APPLICATION OF SPECIAL GEOTECHNICAL CONSTRUCTION EQUIPMENT AT THE ALASKAN WAY VIADUCT REPLACEMENT PROJECT

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The twin decked Alaskan Way Viaduct is a passage to Seattle's downtown waterfront and of great economic importance to the city. In 2001, the Nisqually earthquake damaged the viaduct and led to the redevelopment of this corridor. The project includes two miles of 57.5 ft diameter bored tunnel beneath downtown Seattle and a stretch of new highway and overpass bridges at the southern tunnel entrance. State-of-the-Art special foundation equipment was mobilized for the project to perform a broad range of geotechnical construction. Applications included soil mixing and jet grouting for confinement cells around new bridge foundations, large diameter secant pile walls for the Tunnel Boring Machine launch portal along with an extensive jet grouting regime for ground improvements within the tunnel alignment. This paper will study the evolution and use of advanced special geotechnical construction equipment and describe its application at the Alaskan Way Viaduct Replacement Project.

INTRODUCTION

The evolution of geotechnical construction equipment continues through innovative applications and continued modification or enhancement of machinery. Similarly and in parallel, market expectations continually demand more in terms of construction speed and performance. Together, market demands and contractor innovation have led way to the development of specialty geotechnical construction equipment with capabilities previously not seen feasible or possible. Several examples of this scenario have recently developed during design and construction of the Alaskan Way Viaduct Replacement Project.

The Alaskan Way Viaduct Replacement Project is a joint project between the Federal Highway Administration (FHWA), the Washington State Department of Transportation (WSDOT), and the City of Seattle. Three build alternatives were under consideration for replacing the Alaskan Way Viaduct: the Bored Tunnel Alternative, the Cut-and-Cover Tunnel Alternative, and the Elevated Structure Alternative. Ultimately, the bored tunnel option was selected as the best value approach. The project includes two miles of 57.5 ft diameter bored tunnel beneath downtown Seattle and a stretch of new highway and overpass bridges at the southern tunnel entrance. Several other associated improvements tie into this project that will ultimately lead to the complete demolition of the viaduct and redevelopment of Seattle's waterfront.

The SR 99 Tunnel parrallels the waterfront through the south Seattle area and will be constructed using the world's largest diameter tunnel boring machine (TBM). Construction of such a unique project of this nature within a dense urban environment with poor soil conditions required carefull attention to the geotechnical construction phases. This paper will focus on the evolution and use of special geotechnical construction equipment as selected for the difficult ground conditions present at the south terminus of the Alaskan Way Viaduct and the SR 99 Tunnel launch excavation / portal.

SUBSURFACE CONDITIONS

The south Seattle waterfront sits upon reclaimed lands comprised of decades of undocumented fills, debris, and various organic deposits. Within the upper reaches of the soil profile, numerous piles and buried trestles or railroad ties can be expected. The various fill deposits overlay soft and loose marine sediments that bear on glacial till at depths that ranged from 40 ft at the northern end of the project site to 106 ft at the south. Depth to groundwater is subject to tidal influence and can be as shallow as 5 ft below working grade.

The subsurface conditions at the northern end of this project varied considerably from the southern reaches in that the frequency and extent of wood debris deposits increased extensively. Relic deposits of wood, pulp and decayed organic matter would be encountered in vast areas where little to no granular soils are detected. Likewise, the entire reach of the south tunnel approach and viaduct replacement was deemed contaminated and applicable hazardous waste precautions would be needed when handling soils.

Soils were highly liquefiable and were a concern for new bridge foundations and permanent works. Moreover, due to the nature of the soft, highly saturated and unstable material, along with abandoned wood and timber foundations, critical areas needed ground stabilization in order to mitigate risks associated with tunneling.

