A landslide stabilized by an unloading excavation

Un glissement de terrain stabilisé par excavation

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SYNOPSIS: A natural area of unstable hillside on the north shore of Kamloops Lake has affected train traffic on the Canadian National Railways main line for many years. The movements have a history of starting and stopping without an obvious cause. In 1985 after the rate of movement gradually increased over 3 seasons an unloading excavation was made at the top of the active unstable zone. This excavation stabilized the track movement without upsetting the stability of a zone of ancient landsliding located above the excavation.

1 INTRODUCTION

The CN Rail track leading to Vancouver, British Columbia, is located in terrain where slope stability problems are common (Evans 1980). When the line was built, in 1913, the stability conditions had already been recognized (Stanton 1898) but the pioneer railway officials elected to open the railway for service and use the revenue generated from its operation to finance maintenance and upgrading.

Within the commercial operating environment, the scope of upgrading work which may be undertaken is severely limited by available financial resources. Priorities must be set and choices made between stabilization and ongoing maintenance by regular lifting of the track. It is only within the last 25 years that stabilization based on the principles of geotechnical engineering has become readily available to assist with this task.

Although new technology has become available, the authors have found that simple observation of the settlement and lateral movement of the railway track gives them a unique monitoring device that is both reliable and sensitive to small ground movements. Experienced railway maintenance men can visually detect a few millimeters of track misalignment. Normally it is persistent movement of the track or acceleration of the rate of track movement which are used as the criteria for initiating remedial action.

The events leading to the stabilization of an active landslide 25 kilometers west of Kamloops B.C. reflect the approach towards slope stabilization that is in use within CN Rail.

2 SITE CONDITIONS

At Mile 15.8 Ashcroft Subdivision the CN Rail track is hemmed in between Kamloops lake and a low mountain ridge to the north. A general view of the site is shown on Fig. 1. An area of landslide topography between two rock outcrops extends northward from the lake on an average slope of 17 degrees to a height of 130 meters above lake level. Above the landslide the ground continues to rise on a lower angle.

Figure 1. General View of the Site

The toe of the landslide extends under the lake for an undetermined distance. Soundings in the lake opposite the slide area show that the ground slope continues down uninterrupted to a depth of at least 50 meters below lake level where the soundings were discontinued.

The level of Kamloops Lake fluctuates seasonally through a range of 6 to 8 meters. It is high in the summer and low in the cold winter months.

The climate of the area is arid with average annual precipitation of only 260mm. The only vegetation in the area is grass, cactus and occasional sage brush. There is no nearby human habitation and agricultural use of the area is limited to open range cattle grazing.

3 INITIAL TRACK MOVEMENT - 1978

In March 1978 an 8000 cubic meter block of soil suddenly broke off the upper slope and came to rest a short distance from the track.

A 180 meter long section of the railway track immediately started to settle and go out of alignment.

Examination of air photographs and discussion with a retired maintenance supervisor (McLeod 1978) shed some light on this event:

1. An area of ancient landslide topography shown on Fig. 2 was identified in the air photographs.

2. The site was known to the supervisor as the location that had been one of the most troublesome locations on his territory. He remembered evidence of track lifting at the site dating back for many years. He also remembered that in the middle 1950's the slide became so active that the track required lifting about once a week until it was apparently stabilized by building a rock berm along the lake shore and by improving drainage uphill from the track.

Based on this information, the geotechnical engineer decided that the site should be treated as having developed residual soil strength. Additional movement would not be regarded as a signal that rapid large scale movements were imminent.

The slide debris was removed and the track stopped settling.

4 1982 LANDSLIDE MOVEMENTS RESUME

Late in 1982 after 4 years of stable conditions the track started to move again. A crack was found on the ground surface at the location identified on Fig. 2 as the boundary of the area of active landsliding. This crack did not extend around the entire area identified as landslide topography on the air photographs. It appeared that there was differential movement within the landslide terrain.

The instability of 1982 had two upsetting features:

1. Inclinometers indicated clearly that the 1960 berm was not at the toe of the landslide and was unlikely to ever have had a significant effect on stabilizing the slide movements.

2. There was no apparent cause for the resumption of the movements - no new initiating slide from above, no unusually heavy rain, no toe erosion in the lake, no agricultural irrigation above the site, no changes in the railway, no other human activities near the site.

Nevertheless with faith in the concept of residual strength, the maintenance forces continued to lift the track and the trains proceeded over the slide at reduced speed.

