Quality Built® Tech Alert
April 3, 2014
Volume 2, Issue 2

In This Issue

About the Author

Brian C. Kramer, PE, GE
Chief Executive Officer

Brian Kramer is the Chief Executive Officer of Quality Built. Mr. Kramer is a graduate of San Diego State University with a Bachelor of Science Degree in Civil Engineering and he received his MBA from the University of California at Irvine. He is a Registered Civil and Geotechnical Engineer in the State of California. Mr. Kramer's experience includes providing technical direction and construction oversight on some of the most complex and highest profile projects in California, including high rise towers, major infrastructure projects, and residential developments. Additionally, Mr. Kramer has provided forensic consulting services in the fields of geotechnical engineering, foundation design and construction, moisture intrusion, and materials engineering and testing on thousands of homes.

Quality Built's Commitment

Quality Built is commited to being a visionary leader in the insurance, financial and construction industry by providing reliable and innovative Third Party Quality Assurance Services to our clients and by providing those services in the most professional and efficient manner utilizing cutting-edge technology, proprietary software and employees who maintain the highest level of integrity and expertise.

Optimizing Sub-Slab Design and Construction: Water as Both an Asset and Liability

As I learned in my Construction Methods course while studying Civil Engineering, the three leading causes of damage to structures are water, water, and water. While that may be a slight exaggeration, when it comes to windows, roofs, and exterior wall systems, water is never a good thing. However, for concrete slab-on-grade construction, the answer isn't that simple. The goal of this article is to provide an overview of the role and impact of water in the design and construction of the slab section to help develop a better perspective on this subject. The easiest way to understand the various impacts of water on the slab and sub-slab elements is to look at each of the components separately from the bottom up.

<u>Subgrade Soil</u>
The natural soils or compacted fill located beneath a slab-on-grade is often considered to be relevant to a depth of approximately 12 to 18 inches below the slab section. However, particularly in the case of expansive soils, the active zone should be considered to extend to a depth of 3 to 5 feet below finish grade. For these soils, water is nearly always an asset. Assuming you have met the minimum relative compaction requirement (usually 90% of maximum dry density), then by increasing the amount of water in the soil during grading you reduce the potential for expansive soils to subsequently swell, for sands and/or silts to collapse in the future, and for all soils to become less susceptible to water-induced, post-construction settlement (hydro-consolidation). But don't stop caring about the

Contact Quality Built today at 800-547-5125 or email: sales@qualitybuilt.com

Join Our Mailing List!

Subscribe now to receive the latest Tech Alerts from Quality Built.

water when grading is completed. For sites with highly expansive soils, it is imperative that you keep the subgrade soils wet and in conformance with the engineer's recommendations at all times up to the date of the slab placement. The more water, the better to "pre-swell" the soils, until the point that you have a yielding subgrade or unworkable surface.

Base Layer

Certainly times have changed for the design professional in terms of what should be specified for this element of the slab section. In the past, the sand or gravel layer beneath a slab was often referred to as a capillary break. In other words, it functioned in part to eliminate the potential for negative pore water pressure to draw water in the subgrade soils up to the base of the slab. In the case of using gravel, that works just fine because it only takes an approximately 4-inch-thick layer of gravel to establish that break based on typical aggregate sizes. However, even for coarse-grained sand, it would take more than 12 inches of sand to break the capillary rise.

