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VERTICAL CAPACITY OF PILES USING FUZZY SETS

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by

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16. Abstract

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Because prediction of load-carrying capacity of piles continues to challenge geotechnical engineers, new solutions are needed. The problem is aggravated by the lack of understanding of the phenomena of soil-pile interaction, and the limited quantity and inexact quality of subsurface soil information that can be provided for analysis. The use of fuzzy set theory improves the engineer's ability to handle the uncertainty in the soil parameters and the prediction methods and thus improves the reliability of the predicted capacity.

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EXECUTIVE SUMMARY

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Because prediction of load-carrying capacity of piles continues to challenge geotechnical engineers, new solutions are needed. The problem is aggravated by the lack of understanding of the phenomena of soil-pile interaction, and the limited quantity and inexact quality of subsurface soil information that can be provided for analysis. The use of fuzzy set theory improves the engineer's ability to handle the uncertainty in the soil parameters and the prediction methods and thus improves the reliability of the predicted capacity.

1. INTRODUCTION

Prediction of load-carrying capacity of piles has been and is still one of the most challenging problems facing geotechnical engineers. The problem is complex and difficult, due to the lack of understanding of the phenomena of soil-pile interaction, and the limited quantity and inexact quality of subsurface soil information that can be provided for analysis. Because of imperfect knowledge, existing models for prediction of the pile load capacity are, at best, semi-empirical. Although many prediction methods have been proposed, few of them can yield satisfactory results in predicting all aspects of pile behavior in the field.

This report documents the development of a computer program, FPILE, for predicting the ultimate capacity of single piles. FPILE is the second generation of the computer program PCFS (Juang, et al., 1991a). Both programs use fuzzy set theory to account for uncertainty in the soil parameters and prediction methods. PCFS is only applicable in sandy soils, while FPILE may be applied to both cohesive and cohesionless soils. Computation of uncertain or fuzzy data is more efficient in FPILE than in PCFS. Perhaps, the most significant improvement of FPILE over PCFS is the use of FHWA pile database in the development and calibration of the program.

2. EXISTING METHODS FOR PREDICTING PILE CAPACITY

There are many methods for interpreting the ultimate capacity from pile load tests. A good review of these methods is presented by Fellenius (1980). The plethora of methods is testimony to the uncertainty the profession experiences with predicting pile capacity. This uncertainty underscores the need for improvement in the procedure.

Several popular, current methods of predicting pile capacity are reviewed below. Capacities of piles in sand and in clay are reviewed. Any complete procedure (including charts and equations) for calculating the Q_u, ultimate pile capacity, is called a *deterministic* pile capacity model in this report.

2.1 Methods for Calculating Ultimate Pile Capacity (Q_u) in Clay

The ultimate pile capacity, consists of two components: end bearing, Q_p, and side friction, Q_s, calculated separately (Vesic, 1977).

$$Q_u = Q_s + Q_p \qquad (2\text{-}1)$$

End bearing capacity of a pile in clay is often computed from the classical bearing capacity formula (below) altered to use a special bearing capacity factor N_c. Of the three components of bearing capacity, only the N_c term is considered significant for piles in clays where $\phi = 0$. Thus,

$$Q_p = c_u \ N_c \ A_p \qquad (2\text{-}2)$$

where:

c_u - undrained shear strength of the clay soil,

N_c - deep foundation bearing capacity factor, and

A_p - area of the pile tip.

N_c is often taken as 9 (Bowles, 1988), thus

$$Q_p = 9(c_u)A_p \qquad (2\text{-}3)$$

The side friction component of piles in clays has been the subject of much research. Two methods of evaluating side friction, the α-method and the λ-method, are briefly reviewed below. The α-method computes the side resistance as a fraction of the cohesion of a clay soil:

$$Q_s = \Sigma \ \alpha \ (c_u) \ A_s \qquad (2\text{-}4)$$

where

Q_s - side friction,

Σ - summation over the length of the pile,

α - a factor used to calibrate c_u,

c_u - undrained shear strength in stratum of interest, and

A_s - surface area of the pile in stratum of interest.

Many α functions (some expressed in tabular form) are available in the literature (API, 1981; Tomlinson, 1971, 1987). A large variation in the α value for a given c_u value leads to a great uncertainty in this approach. In this study, the following α function, proposed by API (1981), is adopted:

$$\alpha = 1.0, \qquad c_u \leq 500 \text{ lb/ft}^2$$

$$= 0.5 + (1500-c_u)/2000, \quad 500 \text{ lb/ft}^2 < c_u < 1500 \text{ lb/ft}^2$$

$$= 0.5 \qquad c_u \geq 1500 \text{ lb/ft}^2 \tag{2-5}$$

The λ-method, presented by Vijayvergiya and Focht (1972), computes the side resistance as follows:

$$Q_s = \Sigma\,[\lambda(\sigma_v' + 2c_u)A_s] \tag{2-6}$$

where

Q_s - side friction,

Σ - summation over the length of the pile,

λ - coefficient from Figure 2-1,

c_u - undrained shear strength in stratum of interest,

σ_v' - effective vertical stress in stratum of interest, and

A_s - surface area of the pile in stratum of interest.

2.2 Methods for Calculating Q_u for Piles in Sand

This section reviews methods of predicting the capacity of piles in cohesionless soils. There are several ways to predict the capacity of piles in cohesionless soils. The variety of methods available is testament to the need for improvement in this area of geotechnical engineering. Three models are examined:

FHWA model, as proposed by Vanikar (1985)

Coyle-Castello's method (1981)

Briaud-Tucker's method (1984)

FHWA model, as proposed by Vanikar (1985) breaks pile capacity into the conventional tip resistance and side friction, as defined in Equation 2-1. The tip resistance, Q_p, is calculated using the method proposed by Thurman (1964), expressed as

$$Q_p = A_p\ \alpha_T\ \sigma_{vt}'\ N_q \tag{2-7}$$

where

A_p - area of the pile tip,

α_T - dimensionless factor from Figure 2-2,

σ_{vt}' - effective vertical stress at the pile tip, and

N_q - bearing capacity factor for piles, from Figure 2-3.

The side friction Q_s is calculated using the method proposed by Nordlund (1963), expressed as

$$Q_s = \Sigma\ [K_\delta\ \sigma_v'\ \sin(\delta)\ \ B\ D\ C_f\ ] \qquad (2\text{-}8)$$

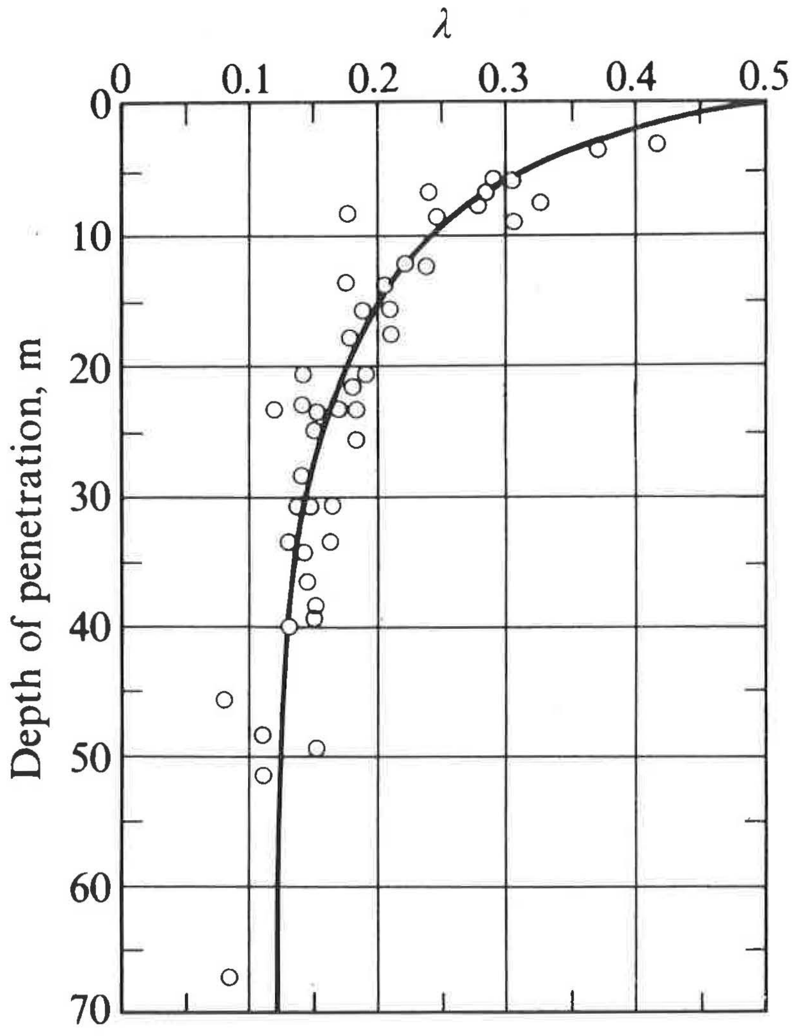

Figure 2-1. λ-coefficient

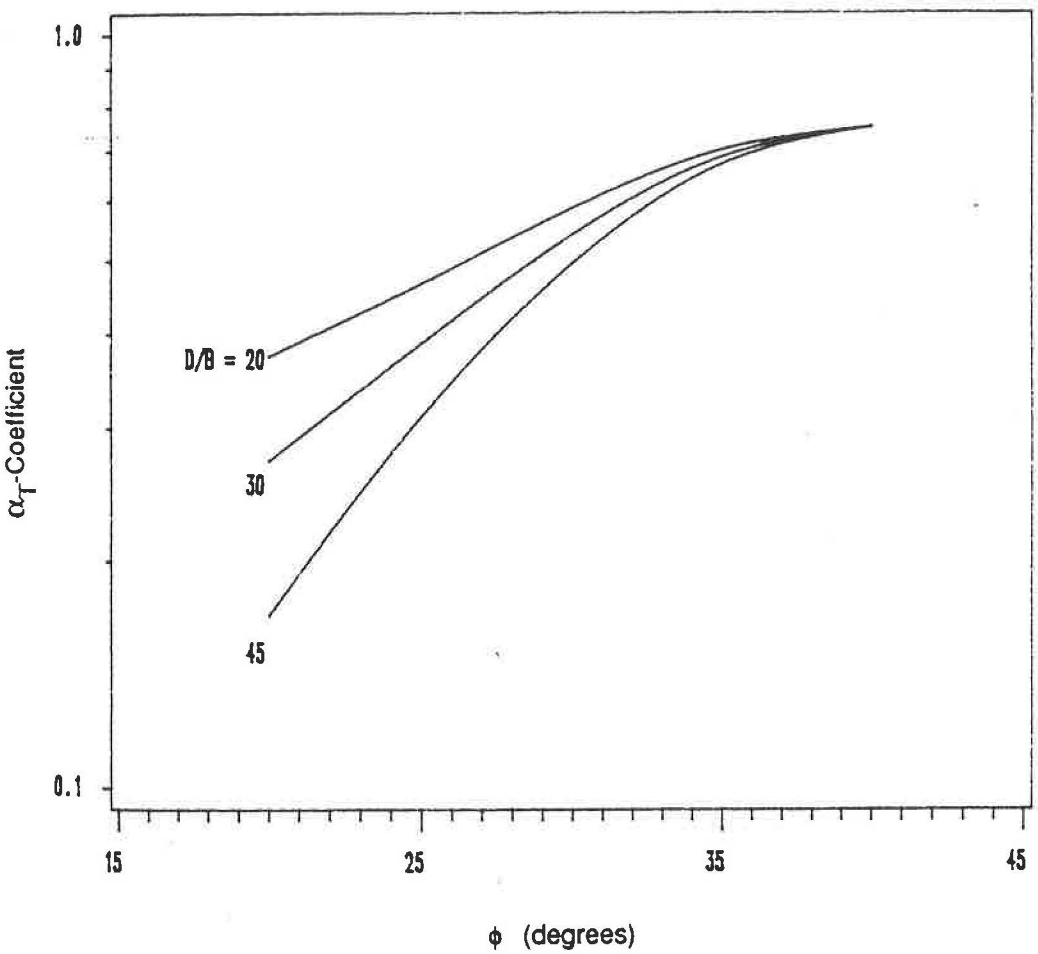

Figure 2-2. Relation Between α_T and ϕ for Various D/B Ratios, Thurman (1964)

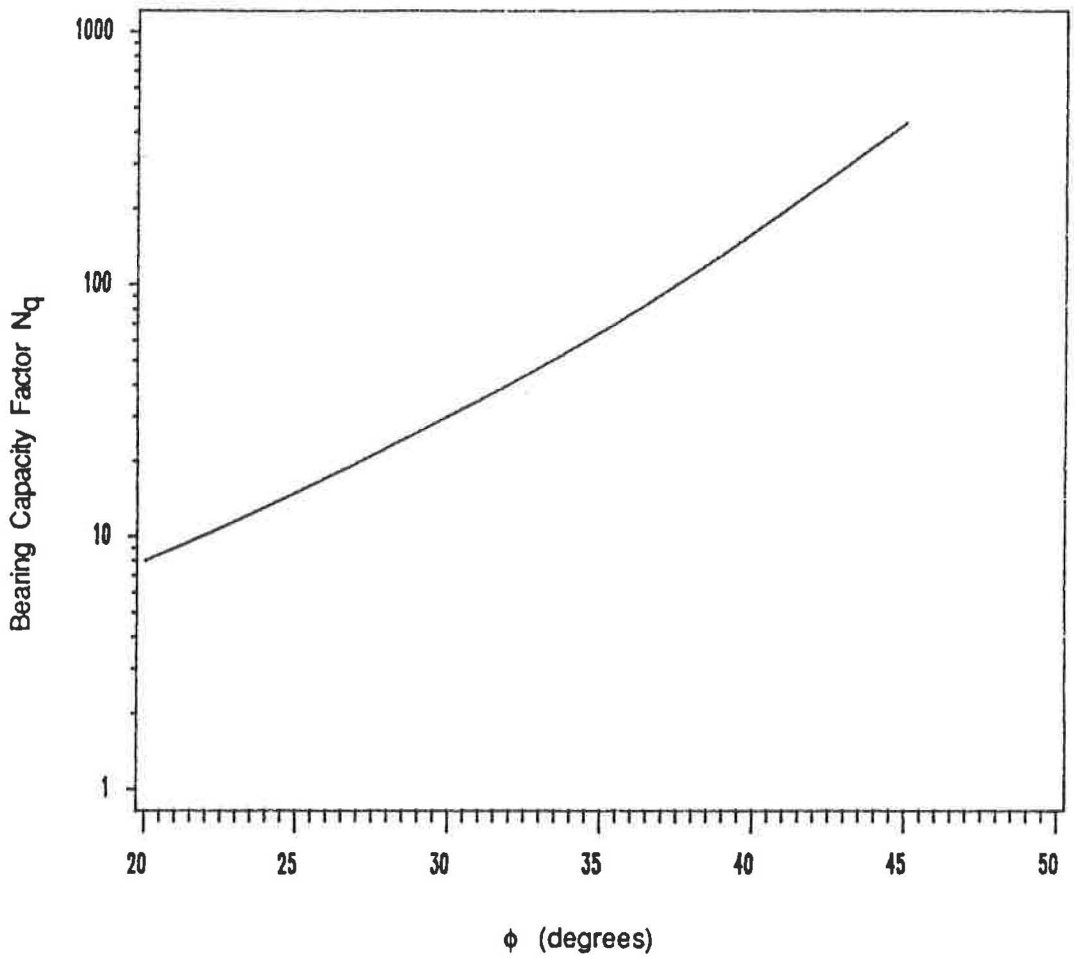

Figure 2-3. Relation Between ϕ and N_q (Thurman, 1964)

where

Σ - summation over the length of the pile,

K_δ - dimensionless factor relating normal and shear stress (Figure 2-4),

σ_v' - effective vertical stress at the layer in question,

δ - angle of friction between pile and soil,

B - pile diameter,

D - depth to layer in question, and

C_f - correction factor for K_δ (Figure 2-5).

