An Investigation of Slide in a Test Trench Excavated in Fissured Sensitive Marine Clay

Recherche sur les glissements dans une tranchée d'essai, creusée dans une argile marine fissurée et sensible au remaniement

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Summary

Several slides in the excavated slope of a test trench in the weathered lightly over-consolidated fissured crust of a sensitive marine clay are described and analysed. The analyses were carried out in terms of total stresses; comparison is made between shear strength values as determined by compression tests, by field vane tests and by the stability computations. Reference is made to the results of vane calibration tests.

No significant difference was observed between the results of triaxial and unconfined compression tests. Vane test results were consistently in excess of compression test results for samples obtained below about 10 feet. Although the vane test values are assumed correct, their use in the analysis would result in a factor of safety as high as 70 per cent on the unsafe side.

Sommaire

Plusieurs glissements du talus d'une tranchée d'essai creusée dans la croûte fissurée, altérée et légèrement surconsolidée d'une argile marine, sensible au remaniement, sont décrits et analysés.

On a fait chaque analyse en contraintes totales ; la comparaison a été effectuée entre les valeurs de la résistance au cisaillement déterminées par essais de compression, par essais in situ au moyen des moulinets, et par le calcul de la stabilité. Les résultats des essais de l'étalonnage des moulinets sont indiqués.

On n'a pas pu discerner de différence significative entre les résultats des essais triaxiaux et ceux des essais de compression simple. Les résultats des essais avec des moulinets se montraient constamment supérieurs aux résultats des essais de compression, pour les échantillons obtenus à une profondeur de plus de dix pieds environ. Bien que l'on suppose justes les valeurs des essais avec des moulinets, l'emploi de ces valeurs dans les calculs aboutirait à augmenter le coefficient de sécurité, jusqu'à 70 pour cent, côté dangereux.

Introduction

Extensive deposits of sensitive post glacial marine clay were encountered during construction of the St. Lawrence Power and Seaway developments. The clay is commonly called Leda clay, Laurentian clay, or Massena clay and numerous references to it appear in the literature. It has been referred to specifically in terms of the Seaway work by Burke and Davis (1957) where both the topography and geology of the area are briefly described.

The upper surface of the clay deposits is usually weathered, lightly over-consolidated and fissured to a depth typically in the order of 20 to 30 feet. Only this surface material was involved in much of the engineering work and discussion in this paper is limited specifically to this fissured crust.

Sampling and testing of samples throughout the sensitive clay deposits presented difficulties and doubt existed as to the application of test results to field problems. Field vane tests were used as a means of avoiding sample disturbance but these usually gave values of strength well in excess of laboratory compression tests. This resulted in a marked reluctance to rely too heavily upon them in design.

The clay was generally non-uniform and the inevitable scatter of test results tended to frustrate attempts to determine the best sampling and testing procedures by means of comparative testing programs. One such test series will be described, however, in which the results of field vane tests and laboratory compression tests were compared.

The outstanding effort to resolve the testing and design difficulties encountered with the clay was the excavation of the Massena Test Trench which was referred to by Burke and Davis. When first examined, the data obtained from the test trench were disappointing, but a more recent analysis of this data forms the major basis of this paper.

Vane Calibration

A test plot was selected near the Ontario Hydro construction offices at Cornwall, Ontario, to carry out in-situ vane tests and to obtain samples for triaxial tests.

Two types of vane were used. The first was the Bishop Vane as described by Skempton (1948) with which strain rate could be accurately controlled. The second was a vane turned by two spring-steel handles whose deflection indicated resisting torque. Control of strain rate was difficult with this vane and failure normally was quite rapid.

Samples were taken at depths of 7 to 8 feet with conventional Shelby tube samplers without piston. In-situ vane tests were carried out at the same depth. Undrained compression tests were performed in the triaxial machine on unconsolidated samples at a confining pressure of 5 psi.

The averaged results of all tests are summarized in Table 1. No significant difference was noted in the results of laboratory compression tests run on any specific portion of the tube samples. No significant difference was noted in the strength values obtained with each of the two vanes nor

Table 1
Correlation of Compression and Vane Tests
Corrélation des essais de compression et des essais avec des moulinets

Test Method	*Shear Strength* tsf	*No. of Tests*
Triaxial undrained $\sigma_3 = 5$ psi, rate $= 0{\cdot}05$ in./min	.345	30
Field vane	.355	23

did variations of strain rate from failure in about 45 seconds to failure in 10 to 15 minutes have an appreciable effect. Of most importance the vane and compression tests gave practically identical results.

Following these tests only the spring-type vane was used for in-situ strength tests because of its simplicity of application. The rate of strain chosen resulted in failure in 3-4 minutes. No correction was applied to the vane results.

