WATERTIGHT CONSTRUCTION JOINTS IN TUNNELS

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Virtually all underground concrete work results in construction joints of one type or another. Every time there is a joint in an underground structure, there is an opportunity for groundwater infiltration into the structure. In some structures, such as manholes or box culverts in a storm drainage system, a certain amount of infiltration is acceptable and will not adversely affect the performance of the system. However, in other structures, such as vehicular tunnels, pedestrian tunnels or underground electrical/mechanical rooms, such infiltration is unacceptable and the design of the structure must be such that the construction joints are made as watertight as possible.

To accomplish watertight joint design, numerous construction products have been developed over time, one of the first being the waterstop. The waterstop is an element introduced into the joint to inhibit the potential path of infiltration into the structure. It does this by causing the joint to create an arduous path for water to enter. Early waterstop designs of tin and copper have evolved into rubber, polyvinyl chloride (PVC), and composite material designs of different shapes and configurations (see figure 1). Items to be considered in the selection of a waterstop include: the type of joint, is it rigid or susceptible to movement; compatibility of the waterstop material with contaminants or other constituents of the groundwater; availability of the material; and skill of the labor force. For large, rigid joints metal waterstops of cast iron, steel, copper, bronze, or lead are typically selected for strength. For smaller joints, complex joints, or joints susceptible to movement, waterstops of rubber, neoprene, or PVC are chosen for their inherent ease of splicing and flexibility. As underground construction became larger and more complex, the need for waterstops that provided flexibility for movement as well as some rigidity for placement and control lead to the development of composite waterstops made of metal and rubber or PVC materials.

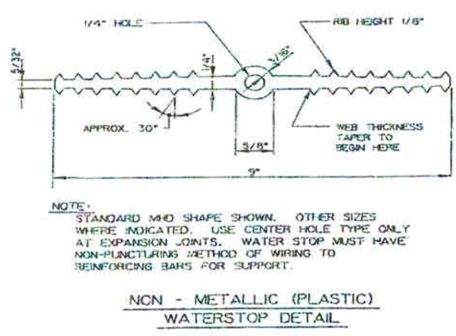

Figure 1

For a waterstop to be effective, its placement in the construction is critical (see figure 2). Even with the development of intricate waterstop designs, the ability to properly place and secure the waterstop during construction was not assured. The positioning of the waterstop in the initial concrete pour is critical to waterstop performance. A waterstop is positioned in the form prior to the placement of concrete. It must be clean, securely held in place, and the concrete must be properly consolidated around it to ensure adequate mechanical bond takes place between the waterstop and the concrete surrounding it. Care must be exercised during placement and vibration of the concrete to get close enough to the waterstop for proper consolidation without knocking the waterstop out of place. If the vibrators don't get close enough to the waterstop, segregation can occur which will inhibit the bonding of the waterstop and the concrete and create potential paths of infiltration.

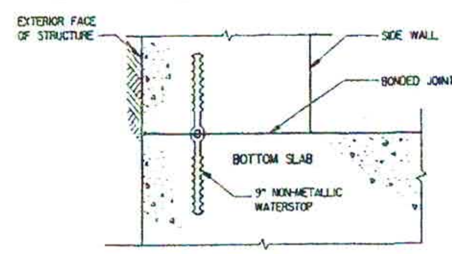

Figure 2

As structures became more complex, the proper positioning of the waterstop and maintaining it in its position during the initial and secondary concrete pours became more difficult. As this was occurring, regulations and economics dictated more stringent leakage allowances in construction specifications. Just as in the early days when different material and shapes of waterstops were used to address the widening range of underground structures, in response to this development the material manufacturers have developed a number of alternatives to the conventional waterstop for use in underground construction.

Recent developments have added new waterstops; we have injectable hoses and hydro-reactive sealing compounds. The injectable hose is made by a number of manufacturers, some even allow for re-injection. The placement of the injectable hose, while critical to its functionality, is much less onerous than the placement of a waterstop. This is primarily because the hose is placed on the initial pour after curing and stripping of the forms and secured in place prior to the second pour. A relatively simple task and, if done properly, the hose is not subject to dislodging by follow-on concrete placement and vibration. It is important that the ends of the hose be positioned for adequate access recognizing space needs for personnel, equipment, and materials for the injection process, and that the ends be carefully labeled.

The materials that can be pumped into injectable hoses range from micro-fine cements to polyurethane's to methyl methacrylates. The type of product used will depend on many of the same type of factors used in determining which waterstop to use, i.e. type of joint, size of joint, amount of leakage, etc. Some of the hoses are re-injectable, either by having multiple tubes or by using a solvent to flush product from the hose before it sets up. Injection hoses, whether re-injectable or single use, work well but are best used only after a joint starts leaking. This makes the use of these hoses a secondary system requiring that a primary system be installed as well, usually a standard waterstop. There are two other issues with the use of injectable hose. First, the injection material can be expensive. The high cost of the material is usually overcome by the value and utility of a non-leaking structure versus a leaking one; however, it is an expense incurred none the less. Secondly, as with all secondary water stopping systems, it is used after a leak problem occurs and treats the area where infiltration appears in the structure and not necessarily where the infiltration enters the structure. This means that while the interior of the structure may be dry and suitable for its intended use, groundwater is still entering the structure from the outside constantly looking for paths into the structure, potentially causing corrosion and degradation of the structure, which could lessen the useful life of the structure.

