

# Rehabilitating Plaza Deck Waterproofing Systems

By Kami Farahmandpour, PE, RRC, RWC, CCS, CCCA  
Building Technology Consultants, PC  
1650 Arlington Heights Rd., #208, Arlington Heights, IL 60004  
Phone: (847) 788-8880 • Fax: (847) 788-8882  
E-mail: [kamif@btcpc.com](mailto:kamif@btcpc.com)

## INTRODUCTION

Rehabilitation of older plaza decks over occupied spaces poses several challenges. Typically, plaza decks that are subject to rehabilitation were constructed years ago and do not include drainage composite or any provisions for proper drainage slope at the waterproofing membrane layer. Adding these components can result in increased system thickness and additional dead loads, making the rehabilitation a challenge. In addition, every plaza project has its own set of unique challenges. These challenges can be related to design or construction.

## TYPICAL CHALLENGES WITH REHABILITATION OF EXISTING PLAZA DECKS

Rehabilitation of existing plaza decks pose several challenges. These challenges can typically be divided into two categories:

### Design Challenges

When tasked with design of a new waterproofing system for a plaza deck, a designer is typically forced to address several issues. Many of the issues are commonly related to anticipating the condition of the existing building components and installation details, and limitations posed by the existing construction. These issues include the following:

#### 1. Condition of the Existing Concrete Deck

Before designing a new waterproofing system, the designer should become thoroughly familiar with the existing condition of the components that will impact the performance of the new waterproofing system. For example, if the existing waterproofing system has been leaking for an extended period of time, it would be reasonable to expect some reinforcing steel corrosion-related damage in the concrete deck. While evaluation of the extent of corrosion damage in many parking garages and other exposed concrete decks is relatively simple, it is very difficult in plaza decks. This is due to the presence of the waterproofing system and the overlaying materials that make it impractical to examine the condition of the deck. The structural decks can sometimes (not often) be viewed from the bottom. However, in most cases, the deterioration begins at the top surface of the concrete deck. Therefore, a relatively flawless soffit surface on a plaza deck does not necessarily indicate that no corrosion damage exists on the top surface. In cases where the entire soffit surface can be examined, non-destructive testing (i.e., half cell potential, impact echo, etc.) of the slab from the soffit surfaces may yield some useful results. However, such testing is typically expensive and may not be practical in all cases.

Selective sounding of the structural slab top surfaces at exploratory openings is a practical method of obtaining information at a limited number of locations. Since exploratory openings are almost always needed to establish the existing deck slope and system configuration, it is typically beneficial to carefully examine the concrete deck surfaces at the exploratory openings.

In cold climates, the designer should also consider the potential for freeze-thaw damage of the structural slab, particularly along the outer edges of non-insulated decks.

Ultimately, the actual condition of the structural deck and the extent of deterioration (if any) will not be known with certainty until during construction. As such, the design documents should anticipate various types of repairs that may be needed to remedy the structural deck condition, and unit prices for such repairs should be incorporated into the contract documents.

Unfortunately, repair of the concrete decks typically causes substantial changes in the construction schedule and can pose the potential for leaving the concrete deck open for several weeks (see Installation Challenges for a discussion on logistical requirements).

## 2. Drainage Slope

One critical factor in evaluating the existing conditions is to determine the drainage slope at the surface where the new waterproofing membrane will be installed.

The 2003 version of the International Building Code (and most prior model building codes) require that "roofs" have a minimum slope of  $\frac{1}{4}$  inch per foot. While one may argue that these requirements may not apply to waterproofing systems, it is the author's opinion that, where possible, such slope should be designed in new waterproofing system. Good drainage slope will minimize water ponding, reduce the rate of waterproofing membrane deterioration, minimize hydrostatic pressure on waterproofing membranes, and reduce the potential for deterioration of other plaza deck components due to extensive exposure to moisture.

Given the critical nature of drainage, it is important that the drainage slope of the existing concrete deck be evaluated. Many older concrete plaza decks were constructed with a level deck. This is due to the difficulty of casting a concrete structural slab with proper drainage slope. Considering normal construction tolerances, creep, elastic deflections in concrete slabs, and normal building settlements, it is not unusual to find that certain areas of a plaza structural deck that were intended to be level, vary in elevation up to two or more inches. If the drains are located at the high points of the slab, this will cause excessive ponding.

