Polymer Rubber Gel Technology High Performance Waterproofing for Shotcrete and Blindside Applications

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ABSTRACT: Polymer rubber gel (PRG) waterproofing technology is effective and proven for the challenges of underground construction. Key characteristics for PRG waterproofing systems: (1) superior substrate adhesion, (2) responsiveness to substrate movement, (3) non-curing, (4) self-healing, (5) chemical resistance, and (6) environmentally friendly. PRG technology combined with durable, flexible, fleece, reinforced HDPE creates a dynamically responsive waterproofing assembly. This blindside system comprises the following (1) 20-mil HDPE fleece sheet installed against the lagging, (2) PRG is spray applied at a thickness of 100 to 115-mil, (3) 20-mil HDPE fleece sheet is embedded into the PRG. Shotcrete or concrete is installed against the assembly. This system is a high-performance membrane providing the benefits of fluid and rigid protection. This technology is successfully used for waterproofing large-scale subway stations. This paper describes (1) PRG's characteristics of a high-performance waterproofing system, (2) PRG providing effective solutions for shotcrete and blindside applications.

1 INTRODUCTION

Selection of a high-performance waterproofing system is essential to the success of any tunnel or below-grade structural waterproofing application. Waterproofing poses distinct challenges in performance, design, and application. One of the key determining factors of a waterproofing system is based on the method of planned construction. Two distinct methods of application are used for waterproofing structures; Positive Side and Blindside application. Positive side application is commonly used when the application of the waterproofing membrane installed directly to the outside surface of a concrete structure. Blindside application is commonly used when the application of waterproofing is installed prior to placing the concrete or shotcrete lining. The substrate for application is usually to the soil support of excavations i.e. sheet pile walls, secant/tangent pile walls, CDSM, etc. For blindside applications, the final lining or structural wall is formed against the waterproofing membrane.

Table 1. Waterproofing application methods

Waterproofing Method	Description
Positive Side (Figure 1)	Waterproofing is installed to the existing structure directly to the outer concrete substrate
Blindside (Figure 2)	Waterproofing is installed to the support of excavation or lagging wall, prior to structural concrete or a spraying shotcrete lining.

The preferred method for waterproofing has been the direct application of waterproofing to the exposed concrete substrate - positive side application. This method is generally preferred because it allows the installer to see the substrate that is receiving the waterproofing and to ensure that proper membrane detailing and proper adhesion of the membrane to the substrate is achieved. However, over excavation of the structure may be impractical due to adjacent lot lines and is typically costlier than utilizing a soil support of excavation method. For this condition, the use of a blindside waterproofing assembly is preferred. Utilizing a blindside waterproofing assembly reduces the amount of excavation necessary for site construction this reduces costs. Traditionally, blindside waterproofing of structures has been accomplished utilizing bentonite clay panels or more recently, composite moisture activated adhesive panels with sheet laminate. Bentonite requires hydration and compaction for effective waterproofing ability. Care must also be taken to protect the exposed membrane prior to concreting from pre-hydration caused by environmental conditions such as rain, site runoff, or sunlight,. Within the last decade, preformed HDPE laminate pressure sensitive adhesive membranes have also been used to varying degrees of success for blindside applications. These preformed blindside membranes do not require compaction or hydration. Various challenges are inherent for both systems, including adhesion, flexibility, durability, and environmental conditions.

Through innovative technological advancements in waterproofing materials, a state-of-the-art solution called Polymer Rubber Gel (PRG) has been utilized for both positive side and blindside membranes for construction. With the introduction of PRG, new hybrid composite waterproofing systems have been developed that attain superior waterproofing performance for underground structures. As an innovative concept in waterproofing, a PRG composite waterproofing system effectively wraps the underground structure in a monolithic layer of flexible, self-healing, adhesive, non-curing gel combined with vapor and chemical resistant HDPE sheets. PRG's unique physical characteristics were specially formulated to effectively retain the integrity of the waterproofing envelope through exceptional engineering properties such as being adhesive, chemical-resistant, environmentally friendly, continuous flexibility, and self-healing.

