Concrete Slab Moisture

Why isn’t my slab dry yet?!

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State of the Industry

- Concrete moisture spans multiple disciplines
  - Building enclosure
  - Concrete structures
  - Concrete materials
  - Roofing, waterproofing
- This presentation focuses on concrete slabs on ground

Why Is My Concrete Slab Wet?!

The Owner summons the project team to job site to discuss the concrete slab moisture...

Engineer: “Do I need to be here?”

Architect: “There must be a pipe leak under the concrete slab.”

Contractor: “Is the testing lab using certified technicians?”

Ready Mix Supplier: “Concrete needs water.”

Testing Lab: “We’ll continue to measure the slab once a week.”

“Snake Oil” Salesman: “Moisture testing doesn’t matter.”

The Expert: “Your expectations aren’t aligned with reality.”

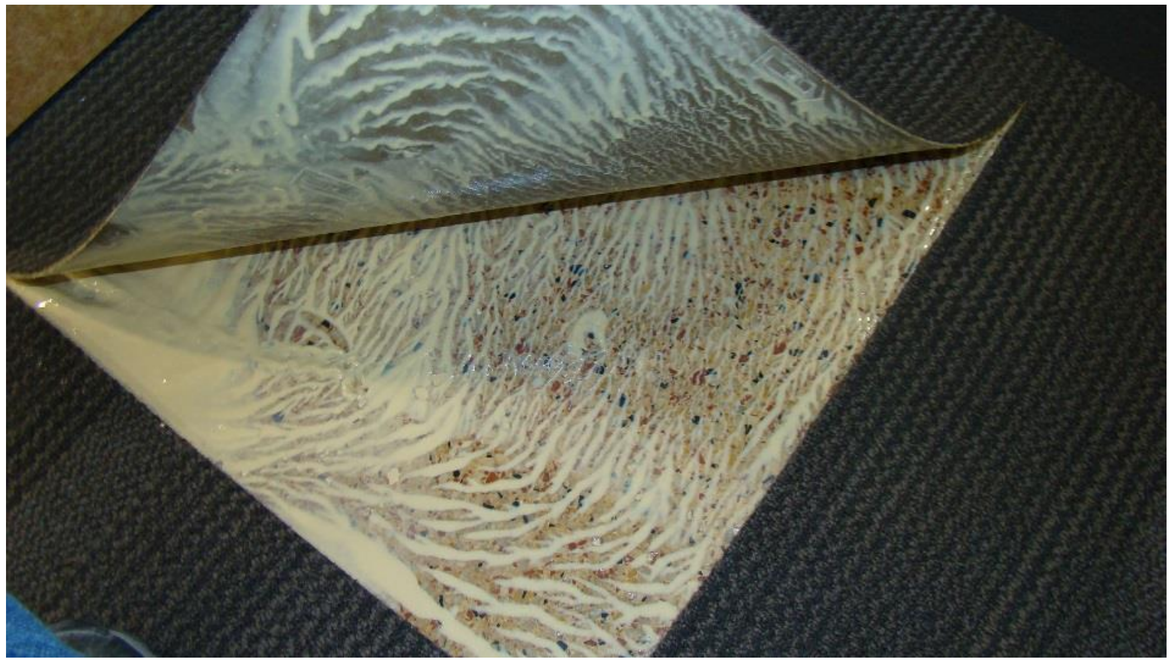
Learning Objectives

At the end of this program, participants will be able to:

1. Understand why we are seeing an increase in slab moisture issues
2. Describe concrete slab moisture test methods
3. Understand planning required to minimize concrete slab moisture
4. Understand how to evaluate flooring failures

Concrete Moisture… What has changed?!

- Construction schedules are more aggressive
- Adhesives have changed
- New test methods have become available
- Contractors are tired of getting “burned”



