

Trenchless Utility Installation Ground Loss Soil Stabilization Emergency Action Plan for Rail Tracks – Case Study

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ABSTRACT

Trenchless boring methods may be utilized to install utilities beneath existing infrastructure, such as rail tracks, that cannot be readily removed thereby precluding conventional cut and cover installation techniques. One risk factor associated with trenchless boring installation is the potential for over-excavation and/or sloughing causing ground loss.

This paper explores a recent incident in Calgary, Alberta, of ground loss generated from trenchless boring beneath a rail structure that produced shutdown level track settlements. An emergency action plan was employed to stabilize the area in as cost-efficient and timely manner as possible to return to safe track operation. The results of the stabilization remediation techniques and lessons learned are provided herein as the general staged approach undertaken is presented.

RÉSUMÉ

Des méthodes de forage sans tranchée peuvent être utilisées pour installer des services publics sous l'infrastructure existante, comme les voies ferrées, qui ne peuvent pas être facilement enlevées, ce qui empêche les techniques conventionnelles d'installation de coupes et de couvercles. L'un des facteurs de risque associés à l'installation de forages sans tranchée est la possibilité d'excavation excessive et/ou de déneigement causant des pertes de sol.

Le présent document explore un incident récent à Calgary, en Alberta, de pertes de sol générées par le forage sans tranchée sous une structure de rail qui a produit des règlements au niveau de la voie d'arrêt. Un plan d'action d'urgence a été utilisé pour stabiliser la zone de la manière la plus rentable et la plus rapide possible afin de retourner à l'exploitation sécuritaire de la voie. Les résultats des techniques d'assainissement de stabilisation et les leçons apprises sont présentés ici au fur et à mesure que l'approche générale par étapes entreprise est présentée.

1 INTRODUCTION

1.1 Background

Tetra Tech Canada Inc. (Tetra Tech) was recently involved as a technical consultant for the geotechnical aspects of design and construction for a subsurface utility project, referred to herein as 'The Project', that required execution through trenchless methods utilizing a Tunnelling Boring Machine (TBM) for installation beneath existing railway track structures.

A geotechnical evaluation subsurface investigation was carried out by Tetra Tech along the proposed trenchless utility alignment prior to installation to evaluate the subsurface conditions of the site sufficiently so that adequate information was available to provide appropriate trenchless design and construction recommendations; however, during the trenchless boring activities, soil loss resulted in the development of a sinkhole at the existing ground surface which undermined the overlying rail track structure leading to an operational shutdown.

To aid in the development of potentially required future mitigation measures for similar track undermining events, this paper presents the factual data related to the emergency response systems enacted to effectively re-establish regular rail operation.

The Project involved the installation of a 1490 mm outside diameter concrete casing pipe at a depth, to the

pipe crown, of approximately 7.1 m progressing an approximate 59.0 m length beneath four sets of existing tracks. Additionally, the trenchless installation continued an approximate 249.0 m beyond the rail track influence zone.

1.2 Rail Track Structure Details

Figure 1 presents The Project general rail structure configuration, which includes a soil subgrade (as discussed in Section 2), granular sub-ballast material, granular ballast material, and wooden sleepers fastened to steel rails.

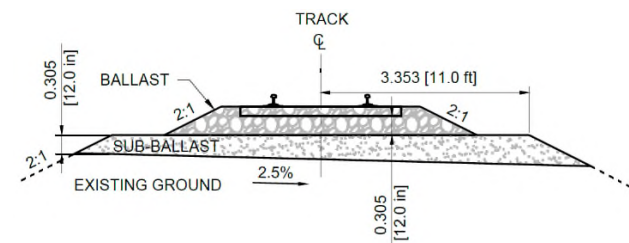


Figure 1. General Rail Track Structure Layout

The general gradation specifications for the sub-ballast and ballast materials within the track structure are presented in Tables 1 and 2, respectively.

Table 1. General Sub-Ballast Gradation Specification

Nominal Size (mm)	Percent Passing by Weight (%)
25	100
20	95-100
10	55-80
5	35-65
2.5	28-52
0.630	13-35
0.315	9-26
0.160	6-18
0.080	0-5

Table 2. General Ballast Gradation Specification

Nominal Size (mm)	Percent Passing by Weight (%)
45	100
32	70-95
25	50-80
19	10-40
13	0-15
5	0-1
0.074	0-1

2 SUBSURFACE CONDITIONS

During the subsurface investigation the soils at the trenchless utility installation depth were generally described as gravel, which was sandy, silty, poorly graded, subrounded to subangular, wet, dense to very dense in consistency, and with trace cobbles. The groundwater table was measured at an approximate depth of 5.1 m below the existing ground surface and groundwater seepage was observed.