Figure 1. Positive side Waterproofing

Figure 2. Blindside Waterproofing

2 GUIDELINES FOR EFFECTIVE WATERPROOFING

2.1 *General design guidelines and waterproofing system selection*

Site factors must be considered for effective waterproofing of underground structures. First, a set of watertightness criteria must be identified specific for the structure. A waterproofing system selection process should then be based on the watertightness criteria considering both physical site conditions and type of construction chosen for the underground structure. The substrate for which the blindside waterproofing system is to be applied should be considered during the soil support of excavation design process. A relatively smooth surface with sufficient rigidity should be specified to prevent the risk of cavitation, tears or punctures in the waterproofing system subsequent to concrete or shotcrete placement. For example, with sheet pile walls, a protection board with some sort of structural fill behind the board in the flutes is necessary to prevent blowouts in the waterproofing system during concrete or shot-crete placement. For CDSM or secant/tangent pile walls, the substrate should either be shotcrete to a relatively smooth surface or the face of the CDSM/secant/tangent pile walls should be shaved flush with the face of the soldier beams. Protrusion or cavitation in the excavated CDSM/secant/tangent pile walls will need to be smoothed to create an acceptable substrate for the application of the blindside waterproofing system. All waterproofing systems require careful consideration of the type of substrate prior to final design.

Effective waterproofing of underground structures requires that the entire waterproofing system must be continuous throughout the building envelope. Proper detailing for tie-backs to other structural systems, penetrations, protrusions (such as tiebacks in secant/tangent pile walls), transitions, terminations and seams within the waterproofing system are essential for maintaining the integrity of the continuous waterproofing envelope. Maintaining the same waterproofing system throughout the structure is preferred to limit any issues of either incompatibility or difficult tie-in details.

2.2 *Site Conditions, Constructability, and Installation*

Site conditions and constructability play a strong role in the waterproofing system design process. Oftentimes, waterproofing systems used on large scale applications will be exposed to the elements for extended periods of time prior to placement of concrete. In addition, other trades must work in direct proximity such as the mud slab on top of the installed waterproofing system. The environmental and physical durability of the exposed waterproofing membrane is important to prevent potential damage to the waterproofing system prior to completion. Preconstruction meetings with the waterproofing applicator and project general contractor should be conducted to ensure proper work staging to limit the exposure to possible damage. Waterproofing systems that are easily damaged or require extensive protection can cause project delays due to the necessity for repairs and/or complicated protection schemes. Manufacturer approved applicators, skilled and experienced in the installation of the specified waterproofing systems, are essential to the positive outcome of any waterproofing installation. Onsite QA/QC for the waterproofing work should also be provided to document and help ensure that the waterproofing system is installed per design specifications and plans.

2.3 *Key physical guidelines of the waterproofing system*

After successful installation and proper detailing, a waterproofing system must perform based on the physical attributes of the product. The following is a list of physical attributes that are important to the long term watertightness of a cut and cover waterproofing system.

Table 2. Important performance criteria of the waterproofing system.

Performance Criteria	Benefit to waterproofing
Adhesion to concrete	Adhesive bond of the waterproofing to the substrate which it is protecting ensures no path for water migration.
Responsiveness to substrate movement (non-curing)	Ability to retain a waterproof seal during seismic events or joints that experience constant movements.
Elongation	Ability to bridge cracks in concrete and construction joints without debonding ensures water tightness.
Hydrostatic pressure resistance	The system must have the durability to withstand continuous hydrostatic pressure without rupture.
Self-healing/sealing capability	Mitigates failure of the system with the ability for it to self-heal if punctured or penetrated.
Chemical resistance	Prevents degradation of the waterproofing system from soil contaminates.
Environmentally Friendly	Made from non-toxic and recycled materials. No significant VOCs during application. Low odor.

