Concrete Deck Moisture Issues: Causes and Preventative Measures

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ABSTRACT

The frequency of moisture-related claims in concrete roof decks has been increasing rapidly over the past few years. The issues are typically encountered on roofs that have not exhibited any leakage and generally appear to have been properly installed, yet when cut open, are found to be damp to wet across the entire roof surface. Reasons for these issues include changes in system buildups, year-round construction in all climates, and accelerated construction schedules. Exacerbating the problem is the increased usage of lightweight structural concrete. This presentation will review the key issues involved and provide practical recommendations for preventing problems, as well as potential remedial approaches in situations where problems have occurred.

SPEAKER

STEPHEN CONDREN, PE — SIMPSON, GUMPERTZ & HEGER INC.

STEPHEN CONDREN, a senior project manager, joined Simpson Gumpertz & Heger in 1980. He specializes in building envelopes, including roofing of all types, masonry, flashings, waterproofing, and thermal and moisture analyses. Condren has designed new and remedial roofing, waterproofing, masonry, sealant systems, and curtain walls and is involved in bid and construction-phase services for new and remedial construction. He has authored articles on roofing and is involved with many construction industry organizations, including the American Society of Civil Engineers and ASTM International.

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JOE SCHWETZ is the Director of Technical Services for Sika Roofing. He has a degree in architectural engineering from SUNY and has worked in the roofing industry for over 30 years in various research and development, technical, and managerial capacities. He is active in various technical standards and code development bodies, including SPRI, SIGDERS, and ASTM, where he cochairs ASTM Subcommittee D08.18. Schwetz received the ASTM Award of Merit in 2015.

NON-PRESENTING COAUTHOR

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CONCRETE DECK MOISTURE ISSUES: CAUSES AND PREVENTATIVE MEASURES

ABSTRACT

The frequency of moisture-related claims involving concrete roof decks has been increasing rapidly over the past few years. Problems have been reported under all types of roof systems in most climates. The issues are typically encountered on roofs that have not exhibited any leakage and that generally appear to have been properly installed, yet when cut open, are found to be damp to wet across the entire roof surface. Legal experts specializing in the construction industry expect this to be the most frequent source of roofing-related litigation in the coming years.

There are numerous reasons for these issues, including changes in system buildups, year-round construction in all climates, and accelerated construction schedules. Exacerbating the problem is the increased use of lightweight structural concrete (LWSC).

Much has been written on the topic, and various trade groups have weighed in on the matter. Most of the published literature highlights potential causes and recommends caution installing roofs on concrete decks, but generally, they provide little to no specific advice on how to avoid problems. This paper will review the key issues involved, provide practical recommendations for preventing problems from occurring, and pose potential remedial approaches in situations where problems have occurred.

INTRODUCTION

The low-slope commercial roofing industry is increasingly faced with moisture-related claims over concrete decks. Roof assemblies over concrete decks are typically no more prone to leakage than similar systems over other types of decks such as steel or wood. There is, however, a general consensus that problems resulting from moisture migration from the deck into the roof assembly are on the upswing. We have been installing roofs over concrete decks for many, many decades. Concrete is still basically a mixture of Portland cement, aggregate, and water. What, if anything, has changed?

Our quest for ever-more-aggressive construction schedules may be a contributing factor. Regardless of the time of the year or a building’s location, builders are striving to get structures “closed-in” as fast as possible, often squeezing the time available between when the concrete deck is poured and when the roof is installed. The initiation of interior work such as pouring floor slabs, drywall installation, and application of interior finishes, is constantly compressed, generating large quantities of moisture that are available to migrate into the newly completed roofing assembly. Although these are no doubt contributing factors, there are other, likely more important mechanisms at play.

Perhaps of greater significance are the changes that have occurred over the past years in the way we construct roofs over concrete decks. In the past, forms upon which the wet concrete was placed to create the deck were removed after the concrete had achieved the desired strength. Once the roof assembly was installed and the interior space was conditioned and occupied, any residual moisture in the deck could migrate into the building, allowing the deck to dry gradually over time. Traditionally, insulation was bonded to concrete substrates in a full mopping of hot asphalt. Regardless of whether plies of felt were included to intentionally create a vapor retarder, the continuous asphalt “adhesive” provided the roofing assembly with a degree of protection from upward moisture migration from the deck.

The ASHRAE Book of Fundamentals lists asphalt, applied at 22 lbs. per 100 sq. ft., with a permeance of 0.1 perm, which makes the film a Class I vapor retarder. In contrast, low-rise urethane insulation adhesives, which have significantly increased in usage, are relatively porous and, more importantly, are applied in ribbons that are discontinuous across the roof surface, thereby providing no barrier to moisture migration.