CONSTRUCTION CONSIDERATIONS – EQUIPMENT

State-of-the-Art special foundation equipment was mobilized for the project to perform a broad range of geotechnical construction. Applications included soil mixing and jet grouting for confinement cells around new bridge foundations, large diameter secant pile walls for the Tunnel Boring Machine launch portal along with an extensive jet grouting regime for ground improvements within the tunnel alignment.

CSM

The CSM (Cutter Soil Mixing**)** system is a modified trench cutter “Hydro Mill” type machine, as used in modern slurry wall construction. Unlike conventional soil mixing techniques that utilize end mixing mechanical tools depending on mechanical mixing between shear blades in axial motion, the CSM system utilizes a set of milling wheels working in the vertical plane. This mechanical action shears the soil into small particles and blends it with the injected grout or other cutting fluids into a homogeneous matrix. The CSM machine has a very stiff non-rotating Kelly bar attached to a base machine. This stiff Kelly, coupled with the CSM’s inclinometers, allow the cutter head to be steered in the “X” axis by altering wheel speed and in the “Y” axis by the base machine’s parallelogram. This telemetry control allows panels to be cut to the required alignment, with real–time monitoring and recorded by the on-board computerized QC system. All processes are controlled by an intensive quality assurance program. All process-specific production and plant-specific operating data are visualized throughout the construction phase and stored for subsequent documentation and evaluation. Information presented includes penetration rates, alignment, and slurry injection rates and volumes. Some of the advantages of the CSM method are that it uses in-situ soil as construction material and that high compressive strengths can be achieved due to the effective blending of all cement particles within the soil matrix. The process is also capable of being advanced into soft rock formations and does not induce vibrations during construction.

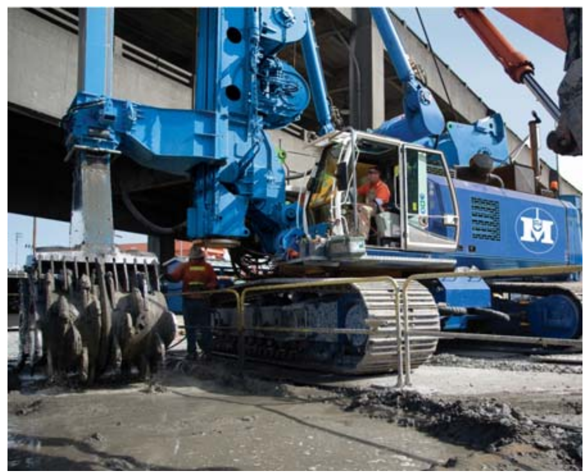

Figure 1: BG 40 with BCM 10, 5 ft wide mixing wheels

Jet Grouting

Jet grouting is essentially a ground improvement technique that increases both the consolidation and cementation of the soil material. The jet grouting process consists of the disaggregation of the soil or weak rock and its subsequent mixing with and partial replacement with a cementing agent. The disaggregation is achieved by injecting a high energy (high pressure and high velocity) fluid jet, which can be the cementing agent itself, through a rotating drill rod thus forming mixed soil and grout columns as the rod is withdrawn from the drilled hole. The grout can be a mixture of water, bentonite, and cement. The Jet Grouting Process is described below in greater detail.

The drill string is drilled into the soil with the use of a drill rig. A suitable drill bit is attached to the bottom end of the jet grouting drill string, followed by the actual jetting unit itself which is fitted with a horizontal high-pressure jetting nozzle(s). The grout suspension is forced through the nozzle under high pressure generating a highly energized fluid jet that first disaggregates the natural structure of the soil and then mixes the soil with the grout to form a soil-grout column. The effective cutting range of the fluid jet is determined by the prevailing types of soil, the soil density and other characteristic soil parameters. By simultaneously rotating and extracting the jet grouting drill string at a predetermined speed, the grout jet progressively cuts the shape of a shallow spiral into the soil and as a result, erodes a cylinder of soil that is filled with a mixture of soil and grout. The cementitious binder causes the mixture to harden and form a jet grouted column.

