LANDSLIDES IN SENSITIVE MARINE CLAY IN EASTERN CANADA

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A brief review of the regional aspects of the landslide problem in the St. Lawrence River lowlands is presented. More detailed studies of landslides in the area around Ottawa are stressed. A method of analysis for slopes is suggested in which particular attention is given to the weathered surface layers of the clay. Some of the conditions leading to large retrogressive landslides are considered.

•THE ST. LAWRENCE RIVER lowlands have extensive deposits of sensitive postglacial marine clay prone to landslide activity. In this respect many similarities exist between the situation in eastern Canada and that in Norway and Sweden. Certain areas have a history of very large landslides of the earthflow type; the most noteworthy recent landslide, which occurred at Saint Jean Vianney in May 1971, resulted in the loss of 31 lives and involved several million cubic yards of clay (30). In such areas the location of transportation routes requires more than the normal geotechnical study. For example, eight bridge sites were investigated for a crossing of the South Nation River in eastern Ontario; several of these sites were rejected because of the dangers presented by a possible earthflow. In May 1971 a large earthflow occurred close to one of the rejected sites (9).

During the past 20 years a number of investigators have conducted detailed geotechnical studies in areas of intense landslide activity. These studies indicate that regional differences exist in the characteristics of the deposits and in the type of landslide activity. This paper reviews certain regional aspects of the problem but concentrates on the analysis of the landslide phenomenon in the Ottawa area. Two examples of earthflows and several smaller landslides will be used to demonstrate the behavior of the Ottawa area Champlain Sea clays in landslides.

REGIONAL FEATURES

An appreciation of the geological history of the sensitive marine clays of the Champlain Sea may be gained from various papers (10, 11, 12, 16). Chagnon (4) prepared an inventory of documented landslides in the province of Quebec; La Rochelle, Chagnon, and Lefebvre (21) extended Chagnon's work by using photogrammetric studies and discussed the landslide problems in Quebec. The major areas of intensive landslide activity are shown in Figure 1. If known landslides in the Champlain Sea clay areas of eastern Ontario were added to Chagnon's inventory, the number of past occurrences would exceed 700. Published information on 50 large flowslides indicates a total loss close to 100 lives and approaching 10,000 acres of uplands.

Although all of these landslides occurred in clay deposits of the Champlain Sea, important regional differences exist in the physical properties of the clays. For example, the consolidation of the clay varies from normally consolidated to an overconsolidation of 10 tons/ft^2 (9.76 kg/cm^2). Plasticity varies from very weakly plastic to plasticity indexes of 40. The one common property is high sensitivity or loss of strength upon disturbance.

Although no generalization is justified without complete knowledge of the geology of a particular basin, the clays occurring along the Saguenay River and lower St. Lawrence valley appear to be either heavily overconsolidated or very strongly cemented or both. The mechanical behavior of such clays is described in some detail by Loiselle, Massiera, and Sainani (23) and Townsend, Sangrey, and Walker (31). The landslide on the Toulnustouc River (5) and the Saint Jean Vianney landslide (20) occurred in these relatively stiff sensitive clays.

In the central St. Lawrence lowland, the clays tend to be softer and only lightly overconsolidated (11). This area has many extensive clay plains of low relief and rather poor drainage conditions. Some stream courses, such as the Maskinonge, show scars of many landslides, frequently side by side (Fig. 2). Karrow (17) describes the landslide problem on two topographic map sheets from the area, and La Rochelle and his coworkers (21) illustrate the situation along the Yamaska River. Other landslides that have been documented from the region occurred at St. Thuribe (28) and at Nicolet (2, 13).

The Ottawa River valley, because of its higher elevation, may in general tend to have better drainage conditions than the area east of Montreal. Many clay slopes in the Ottawa area have developed a weathered crust of clay that is considerably stronger than the underlying clay. The crust may extend to depths of 10 to 20 ft, and a part of the initial slip develops in this weathered material. The Ottawa area clays also have a postglacial history of erosion and redeposition due to influx of fresh water from the Great Lakes through the Ottawa River at one stage (10). Redeposited clays overlie the marine clays to significant depths, and most of the landsliding is thought to develop in the redeposited materials. Sangrey and Paul (29) discuss this situation as it pertains to the Green Creek valley east of Ottawa.