Massena Test Trench

The test trench was intended to establish the relationship in marine clay between test results obtained by various techniques and full-scale field behaviour. The work was carried out under the direct control of the U.S. Army Corps of Engineers following initial discussions between engineers of the various authorities engaged in the Seaway and Power developments, namely, the U.S. Army Corps of Engineers, the Power Authority of the State of New York, the St. Lawrence Seaway Anthority and The Hydro-Electric Power Commission of Ontario. Boring and sampling were carried out prior to excavation by or on behalf of each of the authorities. The test results used in the analysis described below are exclusively those obtained by the Canadian authorities. These results however, are believed not to differ substantially from those obtained by the United States agencies.

The site was located about 3 miles northeast of Massena, New York, near the Long Sault canal. It was chosen as having a deep deposit of relatievely uniform clay. The area was initially covered by about one foot of water but was drained before excavation.

Twenty-one boreholes were put down in the area. Generally continuous soil sampling was carried out with thin-walled tubes. A number of conventional fixed piston samplers were also used. In a few of the borings, vane tests were made on both undisturbed and remoulded clay. The borings showed that clay extended to depths of about 60 feet to glacial till. Most of the borings were sampled only to a depth of 40 feet.

A typical soil profile is shown on Fig. 1. The clay was fissured and had a blocky structure. The results of classification tests appear also on Fig. 1. The water content was consistently above the liquid limit and the liquidity index

$$\frac{w - P_L}{P_I}$$

was constant and below a depth of about 13 feet was equal to 1·5. Dessication of the clay to about 20 feet was indicated.

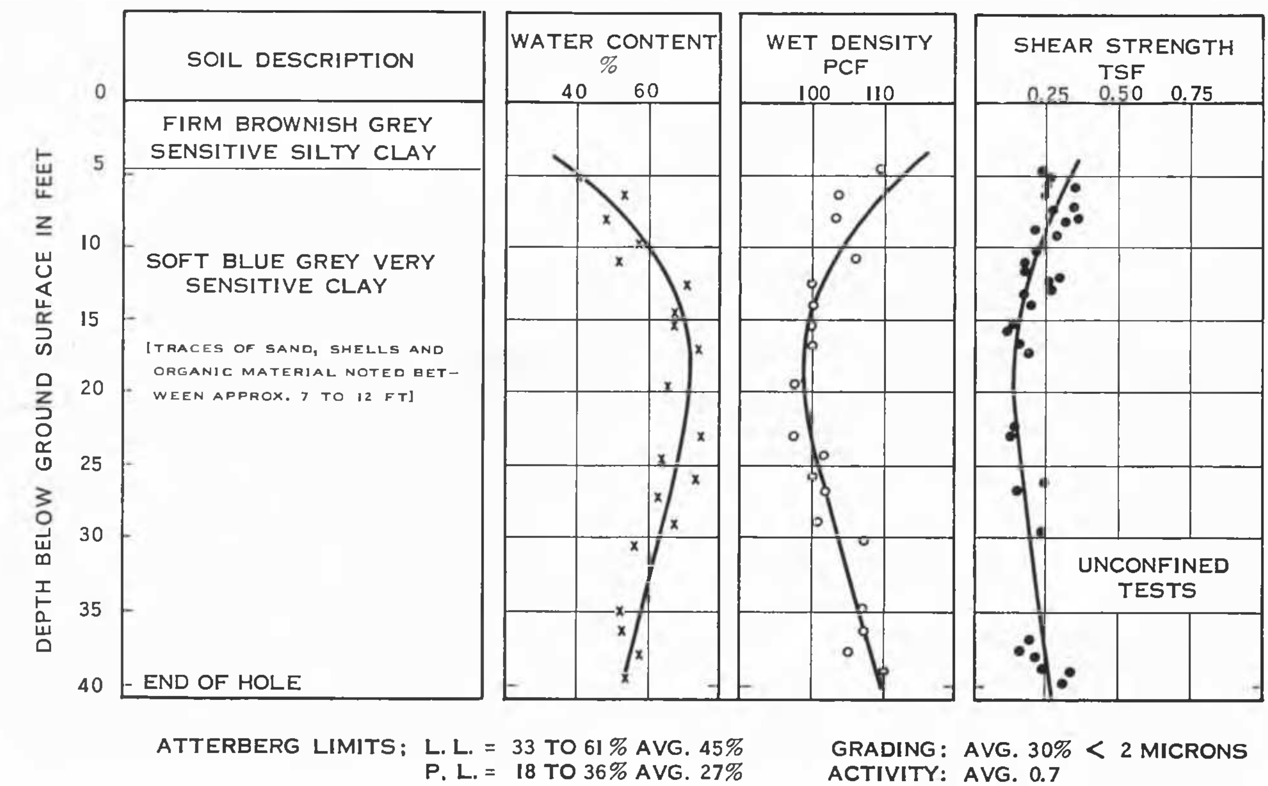

Fig. 1 Soil profile, Borehole T7S - Massena test trench site.
Profil du sol - Trou de sondage T7S - Site de la tranchée d'essai à Masséna.