To assist with quality of jet grout column installation, innovative means of monitoring drilling deviations continue to be developed. This increased control or knowledge of in-situ column placement has given rise to deeper more complex work and less reluctance to perform battered / inclined drilling. Application of real-time drilling deviation monitoring is essential for future development and advancements in jet grouting techniques.

Figure 2: BG 15 with jet grouting attachment

Figure 3: BG 15 inclined jet grouting

Drilled Shafts

Drilled shafts are cylindrical, cast-in-place concrete foundations formed by a “drilled” excavation. They are common where enormous lateral loads from extreme event limit states govern bridge foundation design.

When considering fully cased drilled shafts, the drilling of the pile borehole will be carried out inside a steel casing which will maintain the stability of the borehole in soft soil layers and prevents soil disturbances that could negatively affect adjacent infrastructure. The casing itself will consist of a series of sections which will be bolted together to provide the total length necessitated by the ground conditions. The casing sections will be pushed and drilled into the ground by the drilling rig itself or, as in this case, with the assistance of an oscillator.

The borehole will be excavated using appropriate drilling tools; in the case of mixed ground, augers and buckets will be used, as well as special rock augers for weathered rock. In order to penetrate difficult ground at depth, telescopic lockable kelly bars will be employed ensuring that sufficient vertical force as well as torque is applied to the drilling tool. As excavation proceeds, lengths of casing will be added and installed in the ground as required. If not drilling in dry conditions, water or bentonite suspension will be added to the borehole to stabilize the borehole underneath the casing.

The excavation process is separated in two work sequences. Installation of casing and excavating of inner diameter of bore hole.

When final depth is reached, the pile bottom will be cleaned of any settlements with a special tool, the so called cleaning bucket. After finishing the excavation process reinforcement cage will be installed and concrete will be poured to finalize pile installation.

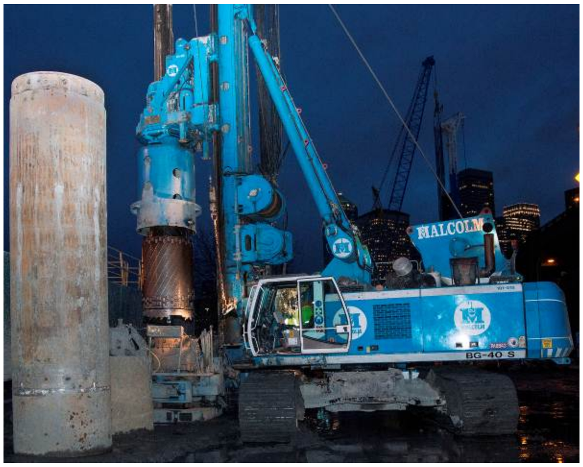

Figure 4: BG40 with 5 ft oscillator installing tangent pile wall

Secant/Tangent pile walls

In addition to drilled shafts secant pile walls have some specific characteristics, only the drilling methodology is similar.

Secant piles may be defined as a linear series of piles, primary and secondary, that are constructed in a configuration such that they intersect one another. They are constructed at center-to-center distances that are smaller than the sum of the radius of the two adjacent piles. In this configuration adjacent piles intersect and therefore interlock to provide a continuous wall.

The installation process starts with first installing a series of primary piles using any of the conventional drilling methods such as the kelly bar driven auger, bucket or the continuous flight auger (CFA). The secondary piles are drilled in between two adjacent primaries so as to intersect these and to cut into their shafts. For this operation to be successful timing becomes of critical importance as the strength gain of the primary pile concrete, which is to be cut to from the interlock, is related to time, temperature and the mix design.

Drilling the secondary piles must proceed with care; special attention being paid to maintaining verticality in order to ensure that the minimum designed amount of intersection is obtained throughout the length of the shaft, particularly at depth. The interlock provides a seal across the joint between adjacent piles. The amount of interlock is designed as a function of the pile diameters, the length of the piles and the type and quality of machinery and equipment that will be used in their construction. Specialty pile walls with no interlock are named tangent pile walls.

