Shaft			Toe		
File No.	D.L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
17	60	n	D20	40	285	238	1.20	112	77	1.45	173	161	1.07
18	60	n	D20	40	270	264	1.02	85	35	2.43	185	229	0.81
19	80	n	D24	27	285	311	0.92	46	66	0.70	239	245	0.98
21	45	n	D12	39	100	64	1.56	44	16	2.75	56	48	1.17
35	100	n	D20	22	209	193	1.08	55	144	0.38	154	49	3.14
36	100	n	D20	24	255	127	2.01	63	77	0.82	192	50	3.84
39	70	n	D16	12	144	70	2.06	50	52	0.96	94	18	5.22
45	30	n	D12	13	75	37	2.03	28	26	1.08	47	11	4.27
48	50	n	D12	35	156	68	2.29	46	22	2.09	110	46	2.39
53	110	n	D24	21	405	118	3.43	52	26	2.00	353	92	3.84
54	70	n	D20	18	143	100	1.43	25	64	0.39	118	36	3.28
90	200	n	D30	15	302	201	1.50	65	137	0.47	237	64	3.70
95	200	n	D30	32	697	548	1.27	127	72	1.76	570	476	1.20
98	200	n	D30	9	519	257	2.02	308	151	2.04	211	106	1.99
99	200	n	D30	22	603	316	1.91	145	190	0.76	458	126	3.63
101	45	n	D12	17	75	45	1.67	13	31	0.42	62	14	4.43
105	45	n	D12	21	85	45	1.89	4	15	0.27	81	30	2.70
122	100	n	D20	23	297	218	1.36	108	19	5.68	189	199	0.95
140	100	n	D24	25	377	865	0.44	28	74	0.38	349	791	0.44
141	100	n	D24	19	378	201	1.88	165	54	3.06	213	147	1.45
107A*	100	n	D20	20	222	61	3.64	26	14	1.86	196	47	4.17

32*	100	n	D20	20	169	97	1.74	26	10	2.60	143	87	1.64
33*	100	n	D20	25	196	384	0.51	90	68	1.32	106	316	0.34
37A	100	n	D24	30	499	531	0.94	137	109	1.26	362	422	0.86
37B	100	n	D24	24	270	273	0.99	88	53	1.66	182	220	0.83
56*	80	n	D20	11	142	188	0.76	81	149	0.54	61	39	1.56
87*	250	n	D30	32	392	412	0.95	117	175	0.67	275	237	1.16
89*	237	n	D30	17	355	271	1.31	55	203	0.27	300	68	4.41
91*	100	n	D20	19	213	241	0.88	81	98	0.83	132	143	0.92
92*	200	n	D30	14	392	192	2.04	110	128	0.86	282	64	4.41
93*	200	n	D30	15	177	193	0.92	111	128	0.87	66	65	1.02
94*	237	n	D30	13	315	217	1.45	135	151	0.89	180	66	2.73
96*	200	n	D30	28	575	533	1.08	179	193	0.93	396	340	1.16

Mean	1.52	Mean	1.35	Mean	2.29
Stand.Dev	0.71	Stand.Dev	1.10	Stand.Dev	1.47
Coeff.Variation	0.47	Coeff.Variation	0.82	Coeff.Variation	0.64

With Jetting N>40 PDA EOD Coastal Concrete Vesic

					Total			Shaft			Toe		
File No.	D. L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
7	100	y	D24	43	425	586	0.73	102	92	1.11	323	494	0.65
8	100	y	D24	75	218	1029	0.21	20	74	0.27	198	955	0.21
9	100	y	D24	100	216	1609	0.13	51	93	0.55	165	1516	0.11
12	60	y	D20	41	188	108	1.74	29	18	1.61	159	90	1.77
13	80	y	D20	50	127	365	0.35	46	41	1.12	81	324	0.25
14	80	y	D20	45	138	307	0.45	95	60	1.58	43	247	0.17
23	85	y	D20	62	389	580	0.67	72	94	0.77	317	486	0.65
24	75	y	D20	51	240	370	0.65	29	36	0.81	211	334	0.63
51	60	y	D20	50	162	432	0.38	23	66	0.35	139	366	0.38
59	250	y	D30	70	645	1716	0.38	275	182	1.51	370	1534	0.24
64	250	y	D30	55	648	1401	0.46	289	192	1.51	359	1209	0.30
71	250	y	D30	100	832	2753	0.30	197	312	0.63	635	2441	0.26
76	250	y	D30	44	529	1055	0.50	135	169	0.80	394	886	0.44
78	250	y	D30	54	529	1262	0.42	96	132	0.73	433	1130	0.38
80	250	y	D30	62	815	1578	0.52	673	196	3.43	142	1382	0.10
107B	100	y	D20	60	274	532	0.52	26	105	0.25	248	427	0.58
58*	253	y	D30	50	681	755	0.90	78	137	0.57	603	618	0.98

Mean	0.55	Mean	1.03	Mean	0.48
Stand.Dev	0.36	Stand.Dev	0.77	Stand.Dev	0.41
Coeff.Variation	0.66	Coeff.Variation	0.74	Coeff.Variation	0.85

No Jetting N>40 PDA EOD Coastal Concrete Vesic

					Total			Shaft			Toe		
File No.	D. L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
140	100	n	D24	62	377	710	0.53	28	89	0.31	349	621	0.56
37A	100	n	D24	60	499	484	1.03	137	123	1.11	362	361	1.00

Mean	0.78	Mean	0.71	Mean	0.78
Stand.Dev	0.35	Stand.Dev	0.57	Stand.Dev	0.31
Coeff.Variation	0.45	Coeff.Variation	0.79	Coeff.Variation	0.40

With Jetting N>40 PDA EOD Coastal Concrete Nordlund

					Total			Shaft			Toe		
File No.	D. L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
7	100	y	D24	43	425	739	0.58	102	253	0.40	323	486	0.66
8	100	y	D24	75	218	1601	0.14	20	246	0.08	198	1355	0.15
9	100	y	D24	100	216	1581	0.14	51	226	0.23	165	1355	0.12
12	60	y	D20	41	188	189	0.99	29	10	2.90	159	179	0.89
13	80	y	D20	50	127	512	0.25	46	80	0.58	81	432	0.19
14	80	y	D20	45	138	403	0.34	95	86	1.10	43	317	0.14
23	85	y	D20	62	389	941	0.41	72	180	0.40	317	761	0.42
24	75	y	D20	51	240	535	0.45	29	75	0.39	211	460	0.46
51	60	y	D20	50	162	634	0.26	23	167	0.14	139	467	0.30
59	250	y	D30	70	645	2337	0.28	275	838	0.33	370	1499	0.25
64	250	y	D30	55	648	1934	0.34	289	1226	0.24	359	708	0.51
71	250	y	D30	100	832	2703	0.31	197	1203	0.16	635	1500	0.42
76	250	y	D30	44	529	1373	0.39	135	726	0.19	394	647	0.61
78	250	y	D30	54	529	1516	0.35	96	618	0.16	433	898	0.48
80	250	y	D30	62	815	2091	0.39	673	1214	0.55	142	877	0.16
107B	100	y	D20	60	274	870	0.31	26	201	0.13	248	669	0.37
58*	253	y	D30	50	681	1687	0.40	78	791	0.10	603	896	0.67

Mean	0.37	Mean	0.47	Mean	0.40
Stand.Dev	0.19	Stand.Dev	0.67	Stand.Dev	0.22
Coeff.Variation	0.52	Coeff.Variation	1.42	Coeff.Variation	0.56

No Jetting N>40 PDA EOD Coastal Concrete Nordlund

				Total			Shaft			Toe		
D. L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
100	n	D24	62	377	881	0.43	28	111	0.25	349	770	0.45
100	n	D24	60	499	630	0.79	137	76	1.80	362	554	0.65

Mean	0.61	Mean	1.03	Mean	0.55
Stand.Dev	0.26	Stand.Dev	1.10	Stand.Dev	0.14
Coeff.Variation	0.42	Coeff.Variation	1.07	Coeff.Variation	0.26

With Jetting N>40 PDA EOD Coastal Concrete Meyerhof (SPT)

					Total			Shaft			Toe		
File No.	D. L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
8	100	y	D24	41	218	421	0.52	20	25	0.80	198	396	0.50
9	100	y	D24	100	216	848	0.25	51	57	0.89	165	791	0.21
12	60	y	D20	41	188	140	1.34	29	11	2.64	159	129	1.23
13	80	y	D20	50	127	220	0.58	46	16	2.88	81	204	0.40
14	80	y	D20	45	138	390	0.35	95	42	2.26	43	348	0.12
51	60	y	D20	50	162	409	0.40	23	36	0.64	139	373	0.37
59	250	y	D30	53	645	775	0.83	275	109	2.52	370	666	0.56
64	250	y	D30	45	648	532	1.22	289	126	2.29	359	406	0.88
68	250	y	D30	56	502	846	0.59	273	177.2	1.54	229	668.8	0.34
69	250	y	D30	50	502	748	0.67	339	240	1.41	163	508	0.32
70	250	y	D30	55	890	800	1.11	235	224	1.05	655	576	1.14
71	250	y	D30	60	832	966	0.86	197	289	0.68	635	677	0.94
76	250	y	D30	44	529	703	0.75	135	96	1.41	394	607	0.65
80	250	y	D30	80	815	433	1.88	673	116	5.80	142	317	0.45
107B	100	y	D20	65	274	594	0.46	26	84	0.31	248	510	0.49

Mean	0.79	Mean	1.81	Mean	0.57
Stand.Dev	0.44	Stand.Dev	1.37	Stand.Dev	0.33
Coeff.Variation	0.56	Coeff.Variation	0.76	Coeff.Variation	0.58

No Jetting N>40 PDA EOD Coastal Concrete   Meyerhof (SPT)

					Total			Shaft			Toe		
File No.	D. L. (Ton)	jetting	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
30	100	n	D20	47	241	383	0.63	60	54	1.11	181	329	0.55
75	250	n	D30	51	659	769	0.86	122	94	1.30	537	675	0.80

Mean	0.74	Mean	1.20	Mean	0.67
Stand.Dev	0.16	Stand.Dev	0.13	Stand.Dev	0.17
Coeff.Variation	0.22	Coeff.Variation	0.11	Coeff.Variation	0.26

With Jetting, Coastal Conc PDA Restrike, Vesic

					Total			Skin			Toe		
File No.	D.L. (Ton)	Pile Size	jetting	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
1*	100	D20	y	23	206	300	0.69	125	79	1.58	81	221	0.37
4A*	100	D24	y	22	218	404	0.54	106	68	1.56	112	336	0.33
4C*	100	D20	y	13	226	179	1.26	161	42	3.83	65	137	0.47
11*	85	D20	y	23	167	207	0.81	23	47	0.49	69	160	0.43
60A*	250	D30	y	18	1128	817	1.38	897	154	5.82	231	663	0.35
63	250	D30	y	17	662	816	0.81	183	163	1.12	479	653	0.73
65	250	D30	y	14	955	740	1.29	655	168	3.90	300	572	0.52
74*	250	D30	y	19	950	870	1.09	759	215	3.53	191	655	0.29
79	250	D30	y	20	877	887	0.99	766	199	3.85	111	688	0.16
81	250	D30	y	35	812	937	0.87	561	121	4.64	251	816	0.31
85*	250	D30	y	4	262	526	0.50	120	183	0.66	142	343	0.41
86*	250	D30	y	13	525	689	0.76	392	130	3.02	133	559	0.24
58*	250	D30	y	50	765	755	1.01	141	137	1.03	624	618	1.01
83	250	D30	y	53	825	1375	0.60	670	163	4.11	155	1212	0.13
84	250	D30	y	56	900	1349	0.67	553	139	3.98	347	1210	0.29

Mean	0.88	Mean	2.87	Mean	0.40
Stand.Dev	0.28	Stand.Dev	1.66	Stand.Dev	0.22
Coeff.Variation	0.32	Coeff.Variation	0.58	Coeff.Variation	0.56

No Jetting, Coastal Conc PDA Restrike, Vesic

					Total			Skin			Toe		
File No.	D.L. (Ton)	Pile Size	jetting	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
32*	100	D20	n	39	265	220	1.20	53	28	1.89	212	192	1.10
33*	100	D20	n	39	266	290	0.92	108	98	1.10	158	192	0.82
56*	80	D20	n	12	247	386	0.64	209	158	1.32	38	228	0.17
87*	250	D30	n	38	540	459	1.18	249	101	2.47	291	358	0.81
89*	237	D30	n	17	701	676	1.04	378	209	1.81	323	467	0.69
91*	100	D20	n	22	288	217	1.33	85	70	1.21	203	147	1.38
92*	200	D30	n	14	719	533	1.35	374	111	3.37	345	422	0.82
93*	200	D30	n	20	712	646	1.10	301	122	2.47	411	524	0.78
94*	237	D30	n	13	629	639	0.98	360	225	1.60	269	414	0.65
96*	200	D30	n	28	650	694	0.94	183	243	0.75	467	451	1.04
107A*	100	D20	n	27	265	269	0.99	96	44	2.18	169	225	0.75

Mean	1.06	Mean	1.83	Mean	0.82
Stand.Dev	0.20	Stand.Dev	0.75	Stand.Dev	0.30
Coeff.Variation	0.19	Coeff.Variation	0.41	Coeff.Variation	0.37

With Jetting, Coastal Concrete Restrike, Nordlund

					Total			Skin			Toe		
File No.	D.L. (Ton)	Pile Size	jetting	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
1*	100	D20	y	23	206	276	0.75	125	221	0.57	81	55	1.47
4A*	100	D24	y	22	218	370	0.59	106	303	0.35	112	67	1.67
4C*	100	D20	y	13	226	118	1.92	161	92	1.75	65	26	2.50
11*	85	D20	y	23	91	121	0.75	22	22	1.00	69	99	0.70
60A*	250	D30	y	18	1128	1011	1.12	897	963	0.93	231	48	4.81
63	250	D30	y	17	662	985	0.67	183	941	0.19	479	44	10.89
65	250	D30	y	14	955	1062	0.90	655	1020	0.64	300	42	7.14
74*	250	D30	y	19	950	1028	0.92	759	967	0.78	191	61	3.13
79	250	D30	y	20	877	1064	0.82	766	1007	0.76	111	57	1.95
81	250	D30	y	35	812	859	0.95	561	608	0.92	251	251	1.00
85*	250	D30	y	4	262	445	0.59	120	403	0.30	142	42	3.38
86*	250	D30	y	13	525	599	0.88	392	583	0.67	133	16	8.31
58*	250	D30	y	50	765	1687	0.45	141	791	0.18	624	896	0.70
83	250	D30	y	53	825	731	1.13	670	711	0.94	155	20	7.75
84	250	D30	y	56	900	735	1.22	553	680	0.81	347	55	6.31

Mean	0.91	Mean	0.72	Mean	4.11
Stand.Dev	0.35	Stand.Dev	0.40	Stand.Dev	3.23
Coeff.Variation	0.39	Coeff.Variation	0.55	Coeff.Variation	0.78

No Jetting, Coastal Concrete Restrike, Nordlund

					Total			Skin			Toe		
File No.	D.L. (Ton)	Pile Size	jetting	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
32*	100	D20	n	39	265	258	1.03	53	38	1.39	212	220	0.96
33*	100	D20	n	39	266	308	0.86	108	88	1.23	158	220	0.72
56*	80	D20	n	12	247	166	1.49	209	160	1.31	38	6	6.33
87*	250	D30	n	38	540	1005	0.54	249	471	0.53	291	534	0.54
89*	237	D30	n	17	701	585	1.20	378	521	0.73	323	64	5.05
91*	100	D20	n	22	288	158	1.82	85	81	1.05	203	77	2.64
92*	200	D30	n	14	719	424	1.70	374	378	0.99	345	46	7.50
93*	200	D30	n	20	712	482	1.48	301	396	0.76	411	86	4.78
94*	237	D30	n	13	629	617	1.02	360	574	0.63	269	43	6.26
96*	200	D30	n	28	650	574	1.13	183	256	0.71	467	318	1.47
107A*	100	D20	n	27	265	234	1.13	96	125	0.77	169	109	1.55

Mean	1.22	Mean	0.92	Mean	3.44
Stand.Dev	0.38	Stand.Dev	0.29	Stand.Dev	2.59
Coeff.Variation	0.31	Coeff.Variation	0.32	Coeff.Variation	0.75

With Jetting, Coastal Concrete Restrike, Meyerhof

					Total			Skin			Toe		
File No.	D.L. (Ton)	Pile Size	jetting	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
1*	100	D20	y	25	206	140	1.47	125	78	1.60	81	62	1.31
4A*	100	D24	y	22	218	85	2.56	106	30	3.53	112	55	2.04
4C*	100	D20	y	13	226	51	4.43	161	22	7.32	65	29	2.24
11*	85	D20	y	23	91	117	0.78	22	27	0.81	69	90	0.77
58*	250	D30	y	30	765	208	3.68	141	69	2.04	624	139	4.49
60A*	250	D30	y	16	1128	164	6.88	897	94	9.54	231	70	3.30
63	250	D30	y	32	662	246	2.69	183	106	1.73	479	140	3.42
65	250	D30	y	20	955	192	4.97	655	126	5.20	300	66	4.55
74*	250	D30	y	24	950	263	3.61	759	164	4.62	191	99	1.93
79	250	D30	y	16	877	206	4.25	766	137	5.59	111	69	1.60
81	250	D30	y	25	812	137	5.93	561	37	15.16	251	100	2.51
83	250	D30	y	35	825	268	3.08	670	73	9.18	155	195	0.79
85*	250	D30	y	4	262	223	1.17	120	162	0.74	142	61	2.33
86*	250	D30	y	16	525	100	5.25	392	34	11.53	133	66	2.02
84	250	D30	y	100	900	209	4.31	553	64	8.64	347	145	2.39

Mean	3.67	Mean	5.82	Mean	2.38
Stand.Dev	1.75	Stand.Dev	4.33	Stand.Dev	1.15
Coeff.Variation	0.48	Coeff.Variation	0.74	Coeff.Variation	0.48

No Jetting, Coastal Concrete Restrike, Meyerhof

					Total			Skin			Toe		
File No.	D.L. (Ton)	Pile Size	jetting	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
32*	100	D20	n	20	265	97	2.73	53	10	5.30	212	87	2.44
33*	100	D20	n	25	266	384	0.69	108	68	1.59	158	316	0.50
56*	80	D20	n	11	247	188	1.31	209	149	1.40	38	39	0.97
87*	250	D30	n	32	540	412	1.31	249	175	1.42	291	237	1.23
89*	237	D30	n	17	701	271	2.59	378	203	1.86	323	68	4.75
91*	100	D20	n	19	288	241	1.20	85	98	0.87	203	143	1.42
92*	200	D30	n	14	719	192	3.74	374	128	2.92	345	64	5.39
93*	200	D30	n	15	712	193	3.69	301	128	2.35	411	65	6.32
94*	237	D30	n	13	629	217	2.90	360	151	2.38	269	66	4.08
96*	200	D30	n	28	650	533	1.22	183	193	0.95	467	340	1.37
107A*	100	D20	n	20	265	61	4.34	96	14	6.86	169	47	3.60

Mean	2.34	Mean	2.54	Mean	2.92
Stand.Dev	1.25	Stand.Dev	1.89	Stand.Dev	2.01
Coeff.Variation	0.54	Coeff.Variation	0.74	Coeff.Variation	0.69

Coastal Concrete Cylinder, Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Ve
26	350	D54	50	640	1114	0.57	342	206	1.66	298	908	
27	350	D54	24	359	645	0.56	272	139	1.96	87	506	
123	450	D66	46	639	1555	0.41	411	229	1.79	228	1326	

Mean	0.51	Mean	1.80	Mean	
Stand.Dev	0.09	Stand.Dev	0.15	Stand.Dev	
Coeff.Variation	0.17	Coeff.Variation	0.08	Coeff.Variation	

Coastal Concrete Cylinder, Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Norc
26	350	D54	50	640	2734	0.23	342	1234	0.28	298	1500	
27	350	D54	24	359	1057	0.34	272	751	0.36	87	306	
123	450	D66	46	639	3174	0.20	411	1674	0.25	228	1500	

Mean	0.26	Mean	0.29	Mean	
Stand.Dev	0.07	Stand.Dev	0.06	Stand.Dev	
Coeff.Variation	0.28	Coeff.Variation	0.20	Coeff.Variation	

Coastal Concrete Cylinder, Meyerhof

		Total			Skin			Toe		
Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
D54	45	640	601	1.06	342	58	5.90	298	543	0.55
D54	15	359	431	0.83	272	375	0.73	87	56	1.55
D66	46	639	552	1.16	411	28	14.68	228	524	0.44

Mean	1.02	Mean	7.10	Mean	0.85
Stand.Dev	0.17	Stand.Dev	7.05	Stand.Dev	0.62
Coeff.Variation	0.16	Coeff.Variation	0.99	Coeff.Variation	0.73

PDA EOD Coastal Concrete Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N @toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
85*	250	D30	4	227	526	0.43	114	183	0.62	113	343	0.33
98	200	D30	8	519	612	0.85	308	152	2.03	211	460	0.46
56*	80	D20	12	142	386	0.37	81	158	0.51	61	228	0.27
105	45	D12	12	85	20	4.25	4	15	0.27	81	5	16.20
4C*	100	D20	13	220	179	1.23	157	42	3.74	63	137	0.46
86*	250	D30	13	135	689	0.20	48	130	0.37	87	559	0.16
94*	237	D30	13	315	639	0.49	135	225	0.60	180	414	0.43
70	250	D30	14	890	922	0.97	235	283	0.83	655	639	1.03
92*	200	D30	14	392	533	0.74	110	111	0.99	282	422	0.67
122	100	D20	14	297	151	1.97	108	45	2.40	189	106	1.78
4B	100	D24	15	417	403	1.03	128	102	1.25	289	301	0.96
39	70	D16	15	144	142	1.01	50	60	0.83	94	82	1.15
60B*	250	D30	16	797	680	1.17	212	117	1.81	585	563	1.04
90	200	D30	16	302	615	0.49	65	123	0.53	237	492	0.48
69	250	D30	17	502	922	0.54	339	276	1.23	163	646	0.25
89*	237	D30	17	355	676	0.53	55	209	0.26	300	467	0.64
60A*	250	D30	18	683	817	0.84	462	154	3.00	221	663	0.33
45	30	D12	19	75	85	0.88	28	32	0.88	47	53	0.89
61	250	D30	19	553	757	0.73	443	126	3.52	110	631	0.17
74*	250	D30	19	565	870	0.65	241	215	1.12	324	655	0.49
141	100	D24	19	378	222	1.70	165	74	2.23	213	148	1.44

93*	200	D30	20	177	646	0.27	111	122	0.91	66	524	0.13
66	250	D30	21	574	807	0.71	455	163	2.79	119	644	0.18
99	200	D30	21	603	646	0.93	145	186	0.78	458	460	1.00
101	45	D12	21	75	95	0.79	13	31	0.42	62	64	0.97
115	100	D24	21	316	215	1.47	51	36	1.42	265	179	1.48
4A*	100	D24	22	107	404	0.26	30	68	0.44	77	336	0.23
46	60	D20	22	155	164	0.95	9	28	0.32	146	136	1.07
91*	100	D20	22	213	217	0.98	81	70	1.16	132	147	0.90
1*	100	D20	23	116	300	0.39	35	79	0.44	81	221	0.37
11	85	D20	23	91	207	0.44	22	47	0.47	69	160	0.43
54	70	D20	23	143	282	0.51	25	67	0.37	118	215	0.55
37B	100	D24	24	270	268	1.01	88	86	1.02	182	182	1.00
52	60	D20	25	211	167	1.26	36	32	1.13	175	135	1.30
55	60	D20	25	238	339	0.70	15	115	0.13	223	224	1.00
114	100	D24	26	223	210	1.06	127	27	4.70	96	183	0.52
19	80	D24	27	285	363	0.79	46	100	0.46	239	263	0.91
62	250	D30	27	505	935	0.54	312	185	1.69	193	750	0.26
107A*	100	D20	27	222	269	0.83	26	44	0.59	196	225	0.87
96*	200	D30	28	575	694	0.83	179	243	0.74	396	451	0.88
117	200	D30	28	461	764	0.60	153	127	1.20	308	637	0.48
3	55	D20	29	156	292	0.53	117	67	1.75	39	225	0.17
5	50	D12	29	117	121	0.97	24.5	60	0.41	92.5	61	1.52
6	100	D24	29	210	436	0.48	18	72	0.25	192	364	0.53
28	100	D20	29	187	361	0.52	112	120	0.93	75	241	0.31
118	200	D30	30	416	857	0.49	210	152	1.38	206	705	0.29

31	100	D20	32	167	299	0.56	40	81	0.49	127	218	0.58
77	250	D30	32	458	838	0.55	52	107	0.49	406	731	0.56
82	250	D30	32	533	966	0.55	406	131	3.10	127	835	0.15
22	85	D20	33	215	295	0.73	51	76	0.67	164	219	0.75
36	100	D20	33	255	407	0.63	63	88	0.72	192	319	0.60
95	200	D30	34	697	715	0.97	127	233	0.55	570	482	1.18
48	50	D12	35	156	136	1.15	46	31	1.48	110	105	1.05
53	110	D24	38	405	440	0.92	52	53	0.98	353	387	0.91
87*	250	D30	38	392	459	0.85	117	101	1.16	275	358	0.77
108	100	D20	38	230	334	0.69	61	83	0.73	169	251	0.67
21	45	D12	39	100	76	1.32	44	18	2.44	56	58	0.97
30	100	D20	39	241	409	0.59	60	101	0.59	181	308	0.59
32*	100	D20	39	169	220	0.77	26	28	0.93	143	192	0.74
33*	100	D20	39	196	290	0.68	90	98	0.92	106	192	0.55
35	100	D20	39	209	513	0.41	55	185	0.30	154	328	0.47
68	250	D30	39	502	1176	0.43	273	258	1.06	229	918	0.25
75	250	D30	39	659	981	0.67	122	153	0.80	537	828	0.65
17	60	D20	40	285	398	0.72	112	107	1.05	173	291	0.59
18	60	D20	40	270	252	1.07	85	62	1.37	185	190	0.97
67	250	D30	40	648	1107	0.59	305	183	1.67	343	924	0.37
12	60	D20	41	188	108	1.74	29	18	1.61	159	90	1.77
7	100	D24	43	425	586	0.73	102	92	1.11	323	494	0.65
76	250	D30	44	529	1055	0.50	135	169	0.80	394	886	0.44
14	80	D20	45	138	307	0.45	95	60	1.58	43	247	0.17
13	80	D20	50	127	365	0.35	46	41	1.12	81	324	0.25

51	60	D20	50	162	432	0.38	23	66	0.35	139	366	0.38
58*	253	D30	50	681	755	0.90	78	137	0.57	603	618	0.98
24	75	D20	51	240	370	0.65	29	36	0.81	211	334	0.63
78	250	D30	54	529	1262	0.42	96	132	0.73	433	1130	0.38
64	250	D30	55	648	1401	0.46	289	192	1.51	359	1209	0.30
37A	100	D24	60	499	484	1.03	137	123	1.11	362	361	1.00
107B	100	D20	60	274	532	0.52	26	105	0.25	248	427	0.58
23	85	D20	62	389	580	0.67	72	94	0.77	317	486	0.65
80	250	D30	62	815	1578	0.52	673	196	3.43	142	1382	0.10
140	100	D24	62	377	710	0.53	28	89	0.31	349	621	0.56
59	250	D30	70	645	1716	0.38	275	182	1.51	370	1534	0.24
8	100	D24	75	218	1029	0.21	20	74	0.27	198	955	0.21
9	100	D24	100	216	1609	0.13	51	93	0.55	165	1516	0.11
71	250	D30	100	832	2753	0.30	197	312	0.63	635	2441	0.26

Mean	0.77	Mean	1.12	Mean	0.82
Stand.Dev	0.51	Stand.Dev	0.89	Stand.Dev	1.73
Coeff.Variation	0.67	Coeff.Variation	0.79	Coeff.Variation	2.10

PDA EOD Coastal Concrete   Nordlund

				Total			Skin			Toe		
File No.	D L(Ton)	Pile Type	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nord
85*	250	D30	4	227	445	0.51	114	403	0.28	113	42	2.69
98	200	D30	8	519	822	0.63	308	718	0.43	211	104	2.03
56*	80	D20	12	142	166	0.86	81	160	0.51	61	6	10.17
105	45	D12	12	85	18	4.72	4	13	0.31	81	5	16.20
4C*	100	D20	13	220	118	1.86	157	92	1.71	63	26	2.42
86*	250	D30	13	135	599	0.23	48	583	0.08	87	16	5.44
94*	237	D30	13	315	617	0.51	135	574	0.24	180	43	4.19
70	250	D30	14	890	1805	0.49	235	1765	0.13	655	40	16.38
92*	200	D30	14	392	424	0.92	110	378	0.29	282	46	6.13
122	100	D20	14	297	117	2.54	108	29	3.72	189	88	2.15
4B	100	D24	15	417	425	0.98	128	392	0.33	289	33	8.76
39	70	D16	15	144	83	1.73	50	60	0.83	94	23	4.09
60B*	250	D30	16	797	727	1.10	212	679	0.31	585	48	12.19
90	200	D30	16	302	536	0.56	65	479	0.14	237	57	4.16
69	250	D30	17	502	1348	0.37	339	1303	0.26	163	45	3.62
89*	237	D30	17	355	585	0.61	55	521	0.11	300	64	4.69
60A*	250	D30	18	683	1011	0.68	462	963	0.48	221	48	4.60
45	30	D12	19	75	46	1.63	28	24	1.17	47	22	2.14
61	250	D30	19	553	816	0.68	443	759	0.58	110	57	1.93
74*	250	D30	19	565	1028	0.55	241	967	0.25	324	61	5.31
141	100	D24	19	378	94	4.02	165	37	4.46	213	57	3.74

93*	200	D30	20	177	482	0.37	111	396	0.28	66	86	0.77
66	250	D30	21	574	657	0.87	455	623	0.73	119	34	3.50
99	200	D30	21	603	521	1.16	145	401	0.36	458	120	3.82
101	45	D12	21	75	59	1.27	13	48	0.27	62	11	5.64
115	100	D24	21	316	133	2.38	51	37	1.38	87	16	5.44
4A*	100	D24	22	107	370	0.29	30	303	0.10	77	67	1.15
46	60	D20	22	155	128	1.21	9	43	0.21	146	85	1.72
91*	100	D20	22	213	158	1.35	81	81	1.00	132	77	1.71
1*	100	D20	23	116	276	0.42	35	221	0.16	81	55	1.47
11	85	D20	23	91	121	0.75	22	22	1.00	69	99	0.70
54	70	D20	23	143	195	0.73	25	168	0.15	118	27	4.37
37B	100	D24	24	270	183	1.48	88	61	1.44	182	122	1.49
52	60	D20	25	211	107	1.97	36	30	1.20	175	77	2.27
55	60	D20	25	238	308	0.77	15	228	0.07	223	80	2.79
114	100	D24	26	223	172	1.30	127	35	3.63	96	137	0.70
19	80	D24	27	285	300	0.95	46	121	0.38	239	179	1.34
62	250	D30	27	505	1246	0.41	312	1138	0.27	193	108	1.79
107A*	100	D20	27	222	234	0.95	26	125	0.21	196	109	1.80
96*	200	D30	28	575	574	1.00	179	256	0.70	396	318	1.25
117	200	D30	28	461	733	0.63	153	555	0.28	308	178	1.73
3	55	D20	29	156	219	0.71	117	71	1.65	39	148	0.26
5	50	D12	29	117	117	1.00	24.5	62	0.40	92.5	55	1.68
6	100	D24	29	210	389	0.54	18	226	0.08	192	163	1.18
28	100	D20	29	187	331	0.56	112	203	0.55	75	128	0.59
118	200	D30	30	416	840	0.50	210	651	0.32	206	189	1.09

31	100	D20	32	167	314	0.53	40	142	0.28	127	172	0.74
77	250	D30	32	458	766	0.60	52	541	0.10	406	225	1.80
82	250	D30	32	533	972	0.55	406	818	0.50	127	154	0.82
22	85	D20	33	215	283	0.76	51	103	0.50	164	180	0.91
36	100	D20	33	255	451	0.57	63	328	0.19	192	123	1.56
95	200	D30	34	697	715	0.97	127	259	0.49	570	456	1.25
48	50	D12	35	156	221	0.71	46	137	0.34	110	84	1.31
53	110	D24	38	405	487	0.83	52	122	0.43	353	365	0.97
87*	250	D30	38	392	1005	0.39	117	471	0.25	275	534	0.51
108	100	D20	38	230	371	0.62	61	128	0.48	169	243	0.70
21	45	D12	39	100	85	1.18	44	13	3.38	56	72	0.78
30	100	D20	39	241	542	0.44	60	262	0.23	181	280	0.65
32*	100	D20	39	169	258	0.66	26	38	0.68	143	220	0.65
33*	100	D20	39	196	308	0.64	90	88	1.02	106	220	0.48
35	100	D20	39	209	554	0.38	55	322	0.17	154	232	0.66
68	250	D30	39	502	1735	0.29	273	1449	0.19	229	286	0.80
75	250	D30	39	659	1100	0.60	122	687	0.18	537	413	1.30
17	60	D20	40	285	440	0.65	112	150	0.75	173	290	0.60
18	60	D20	40	270	293	0.92	85	57	1.49	185	236	0.78
67	250	D30	40	648	952	0.68	305	636	0.48	343	316	1.09
12	60	D20	41	188	189	0.99	29	10	2.90	159	179	0.89
7	100	D24	43	425	739	0.58	102	253	0.40	323	486	0.66
76	250	D30	44	529	1373	0.39	135	726	0.19	394	647	0.61
14	80	D20	45	138	403	0.34	95	86	1.10	43	317	0.14
13	80	D20	50	127	512	0.25	46	80	0.58	81	432	0.19

51	60	D20	50	162	634	0.26	23	167	0.14	139	467	0.30
58*	253	D30	50	681	1687	0.40	78	791	0.10	603	896	0.67
24	75	D20	51	240	535	0.45	29	75	0.39	211	460	0.46
78	250	D30	54	529	1516	0.35	96	618	0.16	433	898	0.48
64	250	D30	55	648	1934	0.34	289	1226	0.24	359	708	0.51
37A	100	D24	60	499	630	0.79	137	76	1.80	362	554	0.65
107B	100	D20	60	274	870	0.31	26	201	0.13	248	669	0.37
23	85	D20	62	389	941	0.41	72	180	0.40	317	761	0.42
80	250	D30	62	815	2091	0.39	673	1214	0.55	142	877	0.16
140	100	D24	62	377	881	0.43	28	111	0.25	349	770	0.45
59	250	D30	70	645	2337	0.28	275	838	0.33	370	1499	0.25
8	100	D24	75	218	1601	0.14	20	246	0.08	198	1355	0.15
9	100	D24	100	216	1581	0.14	51	226	0.23	165	1355	0.12
71	250	D30	100	832	2703	0.31	197	1203	0.16	635	1500	0.42

Mean	0.83	Mean	0.65	Mean	2.35
Stand.Dev	0.73	Stand.Dev	0.86	Stand.Dev	3.11
Coeff.Variation	0.88	Coeff.Variation	1.31	Coeff.Variation	1.33

PDA EOD Coastal Concrete Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
85*	250	D30	4	227	223	1.02	114	162	0.70	113	61	1.85
98	200	D30	9	519	257	2.02	308	151	2.04	211	106	1.99
56*	80	D20	11	142	188	0.76	81	149	0.54	61	39	1.56
115	100	D24	11	316	65	4.86	51	23	2.22	265	42	6.31
39	70	D16	12	144	70	2.06	50	52	0.96	94	18	5.22
4C*	100	D20	13	220	51	4.31	157	22	7.14	63	29	2.17
45	30	D12	13	75	37	2.03	28	26	1.08	47	11	4.27
94*	237	D30	13	315	217	1.45	135	151	0.89	180	66	2.73
92*	200	D30	14	392	192	2.04	110	128	0.86	282	64	4.41
60B*	250	D30	15	797	123	6.48	212	54	3.93	585	69	8.48
90	200	D30	15	302	201	1.50	65	137	0.47	237	64	3.70
93*	200	D30	15	177	193	0.92	111	128	0.87	66	65	1.02
60A*	250	D30	16	683	164	4.16	462	94	4.91	221	70	3.16
86*	250	D30	16	135	100	1.35	48	34	1.41	87	66	1.32
114	100	D24	16	223	105	2.12	127	14	9.07	61	39	1.56
89*	237	D30	17	355	271	1.31	55	203	0.27	300	68	4.41
101	45	D12	17	75	45	1.67	13	31	0.42	62	14	4.43
54	70	D20	18	143	100	1.43	25	64	0.39	118	36	3.28
61	250	D30	18	553	89	6.21	443	25	17.72	110	64	1.72
91*	100	D20	19	213	241	0.88	81	98	0.83	132	143	0.92
141	100	D24	19	378	201	1.88	165	54	3.06	213	147	1.45

32*	100	D20	20	169	97	1.74	26	10	2.60	143	87	1.64
107A*	100	D20	20	222	61	3.64	26	14	1.86	196	47	4.17
53	110	D24	21	405	118	3.43	52	26	2.00	353	92	3.84
105	45	D12	21	85	45	1.89	4	15	0.27	81	30	2.70
3	55	D20	22	156	113	1.38	117	47	2.49	39	66	0.59
4A*	100	D24	22	107	85	1.26	30	30	1.00	77	55	1.40
35	100	D20	22	209	193	1.08	55	144	0.38	154	49	3.14
46	60	D20	22	155	112	1.38	9	9	1.00	146	103	1.42
99	200	D30	22	603	316	1.91	145	190	0.76	458	126	3.63
11	85	D20	23	91	117	0.78	22	27	0.81	69	90	0.77
66	250	D30	23	574	174	3.30	455	92	4.95	119	82	1.45
122	100	D20	23	297	218	1.36	108	19	5.68	189	199	0.95
6	100	D24	24	210	137	1.53	18	32	0.56	192	105	1.83
36	100	D20	24	255	127	2.01	63	77	0.82	192	50	3.84
37B	100	D24	24	270	273	0.99	88	53	1.66	182	220	0.83
74*	250	D30	24	565	263	2.15	241	164	1.47	324	99	3.27
1*	100	D20	25	116	140	0.83	35	78	0.45	81	62	1.31
33*	100	D20	25	196	384	0.51	90	68	1.32	106	316	0.34
52	60	D20	25	211	201	1.05	36	44	0.82	175	157	1.11
140	100	D24	25	377	865	0.44	28	74	0.38	349	791	0.44
4B	100	D24	26	417	171	2.44	128	76	1.68	289	95	3.04
78	250	D30	26	529	167	3.17	96	51	1.88	433	116	3.73
82	250	D30	27	533	161	3.31	406	60	6.77	127	101	1.26
28	100	D20	26	187	187	1.00	112	96	1.17	75	91	0.82
19	80	D24	27	285	311	0.92	46	66	0.70	239	245	0.98

55	60	D20	28	238	169	1.41	15	62	0.24	223	107	2.08
77	250	D30	28	458	182	2.52	52	33	1.58	406	149	2.72
96*	200	D30	28	575	533	1.08	179	193	0.93	396	340	1.16
5	50	D12	30	117	99	1.18	24.5	37	0.66	92.5	62	1.49
37A	100	D24	30	499	531	0.94	137	109	1.26	362	422	0.86
58*	250	D30	30	681	208	3.27	78	69	1.13	603	139	4.34
62	250	D30	30	505	244	2.07	312	110	2.84	193	134	1.44
67	250	D30	30	648	215	3.01	305	73	4.18	343	142	2.42
117	200	D30	30	461	185	2.49	153	45	3.40	308	140	2.20
118	200	D30	30	416	330	1.26	210	73	2.88	206	257	0.80
31	100	D20	32	167	289	0.58	40	61	0.66	127	228	0.56
87*	250	D30	32	392	412	0.95	117	175	0.67	275	237	1.16
95	200	D30	32	697	548	1.27	127	72	1.76	570	476	1.20
22	85	D20	33	215	301	0.71	51	41	1.24	164	260	0.63
24	75	D20	33	240	264	0.91	29	10	2.90	211	254	0.83
48	50	D12	35	156	68	2.29	46	22	2.09	110	46	2.39
7	100	D24	38	425	386	1.10	102	40	2.55	323	346	0.93
23	85	D20	38	389	290	1.34	72	65	1.11	317	225	1.41
21	45	D12	39	100	64	1.56	44	16	2.75	56	48	1.17
108	100	D20	39	230	359	0.64	61	45	1.36	169	314	0.54
17	60	D20	40	285	238	1.20	112	77	1.45	173	161	1.07
18	60	D20	40	270	264	1.02	85	35	2.43	185	229	0.81
8	100	D24	41	218	421	0.52	20	25	0.80	198	396	0.50
12	60	D20	41	188	140	1.34	29	11	2.64	159	129	1.23
76	250	D30	44	529	703	0.75	135	96	1.41	394	607	0.65

14	80	D20	45	138	390	0.35	95	42	2.26	43	348	0.12
64	250	D30	45	648	532	1.22	289	126	2.29	359	406	0.88
30	100	D20	47	241	383	0.58	60	54	2.88	81	204	0.40
13	80	D20	50	127	220	0.58	46	16	2.88	81	204	0.40
51	60	D20	50	162	409	0.40	23	36	0.64	139	373	0.37
69	250	D30	50	502	748	0.67	339	240	1.41	163	508	0.32
75	250	D30	51	659	769	0.86	122	94	1.30	537	675	0.80
59	250	D30	53	645	775	0.83	275	109	2.52	370	666	0.56
70	250	D30	55	890	800	1.11	235	224	1.05	655	576	1.14
68	250	D30	56	502	846	0.59	273	177.2	1.54	229	668.8	0.34
71	250	D30	60	832	966	0.86	197	289	0.68	635	677	0.94
107B	100	D20	65	274	594	0.46	26	84	0.31	248	510	0.49
80	250	D30	80	815	433	1.88	673	116	5.80	142	317	0.45
9	100	D24	100	216	848	0.25	51	57	0.89	165	791	0.21

Mean	1.65	Mean	2.05	Mean	1.84
Stand.Dev	1.21	Stand.Dev	2.39	Stand.Dev	1.54
Coeff.Variation	0.73	Coeff.Variation	1.16	Coeff.Variation	0.84

PDA EOD Coastal Steel HP Vesic

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
10*	40	HP 12 X 53	12	87	76	1.14	62	75	0.83	25	1	25
106*	45	HP 12 X 53	14	110	77	1.43	89	71	1.25	21	6	3.50
49	45	HP 12 X 53	17	107	150	0.71	85	142	0.60	22	8	2.75
100	30	HP 14 X 73	23	63	168	0.38	50	154	0.32	13	14	0.93
50	45	HP 12 X 53	25	102	75	1.36	99	67	1.48	3	8	0.38
102	45	HP 12 X 53	26	96	212	0.45	88	204	0.43	8	8	1.00
104	45	HP 12 X 53	32	98	47	2.09	12	5	2.40	86	42	2.05
16	50	HP 12 X 53	34	94	115	0.82	80	104	0.77	14	11	1.27
110	60	HP 12 X 53	35	192	112	1.71	158	99	1.60	34	13	2.62
103	45	HP 12 X 53	38	72	89	0.81	45	82	0.55	27	7	3.86
121	70	HP 14 X 73	45	202	107	1.89	180	92	1.96	22	15	1.47
43	50	HP 14 X 73	55	111	176	0.63	91	157	0.58	20	19	1.05
44	50	HP 14 X 73	70	151	213	0.71	139	184	0.76	12	29	0.41
57	45	HP 12 X 53	100	68	126	0.54	44	86	0.51	24	40	0.60
111	50	HP 12 X 53	100	103	160	0.64	36	119	0.30	67	41	1.63
112	50	HP 12 X 53	100	169	158	1.07	91	117	0.78	78	41	1.90
113	50	HP 12 X 53	100	159	155	1.03	150	115	1.30	9	40	0.23

Mean	1.02	Mean	0.97	Mean	2.98
Stand.Dev	0.51	Stand.Dev	0.60	Stand.Dev	5.78
Coeff.Variation	0.50	Coeff.Variation	0.63	Coeff.Variation	1.94

PDA EOD Coastal Steel HP Nordlund

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
10*	40	HP 12 X 53	12	87	71	1.23	62	70	0.89	25	1	25.00
106*	45	HP 12 X 53	14	110	109	1.01	89	96	0.93	21	13	1.62
49	45	HP 12 X 53	17	107	141	0.76	85	140	0.61	22	1	22.00
100	30	HP 14 X 73	23	63	151	0.42	50	127	0.39	13	24	0.54
50	45	HP 12 X 53	25	102	112	0.91	99	110	0.90	3	2	1.50
102	45	HP 12 X 53	26	96	130	0.74	88	127	0.69	8	3	2.67
104	45	HP 12 X 53	32	98	32	3.06	12	26	0.46	86	6	14.33
16	50	HP 12 X 53	34	94	133	0.71	80	128	0.63	14	5	2.80
110	60	HP 12 X 53	35	192	127	1.51	158	121	1.31	34	6	5.67
103	45	HP 12 X 53	38	72	31	2.32	45	23	1.96	27	8	3.38
121	70	HP 14 X 73	45	202	95	2.13	180	77	2.34	22	18	1.22
43	50	HP 14 X 73	55	111	123	0.90	91	94	0.97	20	29	0.69
44	50	HP 14 X 73	70	151	150	1.01	139	120	1.16	12	30	0.40
57	45	HP 12 X 53	100	68	87	0.78	44	50	0.88	24	37	0.65
111	50	HP 12 X 53	100	103	146	0.71	36	110	0.33	67	36	1.86
112	50	HP 12 X 53	100	169	125	1.35	91	89	1.02	78	36	2.17
113	50	HP 12 X 53	100	159	127	1.25	150	91	1.65	9	36	0.25

Mean	1.22	Mean	1.01	Mean	5.10
Stand.Dev	0.69	Stand.Dev	0.55	Stand.Dev	7.69
Coeff.Variation	0.56	Coeff.Variation	0.54	Coeff.Variation	1.51

PDA EOD Coastal Steel HP Meyerhof

				Total			Skin			Toe		
File No.	Design Load (Ton)	Pile Type/Size	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
10*	40	HP 12 X 53	12	87	76	1.14	62	75	0.83	25	1	25.00
49	45	HP 12 X 53	17	107	130	0.82	85	129	0.66	22	1	22.00
50	45	HP 12 X 53	25	102	68	1.50	99	65	1.52	3	3	1.00
100	30	HP 14 X 73	25	63	135	0.47	50	108	0.46	13	27	0.48
102	45	HP 12 X 53	32	96	152	0.63	88	147	0.60	8	5	1.60
104	45	HP 12 X 53	33	98	48	2.04	12	38	0.32	86	10	8.60
106*	45	HP 12 X 53	33	110	157	0.70	89	151	0.59	21	6	3.50
16	50	HP 12 X 53	34	94	72	1.31	80	69	1.16	14	3	4.67
110	60	HP 12 X 53	35	192	99	1.94	158	93	1.70	34	6	5.67
121	70	HP 14 X 73	40	202	88	2.30	180	70	2.57	22	18	1.22
43	50	HP 14 X 73	41	111	158	0.70	91	140	0.65	20	18	1.11
103	45	HP 12 X 53	42	72	105	0.69	45	93	0.48	27	12	2.25
44	50	HP 14 X 73	90	151	206	0.73	139	168	0.83	12	38	0.32
57	45	HP 12 X 53	100	68	100	0.68	44	75	0.59	24	25	0.96
111	50	HP 12 X 53	100	103	132	0.78	36	105	0.34	67	27	2.48
112	50	HP 12 X 53	100	169	161	1.05	91	134	0.68	78	27	2.89
113	50	HP 12 X 53	100	159	123	1.29	150	96	1.56	9	27	0.33

Mean	1.10	Mean	0.91	Mean	4.95
Stand.Dev	0.55	Stand.Dev	0.60	Stand.Dev	7.33
Coeff.Variation	0.50	Coeff.Variation	0.66	Coeff.Variation	1.48

Coastal Conc PDA Restrike, Vesic

				Total			Skin			Toe		
File No.	Design Load(Ton)	Pile	N@Toe	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic	PDA	Vesic	PDA/Vesic
1*	100	D20	23	206	300	0.69	125	79	1.58	81	221	0.37
4A*	100	D24	22	218	404	0.54	106	68	1.56	112	336	0.33
4C*	100	D20	13	226	179	1.26	161	42	3.83	65	137	0.47
11*	85	D20	23	91	207	0.44	22	47	0.47	69	160	0.43
32*	100	D20	39	265	220	1.20	53	28	1.89	212	192	1.10
33*	100	D20	39	266	290	0.92	108	98	1.10	158	192	0.82
56*	80	D20	12	247	386	0.64	209	158	1.32	38	228	0.17
60A*	250	D30	18	1128	817	1.38	897	154	5.82	231	663	0.35
63	250	D30	17	662	816	0.81	183	163	1.12	479	653	0.73
65	250	D30	14	955	740	1.29	655	168	3.90	300	572	0.52
74*	250	D30	19	950	870	1.09	759	215	3.53	191	655	0.29
79	250	D30	20	877	887	0.99	766	199	3.85	111	688	0.16
81	250	D30	35	812	937	0.87	561	121	4.64	251	816	0.31
85*	250	D30	4	262	526	0.50	120	183	0.66	142	343	0.41
86*	250	D30	13	525	689	0.76	392	130	3.02	133	559	0.24
87*	250	D30	38	540	459	1.18	249	101	2.47	291	358	0.81
89*	237	D30	17	701	676	1.04	378	209	1.81	323	467	0.69
91*	100	D20	22	288	217	1.33	85	70	1.21	203	147	1.38
92*	200	D30	14	719	533	1.35	374	111	3.37	345	422	0.82
93*	200	D30	20	712	646	1.10	301	122	2.47	411	524	0.78

94*	237	D30	13	629	639	0.98	360	225	1.60	269	414	0.65
96*	200	D30	28	650	694	0.94	183	243	0.75	467	451	1.04
107A*	100	D20	27	265	269	0.99	96	44	2.18	169	225	0.75
58*	250	D30	50	765	755	1.01	141	137	1.03	624	618	1.01
83	250	D30	53	825	1375	0.60	670	163	4.11	155	1212	0.13
84	250	D30	56	900	1349	0.67	553	139	3.98	347	1210	0.29

Mean	0.94	Mean	2.43	Mean	0.58
Stand.Dev	0.28	Stand.Dev	1.43	Stand.Dev	0.33
Coeff.Variation	0.29	Coeff.Variation	0.59	Coeff.Variation	0.57

Coastal Concrete Restrike, Nordlund

				Total			Skin			Toe		
File No.	Design Load(Ton)	Pile	N@Toe	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund	PDA	Nordlund	PDA/Nordlund
1*	100	D20	23	206	276	0.75	125	221	0.57	81	55	1.47
4A*	100	D24	22	218	370	0.59	106	303	0.35	112	67	1.67
4C*	100	D20	13	226	118	1.92	161	92	1.75	65	26	2.50
11*	85	D20	23	91	121	0.75	22	22	1.00	69	99	0.70
32*	100	D20	39	265	258	1.03	53	38	1.39	212	220	0.96
33*	100	D20	39	266	308	0.86	108	88	1.23	158	220	0.72
56*	80	D20	12	247	166	1.49	209	160	1.31	38	6	6.33
60A*	250	D30	18	1128	1011	1.12	897	963	0.93	231	48	4.81
63	250	D30	17	662	985	0.67	183	941	0.19	479	44	10.89
65	250	D30	14	955	1062	0.90	655	1020	0.64	300	42	7.14
74*	250	D30	19	950	1028	0.92	759	967	0.78	191	61	3.13
79	250	D30	20	877	1064	0.82	766	1007	0.76	111	57	1.95
81	250	D30	35	812	859	0.95	561	608	0.92	251	251	1.00
85*	250	D30	4	262	445	0.59	120	403	0.30	142	42	3.38
86*	250	D30	13	525	599	0.88	392	583	0.67	133	16	8.31
87*	250	D30	38	540	1005	0.54	249	471	0.53	291	534	0.54
89*	237	D30	17	701	585	1.20	378	521	0.73	323	64	5.05
91*	100	D20	22	288	158	1.82	85	81	1.05	203	77	2.64
92*	200	D30	14	719	424	1.70	374	378	0.99	345	46	7.50
93*	200	D30	20	712	482	1.48	301	396	0.76	411	86	4.78
94*	237	D30	13	629	617	1.02	360	574	0.63	269	43	6.26

96*	200	D30	28	650	574	1.13	183	256	0.71	467	318	1.47
107A*	100	D20	27	265	234	1.13	96	125	0.77	169	109	1.55
58*	250	D30	50	765	1687	0.45	141	791	0.18	624	896	0.70
83	250	D30	53	825	731	1.13	670	711	0.94	155	20	7.75
84	250	D30	56	900	735	1.22	553	680	0.81	347	55	6.31

Mean	1.04	Mean	0.80	Mean	3.83
Stand.Dev	0.39	Stand.Dev	0.36	Stand.Dev	2.94
Coeff.Variation	0.37	Coeff.Variation	0.45	Coeff.Variation	0.77

Coastal Concrete Restrike, Meyerhof

				Total			Skin			Toe		
File No.	Design Load(Ton)	Pile	N@Toe	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT	PDA	SPT	PDA/SPT
1*	100	D20	25	206	140	1.47	125	78	1.60	81	62	1.31
4A*	100	D24	22	218	85	2.56	106	30	3.53	112	55	2.04
4C*	100	D20	13	226	51	4.43	161	22	7.32	65	29	2.24
11*	85	D20	23	91	117	0.78	22	27	0.81	69	90	0.77
32*	100	D20	20	265	97	2.73	53	10	5.30	212	87	2.44
33*	100	D20	25	266	384	0.69	108	68	1.59	158	316	0.50
56*	80	D20	11	247	188	1.31	209	149	1.40	38	39	0.97
58*	250	D30	30	765	208	3.68	141	69	2.04	624	139	4.49
60A*	250	D30	16	1128	164	6.88	897	94	9.54	231	70	3.30
63	250	D30	32	662	246	2.69	183	106	1.73	479	140	3.42
65	250	D30	20	955	192	4.97	655	126	5.20	300	66	4.55
74*	250	D30	24	950	263	3.61	759	164	4.62	191	99	1.93
79	250	D30	16	877	206	4.25	766	137	5.59	111	69	1.60
81	250	D30	25	812	137	5.93	561	37	15.16	251	100	2.51
83	250	D30	35	825	268	3.08	670	73	9.18	155	195	0.79
85*	250	D30	4	262	223	1.17	120	162	0.74	142	61	2.33
86*	250	D30	16	525	100	5.25	392	34	11.53	133	66	2.02
87*	250	D30	32	540	412	1.31	249	175	1.42	291	237	1.23
89*	237	D30	17	701	271	2.59	378	203	1.86	323	68	4.75
91*	100	D20	19	288	241	1.20	85	98	0.87	203	143	1.42
92*	200	D30	14	719	192	3.74	374	128	2.92	345	64	5.39