Unconfined compression and unconsolidated undrained triaxial tests were run on specimens from each tube at a rate of 0·05 inch/minute (samples 4 and 5 inches in length); the shear strength was taken as one-half the deviator stress. The confining pressures used in triaxial tests approximated the over burden pressure. It was usual for failure to occur at a small strain; failure at a large strain could normally be attributed to obvious sample disturbance or to the effect of fissures. It was arbitrarily considered that any failure occurring at more than 3 per cent strain was indicative of sample disturbance, and all results quoted are for samples failing at less than 3 per cent strain. On this basis the average strength as determined from the unconfined compression test was found to be substantially the same as that determined from the triaxial test.

A plot of unconfined compression shear strength values versus depth for Borehole T 7 S is shown on Fig. 1. The approximate limits of the average shear strength values for 4 boreholes as determined from both unconfined and triaxial tests are plotted versus depth on Fig. 2.

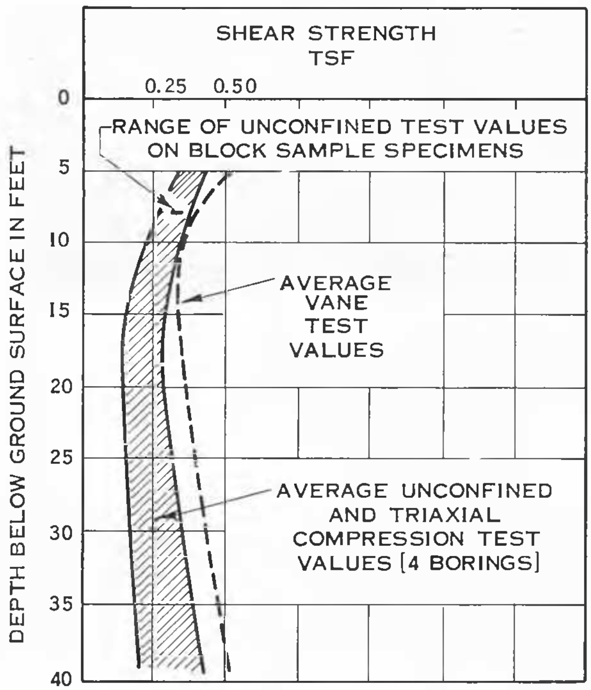

Fig. 2 Average shear strength results.
Résultats des résistances moyennes au cisaillement.

In order to check the effect of sampling disturbance, nine unconfined compression tests were run on samples carefully trimmed from a block sample taken at a depth of about 8 feet. The shear strength values from all specimens were between 0·31 and 0·34 tsf, and compared favourably with the compression strengths used in plotting the graph in Fig. 2.

In-situ vane tests were carried out in two borings, the vane being advanced about one foot past the cased borehole. The results are shown graphically on Fig. 2. The remoulded strength was obtained by rotating the vane at constant depth through six revolutions, allowing one-half minute rest and remeasuring the shear strength. The sensitivity of the clay on this basis was found to average about 7. An increased number of revolutions of the vane and a waiting period less than one-half minute both contributed to decreased strengths and resulted in a limiting sensitivity about double the quoted figure.

Following the site investigation the test trench area was stripped to a depth of about 5 feet. The trench was excavated by two draglines, one operating from each end of the trench. The depth was kept constant along a 50-foot length and the face was maintained at a batter of about 7·5 degrees from the vertical. Excavation was continued until slides occurred. Initially two minor slides occurred when the excavation was at a depth of about 15 feet. The slide material was then cleared away and the trench deepened. When the depth reached was about 22 feet, two major slides occurred. Two additional slides occurred before removal of the initial slide material was completed. Excavation was carried over a period of five days, the first slide occurring on the third day.

Observation indicated that the failure surface of the slides consisted of a vertical tension crack 5 to 8 feet deep and a circular sheared surface passing through the toe of the slope. Fig. 3 shows a plan and sections of the trench and also the extent of the individual slides. A photograph of the trench excavation at completion is shown as Fig. 4.