Wintertime vapor drive typically moves the moisture in the concrete upward toward the roof membrane, where it can condense. Here, changes in materials and technology may be making our roofs more vulnerable to damage. In the past, relatively massive, absorbent materials such as rigid fiberglass and wood fiber insulation were used. Although excessive amounts of moisture would ultimately doom the assembly to failure, these products could safely store a certain amount of moisture without significant loss of performance, particularly if they could seasonally dry under favorable vapor drive conditions.

Products commonly used in today’s roof systems, such as organic-faced polyisocyanurate insulation and gypsum-based cover boards, suffer from significant loss of cohesive strength in the face and/or have dimensional stability issues when wetted to as little as 2 or 3% moisture by weight. The durability performance (i.e., freeze/thaw and traffic resistance of gypsum products) drops significantly when approaching these moisture levels. There appear to be numerous buildings protected by roof assemblies built over concrete decks, with forms left in place, without vapor retarders, incorporating the components listed above that have performed without issue over many years.

The challenge is that in combination, these elements allow for a very small, if any, margin of error with regard to the amount of excess moisture remaining in the concrete at the time they are installed. Although the potential for problems exists on all projects that have concrete decks, the risk is higher when using LWSC, which is made up of very porous aggregate that retains much more water.

Reroofing over concrete decks presents its own unique challenges. Often, buildings are only reroofed after significant leakage has occurred over long periods of time, allowing significant amounts of moisture to accumulate in the roofing system and the concrete deck. By necessity, as the existing roof system is removed, the new system is installed as quickly as practical thereafter in order to protect the interior space. The wet concrete deck may be exposed for a few hours before being covered with the new system. This may allow for surface drying, but is not sufficient to adequately dry a wet concrete deck.
Industry-wide, the issue is compounded by the lack of a reliable test method for determining the amount of moisture in concrete roof decks and by our inability to answer the fundamental question of how dry a concrete deck needs to be before installing the roofing assemblies.

INDUSTRY POSITION

The roofing industry has attempted to notify and educate roofing professionals of the potential issues involved with moisture content.

Various roofing industry trade organizations, such as ARMA, the National Roofing Contractors Association (NRCA), the association representing the Single-Ply Roofing Industry (SPRI), RCI, and the Polyisocyanurate Insulation Manufacturers Association (PIMA), have released position statements regarding the issue of moisture in concrete decks. Basically, these organizations suggest the designer of record be aware of the moisture issues with new concrete and select components and systems that can accommodate the moisture.

The Midwest Roofing Contractor Association (MRCA) T & R Advisory Bulletin 1/2011, “Structural Lightweight Concrete Roof Decks,” suggests its contractors provide the designer of record and general contractor with a copy of the MRCA bulletin that discusses issues on moisture in concrete, along with having them review the American Concrete Institute (ACI) document ACI 214R-03 (“Guide for Structural Lightweight Aggregate Concrete”) and the Portland Cement Association (PCA) Engineering Bulletin 119 (“Concrete Floors and Moisture – 2008”).

The NRCA, in its August 2013 “Industry Issue Update,” suggests that the project structural engineer, general contractor, concrete supplier, and concrete placement contractor recommend when the new concrete is ready to be covered. Their reasoning is that this group will have the best knowledge of the concrete’s cure and moisture-release rates. The NRCA also recommends that LWSC not be used for roof decks or toppings for roof decks. They suggest that if LWSC is used, that designers specify the concrete’s drying parameters, using ASTM F2170 to determine the relative humidity (RH). They suggest decks receiving roofing systems should have a maximum RH of 75% until there is an industry consensus as to what the value should be.

In reroofing situations where the existing deck is LWSC or the existing deck is known to be wet, the NRCA recommends two alternative roof designs. Either provide for above-deck venting with a venting base sheet with a loose-laid ballasted roof system and perimeter venting, which may allow release of the moisture; or seal the moisture into the deck by using an adhered vapor retarder, followed by an adhered roof system.

FM Global initially did not recognize LWSC as an approved substrate, as it did not meet their definition of structural concrete. In the current version of 4470 (dated 2012), FM defines structural concrete as having a density of approximately 150 lbs./ft. ²; LSSC has a density of 90 to 130 lbs./ft. ². FM Global will be addressing the use of LWSC in its revised Loss Prevention Data Sheet (LPDS) 1-29. In the revision, FM will allow the use of the LWSC if the structure cannot support normal-weight concrete. They will suggest that removable forms be used whenever possible. If the forms cannot be removed, they will recommend the lowest water/cement ratio possible.

If LWSC is used, FM Global will require a test to be performed to ensure that the moisture migration will be reduced to the point where any damage to the above-deck components is minimal. Unfortunately, FM Global does not offer a test method to determine the moisture in concrete.

They will also require above-deck components to be resistant to moisture or the installation of a vapor retarder that will limit moisture migration to the components.

