MARINE GEORESOURCES & GEOTECHNOLOGY
https://doi.org/10.1080/1064119X.2017.1321072

Closure to discussion of “experiment and statistical assessment on piping failures in soils with different gradations”

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ABSTRACT
This paper responds to the comments from two discussions. The comments related to the uncertainties in the internal stability criteria and the determination of input soil property for prediction models, which affect the accuracy of predicting critical hydraulic gradient, are addressed and discussed.

ARTICLE HISTORY
Received 15 April 2017
Accepted 16 April 2017

KEYWORDS
Critical hydraulic gradient; soil internal stability; prediction model

Introduction

We thank the discussers for their interest in our work, particularly related to the statistical assessment of soil piping failures. Their valuable and constructive input is highly appreciated. Both discussers commented on uncertainties in the internal stability criteria and the determination of input soil property for prediction models, which affect the accuracy of predicting critical hydraulic gradient. The geotechnical design involves numerous uncertainties such as soil variability in the field, soil sampling and disturbance, soil tests, interpretation of soil properties, and those related to design and prediction methods (i.e., model uncertainty). These uncertainties are inevitable and should be properly assessed through statistical and reliability approaches. Replies to specific comments are provided as follows.

Authors’ reply to Zhao, Yuan, and Feng (2017)

Zhao, Yuan, and Feng (2017) commented on the effect of soil density on the internal stability of granular soils; the authors are in complete agreement. As stated on page 523 in the discussed paper (Yang and Wang 2017), the scatter in Figure 15 was mainly caused by the effect of porosity on the critical hydraulic gradient i_{cr}, which was not considered in the selected stability criteria. Kezdi’s and Kenney and Lau’s methods were selected in this study because these methods are widely used for the assessment of the internal stability of granular soil. The authors are glad to learn that the internal stability criterion proposed by Dallo, Wang, and Ahmed (2013) can be applied to obtain more accurate results by taking the effect of soil density into account.

The authors also agree with the suggestion that the internal stability of soil can be more reliably determined based on test results, although the intention of the discussed paper was to evaluate the uncertainty and accuracy of the prediction methods for i_{cr} if tests are not available. Based on the test results, the uncertainties associated with the determination of the soil’s internal stability surely can be minimized. Furthermore, i_{cr} values can also be obtained from test results and no longer need to be predicted.

Finally, regarding the assessment of the internal stability of Soil D by Skempton and Brogan (1994), the authors confirm that this soil is classified as internally stable. The same conclusion was reached in the source paper by Skempton and Brogan (1994). The discrepancy between the authors’ and discussers’ results was likely caused by uncertainty in reading the grain size distribution curve, especially in fine particle fractions.

Authors’ reply to Dallo, Chen, and Ni (2017)

Dallo, Chen, and Ni (2017) commented on the value of the equivalent particle diameter d_{eq} related to the uncertainty in determining input soil properties for prediction models. For Table 5 in the discussed paper, it was challenging to calculate d_{eq} because the grain size at the 0% finer in a grain size distribution curve could not be accurately determined, and in some cases, the provided grain size distribution curves did not extend to the 0% finer at x-axis (Figure 1). For example, the grain size distribution curve of Soil B as depicted in Figure 5 in Skempton and Brogan (1994) does not appear to extend to the 0% finer. The same situation applies to Soils 2 and 3 in Mörz et al. (2007), Soils b, d, A, B, C, and D in Mao, Duan, and Wu (2009), and so on. Two approaches can be used to overcome the problem of determining the grain size at the 0% finer (the smaller particle diameter d_{si} at the finest soil particle fraction): one is to exclude the fraction of the finest particles from the calculation of d_{eq}, while another one is to assume an arbitrary small value for the grain size at the 0% finer. The first approach was adopted in the discussed paper, and the second approach was used in the discussers’ paper.

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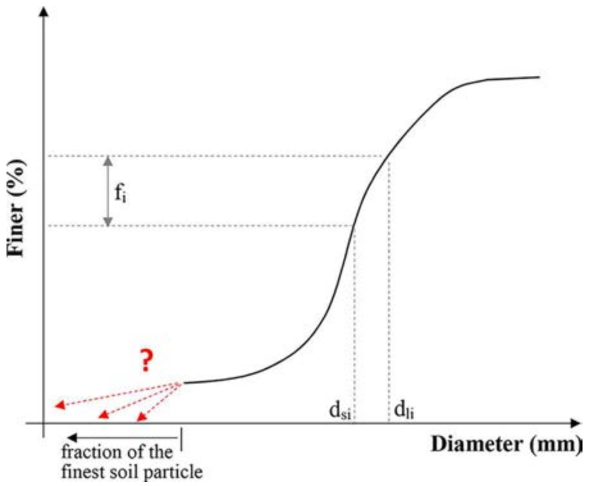

Figure 1. Illustration of the challenge in the determination of the grain size at 0% finer in a grain size distribution curve.