In the spring of 1983 after moving for about 4 months the landslide movements stopped as mysteriously as they had started. The track was stable throughout the summer and early fall of 1983 and the trains were able to run at normal speed.

5 1983 - 1984 MOVEMENTS RESUME AGAIN

Late in 1983 the track movements resumed at an increased rate and continued throughout the winter of 1983-1984. Track lifting of up to 100mm every 3 to 4 days was reported.

At this time it was recognized that there was a seasonal pattern to the movements stable in summer, active in winter corresponding

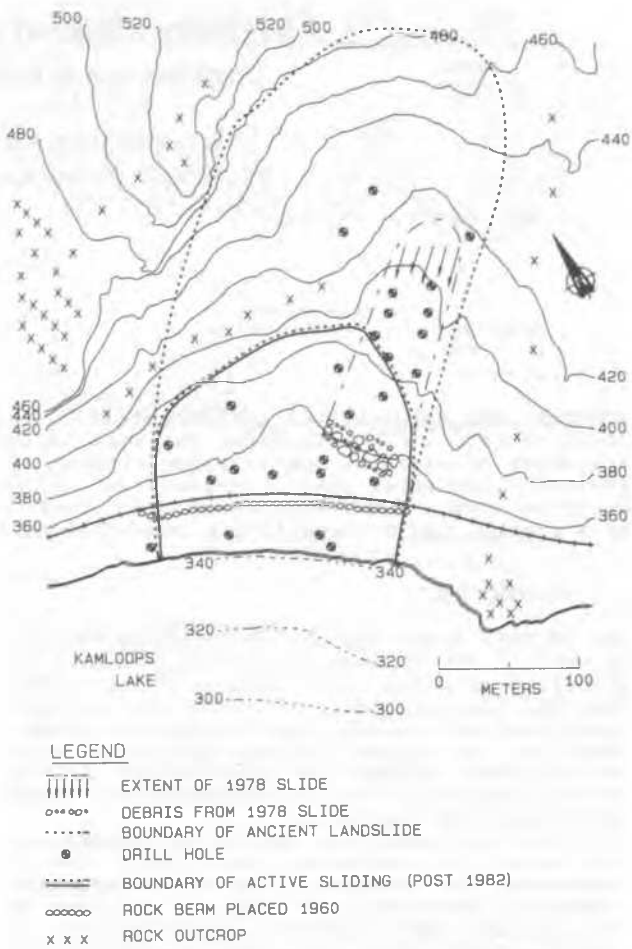

FIG 2 PLAN OF SLIDE AREA

to the cyclic variation in the level of Kamloops Lake.

In the fall of 1984, as feared, the track movements resumed with increased vigor. The maintenance forces were having difficulty keeping up with the ground movements, the train delays due to crossing the unstable area at slow speed were excessive. The situation had become intolerable.

6 SUBSURFACE INVESTIGATION

A preliminary subsurface investigation was undertaken shortly after the small 1978 landslide which triggered track instability. Inclinometers and standpipe piezometers were installed in boreholes drilled near the track.

In 1984 an extensive second stage investigation was undertaken to define the groundwater regime and the geometry of the sliding surface. Drilling was carried out at ten sites throughout the area. Inclinometers and standpipe piezometers were installed. All inclinometers were socketed into competent material.

The seasonal nature of track movement had lead to the hypothesis that instability was closely related to variations in groundwater conditions. Somewhat surprisingly the exploration of the summer of 1984 did not identify any pervious subsurface zones or groundwater sources. Nor did subsequent monitoring of standpipes reveal any large piezometric pressures or unusual fluctuations in the phreatic surface. Nevertheless the second stage of investigation did disclose two significant facts:

1. Ground movement was detectable only within 95 metres of the track.
2. In the upper portion of the slide zone, bedrock was relatively close to ground surface.

It was apparent that the landslide could be considered in two parts: first a lower active portion extending upslope a maximum distance of 100 metres from the track and secondly, a stable portion uphill from the active slide. This conclusion had significant implications in the design of remedial works.

Late in 1984 during a final stage of investigation, inclinometers were installed in the upper portion of the landslide to ensure that it was in fact stable and to facilitate future monitoring.

The location of all borings is shown on Fig. 2. The results of subsurface exploration are illustrated in Fig. 3.

