Never Settle!

Importance of Settlement Analysis and Monitoring in Trenchless Design & Construction

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INTRODUCTION

A major concern among third party owners when trenchless projects are constructed near their infrastructure is settlement. Settlement of the surface can have detrimental effects on roads, railways, buildings, pipelines or other facilities. In the past trenchless installation methods have been the preferred method of these third party owners to cross beneath their infrastructure because of the less intrusive nature of the construction. However, there have been growing concerns of settlement and damage from over excavation, and therefore detailed assessments and plans at the application stage have become a more common requirement, as well as including a plan for inspection or settlement monitoring in the field during construction.

Surface settlement during trenchless construction can occur in various ways. Systematic settlement occurs from normal construction practice. This type of settlement is generally small in magnitude and occurs over a consistent settlement trough extending perpendicular to the trenchless alignment. Collapse of the overcut or annular space in the long term, dissipation of the fluid used during construction leading to volume loss, and convergence of the borehole wall during construction due to excavation and support pressure imbalance are some of the causes of systematic settlement. Random or unplanned settlement is a more severe condition that can be much more detrimental. These types of settlements are unpredictable and can form sinkholes or large amounts of surface displacement at locations along the alignment that would be considered undesirable, at the very least, and in many cases dangerous.

SYSTEMATIC SETTLEMENT AND MITIGATION BY DESIGN

During the design and permit application phase of a trenchless project, it is important to characterize the subsurface conditions, and assess the methodology selected for suitability in those conditions. There are risks associated with shallow depth of cover in some geology such as loose granular soil, and there may be not as much with others, such as clay or bedrock. It is very important to understand the trenchless method selected, and how the support system (I.E. fluid) is used during construction. Systematic settlements can be assessed using simple calculations and Normal Probability Methods (Bennett etal. 2008, "Analysis and Mitigation of Settlement Risks in New Trenchless Installations"), or using more sophisticated finite element analysis models.

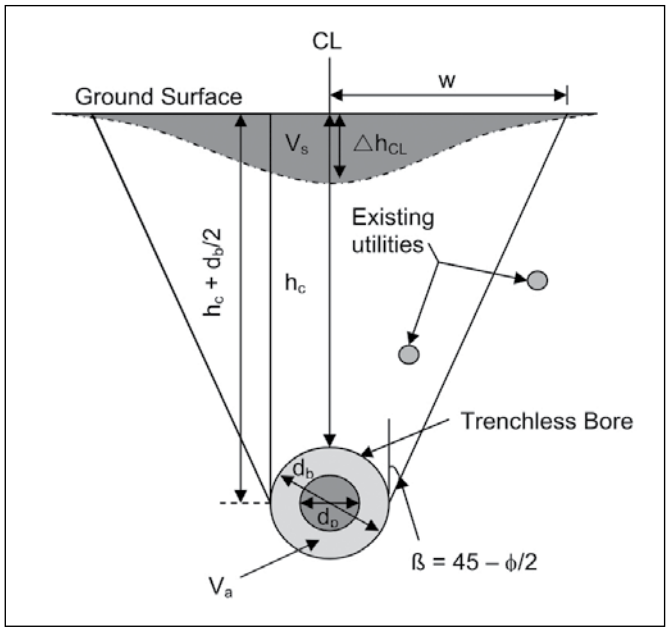

Figure 1: Graphic shows the projected settlement trough development (Bennett etal. 2008)

The depth of the trenchless design can be adjusted to maintain the calculated settlement below the required limits. If two parallel alignments are planned, this needs to be considered in the settlement assessment as both alignments can influence each other and increase the total surface settlement. In the case of parallel alignments, the spacing can be increased which is another design mitigation to decrease the total settlement. Requirements from the third party owners issuing permits may have settlement tolerances that need to be adhered to for their infrastructure. These tolerances need to be met prior to issuing a final design for the permit application.

UNEXPECTED SETTLEMENT AND MITIGATION BY CONSTRUCTION

Concerns for unexpected settlement during construction are more difficult to manage at the design stage, and mainly rely on

Figure 2: Robust self-contained GPS units that can be utilized to monitor settlement remotely

