

BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

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**EVERYONE LOVES A POOL,
BUT WHAT'S LURKING BENEATH THE SURFACE?**

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ABSTRACT

Rooftop swimming pools and similar elevated water structures—be they residential or commercial—present a unique set of considerations that need to be thoroughly compensated for during design and construction. Referencing several case studies, the presenters will discuss the aspects of a properly designed waterproofing system on the interior of the concrete vault, the importance of properly sized pool vaults, the structural loads exerted, and how designers can best utilize aquatic and waterproofing design professionals as members of their team to provide a pool system that won't result in costly leaks.

SPEAKERS

ROBERT HOLMER, PE, GE — TERRACON CONSULTANTS, INC.

ROB HOLMER has served as the engineer of record for over 30,000 swimming pool projects. Rob specializes in large residential and commercial facilities, competition pools, public and private recreation facilities, and water parks. His engineering consultation services include structural, geotechnical, mechanical, hydraulic, water treatment, materials engineering, risk management, code compliance, and expert witness litigation consulting. Holmer holds bachelor's and master's degrees in civil engineering. He is licensed to practice in ten states and has presented at over a dozen technical conferences in the past ten years.

MICHAEL PHIFER — TERRACON CONSULTING ENGINEERS

MICHAEL PHIFER is a graduate of the University of North Carolina, Charlotte, with a bachelor's degree in civil and environmental engineering. Since 2013, he has served as a staff engineer in the Facilities Engineering Division of Terracon Consultants, Inc. He has extensive experience in horizontal and vertical waterproofing systems, fenestration, and roofing. Phifer has performed assessments and investigations for building enclosure systems and pools for new and existing construction.

EVERYONE LOVES A POOL, BUT WHAT'S LURKING BENEATH THE SURFACE?

ABSTRACT

The market for new apartment tenants, hotel guests, and condominium owners is incredibly competitive. Price will always play a role, but it's the amenities these days that set properties apart. Chief among the amenities are swimming pools—especially rooftop or plaza-level pools. Architects are meeting the challenge by designing highly desirable spaces reminiscent of resort-style living.

Rooftop swimming pools and other similar elevated water structures—residential or commercial—present a unique set of considerations that must be thoroughly incorporated in the design and construction of these features.

Water intrusion issues from a pool may result in costly repairs or even require replacement—not to mention potential consequential damages (lost revenue, tenant complaints/claims, reputation, etc.). It is critical that owners, developers, contractors, and architects fully understand and address these unique challenges with pool design.

Through several case studies, the presenters will focus on the importance of properly sized pool vaults, the unique structural loads exerted by these pools, the concern for a properly designed waterproofing system on the interior of the concrete vault, and how architects can utilize aquatics and waterproofing design professionals on their teams to provide a pool system that won't result in costly moisture intrusion issues.

Structural Considerations

As one college professor was fond of saying, "There are only two types of concrete in this world. The first is concrete that is cracked, the second is concrete that is going to crack." All reinforced concrete engineering design procedures (i.e., American Concrete Association standards ACI 318 and 350) allow for cracks to develop in reinforced concrete structures. Some amount of cracking is acceptable in nearly all concrete structures, including slabs on grade, columns, beams, walls, etc. However, swimming pools are unique in that the development of even one single crack is unacceptable and warrants repair.

It is easier to prevent cracking in in-ground pools because they are fully supported by the ground, and their embedment in the ground protects them from the external elements and forces. By contrast, rooftop pools do not have this protection. Therefore, there are very unique structural considerations that must be evaluated when building a rooftop pool in order to prevent cracking and subsequent expensive repairs.

In most cases, rooftop pools are horizontally supported by a concrete slab or vault overlying vertical support columns and/or walls. The slab is designed to structurally span the distance between the sup-

port elements. This span distance will suffer some vertical deflection between the supports, and the amount of vertical deflection is wholly dependent on the distance the slab spans (*Figure 1*). The deflection is often slight and invisible to the naked eye, but in many cases, the deflection is sufficient to induce structural cracking in a swimming pool. Often, the columns supporting the slab are not uniformly spaced beneath the swimming pool. *Figure 2* illustrates non-uniform support beneath the pool, creating eccentric loading, which will create differential deflection of the slab and cause the pool to lean in one direction. If eccentricity