Failure of floor covering adhesive

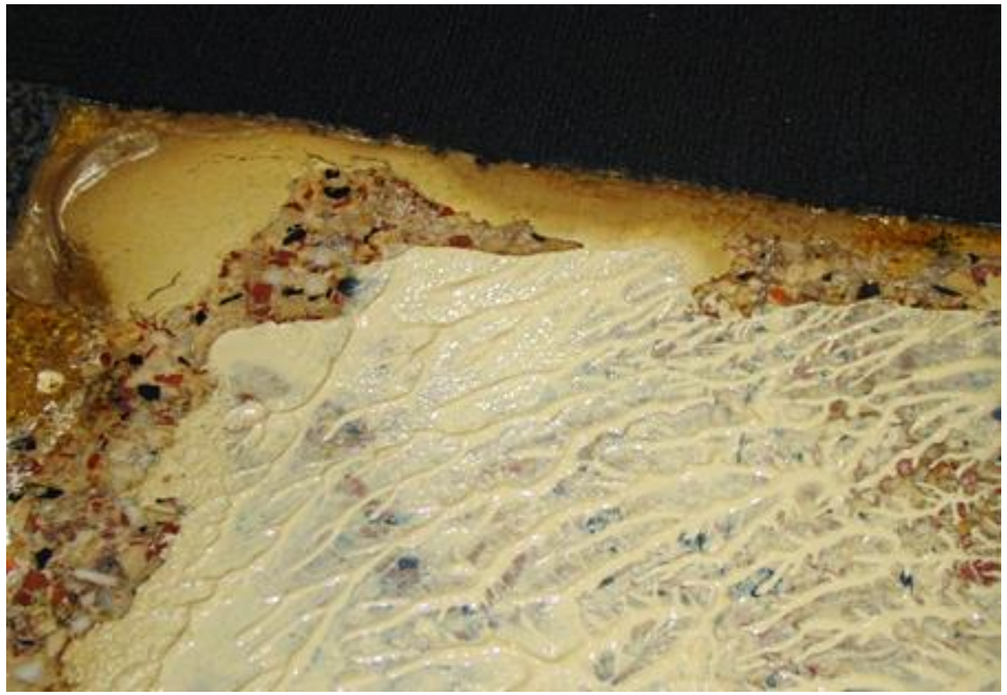
Aggressive Construction Schedules

- Owners expect things to be done quicker
- Buildings may need to be constructed in 120 days
- It may take over 120 days for the concrete slab to *dry out*

Organized chaos - i.e., concrete place and finish operations

Change in Adhesives

- Adhesives with low concentrations of VOC have replaced solvent-based formulations
- Water-based adhesives are not as resistant to moisture and alkalis
- Application of new adhesives during renovations of older buildings can cause failures



Failure of floor covering adhesive

New (relatively) Moisture Test Methods

- MVER (Moisture Vapor Emission Rate) test method was the primary moisture test method for 50+ years
- Within last 5-10 years, industry has accepted RH (Relative Humidity) test method as the preferred approach
- Different test method provides different perspective

Comparison of MVER vs RH testing

Contractors Are Getting Smarter

- Have had flooring failures that hurt them financially
- Will now refuse to proceed with flooring installation
- Perform their own testing and not trust owner's test results
- Operate in a litigious environment

Construction complete, except floor covering…

Overview

- Moisture Problems
- Sources of Moisture
- Measuring Moisture
- Drying of Concrete
- Mitigation
- Case Studies

Caution: Wet Floor!

Moisture Problems

Concrete Slab Moisture Problems

- Efflorescence will accumulate on concrete surface
- Flooring will debond from concrete surface
- Floor covering adhesives will break down

