A CASE STUDY FOR WATERPROOFING BELOW GRADE WALLS SHORED WITH CONTINUOUS SOIL MIX TECHNOLOGY USING A BENTONITE WATERPROOFING SYSTEM

By

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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 system and waterproofing system for the structure.

SITE HISTORY

The project is located on the waterfront in a historical location just south of downtown Seattle in an area that has been reclaimed from Elliot Bay as part of multi phased re-grading conducted at the turn of the century. In the 1880s a wharf was located on the site containing a sawmill, offices, laundry facility and tar warehouse as well as the Queen City Boiler works. 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 Seattle fire. The site is now located less than a ½ mile from Elliott bay, subjecting the groundwater level to tidal fluctuations.

SUBSURFACE CONDITIONS

Due to the history and location of the site near the waterfront, the existing subsurface soil conditions consist 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 down to between 25 and 35 feet below the current ground level is scattered with wood and debris as well as being subject to a very high water table and fluctuating tide.

Below the layer of fill and extending down to between 30 and 40 feet below the existing surface is a layer of marine sands and silts from the former bottom of Elliot bay. These marine deposits are typical to the waterfront area and include loose sand and soft sandy, clayey silt. The fill layer and marine deposit layer consist of soft and loose materials are not suitable to support the structure.

Beyond the marine deposits lies the third layer of ground conditions, a layer of dense glacial sand and silts. This layer which is located at a depth of 30 to 40 feet consists of glacially overridden layers of dense sand and hard clayey silt which are 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 within the site at three levels with the first occurring at approximately 6 to 11 feet below the existing ground surface and 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 within 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 and therefore long term degradation of the material is very slow and thus the methane production is also slow. The Geotechnical survey also noted pockets of petroleum contamination in the fill soils likely a result of scraps contaminated with tar and wood debris from the wharf and sawmill used in the fill.

PROJECT REQUIREMENTS

The project consists of a seven story office building with 4 stories of underground parking at a maximum depth of 43 feet below the existing ground level with an additional 6 feet toward the center of the site for elevator and sump pits, resulting in an average excavation depth of 36 feet below the water table.

In addition, the proposed structure and site are located in an area with adjacent buildings, roads and utilities which are sensitive to settlement. The proposed structure also required portions of the foundation at the adjacent eight-story building directly to the north of the site to be removed. The southern footing line of the adjacent building was supported on pile caps and a series of timber piles of which approximately 1/3 of the piles and pile caps were required to be removed during excavation and were replaced with a new row of micro piles to extend below the current timber piles.

CONSTRUCTION CONSIDERATIONS AND SHORING SELECTION

The primary geotechnical concerns were determined to be the following:

- Excavation of the site below the ground water table and providing a permanent water tight system for the underground parking.
- Addressing lateral and uplift hydrostatic pressures on the foundation and waterproofing.

- Dewatering of a 43 foot deep excavation site adjacent to settlement sensitive structures.
- Mitigating base heave at the bottom of the excavation within a ground water aquifer

Excavation of the site below the water table requires either significant construction site dewatering or, where dewatering of the entire site is not practical, the use of a shoring wall that acts 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 the determination that the shoring system would need to provide a water cut off to allow for dewatering of the soils within the excavation site which was still required to keep the water table below the level of excavation and 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 a relatively watertight cut off wall and providing stability for the adjacent structures, streets and utilities. The shoring walls were also required to extend 25 feet 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 soft and wet nature of the fill and marine deposits.
- Sheet piles which 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 which 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 would not provide a suitable surface for the waterproofing installation.

The final system selected was a cutter soil mix (CSM) shoring system. The CSM shoring wall is a modified soldier pile system which 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 which creates 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 which are slowly driven into the ground. Refer to Photo No. 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 to break up the soil and to lubricate the equipment as well as helping bring spoils in the mixture to the surface. By overlapping the panels which are constructed in alternating sections a continuous wall is achieved. Steel sections similar to conventional soldier pile walls were 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 strength of 200psi was designed for this project.

Another benefit of the CSM over secant pile walls was the method in which the drilling equipment essentially chews through any underground obstructions and thus allows the CSM wall to maintain a straight vertical plane by limiting the effects of encountering subsurface obstructions. A pre-trenching of the perimeter of the site was also conducted prior to the CSM wall installation which allowed for removal of most of the fill layer and any obstructions within this layer which may have caused imperfections and flows 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 which allowed for dewatering of the excavation site without allowing for 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 is adequately strong and watertight. In order to provide adequate lateral support of the CSM shoring walls, tie backs anchors were installed as the excavation proceeded. These tie backs were installed in steel sleeves which are pre-installed in the steel soldier beams that are driven into the CSM wall while it is still wet. These sleeves allow the drilling of the tie backs without damaging or causing water flows at the CSM wall. In some areas where tie backs could not be installed due to underground obstructions, such as adjacent structures and utilities, steel whalers were installed for lateral support. The steel whalers consist of horizontal steel I-beams welded to the vertical steel soldier piles at the face of the CSM walls which were also removed as the structural concrete walls and floor slabs were installed.

The structural engineer designed a five foot thick concrete mat slab with 680 tension pile tie-downs to permanently resist the 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: to use the cutter soil mixing (CSM) slurry wall system, the desire to use a shotcrete applied structural concrete foundation wall, the hydrostatic conditions, and the possibility of methane and petroleum contamination present in the fill soils. Due to the proximity of the site to the Puget Sound, the site ground water table was found to be approximately six to eleven feet below the top of soil. The four stories below grade parking structure is about forty five feet below grade. Temporary dewatering system was utilized during the excavation and construction of the foundation system. Eventually the dewatering system will be deactivated once the structure is in place.

DUAL MEMBRANE SYSTEM

At the perimeter of the below grade foundation walls, where there is conditioned space, storage rooms, electrical rooms and other rooms where water migrations is not desired, a dual waterproofing system was recommended where minimal risk of water infiltration through the wall assembly is desired. A dual membrane assembly typically consisted of a waterproofing membrane that is sandwiched between the shoring wall and the structural below grade foundation walls; in conjunction an integral hydrophobic additive added to the concrete structural walls to restrict 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 un-feasible and the owners determined that they were willing to accept a higher risk of water infiltration by using a single system when compared to a dual system. The owner determined that some moisture on the walls in the parking garage would be acceptable but that liquid water running down the walls was not.

Several of the waterproofing systems that were 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 blindside application. The use of two layers of geotextile fabric installed over the CSM shoring wall would provide an appropriate substrate onto which the membrane would be sprayed. The membrane thickness should 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 the reliance on the membrane applicator to maintain a uniform thickness and quality of the installation and the limited warranty available with this system. The risk of installing the membrane properly was significantly higher when compared to a sheet good product.

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

In the end, from a waterproofing perspective of a single system, preference was given to a 'sheet good' membrane in which would be fully bonded to the structural walls. Sheet good membrane products are produced in a controlled environment where quality control can be monitored and maintained. Having the structural walls fully adhered to the waterproofing membrane will minimize any lateral water movement between the membrane and the substrate should the membrane be breached; therefore, any water leaks can be easier isolated and located for repairs.

One sheet good option considered was a singly ply 80 mil PVC membrane. For the singly ply PVC system, membrane lap joints are typically lapped 3 inches and 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 (HDPE) loose laid over the PVC membrane at the slab as the protection course. The PVC membrane also requires 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 determined to be the most appropriate approach for providing a continuous waterproof assembly. This system included two layers of bentonite with the first layer consisting of a polymer alloy bentonite clay encapsulated in a geo-membrane panel. The second layer of bentonite is similar to the first layer except one side has a high density polyethylene liner on one side of the membrane panel. When the bentonite clay is hydrated the material swells. The first layer of bentonite membrane is mechanically attached directly the shoring wall; with minimum end and side laps of 4" to form a continuous waterproofing membrane. The second layer of bentonite is installed in a similar fashion except that the laps are sealed with bentonite mastic. Refer to Figure 1 for the typical detailing of the bentonite membrane and waterstop.

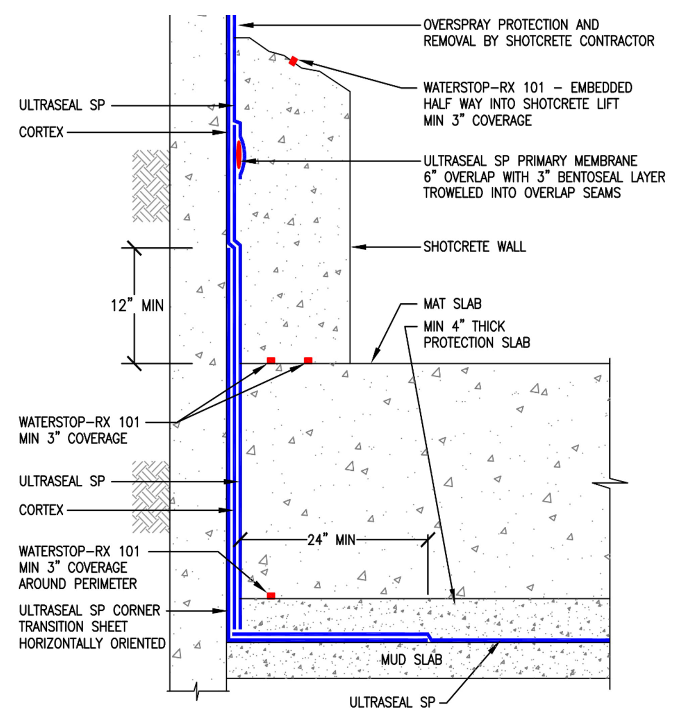

Figure 1 – Typical bentonite membrane and waterstop detailing at slab to wall transition

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 the structural concrete to allow it to bond together.

Samples of the soil and ground water were provided to the bentonite membrane manufacturer to conduct testing which confirmed that the salt and other contaminants within the soil and water were acceptable and would not affect the performance of the bentonite system. In addition the use of the HDPE liner against the CSM wall was able to limit the leakage of any methane gas into the parking garage.

CONSTRUCTION CONSIDERATIONS

During the course of the design and construction of the below grade foundation a number of specific conditions related to the site conditions and selected CSM shoring wall system with 2 layer bentonite waterproofing membrane were identified which needed to be addressed.

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 which is fully bonded to the structural concrete foundation wall and which will expand when it encounters moisture to fill the space between the CSM shoring wall and shotcrete foundation wall.

The installation of the shotcrete posed specific conditions which were required to be considered and addressed during installation. These items included:

- Damage of the membrane during installation of the re-bar 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 towards the bentonite membrane lap joints.
- Achieving adequate coverage and consolidation of the concrete behind all the re-bar in order to provide a solid surface to confine and adhere to the membrane.
- Patching and sealing around re-bar structural ties through the bentonite membrane.
- Limiting and removing overspray of the shotcrete onto adjacent areas of bentonite membrane which would result in inadequate bonding of the bentonite membrane to the structural concrete.
- Striping off a minimum 2 inch wide strip 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 at all horizontal and vertical cold joints within the structural foundation slab and walls. This waterstop provides a secondary line of defence against water leaks at the concrete joints. The bentonite waterstop was provided with a minimum 3 inch clearance of concrete to avoid blowouts of the concrete caused by swelling of the waterstop. The waterstop was set into an adhesive primer applied to the concrete substrate and was adhered at 12 inches on center. This ensured that the waterstop would remain in place even 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 water tight assembly. Refer to Image 1 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 the 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 the placement of the steel reinforcing for the 5 feet mat slab. The top layer of the rat slab as well as the mat slab were also provided with sodium bentonite based waterstops installed at each cold joint as a secondary line of defence against water infiltration at the joints.