Hydro-reactive sealing compounds are a composite material consisting of a hydrophilic material and another inert material. Like the injectable hoses, these are not incorporated into the initial concrete pour but are positioned on the initial pour once it has been cured and stripped. However, unlike the injectable hose, the hydro-reactive sealing compounds can be used as a primary water stopping system thereby negating the need for the installation of a rational waterstop or the like. Again, as with injectable hose and injection materials, there are many different types of hydro-reactive sealing compounds manufactured. Unlike injectable hose systems, it is possible to have hydro-reactive sealing compounds manufactured to meet specific project requirements.

Most hydro-reactive sealing compounds are manufactured to be installed with a minimum of six inches of cover, which usually puts this installation inside the reinforcing steel. This may create a problem in some structures as ground water would be allowed to come into contact with the reinforcing steel, increasing the potential for corrosion and possibly lessening the useful life of the structure. Some hydro-reactive sealing compounds can be installed outside of the reinforcing steel to afford more comprehensive protection to the structure; however, a minimum of two inches of concrete cover

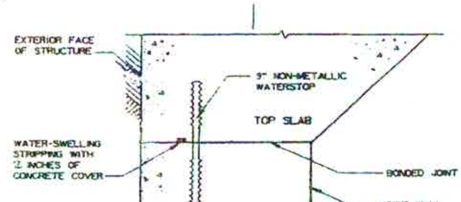

Figure 3

is necessary to prevent spalling of the concrete when the material swells (see figure 3).

On a recent highway project, the watertightness of the construction joints in the tunnel sections was of prime importance to designers. Specifications were written to stipulate the size, material, and swelling characteristics desired. These were not written around any manufacturer's standard, but rather specific to the project and the purpose desired. The specifications were written such that the hydro-swelling strip could be placed on large complex joints outside of the reinforcing steel. Key properties specified were delayed swelling time and maximum swelling size. A number of manufacturers submitted standard products; but some, not comfortable that their off-the-shelf product would meet the specified requirements, submitted either new products or variations of their existing products. DeNeef Chemicals submitted a variation of their Swellseal product. Recognizing that just meeting the specified requirements for delayed swelling and maximum swell size may not result in satisfactory performance, DeNeef designed their product, Swellseal 8, to have a very slow rate of swelling so as not to impart fracturing stresses to the concrete.

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All of the submitted materials were laboratory tested to check for adherence to the specifications. Of the products submitted, the DeNeef product had the greatest delay in swelling, increasing in size only 15% in the first twelve hours. It was also one of the products that met the maximum swell size requirement of 1.9x original value and it took the longest time to reach that value, 9 days compared tot he fastest time of 30 minutes. Based on the laboratory test results, of the five products submitted, only two were accepted for the work, and of the two, only the DeNeef product met the exact specification requirements. This product, developed specifically for the requirements of this project, performed exactly as anticipated.

All of the joints on this project are specified to have multiple waterstops depending on the type of joint and the concern for watertightness. Some have a hydro-swelling strip and a conventional PVC waterstop; others have multiple PVC waterstops, while still others will include injectable hose. The idea is for the designer to use all of the tools available when considering the design of a watertight joint (see figure 4). Lessons learned from previous projects can be valuable such as: the importance of delay time in the swelling of Hydro-reactive compounds, the fact that traditional dumbbell waterstop alone will not ensure a watertight joint, never using an injectable hose without another type of waterstop, and ensuring at least two inches of cover over hydro-reactive sealing compounds. Also, the designer is not limited by what products are currently available; many manufacturers, such as DeNeef in this case, are willing to work with the designer to modify products or develop new ones to meet the needs of the construction project. With the various products available today and the manufacturer's willingness to work with designers, most any joint in underground construction can be designed to be truly watertight.

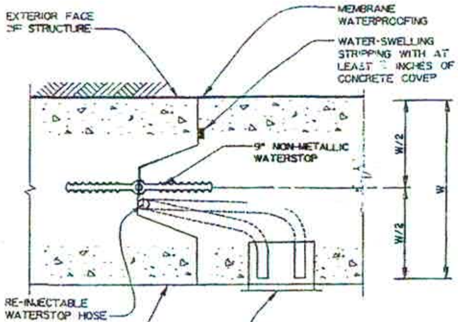

Figure 4

NATM TECHNICAL COMMITTEE MEETS

The AUA NATM Technical Committee, chaired by Nick Chen, National Chief of Tunnel Design, HNTB, held their first meeting in January in New York City. They reviewed the list of issues developed last Fall, and set an initial short-term goal related to the issue of prequalification. It was decided to conduct a study of U.S. NATM tunneling experience with and without the prequalification requirement

A discussion was held on the publication "The Joint Code of Practice for Risk Management of Tunnel Works in the UK," which was published in September 2003 by the British Tunneling Society, and the impact it may have on U.S. tunneling practice.

In addition to Nick Chen, the Committee is comprised of the following individuals: Josef Arnold (Bemo), Buck Atherton (J.F. Shea, Dave Corkum (Donnovan Hatem), Dan Dobbels (Haley & Aldrich), Vojtech Gall (Gall Zeider), Youssef Hashash (University of Illinois), Hannes Lagger (Jacobs Associates) and George Yoggy (GCS). Hugh Caspe (HNTB) is the AUA representative. Individuals interested in serving on the committee should contact Nick Chen at 617-542-6900. A maximum of ten members is desired. The next meeting will be held during NAT 2004 in Atlanta, at a time and place to be named by Nick.