Below-Grade Waterproofing: Failures and Solutions

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ABSTRACT

Sodium bentonite panel-based waterproofing systems have steadily gained in popularity for below-grade application for both blind-side and positive-side use. Many different manufacturers offer different bentonite panels, such as combination water and methane gas barriers, panels for use with shotcrete and cast-in-place concrete application, and combination panels such as heat-weldable PVC and bentonite sandwich. The presentation will include a review of different types of lagging systems used for soil retention and how they impact bentonite panel-based waterproofing systems. The presentation will also include a forensic case study of a failed blindside waterproofing at a large 4-story, below-grade garage in Northern California. Lessons learned from this forensic study include impact of wood lagging, use of shotcrete as opposed to CIP concrete, and how to repair failed waterproofing with polyurethane grout injection technology.

SPEAKER

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In addition to active RCI membership, he is a member of the International Concrete Repair Institute (ICRI), The American Architectural Manufacturers Association (AAMA), the Sealant Waterproofing and Restoration Institute (SWRI), the Construction Specifications Institute (CSI), the National Roofing Contractors Association (NRCA), and the Western Construction Consultants Association (WEST-CON).

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Below-Grade Waterproofing: Failures and Solutions

INTRODUCTION

Sodium bentonite-based waterproofing systems have steadily gained in popularity for below-grade application for both blindside and positive-side construction. Although bentonite is in many household products, it has become one of the more versatile waterproofing materials available on the market today. Bentonite has many applications, including:

- Underslabs
- Zero property line (blindside) construction
- Back-filled walls
- Earth-covered structures
- Tunnels
- Split-slab deck construction
- Hydrostatic and non-hydrostatic site conditions

There are many manufacturers who offer a variety of bentonite waterproofing systems. Some of these product variations include standard bentonite sheet with a HDPE waterproofing membrane for repelling water or a multi-layer (bentonite, HDPE, and woven fabric) sheet membrane combination for repelling water and gas. The multi-layer sheet membrane is designed for use with shotcrete and cast-in-place concrete applications.

For the purpose of this presentation, the focus will be on bentonite adhered to HDPE sheet used in blindside construction. Bentonite systems are considered the most effective for blindside applications compared to other non-bentonite methods. Blindside applications include both cast-in-place concrete and shotcrete foundation walls placed against soldier piles and lagging, steel sheet piling, concrete caisson retaining walls, and diaphragm walls.

There are a number of different types of blindside construction procedures that impact bentonite-based waterproofing systems in different ways. A forensic case study was done of a failed blindside waterproofing system at the second largest below-grade structure in Northern California with two stories below the water table and built on a zero lot line with shotcrete installed against wood lagging and soldier piles. Lessons learned from this forensic study include the impact of wood lagging, use of shotcrete as opposed to cast-in-place concrete, and how to repair failed waterproofing with polyurethane grout injection technology. The repairs were made using injection of several types of chemical grout as a barrier curtain behind the entire surface of the below-grade walls and portions of the slab. Lessons learned from this project prompted the manufacturer of the sodium bentonite/HDPE composite system to make changes in its specifications for application of its products, acceptable substrates, and shotcrete. Additionally, these lessons will help consultants who design below-grade waterproofing systems, as well as monitors who perform quality assurance roles.

HISTORY

In 2005, U.S. was the top producer of bentonite, with almost one-third of the world share, followed by China and Greece, reports the British Geological Survey.

The absorbent clay was given the name bentonite by an American geologist sometime after its discovery in about 1890 at the Benton Formation (a geological stratum, at one time Fort Benton) in Montana's Rock Creek area. Other modern discoveries include montmorillonite discovered in 1847 in Montmorillon in the Vienne prefecture of France, in Poitou-Charentes, South of the Loire Valley.

Most high-grade commercial sodium bentonite mined in the United States comes from the area between the Black Hills of South Dakota and the Big Horn Basin of Wyoming. Sodium bentonite is also mined in the southwestern United States, in Greece, and in other regions of the world. Calcium bentonite is mined in the Great Plains, Central Mountains, and southeastern regions of the United States. Supposedly, the world's largest current reserve of bentonite is Chongzuo, in China's Guangxi province.

WHAT IS BENTONITE?