These days, the granular layer is not designed so much as to mitigate capillary rise, but rather as a proper support for and assistance with the concrete slab finishing and curing. Further, washed concrete sand is no longer considered by design professionals as a preferred or, for some, even an acceptable material for the granular layer. The primary reason is that poorly graded sand is readily deformed when stepped on (e.g., the laborers dragging the hose from the concrete pump across the building footprint). Imagine a design for a 5-inch-thick slab over 4 inches of sand. After one hard push of a foot into the sand layer, you now have a 3 inch thick slab over 6 inches of sand, and one foot over the section consists of 7 inches of concrete over 2 inches of sand. This is not what the designers had in mind. After coring hundreds of slabs over the past 20 years, I can assure you that this condition is not the exception. As a result, ACI 302.1R-04 established guidelines recommending that "the base material should be a compactible, easy to trim, granular fill that will remain stable and support construction traffic." Since the goal for this layer is to remain stable under loading, yet be relatively free draining, the percent fines (silt and clay) is a very important criterion. ACI recommends that at least 10% to 30% of the material pass a No. 100 sieve and that maximum aggregate size be generally less than Â¼ inch, though larger aggregate sizes are permitted under certain circumstances.

In terms of water in the base layer, a minor amount of water in the granular soils does promote stability through a phenomenon called apparent cohesion. Further, after the initial setting of the concrete, it will promote long-term hydration of the cement and make the concrete stronger. This is good. However, as discussed below, any excess water in the granular base layer will become a source for fueling moisture vapor transmission through the slab.

Vapor Retarder

From my perspective as an expert witness providing defense to contractors and design professionals on construction defect litigation cases, this element of the slab section design has been a subject of increasing debate over the past 15 years. The issue of moisture vapor transmission appeared to accelerate to the forefront of defect cases due to the advent of sulfate attack claims and the appearance of discoloration and/or delamination of resilient flooring materials.

In terms of sulfate attack, plaintiffs alleged that highly permeable concrete slabs and insufficient or missing vapor retarders were enabling excess moisture (primarily liquid phase) to reach the footings and slabs and cause damage. The specter of sulfate attack claims subsided after a defense verdict was obtained in the 2005 Castron v. Fieldstone trial, in which I provided expert testimony alongside other defense experts having concrete knowledge well in excess of mine. Therefore, potential damage to foundations caused by subsurface water in the liquid phase faded away.

However, cases involving water in the gas, or vapor, phase and allegedly leading to damage of flooring materials have continued to this day. The number of defect cases alleging damage to flooring materials reaching my desk increased dramatically in the early 2000s. The observable damage typically consisted of staining, blistering, peeling, and/or delamination of resilient flooring materials such as linoleum, vinyl composite tile, and electrostatic dissipating tile, with a common claim that excessive moisture vapor was transmitting through the slab. But what had changed? To the best of my knowledge, the only fundamental change that had occurred in the slab section and flooring materials that could have a direct, adverse impact on the flooring was the adhesive. The Air Quality Management District, in 1998, finalized a rule mandating a reduction in volatile organic compounds (VOCs) in adhesives and sealants. Further, where I primarily work in Southern California, the South Coast Air Quality Management District adopted Rule 1168 (as Amended in 2005), which also had the purpose of reducing the emission of VOCs for adhesives and sealants. Based on an informal, non-published study performed by Bob Higgins with SINAK Corporation, new adhesives were shown to re-emulsify or break down in an alkaline environment as low as pH = 9. Since cement in concrete inherently creates an alkaline condition, then any introduction of moisture in this new environment creates the potential for adhesive failure.

So what can be done to mitigate this problem? In terms of the vapor retarder, when moisture sensitive flooring is a concern but is not your primary slab section design criteria, you should adopt the guidelines set forth in ACI 302.2R-06 and 302.1R-04 by placing a vapor retarder (minimum of 0.3 US perms) beneath 4 inches of granular base material. It is recommended that the retarder be at least 10 mils thick and be properly lapped and sealed at all penetrations. However, any excess bleed water from the concrete (discussed below) or moisture in the base layer still lies above the retarder and will often be driven by a vapor pressure gradient through the slab. To address this issue, some experts have recommended placing the vapor retarder directly beneath the slab. However, experience has shown that this increases concrete early stage shrinkage, creates longer bleeding times, and leads to less long-term strength gain in the slab. The resulting cracking potential and overall lower quality concrete is generally not worth the reduction in moisture transmission through the slab in all but the most moisture sensitive situations.

