Storm Storage Facility (SSF) Geotechnical Monitoring

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Abstract

For the Minnesota Department of Transportation (MnDOT), Barr led a multi-partner team in designing a 17,200 cubic metre underground stormwater-storage facility (SSF) to reduce flooding and create system resiliency along a major interstate artery in Minneapolis. Six diaphragm wall chambers, each approximately 13 metres in diameter and 26 metres deep, are being constructed several metres off the I-35W Interstate shoulder with the groundwater approximately 1 metre below the pavement surface. The SSF is located within a small footprint and near active freeway traffic, local residential neighbourhoods, bridges, and existing utilities. During the design phase, ground conditions and construction methods were investigated, analysed, and reviewed. Acknowledging the potential third-party risks, a geotechnical monitoring system was designed, implemented, and maintained throughout construction to provide critical data to the owner, design team, and contractor. Additionally, contractual criteria for the dewatering program were incorporated and tied to the monitoring program. Data analysis and lessons learned from soil nail wall performance data, contractual criteria associated with dewatering data and I-35W impacts are presented.

Keywords: Deep Excavation, Geotechnical Modelling, Contractual Requirements, Performance Monitoring Data

1. Introduction

During intense precipitation events, lanes of Interstate 35 West (I-35W) freeway in southern Minneapolis flood. The flooding has direct economic and social impacts as it prevents vehicle transport along a major transit corridor. The Minnesota Department of Transportation (MnDOT) needed a remedy providing additional system resiliency to this segment of their transit system from stormwater impacts. To minimize flood related risks that impacts vehicular traffic on I-35W, a deep tank design was developed and is currently in construction. While the project was initially intended to be part of a typical highway upgrade, the volume of storage, high groundwater, and unique ground conditions influenced decisions to make this project separate from an overall highway reconstruction project; the overall highway project consisted of I-35W widening, bridge improvements, new bridge construction, etc. along the interstate corridor between downtown Minneapolis going south approximately 7 kilometres to Highway 62 (also called "Crosstown"). The deep tank construction project, also called the Storm Storage Facility (SSF) construction project, is in the middle of the "Downtown to Crosstown" project.

MnDOT chose a Construction Manager General Contractor (CMGC) alternative delivery approach for the work and awarded the construction contract to a joint venture between Kraemer Construction and Nicholson Construction (JV). Barr Engineering Co. (Barr) led the multi-partnered design team with Brierley Associates and TKDA Engineering. A CMGC project delivery approach allowed for constructability considerations to be considered and incorporated during design. This approach allowed management of risks during construction with a geotechnical monitoring being a critical component for collaboration throughout construction.

2. Storm Storage Facility (SSF)

The SSF design contains a two-sided weir, which under normal low flows, allows for passage of stormwater to be handled by the mainline system. During significant precipitation events, stormwater flows overtop the weir and fall directly into one of the storage cells. The six cells are connected at the base to allow for uniform filling (Figure 1). Once the mainline system has evacuated, a pump station engages, conveying the initial flows from the precipitation event back into the mainline system for traditional stormwater conveyance to the Mississippi River. The six storage cells create approximately 17,300 cubic metres of storage volume.

The SSF diaphragm walls are approximately 1.2 metres wide, with a 45-centimetre-thick cast-in-place concrete liner and an inside finished diameter of 12.8 metre. Each cell is 26 metres deep, and the diaphragm walls extend down 33 metres below ground surface. Diaphragm wall construction consisted of clamshell and Hydrofraise™

milling techniques by the JV with slurry replacement with grout followed by excavation of the soils internal to the cells. Figure 2 shows both diaphragm wall excavation techniques.

