INTRODUCTION
The development of a seven-story office building with a four-story underground parking garage, located adjacent to the Alaskan Way viaduct, just south of downtown Seattle, posed unique challenges. The project was situated on a sensitive site with specific soil conditions and a high water table. The team identified early on the need to develop strategies to minimize the risks associated with the site conditions, both during construction and over the long term. The site conditions, along with the project requirements, were all considered in the selection of the appropriate shoring and waterproofing systems for the structure.

SITE HISTORY
The project is located on the waterfront in an historical location just south of downtown Seattle in an area that has been reclaimed from Elliott Bay as part of multi-phased regrading conducted at the turn of the century. In the 1880s, a wharf with a sawmill, offices, laundry facilities, a tar warehouse, and the Queen City Boiler Works were located on the site. Fill for the site that was deposited in the late 1800s includes sawdust from the sawmills, wood planks and pilings, ship ballast, and brick and wood burn debris from the great Seattle fire. The site is now located less than one-half mile from Elliott Bay, subjecting the groundwater level to tidal fluctuations.

SUBSURFACE CONDITIONS
Due to the history and location of the site, the subsurface soil consisted of three separate layers of varying conditions: deep fill overlying loose and soft marine deposits with very dense glacial soils encountered below the marine deposits. The first layer of deep fill, extending 25 to 35 ft below the current grade, was mixed with wood and debris, as well as being subject to a very high water table and fluctuating tides.

Below the layer of fill and extending 30 to 40 ft below the existing surface was a thin layer of marine sand and silt from what used to be the bottom of Elliott Bay. These marine deposits are typical of the waterfront area and include loose sand and soft, sandy, clayish silt. The fill layer and marine deposit layer that consist of soft and loose materials were not suitable to support the structure.

Beneath the marine deposits lies the third layer of ground conditions, a layer of dense glacial sand and silt. This layer consisted of glacially overridden layers of dense sand and hard clayish silt that were suitable for support of the structure. At the depth of the excavation, a till-like material of very dense, silty sand with gravel was expected.

Water was encountered on the site at three levels, with the first occurring at approximately 6 to 11 ft below the existing ground surface, with the lowest extending below the bottom of the excavation depth. Given the high organic content of the fill, some amounts of methane gas were also present at the site and needed to be accounted for in the design of the subgrade structure. For the most part, the organic fill was located below the water table. Therefore, long-term degradation of the material is very slow, and thus, the methane production is also slow. The geological survey also noted pockets of petroleum contamination in the fill soils, likely a result of scraps contaminated with wood and debris from the wharf and sawmill used in the fill.

PROJECT REQUIREMENTS
The project consisted of a seven-story office building with four floors of underground parking at a maximum depth of 43 ft below the existing ground level, with an additional 6 ft toward the center of the site for elevator and sump pits, resulting in an average excavation depth of 36 ft below the water table.

In addition, the proposed structure and site were located in an area with adjacent buildings, roads, and utilities that were sensitive to settlement. The proposed structure required removal of portions of the foundation at the adjacent eight-story building directly to the north of the site. The southern footing line of the adjacent building was supported on pile caps and a series of timber piles. Approximately one-third of the piles and pile caps required removal during excavation and replacement with a new row of micro piles to extend below the current timber piles.

CONSTRUCTION CONSIDERATIONS AND SHORING SELECTION
The primary geotechnical concerns included the following:
- Excavating the site below the groundwater table and providing a permanent waterproofing system for the underground parking
• Addressing lateral and uplift hydrostatic pressures on the foundation and waterproofing system
• Dewatering of a 43-ft-deep excavation site adjacent to settlement-sensitive structures
• Mitigating the base heave at the bottom of the excavation within a groundwater aquifer

Excavation of the site below the water table required either significant construction site dewatering or, where dewatering of the entire site was not practical, the use of a shoring wall that acted as a watertight cut-off wall. Dewatering of the entire site for a fully drained shoring system was not practical because it would drain the water table of the surrounding sites down to a level that would have severe off-site impacts resulting from settlement of previously buoyant soils. This led to determination that the shoring system would need to provide a water cutoff to allow for dewatering of the soils within the excavation site. Dewatering of the site was required to keep the water table below the level of excavation to allow for removal of the wood infill and to maintain a safe and dry working environment.

The shoring walls needed to provide temporary lateral support to the adjacent loose fill soils while also providing relatively watertight cut-off wall and providing stability for the adjacent structures, streets, and utilities. The shoring walls were also required to extend 25 ft below the depth of the excavation in order to limit the risks of seepage and base heave resulting from the deep aquifer. A variety of shoring options were considered and rejected, including:

• Typical shoring walls with soldier piles and lagging. It was determined that this system was not practical for the project due to the soft and wet nature of the fill and marine deposits.
• Sheet piles that consist of interlocking sheets of steel that are vibrated into the soil. These were not selected due to the depth of the excavation and the risk of interference and blockage of the sheets by existing fill debris.
• Secant piles that are constructed by drilling overlapping shafts and filling to form a continuous concrete wall. This system was originally planned and bid for the project but was determined to be expensive, slow, and unable to provide a suitable surface for the waterproofing installation.

The system that was ultimately selected was a cut-off soil mix (CSM) shoring system. The CSM shoring wall is a modified soldier pile system that makes use of overlapping soil-cement panels to construct a strong and relatively watertight wall. CSM technology mixes the soil in situ with a cement and bentonite slurry, creating a solid and cohesive block.

For this type of shoring wall, two sets of vertically mounted cutting wheels rotate on a horizontal axis, creating a rectangular soil-cement panel. The mixing is performed using mixing paddles attached to the augers that are slowly driven into the ground. See Figure 1 for a view of the soil mix wall installation process. As the auger is rotated, the cement slurry is added through the hollow stem of the auger shaft. The mixing paddles are located above the auger to blend the soil and slurry. The slurry also helps break up the soil, lubricate the equipment, and bring spoils in the mixture to the surface. A continuous wall is achieved by overlapping the panels, which are constructed in alternating sections. Steel sections similar to conventional soldier pile walls are also driven into the panels as soon as the soil/cement mix is installed but still wet. The strength of the soil walls can be tailored to specific project and site conditions. A CSM wall with a compressive strength of 200 psi was designed for this project.

Another benefit of the CSM over secant pile walls was the method in which the drilling equipment essentially chewed through any underground obstructions. This allowed the CSM wall to maintain a straight vertical plane by limiting the effects of encountering subsurface obstructions. Pre-trenching of the site perimeter was also conducted prior to the CSM wall installation. This allowed for removal of most of the fill layer and any obstructions within this layer that may have caused imperfections and flaws in the finished CSM walls.

CSM shoring was selected for a number of reasons, including price, schedule, the ability to provide a solid and generally watertight wall that allowed for dewatering of the excavation site without causing any settlement of the adjacent soil, and the ability of the excavation equipment to cut into obstructions in the soils. The use of the soil mix technology provided a shoring wall that was sufficiently strong and watertight. In order to provide adequate lateral support of the CSM shoring walls, tie-back anchors were installed as the excavation proceeded. These tiebacks were positioned in steel sleeves that were preinstalled in the steel soldier beams and driven into the CSM wall while it was still wet. These sleeves allowed the drilling of the tiebacks without damaging or causing water flows at the CSM wall. In some areas where tiebacks could not be installed due to underground obstructions such as adjacent structures and utilities, steel whalers were positioned for lateral support. The steel whalers consisted of horizontal steel I-beams welded to the vertical steel soldier piles at the face of the CSM walls. These whalers were removed as the structural concrete walls and floor slabs were installed.

The structural engineer designed a 5-ft-thick concrete mat slab with 680 tension pile tiedowns to permanently resist hydrostatic water pressure acting on the foundation once the site dewatering system has been shut off.

**Below-Grade Waterproofing**

Several different below-grade waterproofing systems were evaluated based on the project requirements: the use of a CSM slurry wall system, the desire to use a shotcrete-applied structural concrete foundation wall, hydrostatic conditions, and the possibility of methane and petroleum contamination present in the fill soils. Due to proximity of the site to Puget Sound, the site’s groundwater table was found to be approximately 6 to 11 ft below the top of soil. The four-story, below-grade parking structure was about 45 ft below grade. A temporary dewatering system was utilized during the excavation and construction of the excavation site using mixing paddles attached to the augers that are slowly driven into the ground. See Figure 1 for a view of the soil mix wall installation process.

![Figure 1 – CSM shoring wall installation in progress.](image-url)
the foundation system. The dewatering system was deactivated once the structure was in place.

**DUAL MEMBRANE SYSTEM**

At the perimeter of the below-grade foundation walls, where there is conditioned space (storage, electrical, and other rooms) into which water migration would be undesirable, a dual waterproofing system was recommended. A dual-membrane assembly typically consists of a waterproofing membrane sandwiched between the shoring wall and the structural below-grade foundation walls in conjunction with an integral hydrophobic additive added to the concrete structural walls. The hydrophobic additive restricts capillary action, making the concrete a secondary waterproof barrier.

The advantage of this dual-membrane system is that there is a primary and secondary waterproofing system—a “belt-and-suspenders” approach.

The installation of the dual-membrane system was found to be economically unfeasible, however, and the owners decided that they were willing to accept a higher risk of water infiltration through use of a single system. The owner determined that some moisture on the walls in the parking garage would be acceptable but that water running down the walls was not.

Several of the waterproofing systems that had been considered for the dual waterproofing system were not selected for a single membrane system. These included a reinforced, cold-applied waterproofing membrane. Minor imperfections in the shoring wall would need to be filled with grout to create a smooth and even substrate to receive such a membrane. If a large amount of imperfections occurred in the CSM wall, the use of an asphalt/felt protection board mechanically attached to the CSM wall could be used as a smooth substrate.

Another considered system was a spray-applied liquid waterproofing membrane intended for blind-side application. The use of two layers of geotextile fabric over the CSM shoring wall would provide an appropriate substrate onto which the membrane would be sprayed. The membrane would be a minimum of 100-mil dry-film thickness at both horizontal and vertical surfaces. The use of the spray-applied membrane was eliminated due to reliance on the applicator to maintain a uniform thickness and quality during installation and the limited warranty available with this system. The risk of improper installation of the membrane was significantly higher when compared with a sheet product.

A self-adhering membrane was considered, but this was deemed better suited to positive-side application and would require a very smooth CSM wall substrate. In addition, concerns were raised about the use of a shotcrete wall against the membrane, which could cause damage to the lapped seams.

Ultimately, preference was given to a “sheet-good” membrane that would be fully adhered to the structural walls. Sheet membrane products are manufactured in a controlled environment, where quality can be monitored and maintained. A fully adhered membrane would minimize any lateral water movement between the membrane and the substrate, should the membrane be breached; therefore, water leaks are generally easier to isolate and locate for repairs.

One sheet-good option considered was a single-ply, 80-mil-thick PVC membrane. For such systems, lap joints are typically heat-welded. A second layer of the PVC membrane would have to be installed at the vertical walls as a protection course and a high-density polyethylene sheet (HDPE) loose-laid over the PVC membrane at the slab as the protection course. The PVC membrane also required that the shoring wall be smoothed to avoid puncturing of the membrane by any sharp protrusions.

**BENTONITE MEMBRANE**

In the end, a two-layer bentonite membrane system was chosen because it met project requirements. This system included two layers of bentonite, with the first layer consisting of a polymer alloy bentonite clay encapsulated in a geomembrane panel. The second layer of bentonite is similar to the first layer, except one side of the membrane panel has a high-density polyethylene liner. When the bentonite clay is hydrated, the material swells. The first layer of bentonite membrane was mechanically attached directly to the shoring wall with minimum end and side laps of four inches to form a continuous waterproofing membrane. The second layer of bentonite was installed in a similar fashion, except that the laps were sealed with bentonite mastic. See Figure 2 for the typical detailing of the bentonite membrane and waterstop.

One assembly discussed included the installation of the bentonite membrane between two layers of drainage board. This option was eliminated due to the need for the bentonite to be securely fastened to a solid and smooth substrate and the requirement of the bentonite panels to be in direct contact with and bonded to the structural concrete.

Samples of the soil and groundwater were provided to the bentonite membrane manufacturer to conduct testing. Results confirmed that the salt and other contaminants within the soil and water were at acceptable levels and would not affect system performance. In addition, use of the HDPE liner against the CSM wall limited leakage of any methane gas into the parking garage.

**CONSTRUCTION CONSIDERATIONS**

During the course of design and construction of the below-grade foundation, a number of specific issues related to the site conditions, CSM shoring wall, and two-layer bentonite waterproofing system were identified that needed to be addressed.

![Figure 2](image.png)
SHOTCRETE

The structural concrete foundation walls were installed by shotcrete application. The pressure of the shotcrete, if applied correctly, aids in pressing the bentonite membrane against the CSM shoring wall, resulting in a well confined membrane that is fully bonded to the foundation wall and that will expand when it encounters moisture to fill the space between the CSM shoring wall and shotcrete foundation wall.

Installation of the shotcrete posed specific requirements that had to be addressed during installation. These included:

• Damage of the membrane during installation of the rebar cage, which then limited access to the membrane for repair
• The height of the floors, which resulted in the shotcrete applicators’ being located below the height of the shotcrete while also avoiding spraying at an angle up toward the bentonite membrane lap joints
• Achieving adequate coverage and consolidation of the concrete behind all the rebar in order to provide a solid surface to confine and adhere to the membrane
• Patching and sealing around rebar structural ties through the bentonite membrane
• Limiting and removing overspray of the shotcrete onto adjacent areas of bentonite membrane that would result in inadequate bonding of the bentonite membrane to the structural concrete
• Striking off a minimum 2-in-wide section in each vertical and horizontal termination of the shotcrete lifts to provide a smooth substrate for application of a bentonite waterstop at each cold joint

COLD JOINTS

A bentonite waterstop was installed around all penetrations and at all horizontal and vertical cold joints within the structural foundation slab and walls. This waterstop provided a secondary line of defense against water leaks at the concrete joints. The bentonite waterstop was provided with a minimum 3-in concrete coverage to avoid blowouts of the concrete caused by swelling of the waterstop. The waterstop was adhered to the concrete substrate using a water-based adhesive and then fastened every 12 inches on center to ensure that the waterstop would remain in place under the pressure of the shotcrete application.

SLAB WATERPROOFING

The waterproofing system was required to extend under the mat slab and all sump and elevator pits and to be tied into the wall panels in order to provide a continuous watertight assembly. Refer to Figure 3 for an
overall view of the bentonite membrane over the “rat” slab and tie-down anchor penetrations. A two-layer rat slab was utilized with a single layer of bentonite membrane sandwiched between the slabs after drilling of the tension piles through the bottom slab was completed. The top slab was used to provide a smooth and dry surface for installation of the waterproofing membrane, with the top layer providing a protection layer for the membrane, as well as a solid working surface for equipment staging and placement of steel reinforcing for the 5-ft-thick mat slab. The top layer of the rat slab—as well as the mat slab—were provided with sodium bentonite-based waterstops installed at each cold joint as a secondary line of defense against water infiltration at the joints.

SLAB TIEDOWNS

Sealing was needed around each of the 680 tension piles through the waterproofing membrane. Each of the piles was required to be located within a sleeve, which allowed the piles to move freely in the slab without allowing water seepage into the sleeves as the structure settled. In order to address these requirements, a detail was developed by the team consisting of a 12-in-diameter core hole in the rat slab with a PVC sleeve extending from the bottom of the nut and metal washer plate to the top of the protection slab. A #14 rebar was then installed through the sleeve to allow the bar to withstand tension under hydrostatic pressure with a movement of one-eighth to one-quarter inch. The anchor tie penetrations through the membrane were flashed with a target patch of the bentonite membrane. The field membrane was lapped over the target patch and the penetration sealed with a cant of bentonite.
mastic. Waterstops were wrapped around each PVC sleeve at three different heights above the substrate. The PVC sleeve was primed prior to the installation of the waterstop, and the waterstop was secured with a zip tie or similar device. Bond breaker was then coated over the remaining surface of the sleeve to prevent adhesion of the slab to the sleeve, but the coating was not applied at the areas of the waterstop. Once construction of the entire structure was completed, the top of each tie-down anchor head was grouted over prior to turning off the dewatering system. Refer to Figure 4 for the bentonite waterproofing membrane patching around the tie-down penetrations.

PREPARATION OF THE CSM WALLS

In order for bentonite to perform effectively, the membrane must be in intimate contact with the shoring wall. The shoring wall substrate was required to be prepared either with a layer of shotcrete that was troweled smooth or by filling any voids or large areas of rock pockets with grout. Any fins, ridges, or other protrusions at the shoring wall were ground down to level and smoothed. Refer to Figure 5 for a general view of the CSM wall with a section smoothed and ready to receive the bentonite waterproofing.

The CSM shoring walls, although intended to be flat and relatively smooth, were often wavy and had voids. See Figure 6 to view voids and inconsistencies in the face of the CSM wall. It was determined that the waviness of the walls would not be an issue, but that the bentonite needed be installed in direct contact with the substrate, and any voids larger than 2 inches would require smoothing. A similar CSM shoring wall was reviewed, and it was determined that approximately 10% of the surface of the shoring wall would likely require smoothing. This allowed for the shotcrete structural concrete to be applied directly against the membrane to confine the bentonite.

WATER SEEPAGE

As was expected, the CSM wall did not provide a completely watertight cut-off wall. Seepage from the perimeter water table was common at joints in the CSM and especially at the tie-back anchors. Refer to Figure 7 for typical seepage down a CSM wall. In order to maintain a clean and safe work area, as well as keep the bentonite products from significant hydration and damage, this water needed to be controlled as much as possible. A temporary system of gutters was installed at the upper levels of tiebacks to prevent the majority of the water from dripping down the walls and onto the slab. These gutters were not able to capture all the water, and other methods of addressing it were needed. This included vacuuming ponding water from work areas and heat-drying the concrete substrate at the perimeter walls prior to installation of the waterstop at the horizontal cold joints at floor slabs and shotcrete foundation walls.

In addition to water seepage down the face of the bentonite membrane and onto the floor slab, water seeping behind the bentonite membrane prior to installation of the shotcrete foundation walls resulted in bulging of the membrane away from the CSM walls. The pockets of water pooling behind the bentonite membrane would be enough to resist the pressure of the shotcrete from confining the bentonite between the CSM and shotcrete. This confinement was needed in order for the bentonite to perform properly. Releasing the water from behind the bentonite membrane was necessary and was achieved by cutting drainage slots into the membrane at intervals along the base of the floor lines a minimum of 12 inches above the slab. On the day shotcrete was applied, these slots were vacuumed as dry as possible to eliminate any pockets of water trapped behind the membrane and then patched with two layers of 12-in by 12-in bentonite patches set in bentonite mastic.

TIE-BACK DETAILING

Destressing and cutting off the tie-back anchors resulted in the tiebacks’ being inboard of the exposed side of the shoring wall. The recessed areas were to be grouted flush and smooth with the CSM shoring...
wall. This condition allowed the bentonite membrane to be patched directly over the grouted tie-back anchors without a pre-formed boot over the tieback. Due to the hydrostatic pressure at the tie-backs, a significant amount of water infiltration was experienced once they were cut off. As a result, tiebacks were cut off just prior to patching the bentonite over it. The drainage slots through the membrane at each floor line allowed water from the tiebacks that entered behind the membrane to be removed. Rapidly expanding spray-foam water cut-off was used at the tiebacks to stop gushing water and to provide a smooth surface around the tiebacks. The bentonite patches consisted of one patch of the HDPE-lined bentonite membrane installed between the two field membranes and a second bentonite patch installed over the face of the field membrane with all edges sealed with a 3-in strip of bentonite mastic and fastened at 6 inches on center around the perimeter. See Figure 8 for detailing of the bentonite membrane at the tiebacks and Figures 9 - 11 for photographs of the tieback cutoff process.

FASTENING OF THE MEMBRANE

The selection of appropriate fasteners for securing the bentonite panels to the CSM shoring wall was considered, and the use of low-velocity fasteners with metal washers was determined to be appropriate for securing the waterproofing membrane to the slurry wall. With the resulting seepage through the CSM at joints and tie-back anchors, the bentonite membrane did become damp in some areas. The membrane needed to be securely fastened to the wavy areas in the CSM wall. As a result, a number of these fasteners with washers were either sunken into the softened membrane or pulled out where inadequately driven into the CSM wall. Identifying and patching these minor holes in the membrane prior to installation of the shotcrete foundation walls became one of the most common conditions reviewed during construction.

POSTCONSTRUCTION

Upon completion of the building and tie-in of the bentonite membrane to the hori-
Horizontal waterproofing membrane, water was observed seeping through the below-grade foundation walls into the parking garage. Possible causes were considered and investigation was conducted to review the condition of the bentonite membrane between the CSM shoring wall and the foundation wall. A number of concrete core samples through the foundation walls were taken and visually examined. A small number of cores showed areas of poor concrete consolidation; however, the majority of the core samples were found to be well consolidated. At one core sample, the bentonite membrane was not adhering to the face of the core due to the shotcrete overspray on the bentonite membrane. The other core samples showed that the bentonite nonwoven geotextile fabric side was either partially bonded or not bonded to the concrete, while others had the bentonite membrane fully bonded to the substrate.

The design team, contractors, and bentonite manufacturer determined that as a result of differential movement between the shoring wall and the shotcrete foundation walls, there were areas where the bentonite membrane was not adequately confined; as a result, the performance of the waterproofing was not realized. Both settlement of the CSM shoring wall and deflection of the structural foundation wall were considered as potential contributors. Shrinking of the post-tensioned floor slabs in the underground garage was also identified as a potential source of structural wall deflection. Ultimately, the exact nature of the differential movement was not conclusively proven.

A bentonite-based grout was injected at the three levels of the below-grade parking garage to seal the voids between the foundation wall and the shoring wall. These treated areas were monitored by the design team, contractor, and bentonite manufacturer and were completed without any major difficulties. It was interesting to note that at one area there was a gap between the below-grade walls and the CSM shoring wall that allowed a minor amount of the bentonite-based grout to progress up the walls and, in one instance, enter behind the stone cladding, progress under the sidewalk, and move into the interior insulation through an abandoned electrical conduit. This was mitigated by using a lower pressure at the injection ports and creating relief ports at the upper parking level. Once grout was flowing out the relief ports, the injection process was stopped.

Once the bentonite-based grout injections were completed, the last few minor areas of seepage were treated with a urethane grouting technique. The final result was a dry parking garage, complete with a ten-year manufacturer’s warranty.

**CONCLUSION**

The CSM shoring wall system provided an innovative and effective approach that accommodated the unique constraints of this site. Even with the use of the CSM shoring wall to provide a water cutoff for excavation and dewatering of the site, complete dewatering of the site was not possible.

The two layers of bentonite membrane were found to be the most appropriate waterproofing system to meet the requirements of the project and to address the limitations of the CSM shoring wall. As a result, site-specific detailing to address the challenging hydrostatic conditions was required for the bentonite system installation.

The use of post-tensioned floor slabs and a shortened curing time for the floor slabs may have contributed to the voids created between the CSM shoring and founda-
tion walls. Considerations should be given to potential movement between the shoring and foundation walls for property line waterproofing systems.

For the bentonite to perform properly, it must be confined—in this case, between the shoring and foundation walls. Nonetheless, the bentonite-based grouting employed and the use of urethane injection techniques to seal the CSM shoring and foundation wall voids were effective in providing a fully watertight garage.

Amanda Prot

Amanda Prot has been involved in a variety of projects at Morrison Hershfield, including building envelope assessments (some for litigation), envelope cladding rehabilitations, and third-party review for new construction. She has worked with various cladding and glazing systems, including vinyl, brick façade, and fiber-cement siding; and storefront, curtain wall, and vinyl windows. She also has experience with below-grade, roof, and horizontal waterproofing. She has a bachelor’s degree in architectural science.

Rodney Lock, RRO

Rodney Lock, RRO, has spent 19 years with a variety of architectural, civil/structural, and building engineering firms and is now employed by Morrison Hershfield in Bellevue, WA. He focuses on building envelope consultation, design reviews, and field observations. Lock, who has a bachelor’s degree in architecture, has been involved in numerous green roof system applications, including new construction and retrofitting of existing structures, and offers extensive knowledge of roofing and waterproofing systems.

Stéphane P. Hoffman, PEng

Stéphane P. Hoffman, PEng, of Morrison Hershfield, has extensive technical expertise in building envelope design, rehabilitation, and historic restoration. He has been involved in condition surveys, investigation of building envelope problems, field testing of components, and extensive design and field review encompassing contract administration, trade coordination, and troubleshooting. With master’s degrees in both engineering and architecture and as a professional engineer, he has extensive knowledge of building science with respect to both enclosure and roofing systems.