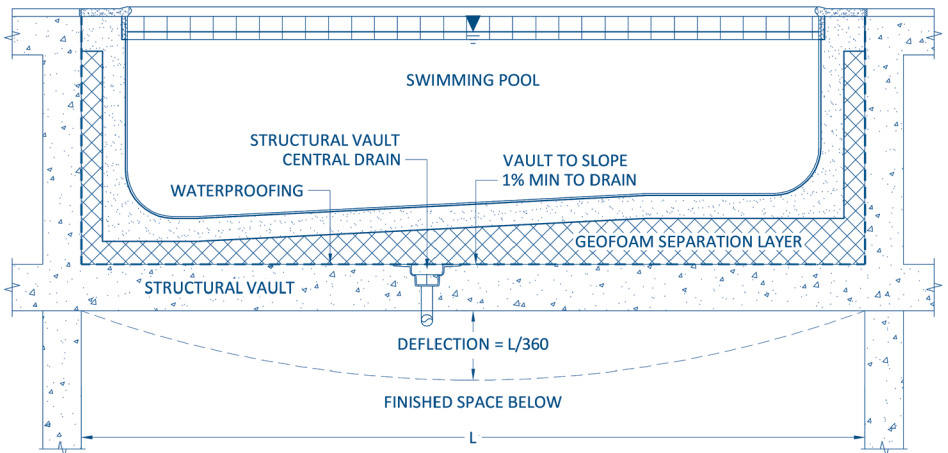


Figure 1 – Illustration of pool slab with uniformly spaced structural support deflection.

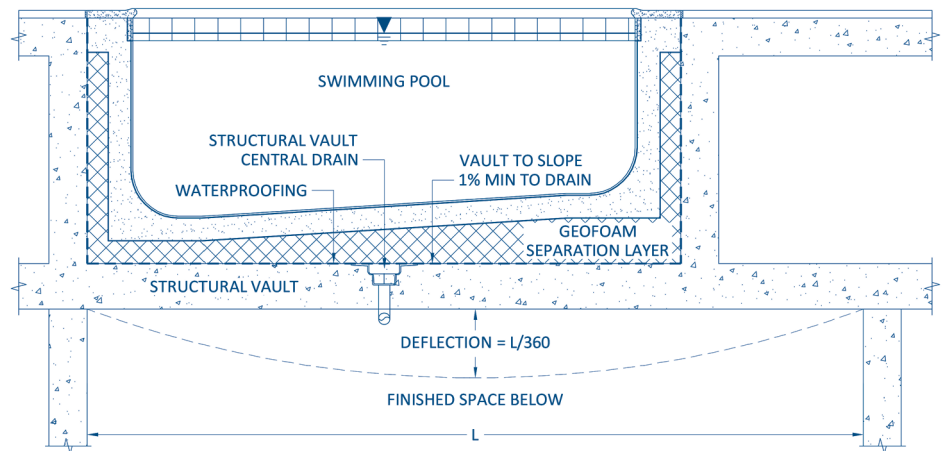
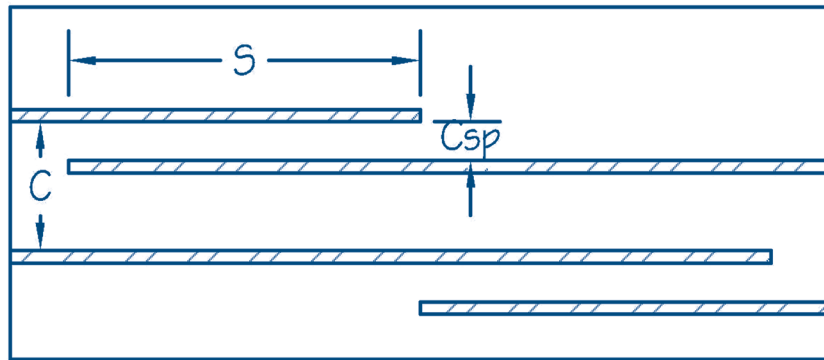


Figure 2 – Illustration of pool slab with eccentrically spaced structural support. This condition shows differential deflection of a vault, causing racking and twisting of pool shell.

SHOTCRETE REINFORCEMENT: NON-CONTACT LAP SPLICE



S: LAP SPLICE LENGTH - VARIES, SEE PLANS

C: CLEARANCE - 2½" MIN FOR #5 BARS AND SMALLER
6 bd FOR #6 BARS AND LARGER

C_{sp}: SPLICE CLEARANCE - 2" MIN

Figure 3 – Non-contact lap splice method.

