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EVIDENCE OF CREEP IN STEEP NATURAL SLOPES OF CHAMPLAIN SEA CLAY

by W. J. Eden

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NOTE

Evidence of creep in steep natural slopes of Champlain Sea clay¹

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Three types of evidence of deep seated creep of steep natural slopes are considered: surface manifestations such as fissures and depressions; inclinometer measurements on three slopes in the Ottawa area; and movements of a bridge superstructure spanning a steep sided ravine.

Results of measurements show that the movements are not continuous but occur in response to seasonal high levels of the groundwater table. The implications of the movements are discussed in relation to the stability of clay slopes.

On considère trois types de symptômes de fluage profond dans des pentes naturelles escarpées: des phénomènes de surface tels que des fissures ou des dépressions; des mesures inclinométriques dans trois pentes de la région d'Ottawa; les mouvements d'un pont traversant un ravin à parois escarpées.

Les résultats des mesures montrent que les mouvements ne sont pas continus mais font suite à l'occurrence saisonnière de hauts niveaux de nappe phréatique. Les conséquences de ces mouvements sont discutées en relation avec la stabilité des pentes argileuses.

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The phenomenon of creep is discussed in this paper in a broad sense; i.e. as movements that occur in steep clay slopes that do not involve the generation of a well-defined surface of rupture, and which may or may not be a continuing nature. Creep should be distinguished from shallow seated downhill movements, such as solifluction, which occur in the layer of soil affected by seasonal frost action.

The most obvious evidence of such movements are found adjacent to slope failures. Behind the back scarp of a landslide, there are tension cracks and in some cases evidence of considerable horizontal and vertical movement. At other steep slopes where no failure has taken place, the visual evidence of movement is more subtle but, as described in this paper, can be detected by measurements made with inclinometers. The final piece of evidence described is the measured movements of a bridge spanning a steep-sided ravine over a period of 15 years (Bozozuk 1976).

The occurrence of these slope movements

is discussed in the context of past studies on slope stability, in which the stability of slopes in the fissured weathered crust of the Champlain Sea clays has been examined. These studies have been previously described by Eden and Mitchell (1970, 1973) and Eden (1975).

Surface Evidence of Creep

The first case illustrates the type of movement that occurs adjacent to an active landslide. In April 1973, a small slope failure developed in a 15-m high bank of the Ottawa River near Cumberland, Ontario. The clay slope had an inclination of about 2.5:1. The slope movement occurred in the fissured weathered crust of the clay and involved about 1600 m³ of material. The slopes beside the failure showed many tension cracks. A fresh fall of wet snow during the night following the landslide provided an opportunity to observe the continuing movements. A photograph (Fig. 1) taken the following morning shows a rupture in the fresh snow cover, which indicates the amount of movement that occurred in the few hours after the end of the snowfall.

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FIG. 1. Movements following recent snowfall.

FIG. 2. Crack in pavement surface near landslide.

The second example of movement is similar to the first case and is located about 1.6 km east of the first site. Landslide activity developed in the narrow strip of land between the highway and the Ottawa River. Figure 2 shows

the crack that developed through the pavement because of the landslide activity.

The third example occurred along the banks of the Ottawa River at the village of Wendover, Ontario, about 16 km east of the slides at

FIG. 3. Movement at back corner of house.

FIG. 4. Highway alignment monument after 20 years at crest of slope.

Cumberland. The slope of the river bank was not quite as steep as at Cumberland. Movements were initiated by water spilling from an incomplete roof drainage system at the front of a house. Although no dramatic slope failure resulted, substantial movement did occur and the bank was very close to the point of total collapse. Figure 3 shows the results of the movement at the back corner of the

partially completed house and gives evidence of both horizontal and vertical movement.

In these three examples, the movements were associated with definite cases of unstable slopes and took place over a relatively short time span (a few days). Near the first example on a seemingly stable slope, there is a highway alignment monument situated near the crest of a clay slope. Figure 4 shows the condition of

FIG. 5. Measured movements at slope G-1.

the monument about 20 years after its installation. Some long-term movement is evident, but no other signs of instability were noted on the slope below.

