

EVALUATION OF Liquid-Applied Waterproofing Systems:

CASE HISTORIES

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INTRODUCTION

Waterproofing concrete substrates such as fountains, water-retaining tanks, plaza decks, parking decks, planters, and other underground structures is substantially different from roofing. For this reason, it is imperative that the designer be aware of the differences and of the potential problems associated with waterproofing concrete substrates.

Improper waterproofing design and installation can lead to leakage, deterioration of concrete substrate materials, and waterproofing membrane delamination. Of particular concern is the application of liquid-applied membranes (LAM) on concrete surfaces. While in most cases the application of liquid-applied membranes over concrete surfaces is trouble-free, there are sometimes cases where premature failure of the system has occurred. These early failures are typically due to debonding of the membrane from the concrete substrate, pinholes in the membrane, curing deficiencies, or inconsistencies in application thickness.

The following are two case histories involving evaluation of deficiencies in liquid-applied waterproofing membranes.

Case 1 - Cincinnati Museum Center Plaza Fountain

Constructed in 1933, the plaza fountain at the Cincinnati Museum Center is a tiered fountain built on a sloping structural deck over occupied space (Figure 1). The lower portion of the fountain and the structural deck beneath the fountain's lower pool extend over a vehicular underpass. The structural deck consists of a reinforced concrete slab and is supported by a grid of steel beams and girders. The fountain's original primary waterproofing system was placed on top of the structural deck and consisted of a 5-ply coal-tar-pitch waterproofing membrane covered with a thin sheet of lead pan). The fountain was cast with concrete to rough elevations on top of the lead pan (Figure 2). A trowel-applied mortar was then used to form the curved surfaces of the cascades before finishing the entire fountain with a green terrazzo surface. No topside waterproofing was originally specified.

As part of a 3-year museum renovation project beginning in 1987, the plaza fountain underwent a major rehabilitation. The fountain restoration included removing deteriorated and unsound concrete and mortar, rebuilding the foun-

tain to original elevations with cementitious and epoxy mortars, and waterproofing the exposed fountain surfaces with a polyurethane waterproofing membrane. The original lead pan was left in place.



Photo 1 - Overall view of the Cincinnati Museum plaza fountain

In 1991, the plaza fountain was placed back in service. During the first year of service, water leakage onto the underpass and blistering of the waterproofing membrane were observed. Blisters were cut out and patched, and the fountain was re-coated with the waterproofing membrane. Prior to re-coating, the surfaces were reportedly cleaned with xylene to partially soften the membrane color coat and enhance adhesion of the new membrane.

After the 1991 repairs, leakage and blistering continued. The leakage onto the underpass was traced to the fountain by using chemical dyes. Further unsuc-

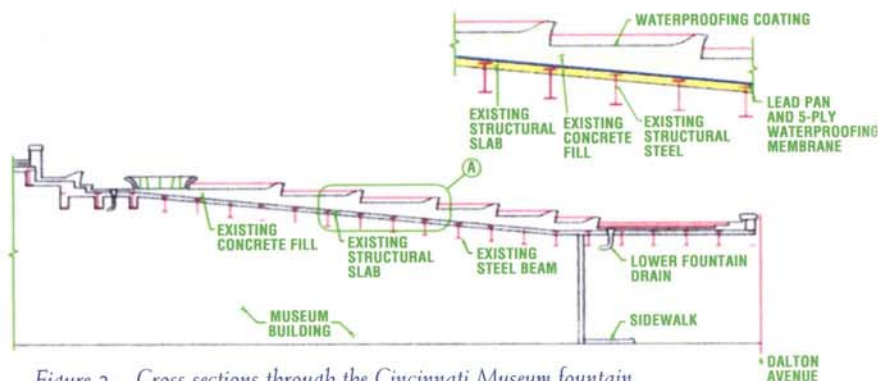


Figure 2 – Cross sections through the Cincinnati Museum fountain.



Figure 3 – Typical example of interlayer disbonding of the membrane between the green top coat and the gray base coat.

cessful attempts were made to stop the leakage by local patching, re-coating, and otherwise repairing the waterproofing membrane, specifically at blistered areas.

Due to the ongoing problems, an evaluation of the fountain waterproofing system was commissioned by the Museum Center. This evaluation was performed in the fall of 1998 after the fountain was drained for the winter months.

1.1 Scope of Investigation

The scope of the investigation included a visual survey of the fountain, a delamination survey of all fountain concrete surfaces, core sampling, peel tests of the membrane, and laboratory examination of the samples taken in the field. The investigation also included a pressure test of the fountain water supply system to rule out the possibility of a plumbing leak.

1.2 Field Investigation

The plaza fountain was taken out of service approximately one week prior to the evaluation. Field investigation included a comprehensive visual review and delamination survey of vertical and horizontal surfaces of the plaza fountain. Concrete and membrane sample removal locations were selected to represent various conditions within the plaza fountain. Samples were removed from areas exhibiting membrane blisters, concrete delaminations, and from areas where no apparent deterioration was observed.