Efflorescence crystals due to moisture in slab

Accumulation of Efflorescence

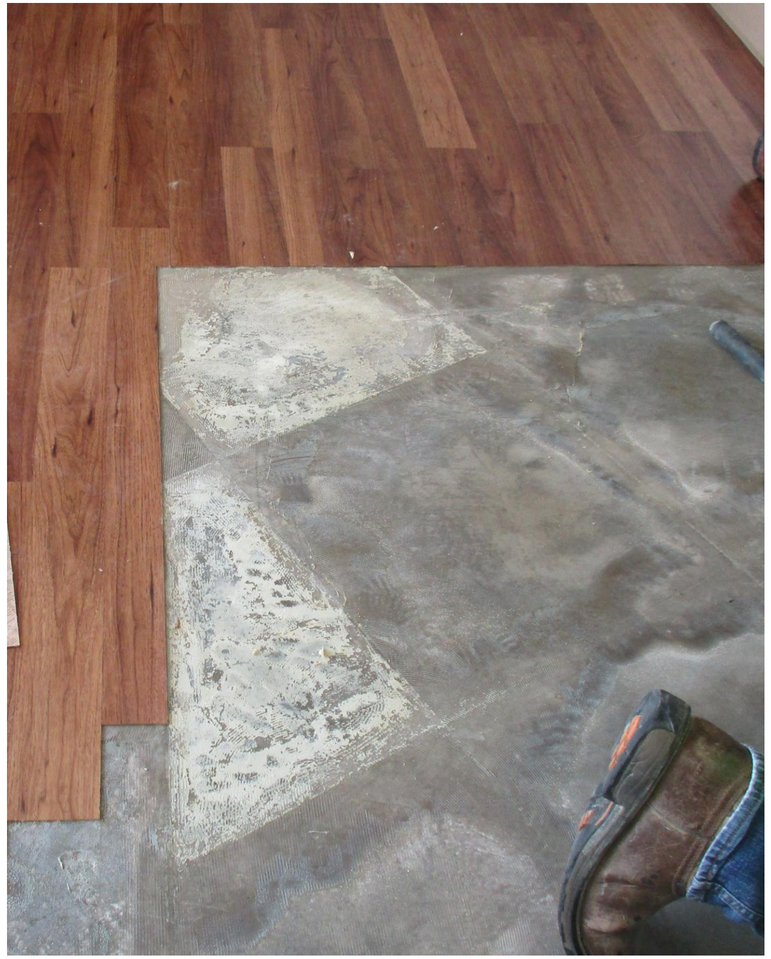
- Efflorescence are white fuzzy crystals that accumulate on concrete surface
- Efflorescence is caused by water vapor migrating through concrete and bringing soluble salts to the surface

Efflorescence accumulated on slab

Debonding of Flooring

- Some floor coverings may require chemical and mechanical bond

Flooring blistering



Floor Covering Adhesives Degradation

- Moisture in the concrete slab breaks down adhesives
  - Blistering
  - Delaminations
  - Gooey adhesive
  - Edge lifting

Edge lifting

Adhesive bleeding through joints

Sources of Moisture

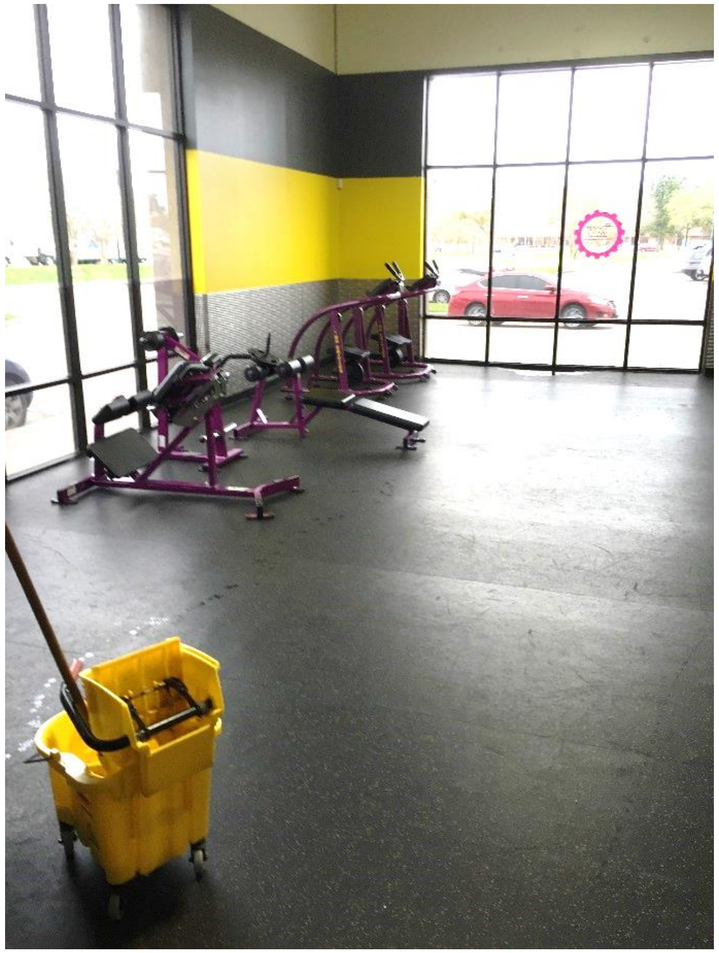
Sources of Concrete Slab Moisture

- Water topically applied to the concrete slab (i.e., maintenance)
- Water vapor transmission from beneath the concrete slab
- Moisture from within the concrete slab

Water intrusion beneath the slab

Water Applied to Concrete Surface

- Maintenance of floor covering
- Building envelope problems
- During construction, precipitation



Cleaning floors or applying water?