In order to find the existing drainage patterns on a plaza deck, exploratory openings will be required. When selecting locations of exploratory openings one should consider the anticipated drainage pattern and select locations next to drains and areas furthest from the drains. The elevation measurements using conventional surveying tools can yield relatively accurate results regarding the existing contour of the structural slab.

Once the existing elevations and drainage slopes are determined, the designer can consider various method to improve drainage. However, in many cases involving older plaza decks, providing a  $\frac{1}{4}$ -inch-per-foot drainage slope is not practical, since the existing adjacent construction, such as doors and curtainwalls is usually placed near the surface of the existing plaza finishes. Providing a  $\frac{1}{4}$ -inch-per-foot drainage slope may require that those components be modified.

The various strategies for providing drainage slope are well-know in the industry. These include the following:

- **Placement of a bonded and tapered cementitious concrete topping over the existing structural deck.** This option is only practical when the additional dead loads imposed by such topping can be safely supported by the structural deck, and the additional thickness of the topping can be accommodated at perimeter conditions.
- **Placement of tapered rigid insulation below the waterproofing system.** This option will limit the designer in choice of waterproofing membrane. If exercised, the changes in condensation potential in the plaza deck assembly should be considered. In addition,

the insulation below the waterproofing membrane should be carefully selected to avoid crushing the insulation under plaza loads.

- **Addition of drains.** While this may be a seemingly simple solution, adding drain over occupied spaces is not always a practical option. Also, in some cases, several new drains will be needed to substantially reduce ponding potential over the waterproofing membrane.

### 3. Overall System Thickness and Flashing Heights

One of the most common challenges in designing new plaza deck assemblies for existing plaza decks is the limitations posed by flashing and penetration heights. Typically, existing adjacent masonry wall weep holes, drainage pans for adjacent curtainwalls, doors, and other penetrations are located within a few inches of the structural deck surfaces. This will make it difficult to modify the plaza assembly to provide subsurface drainage (drainage composites) or tapered topping slabs. For example, take the following case:

A curtainwall adjacent to the plaza deck is located nine inches above the structural slab. The structural slab is constructed level (i.e., no drainage slope), and the deck drains are located 24 feet away from the curtain. If the designer aims to provide a tapered topping slab having a slope of  $\frac{1}{4}$  inch per foot, the rise in the tapered topping slab from the drains to the curtainwall will be six inches. Considering that the tapered topping slab will need to have a finite thickness at the drains (say one inch), the total thickness of the topping slab will be seven inches along the curtainwall. This leaves only two inches for the flashing height at the curtainwall. That dimension will also have to accommodate the thickness of the drainage layer and wearing course.

As indicated by the above example, the designer is often faced with difficult choices. In the example, the only remedy will be to raise the curtainwall assembly to provide sufficient height to properly accommodate the tapered topping slab and other plaza deck assembly components. Alternatively, the designer can "compromise" and reduce the slope of the tapered topping slab to provide for improved flashing heights. Striking the balance between good subsurface drainage and flashing height is often a dilemma faced by the designer. Experience and judgment will play a key role in striking that balance.

### 4. Structural Capacity of the Slab

In the example discussed in Section 3 above, the designer's dilemma can be further complicated by the existing structural slab's structural capacity. Many of the older plaza decks may have been designed for lower live loads than currently required by building codes. Additionally, installing the proper plaza deck assembly components (such as a tapered topping slab) can add significant dead loads to the structural slab. As such, in any situation where the existing load capacity of the plaza slab is questionable, or if the new plaza assembly is expected to impose additional dead loads, a structural evaluation of the existing plaza slab should be performed. If the analysis indicates structural deficiencies, expensive and complicated structural repairs may be needed. Alternatively, the designer can examine all of his/her option for the new plaza assembly to assess potential means of reducing dead loads so that the structural slab can comply with the building code requirements.

Designers should be cautious of situations where a structural slab originally designed as a roof deck has been converted to a sundeck or plaza. In almost all situation, a structural slab designed to serve as a roof deck is not designed to safely carry the code-prescribed live loads.

### 5. Existing Conditions that do not Lend Themselves to Proper Detailing

In many projects, there are existing conditions that do not promote proper detailing of the waterproofing system. For example, some plaza decks will include exterior columns that may be clad with stone or pre-cast panels. Most plaza decks abut adjacent curtainwall systems and

other walls. Often, these structures that interface with the waterproofing system were originally constructed after installation of the waterproofing system. However, providing a new waterproofing system may be impractical without removing the adjacent materials such as curtainwalls and column claddings.

