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Challenges from North to South
Des défis du Nord au Sud

Design and Construction of Shore Line Fortification to Protect Main Line Railway Port Hope, Ontario

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ABSTRACT
The shoreline bluffs along the north shore of Lake Ontario at Port Hope have experienced ongoing erosion for a long period of time. When the CN Mainline was constructed in 1856 the distance between the railway right-of-way and the crest of the bluffs was more than 60 m. Ongoing erosion had reduced this width to a few metres in the late 1990's and would compromise the safety of the railway lines unless arrested. The bluffs are about 16 m high at the shoreline. The soil profile consists of an upper layer of dense silt to fine sand lying on hard silty clay till. Groundwater movement through the upper layer is from north to south, towards the lake, which was causing internal erosion and the development of large chasms at the slope face. Toe erosion was occurring at the base of the slope. Stabilization of the slope was accomplished by construction of a soil-bentonite slurry wall to reduce seepage flow through the upper layer. This was complemented by a dynamic revetment covering the entire height of the slope face to resist the effects of wave erosion and the ice sheet, and to support the oversteepened slope face.

RÉSUMÉ
Les falaises formant la rive nord du lac Ontario à Port Hope subissent une érosion constante depuis une longue période de temps. En 1856, lors de la construction de la voie ferrée principale du CN, la distance séparant l'emprise ferroviaire du sommet des falaises était de plus de 60 m. L'érosion constante de ces falaises a réduit cette distance à quelques mètres seulement à la fin des années 1990, elle aurait compromis la sécurité du chemin de fer si elle n'avait pas été arrêtée. Les falaises ont une hauteur de 16 m le long de la rive. Le profil du sol est constitué d'une couche supérieure allant du silt dense au sable fin, reposant sur un till d'argile limoneuse dur. Dans la couche supérieure, les eaux souterraines s'écoulent du nord au sud, en direction du lac, ce qui provoquait l'érosion interne du sol et la formation de gouffres sur la paroi de la falaise. Il y avait également érosion à la base de la paroi. Le talus a été stabilisé grâce à l'édification d'un mur composé d'un mélange de sol et de boue bentonitique, permettant de réduire le courant de filtration dans la couche supérieure. Cette mesure a été complétée par l'installation d'un revêtement dynamique sur toute la hauteur de la paroi afin de contrer l'érosion causée par les vagues et la glace et pouvoir soutenir les parois ayant une trop forte inclinaison.

1 INTRODUCTION

Topographic mapping shows that at the time of construction of the Grand Trunk (now CN) Railway line at the site in 1856, there was a width of more than 60 m from the south side of the railway right-of-way to the crest of the shoreline bluffs. Shoreline erosion has occurred on an ongoing basis since that time and by the 1990's, the proximity of the crest of the shoreline bluffs to the right-of-way was threatening to compromise the stability of the land supporting the railway tracks. The topography in the area of the study site shows that the land rises gently to the north from the slope crest; the shoreline bluffs are about 16 m high. The site location is shown in Figure 1. A typical section through the shoreline bluffs is shown in Figure 2.

Subsurface investigations at the site show a soil profile which consists of an upper soil unit of dense sandy silt to silty fine sand which extends from the ground surface on the tableland to a depth about 7 m. The results of grain size distribution tests carried out on the upper soil unit show that more than 80% of the particle sizes lie within the fine sand and coarse silt fractions, there was found to be a small clay fraction in the soil material (Figure 3). The compactness condition of the soil is dense to very dense, as evidenced by standard penetration test N-values ranging from 35 to 80 blows/300 mm. The underlying soil deposit consists of a silty clay till which includes a trace to some gravel and occasional cobbles and boulders. This material is of hard consistency, on the basis of 'N'-values ranging from 40 to 90 blows/300 mm.