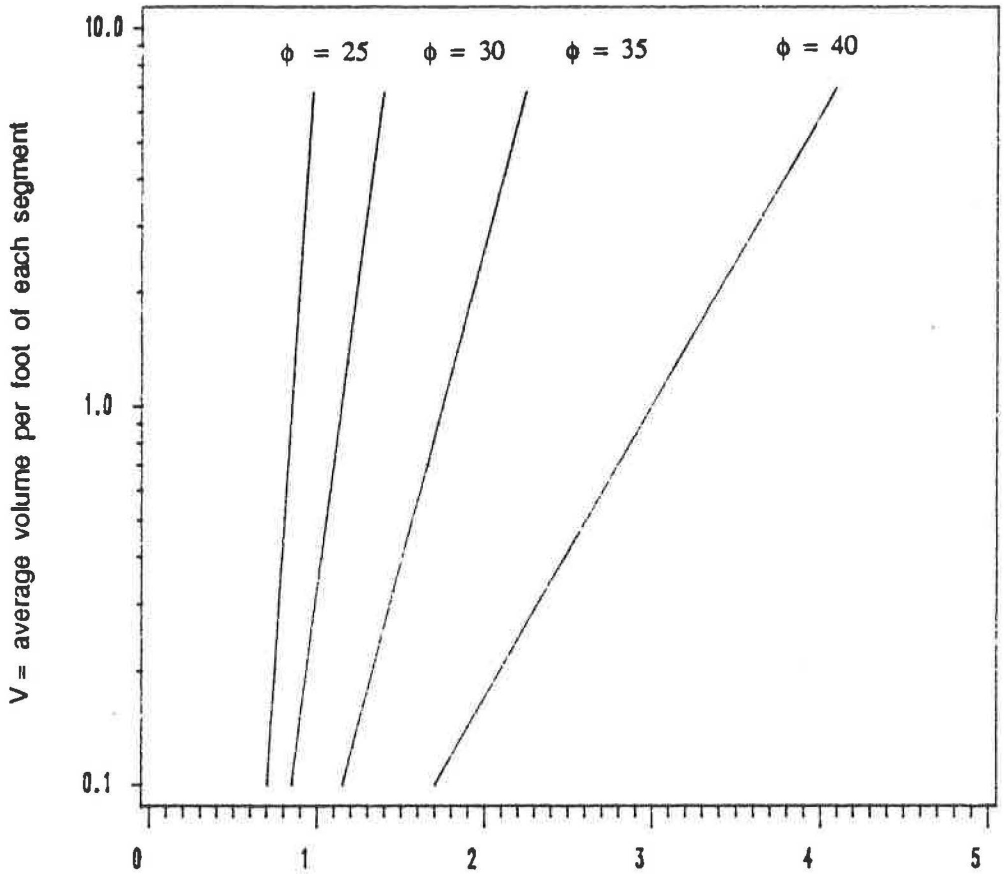

Figure 2-4. Dimensionless factor, K_δ

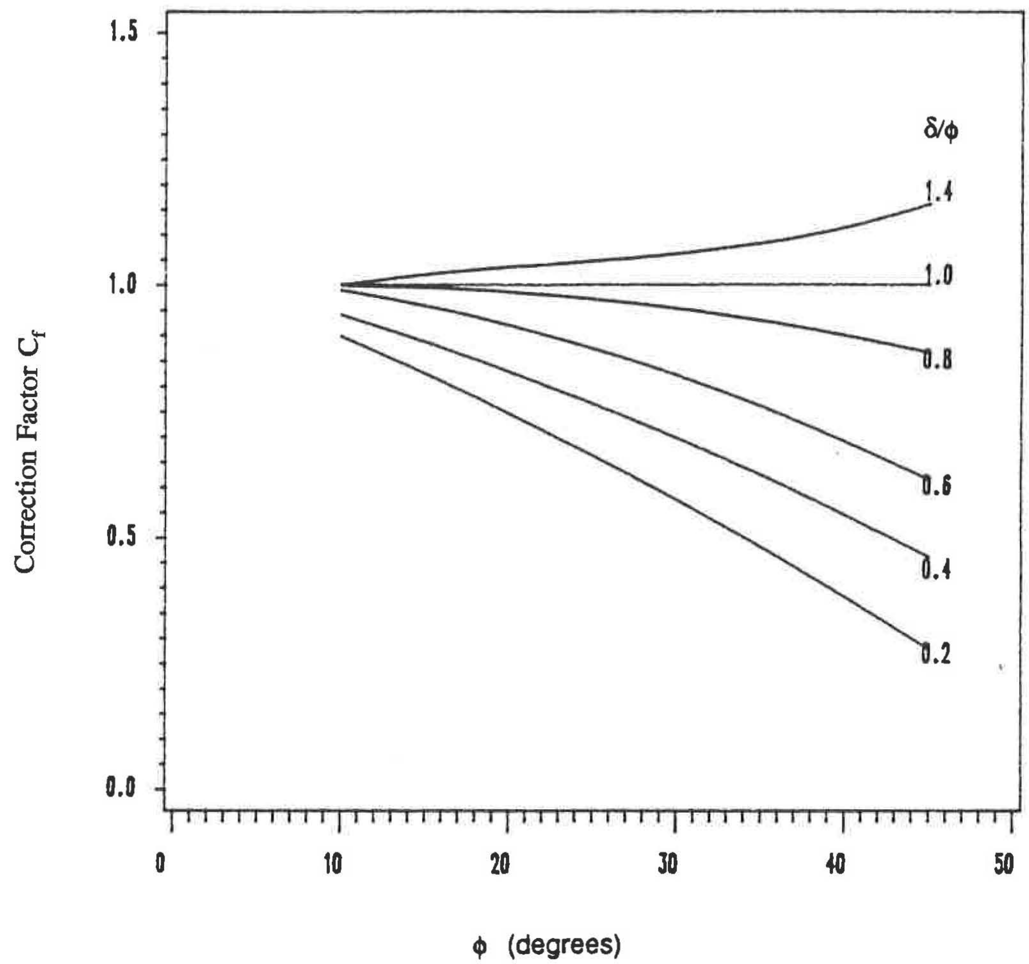

Figure 2-5. Correction Factor, C_f

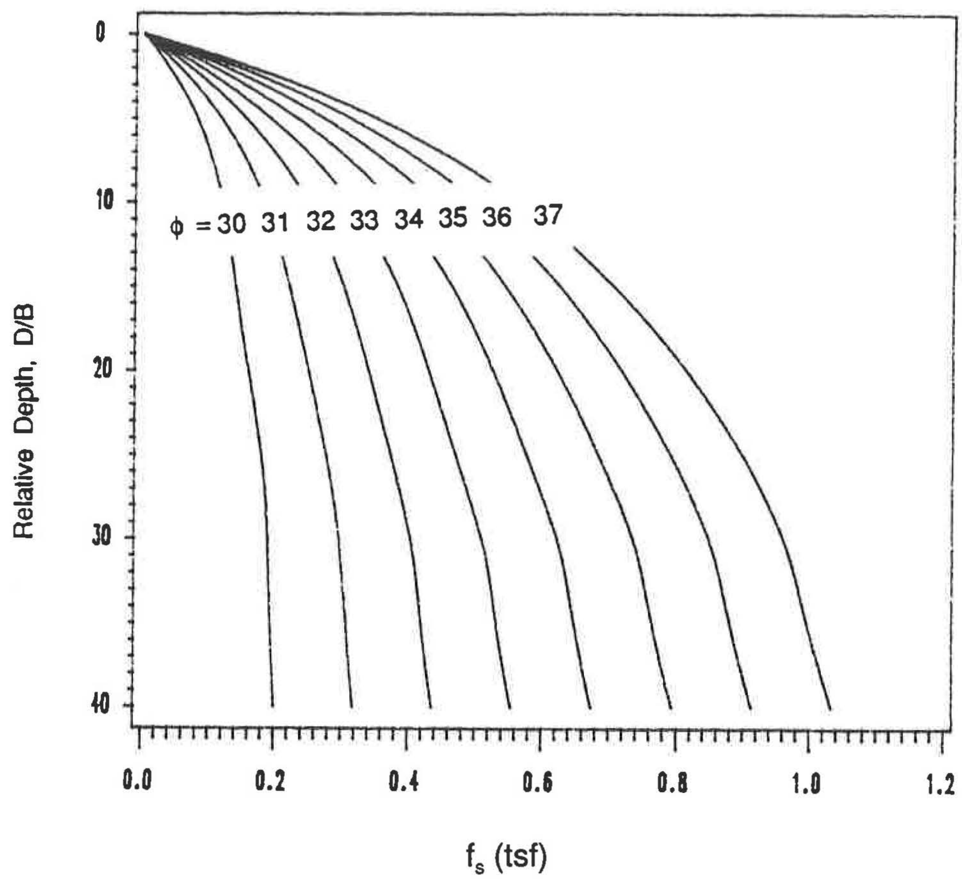

Figure 2-6. f_s for the Coyle-Castello method

Coyle and Castello's Method. This method uses the relative depth (depth of point in question / pile width, D/B) and friction angle, ϕ, of adjacent sand to estimate side friction and point resistance. For point resistance, D is the full length of the pile. D is taken to the midpoint of the soil layer in question, otherwise. Figures 2-6 and 2-7 are used to obtain the unit side friction (f_s) and point resistance (q_p), respectively. The ultimate capacity of the pile is then calculated as follows:

$$Q_u = Q_s + Q_p$$

$$= f_s A_s + q_p A_p \qquad (2\text{-}9)$$

Briaud and Tucker's Method. This method is different from most existing methods, in that it takes into account the effect of the residual stresses due to driving. Based on a 33-pile data base, and on the results of Standard Penetration Tests (SPT), a hyperbolic model was used to describe the side friction

(f) and point pressure (q) curves. The f-w (w denotes the movement of pile at any depth) and q-w curve for this method do not go through the origin, but are off by an amount equal to the residual stresses after driving (see Figure 2-8). Both curves are modeled by a hyperbola expressed as

$$q = \frac{w}{\dfrac{1}{K_p} + \dfrac{w}{q_{\max} - q_{res}}} + q_{res} \qquad (2\text{-}10)$$

$$f = \frac{w}{\dfrac{1}{K_\tau} + \dfrac{w}{f_{\max} + f_{res}}} - f_{res} \qquad (2\text{-}11)$$

where

K_p	$= 467.1\ (N_{pt})^{0.0065}$,	(2-12)
q_{max}	$= 19.75\ (N_{pt})^{0.36}$,	(2-13)
q_{res}	$= 5.57\ LW$,	(2-14)
W	$= (K_\tau P/AE_p)^{0.5}$,	(2-15)
K_t	$= 5.01\ (N_{side})^{0.27}$,	(2-16)
f_{max}	$= 0.224\ (N_{side})^{0.29}$,	(2-17)
f_{res}	$= q_{res}(A_p/A_s) < f_{max}$	(2-18)

in which K_p and K_τ are in tons/ft^2/in.; q_{max}, q_{res}, f_{max} and f_{res} are in tons/ft^2; L, P, E_p, A are the pile length, perimeter, Young's modulus and cross sectional area; A_p and A_s are the pile point and pile shaft areas; N_{pt} is the uncorrected average SPT N value over a distance of four diameters either side of the pile point; and N_{side} is the uncorrected weighted average SPT N within the shaft length considered. It should be noted that the accuracy of the ultimate capacity prediction (using $Q_u = f_{max} \bullet A_s + q_{max} \bullet A_p$) is much greater than the accuracy of settlement prediction. This is due to the higher correlation of f_{max} and q_{max} with N compared to very poor correlation of K_p and K_τ with N. The Briaud-Tucker procedure is only valid for driven piles. Pile installed with a vibratory hammer or jetted may not develop the residual point pressure indicated by their prediction method. H-piles are also not included in the above correlations.