In some cases, these conditions can be addressed through a combination of design compromises and creative details. In other instances, other construction materials and building systems will have to be removed to accommodate the proper detailing of the waterproofing system.

## **6. Selection of an Appropriate Assembly**

A plaza deck is typically designed very differently than a roofing system. The deck surface will often need to accommodate heavy traffic and abuse. For that reason, the designer should separate the waterproofing membrane from the wearing surface. Plaza deck assemblies can be divided into two categories. These are typically referred to as "open joint systems" and "closed joint systems."

The closed joint systems are the most traditional types of plaza assemblies. In the "closed joint systems," a vast majority of the stormwater drains onto the plaza wearing surface, necessitating the use of a two-tier deck drain assembly. The wearing surface is typically constructed of cast-in-place concrete or mortar-set pavers. The pavers can be stone, brick, or pre-cast concrete. The joints between the pavers (or the control joints in the cast-in-place concrete wearing slab) will then be sealed with sealant or mortar. These joints will inevitably crack or deteriorate over time. The waterproofing system in a closed joint system is placed below the wearing surface (i.e., the mortar setting bed or concrete wearing slab). In earlier generation of waterproofing systems, no drainage composite was typically provided over the waterproofing membrane. However, more recently, closed joint systems typically include a drainage composite over the waterproofing membrane to facilitate drainage. Another advantage of placing a drainage composite over the waterproofing membrane is that it reduces the potential for critical saturation of the mortar setting bed or the concrete wearing slab. In cold climates, critical saturation of the mortar setting bed or the concrete wearing slab can lead to freeze-thaw damage and deterioration. For this reason, closed joint systems should be selected for cold regions with caution. Careful attention to the selection of the mortar or concrete mix, and quality control will be needed. Another consideration is that the salts and lime from the concrete or mortar setting bed will tend to be washed out and clog the drainage composite or its filter fabric. Application of de-icing salts can also lead to damage to the mortar setting beds and concrete surfaces due to crystallization pressure.

Recently, "open joint systems" have gained more acceptance since they offer many advantages. These systems are also commonly referred to as "pedestal paver systems." In open joint systems, the vast majority of the stormwater is drained through the wearing surface open joints down to the waterproofing membrane level. As such, primary waterproofing is provided by the waterproofing membrane. In many cases, the use of a drainage composite is not required since the wearing surface pavers are typically supported on pedestals or shims. This creates an open cavity below the pavers that facilitates good drainage. Another advantage offered by open joint systems is that the wearing surface can be constructed level for improved aesthetics. There is typically no need for the use of surface drains. Therefore, deck drains can also be concealed below the pavers. However, like any other alternative, open joint systems have their disadvantages. Without careful installation, the pavers can rock, crack, or get displaced. Typically, the perimeter confinement of the pavers should be carefully designed to minimize the potential for paver shifting. Also, pedestal-supported paver systems are not suitable for plaza surfaces subjected to heavy vehicular traffic.

## **7. Membrane Selection**

The appropriate selection of a waterproofing membrane deserves a long discussion. For the purposes of this article, it should be emphasized that one of the factors in selecting a waterproofing membrane is the practicality of its installation. For example: selecting a hot rubberized asphalt or bituminous roofing membrane may pose installation challenges when the installation is expected to take place in an environment with little or no tolerance to odors. Another consideration is the time required for curing of the substrate and the waterproofing membrane. Cold-applied waterproofing membranes typically require longer curing times and are more susceptible to problems associated with moisture emission from the substrate concrete.

## **Installation Challenges**

Ideally, most detailing and installation issues should be anticipated during the design process. In addition to detailing and installation issues, the designers are also often forced to consider logistical problems associated with rehabilitating plaza decks over occupied spaces. Every project can have its own set of logistical and field problems. However, in the author's experience, logistical challenges associated with environmental issues, temporary weather protection, and surface preparation are common to most projects.