The Steel Deck Institute (SDI) issued a Position Statement in May 2012 to address inquiries regarding the use of vented steel form decks. They note that vented steel form decks traditionally have been used to drain “excess” mix water from the cementitious slurry of lightweight insulating concrete (LWIC). The venting allows for the reduction of vapor pressure once the roof cover is installed over the LWIC. They caution that LWIC is quite different from LWSC. When designing for LWSC, SDI notes:

While it is known that the inclusion of slots has little effect on the strength of the steel deck, it is unknown what the effect of draining mix water through the bottom of the deck has on the properties of the cured concrete and the bond of the concrete to the deck. Specifiers should proceed with caution when requiring slots in this application.

The steel deck acts as a vapor retarder, preventing diffusion of water vapor out of the bottom of the slab. Some publications note that the amount of diffusion is directly proportional to the open area in the vapor retarder (Fick’s Law). For example, providing a hypothetical 1.5% open area will increase the diffusion of water vapor by 1.5%, an inconsequential amount. This has been experimentally verified through testing sponsored by the Expanded Shale Clay and Slate Institute, which has shown that the rate of concrete drying is not increased by venting the steel deck.

To summarize, the roofing industry has generally taken the position that the building’s designers must be aware of the issues and take responsibility for the selection and timing of roofing system placement when there is a concern with moisture in concrete. Some industry stakeholders have taken the position that if at all possible, LWSC should not be used for the roof deck. The designer should contact all parties involved with the roofing portion of the project to establish requirements on the schedule for covering the concrete. The method used may be to allow for venting of the moisture or encapsulating the moisture by using a well-secured vapor retarder, both of which are discussed below. Testing of the concrete is suggested by some organizations, specifically using ASTM F2170, even though this test method is not designed for an exposed concrete slab.

CONCRETE

Concrete Composition

Concrete is a mixture of Portland cement, aggregates, air voids, water, and other additives. Concrete hardens by the occurrence of a chemical process; a portion of the mix water reacts with the cement and any pozzolanic additives present to form the hydrated binder of the hardened concrete. Concrete does not harden by drying.

Concrete contains additional water to provide the fluidity for placement and finishing of the freshly mixed concrete. Although chemical admixtures may reduce
the amount of additional water required, all freshly placed concrete will contain more water than what is consumed in hydration reactions.

The mix water added to the concrete mixture is expressed as the water-to-cementitious material ratio (w/cm). Most concrete mixes are batched at 0.40 to 0.55 w/cm. The cement hydration process (most of which occurs within the first month) consumes about 0.25 w/cm. This leaves an additional 0.15 to 0.30 w/cm, which will remain in the concrete as liquid water in the capillaries and pore spaces; this is sometimes referred to as “free water.”

In addition, the aggregates absorb water: 0.1 to 2% for normal-weight aggregates, and between 10 and 30% for lightweight aggregates. This water will also be contained as free water within the concrete after it has been placed.

### Differences Among Concretes

Concretes used in roof decks fall into three categories: structural concrete (SC), structural lightweight concrete (SLWC), and cellular lightweight concrete (CLWC). Structural and lightweight structural concrete contain graded aggregates. Cellular concrete is made from cement, water, and a foaming agent and does not typically contain any aggregates. Lightweight insulating concrete (LWIC), containing a large quantity of water, is also used in roof decks, but we did not include the material in this study.

The aggregates in SC are graded, dense stone with a density of 110 pounds per cubic foot (pcf), resulting in concrete that weighs 150 pcf. The aggregates in SLWC are porous stone, either natural or man-made, with a density of less than 70 pounds per cubic foot (pcf), resulting in concrete that weighs 90 to 115 pcf. Precast concrete can be made from SC or SLWC.

Cellular concrete used in roofing cures to produce a medium of closed-cell cement foam with a dry density ranging from 26 to 32 pcf and compressive strength of 180 to 280 psi. Cellular concrete is not structural and is typically used to provide slope to structural roof decks to promote drainage.

### Moisture Sources in Concrete Decks

#### New Construction

New concrete roof deck construction will contain varying amounts of water, based on the type of concrete and the aggregates used in the mix. Most concrete roof decks constructed today are placed over a steel deck that serves as a form that remains in place. The metal deck essentially prevents moisture from evaporating from the underside of the deck. Although some metal decks are slotted along the ribs (flutes) on the corrugated forms, the area of these perforations is only 0.25% to 1.5% of the metal deck surface, allowing only a minimal amount of moisture evaporation through the metal deck. Precast concrete will not have forms.

*Table 1* presents a summary of conditions for typical concretes that are used for roof decks. The numbers are based on a 6-in. thickness for the roof deck. The last line includes how much free water remains in the concrete after the concrete has cured for 30 days by hydration of the cementitious components.

A new 6-in.-thick concrete deck will contain 0.9 to 2.6 quarts of the original mix water per square foot at one month of age. This assumes that no additional water is provided during placement and finishing and the curing process. This is the typical time when the construction schedule will expect the application of the roofing system.