<u>Concrete Slab</u>

Much of this element has been indirectly discussed above, but here is some additional information relative to water in concrete. Excess water in concrete goes from being purely a liability to both an asset and a liability over the life of a concrete slab. According to the

Portland Cement Association, the minimum water to cement ratio (by weight) for complete hydration of all cement in a concrete slab is approximately 0.22 to 0.25. Therefore, even when using high strength/quality concrete in high sulfate exposure areas or post-tensioned slabs, you have nearly twice as much water in the mix than can be utilized by the cement. At this point, all of this excess water (though generally needed for workability and cost reduction) has an adverse impact on the strength and durability of the concrete slab. More specifically, the excess water in the pore spaces of the concrete yields no strength to the concrete, creates additional porosity and permeability, and leads to less durable concrete.

The water at this point is also problematic in terms of moisture vapor transmission. Keep in mind that only the excess bleed water that rises to the surface and the water near to the finish surface that evaporates prior to flooring placement is dissipated. The rest is held in the base layer and within the pore spaces of the concrete and will generally transfer through the slab as moisture vapor. Plaintiff experts have tried valiantly to tie results from moisture vapor emission rate (MVER) tests (ASTM F1869-11) to excess slab permeability and flooring failure. However, the courts have often rejected this methodology as "junk science" and the industry generally understands that MVER testing can, at best, give you an approximate of the amount of moisture "gassing off" of the slab at a given point in time and at a specific set of environmental conditions. The MVER test data is important for the initial set up of an adhesive, but not very relevant to long-term performance of floor coverings. A better method to determine the amount of water in a concrete slab is in-situ relative humidity testing (ASTM F2170-11). The aforementioned excess water may show up in the MVER testing, but it will show up in the humidity testing.

Though this water vapor is potentially bad for certain flooring materials, it is a continuing asset to the concrete slab. Provided that the relative humidity within the concrete remains above approximately 80%, the concrete will continue to gain strength under most circumstances for many decades.

Current Industry Practice

So what are you designing and building? Are you meeting the standard of care in terms of design and achieving the performance standards related to water in the slab section? One of the benefits of being CEO of Quality Built is having access to all of the data. Here is what we see in general terms for the slab section across the country:

- Base Layer - material type
  - There is a tremendous divergence of data when looking at what is specified in design and what we see in construction, and there is also substantial variation based on geographic region.
  - To somewhat oversimplify, we observe base layers that generally conform to the ACI recommendation (compactible, easy-to-trim, granular fill that will remain stable and support construction traffic) on about 50% to 80% of our projects.
  - The remainder includes washed concrete sand, silty fine-grained sand, gravel, or even limestone.
- Vapor Retarder - type and location
  - Vapor retarders are specified and placed in

approximately 90% to, in some regions, 100% of the slab sections for livable areas.
    - The most common thickness is 10 mils and deviations from this thickness are usually on the side of a thicker membrane.
    - The location of the vapor retarder is another area of wide disparity of data. However, in this instance, the variation appears to be primarily driven by geographic region. Overall, the most commonly location of the retarder is at the bottom of the base layer, but this is followed closely by it being sandwiched in the middle of the base layer. However, certain parts of the country, like Florida, has the vapor retarder located at the top of the base layer in almost every instance we observe.
- Concrete Slab
    - Detailed recommendations for the design and construction of the concrete slab are beyond the scope of this article. However, in order to reduce the permeability, improve the durability, and increase the strength and overall performance of the concrete, the water to cement ratio of the mix should be reduced. In other words, even when you do not have special design constraints such as sulfate exposure or increased concrete strength necessitated by post-tensioned loading, the w/c ratio should be reduced to the lowest levels that are economically feasible.

<u>Recommendations</u>

As a Registered Civil Engineer and Geotechnical Engineer in the litigation prone State of California, I am always very careful about providing recommendations that are not tailored to a specific project. Therefore, I would rather provide ideas for you to consider based on the information presented above.

