The previously mentioned question did not exist for Case 26/3. Similar to Cases 26/1 and 26/2, which were not mentioned by the discusser, q' values were calculated directly using the effective (buoyant) unit weight for these surface footings.

As with all studies using extensive databases derived from many sources, some judgments have to be made in a very small number of case histories. As long as the numbers are small, there will be no significant influence on the overall results and conclusions.

Discussion of "Probabilistic Analysis of Coupled Soil Consolidation" by Jinsong Huang, D. V. Griffiths, and Gordon A. Fenton

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The paper written by Huang, Griffiths, and Fenton is very interesting. However, the discussers would like to point out some considerations.

The writers of the paper have only taken a lognormally distributed stochastic component of k and m_v into account and probably deliberately overlooked the deterministic component, which, it is believed, cannot be neglected (Pishgah and Jamshidi 2011). The discussers think it is better for engineering purposes if a simplification is introduced: a model in which spatial variability (k, m_v) is separated into two parts: (1) a known deterministic trend; and (2) residual variability about that trend.

With regard to natural processes, all soil properties in situ will vary vertically and horizontally; trend analysis is concerned with distinguishing deterministic trends for k and m_v based on in situ tests. As shown in Fig. 1, this spatial variation can be decomposed conveniently into a smoothly varying trend function $[t(z)]$ and a fluctuating component $[w(z)]$ as follows (Phoon et al. 1995):

$$\xi(z) = t(z) + w(z) \tag{1}$$

where ξ = in situ soil property; and z = depth. The inherent soil variability can be represented by the fluctuating component, if $w(z)$ is modeled as a homogenous random field, as suggested by Vanmarcke (1983). For this reason, the discussers would like to emphasize the combined effect of deterministic and stochastic variability that is called inherent variability on the consolidation behavior of natural alluvial deposits.

For this aim, a simple uncoupled (Terzaghi) approach was invoked to show the effect. The involved parameters, k and m_v, were considered equally important and embodied into a single coefficient of consolidation just for simplicity. Therefore, m_v was