In reality, additional water is often added to the fresh concrete to assist with pumping and placement. Finished concrete needs to be wet-cured by sealing the surface to prevent evaporation or by applying water onto the surface until the concrete has developed sufficient strength to prevent surface cracks due to surface drying. It is also unreasonable to assume that the exposed deck will not be exposed to precipitation between its construction and full cure. Placement, curing, and precipitation will add an undetermined amount of water to the deck.

When the roofing system is being installed, the new roof deck will contain a minimum of 0.9 to 2.6 quarts of free water (for a 6-in.-thick deck) that will be available to migrate into a roofing system.

### Reroofing

The conditions described above are what can be expected for new construction. The assumptions (i.e., no water added during
Normal-Weight Lightweight Structural Cellular Concrete (qt./sq. ft.)

<table>
<thead>
<tr>
<th></th>
<th>Normal-Weight Concrete (qt./sq. ft.) (% of evaporable water)</th>
<th>Lightweight Structural Concrete (20% Aggregate Absorption) (qt./sq. ft.) (% of evaporable water)</th>
<th>Cellular Concrete @ 14 days (qt./sq. ft.) (% of evaporable water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold-moist climate</td>
<td>0.7 (80%)</td>
<td>2.2 (87%)</td>
<td>0.5 (33%)</td>
</tr>
<tr>
<td>International Falls, MN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm-humid climate</td>
<td>0.7 (80%)</td>
<td>2.2 (187%)</td>
<td>0.6 (35%)</td>
</tr>
<tr>
<td>Miami, FL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm-dry climate</td>
<td>0.6 (70%)</td>
<td>2.1 (83%)</td>
<td>0.3 (15%)</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 – Water remaining in concrete roof decks exposed for one month.

SGH found that the amount of water evaporating from the exposed concrete roof decks during the month before applying the roofing system, with the exception of cellular concrete, is only a small portion of the available excess water remaining in the concrete roof decks. The water that remains in the deck after this initial period of evaporation is shown in Table 2.

The results show that there is no location in the United States that will dry all of the excess water contained in the concrete within 30 days after placing.

In Figure 1, we show how much drying can occur if the evaporation time is extended to one year. The graphs are based on the assumption that the deck can be left exposed for one year without precipitation, an unlikely condition without providing temporary protection. Both the normal-weight and lightweight concrete decks will still contain free water if allowed to dry for one year in all regions.

In the real world, water from curing and precipitation must be taken into account, which means the free-water content within the concrete can be expected to remain significantly higher for prolonged periods.

To evaluate the effect that the free water in the concrete deck has on the roofing materials, we need to consider the vapor drive of the moisture into the roofing materials from the concrete in a roofing assembly that does not contain a vapor retarder. We use RH to evaluate the vapor drive. When the concrete begins drying, the RH within...
In addition, conditions may change as the work moves into a different area of the deck.

Comments Regarding the Qualitative Methods

Both of these methods have limitations, including locations of the test areas, such as in direct sun or shaded areas, as well as primarily evaluating only the moisture at the upper thickness of the roof deck.

The plastic film test is no longer considered a valid test, especially with LWSC. The NRCA stated in an Industry Issue Update titled “Moisture in Lightweight Structural Concrete Roof Decks” that this method is unreliable. The NRCA notes the difficulty in achieving an airtight seal between the film and the concrete deck. It also states that if the temperatures on both the top and bottom of the concrete slab are not nearly identical, the pressure difference can result in a false “dry” result. Additionally, Mark Graham of the NRCA (in a presentation, “Problems and Risks Posed by Concrete Roof Decks,” at the September 2013 NLRRC Conference) noted that the “historical guidelines”—including the plastic film test and the application of hot bitumen—are not appropriate for current generations of concrete mixes.

Quantitative Methods

Quantitative methods include:

ASTM F1869, Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride

This test method measures the rate of moisture vapor emitted from concrete, in pounds of moisture over a 1,000-sq.-ft. area during a 24-hour period. The requirement for this test is for it to be conducted at the same temperature and humidity expected during normal use. If this is not possible, then the test conditions will be 75° ± 10°F and 50 ± 10% relative humidity, for 48 hours prior to and during testing. These conditions will be very difficult, if not impossible, to achieve when testing an exposed concrete roof deck. The ASTM standard also notes, “The results obtained reflect the conditions of the concrete at the surface at the time of the testing.

Table 3 – RH of one-month-old concrete.

<table>
<thead>
<tr>
<th>Location</th>
<th>Normal-weight Concrete (% RH)</th>
<th>Lightweight Concrete (20% Aggregate Absorption) (% RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoenix, AZ</td>
<td>94</td>
<td>98</td>
</tr>
<tr>
<td>International Falls, MN (cold and moist)</td>
<td>97</td>
<td>99</td>
</tr>
<tr>
<td>Miami, FL (hot and humid)</td>
<td>97</td>
<td>99</td>
</tr>
</tbody>
</table>

Qualitative Methods

Qualitative methods include:

ASTM D4263, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method

This method uses a transparent polyethylene sheet approximately 4 mils thick, secured to the concrete substrate with a 2-in.-wide adhesive tape. The secure plastic sheet remains in place for a minimum of 16 hours. After the allotted time has elapsed, the film is removed and the surfaces are visually inspected for the presence of moisture—typically a darkened concrete surface or condensation on the underside of the plastic sheet.