Notably, both approaches could introduce a certain degree of uncertainty in calculating d_{eq} using Eq. 7 in the discussed paper because of the determination of the d_{si} at the finest soil particle fraction.

Table 1 presents an example of detailed calculation of the equivalent particle diameter of Soil D in Skempton and Brogan (1994). In Table 1, grain size values were first selected according to typical sieve sizes used in the sieve analysis (i.e., 3/4 in, 3/8 in, #4, #10, #20, #40, #60, #100, and #200). The percent finer values in a grain size distribution curve were then obtained, corresponding to the selected grain size values. Afterward, the d_{eq} value was calculated by excluding the fraction of the finest particles (finer than the #60 sieve in this case in Table 1), according to the first approach.

Table 2 shows a comparison of the d_{eq} values obtained by excluding the fraction of the finest soil particles as adopted in the discussed paper, by assuming $d_{si} = 0.15$ mm at the fraction of the finest soil particles corresponding to #100 sieve, and by assuming $d_{si} = 0.06$ mm as used by the discussers (Table 1, Dallo, Chen, and Ni 2017). As shown in Table 2, $d_{eq} = 2.27$ mm, calculated by assuming $d_{si} = 0.06$ mm at the finest soil particle fraction, is close to the $d_{eq} = 2.24$ mm obtained by the discussers (Table 2, Dallo, Chen, and Ni 2017). The approach adopted in the discussed paper has a higher value than the other two approaches, which also explains why the d_{eq} values calculated by the authors were consistently higher than those calculated by the discussers. Other uncertainties in determining the d_{eq} value may come from reading the grain size distribution curve and from selecting the interval size for each soil particle fraction in the grain size distribution curve. The authors determined the intervals of soil particles according to sieve sizes, as suggested by Carrier (2003), whereas the discussers separated soil particles into many fractions, as shown in Table 1 and Figure 2 in Dallo, Chen, and Ni (2017).

Table 1. Detailed calculation of equivalent particle diameter of Soil D in Skempton and Brogan (1994).

Sieve #	d_i (mm)	Percent finer (%)	$d_{ave,i}$ (mm)	f_i (%)	$f_i/d_{ave,i}$	d_{eq} (mm)
3/4 in	19	100	12.55	4	0.32	2.53
3/8 in	9.51	96	6.28	41	6.53	
4	4.75	55	2.83	38	13.41	
10	2	17	1.20	11	9.16	
20	0.85	6	0.56	5.3	9.42	
40	0.425	0.7	0.31	0.2	0.64	
60	0.25	0.5	–	0.5	–	
			Sum	100.00	39.47	

Table 2. Comparison of the d_{eq} values obtained by various approaches.

d_{is} (mm) at the finest fraction	$\Sigma f_i/d_{ave,i}$	d_{eq} (mm)	Approach
–	39.47	2.53	Exclude the fraction of the finest particles from calculating d_{eq}
0.15	42.18	2.37	Assume $d_{si} = 0.15$ mm corresponding to #100 sieve
0.06	44.14	2.27	Assume $d_{si} = 0.06$ mm as used by the discussers

Despite the uncertainty and discrepancy in determining the d_{eq} value, in the authors' opinion, all three d_{eq} values listed in Table 2 can represent the equivalent particle diameter of Soil D in Skempton and Brogan (1994), although one may argue there should be only one true answer of d_{eq}. The authors' statement can be justified by the fact that all three d_{eq} values fall between d_{50} (0.5 mm) of the fine soil component and d_{50} (4.2 mm) of the coarse soil component of Soil D. Additionally, the statistical assessment results in the discussed paper revealed that prediction methods for i_{cr} generally produce reasonable mean values ($\mu = 1.20$–1.75), indicating that the d_{eq} values determined by authors did not impose a consistent bias on the predicted i_{cr} results.

Summary

The authors respond to the comments from the two discussers on uncertainties in the internal stability criteria and the determination of input soil properties for prediction models, which affect the accuracy of i_{cr} prediction methods. Similar to many other geotechnical design problems, uncertainties from many sources are inevitable and should be properly assessed through statistical and reliability approaches. The authors also agree with the discussers' suggestion that the use of test results to determine the internal stability of soil is a more reliable approach than others. As stated on page 524 in the discussed paper, because the prediction methods for i_{cr} remain uncertain, a few supplementary experimental tests should be conducted to calibrate the input parameters of the prediction method and validate the predicted critical hydraulic gradient.

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