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Stabilization of Rail Track, CN Dundas Sub, Dundas to Copetown, Ontario

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ABSTRACT
The paper summarizes the design of stabilization measures which were constructed in the portion of the Dundas Sub which lies between the towns of Dundas and Copetown, Ontario. Construction of the initial single rail track on the Sub took place in the early 1850's; the track was twinned in the 1890's. The affected section of track rises up from the base to the top of Hamilton Mountain (Niagara escarpment). It features a series of cuts, side slope fills, and embankments. Railway construction was carried out without the benefit of sophisticated construction equipment; construction fills were not subject to dense compaction. Cuts were made into hillsides to construct a level platform to support the track with fill being placed on the downhill side to add platform width. Design of the various sections of earth work associated with track construction was based on experience rather than analytical design methods. Over the past few decades, some sections of rail track which are supported by fill soils and track lying above native slopes on the downhill side, have experienced downhill movements as a results of much increased axles loads and much increased length of trains compared to the initial train loads.

The paper reviews the design of stabilization measures at five sections of track. These stabilization designs have featured: a conventional gravity berm; a gravity berm featuring geosynthetic reinforcement to provide an oversteepened slope face; tie backs which are anchored into bedrock; soil nails to stabilize the slope height from rail track down to base of slope; and soil anchors to support the outer rail track at the top of a high slope. The rationale for design method selection is discussed for each site in conjunction with site constraints such as urgency, property limits, ensuring minimal effect on rail operations, site access restrictions, and cost.

RÉSUMÉ

L'article résume la conception de mesures de stabilisation qui ont été construites sur la portion de la subdivision Dundas, située entre les villes de Dundas et de Copetown, en Ontario. La construction de la première voie ferrée unique sur la subdivision a eu lieu au début des années 1850, et cette voie a été doublée à la fin des années 1890. La section de la voie concernée s'élève de la base au sommet de la montagne Hamilton (escarpement de Niagara). Elle est dotée d'un ensemble de déblais, de remblais et de remblais de talus. La construction de la voie ferrée a été effectuée sans l'avantage d'un équipement de construction sophistiqué, et les remblais de construction n'étaient pas assujettis à un compactage dense. Des déblais ont été faits dans les versants pour construire une plateforme horizontale pour soutenir la voie, et des remblais ont été placés du côté descendant pour ajouter de la largeur à la plateforme. La conception des différentes parties du terrassement associé à la construction de la voie a été basée sur l'expérience plutôt que sur des méthodes de conception analytiques. Au cours des dernières dizaines d'années, certaines sections de la voie ferrée qui sont soutenues par de la terre de remblaiement et la voie située au-dessus des pentes originaires du côté descendant se sont affaissées en raison de grandes augmentations du poids par essieu et de la longueur des trains comparativement à la charge initiale des trains.

L'article examine la conception de mesures de stabilisation au niveau de cinq sections de la voie. Ces conceptions de stabilisation ont compris : une berme de type poids classique, une berme de type poids dotée d'un renforcement géosynthétique pour produire un versant plus incliné, des ancrages sous tension ancrés dans le substrat rocheux, des clous de sol pour stabiliser la hauteur de la pente de la voie ferrée à la base de la pente et des ancrages de sol pour soutenir la voie ferrée extérieure au sommet d'une pente élevée. La raison du choix de méthode de conception est discutée pour chaque site, de même que les contraintes du site, comme l'urgence, les limites de la propriété, la garantie d'une incidence minime sur les opérations ferroviaires, les restrictions d'accès au site et le coût.

1 INTRODUCTION

The design and construction of rail tracks built in the 1850's and later were reliant on observations and experience. At that time, train speeds were slow by today's standards and train loads were relatively light; the length of trains was short. Compaction of fills was mostly by self-weight, passage of construction equipment, and natural processes. Typically, embankments and slope flanking fills were constructed using materials originating from nearby cuts and were allowed to develop to the fill material's natural angle of repose. Through the years of operation since the tracks were first constructed, train speeds have increased, as have axle loads and the length of trains. These changes in railway operations have resulted in increased stresses being transferred to the track subgrade soils and have affected the underlying soils to an increased depth. In turn, these effects have resulted in a requirement for ongoing maintenance to accommodate settlement caused by the additional stresses; from time to time those increased stresses have exceeded the load carrying capacity of the supporting soils and cause instability. Those increased stresses have resulted in destabilization of slopes which rest at their angle of repose.