Groundwater flow beneath the site area is from north to south, towards the Lake Ontario shoreline. Typically, the water table lies at a depth of about 4 m below the ground surface, beneath the Right-of Way. Mostly, groundwater flow occurs through the upper silt to fine sand soil unit. The gradation of the upper silt to sand soil unit is prone to development of internal erosion, (Glossop and Skempton, 1945) which is manifest by the development of chasms at the slope face within the upper soil unit. These chasms develop to a width of several metres and in places, extend above the interface of the lower silty clay fill silt to sand to close to the ground surface. Apparent cohesion in the silt to sand soil provides support to the roof of the developed chasms, until gravitational forces overcome the apparent cohesion and collapse occurs. This mechanism results in regression of the portion of the slope which is in the upper soil unit. A photograph showing outwash of soil at the base of a chasm at the slope face is shown in Figure 4.

Wave action at the base of the slope was causing toe erosion in the lower silty clay till soil unit and this effect resulted in loss of ground of up to a width of about 1 m/year at the base of the shoreline bluffs. Thus, ongoing erosion was occurring in both the upper and lower soil units which resulted in oversteepened slopes constantly being present at the shoreline

2 GEOTECHNICAL DESIGN

The design of appurtenances to arrest slope movement involved consideration of both of the two components contributing to shoreline regression. The first design component involved substantially reducing the flow of water through the upper sand and silt soil unit to mitigate the detrimental effects of internal erosion. It was determined that this desired effect could be accomplished by construction of an intercepting low permeability barrier wall. The gradation of the silt to sand soil is conducive to addition of powdered bentonite to form a low permeability soil-bentonite mix and thus, a slurry wall design was selected to provide a low permeability barrier (Nash and Jones , 1963; D'Appolonia and Ryan, 1979; Ryan 1980). The second component was to provide an erosion resistant facing to the shoreline bluffs to prevent further toe erosion. In addition, the emplaced facing must provide long term support to the oversteepened sections of the bluffs.

2.1 Barrier Wall

Development of internal erosion in the silt to sand soil in the affected zone of shoreline was arrested by construction of a soil-bentonite slurry wall to cut off most of the seepage flow to the slope face for a length of 200 m. The slurry wall was embedded into the underlying low permeability silty clay till soil stratum for a depth of not less than 0.5 m to provide an effective seal at the base of the wall (Navfac DM 7.2, 1982). The wall design specified a minimum width of 600 mm, the performance specification of the soil-bentonite mix was that the constructed wall should achieve a permeability of 10^{-7} cm/s, or better. A french drain was positioned on the north (upgradient) side of the slurry wall, with the drain invert positioned at the water table elevation to collect the intercepted southerly flow of groundwater and prevent a build up of groundwater level as a result of a slurry wall construction. The collected water was directed to an existing culvert which carried a southerly flowing natural stream beneath the CN rail tracks to discharge at the slope face. A section through the slurry (barrier) wall showing the upgradient drain and the geometry of the slurry wall is shown in Figure 5.

2.2 Shoreline Fortification

Complementing the contribution of the soil-bentonite slurry wall, to arresting slope movement at the shoreline, fortification was provided by constructing a dynamic revetment. The basic strategy of such a revetment is to build an extensive stone berm which can adjust and deform in response to severe wave action. The revetment consists of a relatively large mass of rockfill which is placed on the slope face at the shoreline, which material develops to its natural angle of repose. The stone revetment is then capable of dissipating wave energy (Ahrens 1990, Ahrens 1995). The rockfill is dumped from the crest of the shoreline and the fill material is continually fed until it develops its natural angle of repose. Any loss in the rockfill revetment which occurs as a result of severe weather events and action of any winter ice sheet can be replenished by tipping additional material from the top, if and when found necessary. The selected design of revetment has an advantage over conventional armour stone as the stone size is significantly smaller, and placement of the rockfill does not require special care or mobilization of equipment to the beach area at the base of the slope. Furthermore, maintenance of the revetment is relatively economical and easy to effect. The design of a typical section of the dynamic revetment is given in Figure 6.

3 SYSTEM PERFORMANCE

Construction of the soil-bentonite slurry wall and the groundwater collector drain was effected using a Track Mount excavator for trench excavation. A bentonite slurry batching and recycling plant was set up nearby the slurry wall location. A small dozer was used to mix the excavated silt to sand soil and the added powdered bentonite on the side of the trench, the dozer then pushed the soil-bentonite mixture into the bentonite slurry filled trench to displace the bentonite slurry. The methodology used was in accordance with normal soil-bentonite wall construction (D'Appolonia and Ryan 1979; Ryan 1980).

