Feature

# Blindside Waterproofing Systems for Hydrostatic Conditions: Lessons Learned & Good Practices

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*This paper was presented at the 2024 IIBEC/OBEC BES.*

## INTRODUCTION

With the increasing demand for housing and expansive growth of multi-unit residential building (MURB) developments in downtown Toronto and neighboring communities, the number of below-grade levels, particularly for parking, continues to extend deeper. Blindside below-grade waterproofing has become an essential component of multi-unit residential building developments in constructing watertight foundation walls, primarily to accommodate parking spaces. The proximity of the communities in and around downtown Toronto to Lake Ontario has led to these below-grade assemblies inevitably reaching hydrostatic conditions with high water table conditions.

Given the current local municipal restrictions on collecting and discharging water around and below-grade foundations into the municipal storm and sanitary systems, all new buildings within the Toronto municipal area are required to be 100% watertight through an application method of below-grade waterproofing, widely known as "bathtubbing." This is achieved through a combination of excavations using caisson wall soil retention (tiebacks, rakers, and other retention methods), site dewatering (removal of active water to lower the water table during construction), raft slabs, and a waterproofing system that fully encompasses the below-grade structure ("bathtub" waterproofing).

To improve project schedules and reduce construction costs, developers consistently source alternative construction methods, and one such method is shotcrete. Shotcrete is a method of concrete placement that has been in the industry for several decades and has recently been used for foundation wall construction with blindside waterproofing applications. Shotcrete allows for faster foundation wall construction, which allows for a reduction in the construction schedule. There are also the A-frame (**Fig. 1**) and the conventional poured methods (utilizing a wall form with threaded rods to hold forms in place) (**Fig. 2**). The A-frame allows for the construction of foundation walls that would produce the fewest penetrations through the blindside waterpoofing. This is achieved by supporting the reinforcement cage above the forms and above the waterproofing system and then removing the anchors when the next level is poured, allowing for waterproofing to be installed without penetration. The conventional poured method utilizes a threaded rod technique that holds the interior form in place by anchoring it to the soldier piles. This method will require the securement of the form and the reinforcement bar cage through the membrane, and it will be necessary for the waterproofing to be detailed around them.

In addition to the construction methods, considering the water table for a specific site is also important. Understanding if a site has a high, medium, or low water table and the number of below-grade floors being constructed helps to identify what type of hydrostatic condition the below-grade floors will be under. Once the level of hydrostatic pressure is confirmed, selecting suitable materials and the details to accompany them is the next step.

With the new requirements needing "bathtub" application of blindside waterproofing and the condition of hydrostatic pressure behind the foundation walls, shotcrete foundation walls have proven to contribute to failures in achieving the watertight condition required

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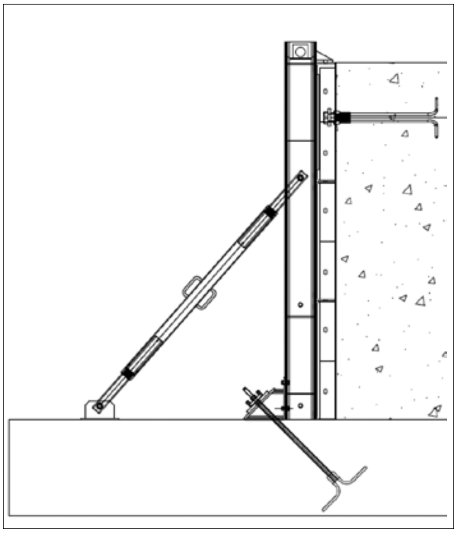