The gravels were overlain with an approximate 1.5 m thick clay layer (Sand – 8%; Silt – 65%; Clay – 27%) and an approximate 1.2 m thick gravel fill layer up to the existing ground surface. The base of the utility casing was approximately 0.1 m from the observed interpreted soil/mudstone bedrock interface.

Figure 2 presents the particle-size analysis laboratory test results conducted on samples within the gravel deposit near the trenchless installation depth collected during the subsurface investigation at the borehole locations advanced in closest proximity to the track sinkhole.

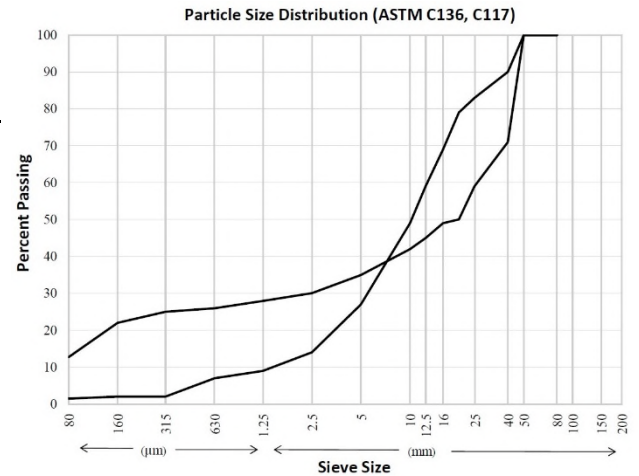


Figure 2. Particle-Size Analysis Results in Soils Near the Sinkhole

Figure 3 presents the results of the in situ Standard Penetration Testing (SPT) conducted at the borehole location advanced in closest proximity to the track sinkhole (approximate 5.0 m offset) in the soils overlying and at the casing installation location, organized by depth from the existing ground surface.

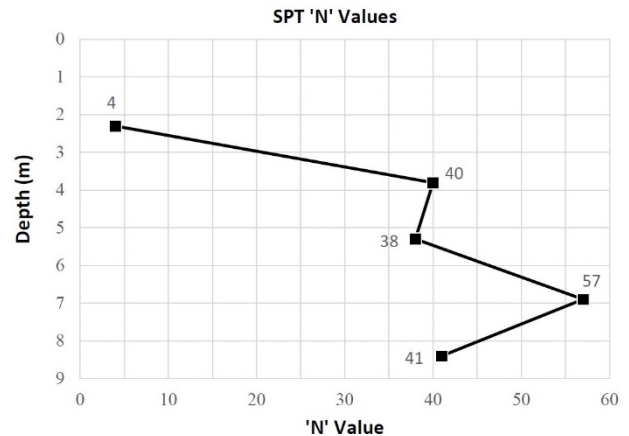


Figure 3. SPT Results in Soils Near the Sinkhole

Photo 1 depicts the general soils removed during trenchless boring at the approximate location of the track sinkhole.



Photo 1. Soils Removed at Approximate Sinkhole Location

3 RAIL DISPLACEMENT MONITORING PROGRAM

Ground movement may occur during trenchless utility installation due to the instability of the face of the bore or from the instability of ground caused by any over-excavation along the alignment. To safeguard against potential adverse effects of ground movement to rail structures, displacement monitoring programs are generally established prior to construction for regular survey measurements prior to, during, and after trenchless installation to determine the vertical settlement along the utility alignment.

Through consultation with the client and rail owner, a displacement monitoring program was developed for The Project outlining the survey target locations, threshold 'alarm' levels, and monitoring frequencies to safeguard against potential displacements that may affect track operations.

Five sets of survey targets were attached to the side of the rails centered at the trenchless utility crossing location with readings taken either directly, (when train traffic and/or adjacent construction permitted) or from a survey platform located nearby. Surveys were typically performed two to

four times a day during trenchless installation with an accuracy of ± 2 mm (sometimes survey target readings were missed due to obstructions such as trains and snow cover). Survey monitoring continued for three days following the completion of the trenchless installation as well as taken monthly for three months for a measure of potential long-term settlements.