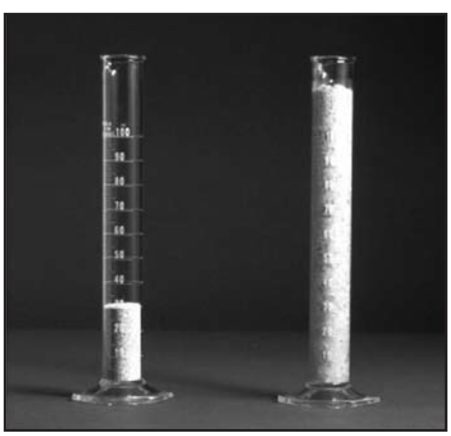
Bentonite was formed from volcanic ash deposited in an ancient sea where it was modified by a geological process into sodium bentonite. Bentonites were calculated to have accumulated

Sodium bentonite granules.

between 74.5 and 70 million years ago. At that time, the area was the center of a huge, shallow inland sea stretching from the Arctic Ocean to present-day Mexico and was nearly a 1,000 miles wide.

Bentonite is an absorbent aluminum phyllosilicate generally composed of impure clay. There are two types of bentonite: a swelling sodium bentonite and a non-swelling calcium bentonite. It forms from weathering of volcanic ash, most often in the presence of water.

Sodium bentonite expands when wet, absorbing up to eight times its dry mass in water, which gives it tremendous sealing properties. Sodium bentonite has been called the clay of a thousand uses. It contains exchangeable sodium cations, which are positively charged ions that attract the cathode in electrolysis. When the cations are dispersed in water, they separate into plate-like particles, which are negatively charged on the surface and positively charged on the edges. This unique ion exchange relationship is responsible for the expansion, binding, or absorbing action that takes place. Bentonite's small plate-like particles provide a tremendous potential for increasing surface area. It forms thixotropic gels with water, even when the amount of bentonite is relatively small. Modern chemical processes can modify the ionic surface of sodium bentonite, dramatically intensifying the binding or absorbing action. This result is so remarkable that dough-like casting sand mixes can endure molten metal temperatures. These characteristics and modifications give bentonite an enormous range of potential uses.



Sodium bentonite expansion dry/wet.

Besides below-grade waterproofing as an industrial application, it is commonly used in drilling mud for oil and gas wells in geotechnical and environmental investigations, in the sealing of subsurface disposal systems for spent nuclear fuel, and for quarantining metal pollutants of groundwater. Other uses include making slurry walls, forming other impermeable barriers such as plugging old wells, lining the base of landfills to prevent migration of leachate into the soil, as an animal feed binder, kitty litter, or as a stucco and mortar plasticizer.

The binding action of bentonite allows high-pressure ramming or pressing of the clay into molds to produce hard, refractory shapes, such as model rocket nozzles. An easy demonstration of this would be to get a brand of cat litter known to be bentonite.

Sodium bentonite mining quarry.

Simply ram a sample of the granules with a hammer into a sturdy tube with a close-fitting rod. It will form a very hard consolidated plug that is not easily crumbled.

Bentonite also has the unique property of adsorbing relatively large amounts of protein molecules from liquids. This property has become useful in the process of winemaking, where it is used to remove excessive amounts of protein from white wines. Bentonite prevents most white wines from precipitating undesirable flocculent clouds or hazes upon exposure to warmer temperatures as these proteins denature. It also induces more rapid clarification of both red and white wines.

Calcium bentonite, the non-swelling bentonite, is sold in the alternative health market for its purported cleansing properties. It is usually combined with water and ingested, often as part of a detox diet. Calcium bentonite may be converted to sodium bentonite and take on properties typical of sodium bentonite by a process known as “ion exchange.” Commonly, this means adding 5-10% of sodium carbonate to wet bentonite, mixing well, and allowing time for the ion exchange to take place. Calcium bentonite is not used in below-grade waterproofing.

MINING PROCESS

Mining of bentonite is much different from traditional mining methods. The process allows the reclamation of the mining site to be restored to its near original condition, making this an acceptable product for sustainable building. Before mining bentonite can begin, a detailed plan for extracting the mineral is developed by drilling and sampling. Once the area and depths are defined, mining begins by removing the overburden from the mineral deposit with large earth movers. The overburden is then stockpiled nearby for reclamation after the bentonite has been removed from the bed. When extracting the bentonite from the bed, extreme care is taken to avoid contaminating the mineral deposit with the overburden, thus ensuring a high quality of the raw material. Care is also taken to conserve as much bentonite as possible when trimming the overburden from the bentonite.

When all the bentonite has been removed from the bed, reclamation begins. The surface of the mine site is returned to a condition equal or superior to that prior to mining. Many bentonite mining companies return the mining sites back to their natural habitat for plants and animals, and recognize other environmental considerations.

The bentonite from each bed is stockpiled and tested for quality. It is then carefully dried and ground to meet product specifications. The finished product is stored in silos until it is shipped to manufacturers of bentonite products.