Although some of the marine clays in the Ottawa area exhibit a brittle type of behavior (5), the redeposited clays and the clays in the weathered crust show a dilatant frictional type of shear behavior under low normal stress levels, such as prevail in the initial stages of a landslide. This type of shear mechanism has been demonstrated by Jarrett (15) and Ladanyi and Archambault (19) as well as by the present authors (7). The shear mechanism is considered to arise because of inherent defects or planes of weakness in the clay and results in a curved failure envelope. In many cases the landslide activity is confined to one or two slips (Fig. 3). The debris from such slides has a granular-like appearance and is composed mainly of fissured clay. Occasionally large-scale retrogressive failures follow the initial slip, with the softer, more sensitive, underlying clay becoming involved, and large earthflows develop such as the South Nation River landslide (Fig. 4). In such cases much of the debris becomes completely remolded with only the dry surface layers remaining intact as blocks in a mass of semifluid material.

LANDSLIDE ANALYSES

Initial Sliding

For the curved failure envelope generally found to be applicable to initial slope failure in the Ottawa valley the empirical strength parameters c' and ϕ' are variables that depend on the effective normal stress. c' and ϕ' are apparent strength parameters determined in drained triaxial strength tests in the appropriate range of normal stresses. These apparent properties reflect the dilatant tendencies of the material, such as described by Ladanyi and Archambault (19). Although it is possible to develop analytical procedures for variable strength parameters, the critical stress curve method or a linear approximation of the curved failure envelope over the appropriate stress range is an acceptable alternative in computing factors of safety.

The critical stress curve method can be facilitated by the use of computers; a direct solution to Bishop's equation will yield the value of c' that gives a factor of safety of unity for a given ϕ' and given slope conditions. Various combinations of c' and ϕ' giving a factor of safety of unity for the critical circle will define a critical stress point in (τ, σ_n') space. The critical stress curve joins critical stress points calculated for circles found to be critical for the range of ϕ' values applicable to the curved strength envelope. This subroutine has been programmed by Arseneault (1), and the program was later modified to incorporate a variable r_u parameter (7), where r_u is the pore pressure ratio as defined by Bishop and Morgenstern (3).

Figure 1. Marine clay and landslide distribution in Quebec (21).

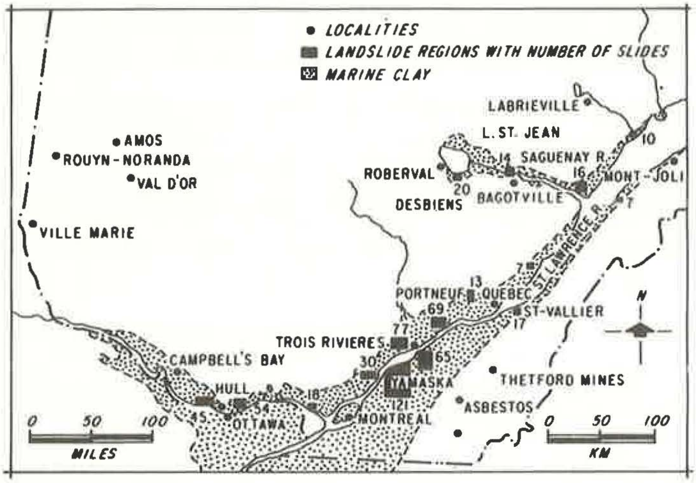

Figure 2. Landslide scars along Maskinonge River (RCAF photograph).

Figure 3. Landslide on Green Creek, 1971.

Figure 4. South Nation River landslide, 1971.