1.2.1 Waterproofing Membrane Observations

The coating had disbonded (separated from the substrate) and delaminated (separated from its underlying layers) in many areas of the fountain (Figures 3 and 4). Large sheets of membrane and color coat peeled away easily in some areas. In general, second and third applications of the

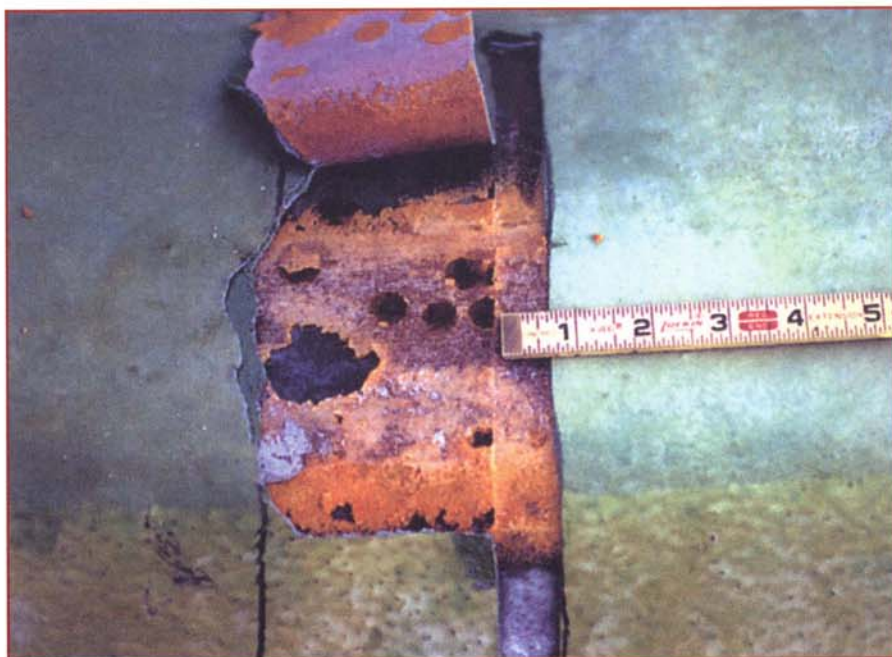


Figure 4 – Typical example of membrane disbonding from the epoxy patching material.

coating were poorly bonded and could be separated readily. In a few cases, individual layers of the first application of membrane and color coat exhibited interlayer delamination. In most cases, the primer appeared to be well-adhered to the concrete.

Numerous water-filled blisters, ranging in size from 1/4 inch to 4 inches in diameter, were observed (Figure 5). Several of these blisters were cut open to determine the location of the water layer within the coating system. The location of blistering varied, occurring between coats (layers) of the first application membrane, at the primer/membrane interface, at the color coat/membrane interface, or between layers of the color coat.

In some areas, the coating contained embedded sand (aggregate) within the first application of membrane. In these areas the coating exhibited a rough surface texture with the tips of aggregate commonly exposed. A second application of coating did not completely cover the exposed aggregate. When this coating was peeled away, it contained numerous pinholes.

In several areas, cracking of the substrate concrete had reflected through the membrane directly over the crack (Figure 6).

1.2.2 Concrete Delamination Survey

A delamination survey was performed at all horizontal and vertical surfaces of the fountain to locate subsurface delaminations within the concrete. A delamination is an internal crack in