Figure 5: BG 50 installing 5 ft diameter secant pile wall

CONSTRUCTION SUMMARY

New Bridge Foundations

The southern mile of the Alaskan Way Viaduct was replaced with two new side-by-side bridges that meet current earthquake standards, have wider lanes and improve mobility for people and goods in the south of downtown area. These new bridges are founded on a hybrid foundation system consisting of drilled shafts encompassed by deep cement soil mixed confinement cells. The combined system of drilled shafts and ground improved confinement cells mitigates against seismic soil liquefaction, down-drag effects and protects the drilled shafts from global lateral spreading.

CSM panels were installed to depths reaching 106 ft to confine the new drilled shafts and protect against soil liquefaction. The designed outer wall thickness was 5 ft minimum. In order to meet the wall thickness requirement with a single mixing pass a custom set of 5 ft wide cutter wheels were fabricated specifically for this project to mate with a modified BCM 10 cutter head carried by a BG40 drill machine. This size of CSM panel had never been attempted and pushed the envelope with respect to what is achievable with current equipment. A modified two-phase cutting technique was used to complete installation of the deep panels (>100 ft), while conventional single phase cutting was used for all work less than 100 ft deep.

As an alternate to CSM techniques, multiple rows of conventional deep soil mixed (DSM) columns were considered but never pursued. The primary disadvantage of conventional DSM column installation was considered to be the inability to mix past or through buried obstructions. The depth of fill was known to be laden with timber piles and various debris deposits. Moreover, the DSM method would require many column overlaps or joints, which are seen as potential areas of column discontinuity. The CSM technique alleviated concerns with respect to buried obstructions of moderate opposition and also resulted in fewer panel joints.

Demolition of the viaduct and construction of the new bridges was performed in two phases to maintain existing traffic patterns. Joining the two phases of CSM confinement cells together would have resulted in a construction cold joint. Upon completion of the phased CSM work, jet grouting was employed to mate the two phases of work together, Figure 6. At the phased joint jet grout columns were installed in a ball-joint or knuckle configuration to fully encapsulate the phase interface and provide a robust continuous wall without any structural deficiencies. A BG15 jet grout drill with lattice extensions was able to build continuous columns to 106 ft depth without requiring rod addition/subtraction that would otherwise interrupt the column construction process. Continuous cores and in-situ wet grab samples provided verification of the wall strength and continuity throughout its depth.

The combination of Jet Grouting with CSM panel installation provided a means of overcoming buried obstructions that when encountered would otherwise be difficult with CSM techniques alone. Similarly, panel installation around an existing and active rail spur was not possible with CSM without decommissioning and removing the spur, while jet grouting provided a means to drill from an angle at either side of the rail line to create a continuous wall beneath it.

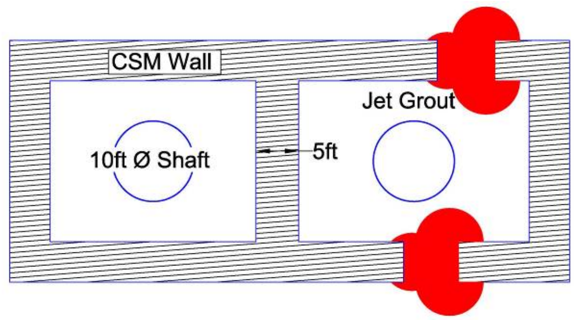

Figure 6: Typical bridge foundation system

Tunnel Excavation and Support

The excavation required to launch the world's largest TBM was greater than 1000 ft in length and was supported by 3.3 ft and 5 ft diameter drilled secant piles. A series of overlapping secant pile headwalls and struts created the ramped excavation that reached approximately 85 ft in depth at the TBM breakout. Pile depths ranged from 95 ft to 138 ft where they were founded within dense glacial till that acted as an aquitard to assist in controlling groundwater infiltration.