**Figure 1.** *A-frame for foundation walls construction method cross section.*

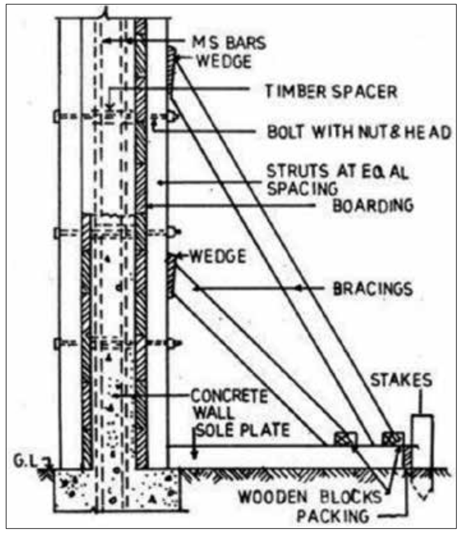


**Figure 2.** *Conventional framing for foundation walls construction method cross section.*

for the below-grade structure. The installation process of the shotcrete creates situations that are detrimental to the waterproofing adhesion process, wherein for most systems 100% adhesion is required to be an effective and reliable waterproofing system. Therefore, other means of construction, aside from shotcrete, are required to achieve a watertight condition for the blindside "bathtub" waterproofing systems.

## WATERPROOFING MATERIALS FOR BLINDSIDE "BATHTUBBING"

Understanding the problem is only the beginning of establishing a path toward a successful watertight structure. To start, let us review the different types of waterproofing systems that are presented by their various manufacturers as being the right product for the site conditions. Some systems are sheet and liquid membranes that require 100% adhesion, while others require a two-stage system utilizing sheet membranes and a bentonite layer in hydrostatic conditions. The two-stage system is required to have a sheet membrane over the entire foundation wall structure but also requires a bentonite sheet layer within and just above the water table area. This additional layer of protection provides a back up to the main waterproofing membrane sheet. The bentonite is intended to swell and seal a breach in the main sheet reducing the possibility of water penetrating through the membrane and subsequently through the foundation walls.

There are several types of blindside waterproofing products, but the most common fully adhered systems are high-density polyethylene (HDPE) sheets, elastomeric sheets, styrene-butadiene-styrene (SBS) modified bitumen sheets, bentonite sheets, and spray-applied elastomeric coatings. There are other waterproofing systems that are used in the industry that are not as common in the residential construction industry. These materials are thermoplastic polyolefin (TPO), polyvinyl chloride (PVC) and Bentonite systems. These are not all fully adhered systems and depending on the soil and ground water conditions these systems may not be suitable for selection. With all the different types of materials, it is a challenge to know when to use which product to give the project the best chance for success.

The more we allow for a hydrostatic condition to occur around the below-grade structure, the higher the waterproofing system's risk of failure. It has been recently identified that the use of drainage boards for the "bathtub" waterproofing systems can allow for water to flow freely around the structure and fill up with water to a point that is equal in elevation to the existing water table. Therefore, under these conditions, hydrostatic pressure has not been eliminated as intended with the introduction of a drainage board. If the drainage board can be eliminated and the waterproofing applied to a relatively smooth surface, this could reduce the amount of water directly behind the foundation wall and reduce the risk of excessive water infiltration. This can also be achieved by installing diaphragm soil retention walls, which have a higher strength than the conventional caisson walls we see in today's construction. This can act as an additional line of defense for keeping the water away from the foundation walls and assist the waterproofing system to achieve watertightness protection.

## INVESTIGATION OF WATER INGRESS THROUGH FOUNDATION WALLS

Having had the opportunity to investigate a couple of structures with systemic failures of their waterproofing systems, we have begun to understand the causes of the failures and understanding these are common occurrences on construction sites. These failures are resulting in excessive amounts of water leakage through the foundation walls at cracks and construction joints. These investigations involved foundation walls constructed using a shotcrete method, and the structure was subjected to high water table conditions (high hydrostatic head). We utilized a number of nondestructive investigation methods for this investigation. One of the investigation techniques was the review of documentation from the construction process, such as third-party or Bulletin 19 (B19) field observation reports (Ontario requirement for new homeowner constructed developments), manufacturer reports, and a review of the dewatering decommissioning process. Using this information, we were able to identify suspected failure modes. Shotcrete foundation wall construction introduces several high-risk situations if not completed correctly or in the appropriate timelines. Due to shotcrete's low water to cement ratio, the dryer mix will cure much faster and will result in waterproofing adhesion failures if not applied in smaller increments. There is also the potential for rebar shadowing, unconsolidated material (voids), and overspray on the membrane creating a bond breaker within the waterproofing system, this has led to several failure modes of the waterproofing membrane not bonding as required and allowing for water travel through the foundation wall. If water leaks in the foundation wall are more localized and isolated, this could potentially point to a single failure mode as the source of the issue. One of the non-destructive testing methods we utilized to confirm a failure mode was ultrasonic pulse echo (UPE) analysis. The UPE analysis helped to assess the condition of the shotcrete while also identifying items such as tiebacks, potential waterproofing membrane failures, and the thickness of the walls at given locations.