93*	200	D30	15	712	193	3.69	301	128	2.35	411	65	6.32
94*	237	D30	13	629	217	2.90	360	151	2.38	269	66	4.08
96*	200	D30	28	650	533	1.22	183	193	0.95	467	340	1.37
107A*	100	D20	20	265	61	4.34	96	14	6.86	169	47	3.60
84	250	D30	100	900	209	4.31	553	64	8.64	347	145	2.39

Mean	3.11	Mean	4.43	Mean	2.61
Stand.Dev	1.67	Stand.Dev	3.83	Stand.Dev	1.56
Coeff.Variation	0.54	Coeff.Variation	0.86	Coeff.Variation	0.60

APPENDIX D

Reliability

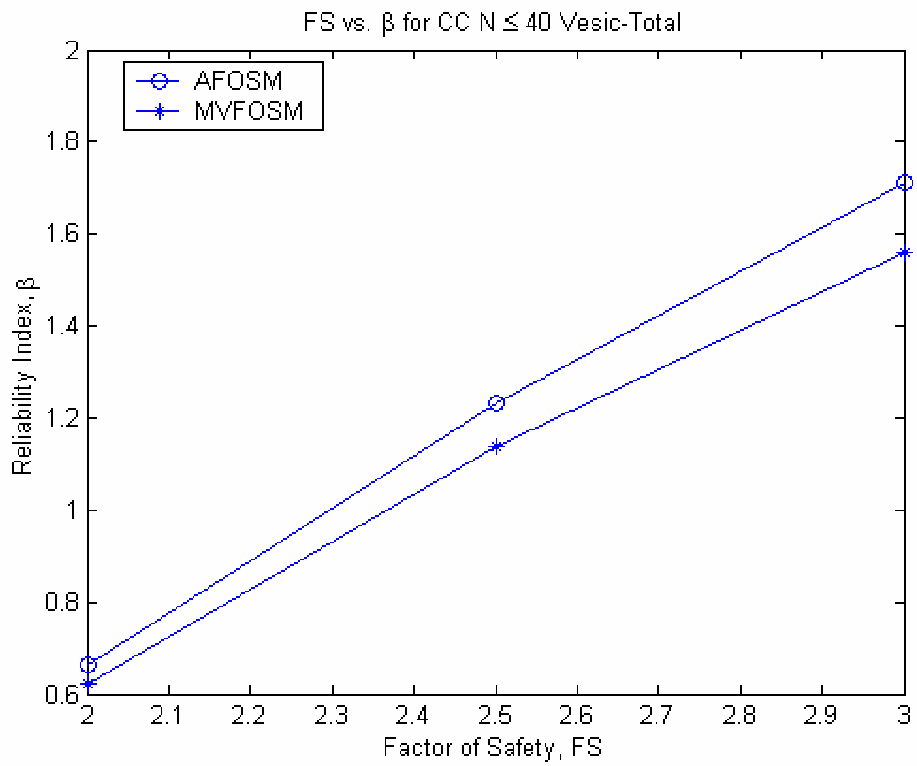
CC N<=40 VESIC

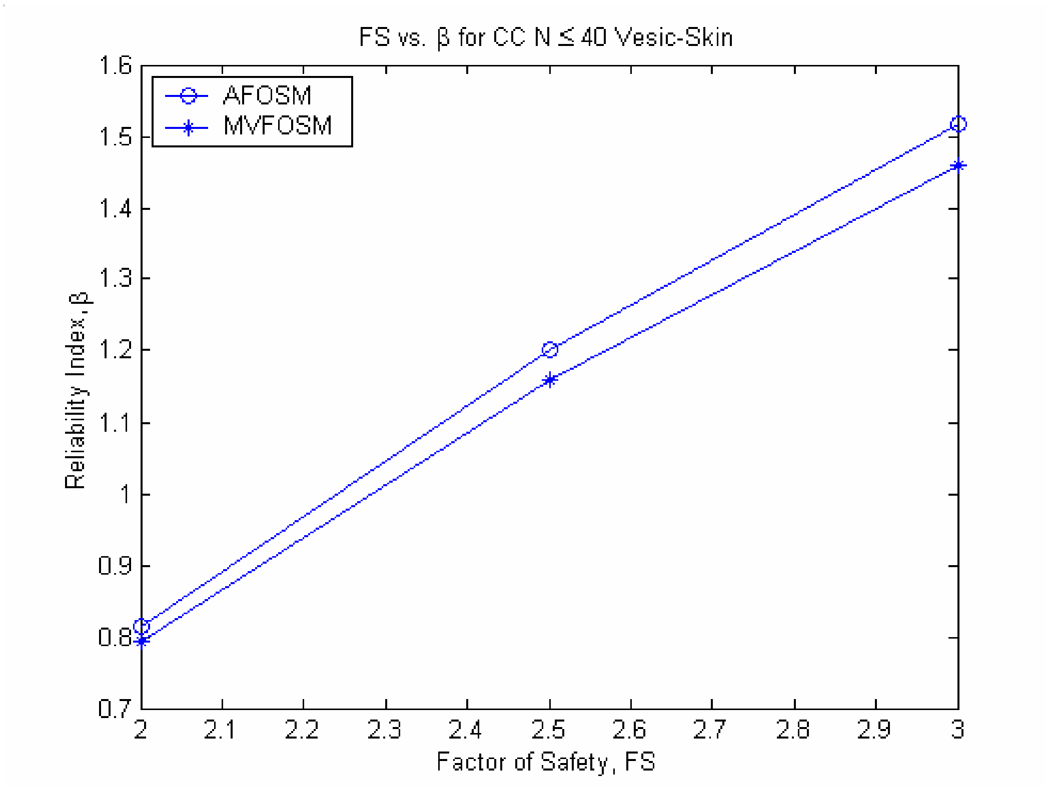
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.663	0.624	0.814	0.793	0.384	0.381
2.5	1.234	1.140	1.200	1.160	0.851	0.816
3	1.711	1.562	1.516	1.459	1.225	1.171

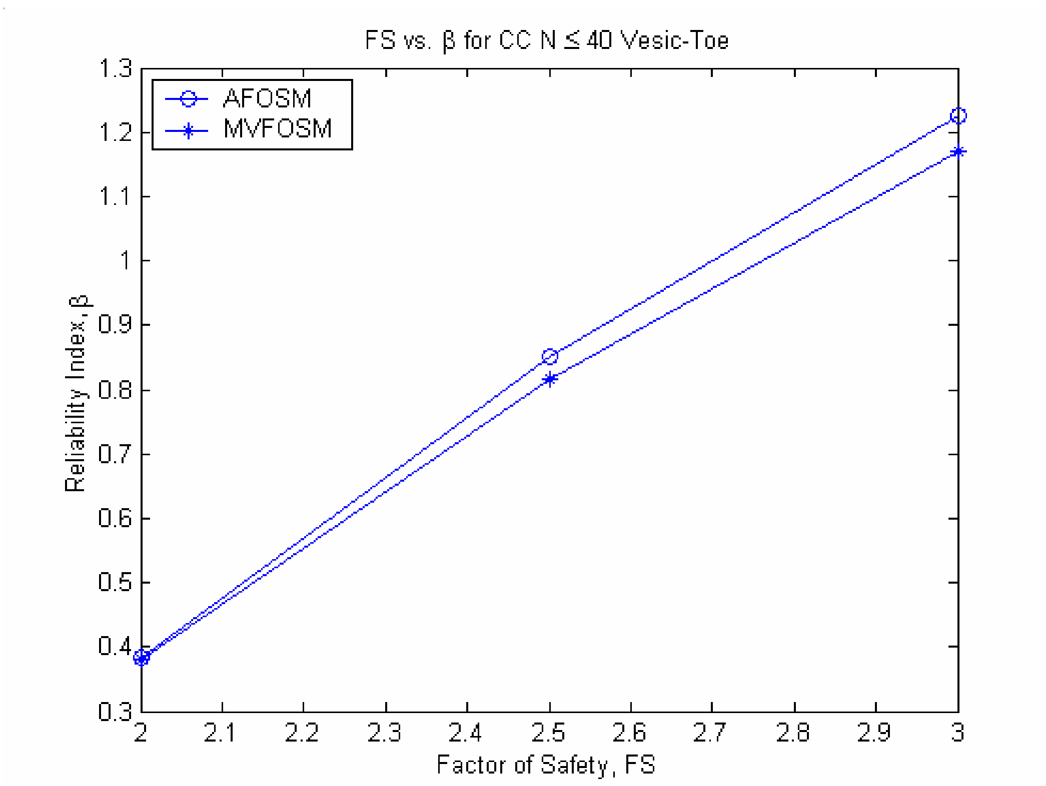
Mean Value 0.759
Standard Deviation 0.293
Coefficient of Variation 0.386

Mean Value 1.029
Standard Deviation 0.634
Coefficient of Variation 0.616

Mean Value 0.732
Standard Deviation 0.359
Coefficient of Variation 0.490



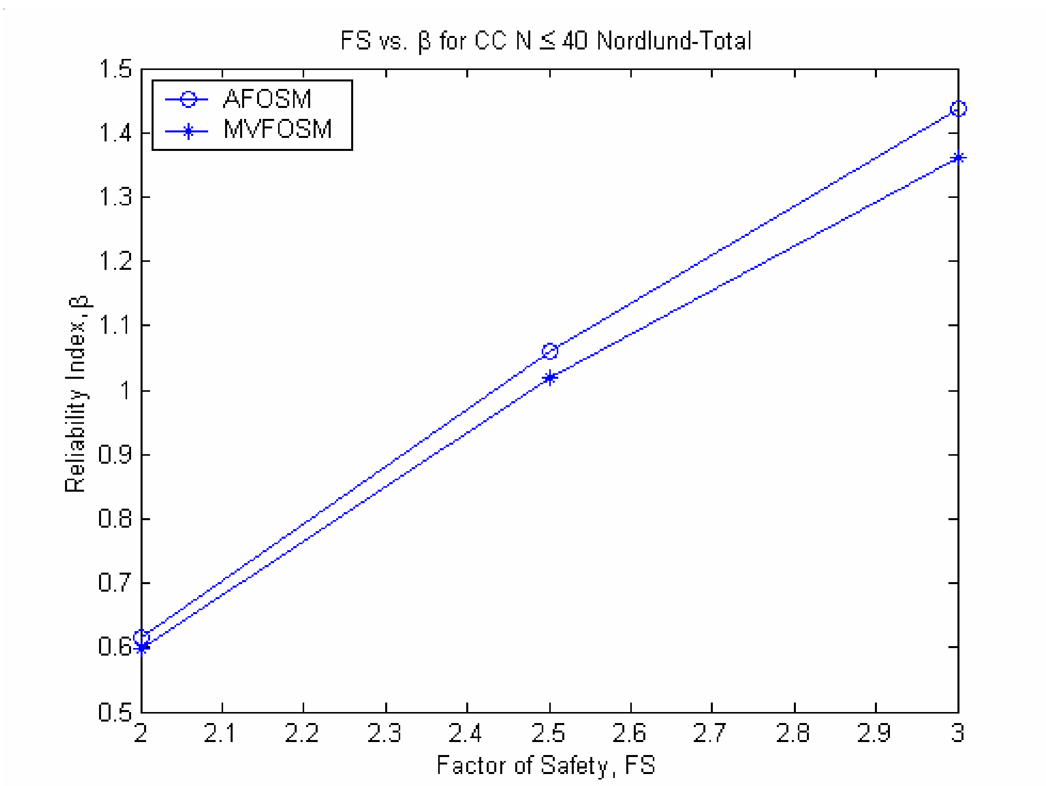

FS vs. β for CC N ≤ 40 Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

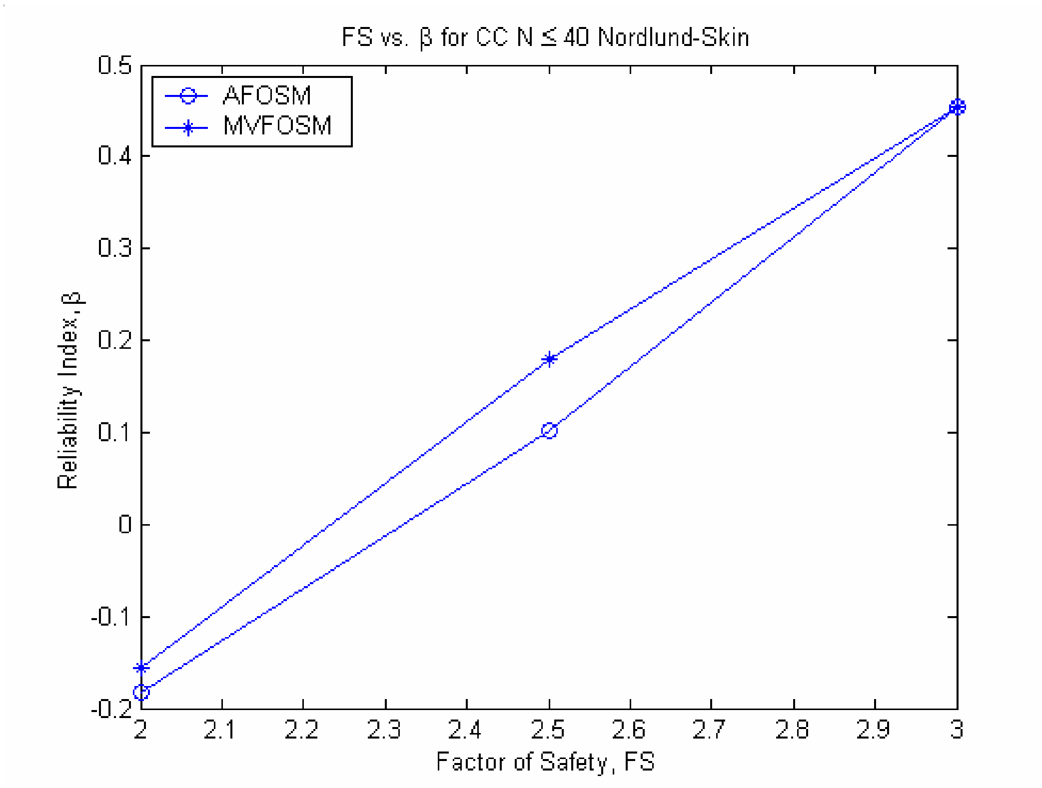

FS vs. β for CC N ≤ 40 Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

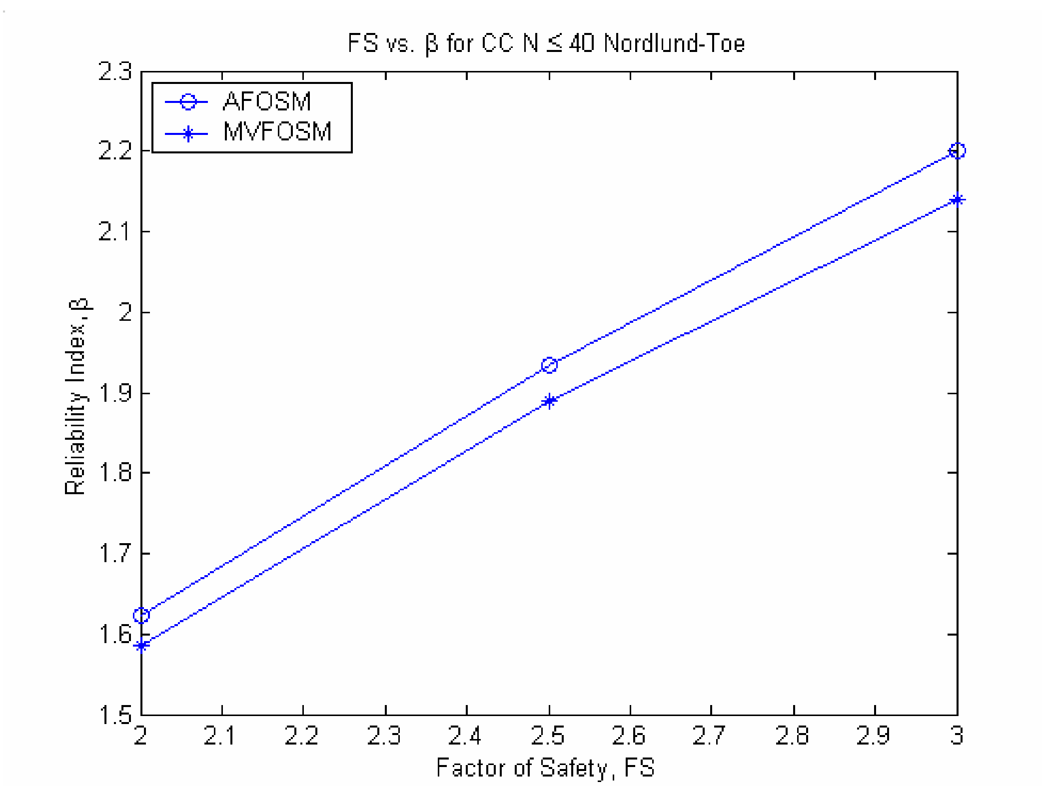
CC N<=40 NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.616	0.598	-0.182	-0.155	1.623	1.585
2.5	1.060	1.019	0.103	0.180	1.934	1.891
3	1.436	1.362	0.454	0.453	2.201	2.140

	Total	Skin	Toe
	Mean Value 0.835	Mean Value 0.594	Mean Value 2.193
	Standard Deviation 0.428	Standard Deviation 0.414	Standard Deviation 1.732
	Coefficient of Variation 0.513	Coefficient of Variation 0.697	Coefficient of Variation 0.790



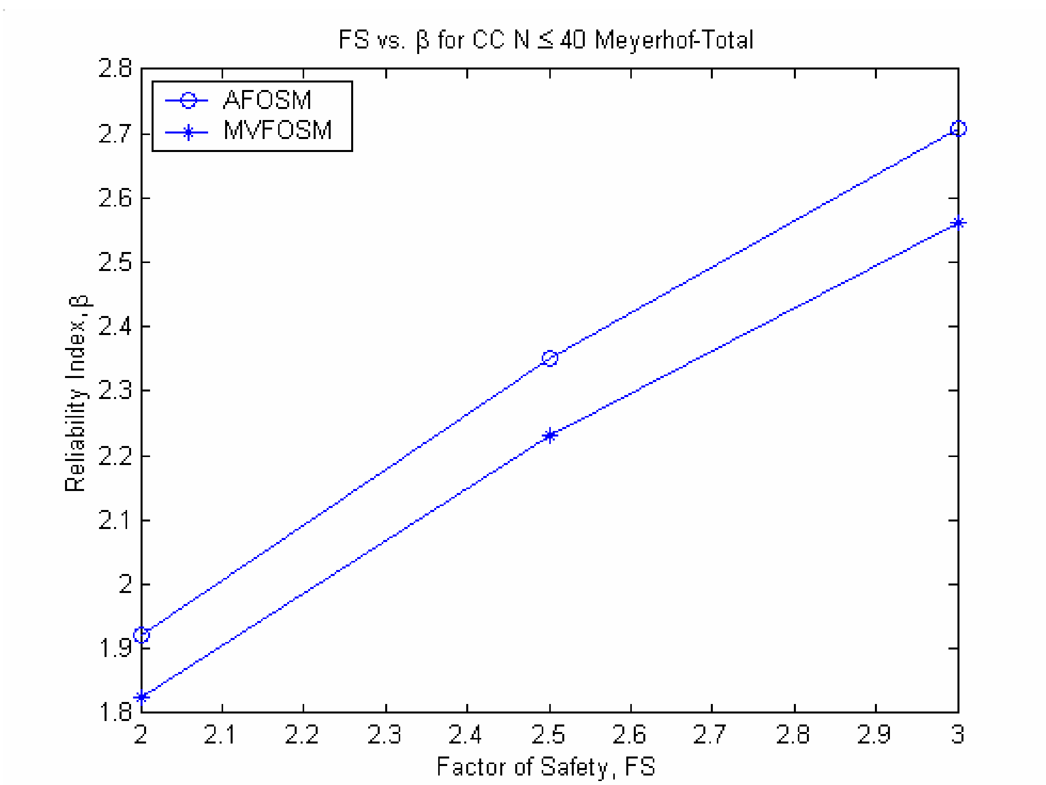

FS vs. β for CC N ≤ 40 Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

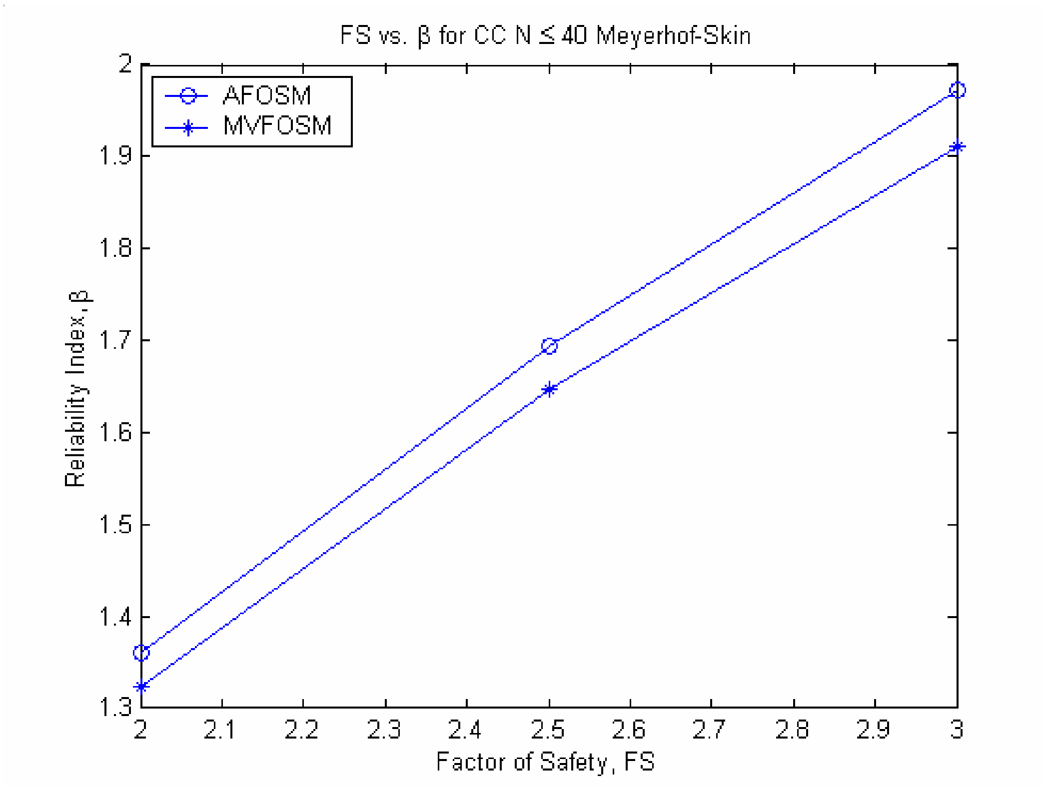

FS vs. β for CC N ≤ 40 Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

CC N<=40 MEYERHOF

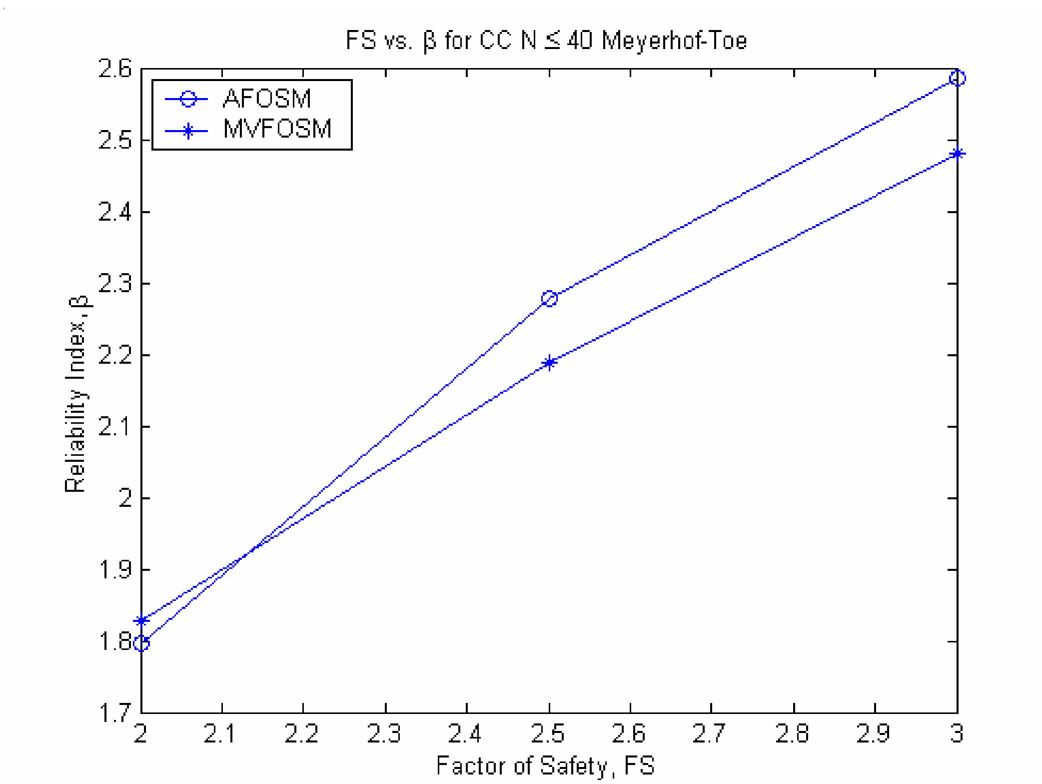
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.922	1.826	1.359	1.324	1.796	1.828
2.5	2.351	2.231	1.694	1.648	2.279	2.187
3	2.709	2.562	1.972	1.912	2.586	2.480

	Total	Skin	Toe
	Mean Value 1.680	Mean Value 1.670	Mean Value 1.998
	Standard Deviation 0.906	Standard Deviation 1.220	Standard Deviation 1.269
	Coefficient of Variation 0.539	Coefficient of Variation 0.731	Coefficient of Variation 0.635





FS vs. β for CC N ≤ 40 Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

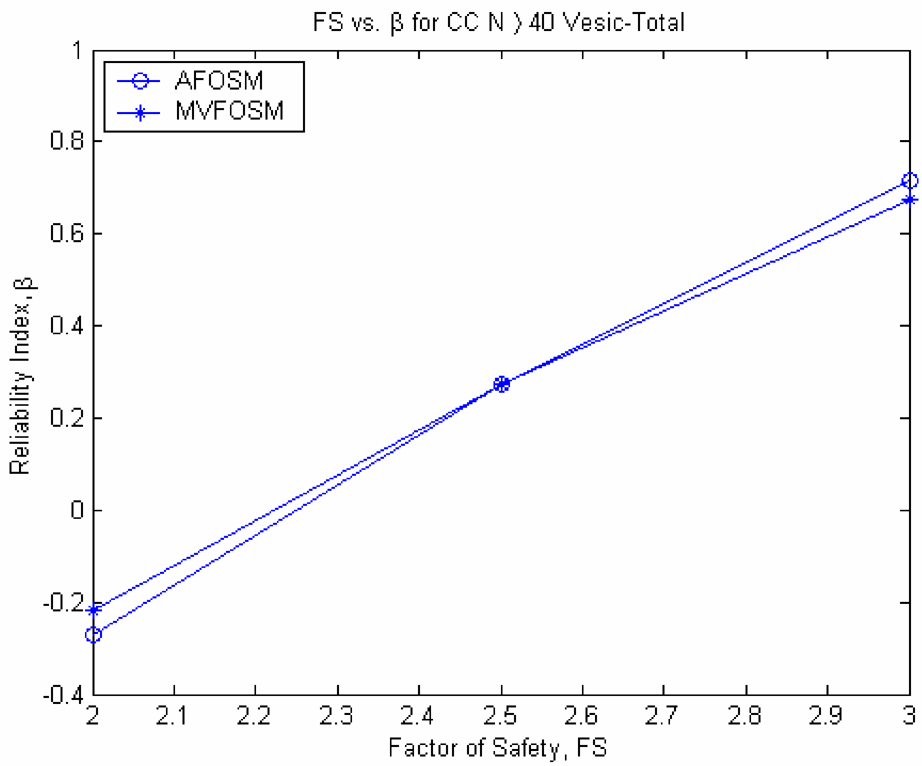


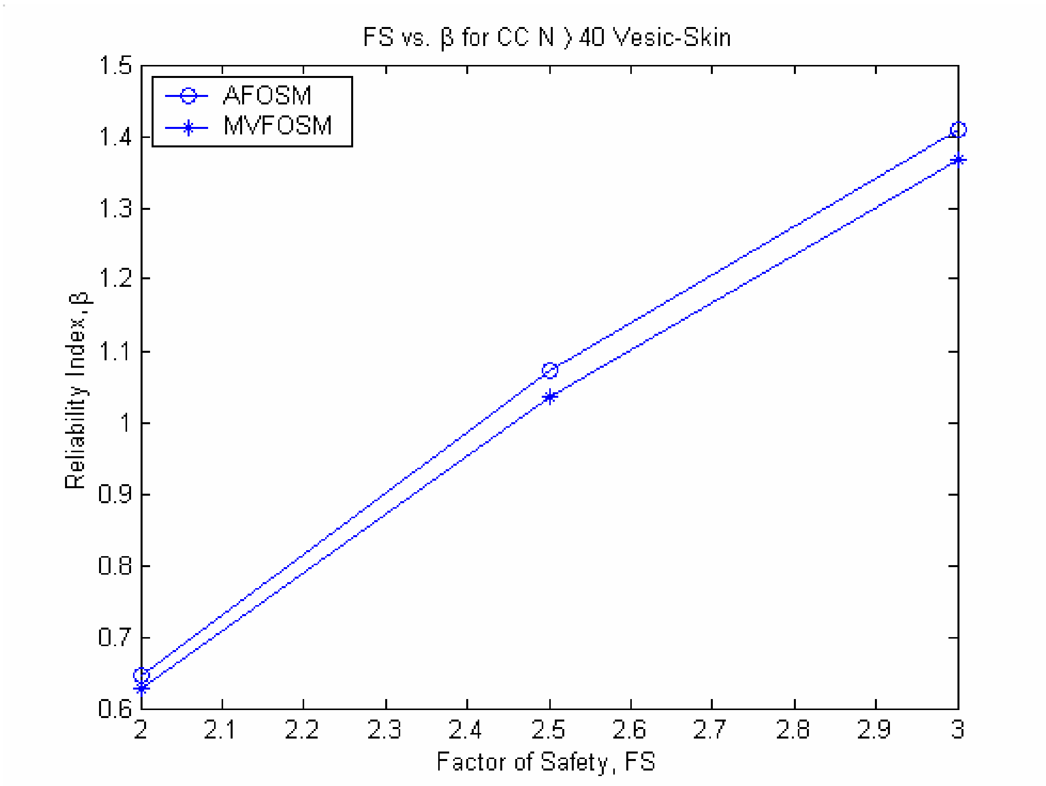
FS vs. β for CC N ≤ 40 Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

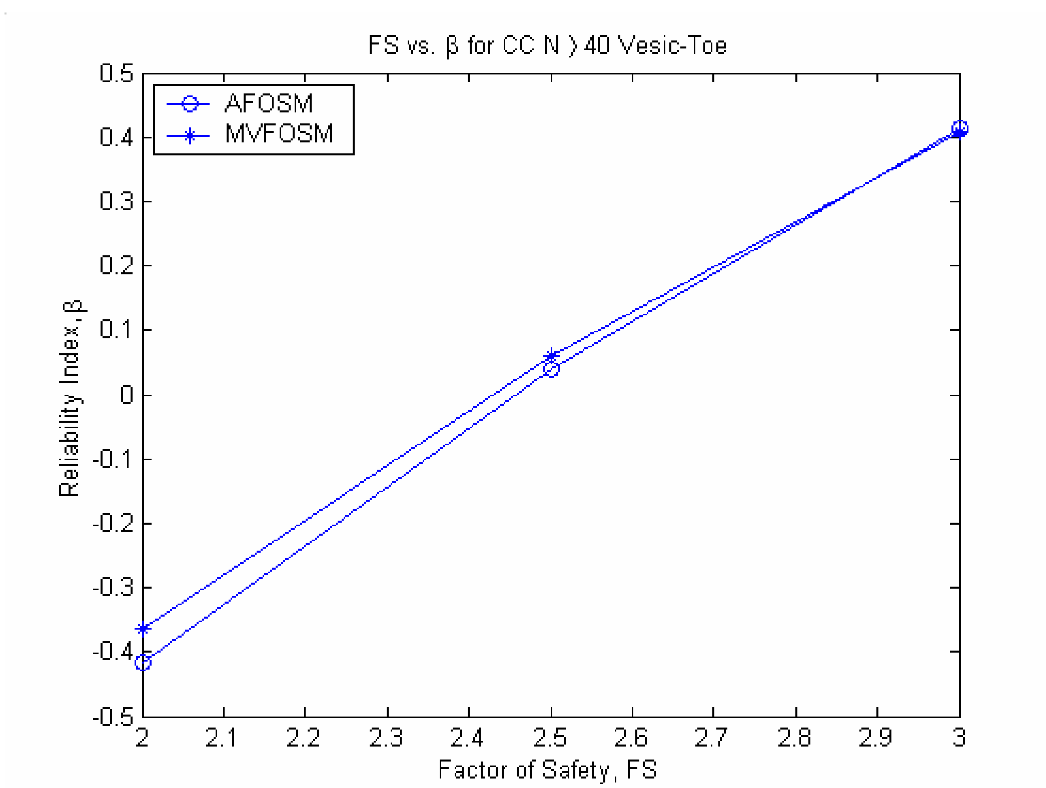
CC N>40 VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	-0.272	-0.218	0.646	0.628	-0.417	-0.364
2.5	0.272	0.274	1.073	1.035	0.040	0.061
3	0.715	0.676	1.410	1.368	0.413	0.409

Total	Skin	Toe
Mean Value 0.530	Mean Value 0.866	Mean Value 0.501
Standard Deviation 0.219	Standard Deviation 0.464	Standard Deviation 0.253
Coefficient of Variation 0.413	Coefficient of Variation 0.536	Coefficient of Variation 0.505



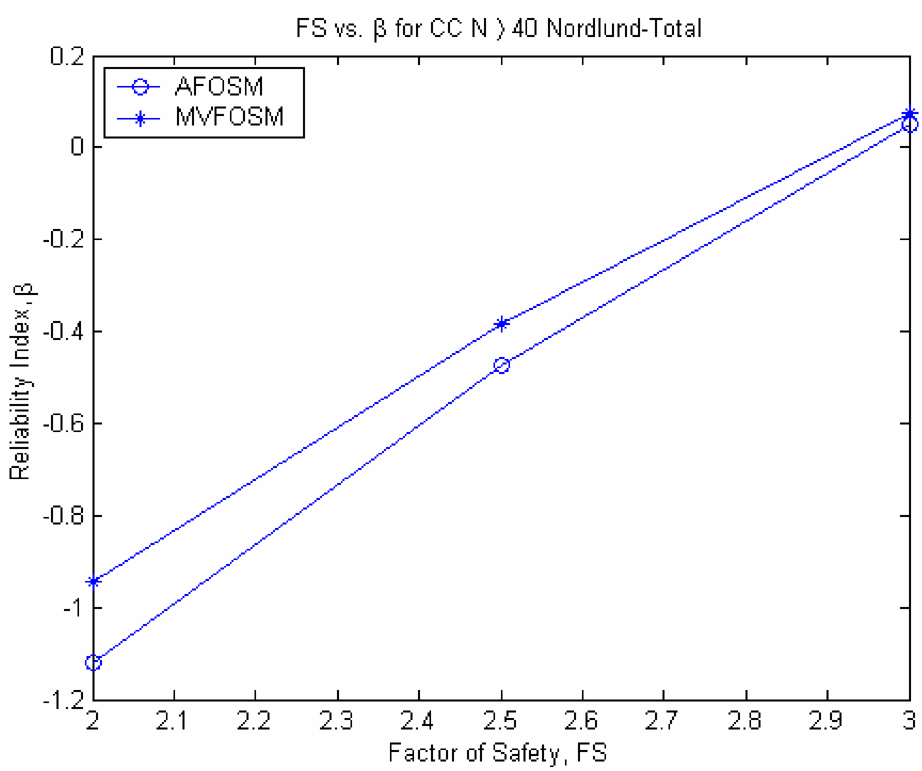

FS vs. β for CC N 〉40 Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

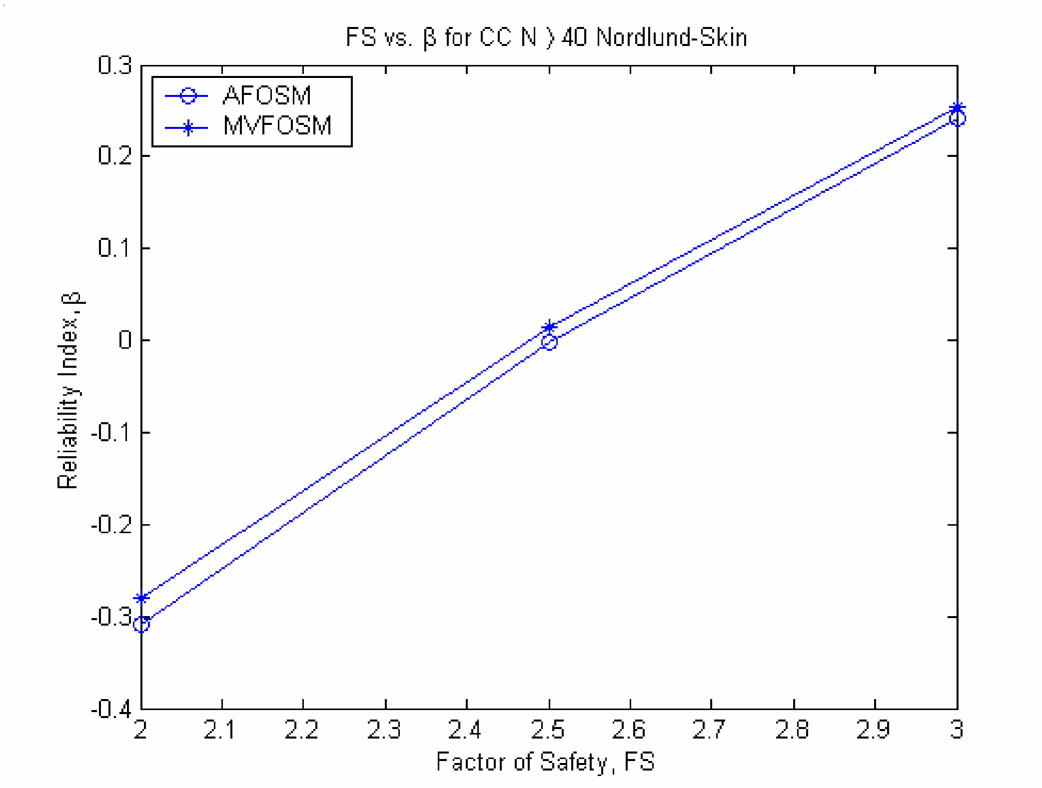

FS vs. β for CC N 〉40 Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

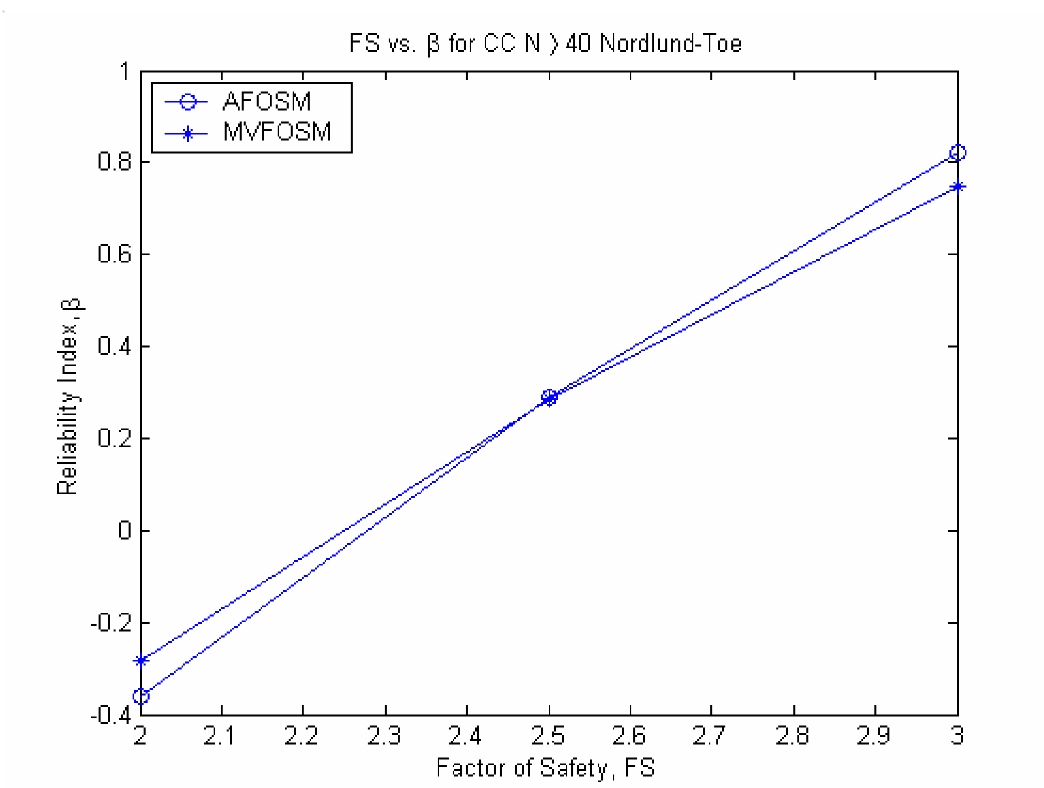
CC N>40 NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	-1.118	-0.944	-0.309	-0.279	-0.363	-0.284
2.5	-0.474	-0.383	-0.002	0.014	0.290	0.285
3	0.049	0.075	0.241	0.254	0.823	0.750

	Total	Skin	Toe
	Mean Value 0.392	Mean Value 0.570	Mean Value 0.510
	Standard Deviation 0.134	Standard Deviation 0.476	Standard Deviation 0.170
	Coefficient of Variation 0.342	Coefficient of Variation 0.836	Coefficient of Variation 0.334



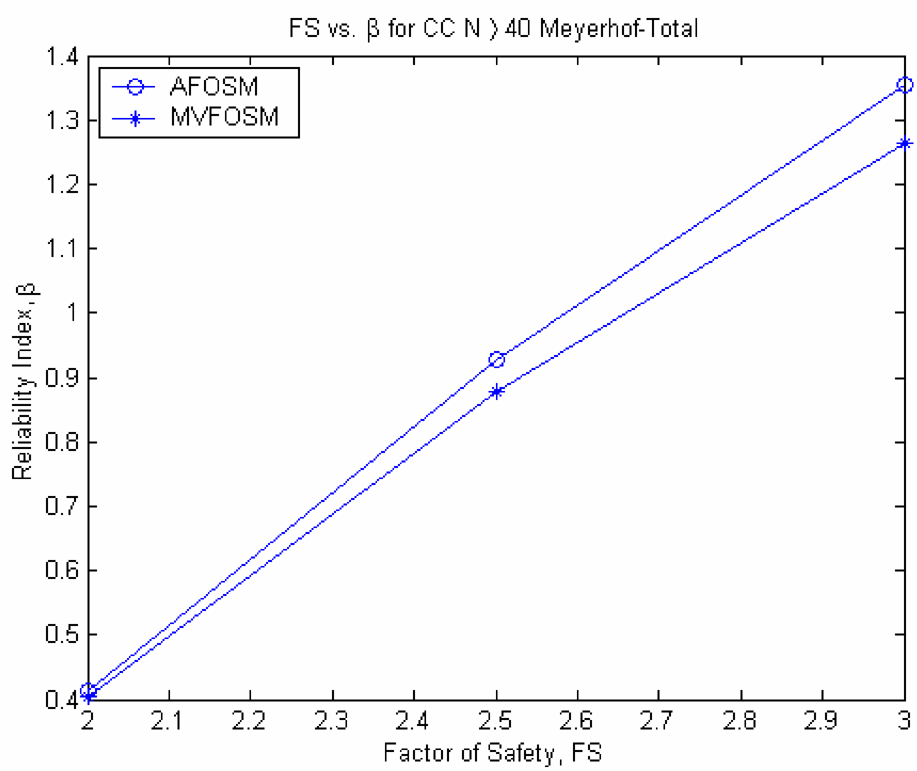

FS vs. β for CC N 〉40 Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

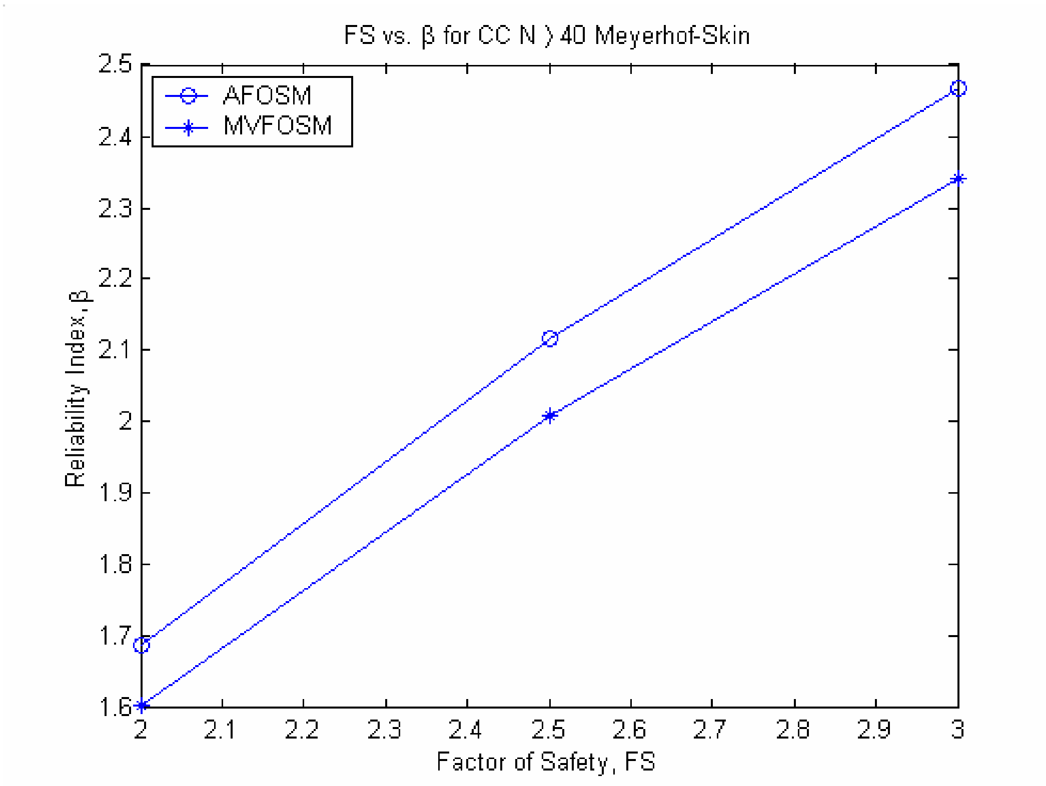

FS vs. β for CC N 〉40 Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

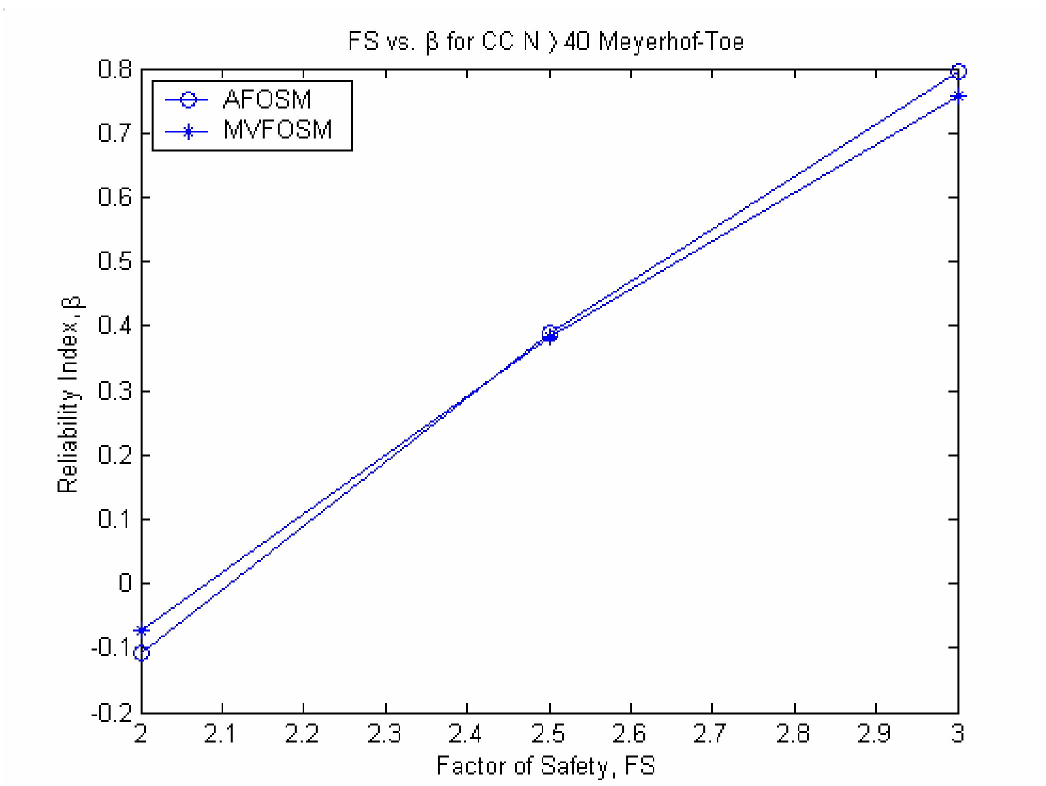
CC N>40 MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.413	0.404	1.687	1.604	-0.109	-0.074
2.5	0.929	0.877	2.118	2.010	0.390	0.384
3	1.355	1.264	2.468	2.341	0.796	0.759

	Total	Skin	Toe
	Mean Value 0.714	Mean Value 1.483	Mean Value 0.573
	Standard Deviation 0.311	Standard Deviation 0.798	Standard Deviation 0.261
	Coefficient of Variation 0.436	Coefficient of Variation 0.538	Coefficient of Variation 0.456