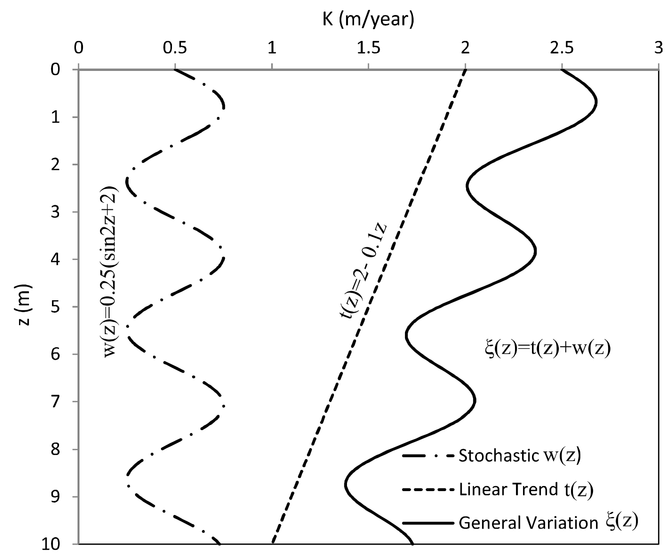

Fig. 1. Inherent soil variability

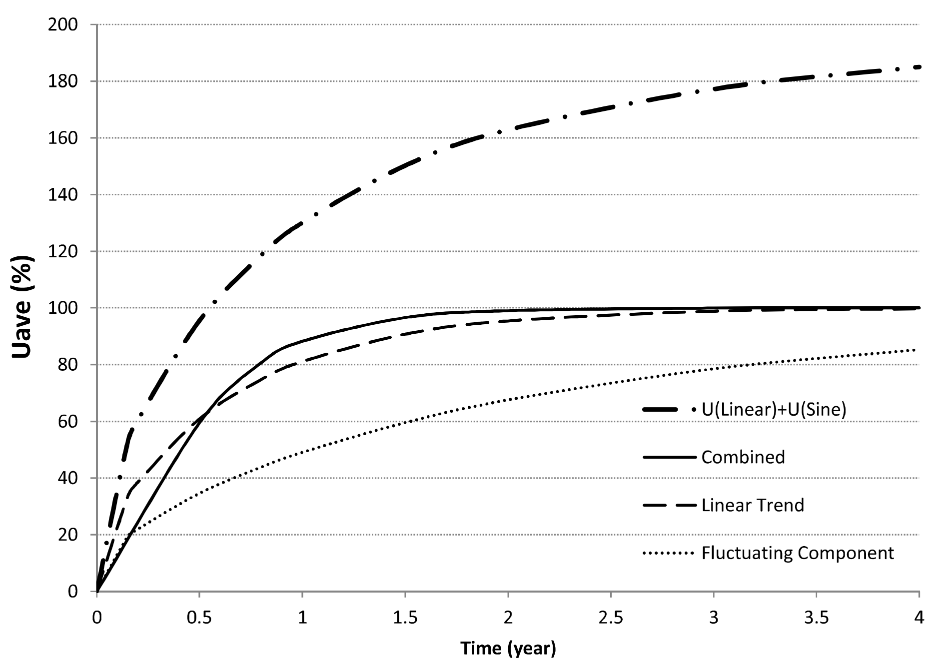

Fig. 2. Average degree of consolidation versus time for inherent soil variability

held constant while k was assumed to bear a linearly depth-decreasing trend along with a sinusoidal fluctuating component that is believed to represent stochastic behavior.

A simple example shows the effect of trend analysis on the result, described in the following. If one detrends the simple general variation of k, as illustrated in Fig. 1, and assumes a depth-constant initial pore pressure profile (u_i), the uncoupled equation for isochrones will be

$$u_z = \sum_{m=0}^{\infty} \frac{2u_0}{M} \sin\left(\frac{Mz}{H}\right) \exp(-M^2 T_V) \qquad (2)$$

Introducing the linear and sinusoidal components into the T_V formulation, separately and combined, the average degree of consolidation for different analyses; namely, linearly varying, sinusoidal fluctuation, and the general property will be calculated and provided as depicted in Fig. 2. The superposition of the results of analysis are also plotted for individual components.

For the example presented previously, if different components of permeability are considered individually while leaving the other components for subsequent analyses, this may lead to erroneous results in view of average degree of consolidation.

Simple calculations showed that the problem is nonlinear with respect to k and m_v. Therefore, it is strongly suggested that both deterministic and stochastic variability should be embodied in an integrated analysis to draw conclusions about the effects of different parameters in parametric studies.

The final remark is that for consolidation and even bearing capacity or slope stability problems, it is crucially important to simultaneously take different components of inherent variability into consideration. The combined effect of deterministic and stochastic analyses will pave the way toward a better understanding of the effects of the different parameters involved.

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Phoon, K. K., Kulhawy, F. H., and Grigoriu, M. D. (1995). "Reliability based design of foundations for transmission line structures." *Rep. TR-105000*, Electric Power Research Institute, Palo Alto, CA.

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The writers wish to thank the discussers for their interest in our paper. They have raised an important issue relating to the potential variation of mean soil properties in the vertical direction. The problem with the discussers' demonstration, however, is that they used an uncoupled approach, when it is well known that both the coefficient of volume compressibility and the soil permeability play important roles in the consolidation of heterogeneous soils. These two properties must be treated independently, and cannot be embodied into a single coefficient of consolidation. Comparisons between coupled and uncoupled responses of consolidating layers were shown in our paper (Figs. 3 and 4), and also in a related paper by the same writers (Huang and Griffiths 2010).

The methodology presented in our paper could easily be extended to model the mean trend of soil properties mentioned by the discussers. The one-dimensional model (Fig. 1 in the paper) is reanalyzed using 11 elements with a total length of 1.1, and four cases are considered with the unit weight of water set to 1.0 for simplicity in all cases.

