Discussion of paper: Factor of Safety and Reliability in Geotechnical Engineering (Paper 20950) by J.M. Duncan Apr. 2000, Vol. 126, No.4

Discussion by Roger A. Failmezger,[5] Member, ASCE

The author has presented a practical approach for using probability in geotechnical engineering design. The numeric examples are very beneficial for understanding probability concepts.

The discusser believes there is an error in some of the values contained in Table 2. The probability of failure should not exceed 50% for an F_{MLV} that exceeds 1.0. For a uniform probability distribution (the distribution with the highest coefficient of variation and all possibilities equally likely) with an F_{MLV} = 1.05 and limits from 0 to 2.1, the probability of failure = 1.0/2.1, or 48%. In Table 7, the discusser feels that it is not possible for the coefficient of variation to increase and the probability of failure to decrease as is the case for SR = 1.10.

The discusser also questions the use of the lognormal probability distribution for geotechnical design applications. The lognormal distribution has limits of zero and positive infinity, and thus the distribution is always skewed to the left. With probability design, the engineer evaluates the area beneath the probability distribution function at the tail ends. The failure zone will be the area beneath the left tail below 1.00 for factor of safety based designs (the factor of safety is the abscissa). For settlement based design, the failure zone will be the area beneath the right tail above a maximum settlement threshold value (the settlement is the abscissa). Because of the left skewness of the lognormal distribution, designs where the failure zone is along the left tail will tend to be conservative and those with the failure zone along the right tail will tend to be unconservative.

The normal probability distribution function is symmetrical about its mean and has limits from negative infinity to positive infinity. These limits are not realistic and probably cause some error when evaluating the failure zone. The discusser suggests that a beta probability distribution be used because its limits can be realistically chosen by the engineer (Harr 1977). (The normal distribution is a subset of the beta distribution.) Where the average value occurs with respect to those limits will determine the skewness of the beta distribution.

In the example for determining the probability of unsatisfactory performance for settlement of footing on sand, the author uses settlement predictions based on SPT N_{60} values. He evaluates the coefficient of variation of how well the model predicts what has been measured based on case study data as 67%. This high coefficient of variation is partly due to using a dynamic penetration test to predict the static deformation properties of sand. In addition to the uncertainty of the model, there is uncertainty from measurement noise (test repeatability) and the spatial (subsurface) variability of the site. The discusser believes that these sources of uncertainty are independent and should be summed using the following equation:

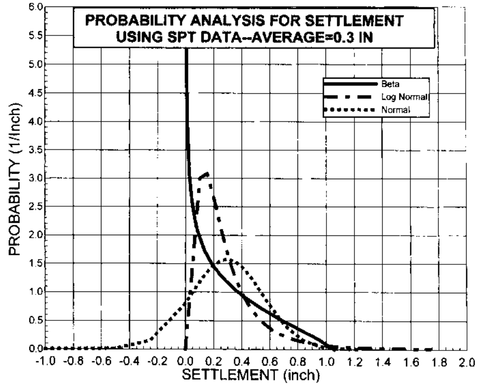

FIG. 7. Probability Analysis for Settlement Using SPT Data: Average = 0.3 in.

$$\sigma_{\text{overall}} = \sqrt{[(\sigma_{\text{model}})^2 + (\sigma_{\text{noise}})^2 + (\sigma_{\text{spatial}})^2]} \qquad (12)$$

where σ_{overall} = overall standard deviation; σ_{model} = standard deviation from model uncertainty; σ_{noise} = standard deviation from measurement noise; and σ_{spatial} = standard deviation from spatial variability.

The uncertainty from measurement noise for SPT can be as high as 45–100% (Schmertmann 1978; Kuhawy 1996). Wickremesinghe (1989) showed that measurement noise for piezocone (CPTU) equaled 5% and dilatometer tests (DMT) equaled 6% at the McDonald Farm test site in Vancouver. From case study data (Schmertmann 1986), the coefficient of variation for the DMT model for predicting settlement was 21% when the dilatometer is pushed and excluding quick clayey silts (Failmezger et al. 1999).

As shown in Table 13 and Figs. 7 and 8, the discusser analyzed the different probability distributions and the test and analysis methods to determine their effects on the probability of unsatisfactory performance of exceeding a threshold settlement. The probability of success equals 1.0 minus the probability of unsatisfactory performance. Because the overall standard deviation was so high in comparison to the average value for the SPT case, the left side of all three distributions was distorted (Fig. 7). The probability analysis for settlement, however, focuses on the right side of the distribution curve. Because of its left skewness, the lognormal distribution for SPT with a threshold settlement of 0.5 in. gave a higher probability of success (86%) (unconservative) than beta or normal distributions (79%). A higher threshold settlement lessens the effect of the probability distribution.

TABLE 13. Analysis of Probability Distributions and Test and Analysis Methods

Probability distribution function	Test and analysis method	Average settlement (in.)	Standard Deviation From: Spatial variability	Standard Deviation From: Measurement noise	Standard Deviation From: Model error	Overall standard deviation[a]	Threshold settlement (in.)	Probability of unsatisfactory performance	Probability of success
Beta	SPT	0.30	0.059	0.148	0.198	0.254	0.50	0.21	0.79
Lognormal	SPT	0.30	0.059	0.148	0.198	0.254	0.50	0.14	0.86
Normal	SPT	0.30	0.059	0.148	0.198	0.254	0.50	0.21	0.79
Beta	SPT	0.30	0.059	0.148	0.198	0.254	0.90	0.02	0.98
Lognormal	SPT	0.30	0.059	0.148	0.198	0.254	0.90	0.03	0.97
Normal	SPT	0.30	0.059	0.148	0.198	0.254	0.90	0.01	0.99
Beta	DMT	0.30	0.059	0.018	0.062	0.087	0.50	0.00	1.00
Lognormal	DMT	0.30	0.059	0.018	0.062	0.087	0.50	0.02	0.98
Normal	DMT	0.30	0.059	0.018	0.062	0.087	0.50	0.01	0.99
Beta	DMT	0.30	0.059	0.018	0.062	0.087	0.90	0.00	1.00
Lognormal	DMT	0.30	0.059	0.018	0.062	0.087	0.90	0.00	1.00
Normal	DMT	0.30	0.059	0.018	0.062	0.087	0.90	0.00	1.00

[a] See Eq. (12).

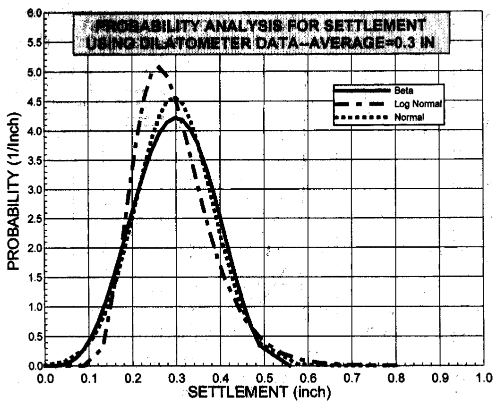

FIG. 8. Probability Analysis for Settlement Using Dilatometer Data: Average = 0.3 in.

However, the choice of test and analysis method in Table 13 had a much more significant effect than the probability distribution. The standard deviation from spatial variability was assumed to be equal to 20% of the average settlement value for all the SPT and DMT cases. The standard deviations from measurement noise and model uncertainty from SPT were much larger than those from DMT. In fact, they were huge! The overall standard deviation for the SPT was 86% of the average value, as compared with only 29% for the DMT. The discusser questions the value of using the SPT as a method to compute settlement altogether.

The high SPT variability shown above emphasizes that, for geotechnical design, the engineer should select the best available test and analysis method and attempt to minimize model uncertainty and measurement noise. The engineer should then focus on and quantify the spatial variability of the site, which is often beyond his or her control. Probabilistic design methods provide a good means to address variability. The probability distribution chosen for analyses should provide an appropriate result. The more heterogeneous the site is, the more uncertainty there is, the flatter the probability distribution will be, and the more conservative the design should be. The reverse is also true.

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Discussion by John A. Focht Jr.,[6] Fellow, ASCE, and John A. Focht III,[7] Member, ASCE

The author is to be commended for developing a rational technique for incorporating reliability into routine factor of safety analyses that can be understood and effectively utilized by a geotechnical engineering practitioner. Most practitioners, including the discussers, do not have enough confidence in "reliability based design" (RBD) to substitute it for their more conventional deterministic approaches. Most RBD papers suggest the blind application of statistical analyses of data without much engineering judgment regarding individual data points, trends in data, the type of design problem, or spatial variations within the data. The discussers believe that the application of RBD-based design approaches does not eliminate the need for sound engineering judgment. The author's proposed approach will certainly enhance the value of problem solutions for the engineering practitioner. The author also assumed that sound engineering judgment would be applied to both the data and the engineering problem, but still seemed to use the numerical average as the "most likely value." The discussers concur with the author's belief that the use of sound engineering judgment is always a criteria for properly evaluating engineering problems. This view is neither new nor unique; Karl Terzaghi very pointedly addressed the importance of sound engineering judgment in his May 1936 Presidential Address to the First International Conference on Soil Mechanics and Foundation Engineering (ICSMFE):

> The major part of the college training of civil engineers consists in the absorption of the laws and rules which apply to relatively simple and well-defined materials, such as steel or concrete. This type of education breeds the illusion that everything connected with engineering should and can be computed on the basis of a priori assumptions. As a consequence, engineers imagined that the future science of foundations would consist in carrying out the following program: Drill a hole into the ground. Send the soil samples obtained from the hole through a laboratory with standardized apparatus served by conscientious human automatons. Collect the figures, introduce them into the equations, and compute the result. Since the thinking was already done by the man who derived the equation, the brains are merely required to secure the contract and to invest the money. The last remnants of this period of unwarranted optimism are still found in attempts to prescribe simple formulas for computing the settlement of buildings or of the safety factor of dams against piping. No such formulas can possibly be obtained except by ignoring a considerable number of vital factors.

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