The effect of the soil-bentonite slurry wall in reducing southerly groundwater flow was monitored by water level measurements made in piezometers. Water level recordings showed that there was no build-up in the water level on the north side of the wall above the prior water level elevation; there was a substantial lowering of water level on the south (shoreline) side of the wall (Figure 7), which resulted in a large decrease in seepage flow at the slope face.

The rockfill used for construction of the stabilizing revetment was end-dumped from trucks near the crest of the shoreline slope and pushed over the crest with a small dozer. The rockfill was placed in sufficient quantity to enable the material to establish intimate contact with the slope, and to develop its natural angle of repose. A photo illustrating the completed revetment is given in Figure 8.

Monitoring of the performance of the shoreline fortification was carried out by placing a series of concrete blocks at the crest of the slope following completion of placing the rockfill revetment. The blocks were surveyed and monitored for line and level to determine if any ground movements were occurring at the slope crest. Visual inspections of the profile of the dynamic revetment have been made to determine if there has been any requirement for additional materials to replace any rockfill material taken away by wave action and the winter ice sheet. Additionally, the vertical and horizontal alignments of the rail tracks are monitored on a frequent basis.

The results of the monitoring have shown that:

- There has been no movement in the monitoring blocks placed at the crest of the dynamic revetment;
- There has been no internal erosion occurring in the upper silt to sand soil layer, which would have been exhibited by the development of sink holes at the ground surface;
- Visual inspection of the dynamic revetment shows there has been, to date, no need to replenish any rockfill material;
- There has been no requirement to institute measures to maintain the vertical and horizontal alignment of the rail track beyond normal measures.

These observations confirm the satisfactory performance of the constructed stabilization measures.

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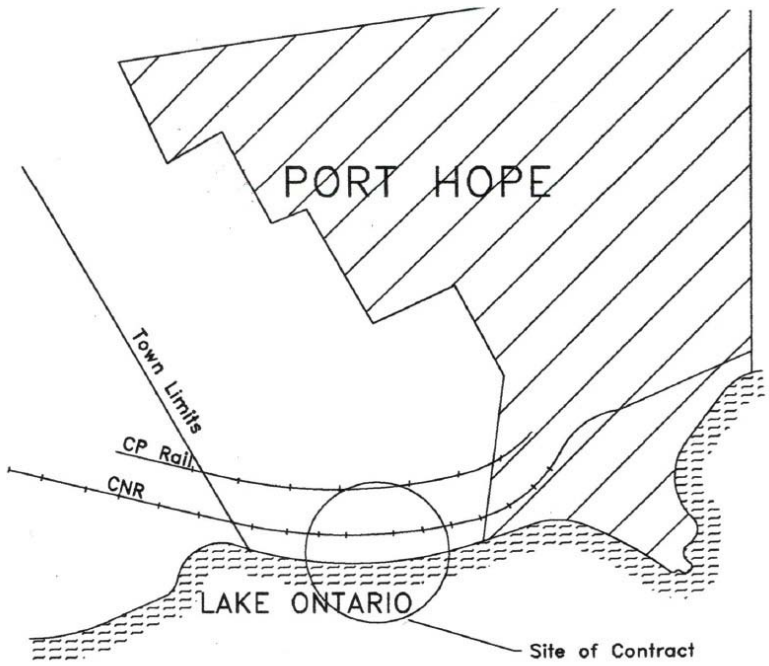