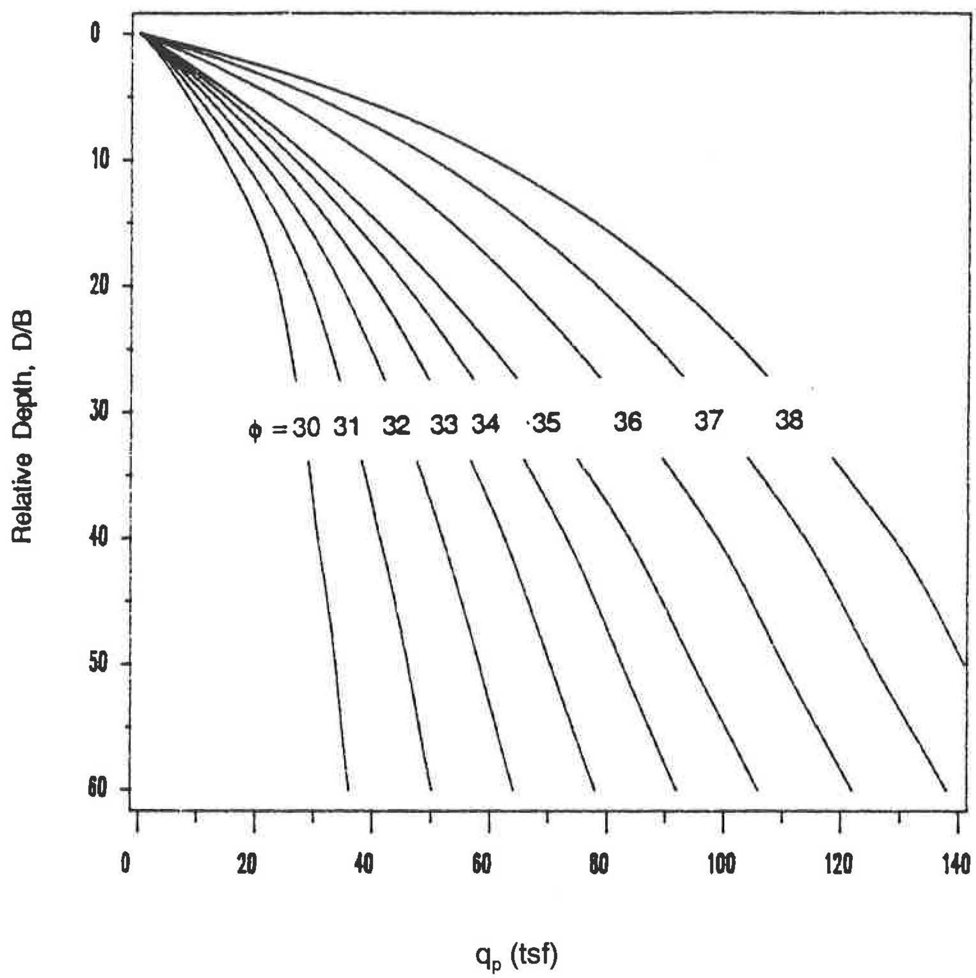

Figure 2-7. q_p for the Coyle-Castello method

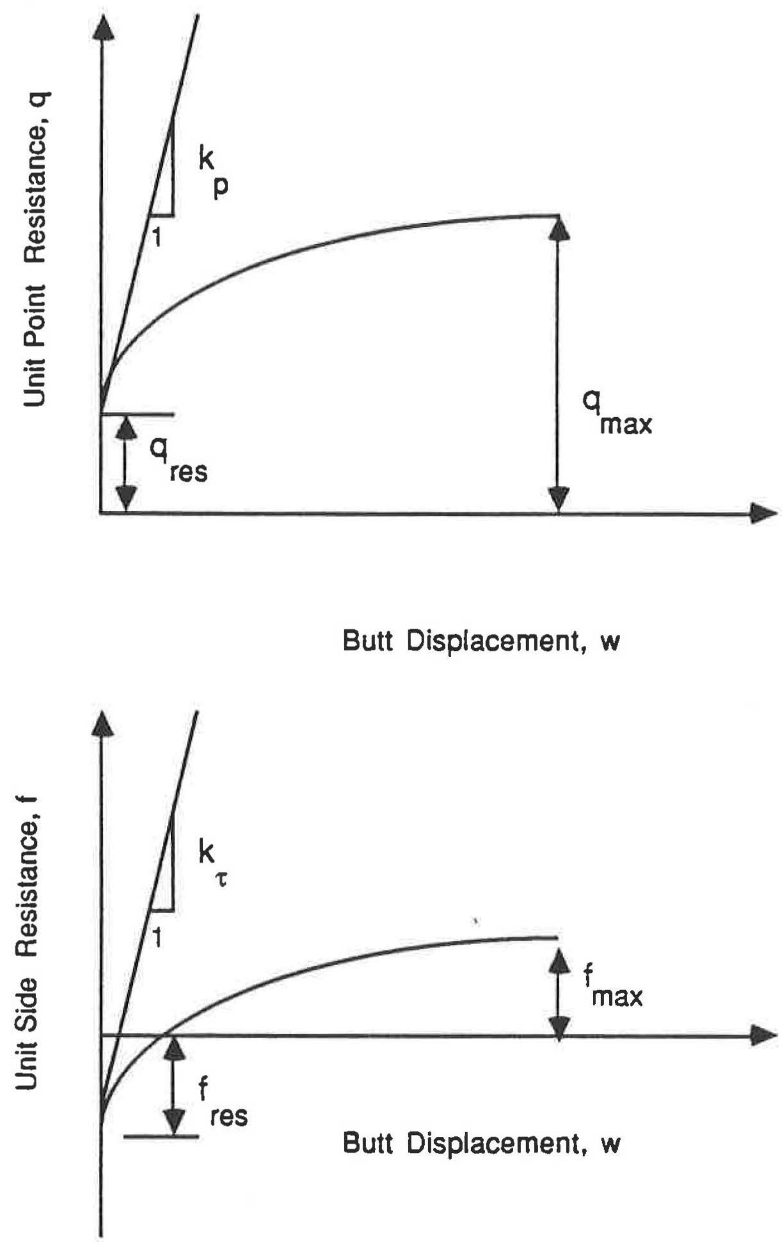

Figure 2-8. Example of hyperbolic load transfer curves

3. UNCERTAINTY MODELING AND PROCESSING

3.1 Uncertainty Modeling in Geotechnical Engineering

Geotechnical engineers almost always have to deal with uncertainty, whether it is formally acknowledged or not. While uncertainty may be overcome to some extent by the observational method, as demonstrated by Peck (1969), such a method is "applicable only if the design can be changed during the construction on the basis of the observed behavior" (Christian, et al., 1994). Uncertainty is often dealt with in geotechnical practice by using the concept of "calculated risk" (Casagrande, 1965). In this approach, the problem of dealing with uncertainty was considered internal to the engineer in the design process, in which the uncertainty about soil parameters was offset by selection of an acceptable risk (in terms of a factor of safety). With this notion, "there is no need to communicate judgment about geologic uncertainty to those who would gauge acceptable risk", since they were one and the same (Vick, 1992).

In today's society, it is unrealistic to believe that engineers can continue to exercise their former authority in determining "acceptable risk". For example, in siting a locally-unwanted-landuse (LULU) facility, the decisions regarding acceptable risk are now undertaken by clients, owners, regulatory bodies, interest groups, and the public at large, although engineers may be called upon to conduct a comprehensive siting study (Juang, et al., 1995a). As a result, uncertainties in the input parameters, which in the past were handled internally by judgment, must now be incorporated in the analysis and be scrutinized as well. This demands an effective tool to model and process the uncertainty. Use of the probability theory to handle uncertainty in geotechnical engineering began to emerge in the 1970s (Wu and Kraft, 1970; Wu, 1974; Grivas and Harr, 1975; Ang and Tang, 1975; Harr, 1977; Vanmarcke, 1977; Haldar and Tang, 1979). A comprehensive assessment of the progress made by the geotechnical profession was given by Whitman (1984). While much progress has been made since then, one objective set forth by Whitman (1984), namely, "to encourage the profession to seize all possible opportunities to employ available methodology as an aid to actual engineering decisions", still applies today. Even on the problem of slope stability, which has been the focus of many probabilistic studies, "formally probabilistic methods have had little impact on practice" (Christian, et al., 1994).

To accomplish Whitman's (1984) objective quoted above, the geotechnical profession must be open-minded towards different approaches for modeling uncertainty. To this end, the view expressed by Vick (1992) that geotechnical uncertainties "must only be described as fairly as possible from opinions, experience, and information at hand" is worth investigating, as this appears to be in the right direction to encourage consideration and incorporation of uncertainty in routine geotechnical analysis. Following this viewpoint, a methodology is presented in this report in which uncertainty is modeled by "fuzzy numbers."

There are basically two types of uncertainty (Casti, 1990): 1) ignorance, including measurement error, indecision about the mathematical form of the model, and confusion about the appropriate level of abstraction, and 2) variability, including stochasticity, spatial variation, and individual heterogeneity. Ignorance and variability are fundamentally different. Variability is an objective, random type of uncertainty (since it exists whether or not engineers observe it), and can be readily interpreted in terms of probability. On the other hand, ignorance is subjective (non-random type) and cannot be translated into probability in the same way. While treating these two types of uncertainty separately is more desirable in principle (Hoffman and Hammonds, 1994; Hattis and Burmaster, 1994), routine practice in environmental risk assessment often treats them in a single analysis with satisfactory results.

While probability theory has been the most formidable tool for handling uncertainty, requirements in treating both types of uncertainty in a rigorous way might not be practical for routine geotechnical analysis. Christian, et al. (1994) reported that the most effective applications of probabilistic methods are "those involving relative probabilities or illuminating the effects of uncertainties in the parameters. Attempts to determine the absolute probability of failure are much less successful." In this regard, the line of argument by Vick (1992) that uncertainties "must only be described as fairly as possible from opinions, experience, and information at hand," will be followed in this paper. To this end, uncertainty parameters may be expressed as an interval, involving an estimate of the lower and upper bounds. If there is some reason to believe, based on experience and information at hand, that not all values in the interval have the same degree of support, the uncertain parameter may be expressed as a fuzzy set.

A fuzzy set (Zadeh, 1965) is defined as a set of paired values, [x, m(x)], where x belongs to the set to a degree of m(x), ranging from 0 to 1. In other words, partial membership in a fuzzy set is allowed. For routine geotechnical uncertainty modeling, use of a subset of a fuzzy set, called a *fuzzy number*, suffices. A fuzzy number is a fuzzy set that achieves unity and is convex--the distribution is single humped and has at least one value at which the membership grade is 1. If there is no reason to suggest otherwise, the shape of the distribution may be taken as triangular for its simplicity in formulation and ease in computation (although other shapes may and have been used). In this case, a triangular fuzzy number is recommended.

A triangular fuzzy number is defined by three values: a minimum, a maximum, and a mode (the most-likely value). The mode has the highest degree of support (100%) to represent the uncertain parameter. As the value of the parameter departs from the mode, the degree of support (or the assessor's confidence) decreases, and when the value reaches the minimum (or the maximum), the degree of support reduces to zero. The triangular fuzzy number is different from an interval where the same degree of support (100%) is assumed at all points in the interval. An extension to the triangular fuzzy number is a trapezoidal fuzzy number where a range of values, rather than a single value (the mode), has a degree of support of 100%. In routine geotechnical practice, a statistically significant database is almost always unavailable (or too costly to obtain) and, thus, use of a fuzzy number to represent the best estimate as well as to reflect the uncertainty is deemed appropriate. The uncertainty incorporated in a fuzzy number is seen here as a result of "valuation", not randomness. These issues, and a deeper discussion of the philosophy of fuzzy sets and fuzzy logic, are given in Kosko (1993).

Both parameter uncertainty and model (method) uncertainty may be assessed and expressed in fuzzy numbers. Use of triangular fuzzy numbers to represent uncertainty events requires an estimate of only three values, the lower bound, the upper bound, and the mode. Obviously, uncertainty representation is only the first step; the issues of uncertainty processing and interpretation and the ease of use for routine practice remain to be addressed. However, modeling geotechnical uncertainty with fuzzy numbers exactly follows the line of argument by Vick (1992) noted earlier.

3.2 Propagatiȯn of Uncertainty in Determinstic Pile Capacity Models

Almost all routine geotechnical analyses such as pile capacity prediction are performed with deterministic models. If part or all of the input soil parameters take fuzzy numbers as their values, the output of the deterministic model will be a fuzzy number (or fuzzy numbers). In this case, uncertainty is propagated through the solution processes. Three approaches are available to evaluating the deterministic model with fuzzy input parameters. The first one is a direct implementation using Zadeh's (1975) extension principle, the principle that guides the extension of ordinary arithmetic operations into fuzzy arithmetic operations (Kaufmann and Gupta, 1985). The second approach is by means of the Monte Carlo sampling technique. While fuzzy numbers, representing the uncertainty in the input parameters, are established through valuation, they are nonetheless "quasi" distributions. As such, the Monte Carlo technique may be used to "sample" values for the input parameters that are expressed as fuzzy numbers (Juang, et al., 1991a, 1992a, 1993). The third approach is by means of interval analysis with the vertex method described below.

The vertex method, a technique developed at Stanford University (Dong and Wong, 1987; Dong et al., 1987), is based on the α-cut concept of fuzzy numbers and involves an interval analysis. The basic idea is to "discretize" a fuzzy number into a group of α-cut intervals (Figure 3-1). By replacing fuzzy numbers in the solution model with intervals, the fuzzy computation reduces to a series of interval analyses that use only conventional mathematics. While the Monte Carlo method *randomly* samples one value at a time from an input fuzzy parameter, the vertex method takes one interval at a time *deliberately* (at a selected α-level). Both methods are applicable to different shapes of fuzzy numbers, although the triangular shape is used in this study.

Existing methods of predicting pile capacity are all empirical or semi-empirical. Uncertainties exist in the prediction methods as well as in soil parameters. In this study, these uncertainties are represented with fuzzy numbers and processed by the vertex method.