2.4 *Additional water mitigating components to the waterproofing system*

In addition to an underground structure's primary waterproofing system, additional consideration must be given to accessory waterproofing components such as prefabricated drainage composites and various types of waterstops. For underground structures that are not below the water table or where additional water control measures are desired, prefabricated drainage composites may be a suitable addition to the waterproofing system. A drainage system removes direct hydrostatic pressure from the waterproofing membrane. It is also advisable to utilize waterstops on critical construction joints as a last means of defense against water inflow. Regroutable injection tubes should also be considered for critical interfaces, such as between subway stations, structures, and tunnels, and construction of a thick base slab in stages. There are many various forms of prefabricated drainboards, waterstops and reroutable injection tubes to help with additional unforeseen water intrusions.

3 POLYMER RUBBER GEL WATERPROOFING SYSTEM

3.1 *Introduction*

PRG waterproofing systems have excelled in meeting the requirements of challenging underground waterproofing applications. Developed specifically for the waterproofing industry, PRG is composed of a polymer modified rubberized asphalt emulsion. However, unlike typical rubberized asphalt materials, PRG's polymers never completely cross-link. This retains the gel always in a semi-cured state. This innovation enables PRG to act as an exceptionally flexible, adhesive, never-cured, continuously self-healing membrane. As a proven concept in waterproofing, composite waterproofing systems utilizing a PRG component exhibit superior elongation properties, adhesion and self-healing ability. A PRG composite waterproofing system consists of a layer of polymer rubber gel at minimum thickness of 2.5 mm +/- .5 mm combined with a sheet membrane of laminate fleece reinforced HDPE. PRG with varying manufacturer-produced viscosities permits different delivery methods including (1) spray applied, (2) trowel applied, and (3) preformed waterproofing sheet applied. The flexible, non-curing, highly adhesive PRG combined with a durable, chemical resistant, hydrostatic pressure resistant HDPE sheet creates a dynamically responsive high-performance waterproofing system for demanding conditions of underground structures. Application of a PRG system is effective, efficient, and economical.

3.2 *Unique physical characteristics of polymer rubber gel (PRG)*

PRG exhibits many unique physical characteristics that make it an ideal component to a dynamic waterproofing system. The physical characteristics that are unique to PRG are principally the gel's ability to remain in an uncured state and its extreme cohesion and adhesion attributes. PRG's elongation to break is greater than 350% (ASTM C1135). PRG's adhesion to concrete is rated one (1) for excellent (ASTM D412-98). PRG's self-healing ability has been tested to 3.0 bar of direct hydrostatic head (2 mm thickness of PRG membrane). (Figure 3)

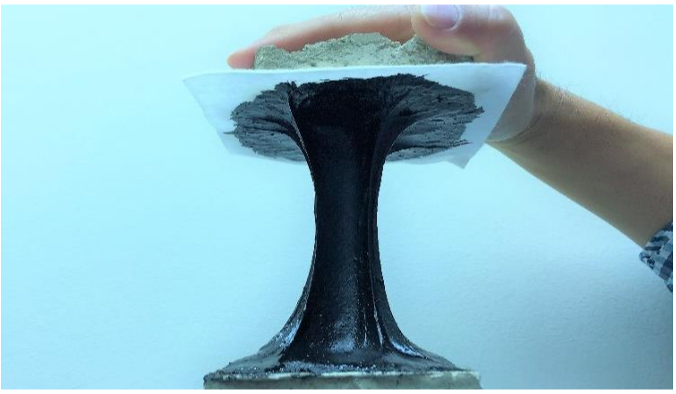

Figure 3. Polymer rubber gel's exceptional elongation property

3.3 *Advantages of polymer rubber gel waterproofing systems*

Sheer force of the waterproofing membrane against the concrete substrate caused by either seismic activity, foundation settlement, vibration, thermal expansion and contraction or shrinkage cracks in concrete can cause traditional waterproofing membranes to de-bond from the substrate and fail. Since PRG is a non-cured flexible gel, it effectively creates a ball bearing effect that allows it to dynamically respond to the movement of two substrates moving independently of one another. This non-cured, flexible bond retains the integrity of the waterproofing envelope better than traditionally fully adhered, cured waterproofing systems. (Figure 4)