Image 1 – Bentonite waterproofing membrane installed over rat slab and sealed around tie down penetrations

SLAB TIE DOWNS

Sealing was needed around each of the 680 tension piles through the waterproofing membrane while also allowing for the piles to be located within sleeves which allowed the piles to move freely of the slabs as the structure settled without allowing water seepage into the sleeves. In order to address these requirements a detail was developed by the team which consisted of a 12" 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 bar was then installed through the sleeve to allow the bar to go under tension under hydrostatic pressure with a movement of 1/8” to ¼”. 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 also wrapped around each VPC sleeve at three different heights above the protection slab. 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 is complete the top of each tie down anchor head was grouted over prior to turning off the dewatering system. Refer to Figure 2 for the bentonite waterproofing membrane patching around the tie down penetrations.

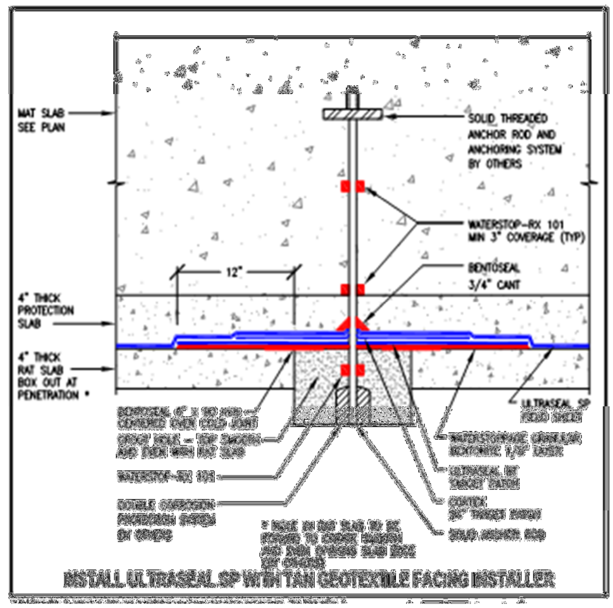

Figure 2 – Bentonite slab waterproofing around tie down penetration

PREPARATION OF THE CSM WALLS

In order for the bentonite to perform effectively the membrane must be in intimate contact with the shoring wall. The shoring wall substrate is 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 should be ground down to level and smooth. Refer to Image 3 of the for a general view of the CSM wall with a section smoothed and ready to receive the bentonite waterproofing.

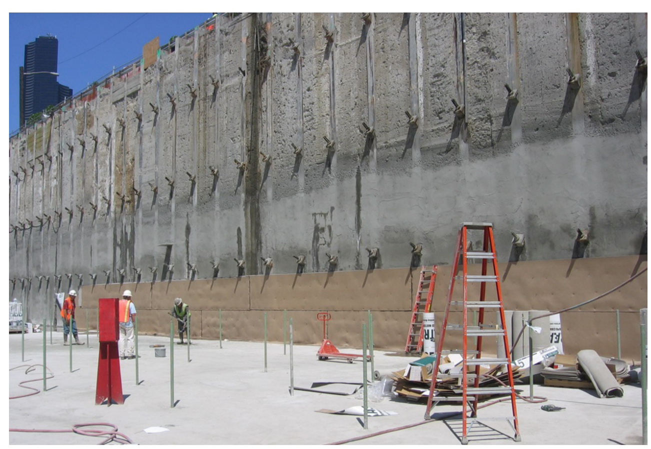

Image 2 – Overall view of CSM shoring wall with section smoothed and prepared for receiving bentonite membrane

The CSM shoring walls although intended as flat and relatively smooth are often wavy and have areas of voids. Refer to Image 4 for view of 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 must be installed in direct contact with the substrate and any voids larger than 2 inches would require to be smoothed. Review of a similar CSM shoring wall was reviewed and it was determined that only approximately 10% of the surface of the shoring wall would be likely to require smoothing out. This allows for the shotcrete structural concrete to be applied directly against the membrane to confine the bentonite.