There is a note in Section 4.0 of the standard that cautions that the test should be conducted when the surface temperature and ambient conditions are within the parameters for application of the coating system, and to avoid direct sunlight, direct heat, or damage to the plastic sheet. These conditions are not feasible on a roof deck exposed to the elements.

The Application of Hot Bitumen Directly to the Concrete

While this is not a standard test method, this procedure has been used by the roofing industry for many decades to determine if components may be hot-mopped to the concrete. The concept is if there is foaming of the hot asphalt or the asphalt is easily removed after it has cooled, the concrete is too wet to install the roof system. Not being a standard test method, there is no direction as to any precautions that should be taken for this procedure.

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and may not indicate future conditions." The National Ready-Mixed Concrete Association (NRMCA), in its Concrete in Practice technical bulletin CIP-28, comments on ASTM F1869, "...[F1869] has some major shortcomings: it determines only a portion of the free moisture at a shallow depth of concrete near the surface of the slab." While this test method is relatively inexpensive, it is not very accurate, is sensitive to air temperature and humidity, and only measures the effect of moisture from minimum or shallow depths.

**ASTM F2170, Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In-Situ Probes**

This test method requires cores for placing the liner/sleeve into the central region of the concrete deck for determining the RH of the material (Figures 2 and 3). It requires that the holes reach thermal and moisture equilibrium before starting the measurement for RH. This time may be anywhere from several hours to several days, depending on temperature differences between the probes and the concrete in a stable interior environment. When testing an exposed roof deck, however, the changing conditions on the topside of the concrete roof deck make obtaining accurate, reproducible readings difficult to achieve.

**ASTM F2659, Standard Guide for Preliminary Evaluation of Comparative Moisture Condition of Concrete, Gypsum Cement, and Other Floor Slabs and Screeds Using Nondestructive Electronic Moisture Meter**

This guide notes in its scope, "Results from this guide do not provide vital information when evaluating thick slabs...[of] lightweight aggregate concrete." The guide notes that the depth of the signal penetration will vary, depending on the material and moisture content, and they generally will read between 0.5 and 1.0 in. (Figure 4). This method may provide a moisture level based on the reading of the top 1-in. level, but it will not measure moisture conditions within the deeper regions of the deck.

**Core Sampling and Gravimetric Moisture Content**

This procedure is used within the concrete industry to determine moisture content in cured concrete. However, it is not a consensus test method, nor could we find an ASTM test method for determining the moisture content in concrete after removing core samples. Ideally, the core sample should be the full depth.
are, at best, shallow deck test methods, providing information down to a depth of one inch. These two methods will not give any indication of any moisture available in the deeper regions of the concrete and may provide erroneous information, allowing one to assume the deck is “dry.”

Based on the review of the typical concrete moisture test methods noted above, there is not a reliable, accurate method available for determining the moisture conditions in concrete decks exposed to the weather, and there is no agreed-upon acceptable moisture value for roofing systems as there is for the flooring industry.

**POTENTIAL PREVENTATIVE STRATEGIES**

**Concrete Admixtures**

Of the many admixtures used in concrete, there are chemical additives available that allow the reduction of water content while still achieving or improving on the required workability needed to place and finish fresh concrete. Water-reducing admixtures and mid-range and high-range water-reducing admixtures (superplasticizers) can typically be used to reduce the design water content by about 20%. Many applications take advantage of the fluidifying characteristics of these products to make the concrete mix more workable for placement. Most concrete placed today has some form of water-reducing admixture incorporated in the mix, and therefore has less water present and less porosity than an untreated concrete. Concrete admixtures can reduce but will not eliminate the water needed to work the concrete.

**Curing and Sealing Compounds**

There is confusion at times to understand the difference between curing compounds and sealing compounds.

Curing compounds are used to slow or reduce the evaporation of moisture from the concrete to prevent cracks due to drying shrinkage. A liquid-type, membrane-forming curing compound typically consists of waxes, chlorinated rubber, resins, or similar materials applied to retard the evaporation rate. These curing compounds are applied with spray equipment immediately after the finishing of the concrete, while the surface is still damp. Some curing compounds may affect the adhesion of products to the concrete surface. Since curing compounds reduce the rate of evaporation, they keep the excess water entrapped for a longer period of time.

Sealing compounds used for exterior concrete is usually an optional procedure, typically used to protect the concrete from freeze/thaw, corrosion of reinforcing steel, or acid attack by reducing the absorption of liquids such as water. Sealers used on interior concrete allow for easier cleaning, reduce dust, and protect from the absorption of spills. Sealers are applied to the finished, hardened concrete after the cure time—typically 28 days.