Typical results from a critical stress curve analysis are shown in Figure 5. Limiting equilibrium is predicted when the slope conditions are such that the critical stress curve becomes tangent to or coincident with the failure envelope. The latter condition, indicating that a number of slip circles reach critical equilibrium at the same time, is often found to be the case when retrogressive failures have followed initial sliding. The minimum factor of safety can be obtained as the minimum ratio $\tau/\bar{\tau}$, where τ is the shear strength at a given value of σ_n' and $\bar{\tau}$ is the average shear strength required for stability and is obtained from the critical stress curve at that value of σ_n'. If it is shown that factors of safety can be predicted to greater accuracy than obtained by this graphical method, these factors can be calculated for the critical circles by means of an iterative subroutine. The graphical method facilitates direct comparison of stability of slopes with variable r_u factors and variable strength parameters.

A number of documented slope failures in the Ottawa area have been analyzed by using this method; relevant data are given in Table 1. A calculated factor of safety close to unity was found to correspond, in most cases, to hydrostatic saturation of the slope. Tension cracks have been noted prior to failure (26), and hydrostatic saturation may be due to surface water infiltration into these openings. Eden (6) describes a case where surface water was observed entering the soil via tension cracks a few hours prior to failure of the slope.

The large variations in the values of c' and ϕ' used in the analyses given in Table 1 result from the variations in average depth of failures, hence the point of tangency of the critical stress curve and the curved failure envelope. Actual variations in soil strength from various sites in the Ottawa valley region are shown in Figure 6. The data in Figure 6 include a variety of sample sizes, sample orientations, and type of samples (block and tube samples); little, if any, reduction in shearing resistance after failure occurs in this stress range (25). There are a few outcroppings of the intact marine clay in the Ottawa valley (10, 29), and these clays yield a peak strength envelope, represented by the dashed line in Figure 6, with considerable loss in shearing resistance after peak strength. A 30 percent variation in strength of samples obtained from different sites is shown in Figure 6. Detailed strength testing is necessary at any given site if usually accepted factors of safety (1.2 to 1.5) for long-term slope stability are to be used. These data also indicate that $\phi' \geq 55$ deg for $c' = 0$, where ϕ' is the apparent angle of obliquity.

The depth of initial failure in most of the cases documented is considered to extend below the depth of active weathering. For a curved failure criterion, the depth and location of the critical circle depend mainly on the slope geometry and any adverse groundwater conditions. Three examples will serve to indicate this dependence.

Breckenridge Landslide, 1963—A critical circle encompassing the entire slope at Breckenridge and giving a factor of safety of about 1.05 is predicted on the computer by using the average measured groundwater conditions ($r_u = 0.4$). When the variation in groundwater pressure was considered and by using the variable r_u program, a calculated factor of safety of 0.98 was obtained and the critical circle was predicted to emerge about midway up the slope (7). The position of this predicted circle satisfies the kinematic restrictions suggested by Kenney and Ali (18). This example shows that the location of the critical circle is dependent on variations in r_u, a factor of importance in considering stabilization methods and the possibility of retrogression.

South Nation River Landslide, 1971—Almost ½ mile of initial failure at this site occurred in slopes with profiles as shown in Figure 7. An analysis of the overall slope yields a factor of safety of about 1.5. It is known, however, that the failure occurred under drawdown conditions (9). When a toe failure was considered (using $r_u = \gamma_w/\gamma_{soil}$ to approximate rapid drawdown), a factor of safety of 1.02 was obtained. Table 1 shows that an identical factor of safety was obtained for a uniform 20-deg slope that failed near the southwesterly limits of this landslide. The strength parameters applicable to these two failures in exactly the same material are different because of the different depths of material involved in the initial slide. This example shows the importance of allowing sufficient latitude in the search area and considering the experimental variations of c' and ϕ' when slopes with variable two-dimensional geometry are analyzed. The relevant critical circles are shown in Figure 7.

Figure 5. Critical stress curve analysis.