Total stress analyses were carried out for slides 1, 3 and 4. For purposes of the analysis a 6-foot tension crack was assumed, without water thrust. Conventional slip circle analyses were carried out for slides 1, 3 and 4 using the modification of the method of slices proposed by May (1936). The observed failure surfaces were ignored and numerous trial circles were drawn in a search for the least factor of safety. Wedge analyses were also carried out. These were extremely simple to perform and tended to give answers approximating the circular failure surfaces. It may be noted that the purpose of the wedge analyses was primarily to provide a simple means of carrying out effective stress analyses in which the pore pressure assumptions could be easily varied. In the absence of field pore pressure measurements this phase of the analysis has proved to be unsatisfactory and will probably remain so unless an adequate means of estimating pore pressures from a stress analysis of the material surrounding the excavation becomes available.

The results of the total stress analyses are shown both in terms of required shear strength and as calculated factors of safety in Table 2. It can be seen that factors of safety

Table 2
Summary of Stability Analyses
Résumé des calculs de stabilité

Slide No.	*Depth of Slide*	*Req'd Shear Strength for F = 1*	*Compression Tests*		*Vane Tests*	
			Available Shear Str.	*Factor of Safety*	*Available Shear Str.*	*Factor of Safety*
		tsf	tsf		tsf	
1	14·5	0·21	0·22	1·0(5)	0·35	1·6(6)
3	21·5	0·30	0·22	0·7(3)	0·37	1·2(3)
4	21·8	0·26	0·22	0·8(5)	0·37	1·4(2)

Fig. 3 Location of slides - Massena test trench.
Emplacement des glissements - Tranchée d'essai à Masséna.

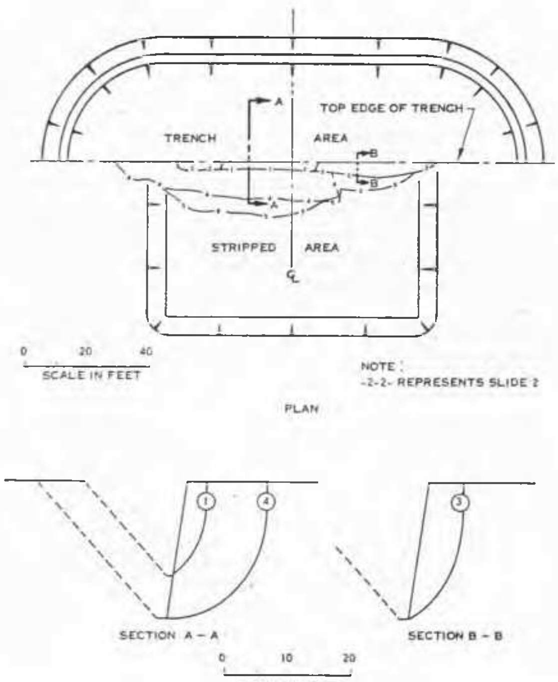

Fig 4 Test trench after failure.
Tranchée d'essai après la rupture.

obtained by use of the vane test data were consistently high, i.e., on the unsafe side, varying between 1·2 and 1·7. These results are moderatelly sensitive to variations in the depth of tension crack; a 2-foot variation in the tension crack affected the calculated factor of safety by about 10 per cent.

Discussion

The vane tests in careful comparison with compression tests at shallow depths gave substantially the same results and there appears no reason to doubt the validity of the vane tests (Bjerrum, 1954). It may be noted that at the test trench, the results of vane tests above a depth of about 10 feet were in reasonable agreement with compression test results on samples taken from corresponding depths.

Below a depth of about 10 feet however, the vane and compression test results diverged, the average compression results being consistently less than the vane results. This is typical of experience with the vane and has been frequently reported, for example by Carlson (1948). Bjerrum (1954) also noted the divergence but found that with very careful sampling and testing techniques a close relationship between the two tests could be obtained to depths of about 80 feet (25 metres). The difference between the two tests is usually attributed to the effect of sample disturbance or stress relief on the compression test results.

The results of compression tests did not correspond to calculations of the slope stability but their use in analysis would be conservative. The use of the vane measurements resulted in a serious overestimate of stability. The degree of error was not consistent for the three slides analyzed even with allowances for a reasonable error in the assumed depth of tension crack.

It is believed that the vane tests are accurate and that the discrepancy with field behaviour follows the allowance of stress relief or lateral expansion of the material in the side of the excavation. For discussion of this point reference may be made to BJERRUM (1955). The stress relief may be accompanied by dissipation of pore water pressures at the fissures and some confirmation of this concept is provided by DIBIAGIO and BJERRUM (1955) who have reported a rapid change of pore pressures in a fissured clay during excavation of the Oslo test trench.

Conclusions

In the analysis of 3 slips in a test trench involving fissured sensitive marine clay, the use of vane test values resulted in factors of safety on the unsafe side involving errors as great as 70 per cent. It is argued that stress relief has altered conditions in the embankment.

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