Sealers are typically a surface treatment, with minimal penetration into the concrete. Sealers may be acrylics, polyurethanes, or epoxies. Penetrating-type sealers include silanes and siloxanes, based on silicone chemistry. While these sealers are penetrating, they will allow moisture vapor from the concrete to vent out.

In summary, curing compounds retard the movement of water from the concrete, while sealers protect the absorption of liquids into the concrete. In both cases, the films used may adversely affect adhesion of the roofing components, which will affect the uplift performance of the system. Neither of them will prevent moisture migration from the roof deck into the roof assembly after it has been installed.

**Vapor Retarders**

Philosophies regarding the use of vapor retarders have been somewhat fluid over time, ranging from “when in doubt, use one,” to “when in doubt, leave it out,” to “when in doubt, think it out.” Typically,
decisions as to whether to use a vapor retarder have been based primarily on temperatures (interior and exterior design values) and the moisture occupancy (RH) of the interior. With the exception of situations where significant interior moisture may be generated after the roof has been installed, this approach may have been successful for steel and wood decks.

Whether to include a vapor retarder—particularly on a concrete deck—is one of the most significant roofing system assembly decisions that a design professional must face today. A troubling habit in the industry is to design the roofing system to warranty coverage. Many elements of roof design revolve around the designer’s and/or the owner’s expectations regarding warranty coverage (duration, wind speed, hail, etc.) and the roof system manufacturer’s requirements for issuing warranties meeting these expectations. Most, if not all, roof system suppliers disclaim any and all responsibility for deciding whether to include a vapor retarder in any project, and most go so far as to explicitly exclude damage resulting from condensation within the roof assembly from warranty coverage.

The hygrothermal modeling (WUFi) that we used to determine the drying rates for the various types of concrete can also be used to design the components of the roofing system for various climatic regions. We demonstrate herein that virtually all concrete decks contain more moisture than many modern roofing systems that don’t include a vapor retarder can tolerate.

Providing a vapor retarder on top of the concrete is the only practical solution available to control the water entrapped in the concrete deck and prevent it from entering and condensing in the roofing assembly. The type of vapor retarder must be selected based on the relative permeability between the membrane and the vapor retarder.

The WUFi model software is a powerful tool, using the thermal and hygrothermal properties of building components, combined with regional weather records, which can provide realistic predictions of the seasonal performance of buildings. The model can be extended to determine cumulative effects as the building ages.

However, as with any computer tool, the results are only as reliable as the data that is provided. Proper application of the model requires experience in the field of hygrothermics. As a starting point, WUFi has a database of hygrothermal material data for many of the components used in building construction and weather data derived from ASHRAE records. The data can be further refined if the specific material properties are known.

WUFi computes the evolution of the temperature and moisture conditions in the building components, which allows the user to observe predicted trends in overall behavior of the system. Components can be adjusted, and materials added, deleted, or replaced, to observe their effect on the overall performance. Provided the material properties and weather data input are accurate, WUFi is a tool that can be used to design for the long-term moisture performance of roofing and other building envelope systems.

Running the hygrothermal model will confirm the performance of the selected vapor retarder in a roofing assembly or guide the designer toward a proper solution.

It is beyond the scope of this paper to conduct an in-depth analysis of the various types of vapor retarders available and their relative merits. All standard technologies (self-adhered, hot-applied, cold-applied, torched-on, etc.), properly used in a given assembly typically can be effective. The ultimate solution will depend on a number of variables, including ambient conditions at the time of installation, the build-up of and attachment methods to be used, the components installed above the vapor retarder, wind uplift requirements, insurance or other approvals to be fulfilled, and system manufacturers’ available options, to name but a few.

The use of a vapor retarder is not to be used as a shortcut around sound roofing practices. A vapor retarder will only be effective in preventing future moisture or condensation-related damage if properly designed and installed at the outset. The surface of the concrete deck must be sufficiently clean, dry, and properly primed to achieve the required level of adhesion. If adhered, the adhesive should be stable in a moist environment so the attachment does not degrade. It is strongly recommended to conduct on-site adhesion tests prior to the actual installation. The vapor retarder must be detailed and installed such that it is sealed at all parapets, curbs, and other penetrations to prevent moisture from “short-circuiting” it and migrating into the roof system at these locations. Where the vapor retarder is to also perform as an air barrier, it must be tied into the wall air barrier system to achieve continuity.

If the concrete is dry on the surface, in all likelihood it still contains a significant amount of moisture. If the forms are left in place, the moisture is effectively trapped between two highly impermeable surfaces after the application of the vapor retarder,
which will not create any issues, provided the interface between the vapor retarder and the concrete remains at a temperature well above the dew point. For example, a problem could occur if the vapor retarder is installed and left exposed in winter conditions and the space below the deck is conditioned. This could result in the moisture migrating to the outer surface and condensing at the deck level, resulting in a loss of bond. Conversely, during hot summer conditions, dark-colored vapor retarders can heat up sufficiently to cause blisters to form at any void between the vapor retarder and the deck, leading to blister formation, which if not addressed prior to installing the balance of the system, could eventually impact the finished system’s resistance to wind uplift and other forces over time.