In Case 1, the soil permeability (k) and coefficient of volume compressibility (m_v) are deterministic and set to 1.0 for all depths, as shown in Fig. 1. The coefficient of consolidation (c_v) is thus also equal to 1.0 at all depths. The uncoupled approach gives the same answers as the coupled approach in this case. In all figures, values in the middle of elements are displayed.

In Case 2, the soil permeability (k) and coefficient of volume compressibility (m_v) are also deterministic, but decrease linearly with depth, as shown in Fig. 2. The coefficient of consolidation (c_v) however, remains equal to 1.0 at all depths as in Case 1. In this case, the uncoupled (Terzaghi) approach gives different solutions to the coupled approach.

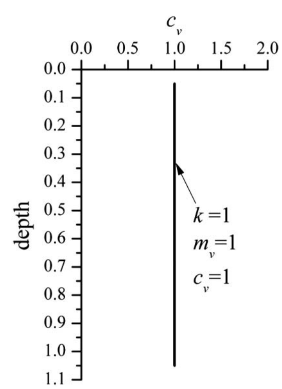

Fig. 1. Case 1: distribution of coefficient of consolidation

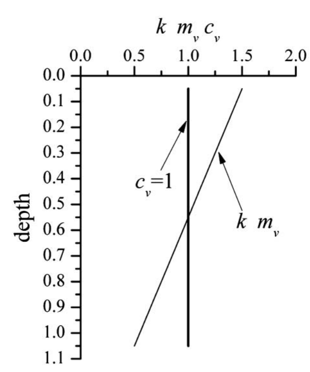

Fig. 2. Case 2: distribution of coefficient of consolidation (c_v), permeability (k), and mean coefficient of volume compressibility (m_v)

held constant while k was assumed to bear a linearly depth-decreasing trend along with a sinusoidal fluctuating component that is believed to represent stochastic behavior.

A simple example shows the effect of trend analysis on the result, described in the following. If one detrends the simple general variation of k, as illustrated in Fig. 1, and assumes a depth-constant initial pore pressure profile (u_i), the uncoupled equation for isochrones will be

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Simple calculations showed that the problem is nonlinear with respect to k and m_v. Therefore, it is strongly suggested that both deterministic and stochastic variability should be embodied in an integrated analysis to draw conclusions about the effects of different parameters in parametric studies.

The final remark is that for consolidation and even bearing capacity or slope stability problems, it is crucially important to simultaneously take different components of inherent variability into consideration. The combined effect of deterministic and stochastic analyses will pave the way toward a better understanding of the effects of the different parameters involved.

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In Case 2, the soil permeability (k) and coefficient of volume compressibility (m_v) are also deterministic, but decrease linearly with depth, as shown in Fig. 2. The coefficient of consolidation (c_v) however, remains equal to 1.0 at all depths as in Case 1. In this case, the uncoupled (Terzaghi) approach gives different solutions to the coupled approach.

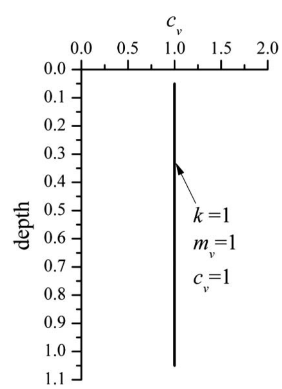

Fig. 1. Case 1: distribution of coefficient of consolidation

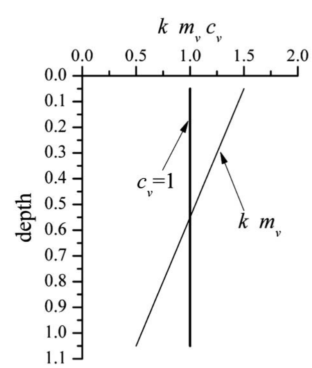

Fig. 2. Case 2: distribution of coefficient of consolidation (c_v), permeability (k), and mean coefficient of volume compressibility (m_v)