Figure 1: Concept design of the six cell Stormwater Storage Facility (SSF) – looking southeast

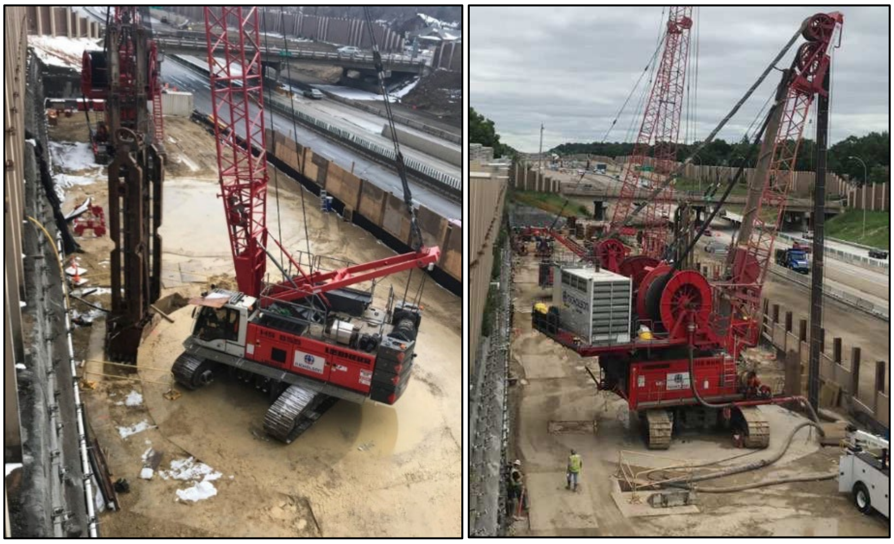

Figure 2: Cell 2 Diaphragm Wall Excavation with Clamshell (left)
Cell 3 Diaphragm Wall Excavation with Hydrofraise^{TM} (right)

2. Geology

The general geological stratigraphy in the Minneapolis area contains glacial drift overlaying the Platteville Limestone followed by Glenwood Shale on top of the St. Peter Sandstone. In several areas, stream erosion cut deep valleys in the sedimentary rock sequence before glacial advancements filled the valleys with glacially derived sediment and till. The final location of the SSF is in one of these erosional valleys filled with Pleistocene glacial outwash over glacial till. Outwash deposits consist of sand, sometimes with significant gravel or fines with glacial till tending to be sandy clay, silty sand, or clayey sand with occasional boulders throughout. Together, the outwash and till ranged from to be 15 to 55 metres thick within the vicinity of the project area.

3. Risks

While the SSF project poses several risks that require management, the application of geotechnical monitoring was specifically well-suited for providing insight into three risks identified during the design process:

1. soil nail wall movement
2. groundwater pressures during excavation
3. I-35W subsidence

To estimate the deformation response extents to cell excavation with the diaphragm walls in-place, geotechnical deformation modelling was performed using MIDAS GTS and FLAC3D. Results indicated vertical, and to a lesser extent, horizontally related displacements from excavation of the cells. Vertical displacement estimates were less than 10 millimetres for the steel water main, less than 10 millimetres for the private residences, and approximately 20 millimetres for surface of I-35W.

3.1 Soil Nail Wall Movement

Soil nail wall construction was necessary to create a flat workspace to construct the SSF. Soil nail wall movement, if excessive, posed several consequences to the construction project. The soil nail wall, being approximately 8-metres tall, supports an 8-metre sound wall comprised of concrete piling and timber lagging, a city street with a steel water main below it, and private residences. The steel water main, of unknown condition and joint configuration, was approximately 3 metres or less below the city street. The steel water main was assumed to be constructed of 6-metre pipe segments and assumptions were made to determine a conservative allowable bending or rotation about pipe joints. The design team estimated steel water main displacement to range from approximately 5 to 10 millimetres with approximately double that amount at the face of the soil nail wall after post construction being possible. Although it was planned to be lined prior to construction, if the steel water main were to leak due to excessive soil nail wall movement from additional saturated soil loading, then SSF construction would be jeopardized.