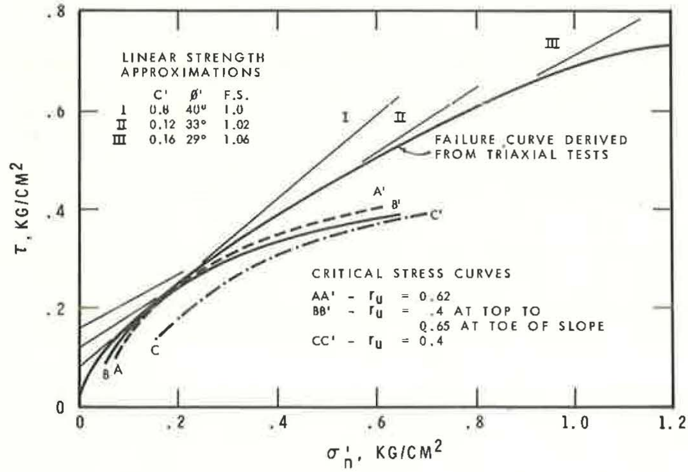

Table 1. Details of landslide analyses.

Slope Failure	Height of Slope (m)	Average Slope Angle (deg)	Critical Strength Parameters: c' (kg/cm²)	Critical Strength Parameters: ø' (deg)	r_u	Remarks	Calculated Factor of Safety
Breckenridge, 1963 (25)	28	24	0.06	35	0.4 to 0.65	Piezometer readings; artesian toe pressure	1.05 0.98
Rockcliffe, 1967 (25)	12	27	0.12	33	0.62	Hydrostatic saturation indicated	1.02
Orleans, 1965 (8)	10	35	0.11	34.5	0.59	Assumed hydrostatic saturation	0.95
Rockcliffe, 1969 (27)	12	24	0.092	36.8	0.62	Assumed hydrostatic saturation	0.99
Green Creek, 1955 (27)	18	19	0.05	41.5	0.6	Assumed hydrostatic saturation	1.05
Green Creek, 1971 (26)	10	25	0.10	36	0.6	Assumed hydrostatic saturation	0.96
Breckenridge, 1970 (26)	26	22	0	55[a]	0.62	Assumed hydrostatic saturation	1.0[b]
South Nation River (9)	9 20	29 20	0.09 0.14	36 27	0.60 0.54	Assumed hydrostatic saturation	1.02 1.02

[a] ø' calculated with c' = 0. [b] Assumed.

Figure 6. Strength data for several sites in Ottawa area.

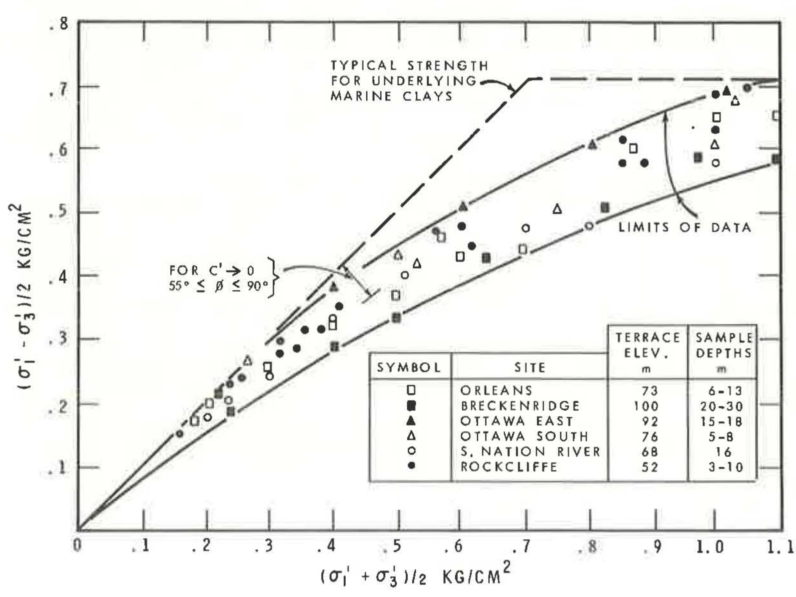

Figure 7. South Nation River landslide analysis.