Figure 1. Key Plan

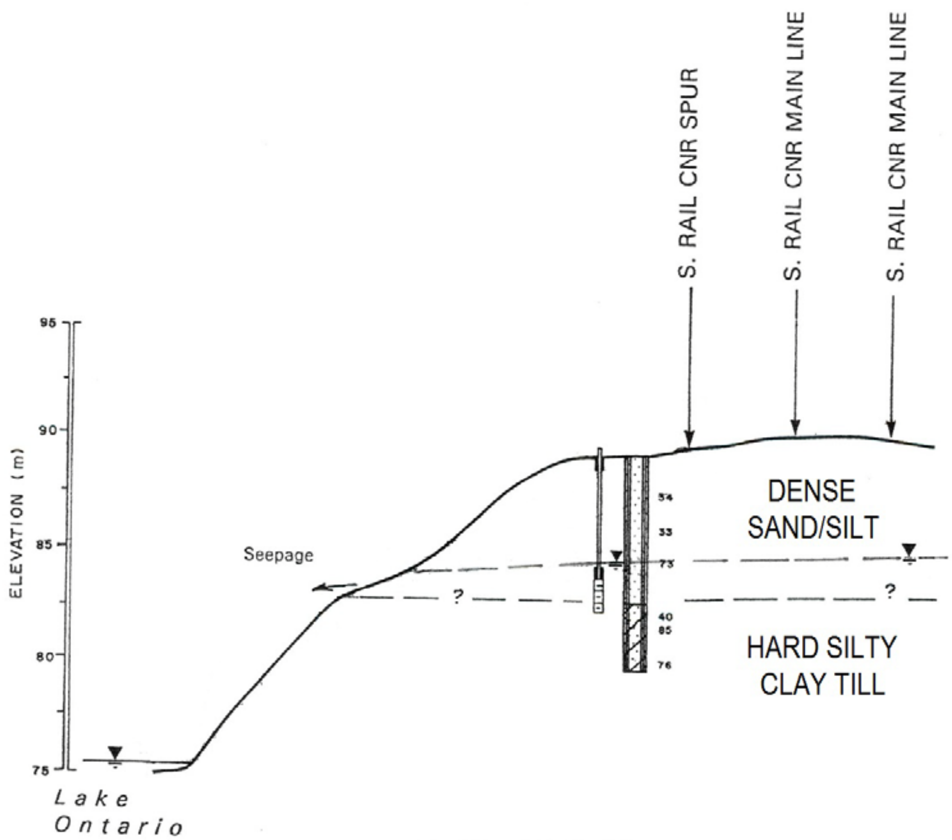

Figure 2. Cross Section at Shore Line

Figure 3. Seepage at Base of Silt/Sand Stratum

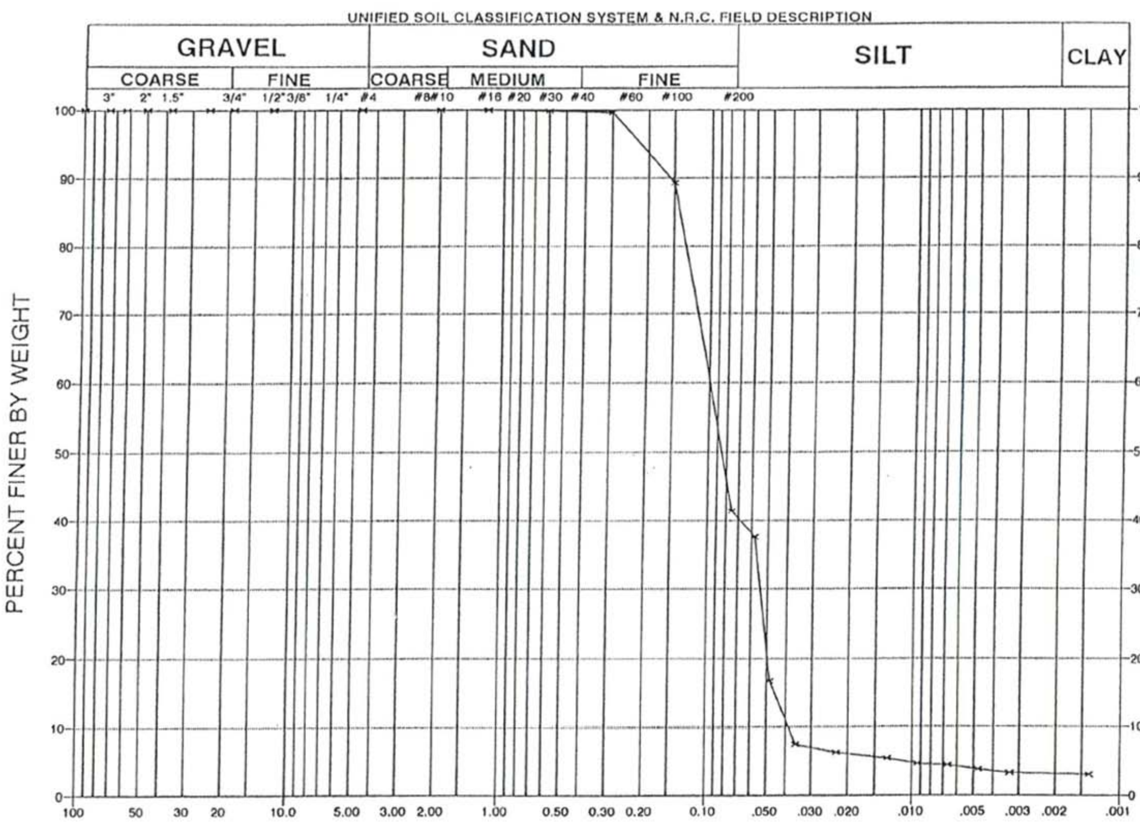