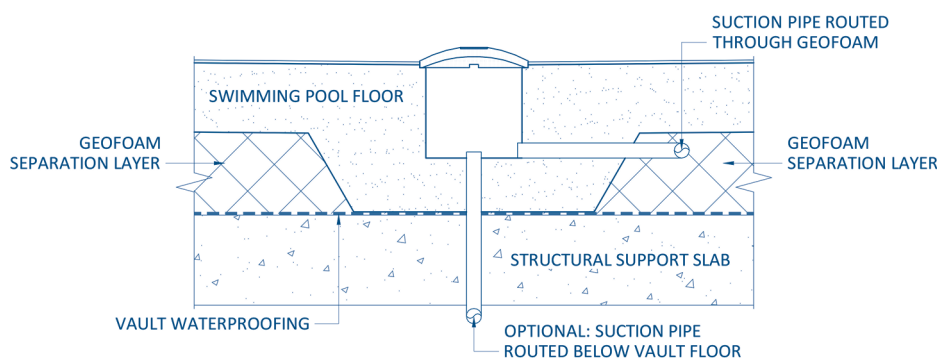


Figure 4 – Piping penetrations should be routed either through the geofoam or beneath the slab. Never embed piping through the pool structure.

exists in both directions, the pool can rack or twist—a far more serious structural condition. This deformation not only increases the risk of structural cracking, but also results in a pool that is not level. Rim flow pools with deck-level gutters can be very problematic, as they require the rim to be perfectly level for proper operation.

Often, the building structural engineer designs concrete slabs with an anticipated deflection of $L/360$, where L equals the span length between the supports (ACI 318, immediate deflection due to live load). For example, a 20-ft.-wide rooftop swimming pool with wall supports located directly beneath the swimming pool walls, can be expected to suffer 0.7 in. of deflection at its center. This amount of deflection is more than sufficient to develop cracks in a pool structure.

In an effort to reduce deflection, it is imperative to decouple the swimming pool structure from its slab support so that deflection of the pool does not mirror the deflection of the underlying slab. We have found that using a separation barrier consisting of a 4-in. layer of structural-grade foam, such as geofoam, is effective in reducing both differential and total deflection of the pool. The geofoam provides the added benefit of serving as a bond break, which prevents cracks in the underlying support slab from telescoping through to the swimming pool structure.

The geofoam separation layer is effective in reducing but not eliminating the deflection suffered by the pool. Any deflection of the pool floor slab will generate tensile forces in the pool structure. Therefore, it is important to consider this tensile loading in

the structural design of the pool. This additional loading will necessitate a significant increase in the reinforcing used to construct the pool. The additional reinforcement will not eliminate crack development in the pool, but it will reduce the frequency and thickness of cracks and keep the cracks very narrow so that they remain watertight (ACI 350) and mitigate telescoping through the plaster finish, revealing themselves on the pool surface.

A rebar schedule consisting of #5 bars at 5 in. on-center is the maximum reinforcement schedule the building code allows in shotcrete/gunite construction without building and testing preconstruction test panels. Many rooftop pools are specified with this reinforcement schedule. In order to reduce shadowing behind the rebar and maintain the utmost structural integrity, it is important to use the non-contact lap splice method to tie all reinforcement (Figure 3). Furthermore, all plumbing pipes should be routed either through the geofoam separation layer or beneath the structural slab (Figure 4). Plumbing pipes should never be embedded in the gunite/shotcrete swimming pool shell because the pipe creates a thin structural section at the pipe location where cracking can develop.

Waterproofing Systems and Selection

Without proper maintenance, every swimming pool, at some time during its life, can experience water intrusion. Seals around light niches and skimmer throats deteriorate, and mechanical equipment will eventually fail if not properly maintained and/or replaced.

In the event of a leak, in order to protect the finished spaces below, the concrete vault must be waterproofed. A properly specified waterproofing system is twofold. First, there must be a waterproofing membrane in place that thoroughly protects against water penetrating through the vault and routes the water to a drain inlet. Second, the drain inlet must have provisions in place to route the water to sanitary or storm drainage systems. It is imperative that the drain assemblies be water-tested and all connections properly secured prior to concealment, as the drain assembly will no longer be readily accessible once the pool structure is in place.