HISTORICAL USE IN BELOW-GRADE WATERPROOFING APPLICATIONS

Bentonite waterproofing materials were introduced in the mid-1920s and primarily used in granular form for the sealing of pond liners and compacted-earth dams until the late 1950s. Shortly after, they were introduced into the building waterproofing market and by the mid-1960s a line-up of bentonite products were made available in panels, sheets, and trowelable and sprayed forms. These distinct applications are the precursors of what may be considered to be one of today's more versatile products.

Sprayed and troweled applications have nearly gone away due to the difficulty in applying uniform thickness and a tendency to hydrate prematurely. Bentonite-filled cardboard panels, the first commercially available bentonite system, are not widely used today. The panel system has been supplemented by composite products consisting of bentonite combined with HDPE geomembranes or durable geotextiles. These new composite materials are easier to install and provide better barrier performance. Typical composite roll widths are four feet and lengths varying from 15 feet to 24 feet. The common forms of composite bentonite waterproofing products have bentonite granules either encapsulated between polypropylene geotextile fabrics or laminated to one side of a HDPE geomembrane sheet. Both of these product forms are appropriate for blindside and positive-side construction. They contain roughly one pound of bentonite granules per square foot.

The product installed on this case study project was the bentonite/HDPE composite system. The HDPE layer is intended to provide the first water barrier layer and prevent pre-hydration from rain or existing groundwater. Because the HDPE liner does not encapsulate and contain the bentonite, the bentonite can be susceptible to pre-hydration and free swell, which can result in diminished performance potential.

COMMERCIAL BENTONITE/ HDPE PRODUCTS

Tremco produces several different bentonite/HDPE composite waterproofing products. Paraseal and Paraseal LG are described below. Both systems are used in blindside construction applications, but have different design characteristics. These characteristics are described and a technical data table provided herein.

TREMCO - PARASEAL LG

Paraseal LG is a multi-layer sheet membrane waterproofing system. It consists of a self-sealing, expandable layer of granular bentonite. The bentonite layer is laminated at the rate of up to one pound per square foot to an impermeable, high-density polyethylene (HDPE). The third component is a protective layer of spun polypropylene. Together, these three components form a waterproofing membrane manufactured in controlled thicknesses of 170 mils to 200 mils. This multiple-component sheet membrane waterproofing system is specially designed for blindside installations such as lagging, under floor slabs, and elevator pits. Tremco allows the use of Paraseal LG applications where shotcrete is blown directly into the face of the membrane.

Paraseal LG can be used for waterproofing from the blindside (lagging, etc.) where the waterproofing membrane is applied before the walls are poured. It is designed to resist damage from some exposure to inclement weather, normal concrete pours, or direct installation of shotcrete. Paraseal LG is sold for use in the water table for application in hydrostatic head conditions.

Inherent limitations of bentonite HDPE composite membrane include application in brackish or slightly salty groundwater, in standing water during construction, or over snow. For brackish conditions, Saltwater Paraseal is available, which contains a chemically treated bentonite to swell when soils have high alkalinity. However, the bentonite only swells to half the rate compared to standard bentonite in freshwater conditions. Additionally, Paraseal products require compaction/confinement to be effective in fresh or brackish conditions. A minimum confinement of 24 psf is required. Achieving proper confinement can sometimes be challenging in wood lagging and other conditions.

All blindside installations have the bentonite side facing the installer so that the bentonite is in direct contact with the concrete to be waterproofed. Examine all surfaces prior to starting application. All spaces between lagging larger than 1 in (2.5 cm) shall be covered with 3/4 in (6.4 mm) treated plywood prior to installation.

Lagging Installation:

In lagging applications, it is critical that all voids and spaces between the lagging and soil be fully grouted or filled with sand. Voids behind the lagging can cause the lagging to be displaced and will result in reduced or absent confinement between the bentonite panel and lagging. This problem is further exacerbated by shotcrete application, which produces limited or no hydrostatic pressure during application of shotcrete, as opposed to cast-in-place concrete. Vibrated cast-in-place concrete produces hydrostatic pressure, which can push against the bentonite panel and displace the lagging while the concrete is still fluid, creating consolidation. Such is not the case with Shotcrete, which is blown in place with extremely high slump material and does not create sufficient hydrostatic pressure to push the lagging back into the void and potentially create a lack of confinement.

Paraseal LG may be installed in a vertical or horizontal direction. Lap joints 3 inches (7.6 cm) shingle fashion (top over bottom) when pouring against; 4 inches (10.2 cm) shingle fashion (bottom over top) when shotcreting against. Fasten all seams at 4 inches (10.2 cm) over center. Apply paramastic, TREMproof 201/60T, or TREMproof 250GC-T around all tiebacks and penetrations. To avoid prehydration, protect the installed panels from flooding prior to concrete pour. If the product has been exposed to inclement weather, check panels to make sure it has not hydrated.