### **1. Environmental Issues**

The installation of some waterproofing systems (such as loose-laid thermoplastic membranes) may have little or no impact on the surrounding environment. Such systems typically lend themselves well to installation in areas where there are sensitivities to odors, VOCs, and fumes generated during installation of chemically-cured waterproofing systems or hot-applied systems. However, in many instances, VOCs, fumes, and odor issues can be managed to acceptable levels through implementation of controls and processes during installation. Such controls and processes can include the following:

- Installation can occur during hours where there is less sensitivity to environmental issues (i.e. off hours for an office or school buildings).
- Fume, VOC or odor generation can be reduced significantly through the use of alternative materials. For example, when applying a traffic bearing waterproofing membrane, two-component materials with less VOCs can be specified.
- The impact of the generated VOCs, fumes and odors can be minimized by re-routing air intakes into occupied spaces and ensuring that air leakage paths in the building envelope are sealed properly.

### **2. Temporary Weather Protection**

Rehabilitating a plaza deck over occupied spaces will almost always involve the removal (or damage of) the existing waterproofing membrane. While in many instances the existing waterproofing membrane is already deteriorated and leaks in several locations, its complete removal can only exacerbate the potential for leaks during construction.

Unlike roofing where the same areas torn off in a day are typically covered the same day, rehabilitation of waterproofing systems requires much more extensive surface preparation. Factors that influence how much time elapses between the removal of the waterproofing membrane and installation of a new one include the following:

- Waterproofing membranes are typically fully-adhered and will need to be removed with power equipment. In some instances, the entire surface will have to be ground or scarified to remove the existing waterproofing system. This is typically a time consuming process that does not allow removal and installation of new waterproofing membrane in the same day.

- In many cases, the existing concrete structural slabs will require repairs. These repairs will take a few days to implement, and many more days to properly cure before they can be overlaid with a new waterproofing membrane. If the new waterproofing membrane is fully-adhered, then moisture emission issues from the newly repaired areas should also be considered. Without some sort of forced drying and moisture protection, occasional rainfall can result in weeks of delays.
- In some cases, a new tapered cementitious topping slab is required to provide adequate drainage slope.

### **3. Surface Preparation**

Surface preparation can play a key role in the long-term performance of the waterproofing membrane. It is often believed that surface preparation for loose-laid waterproofing membranes is not critical. The author has observed single-ply loose-laid waterproofing membrane failures resulting from inadequate surface cleaning prior to application of membrane. When small pieces of gravel or large sand particles are left on the substrate surface and the membrane is applied directly over the substrate, punctures can result.

When using a fully-adhered waterproofing membrane, surface preparation becomes one of the most critical factors in performance of the membrane. Fully-adhered membranes will depend on their bond to the substrate for proper performance. In addition, the structural integrity of the substrate can impact them significantly, since any un-accommodated movements in the substrate can result in failures in the membrane.

Surface preparation problems can be divided into several categories, as follows:

#### **A. Laitance, Dust and Chemical Contamination on the Substrate**

In many instances, dust, grease or other surface contaminants can result in poor adhesion. Other factors that are often overlooked include the presence of laitance (particularly on newer concrete surfaces), presence of concrete curing compounds, or surface sealers.

When specifying new concrete topping slabs over existing concrete decks, the designer should carefully consider curing methods and other potential factors that can inhibit the bond of the new waterproofing membrane to the substrate. In the author's opinion, wet curing using burlaps is one of the best methods for curing fresh concrete. However, even in instances where the use of sealers and curing compounds is avoided, laitance can form on the surface. Therefore, when the bond of the membrane to the substrate is critical (as is the case in almost all of the bonded waterproofing membranes), surface preparation using shot blasting or similar methods would be beneficial. Slightly roughened concrete surfaces promote better primer penetration and mechanical bond between the waterproofing membrane and the substrate. They also help remove the weak laitance layer that typically forms on fresh concrete surfaces. When performing surface preparation using mechanical methods, care should be exercised to avoid over-roughening the substrate, as large peaks and valleys in the substrate can result in undesirable membrane thickness variations.

One good source for specifying the required surface roughness for concrete substrates is ICRI Guideline No. 03732 – Selecting and Specifying Concrete Surface Preparation for Sealants, Coatings, and Polymer Overlays. This guide provides an overview of various surface preparation methods and establishes nine concrete surface profiles (CSP) that can be specified. Typically, a surface profile ranging from CSP 1 to CSP 4 is used for waterproofing membrane.<sup>i</sup>

In some cases, roughening of substrates can be performed using acid etching. However, if not properly performed, acid etching can result in damage to the concrete substrates. Furthermore, acid etching will require neutralizing and a thorough wash after application of diluted acid solution. This process introduces more moisture into the substrate that will necessitate longer drying if an adhered waterproofing system is used. When performing any chemical cleaning of

the concrete substrates, the pH of the substrate should be tested in accordance with ASTM D-4262 prior to application of the waterproofing membrane.<sup>ii</sup>

Removal of grease can be performed with detergent cleaning. Once again, the final rinse will result in introduction of moisture into the substrate.