The section of rail track which extends from Dundas to Copetown, Ontario features a long uphill grade as the track rises up Hamilton Mountain.

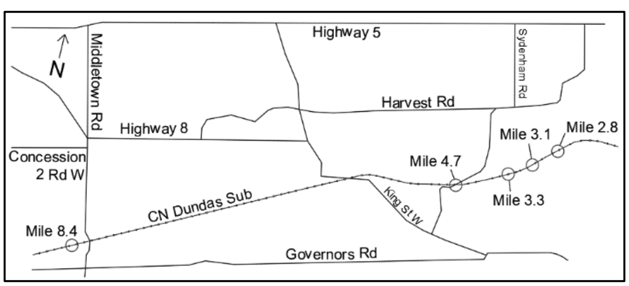

Figure 1. Map of sections of stabilized rail track along Dundas Sub

The rail track progresses through several significant cuts and is supported by many areas of fill (The Globe, 1853). In several locations, a slope cut has been made into the hillside to construct a platform with the excavated soil being cast on the downhill side to increase rail platform width. Following construction of the initial single rail corridor, widening of the platform to support two parallel tracks resulted in placing an additional width of flanking fill on the natural slope.

Instabilities in the slope supporting the rail track have occurred in several locations in the described section of track. Sections of previously stable track have experienced instability following increases in rail train length and increases in axle load. Mostly such instabilities have been manifest as settlement in the rail track, which has been progressive. However, some instabilities have been more important and required short term or more immediate attention. All instabilities have required implementation of stabilization measures to maintain safe rail operations. In the case of progressive movement, there has been enough time to carry out a conventional geotechnical investigation to characterize the site, which has then been followed by conventional design. In the situation of more active instability, priority attention is required; which implies committing more resources in a short term schedule to collect relevant data and sometime design innovative methods to adapt to site constraints. In such situation, knowledge of the local conditions and experience of the railway engineers and workers are a great asset in order to initiate remedial measures with the most reasonable assumptions to be confirmed as design and construction progresses.

Ideally, construction of measures to improve the margin of stability of the rail track platform supporting slopes require that there be a minimum of interference with rail operations. For a limited construction period, the impact of operating trains at slow speed may be unwelcome but acceptable. However, full interruption of rail traffic for more than a few hours has high negative impact on operations. Rail tracks lie within a right-of-way that is owned by the Railway Company and all construction work should normally be carried out within that right-of-way. Thus, for example, construction within the relatively narrow corridor of ownership along the Dundas Subdivision often prohibits construction of a stabilizing gravity berm where the toe of berm would extend beyond the right-of-way on adjacent private properties. Mostly, access for construction equipment and materials to the section of track experiencing ground movements needs to be along the rail tracks from the closest road crossing. Such constraints impose corresponding restrictions on design of stabilization measures.

Five case histories are presented, each case illustrates a different approach to stabilization and describes the logistical constraints associated with each site.

2 MILE 2.8 DUNDAS SUB

There is an approximately 12 m high embankment side slope at the study site which rested at a slope angle of about 35° to the horizontal. Settlement effects had been occurring over a track length of about 30 m. Prior to undertaking stabilization work, ongoing settlement at track level had been experienced over a period of several years and was increasing. Also, a site reconnaissance showed that a distinct toe bulge had developed at the toe of slope. The limits of the railway right-of-way lie at the toe of the existing embankment. Private homes lie adjacent to the property line. Geotechnical exploration showed that the embankment fill consists of sand with a variable gravel fraction; also included in the fill are ash and cinders, and seams of silty clay. Based on in situ test results consisting of standard penetration tests, soundings carried out with a Marchetti Flat Plate Dilatometer, and dynamic cone penetrations tests, the friction angle of the mainly granular embankment fill materials is in the range of 27° to 30°, and the undrained shear strength of the included clayey seams was interpreted to be about 25 to 30 kPa. Adoption of these soil parameters in conventional analysis showed that the slope didn't have factor of safety as per today's standard at the time of construction. Since that time, the increased train loads have, in turn, reduced the margin of stability. Analysis of the stability of the slope supporting rail traffic showed that if the lower portion of the existing slope material could be replaced with engineered fill exhibiting a high friction angle, the factor of safety of the slope with respect to global stability could be sufficiently improved to provide a stable platform at the slope crest (Alston, Ruel, 2017). The project design requirement could be met by construction of a berm featuring high quality granular materials stabilized with geosynthetic reinforcement (Task Force 27, 1990; TRB 1987) to provide a stable, oversteepened slope.