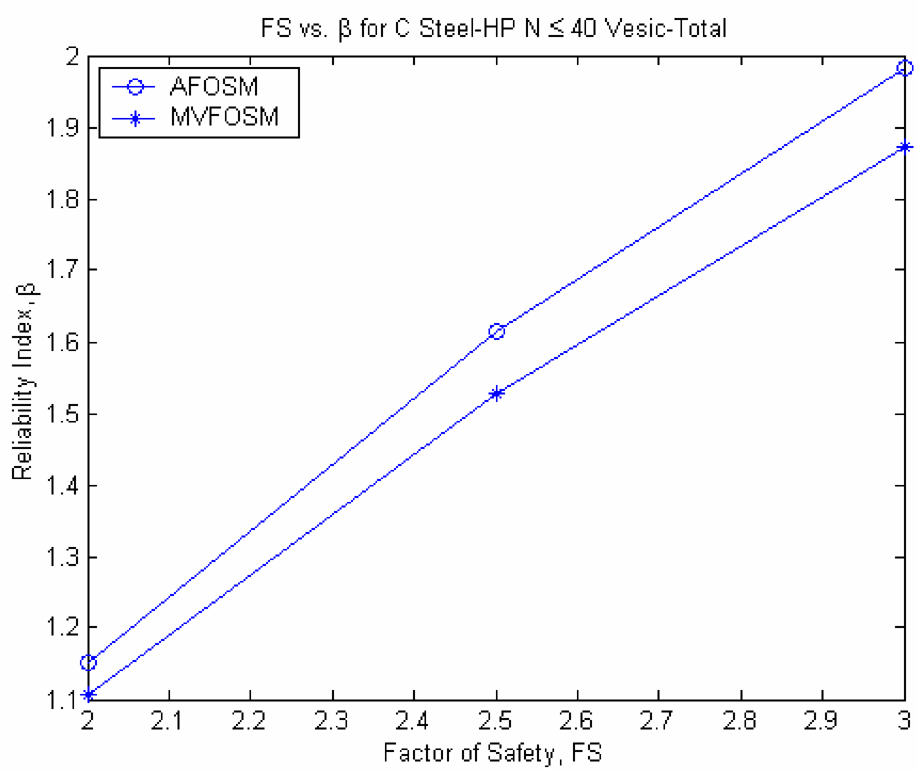

FS vs. β for CC N 〉40 Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

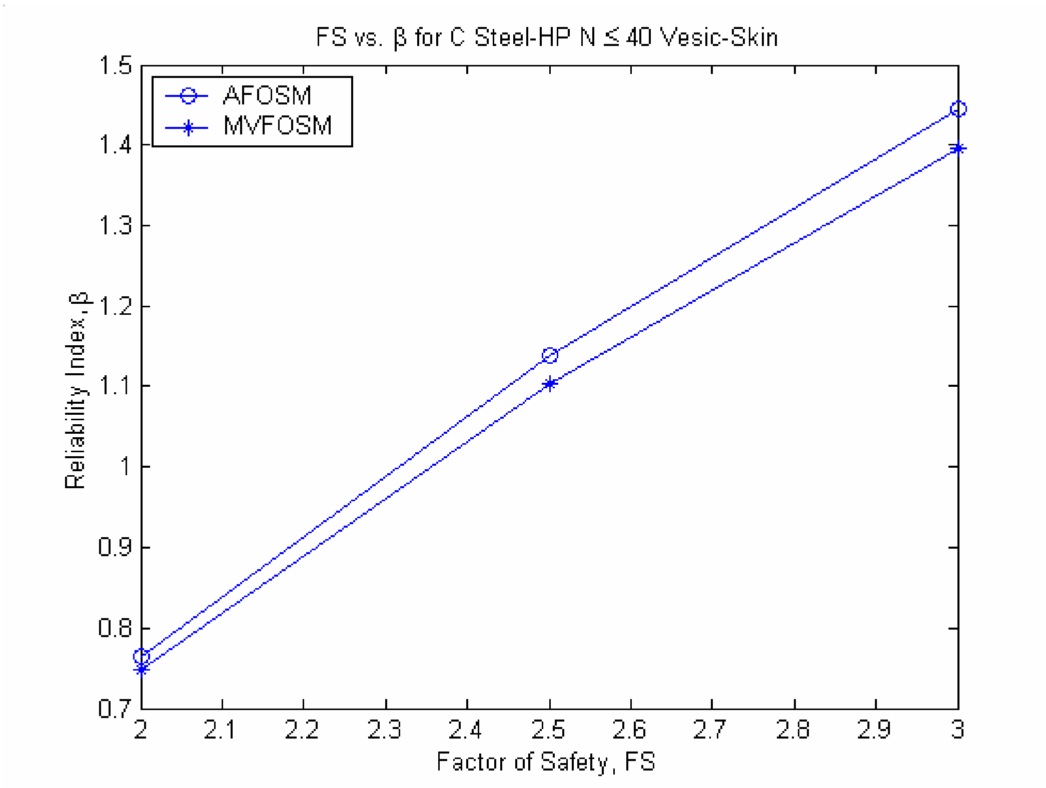

FS vs. β for CC N 〉40 Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

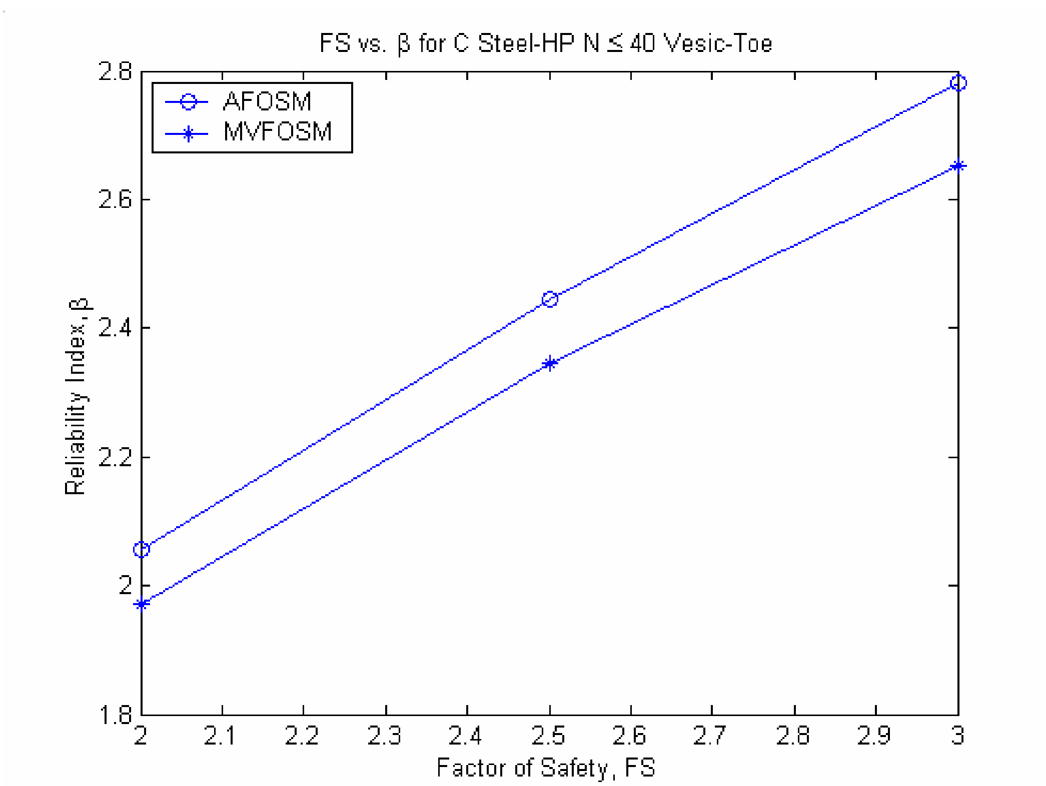
C Steel-HP N<=40 VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.152	1.107	0.764	0.747	2.057	1.972
2.5	1.615	1.529	1.139	1.104	2.446	2.346
3	1.984	1.873	1.446	1.396	2.780	2.652

Total	Skin	Toe
Mean Value 1.090	Mean Value 1.023	Mean Value 2.040
Standard Deviation 0.556	Standard Deviation 0.653	Standard Deviation 1.222
Coefficient of Variation 0.510	Coefficient of Variation 0.638	Coefficient of Variation 0.599



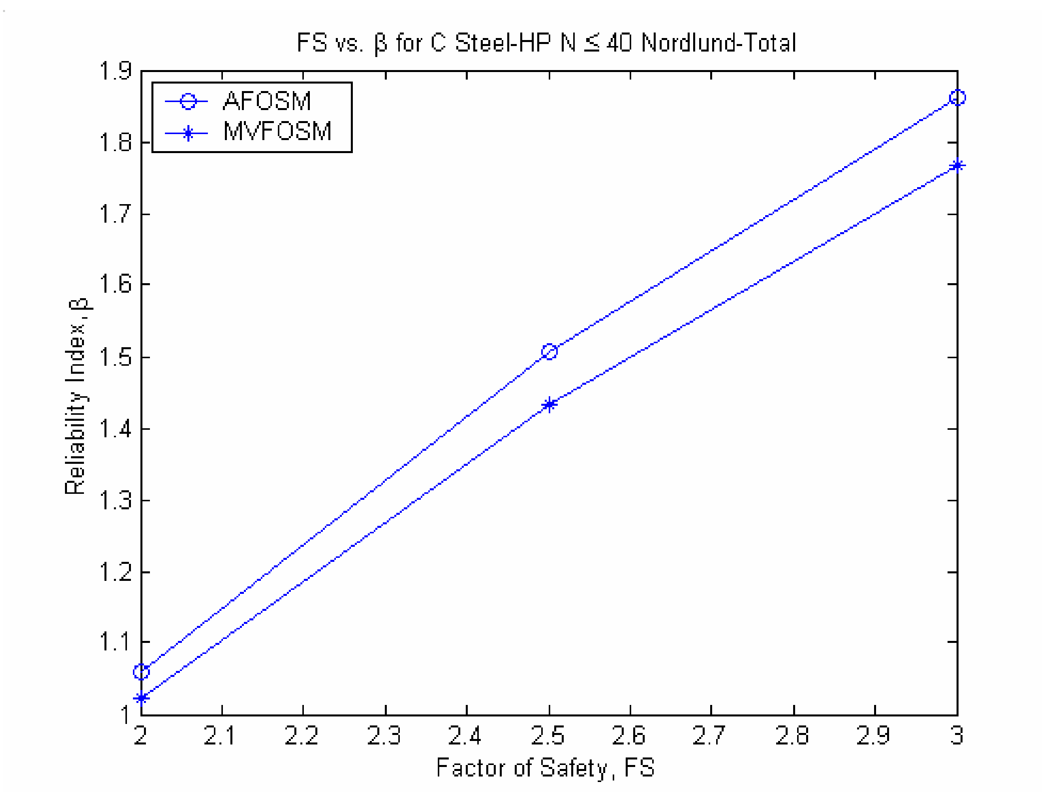

FS vs. β for C Steel-HP N ≤ 40 Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

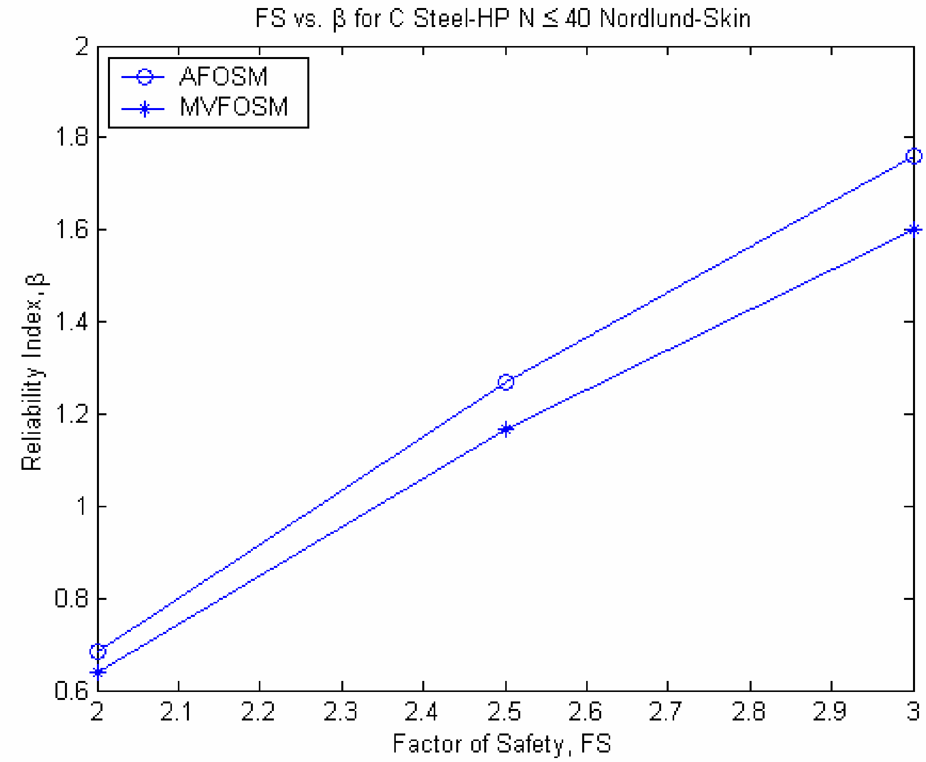

FS vs. β for C Steel-HP N ≤ 40 Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.8
2.6
2.4
2.2
2
1.8
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

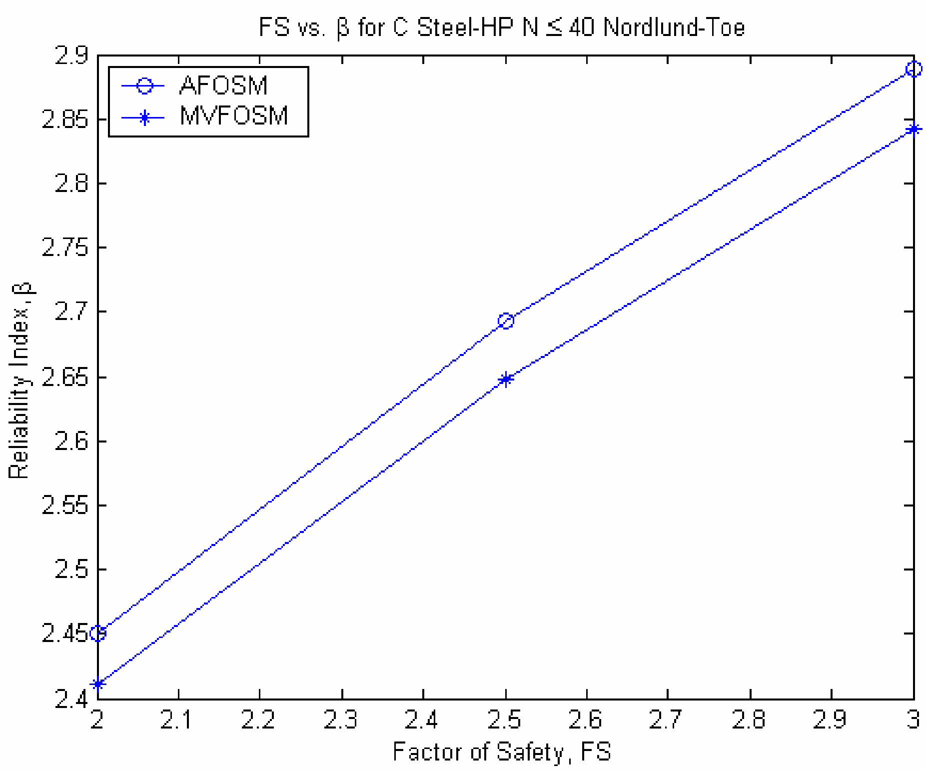
CS HP N<=40 NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.06	1.02	0.69	0.64	2.45	2.41
2.5	1.51	1.43	1.27	1.17	2.69	2.65
3	1.86	1.77	1.76	1.60	2.89	2.84

Mean Value 1.068	Mean Value 0.757	Mean Value 7.951
Standard Deviation 0.567	Standard Deviation 0.283	Standard Deviation 9.104
Coefficient of Variation 0.531	Coefficient of Variation 0.374	Coefficient of Variation 1.145



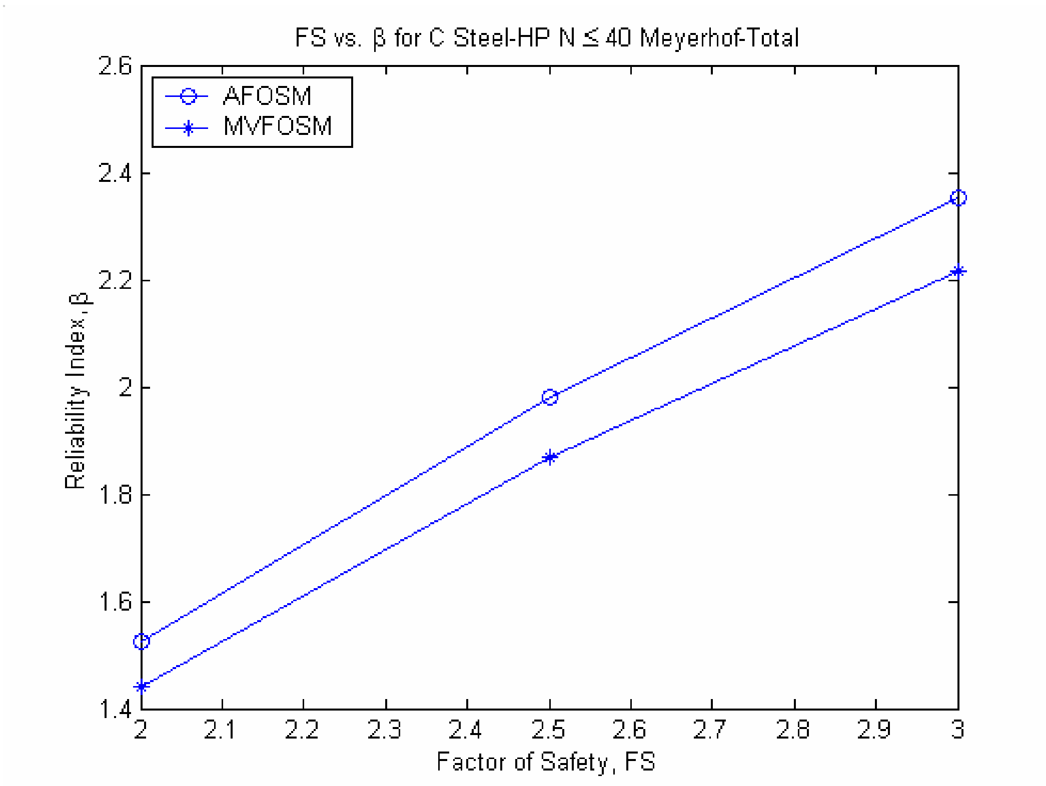

FS vs. β for C Steel-HP N ≤ 40 Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2
1.8
1.6
1.4
1.2
1
0.8
0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

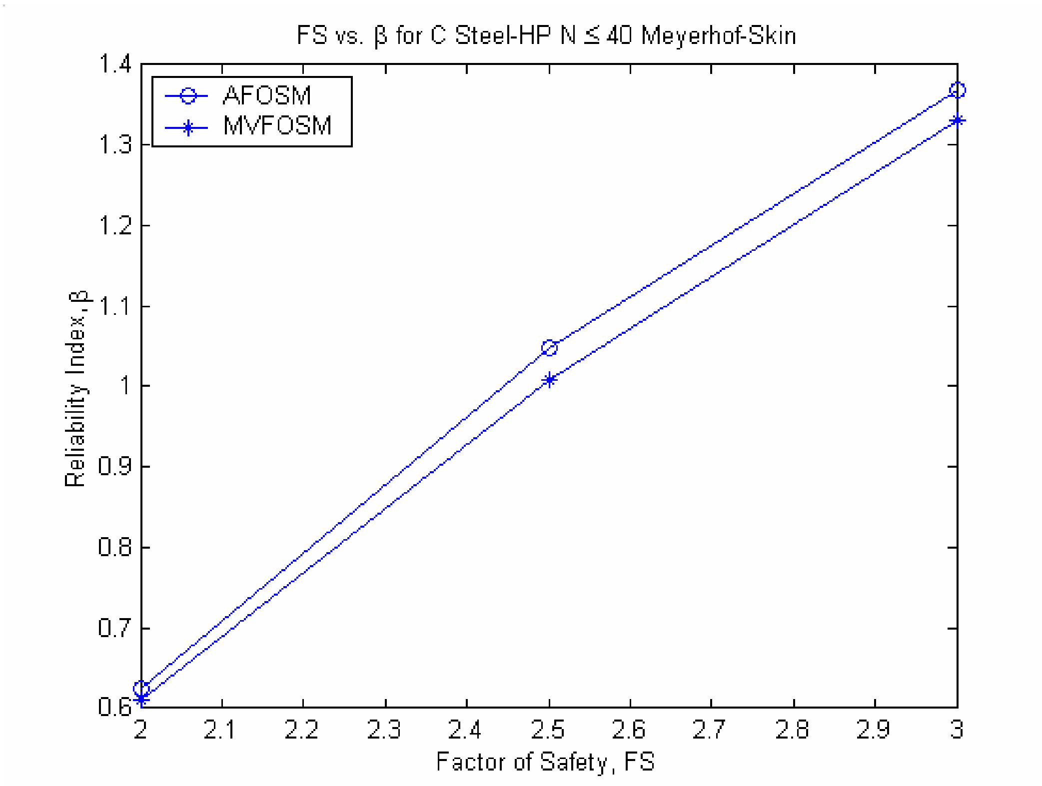

FS vs. β for C Steel-HP N ≤ 40 Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.9
2.85
2.8
2.75
2.7
2.65
2.6
2.55
2.5
2.45
2.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

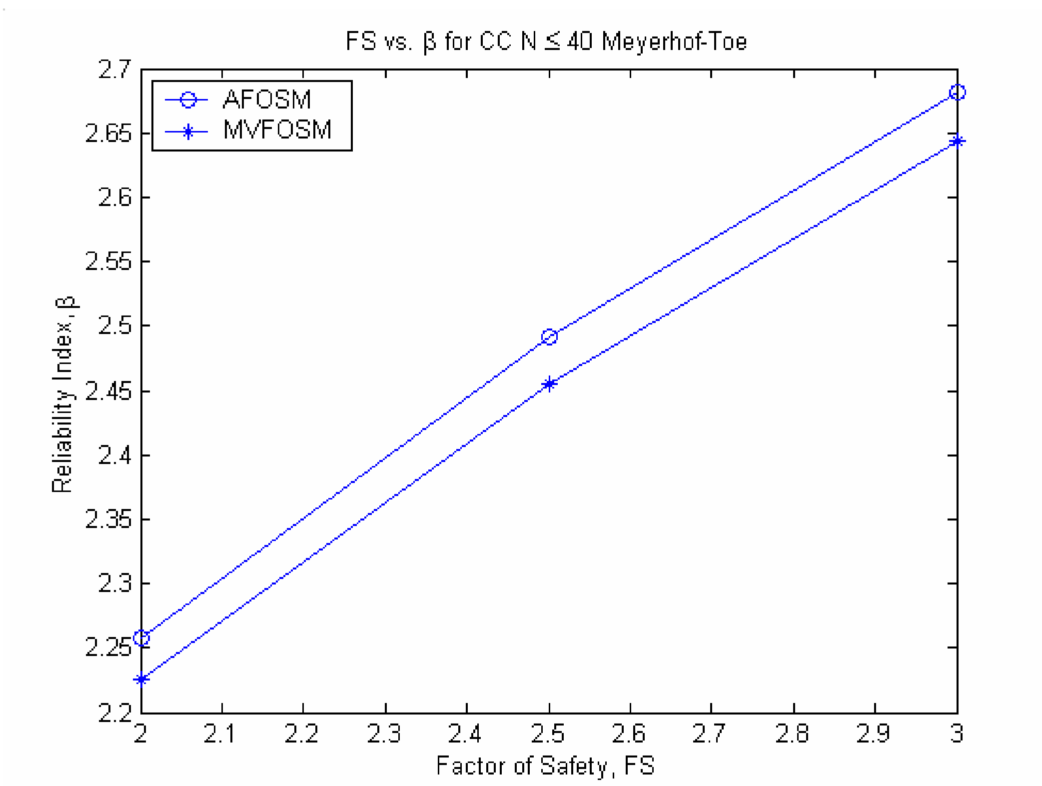
CS HP N<=40 MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.523	1.441	0.625	0.610	2.258	2.226
2.5	1.982	1.868	1.048	1.007	2.492	2.455
3	2.354	2.217	1.368	1.332	2.682	2.643

Mean Value 1.285	Mean Value 0.871	Mean Value 7.374
Standard Deviation 0.645	Standard Deviation 0.483	Standard Deviation 8.886
Coefficient of Variation 0.502	Coefficient of Variation 0.554	Coefficient of Variation 1.205



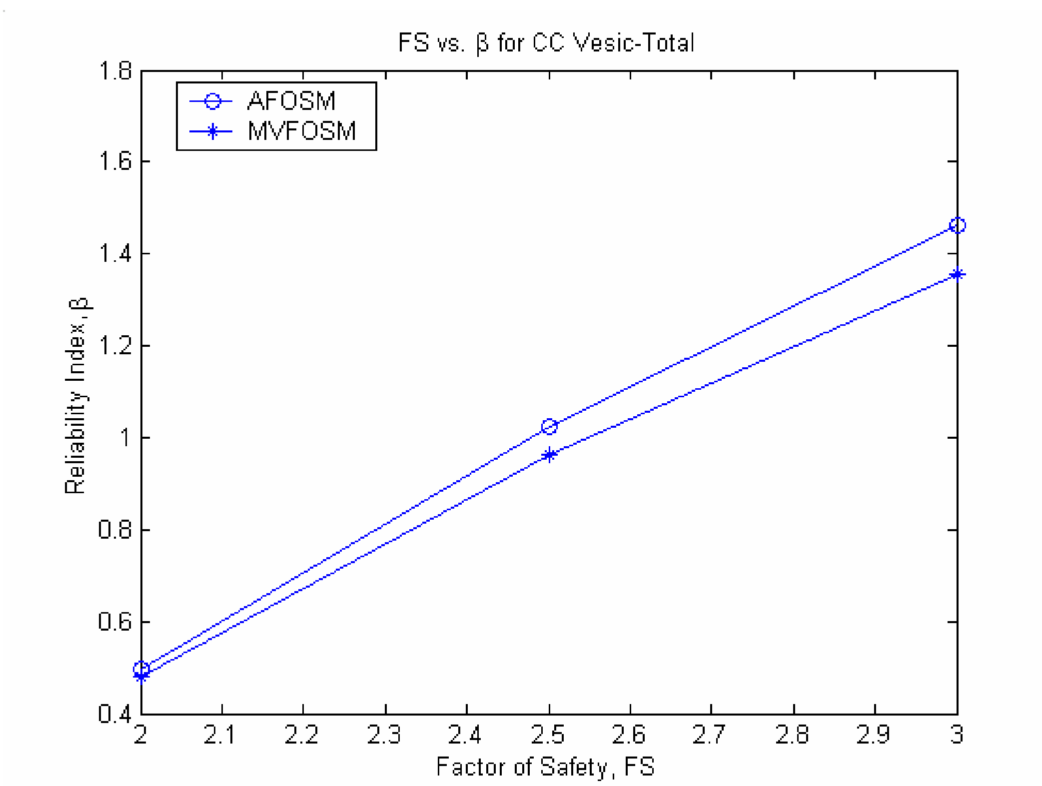

FS vs. β for C Steel-HP N ≤ 40 Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

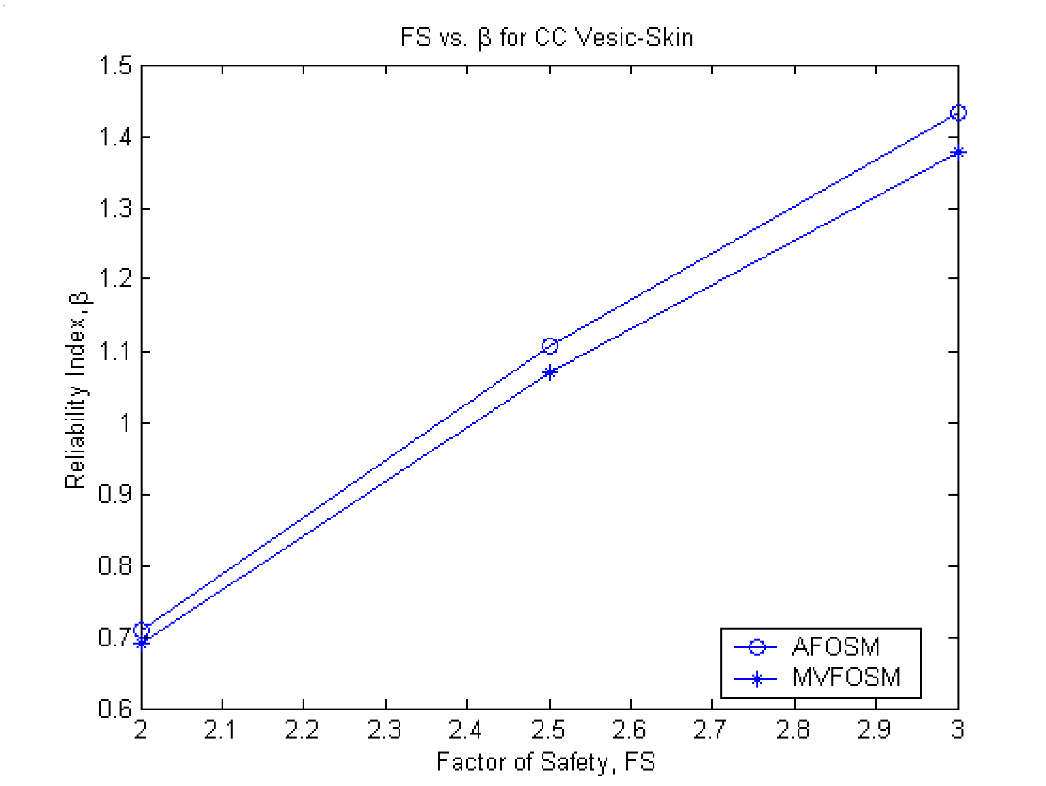

FS vs. β for CC N ≤ 40 Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.7
2.65
2.6
2.55
2.5
2.45
2.4
2.35
2.3
2.25
2.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

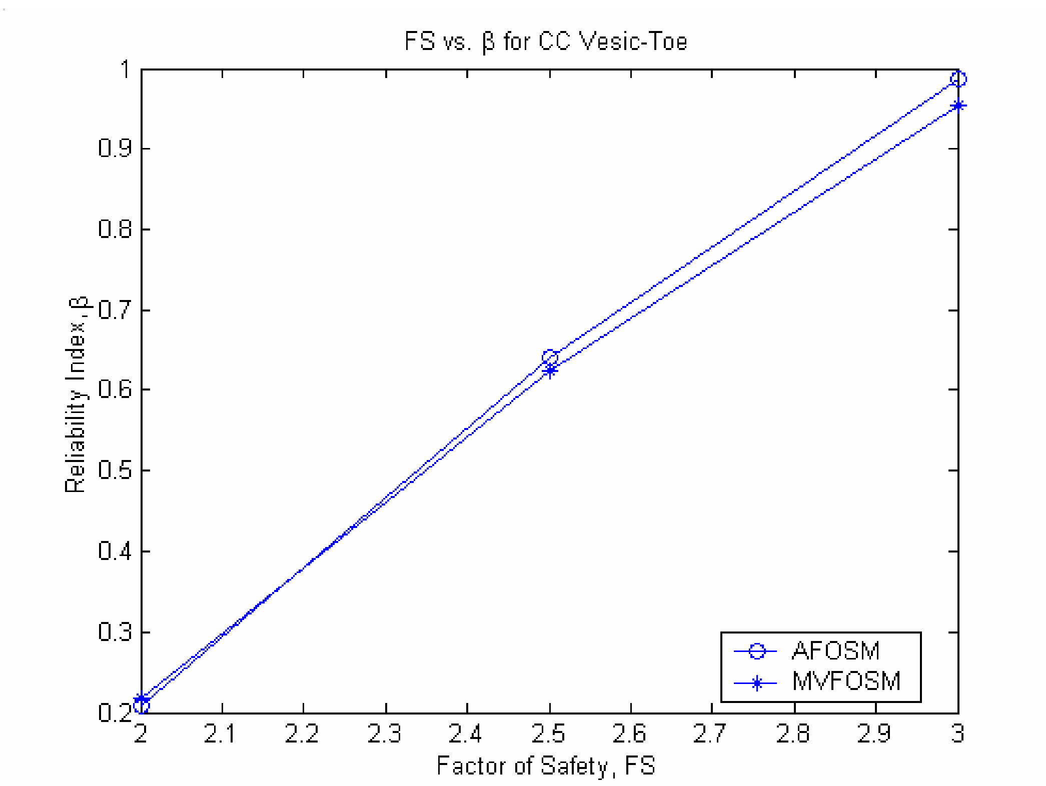
CC All N's VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.496	0.478	0.709	0.692	0.209	0.218
2.5	1.025	0.962	1.108	1.069	0.640	0.624
3	1.463	1.357	1.434	1.377	0.986	0.955

Total	Skin	Toe
Mean Value 0.732	Mean Value 0.946	Mean Value 0.693
Standard Deviation 0.309	Standard Deviation 0.561	Standard Deviation 0.373
Coefficient of Variation 0.423	Coefficient of Variation 0.593	Coefficient of Variation 0.538



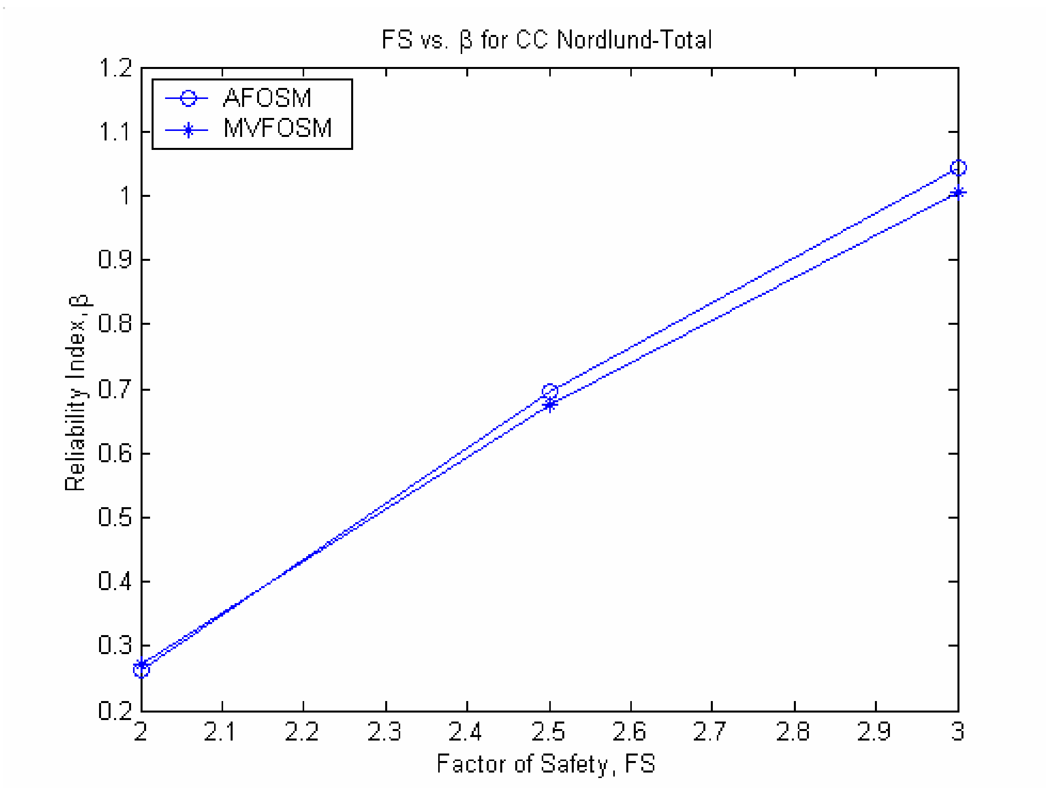

FS vs. β for CC Vesic-Skin
Reliability Index, β
Factor of Safety, FS
AFOSM
MVFOSM

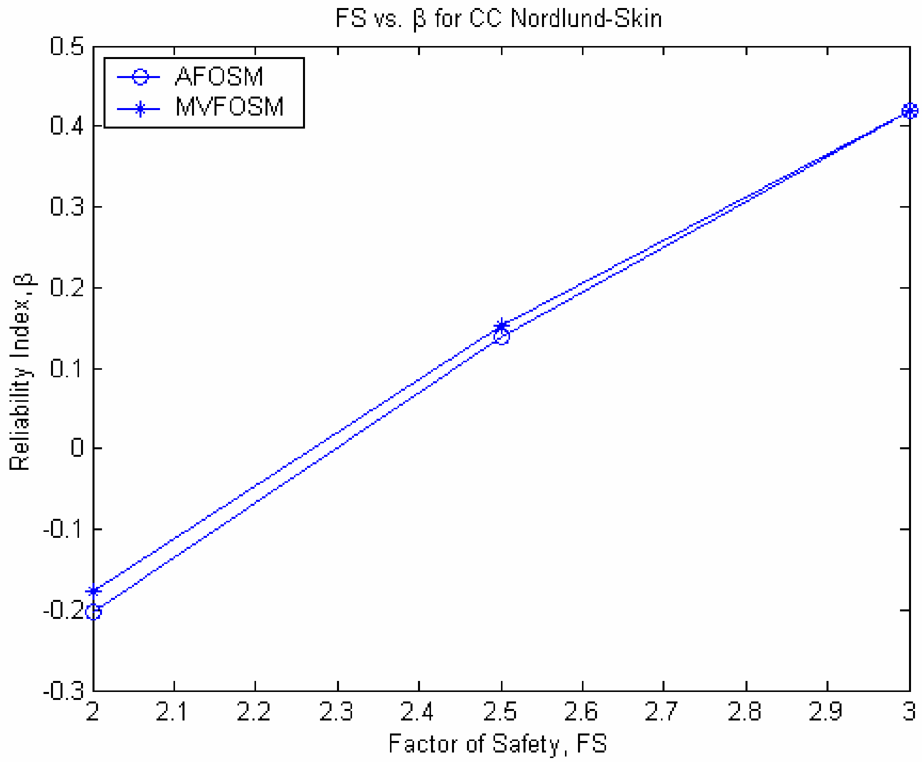

FS vs. β for CC Vesic-Toe
Reliability Index, β
Factor of Safety, FS
AFOSM
MVFOSM

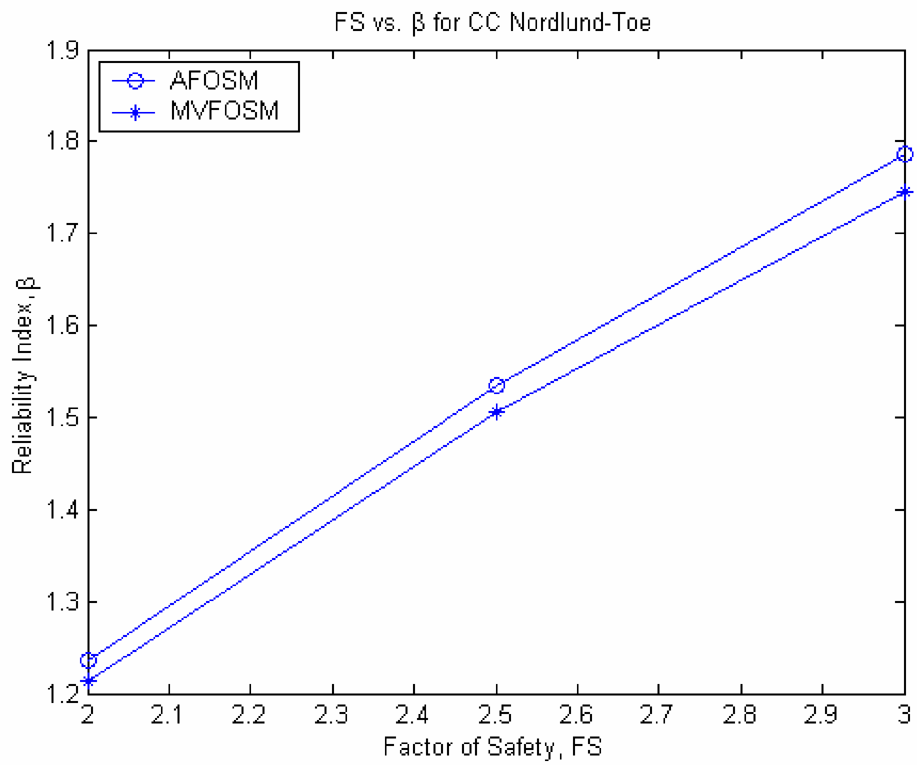
CC All N's NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.263	0.270	-0.204	-0.177	1.236	1.214
2.5	0.696	0.676	0.138	0.152	1.536	1.506
3	1.043	1.007	0.418	0.420	1.786	1.745

	Total	Skin	Toe
	Mean Value 0.713	Mean Value 0.590	Mean Value 1.786
	Standard Deviation 0.384	Standard Deviation 0.422	Standard Deviation 1.502
	Coefficient of Variation 0.539	Coefficient of Variation 0.716	Coefficient of Variation 0.841



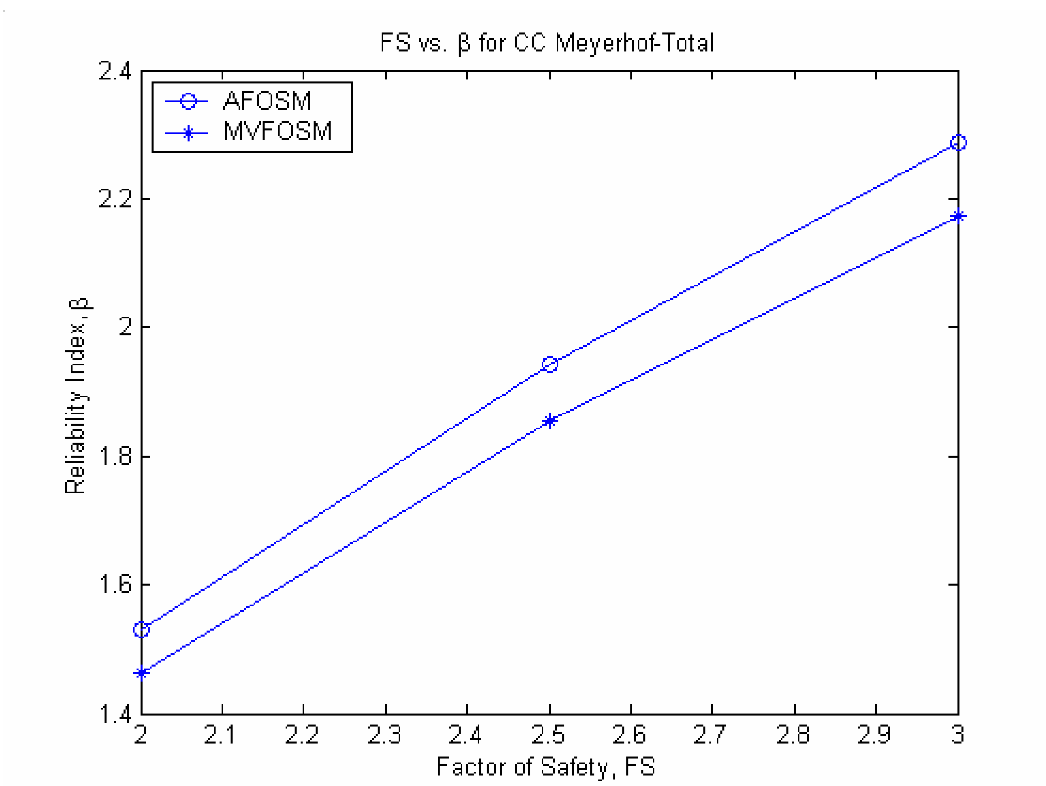

FS vs. β for CC Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

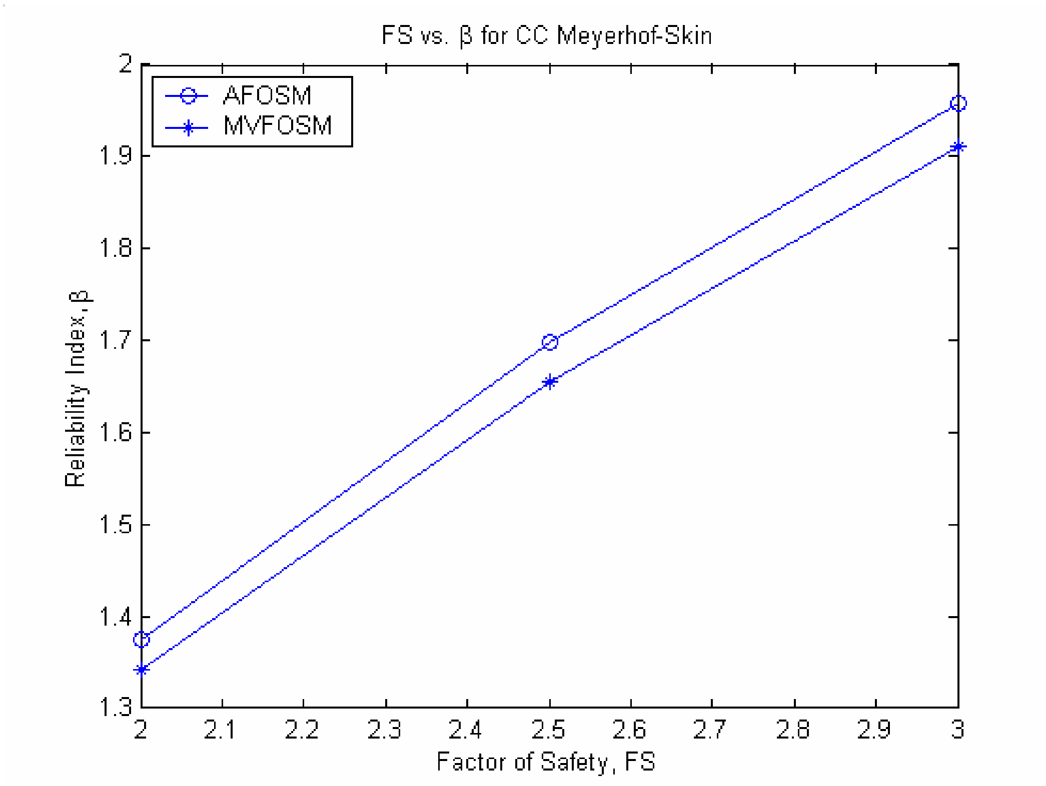

FS vs. β for CC Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

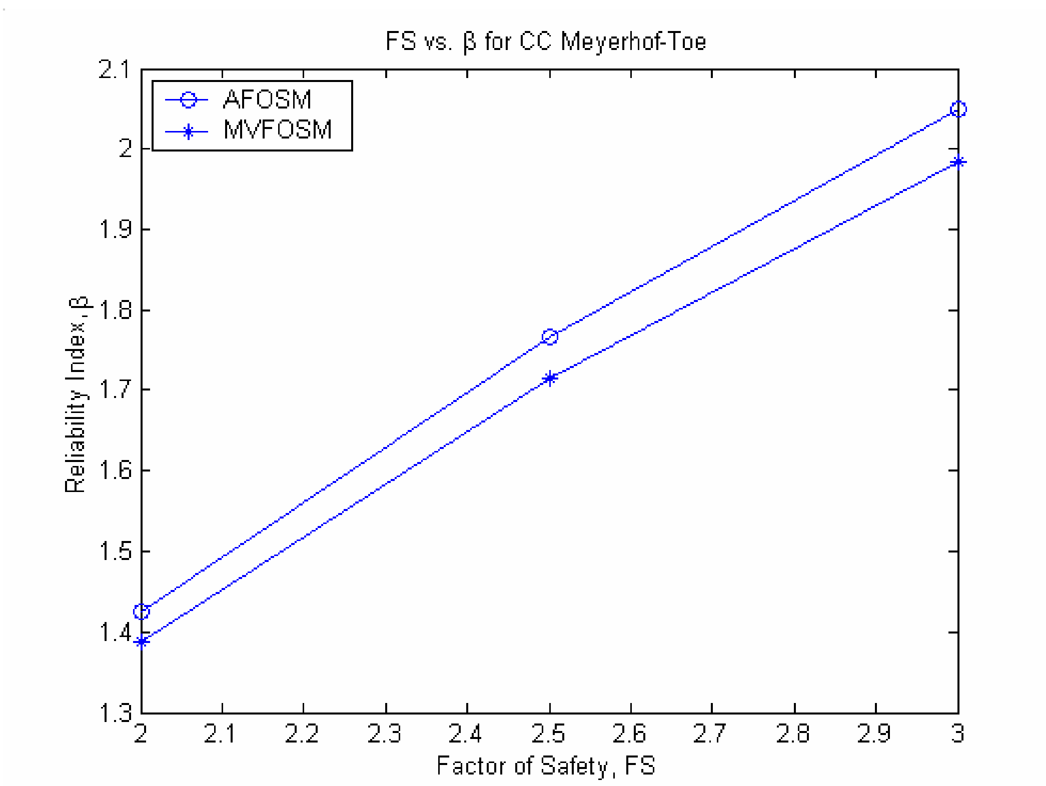
CC All N's MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.529	1.461	1.375	1.342	1.426	1.387
2.5	1.944	1.854	1.698	1.655	1.767	1.716
3	2.287	2.174	1.959	1.911	2.050	1.985

Mean Value 1.425	Mean Value 1.771	Mean Value 1.702
Standard Deviation 0.802	Standard Deviation 1.353	Standard Deviation 1.215
Coefficient of Variation 0.563	Coefficient of Variation 0.764	Coefficient of Variation 0.714



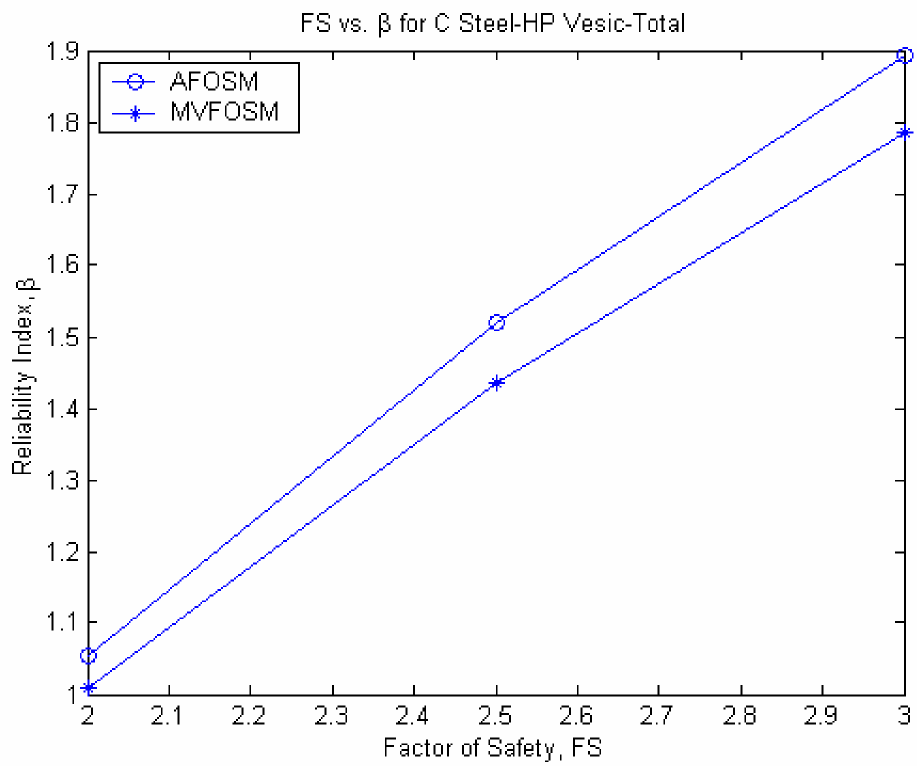

FS vs. β for CC Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

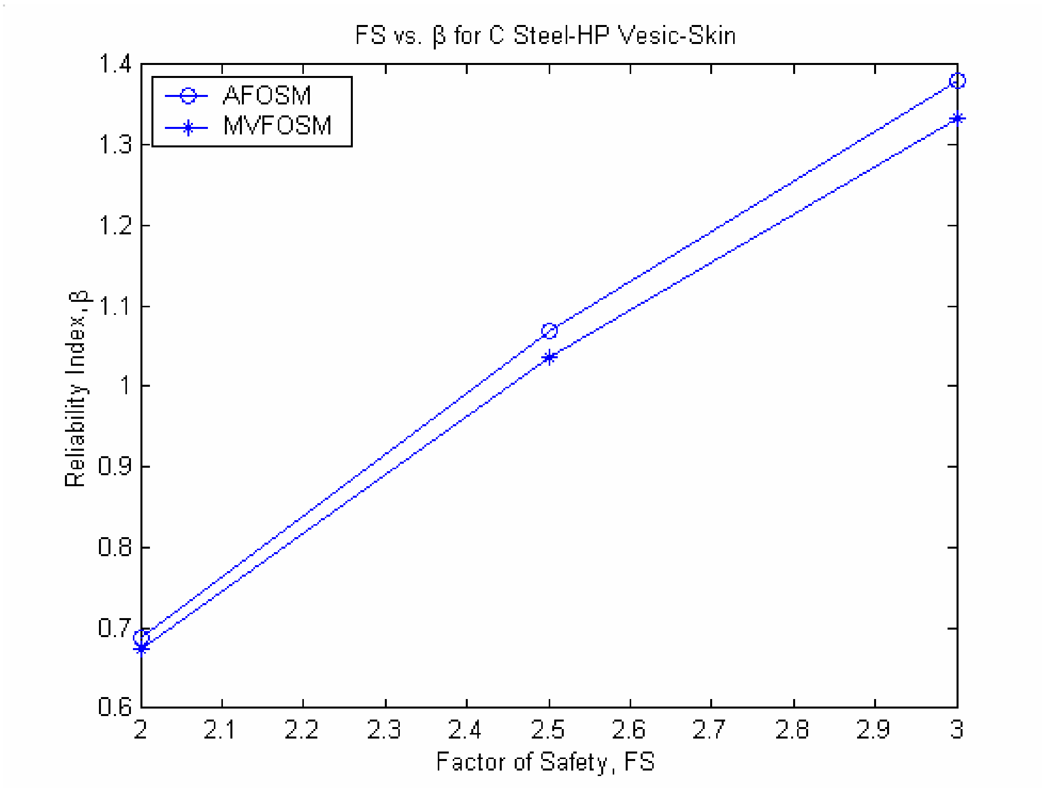

FS vs. β for CC Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

C Steel-HP VESIC

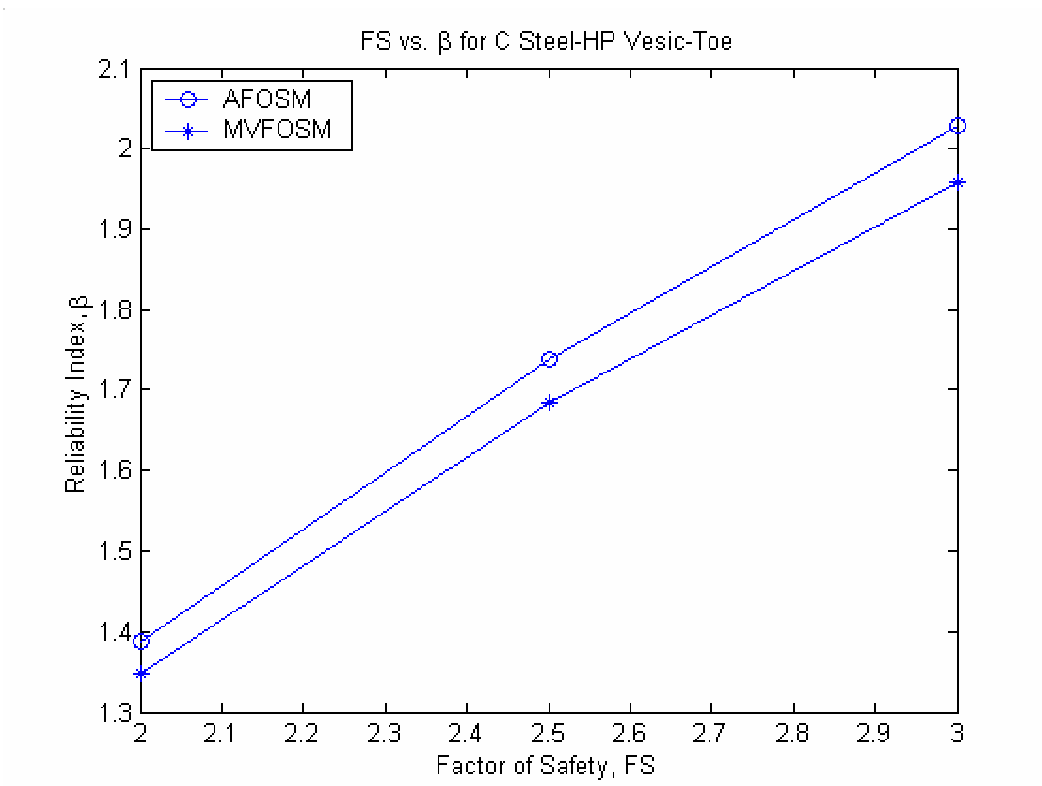
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.053	1.009	0.688	0.674	1.387	1.347
2.5	1.519	1.437	1.069	1.036	1.738	1.684
3	1.894	1.786	1.381	1.333	2.028	1.959