The geotechnical instrumentation and monitoring program was designed to measure small scale (strains and stresses) for early detection to large scale (displacements) for potential impact assessment and soil nail wall coverage with redundancies. Table 1 lists the instrumentation, general placement, and purpose for monitoring the soil nail wall.

Instrumentation	General Placement	Purpose
Vibrating Wire, Sister Bar Strain Gages (VWSG)	Installed on select soil nails at varying lengths along nails and doubled per location for redundancy	At varying lengths along select soil nails, measure strain accumulation, and identify potential active wedge formation or soil nail engagement with surrounding soils
Horizontal Earth Pressure Cells (HEPC)	Installed in boulevard between soil nail wall and city street behind sound wall at varying depths	If active wedge formation occurs, measure the change in stress on soil nail wall
ShapeArray (SAA)	Installed in boulevard between soil nail wall and city street behind sound wall to depth approximately equal to design depth of cells	Measure lateral displacement and compare to VWSG and HEPC for potential explanation of changes
Automated Motorized Total Stations (AMTS) with monitoring prisms	Monitoring prims placed on sound wall and soil nail wall at horizontal intervals ranging from 6 metres to 12 metres and at 3-metre elevation intervals	Measure lateral and vertical displacement of soil nail wall face and compare to SAA

Table 1: Types of instrumentation used for soil nail wall monitoring

3.2 Groundwater Pressures

Figure 3 shows the cell construction sequence. With shallow groundwater and construction of six 26-metre-deep cells, a groundwater pumping program (depressurization program) was identified by the CMGC team as the highest risk to the project with the greatest consequences. It was recognized that a robust and redundant dewatering system was needed, and as result, a robust and redundant instrumentation system providing near real-time pore water pressure measurements was also needed. As a result, groundwater depressurization requirements were entered into the contract. Loss of dewatering capabilities and uncontrolled pressurization in the cell during excavation meant that excavation base could liquefy, thereby potentially creating an emergency rescue effort, loss of equipment, and schedule delays.

Figure 3 shows a typical cross section of an SSF cell highlighting vibrating wire piezometer (VWP) installation depths and a plan view of the SSF cells with boring locations for VWPs. All VWPs were installed using the fully grouted method (Contreras et. al., 2007) as the soils generally varied between clays, clayey sands, and silty sands. Multiple VWPs were installed at the bottom tips of the diaphragm walls and lower since the JV was planning to have multiple dewatering wells running around the perimeter of each cell. Redundancy was needed because as groundwater was being pumped, the hydraulic gradients were estimated to vary substantially around the diaphragm wall tips and it was possible that VWPs would become damaged during construction. The contractual depressurization requirements were measured using the VWPs located below the diaphragm wall tips at elevation 215.5 metres. One VWP was installed below the centre of the proposed base since this location would be sensitive to depressurization system performance as seen in steps 4, 5, and 6 in Figure 3.