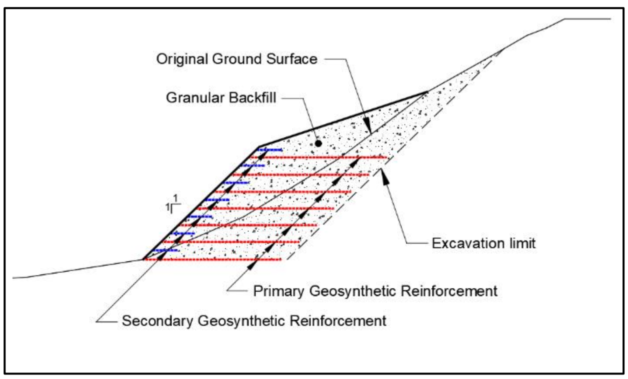

Figure 2. Cross section of reinforced soil slope

To maintain rail operations, careful review of possible construction methodologies showed that if construction could be effected in a set of short sections, with each of these sections being closed up at the end of the day, digging of excavations in the existing slope was feasible. A small storage area could be utilized at one end of the work area. The closest point of access was at the crossing 2 km east of the site and from that point, fill materials required for berm construction would be transported along the tracks in dump trucks, and to the base of slope from track level by an access road constructed on the side of the rail embankment. Preparation for construction required careful preplanning; geotechnical supervision of site work was carried out by a very experienced geotechnical technician. A slow order of 10 mph was imposed on rail traffic for the duration of construction. The work was carried out without inducing any significant sliding in the construction excavations, there was no significant settlement experienced in the track in the course of construction. The constructed berm has arrested the ground movements at the site.

3 MILE 3.1 DUNDAS SUB

Relatively small settlement effects were being experienced over a section of track which was about 15 m long, over a period of years. An approximately 10 m wide slide in the dipping side slope on the north side of the tracks occurred immediately following a significant rainfall event. The depth of the slide and the proximity of the head of the scarp to the rail tracks required priority attention. Geotechnical explorations were carried out which showed that the rail track had been constructed on a platform which has been partially cut into a hillside, with excavated fill material being cast onto the slope on the downhill side. Rockhead was at shallow depth and dipped to the north at an angle of about 20° to the horizontal. The supporting slope exhibits a side slope gradient of about 35° from north to south and is about 12 m high. The downward slope continues beyond the property line, at a flatter angle. There is no adequate work staging area at the site.

The side slope fill consists of granular materials which lie on a layer of firm silty clay, which in turn rests on a sloping rockhead. Analysis of the site situation showed that occurrences of ground movements occurred intermittently at times of heavy precipitation.

Geotechnical exploration showed that the track platform is underlain by soft to firm becoming firm, plastic silty clay which in turn rests on sloping bedrock; the near surface sub-unit of the bedrock is heavily fractured and is relatively permeable. Geotechnical explorations also confirmed that the rail platform had been widened on the downhill side by casting excavated soil. Stability analysis showed that a modest increase in phreatic pressure in groundwater in the bedrock layer was sufficient to decrease the factor of safety to the point of causing straining movements in the overburden slope soil. Evaluation of design alternatives and consideration of space restrictions showed that stabilization could most efficiently be provided by installing a set of tie backs from the slope of the existing embankment, which tie banks extend from the embankment face into the bedrock stratum. Transfer of downslope loads resulting from ground movement to the tie back anchors was effected by a system incorporating laying a geogrid sheet on the slope surface through a network of flat steel strips which were in turn attached to the tieback anchors. The design slope covering is flexible, allows winter heave to occur without distress, and permits efficient drainage through the facing (Alston 1991).