The highly variable ground conditions required a fully cased piling system. As expected, drilling obstructions were routinely encountered and overcome by means of brute force. A pair of BG50 drill machines would regularly drill through concrete filled steel piling, timber piles, various nested layers of timber ties and decking or other opposing debris without interrupting the critical primary/secondary secant pile installation sequence.

To maintain the critical schedule a BG40 with torque multiplier was utilized to assist with the work load by working alongside the two BG50s. Without torque multipliers, two additional BG40 drills worked on less demanding areas of the excavation or tunnel alignment installing tangent piles or primary piles of the secant wall sequence.

Many factors needed to be considered to mitigate tunneling risks within this given area. A main concern was containing all horizontal ground influences as the tunnel alignment parallels the active portion of the Alaskan Way Viaduct. To assist with tunneling operations a series of safe havens were created with installation of secant pile cells that encapsulated ground improved by jet grouting. Similar to the safe havens, TBM mining operations using earth pressure balance techniques required ground improvements to compensate for the upward buoyant forces and to contain the EPB soil conditioning fluid forces. Therefore, a continuous tangent pile or secant pile wall was installed on either side of the tunnel alignment to contain horizontal ground movements within the project limits. Soft soils within the tunneling alignment were improved with jet grouting. Over 400 jet grout columns with diameters ranging from 7.5 ft to 11.5 ft were used to remediate the heavily debris laden soft soils within the upper reaches of the tunnel horizon. To further contain the mining fluid forces and buoyant uplift forces the ground improvement was capped with a 5 ft thick reinforced concrete buoyancy slab, Figure 7. The combined application of secant or tangent piles with jet grouting as shown in Figure 7 was maintained along the tunnel alignment until the TBM had gained enough depth and overburden to minimize the aforementioned risks.

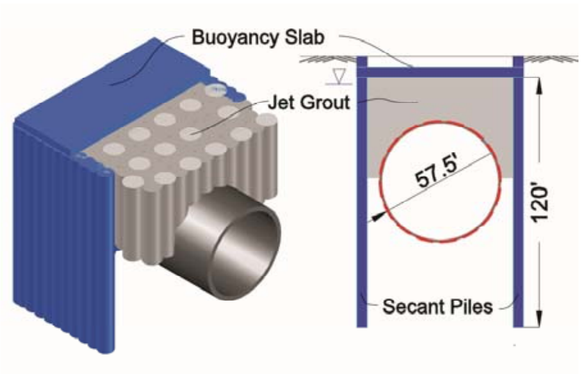

Figure 7: Tunnel Boring Machine ground improvements and horizontal containment

LESSONS LEARNED

- Given appropriate ground conditions 5 ft wide CSM panel walls can be successfully constructed to greater than 100 ft depth while maintaining continuous continuity with adjacent panels to within 6-inch tolerance.
- Modified 2-phase CSM panel installation is more productive than conventional 2-phase.
- Jet grouting large diameter columns within highly organic debris fill soils will require additional care in QA testing and verification.
- Double cutting or double mixing jet grout columns within soft highly organic soil deposits to increase cement content and strength can also result in underestimated column geometry.
- Torque multipliers used on top drive machines for secant pile installation require care and attention. A larger purpose built machine will easily outperform a smaller machine outfitted with a torque multiplier.

SUMMARY

A broad range of geotechnical construction has been completed for the Alaskan Way Viaduct Replacement Project and the SR 99 Tunnel. Difficult ground conditions along with a condensed work schedule contributed to the complexity of the work. State-of-the-Art special foundation equipment was mobilized, including two BG50 and three BG40 which worked concurrently. Applications included soil mixing (largest CSM panels ever constructed), various jet grouting scopes including confinement cells around new bridge foundations and large diameter secant pile walls for the TBM launch excavation and initial critical alignment. Current equipment capabilities have been tested while new limits have been established. Subsequently, the critical schedule could be maintained with appropriate equipment selection for the overall success.