During the review of the documentation, we were able to identify several areas where the waterproofing was covered in overspray material from the shotcrete process (**Fig. 3** and **4**). This information helped us to see a possible correlation between some of the leak locations of the constructed walls (**Fig. 5** and **6**). We used this information to help in the selection of walls

**Figure 3.** *Shotcrete overspray on sheet membrane after form work was removed. No additional overspray removals were expected.*

**Figure 4.** *Shotcrete installation on sheet membrane and overspray is approximately 2 ft (0.6 m) beyond construction joints.*

**Figure 5.** *Water infiltration through foundation wall at column location.*

**Figure 6.** *Water infiltration through foundation wall cracks at corner.*

for the non-destructive investigation method utilizing the UPE analysis.

The UPE analysis provides information through acoustic stress waves from the interior surface of the foundation wall to the caisson wall and, in some cases, through the caisson wall. These waves help to locate defects or anomalies in the concrete wall that are dissimilar to solid concrete. This information can be utilized to extract information pertaining to the condition of the shotcrete, which identifies anomalies along the path of the UPE signal. A review of these results can tell us if there are areas of voids, cavities, or gaps in construction. We were able to use this information to not only find areas of concern in the shotcrete but also to find areas of membrane bonding issues, with a good degree of accuracy. In addition, we found and mapped out the locations of tiebacks where the signal reflection was much shorter due to the tieback being closer than the expected thickness of the foundation walls. Utilizing this process, we were able to select locations to conduct concrete coring through the foundation wall to collect physical data and compare them with the analysis information.

Following the coring process, it was confirmed that the membrane had adhesion issues. This appears to have been caused by shotcrete overspray, unconsolidated concrete (voids) and material bonding issues with the dryer mix of the shotcrete. What we did not expect to find was that the shotcrete and liquid waterproofing materials that are used to detail tiebacks were not adhered, either. It was also discovered that one area had unconsolidated concrete at the backside of the foundation wall (**Fig. 7** and **8**), rebar shadowing had occurred (**Fig. 9** and **10**), and a waterproofing lap joint was not fully adhered (**Fig. 11** and **12**). The extensive water intrusion through the foundation wall was the result of several failure modes such as tieback anchors, unbonded membrane at shotcrete overspray locations, and partially bonded overlap joints. For more information on this subject please refer to my first paper published through the 16th annual Canadian Conference on Building Science and Technology titled "Lessons Learned: Moisture Ingress Protective Waterproofing Systems."

## HOW TO REMEDIATE A SYSTEMIC "BATHTUB" WATERPROOFING SYSTEM FAILURE

As there are several products to waterproof the blind side of a below-grade structure, there are also several materials available to assist in remediating a systemic failure of the waterproofing system. A repair method called curtain grout injection uses the following materials currently on the market: bentonite polymers, acrylic/ acrylates, polyurethane foams, and rubber polymer gels. These materials are either hydrophobic or hydrophilic in nature. Hydrophobic materials are those that repel water; while they will use some water for the activation process, once the curing process has begun, they will disperse water away. Hydrophilic materials are those that absorb water; they will use the water as part of the curing process and require moisture to maintain their gelatinous states. There are pros and cons to each material, and the site condition is critical to the selection of the appropriate materials. The curtain grouting process is an intrusive procedure and will act as the new watertightness defense if the