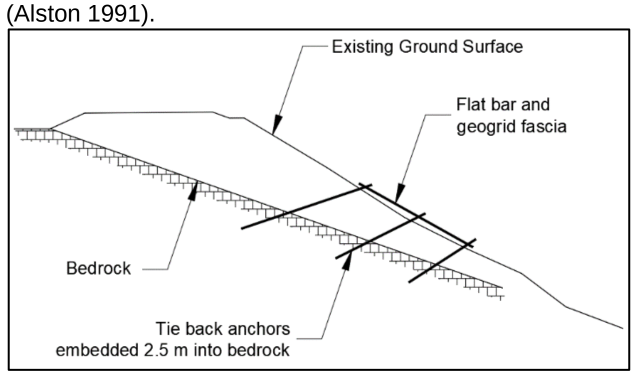

Figure 3. Cross section of tie bank anchors and flat bar / geogrid fascia

Construction was carried out using a drill rig mounted on the slope face. The drill rig was held in position on the slope by attaching the rig to anchors installed at the slope crest with a set of cables. All equipment and supplies were taken to the site along the tracks from an access point located 1.5 km west of the study site. The constructed slope reinforcement has successfully arrested slope movement.

4 MILE 3.3 DUNDAS SUB

The affected section of track is about 40 m long and consists of a slope which rises to the north of the tracks and falls to the south, at a slope angle of about 30°. The rail platform has been cut into the slope, casting of spoil from the northerly (high side) cut onto the southerly, lower slope. Placing of the excavated spoil increased the slope angle to about 35°, the affected slope is about 10 m high. Ongoing attention and maintenance have been required prior to implementing remedial work. The boundary of the right-of-way lies above the toe of slope on the south side of the tracks; private properties line the right-of-way. The soil profile consists of about 2.5 to 3 m of loose sand overlying firm silty clay. Rockhead lies at a depth of about 5 m. Groundwater is present at the base of the surficial sand deposit. Site inspection showed a distinct toe bulge at the base of the slope (Figure 4).

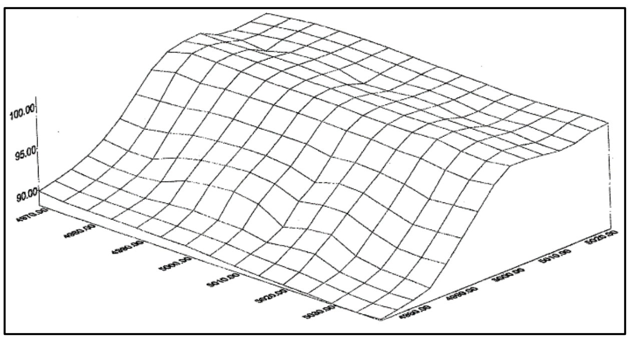

Figure 4. Isometric view of slope illustrating toe bulge

There being no flat land at the base of the slope to serve as a working platform, the alternative of construction of a gravity berm from a working platform was eliminated from consideration. Analysis showed that the site could be stabilized using the soil nail stabilization technique (Gassler, Gudehus, 1983). As the installation of the soil nail reinforcement was to be effected from the face of the slope, construction would result in minimal impact to rail operations. Design showed that installation of a set of 9 m long soil nails on a 1.5 m grid would satisfy factor of safety considerations. Restraint of the slope face to the soil nails was provided by geogrid reinforcement laid on the slope face and connected to the soil nails through a system of steel straps. Following completion of construction, movement at track level was arrested after a period of a few months following installation, after the restraint system had been tensioned by the then ongoing ground movement.

5 MILE 4.7 DUNDAS SUB

The site location is situated in an area in which the south track had been constructed at the top of the prior slope and supported by an approximately 3 m high gravity retaining wall consisting of a set of concrete blocks topped by rail ties. The concrete block retaining wall was experiencing distress such that further deterioration would eventually threaten support to the south rail track. No track movement had been experienced however. The slope below the toe of the existing retaining wall dips to the south and lies at an inclination of approximately 35° to the horizontal; it is about 40 m high. A visual examination of the slope showed no evidence of distress, nor of a toe bulge from below the retaining wall to the toe of slope. On this basis, it appeared that the natural soil slope was stable. The limit of the right-of-way lies about 12 m outside (down slope) from the slope crest, and in the upper portion of the slope. Analysis of the global stability of the natural slope using borehole data and laboratory test results showed that the margin of stability was positive but not sufficient as per today's standard.
Analysis of the stability of the upper slope showed that a wall fascia restrained by a suitable array of screw anchors drilled into the slope below the rail lines could support the upper slope and the rail tracks, and improve global slope stability by about 15%. The design utilized a "Bin Wall" fascia (Lowry, 2010) to restrain the ground to the previous slope geometry.