1. Compact your fill soils, particularly highly expansive clays, at a moisture content that is preferably well above optimum.
2. Stop using washed concrete sand as a base layer, and utilize compactible, easy-to-trim, granular fill in accordance with ACI 302.1R-04.
3. Do not use angular gravel in your base layer or near the surface of your subbase/subgrade layer to avoid perforating your vapor retarder. If unavoidable, increase the thickness of the membrane to obtain greater puncture resistance.
4. Provided that you do not have angular gravel in the subbase or subgrade, the decision where to place the vapor retarder should be driven by whether your priority is the concrete or moisture vapor transmission. By placing the membrane below the base layer, the concrete slab will be less likely to crack or curl, to exhibit shrinkage or rebar settlement cracking, or be difficult to finish. If you place the membrane on top of the base layer, you will minimize the amount of vapor transmission by cutting off the reservoir and often by indirectly necessitating the use of a lower water to cement ratio mix to control performance. Please refer to ASTM E1643 for more information and discussion on this topic.
5. For highly moisture sensitive floor coverings, you should consider using a more robust membrane (Stego Wrap 15-mil Vapor Barrier or equivalent) and pay very close attention to sealing all laps and penetrations. As stated above, in order to

remove the reservoir of excess bleed water in the granular layer, you may consider placing the membrane directly underneath the concrete. However, a structural or materials engineer specializing in concrete mix design, joint placement, curing, etc. should be consulted to minimize the potential for slab cracking and/or curling.

6. In order to reduce the permeability, improve the durability, and increase the strength and overall performance of the concrete slab, the water to cement ratio of the mix should be reduced. In other words, even when you do not have special design constraints such as sulfate exposure or increased concrete strength necessitated by post-tensioned loading, the w/c ratio should be reduced to the lowest levels that are economically feasible.
7. In the event you are experiencing what appears to be moisture related damage to floor coverings, any negative side treatment of the slab should include a penetrant to reduce the pH of the concrete surface in order to help improve the performance of the adhesive.

Hopefully you have gained a better understanding of the impact of water on the various components of the slab section. For the more technical reader, I encourage you to provide your comments and critiques to promote our shared goal of promoting quality in the design and construction of our homes. Please contact me at bkramer@qualitybuilt.com or through my posting on LinkedIn.

References:

ACI Committee 302, Guide for Concrete Floor and Slab Construction, American Concrete Institute, 2004, ACI 302.1R-04.

ACI Committee 302, Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials, American Concrete Institute, 2006, ACI 302.2R-06.

Kosmatka, Steven H. and Panarese, William C., Design and Control of Concrete Mixtures, Portland Cement Association, 1988.

About Quality Built

Quality Built, headquartered in Fort Lauderdale, Florida, is a leading national construction quality assurance and inspection management company. Quality Built provides third-party quality assurance services and a full spectrum of quality and risk management solutions such as property condition assessments, tainted drywall assessments, building evaluations, data collection tools, collateral inspection services, reporting and support services on high-quality residential and commercial construction projects nationwide.

Quality Built is well known for its work in Total Quality Management and was one of first firms to transition from using a traditional quality assurance approach into implementing a proven, user-friendly and fully automated, online inspection system. Quality Built's proprietary software is cost efficient, paperless, fully customizable and completely scalable to handle the demands of most inspection and quality assurance protocols.

Quality Built's Quality Management System is ISO 9001:2008 registered
For more information about Quality Built and its services, contact Beth R. Michaelis, President, at bmichaelis@qualitybuilt.com. Quality Built, 401 SE 12th Street, Suite 200, Ft. Lauderdale, FL, 33316, 954.358.3500, www.qualitybuilt.com.

To stay connected with us at Quality Built, visit us at www.qualitybuilt.com.

Sincerely,

QB QUALITY BUILT
The Next Generation of Quality Assurance®

Elizabeth Michaelis - President
Quality Built LLC