	Total	Skin	Toe
	Mean Value 1.024	Mean Value 0.966	Mean Value 1.603
	Standard Deviation 0.513	Standard Deviation 0.605	Standard Deviation 1.107
	Coefficient of Variation 0.501	Coefficient of Variation 0.626	Coefficient of Variation 0.691





FS vs. β for C Steel-HP Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

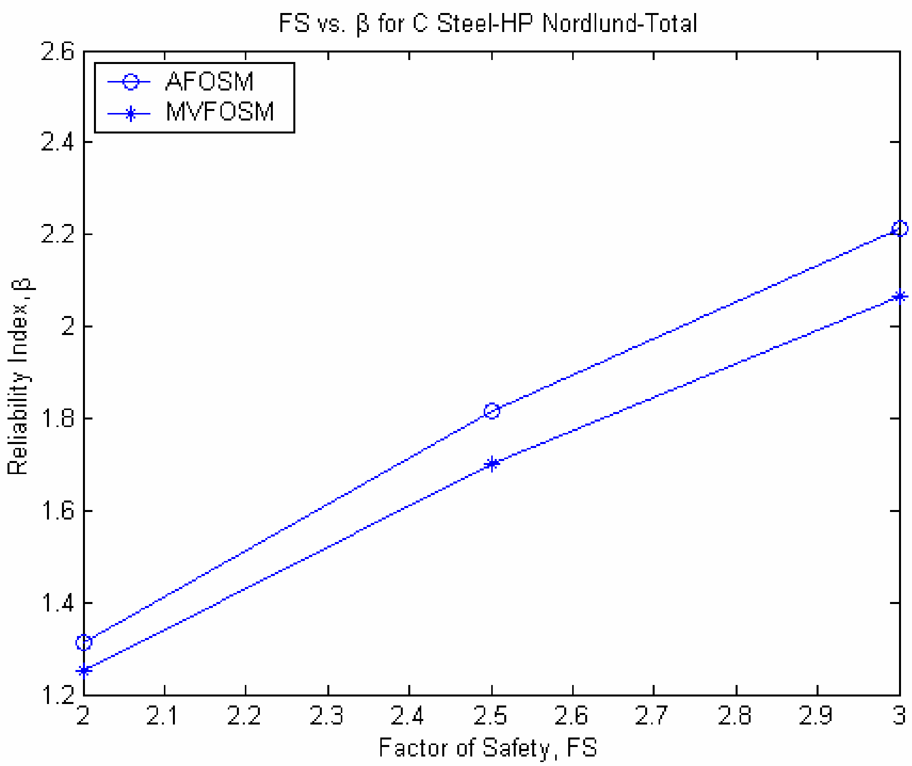


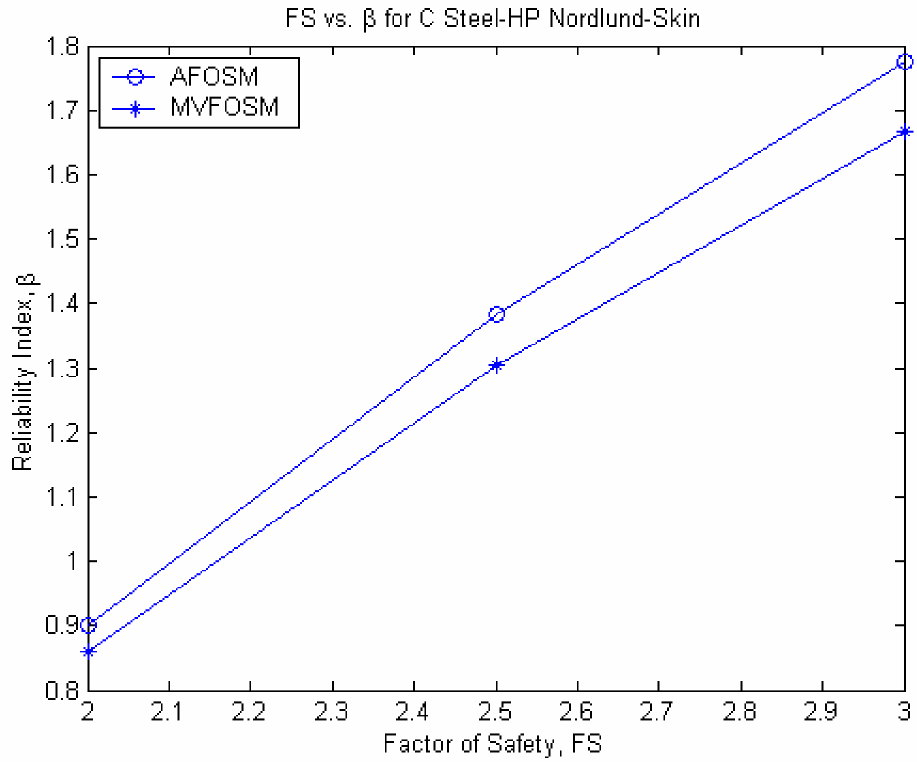
FS vs. β for C Steel-HP Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

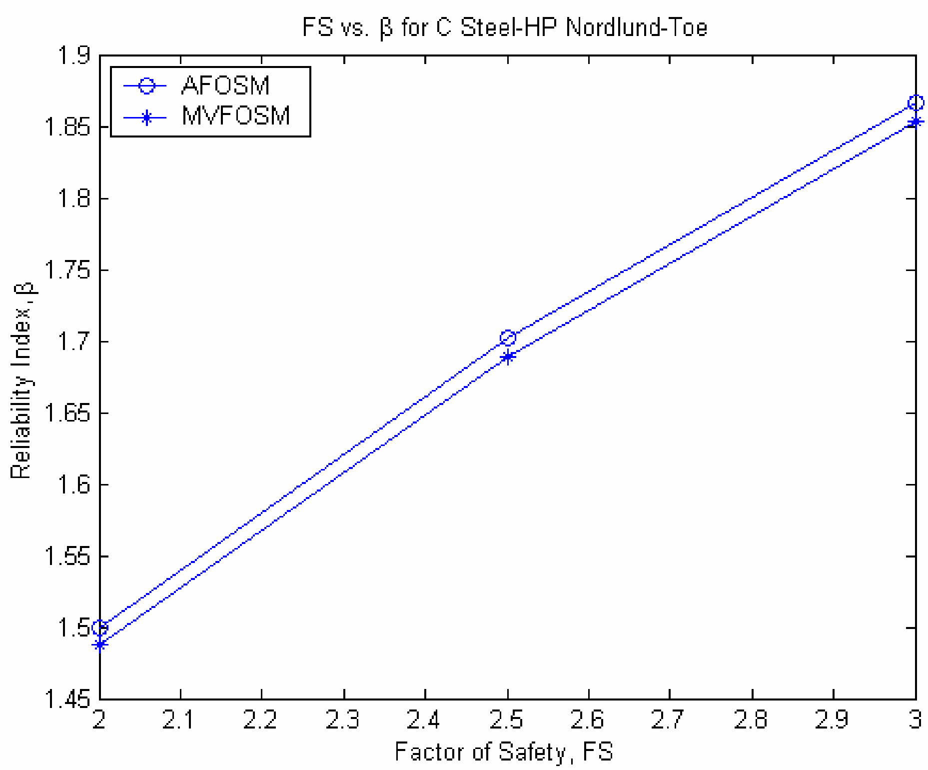
C Steel-HP NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.314	1.250	0.901	0.860	1.499	1.488
2.5	1.816	1.700	1.383	1.304	1.702	1.689
3	2.214	2.068	1.775	1.666	1.866	1.853

Total	Skin	Toe
Mean Value 1.109	Mean Value 0.924	Mean Value 5.103
Standard Deviation 0.518	Standard Deviation 0.441	Standard Deviation 7.690
Coefficient of Variation 0.467	Coefficient of Variation 0.477	Coefficient of Variation 1.507



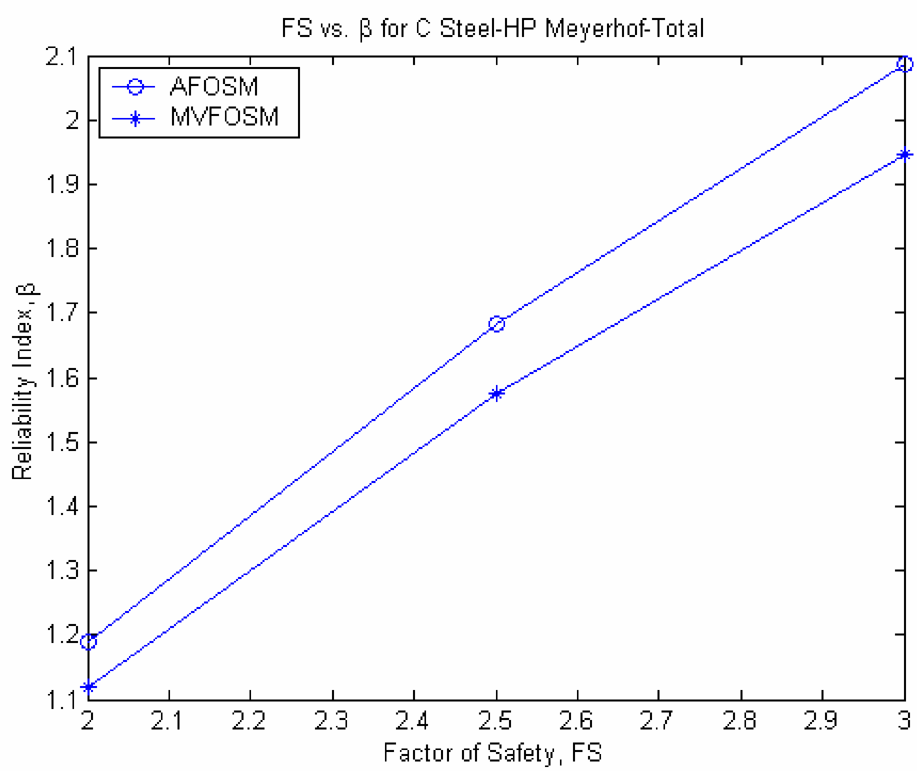

FS vs. β for C Steel-HP Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

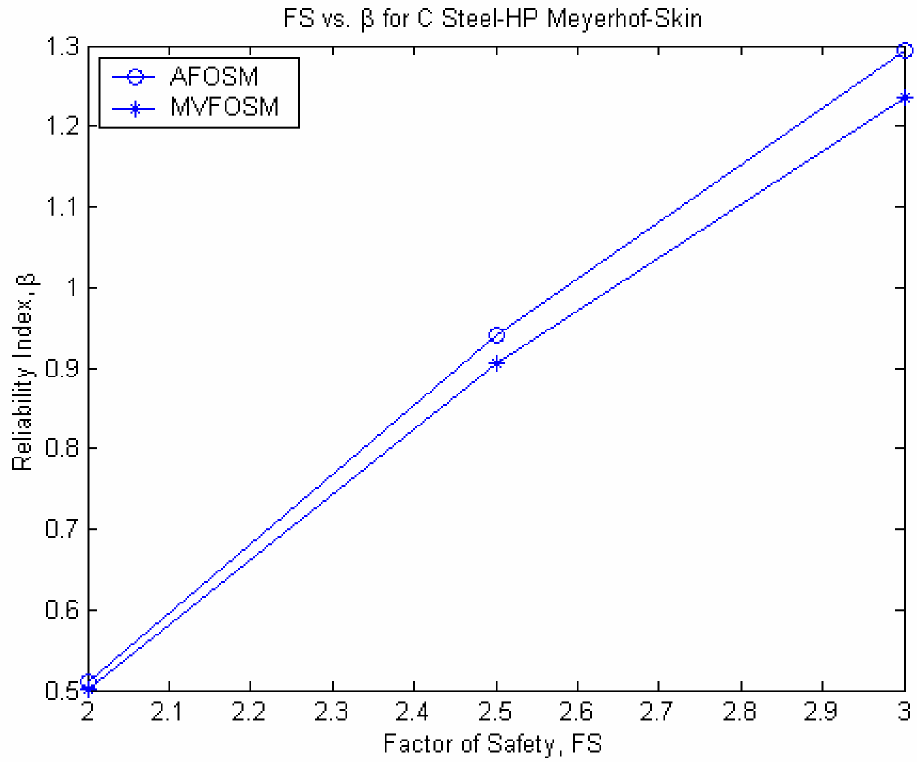

FS vs. β for C Steel-HP Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

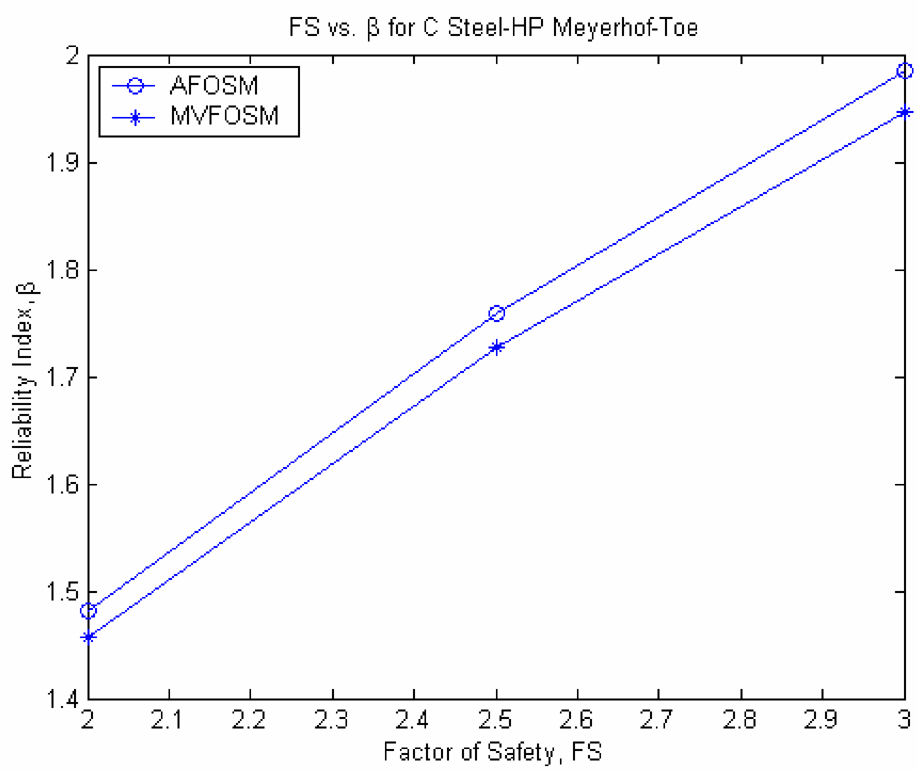
C Steel-HP MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.189	1.119	0.510	0.501	1.482	1.456
2.5	1.684	1.575	0.942	0.906	1.760	1.726
3	2.087	1.948	1.294	1.236	1.985	1.947

Total	Skin	Toe
Mean Value 1.029	Mean Value 0.811	Mean Value 2.472
Standard Deviation 0.473	Standard Deviation 0.438	Standard Deviation 2.326
Coefficient of Variation 0.459	Coefficient of Variation 0.541	Coefficient of Variation 0.941



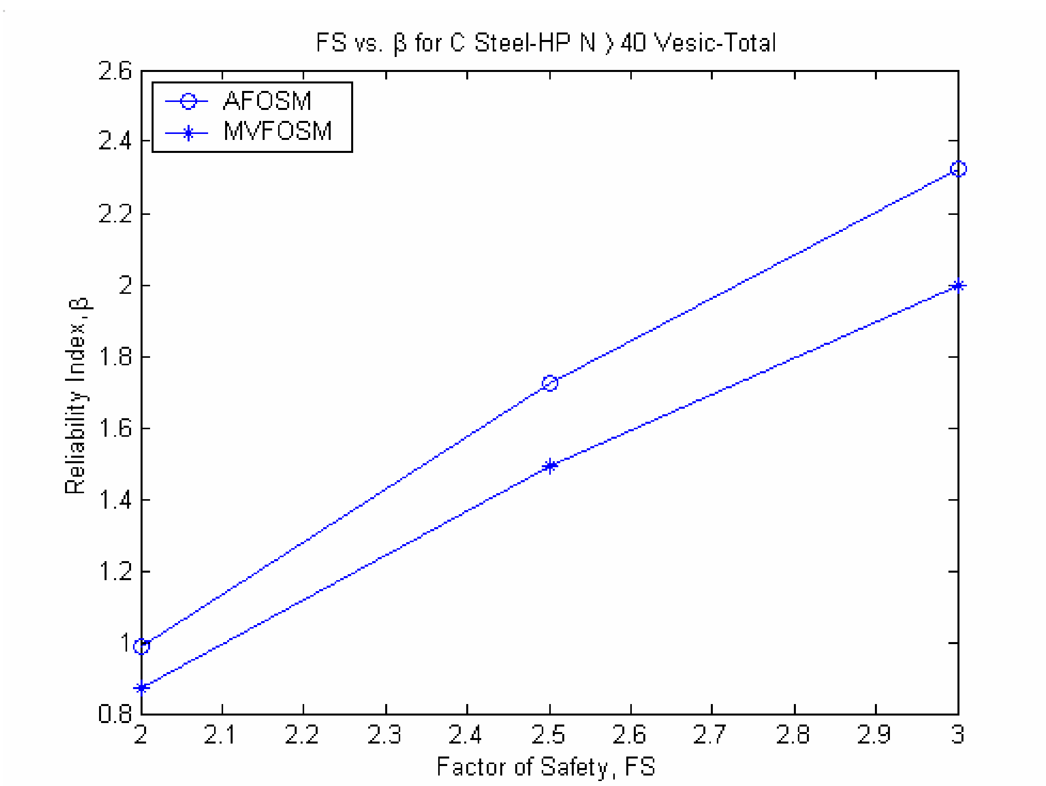

FS vs. β for C Steel-HP Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

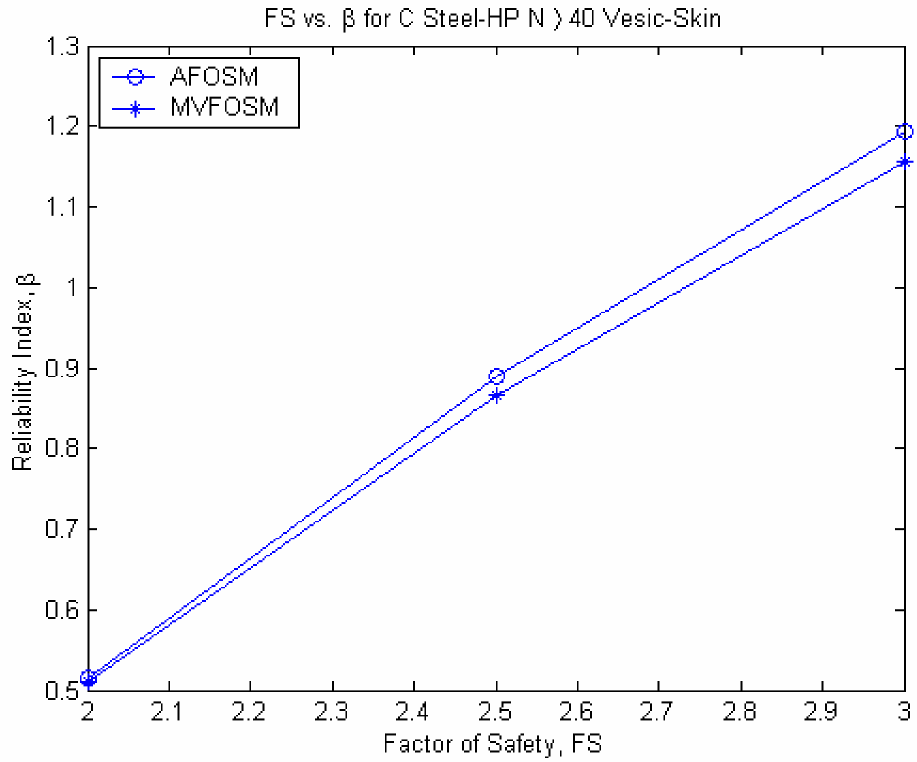

FS vs. β for C Steel-HP Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2
1.9
1.8
1.7
1.6
1.5
1.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

C Steel-HP N>40 VESIC

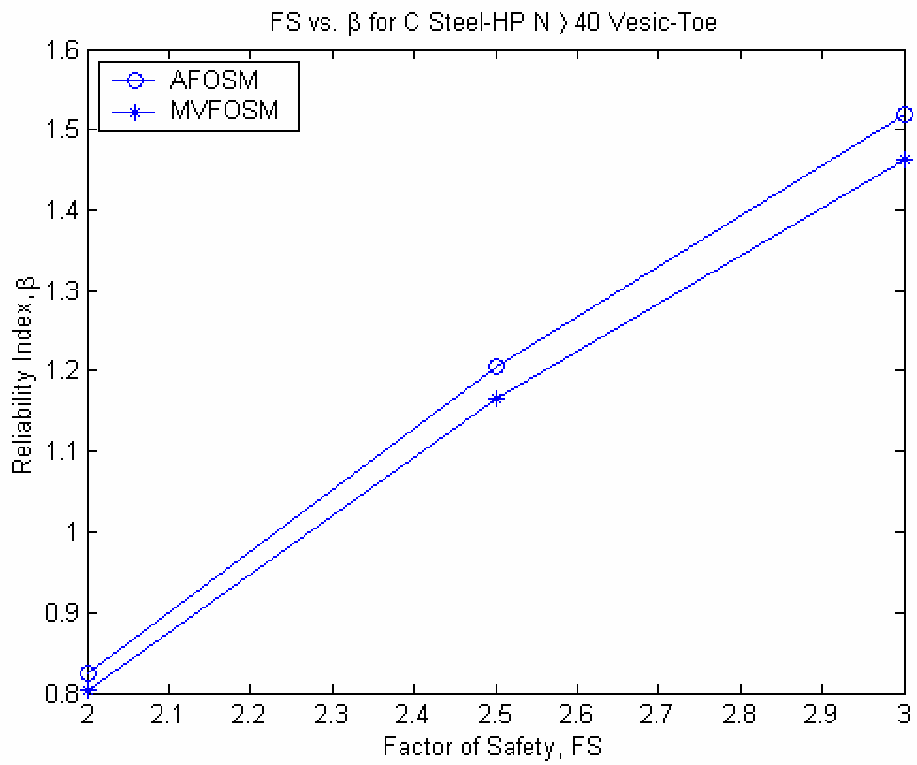
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.987	0.870	0.514	0.510	0.823	0.802
2.5	1.722	1.490	0.888	0.866	1.207	1.167
3	2.321	1.997	1.194	1.157	1.520	1.464

Total	Skin	Toe
Mean Value 0.770	Mean Value 0.884	Mean Value 1.041
Standard Deviation 0.224	Standard Deviation 0.567	Standard Deviation 0.648
Coefficient of Variation 0.291	Coefficient of Variation 0.641	Coefficient of Variation 0.622





FS vs. β for C Steel-HP N ⟩ 40 Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS

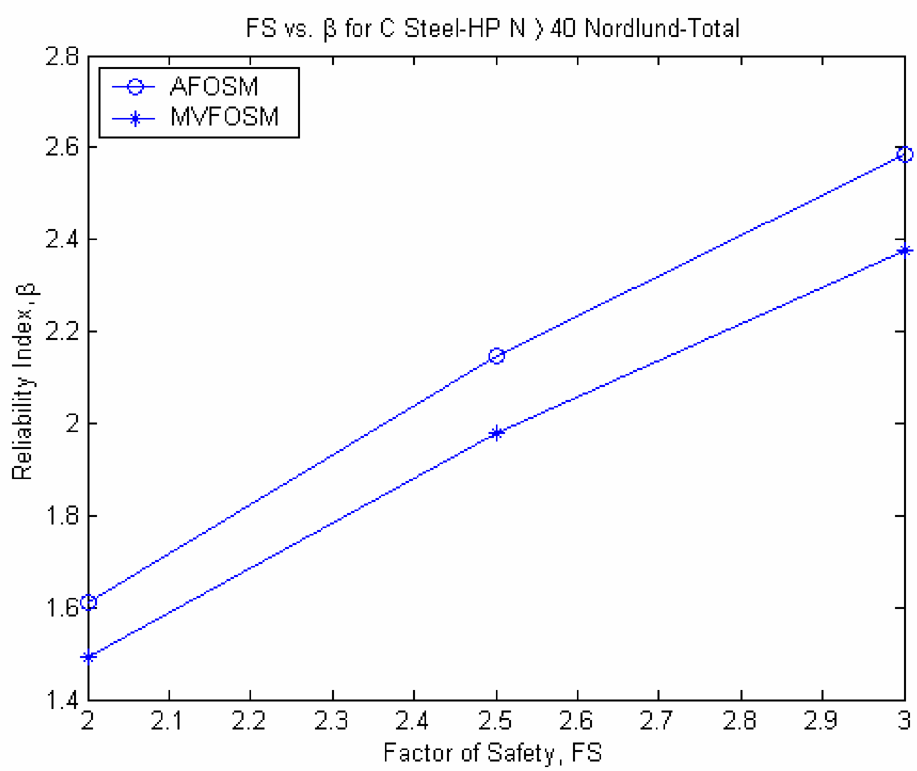


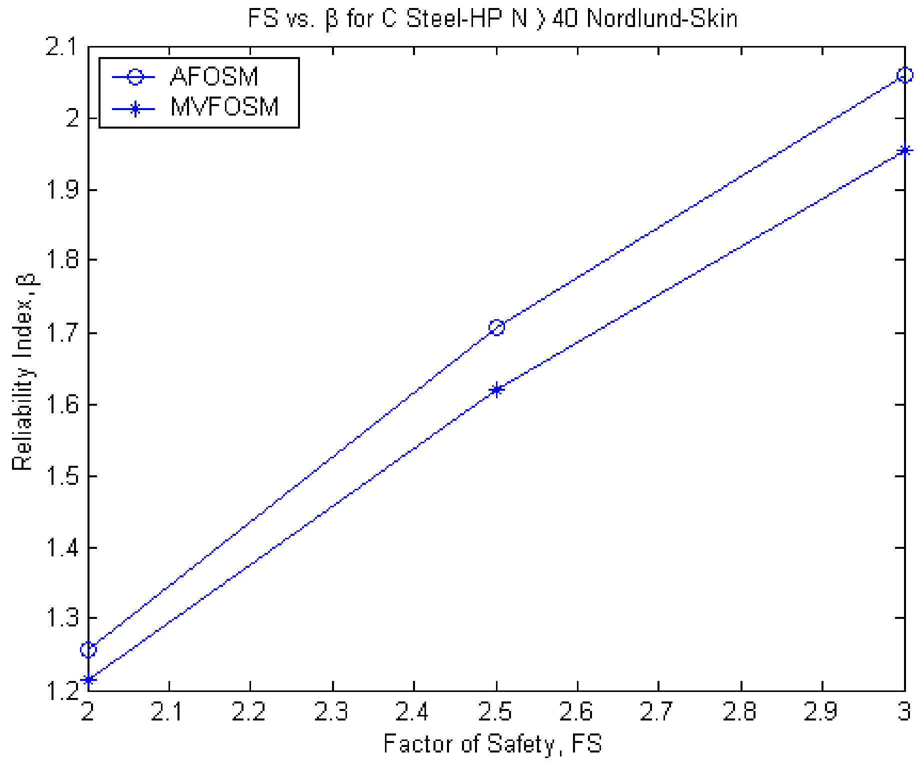
FS vs. β for C Steel-HP N ⟩ 40 Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS

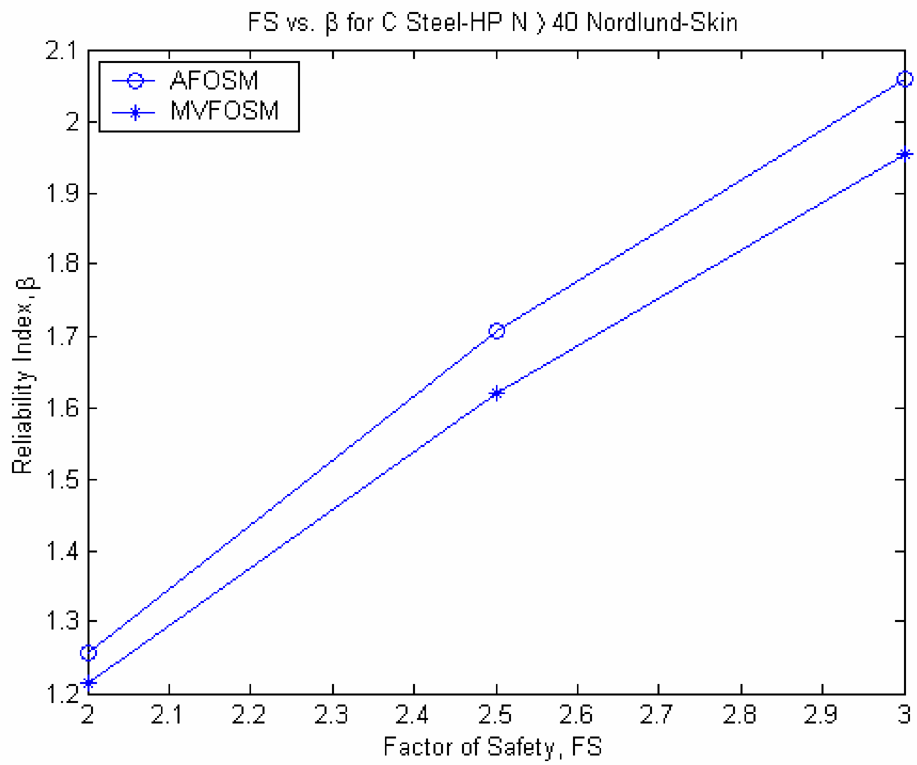
C Steel-HP N>40 NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.612	1.491	1.256	1.214	0.658	0.650
2.5	2.148	1.978	1.706	1.621	1.000	0.978
3	2.587	2.376	2.059	1.954	1.280	1.246

	Total	Skin	Toe
	Mean Value 1.161	Mean Value 1.193	Mean Value 1.034
	Standard Deviation 0.487	Standard Deviation 0.639	Standard Deviation 0.740
	Coefficient of Variation 0.419	Coefficient of Variation 0.535	Coefficient of Variation 0.716



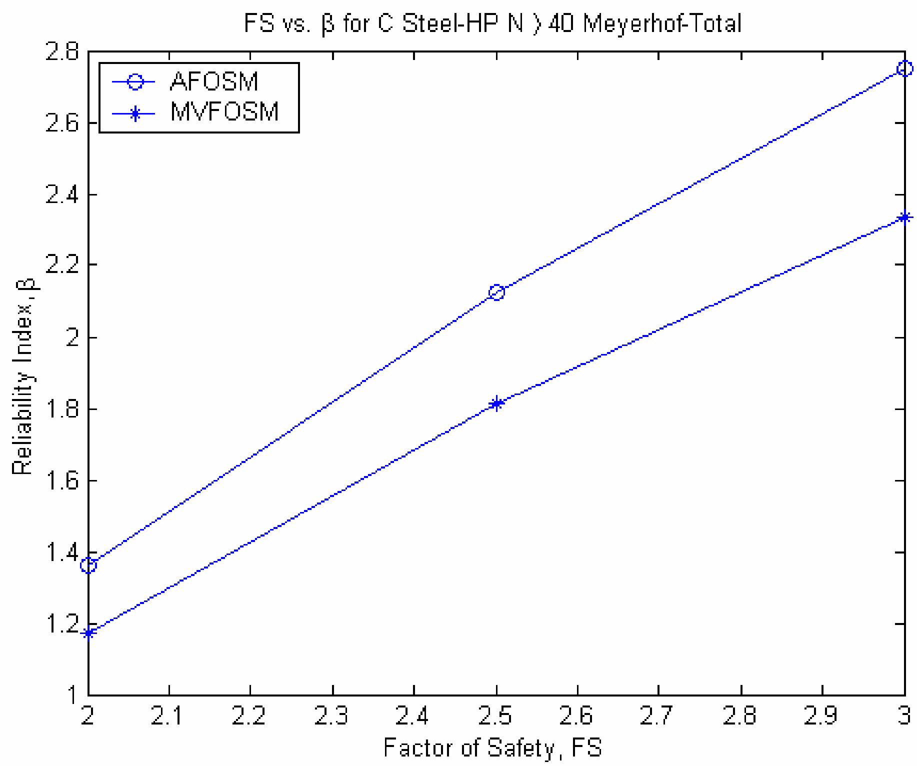

FS vs. β for C Steel-HP N ⟩ 40 Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

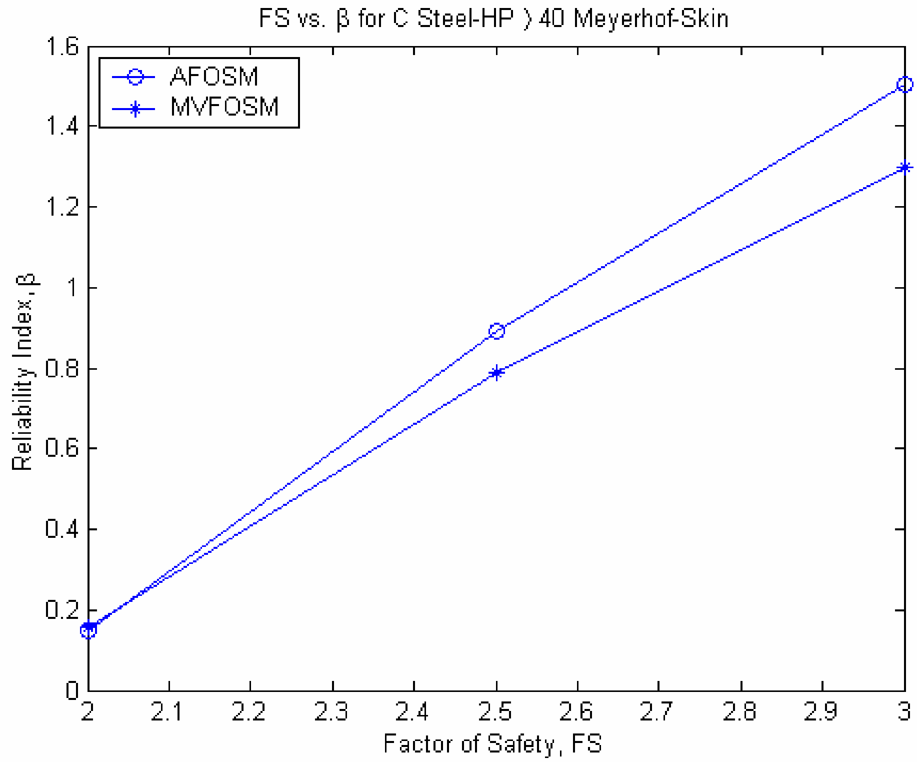

FS vs. β for C Steel-HP N ⟩ 40 Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

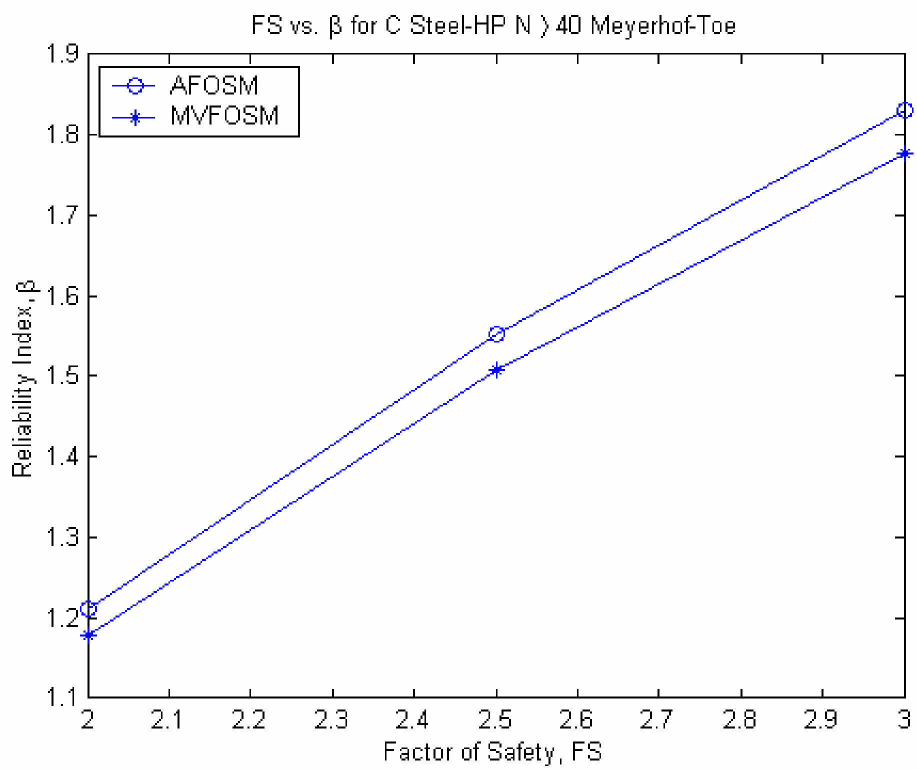
C Steel-HP N>40 MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.358	1.173	0.147	0.159	1.210	1.179
2.5	2.125	1.812	0.893	0.787	1.553	1.509
3	2.749	2.333	1.504	1.300	1.831	1.778

	Total	Skin	Toe
	Mean Value 0.846	Mean Value 0.595	Mean Value 1.477
	Standard Deviation 0.234	Standard Deviation 0.170	Standard Deviation 1.053
	Coefficient of Variation 0.277	Coefficient of Variation 0.285	Coefficient of Variation 0.713



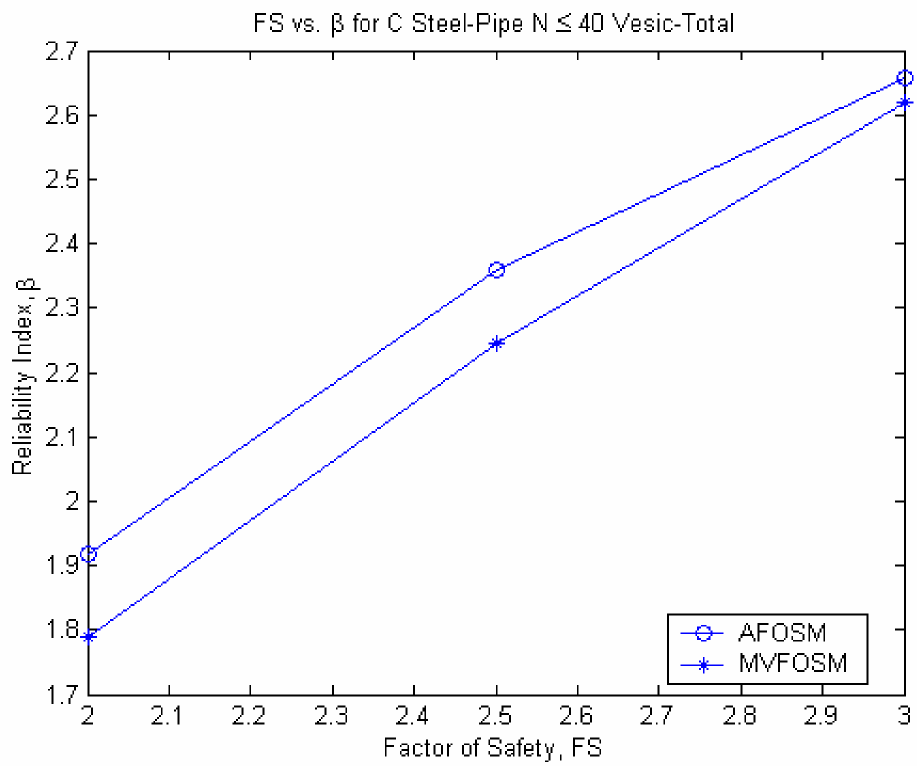

FS vs. β for C Steel-HP) 40 Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

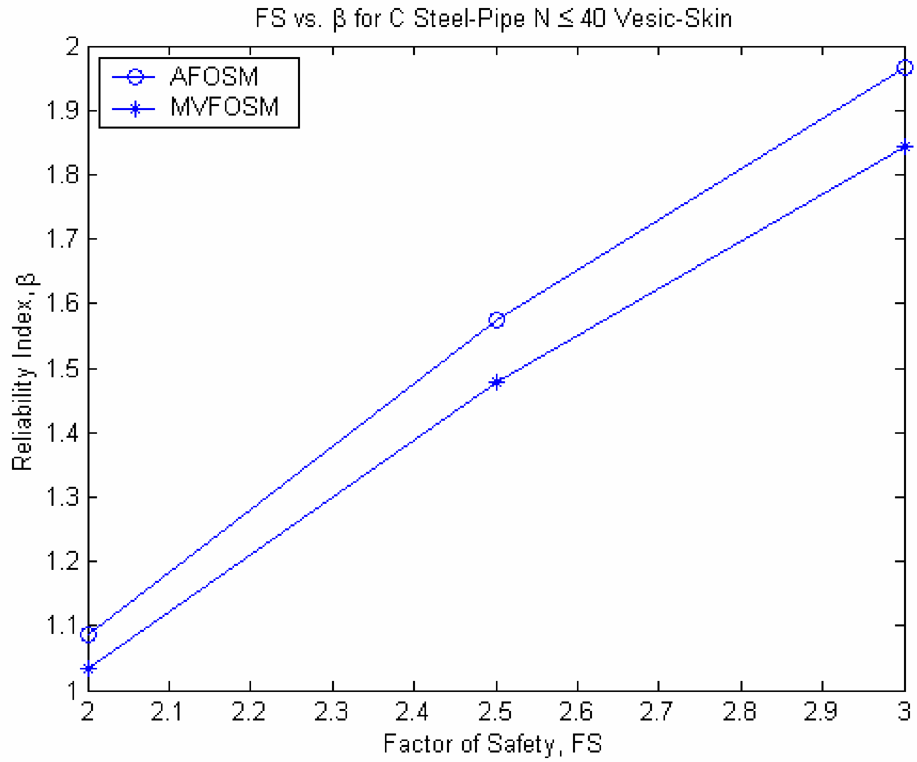

FS vs. β for C Steel-HP N) 40 Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

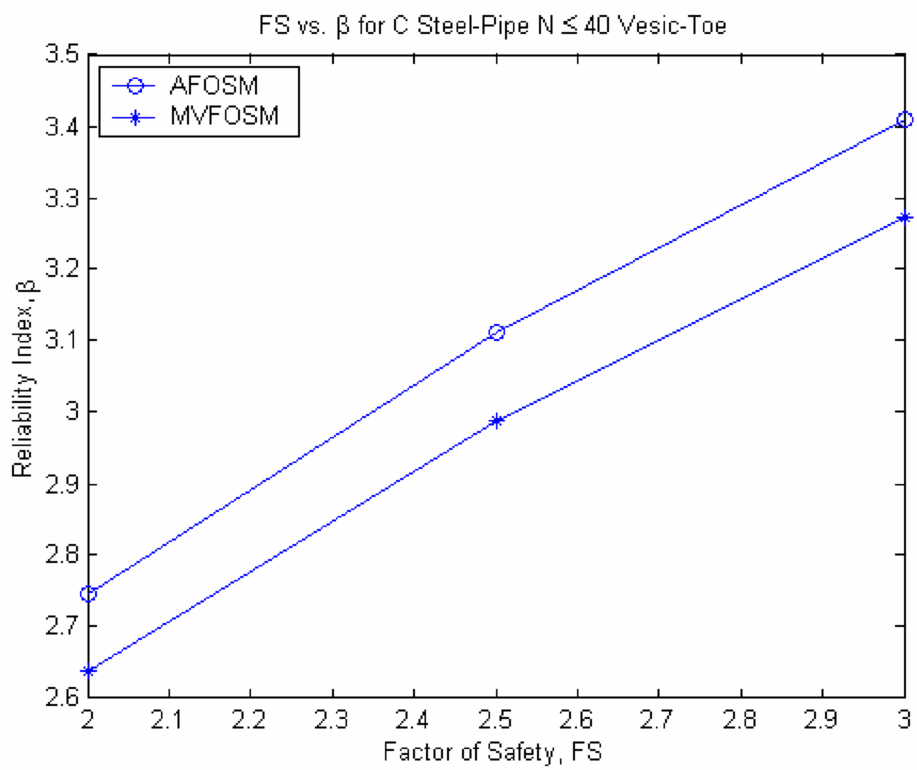
C Steel-Pipe N<40 VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.918	1.789	1.086	1.033	2.746	2.639
2.5	2.359	2.246	1.574	1.479	3.111	2.988
3	2.658	2.620	1.968	1.843	3.410	3.272

	Total	Skin	Toe
	Mean Value 1.424	Mean Value 1.004	Mean Value 3.511
	Standard Deviation 0.652	Standard Deviation 0.476	Standard Deviation 2.318
	Coefficient of Variation 0.458	Coefficient of Variation 0.474	Coefficient of Variation 0.660



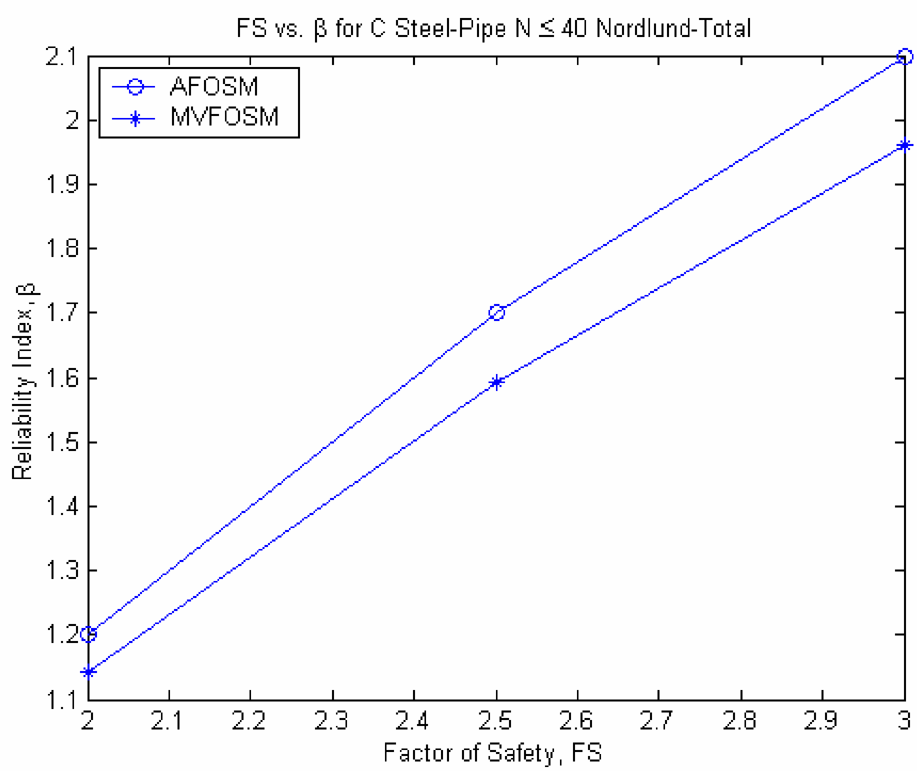

FS vs. β for C Steel-Pipe N ≤ 40 Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

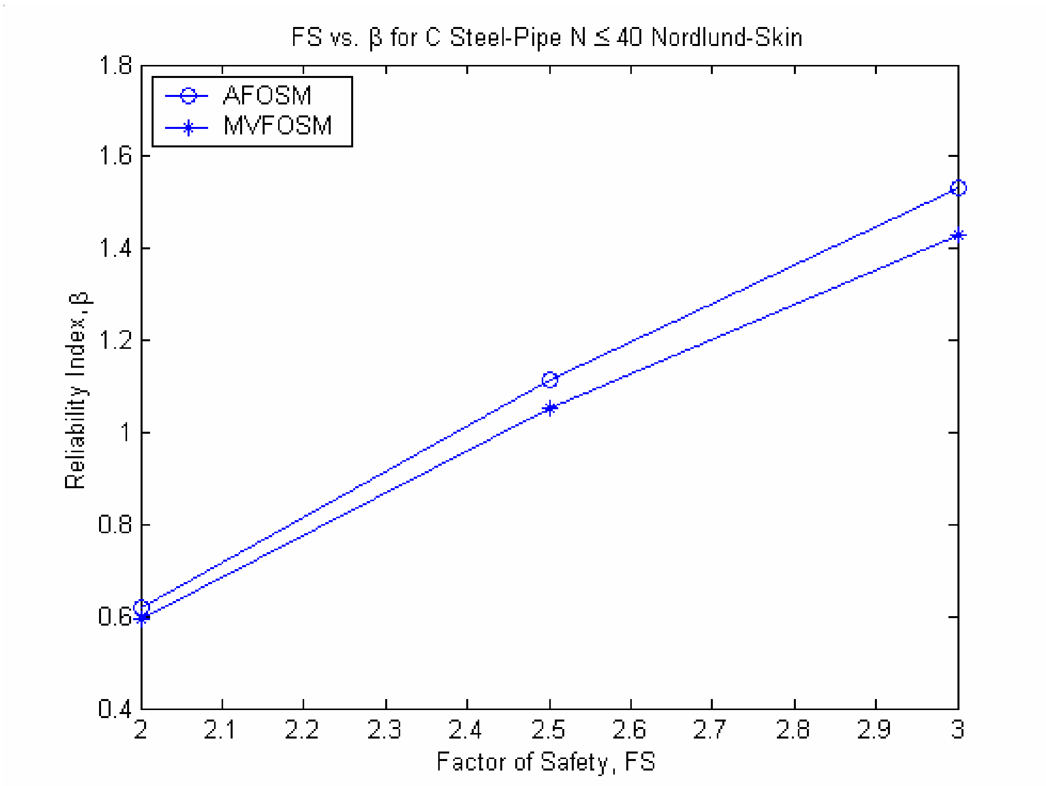

FS vs. β for C Steel-Pipe N ≤ 40 Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

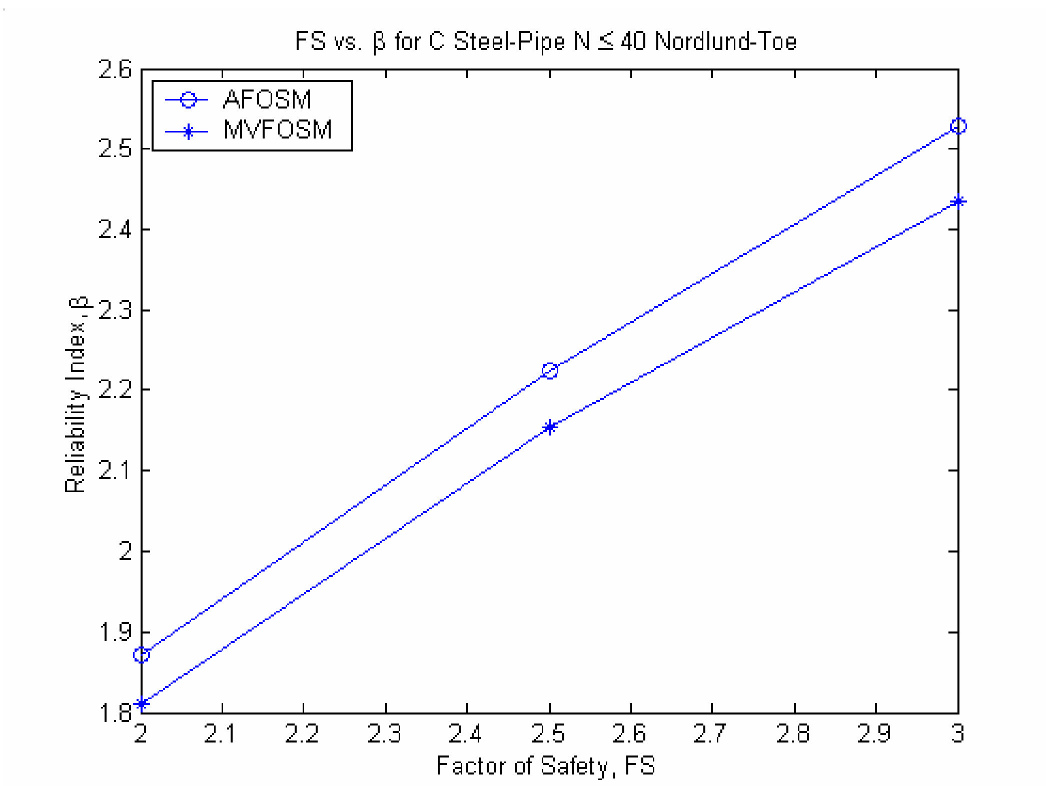
C Steel-Pipe N<40 NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.202	1.142	0.618	0.594	1.872	1.812
2.5	1.7	1.592	1.114	1.054	2.225	2.155
3	2.098	1.961	1.53	1.431	2.529	2.436

Mean Value 1.051	Mean Value 0.791	Mean Value 2.116
Standard Deviation 0.491	Standard Deviation 0.358	Standard Deviation 1.425
Coefficient of Variation 0.467	Coefficient of Variation 0.453	Coefficient of Variation 0.673



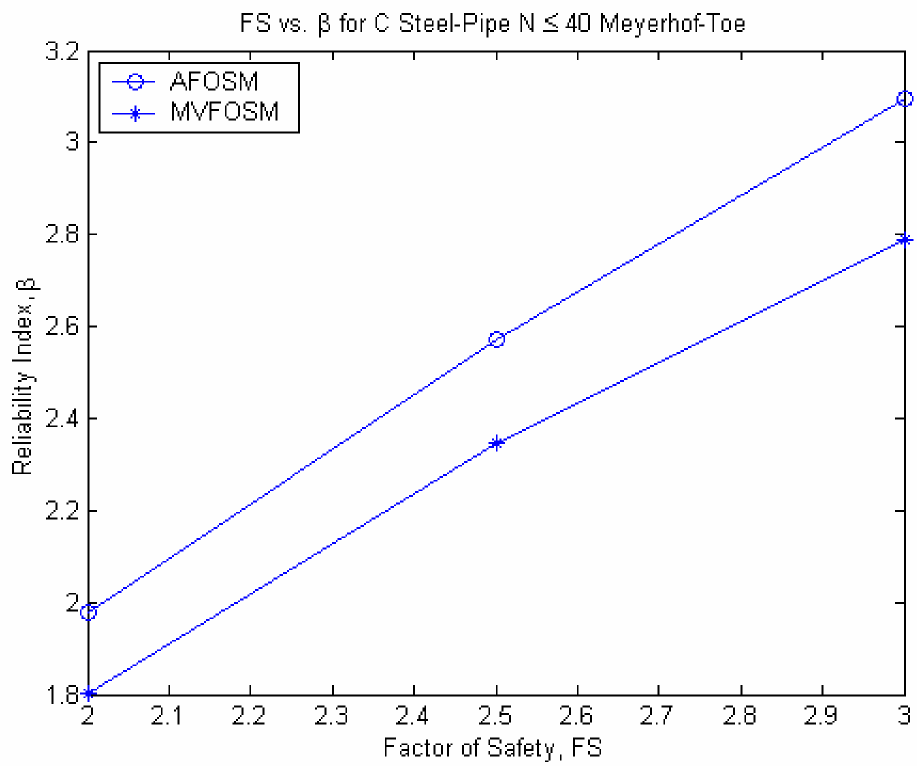

FS vs. β for C Steel-Pipe N ≤ 40 Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