7 SUBSURFACE CONDITIONS

Surficial soils at the site are clayey sands and silts trending to highly plastic clays with depth. Traces of gravel and fragments of angular broken rock are evident throughout. The underlying bedrock was identified as shale and bentonitic sandstone. Particularly significant is an abrupt rise in the bedrock surface about 70 meters north of the track. This rise roughly coincides with the boundary between the unstable and stable sections of the ancient landslide.

Near the bedrock interface the materials are highly plastic. Plasticity indices as high as 185% were recorded. Natural moisture contents ranged between 30% and 40% and only slightly exceeded the plastic limit of the soil. Strength indices indicated that the material was stiff to very stiff.

The results of consolidated drained direct shear tests on samples taken from near the shear zone are shown in Figure 4. Peak and residual tests were run on undisturbed and remolded samples respectively. The laboratory conducting the tests reported that true residual conditions may not have been achieved during testing. Residual strength parameters are therefore viewed with some skepticism.

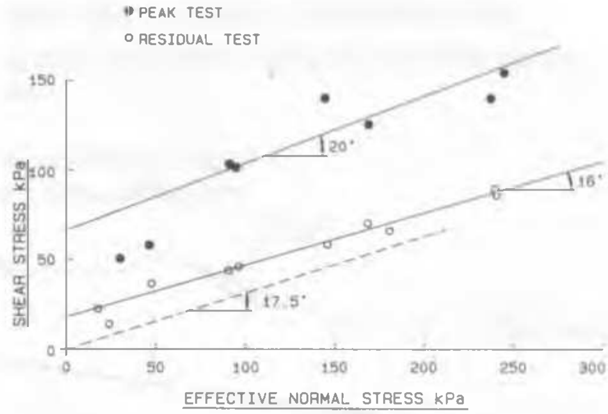

FIG 4 DIRECT SHEAR TEST

8 LANDSLIDE ANALYSIS

The slide surface was defined by monitoring of nineteen inclinometers scattered over the area of the landslide and by the observation of track misalignment and surface cracking.

The model failure surface selected runs from a visible scarp through a series of points defined by inclinometers to an arbitrarily chosen toe beneath Kamloops Lake. As shown in Fig. No. 3, the failure surface was characterized by a classic circular arc.

In view of the history of ground movement at the site, effective cohesion along the model failure surface was assumed to be zero. Back calculation employing the simplified Bishop technique yielded an effective friction angle of 17.5°. Although the back calculated friction angle appears high relative to the laboratory measured residual strength, a value of 17.5° was employed in all subsequent analyses.

Factors leading to this decision were:

1. As shown in Fig. 4 the back calculated friction envelope lies below the laboratory

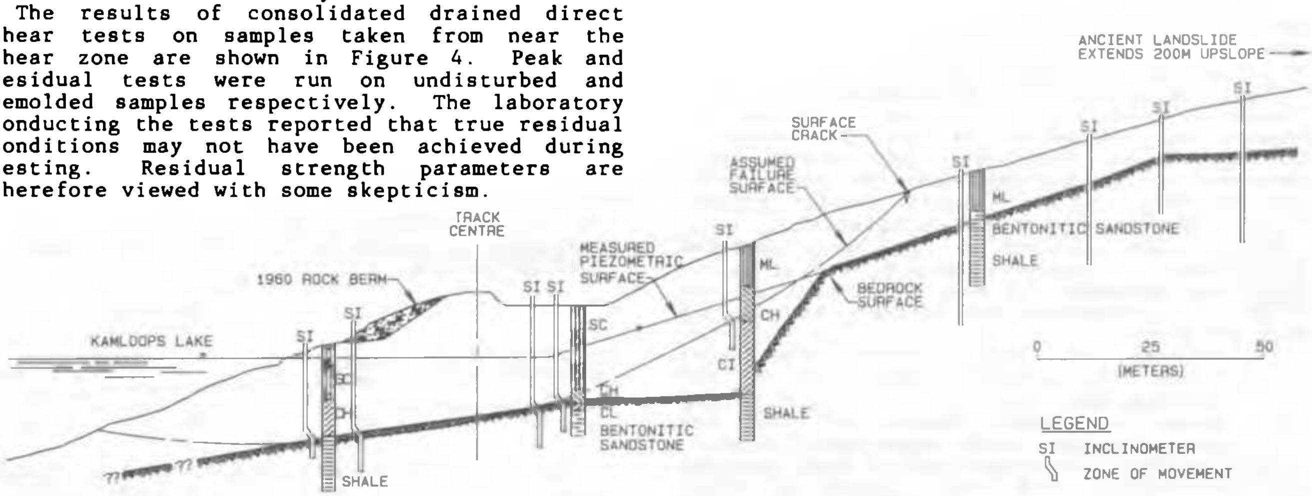

FIG. 3 PROFILE OF LANDSLIDE

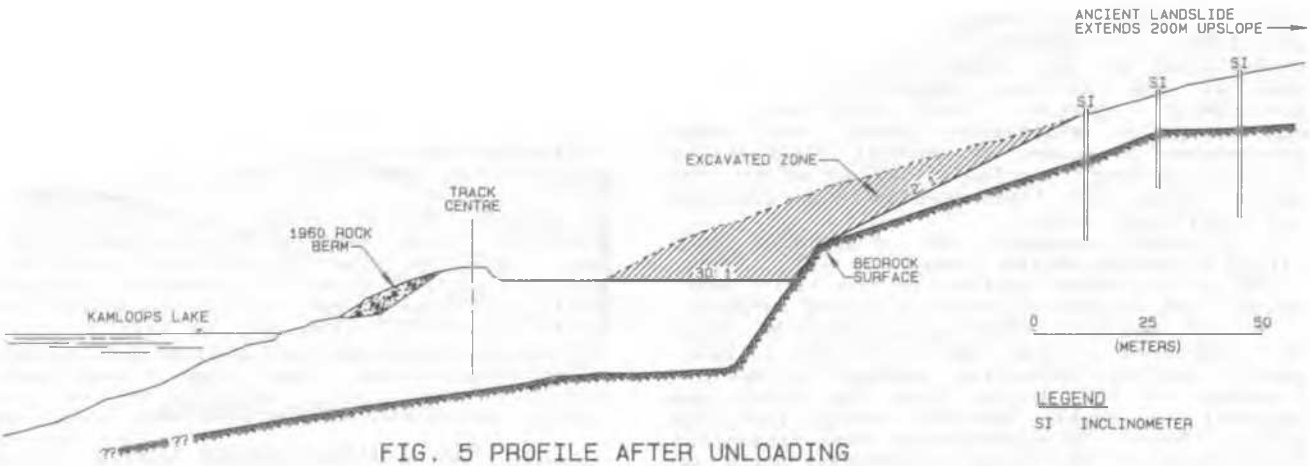

FIG. 5 PROFILE AFTER UNLOADING

measured residual strength envelope for all normal stresses significant in the analysis.

2. The behaviour of the upper portion of the landslide indicated that the use of a residual strength friction angle greater than 16° was justified.

9 REMEDIAL ACTION

Due to the depth and gradient of the underwater slope, a stabilizing berm at the toe of the landslide was dismissed early in the evaluation process.

Drainage, if feasible, was recognized as the most attractive option in a landslide of this magnitude. Unfortunately, the subsurface investigation had failed to either identify any extraordinary piezometric pressures or target any pervious zones which could be tapped.

Calculations showed that the best that could be hoped for with horizontal drains, would be a 5% increase in stability. Local drawdown of the phreatic surface with well points to an elevation 20 metres below lake level would effect a 17% increase. These modest projections combined with nagging doubts about the impervious nature of the soil lead the authors to dismiss the drainage option.

Thus, by process of elimination, unloading became the remedial action chosen. Calculations showed that unloading of the active lower portion of the landslide could result in a decrease in the driving force of nearly 40%. The proposed excavation would involve removal of some 60,000 cubic metres of material.

While the unloading option appeared attractive, it would undercut and possibly reactivate movement of the upper part of the slide. In addressing that concern, two options were available:

1. Excavate the upper slide. The total volume of material would be 200,000 cubic metres.
2. Accept a certain degree of risk and leave the upper slide essentially intact.

After careful consideration of both economic and risk factors, the latter course of action was chosen. Calculations based upon both circular arc and infinite slope models indicated that the upper slide would probably be marginally stable. Remedial action could be initiated later if the instrumentation showed significant ground movements. Finally, even in a scenario in which the upper slide failed catastrophically, the railway embankment would be partly protected by the catchment produced by the unloading excavation.

In the Spring of 1985 the unloading excavation shown on Fig. 5 was made. Excavated material was wasted on a stable alluvial fan one kilometre east of the site.

10 RESULTS

The remedial work has proven entirely successful. Since completion of the excavation, maintenance forces have reported a dramatic decrease in track subsidence and misalignment. Trains operate without speed restriction. There has been no evidence of movement in the ancient upper portion of the landslide.

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