Image 3 – Sample of CSM shoring wall prior to being prepared as bentonite substrate

WATER SEEPAGE

As was expected, the CSM wall did not provide a completely water tight cut off wall. Water seepage from the perimeter water table was common at joints in the CSM and especially at the tie back anchors. Refer to Image 4 for typical seepage down CSM wall. In order to maintain a clean and safe work area as well as keeping the bentonite products from premature 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 tie backs to direct the water away from dripping down the walls and onto the slab. These gutters were still not able to capture all the water and other methods of addressing the water were needed. This included vacuuming ponding water from work areas, 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.

Image 2 – Water seepage through CSM wall at tie backs

In addition to water seepage down the face of the bentonite membrane and onto the floor slab, water seeping in behind the bentonite membrane prior to installation of the shotcrete foundation walls resulted in bulging of the membrane away from the CSM walls. The presence of 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 which is needed for the bentonite to perform properly. Releasing the water from behind the bentonite membrane was required 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 of shotcrete, these slots would be vacuumed to as dry as possible to eliminate any pockets of water trapped behind the membrane and then patched with a 2 layers of 12 inch by 12inch bentonite patches set in bentonite mastic.

TIE BACK DETAILING

De-stressing and cutting off the tie back anchors resulting in the tie backs 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 these grouted tie back anchors without a boot over the tie back. Due to the hydrostatic pressure at the tie backs, significant amounts of water infiltration was experienced at these tie backs once they were cut off. As a result, tie backs were cut off just prior to patching of the bentonite over the tie backs. The drainage slots through the membrane at each floor line allowed water from the tie backs that entered behind the membrane to be removed. Rapidly expanding spray foam water cut off was used at the tie backs to stop gushing water and to provide a smooth surface around the tie backs. 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 inch strip of bentonite mastic and fastened at 6” on center around the perimeter. Refer to Figure 3 for detailing of the bentonite membrane at the tie backs and Image 5 for photographs of the tie back cut off process.

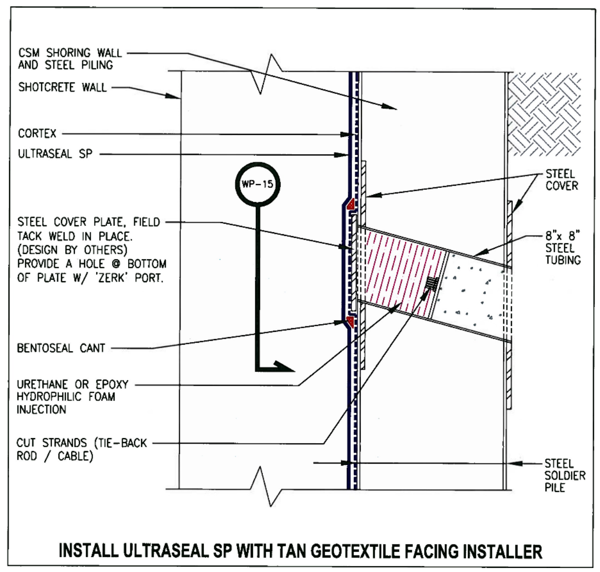

Figure 3 – Tie back cut off and sealing at bentonite membrane

Image 3 – Tie Back removal, capping to prevent water seepage and bentonite patching over tie backs

FASTENING OF THE MEMBRANE

The selection of appropriate fasteners for securing the bentonite panels to the CSM shoring wall was also considered and the use of low velocity fasteners with metal washers were determined to be appropriate for securing 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 also 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.