4 SINKHOLE DEVELOPMENT

As the TBM progressed beneath the existing rails, ground loss at the trenchless installation boring depth propagated to an observable sinkhole at the existing ground surface immediately underlying the track structure. The resulting sinkhole is depicted in Photos 2 and 3.



Photo 2. Sinkhole Observed from Utility Alignment



Photo 3. Sinkhole Observed from Rail Alignment

Probable factors that may have contributed to the sinkhole event were suspected to include, but not necessarily limited to, saturated granular soils at install depth prone to sloughing, occurrence of groundwater seepage, inadequate communication during advancement, insufficient overcut control, and improper slurry/lubrication

fluid management. These probable factors and potential control measures which could be improved are further explored in Section 5.

5 EMERGENCY 'ACTION PLAN'

Following the development of the sinkhole, the compromised track structure was reinstated and returned to operation by means of progressing through the following sequential steps, which may be used as a general procedural approach for similar track undermining events.

1. Immediate shutdown of track operations.
2. Removal of the wooden sleepers and steel rails in the sinkhole area and initial backfill with granular fill/lean mix grout to limit further degradation of the track structure(s). Note that much of the area effected by the ground loss may be directly underlying and concealed by the existing surface materials; accordingly, equipment should approach the general sinkhole area with extreme caution and only following a visual assessment from qualified geotechnical personnel.
3. Reinstatement of the rail tracks and re-establishment of the rail displacement monitoring program survey baselines with an increase in both the number of points and reading frequency in proximity to the sinkhole.
4. Comprehensive review of the tunnelling means and methods by the tunnelling contractor to ascertain any deficiencies and/or areas of potential improvement whilst developing a corrective 'Action Plan'.
5. 'Action Plan' approval from all invested parties, which may detail, but is not necessarily limited to:
 - a. The probable geotechnical causes resulting in the sinkhole event. For This Project, saturated granular soils at the tunnelling depth with an increased potential for sloughing was determined as a probable geotechnical cause.
 - b. The identification of trenchless means and methods that can be improved, modified, or changed to allow for increased tunnelling control. Examples of potential controls that may be refined and were considered/employed during The Project include:
 - i. Increased radio communication between trenchless operator, site engineers, and rail flag person to better report obstructions or difficult/changing ground conditions.
 - ii. Additional pumps to ensure continued bore face pressure.
 - iii. Overcut ratio adjustment.
 - iv. Enhanced slurry viscosity.
 - v. Regular/increased cutter head inspection.
 - vi. Cutter head tooth arrangement adjustment.
 - vii. Additional ports in the lead casing to improve continuous lubrication.
 - viii. Creation of additional checklists to be conducted daily (e.g., pre-start equipment checklist, periodic maintenance inspection checklist).
 - c. Backfill plan specifics for any supplementary surface granular fill/lean mix grouting and/or slurry

grout via subsurface injection. The remedial grouting program employed for This Project comprised open-ended pipe grouting and sleeve port pipe injection grouting.

6. Execution of the 'Action Plan'.
7. Return to regular track operation with continued rail settlement monitoring until measurements are below tolerances. Some track lifting and tamping may be required over this period.

6 REMEDIAL GROUTING PROGRAM

The Project remedial grouting program comprised two separation zones (identified as 'Zone 1' and 'Zone 2'), which included a total of 8 open-ended pipe locations and 23 sleeve port pipe injection locations spaced at approximate 1.5 m to 2.0 m intervals.

'Zone 1' encompassed the estimated area in which granular fill was initially used to backfill the sinkhole to limit further track undermining (emergency 'Action Plan' Step 2) and was considered highly disturbed. A weaker grout mix design (<2 MPa) was used in this area given proximity to the TBM equipment.

'Zone 2' encompassed the remaining portion of the trenchless installation whose purpose was to stabilize and improve the cohesion of the coarse granular deposits to reduce the risk of further sinkhole development. Only sleeve port pipe injection locations were used in 'Zone 2' as well as a slightly stronger grout mix design (5 MPa).

The open-ended pipe locations were drilled to an approximate depth of 1.0 m above the TBM crown, followed by replacement of the inner drill rods with a grout injection cap. Drill casing was then removed in 1.0 m intervals up to surface once either grout volume reached >1,500 L or pressure flow refusal was exceeded over each interval.