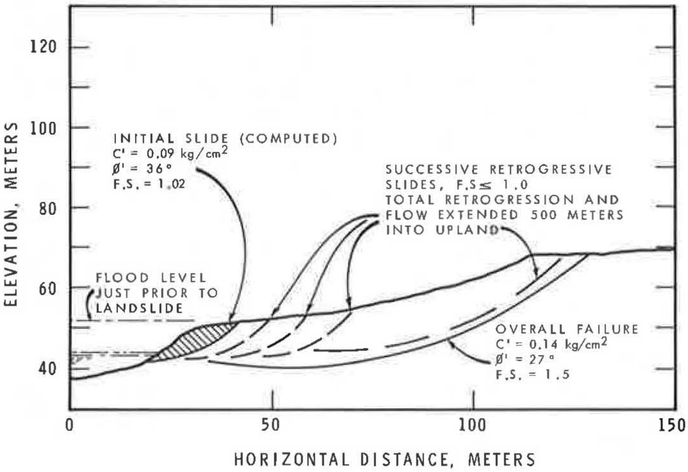

Figure 8. Infinite slope type of failure, Breckenridge Creek.

Breckenridge Landslide, 1970—If the curved failure envelope in Figure 6 is presumed to pass through the origin of coordinates, the critical circle may be surficial; surficial sloughing is noted in actively eroding slopes with little vegetative cover, but several documented initial failures approximate reasonably well to circular arc sliding (8, 27). The end condition at the toe, stiffer weathered crustal material, and reinforcing root structures are factors that make surficial infinite slope failure less critical. Where sufficient removal of toe support occurs because of natural erosion or construction activities, infinite slope sliding may occur; an example of this type of sliding on the Breckenridge Creek is reported by Mitchell and Eden (26) and is shown in Figure 8. By using the equation for infinite slope sliding (2), with $r_u = \gamma_w/\gamma$ and $\beta = 22$ deg (conditions applicable to this failure), a value of $\phi' = 55\frac{1}{2}$ deg is obtained at critical equilibrium (factor of safety = unity). Analyzed by using the values of c' and ϕ' applicable to the 1963 Breckenridge landslide, a factor of safety in excess of unity would be obtained for the critical circle.

The 10 analyses of slope failures given in Table 1 were carried out using strength data from laboratory tests. Calculated factors of safety are 1 ±0.05. These data suggest that the long-term factor of safety of a slope in the Ottawa area can be calculated with some confidence by using the approach outlined above.

Retrogressive Sliding

Early Canadian geological literature contains many classic descriptions of large landslides in the Champlain Sea clays. Very little information about soils is contained in these reports and the geotechnical research effort has been concerned mainly with mapping areas of known slide activity (14, 21). Meyerhof (24), however, presents and compares some soils data from various large landslides. The occurrence of two very large landslides in the spring of 1971—the Saint Jean Vianney slide (30) and the South Nation River slide (9)—provided opportunities for the soils conditions at the sites of these landslides to be investigated. Because these investigations are still in progress, the discussion herein will be restricted to a description of retrogressive mechanisms.

Eden and Mitchell (7) showed that computed factors of safety for circular arc retrogression following initial slope failure are significantly less than unity in cases where field observations indicated that retrogressive sliding did occur. Stability analysis based on drained test data cannot, however, be extended to multiple retrogressions; after several retrogressive slides have developed, further retrogression must be treated as a "short-term" undrained stability problem. Elements of soil are sheared undrained from the in situ K_o condition, and the peak shearing resistance is represented, for Champlain Sea clays, by a cementation strength (5, 31). Because the cementation strength is in excess of the frictional strength commensurate with the in situ voids ratio, a reduction in shearing resistance in undrained tests is observed after the peak strength. Such strain-softening characteristics should be considered if accurate factors of safety are to be calculated for undrained slope failures. A method for developing local residual factors to be applied in the standard upper bound solution to short-term slope stability in Champlain Sea clay has been presented by Lawrence (22).