Penetration:

Tiebacks, tie bolts, misaligned soldier piles, whalers, and bracking may all penetrate the Paraseal LG membrane and must be detailed properly.

Protection:

The Paraseal LG dual waterproofing system has a puncture-resistant HDPE liner of 169-lb point load (76.6 kg) and does not require an additional protection course for most applications.

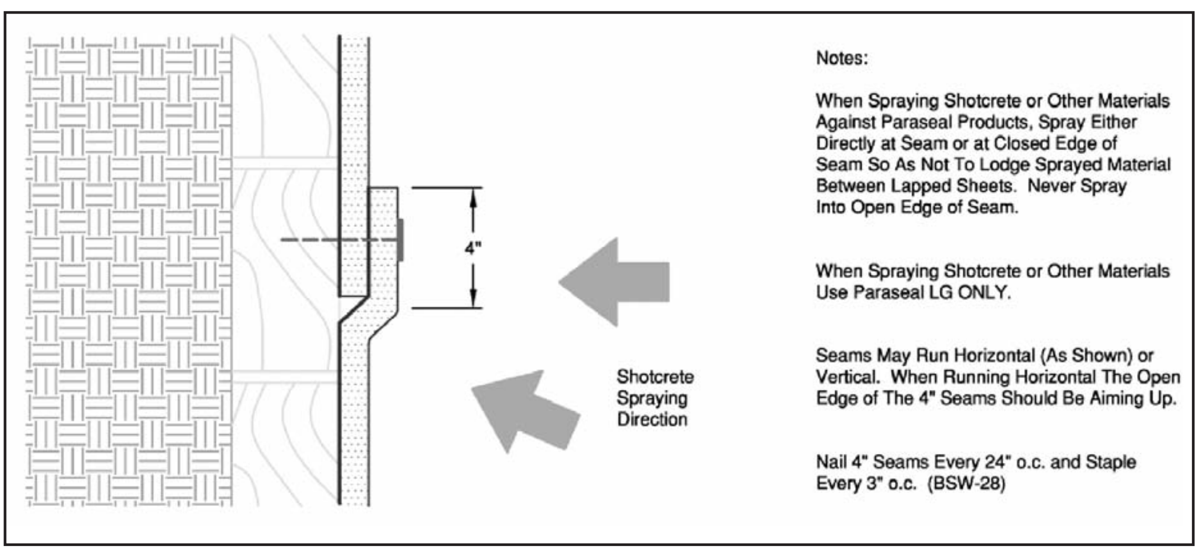
Storage:

Protect from moisture. Store on skid or pallet; cover with polyethylene or tarp. Do not double stack pallets.