One of the most critical surface preparation factors for adhered waterproofing membranes is dust. Dust should be thoroughly cleaned with oil-free compressed air. However, in many instances, blowing the surface clean with compressed air will simply result in re-depositing the dust elsewhere. In the author's opinion, the most suitable method for removing dust from the substrates is vacuum cleaning. To verify that dust has been removed from concrete surface, the concrete surface can be wiped with a clean black cloth. Any dust deposits on the concrete surface will be readily observable on the black cloth.

## **B. Moisture Emission through the Substrate**

One of the most prevalent modes of failure in liquid-applied membranes (LAM) is blistering and debonding due to substrate moisture emissions

The mechanism of moisture emission from concrete substrates is a complex one that requires thorough understanding of concrete properties, moisture vapor pressure in concrete, and environmental factors. The author has attempted to discuss this phenomenon in a separate article.<sup>iii</sup> Portions of that discussion are repeated in this article.

Concrete is a porous material. The porosity of concrete greatly depends on its quality and water-to-cement ratio (w/c). As such, concrete always contains some moisture. Depending on the relative humidity and temperature of the concrete, and relative humidity and temperature of the ambient air, concrete either emits or absorbs moisture in vapor form. In addition, concrete can also absorb significant amounts of liquid water when exposed to it.

In most cases, concrete surfaces that appear to be dry are either emitting or absorbing water vapor. If liquid water moves through the concrete, as long as the rate of evaporation from the surface is greater than the rate of moisture emission, the concrete surface appears dry. If moisture moves through the concrete in vapor form, the concrete surface will not have a wet appearance, regardless of the evaporation rate.

When a membrane is applied to the surface of concrete in fluid form, it creates a vapor retarder at the concrete surface that prevents evaporation or moisture emission. Therefore, water vapor moving to the surface of the membrane cannot escape, thus causing a build-up of water vapor pressure between the membrane and concrete surface. This phenomenon can occur within minutes of applying a membrane to concrete surfaces. In the case of hot-applied membranes, the moisture emission mechanism is further complicated by the heat transfer into the concrete. Build-up of water vapor pressure shortly after application can inhibit development of a proper bond between the membrane and the concrete substrate.

In some cases, the moisture being emitted from the concrete surface works its way to the outer surface of the membrane before the membrane cures or cools. This typically manifests as pinholes in the membrane that can lead to leakage under hydrostatic pressure. However, it is important to note that other causes of pinhole formation, such as entrained air due to application and formation of gases due to the membrane's chemical curing mechanism, do exist.

There are also some myths regarding the causes of failure. For example, some believe that moisture vapor emission long after the membrane has cured can cause debonding and failure. With the exception of those few membranes that are susceptible to alkali attack at the bond line, such mechanism cannot cause debonding of the membrane after it has cured and established proper bond to the substrate. The bond value of most membranes to concrete is in excess of 200 PSI, while the water vapor pressure differences are less than 1 PSI. As such, water vapor pressure alone cannot cause a physical failure at the bond line between a well-bonded membrane and the concrete substrate.

Another common myth in the industry is that if the concrete is cured for 28 days, it will be suitable for application of liquid-applied membranes. Several membrane manufacturer application instructions indicate "fully-cured" or "28-day cured concrete" as the only moisture criteria for application of their membrane. The most important factor to consider is service environment. If the concrete has cured for 27 days and then is exposed to rain, the moisture content in the concrete will be increased to a level close to the initial moisture content and will require a longer drying time than concrete that is kept continuously dry. Other factors such as ambient temperature and humidity during curing will affect the rate of drying. While the age of concrete can be one factor, it does not correlate well with its moisture vapor emission rate (MVER).

Other manufacturers stipulate that the concrete "shall be dry" prior to application of their material. If "dry" implies completely free of moisture, in the author's opinion, obtaining "dry" concrete in most construction projects is impractical. The term "dry" needs to be clearly defined by the manufacturer and specific acceptance criteria should be provided.

