Corrected Field Vane Strength for Embankment Design

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Introduction

End-of-construction instability represents a serious design consideration for embankments built on soft to stiff saturated clay foundations and is principally controlled by the initial in situ undrained shear strength, s_u, of the clay. At present, estimates of s_u are frequently based on measured field vane strengths, $s_u(FV)$, which are then adjusted by the correction factor, μ^o, developed by Bjerrum (3). Based on 14 case histories of embankment failures (i.e., with a known factor of safety of unity), Bjerrum (3) computed the plane strain factor of safety, F^o, corresponding to the measured $s_u(FV)$ and recommended the $\mu^o(= 1/F^o)$ vs. plasticity index (P.I.) correction curve plotted in Fig. 1.

However, all embankment failures have "end effects"; i.e., an additional resistance due to the actual three-dimensional mode of failure, which is ignored in plane strain analyses. In this article, three-dimensional stability analyses of 18 case histories of embankment failures are performed and a new correction factor estimating the actual in situ undrained shear strength from the measured field vane strength data is proposed.

Three-Dimensional Stability of Embankments

Azzouz and Baligh (1) developed a systematic three-dimensional method to include end effects on the stability of slopes. The method considers shear surfaces of revolution consisting of ellipsoids and cones attached to cylinders instead of the infinite cylinders assumed in two-dimensional (plane strain) circular arc methods. The stability analyses are carried out using the computer program STAB3D.

Table 1 lists the case histories considered herein. They include seven

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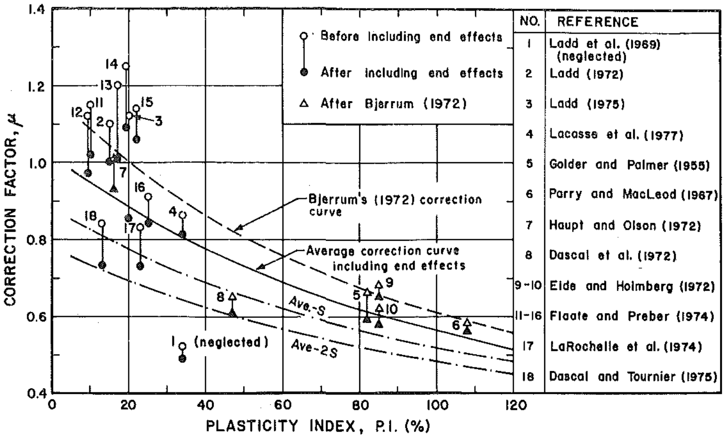

FIG. 1.—Field Vane Correction Factor

cases considered by Bjerrum and having known failure lengths (numbers 2 and 5–10). The results, presented in Table 1 and Fig. 1, were obtained in the following manner:

1. The stability was first analyzed by the conventional two-dimensional circular arc technique using the geometry and the field vane strength profiles provided in the references listed. These analyses gave values of F^o and μ^o (= $1/F^o$) and the depth of the shear surface, $DR(= R_{max} - R_{min}$; where R_{max} and R_{min} are the maximum and minimum radii of the shear surface, respectively).
2. Three-dimensional analyses were then performed for cases 1–4 using the actual loading geometry and soil profile as described by Azzouz, et al. (2). The other cases utilized the following relationship between the end effects (F/F^o) and total failure length, $2L$, normalized by $DR(2L/DR)$:

$$\frac{F}{F^o} = \left[1 + 0.7\left(\frac{DR}{2L}\right)\right] \quad (1)$$

Equation 1 represents the best fit from the curves developed by Azzouz and Baligh (1) for homogeneous slopes with different inclinations and uniform cross sections. This equation is believed to be reasonable except for unusual loading conditions. Equation 1 would yield good predictions for Case numbers 1, 2, and 4 in Table 1 (but not with case No. 3) involving the placement of additional fill on top of an existing embankment.
3. Knowing F^o and F/F^o, the three-dimensional factor of safety, F, and the correction factor $\mu = 1/F$ were computed.

Analysis

The results presented in Table 1 and Fig. 1 (solid symbols) show that end effects can have a significant influence on stability in certain cases. For example, for the I-95 embankment failure on Boston Blue Clay, (Case

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TABLE 1.—Field Vane Correction Factors