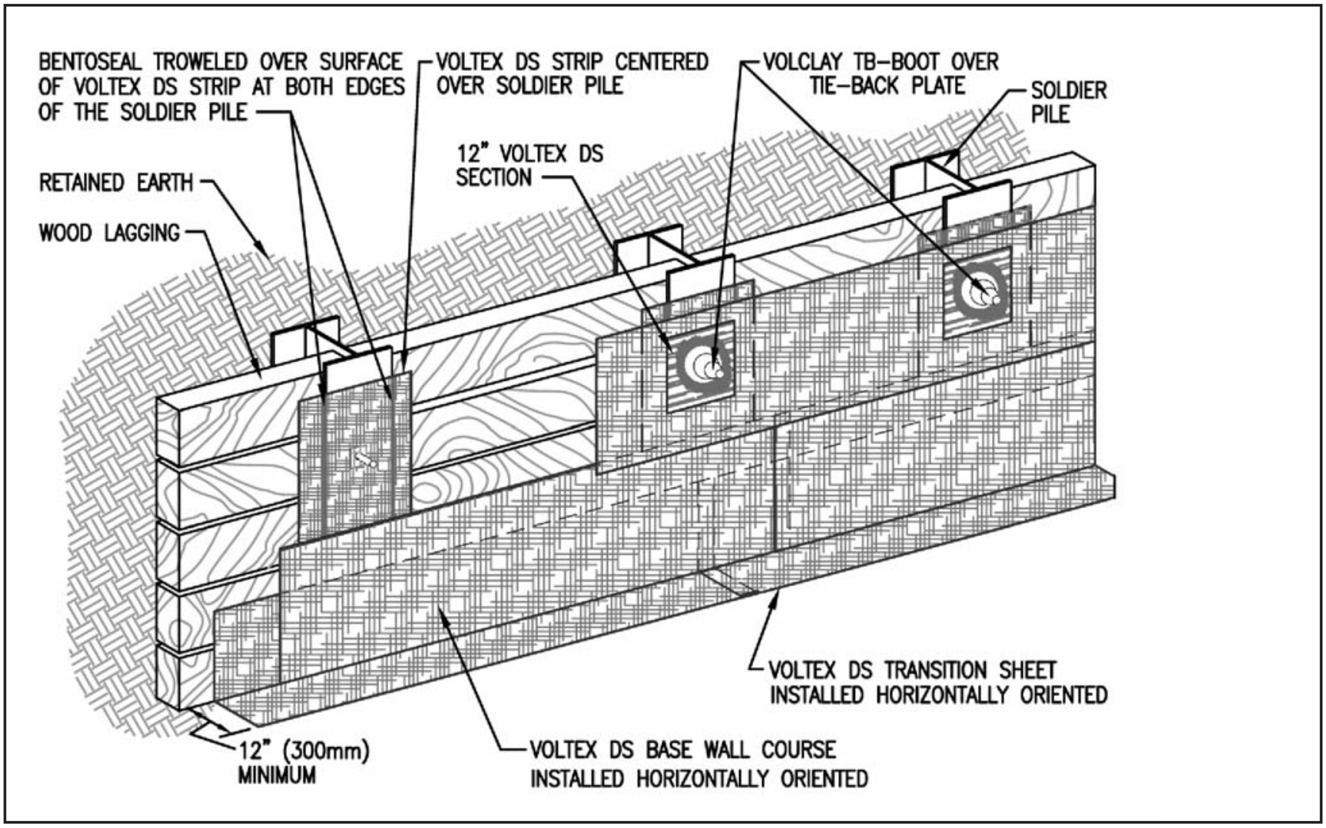
CETCO - VOLCLAY VOLTEX DS

Voltex is the geotextile line of the Volclay bentonite waterproofing panel systems. The Voltex composite is comprised of two high strength geotextiles sandwiching 1.10 lbs of sodium bentonite per square foot. The Voltex DS adds an integrated polyethylene liner to the geotextile layer for added protection and vapor retarder. The two geotextiles are interlocked by a patented needle-punching process which sandwiches and holds the granular bentonite in place for a more consistent application of material.

Voltex DS is engineered for waterproofing under slabs and blindside applications. Under slabs, Voltex DS can be installed directly over a properly prepared substrate without the need for a



Proper installation of shotcrete against Paraseal LG.



concrete mud slab; however, a mud slab does provide a more consistent and sound substrate.. While its durable composite construction resists damage from tradesman installing reinforcing steel over it, a 3-inch protection slab provides better defense from construction damage and is recommended (by this author) for thick Mat slabs that require a lot of reinforcing steel. For blindside applications, Voltex DS is simply installed against the retention wall and then the concrete is poured directly against it using a single-sided form. For shotcrete application, CETCO recommends two layers of bentonite waterproofing, generally Voclay cardboard type panel followed with Voltex DS or Ultraseal SP. Other applications include backfilled concrete foundation walls, shotcrete, and cut-and-cover tunnels.

Installation of Voltex DS involves positioning the woven geotextile side (dark gray) facing the installer so that the shotcrete will be shot against the geotextile side. The panels are secure with washer head mechanical fasteners. Voclay and Voltex can be installed to green concrete without primers or adhesives, in bad weather, including freezing temperatures and damp conditions. When concrete is poured against Voltex DS, a mechanical bond yielding an average adhesion value of 15 pounds per linear inch (15 pli) is created by the wet concrete solidifying (clinging) around the geotextile fibers. Voltex DS can also be used with reinforced shotcrete walls, a minimum of 8 inch thick, applied from the bottom up to their full design thickness in a single application with lift heights limited to a maximum of four feet. Due to the mechanical bond being created between concrete and the geotextile fabric, Voltex DS provides an added measure of consolidation against concrete or shotcrete.

Voltex DS is designed only for below-grade and/or confined waterproofing applications. Volclay products should not be installed in standing water. If groundwater contains strong acids, alkalies, salts, or is of a conductivity of 2,500 μmhos/cm or greater, water samples should be submitted for compatibility testing. Volclay Ultraseal SP may be required if contaminated groundwater or saltwater conditions exist.