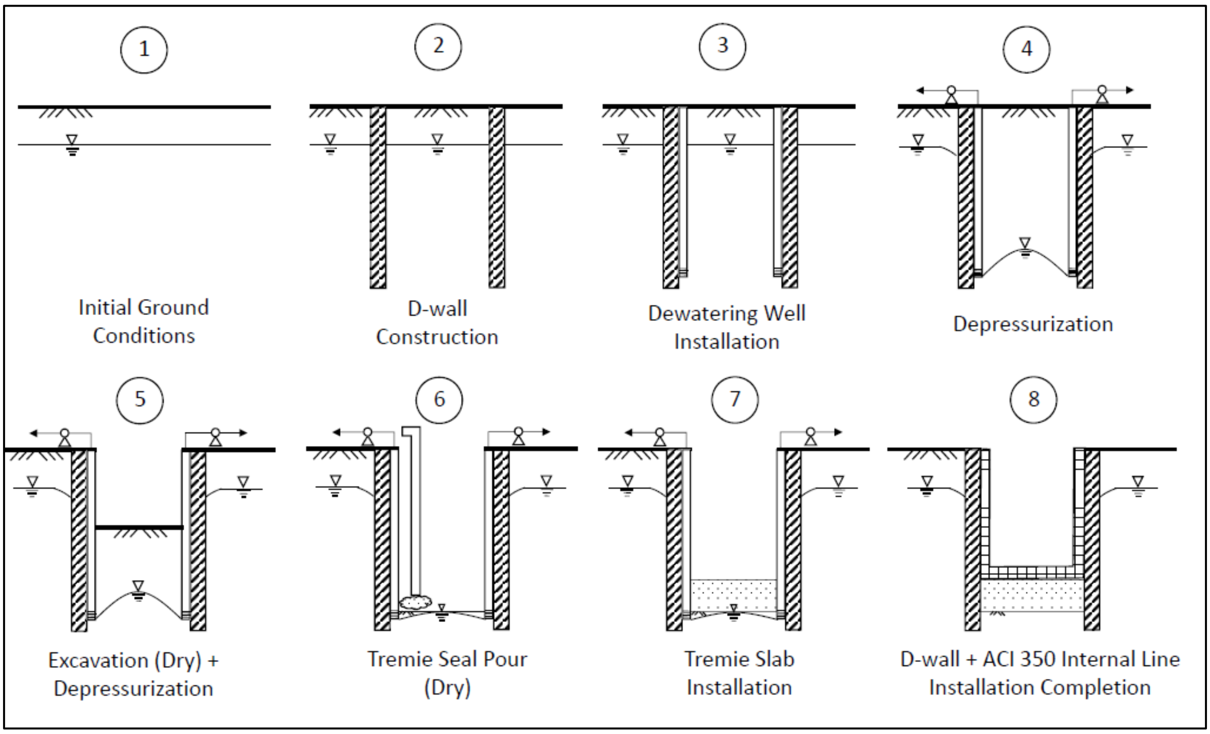

Figure 3: Cell construction sequence

3.3 I-35W Subsidence

Clamshell and Hyrdrofraise^{TM} diaphragm wall excavations were expected to encounter clays to boulders. Both excavation techniques were completed with slurry to maintain trench stability, and with slurry in the trenches, it was not possible to assess excavation sidewall conditions visually. In the event of the excavation process encountering boulder, aggressive excavation methods would be used to break down the boulders for extraction. This, in combination with the depressurization program and geotechnical modelling work, presented subsidence risk to I-35W. If the trench slurry was unable to provide adequate pressures and an excavation sidewall collapsed, the ground loss may propagate to the ground surface and I-35W. Therefore, the CMGC team needed to monitor I-35W subsidence to minimize the impacts to the public using the interstate. Table 2 lists the instrumentation, general placement, and purpose of instrumentation for monitoring I-35W subsidence.

Instrumentation	General Placement	Purpose
Inclinometer casing for traversing probe and ShapeArray (SAA)	Installed between the cell and shoulder of I-35W	Measure lateral displacement and compare during diaphragm wall construction and cell excavation
Automated Motorized Total Stations (AMTS) with monitoring prisms and reflectorless pavement measurements	Monitoring prims placed along traffic protection (concrete barriers) on shoulder and reflectorless shots on grid in traffic lanes	Measure vertical displacement of concrete barriers and road surface and compare to SAA lateral displacements

Table 2: Types of instrumentation used for subsidence monitoring

4. Instrumentation Data Analyses

For purposes of this paper cell 3 instrumentation, the third of six cells from the southernmost cell, will be highlighted. Figure 4 shows an instrumentation cross section schematic through cell 3.