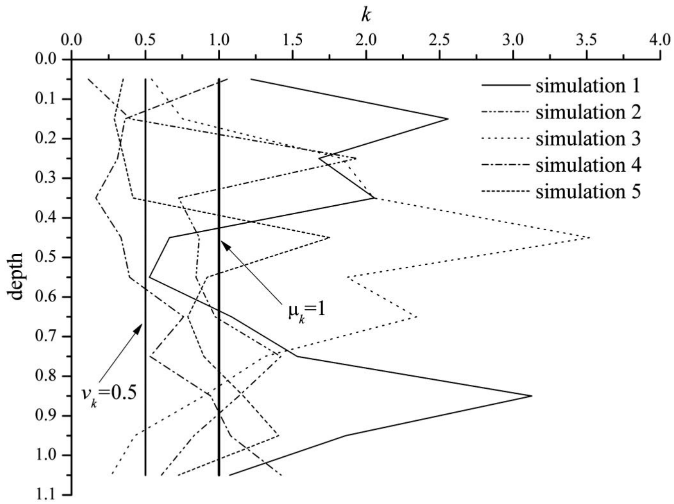

Fig. 3. Case 3: distribution of mean permeability (μ_k) and coefficient of variation of permeability (ν_k) (five typical simulations are shown)

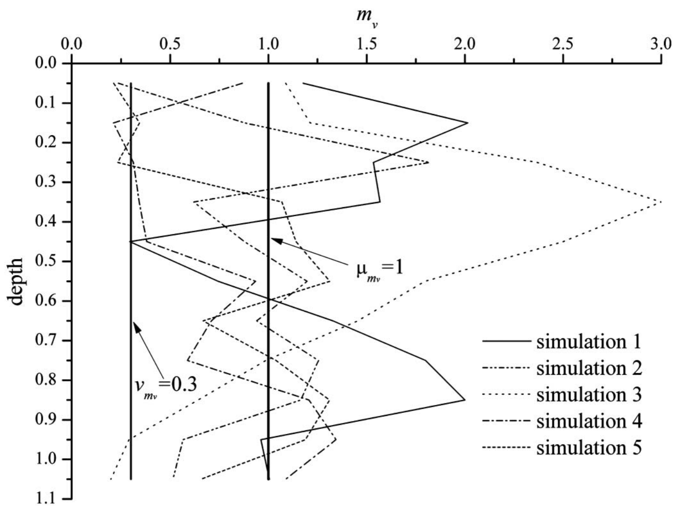

Fig. 4. Case 3: distribution of mean coefficient of volume compressibility (μ_{m_v}) and coefficient of variation of coefficient of volume compressibility (ν_{m_v}) (five typical simulations are shown)

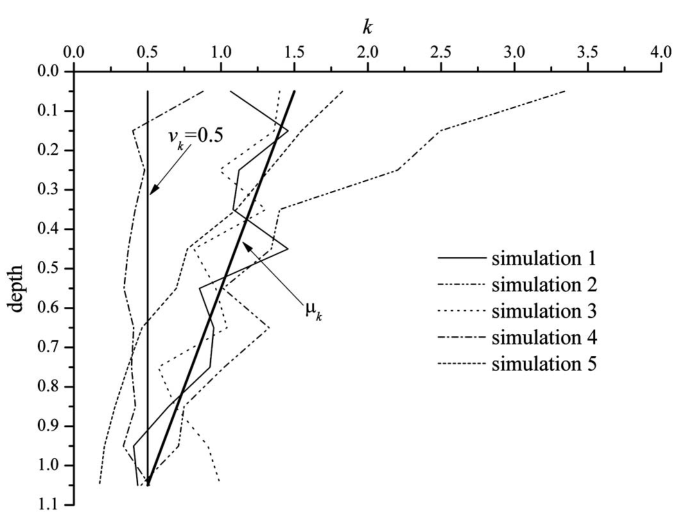

Fig. 5. Case 4: distribution of mean permeability (μ_k) and coefficient of variation of permeability (ν_k) (five typical simulations are shown)