Due to PRG's non-curing characteristic, it has the unique ability to repeatedly self-heal under direct hydrostatic pressure. This ability helps mitigate some common pre-construction waterproofing system damage, such as; accidental formwork penetrations, construction site debris (nails, fasteners, etc.) or applicator installation mistakes. This allows for a greater "margin of error" in the waterproofing system resulting in a system that achieves a higher level of predictable performance. (Figure 5)

PRG also does not require substrate primers or conditioners. It can be applied to freshly poured or cast concrete, eliminating a 28-day cure time prior to waterproofing application. Since the PRG never completely cures, there is no cure wait time for application of other components to the waterproofing system and concreting can be completed immediately after application of the waterproofing system. Easy surface preparation and simple application procedures of the PRG help shorten time for project completion, thus saving construction costs. (Figure 6)

Spray application of the PRG allows for fast application, because PRG uses thermal heat and not a chemical reaction to reduce viscosities for application. Prior to application, PRG is heated to 87 degrees Celsius in a specialized spray pump kettle. The low heated temperature is ideal for enclosed areas, allows for safe application and has low VOC's. The spray application allows for a monolithic coverage of the material allowing the PRG to be applied on many types of substrates in a timely manner. Contactors have improved scheduling and sequencing of waterproofing installations with these properties. This spray system allows for waterproofing application to be installed in temperatures below zero centigrade.

Figure 4. Polymer rubber gel's ball bearing effect

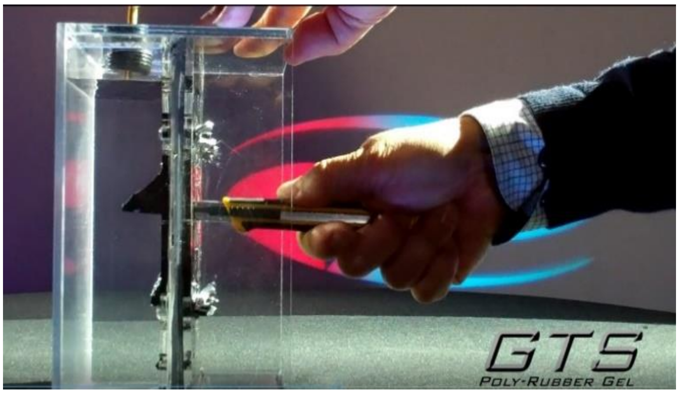

Figure 5. Testing PRG's self-healing ability by slicing through the PRG with a knife

Figure 6. Field application of polymer rubber gel composite waterproofing system

4 PRG COMPOSITE SHOTCRETE AND BLINDISDE WATERPROOFING

4.1 *Introduction: the challenges of shotcrete assembly and blindside assembly*

For underground construction, shotcrete and blindside waterproofing systems play a significant role to protect from water intrusion. The challenge in this type of construction is that the waterproofing must endure the exposure to adverse environments, survive and withstand the concrete pour of shotcrete pressure. In addition, rebar must be supported, the waterproofing will have numerous penetrations from tie-backs and rebar making these areas prone to water leakage. Most importantly, it is critical that concrete or shotcrete must bond to the waterproofing after placement. This will ensure that water does not migrate between the membrane and the concrete. Inspection and monitoring during application is critical since the waterproofing will be inaccessible once concrete is in place.

4.2 *Polymer Rubber Gel Shotcrete or Blindside assembly*

Each assembly is composed of a composite system of two layers of 20-mil HDPE fleece reinforced sheets sandwiched with a 100-mil to 110-mil thick PRG in the center. The durability and additional chemical resistance of the sheet combined with the flexibility of the gel creates the dynamically responsive waterproofing system. The final layer of 20-mil HDPE is applied to the negative face of the system with the fleece facing the installer to protect the waterproofing system from job site contamination, weather, or damage. The fleece layer forms a mechanical bond to the concrete. This 3 layered PRG waterproofing system allows greater flexibility for timing of pours during construction. (Figure 7)