For contaminated water or brackish conditions, Voltex DS is available with a contaminant-resistant Volclay sodium bentonite - Voltex DSCR. Volclay sodium bentonite combines natural sodium bentonite and a chemically resistant hydrophilic polymer to form a bentonite-polymer alloy (BPA). Ultraseal is a bentonite-polymer interaction formed through a proprietary blending process that produces a homogeneous alloy with improved contaminant resistance, enhanced swelling properties, and a baseline permeability one magnitude better than natural sodium bentonite. Ultraseal has a lower permeability; it weighs 50% less than traditional bentonite products, which makes it easier to handle and install. According to CETCO,

PARASEAL & VOLTEX VOLCLAY TECHNICAL DATA COMPARISON

Physical Properties Method	Paraseal LG Value	Voltex Volclay Value	Test
Tensile strength: membrane (PSI)	4,000 PSA (27.6MPa)		ASTM-D412
Resistance to micro-organisms (bacteria, fungi, mold, yeast)	Unaffected	Unaffected	
Elongation – ultimate failure of membrane	700%	N/A	D412 Dumbbell
Puncture resistance	169 lbs (76.6 kg)	140 lbs (63.5 kg)	FTMS 101B / ASTM D 4833
Hydrostatic pressure resistance	150 ft (45.6 m)	231 ft (70 m)	Paraseal – ASTM D751 Method A, Footnote #1below; Voltex - ASTM D 5385 mod.
Resistance to water migration under membrane: zero leakage	150 ft (45.6 m)/head		Footnote #2
Grab tensile strength		95 lbs (422 N)	ASTM D 4632
Permeance	2.7x10-13 cm/sec	1 x 10-10 cm/sec.	ASTM D 5084
Installation temperatures	-25°F to 130°F (-31.7°C to 54.4°C)		
Non-toxic	Do not ingest	Do not ingest	
Low temperature flexibility	No effect before or after installation	Unaffected at -25°F (-32°C)	ASTM D 1970
Non-staining Resistance to chemicals & gasses: Extremely high resistance – contact manufacturer for specific information			
Life expectancy: Both high density polyethylene and bentonite have life expectancy measurable in the thousands of years.			

Footnotes for Technical Data:
1. A 1-in. (2.5 cm) diameter hole was cut in the middle of a 3-1/2-in (8.9-cm) diameter sample of Paraseal LG. Sample clamped in 3-in (7.6-cm) diameter permeameter, 150-ft (45.6-m) waterhead applied.

2. Membrane applied to porous stone and placed in permeameter. Pressure increased to equivalent of 150-ft (45.6m) waterhead.

the active, swelling properties of the bentonite-polymer alloy seals small concrete cracks and works under continuous and intermittent hydrostatic conditions.

PROJECT CASE STUDY - SUNNYVALE TOWNE CENTER PARKING FACILITY

In Sunnyvale, California, a forensic case study of the waterproofing failure of the Downtown Sunnyvale Garage was performed for a construction defect litigation case where a bentonite/HDPE composite system was installed. The project is the second largest below-grade structure in Northern California, with six stories above grade and four stories below grade, two of which were below the water table. Additionally, this project was the largest below-grade waterproofing repair of its kind in California.

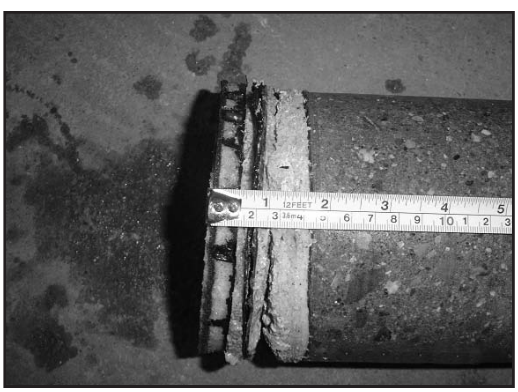
The structure experienced extensive leakage throughout the perimeter

Excavation of the soil behind the wood lagging revealed that once the wood gets wet, it swells, bends, and twists, especially if there are voids between the soil and wood.