Figure 3: Robotic Total Station or Levels can also be used by qualified personnel to complete the monitoring or construction surveys

the contractor's utilization of best practice and proper mitigation strategies. Over-excavation is generally the leading cause of unexpected settlement. This happens when the volume of soil removed from the tunnel or borehole is greater than the diameter of the downhole tools or cutting faces used. Sand, Gravel, cobble or other unconsolidated granular soils are the most prone to over excavation if the support fluids aren't adjusted accordingly. These soils do not exhibit cohesive strength, and therefore once confining pressure is relieved the soils will collapse. The confining pressure that is relieved during excavation is generally replaced

by fluidic support pressure, which stabilizes the borehole wall. The properties of the fluid need to be designed in accordance with the geotechnical formation because if the fluid dissipates into the surrounding soil its support function is lost, and there is an increased risk of collapse or over excavation. Specific to HDD construction, drill path designs which include portions of the hole above HDD entry elevation are understood to have limited, if any fluid support pressure. In cases where sand or other loose granular soils are present at elevations above rig elevation, sinkholes or excessive over excavation are likely. Additional risks to be considered in the case of tunnelling are the size of the soil grains relative to the tunnelling equipment internals. If a large cobble is encountered and passes through the crushing chamber without being broken down there is a risk of blockage leading to limited face pressure and collapse of the soil, at the face of the formation. In both tunneling and HDD applications, improper rate-of-penetration can also lead to over-excavation. These are a few scenarios which can lead to unexpected settlements during trenchless construction. It is important to identify these issues for a particular project and for the contractor to have mitigation plans for these potential settlement hazards. It is also important for the contractor to have contingency plans available and ready to implement in a short timeframe to protect the public in the case any unexpected settlement does happen. Although contingency plans are very important, the best way to eliminate unexpected settlement is by prevention and mitigation through the contractor following good construction practices.

MONITORING

Once the planning, design, and permitting phase has been completed and approved, a monitoring plan needs to be completed and implemented during construction. The monitoring plan needs to outline the methods and means used to systematically measure the ground surface and report any changes. These plans should also include the visual observations that would take place during construction to monitor potential locations of over excavation. The monitoring could include surface and subsurface monitoring points laid out along the projected settlement trough. These points can be measured using conventional survey techniques, remote highly accurate GPS units or other means, however the accuracy of the measurement system needs to be considered.

Generally, a measurement system with errors within +- 1mm (1/32”) are required to ensure reliable measurement. It is important to note that if settlement in excess of the tolerances outlined by the third party owner are realized, there may be a requirement to stop construction and review, or even submit a new crossing plan.

This could be detrimental to the project, and therefore, the engineer of record needs to ensure the measurements taken are trustworthy and reliable. Visual observation and communication with the contractor are other tools that should be utilized in order to make a proper assessment of potential unwanted settlement. Following the completion of construction, it is important to communicate the results of the monitoring to the client, and/or the third party owner, and state that the construction has been complete and there is no expectation of further settlement.

Normally this is the final stage and closes out the settlement monitoring process, and allows the third party owner as well as the client to move forward confident their infrastructure is safe. Depending on the client, the timeframe for how long after construction the settlement measurements are required to be monitored can vary. In cases where excessive or continuing settlement are identified, additional measures such as grouting may be necessary. Although such instances are rare (with proper front end design and planning), accurate monitoring ensures these issues are caught and addressed before they can become catastrophic.

CONCLUSION

Settlement of third party above ground or underground infrastructure has become a prominent concern that needs to be addressed both in design and through permit application, as well as construction mitigations. There are many forms of systematic settlement that can be predicted with relative confidence, and these forms of settlement should be mitigated during design in order to set the contractor and the project up for success. Unpredictable settlements are of much more concern as they may happen rapidly and in undesirable locations. These types of settlement need very careful input from the contractor to assist in providing mitigations for these issues. In addition, if these large, unpredictable settlements do occur, it is very important that contingency plans are developed and implemented in a very short timeframe to ensure public safety is maintained.

Observations and careful monitoring needs to be a focus during the construction planning and the monitoring program must be specific to the project. Communication between all parties is paramount to ensure clear instruction is given and trust between third parties, owners and contractors are maintained. The final documents written for the project need to summarize the construction works, and issues that arose and document that there is not expected to be issues moving forward. This document is important to give peace of mind to all owners that their infrastructure will be safe in the future.

The trenchless industry needs more successful stories in the area of settlement monitoring. Sinkholes, heaves or other settlement related mishaps place a black mark on the trenchless industry. Proper planning by the owner, consultant and contractor can limit many negative occurrences which will move our industry even further forward and establish a much lower perceived risk for third party owners.

ABOUT THE AUTHOR:

Stefan Goerz *has over 10 years of direct experience in projects related to trenchless pipeline construction, geotechnical investigation and assessment for pipeline and trenchless design, geotechnics for tunnel/microtunnel design as well as geohazard assessment for linear infrastructure. Stefan is the Geotechnical Manager for the CCI Group of Companies.*