The sleeve port pipe injection locations were drilled to an approximate depth of 1.0 m above the TBM crown (when above) or to the approximate TBM base (when alongside), followed by replacement of the inner drill rods with a 38.1 mm (1.5 inch) polyvinyl chloride (PVC) pipe. The internal PVC pipe included grout sleeve ports at regular intervals of approximately 0.5 m and the annular space between the PVC and drill casing was grouted prior to drill casing removal. Pressure grouting was then conducted at each sleeve port until either the grout volume reached >750 L or pressure flow refusal was exceeded. For every sleeve port that reached volume refusal prior to pressure flow refusal, the sleeve port was re-fractured with water and re-grouted under the same criteria (a third stage of grouting was required in a few instances).

7 CONCLUSION AND DISCUSSION

7.1 Remedial Grouting Effectiveness

A total of approximately 26,625 L of grout was injected into The Project sinkhole area, which was calculated as an approximate 4.5% of the total volume (based on an estimation of the total injection footprint). The extent of

grout and potential presence of remaining voids was then assessed through open-ended pipe testholes between previously grouted locations. Visual observations suggested the general absence of voids.

7.2 Displacement Monitoring Program Results

Over the duration and following The Project remedial grouting program conducted for the sinkhole, the measured rail monitoring point settlements did not exceed shutdown limits (as determined prior to construction and discussed in Section 3). For information purposes, Figures 4 through 9 present the track settlement monitoring results on a weekly basis from the time of sinkhole occurrence to The Project completion. The predetermined 'alarm' levels are indicated by dashed yellow ('warning' level) and red ('shutdown' level) lines.

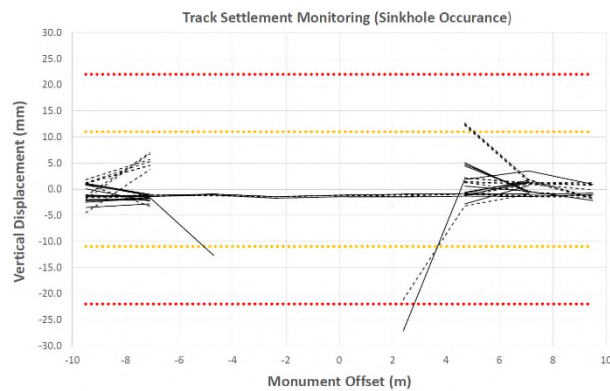


Figure 4. Track Settlement Monitoring Results at Sinkhole Occurrence

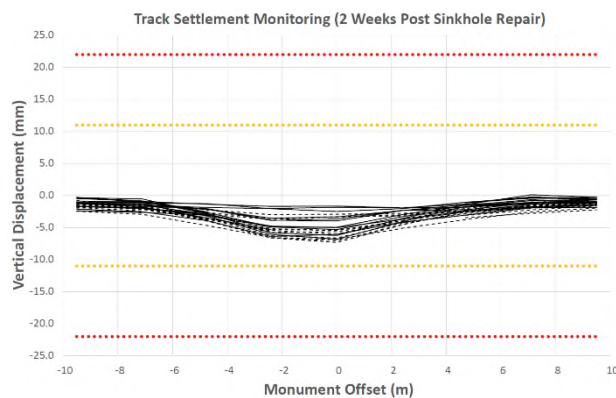


Figure 5. Track Settlement Monitoring Results (2 Weeks Post Sinkhole Repair)

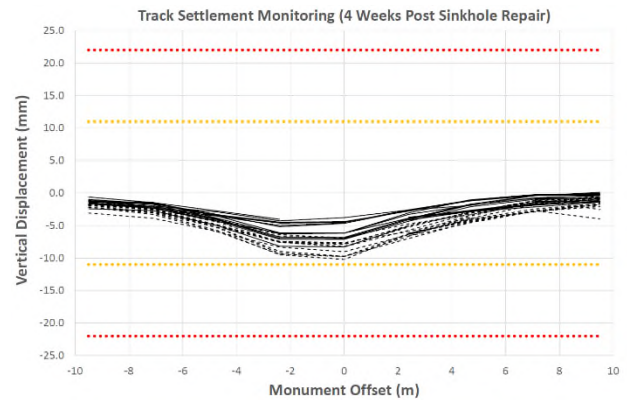


Figure 6. Track Settlement Monitoring Results (4 Weeks Post Sinkhole Repair)