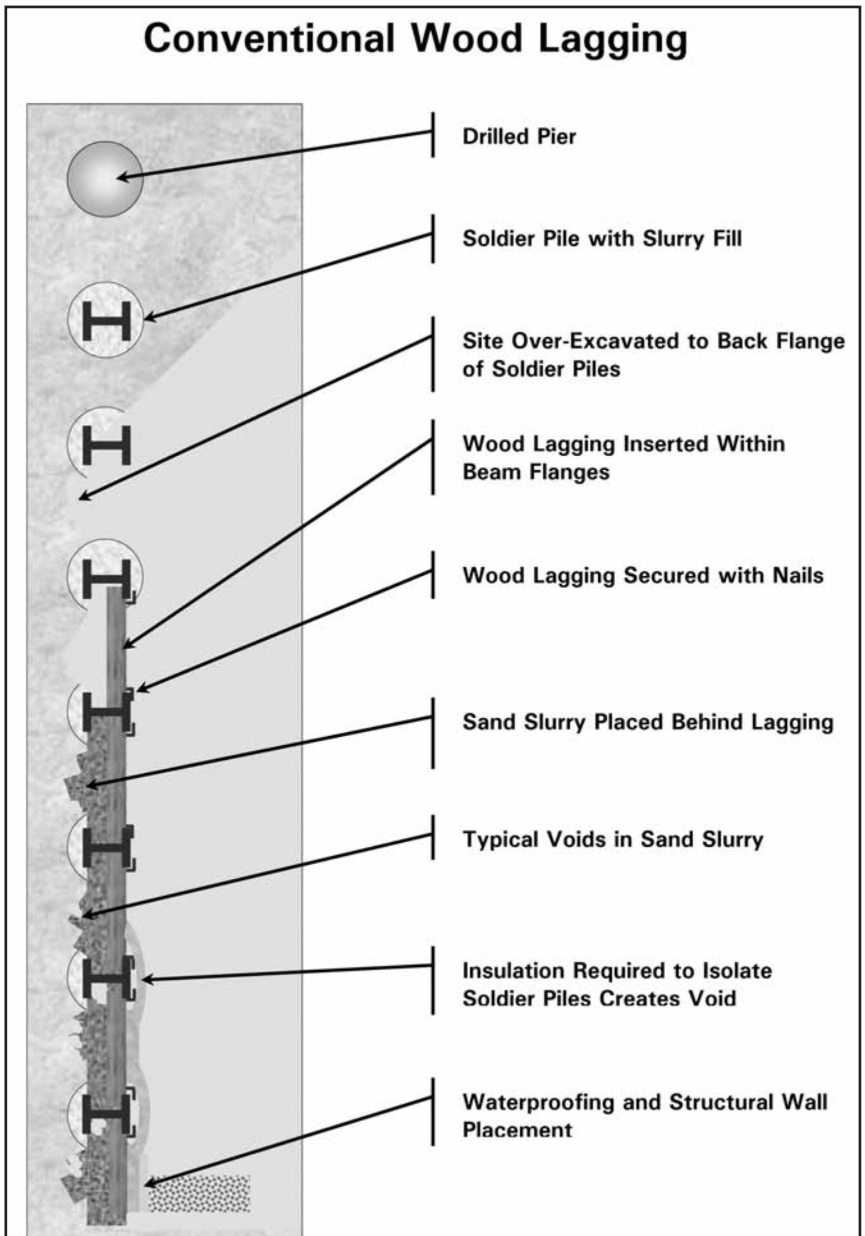
walls in the below-grade parking levels. The structure was built on zero lot line with shotcrete foundation walls placed against wood lagging and soldier pile retention walls. The study included performing core sampling through the 18-inch-thick shotcrete walls, partial excavation behind the lagging, review of original construction drawings, review of lagging installation photos and soil consolidation, visual observations of

5/8-in Zirq Fitting drilling through 18-in foundation wall.

Void between solder pile and foam protection board was also evident and may have contributed to the failure of the bentonite waterproofing system.



Voids were present on both sides of the retaining wall. Voids ranged from 1 inch thick to up to 4 inches thick.

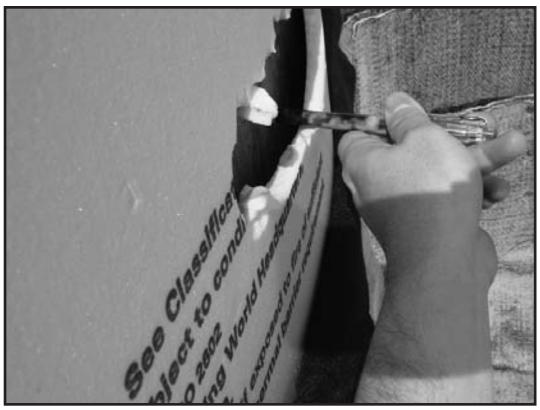


leaks, and water testing.

Excavation of the soil behind the wood lagging revealed that once the wood gets wet, it swells, bends, and twists, especially if there are voids between the soil and wood.