To achieve the best performance, the vapor retarder should be insulated by installing the insulation and membrane soon after installing the vapor retarder. in instances where the vapor retarder is to be used as a temporary roof, pending completion of other construction activities, careful consideration should be given to all relevant factors and impacts and addressed accordingly.

CONSEQUENCES: CASE STUDIES
New Construction

A new office building was constructed in New England. The building had a modest footprint with a total roof surface of 10,000 sq. ft. on two levels.

The roof assembly consisted of a 14-in.-thick concrete deck and tapered polyisocyanurate insulation installed in two to four layers. The layers of insulation were bonded to the concrete deck and to each other with low-rise urethane foam adhesive applied in ribbons. A felt-backed thermoplastic membrane was adhered to the insulation using a solvent-based adhesive.

For approximately seven years after the roof system was installed, it performed problem-free, and no leaks had been reported. In the fall of the seventh year, after a storm with wind speeds up to 65 mph, the membrane was observed to have become unattached across practically the entire surface of both levels of the roof (Figure 7). The assembly is rated for 465 lbs./sq. ft. of uplift pressure. A wind speed of 65 mph should only have exerted an uplift force of approximately 17 lbs./sq. ft. in the field of the roof and approximately 36 lbs./sq. ft. in the corners.

Test cuts revealed that the felt-backed membrane was very well-bonded to the underlying insulation, although the felt backing was damp. Failure occurred within the top facer of the top layer of insulation.

The facers were organic and were damp, and had clearly been in that condition for quite some time (Figures 8 and 9). They were severely wrinkled in all locations observed, and in some areas, exhibited mold growth.

The lack of any record or evidence of leakage, and the presence of moisture across essentially the entire roof surface, clearly pointed to condensation as the source of water that allowed the failure. Based on the occupancy of the building and the local climate, it was concluded that residual moisture migrating from the concrete deck into the roofing system was in all likelihood the source of the problem.

The involved parties ultimately decided to secure the membrane with fixation bars and cover strips.

Reroofing

An office tower located in the Midwest consists of three distinct, isolated roof levels. The original roof construction consisted of a structural concrete deck, topped with a tapered LWSC screed, a single layer of wood fiberboard insulation, and a built-up membrane. After approximately 13 years, the roof was removed and replaced with an adhered single-ply system.

The original fiberboard roof insulation was reportedly wet across large sections of each roof level when it was removed. The fiberboard and built-up roof were removed down to the deck. Although much of the original mopping asphalt came off with the insulation, sporadic patches remained stuck to the concrete at random locations. The replacement system consisted of a 2-in. layer of organic-faced polyisocyanurate insulation and a ½-in. layer of a glass-faced gypsum protection board, both of which were secured with low-rise polyurethane foam adhesive. A thermoplastic membrane was adhered to the cover board using a solvent-based adhesive.

A storm during reroofing resulted in localized wetting of the newly installed roof assembly and the occupied space below it.

![Figure 8](image-url) - The organic insulation facer, which was damp, failed cohesively.

![Figure 9](image-url) - Cohesive separation of the damp organic facer. The deep “notch” is a deeper-than-usual “knit” line from the manufacturing process.
The affected area was reportedly replaced with new, dry materials prior to the completion of the new roof. After the roof was completed, one small, isolated leak was reported and repaired. For approximately two years, the roof performed without any reported issues. A tenant wanted to install a rooftop terrace above their offices. During the installation of structural elements to support the terrace and associated planters, etc., the surface of the cover board was found to be damp. Subsequent investigations revealed similar conditions across all three roof levels.

The cover board was generally found to be dry in a narrow band around all roof perimeters and penetrations.

Although the moisture level in the gypsum cover board was low, it was sufficient to cause separation between the glass facer—which was well bonded to the underside of the membrane—and the gypsum core of the cover board, leaving the thermoplastic sheet essentially loose over most of the roof surfaces. The roofs were temporarily ballasted while various investigations were carried out (Figure 10).

The owner hired a consultant who, after analyzing the moisture content of the air within the plenums on the underside of the deck (Figure 11), concluded that condensation due to air migration from within the building was highly unlikely to be the source of the moisture observed in the cover boards. There was some debate as to whether sufficient material had been replaced after the storm damage during construction. Even if this had in fact been the case, it did not explain the widespread moisture in the roofs on the other two levels. The most likely source was residual moisture in the concrete deck that did not dry in the minimal time each section was exposed to ambient conditions between tear-off and replacement. Deck-to-parapet joints and penetrations through the deck had not been sealed, and it is assumed that these voids allowed sufficient venting to keep the cover board facers dry in these locations.