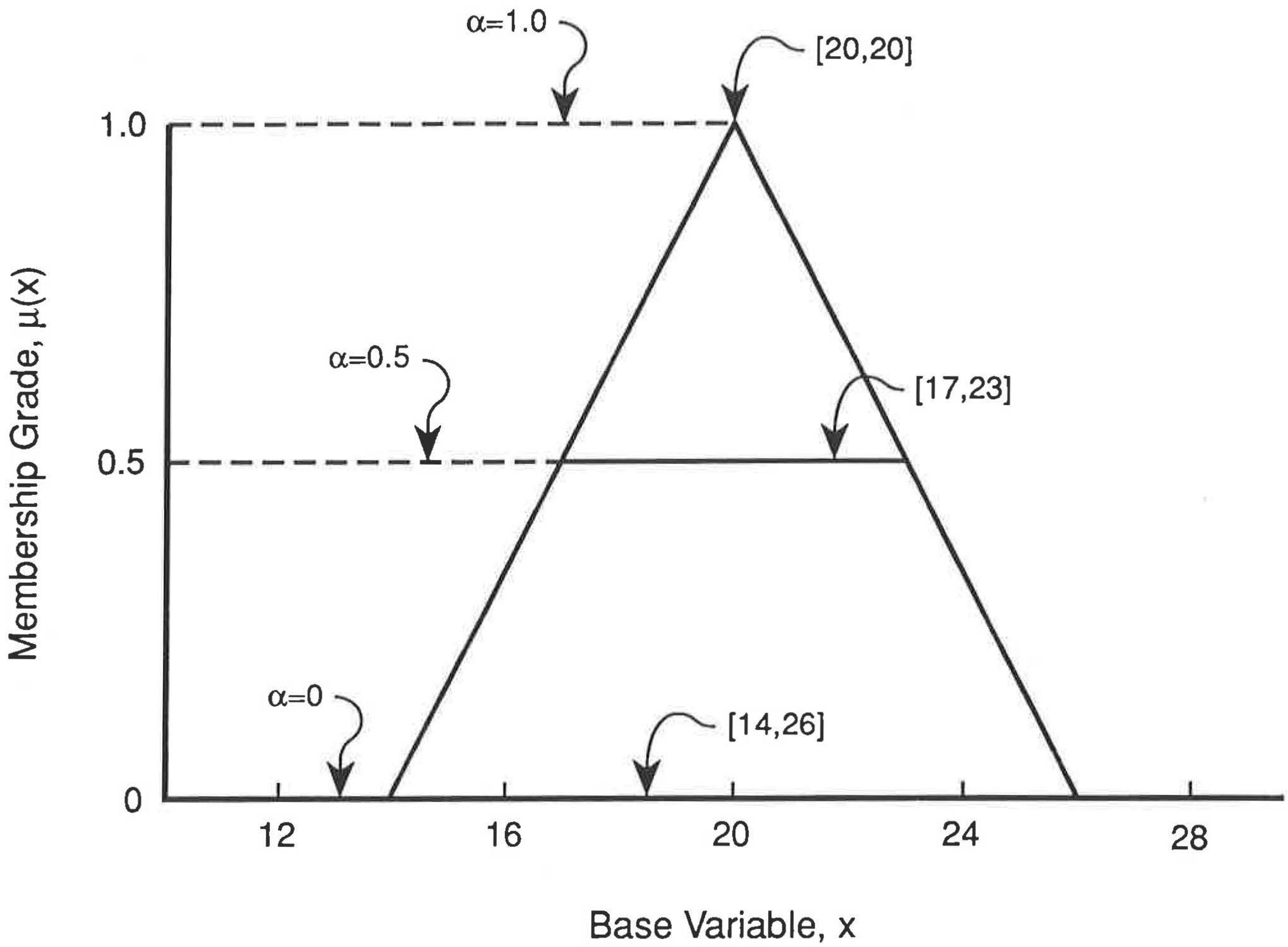

Figure 3-1. α-cut concept and α-cut intervals

4. METHODOLOGY AND COMPUTER CODE FOR PILE CAPACITY CONSIDERING UNCERTAINTY

4.1 Methodology

Uncertainty in soil properties as well as in the prediction models used are considered in this study. Uncertainty in soil parameters such as the SPT N value and undrained shear strength (c_u) is modeled with fuzzy numbers. These fuzzy numbers along with other non-fuzzy parameters are entered into the selected deterministic models for calculating Q_u. In this study, the vertex method is used to process fuzzy data in deterministic pile capacity models. Figure 4-1 illustrates this procedure. The uncertainty in the prediction models is implicitly dealt with by using a fuzzy weighted average technique to combine results from different models.

Figure 4-2 shows the organization of the methodology based on existing methods for pile capacity calculation. For piles in sands, three existing models-FHWA (Vanikar, 1985), Coyle and Castello (1981), and Briaud and Tucker (1984)-are used for pile capacity prediction. The results obtained from these three models are then combined based on the developed weighted average technique. For piles in clay, two existing models, the α method (API, 1981) and λ method (Vijayvergiya and Focht, 1972), are used and the results are combined.

For piles in mixed soils (clay-sand), the procedure is described in the following. For Q_p, use Equation 2-3 if the pile is clay or use Thurman's method (Equation 2-7) if the pile is in sand. For Q_s, four combined methods are used: 1) calculating Q_s of sand layers by Coyle and Castello's method and Q_s of clay layers by the α method, 2) calculating Q_s of sand layers by the Briaud and Tucker method and Q_s of clay layers by the α method, 3) calculating ${}_sQ$ of sand layers by Coyle and Castello's method and Q_s of clay layers by the λ method, and 4) calculating Q_s of sand layers by the Briaud and Tucker method and Q_s of clay layers by the λ method. In each of these methods, Q_u is taken as the sum of Q_p and Q_s. The results obtained from these four methods are then aggregated by using the fuzzy weighted average technique.

The fuzzy weighted average (FWA) is defined as follows:

$$\frac{\sum_{i=1}^{4} Q_{u,i} W_i}{\sum_{i=1}^{4} W_i} \qquad (4\text{-}1)$$

where Q_u is the fuzzy weighted average, $Q_{u,i}$ is the ultimate pile capacity obtained with method i, and W_i is the weight assigned to the method i. Note that since both $Q_{u,i}$ and W_i are fuzzy numbers, the resulting fuzzy weighted average Q_u will be a fuzzy number.

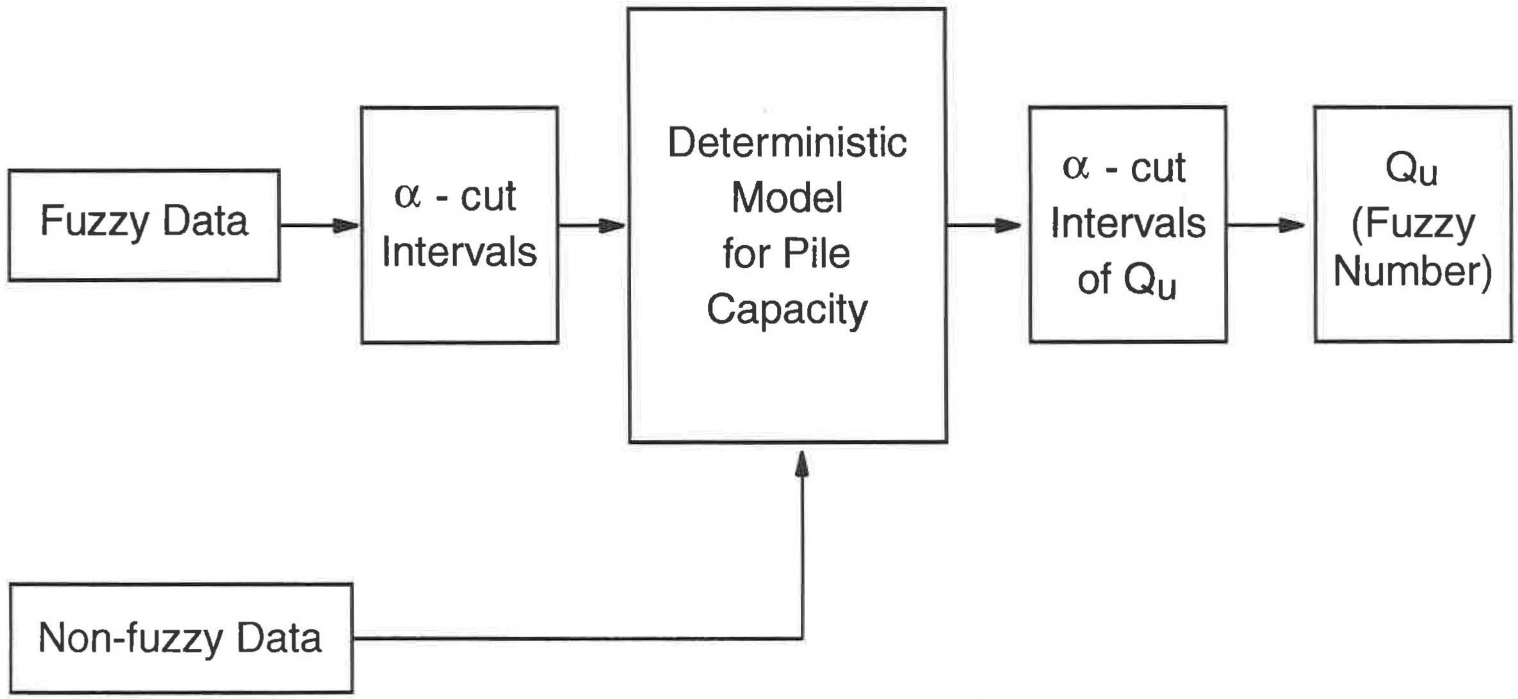

Figure 4-1. Vertex Method for Processing Fuzzy Information in a Deterministic Model

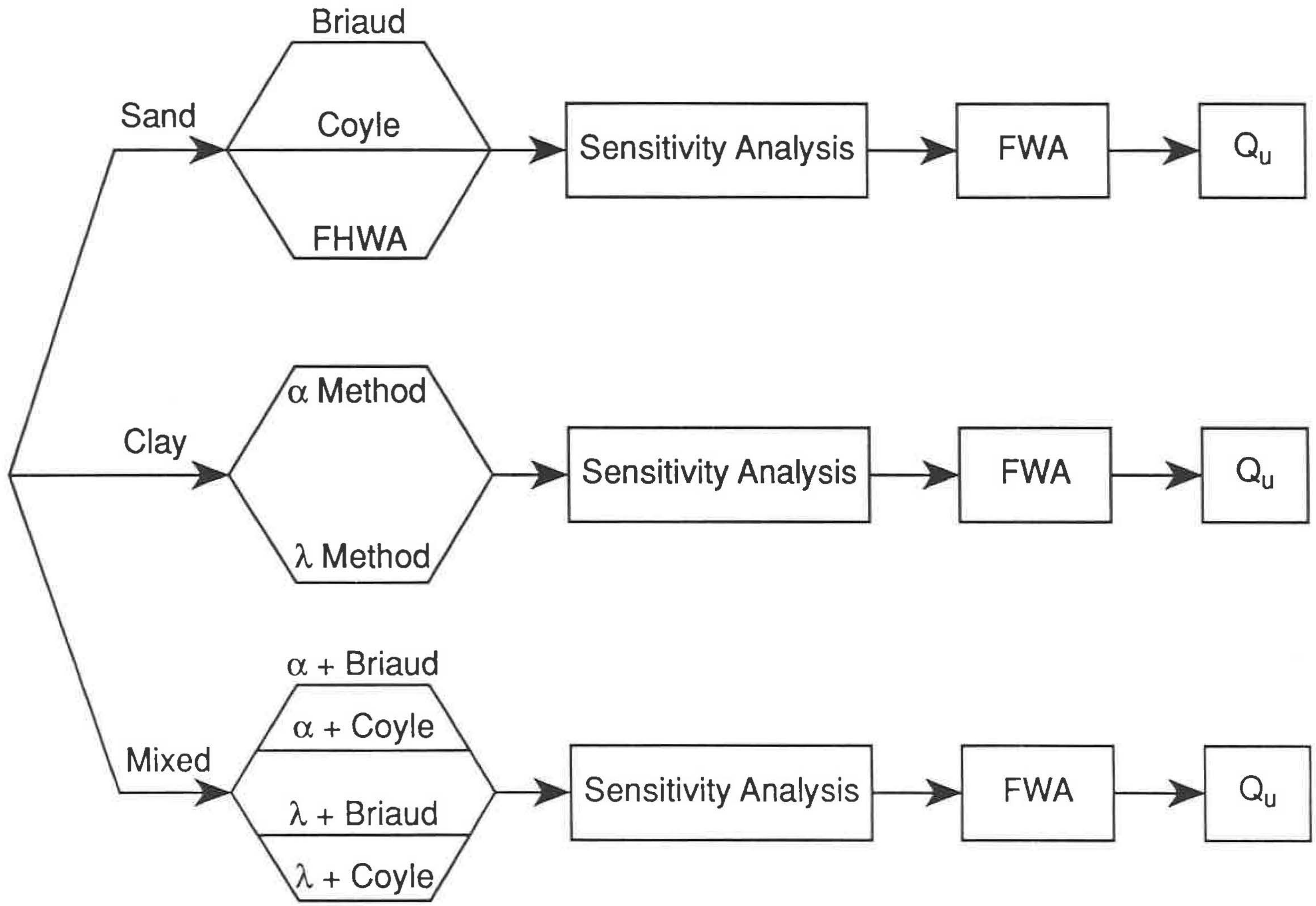

Figure 4-2. Organization of the FPILE Methodology

4.2 Determination of Weights

The weight term, W_i, in Equation 4-1 may be determined based on results of sensitivity analyses. The procedure is described in the following. Sensitivity is defined here as the percentage change in the resulting Q_u caused by a one percent change in the uncertain input parameter, such as SPT N value or undrained cohesion c_u. For piles embedded in a *n*-layer soil system (Figure 4-3), Q_u has *n+1* components, including one Q_p (pile tip resistance) and *n* Q_s's (side frictions). The sensitivity of each component may be calculated as follows:

$$S_j = \frac{Q_{u,j} - Q_u}{Q_u} \tag{4-2}$$

where S_j is the sensitivity of the j^{th} component of Q_u, and $Q_{u,j}$ is the ultimate pile capacity calculated with one percent change in the input SPT N value (or undrained cohesion c_u) in the j^{th} layer or at the pile tip.

The overall sensitivity of Q_u due to the change in the input soil parameter is determined with the concept of a weighted average. Here, the weight depends on the contribution of each component ($Q_{u,j}$) to the ultimate pile capacity Q_u. Thus, the overall sensitivity S_i in the determination of Q_u based on the method *I* may be calculated as follows:

$$S = \frac{\sum_{j=1}^{n} S_j Q_j}{\sum_{j=1}^{n} Q_j} \tag{4-3}$$

where Q_j is the j^{th} component of Q_u (where j= 1, n+1). Once the overall sensitivity for each method is obtained, the weight W_i may be determined as follows:

$$W_i = \frac{\left(\frac{1}{S_i}\right)^p}{\sum_i \left(\frac{1}{S_i}\right)^p} \tag{4-4}$$

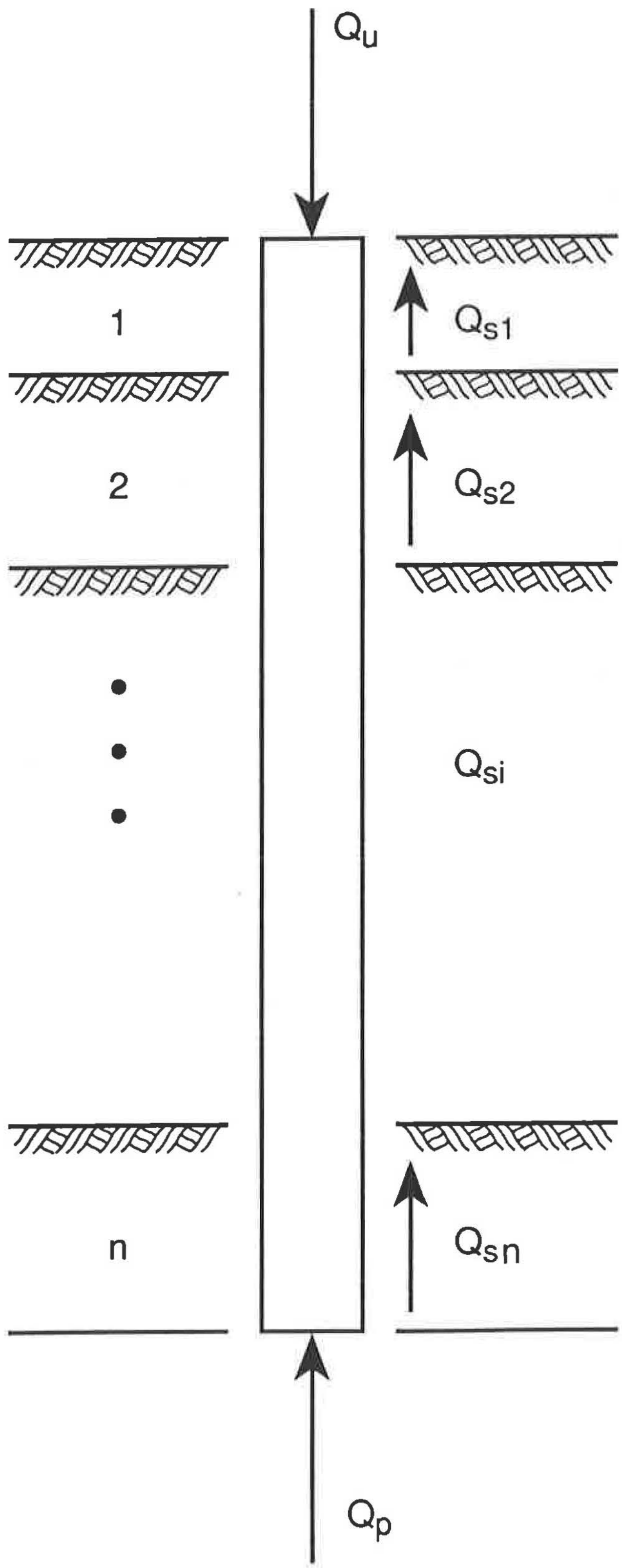

Figure 4-3. Pile-soil layer system

The rationale of this weighting model is that the method that is more sensitive to the minor change in input data should be given less weight in the weighted average operation. The inclusion of a correction factor p in Equation 4-4 is to account for the possible discrepancy in the determination of sensitivity and in the assumed correlation between sensitivity and weight. The determined weights may then be used in Equation 4-1 to calculate the fuzzy weighted average of the ultimate pile capacity obtained by different methods. The value of the factor p may be back-calculated based on pile load test results. A p value of 0.5 yielded satisfactory predictions in a previous study (Chang, 1994) and is used in the present study.