Figure 4. Typical Grain Size Distribution - Upper Sand/Silt Stratum

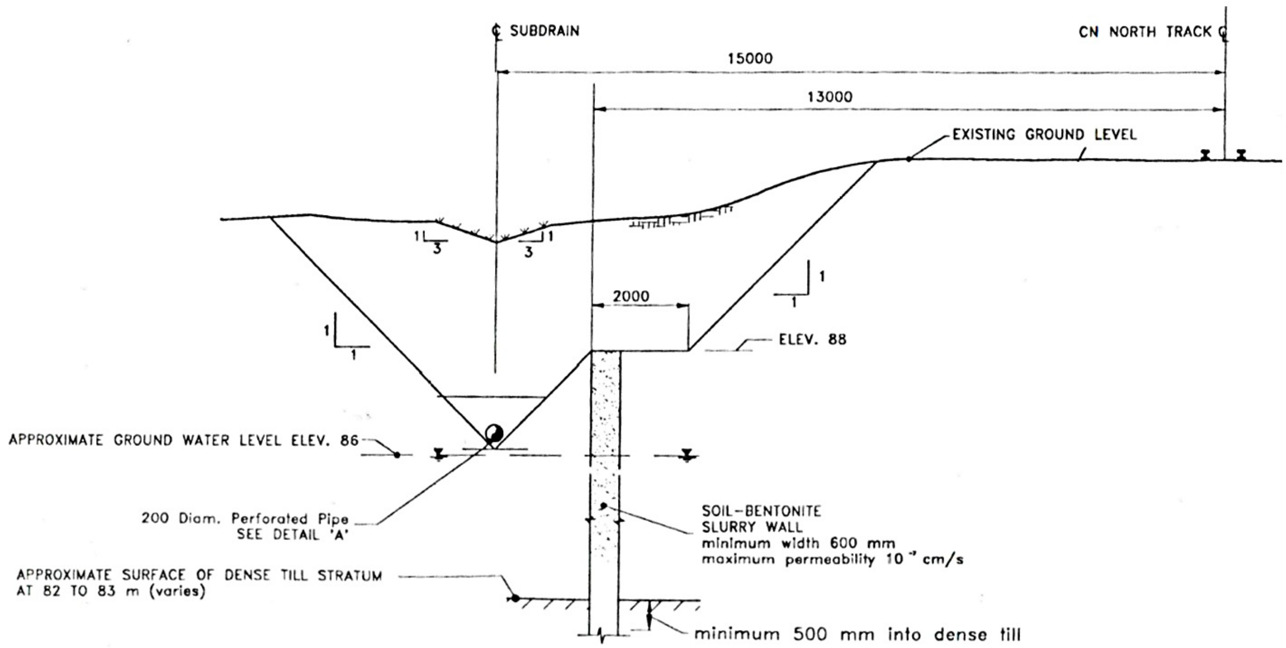

Figure 5. Trenching Detail for Slurry Wall and Subdrain Installation

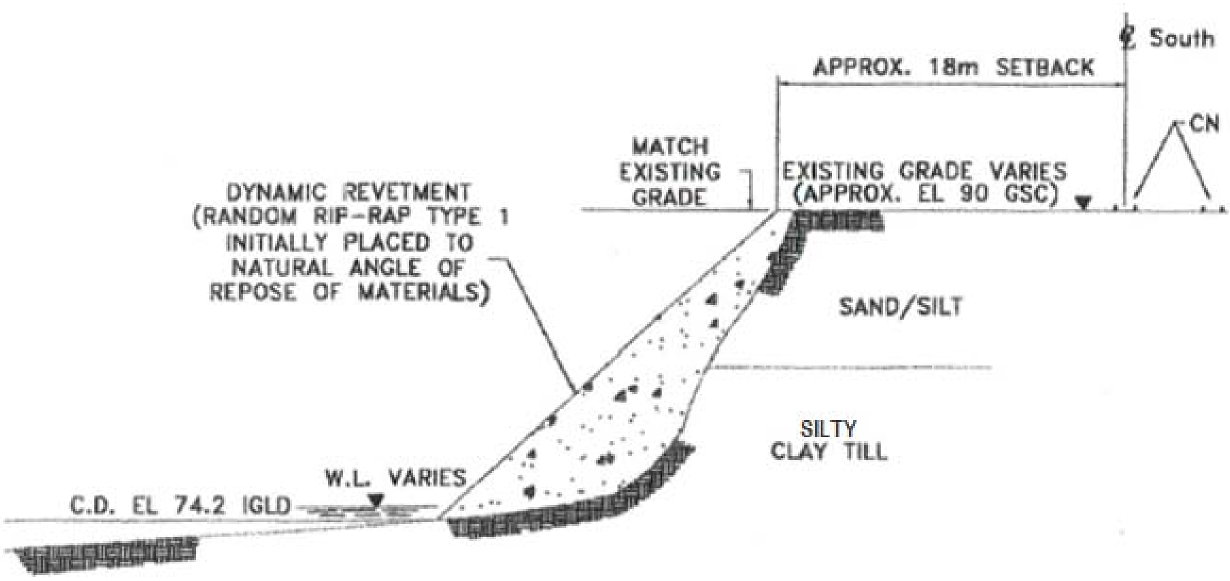

Figure 6. Section Through Dynamic Revetment