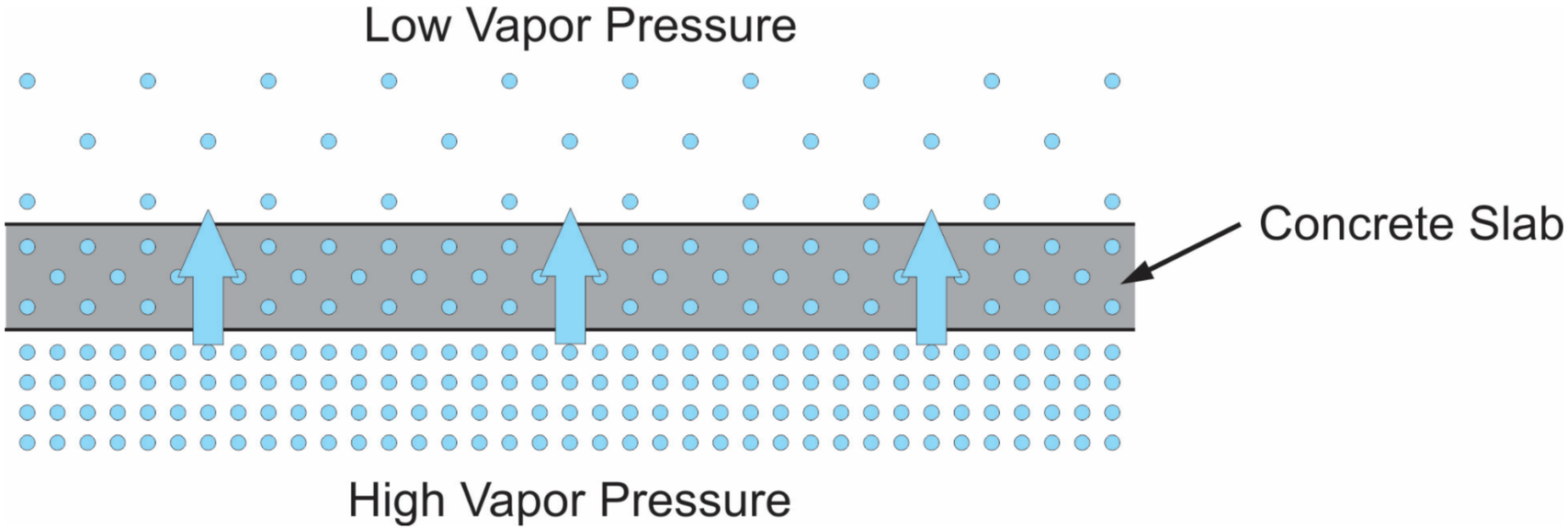
Moisture Beneath the Concrete

- Subgrade vapor
  - No vapor retarder
  - Poor installation of vapor retarder
  - Old vapor retarder
- External sources
  - Broken pipes
  - Poor drainage

Vapor retarder that deteriorated after 50 years

Water Vapor Transmission

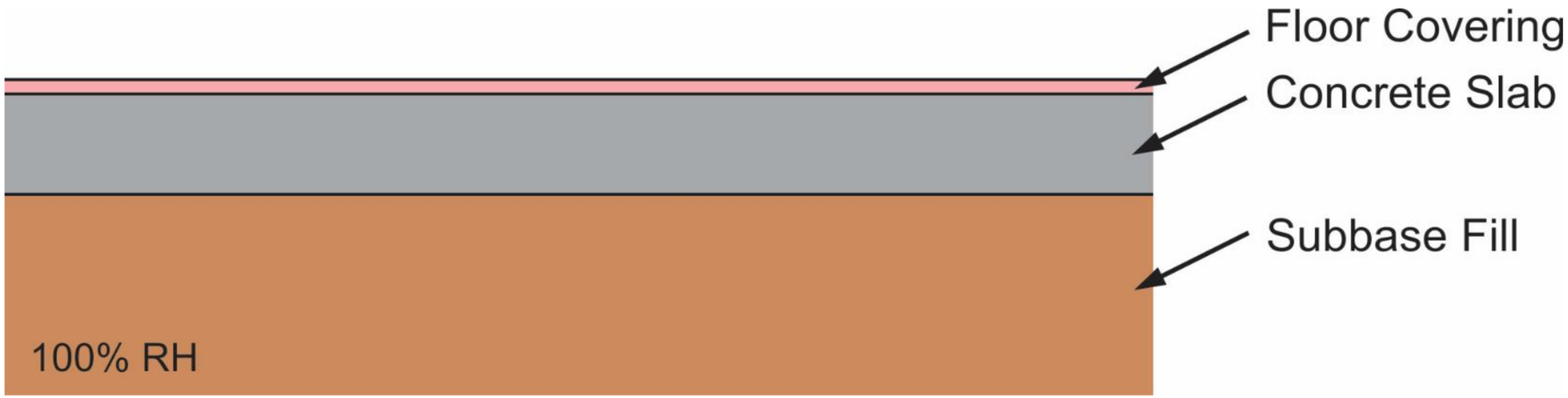
- Moisture typically migrates through the slab by diffusion
- Diffusion is the movement of molecules from a region of high concentration to a region of low concentration



