Discussion of "Probabilistic Foundation Settlement on Spatially Random Soil" by Gordon A. Fenton and D. V. Griffiths

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The authors have presented an interesting and original contribution to understanding the uncertainties in behavior of foundations. We wish to add an additional, complementary comment to one of the findings in the paper. The discussion of Eq. (16) and Fig. (7) notes that the largest values of the standard deviation in the differential settlements occur when the correlation distance for the foundation modulus is of the same order of magnitude as the separation between the footings. The paper also shows that the relative settlement is normally distributed with zero mean and a standard deviation that depends on the geometry and correlation structure. We note that, in this case, the expected value of the absolute value of the differential settlement is $0.797\sigma_{\Delta}$.

Baecher and Ingra (1981) employed a different finite element methodology and studied a somewhat different problem of a uniform load on an elastic layer. They found that the maximum influence factor for absolute differential settlement had its maximum values for correlation distances between 0.75 and 1.00. In view of the differences between the problems studied and the analytical techniques, it is not surprising that the results differ. However, we believe it is significant that the maximum differential effects occur when the correlation distances for the material properties are approximately the same as the separation between the points at which differential settlement is calculated. This result should be borne in mind when performing statistical analyses of differential settlement.

References

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The authors wish to thank the discussors for drawing attention to their interesting earlier contribution to the settlement problem.

The contribution by Baecher and Ingram (1981) is distinguished as follows:

1. It describes the behavior of a single perfectly flexible footing modeled as a series of point loads applied directly to the surface of an elastic layer; and
2. It utilizes a first-order stochastic finite element model, an approach which is well known to show reasonable accuracy for coefficients of variation up to about 0.2–0.3.

The major differences between the authors' work and that by Baecher and Ingram are as follows:

1. The differential settlement of a perfectly flexible footing from edge to edge is analogous to the rotation of a rigid footing, aside from some secondary local averaging issues. On the other hand, the settlement of two distinct rigid footings, as considered by the authors, includes the issues of footing spacing and width which are both generally of concern in the differential settlement problem. In addition, the authors provide a relatively simple way to estimate probabilities associated with settlement and differential settlement by way of geometric averages that depend on footing width.
2. The Monte Carlo approach employed by the authors is only limited in accuracy by the number of realizations employed, aside from the usual finite element discretization issues. With 5000 realizations employed in the study, the estimator error is about 1% of the estimated standard deviation (and so quite a small error even for the large coefficients of variation of up to 4.0 considered by the authors).

Baecher and Ingram define their differential settlement influence factor as $I=\mu_{|\Delta|}\times\mu_E$, which is essentially a constant times $\mu_{|\Delta|}$ in their "homogeneous" case. Their plot of I versus the scale of fluctuation is somewhat similar to the authors' Fig. 7, which is also a plot of a constant times $\mu_{|\Delta|}$ [the constant in this case being $\sqrt{\pi/2}$, see Eq. (19)]. The similarity lies in the interesting fact that both plots reach a maximum at some intermediate scale of fluctuation.

That both papers achieved similar results regarding this aspect of differential settlement is encouraging. In particular, when two quite different approaches to somewhat different problems lead to the similar conclusion that differential settlement is maximized for a scale of fluctuation approximately equal to the distance be-

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tween the loads, it provides additional support to the idea that this ''worst-case'' scale can be conservatively used in probability estimates when improved information is unavailable. The authors' paper points out that this worst-case scale is possibly overly conservative and recommends that a scale equal to some fraction of the inter-footing distance be used when the actual scale is unknown.

Finally, the discussors are quite right to emphasize the result that the authors gave in Eq. (19), namely, that the expected absolute value of a normal distribution is $\sqrt{2/\pi}$ times the standard deviation.

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Discussion of "Evaluating Site Investigation Quality Using GIS and Geostatistics" by R. L. Parsons and J. D. Frost

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The authors present an interesting and innovative approach to capturing the completeness of site characterization and the dependability of resulting soil property estimates. The combination of traditional spatial statistical methods and modern information technology holds great promise for geotechnical engineering. This paper suggests a concrete approach to building on that promise.

The approach presented in the paper builds on so-called Kriging estimators of geostatistics. This is a well-tested method of proven value in the mining and environmental industries, with clear applications to geotechnical practice. With no intent of criticizing the present paper, which is excellent, one caution needs to be voiced. It is sometimes, and erroneously, presumed by new users of geostatistics that Kriging estimator variances pertain to uncertainty in the soil property being estimated, and thus that GIS maps of standard deviations portray soil property uncertainty. They do not. These variances are measures of the variability of the mathematical estimators over repeated sampling.

Kriging estimators are weighted sums of a set of measurements taken from a site. Were measurements made at slightly different locations, the outcomes would differ. The outcomes differ because, first, the soil itself differs from point to point, and, second, slight differences in procedure may lead to differences in results. Applying the weighted sum (Kriging) formula to these now slightly different outcomes leads to a slightly different estimate. The Kriging variance is a measure of how much this weighted sum would vary across multiple sets of measurements, presuming a known autocorrelation function (or, equivalently, a known variogram).

Two points are worth keeping in mind. First, the autocorrelation structure of soil engineering properties in the field is imprecisely known (DeGroot 1996). This imprecision is not captured by sampling variance in the Kriging estimates. This is akin to the well-known problem in statistics text books of, ''sampling from a Normal process with known variance.'' Second, capturing the uncertainty in the estimated soil property itself (i.e., rather than in the estimator) is an exercise in inverse probability (Baecher et al. 2002). It requires a Bayesian calculation and an implicit or explicit prior distribution of probability on the soil property. While the numerical outcomes of statistical calculations involving Normal process and linear estimators are thankfully robust to our abuses of practice, sometimes these subtleties of theory can lead to large practical errors of interpretation.

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The authors thank Dr. Baecher and Dr. Christian for their comments and clarification of important concepts concerning the use of Kriging estimator variances and the estimation of the variability of soil properties. It is important to acknowledge that with all of the benefits of automated data management, the engineer still carries the responsibility for understanding the limitations of the tools he or she is using.

Given those limitations, the potential uses of GIS in the management of site investigation data continue to expand. Capabilities similar to those developed for the original GIS-ASSESS program are now available in commercial software and have been used to evaluate a range of soil properties (Kosasi 2001). The use of quality analysis maps has also been integrated with a system for evaluating and ranking the quality of individual data sources (Deaton et al. 2001). Through these and similar advances, the potential now exists for data quality to also be quantitatively incorporated into geotechnical databases. This represents an important opportunity for practice in a number of ways. First, it provides the opportunity for a site investigation quality database to be developed and continuously updated in real time, enabling office and field crews to coordinate adjustments in the investigation plan thereby allowing for optimization of the investigative effort while field work is still in progress. Second, it provides the

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