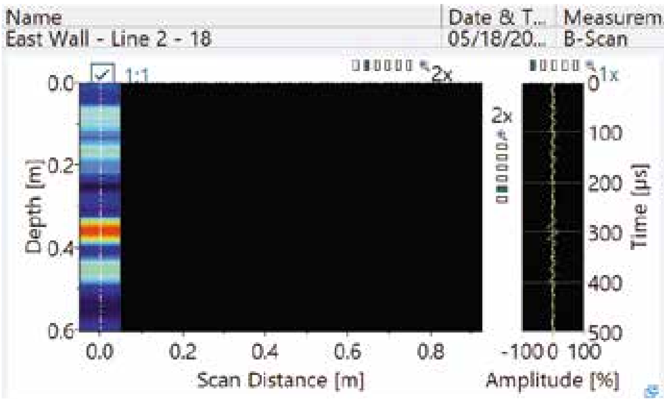


**Figure 7.** *Ultrasonic pulse echo analysis measurement at unconsolidated concrete location.*

**Figure 8.** *Extracted core from foundation wall showing unconsolidated concrete.*

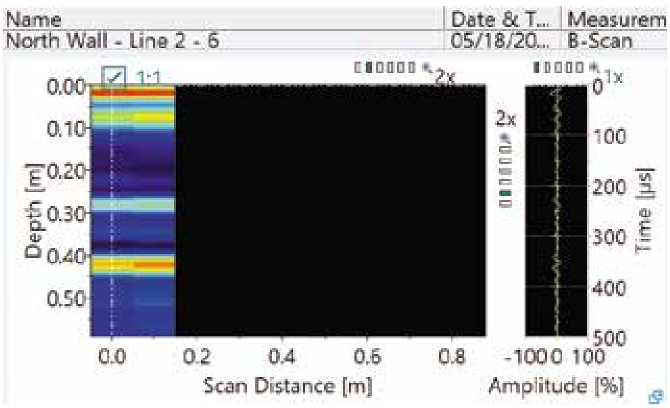


**Figure 9.** *Ultrasonic pulse echo analysis measurement at reinforcement bar shadowing location.*

**Figure 10.** *Extracted core from foundation wall showing reinforcement bar shadowing.*

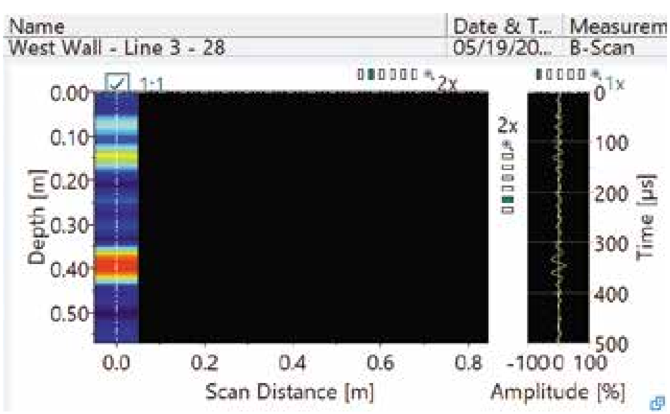


**Figure 11.** *Ultrasonic pulse echo analysis of concrete where lap detail and waterproofing adhesion failure were found.*

**Figure 12.** *Extracted core of foundation wall waterproofing where the membrane was not adhered due to shotcrete overspray.*

membrane and construction system have failed to keep the building in a dry condition. Therefore, material warranty and material selection to accommodate the site conditions are critical to ensuring a successful remediation process. This is a scenario where one solution does not fit all, and therefore appropriate research into the product and retaining a consultant that has adequate experience is essential. Most of these materials require water to be present behind the walls during the injection process, which is beneficial, as dewatering the site after the structure is in place is extremely costly and difficult.