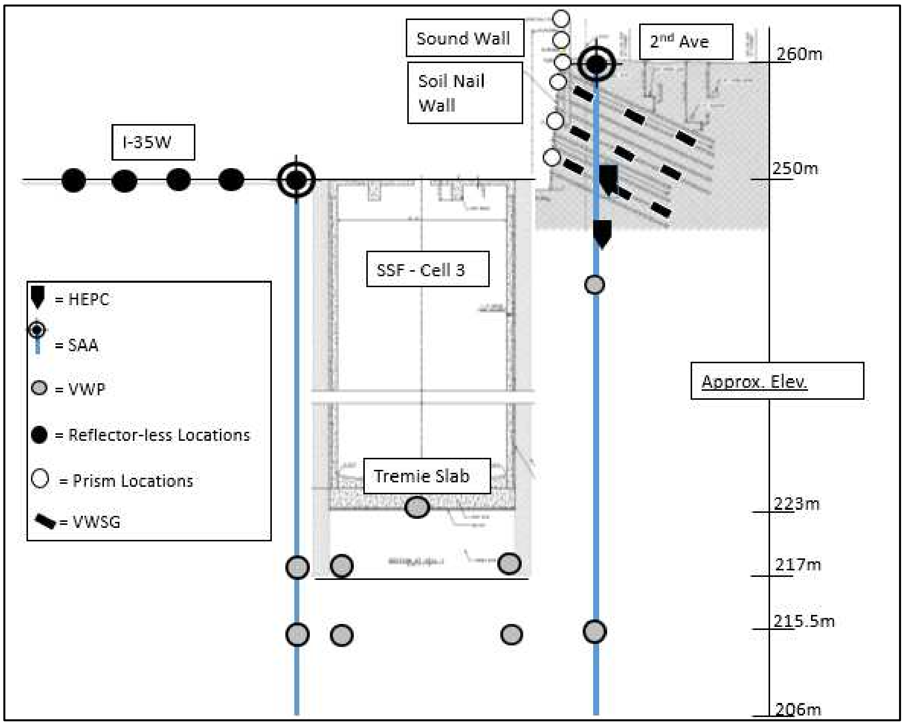

Figure 4: Cell 3 instrumentation cross section schematic

4.1 Soil Nail Wall Performance

Soil nail wall performance monitoring was measured with ShapeArrays (SAA), prisms, and vibrating wire strain gauges (VWSG), and horizontal earth pressure cells (HEPCs); Figure 5 shows data from each of these sensors, respectively. General construction timelines and groundwater pressure measurements are included as well.

