

Spraying Shotcrete on Synthetic Sheet Waterproofing Membranes

INTRODUCTION

Applying shotcrete for final linings against synthetic sheet waterproofing membranes has become more common in underground projects. The sprayed shotcrete is propelled at high velocity against the membrane and the dynamic energy consolidates the plastic shotcrete in place. However, the smooth surface and potential pillowing or vibrating of the waterproofing membrane poses a challenge compared to a shotcrete application against a stiff and rough surface.

The use of shotcrete final linings in underground applications is a standard placement technique. However, improper application of shotcrete against waterproofing membrane in a double shell system, with a separate temporary lining at the extrados and the final lining at the intrados of the membrane, can lead to poor-quality shotcrete due to delamination and voids, and produce local or large-scale fallouts, and can be the subject of technical disputes about cause and effect responsibilities.

This position paper discusses the basic elements of the adhesion of overhead and vertical shotcrete on a waterproofing membrane, the proper application techniques, and emphasizes the use of mockups. This position paper also provides recommendations for contractors and owners, from ASA's perspective, on how to properly apply, specify, and inspect shotcrete applied against waterproofing membranes.

ADHESION OF SHOTCRETE ON WATERPROOFING MEMBRANES

The phase immediately after application, when the shotcrete is still in a plastic state and has not gained any significant strength prior to the initial set, is referred to as "plastic shotcrete." The strength development starts after the initial and final set.^{1,2} One of the major forces supporting the shotcrete against fallout, especially if applied overhead, is the adhesion of the shotcrete to the substrate.² If shotcrete is applied against a waterproofing membrane, the

plastic shotcrete adheres to the membrane. However, because the membrane on the extrados is not directly applied to the initial lining over the entire area, the membrane cannot directly transfer the forces from the shotcrete weight into the initial lining. Adhesive forces of the plastic shotcrete can only be transferred into the initial lining at the fixation points of the membrane or where the membrane is supported by a self-supporting reinforcing bar cage.

REINFORCEMENT AND LATTICE GIRDERS

To avoid fallouts, plastic shotcrete must be supported by other means than the adhesion of the plastic shotcrete against the membrane. If the final lining is reinforced by reinforcing bar or welded wire fabric, the weight of the shotcrete is typically supported by the reinforcement. The reinforcement, on the other hand, is either suspended from anchors or is self-supporting, typically using lattice girders. In both scenarios, adhesion to the membrane is not required to keep the plastic shotcrete in place.

If the structural reinforcement bar is replaced with fiber-reinforced shotcrete, the plastic shotcrete is not supported by the reinforcement bar anymore. Despite the fact, that the reinforcement bar is not structurally required, a light reinforcement, suspended from anchors, might still be required to hold the shotcrete in place and as a support to potentially push the waterproofing membrane against the substrate. Alternatively, lattice girders are used and embedded with shotcrete first; as soon as the shotcrete around the lattice girders sets, the bay between two adjacent lattice girders can be filled, with the shotcrete in the bay bridging between the two lattice girders.

Spraying steel fiber-reinforced shotcrete does not damage or puncture the membrane because the forces acting on the fiber are not strong enough to push the fiber into the membrane and typically the fibers tend to orient parallel to the membrane on impact.

INSTALLATION OF WATERPROOFING SYNTHETIC SHEET MEMBRANES

Most waterproofing membranes are installed in sheets and anchored back in a 5 ft (1.5 m) or more spacing. However, if thicker shotcrete placement is envisioned, the spacing of the anchors may need to be reduced to carry a heavier load. Despite the fact, that the weight of the shotcrete is supported by other means, the installation of shotcrete on the waterproofing membrane is more challenging than in a poured concrete application. So-called “pillowing” of the membrane (a trapped air or water pocket or unwanted undulation underneath the waterproofing preventing the proper filling of materials) between fixation points must be avoided. Otherwise, the adhered shotcrete might rip the membrane. If hydrostatic water pressure builds up behind the membrane, the water pressure may further push the membrane in. The buildup of water pressure behind the membrane during the final lining installation must, therefore, be avoided by adequate water control measures. Pretreatment with injection (epoxy, polyurethane, or other chemicals) to minimize the hydrostatic water pressure may be required prior to installation of the waterproof membrane.

If the membrane is loosely spanning between adjacent fixation points, either because they are too far apart relative to the curvature of the arch or due to too-large outward waviness of the initial lining, the membrane may vibrate and prevent shotcrete adhesion during or immediately after application and cause increased rebound. Excessive spanning of the membrane must, therefore, be avoided.

The maximum spacing of the fixation points must be designed properly and should be tested in a mockup. The initial lining needs to be inspected before the waterproofing membrane installation, including but not limited to pillowing and spanning, before the shotcrete installation.

Distancers installed on the extrados reinforcement layer and the lattice girder provide a suitable means to avoid local pillowing and spanning.

PVC waterproofing membranes are more flexible compared to stiffer HDPE membranes. If rounded shapes prevail, HDPE membranes potentially have a higher risk of pillowing compared to PVC waterproofing membranes.