## MATERIAL MOCK-UP PROCESS

We conducted a full-scale mockup of four blindside "bathtub" waterproofing system material types on an A-frame and a conventional form and pour construction process. We incorporated the different types of details in the mockups that would reflect in-situ construction practices, such as pre- and post-applied penetrations, reinforcement anchors, tieback boxes, changes in surface elevation (soil retention), and smooth surface application (soil retention) without drainage

| Hydrophobic Pros | Hydrophobic Cons | Hydrophilic Pros | Hydrophilic Cons |
|---|---|---|---|
| Pushes water away | Displaces water | Absorbs water; will continue to absorb water | Shrinks when it dries |
| Remains in a solid state, regardless of moisture presence | Has poor adhesion on wet surfaces | Is flexible and can bridge cracks | Loses flexibility when it dries |
| Becomes lighter than water when curing | Has poor flexibility after curing; cannot bridge cracks | Has better adhesion to wet surfaces | |

**Figure 13.** *Elastomeric sheet waterproofing installed.*

**Figure 14.** *High-density polyethylene sheet waterproofing installed.*

**Figure 15.** *Elastomeric spray applied waterproofing installed.*

**Figure 16.** *Styrene butadiene styrene modified bitumen waterproofing installed.*

**Figure 17.** *Formwork in place for pouring of concrete from bucket.*

**Figure 18.** *Concrete splatter is found on overlap joint above the concrete pour.*

boards (**Fig. 13-16**). The intent of these mock-ups was to review the waterproofing systems following the installation of reinforcement and concrete for a 1.83 m (6 ft) high wall with details reflective of real-world construction practices (as can be reasonably duplicated). The concrete was poured using a bucket attached to a crane to drop the concrete into the forms with no protection to the overlap waterproofing material.

Once the concrete reached acceptable structural capacity (confirmed using concrete cylinders cast for each wall) the backside of the forms where the waterproofing was installed against were removed (**Fig. 17**). This exposed the waterproofing material which was bonded against the exterior face of the foundation wall mock-up. Following the exposure of the waterproofing materials, we removed the drainage boards where possible (some of the systems the drainage board are bonded to the membrane as part of the installation process) to expose the membrane at these drainboard locations. A visual and tactile review of the membranes took place to identify possible areas of debonding. Areas that were suspected of debonding were checked by completing a field adhesion test (the membrane was cut with a knife in a rectangle around the suspected area and grabbing the top of the cut section and attempting to remove by pulling perpendicular to the wall). A majority of the suspected areas were unbonded with some membranes performing better than others. A contributing factor to the unbonded waterproofing appears to be due to consolidation issues of the concrete (vibration was inadequate). During the visual review we also noted that the top of the waterproof membranes were covered in concrete splatter from the installation of the concrete (**Fig. 18**). Based on these findings the details and material selection are not the only major requirements but also the installation of concrete and the placement of the reinforcement within the foundation walls.

Lastly the walls were then sectioned off and laid down on their backs to facilitate the dissection and collection of the samples to be sent to an ASTM rated lab. We are having three tests performed for each membrane type: Hydrostatic Head Testing (ASTM D5385—Modified), Lateral Water Migration (AATCC TM127) and Concrete Adhesion ASTM D4541. These tests are to verify how the waterproofing would perform in the hydrostatic conditions of a blindside "bathtub" application including their ability to bond to post applied poured concrete. Quantitative test results are currently outstanding and will be received later.

## HIGH TO MEDIUM HYDROSTATIC CONDITIONS

Understanding the performance of the materials and their restrictions can help in identifying what changes are needed to the design of the soil retention system and the selection of a framing method. In some cases the height of the water table could dictate which measures are needed to increase the chance of success. In a high to medium hydrostatic conditions, the water table could be four (or more), to two levels above the slab on grade. Understanding the site at the design stage and its expected hydrostatic condition is more important these days, due to the inherent risk it poses to ensuring the watertight condition of the below-grade structure. Upgrading the soil retention system to a higher-strength wall with water impermeability, specifically in the use of a Diaphragm wall, needs to be greatly considered. The implementation of this soil retention can allow for minimal damage to the caisson wall during the excavation process, resulting in a smoother surface. This will allow the waterproofing membrane to be installed directly on the wall without the use of a drainage board. Without the drainage board present, the chance for excess water to build behind the foundation wall will be reduced. Isolation of the tiebacks using tieback boxes is required at the structural design stage by the structural engineer. This detail will allow for the isolation of the tieback from the foundation wall embedment and remove the risk of difficult detailing of the tieback.