4.3 Development of FPILE

A computer program called FPILE has been developed to implement the methodology presented above. The program was initially developed by Wey (1987) for piles in sand, as reported in Juang, et al (1991a), and was subsequently revised to adopt the vertex method for processing fuzzy data by Chang (1994). Chang (1994) produced three separate programs for predicting capacity of piles in sand, clay, and mixed soil. These programs have been combined with substantial modifications into FPILE, a stand-alone FORTRAN program. Extensive testing of FPILE has been performed and the reliability of the program has been verified.

The structure of the program FPILE basically follows the one shown in Figure 4-2. The soil is classified into one of three types: clay, sand, and mixed soil. Depending on the soil type, the program executes one of the three corresponding subprograms, CLAY, SAND, and MIXED. The program can handle both fuzzy and non-fuzzy input data. Fuzzy data is assumed to take the form of a triangular fuzzy number. To use fuzzy data option, the user is required to enter one extra piece of data, the estimated percent variation in the SPT N value or c_u. If fuzzy data are present, the program will use the vertex method to process these data. In each route, more than one method is used for determining Q_u. Sensitivity analysis is performed within the program execution and the weights for the adopted methods are determined according to the methodology and formulation presented above. The fuzzy weighted average operation is then performed, which yields the final Q_u. Table 4-1 lists all the subroutines that are implemented in FPILE.

Table 4-1 Map of Subroutines in FPILE.FOR

Subroutine	Function/Purpose	Calling	Called by
MAIN	Main program	CLAY, MIXED, SAND	n/a
ACUT	To find α-cut values	n/a	CLAY, MIXED, SAND
AEOP	To determine average effective stress	n/a	CLAY, QST, SAND, WPCFS1, WPCFS2
ALPHA	Alpha method	n/a	CLAYQS, QT
CHENEY	To determine f from N	n/a	FINDPHI
CLAY	To determine Qu for piles in clay	AEOP, ACUT, WPC1, WPCFS1	MAIN
CLAYQP	To determine Qp - clay	n/a	QST
CLAYQS	To determine Qs - clay	ALPHA, LAMBDA	QST
CORRECTN	To correct N value for overburden pressure	n/a	COYLE, FHWA, QST
COYLE	Coyle method	CORRECTN, CQP, CQS, FINDPHI	SAND, WPCFS2
COYLEQP	Coyle method - Qp	n/a	COYLE, QST
COYLEQS	Coyle method - Qs	n/a	COYLE, QST
FHWA	FHWA method for determining Qu for piles in sand	CORRECTN, FINDPHI, THURMAN, NORDLUND	SAND, WPCFS2
FINDPHI	To determine f from N	CHENNEY, PECK	COYLE, FHWA, QST
FWA	Fuzzy weighted average	QST, WPC3	MIXED

(Continued)

Table 4-1 Map of Subroutines in FPILE.FOR (Continued)

Subroutine	Function/Purpose	Calling	Called by
LAMBDA	Lambda method	n/a	CLAYQS, QT
MIXED	To determine Qu for pile in clay-sand system	ACUT, FWA, QST, WPC3	MAIN
NORDLUND	Nordlund method - Qs	n/a	FHWA, SANDQS
PECK	To obtain f from N	n/a	FINDPHI
QST	To determine Qu for piles in clay-sand layered system	AEOP, CLAYQP, CLAYQS, CORRECTN, COYLEQP, COYLEQS, FINDPHI, SANDQP, SANDQS	FWA, MIXED
QT	To determine Qu in clay	ALPHA, LAMBDA	CLAY, WPCFS1
SAND	To determine Qu for piles in sand	AEOP, ACUT, COYLE, FHWA, TUCKER, WPC2, WPCFS2	MAIN
SANDQP	To obtain Qp in sand	THURMAN	QST
SANDQS	To obtain Qs in sand	NORDLUND	QST
BTS	Sensitivity analysis of Briaud-Tucker method	n/a	TUCKER
THURMAN	Thurman's method - Qp	n/a	FHWA, SANDQP
BRIAUD	Briaud-Tucker method	BT	SAND, WPCFS2
WPC1	Aggregating Qu - clay	n/a	CLAY, WPCFS1
WPC2	Aggregating Qu - sand	n/a	SAND, WPCFS2
WPC3	Aggregating Qu - mixed	n/a	FWA, MIXED
WPCFS1	Aggregating Qu - clay	AEOP, QT, WPC1	CLAY
WPCFS2	Aggregating Qu - sand	AEOP, COYLE, FHWA, WPC2, TUCKER	SAND

The resulting Q_u, a fuzzy number, is presented as α-cut intervals at three levels of support, α= 0, 0.5, and 1.0. At α= 1.0, the interval shrinks to a point which represents the most likely value of Q_u based on input data. At α= 0.5, the interval represents a probable range of Q_u. At α= 0, the interval represents the absolute lower and upper bounds based on the input data. A range of Q_u between the lower end of the interval at α= 0.5 to the most likely value at α= 1.0 is recommended for design use.

4.4 Use of FPILE

FPILE may be run from DOS prompt. The data required may be entered one-by-one at run time through the keyboard or all at once using an input file. The input instructions are shown in Table 4-2. An example input file is shown in Figure 4-4, while an input screen with which the data can be entered one-by-one at run time is shown in Figure 4-5. The output of FPILE is stored in an output file. Figure 4-6 is an example output file.

Table 4-2 Input Instruction for FPILE.EXE

Line No.	Variables	Format/Column	Remarks
1	FREE	A72 (Cols. 1-72)	Up to 72 columns of text can be entered in this line. It is recommended that a desired filename of the input data be entered here for bookkeeping purpose.
2	TITLE	A72 (Cols. 1-72)	Title of the project, operator, date, etc. (up to 72 columns of text) can be entered.
3	NL,	I5 (Col. 5)	NL= No. of soil layers surrounding the pile (maximum = 10).
	DEPTH,	F10.1 (Cols. 6-15)	Depth from original ground surface to top of the pile (ft); this is needed only if the pile top is to be positioned at this depth and the soil above this depth is to be excavated.
	STRESS	F10.1 (Cols. 16-25)	Effective overburden pressure (stress) from ground surface to top of the pile (lb/ft^2).
4			This data card (line) must be repeated NL times. Each line specifies the data for one soil layer:
	K(I),	I5 (Col. 5)	Col. 5: enter layer number (if there are 10 layers, the layer number of the last layer occupies columns 4 and 5).
	H(I),	F10.1 (Cols. 6-15)	Cols. 6-15: enter thickness of this layer (ft).
	W(I),	F10.1 (Cols. 16-25)	Cols. 16-25: enter effective unit weight of the layer (lb/ft^3).
	ST(I), SP(I),	2I5 (Cols. 30 & 35)	Col. 30: enter soil type of this layer (1--clay, 2--sand). Col. 35: if ST=1, skip this data; if ST=2, enter 1, 2, 3, or 4 (1--fine sand; 2--medium sand; 3--coarse sand; 4--don't know).
	CU(I) or N(I),	F10.1 (Cols. 36-45)	Cols. 36-45: if ST=1, enter undrained shear strength c_u (lb/ft^2); if ST=2, enter uncorrected SPT N value.
	COV(I)	F10.1 (Cols. 46-55)	Cols. 46-55: enter an estimated percent of error (or variation) of the value of c_u or N; enter -1 if the default value is to be used. (Default value: 40 if ST=1; 26 if ST=2).

Table 4-2 Input Instruction for FPILE.EXE (Continued)

Line No.	Variables	Format/Column	Remarks
5		25X,	This line specifies soil data at pile tip. The data format is the same as line 4 except that the first 25 columns of this line is skipped.
	ST(NL+1), SP(NL+1), CU(NL+1) or N(NL+1), COV(NL+1)	I5 (Col. 30) I5 (Col. 35) F10.1 (Cols. 36-45) F10.1 (Cols. 46-55)	Col. 30: enter the soil type of this layer (1--clay, 2--sand). Col. 35: if ST=1, skip this data; if ST=2, enter 1, 2, or 3 (1--fine sand; 2--medium sand; 3--coarse sand). Cols. 36-45: if ST=1, enter undrained shear strength c_u (lb/ft^2); if ST=2, enter uncorrected SPT N value. Cols. 46-55: enter an estimated percent of error (variation) of the value of c_u or N; enter -1 if the default value is to be used (default values: 40 if ST=1; 26 if ST=2).
6			This line specifies pile data:
	INDEX1, INDEX2, PL,PA,PD,PP	I5 (Col. 5) I5 (Col. 10) 3F10.2 (Cols. 21-60)	Col. 5: enter pile material; 1--steel, 2--concrete. Col. 10: enter 1 for large displacement pile, enter 2 for small displacement pile. Cols. 21-30, 31-40, 41-50, 51-60: enter pile length (ft), pile cross-sectional area (ft^2), diameter or width (ft), and pile perimeter (ft).

```
Data Filename = GRL106.IN
pa steel H pile in clay, GRL-106, PA, OUTPUT= GRL106.OUT
    3        .0        .0
    1      20.0      50.0    1    0    1000.0        -1.0
    2       5.0      52.5    1    0    1250.0        -1.0
    3      45.0      55.0    1    0    1750.0        -1.0
                             1    0    1500.0        -1.0
    1    2      70.00      1.00      1.00      4.00
```

Figure 4-4. Sample input file for FPILE

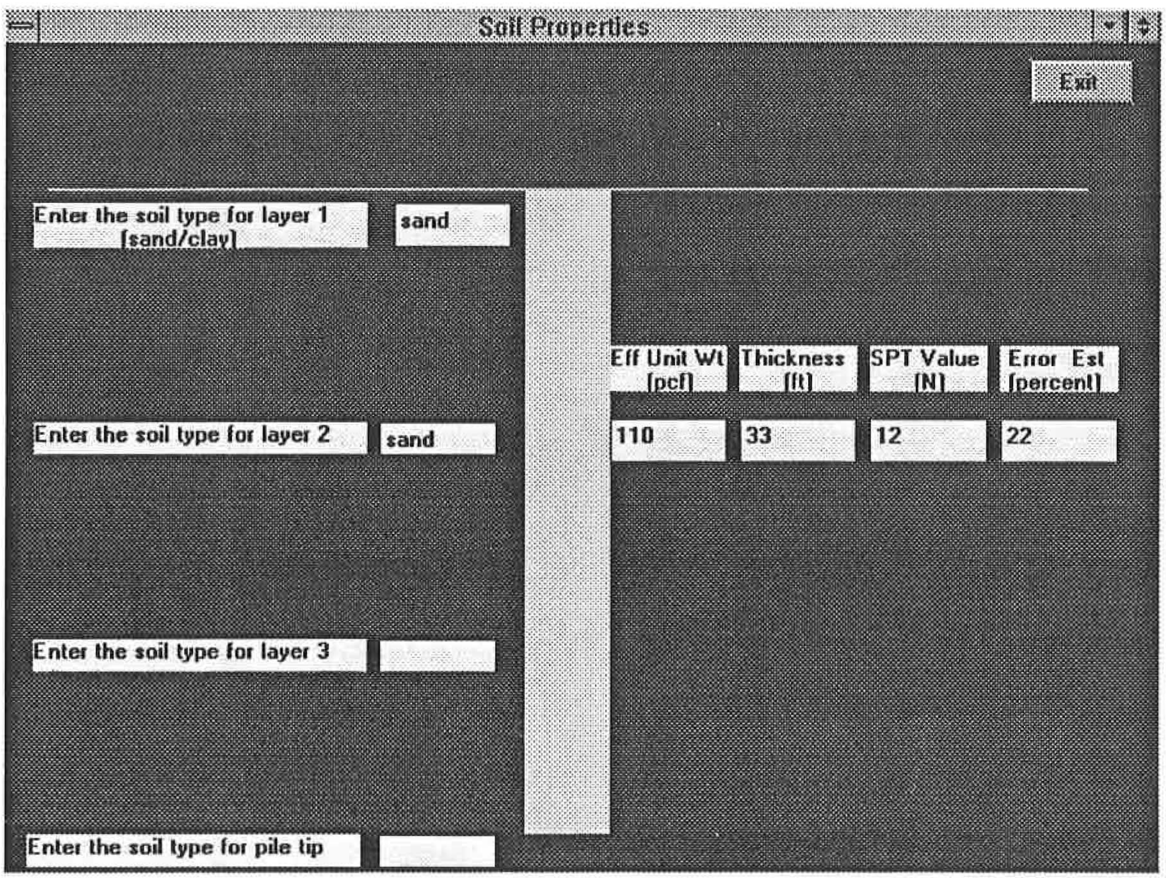

Figure 4-5. Sample screen input for FPILE

```
**** FPILE - Pile Capacity By Fuzzy Set Analysis *****


pa steel H pile in clay, GRL-106, PA, OUTPUT= GRL106.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) =  3

Layer      Thickness   Effective     Soil Type   Cohesion or N value  Variation
             (ft)     unit wt.(pcf)                (psf)                  (%)
   1          20.0        50.0          1        1000.         0.        -1.0
   2           5.0        52.5          1        1250.         0.        -1.0
   3          45.0        55.0          1        1750.         0.        -1.0
 NEAR PILE TIP                          1        1500.         0.        -1.0

NOTE--->  SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value
            of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 70.00 (ft)

PILE TIP AREA (PA) =  1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) =  1.00 (ft)

PILE PERIMETER (PP) =  4.00 (ft)


*********** RESULTS OF ANALYSIS ***********

 SUPPORT LEVEL     Qu (min)      Qu (max)
 ------------------------------------------
 ALPHA = 1.0         121           121
 ALPHA = 0.5         106           138
 ALPHA = 0.0          94           155
 ------------------------------------------
```

Figure 4-6. Sample output file from FPILE

5. THE PERFORMANCE OF FPILE

5.1 Pile Load Test Database

The Federal Highway Administration provided a searchable pile load test database to assist in the development of FPILE. The database contained information on pile load tests, including pile properties, site conditions, soil properties, and installation conditions. The database also included load test information. The extracted load-deformation data for each pile were examined to determine the load at failure, using pile load test criteria that could be applied successfully to the load-deformation data. A total of 17 sets of pile load test data were extracted and used to "validate" the developed program FPILE. These data sets are listed in Appendix 1.