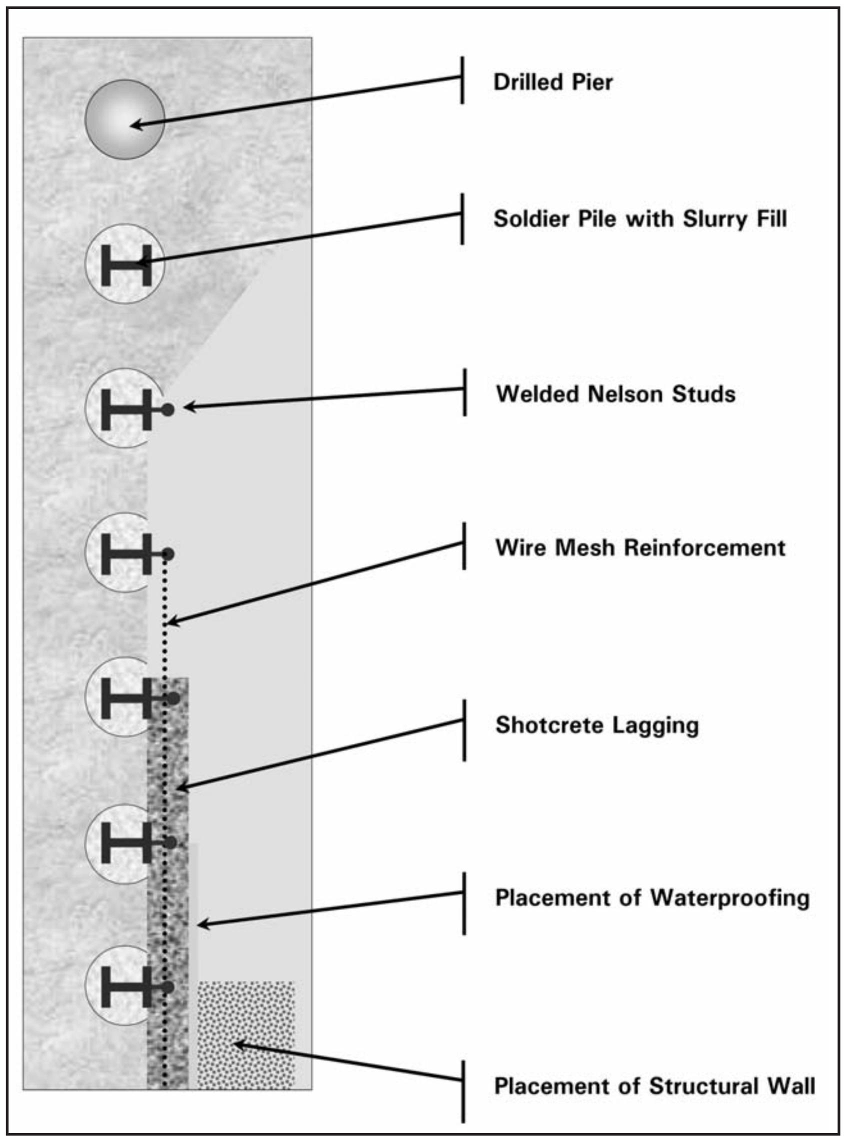
The repair included drilling 5/8-in diameter holes in four feet on center grid formation through the 18-inch shotcrete foundation wall. Several types of hydroactive grouts were injected through the holes to reach behind the foundation walls. Upon contact with water, the grout quickly expands and cures to form a water barrier behind the entire surface of the wall and under portions of the slab. The grout injection process is designed to fill any voids behind the foundation wall. Once the injected grout reached maximum confinement, the material would continue to internally expand, thus increasing the density. Upon completing the injection repairs, the project was further studied by performing core samples through the concrete to assess the effectiveness and migration of the grout injection. In many core samples, it was evident the grout migrated and expanded

Conventional wood lagging.



Void behind foam protection board, shotcrete lagging.

Shotcrete lagging.



Shotcrete lagging.

so quickly and with such force it filled in voids on both sides of the bentonite.

CASE STUDY CONCLUSION

Use of shotcrete as opposed to traditional cast-in-place concrete was a factor in the failure, as was lagging and soil consolidation. While CIP concrete does a better job of consolidation, care must be taken to fill voids behind wood lagging to ensure good consolidation. Shotcrete lagging as opposed to wood lagging greatly eliminates the potential for voids and is better then wood lagging in ensuring consolidation. Lessons learned have helped the manufacturer of the sodium bentonite/HDPE composite, as it has led to changes in its requirements for its own products. Tremco added language in its application requirements to ensure that builders fill voids behind wood lagging. CETCO now requires two layers of bentonite panel/roll to improve consolidation. Lessons will help consultants who design below-grade waterproofing systems, as well as monitors that perform quality assurance roles, to check not only for proper application of the waterproofing membranes, but also the lagging and soil issues.

CONCLUSION

Sodium bentonite can be a very effective below-grade waterproofing system, given appropriate products are specified and installed properly, soil testing is performed, and quality control processes are implemented during application. Construction techniques and materials will continue to evolve as case studies similar to the Sunnyvale Towne Center Parking Garage are documented so that architects, engineers, contractors, and manufacturers can determine the post-construction effects of these systems and where and why the failures occur.