PROPER SPRAYING OF SHOTCRETE OVERHEAD

In general, shotcrete placement should start by spraying the base of the structure and continuing upwards and into the previously placed material, oscillating from one side to the other while moving up. This technique is also referred to as “bottom-up.” Once shotcrete is placed at approximately 2 and 10 on a clock, the placement technique should change

to using the anchor to anchor method with shotcrete placement in layers.²

The shooting should generally start at the load-bearing members (lattice girder or anchors), followed by bridging and material buildup in multiple passes between the load-bearing members. Overhead application (above springline) should always start from the bottom and work its way up continuously.²

If lattice girders are used, the lattice girders should be embedded with shotcrete first over the entire arch starting from the bottom. After two adjacent lattice girders have been properly embedded, the bay between adjacent embedded lattice girders can be sprayed from the bottom up. Depending on the total thickness of the lining, several passes may be required until the full shotcrete thickness is achieved. A sufficient time lag between each pass allows the previous pass to set and develop strength, mitigating the risk for fallout.² It is important to conduct preconstruction trial shotcrete placement and determine the acceptable time between each pass.

If the reinforcement cage is suspended from anchors, the area around the anchors should be embedded first, followed by bridging between adjacent anchors, preferably from the bottom up in a similar fashion to the lattice embedment girder process described earlier.²

If fiber-reinforced shotcrete is used, the use of lattice girders and a light reinforcement installed against the waterproofing membrane should be considered. The spraying process then follows the steps outlined previously. If neither reinforcement and lattice girders or anchors are used, the plastic shotcrete is suspended from the fixation points of the waterproofing only. The spacing of the fixation points must be reduced accordingly. Producing high-quality shotcrete under these conditions is a challenge and requires a tightened quality control process and a highly skilled nozzleman. In this case, it is recommended to build a buttress starting in the bench until the lining becomes slightly overhanging. Above springline, stripes of arching shotcrete should be produced first, followed by the closing of the bay areas between the stripes (similar to the approach with lattice girders). This is also referred to as “ribbon shooting.”

In general, pillowing of the membrane as well as spanning distances between fixation points needs to be minimized in either case prior to the start of shotcreting.

Higher rebound, compared to spraying on a stiff and rough surface of the ground, is to be expected when spraying on waterproofing membranes.

The use of accelerator, especially when spraying overhead, is recommended following the manufacturer’s guidelines.

MOCKUP

Following the ACI 506 guidelines, preconstruction testing and production of a mockup is strongly recommended.³⁻⁵ The mockup should reflect the project-specific waterproofing and reinforcement conditions and mimic the on-site logistical and atmospheric conditions to reflect the expected placement conditions. It is not unusual to have several mockup trials to optimize the system and prove the envisioned concept works. In addition, the mockup allows the nozzleman to train under project-specific conditions.

RECOMMENDATIONS FOR THE CONTRACTOR

There is typically a contractual interface between the waterproofing installer and the shotcrete contractor and it can also include an interface with the reinforcing bar installer. To ensure quality and avoid deficiencies, these interfaces and handover requirements should be inspected and documented in detail by the shotcrete contractor. This includes but is not limited to smoothness criteria and conditions of the initial lining, pillowing or spanning of the membrane, water control measures, sufficient and properly placed membrane fixations and anchors, welding and potential damages of the membrane, and proper reinforcement and lattice girder installation.

Shotcreting should be tested on a mockup mimicking the project-specific installation of the waterproofing membrane the reinforcement and lattice girder installation.

The shotcrete nozzlemen should be ACI certified, experienced, skilled, and specifically briefed and trained for the installation of shotcrete against a waterproofing membrane. Prior to the application, nozzleman should be qualified for the project by shooting a mockup section with the waterproofing membrane. Proper shooting procedures and application sequence should be laid out in writing in the work plan and tested during the preconstruction mockup construction.

RECOMMENDATIONS FOR THE OWNER

The owner should provide a design reflecting the specific challenges for a final lining applied on a waterproofing membrane. Minimum key criteria need to be specified such as smoothness criteria, fixation and anchor spacing, reinforcement suspension or support, water control, and shotcrete specification following the applicable ACI 506 guidelines.³⁻⁵

A key element is the preconstruction testing and the project-specific mockups, which should be mandatory and in accordance with the ACI 506 guidelines.³⁻⁵ The mockup

should be saw-cut to clearly identify any delamination or defective shotcrete. The owner should not allow the start of the works until the contractor has proven that the contractor's means and methods and procedures can provide the envisioned quality of shotcrete.

In addition, the owner should focus on the inspection of the installation of the waterproofing membrane prior to the shotcrete installation to verify it has been placed correctly and then to inspect the shotcrete application.

CONCLUSION

Installation of shotcrete final linings is an efficient construction method that saves both time and cost. However, the installation of shotcrete on waterproofing membranes in underground applications is challenging.

The owner and contractor should face and meet the expected challenges prior to the start of construction. Experienced staff on either side are required for the successful execution of the project.

This position paper provides recommendations for a general approach to spraying shotcrete on synthetic sheet waterproofing membranes.

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References

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3. ACI Committee 506, "Guide to Shotcrete (ACI 506R-16)," American Concrete Institute, Farmington Hills, MI, 2016, 52 pp.
4. ACI Committee 506, "Specification for Shotcrete (ACI 506.2-13)," American Concrete Institute, Farmington Hills, MI, 2013, 12 pp.
5. ACI Committee 506, "Guide for Specifying Underground Shotcrete (ACI 506.5R-09)," American Concrete Institute, Farmington Hills, MI, 2009, 52 pp.
6. ASA Underground Committee, "Position Statement #3, Robotic Shotcrete in Underground Applications," American Shotcrete Association, Farmington Hills, MI, 2019. (in development)

Position Statements

ASA has produced position statements on the best practices for proper shotcrete placement. To date, six position statements from our Pool & Recreational Shotcrete Committee, two from our Underground Committee, and one from our Board of Direction have been issued. These statements have also been published in *Shotcrete* magazine.

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