		Two-Dimensional Analysis			Three-Dimensional Analysis					
Number (1)	Plasticity index, as a percentage (2)	F^o (3)	μ^{o}[a] (4)	DR,[b] in feet (5)	$2L$,[c] in feet (6)	$2L/DR$[b] (7)	F/F^{o}[d] (8)	F (9)	μ[e] (10)	References (11)
1	34	1.92	0.52	33.5	240	7.20	1.07	2.05	0.49	Ladd, et al. (13)
2	15	0.91	1.10	42.4	300	7.10	1.10	1.00	1.00	Ladd (12)[f]
3	20	0.89	1.12	108.2	1,030	9.54	1.30	1.17	0.85	Ladd (11)
4	34	1.16	0.86	34.8	325	9.34	1.07	1.24	0.81	Lacasse, et al. (10)
5	82	1.52	0.66	32.0	215	6.72	1.11	1.69	0.59	Golder and Palmer (8)[f]
6	108	1.65	0.60	15.0	300	20.00	1.04	1.72	0.58	Parry and McLeod (15)[f]
7	16	0.99	1.01	60.0	500	8.33	1.08	1.07	0.93	Haupt and Olson (9)[f]
8	47	1.53	0.65	34.0	400	10.95	1.06	1.63	0.61	Dascal, et al. (5)[f]
9	85	1.46	0.68	22.0	250	11.36	1.06	1.55	0.65	Eide and Holmberg (6)[f]
10	85	1.61	0.62	25.5	250	9.80	1.07	1.72	0.58	Eide and Holmberg (6)[f]
11	8	0.87	1.15	10.0	54	5.40	1.13	0.98	1.02	Flaate and Preber (7)
12	8	0.89	1.12	8.8	40	4.55	1.15	1.03	0.97	Flaate and Preber (7)
13	17	0.83	1.20	10.0	50	5.00	1.14	0.99	1.01	Flaate and Preber (7)
14	20	0.80	1.25	7.6	35	4.61	1.15	0.92	1.09	Flaate and Preber (7)
15	22	0.88	1.14	6.0	50	8.33	1.07	0.94	1.06	Flaate and Preber (7)
16	25	1.10	0.91	8.7	72	8.28	1.08	1.19	0.84	Flaate and Preber (7)
17	23	1.20	0.83	20.0	100	5.00	1.14	1.37	0.73	La Rochelle, et al. (14)
18	13	1.19	0.84	60.0	282	4.70	1.15	1.37	0.73	Dascal and Tournier (4)

[a] $\mu^o = 1/F^o$.
[b] Difference between the maximum and minimum radii of the shear surface = $R_{max} - R_{min}$.
[c] $2L$ = total length of failure.
[d] F/F^o obtained from Eq. 1, except for cases 1–4.
[e] $\mu = 1/F$.
[f] Case studies considered by Bjerrum (3).
Note: 1 ft = 0.305 m.

3 in Table 1), $F^o = 0.89$ and $F = 1.17$. Without consideration of end effects, Bjerrum's method predicts $\mu^o = 1/0.89 = 1.12$, whereas the actual value to provide the best estimate of the in situ shear strength should be based on $\mu = 1/1.17 = 0.85$. The latter value of μ is believed to be more appropriate for use in the design of embankments on Boston Blue Clay and for comparisons with other methods of estimating the in situ s_u; e.g. from cone penetration tests or SHANSEP laboratory testing.

With the exception of the aforementioned embankment failure which was subjected to unusual loading conditions, end effects increased the plane strain factor of safety by about 10 ± 5%. The solid curve in Fig. 1 represents the least squares fit for the 17 cases considered based on a linear regression analysis between $1/\mu$ vs. plasticity index (P.I.). The curves drawn for minus one and two standard deviations from this average give an indication of the scatter associated with this new relationship.

Conclusions

1. Three-dimensional stability analyses of 18 case histories of embankment failures show that end effects generally increase the conventional plane strain factor of safety by 10 ± 5%. Equation 1 presents a simple means for estimating the influence of end effects for typical embankment geometries.

2. Figure 1 presents a revised field vane correction factor vs. plasticity index relationship that considers the influence of end effects. This new relationship: (1) Gives corrected field vane strengths about 10% lower than recommended by Bjerrum in 1972; (2) should represent a better estimate of the "true" in situ undrained strength for comparison with other approaches such as from cone penetration tests or SHANSEP laboratory testing; and (3) is recommended for use in stability evaluations based on corrected field vane strength data for field situations approaching a plane strain mode of failure or when the designer wants to explicitly consider the influence of end effects.

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POROUS MEDIUM DEFORMATION IN MULTIPHASE FLOW

By J. Bear[1] and George F. Pinder[2]

In order to obtain a complete mathematical statement of multiphase flow (say, simultaneous flow of oil and water) in a deformable porous medium at the macroscopic level, Bear and Pinder (3) start by stating the problem at the microscopic level and then average the microscopic description to obtain a macroscopic one. By following this procedure, (e.g., Refs. 2, 4, and 5) they obtain a complete mathematical statement of the problem.

The analysis leads to the introduction of the effects of surface tension between phases, and especially the capillary pressure between the fluid

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