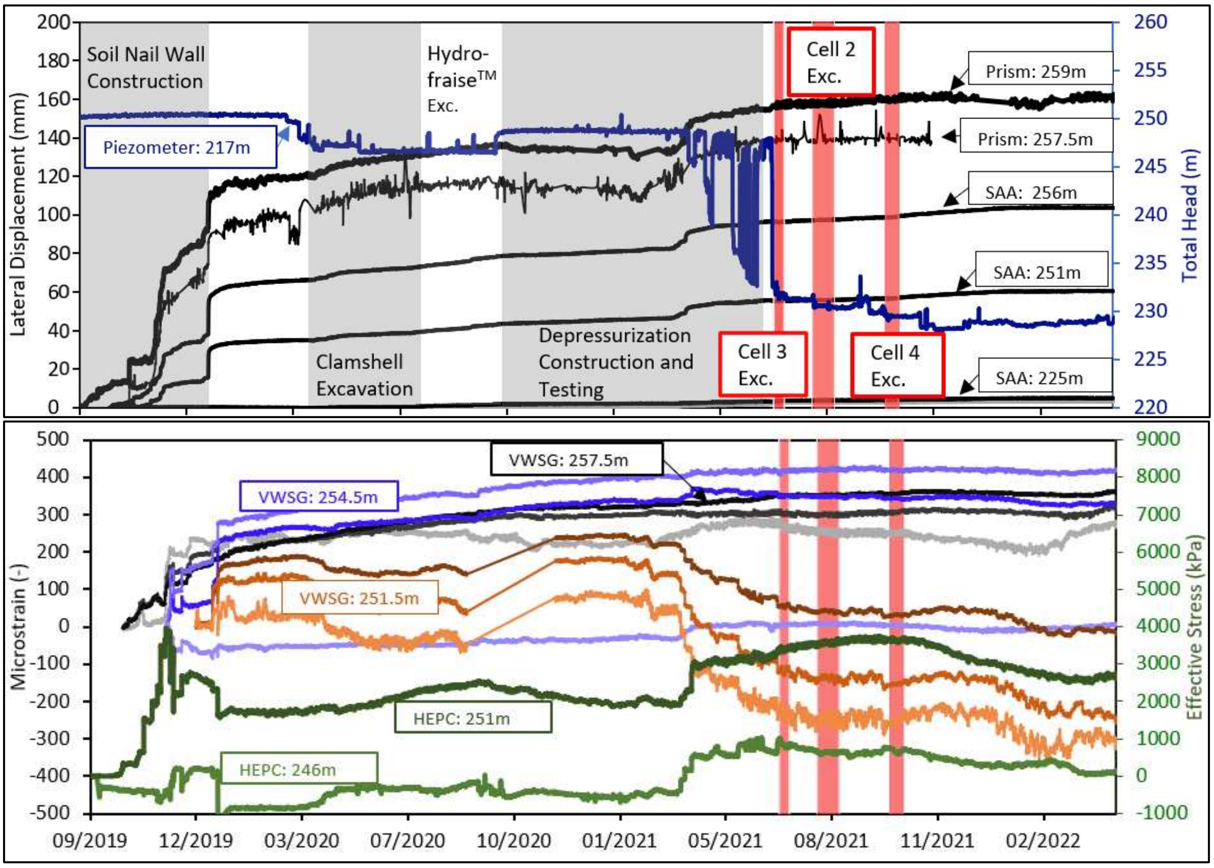

Figure 5: SAA-Prisms Data (Top), HEPC-VWSG Data (Bottom)

Most lateral displacement of the soil nail wall occurred during construction of the wall itself. Minimizing the height of the exposed soil between soil nailing/shotcrete and the construction bench proved to be effective at minimizing lateral displacement. After the soil nail wall was substantially complete, the JV installed (vibrated) 8 to 10 metres of steel sheeting at the toe of the soil nail wall to provide additional ground stiffness for clamshell and Hydrofraise™ guide beam construction in late December 2019 and early January 2020. This resulted in abrupt lateral displacements between approximately 20 to 40 millimetres. Final well installation and development at the soil nail wall toe occurred in April 2021 which led to additional lateral displacement. Change in stress and strain measured by HEPC and soil nail VWSG indicate that horizontal stresses increased during soil nail wall construction as the soil nails engaged. However, the lowest row of soil nail VWSG indicate a decrease in strain following the installation of wells in between the cell wall and toe of the soil nail wall. The VWSG data also indicates decreasing strain with distance along the soil nail while the dewatering program or cell excavation appear to have little to no impact on soil nail wall performance except that a low rate of creep continues, likely due to the ongoing depressurization program. The construction activities that appeared to have the largest impact on the soil nail wall were top-down excavation methods and working at the toe (installing/vibrating steel sheeting, installing dewatering wells with rotosonic drilling methods, and well development).

4.2 Groundwater Depressurization Program

The groundwater depressurization program measured groundwater pressures with piezometers installed at a depth of 35.4 metres (elevation of 215.5 metres). The JV installed 8 to 10 dewatering wells around each cell. Figure 6 shows cell 3 depressurization data with cell excavation periods shaded and maximum allowable groundwater pressures for several excavation depths (in red).