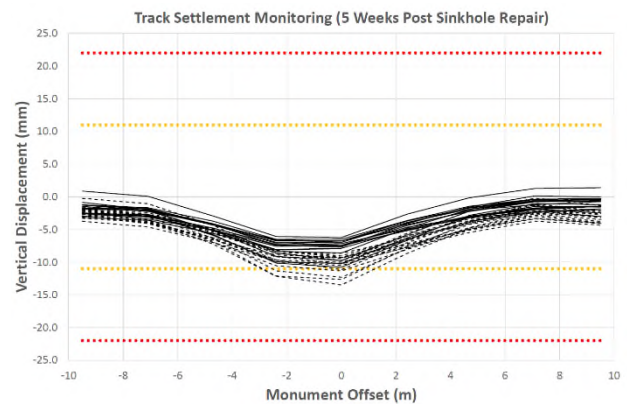


Figure 7. Track Settlement Monitoring Results (5 Weeks Post Sinkhole Repair)

Note that track maintenance through rail lifting, additional ballast placement, and tamping was conducted between the timeframes of Figure 7 (above) and Figure 8 (below), as mentioned as a potential requirement of the emergency 'Action Plan' in Section 5 (Item 7). This was conducted given a few of the rail monitoring point settlement measurements had once again reached the 'warning' level threshold (yellow dashed line).

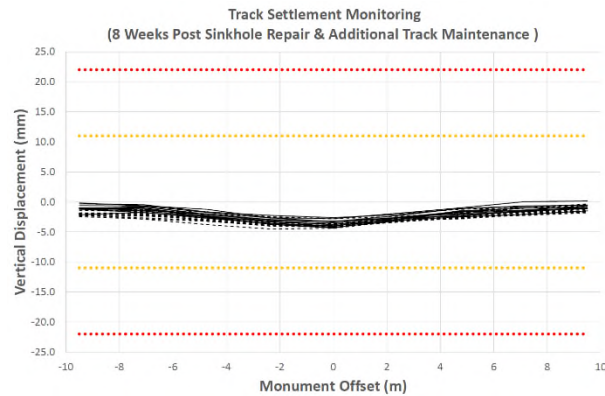


Figure 8. Track Settlement Monitoring Results (8 Weeks Post Sinkhole Repair and Additional Track Maintenance)

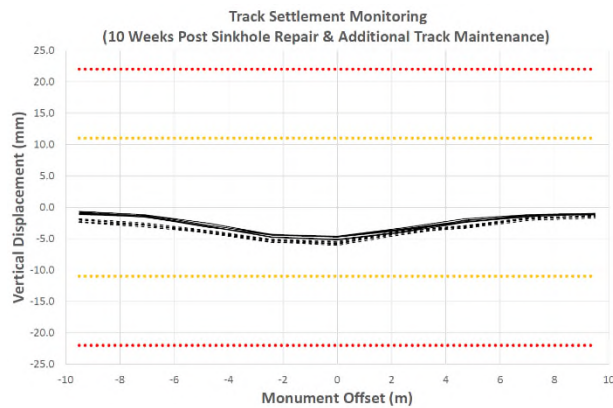


Figure 9. Track Settlement Monitoring Results (10 Weeks Post Sinkhole Repair and Additional Track Maintenance)

7.3 Emergency 'Action Plan' Performance

After progressing through the emergency 'Action Plan' stepped procedural approach as outlined in Section 5, inclusive of immediate actions, comprehensive reviews, and remedial programs, the possibility of additional adverse vertical displacements was considered remote.

This allowed effective return to regular track operation in as cost-efficient and timely manner as possible.

7.4 Potential Sinkhole Prevention Measures

To better understand the magnitude of potential displacements of overlying soils during trenchless tunnelling operations, estimates can be made based on:

1. Empirical methods from the observed subsurface conditions.
2. Comprehensive reviews of the contractor's means and methods prior to construction.
3. The experience of the specialized contractor in similar conditions.

These types of precursory reviews may give an indication of whether preventative measures are required to be implemented in advance of construction.

One preventative measure that may be applied is soil stabilization through a pre-grouting injection program, like that conducted as a remedial measure along The Project trenchless alignment.

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