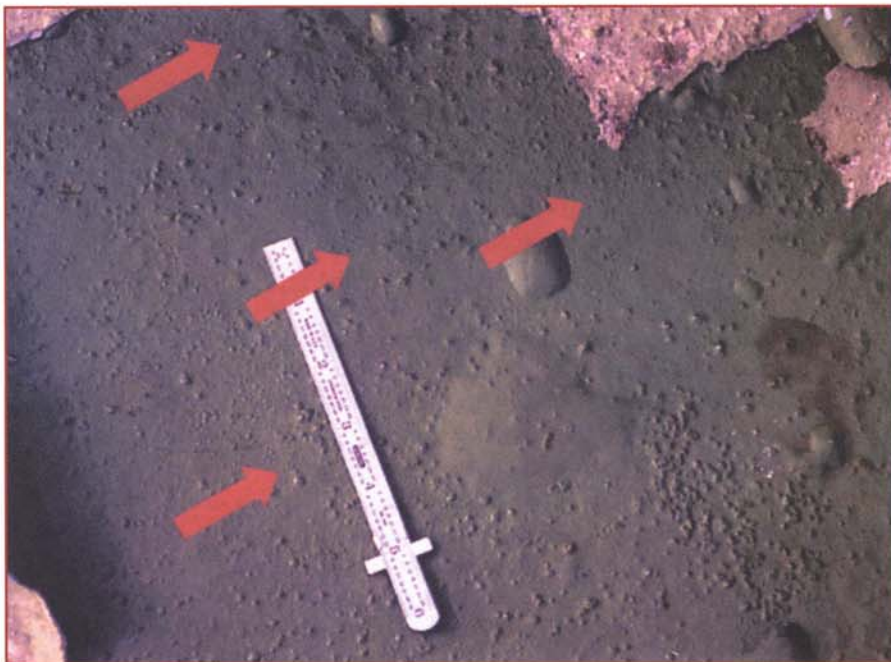

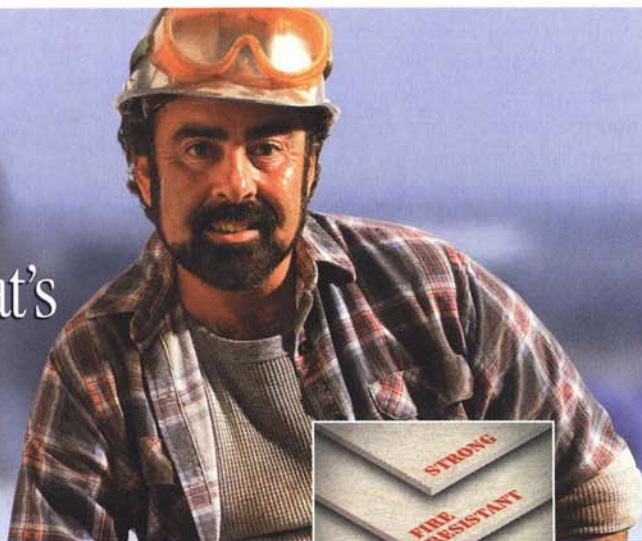


Figure 5 – Surface blisters in the membrane (red arrows).

a concrete member that is oriented parallel to the exposed surface of that member, resulting in a planar discontinuity. The survey was conducted using the hammer-sounding method in general accordance with ASTM D-4580¹. Using this method, changes in emitted acoustical frequency between delaminated and sound concrete can be readily detected, provided the delam-

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ination is within a few inches of the top surface of the concrete. Delaminations deep within the concrete cannot be detected using the hammer-sounding method.

Approximately ten percent of the fountain surfaces exhibited sub-surface delaminations when sounded with a hammer (Figure 7). The delaminations were primarily in areas where previous repairs were performed using an epoxy repair mortar. Core sampling at these locations showed that the epoxy repair material had debonded from the substrate concrete.

Examination of cores during sampling indicated widespread delaminations deep within the fountain concrete. Most of these areas containing deep delaminations were not detectable by hammer sounding (Figure 8).

1.2.3 Exploratory Opening Observations

Two exploratory openings were made to evaluate the condition of the lead pan. Observations indicated that the lead pan was in good condition with no signs of lead corrosion products. Thickness measurements averaged 0.078 inch.

At the lower exploratory opening, water was observed running into the opening at the level of the lead pan, indicating water had migrated to and was ponding on the lead pan. Water continued to enter the exploratory opening for the duration of the field investigation. The drain within the exploratory opening did not appear to be original. The existing 3-inch drain line was placed in an 8-inch diameter hole in the structural slab, presumably from the previous drain line. Backer rod was placed in the annular space between the 3-inch drain line and the concrete, and approximately 1 inch of grout was poured on top of the backer rod. The lead pan overlapped the original drain flange (still in place) but was not

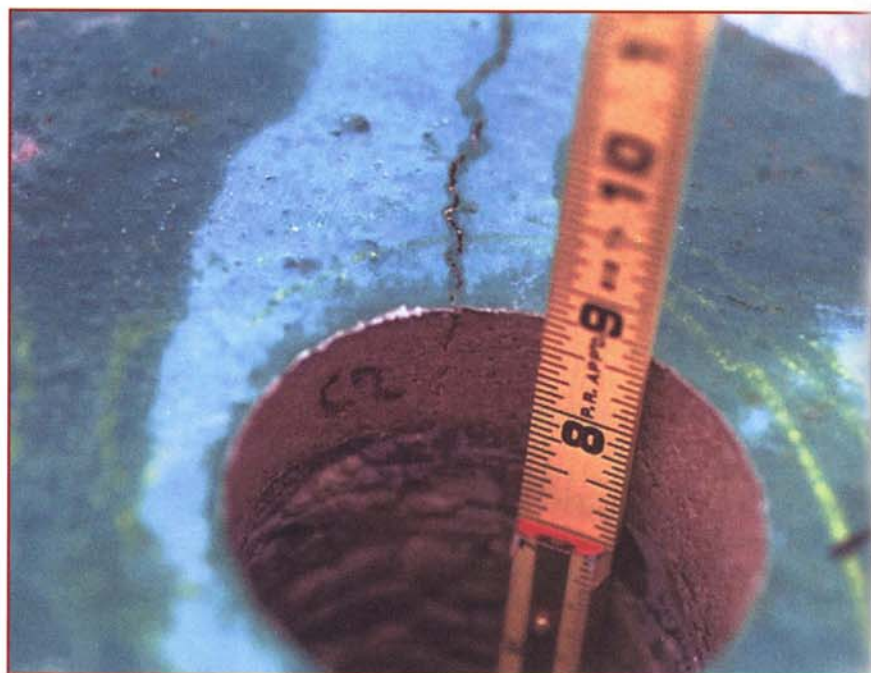


Figure 6 – Substrate cracks reflecting through the membrane.