Currently, the most widely used method for evaluating surface moisture condition of the concrete substrates for application of waterproofing membranes is ASTM D-4263.<sup>iv</sup> This test method involves installing a plastic sheet on the concrete surface and monitoring it for formation of visible moisture below the sheet. This test method can provide useful information for acceptance of a concrete substrate for waterproofing system application. However, it does not provide any qualitative results. Furthermore, in the author's experience, it may indicate false results under certain conditions.

Another method that can be used for qualitative measurement of moisture emission from a concrete substrate is ASTM F-1869.<sup>v</sup> This test takes approximately 72 hours to complete, which may make it impractical to use in many waterproofing situations. The results are expressed in pounds of moisture vapor emitted through the surface in 24 hours for 1000 square feet of concrete surface. The results obtained reflect only the condition of the concrete at the time of the test. Another drawback to this test is that there are currently no industry standards for threshold MVER values obtained through ASTM F-1869 prior to application of waterproofing membranes. However, a value of 3.0 pounds in 24 hours/1000 sf has been used by some as the threshold for application of impermeable membranes.

While concrete MVER can be remotely related to its moisture content, other factors such as ambient relative humidity and temperature and concrete temperature play a large role in determining MVERs from concrete surfaces.

Despite its drawbacks, in the author's opinion, this test method is a good tool for evaluating the MVER of concrete surfaces.

Other methods, such as measuring the relative humidity gradients within the concrete slabs, have been used with success. This method involves drilling holes in the concrete, placing relative humidity probes at different depths, and monitoring relative humidity profiles in the concrete. Experienced operators are required to gather and interpret the data. These methods are currently somewhat more sophisticated for everyday use at construction sites and have not gained widespread acceptance.

Ultimately, the objective is to achieve good bond to the substrate without blister formation. To that end, a simple patch test (applying the waterproofing membrane to a small area) may provide the best results. In the case of hot fluid-applied membranes, this may be the most practical method. However, in the case of chemically cured membrane that take longer to cure, this may not provide a practical solution for evaluating substrate moisture conditions.

In the author's opinion, more research is required in this area to develop realistic test methods and acceptance criterion for substrate moisture emission rates.



### C. Physical Deficiencies in the Substrate

For a waterproofing membrane to perform properly, it will have to be placed over a sound substrate. Physical deficiencies in concrete substrates can result in premature waterproofing membrane failures. These physical deficiencies can include cracking, delamination, scaling, etc. These issues are more critical in the case of fully-adhered waterproofing membrane.

Requirements for treatment of cracks can vary significantly from one manufacturer to another. In general, most manufacturers of adhered membranes would require that moving or dynamic cracks will have to be treated with a detail coat or additional reinforcing layer. The additional reinforcing layer is required to distribute the strain caused by the movement over a wider area, thus reducing stresses in the waterproofing membrane. In the author's opinion, the ultimate movement capability of the waterproofing membrane should not be relied upon to design for movements over cracks since the membrane's movement capabilities can diminish over time.

Consideration should also be given to cracks that are too narrow to be identified visually, but can widen over time. A crack measuring 2 mils wide can easily widen to 20 mils wide, resulting in a theoretical movement of 1000%. This can happen with freshly placed concrete substrates where the concrete substrates can undergo drying shrinkage. For this reason, initial wet curing and allowing the concrete to undergo shrinkage for some time is critical.

### CONCLUSION

When designing a replacement waterproofing system for an existing plaza deck, the designer is faced with many challenges. Ultimately, the designer should address all of these challenges while maintaining the integrity of the design and considering the impact of the solutions on the durability of the system. In many instances, the designer is faced with difficult decisions and is forced to compromise on certain design principles that can result in code violations, reduced durability, or higher potential for future leaks. The decision on where to compromise will largely depend on the designer's experience and understanding of the particular requirements of the project.

In addition to design considerations, site factors and logistical issues should also be considered. Proper consideration of these factors will require a thorough understanding of the construction and installation process, and site limitations.

### REFERENCES

- i ICRI Guideline No. 03732 – "Selecting and Specifying Concrete Surface Preparation for Sealants, Coatings, and Polymer Overlays," International Concrete Repair Institute.
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- iii Farahmandpour, K. "How Dry Should Concrete Decks Be...For Application of Liquid-Applied Waterproofing Membranes?" *RCI Interface*, October 2001.
- iv American Society for Testing and Materials, ASTM D-4263 "Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method."
- v American Society for Testing and Materials, ASTM F 1869, "Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride"