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NICOLET LANDSLIDE OF NOVEMBER 1955, QUEBEC, CANADA

BY

C. B. CRAWFORD AND W. J. EDEN

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Abstract.

The problem of slope stability in the valleys of the St. Lawrence and Ottawa rivers in eastern Canada is complicated by the unusual properties of the marine clay that occurs in the region. This "extra-sensitive" clay liquefies when it is disturbed from its natural state, and this characteristic complicates both the testing of the soil and soft sediments and the field analysis of its performance. It is necessary for design purposes, therefore, to rely on the study of "case records" until knowledge of the engineering properties of the material improves. The description of the Nicolet slide is presented as a case record together with suggestions of the geological factors that contributed to the instability. The actual failure is attributed to construction work proceeding at the time.

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*This is a contribution from the Division of Building Research, National Research Council, Ottawa, Canada, and is published with the approval of the Director of the Division.

Photo 1. Aerial photograph of Nicolet landslide area before the slide

Photo 2. Aerial photograph of Nicolet landslide area after the slide

INTRODUCTION

From the very first reports, it was known that the Nicolet landslide of November 1955 was a "flow" type, common to the marine clays of the valleys of the St. Lawrence and Ottawa rivers. The most recent landslide of this type to attract widespread interest had occurred in August 1951 at Rimouski, Quebec (Hurtubise, Gadd, and Meyerhof, 1957). Similar slides are recorded with alarming frequency in the geological literature of the past century. The scar-studded river banks of the St. Lawrence drainage system serve as evidence of the innumerable slides that have occurred in the region.

HISTORY OF SLIDE

Just before noon on November 12, 1955, a disastrous landslide occurred on the north bank of the Nicolet River at the village of Nicolet, Quebec, located 2 miles upstream from the mouth of the river. Three lives were lost, and damage was estimated at several million dollars.

During the summer of 1955, aerial photographs of the Nicolet region had been taken, and to aid in assessing the damage and causes of the slide the area was rephotographed a few days after the disaster (Photos 1 and 2). From this base photography, a sketch map was prepared showing the crater and the relative position of structures and vegetation

before and after the slide (Fig. 1).

SITE INVESTIGATIONS

Soil and soft sediments at the site of the slide consisted of a bed of stratified fine sand at the surface about 8 feet thick overlying a thick, stratified gray clay. This gray clay bed (27 feet thick) extends to a depth of about 35 feet. Below this, the clay becomes darker with black mottling. The total thickness of clay is nearly 100 feet (gray and mottled units).

Boring No. 1 (Fig. 1) was located at the edge of the river and near the northeast edge of the mouth of the crater. Boring No. 2 was located near the crest of the river bank south of the crater. A third hole was bored within the slide crater to obtain a sample of the clay involved in the slide. In all, eight samples were obtained, using a 3-inch-diameter piston sampler.

The samples were subjected to strength, consolidation, and classification tests, and the results are summarized in Table 1. Generally, the clays contain a high percentage of clay-sized particles and have a natural water content above the liquid limit. Sensitivity measurements place the clays in the "extra-sensitive" to "quick" class. The activity of the clays suggests that the clay fraction has a large amount of inert minerals or rock flour. Salt concentration in the pore water of the clays was measured

Figure 1. Plan map of Nicolet landslide, November 1955

to determine whether leaching of the salt could have been a contributing cause of the slide.

The salt concentration of the clays in hole No. 1 (Fig. 1) ranged from 6.5 to 11.0 grams per liter, while that of holes No. 2 and 3 was less than 1.0 gram per liter. Although a significant difference in salt concentrations was revealed, no reliable estimate of the original salt concentration of the clays could be obtained; in situ leaching could therefore not be proven.

N. R. Gadd (1956, personal communication) considers that the clays in the Nicolet area were deposited in brackish water of unknown salt concentration. Clays with black mottling were laid down in stagnant waters with relatively high salt concentration. Stratified clays suggest a considerable influx of fresh water and could be expected to have a lower salt concentration. Leaching may have taken place in the upper portion of the clays involved in the Nicolet slide.

Consolidation tests show the clays to be slightly overconsolidated. Undrained shear-strength determinations indicate that the upper clays (hole No. 2) have an apparent cohesion of about 550 pounds per square foot and the lower clays about 1000 pounds per square foot. These results have been confirmed in general by recent vane and laboratory tests (Hurtubise and Rochette, 1957).

Studies determined that two types of marine clay are present at the site of the landslide: (1) an upper stratified clay with a very low salt concentration; and (2) a lower gray clay with black mottling and a salt concentration of about 8 grams per liter. Both clays were slightly overconsolidated, extremely sensitive, and have a liquid index greater than 1. The soft sediments involved in the landslide appeared to be mainly the upper stratified clay, although the failure plane may have been in the lower clay.

MODE OF FAILURE

There are indications that the initial failure occurred at the upstream end of the present throat of the slide, and it is believed that the direct and immediate cause of the slide was due to surface and underground construction being carried out at that point. Probably the initial failure was similar to a conventional circular-type slip involving only a limited amount of material in the river bank. Slides in the sensitive marine clay are known to retrogress by failure of successive slices until equilibrium conditions are reached. Eyewitness accounts confirm that this progressive type of failure did occur.

A study of the aerial photographs and of the debris in the river suggests a series of events which describe the progression of the slide. In Figure 1, the original position of a grove of trees is shown, and the post-slide location of some of these trees is plotted in the debris. The approximate limits of the debris of the garage and school are shown. Of particular significance is the final location of riprap at the upstream extremity of the slide indicating that the debris from the initial failure was swept aside by subsequent flow. The orientation of large blocks of clay shown on Photo 2 give some indication of the direction of slide

movement.

Field observations indicate that the initial movement occurred at the upstream edge of the slide with material moving straight out into the river and then flowing either way. This was followed by retrogression until the grove of trees moved out into the river and was deflected downstream by material that had previously flowed out (Fig. 1 foreground). The post-slide location of the debris of the garage suggests that it was swept away after part or all of the grove of trees had slipped into the river, and was confined to a path along the river bank by previously distributed flow material. The school structure, located north of the garage (Fig. 1), apparently followed the path of the garage until movement stopped. Finally, two occupied houses (Dr. Roy and Dr. Vigneault, Fig. 1) and the portion of the Bishop's Palace destroyed by the slide moved through a relatively short horizontal distance. Dr. Roy's house remained relatively intact; the other buildings were reduced to rubble (Fig. 1).

CAUSES OF THE SLIDE

Landslide or "flow" slides of this type cannot be analyzed by standard methods. One cross section of the failed river bank was analyzed by the = 0 method and was found to have a factor of safety of about 0.6. This cross section, at the foot of Avenue du Seminaire, had a slope of about 45°. It is apparent, therefore, that any theories on the failure of this bank must be open to question until the engineering properties of marine clay are more fully understood.

The writers concluded that the geological events that affected the area provide a general understanding of the failure. Following deposition and drainage of the sediment-collecting basin, the surface of the newly deposited clay was essentially horizontal and no external forces were active to cause lateral movement (estimated condition during late Wisconsin time). The initial tendency for lateral movement probably began when the Nicolet River started to cut its channel in the clays, several thousand years ago. In most soft sediments, the downcutting of a channel is usually accompanied by an increase in strength of the bank materials, because of a lowering of the ground-water table and desiccation. An exception to this normal phenomenon appears to occur in the marine clays of the St. Lawrence valley as indicated by the large number of modern and prehistoric landslides in the region. The precise difference between this soil and soft sediments and others is not yet clear. Work in Norway has suggested that marine soils lose part of their strength because of leaching of salt from the pore water (Bjerrum, 1954). Preliminary tests suggest that this may be part of the reason for the Nicolet failure; however, the 6-month delay in carrying out field investigations may have "lost" some features of the soil. In any case, assessment of changes in the properties of soil and soft sediments during its geological history is a long process which has not yet been satisfactorily evaluated. It is only possible to say that slopes in marine clay become potentially unstable by long-term natural processes.

Table 1. Properties of soil and soft sediments at Nicolet landslide

For location of borings, see Figure 1.

Boring	Sample	Depth (ft)	Geodetic elev. (ft)	w/c (%)	LL (%)	PL (%)	Clay size (%)	Activity	Salt content* (g/l)	Sensitivity+ (St)	Av. shear strength** (tons/ft ²)	Precon- solida- tion load (tons/ft ²)
1	68-1	8.0	20.0	47.8	50.1	25.1	54	0.46	8.3	8.8	0.44	
1	68-2	9.8	18.2	52.7	44.4	24.4	50	0.49	10.2	13.8	0.65	2.0
1	68-3	11.4	16.6	52.9	45.9	22.4	47	0.50	6.6	12.1	0.45	1.3
1	68-4	12.9	15.1	52.6	51.0	23.1	47	0.59	11.0	16.3	0.62	
1	68-5	14.6	13.4	54.0	51.0	25.0	50	0.52	7.8	13.8	0.36	1.4
2	68-6	12.0	38.0	56.6	50.1	24.3	75	0.34	0.2	9.7	0.30	1.2
2	68-7	14.0	36.0	62.9	60.3	25.2	71	0.49	0.8	9.1	0.23	1.2
3	68-8	Clay remolded by landslide		57.7	44.5	23.3	69	0.31	0.9	79.0		

* grams of salt per liter of extracted pore water

unconfined compression shear strength

+ St = Laboratory vane shear strength (remolded)

** by unconfined compression test

It is reasonable then to believe that regional and local short-term effects become dominant. The climatic cycle over a period of a few years may considerably affect the stability of slopes. Artificial infiltration of water from man-made structures may begin to play an important part. Very often the immediate cause of the failure may be due to a local disturbance which "triggers" the entire movement, but cases of failure reported in the literature have not always indicated any obvious direct cause. A variety of circumstances can be cited for the immediate cause of a slope failure: (1) heavy rains; (2) vibrations may "trigger" action, although, to the writers' knowledge, quick-clay failures have not been generally associated with major earth tremors; (3) stream erosion and undercutting, but unlikely in the case of the Nicolet slide; (4) improper placing of earth fill, and excavating or bank steepening; and (5) surface and subsurface construction operations.

Although the full cause of the "flow" slide cannot be determined at present, the mode of failure has been inferred from the evidence. This suggests that the construction work in progress in November 1955 at the river bank created the "triggering" ac-

tion which began the failure. Roadway construction and sewer excavation were proceeding at the time of the Nicolet failure, and some heavy construction equipment was swept away in the slide. The basic cause of failure was probably a gradual weakening of the soft sediments during recent geologic time, and the immediate cause which "triggered" the slide was simply a chance occurrence.

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