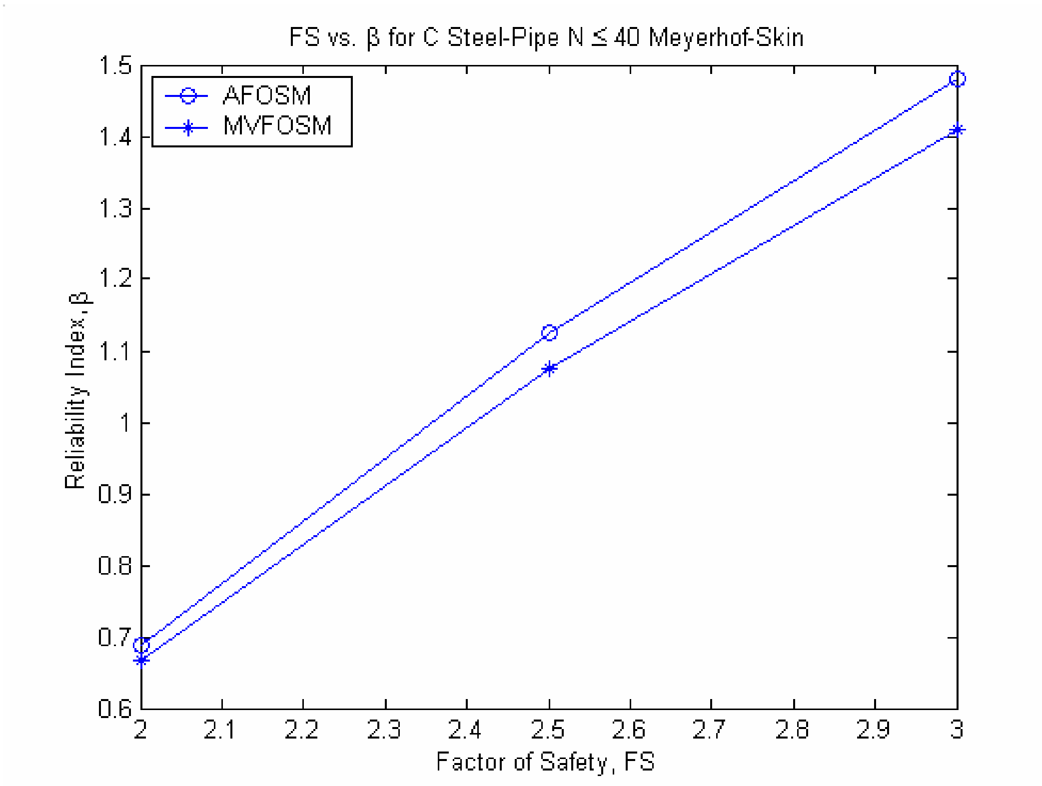

FS vs. β for C Steel-Pipe N ≤ 40 Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

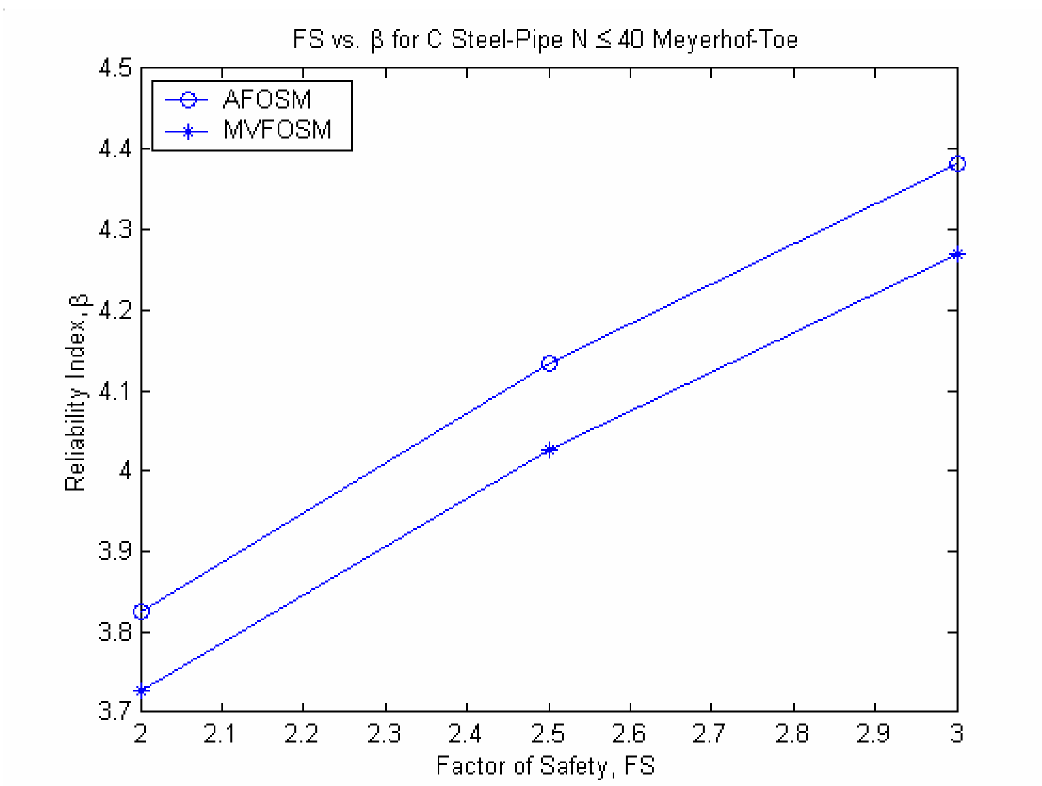
C Steel-Pipe N<40 MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.977	1.804	0.689	0.668	3.825	3.728
2.5	2.573	2.346	1.124	1.076	4.133	4.026
3	3.097	2.790	1.480	1.409	4.382	4.269

	Total	Skin	Toe
Mean Value	1.206	0.884	11.444
Standard Deviation	0.432	0.473	9.381
Coefficient of Variation	0.358	0.535	0.820



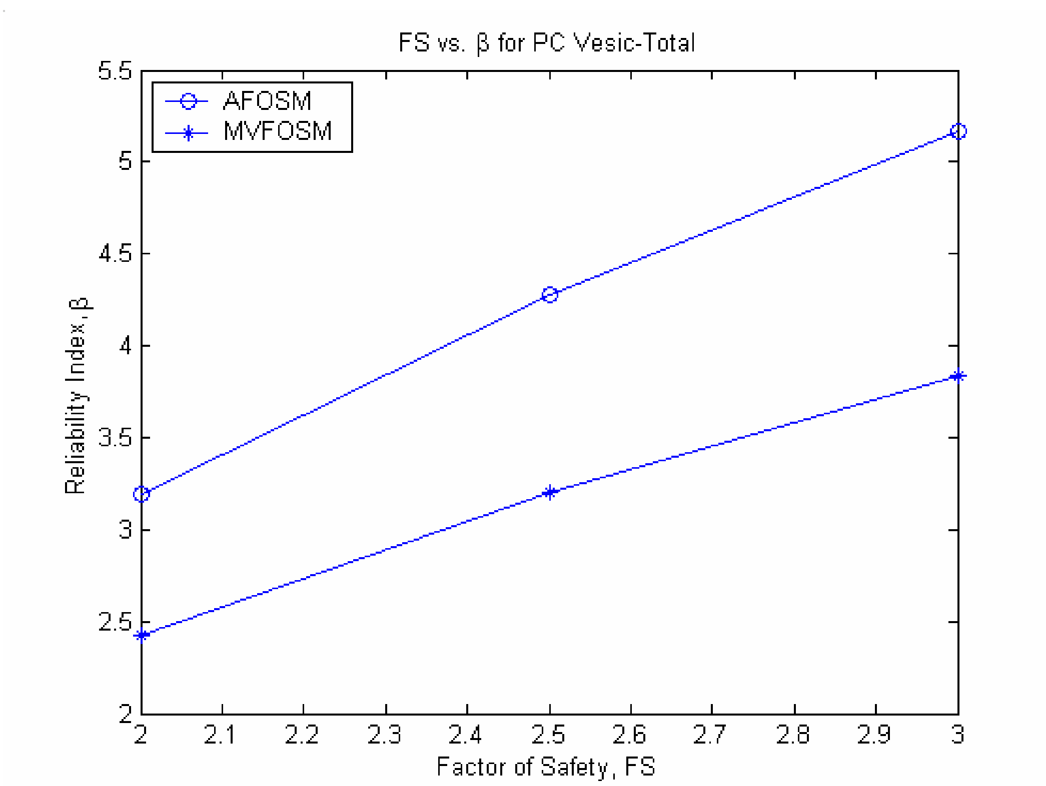

FS vs. β for C Steel-Pipe N ≤ 40 Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

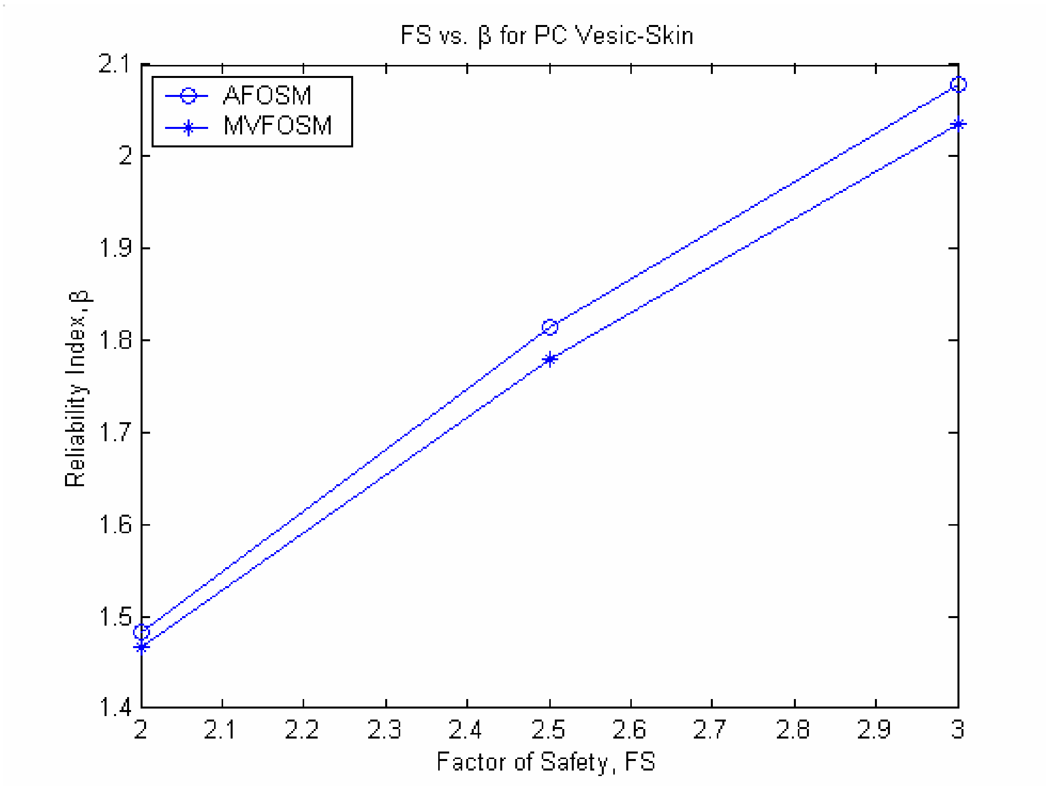

FS vs. β for C Steel-Pipe N ≤ 40 Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

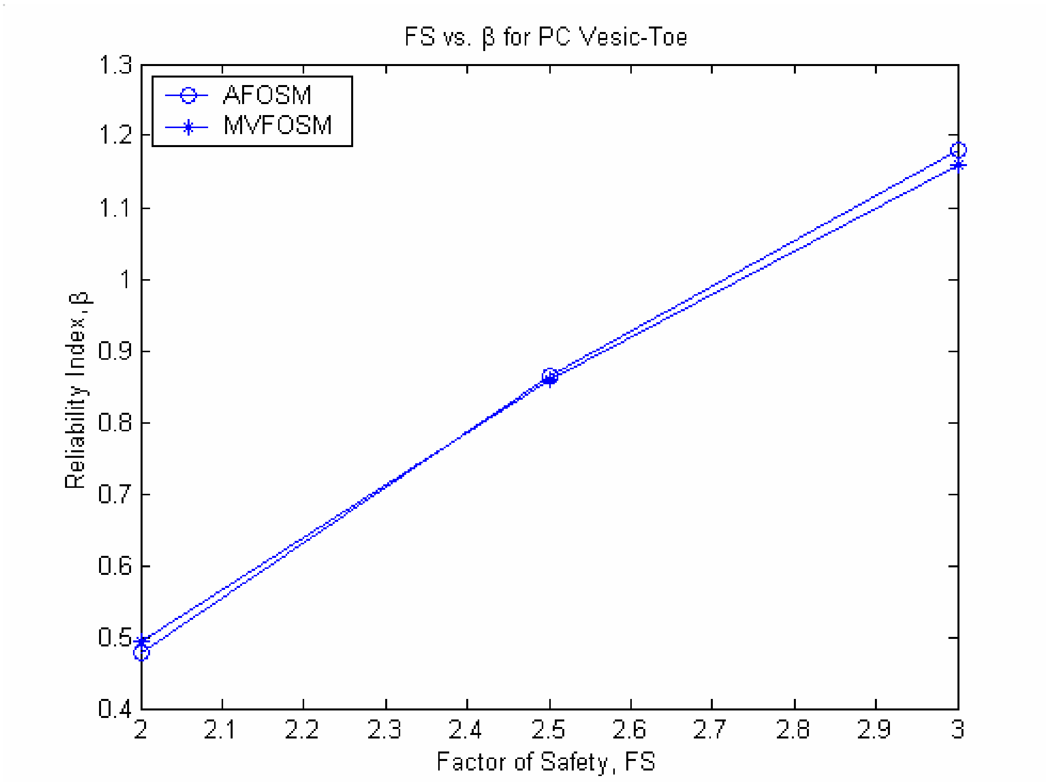
PC VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	3.195	2.420	1.482	1.467	0.477	0.493
2.5	4.278	3.198	1.814	1.780	0.865	0.860
3	5.167	3.833	2.079	2.036	1.181	1.160

Mean Value 1.102	Mean Value 1.940	Mean Value 0.857
Standard Deviation 0.205	Standard Deviation 1.484	Standard Deviation 0.527
Coefficient of Variation 0.187	Coefficient of Variation 0.765	Coefficient of Variation 0.615



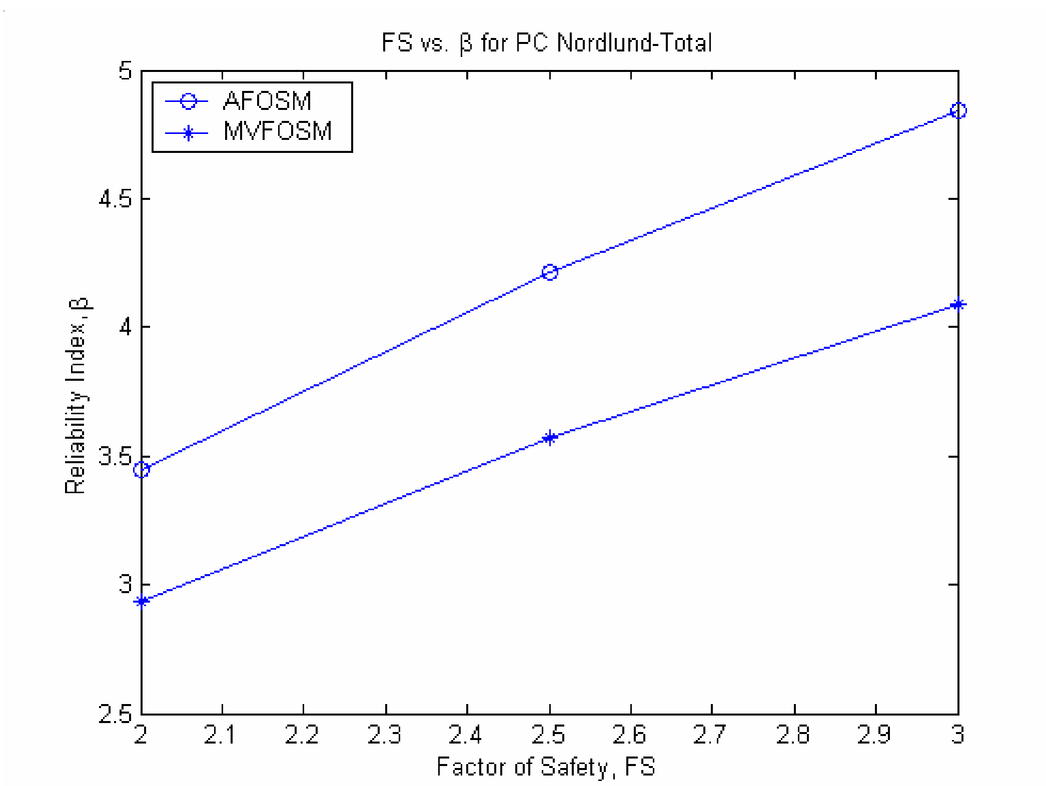

FS vs. β for PC Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

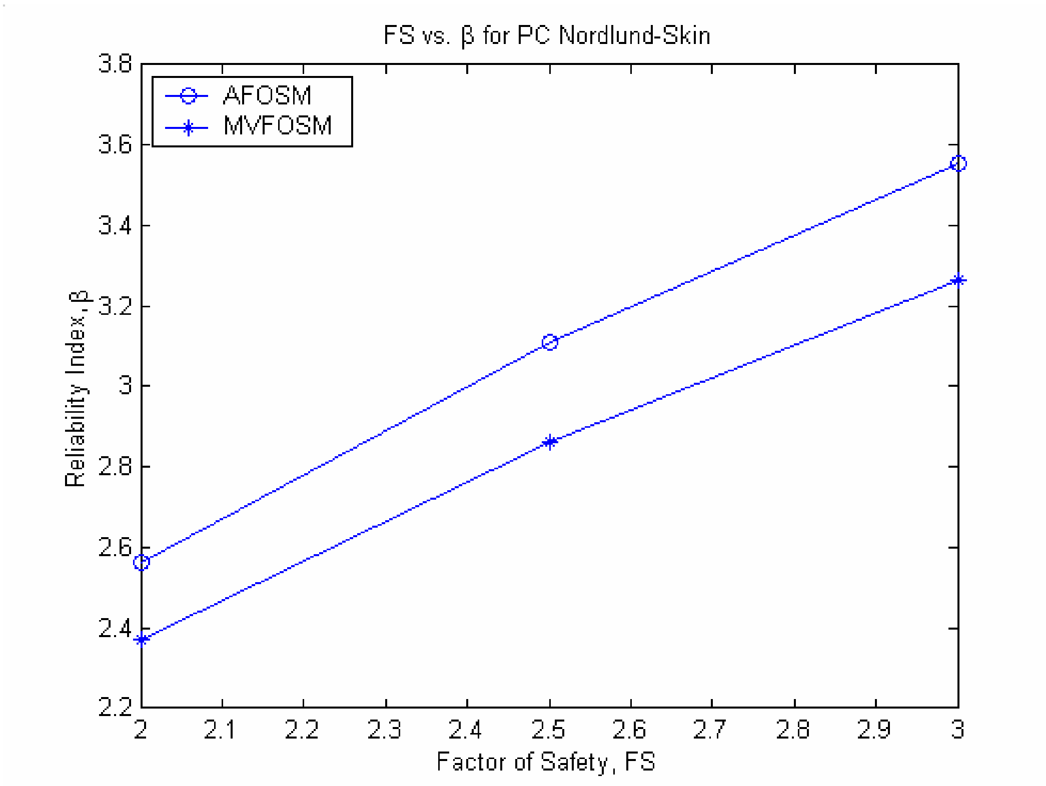

FS vs. β for PC Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

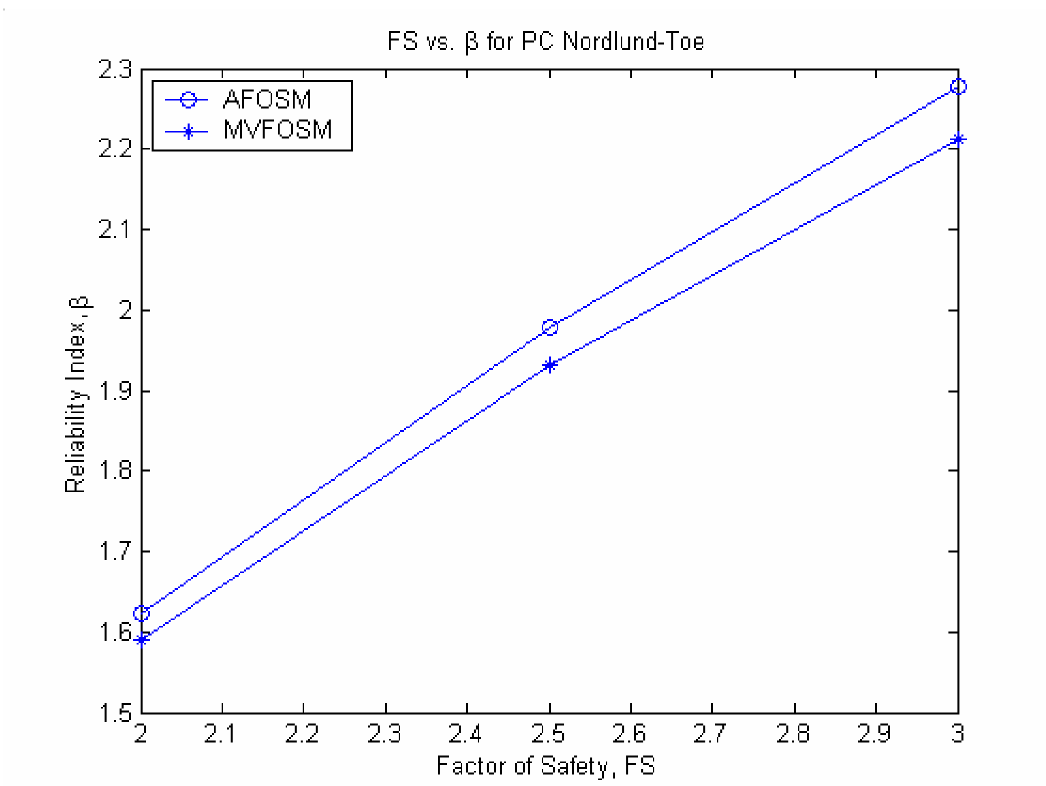
PC NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	3.446	2.934	2.563	2.370	1.623	1.589
2.5	4.216	3.570	3.109	2.862	1.978	1.932
3	4.846	4.089	3.555	3.265	2.278	2.212

Mean Value 1.573	Mean Value 1.712	Mean Value 1.835
Standard Deviation 0.440	Standard Deviation 0.706	Standard Deviation 1.238
Coefficient of Variation 0.279	Coefficient of Variation 0.412	Coefficient of Variation 0.675



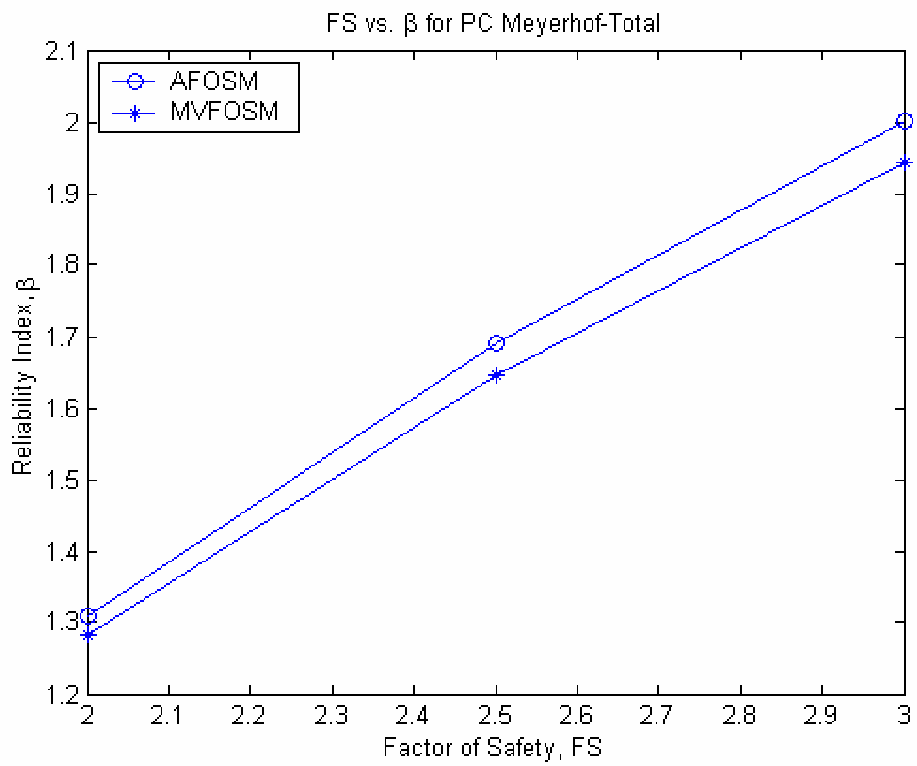

FS vs. β for PC Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

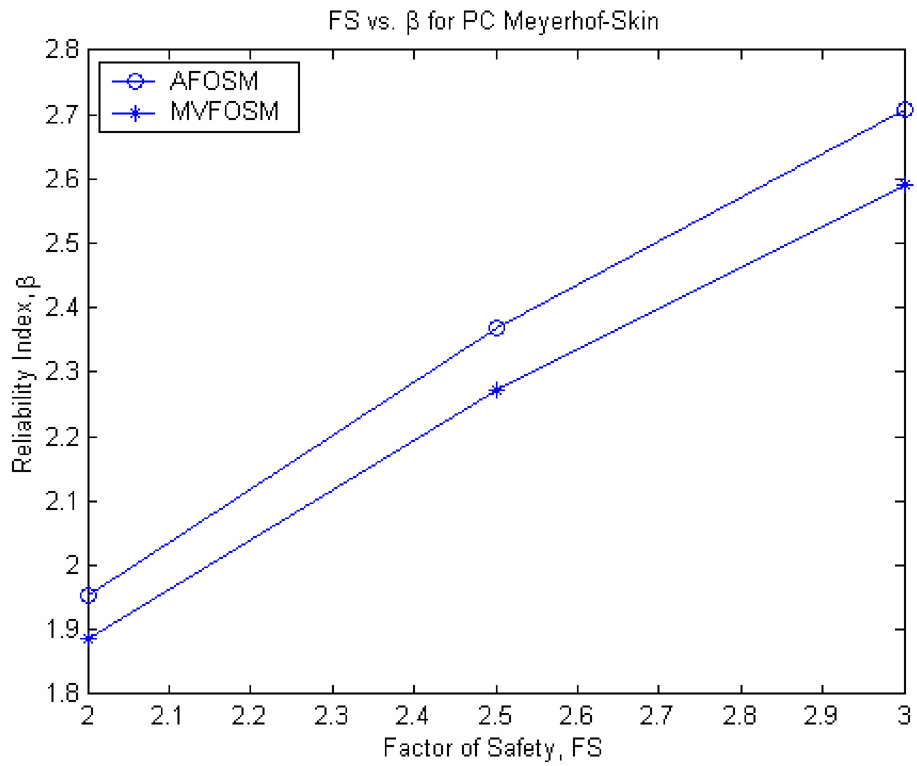

FS vs. β for PC Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

PC MEYERHOF

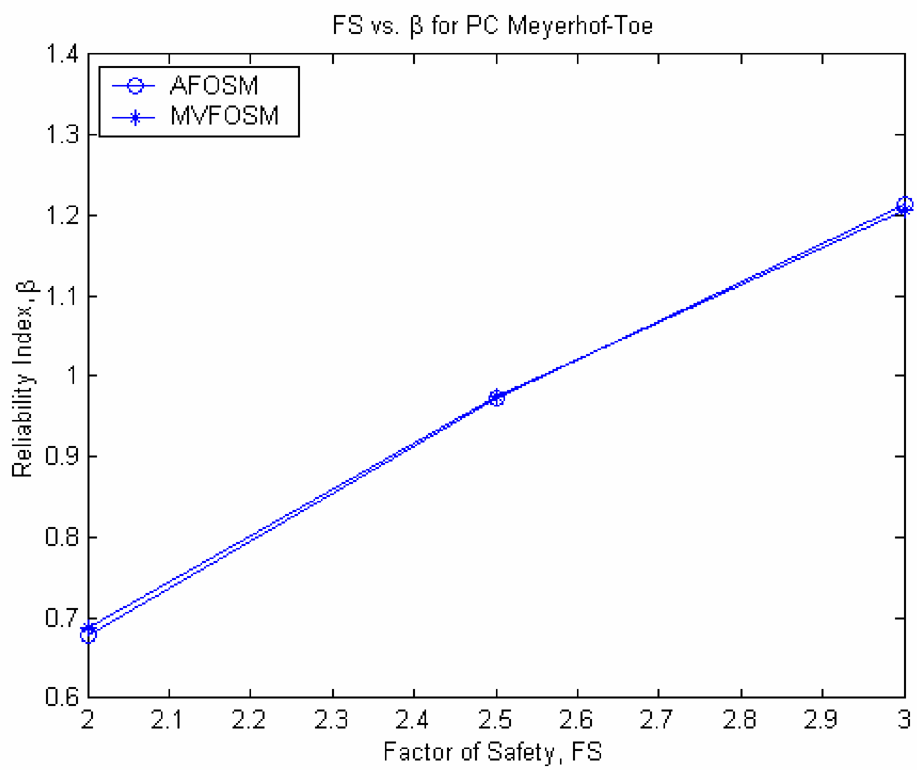
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.31	1.28	1.95	1.89	0.68	0.69
2.5	1.69	1.65	2.37	2.27	0.97	0.98
3	2.00	1.94	2.71	2.59	1.22	1.21

Total	Skin	Toe
Mean Value 1.405	Mean Value 1.840	Mean Value 1.227
Standard Deviation 0.879	Standard Deviation 1.050	Standard Deviation 1.065
Coefficient of Variation 0.626	Coefficient of Variation 0.571	Coefficient of Variation 0.868





FS vs. β for PC Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

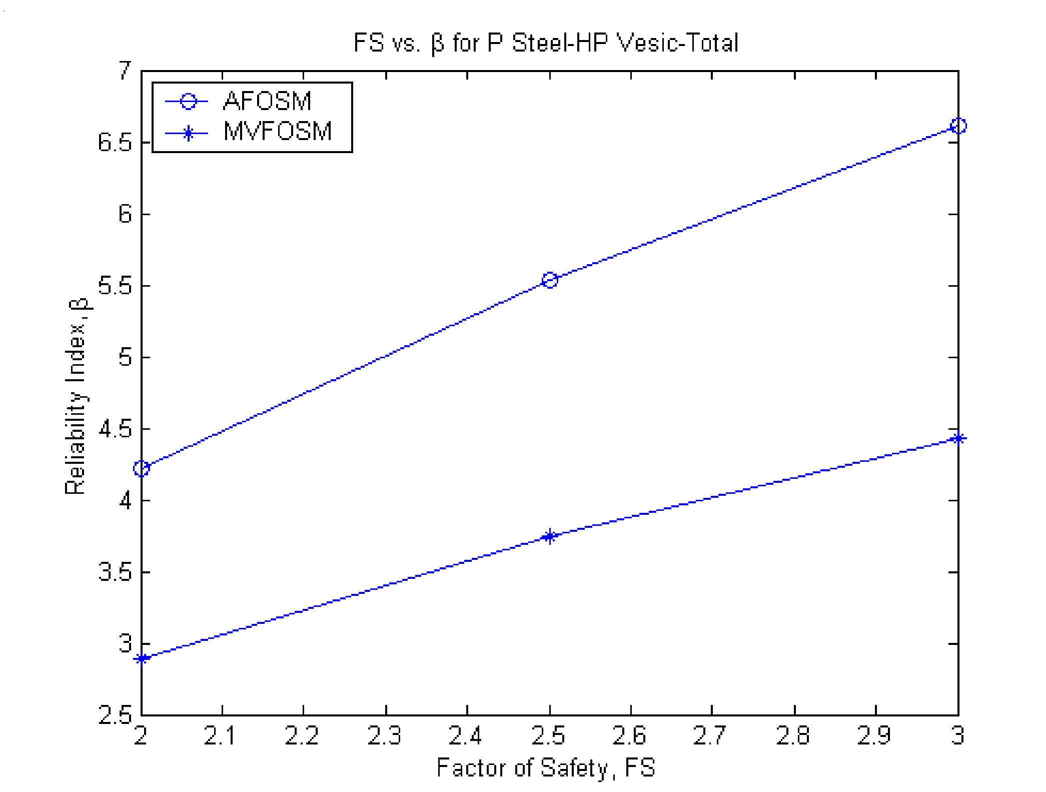


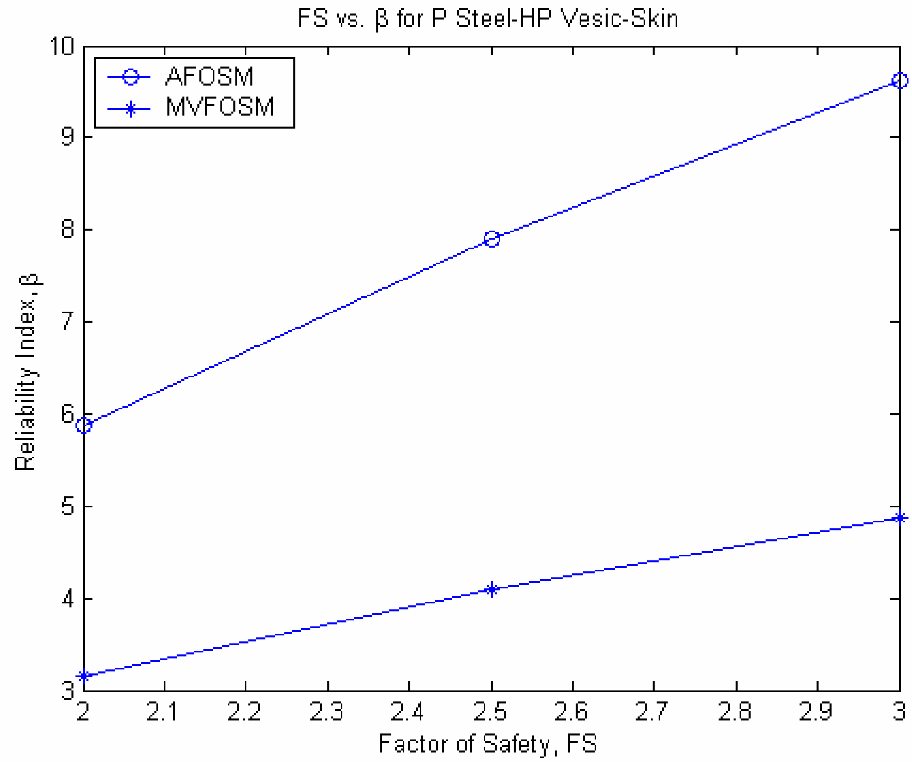
FS vs. β for PC Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

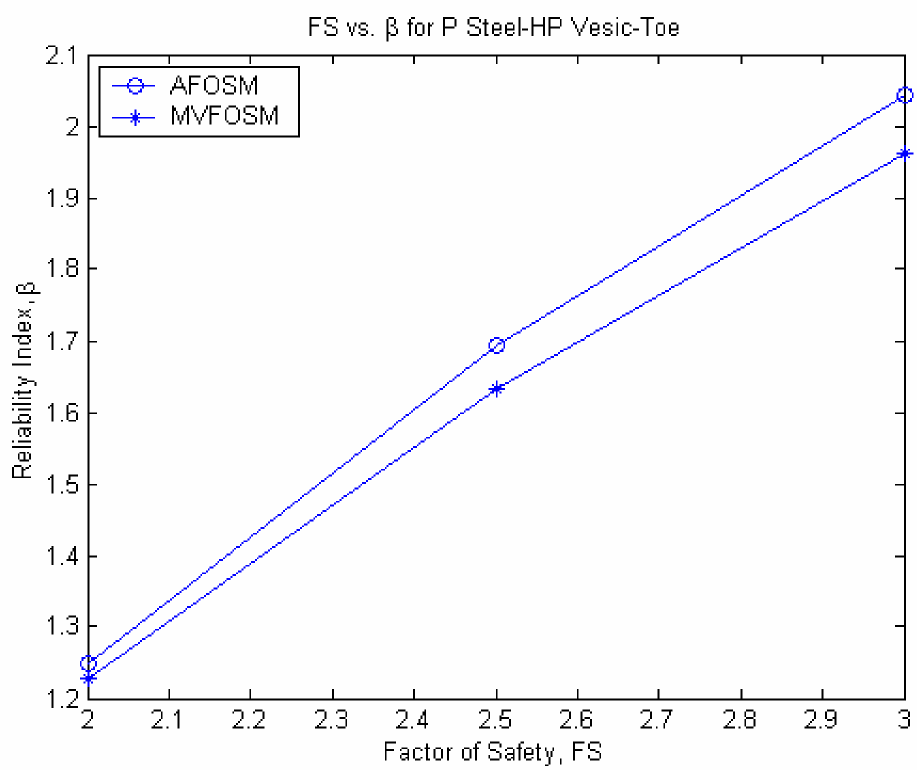
P Steel-HP VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	4.216	2.893	5.878	3.154	1.248	1.229
2.5	5.529	3.738	7.912	4.105	1.694	1.632
3	6.613	4.428	9.612	4.882	2.045	1.962

Mean Value 1.174	Mean Value 1.138	Mean Value 1.214
Standard Deviation 0.174	Standard Deviation 0.095	Standard Deviation 0.658
Coefficient of Variation 0.148	Coefficient of Variation 0.084	Coefficient of Variation 0.542



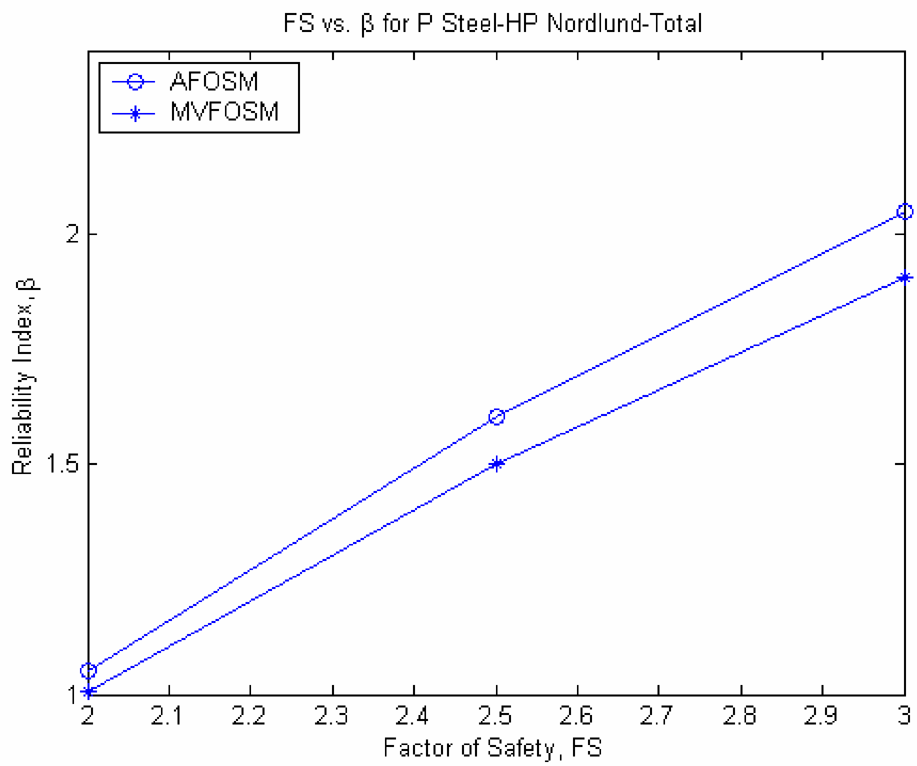

FS vs. β for P Steel-HP Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
10
9
8
7
6
5
4
3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

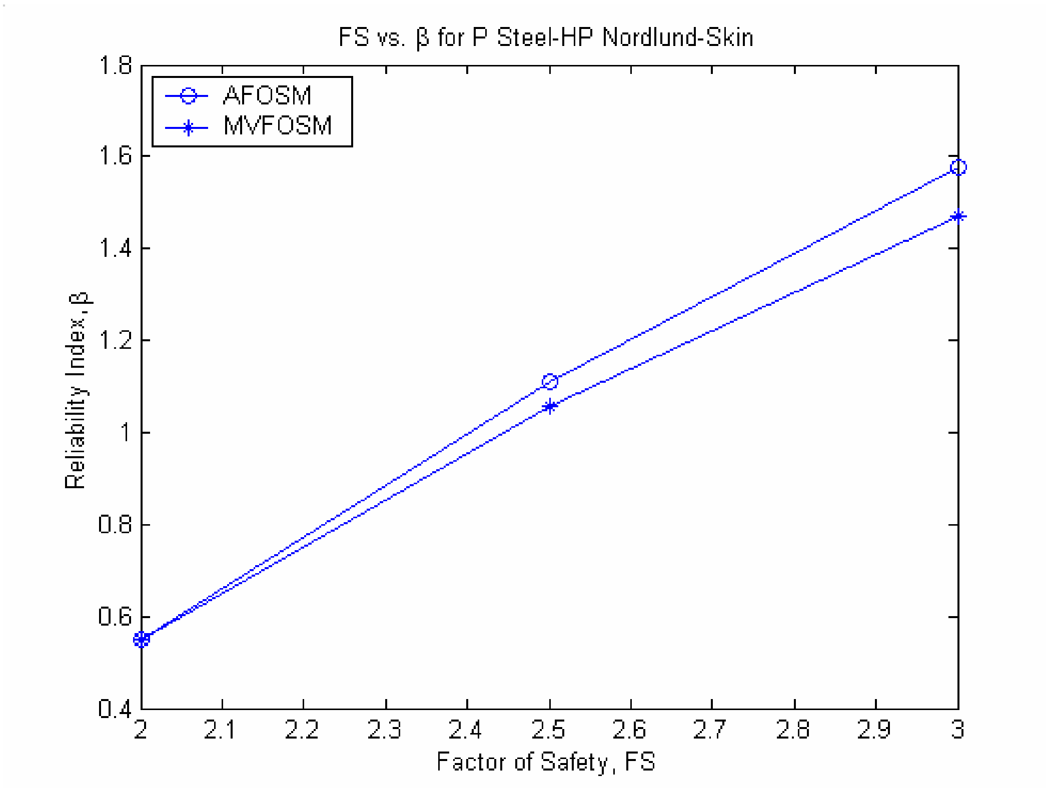

FS vs. β for P Steel-HP Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

P Steel-HP NORDLUND

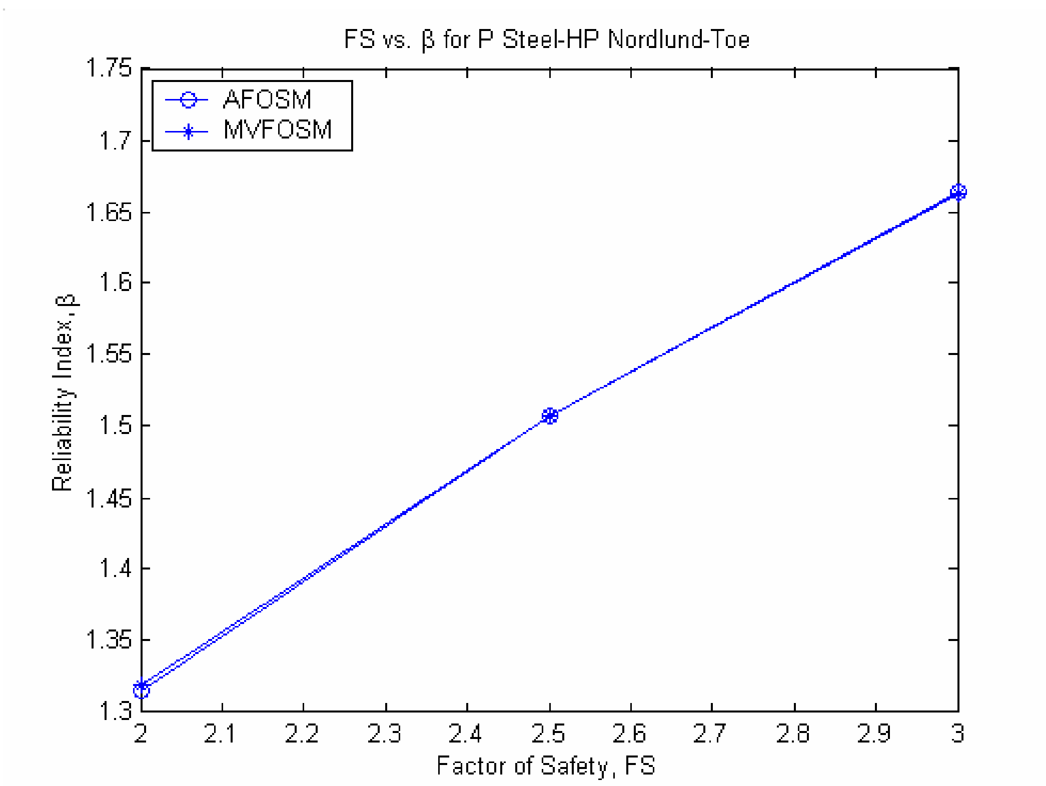
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.051	1.007	0.550	0.549	1.315	1.318
2.5	1.603	1.502	1.111	1.057	1.507	1.508
3	2.051	1.907	1.578	1.472	1.664	1.662

Total	Skin	Toe
Mean Value 0.920	Mean Value 0.740	Mean Value 5.004
Standard Deviation 0.377	Standard Deviation 0.292	Standard Deviation 8.410
Coefficient of Variation 0.409	Coefficient of Variation 0.395	Coefficient of Variation 1.681





FS vs. β for P Steel-HP Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

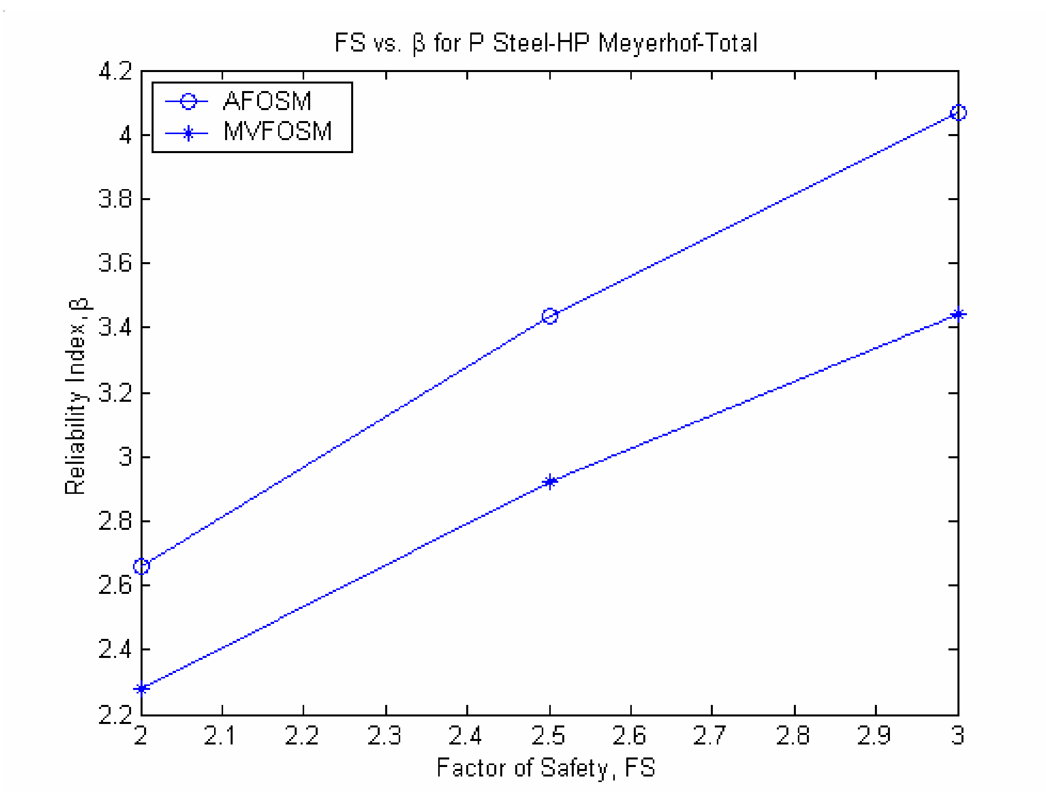


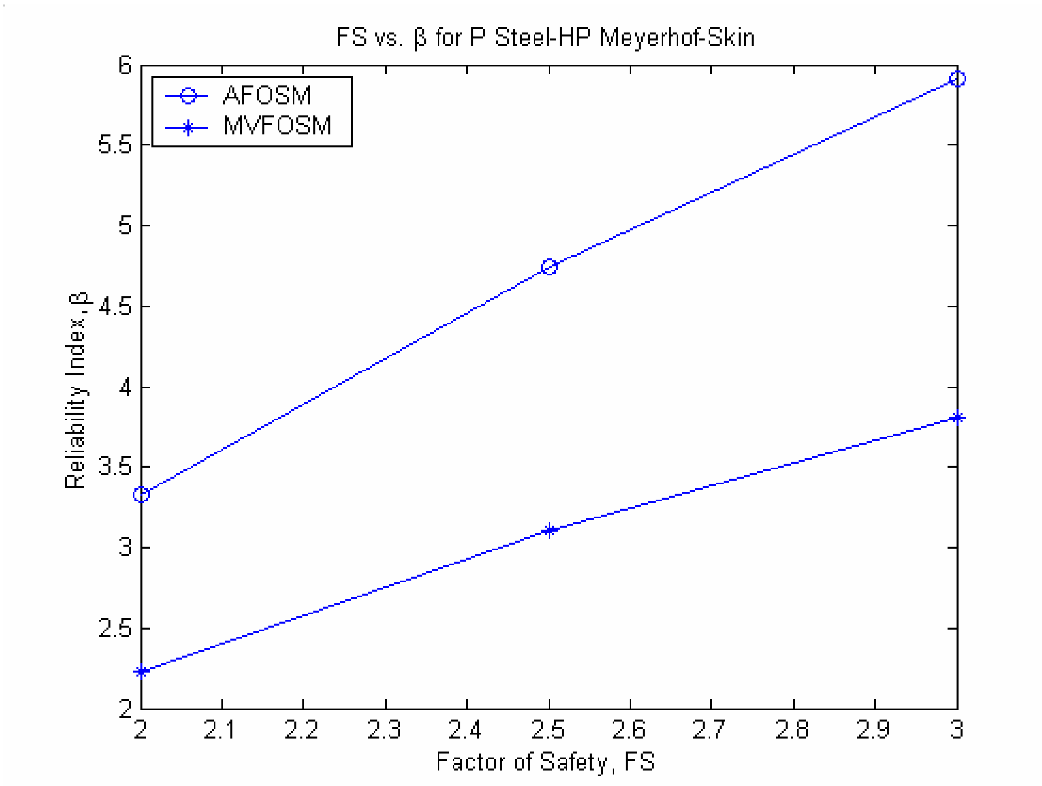
FS vs. β for P Steel-HP Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

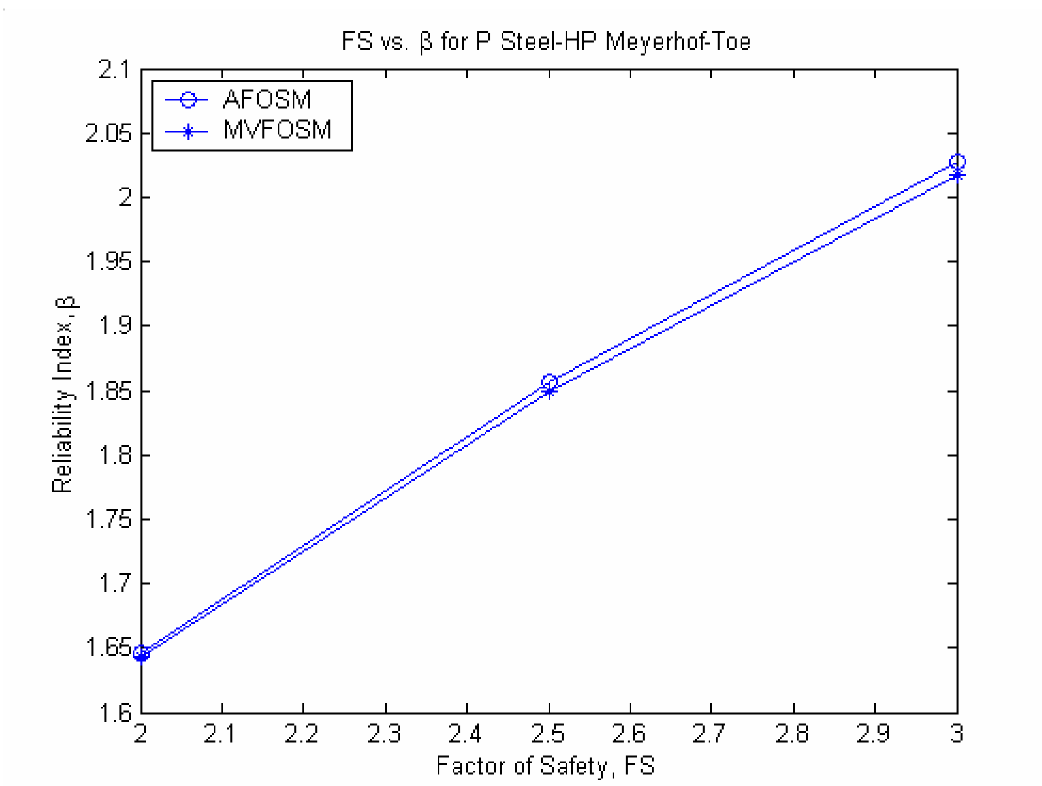
P Steel-HP MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	2.661	2.281	3.322	2.229	1.647	1.643
2.5	3.434	2.919	4.743	3.100	1.856	1.849
3	4.067	3.441	5.912	3.811	2.027	2.017