5.2 Predicting Performance of FPILE

A summary of the predicted capacity versus the measured capacity for various piles in different types of soils is given in Table 5-1. The pile information and soil parameters were entered into FPILE to obtain the predicted pile capacity. The measured pile capacity refers to the interpreted pile capacity based on the load-settlement curve obtained from pile load tests. The pile capacity was interpreted based mainly on the criterion of 0.05 in./ton settlement rate and/or the criterion of 0.1D settlement; Davisson's criterion, which usually yields a more conservative result, was used primarily as a reference. The pile capacity was calculated with the default variation in SPT N and/or c_u. The predictions are shown in terms of most probable value, probable range, and extreme range.

Figure 5-1 shows the measured pile capacity versus the predictions made with FPILE. As seen in this figure, the most probable values predicted by FPILE generally fall within 20% of the measured pile capacity. Because of the uncertainty in strength parameters of the soil (SPT N or c_u), the pile capacity may be above or below the most probable value. Figures 5-2 and 5-3 show the measured capacity versus predicted capacity using the probable range and the extreme range, respectively. These figures show that the predicted pile capacity may or may not fall within 20% of the measured capacity, if the variation in strength parameters is significant. For conservative design, if the uncertainty in strength parameters is high, the lower of the probable range (or even the lower

Table 5-1 Comparison of Measured and Computed Vertical Capacity of Piles

Pile Design-ation	Pile Type	Pile Length (ft)	Soil Type	Measured Capacity (tons)	Calculated Vertical Capacity: Most Probable Value (tons)	Calculated Vertical Capacity: Probable Range (tons)	Calculated Vertical Capacity: Extreme Range (tons)
GRL106	steel H	70	clay	148	121	106-138	94-155
GRL123A	conc sq.	90	mixed	405	447	386-498	321-548
GRL123B	conc sq.	80	mixed	272	257	221-287	183-316
MN	steel H	100	mixed	382	335	291-375	242-410
LT1	conc sq.	57	sand	882	770	744-803	677-832
OR	conc sq.	135	sand	814	908	892-1028	846-1073
PASH2	steel H	35	mixed	172	128	116-140	103-147
PASH3	steel H	70	mixed	312	242	232-254	206-259
PASH5	steel H	50	mixed	206	168	151-185	130-196
PASH6	steel H	33	mixed	160	148	136-163	115-176
P13	conc sq.	33	sand	145	157	147-167	139-176
P18	conc sq.	49	sand	167	202	189-215	179-228

Note 1: Measured capacity refers to the vertical pile capacity obtained from pile load tests using 0.05in./ton criterion and/or 0.1D criterion.

Note 2: The probable range and the extreme range of the calculated pile capacity were obtained using default values for parameter uncertainty (for clay, c_u is the best estimate ±40%; for sand, N is the best estimate ±26%).

Table 5-1 Comparison of Measured and Computed Vertical Capacity of Piles (Cont.)

					Calculated	Vertical	Capacity
Pile Design-ation	Pile Type	Pile Length (ft)	Soil Type	Measured Capacity (tons)	Most Probable Value (tons)	Probable Range (tons)	Extreme Range (tons)
P23	conc sq.	55	sand	155	172	164-182	156-193
P34	conc sq.	52	sand	189	162	151-172	140-181
P35	conc sq.	49	sand	188	222	208-232	192-246
P43	conc sq.	60	sand	215	197	189-226	174-239
P44	conc sq.	28	sand	87	97	84-104	77-110

Note 1: Measured capacity refers to the vertical pile capacity obtained from pile load tests using 0.05 in./ton criterion and/or 0.1D criterion.

Note 2: The probable range and the extreme range of the calculated pile capacity were obtained using default values for parameter uncertainty (for clay, c_u is the best estimate ±40%; for sand, N is the best estimate ±26%).

end of the extreme range) may be taken as the ultimate pile capacity. The cost and benefit of taking the most probable value as opposed to these lower-end values should be compared. In general, the higher end of the probable range and the extreme range should not be used.

The performance of FPILE as a tool for predicting vertical pile capacity, as revealed in Figures 5-1 through 5-3, is satisfactory. The capability of FPILE to consider the uncertainty in soil strength parameters enables an assessment of the variation in the predicted pile capacity. Thus, a better design decision may be made using FPILE as a tool.

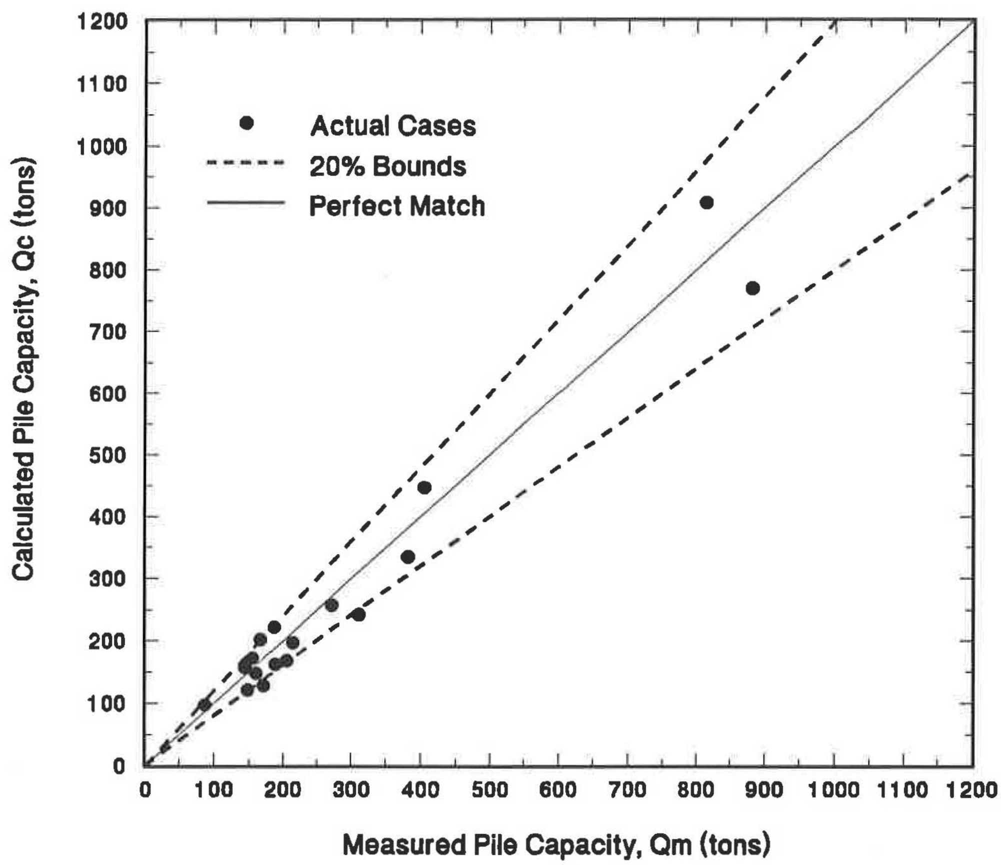

Figure 5-1. Measured Pile Capacity Versus Calculated Pile Capacity
(Qc based on Most Probable Value)

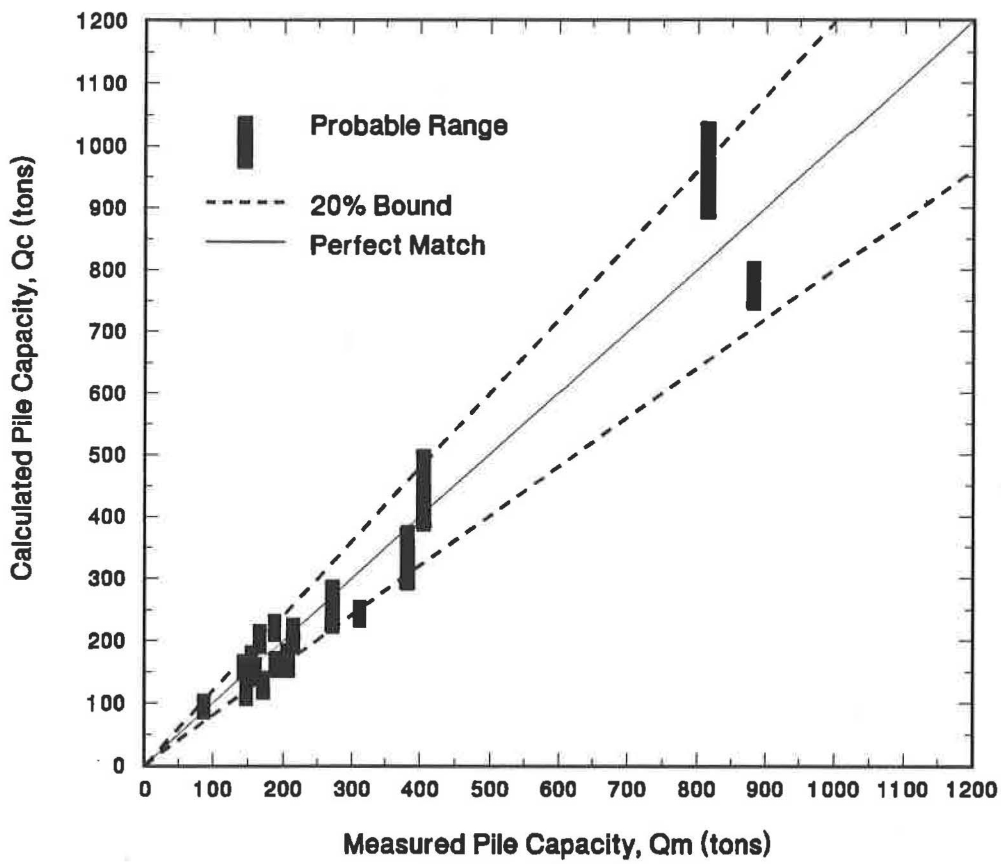

Figure 5-2. Measured Pile Capacity Versus Calculated Pile Capacity
(Qc based on Most Probable Range)

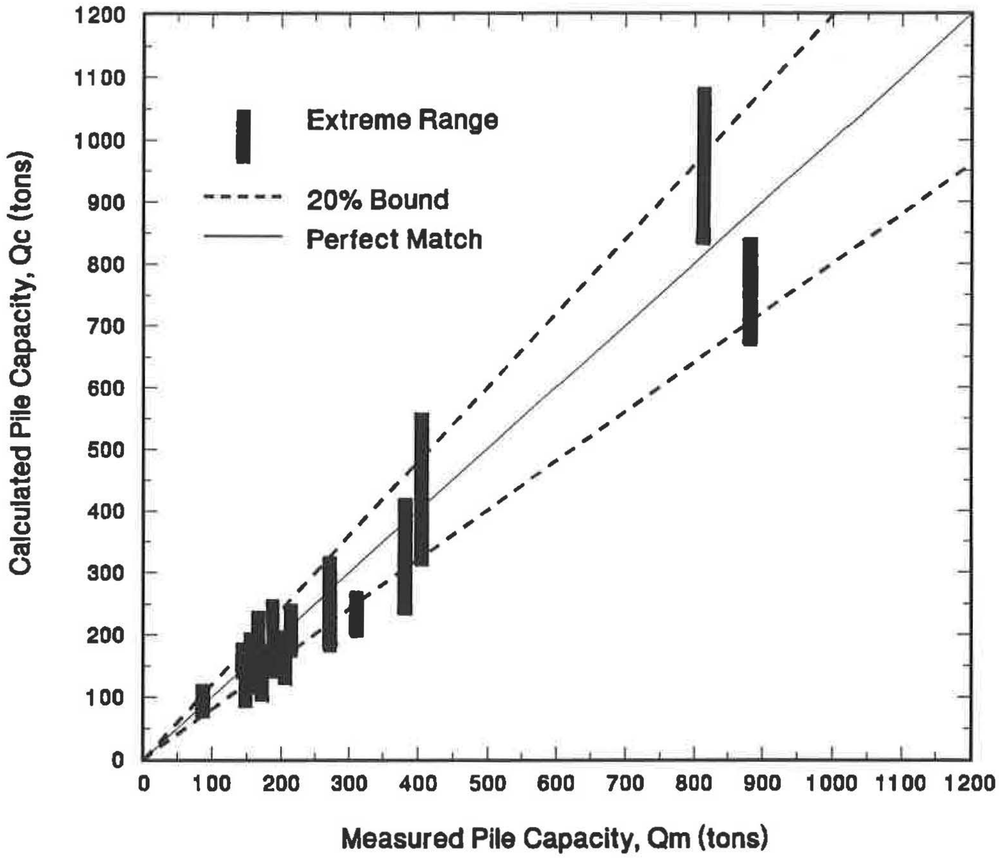

Figure 5-3. Measured Pile Capacity Versus Calculated Pile Capacity
(Qc based on Extreme Range)

5.3 Effects of Parameter Uncertainty on Predicted Pile Capacity

To further investigate the effects of strength parameter uncertainty on the calculated pile capacity, three piles were analyzed with different degrees of variation in the input data. Table 5-2 shows the measured pile capacity along with the calculated pile capacity under different assumptions of the degree of uncertainty. The results are plotted in Figures 5-4, 5-5, and 5-6 for a steel H pile in clay, a concrete pile in sand, and a H pile in clay-sand, respectively. These results confirm that as the parameter uncertainty increases, the range of possible Q_u values widens. Thus, it is very important for the engineer to assess the soil parameter uncertainty and incorporate this information in the design process.