Inclinometer Measurements

In 1968, six inclinometer tubes were installed at three locations in the Ottawa area, in steep slopes adjacent to slopes that had landslide activity. The precise location and description of the inclinometer installations have been reported by Mitchell and Eden (1972) along with the measurements made

over the first three years. Very briefly, two installations (G-1 and G-2) were located along Green Creek, two (R-1 and R-2) were located on the banks of the Ottawa River at the former Rockcliffe Airport, and two (B-1 and B-2) were located along Breckenridge Creek. Subsequent to the 1972 paper, both installations along Breckenridge Creek were disrupted by slope movements. Installation G-2 along Green Creek has also been destroyed by landslide activity. Readings have been taken occasionally on the three remaining installations (G-1, R-1, and R-2). Figures 5-7 show the inclinometer

FIG. 6. Measured movements at slope R-1.

measurements made at these three sites from the date of installation in 1968 to April 1976. Because of difficulties in maintaining a precise reference in a horizontal plane over a period of years, the absolute accuracy of any one measurement in the inclinometer tube is probably no better than ± 1 cm. Horizontal movements are computed assuming the bottom of the tube to be stable.

Slope G-1 (Fig. 5) located along Green Creek has shown progressive movement to a depth of 4 m with a movement of about 1 cm/year at a depth of 1 m. The steep portion of slope R-1 (Fig. 6) next to the river has

been steadily eroding; this is evident from the apparent acceleration in rate of movement. Slope R-2 (Fig. 7) was graded in 1968 as part of slope protection measures to protect a large hangar structure. Most of the movement is taking place in the fill placed on the lower part of the slope. As described previously (Mitchell and Eden 1972), the movements occur in early spring when the groundwater table is high.

Mud Creek Bridge

The Mud Creek bridge spans a V-shaped ravine about 21 m deep. The bridge is 112 m

FIG. 7. Measured movements at slope R-2.

long and is supported on five piers, each pier being founded on end-bearing steel piles driven to rock. Figure 8, a profile of the bridge, shows the profile of the ravine along the bridge alignment; Fig. 9 is a view of the ravine at the bridge site. Measurements have been taken of the convergence of the bridge piers since 1959 (Bozozuk 1976). Sixteen years of measurements have indicated a convergence of nearly 5 cm. Specifically, between 1959 and 1973 the convergence between the west abutment and pier 1 was 0.70 cm; between piers 1 and 2 it

was 1.77 cm; and piers 2 and 3 converged by 1.61 cm. The actual soil movements were probably more than these amounts, as all piers were supported on end-bearing piles with two rows of batter piles to resist lateral movement.

The Regional Municipality of Ottawa-Carleton installed a major high pressure water main through the ravine immediately south of the bridge. In April 1973 a rupture occurred in a trunk water main located on the east slope of the ravine. The precise cause of the break was difficult to determine because of construction

FIG. 8. Profile of Mud Creek Bridge.

FIG. 9. Mud Creek ravine looking south. Pier 3 in centre of photograph.

activities in the installation of an underground telephone duct system. One explanation advanced was movement in the slope.

Possible Mechanism of Creep

Previous studies at specific landslides in the Ottawa area have revealed that landslides take place during periods of high groundwater levels and when there is a supply of surface water available. The availability of water satisfies the dilatancy resulting from shear strain in the fissured clay. The strength behavior of the fissured crust has been shown to be predominantly frictional shear resistance at low levels of normal stress and a concept of a curved failure envelope has been advanced (Eden and Mitchell 1973). Such a concept would explain the observation of numerous tension cracks and other evidence of movement

and the variation in geometric form observed in the landslides.

The influence of small changes in groundwater level can be illustrated by the results of a special drained test reported by Mitchell and Eden (1972). This was a stress controlled drained test on a sample of fissured clay from the Rockcliffe site (inclinometer R-2). The specimen was loaded incrementally to 90% of its anticipated failure load. A change in groundwater level of 0.5 m was simulated by increasing the back pressure on the drainage system by 5.49 kPa or 0.56 m of water. In 1 min the specimen strained 0.4 mm. When the back pressure was returned to its former level the strain stopped and no further axial deformation was observed during the next 2-min period. The process was repeated for several cycles until the axial strain reached

3.5% without failure. This test demonstrated that shear strain could be induced by small changes in water pressure in a fissured clay specimen under a significant level of shear stress.

It is suggested that this process is prevalent in steep slopes, and that movements coincide with periods of high groundwater level.

Conclusions

Evidence has been presented to indicate that sheep clay slopes are subject to significant movements that extend to a considerable depth in a fissured clay crust. The inclinometer measurements suggest the movements extend to a depth of 4 m and that this depth is dependent to a large extent on the geometry of the slope.

The movements do not seem to be of a continuing nature but take place when groundwater levels are high. The amount of movement each year is appreciable and must be considered when attempting construction activity close to clay slopes.

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