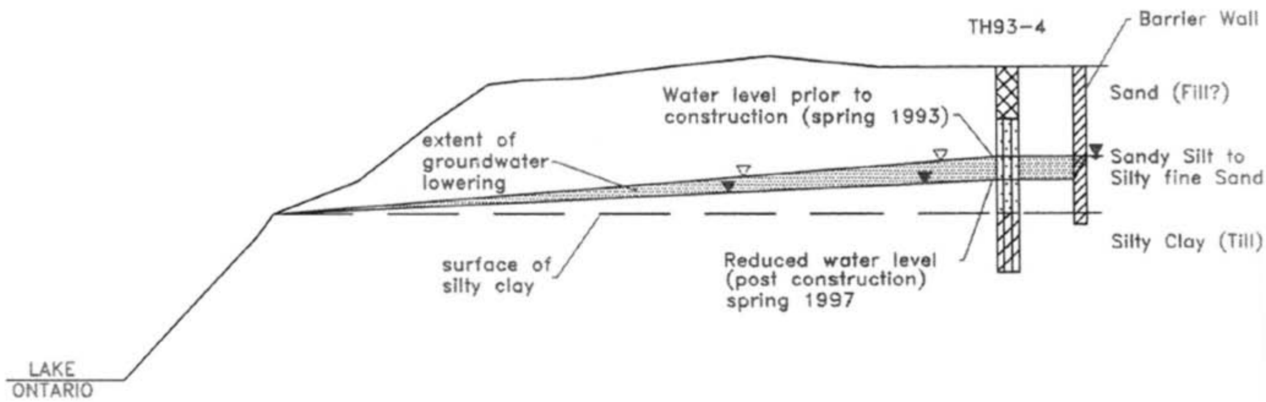

Figure 7. Schematic Illustration of Lowering of Groundwater Table Effected by Soil-Bentonite Barrier Wall Construction at TH93-4

Figure 8. Completed Dynamic Revetment