Field evidence indicates that spoil from large retrogressive landslides is largely remolded and exhibits viscous or plastic flow. These landslides are generally associated with soft underlying materials or with interbedded silts and fine sands. It would appear that the failure mechanism involves extrusion and/or liquefaction. Extrusion may occur where the material is cohesive (largely clay minerals), whereas liquefaction is a possible mechanism when loose silts and sands are interbedded with the clays. An elastic, perfectly plastic, finite-element stress analysis for slopes in Champlain Sea clay (22) indicates that a confined plastic zone (yielded zone) would form near the base of a slope and would extend to a free boundary near the toe (such that extrusion would occur) when the factor of safety, based on upper bound analyses, approached unity. Strain softening would lead to greater yielding and earlier extrusion. Landslides that continue to retrogress in an undrained manner by either extrusion or liquefaction are termed "flowslides."

It is believed that all landslides in the Ottawa area were initiated by a single rotational slide. In many cases several retrogressive slices failed, but the slope height was insufficient to cause undrained failure and the retrogression was terminated. In a few cases the retrogression developed into a flowslide.

At least one case record indicates that large landslides may develop by mechanisms other than flowsliding. A landslide on the Toulnustouc River, Quebec, involving about 5 million cubic yards of Champlain Sea deposits, is considered to have developed as a progressive, infinite slope type of slide (5). The deposits at the site of the slide are interbedded overconsolidated silts and clay silts that dip at a maximum angle of 10 deg toward the Toulnustouc River. The failure plane is considered to have followed the bedding planes. This case record indicates that progressive failure at or near residual strength may develop under the appropriate geological conditions. As already mentioned, the Ottawa area Champlain Sea deposits are normally lightly overconsolidated and the mechanism of progressive sliding is not considered relevant.

DESIGN AND CONTROL CONSIDERATIONS

High groundwater pressures and active toe erosion appear to be the major natural factors that cause a slope to become unstable. Ideally, pore water pressure measurements should be taken when the stability of a slope is evaluated; such measurements are considered essential if there is any indication of artesian conditions. Mitchell and Eden (26) measured deep-seated creep movements in slopes where the calculated factor of safety was less than 1.25. The possibility of creep movements opening up tension cracks and permitting the direct entry of surface water to critical zones, thus promoting failure, must be considered. If the calculated factor of safety of a slope, where r_u is everywhere less than γ_w/γ, is less than about 1.5, it is recommended that the long-term factor of safety of that slope be evaluated by using $r_u = \gamma_w/\gamma$ (full hydrostatic saturation). If tension cracks are noted in a slope it would be advisable to cover or seal them with relatively impervious materials until permanent stabilization methods can be adopted. The writers know of several slopes in the Ottawa area where tension cracks were visible 1 or 2 years prior to slope failure. Testing of soils in the low stress range (under low confining pressures) and considering the variance of c' and ϕ' with confining pressure at failure are necessary if the minimum factor of safety for a given slope is to be obtained from an analysis.

A large measured frictional component of strength and the general high groundwater conditions in natural slopes suggest that toe drains may be useful in ensuring the stability of slopes. A small slope failure occurred just east of Ottawa in May 1972, but similar adjacent slopes with toe drains remained stable. The toe drains had been installed in connection with a development close to the slope terrace. No other field experience with this type of drain in the Ottawa area is known to the writers.

Possible future erosion of the toe must be considered when the long-term stability of river banks is evaluated. A section of the south bank of the Ottawa River is currently being stabilized against ice and water erosion with rock from excavations in downtown Ottawa. Cooperative endeavors such as this would appear to provide an economical answer to eventual stabilization of natural slopes on well-developed river banks. In actively eroding river systems, where erosion will inevitably initiate sliding, measures of controlling or preventing retrogression and/or flowsliding may be possible. Landslide warning systems perhaps similar to systems used in the mining industry to warn against rock bursts should be developed in hopes of preventing loss of life due to flowsliding.