	Total	Skin	Toe
	Mean Value 1.246	Mean Value 0.966	Mean Value 5.610
	Standard Deviation 0.346	Standard Deviation 0.129	Standard Deviation 8.080
	Coefficient of Variation 0.277	Coefficient of Variation 0.133	Coefficient of Variation 1.440



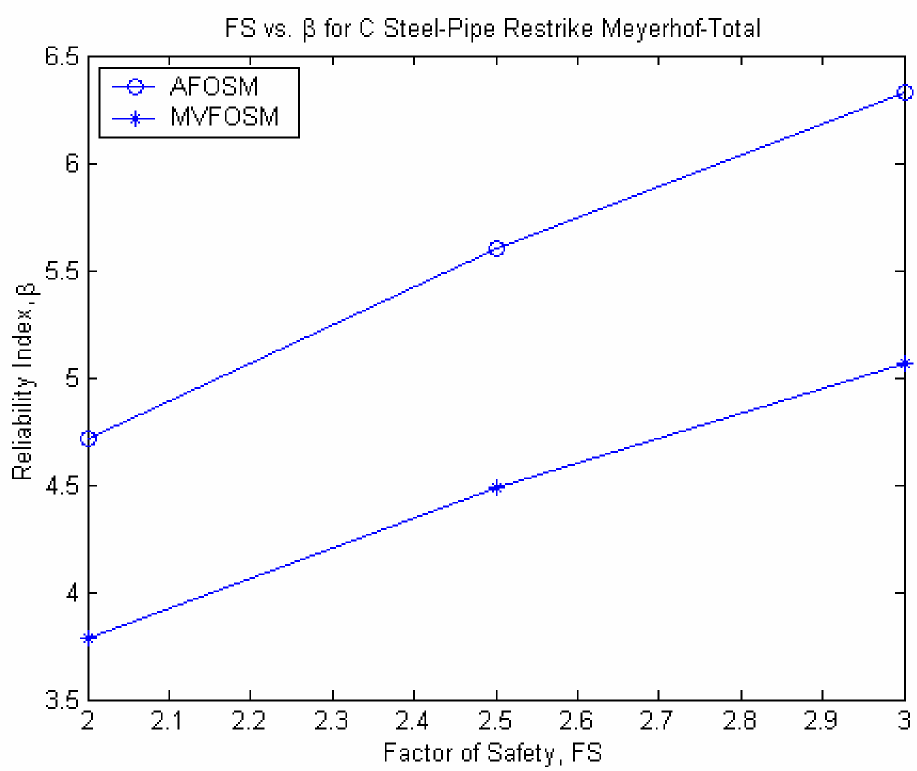

FS vs. β for P Steel-HP Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
6
5.5
5
4.5
4
3.5
3
2.5
2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

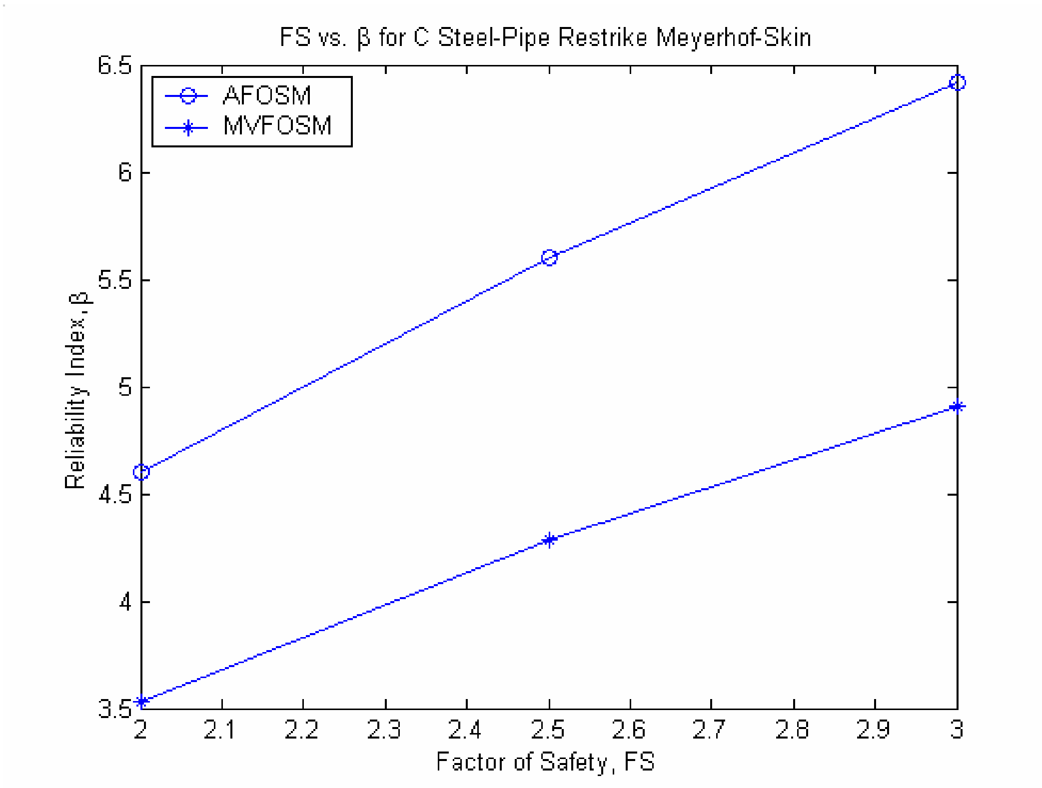

FS vs. β for P Steel-HP Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.1
2.05
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

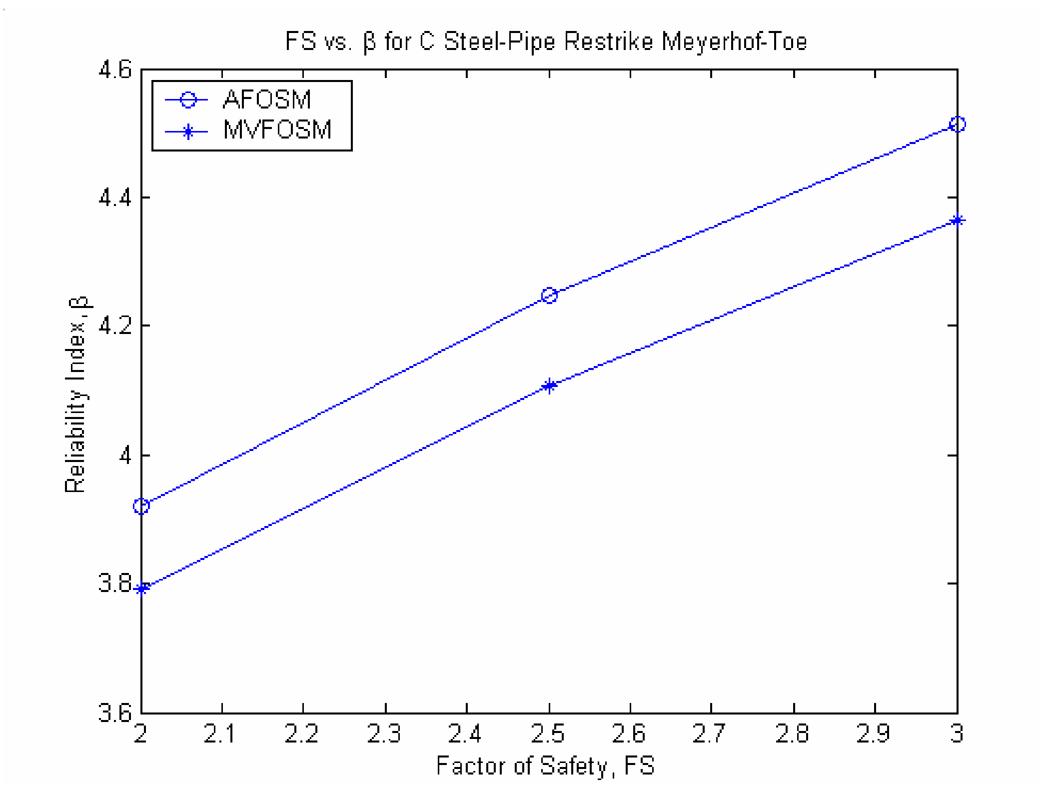
C Steel-Pipe Restrike MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	4.715	3.783	4.600	3.530	3.919	3.790
2.5	5.605	4.490	5.598	4.288	4.247	4.106
3	6.326	5.067	6.413	4.908	4.515	4.364

Total	Skin	Toe
Mean Value 1.831	Mean Value 1.559	Mean Value 9.866
Standard Deviation 0.421	Standard Deviation 0.309	Standard Deviation 7.450
Coefficient of Variation 0.230	Coefficient of Variation 0.198	Coefficient of Variation 0.755



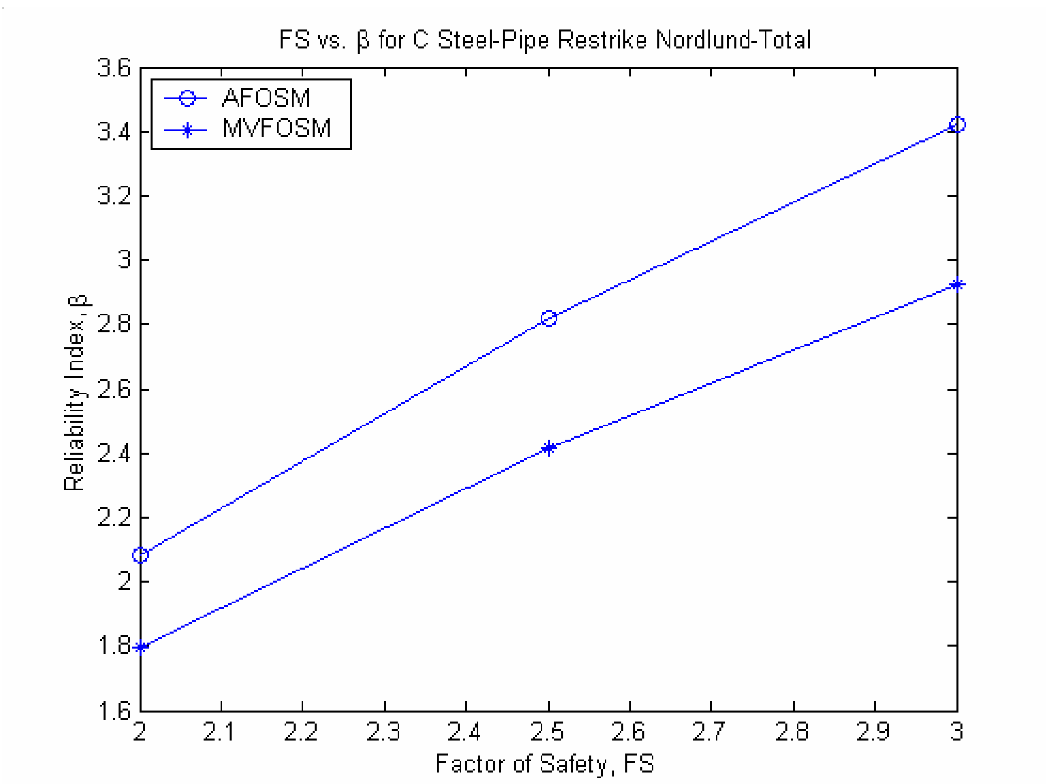

FS vs. β for C Steel-Pipe Restrike Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
6.5
6
5.5
5
4.5
4
3.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

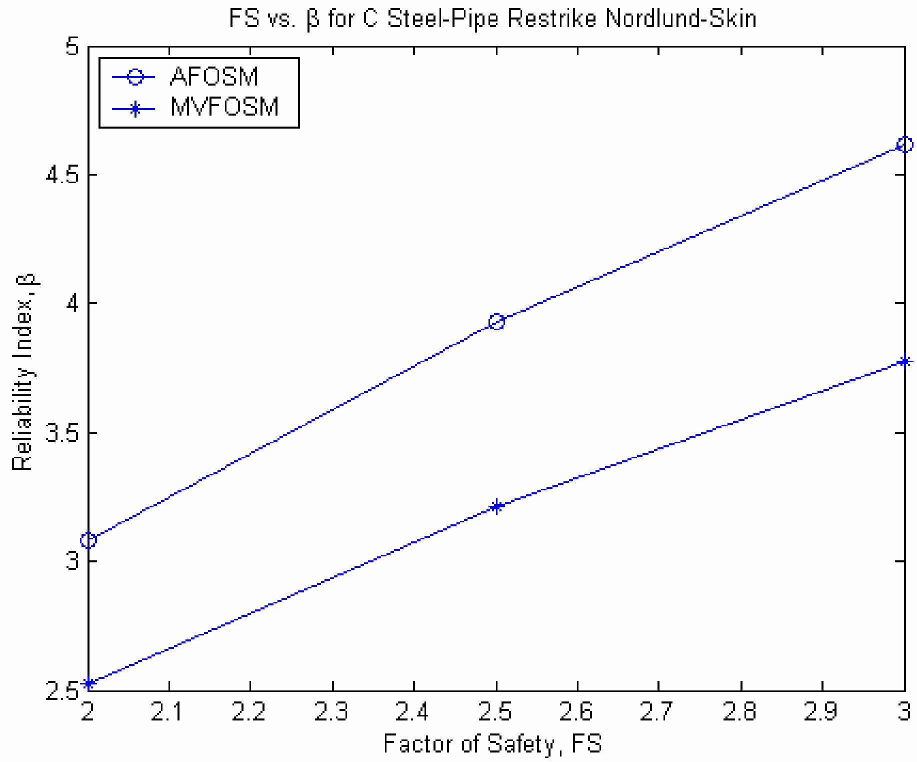

FS vs. β for C Steel-Pipe Restrike Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
4.6
4.4
4.2
4
3.8
3.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

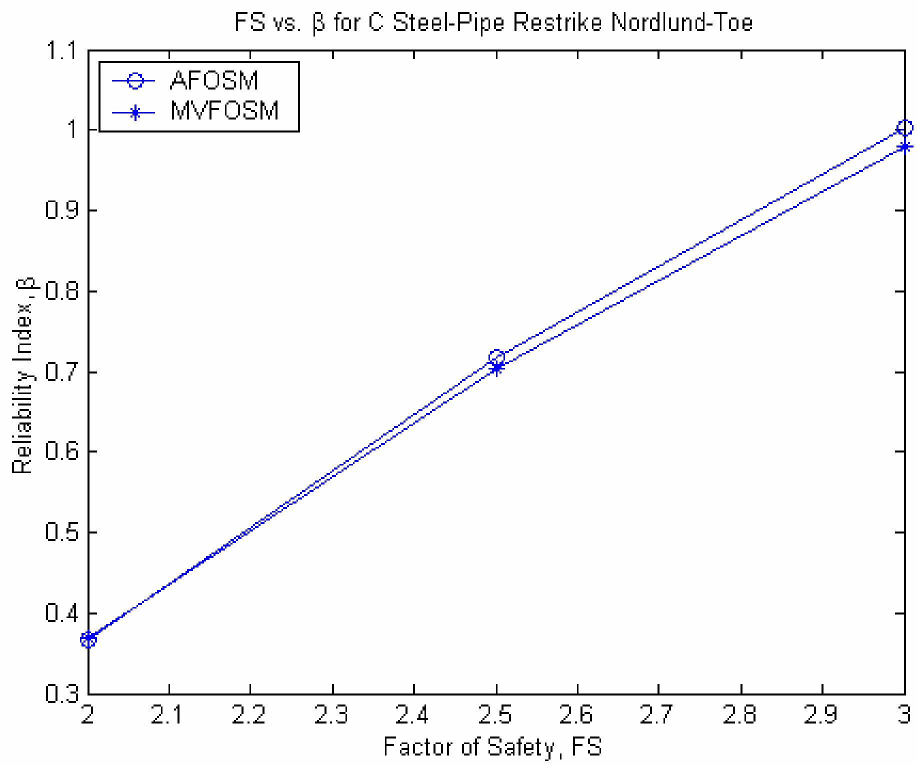
C Steel-Pipe Restrike NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	2.083	1.795	3.082	2.529	0.366	0.369
2.5	2.818	2.416	3.928	3.214	0.716	0.705
3	3.419	2.924	4.619	3.773	1.003	0.979

	Total	Skin	Toe
	Mean Value 1.073	Mean Value 1.270	Mean Value 0.841
	Standard Deviation 0.311	Standard Deviation 0.311	Standard Deviation 0.584
	Coefficient of Variation 0.290	Coefficient of Variation 0.245	Coefficient of Variation 0.694



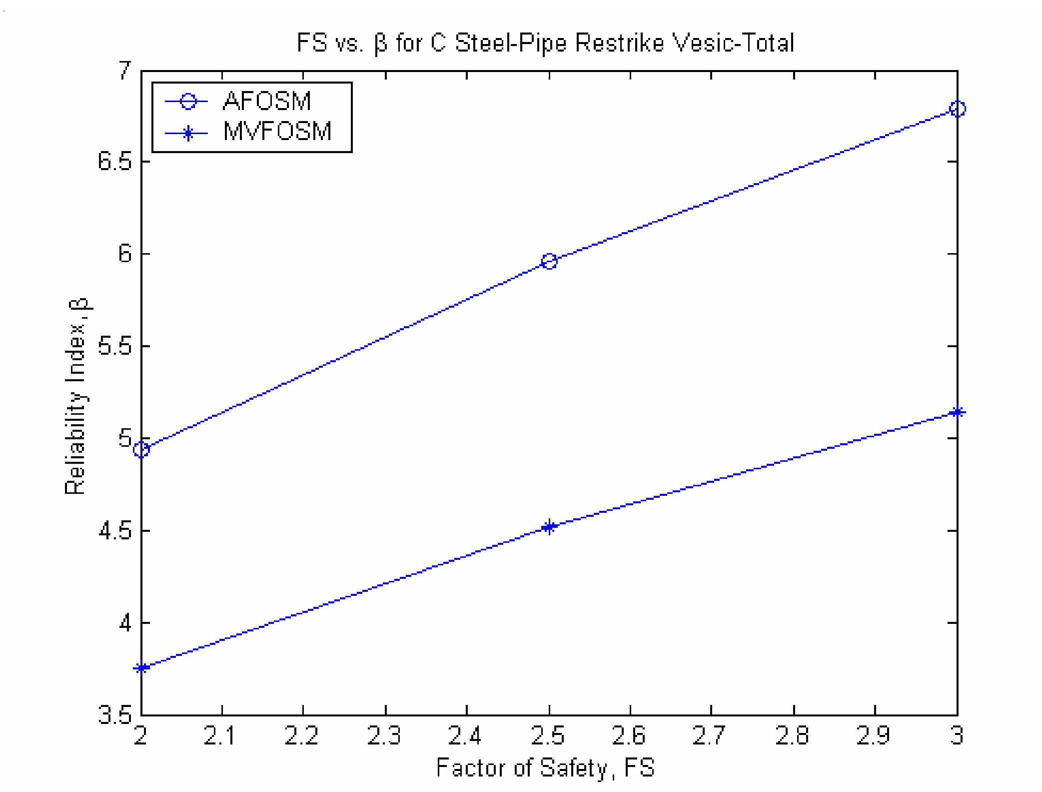

FS vs. β for C Steel-Pipe Restrike Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
5
4.5
4
3.5
3
2.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

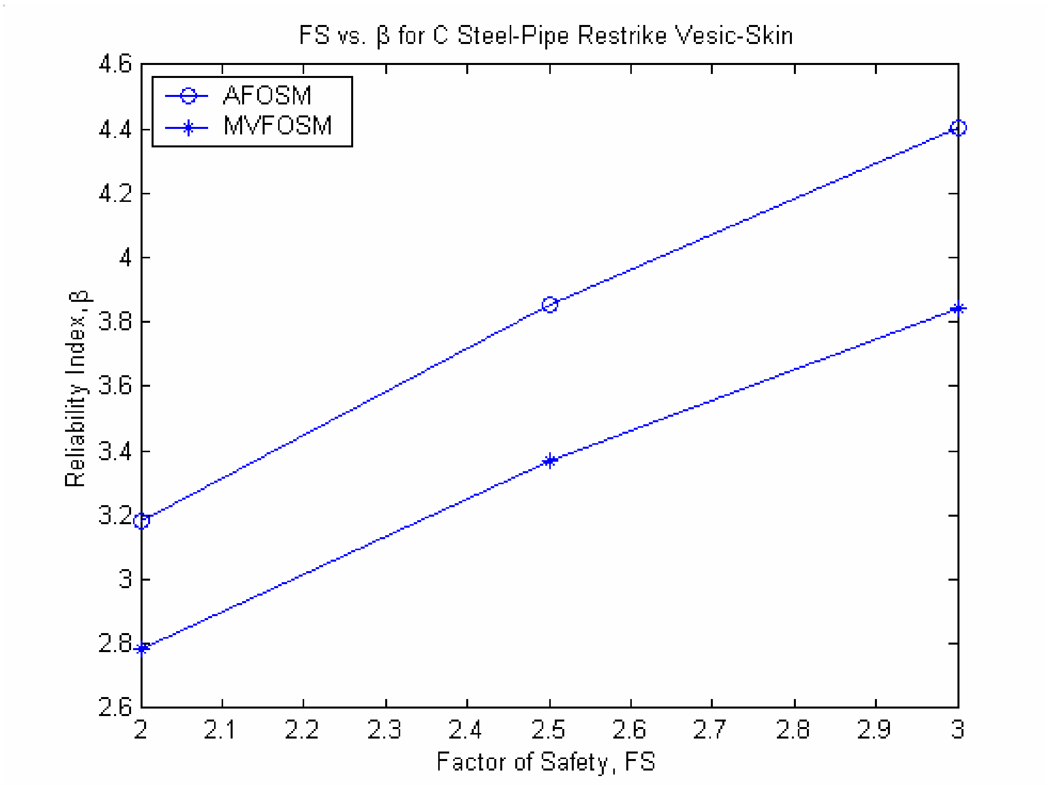

FS vs. β for C Steel-Pipe Restrike Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

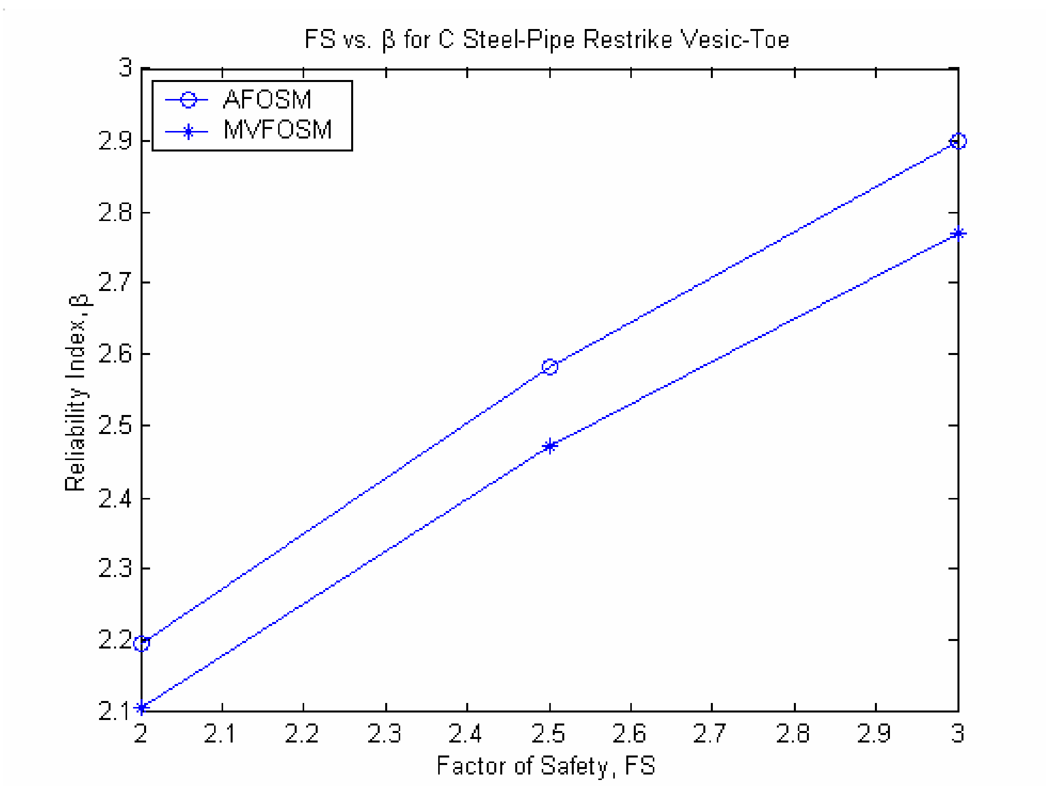
C Steel-Pipe Restrike VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	4.937	3.751	3.179	2.784	2.196	2.106
2.5	5.958	4.519	3.852	3.366	2.583	2.472
3	6.790	5.146	4.402	3.842	2.898	2.771

	Total	Skin	Toe
	Mean Value 1.638	Mean Value 1.651	Mean Value 2.295
	Standard Deviation 0.315	Standard Deviation 0.532	Standard Deviation 1.419
	Coefficient of Variation 0.192	Coefficient of Variation 0.322	Coefficient of Variation 0.618



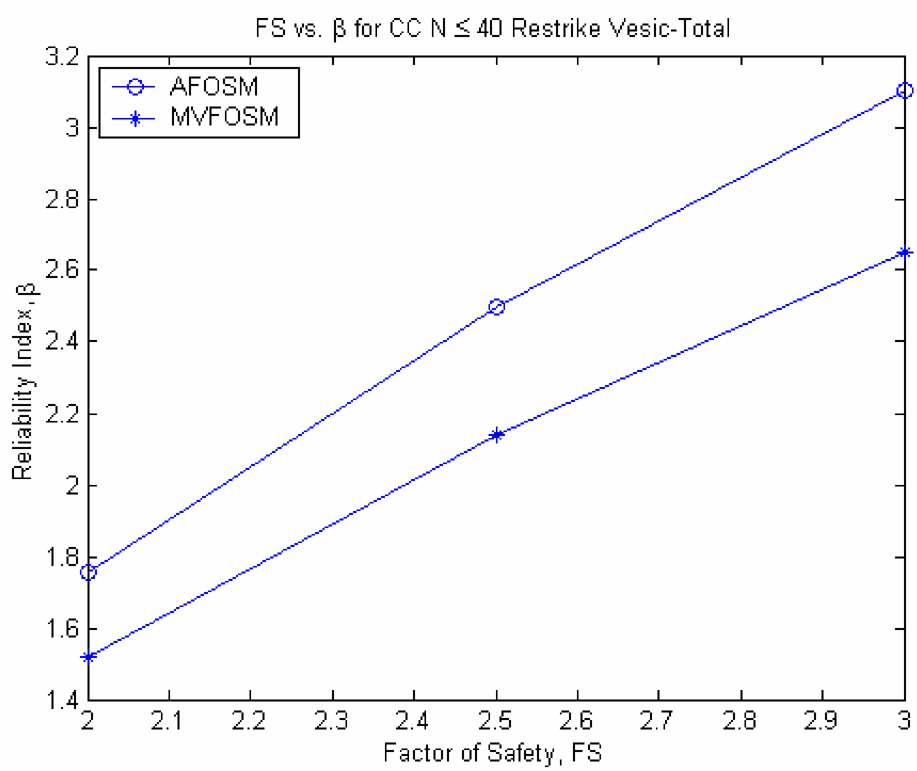

FS vs. β for C Steel-Pipe Restrike Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

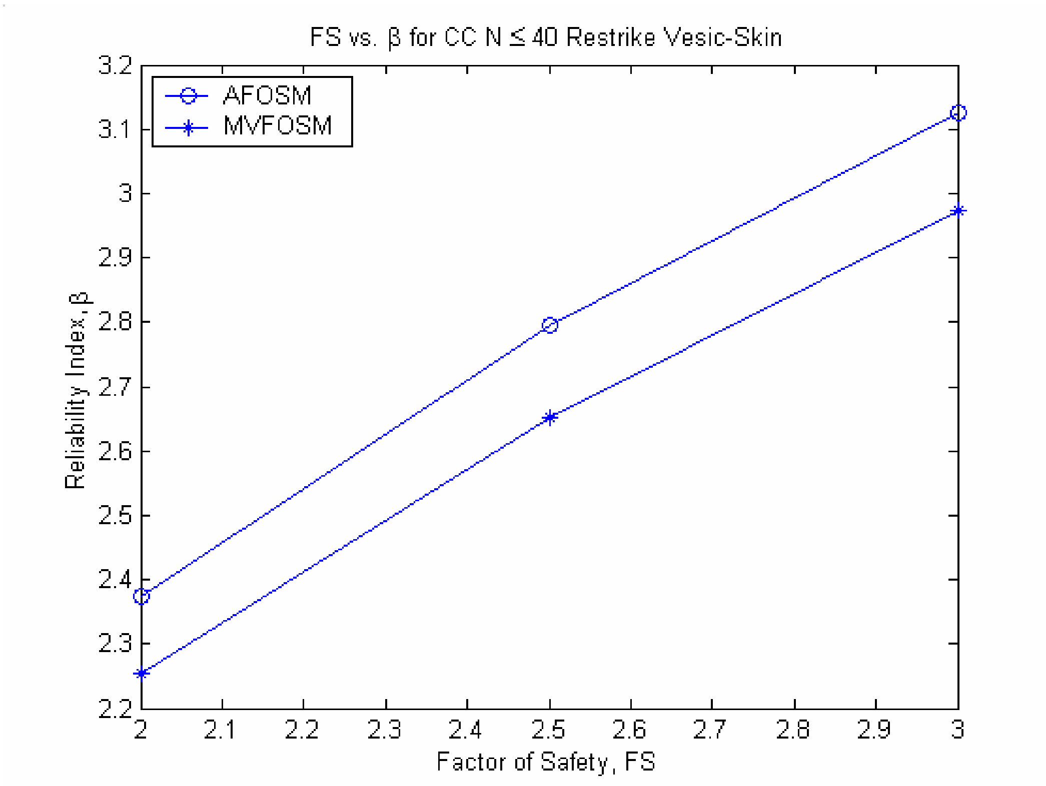

FS vs. β for C Steel-Pipe Restrike Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

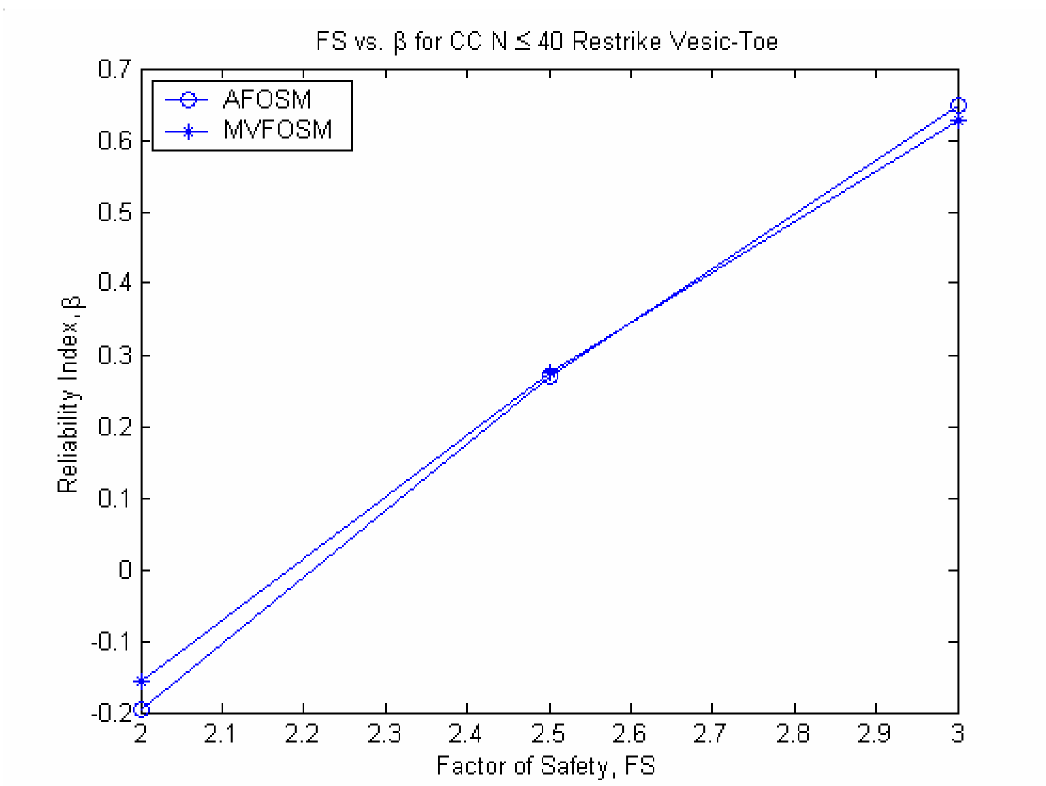
CC Restrike N<=40 VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.758	1.518	2.374	2.254	-0.195	-0.157
2.5	2.496	2.142	2.796	2.650	0.270	0.275
3	3.100	2.651	3.124	2.974	0.649	0.628

Total	Skin	Toe
Mean Value 0.969	Mean Value 2.197	Mean Value 0.556
Standard Deviation 0.280	Standard Deviation 1.218	Standard Deviation 0.275
Coefficient of Variation 0.288	Coefficient of Variation 0.555	Coefficient of Variation 0.495



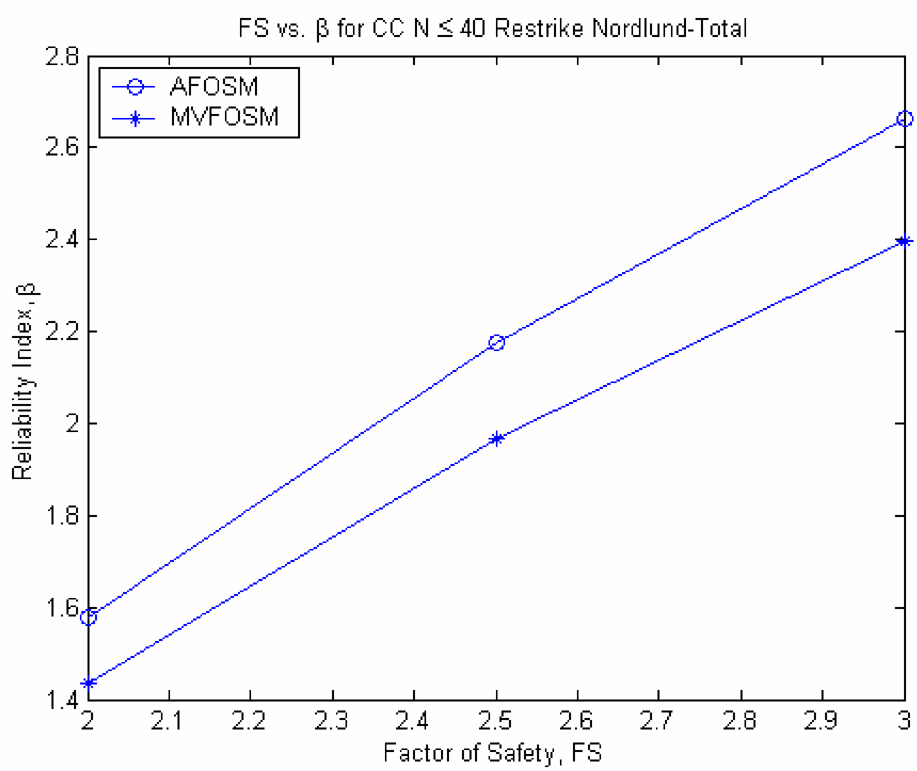

FS vs. β for CC N ≤ 40 Restrike Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

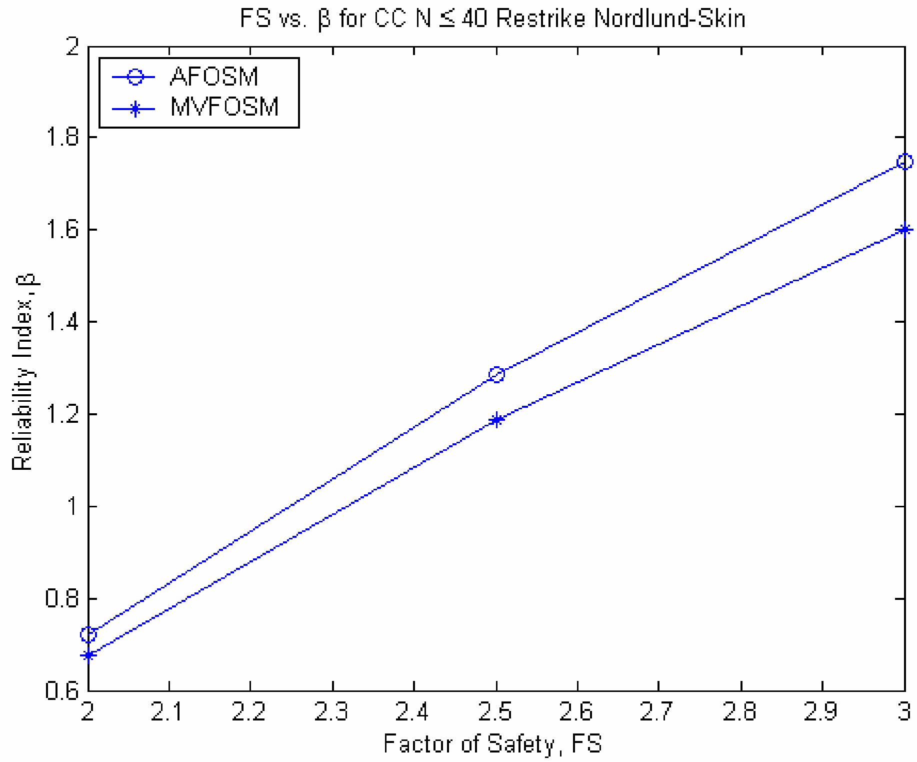

FS vs. β for CC N ≤ 40 Restrike Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

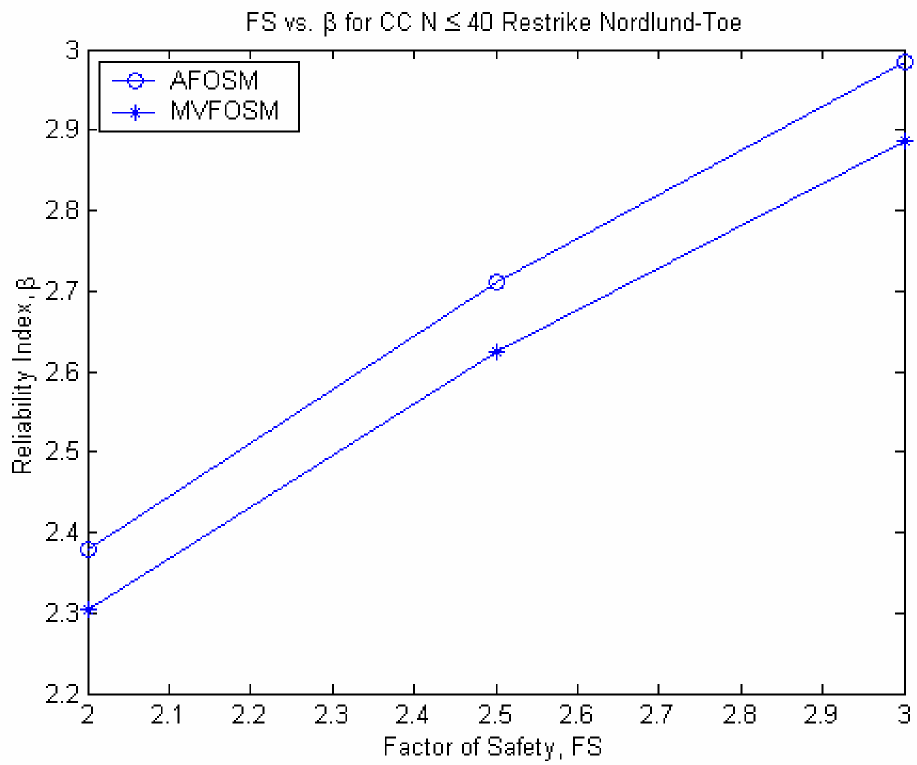
CC Restrike N<=40 NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.579	1.435	0.720	0.677	2.380	2.305
2.5	2.174	1.965	1.287	1.185	2.712	2.625
3	2.662	2.398	1.749	1.601	2.984	2.887

Mean Value 1.055	Mean Value 0.782	Mean Value 3.357
Standard Deviation 0.391	Standard Deviation 0.308	Standard Deviation 2.488
Coefficient of Variation 0.371	Coefficient of Variation 0.394	Coefficient of Variation 0.741



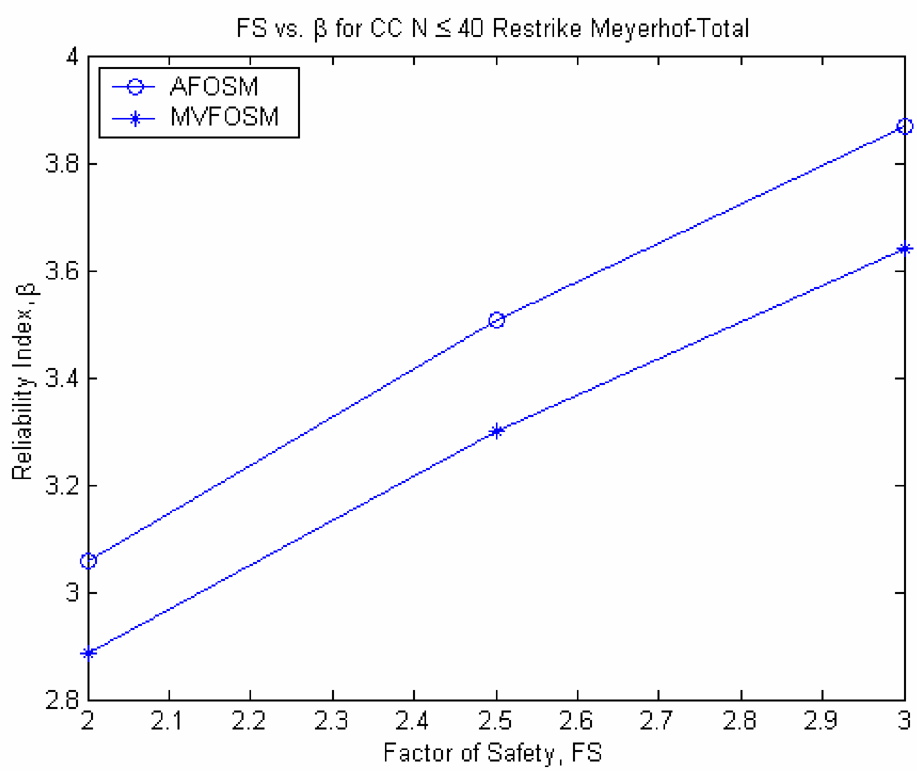

FS vs. β for CC N ≤ 40 Restrike Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2
1.8
1.6
1.4
1.2
1
0.8
0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

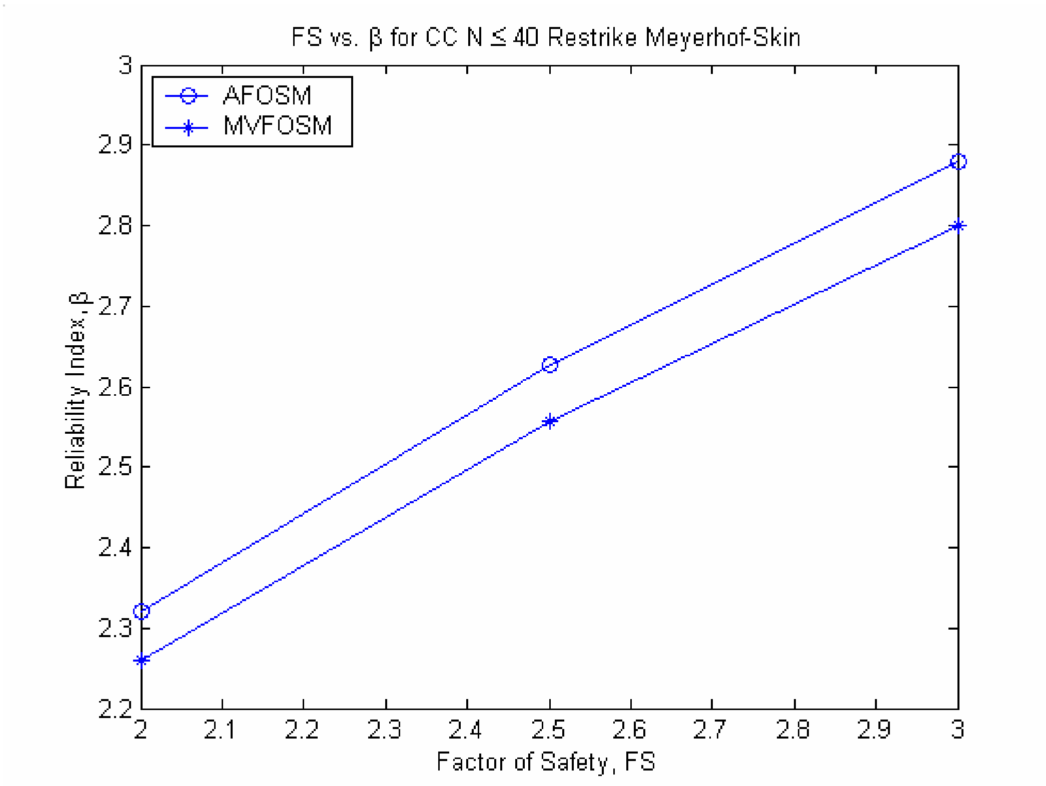

FS vs. β for CC N ≤ 40 Restrike Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

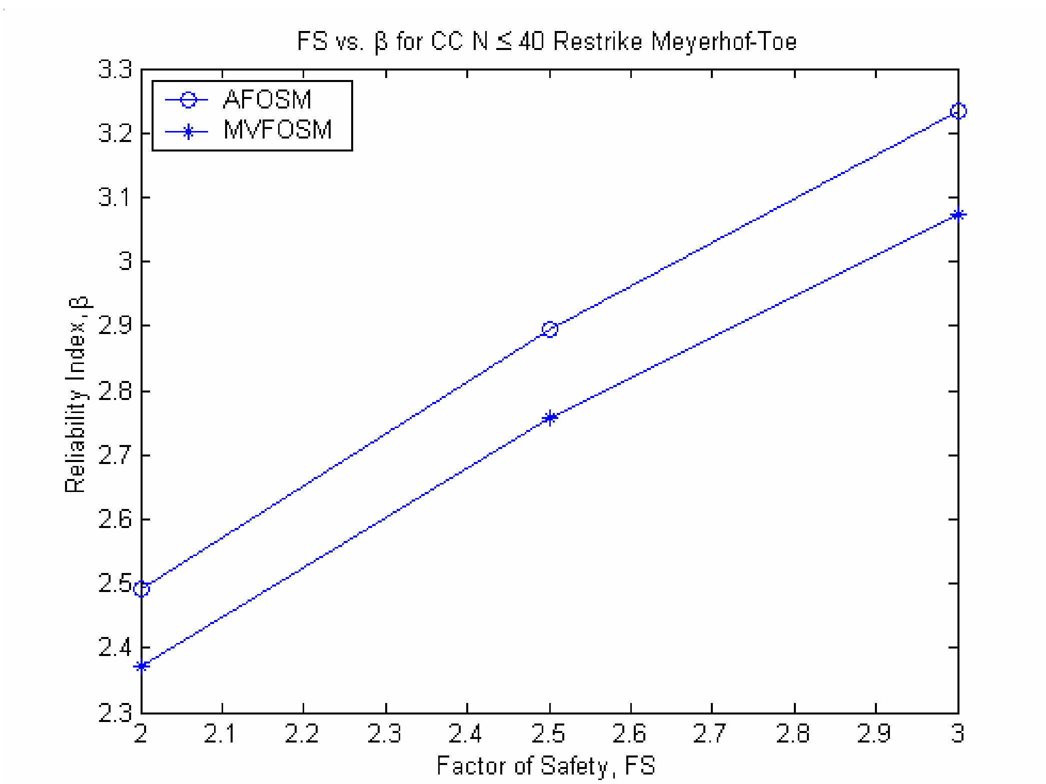
CC Restrike N<=40 MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	3.057	2.888	2.321	2.260	2.492	2.373
2.5	3.508	3.301	2.628	2.557	2.896	2.758
3	3.868	3.639	2.879	2.801	3.235	3.074

Mean Value 2.900	Mean Value 3.805	Mean Value 2.460
Standard Deviation 1.520	Standard Deviation 3.119	Standard Deviation 1.416
Coefficient of Variation 0.524	Coefficient of Variation 0.820	Coefficient of Variation 0.576



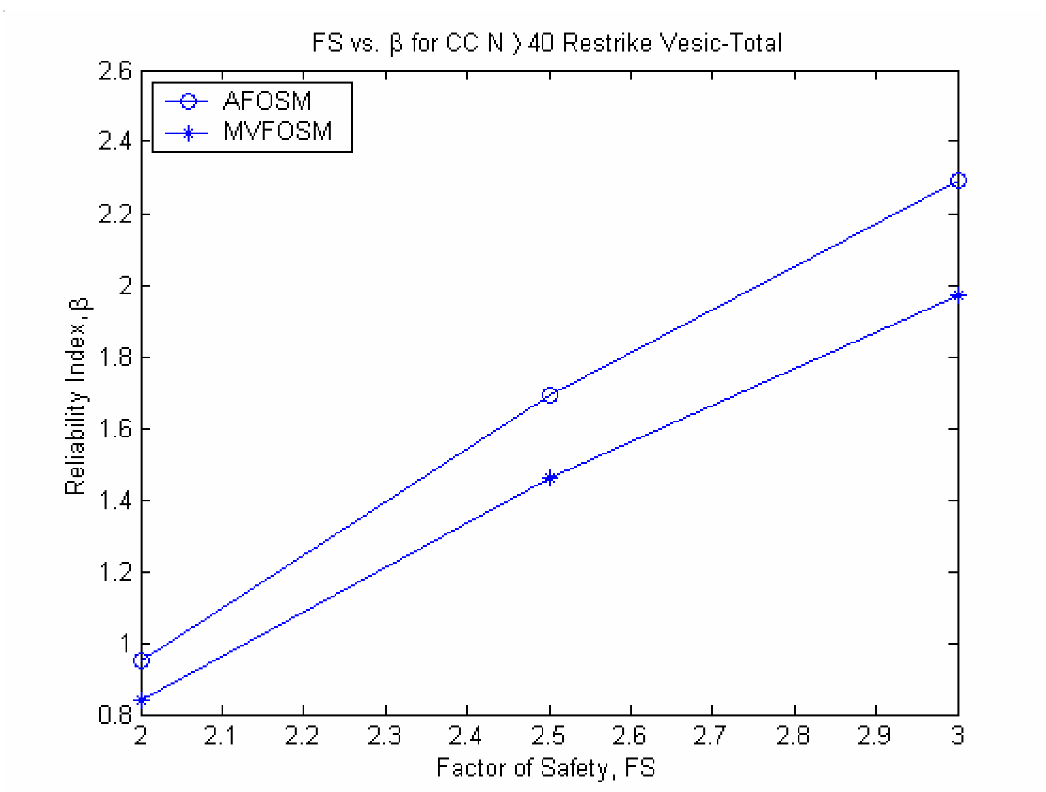

FS vs. β for CC N ≤ 40 Restrike Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

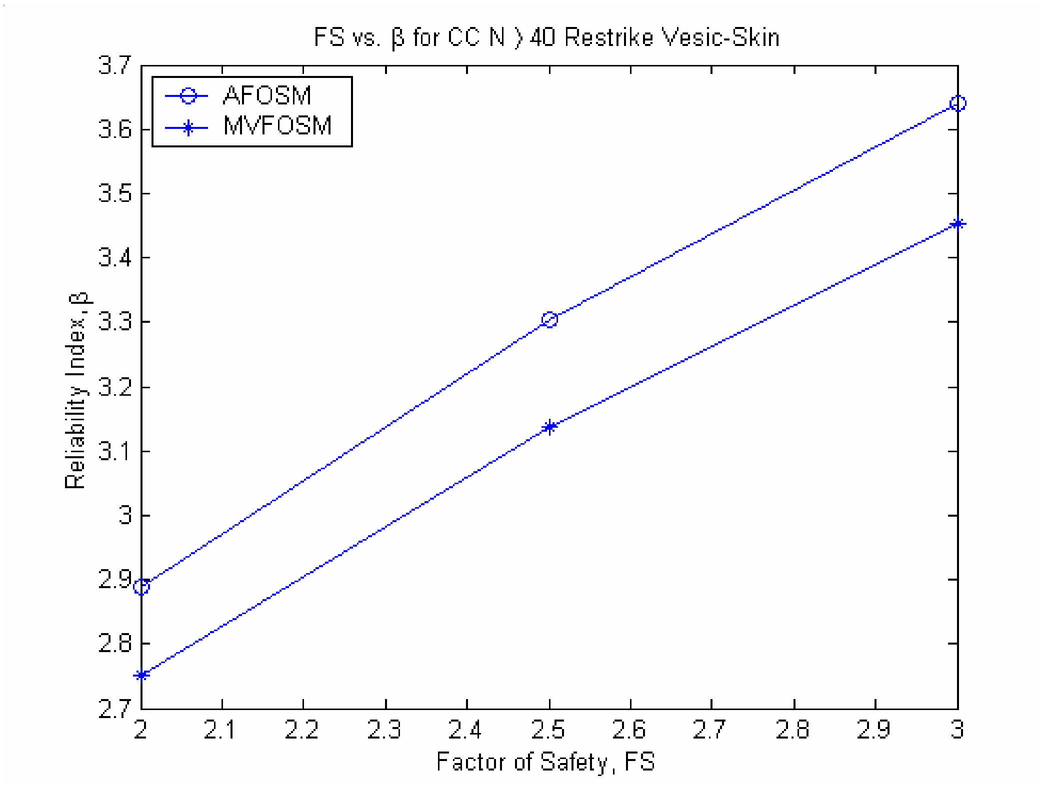

FS vs. β for CC N ≤ 40 Restrike Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