Moisture transmitting through concrete slab

Vapor Transmission from Soil

- Soil beneath concrete slab will reach 100% RH
- Concrete will slow rise of moisture, but not stop it
- Moisture level in the concrete slab will increase if concrete surface is covered with non-breathable material



Concrete slab placed directly onto soil

Installation of Vapor Retarder

- Installation of vapor retarder mitigates moisture from ground
- Concrete slab should be in direct contact with vapor retarder

Concrete slab placed directly on vapor retarder

Moisture Within Concrete

- Free water (i.e., water of convenience) is the unreacted water that does not chemically react with the cement particles
- Free water remains in the concrete after it has hardened
- Water will eventually migrate through concrete and evaporate

Adding 30 gallons at the slump stand

Amount of Water Required

- Only 0.3 units of water combines chemically with 1.0 unit of cement
- For a 5-1/2 sack mixture with w/c=0.50, this is 103 lbs of water per cubic yard of concrete or 230 gallons of free water in 1,000 ft^2 (6” slab)

Concrete placement activities

Measuring Slab Moisture

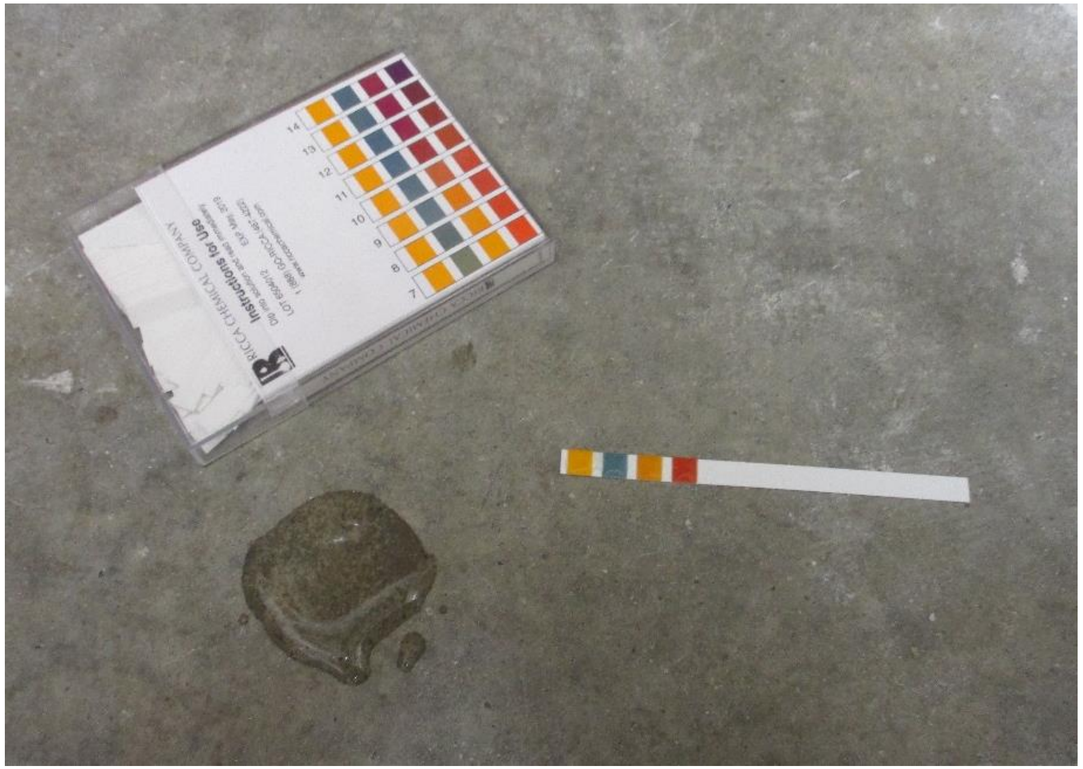
Measuring Concrete Slab Moisture

- pH testing
- Moisture Vapor Emission Rate
- Relative Humidity

Measurement of concrete slab RH

pH Testing (*ASTM F710, 5.2*)