CONCLUSIONS

In this paper, the authors have attempted to describe some of the facets of the landslide problem in the marine clay deposits of eastern Canada. The importance of local geological conditions has been indicated by reference to several landslides studied in the Ottawa area. The type and extent of the landslide are determined by the prevailing local geology. From a study of a number of landslides, an analytical and testing procedure has been found that has been reasonably successful in its application to stability problems. Although the detailed sampling and testing required in the application of these procedures may not be applicable to all routine slope stability investigations, an understanding of the concepts of a highly frictional behavior and dilatancy at low stress levels and a curved failure envelope may assist in assessing remedial measures such as slope flattening, toe berms, or drainage provisions. In studies of critical slopes, detailed testing and analysis should be justified so that a better correlation can be conducted against the existing background of information.

When detailed investigations indicate that a failure may occur, the consequences of subsequent retrogression and a possible flowslide must be considered. Until the mechanisms and conditions leading to retrogression are better understood, the mapping of areas of past retrogressive landslide activity appears to be the best approach for planning purposes.

In summary this paper has attempted to demonstrate that

1. Local geological conditions are important to the type and extent of landslide activity;
2. The initial phases of a landslide frequently take place in fissured clay, which behaves in a distinct manner;
3. No single shear failure criterion is valid because failure may develop simultaneously on a number of planes; and
4. The possibility of retrogressive landslides and large earthflows must be considered.

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REFERENCES

1. Arseneault, J. G. A Program for Solving Slope Stability Problems. National Research Council of Canada, Div. of Building Research, Comp. Prog. 27, Ottawa, 1967.
2. Béland, J. Nicolet Landslide, November 1955. Proc. Geological Association of Canada, Vol. 8, Pt. 1, 1956, pp. 143-156.
3. Bishop, A. W., and Morgenstern, N. R. Stability Coefficients for Earth Slopes. Geotechnique, Vol. 10, No. 4, 1960, pp. 129-150.
4. Chagnon, J-Y. Les Coulées d'Argile dans la Province de Quebec. Naturaliste Can., Vol. 95, 1968, pp. 1327-1343.
5. Conlon, R. J. Landslide on the Toulnustouc River, Quebec. Canadian Geotechnical Jour., Vol. 5, No. 1, 1966, pp. 28-45.
6. Eden, W. J. Some Observations at Le Coteau Landslide, Gatineau, Quebec. Canadian Geotechnical Jour., Vol. 9, No. 4, 1972, pp. 508-514.
7. Eden, W. J., and Mitchell, R. J. The Mechanics of Landslides in Leda Clay. Canadian Geotechnical Jour., Vol. 7, No. 3, 1970, pp. 285-296.
8. Eden, W. J., and Jarrett, P. J. Landslide at Orleans, Ontario. National Research Council of Canada, Div. of Building Research, Tech. Paper 321, Ottawa, 1971.
9. Eden, W. J., Fletcher, E. B., and Mitchell, R. J. The South Nation River Landslide, 16 May 1971. Canadian Geotechnical Jour., Vol. 8, No. 3, 1971, pp. 446-451.
10. Gadd, N. R. Surficial Geology of Ottawa Map Area, Ontario and Quebec. Geological Survey of Canada, Paper 62-16, 1962.
11. Gadd, N. R. Pleistocene Geology of Central St. Lawrence Lowland. Geological Survey of Canada, Memo. 359, 1971.
12. Gadd, N. R., Lasalle, P., Dionne, J. C., Shilts, W. W., and McDonald, B. C. Quaternary Geology and Geomorphology, Southern Quebec. 24th Internat. Geological Congress, Montreal, Guidebook, Field Excursion A-44 C-44, 1972.
13. Hurtubise, J. E., and Rochette, P. A. The Nicolet Slide. Committee on Soil and Snow Mechanics, National Research Council of Canada, Ottawa, Tech. Memo. 48, May 1957.