CC Restrike N>40 VESIC

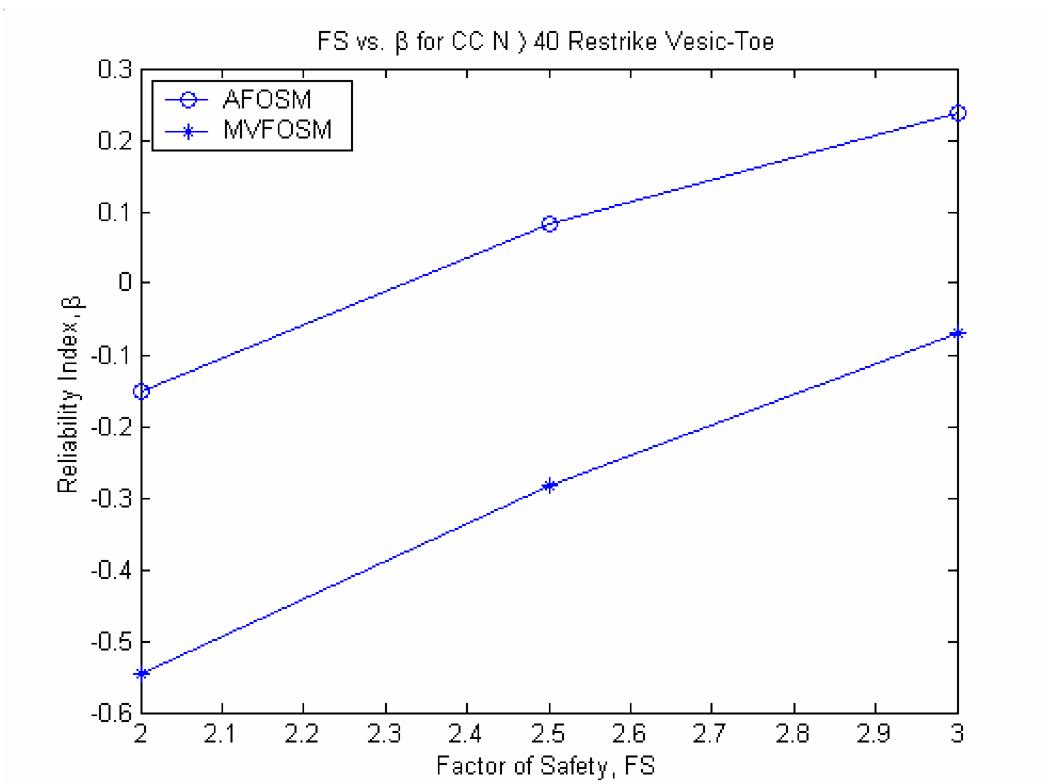
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.951	0.839	2.888	2.750	-0.150	-0.546
2.5	1.691	1.462	3.303	3.137	0.082	-0.284
3	2.295	1.972	3.640	3.453	0.237	-0.069

Total	Skin	Toe
Mean Value 0.760	Mean Value 3.040	Mean Value 0.477
Standard Deviation 0.219	Standard Deviation 1.742	Standard Deviation 0.469
Coefficient of Variation 0.289	Coefficient of Variation 0.573	Coefficient of Variation 0.983





FS vs. β for CC N > 40 Restrike Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

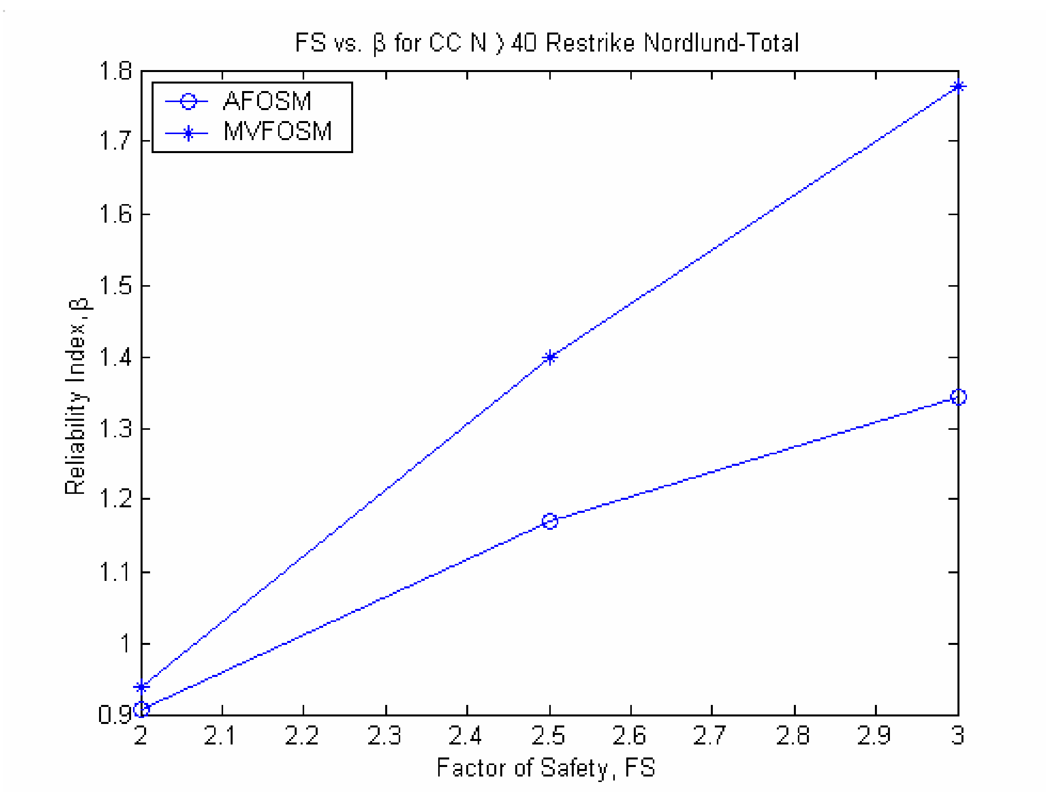


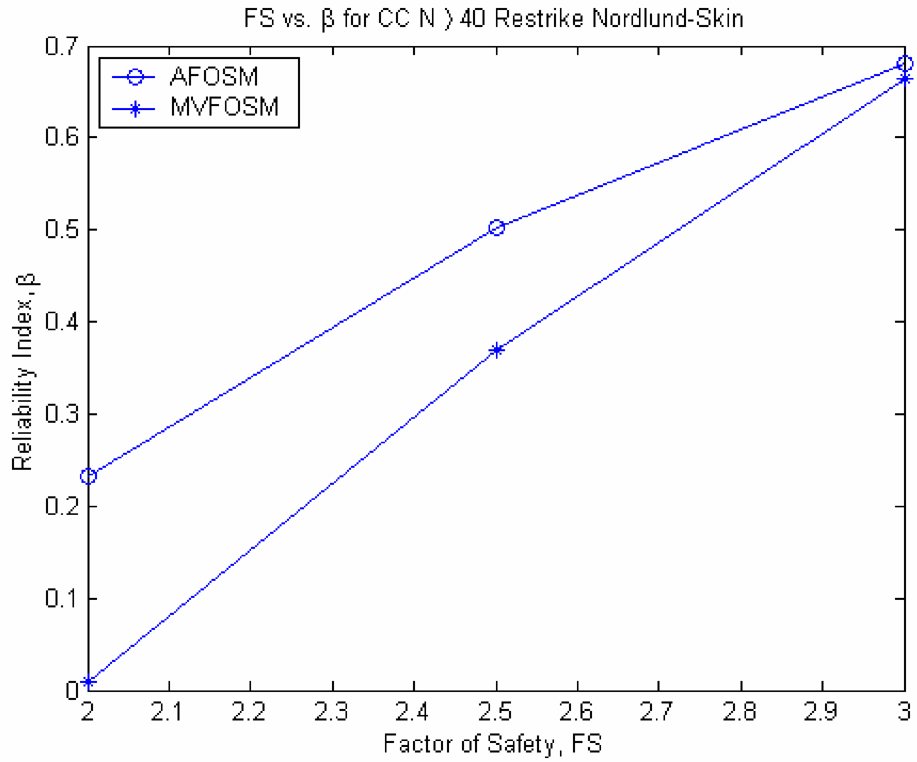
FS vs. β for CC N > 40 Restrike Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

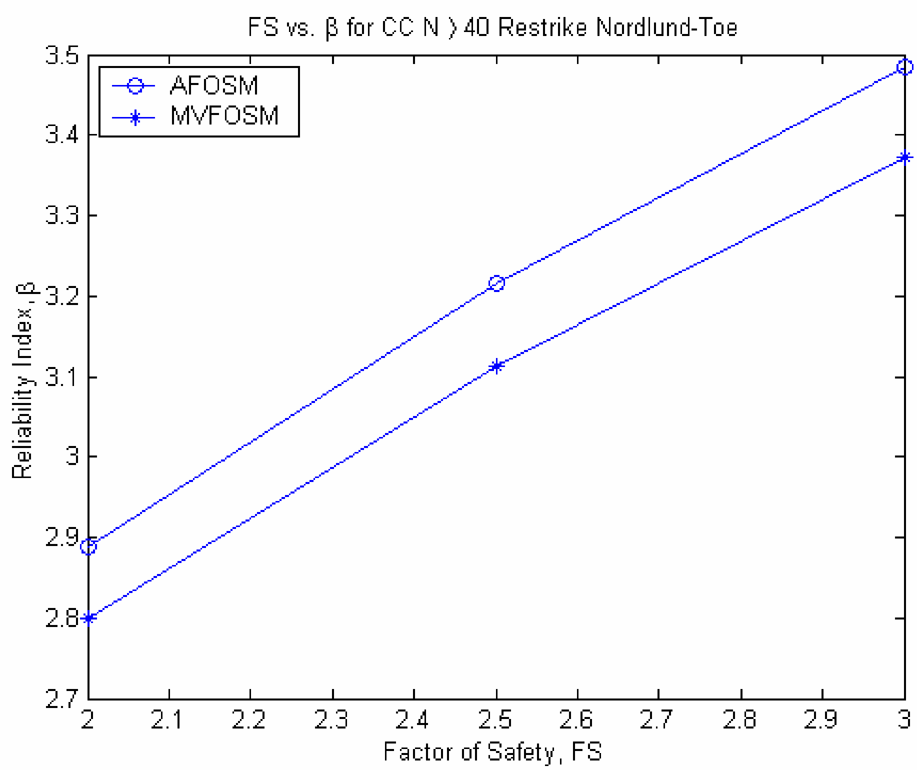
CC Restrike N>40 NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	0.908	0.938	0.233	0.009	2.889	2.799
2.5	1.169	1.400	0.502	0.369	3.216	3.114
3	1.344	1.777	0.681	0.663	3.484	3.371

ean Value 0.933	Mean Value 0.643	Mean Value 4.920
Standard Deviation 0.421	Standard Deviation 0.406	Standard Deviation 3.725
Coefficient of Variation 0.451	Coefficient of Variation 0.632	Coefficient of Variation 0.757



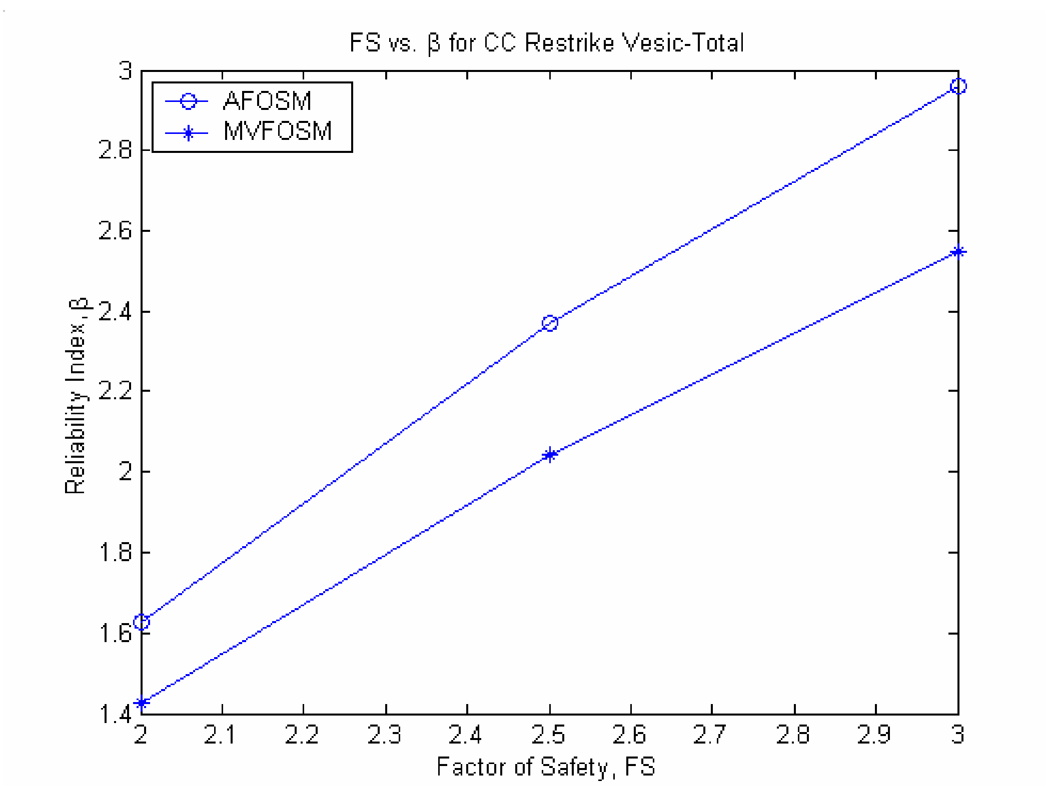

FS vs. β for CC N ⟩ 40 Restrike Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

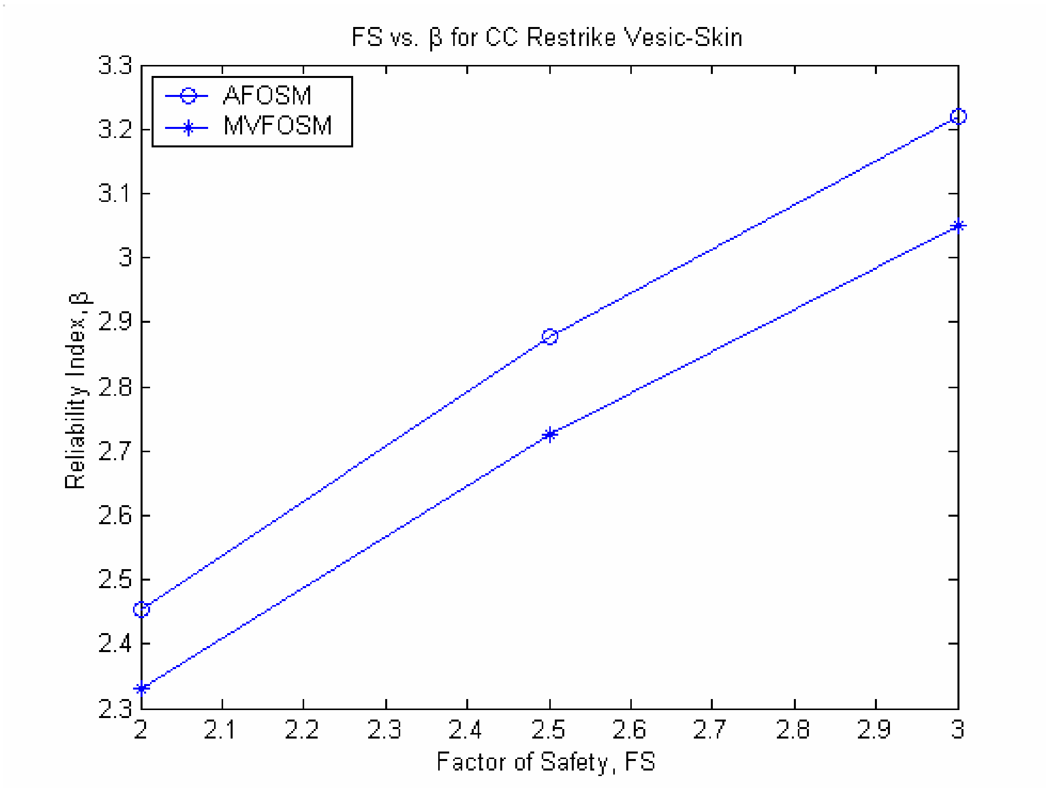

FS vs. β for CC N ⟩ 40 Restrike Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

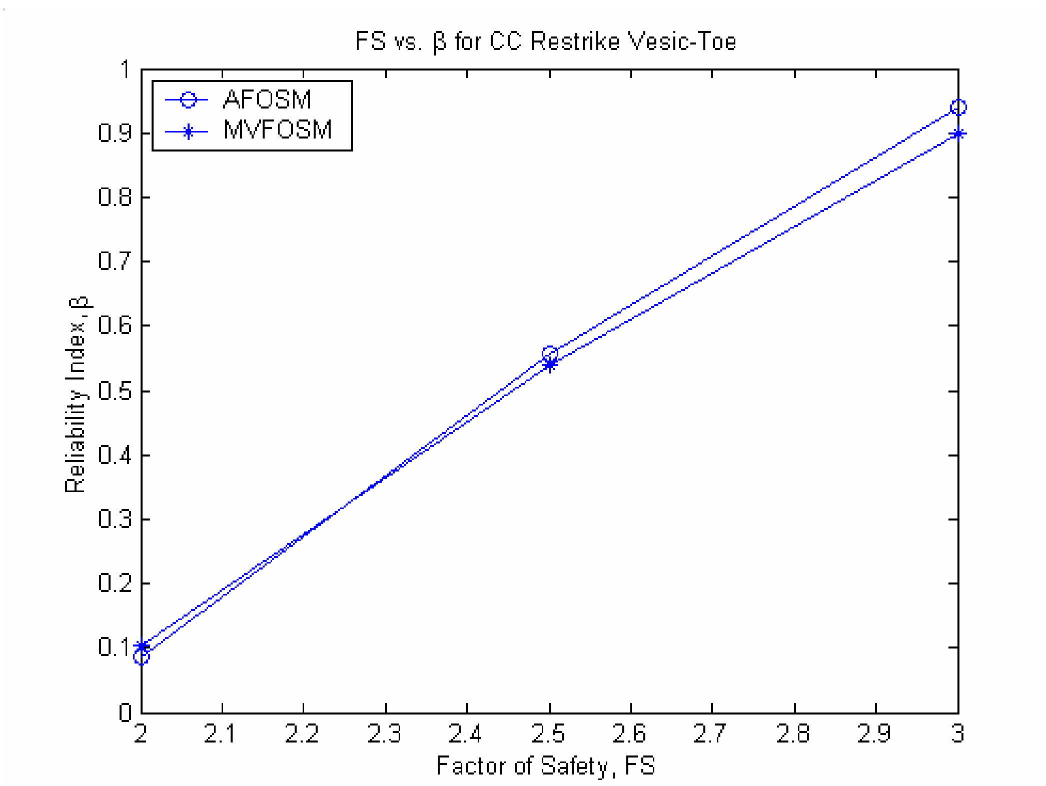
CC Restrike VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.627	1.427	2.455	2.330	0.086	0.104
2.5	2.369	2.043	2.876	2.726	0.557	0.541
3	2.962	2.546	3.221	3.050	0.939	0.898

Mean Value 0.945	Mean Value 2.298	Mean Value 0.634
Standard Deviation 0.278	Standard Deviation 1.277	Standard Deviation 0.309
Coefficient of Variation 0.294	Coefficient of Variation 0.556	Coefficient of Variation 0.487



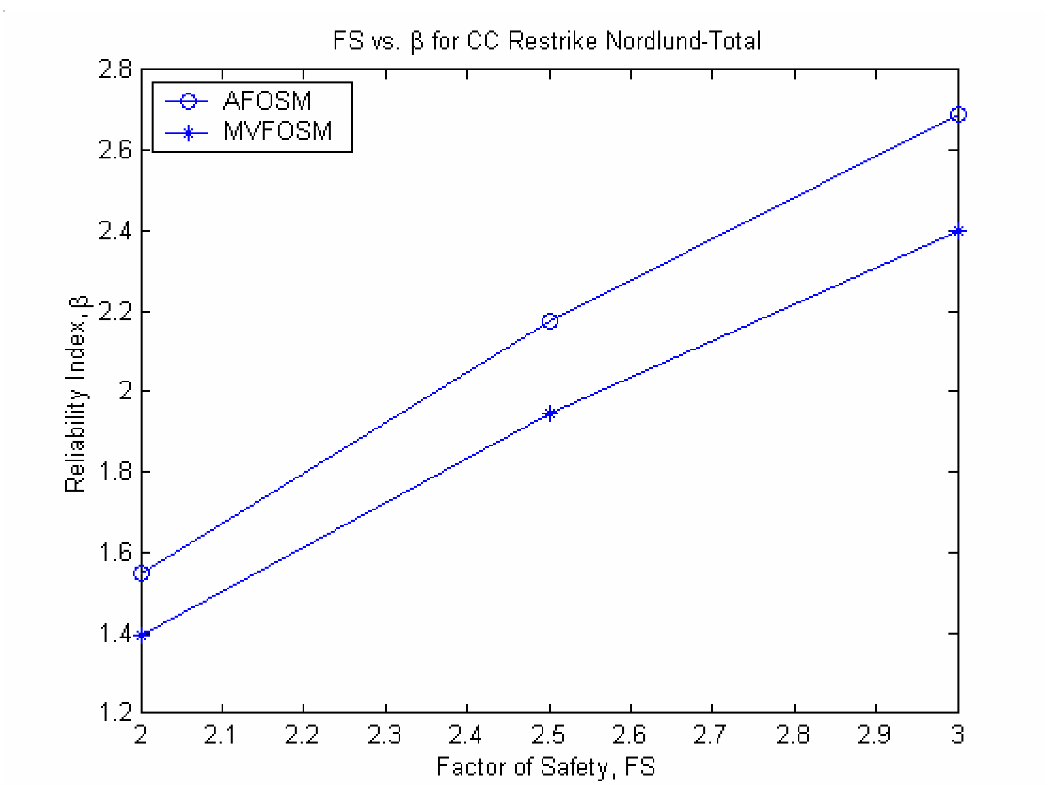

FS vs. β for CC Restrike Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

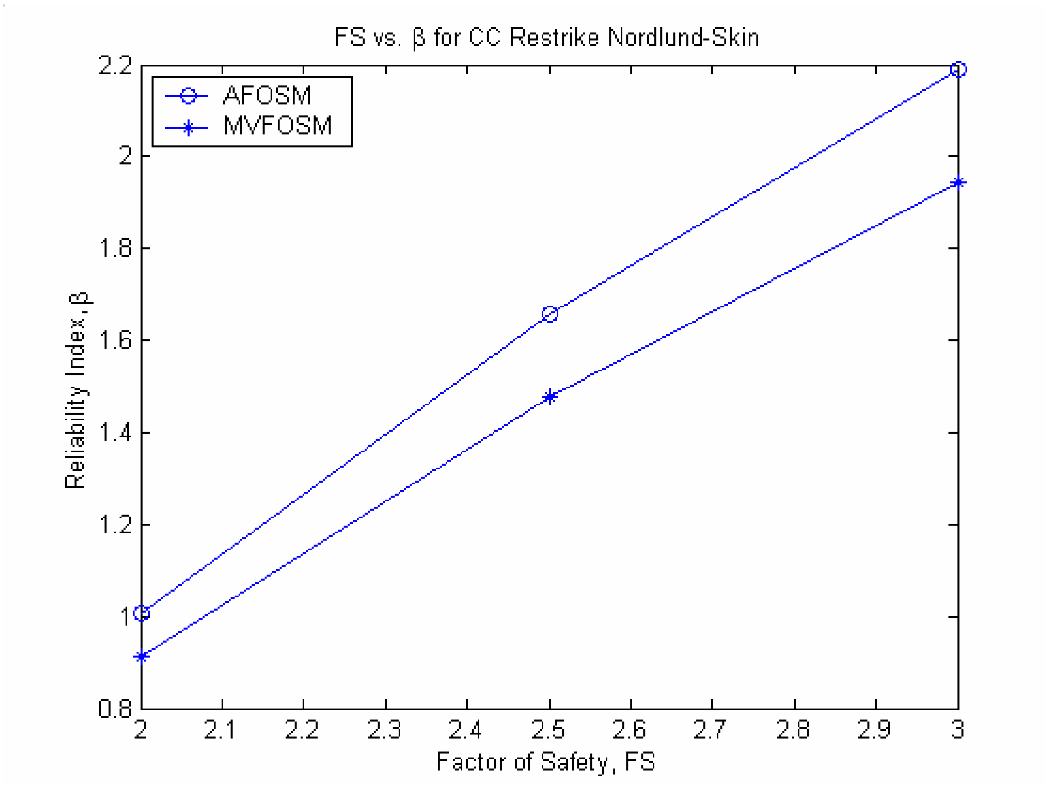

FS vs. β for CC Restrike Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

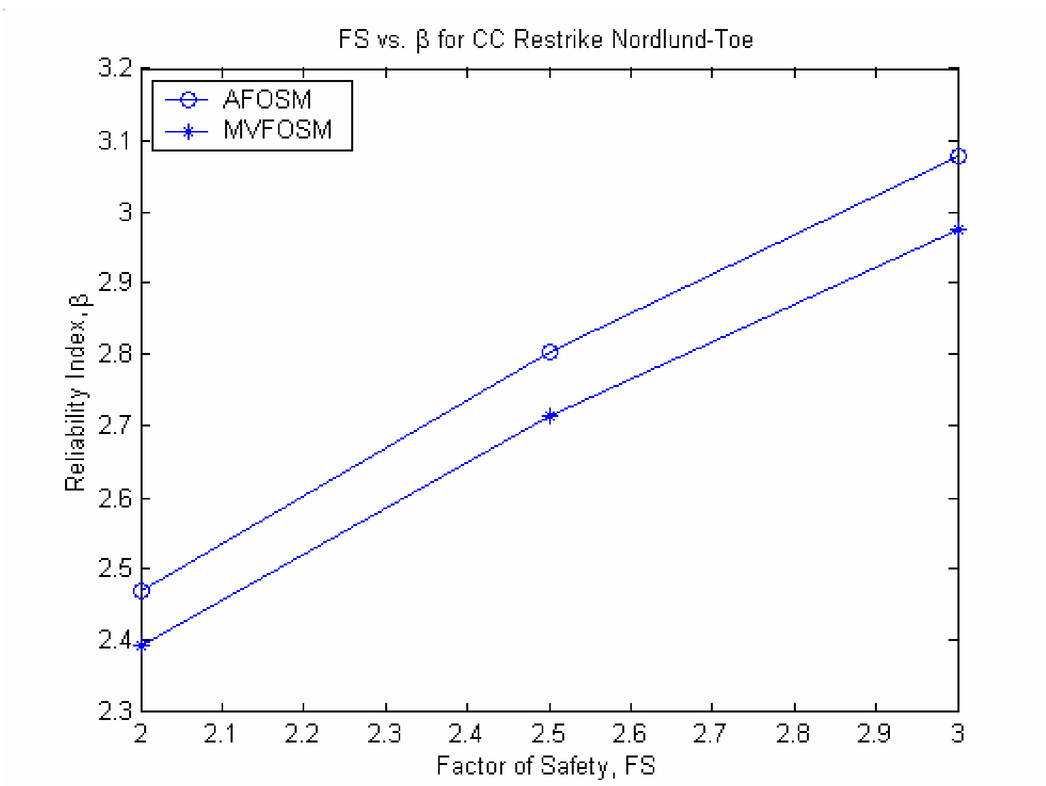
CC Restrike NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.549	1.394	1.007	0.912	2.471	2.393
2.5	2.177	1.946	1.659	1.479	2.805	2.714
3	2.690	2.398	2.190	1.943	3.077	2.976

Total	Skin	Toe
Mean Value 1.006	Mean Value 0.816	Mean Value 3.545
Standard Deviation 0.351	Standard Deviation 0.273	Standard Deviation 2.616
Coefficient of Variation 0.349	Coefficient of Variation 0.335	Coefficient of Variation 0.738



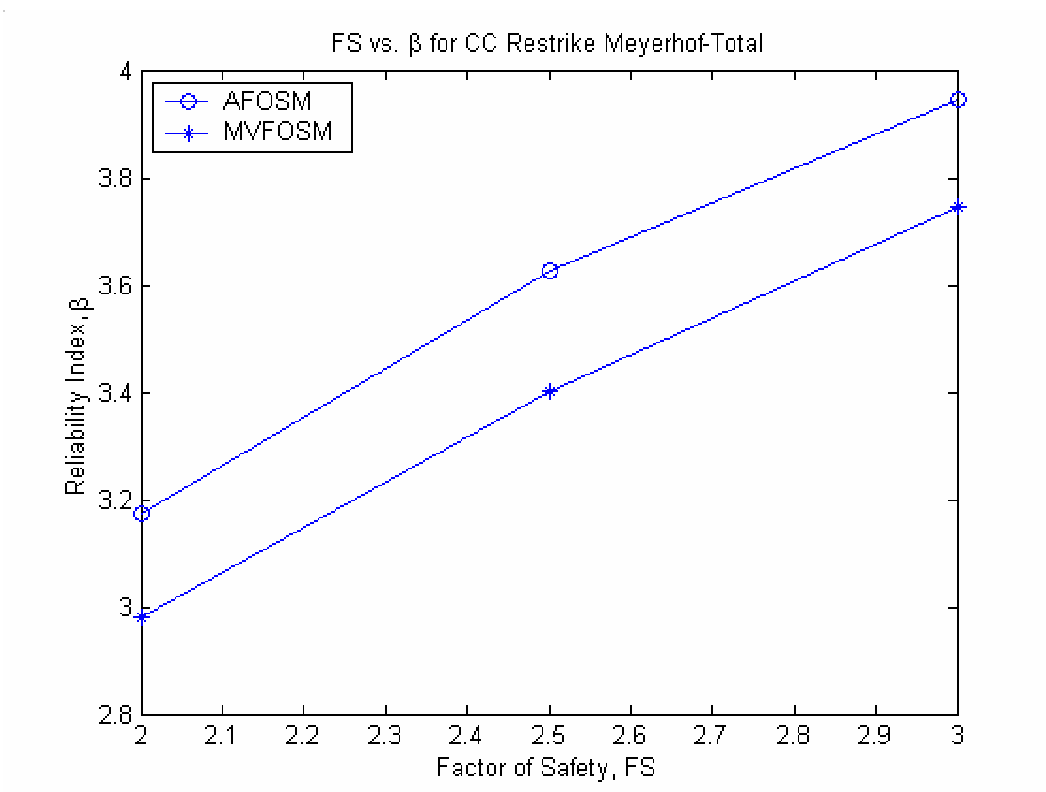

FS vs. β for CC Restrike Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.2
2
1.8
1.6
1.4
1.2
1
0.8
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

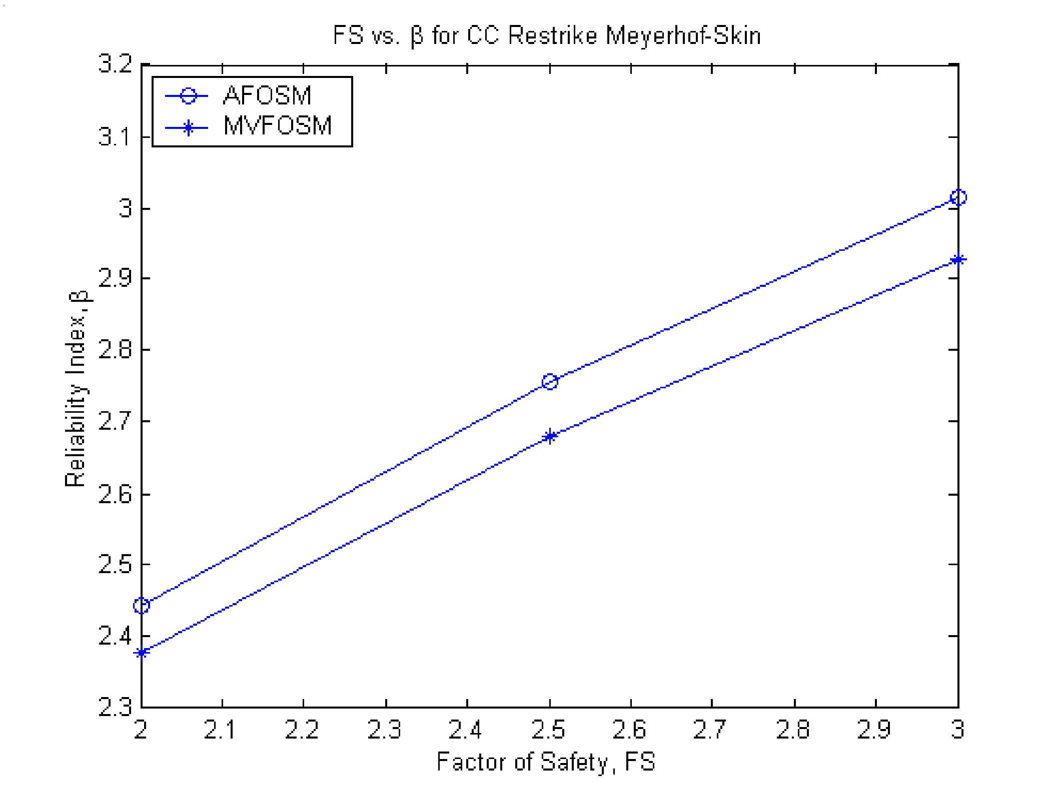

FS vs. β for CC Restrike Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

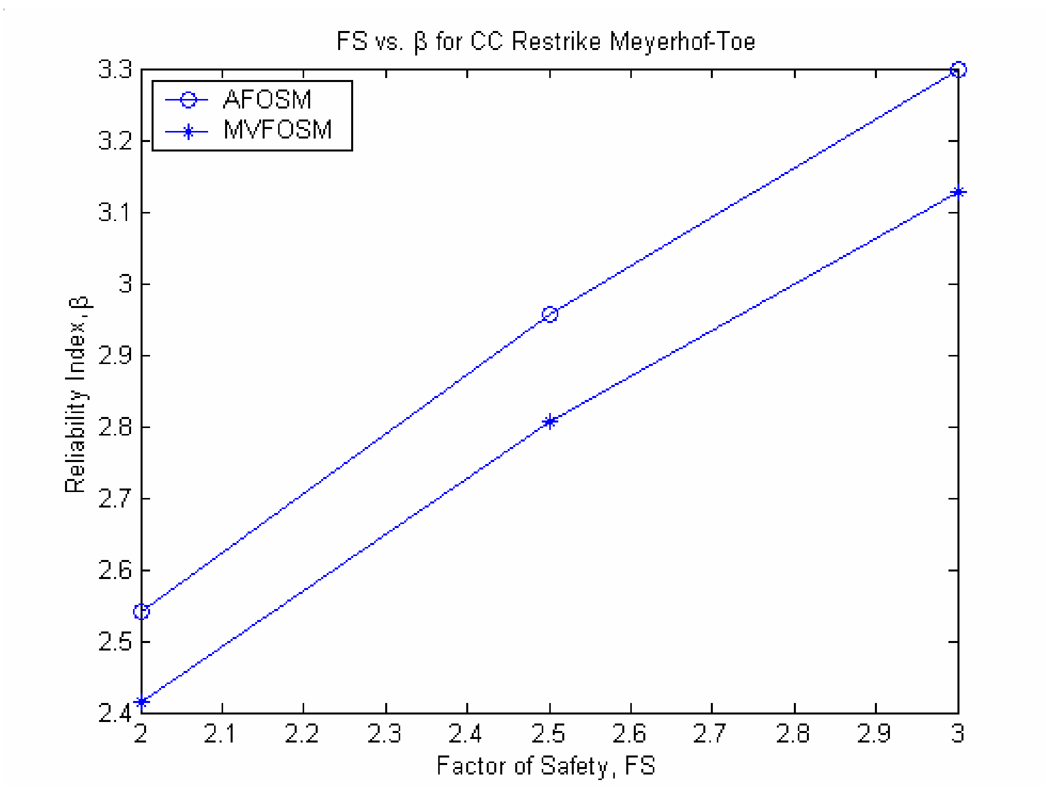
CC Restrike MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	3.174	2.982	2.444	2.377	2.542	2.415
2.5	3.625	3.403	2.758	2.680	2.957	2.807
3	3.946	3.747	3.014	2.927	3.298	3.127

	Total	Skin	Toe
Mean Value	2.956	3.999	2.458
Standard Deviation	1.515	3.203	1.387
Coefficient of Variation	0.512	0.801	0.564



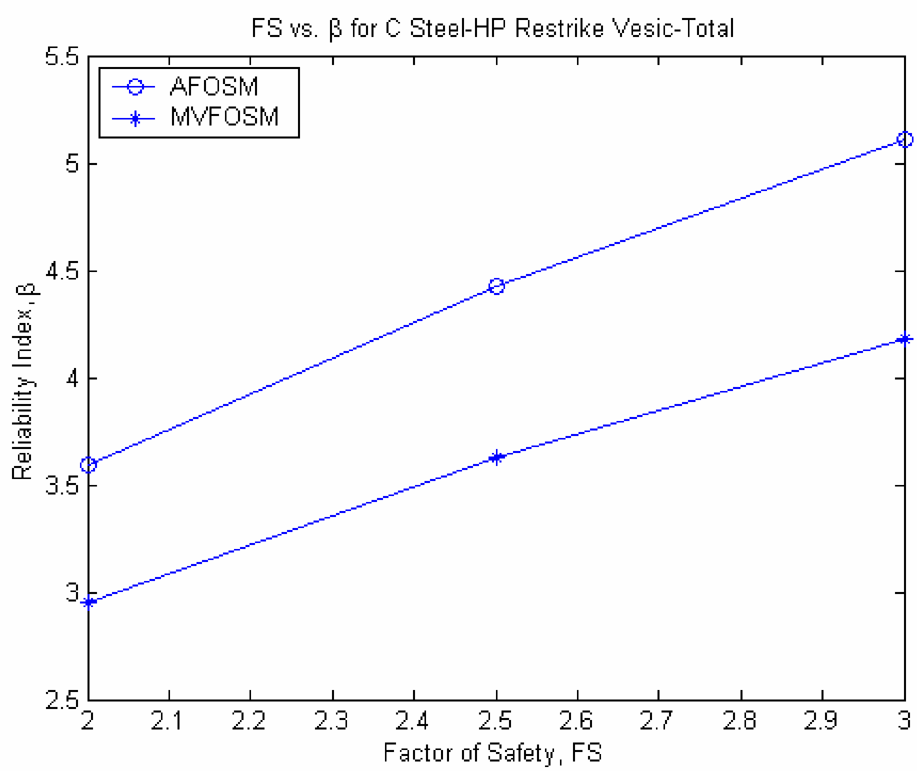

FS vs. β for CC Restrike Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

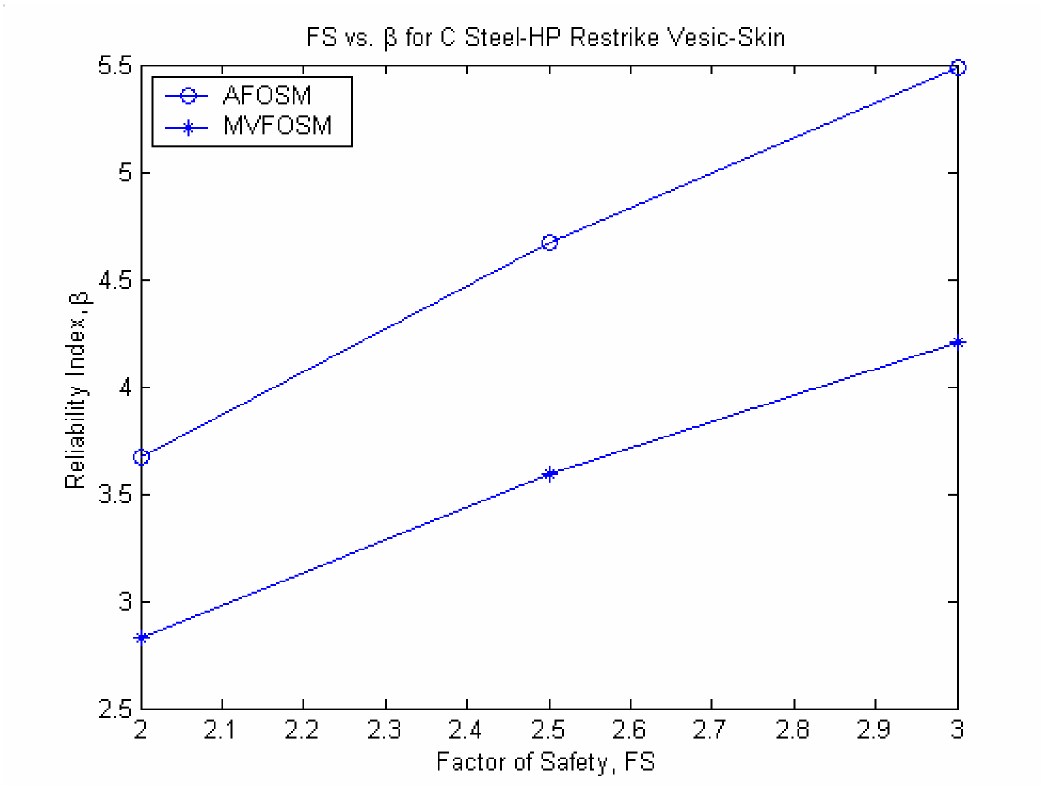

FS vs. β for CC Restrike Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

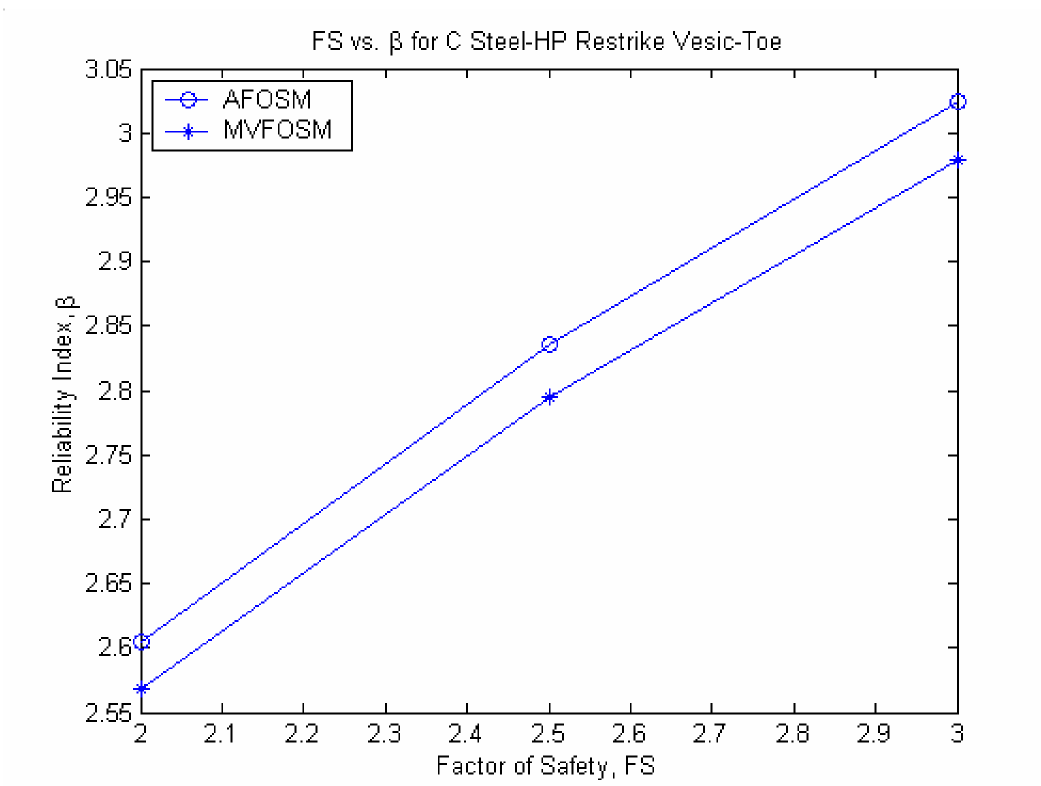
C Steel-HP Restrike VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	3.588	2.949	3.675	2.831	2.605	2.568
2.5	4.426	3.628	4.672	3.588	2.836	2.794
3	5.110	4.184	5.486	4.207	3.024	2.979

	Total	Skin	Toe
	Mean Value 1.467	Mean Value 1.270	Mean Value 10.750
	Standard Deviation 0.364	Standard Deviation 0.252	Standard Deviation 13.226
	Coefficient of Variation 0.248	Coefficient of Variation 0.199	Coefficient of Variation 1.230



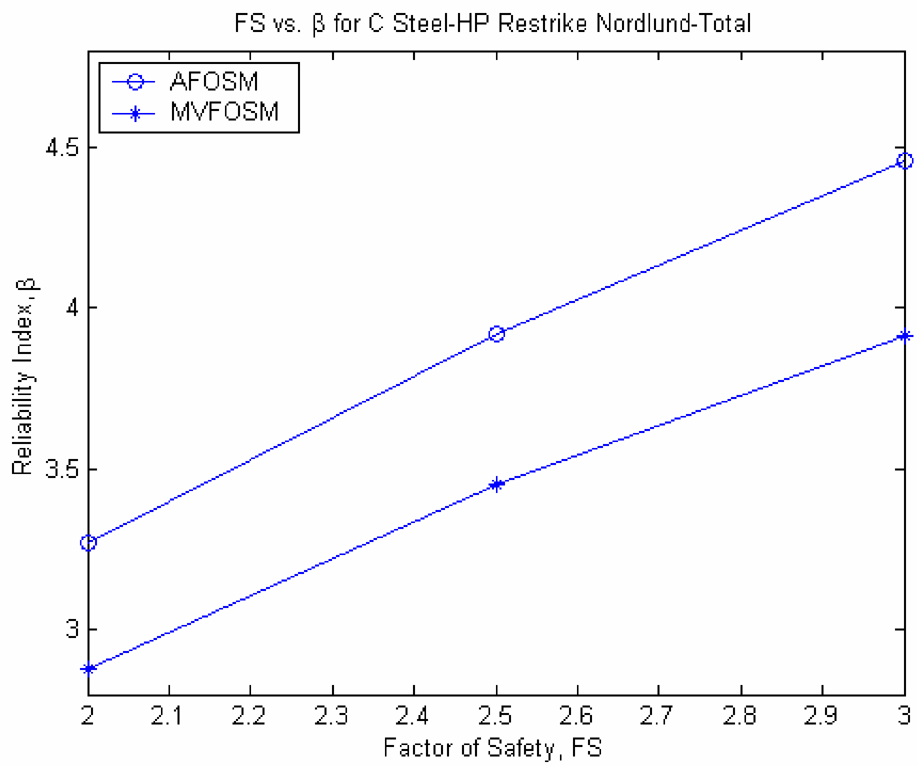

FS vs. β for C Steel-HP Restrike Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
5.5
5
4.5
4
3.5
3
2.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

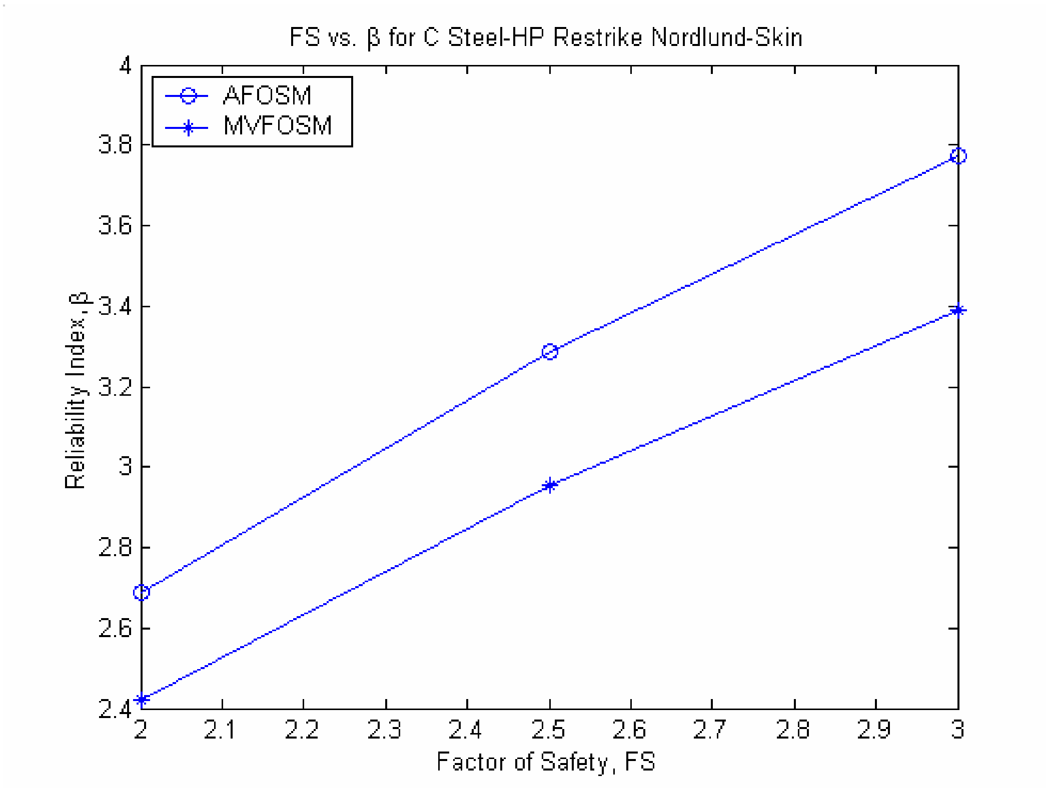

FS vs. β for C Steel-HP Restrike Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
2.65
2.6
2.55
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

C Steel-HP Restrike NORDLUND

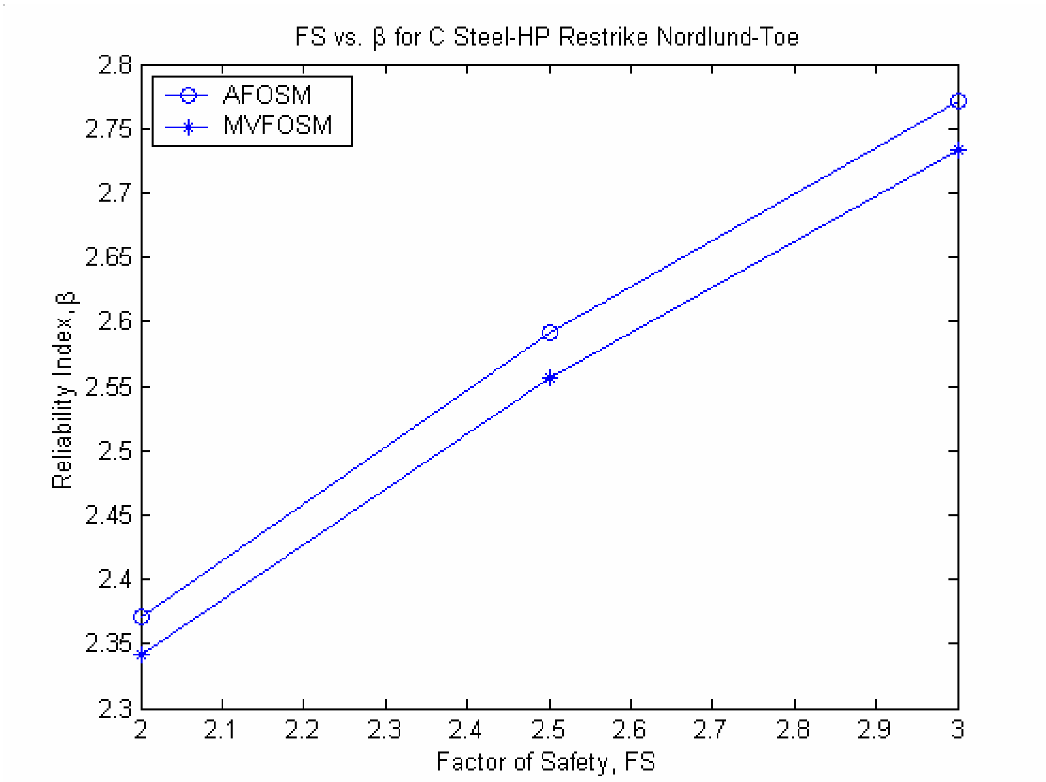
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	3.268	2.880	2.689	2.420	2.371	2.342
2.5	3.921	3.450	3.288	2.953	2.591	2.557
3	4.457	3.916	3.774	3.387	2.771	2.733

Mean Value 1.760	Mean Value 1.590	Mean Value 10.223
Standard Deviation 0.586	Standard Deviation 0.587	Standard Deviation 13.675
Coefficient of Variation 0.333	Coefficient of Variation 0.369	Coefficient of Variation 1.338





FS vs. β for C Steel-HP Restrike Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS

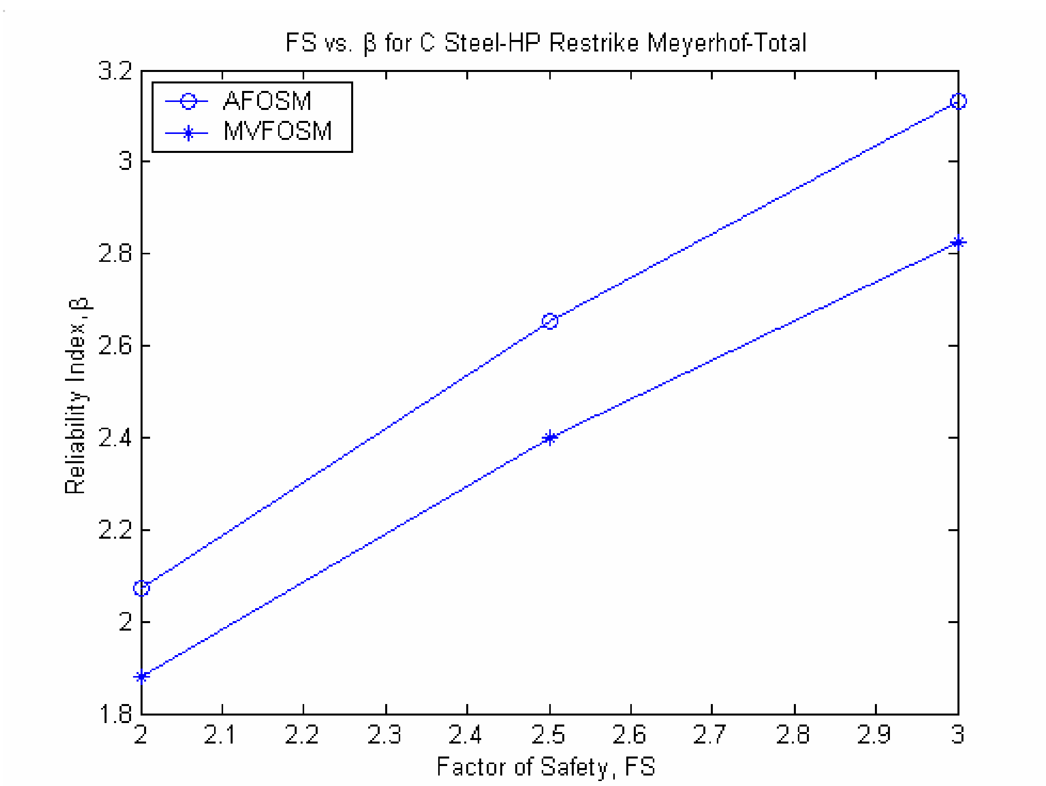


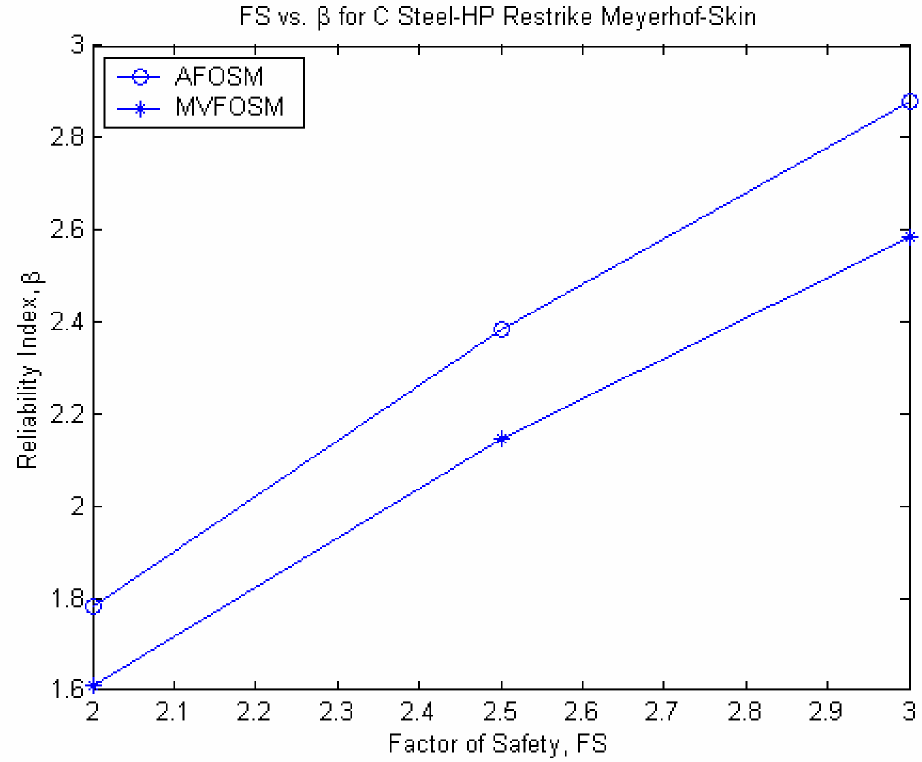
FS vs. β for C Steel-HP Restrike Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS

C Steel-HP Restrike MEYERHOF

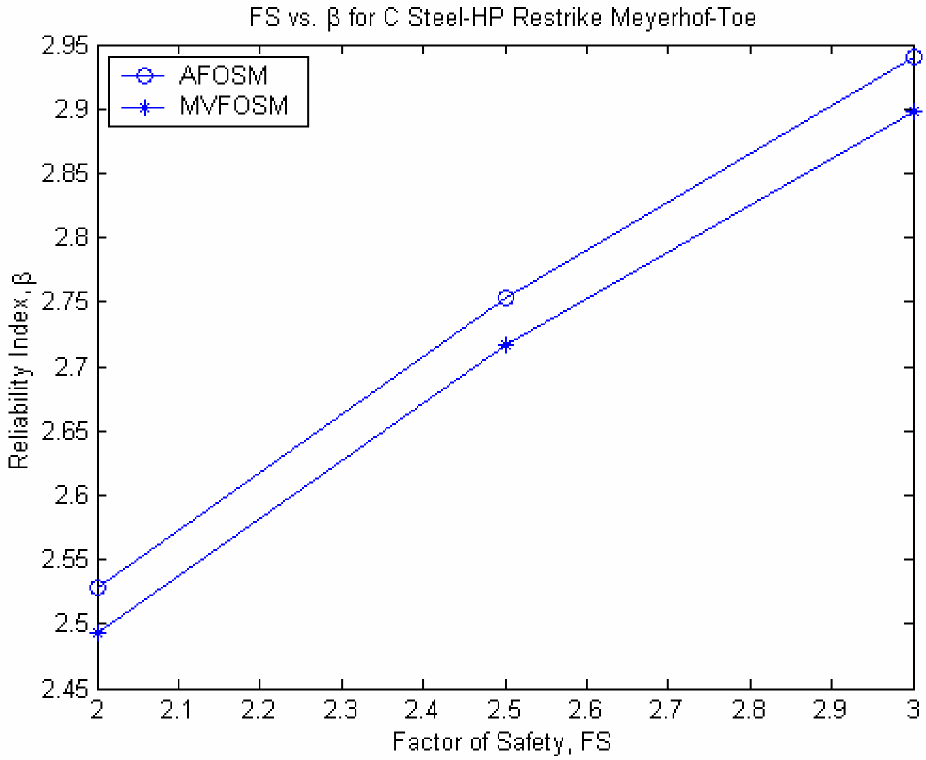
Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	2.071	1.880	1.781	1.611	2.528	2.493
2.5	2.654	2.401	2.384	2.146	2.754	2.716
3	3.131	2.827	2.878	2.584	2.940	2.898

Mean Value 1.293	Mean Value 1.127	Mean Value 10.587
Standard Deviation 0.492	Standard Deviation 0.412	Standard Deviation 13.382
Coefficient of Variation 0.380	Coefficient of Variation 0.366	Coefficient of Variation 1.264





FS vs. β for C Steel-HP Restrike Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3
2.8
2.6
2.4
2.2
2
1.8
1.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

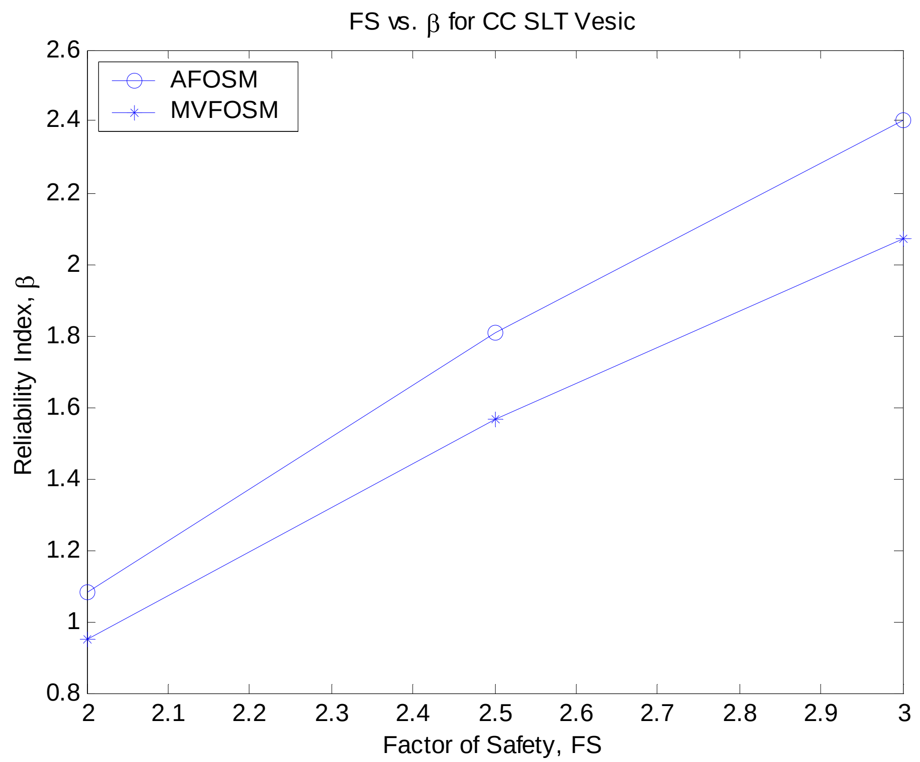


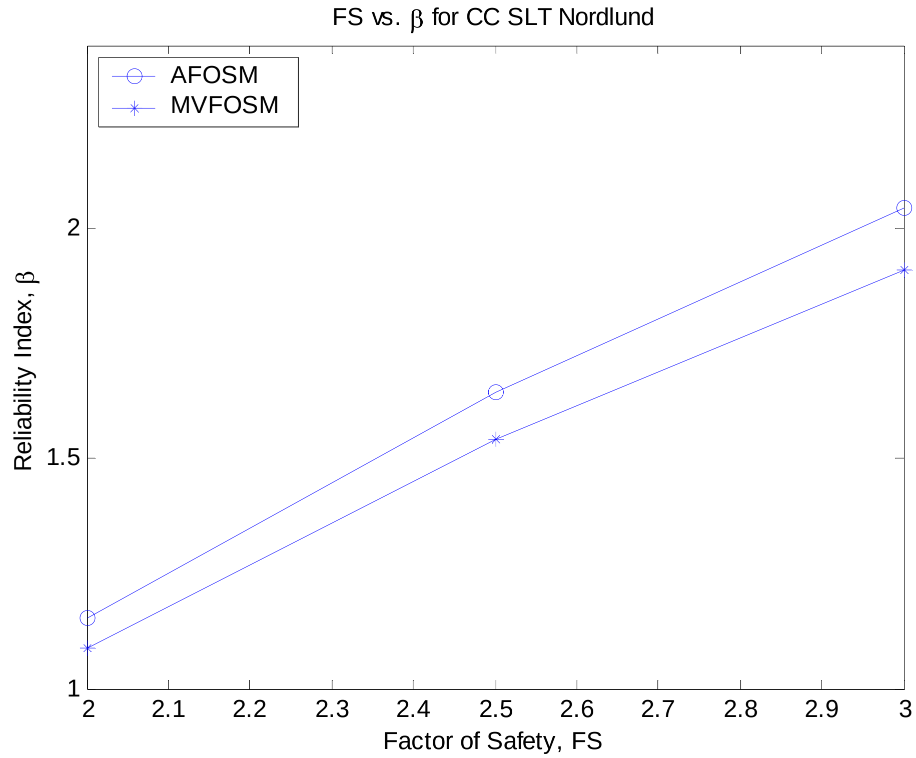
FS vs. β for C Steel-HP Restrike Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2.95
2.9
2.85
2.8
2.75
2.7
2.65
2.6
2.55
2.5
2.45
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

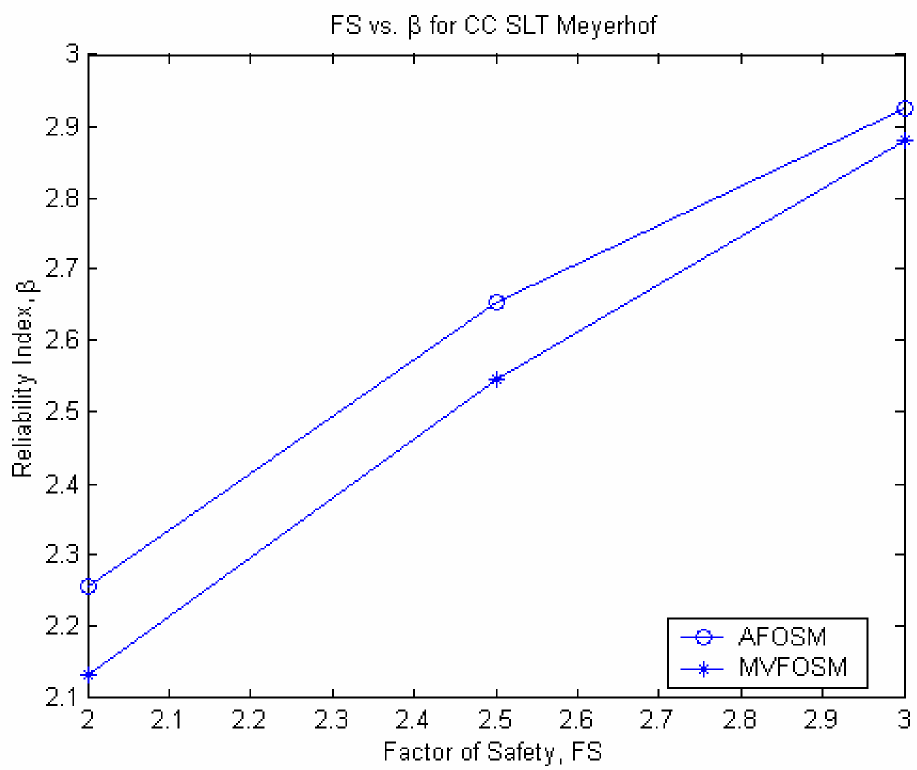
CC Static VESIC-NORDLUND-MEYERHOF

Factor of Safety (FS)	Vesic		Nordlund		Meyerhof	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.082	0.951	1.154	1.089	2.257	2.134
2.5	1.810	1.568	1.645	1.541	2.655	2.545
3	2.404	2.072	2.047	1.910	2.924	2.881

	Vesic	Nordlund	Meyerhof
	Mean Value 0.795	Mean Value 1.020	Mean Value 1.950
	Standard Deviation 0.234	Standard Deviation 0.474	Standard Deviation 1.031
	Coefficient of Variation 0.294	Coefficient of Variation 0.465	Coefficient of Variation 0.529



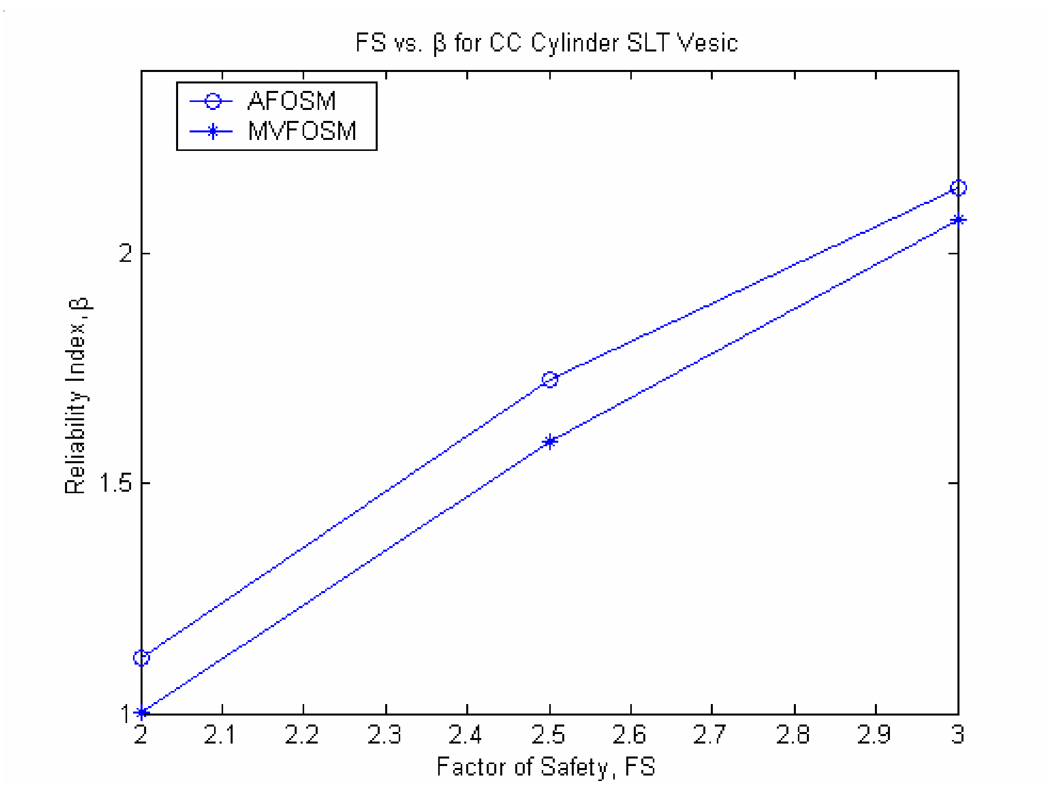

FS vs. β for CC SLT Nordlund
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
2
1.5
1
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

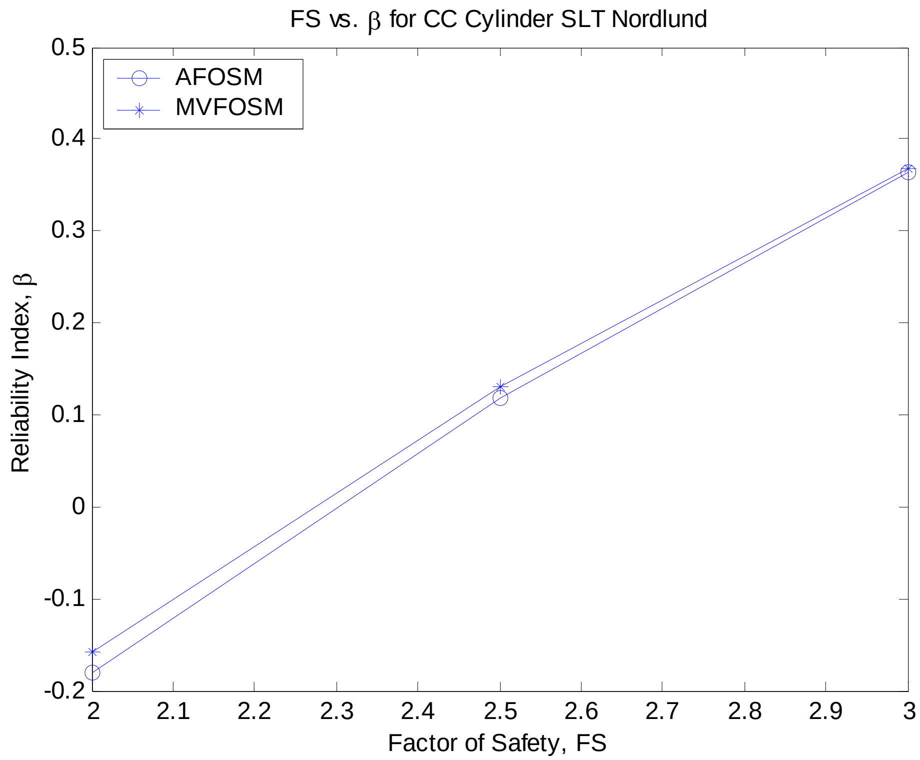

FS vs. β for CC SLT Meyerhof
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

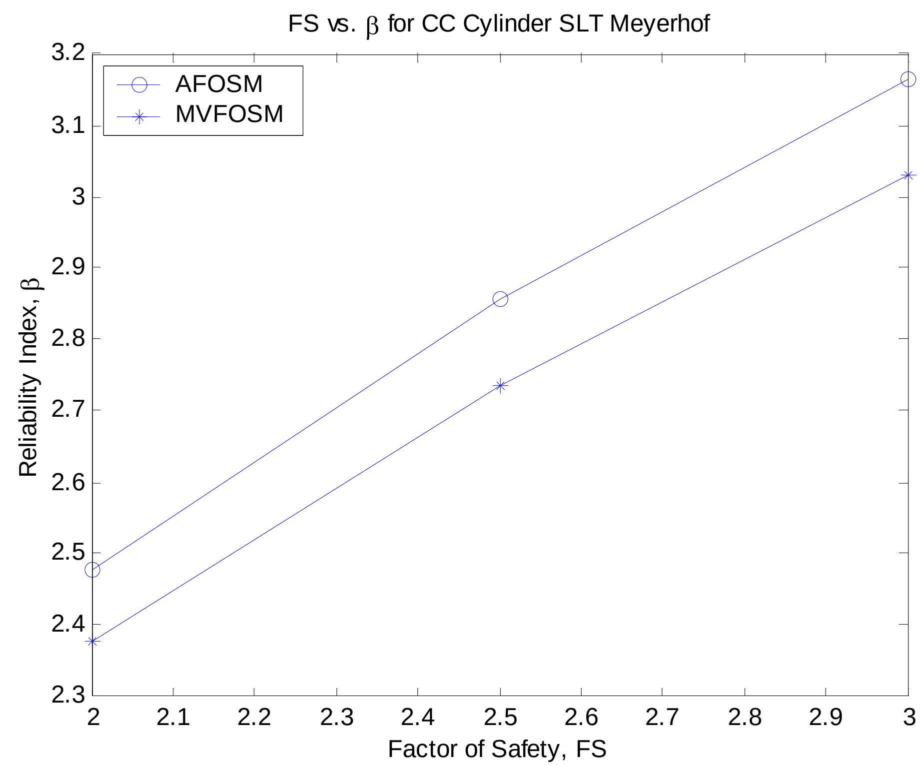
CC Cylinder Static VESIC-NORDLUND-MEYERHOF

Factor of Safety (FS)	Vesic		Nordlund		Meyerhof	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	1.122	1.001	-0.181	-0.159	2.478	2.377
2.5	1.726	1.591	0.119	0.131	2.856	2.736
3	2.143	2.074	0.363	0.368	3.165	3.030

Vesic	Nordlund	Meyerhof
Mean Value 0.828	Mean Value 0.628	Mean Value 2.796
Standard Deviation 0.261	Standard Deviation 0.534	Standard Deviation 1.769
Coefficient of Variation 0.315	Coefficient of Variation 0.850	Coefficient of Variation 0.633



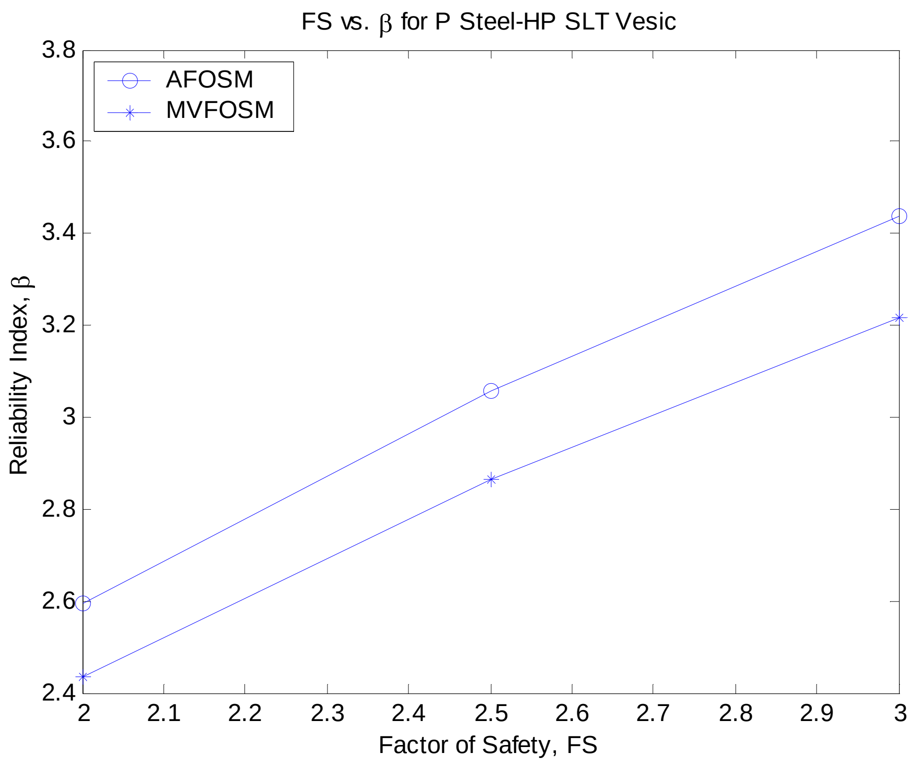

FS vs. β for CC Cylinder SLT Nordlund
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

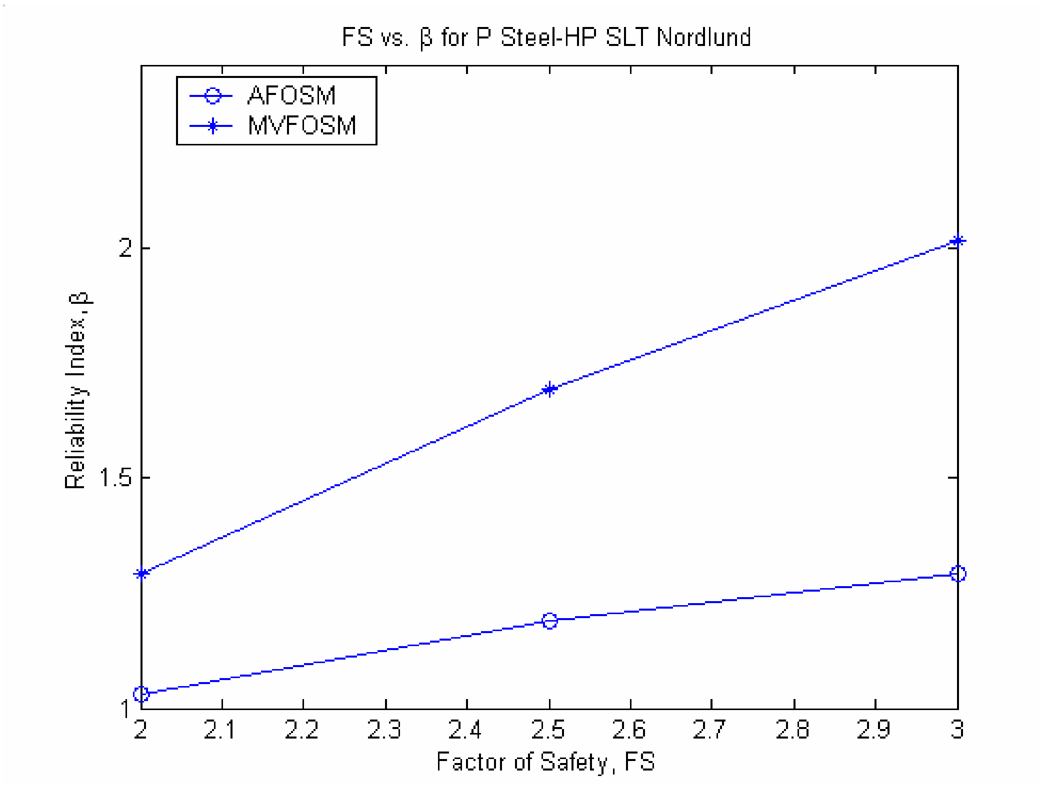

FS vs. β for CC Cylinder SLT Meyerhof
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

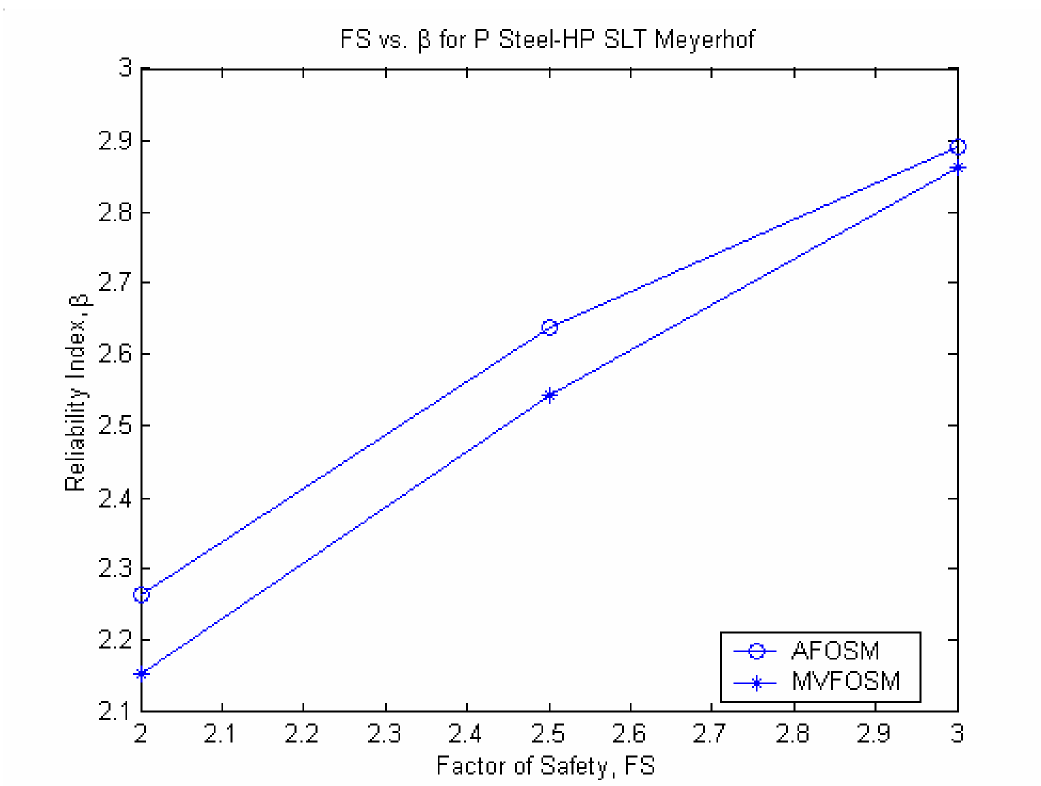
P Steel-HP Static VESIC-NORDLUND-MEYERHOF

Factor of Safety (FS)	Vesic		Nordlund		Meyerhof	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	2.595	2.434	1.031	1.294	2.264	2.155
2.5	3.059	2.865	1.189	1.693	2.637	2.544
3	3.438	3.217	1.294	2.019	2.890	2.861

Vesic	Nordlund	Meyerhof
Mean Value 2.130	Mean Value 1.274	Mean Value 2.147
Standard Deviation 1.057	Standard Deviation 0.701	Standard Deviation 1.225
Coefficient of Variation 0.496	Coefficient of Variation 0.551	Coefficient of Variation 0.570



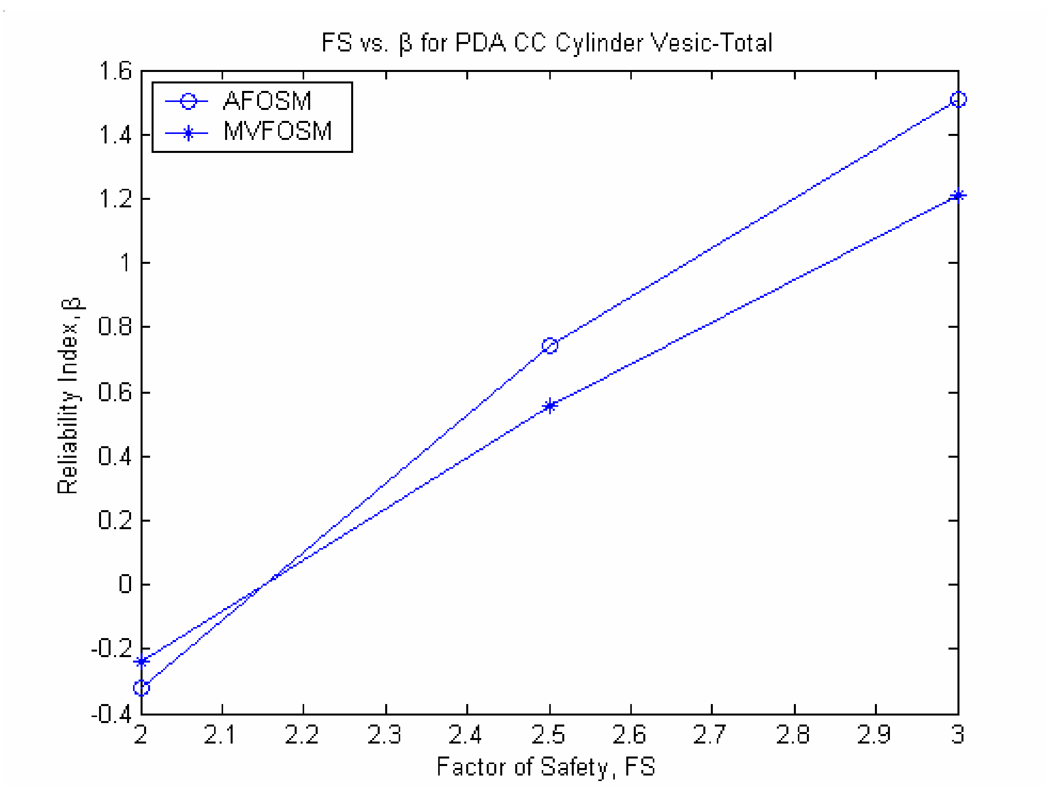

FS vs. β for P Steel-HP SLT Nordlund
AFOSM
MVFOSM
Reliability Index, β
2
1.5
1
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Factor of Safety, FS

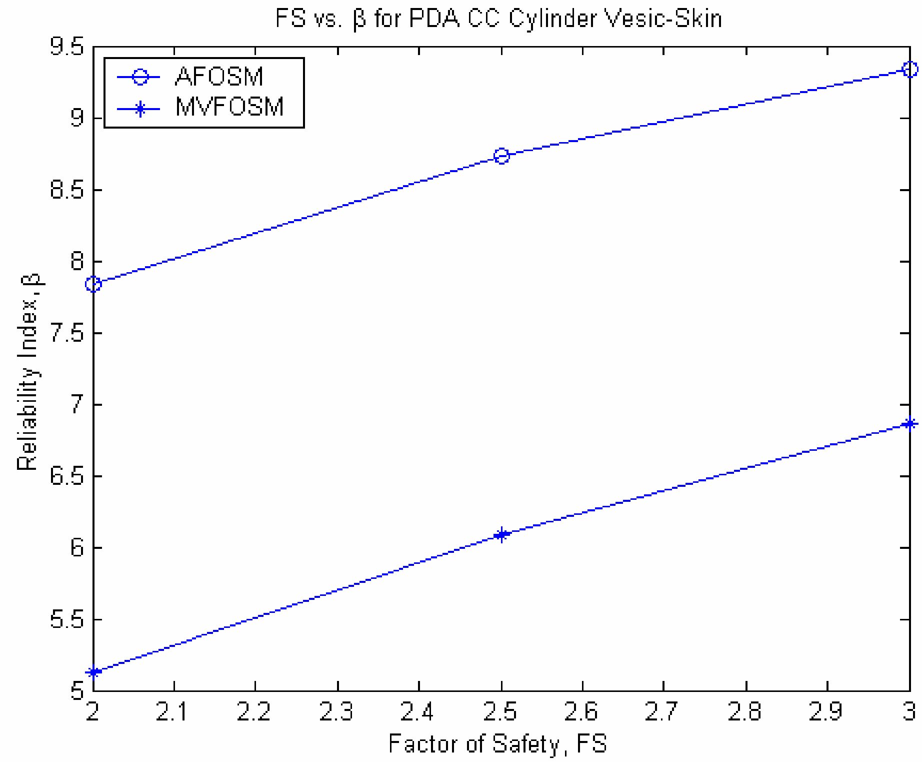

FS vs. β for P Steel-HP SLT Meyerhof
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
Reliability Index, β
AFOSM
MVFOSM
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Factor of Safety, FS

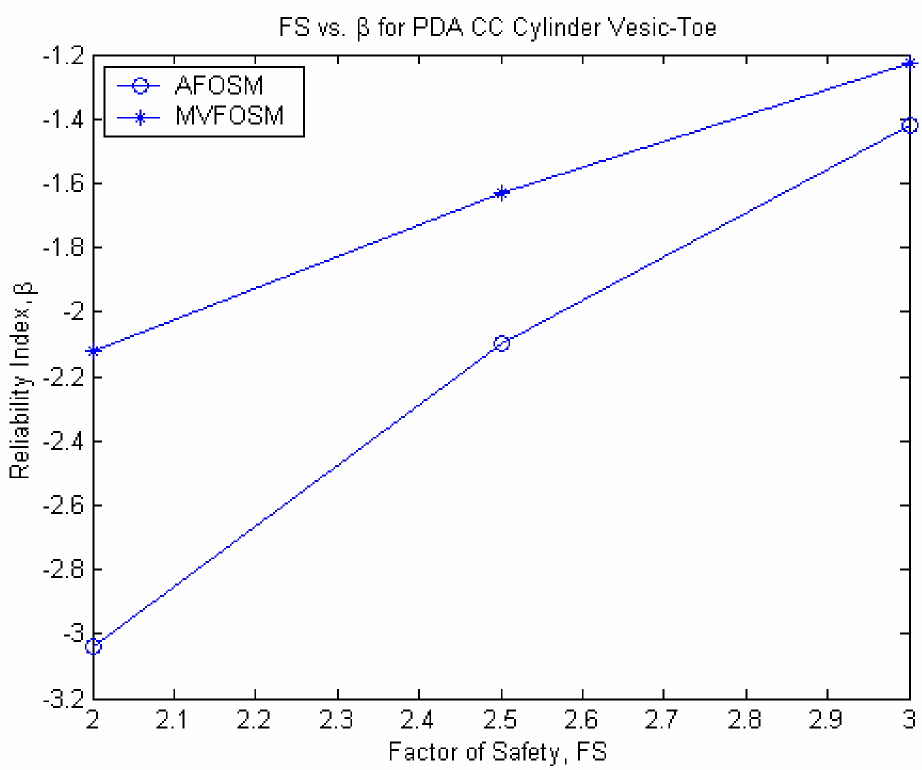
CCcylinder PDA VESIC

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	-0.322	-0.240	7.832	5.127	-3.037	-2.122
2.5	0.745	0.558	8.733	6.080	-2.097	-1.631
3	1.510	1.210	9.333	6.858	-1.422	-1.229

	Total	Skin	Toe
Mean Value	0.513	1.804	0.223
Standard Deviation	0.090	0.149	0.092
Coefficient of Variation	0.175	0.082	0.414

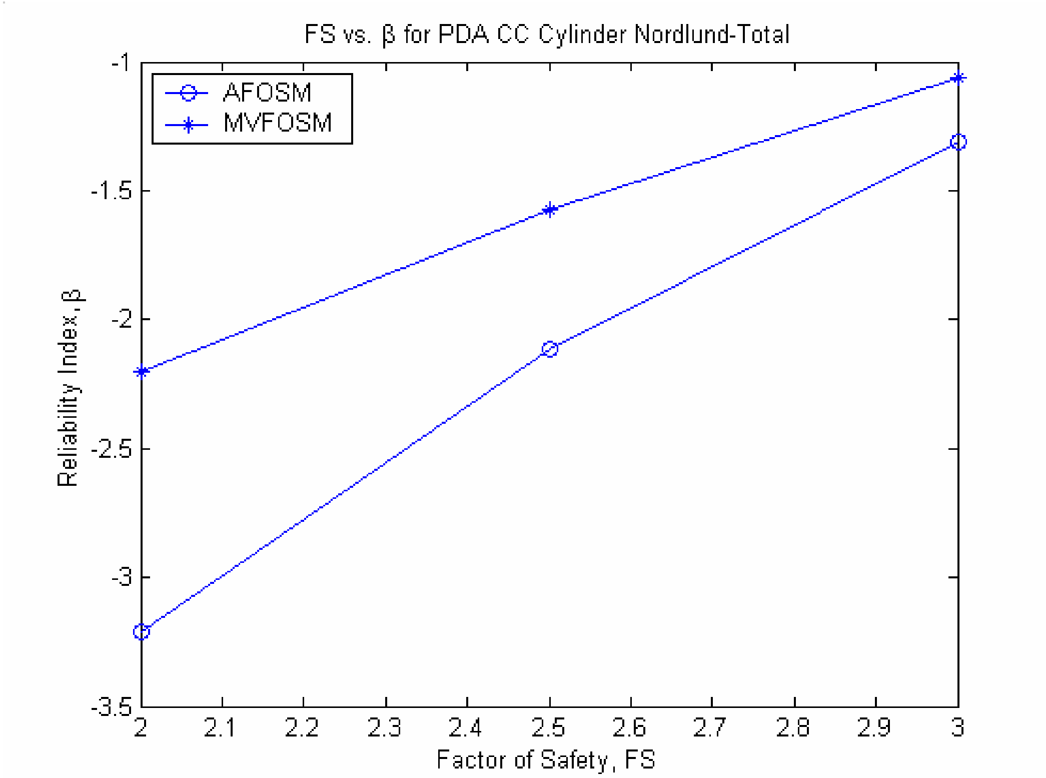


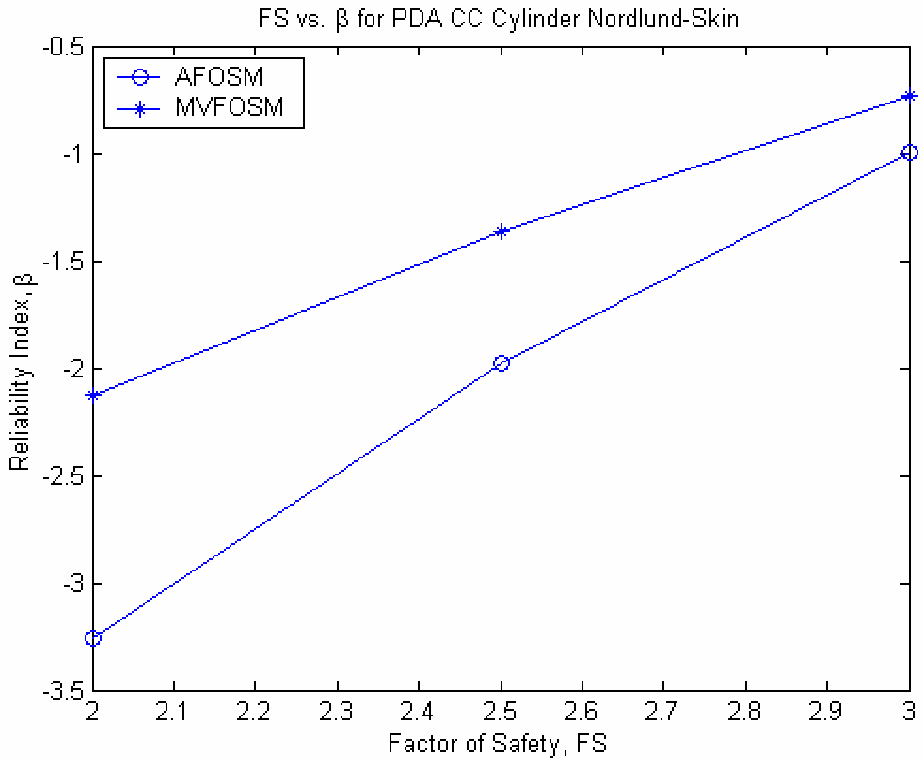

FS vs. β for PDA CC Cylinder Vesic-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

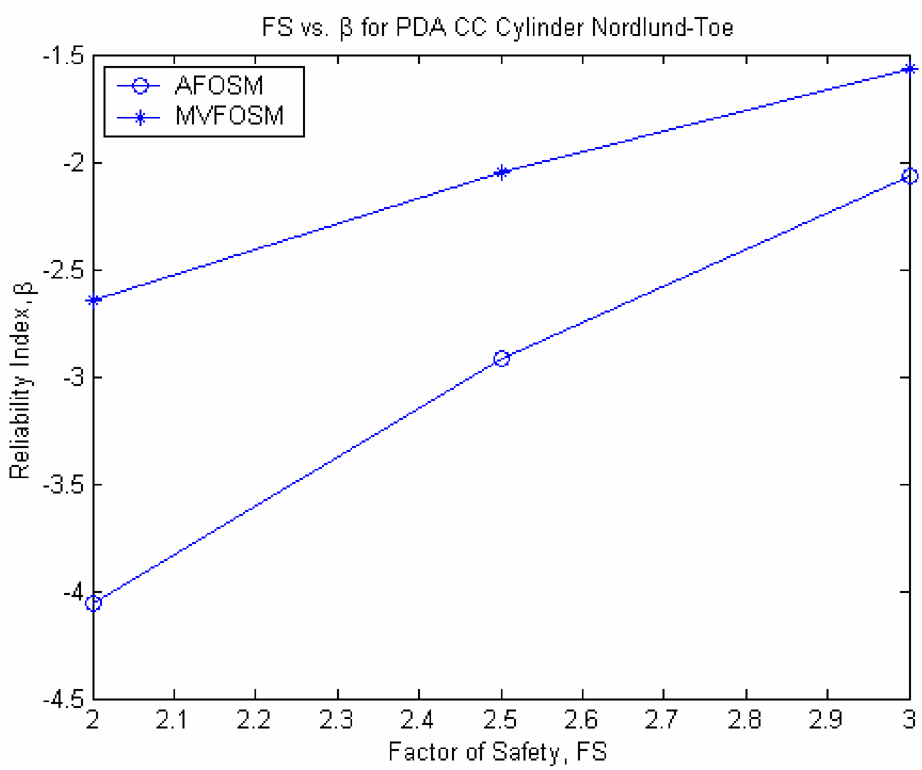

FS vs. β for PDA CC Cylinder Vesic-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
-2.8
-3
-3.2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

CCcylinder PDA NORDLUND

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	-3.211	-2.199	-3.262	-2.132	-4.061	-2.642
2.5	-2.116	-1.574	-1.975	-1.363	-2.915	-2.048
3	-1.311	-1.063	-0.995	-0.734	-2.064	-1.562



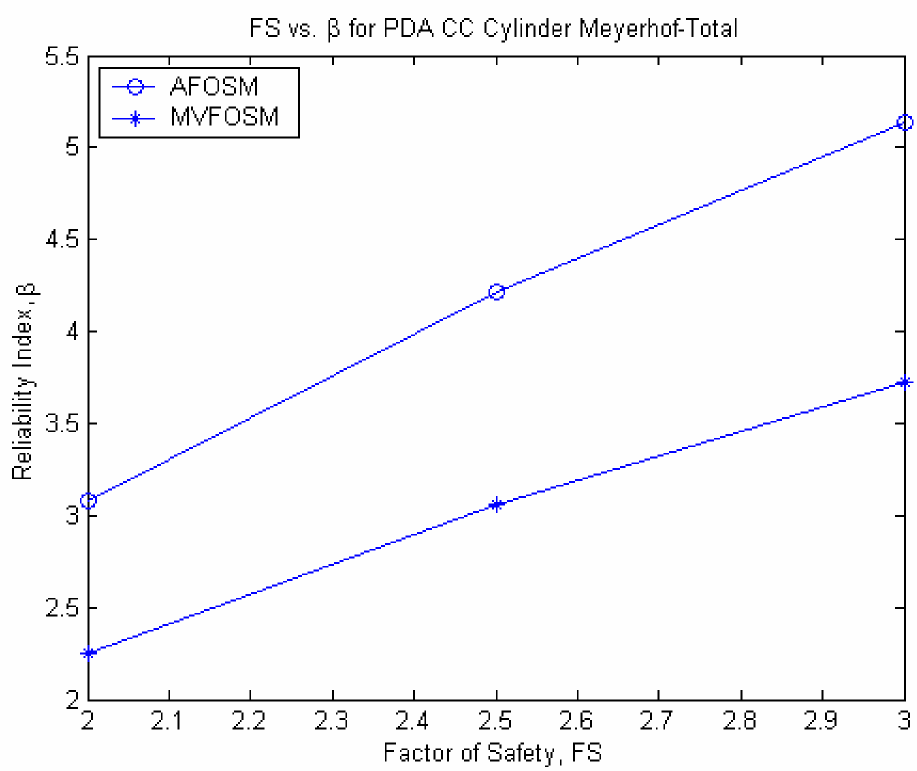

FS vs. β for PDA CC Cylinder Nordlund-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

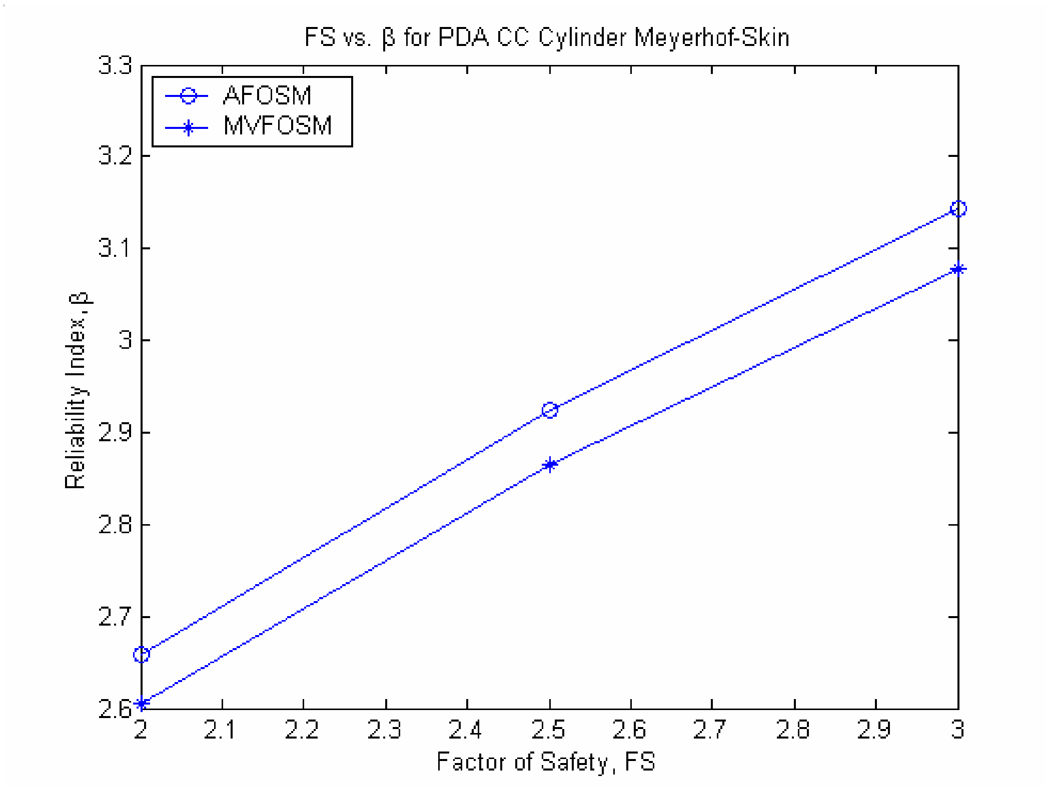

FS vs. β for PDA CC Cylinder Nordlund-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3

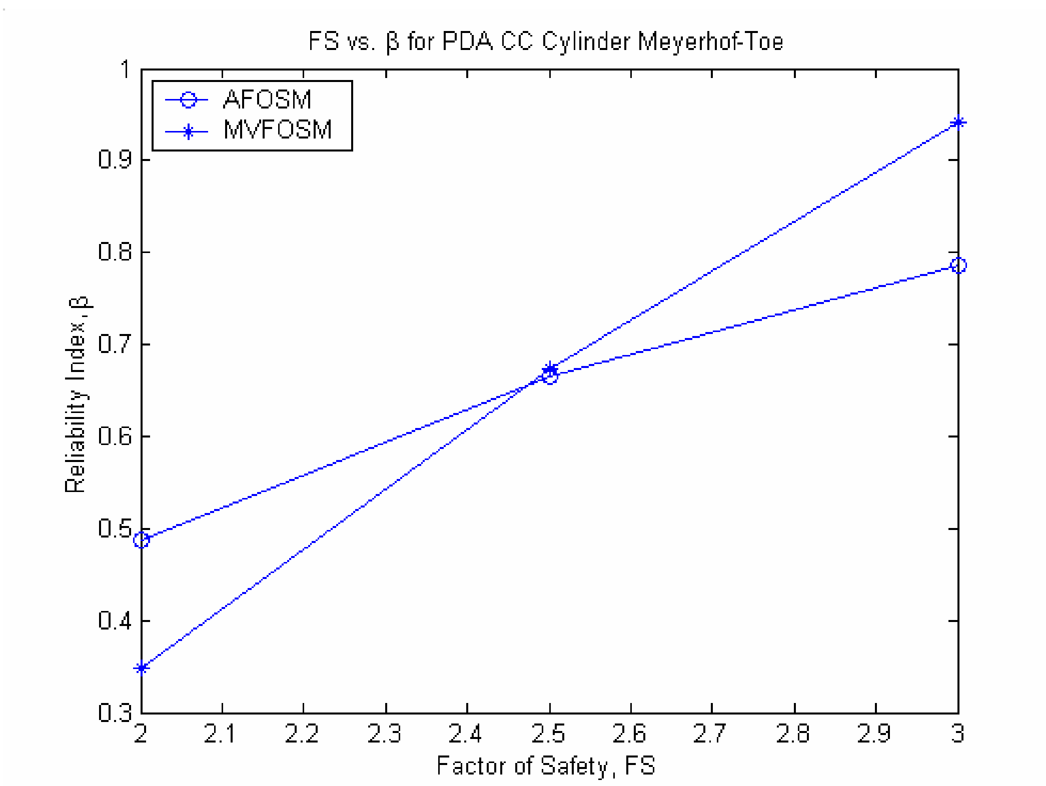
CCcylinder PDA MEYERHOF

Factor of Safety (FS)	Total		Skin		Toe	
	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM	Reliability Index (β) for AFOSM	Reliability Index (β) for MVFOSM
2	3.079	2.248	2.658	2.605	0.487	0.348
2.5	4.214	3.061	2.925	2.866	0.666	0.674
3	5.140	3.724	3.143	3.079	0.786	0.941

	Total	Skin	Toe
	Mean Value 1.017	Mean Value 7.103	Mean Value 0.847
	Standard Deviation 0.169	Standard Deviation 7.052	Standard Deviation 0.612
	Coefficient of Variation 0.166	Coefficient of Variation 0.993	Coefficient of Variation 0.722




FS vs. β for PDA CC Cylinder Meyerhof-Skin
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3


FS vs. β for PDA CC Cylinder Meyerhof-Toe
AFOSM
MVFOSM
Reliability Index, β
Factor of Safety, FS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3