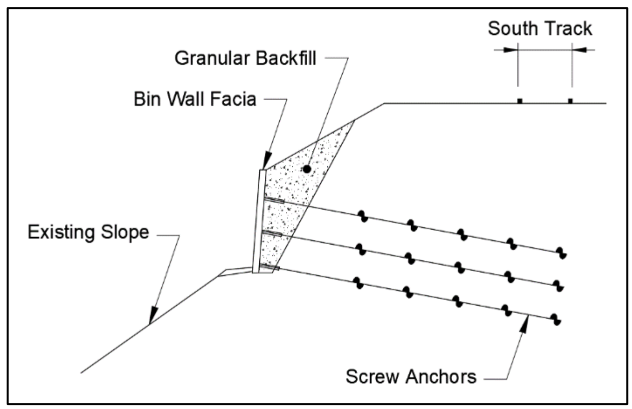

Figure 5. Cross section of bin wall and soil anchor assembly

Work to construct the replacement retaining wall and restraining screw anchors was effected from a 4 m wide platform located on the slope crest on the south side of the south track, without interference to train movements. The approximately 20 m long retaining wall system has effectively eliminated settlement on the nearby south rail track. Access to the site was available from the north side of the north track, across a temporary crossing. Equipment to install screw anchors and the wall fascia stood on the flat platform between the south track and the crest of the slope.

6 MILE 8.4 DUNDAS SUB

A drainage ditch is located on the north side of the north track at the study site. The invert of the drainage ditch was situated approximately 6 m below rail track level. For most of the year, the ditch is dry, however, run off at the time of the spring freshet had caused both side cutting and down cutting in the ditch which has compromised the safety of the rail tracks which were supported by the side slope. Although abnormal settlement was not being experienced at track level, the margin of stability in the slope was adjudged inadequate for unrestricted rail operations. The width of right-of-way in the affected length of track was such that the alignment of the drainage ditch could be sufficiently moved to the north to allow a conventional unreinforced gravity berm (Skempton, Hutchinson 1969) to be constructed to support the track and improve its factors of safety. The eroded flanking slope was adjudged unsuitable to setup equipment for installation of soil nails. Temporary storage space was available.

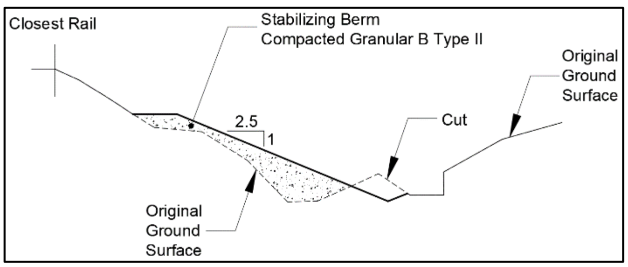

Figure 6. Cross section of gravity berm

Access for materials and equipment could be made at the eastern limit of the affected area such that the materials could be taken to the site across a temporary crossing without a need to travel along the tracks.

The north ditch being considered fish habitat by the local Conservation Authority, environmental measures were implemented as part of the stabilization measures, which contributed to delay the commencement of the stabilizing work for a period of about two years.

7 CONCLUSIONS

In assessing the costs of undertaking slope stabilization, account must be taken of cost effects on rail operations including need for slow orders on train work, work blocks required to use the rail corridor for access of materials and equipment, and safety of track operations for duration of construction.

Design of stabilization measures requires that account must be taken of the operation constraints imposed by working from a surface that consists of the face of a slope which is often inclined at 30° to 35° to the horizontal, which limits equipment selection and is a factor in system choice. Typically, soil movements continue to occur over a period of several months following the installation of the stabilization system as that system tensions from ongoing ground movements. Thus, allowance must be made for track maintenance in this time period.

Integral with design of the stabilization measures is a detailed evaluation of constructability and temporary works design. This includes such facilitating measures as access ramps, temporary slopes and excavations, and availability of working space which on other projects would be the purview of the contractor.

In implementing a design option which may involve excavation into a marginally stable slope, the design of excavation sections in both vertical and horizontal extent as well as time effects is essential.

Assessment of the target improvement in calculated Factor of Safety involves selection of the percentage increase, rather than target of a unique value. Experience has shown that in the situation of a slow but progressive slope movement, a 10% increase is generally adequate to arrest slope movement and 15% adds an adequate margin of safety.

In the course of selecting the preferred system for stabilization, a full set of “what ifs” must be considered. This includes; what if a dump truck travelling of the tracks experiences a breakdown? What if there is an interruption in service?

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