Waterproofing of the concrete vault is typically performed using reinforced fluid-applied membranes, which are preferred for

their seamless installation. As this waterproofing is no longer readily accessible once the pool is installed, system selection is critical for project success. Therefore, careful consideration should be given on a project-by-project basis. A few things should be considered on each project:

- Does the product have a proven track record?
- What is the experience level of contractors in the project area?
- Does the owner have any insurance requirements, or does the local municipality have restrictions that will inhibit the use of heating kettles?
- What time of year will the waterproofing system be installed?
- Is there sufficient slope in the underlying substrate to prevent standing water?
- If there is likely to be standing water, can the specified membrane handle continued immersion in water?

Hot rubberized asphalt and modified polyurethane cold-applied fluid systems are the most common systems used. Poly(methyl) methacrylate (PMMA), a liquid-applied waterproofing, has made its way into the market and is being specified more frequently. However, PMMA is typically less common and does not have a proven track record for this specific application. No matter which waterproofing system is selected, in all systems, proper application is critical to achieving the desired results. As is often said, “You don’t get what you expect, you get what you inspect.”

Waterproofing Quality Assurance

Prior to installing any material, it is recommended that the underlying concrete be properly cured. Verification to confirm that the concrete substrate is sufficiently cured to reduce the potential for trapped water vapor is essential for all projects. Previously, a common industry practice used to confirm sufficient concrete cure was ASTM D4263, *Standard Test Method for Indicating Moisture in Concrete (the Plastic Sheet Method)*, performed in the field prior to the installation of the waterproofing materials. Another accepted method is a pass/fail test involving the application of hot rubberized asphalt to the concrete surface to determine if the asphalt bubbles from the reaction of hot asphalt with water

within the concrete. While the latter may not be a standardized test method, it has been used—most notably within the waterproofing and roofing industry for nearly a century with success. However, with accelerated construction schedules, new concrete admixtures, and other changes in modern concrete construction, other methods such as relative humidity (RH) moisture probes (ASTM F2170, *Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in Situ Probes*) or calcium chloride testing (ASTM F1869, *Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride*) are often used to confirm sufficient cure of the concrete. It is recommended that a combination of these tests be used as recommended by the waterproofing manufacturer and the waterproofing consultant/professional prior to the installation of the waterproofing system.

In addition, prior to installing any waterproofing material, it is recommended to verify the bond of the waterproofing material to the substrate. This field test is performed as a pass/fail pull test to confirm sufficient adhesion of the waterproofing system. It can be performed immediately after the hot rubberized asphalt-applied waterproofing has cooled, but cold fluid-applied waterproofing will need to cure fully prior to testing. Cure times for cold fluid-applied waterproofing vary and are dependent upon environmental factors such as temperature and RH.

In-Situ Waterproofing Inspection/Testing

Manufacturers may require field inspections by a qualified testing agency during the installation of the waterproofing system in order to provide a warranty. Inspections may be specified as periodic or full-time. Project complexity, materials utilized, and size will usually dictate the frequency of the inspections. We recommend inspections on a weekly basis and at all benchmark stages to ensure conformance with the project specifications and manufacturers’ requirements. At a minimum, the inspector should be on-site during the first day of installation and prior to waterproofing membrane concealment. During the site visit, the inspector should provide written documentation of the following:

- Substrate conditions prior to waterproofing installation
- Substrate preparation procedures

(primer application rates, etc.)

- Waterproofing application procedures
- Verification of membrane thickness using a wet mil gauge or a pin tester
- Documentation of the waterproofing membrane prior to concealment

Once the swimming pool construction is complete, the waterproofing membrane will no longer be readily accessible, and failures related to the waterproofing membrane could prove costly. In addition to field inspections, it is advisable to perform quality assurance testing of the in-place waterproofing prior to concealment. There are various waterproofing testing methods that are generally accepted by the industry, including ASTM D5957, *Standard Guide for Flood-Testing Horizontal Waterproofing Installations*, and ASTM D7877, *Standard Guide for Electronic Methods for Detecting and Locating Leaks in Waterproof Membranes*. However, because flood testing does not pinpoint the location(s) of water penetration, nor will it detect breaches that are not currently leaking, electronic leak detection methods are preferred. High-voltage leak detection is preferred over low-voltage leak detection due to the fact that high-voltage testing can be used to test the vertical surfaces of the vault without requiring the application of water. Because the membrane is dry throughout the testing process, the high-voltage test method allows for immediate repairs. For hot-applied systems, the repaired waterproofing membrane can be retested once cooled to verify if the deficiency has been corrected. In instances where cold-applied waterproofing is utilized, the waterproofing system will be required to properly cure prior to testing.

Following a successful test, subsequent construction of the pool shape will ensue. It is imperative that other involved trades protect the waterproofing during the installation of overlaying systems. It is advised that a preinstallation meeting be convened at the project site to include the various trades involved with installing the overlaying systems. It should be stressed that all necessary means should be implemented to ensure the waterproofing system is protected. In some instances, the waterproofing contractor will provide a monitor to be on-site full time during the installation of the overlaying systems to ensure the waterproofing system is protected.

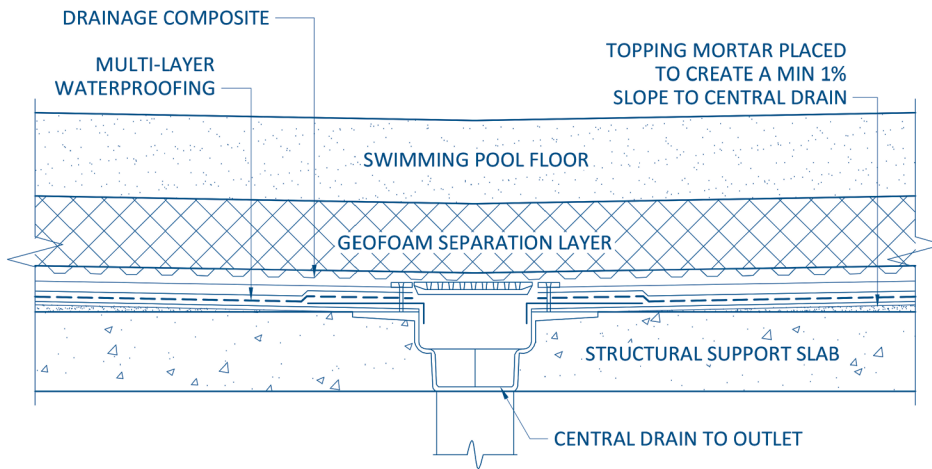


Figure 5 – Example waterproofing system with primer coat, hot rubberized asphalt, and geotextile drainage composite sloped to a drain inlet.

Drainage Systems

Because water will inevitably make its way to the interior space of the vault, it is necessary to install a drainage system that will collect swimming pool leak water and divert it quickly to drain inlet(s) (Figure 5). In most circumstances, the floor of the vault is constructed flat. On flat floors, a topping slab needs to be applied to the vault that slopes to a drain inlet. While there is no code requirement that dictates slope, it is recommended to provide a minimum slope of $\frac{1}{4}$ in. per ft. to ensure proper drainage. A drain inlet must be provided at the lowest portion of the vault, and the inlet must be properly flashed into the waterproofing system. Once the waterproofing system and drain inlet are installed, a drainage composite is installed atop the waterproofing membrane. The drainage composite helps to route any water that makes its way into the vault to the drain inlet.

Collaboration with the Building Architect

Many of the risks associated with pool construction can be reduced or even eliminated through careful collaboration with the project architect. The architect must coordinate with the structural engineer to ensure that the structural vault is properly sized to accommodate all of these elements, including the geofoam, drainage composite, waterproofing, and topping slab. The architect should also facilitate collaboration between the aquatic consultant and the structural engineer very early in the design process to ensure the performance requirements are fully considered in the design of the structure. In an effort to reduce slab deflection,

additional structural support—including a stiffer slab, beams, columns, or walls—can be installed to reduce the span length and the resulting vertical deflection. The design of the swimming pool support structure should be planned to provide uniformly spaced support under the pool and thereby eliminate differential deflection.

In many cases—especially in high-rise projects—the architect cannot make building modifications to accommodate the swimming pool that was intended due to concerns that arise as the design progresses. On one recent high-rise project, the structural engineer predicted the pool could deflect differentially as much as 4

inches across the eccentrically supported swimming pool. Yet, the architect had designed the rooftop pool to be rim-flow. It was decided that a shotcrete structure could not accommodate this much deflection. As a result, the project was redesigned as a stainless steel pool, and the rim flow was eliminated, which led to unforeseen increased project costs and impact on the project schedule.

Enlisting the services of a waterproofing design professional will help minimize the risk of an improperly specified and installed waterproofing system. By providing inspections and testing of the waterproofing system, installation defects can be corrected prior to subsequent installation of the pool shape.

CASE HISTORY #1

Wyoming Ski Lodge Rooftop Spa

A new Wyoming ski lodge that incorporated a rooftop spa was constructed in 2009. The 300-sq.-ft. spa was 3 ft. deep and included a 26-ft.-long vanishing edge (Figure 6). The spa was located on the third-floor balcony and was built over a ballroom/banquet room. The spa was constructed inside a concrete vault, and the vault received a comprehensive waterproofing and drainage system similar to the recommendations herein. The interior surface of the vault was waterproofed with an approved water sealant product, and the entire vault

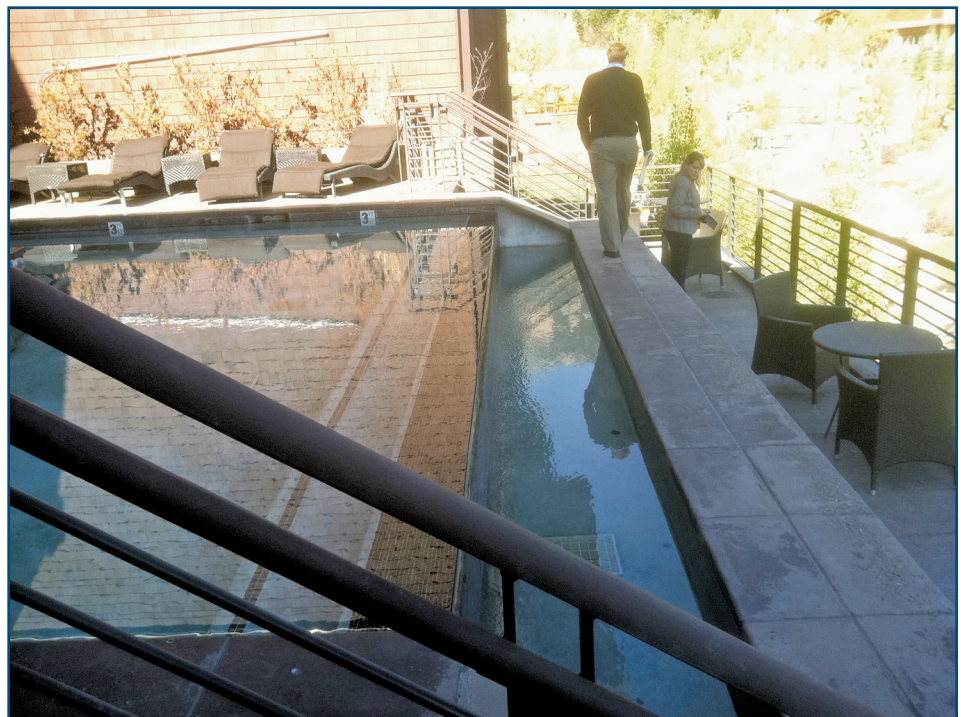


Figure 6 – Spa with vanishing edge built on third-floor balcony.



Figure 7 – Drain line plugged with fireproofing.

floor and sidewalls were lined with a geotextile drainage composite. Drain inlets were located in the floor of the vault to collect water and discharge to the landscape area below the spa. The plumbing penetrations through the walls were sealed using waterproofing sleeves and rings.

Two years after construction, water was found dripping into the ballroom below. A leak in the spa was discovered at one of the swimming pool's main drain locations where two pipe penetrations were spaced too close together to allow for proper gunite encasement. A piece of the gunite between the two

applied fireproofing. At the time the fireproofing was applied, only the drain inlet was installed in the vault. The drainpipe connection to the landscaping discharge had not yet been installed. When the fireproofing was applied, the inlet was plugged and remained plugged when the pipe connection was later completed.

Without a means of drainage egress, the water backed up in the drainage composite

pipes had spalled, allowing the leak to develop.

Leaking water from the spa should have collected within the drainage composite and discharged through the drainpipe to the landscape area as designed. However, the drainpipe was found to be plugged with spray-applied fireproofing material (Figure 7). The structural framing above the ballroom was protected with a coat of spray-

that lined the vault, extending up the sidewalls of the vault and spilling out onto the ballroom floor below. When the plugged section of pipe was cut from the drain line, the water that was trapped in the drainage composite crashed into the ballroom below.

With the problem diagnosed, it should have been a simple issue to repair the drain line and fix the spall that had developed in the main drain inside the spa. However, the owner of the lodge retained some experts who concluded that the whole spa needed to be demolished and reconstructed. Legal action then ensued that involved the owner, general contractor, spa subcontractor, and a multitude of other subcontractors. After two years, it was ultimately determined that the removal of the spa was not required for repairs, but not before all parties invested significant time, money, and stress.

It is important to note that the contractor who built the spa held only a small fraction of the accountability. The spall that developed in the main drain that caused the leak was a simple warranty issue that, if properly resolved, would not have required litigation. Furthermore, the issue should have been completely resolved during con-



Figure 8 – Vanishing-edge rooftop swimming pool.



Figure 9 – Geotextile drainage composite laid flat.



Figure 10 - Efflorescence and tile delamination due to water intrusion.

Figure 11 - Damaged finishes inside the residence.



Figure 12 - Water leaking through residence utilities. Note the formation of stalactites from chronic leakage. The swimming pool is directly above this finished living space.



struction had proper protection, quality control, and quality assurance been performed. A small piece of plastic with a rubber band to cover the drainpipe would have prevented the blockage. Furthermore, the plumber who later plumbed the line should have inspected the drainpipe and cleared it of the obvious blockage.

CASE HISTORY #2

Residential Rooftop Pool, San Diego, CA

This vanishing-edge rooftop swimming pool (Figure 8) was constructed at a beachfront residential home in San Diego, California. The pool was constructed over a pool equipment room, garage, and finished living space. The pool was underlain by a geotextile drainage composite and included foam insulation as a separation layer. However, waterproofing of the structural slab was insufficient, and the geotextile drainage composite was laid flat (Figure 9) so that accumulated water would not drain to the inlet. The pool structure was also under-reinforced.

When the pool ultimately developed a leak, the water collected in the drainage layer had no ready means of egress. What resulted was a multitude of water penetrations into both interior and exterior spaces. Significant water intrusion with efflorescence developed in the exterior foundation walls, mosaic tile delaminated due to the water pressure, and water intrusion entered interior spaces, causing flooding, mold, and damage (Figures 10 through 13).



Figure 13 - Exterior leaking, efflorescence, structural cracks, and rust.



Figure 14 –
Water intrusion
into parking
structure.

Figure 15 –
Overview of
pool during
construction.



CASE HISTORY #3

Commercial Rooftop Pool, Greenville, SC

The saltwater rooftop swimming pool was constructed above a parking deck at a high-end apartment complex located in Greenville, South Carolina. Water intrusion was occurring into the parking deck (Figure 14). Based upon existing construction photos and drawings received by the client, the surfaces of the vault were waterproofed with a fluid-applied waterproofing system (Figure 15). Within the vault, expanded polystyrene and wooden pour forms were used to create the shape of the pool. Shotcrete was installed into the vault over the expanded polystyrene shapes and prepared for the pool surface coating. The vertical wall for the vault slab extended slightly higher than the top surface of the vertical wall for the pool shape. It was observed that waterproofing did not continue across the

top section of the vertical wall of the vault to the top section of the vertical wall of the pool shape, nor was there any apparent means to divert water away from the joint.

A copingstone was present on top of a bed of grout covering the top section of the vertical wall for the pool shape and part of vertical wall of the vault. The backside of the cop-

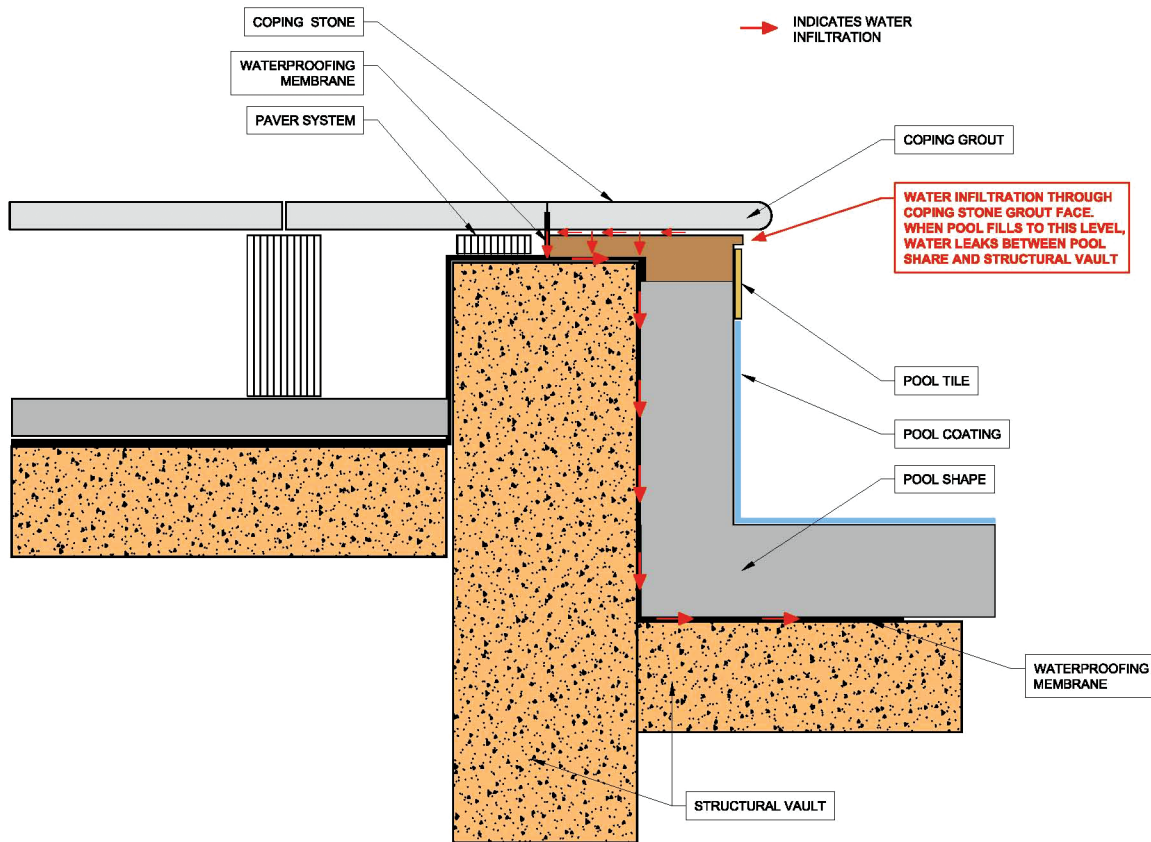



Figure 16 – Pool construction showing water infiltration.

ingstone was observed to be waterproofed, but no waterproofing was believed to exist beneath the copingstone on the top section of the vertical wall of the pool shape.

A drain inlet in the vault was not specified by the project architect. As an afterthought following construction, two portholes were cored through the vault slab. This was done so that in the event of a pool leak, building maintenance personnel would be made aware of the issue. When the portholes were cored, water immediately ran out. Leakage into the vault had apparently been ongoing for an extended period of time. In addition to not having a drain inlet, it was observed that there was no pool

overflow system in place to control the water level of the pool. The pool was filled to just below the top edge of the copingstone under the assumption that excess water would leak through the front mortar joints on the bottom of the copingstone (*Figure 16*). Once the pool was filled above this mortar joint, the measured leak volumes increased substantially in a short period of time. The level of the pool lowered from the center of the copingstone to just below the mortar joint of the pool tile overnight.

The coping stone was removed, and it was discovered that the waterproofing was not continuous, resulting in water infiltration at the intersection of the pool wall and the

tem—are just a few things that must be considered when designing these unique water features. Even with a proper design in place, collaboration and communication among the various trades involved throughout construction must also be carefully coordinated. As presented through the various case studies herein, construction defects such as insufficient waterproofing, clogged drain lines from construction debris, etc., can prove costly for all parties involved. It is imperative to enlist the services of qualified design professionals and contractors to ensure the project doesn't result in costly water intrusion issues. 

vault wall beneath the coping cap. Following the discovery, a continuous waterproofing system was applied beneath the coping stone, resulting in a significant reduction in the moisture intrusion experienced in the parking garage.

CLOSING

Designing a rooftop pool or other similar elevated water structure presents a unique set of challenges that will require communication and collaboration between an array of design professionals. Structural considerations—such as support beams, columns or walls, proper sizing of the structural vault, and selecting the proper waterproofing sys-