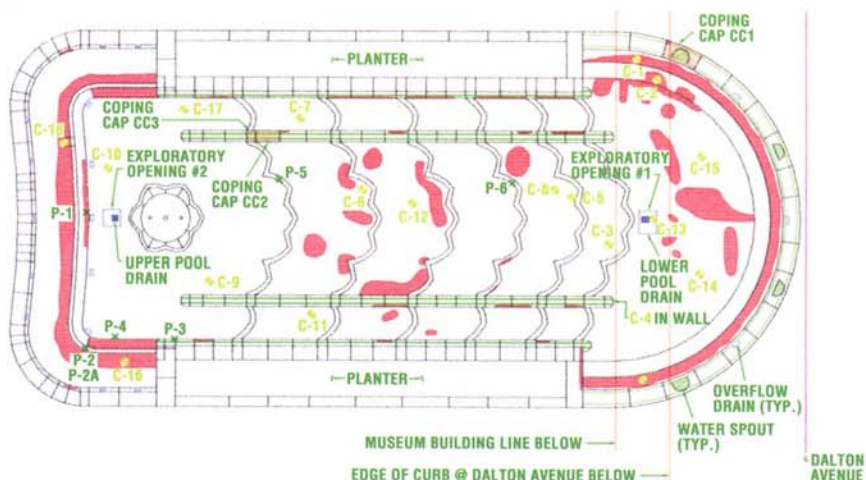


Figure 7 – Above, delamination survey of fountain surfaces revealed significant areas of delamination concrete (red areas).

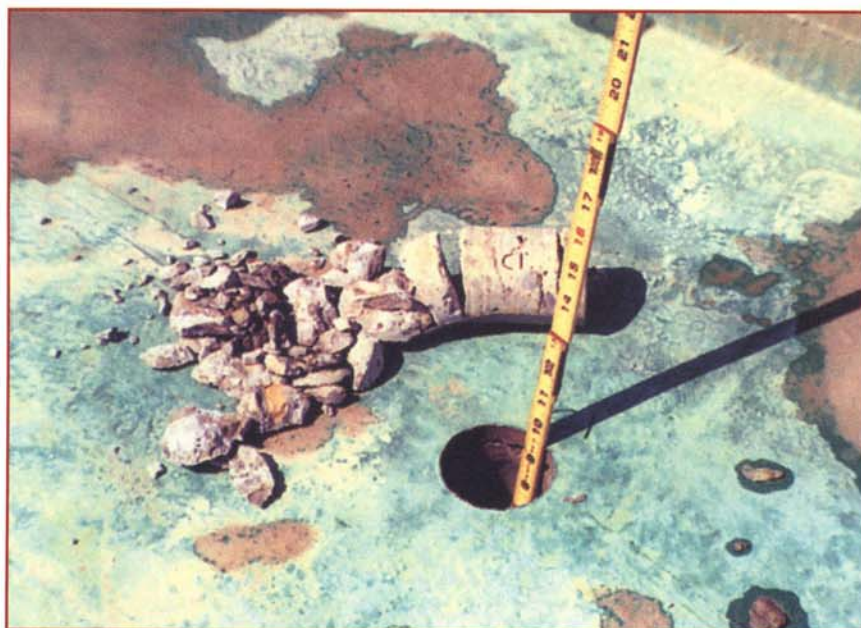


Figure 8 – Coring of the substrate revealed extensive freeze-thaw deterioration.

attached to the new drain. Therefore, the waterproofing system was not continuous and did not protect the structural slab around the drain.

A portion of the lead pan and bituminous waterproofing membrane was removed. The surface of the underlying structural deck was damp.

A partial-depth concrete core (taken from Exploratory Opening No. 1 to evaluate the condition of the structural slab) indicated that the structural slab near the lower pool drain was severely cracked and delaminated.

1.2.4 Stone Coping Cap Observations

Two stone coping caps on the perimeter of the fountain were removed to evaluate the waterproofing system terminations. Several holes were



Figure 9 – One of the large marine tanks at Newport Aquarium during construction.

observed in the sealant joints between the stone coping caps around the perimeter of the plaza fountain. No holes were observed between the coping caps within the pool. Upon removal of the coping caps, the underlying waterproofing membrane and Neoprene flashing appeared intact.

1.2.5 Fountain Plumbing

A pressure test of the fountain plumbing was performed to evaluate the possibility of plumbing leaks. The test revealed no loss of pressure within the fountain supply piping. Therefore, it was unlikely that the fountain water supply system contributed to the leaks.

1.3 LABORATORY TESTING

1.3.1 Microscopic Examinations – Concrete Cores

Core samples removed from delaminated areas of the fountain concrete confirmed the presence of subsurface delaminations in those areas. Furthermore, during drilling of concrete samples, the drill water traveled through the horizontal delamination plane and emerged through a vertical crack approximately 6 inches from the core location. This indicated that paths were available for water to penetrate into the concrete and travel through the horizontal delaminations.

In addition to the surface delaminations, many cores exhibited extensive cracking and delaminations deep within the fountain concrete. Core samples removed from areas where hammer sounding did not detect surface delaminations indicated that deep delaminations and cracking were widespread throughout the fountain.