The use of A-frame construction to reduce the number of penetrations through the membrane will increase the chances of a successful watertight structure. The use of a dewatering system that carries the water behind the waterproofing system through the collection at pits can be very beneficial to the success of the waterproofing system. Some dewatering systems are completed with a series of water tubes and follow behind the waterproofing. However, this method requires that a large breach in the membrane be used to collect the tubes at one location from the dewatering wells. This penetration and method of dewatering can lead to water infiltration if the details are not completed adequately or if there is water coming through the dewatering system if it is not adequately sealed. Finally, the selection of a waterproofing system that is designed and approved for these hydrostatic conditions is important. The system must be able to withstand the hydrostatic conditions at the weakest points of the system (that is, penetration details, lap joints, and repair patches). If the system cannot demonstrate successful applications in similar project conditions and the manufacturer cannot provide a letter of approval for the use of their system for your specific site conditions, a new material or system needs to be considered

## LOW TO MINIMAL HYDROSTATIC CONDITIONS

Low to minimal hydrostatic conditions can be considered with a water table being one to zero levels above the slab on grade, respectively. These conditions are at less risk of failure but still need to be given respect and attention to achieve the successful performance required. Use of the A-frame method in water table conditions for the site and tieback boxes are still recommended, but this process could potentially be modified in the non-hydrostatic levels. The membrane system will still need to be capable of preventing water infiltration, but the areas with no hydrostatic conditions may alter the manufacturers' requirements for a successful system. In these scenarios, it is often the under-slab waterproofing and the lowest level of the structure that are in the water tables. This will allow for a more conventional process for the levels above the water table that should be able to be performed as required.

## CONCLUSION

Construction methods and blindside "bathtub" waterproofing systems have their appropriate uses, and knowing their limitations or restrictions is vital. Identifying the necessary construction methods early in the design stage can reduce the risk of critical items during the construction process. It is necessary to select appropriate waterproofing systems with the intention to protect the reinforced concrete elements and reduce the moisture ingress into spatial conditions. The waterproofing of below-grade structures is successful only when it is done correctly the first time. Repairs or remedial measures to a failed waterproofing system applied to a buried structure are financially impractical from an excavation and repair standpoint. Remedial repairs from the negative side (interior space) by way of curtain grout injection can be a viable option, but they are very costly and intrusive due to the required process. The extent of water migration is dependent on the path that the water finds through the concrete elements and its ability to move laterally between the membrane system and the structure. If the waterproofing membrane system is not fully bonded to the structure, water can travel to areas that have a high risk of moisture ingress. Therefore, an appropriate material selection and construction methodology at the design stage, accompanied by quality control during the construction stage, is essential to mitigate potential failures of the waterproofing system and premature failure of the building components.

## APPLICABLE STANDARDS


*Ontario Building Code, 2012*

ASTM D903-98(2017), *Standard Test Method for Peel or Stripping Strength of Adhesive Bonds*

ASTM D5385-93(2006), *Standard Test Method for Hydrostatic Pressure Resistance of Waterproofing Membranes*

ASTM E154-08, *Standard Test Methods for Water Vapor Retarders Used in Contact with Earth under Concrete Slabs, on Walls, or as Ground Cover*

ASTM E96/E96M-14, *Standard Test Methods for Water Vapor Transmission of Materials*

ASTM D412, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension*

ASTM D1970, *Standard Specification for Self-Adhering Polymer Modified Bituminous Sheet Materials Used as Steep Roofing Underlayment for Ice Dam Protection*

ASTM D4833, *Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products*

ASTM D4068, *Standard Specification for Chlorinated Polyethylene (CPE) Sheeting for Concealed Water-Containment Membrane*


## ABOUT THE AUTHOR

CHRIS MCCONNELL


*Over his 10-years-plus career,* **Chris McConnell** *has gained experiences in a wide variety of fields and disciplines, including custom house design, general contracting, and consulting services related to noise, vibration, new construction, concrete rehabilitation, facade restoration, and waterproofing failure problem solving. At Synergy Partners, he provides a variety of services to several types of clients in the commercial, industrial, and residential sectors, including services across Canada where he remotely liaise with local teams to deliver highly successful projects. He is a graduate of McMaster University, where he finished summa cum laude in his Bachelor of Technology program.*