Table 5-2 Effects of Parameter Uncertainty on Calculated Pile Capacity

Pile Designation	Variation in N and/or c_u (%)	Measured Capacity (tons)	Calculated Vertical Capacity		
			Most Probable Value (tons)	Probable Range (tons)	Extreme Range (tons)
MN	0	382	335	N/A	N/A
MN-A	10	382	335	323-347	311-358
MN-B	30	382	335	301-365	265-394
MN-C	50	382	335	278-384	220-428
P44	0	87	97	N/A	N/A
P44-A	10	87	97	95-100	93-103
P44-B	30	87	97	83-105	75-111
P44-C	50	87	97	78-109	65-116
GRL106	0	148	121	N/A	N/A
GRL106-A	10	148	121	117-126	112-130
GRL106-B	30	148	121	108-134	104-142
GRL106-C	50	148	121	104-142	86-163

Note 1: Measured capacity refers to the vertical pile capacity obtained from pile load tests using 0.05 in./ton criterion and/or 0.1D criterion.

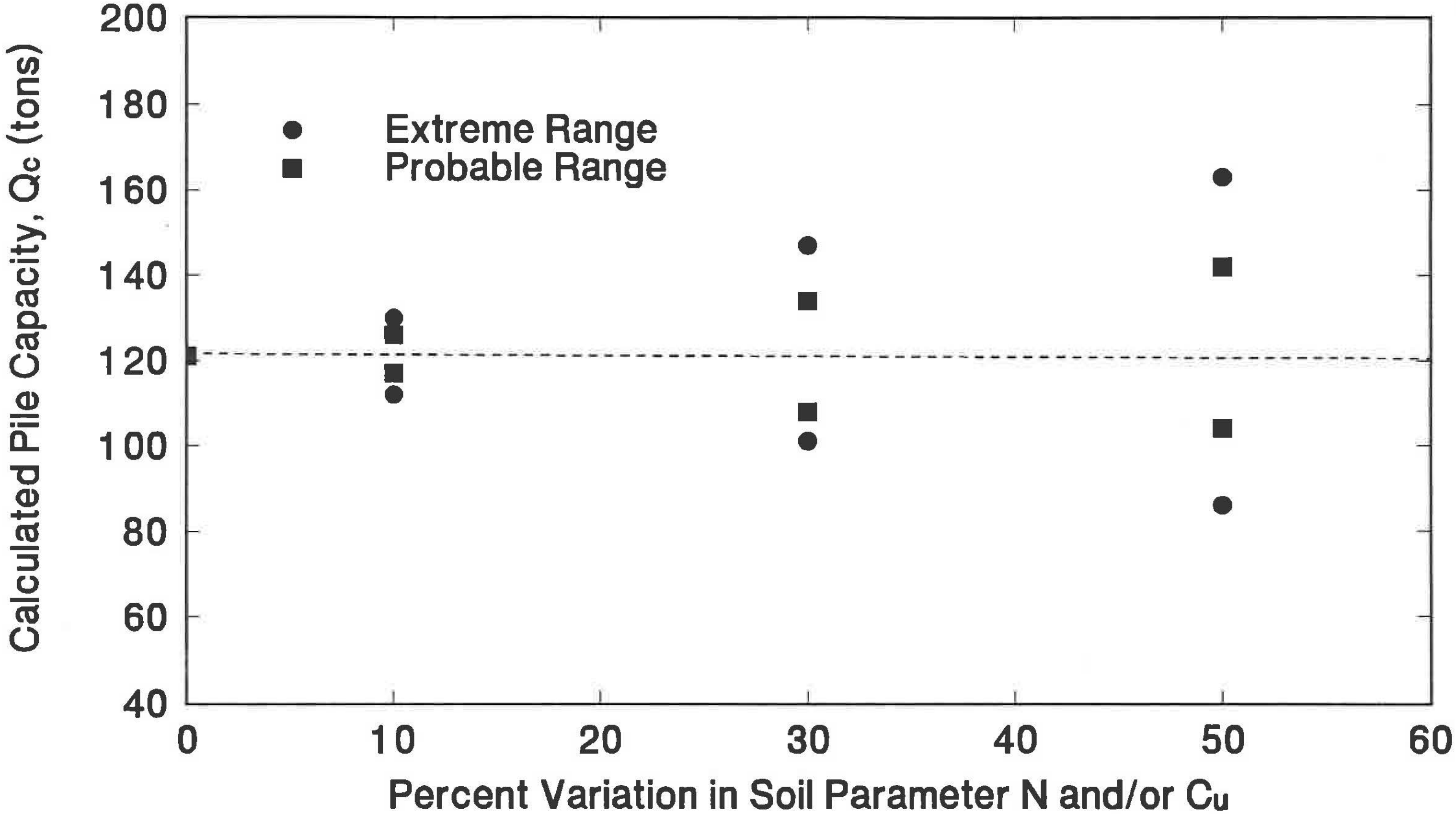

Figure 5-4. Effect of Parameter Uncertainty on Calculated Pile Capacity
Steel H Pile in Clay, GRL-106, File = GRL 106.IN

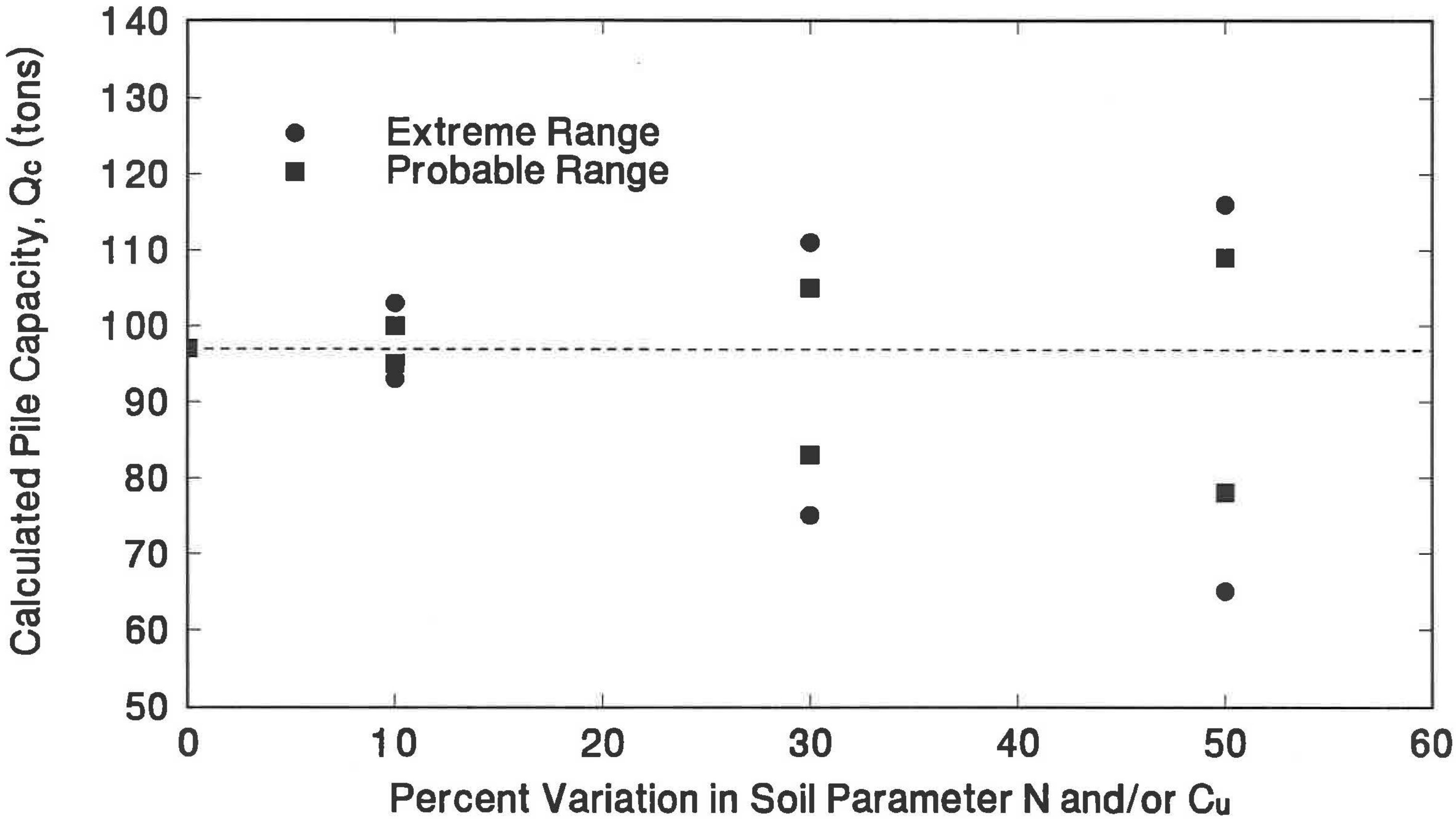

Figure 5-5. Effect of Parameter Uncertainty on Calculated Pile Capacity
Square Concrete Pile in Sand, File = P44.IN

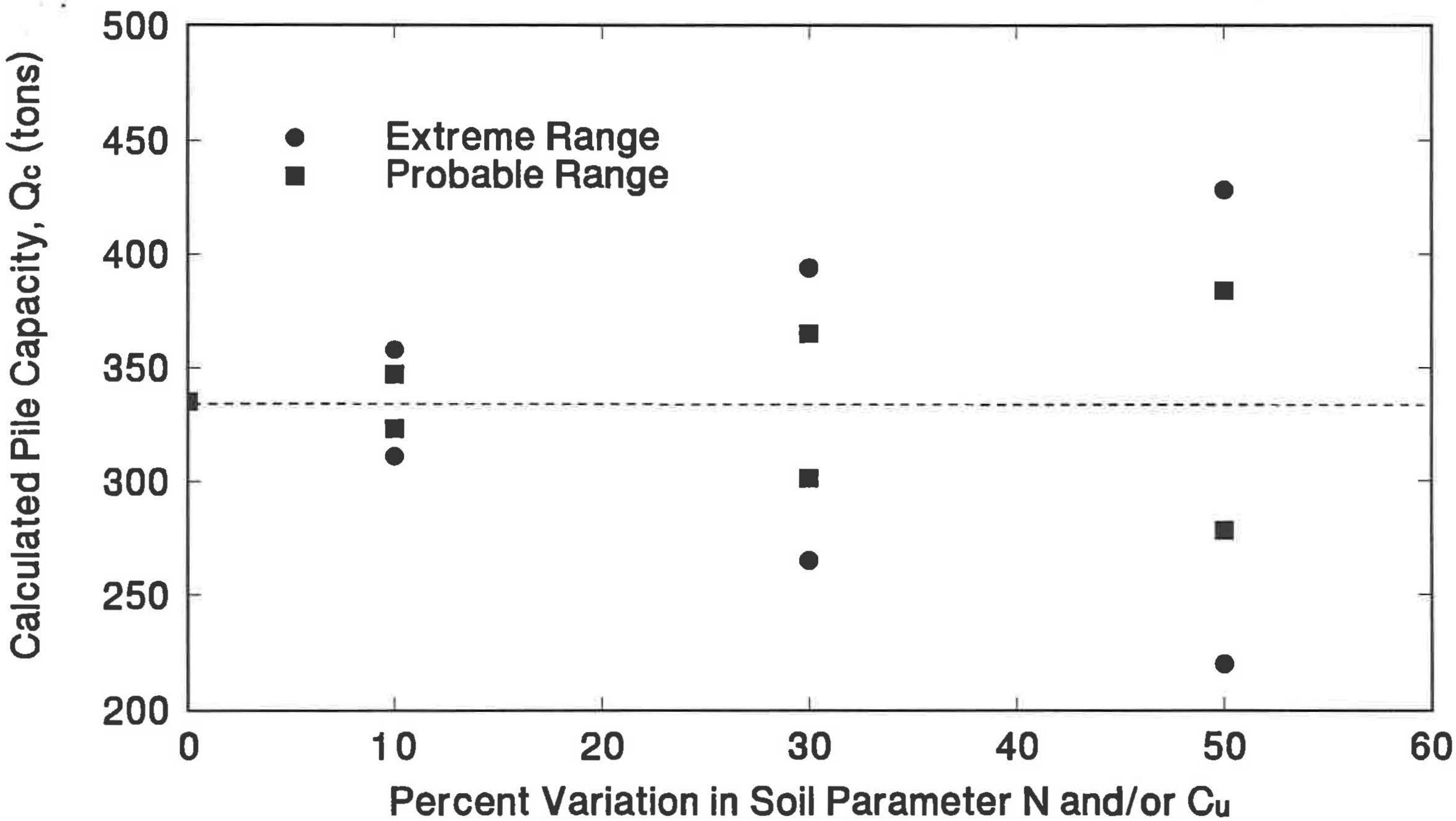

Figure 5-6. Effect of Parameter Uncertainty on Calculated Pile Capacity
Steel H Pile in Clay-Sand, GRL-113, File = MN.IN

6. CONCLUSIONS

This study presented a new method of incorporating the effects of soil parameter uncertainty into pile capacity prediction. The method uses fuzzy sets to characterize the uncertainty in the soil parameters SPT N and c_u. The vertex method is then used to process the fuzzy data in deterministic pile capacity models. The new method produces improved results. Based on 17 pile load test cases studied, in which FPILE consistently predicted the *most probable pile capacities* within 20% of the measured capacities, the performance of FPILE is judged to be excellent.

Increasing soil property variability increases the uncertainty in predicted pile capacity, as expected. This effect is quantified in Figures 5-4, 5-5, and 5-6. The capability of FPILE to consider the uncertainty in soil strength parameters enables an assessment of the variation in the predicted pile capacity. This is important, as the engineer may overestimate (or underestimate) the pile capacity if the "real" soil parameters deviate from the estimated values used in the analysis. With FPILE, the designer can now systematically incorporate perceived or estimated uncertainty into pile capacity analysis and obtain an informed estimate with more confidence.