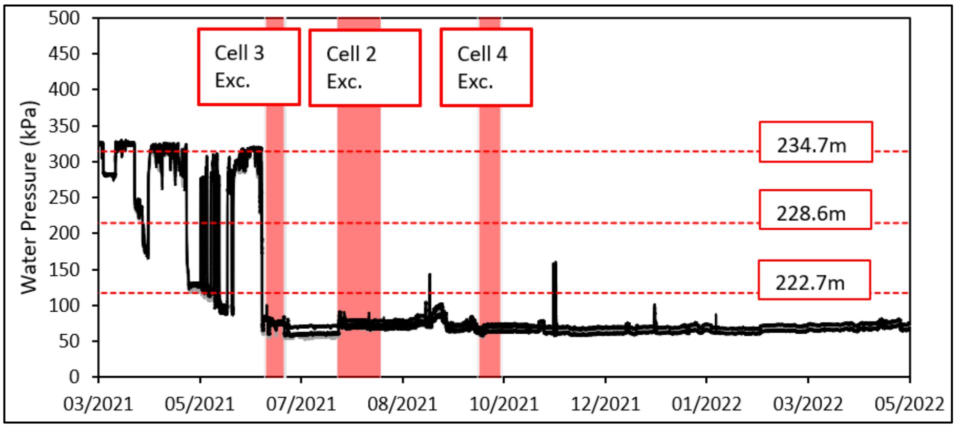

Figure 6: Plot of Depressurization Program Monitoring Data

Prior to cell 3 excavation, the JV obtained the depressurization goal in June 2021. During excavation and before base slab placement, several alerts were issued as the JV was either testing the system or experienced short pumping outages. The JV conducted a brief test in early September 2021 by turning off pumps around Cell 3 after excavation was complete and before the base slab was poured. Pumps were off for approximately 1 hour and pressures increased approximately 70 kPa with minor groundwater observed seeping into the excavation with no liquefaction occurring. This allowed the JV to investigate scenarios to optimize pumping rates and, if pumps stopped, refine plans based on re-pressurization for potential evacuation. The groundwater depressurization program, as simple as it may be in terms of alerting on measured pressure values, proved to be a concept easily understood by the project team.

4.3 I-35W Subsidence

Lateral displacement due to excavation of diaphragm wall panels was measured by the SAAs between the interstate shoulder and the side of the cells. Vertical displacement of the interstate north bound lane was measured with automated motorized total stations and reflectorless measurements on pavement with live traffic. Although these timelines do not overlap, Figures 7 and 8 show that diaphragm wall construction and cell excavation did not result in lowering the road surface elevation. The sidewalls of the slurry filled diaphragm walls remained intact at the shoulder of the highway despite the construction technique and encountering boulders. However, the Hydrofraise™ appears to have had resulted in a distinctive increase in lateral displacement when compared to clamshell excavation (Figure 7). Well installation was completed near the SAA and well installation impacts are seen in the disjointed time history data.

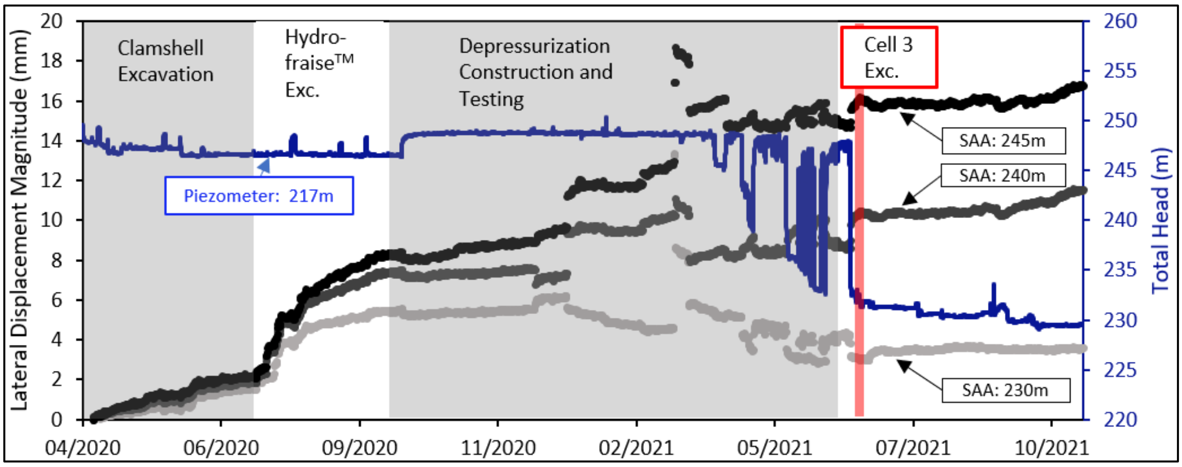

Figure 7: Cell 3 diaphragm wall excavation and lateral displacement magnitudes with depth

