Waterproofing Challenges in Hydrostatic Conditions

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UNDERGROUND BUILDINGS AND other structures that are constructed underground may face distinctive waterproofing challenges, and these challenges are amplified if the structure will encounter either permanent or intermittent hydrostatic pressure from groundwater through the service life of the structure, or if the project site has contaminated soils. The challenges imposed by hydrostatic pressures include the increased reliance on proper detailing of the waterproofing system and the inclusion of various redundancies in the waterproofing strategy.

Successful strategies to address these challenges are critical for several reasons. In highly populated areas, there will be a growing need of more underground construction for buildings, mass transit and water supply tunnels, tanks, and even waste storage. There could also be more pressure to develop underground properties and infrastructure in less-than-ideal geographic locations as development continues across the globe. Finally, the impacts of climate change in some areas (such as coastal regions) will increase the demands on waterproofing systems for existing and future underground structures.

Figure 1. *Construction adjacent to water.*

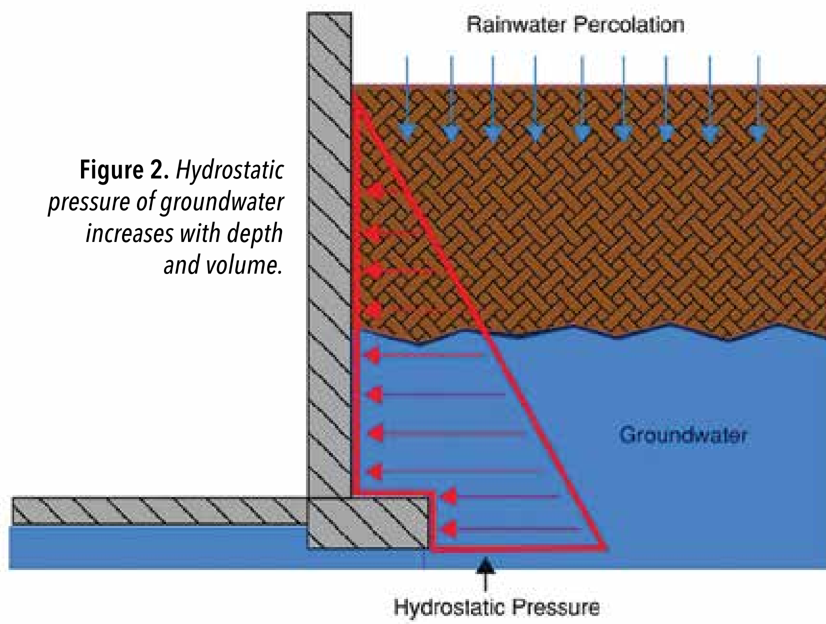

Figure 2. *Hydrostatic pressure of groundwater increases with depth and volume.*

HYDROSTATIC PRESSURE

Hydrostatic pressure is the stress that any fluid in a confined space exerts against adjacent bodies, including building structures. This pressure can be permanent if the structure is located well below the water table or in a coastal region (**Fig. 1**), or it can be intermittent. Causes of intermittent hydrostatic pressure include precipitation such as rainfall or snow melt, other seasonal changes, proximity to aquifers and other underground features (water reservoirs, subterranean rivers, etc.), and tidal fluctuations, particularly in marine structures.

Soil conditions can influence hydrostatic pressure. Low-impermeability strata such as rock and clay can prevent water from passing through soil, creating pockets of perched water as the buildup of water cannot pass through the ground. The hydrostatic pressure of the soil and groundwater increases relatively proportional to the depth of the structure below ground (**Fig. 2**).

In addition to hydrostatic pressure, designers and engineers must also consider the pressure that soil exerts against a structure. For example, foundations are distinctively affected by soils

Figure 3. *Rock anchor penetrations through foundation waterproofing.*

Figure 4. *Mat slab under construction.*

containing minerals such as smectite clays because these clays can retain water and will swell as they are saturated. Liquefaction of saturated soils in areas prone to earthquakes will also influence the design of a building's foundation.