In general, the epoxy repair mortar had delaminated from the cementitious substrate. The majority of the deterioration and cracking was found in the original concrete layer. The original concrete was not air-entrained. Therefore, it is susceptible to freeze-thaw damage when saturated with water. Extensive sub-

parallel cracking, typical of freeze-thaw damage, was present in the original concrete

1.3.2 Microscopic Examination - Coating System

Project background information indicated that the first application of the coating system (waterproofing membrane) took place in 1991. The specified coating system consisted of an epoxy primer followed by three layers of one-component polyurethane membrane averaging 12 dry mils each (one mil = 0.001 inch) and topped with two layers of a green color coat averaging 3.5 mils each. The design total coating system thickness was 43 mils.

Microscopic examination of samples obtained in the field indicated the first application of coating system consisted of a red primer applied directly to the concrete/repair mortar substrate followed by multiple coats of a light gray membrane topped with multiple coats of a green color coat. In some areas, the membrane contained embedded aggregate up to 52 mils in diameter, while the membrane did not contain aggregate in other areas. The first application coating system thickness was highly variable.

Primer thickness ranged from 1 to 5 mils. Membrane thickness ranged from 1 to 57 mils, and color coat thickness ranged from 1 to 20 mils. The coating system on sidewalls and sloped surfaces typically was thinner.

An additional application of the coating system was applied after the fountain's first operational season. In some areas, it appears that second and third applications of the coating system were applied. The second application of membrane ranged from 5 to 45 mils in thickness, with its color coat thickness ranging from 1 to 10 mils. The third application of membrane ranged from 17 to 20 mils thick, with its color coat thickness ranging from 2 to 5 mils.

Examination of the coating system revealed numerous small pinholes in the primer and water-filled blisters at the primer/membrane interface. The polyurethane membrane also contained small pinholes, waterfilled blisters, and air voids. Some voids reflected over voids in the primer. Interlayer disbonding of the membrane was common. In general, second and third applications of the coating were poorly bonded and could readily be separated. In a few cases, individual layers of the first application of membrane and color coat exhibited interlayer delamination. In most cases, the primer appeared well adhered to the concrete. Tears and breaches of the membrane were typically reflections of cracks in the substrate.

1.4 Conclusions

Failures in the waterproofing membrane consisted primarily of cracks in the membrane reflecting over cracks in the substrate and, to a lesser extent, the membrane blistering and delaminations. Once the water had bypassed the topside waterproofing system, it dispersed through a large network of delaminations and cracks within the fountain substrate until it reached

the original waterproofing system, the lead pan, and underlying membrane.

Cracks observed within the membrane lined up with cracks in the substrate. These cracks were attributed to deterioration of repair patches, as well as to cracking and deterioration of the original concrete within the fountain. Since the original fountain concrete was not air-entrained and did not have a topline waterproofing membrane for many years, it was susceptible to freeze-thaw deterioration. Also, a drainage layer was not provided at the level of the lead pan. Therefore, water penetrated and saturated the concrete above the lead pan. During winter months, the trapped water froze and cracked the saturated concrete. This deterioration likely began early after construction and had continued through the life of the fountain.

During the fountain rehabilitation, hammer sounding was used to locate deteriorated concrete to be removed and replaced. However, the hammer sounding method could not detect the extensively cracked and delaminated concrete deep within the fountain, above the lead pan. Therefore, this deteriorated concrete was not removed. Patch repairs placed over the deteriorated concrete cracked and delaminated due to the instability and further cracking of the concrete substrate.


Numerous small pinholes and blisters in the first application of the primer and membrane were observed. There was no record of water vapor emission tests having been performed prior to application of the liquid-applied membrane. Therefore, it was concluded that the concrete substrate was saturated and exhibited high water vapor emission rates during and immediately after application of the membrane system. This high water vapor pressure resulted in the formation of numerous pin-

holes in the primer. These pinholes provided a path for water vapor to penetrate the porous membrane from the substrate below, and fill air voids with water, producing blisters.

Subsequent coats of membrane within the first membrane application also contained pinholes and air voids. The pinholes and air voids typically lined up with those in the primer and first coat of membrane that, under hydrostatic pressure, could result in water leakage through the membrane during normal fountain operation.



Figure 10 – Large blister at the base of a marine tank.

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In some areas of the fountain, sand particles had been broadcast into the membrane during installation. The tips of the sand particles typically were exposed, creating pinholes within the membrane. These pinholes could allow water penetration under hydrostatic head, filling voids and creating interlayer blisters. The inclusion of sand particles was not specified by the membrane manufacturer and is not common to waterproofing systems designed for this service condition. The sizes of sand particles placed in the first membrane application were large enough that their tips were typically exposed through subsequent membrane applications. In combination with pinholes and air voids, these sand particles provided potential paths for water to penetrate through membrane layers to the substrate under hydrostatic head.

Re-application of the membrane had failed in numerous areas, primarily due to lack of proper bond between the first membrane application and subsequent applications. Bond failure was typically caused by inadequate surface preparation techniques. The lack of interlayer bond provided voids that collected water and created blisters. The water collecting in these voids penetrated through pinholes and other deficiencies in the membrane.