14. Hurtubise, J. E., Gadd, N. R., and Meyerhof, G. G. Les Eboulements de Terrain dans l'Est du Canada. Proc. 4th Internat. Conf. on Soil Mechanics and Foundations Engineering, Vol. 2, London, 1957, pp. 325-329.
15. Jarrett, P. M. The Effects of Soil Structure on the Engineering Behavior of a Sensitive Clay. Quarterly Jour. Engineering Geology, Vol. 5, 1972, pp. 103-109.
16. Karrow, P. F. The Champlain Sea and Its Sediments. In Soils in Canada (Legget, R. F., ed.), Royal Society of Canada, Spec. Publ. 3, Univ. of Toronto Press, 1961.
17. Karrow, P. F. Earthflows in the Grondines and Trois Rivières Areas, Quebec. Canadian Jour. Earth Sciences, Vol. 9, No. 5, 1972, pp. 561-573.
18. Kenney, T. C., and Ali, M. Discussion: Stability of Natural Slopes in Sensitive Clay. Proc. ASCE, Jour. Soil Mechanics and Foundations Div., Vol. 94, No. SM5, 1968, pp. 1185-1190.
19. Ladanyi, B., and Archambault, G. Simulation of Shear Behavior of a Jointed Rock Mass. 11th Symposium on Rock Mechanics, Berkeley, Calif., 1969.
20. La Rochelle, P. Les Coulées d'Argile au Quebec. L'Ingénieur, Vol. 58, No. 280, 1972, pp. 47-53.
21. La Rochelle, P., Chagnon, J-Y., and Lefebvre, G. Regional Geology and Landslides in Marine Clay Deposits of Eastern Canada. Canadian Geotechnical Jour., Vol. 7, No. 2, 1970, pp. 145-156.
22. Lawrence, V. M. Stability of Slopes in Naturally Cemented Soils. PhD thesis, Queen's Univ., Kingston, Ontario, 1971.
23. Loiselle, A., Massiera, M., and Sainani, U. R. A Study of the Cementation Bonds of Sensitive Clays of Outardes River Region. Canadian Geotechnical Jour., Vol. 8, No. 3, 1971, pp. 479-498.
24. Meyerhof, G. G. The Mechanism of Flow Slides in Cohesive Soils. Geotechnique, Vol. 7, No. 1, 1957, pp. 41-49.
25. Mitchell, R. J. Landslides at Breckenridge, Pineview Golf Club and Rockcliffe. National Research Council of Canada, Div. of Building Research, Tech. Paper 322, Ottawa, 1970.
26. Mitchell, R. J., and Eden, W. J. Measured Movements of Clay Slopes in the Ottawa Area. Can. Jour. of Earth Sciences, Vol. 9, No. 8, 1972, pp. 1001-1013.
27. Paul, M. J. Landsliding in Sensitive Clay Soils at Ottawa. MSc thesis, Queen's University, Kingston, Ontario, 1970.
28. Peck, R. B., Ireland, H. O., and Fry, T. S. Studies of Soil Characteristics in Earthflows of St. Thuribe, Quebec. Dept. of Civil Engineering, Univ. of Illinois, Urbana, Soil Mech. Ser. 1, 1951.
29. Sangrey, D. A., and Paul, M. J. A Regional Study of Landsliding Near Ottawa. Canadian Geotechnical Jour., Vol. 8, No. 2, 1971, pp. 315-335.
30. Tavenas, F., Chagnon, J-Y., and La Rochelle, P. Saint Jean-Vianney Landslide: Observations and Eyewitnesses Accounts. Canadian Geotechnical Jour., Vol. 8, No. 3, 1971, pp. 463-478.
31. Townsend, D., Sangrey, D. A., and Walker, L. K. The Brittle Behaviour of Naturally Cemented Soils. Proc. 7th Internat. Conf. on Soil Mechanics and Foundations Engineering, Mexico, Vol. 1, 1969, pp. 411-417.