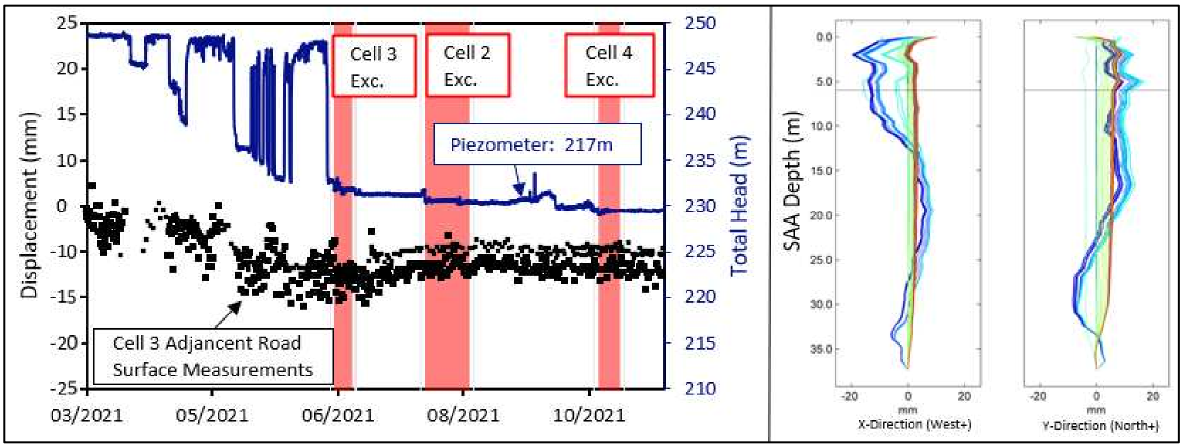

Figure 8: I-35W surface displacement and lateral displacement with depth

Lastly, the excavation of cell 3 appears to have resulted in no measurable interstate vertical displacement. This is consistent with the total station measurements on the highway surface and appears to have occurred while lowering the water table. Figure 8 shows that the dewatering test program appears to have lowered the highway elevation between 10 to 15 mm, likely attributed to the increased vertical effective stresses with water levels lowering by approximately 20 metres, which corroborated the geotechnical deformation models estimates.

5. Conclusions

For the Minnesota Department of Transportation (MnDOT), Barr led a multi-partner team in designing a 17,200 cubic metre underground stormwater-storage facility (SSF) to reduce flooding along a major interstate artery in Minneapolis, Minnesota. Six diaphragm wall cells, each approximately 13 metres in diameter and 26 metres deep, are constructed several metres off I-35W with groundwater near the pavement surface. The SSF is in an erosional valley filled with glacial till and near active freeway traffic, residences, a bridge, and existing utilities.

Soil nail wall, groundwater depressurization program, and I-35W subsidence geotechnical performance monitoring data were presented. The construction activities that appeared to have the largest impact on the soil nail wall were top-down excavation methods and working at the toe (installing/vibrating steel sheeting and dewatering wells with rotosonic drilling methods). The groundwater depressurization program proved to be effective and simple such that the JV achieved depressurization contractual requirements prior to excavating allowing the JV to investigate scenarios to optimize pumping rates or, if pumps stopped, plans based on re-pressurization could be made for evacuation. I-35W subsidence was likely due to dewatering and measurements corroborated geotechnical deformation modelling estimates.

References

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