Preparation of the soil support or excavation substrate for blindside application of the PRG system may require the application of a plywood protection board or application of a shotcrete smoothing layer to create a sufficiently rigid and smooth substrate for the mechanical attachment of the waterproofing sheet. Typical applications where this would be necessary are for sheet pile/secant/tangent pile walls or some types of deep soil mix walls. Care must be taken to prevent the possibility of protrusions from the wall or cavities that could damage the waterproofing assembly either during assembly or at the time of concrete pour. (Figure 8, Figure 9)

The principal design concept with a PRG waterproofing system is to achieve a complete monolithic building envelope of the gel system. This requires proper detailing of the transitions from base slab to walls and walls to ceiling. Once the first layer of 20-mil HDPE is installed and penetrations and transitional details are in place, a layer of PRG is sprayed creating a monolithic non-curing, self-healing membrane. (Figure 10)

Once the PRG spray layer is in place, a final layer of fleece reinforced HDPE is installed with the fleece layer facing the rebar. This HDPE layer bonds to the PRG and creates a mechanical bond with the shotcrete or cast concrete. Due to the seal-healing aspect of the PRG waterproofing assembly, the risk of damage during rebar installation is minimized and mitigated. (Figure 11)

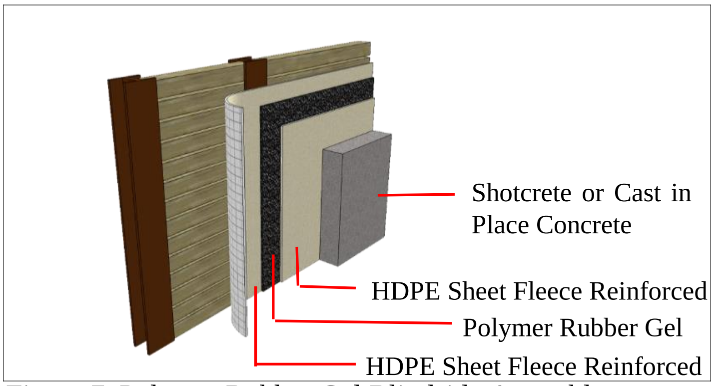

Figure 7. Polymer Rubber Gel Blindside Assembly

Figure 8. Installation of the outer fleece reinforced HDPE sheet.

Figure 9. Spray application of PRG on fleece reinforced HDPE.

Figure 10. Spray application of PRG on fleece reinforced HDPE.

5 PRG CASE STUDY CENTRAL SUBWAY SAN FRANSISCO, CA

5.1 *Introduction*

The Central Subway Project will improve public transportation in San Francisco by extending the Muni Metro T Third Line through SoMa, Union Square and Chinatown. By providing a direct, rapid transit link between downtown and the existing T Third Line route on 3rd Street, the Central Subway will greatly improve transportation to and from some of the city's busiest, most densely populated areas. When the Central Subway is completed, T Third Line trains will travel mostly underground from the 4th Street Caltrain Station to Chinatown, bypassing heavy traffic on congested 4th Street, Union Square, and Stockton Street. Four new stations will be built along the 1.7-mile alignment: 4th and Brannan Station; Yerba Buena/Moscone Station; Union Square/Market Street Station; Chinatown Station.

The Central Subway Project is funded by the Federal Transit Administration (FTA), the State of California, the Metropolitan Transportation Commission, the San Francisco County Transportation Authority and the City and County of San Francisco. (Figure 11)