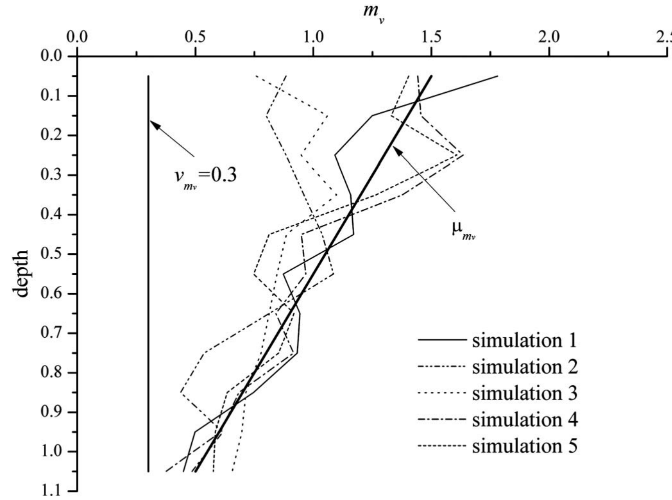

Fig. 6. Case 4: distribution of mean coefficient of volume compressibility (μ_{m_v}) and coefficient of variation of coefficient of volume compressibility (ν_{m_v}) (five typical simulations are shown)

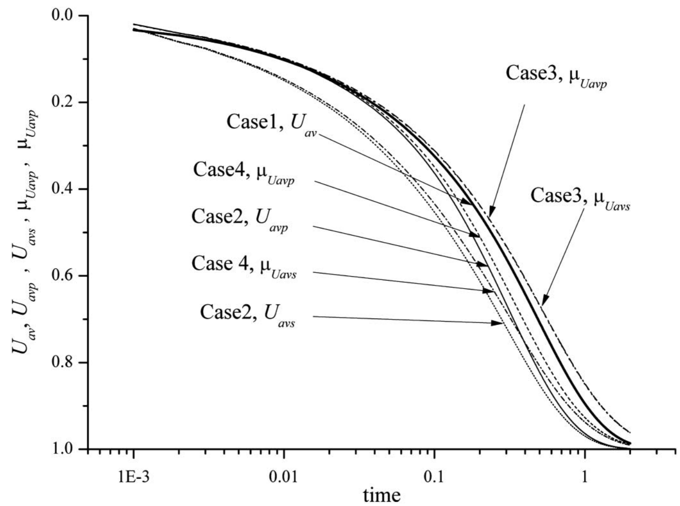

Fig. 7. Average degree of consolidation defined by pore pressure (U_{avp}) and settlement (U_{avs}), mean average degree of consolidation defined by pore pressure ($\mu_{U_{\text{avp}}}$) and settlement ($\mu_{U_{\text{avs}}}$)

In Case 3, the soil permeability (k) and coefficient of volume compressibility (m_v) are lognormally distributed random variables, as shown in Figs. 3 and 4. The mean permeability (μ_k) and the mean coefficient of volume compressibility (μ_{m_v}) are both set to 1.0 for all depths. The coefficient of variation of permeability (ν_k) is set to 0.5 and remains constant with depth. The coefficient of variation of the coefficient of volume compressibility (ν_{m_v}) is set to 0.3, and also remains constant with depth. Although there is evidence that the cross-correlation between k and m_v is positive, it is set to zero in this case for simplicity.

In Case 4, the mean permeability (μ_k) and mean coefficient of volume compressibility (μ_{m_v}) both decrease linearly with depth, as shown in Figs. 5 and 6. They have the same coefficients of variation and cross-correlation as in Case 3.

Five thousand Monte Carlo simulations were conducted for Cases 3 and 4. The effects of the mean trend of soil permeability and compressibility on the consolidation behavior are clearly shown in Fig. 7. In Case 3, the mean average degree of consolidation defined by settlement and pore pressure was indistinguishable. The difference becomes larger for larger coefficients of variation of k and m_v, as demonstrated in the paper.

In summary, the authors have shown that the random field approach described in the paper can easily be adapted to model a mean trend with depth for any soil property. The reply has also reiterated the importance of using a coupled approach (k and m_v are input separately) for proper modeling of the consolidation behavior of heterogeneous soils.

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