Twenty months after the condition was discovered, the parties agreed that the small area in the location of the proposed terrace (approximately 15% of the total roof area) would be replaced with new materials, and the balance of the surfaces would be ballasted. The remediation cost approximately $6.00 per square foot. The combined attorney and consultant fees and other expenses of all parties no doubt exceeded the repair costs. It is estimated that the installation of a vapor retarder in the new roof system would have added approximately $1.00 to $1.25 per sq. ft. to the cost, had it been installed during the reroofing project.

**REMEDIATION OPTIONS**

In extreme situations, the only appropriate remedy to such issues may be the complete removal of the entire roof system and replacement with a new roofing system, including a vapor retarder to prevent a reoccurrence. As noted previously, damage resulting from condensation, regardless of the source of the moisture, is explicitly excluded from the coverage of most manufacturers’ warranties. The involved parties will need to agree upon the funding of the roof replacement, or litigation inevitably ensues.

Complete removal and replacement may not be necessary, and in some cases may even be undesirable, due, for example, to access issues once new construction is complete, or the potential impact on the occupants and/or operations below the affected areas.

With adhered roof assemblies on concrete decks, the most common issue in such cases is a loss of cohesive strength, typically at an insulation or cover board facer, leaving the roof vulnerable to catastrophic failure due to wind blow-off. Providing long-term resistance to wind loads will generally drive the choice of remediation strategy implemented in such cases.

The two case studies noted above highlighted the two most common options: fastening the existing assembly to the structural deck or ballasting the now-loose roof system. Ballasting will generally be the less expensive solution if the structure can accommodate the additional load. Even when there is sufficient structural capacity, this may not be an appropriate solution in some jurisdictions. For example, in hurricane-prone regions, IBC does not allow aggregate ballast, and paver ballast can only be used if it complies with RP-4. Similarly, some buildings, such as high-rise structures without parapets, may not be suitable candidates for ballasting by code, or the owner’s insurance carrier may not allow it.

Mechanically attaching the assembly through the existing roof membrane may, in some instances, be a more viable option. Beyond doing pullout tests, an assessment must be carried out to determine the risk of hitting rebar or tensioning cables in the deck. Tapered insulation can increase the cost of this option significantly.

Although both options will avert the potential for catastrophic failure under wind load, neither addresses the moisture that is entrapped within the system. In all cases, serious consideration must first be given to the amount of moisture in the system and what impact this moisture will have...
on the different components in the system over time.

Some success has been reported with the use of one-way vents (i.e., an air-pressure equalized system) in such situations. Wind moving across the roof surface draws air containing moisture from the assembly and exhausts it to the atmosphere. Furthermore, the air being drawn from the assembly equalizes the pressure on the top and bottom surfaces of the membrane, thereby holding the membrane in place and eliminating the need for additional fixation or ballast. The effectiveness of these systems is highly dependent on having an air-impermeable substrate below the roofing system to prevent billowing of the membrane. The degree of drying will depend on the potential for lateral movement of the moisture within the roofing system so it can reach the vents, as well as the number of vents and their locations. The insulation or another medium needs to be air-permeable to allow air movement within the sealed system. Such an approach should only be considered after consultation with experts in the use of the approach.

Although the costs of the approaches listed will typically be significantly less than the cost to remove and replace the roof, ultimately someone still needs to pay for them. Experience has shown, however, that the lower the cost to resolve these problems, the more amenable various stakeholders are to working out some form of cost-sharing arrangement and avoiding litigation.

CONCLUSIONS

The roofing industry must address the issues of moisture in concrete, beginning with educating the designers, construction managers, general contractors, roofing contractors, and material suppliers of the problems that may occur due to moisture migrating from the deck into the roofing system. The structural engineer selects the type and strength of the concrete, and the supplier typically designs the concrete mix to achieve the required compressive strength and mix properties required to place and finish the concrete to meet the construction schedule. We commonly look at this to be the 28-day cure period. While the concrete will meet the specified compressive strength in the designated time frame, as noted above, the new concrete still has almost all of its initial water. The construction industry must accept this fact and not use cure time as the notice to begin roofing. The same can be stated for an existing concrete roof deck that has been subjected to leaks for a period of time and is likely wet. Removing the existing roof system and letting the deck dry for a few hours will not allow the free water within the deck to evaporate.

Developing a moisture test for new concrete roof decks is likely to be an exercise with little to no return. As demonstrated above, the free water in the deck escapes so slowly, and construction schedules are so demanding, that any test that is developed will take too long and will be impractical. Therefore, we must accept that the roofing system will be installed over a wet deck.

The authors believe that using the WUFI software or similar modeling software, with proper and adequate data, will provide the best solution for designing a roofing system that contains the vapor barrier needed to provide long-term performance over a wet concrete deck.

REFERENCES

ASTM Standards D4263, F1869, F2170, F2659, ASTM International.