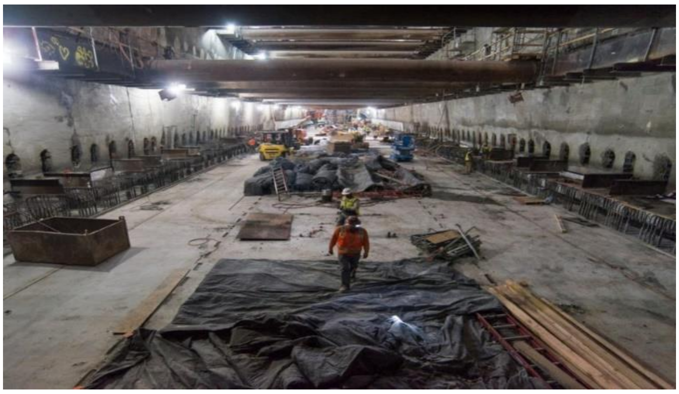

Figure 11. Central Subway under construction

5.2 *Polymer rubber gel waterproofing selection*

A PRG waterproofing system was specified for use on all 4 subway stations within the scope of work. Project design calls for the construction of four subway stations, constructed utilizing the top down constructions methods. In conjunction with SFMTA, the stations were designed by WSP/Parsons Brinckerhoff. The design consisted of different but unique box structures, with twin bore TBM tunnels, connecting into the stations. Total square footage for all installed PRG waterproofing is greater than 1,000,000 sq. ft. Because of the significance of this project and the high-profile use of the PRG product on the Subway System, a pre-evaluation and mock-up were required prior to installation. Based on the evaluation and mock-up results, PRG was the chosen waterproofing system by the SFMTA. Many waterproofing systems were evaluated for specification for the Central Subway project including typical bentonite panel and pressure adhesive systems. However, known limitations with these systems in seismic areas precluded their use. Structural engineers were particularly concerned with improving seismic performance of the construction. PRG's superior flexibility, non-curing, and self-healing characteristics help ensure that the tunnel and station waterproofing system can better withstand seismic events. In addition, the owner was given a watertight performance guarantee that covers both labor and materials for 15 years after completion of the project.

5.3 *Polymer rubber gel waterproofing system application*

The concrete box with embedded steel beams provided the support of excavation for the station. The face of the walls was shaved flush with the beam flange and a 3" smoothing layer of shotcrete was applied. Construction required a blindside PRG waterproofing system as the structure was not over-excavated. The structural walls of the stations were formed directly against the shotcrete walls. As the stations were expected to withstand constant hydrostatic pressure, a prefabricated drainage composite was applied to assist and control water in the shotcrete walls. The blindside PRG assembly was applied directly to the prefabricated drainboard composite. A shotcrete application to the PRG system was then installed and mechanically fastening to the fleece on the HDPE sheet. This creates a dry and protected final lining in the underground structure. (Figure 12)

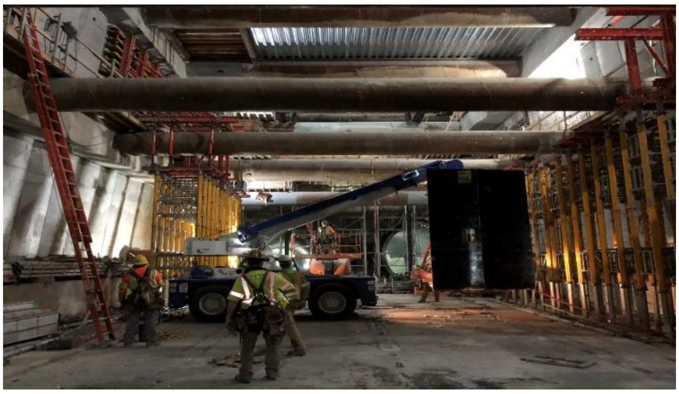

Figure 12. Central Subway top down construction

6 CONCLUSION

Polymer rubber gel technology for shotcrete and blindside applications provide a high-performance waterproofing solution for underground construction. PRG waterproofing has been successfully installed internationally since 2005. Notable North-American large-scale infrastructure applications utilizing PRG waterproofing technology include the following projects: WSX, Bay Area Rapid Transit, Presidio Parkway, Caltrans and Downsview Park/ Shepard West, Toronto Transit Commission. The unique physical characteristics of PRG composite waterproofing assemblies ensure peace of mind and performance against water intrusion. Specification of composite PRG waterproofing assemblies provides effective solutions to construct and protect underground structures.

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