Figure 11 – A marine tank being filled with water.

Given the service conditions for the plaza water fountain, the overall durability of the rehabilitated fountain was considered poor. The original concrete components above the lead pan were extensively cracked and delaminated due to freeze-thaw deterioration. Patch repairs had cracked and delaminated in only seven years due to the unsound substrate. The cracks in these patches had reflected through the waterproofing membrane, allowing a direct path for water to enter and saturate the concrete and thus continue the freeze-thaw cycles. Deterioration of the fountain was expected to continue and become progressively worse with time.

1.5 Recommendations

Based on the findings of this investigation, it was concluded that the only viable long-term solution for rehabilitation was a complete reconstruction of the fountain above the lead pan.

Case 2 – Waterproofing Of Marine Tanks At Newport Aquarium

The Newport Aquarium in Newport, Kentucky, was constructed in 1998. The aquarium features several large concrete marine tanks. The marine tanks consist of reinforced concrete walls and floors cast in place using a silica-fume enhanced concrete mix (Figure 9). The floor slabs were cast directly over ground without the use of a vapor retarder. A cementitious pargel coat was applied over the cast concrete surfaces to fill surface irregularities such as bugholes.

The waterproofing system specified for the tanks was a spray-applied polyurea system with a low-viscosity epoxy primer. All concrete tank walls and floors were scheduled to receive the waterproofing system prior to installation of marine features.

The first tank to receive the waterproofing system was a relatively small backwash recovery tank. The membrane in that tank was installed in early July 1998. It was reported that, a few days prior to the application of the membrane, the tank was flooded due to rainstorms. Within hours of application of the waterproofing system, blisters were observed in the membrane. The blisters were primarily limited to the tank floor. However, a limited number of large blisters was also observed on the bottom sections of the tank walls (Figure 10). The observed blistering triggered an investigation of the waterproofing system to avoid similar problems in the larger tanks scheduled to receive waterproofing within the following weeks. The investigation was performed by a consulting firm retained by the general contractor. Assistance to the consultant was provided by the project's designated testing laboratory.

2.1 Scope of Investigation

The scope of the initial investigation included the following:

- Moisture vapor emission tests were performed on concrete surfaces exhibiting membrane failure.
- Material literature for the specified waterproofing system was reviewed.
- Samples of concrete and membrane were removed in the areas exhibiting membrane failure.
- Microscopic examinations of concrete core samples removed adjacent to blistered areas were performed.

After the initial investigation, a trial phase was initiated to investigate various application conditions and surface preparation schemes. During this trial phase, bond pull-off tests were performed on sample panels to evaluate the effectiveness of surface preparation methods on performance of the membrane.

2.2 Initial Investigation Findings

The moisture vapor emission rate (MVER) testing performed by the testing laboratory indicated vapor emission rates ranging from 9 to 17 lbs/1000 sf in 24 hours in various tanks throughout the complex. The tests were performed in accordance with ASTM F-1869². They were primarily performed on the floors of the tanks where the MVERs were suspected of being excessive. An MVER of 17 lbs/1000 sf in 24 hours is considered very high for application of a waterproofing membrane. Typically, a substrate MVER of 3 lbs/1000 sf in 24 hours is specified by product manufacturers prior to application of impermeable coatings and membranes.

At the time of the first field visit, the waterproofing membrane had been removed from the tank floor. The majority of the blisters were reported to have occurred on the tank floor. Two blistered areas approximately 6 inches in diameter were also observed on the tank walls within 24 inches of the floor. No other blisters were observed on the tank walls, where the membrane had been left intact. Small delaminations in the membrane were observed at a limited number of locations. Subsequent conversations with the membrane manufacturer and research into the polyurea chemistry revealed that such deficiencies are likely due to reaction of isocyanates in the polyurea with moisture. This reaction results in formation of carbon dioxide that can cause small blisters to form within the membrane. This phenomenon is usually caused by improper mixing of the polyurea at the gun and can be alleviated through better mixing and application practices.

Two core samples were removed from the tank—one adjacent to the blister at the base of the wall where the membrane had debonded from the substrate and the other at a small delamination within the membrane. The samples were subsequently examined under a microscope. The findings indicated the following:

- The failure at the blistered area near the floor (Core A) generally occurred at the interface between the primer and the substrate parge coat.
- Incipient failure of the parge coat was observed in Core B (from the area exhibiting blistering within the polyurea membrane).
- Substrate surfaces did not appear to have been aggressively roughened by sandblasting to promote mechanical bond.

2.3 Trial Phase

The initial investigation findings had indicated that the failure could have been due to excessive MVERs in the concrete substrate and/or inadequate surface preparation to promote mechanical bond. Therefore, a trial phase was implemented to assess the influence of surface preparation on membrane bond to the substrate.

During the trial phase, the membrane was applied at several test areas in a location where substrate moisture vapor emission rates were the highest. The moisture vapor emission rates were measured using standard calcium chloride tests. As indicated before, initial tests had indicated an MVER of 17 lbs/1000 sf in 24 hours on the floor of the selected tank. To produce a severe case for application of the membrane, no attempts to dehumidify or provide forced ventilation were made prior to application of the membrane on the test areas. Six test areas were selected on the tank floor, each measuring approximately 5 feet by 6 feet. The test areas were to receive the following:

Test Area 1: More aggressive sandblasting than previously performed plus the standard waterproofing system (primer and polyurea membrane).

Test Area 2: Standard surface preparation (light sandblasting) and standard waterproofing system with an additional coat of the primer.

Test Area 3: Standard surface preparation and standard waterproofing system.

Test Area 4: Standard surface preparation, a proprietary surface treatment to reduce water vapor emission rate, and standard waterproofing system.

Test Area 5: Standard surface preparation, one coat of a proprietary urethane primer, and polyurea membrane (no epoxy primer).

Test Area 6: Standard surface preparation, two coats of the urethane primer, and polyurea membrane (no epoxy primer).

At each test area, the substrate MVER was measured on the tank floor immediately prior to application of the primer. Vapor emission rate after installation of each primer was also measured in a 1-foot strip of each test area that did not receive the membrane. After the installation of the membrane, bond pull-off tests were performed to evaluate the bond of the membrane system to the substrate at each test area.

Test Area	MVER Before (lbs/1000sf- 24 hrs)	MVER Before (lbs/1000sf- 24 hrs)	Bond (PSI)
More aggressive surface prep	9.4	1.6	280
Additional coat of primer	7.7	1.1	260
Standard application	7.8	0.9	390
Proprietary treatment	7.5		
One coat of urethane primer	7.5	4.9	410
Two coats of urethane primer	7.9	3.6	310

Table 1 — Trial phase test results.

Results of the trial phase testing are shown in Table 1. Measured substrate moisture vapor emission rates ranged from 7 to 9 lbs/1000sf/24 hrs. After application of the primers, the water vapor emission rates were significantly lower in all areas, with the least reduction indicated through the urethane primers and the highest reduction in Test Area 1 (more aggressive sandblasting and one layer of low-viscosity epoxy). In Test Area 1, the water vapor emission rate was reduced from 9 lbs/1000 sf in 24 hrs before application of the primer to 2 lbs/1000 sf in 24 hrs after application of the primer.

Bond pull-off tests indicated average bond values of over 280 psi in all test areas with the exception of Test Area 2, where two coats of the primer were used. It was hypothesized that the two layers of the epoxy primer resulted in a smoother surface that inhibited bond between the membrane and the primed substrate.

The debonded portions of the bond pull-off test specimens were analyzed. Visual examination of the failure planes indicated that, generally, the polyurea membrane exhibited good bond to the primer. The failure plane was primarily at the primer-concrete interface, with very little concrete adhering to the primer.

2.4 Other Tests

Two bond pull-off tests were performed on the walls of the first tank where blistering of the membrane was reported on the floor. The results indicated bond pull-off values of 276 and 210 psi. These bond values correlated well with the bond values obtained in the floor test areas.

Substrate pH values were also measured in each test area. Results of the tests indicated that the substrate pH ranged from 7.5 to 8.0. Based on test results, it did not appear that unusually high pH levels existed on the concrete surfaces. pH levels of 11.0 and higher have been reported by some to attack certain adhesives used for flooring applications.

2.5 Conclusions

Based on the initial MVER measurements, it appeared that the blistering of the first membrane application in the first tank was due to high MVER through the floor of the tank. The high MVER was attributed to lack of an effective vapor retarder under the tank floor slab and flooding of the tank a few days prior to application of the membrane. These high moisture vapor emission rates were somewhat consistent throughout most of the tanks. At that time, the tanks were not protected from rain. Therefore, exposure to rain increased the moisture content of the slab resulting in a sustained high vapor emission rate.

Subsequent testing at other test areas in an adjacent tank (West Salt Water Reserve Tank) indicated that natural ventilation and prevention of flooding can significantly reduce the MVER to below 10 lbs/1000 sf in 24 hours. Moisture vapor emission rate on the tank floor was measured to be 17 lbs/1000 sf in 24 hours between July 1 and July 4, 1998. This rate was reduced to 7 to 9 lbs/1000 sf in 24 hours between July 10, and July 13, 1998.

At the test areas in the West Salt Water Reserve Tank, the highest reduction in moisture vapor emission rates was obtained where more aggressive sandblasting and the epoxy primer was installed. After installation of the primer, substrate vapor emission rate was measured to be 2 lbs/1000 sf in 24 hours. Bond pull-off values were greatest where a urethane primer was used. Although no correlation between bond pull-off values and vapor emission after application of primer was observed, all test areas with the exception of where two coats of the epoxy primer were installed exhibited average bond pull-off values exceeding 280 psi. Such bond pull-off values are considered adequate for the waterproofing system.

2.6 Recommendations

The following recommendations were made for application of the epoxy primer and polyurea waterproofing membrane:

1. Remove all laitance, oil, grease, and other surface contaminants from surfaces prior to installation of the system. Scarify surfaces by sandblasting or other techniques to produce a rough surface. It was recommended that the parge coat used to fill bugholes in the concrete be entirely removed from the concrete surfaces (but not from the bugholes) by sandblasting or other appropriate means. It was also recommended that the sandblasting provide a surface roughness similar to that of Test Area 1 or rougher. If surface preparation exposes additional bugholes, re-fill the bugholes and repeat surface preparation. After sandblasting, substrate surfaces should be cleaned carefully with

compressed air or a similar method to remove dust and loose sand from the surface.

2. Prior to application of the waterproofing system, measure substrate MVER at a minimum of two locations on the tank floors. If the substrate MVER is above 7 lbs/1000 sf in 24 hours, do not proceed with the installation of the system. To reduce MVER to acceptable levels:

- Prevent exposure of the tanks to any liquid water;
- Ventilate the tanks for several days prior to and during application using high-volume displacement fans; and
- Dehumidify the enclosed tanks for several days prior to application of the system. However, dehumidification should be stopped approximately 24 hours prior to application of the system.

3. Measure concrete surface temperatures with a temperature probe immediately prior to application of the system. Ensure that concrete surface temperature is lower than or equal to the ambient temperature inside the tank and that concrete surface temperature is at least 5 degrees higher than ambient dew point temperature.

4. Ensure that, after initial installation of the calcium chloride moisture kits, the slabs and walls remain dry and are not subject to flooding or run-off water.

5. Install the waterproofing system in accordance with the manufacturer's written instructions. Carefully monitor primer application rates and elapsed time between application of the primer and the polyurea membrane.

6. Carefully monitor the spray equipment for proper mixing ratios.

7. After application of the membrane, visually inspect all waterproofing membrane surfaces. If no blisters are detected, perform bond pull-off tests on the floor and walls of each tank. A minimum of three tests for each 5,000 sf of waterproofing is recommended. If the tank surfaces were less than 5,000 sf, we recommend a minimum of three tests for each tank. The majority of the tests were to be performed on the floor slabs. If individual bond pull-off values fall below 200 psi, re-assess the adequacy of the installation. Patch the test areas in accordance with the manufacturer's instructions. ■

ACKNOWLEDGEMENTS

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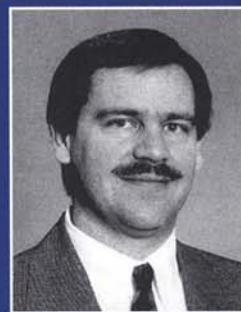
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Kami Farahmandpour is the principal of Building Technology Consultants, a forensic engineering firm specializing in the evaluation and repair of building envelope problems. Over his 17-year career in the construction industry, he has managed over 150 projects involving the evaluation and repair of building components. Mr. Farahmandpour is a Licensed Professional Engineer, Registered Roof Consultant, Certified Construction Specifier, and Certified Construction Contract Administrator. His expertise is concentrated in the area of building envelopes. He has performed numerous evaluations of concrete and masonry facades and roofing and waterproofing systems. Kami is an active member of several professional organizations, including the Roof Consultants Institute, International Concrete Repair Institute, and American Concrete Institute. He has authored a number of articles on building envelope evaluation and repair and has spoken at several seminars on the topic.

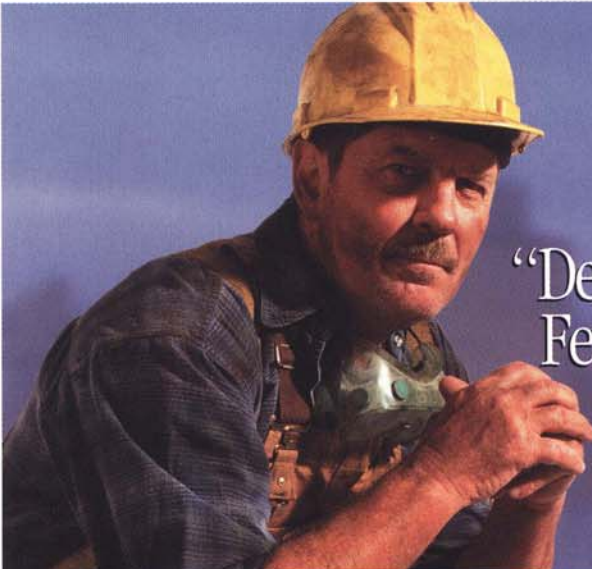



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Terry J. Willems is a Senior Materials Scientist at CTL, Inc., in Skokie, Illinois, with over 22 years of experience in the evaluation of engineered structures and construction materials. He has extensive experience in assessing concrete floor conditions, investigating problems, and recommending floor-coating systems. Mr. Willems has evaluated numerous concrete and masonry structures, including buildings, bridges, parking garages, tanks, dams, chimneys, and manufacturing facilities. His experience includes petrographic examination of concrete and other construction materials to ascertain causes of deterioration, identify materials, and assess quality for repair and rehabilitation projects. He is a member of the American Concrete Institute Committee 515 on use of waterproofing, dampproofing, and protective and decorative barrier systems for concrete. Willems has authored over 500 contract reports in the areas of materials evaluation and field troubleshooting of materials problems.




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