Soil types and groundwater conditions are typically determined by a geotechnical engineering investigation. When the soil is below the water table, its pressure is calculated based on the weight of soil, which is then reduced by the buoyancy of the groundwater. Estimating this pressure typically requires testing and calculations by an experienced geotechnical engineer. For waterproofing design of a typical structure, a linear equation is typically used, which generally provides a somewhat conservative estimate.

Various foundation systems can be used to resist hydrostatic forces. The selection of these systems is critical for managing another effect of hydrostatic pressure: the ability of the building to resist water penetration. For example, foundations using stabilization systems such as rock and soil anchors require different waterproofing approaches than foundations using secondary structural elements such as "mat slabs" (thickened mat or raft foundation). Stabilization systems can include post-tensioned cables or rods grouted into the rock and/or soil. After the permanent foundation elements have been constructed, the anchors are tensioned and locked off with an anchor plate and nut (**Fig. 3**).

Secondary structural systems are another commonly used method to structurally resist hydrostatic pressure. These foundation types can be as thick as several feet to spread the load of the structure over the entire area of the building footprint (**Fig. 4**). Piles are also used to help overcome uplift pressures from either overturning of the building or hydrostatic pressure from below.

All of these structural elements can greatly influence the subgrade waterproofing system. As the number of penetrations through the waterproofing increases, the risk of water intrusion also increases because many leaks often occur at penetrations and other flashing details. Furthermore, when thickened mat slabs are used, the waterproofing system is placed below several rows of concrete reinforcement bars, making it very difficult or impossible to repair the waterproofing before concrete placement. Pile caps typically incorporate many reinforcing elements that are needed to connect the floor slab to the piles (**Fig. 5**).

Figure 5. *Pile caps.*

GROUNDWATER MANAGEMENT

The management of groundwater under hydrostatic pressure is a challenge for almost any type of waterproofing design because the pressure can force water through a foundation. Hydrostatic pressure increases as structures are built further below the water table, and the increased pressure creates greater energy to push water through breaches at any deficiency and then through cracks and construction joints in the structure itself.

Positive-side waterproofing membrane systems are appropriate systems for hydrostatic conditions; however, even these systems are vulnerable to damage from the force of the hydrostatic pressure if the hydrostatic pressure is great enough to push the membrane up against irregular substrates such as voids and/or protrusions in the foundation. Once water leaks occur, grout repair treatment can displace the water to alternate pathways into the structure and subsequent "chasing of leaks."

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The type of foundation material can also affect the management of groundwater under hydrostatic pressure. For example, if shotcrete is used as a foundation structure in hydrostatic conditions, the voids within shotcrete (such as shadowing behind reinforcement and rock pockets) can create numerous, interconnected pathways within the structure for water to travel great distances from the points of initial ingress, leading to leakage or other damage.

From a waterproofing perspective, it is almost always better to dewater than to fight the hydrostatic pressure. A common strategy to manage groundwater is to include a permanent dewatering system. This system is a subslab drainage system consisting of gravel and drainpipes. The drain piping can lead to sump pits, where the water is then pumped up and out of the structure. When a dewatering system is used, the slab can be thinner because it does not have to resist the hydrostatic pressure of the groundwater. However, there will be a long-term maintenance cost associated with operating and maintaining the pumps. Also, subslab drainage systems can become clogged over time and may not be suitable for every condition. Clean-outs should be provided in the drain lines to maintain the drain piping. Owners and designers must recognize that there is increased risk of structural damage and water intrusion if these systems are not maintained.

Another consideration for dewatering is that local ordinances may require that contaminated water be treated before it is discharged. There may be associated costs from the local utility depending on the volume of discharge.

In lieu of subslab drainage, footing drains can also be used to evacuate water from the foundation walls that are not under permanent hydrostatic conditions. However, to be effective, the footing drains must be able to discharge the water to an outlet away from the building structure or a sump pump. Otherwise, they simply fill and retain water, and are therefore unable to provide effective dewatering relief for the structure.

WATERPROOFING SYSTEMS

In addition to managing the groundwater, waterproofing systems can provide a barrier protection to prevent water from entering the structure. There are several types of waterproofing systems available, including, but not limited to, built-up bituminous (either asphalt or coal tar pitch) membranes, modified bituminous sheet membranes, composite membranes, fluid-applied membranes, bentonite-based membranes, polyvinyl chloride (PVC) membranes, and cementitious products. There are also different application methods such as fully adhering the membrane to the structure or loosely laying the membrane around the building structure. Blindside vertical applications come with additional complications of applying the waterproofing on the support of excavation and the potential damage to the waterproofing from the ensuing construction.

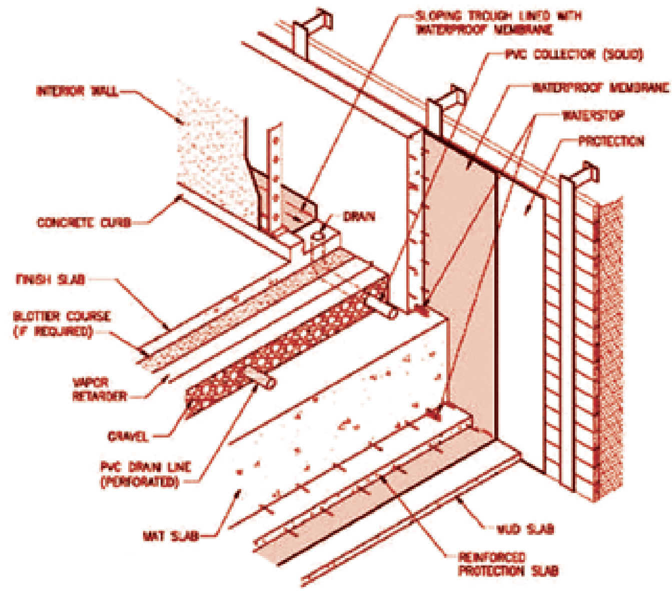


Figure 6. *Internal water management strategy of a positive-side waterproofing and internal drainage system.*

Each type of membrane system and each application method has advantages and disadvantages that must be considered and carefully evaluated before a system is specified for a particular use. No one product or system is without limitations. Among the issues to consider when selecting options for a particular project are the following:

- Clearance to install the waterproofing.
- Whether to use a blindside preapplied membrane or instead choose a postconstruction application of the membrane. However, this is often dictated by the access to the positive side of the wall.
- Whether to use an attached or loose-laid system.
- Concrete cure times.
- The quantity of joints and seams in sheet products.
- The complexity of details.
- Proposed project phasing.
- Penetrations of and proposed "tie-ins" to existing waterproofing systems.

A less effective alternative to positive-side waterproofing systems in hydrostatic conditions is the use of a negative-side waterproofing. These methods do not prevent water penetration into the structure; rather, water may migrate through structural pores, cracks, joints, and other openings. As a result, the concrete reinforcing could be saturated with potentially contaminated groundwater. Another drawback to using a negative-side waterproofing is that it can become more easily damaged because it is often left exposed to the building interior and is also vulnerable during interior construction activities.

The application of water retardants within the structural elements (such as concrete additives) is less effective in hydrostatic conditions. Water retardants typically do not bridge larger cracks in the concrete or construction joints. Concrete admixtures, however, can be a relatively inexpensive redundant type of waterproofing to be used with a waterproofing membrane or dewatering strategy. They will densify the concrete, which provides corrosion protection to steel reinforcement.

Some subgrade structures, particularly in high-risk uses with no tolerance for water intrusion, employ redundancy in the waterproofing design. This redundancy creates an alternative system to augment the water management of the structure. Such redundant systems may include, but are not limited to, a

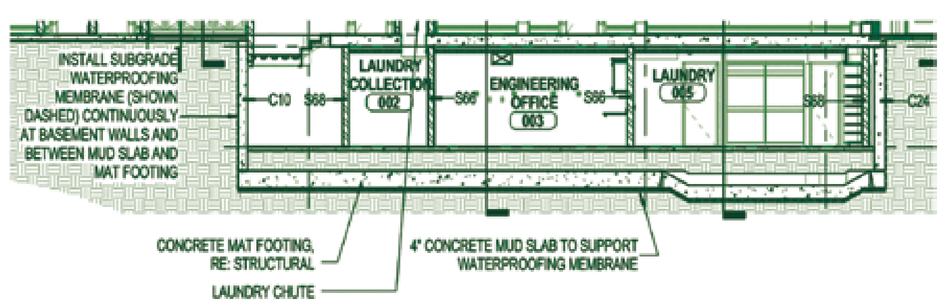


Figure 7. *Architectural cross section for below-grade building area.*

Figure 8. *A dewatering pump station at a perimeter trench at the corner of the building pad.*

combination of external dewatering (subslab or perimeter walls or both) and waterproofing, compartmentalizing and grouting, or interior water collection systems used in conjunction with a waterproofing membrane (**Fig. 6**). Some waterproofing membranes also have redundancy such as composite waterproofing systems with a thermoplastic membrane combined with a swelling "bentonite type" inner fabric.

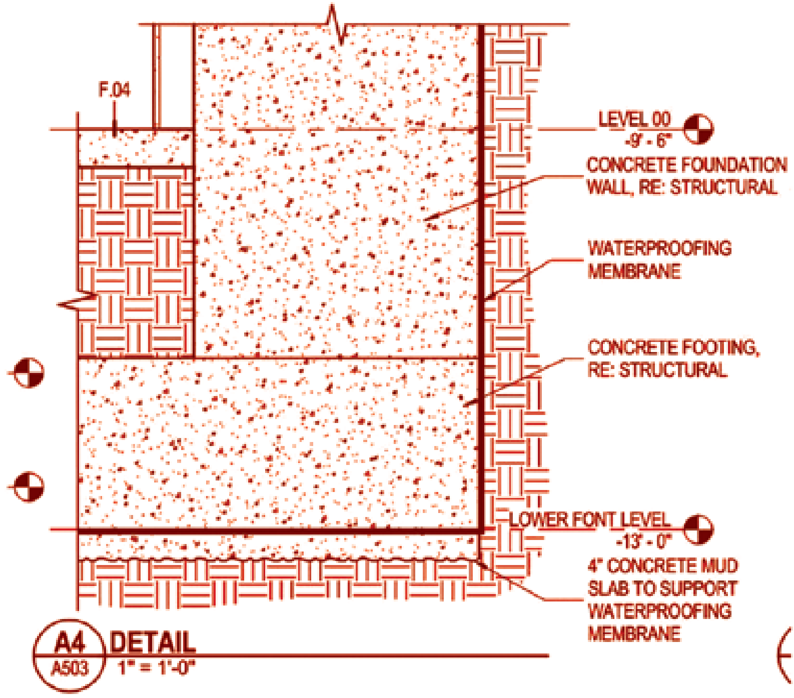


Figure 9. *Enlarged design detail of horizontal waterproofing confined between the structural slab and mat slab.*

CASE STUDIES

To further elaborate on the waterproofing principles and strategies described in the previous sections, we are presenting two case studies. The first case study explores a waterproofing practice for subsurface conditions subjected to a permanent or constant hydrostatic pressure. The second case study involves waterproofing subsurface conditions subjected to a cyclic or seasonal hydrostatic pressure. Both case studies focus on new construction projects.

Case Study 1: Constant Hydrostatic Pressure

This case study involves a two-story, low-rise structure in south Florida. The project is located on the fringe of the Everglades swamp, within the Biscayne Aquifer, where many subsurface structures are subjected to constant hydrostatic pressure. The site is positioned in a suburban environment and adjacent to an interstate roadway. The building has one level on ground and one level below grade (**Fig. 7**). The lower level includes a weighted slab designed to resist uplift pressures, has a conditioned interior space, and is served by a holeless hydraulic elevator.

With the project being subjected to constant hydrostatic pressure, an active or expanding sodium bentonite waterproofing material was a practical choice. As soon as the waterproofing becomes submerged within the high groundwater level, the putty-like material will hydrate or expand up to seven times its original thickness. This process can occur within a week or take up to a month to happen. The swelling of the waterproofing membrane increases its material thickness and creates a compressive seal between the building structure and the surrounding soil conditions. The contact submersion in groundwater will keep the bentonite material hydrated and sealed in place.

The selected bentonite sheet waterproofing product includes a 15-mil sheet of high-density polyethylene (HDPE) and a layer of expandable, granular bentonite. A functional part of the waterproofing is the layer of granular bentonite clay material, which will "hydrate" and expand up to 10 times its original thickness once subjected to prolonged exposure to water. The HDPE is extremely resistant to chemical contaminants. This expansion of the bentonite creates a compressive seal to block the flow of groundwater.

To function properly, the compressive seal of the bentonite waterproofing must remain in constant compression between the building structure and ground conditions. Given the presence of the constant groundwater, this waterproofing system does not traditionally manage the groundwater by means of drainage.

An expanding hydrophilic water stop composed of bentonite material was also planned to be provided at the concrete cold joints as a secondary means of protection. The location of the expanding water stop is important within the concrete joint to properly confine the material and create the compressive seal. If the water stop is placed too close to a concrete surface, it will swell when hydrated and can crack or displace the concrete, thereby affecting the confinement of the bentonite waterproofing at that location.

Other design considerations and strategies included sloping the surfaces at the elevator pit to ease the geometry of the structure to be waterproofed, not permitting any penetrations into the horizontal waterproofing surfaces, and coordinating specific locations of the concrete cold joints and placement of water stops.

To aid in the design of this waterproofing system, which is expected to be subjected to hydrostatic pressure, samples of the soils and groundwater were obtained and submitted to the waterproofing material manufacturer for evaluation of their pH and alkalinity levels. This testing was done because sodium bentonite swell rates are affected by pH. From the testing results, it was determined that the specified waterproofing material did not need to be modified for saltwater conditions (which had been a potential concern because the project is near the ocean).

During construction, a dewatering moat-style trench was used around the perimeter of the building pad. This trench remained filled with groundwater and was constantly serviced by a dewatering pump station (**Fig. 8**). The dewatering pump station included separate primary and secondary emergency pumps.

The bentonite waterproofing was installed horizontally on a mat or mud slab (**Fig. 9**). The building's concrete floor slab was cast onto the waterproofing, which was turned up at the

Figure 10. *A horizontal bentonite waterproofing sheet being placed at the elevator pit.*

Figure 11. *Architectural cross section for below-grade building area.*

vertical walls. If the material were to become displaced, gaps could form in the membrane seams, allowing groundwater and soil to breach the assembly. Therefore, critical seams were supplemented with a bentonite-based mastic to reinforce the watertight seal of the overlapping seams.

Once the foundation walls were cast in place, sheets of vertical bentonite waterproofing were mechanically attached to the outer side of the foundation walls in a postapplied condition. The seams of the vertical waterproofing were sufficiently overlapped to maintain the continuity of the compressive seal.

Lastly, the membrane detailing was especially critical for this concealed waterproofing. Transitions, terminations, and penetrations are common locations where leaks can occur in waterproofing assemblies. Also, if unconfined bentonite waterproofing hydrates and expands, it cannot perform as designed and must be replaced with new material. Taking all of this into account, and in consideration of the constant in situ hydrostatic conditions, the waterproofing detail had to be double-checked before it was concealed as a quality assurance measure.

A key lesson learned from this project occurred at the elevator pit. The horizontal mat slab was sloped to avoid additional cold joints and 90-degree transitional corners at the membrane (**Fig. 10**). The reinforced horizontal concrete slab at the pit was designed to be thick enough to resist the force of the hydrostatic pressure.

During construction, water leaks were observed inside the elevator sump pit area. A repair using a modified thermoplastic membrane and perimeter sealants was developed from the negative side for this condition. The thermoplastic material was selected for its material pliability in a confined space; and acceptance from material manufacturer to include the repair condition into the project's warranty provisions for the new installation. Future leaks might be possible if the seams in the waterproofing membrane become displaced for any reason. The elevator pit was especially vulnerable to this risk because it was located near the edge of the slab where the vertical and horizontal waterproofing sheets overlapped each other.

Case Study 2: Cyclic Hydrostatic Pressure

The second case study involves a six-story, midrise structure in Boulder, Colorado, at the foothills of the Rocky Mountains, where the subsurface structures are subjected to cyclic or seasonal hydrostatic pressure. The site includes a zero-lot-line waterproofing in an urban setting. The building has four levels above grade and two levels below grade (**Fig. 11**). The lower levels include subsurface parking featuring a fully automated robotic parking system.

At this project site, the groundwater pressures and levels typically vary seasonally, with the fluctuations based largely on snow melt in the mountains above. In the spring and early summer, the snow accumulation will melt, creating extensive water runoff into the creeks and streams. This runoff will cause the water table to rise and fall multiple times during the year. These pressures are usually not constant or consistent. If mountain snowfall in the winter is heavy, the resulting water table in the foothills in the spring and early summer will be high, and if the snowfall is light, the water table will be low. Given these variations, it can be beneficial to periodically monitor the water levels with piezometers.

Because the exterior face of the concrete foundation walls would be inaccessible, a preapplied or blindside waterproofing system was the most appropriate design choice for this project (**Fig. 12**). Given the inconsistent hydrostatic pressure, it would have been much more challenging to use a bentonite waterproofing because the material might have been subject to cycles of hydration. A sheet waterproofing made up of a composite HDPE film/adhesive membrane was selected for use on

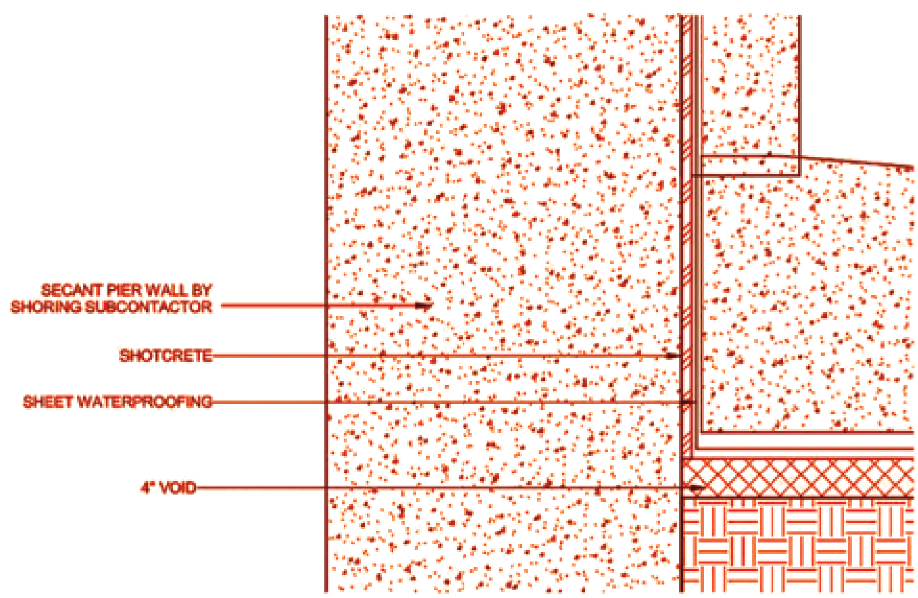


Figure 12. *Enlarged design detail of blindside sheet waterproofing located between concrete shoring and concrete foundation wall.*

Figure 13. *View of the preapplied sheet waterproofing being installed over the support of an excavation wall at a zero-lot-line condition.*

Figure 14. *Reinforcing steel being installed over the top of preapplied sheet waterproofing.*

the subject project. This waterproofing material selection is a reasonable choice since the heat of hydration of the concrete bonds the membrane back to the structure, which is advantageous as it mitigates the chance of water migration between the waterproofing membrane and the building structure if a breach in the membrane should occur. As in the first case study, the HDPE film is exposed to the soil and provides good chemical resistance to contaminants in the soil and water.

Unlike the first case study, on this project there were several penetrations into the horizontal waterproofing at the lower slab level so the reinforcing steel could connect the slab to the deep foundation system. Most structural engineers object to waterproofing between these elements because a bond separator is formed between the concrete surfaces of the deep foundation and the horizontal structure, and that can reduce the strength of these connections. The compressive strength of the membrane can be another issue for the engineer if the membrane can compress between these two structural elements. The feasibility of flashing all the reinforcement bar penetrations is also very difficult with a sheet membrane. Given these conditions, the sheet waterproofing systems on this project required careful detailing. Most HDPE waterproofing systems also include liquid membrane flashings and mastics to assist in detailing the terminations and penetration edges in these areas. Because the exterior sides will all be inaccessible, all layers that are outboard of the waterproofing membrane had to be installed and properly secured before the concrete structure was placed. The drainage mat was only a requirement at the vertical walls of this project to help relieve the hydrostatic pressure from the fluctuating groundwater levels.

As the pit was excavated, some dewatering was required because water tables were high following a snow melt. In this region, it is preferable to schedule excavation in the early fall, if possible, to avoid the need for dewatering.

The composite HDPE film/adhesive sheet waterproofing and drainage mats were laid out before the placement of the reinforcing steel and concrete (**Figs. 13** and **14**). The waterproofing seams were all overlapped as the membrane was set into place. The selvage edge seams for the sheet waterproofing membrane were enhanced by the application of seam tape. This adhesive edge is sometimes integrated into the membrane side lap edge for added protection. Rolled tapes can be applied to reinforce the membrane seams or outright seal them.

Another key consideration during the waterproofing installation was to protect the membrane. Strategies to protect the membrane against cuts, tears, and burns from the placement of the reinforcing steel can include not locating reinforcing bar chairs on top of the horizontal membrane seams. For this project, continuous reinforcing bar chairs with plastic tips were used to support the horizontal reinforcing steel on the horizontal surface. To further protect the membrane, it was important to ensure that the reinforcing steel was not cut with torches or grinders in the vicinity of the waterproofing material.

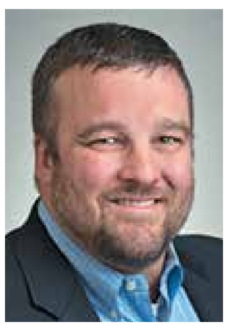
As a cost-saving measure on concrete formwork, the design team decided to use shotcrete instead of traditional cast-in-place concrete at the foundation walls. This modification required changes to the design and installation of the sheet waterproofing. The design changes entailed confirming the appropriateness of the waterproofing material selection for shotcrete applications. Getting consistent and consolidated coverage in the shotcrete placement was also critical. Ideally, the shotcrete placement would not create voids or reinforcing bar "shadowing" in the structure.

As water leaks appeared at cold joints and cracks in the shotcrete foundation walls, an injectable polyurethane foam was used to seal the leaks. The foam was injected through ports drilled into the interior side of the concrete wall. The ports were drilled on an angle into the joint or crack in an offsetting pattern at a consistent spacing. One problem with this method of repair is that it is a "trial and error" approach and could require multiple attempts to seal the leaks at each location. It should also be noted the shotcrete can complicate the grouting repair process because there are small voids and gaps in the structural material that facilitate the flow of water through the wall.

CONCLUSION

Groundwater pressures and activities are very "fluid" and reactive to their surroundings. Effective groundwater management in hydrostatic conditions can require a combination of drainage strategies and waterproofing protection. Managing water before it gets to the waterproofed surface by means of drainage or diversion is always the preferred option. Proper installation of an appropriate type of waterproofing system will also help ensure that the building structure remains dry. IIBEC

ABOUT THE AUTHORS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Special interest

Workers Gain 95,000 Minutes after Office-Meeting Cancellations

How many hours do you spend in meetings? Perhaps too many.

"Meetings are the new corporate hobgoblin," wrote Lauren Weber in the *Wall Street Journal*. "Executives at Shopify Inc., Wayfair Inc., and other firms say overstuffed calendars waste thousands of hours and cut into productivity."

Weber noted that the number of hours spent in meetings "skyrocketed" during the COVID-19 pandemic. This increase can be partly attributed to remote work eliminating opportunities for quick, serendipitous gatherings among office mates. With offices closed, the number of meetings an average user of Microsoft Teams attended each week more than doubled from February 2020 to February 2022 while the amount of time spent in those meetings tripled. "Whether workers had the bandwidth or not, they were in a frenzy of circling back, touching base, and bringing something to the table, unless there was a hard stop, in which case they'd make a plan to take it offline later," Weber wrote.

To end this trend, some companies are taking decisive action. Recently, Shopify Inc. deleted 12,000 events from workers' calendars. The company estimates that this action freed up 95,000 minutes for employees to focus on other work.

Source: *The Wall Street Journal,* Min C. Chiu/shutterstock.com