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APPENDICES

APPENDIX I

Pile Load Test Data

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay, GRL-106, PA, OUTPUT= GRL106.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	50.0	1	1000.	0.	-1.0
2	5.0	52.5	1	1250.	0.	-1.0
3	45.0	55.0	1	1750.	0.	-1.0
NEAR PILE TIP			1	1500.	0.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 70.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	121	121
ALPHA = 0.5	106	138
ALPHA = 0.0	94	155

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

sc square concr pile in sand-clay, GRL-123, South Carolina, GRL123A.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 5

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	3.0	110.0	2	0.	6.	-1.0
2	7.0	47.6	2	0.	6.	-1.0
3	24.0	50.0	1	500.	0.	-1.0
4	15.0	52.5	2	0.	50.	-1.0
5	41.0	55.0	1	2500.	0.	-1.0
NEAR PILE TIP			1	2750.	0.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 90.00 (ft)

PILE TIP AREA (PA) = 4.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 2.00 (ft)

PILE PERIMETER (PP) = 8.00 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	447	447
ALPHA = 0.5	386	498
ALPHA = 0.0	321	548

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

sc square concr pile in clay-sand, South Carolina, file= GRL123B.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 5

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	3.0	110.0	2	0.	6.	-1.0
2	7.0	47.6	2	0.	6.	-1.0
3	24.0	50.0	1	500.	0.	-1.0
4	15.0	52.5	2	0.	50.	-1.0
5	31.0	55.0	1	3000.	0.	-1.0
NEAR PILE TIP			1	3000.	0.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 80.00 (ft)

PILE TIP AREA (PA) = 1.78 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.33 (ft)

PILE PERIMETER (PP) = 5.33 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	257	257
ALPHA = 0.5	221	287
ALPHA = 0.0	183	316

**** FPILE -- Pile Capacity By Fuzzy Set Analysis *****

mn steel H pile in clay-sand, GRL-113, MN, file= MN.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	55.0	50.0	1	1000.	0.	-1.0
2	12.0	52.5	2	0.	38.	-1.0
3	33.0	55.0	1	2750.	0.	-1.0
NEAR PILE TIP			1	2750.	0.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value
of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) =100.00 (ft)

PILE TIP AREA (PA) = .15 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.17 (ft)

PILE PERIMETER (PP) = 7.21 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	335	335
ALPHA = 0.5	291	375
ALPHA = 0.0	242	410

**** FPILE -- Pile Capacity By Fuzzy Set Analysis *****

calif sq concr pile in sand, Load Transfer #35, CA, output= LT1.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 2

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	45.0	50.0	2	0.	14.	-1.0
2	12.0	55.0	2	0.	100.	-1.0
NEAR PILE TIP			2	0.	100.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 57.00 (ft)

PILE TIP AREA (PA) = 4.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 2.00 (ft)

PILE PERIMETER (PP) = 8.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)		
1.0	770	--	770
0.5	744	--	803
0.0	677	--	832

**** FPILE -- Pile Capacity By Fuzzy Set Analysis *****

Oregon sq. concrete pile in sands, GRL-102, output file= OR.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 7

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	40.0	47.6	2	0.	30.	-1.0
2	10.0	50.0	2	0.	20.	-1.0
3	10.0	52.5	2	0.	18.	-1.0
4	25.0	55.0	2	0.	25.	-1.0
5	20.0	57.5	2	0.	70.	-1.0
6	12.0	60.0	2	0.	22.	-1.0
7	18.0	62.5	2	0.	100.	-1.0
NEAR PILE TIP			2	0.	100.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value
of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) =135.00 (ft)

PILE TIP AREA (PA) = 2.78 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.67 (ft)

PILE PERIMETER (PP) = 6.67 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)
1.0	908 -- 908
0.5	892 -- 1028
0.0	846 -- 1073

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay-sand, GRL-131, Pittsburg, PA, output= PASH2.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	17.0	50.0	1	1000.	0.	-1.0
2	8.0	52.5	2	0.	60.	-1.0
3	10.3	55.0	2	0.	34.	-1.0
NEAR PILE TIP			2	0.	40.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 35.30 (ft)

PILE TIP AREA (PA) = .69 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = .83 (ft)

PILE PERIMETER (PP) = 3.33 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	128	128
ALPHA = 0.5	116	140
ALPHA = 0.0	103	147

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay-sand, GRL-131, Pittsburg, PA, output= PASH3.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 4

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	17.0	50.0	1	1000.	0.	-1.0
2	8.0	52.5	2	0.	60.	-1.0
3	30.0	55.0	2	0.	40.	-1.0
4	15.3	57.5	2	0.	100.	-1.0
NEAR PILE TIP			2	0.	100.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value
of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 70.30 (ft)

PILE TIP AREA (PA) = .15 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 6.20 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	242	242
ALPHA = 0.5	232	254
ALPHA = 0.0	206	259

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay-sand, GRL-131, Pittsburg, PA, output= PASH5.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	17.0	50.0	1	1000.	0.	-1.0
2	8.0	52.5	2	0.	60.	-1.0
3	25.0	55.0	2	0.	35.	-1.0
NEAR PILE TIP			2	0.	35.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 50.00 (ft)

PILE TIP AREA (PA) = .69 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = .83 (ft)

PILE PERIMETER (PP) = 3.33 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	168	168
ALPHA = 0.5	151	185
ALPHA = 0.0	130	196

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay-sand, GRL-131, Pittsburg, PA, output= PASH6.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	17.0	50.0	1	1000.	0.	-1.0
2	8.0	52.5	2	0.	60.	-1.0
3	8.5	55.0	2	0.	30.	-1.0
NEAR PILE TIP			2	0.	36.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value
of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 33.50 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	148	148
ALPHA = 0.5	136	163
ALPHA = 0.0	115	176

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Sq. concrete pile, Dan Brown's database, output= P13.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	10.0	110.0	2	0.	5.	-1.0
2	4.0	110.0	2	0.	12.	-1.0
3	19.0	47.6	2	0.	12.	-1.0
NEAR PILE TIP			2	0.	14.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value
of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 33.00 (ft)

PILE TIP AREA (PA) = 2.25 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.50 (ft)

PILE PERIMETER (PP) = 6.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)		
1.0	157	--	157
0.5	147	--	167
0.0	139	--	176

**** FPILE -- Pile Capacity By Fuzzy Set Analysis *****

Squared Concrete Pile, Dan Brown's database, output= P18.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 2

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	9.0	110.0	2	0.	8.	-1.0
2	40.0	57.6	2	0.	13.	-1.0
NEAR PILE TIP			2	0.	13.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 49.00 (ft)

PILE TIP AREA (PA) = 2.25 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.50 (ft)

PILE PERIMETER (PP) = 6.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)
1.0	202 -- 202
0.5	189 -- 215
0.0	179 -- 228

**** FPILE -- Pile Capacity By Fuzzy Set Analysis *****

Squared Concrete Pile, Dan Brown's database, output= P23.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	12.0	27.6	2	0.	1.	-1.0
2	6.0	37.6	2	0.	4.	-1.0
3	37.0	57.6	2	0.	10.	-1.0
NEAR PILE TIP			2	0.	11.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value
of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 55.00 (ft)

PILE TIP AREA (PA) = 2.25 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.50 (ft)

PILE PERIMETER (PP) = 6.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)
1.0	172 -- 172
0.5	164 -- 182
0.0	156 -- 193

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Sq. concrete pile, Dan Brown's database, output= P34.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	47.6	2	0.	22.	-1.0
2	10.0	47.6	2	0.	7.	-1.0
3	22.0	47.6	2	0.	14.	-1.0
NEAR PILE TIP			2	0.	16.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 52.00 (ft)

PILE TIP AREA (PA) = 1.36 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.16 (ft)

PILE PERIMETER (PP) = 4.67 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)		
1.0	162	--	162
0.5	151	--	172
0.0	140	--	181

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Squared Concrete Pile, Dan Brown's database, output= P35.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 1

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	49.0	52.6	2	0.	15.	-1.0
NEAR PILE TIP			2	0.	15.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 49.00 (ft)

PILE TIP AREA (PA) = 2.25 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.50 (ft)

PILE PERIMETER (PP) = 6.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)		
1.0	222	--	222
0.5	208	--	232
0.0	192	--	246

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Concrete Pile, Dan Brown's database, output= P43.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	30.0	37.0	2	0.	3.	-1.0
2	20.0	47.6	2	0.	35.	-1.0
3	10.0	47.6	2	0.	23.	-1.0
NEAR PILE TIP			2	0.	24.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 60.00 (ft)

PILE TIP AREA (PA) = 1.36 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.16 (ft)

PILE PERIMETER (PP) = 4.67 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)
1.0	197 -- 197
0.5	189 -- 226
0.0	174 -- 239

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Squared Concrete Pile, Dan Brown's database, output= P44.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 2

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	37.0	2	0.	1.	-1.0
2	8.0	47.6	2	0.	28.	-1.0
NEAR PILE TIP			2	0.	28.	-1.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

NOTE 2--> If Variation (%) = -1, then a default value of 40 (clay) or 26 (sand) is used.

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 28.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)		
1.0	97	--	97
0.5	84	--	104
0.0	77	--	110

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

mn steel H pile in clay-sand, GRL-113, MN, file= MNA.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	55.0	50.0	1	1000.	0.	10.0
2	12.0	52.5	2	0.	38.	10.0
3	33.0	55.0	1	2750.	0.	10.0
NEAR PILE TIP			1	2750.	0.	10.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) =100.00 (ft)

PILE TIP AREA (PA) = .15 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.17 (ft)

PILE PERIMETER (PP) = 7.21 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	335	335
ALPHA = 0.5	323	347
ALPHA = 0.0	311	358

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

mn steel H pile in clay-sand, GRL-113, MN, file= MNB.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	55.0	50.0	1	1000.	0.	30.0
2	12.0	52.5	2	0.	38.	30.0
3	33.0	55.0	1	2750.	0.	30.0
NEAR PILE TIP			1	2750.	0.	30.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) =100.00 (ft)

PILE TIP AREA (PA) = .15 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.17 (ft)

PILE PERIMETER (PP) = 7.21 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	335	335
ALPHA = 0.5	301	365
ALPHA = 0.0	265	394

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

mn steel H pile in clay-sand, GRL-113, MN, file= MNC.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	55.0	50.0	1	1000.	0.	50.0
2	12.0	52.5	2	0.	38.	50.0
3	33.0	55.0	1	2750.	0.	50.0
NEAR PILE TIP			1	2750.	0.	50.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) =100.00 (ft)

PILE TIP AREA (PA) = .15 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.17 (ft)

PILE PERIMETER (PP) = 7.21 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	335	335
ALPHA = 0.5	278	384
ALPHA = 0.0	220	428

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Squared Concrete Pile, Dan Brown's database, output= P44A.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 2

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	37.0	2	0.	1.	10.0
2	8.0	47.6	2	0.	28.	10.0
NEAR PILE TIP			2	0.	28.	10.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 28.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)
1.0	97 -- 97
0.5	95 -- 100
0.0	93 -- 103

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Squared Concrete Pile, Dan Brown's database, output= P44B.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 2

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	37.0	2	0.	1.	30.0
2	8.0	47.6	2	0.	28.	30.0
NEAR PILE TIP			2	0.	28.	30.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 28.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)
1.0	97 -- 97
0.5	83 -- 105
0.0	75 -- 111

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

Squared Concrete Pile, Dan Brown's database, output= P44C.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 2

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	37.0	2	0.	1.	50.0
2	8.0	47.6	2	0.	28.	50.0
NEAR PILE TIP			2	0.	28.	50.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : CONCRETE-SOIL

INSTALLATION METHOD : LARGE-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 28.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

Support Level	Alpha-cut Interval (ton)		
1.0	97	--	97
0.5	78	--	109
0.0	65	--	116

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay, GRL-106, PA, OUTPUT= GRL106A.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	50.0	1	1000.	0.	10.0
2	5.0	52.5	1	1250.	0.	10.0
3	45.0	55.0	1	1750.	0.	10.0
NEAR PILE TIP			1	1500.	0.	10.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 70.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	121	121
ALPHA = 0.5	117	126
ALPHA = 0.0	112	130

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay, GRL-106, PA, OUTPUT= GRL106B.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	50.0	1	1000.	0.	30.0
2	5.0	52.5	1	1250.	0.	30.0
3	45.0	55.0	1	1750.	0.	30.0
NEAR PILE TIP			1	1500.	0.	30.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 70.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	121	121
ALPHA = 0.5	108	134
ALPHA = 0.0	101	147

**** FPILE - Pile Capacity By Fuzzy Set Analysis *****

pa steel H pile in clay, GRL-106, PA, OUTPUT= GRL106C.OUT

************ SOIL PROFILE DATA ************

NUMBER OF SOIL LAYERS SURROUNDING PILE (NL) = 3

Layer	Thickness (ft)	Effective unit wt.(pcf)	Soil Type	Cohesion (psf)	or N value	Variation (%)
1	20.0	50.0	1	1000.	0.	50.0
2	5.0	52.5	1	1250.	0.	50.0
3	45.0	55.0	1	1750.	0.	50.0
NEAR PILE TIP			1	1500.	0.	50.0

NOTE---> SOIL TYPE: 1-Clay, 2-Sand

*********** PILE PROPERTIES DATA **********

PILE-SOIL INTERFACE : STEEL-SOIL

INSTALLATION METHOD : SMALL-DISP., DRIVEN

EFFECTIVE PILE LENGTH (PL) = 70.00 (ft)

PILE TIP AREA (PA) = 1.00 (sq. ft)

DIAMETER OR WIDTH OF PILE (PD) = 1.00 (ft)

PILE PERIMETER (PP) = 4.00 (ft)

*********** RESULTS OF ANALYSIS ***********

SUPPORT LEVEL	Qu (min)	Qu (max)
ALPHA = 1.0	121	121
ALPHA = 0.5	104	142
ALPHA = 0.0	86	163

APPENDIX II

FPILE Installation Instructions

Instructions for installing and running FPILE

FPILE requires Windows 3.1 to run.

To install FPILE:

1. create subdirectory FPILE from the root directory
2. copy dbttip.vbx, fpile2.exe, and run.exe from the \FPILE directory on the enclosed floppy diskette to the FPILE directory on your hard drive
3. copy vbrun300.dll and cmdialog.vbx from floppy directory FPILE\WINDOWS\SYSTEM directory on the enclosed floppy diskette to the \WINDOWS\SYSTEM directory on your hard drive (these files may already be in this directory)

To run FPILE:

1. from Windows Program Manager screen, open FILE, then RUN. Enter c:\fpile\run <return> to start FPILE.
2. follow directions in FPILE.

Note: FPILE creates an input and output file. Subsequent runs of FPILE may be made directly from the input file, at the DOS prompt.

To run FPILE using an input file, at the DOS prompt, type

FPILE2 <input filename>

and follow the directions.

The input and output files may be edited with an ASCII editor.