1. Place 1 inch diameter puddle of distilled water on slab
2. Allow puddle to set for 60 seconds
3. Dip pH paper into water and compare to chart



pH testing of concrete slab

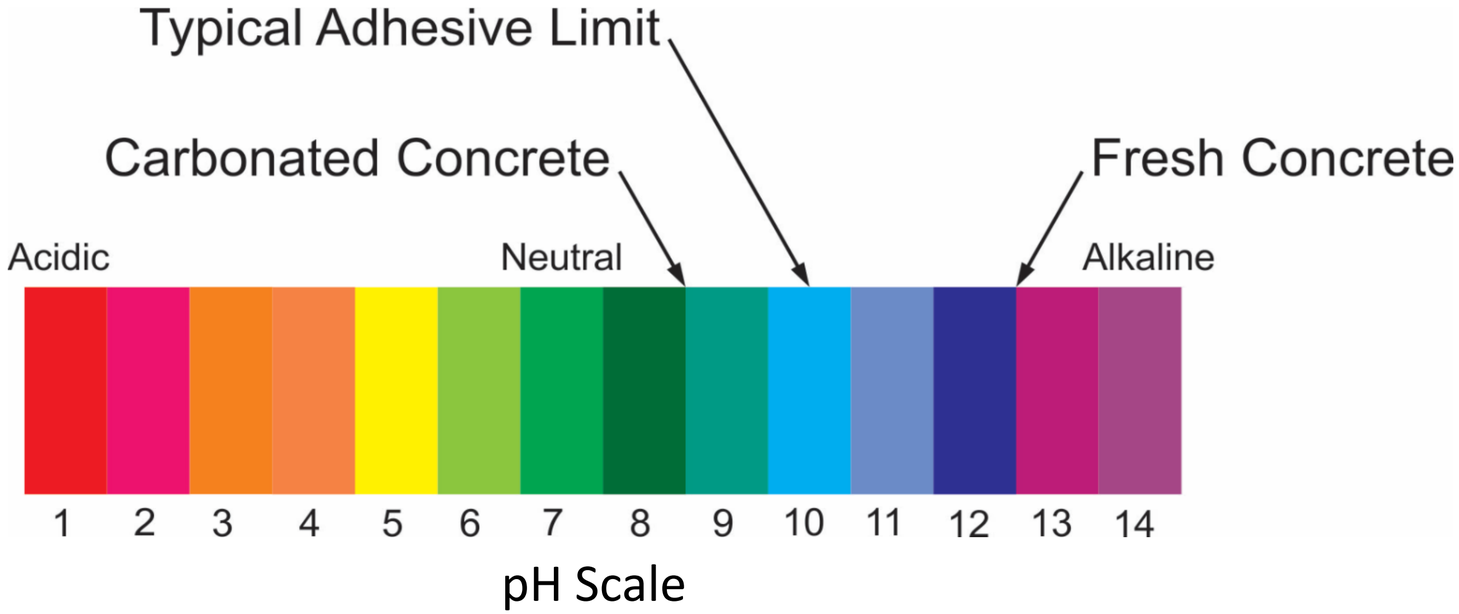
Typical Concrete Moisture Specification

Cementitious Sub-floor Surfaces: Verify that substrates are dry enough and ready for resilient flooring installation by testing for moisture and pH.

1. Test in accordance with ASTM F710.
2. Obtain instructions if test results are not within limits recommended by resilient flooring manufacturer and adhesive materials manufacturer.

Challenges with pH Testing

- pH requirements have an inherent conflict
  - Most adhesive manufacturers limit the slab pH to 10
  - Fresh/early-age concrete has a pH of 12 to 13



Moisture Vapor Emission Rate (ASTM F1869)

1. Weigh test dish of calcium chloride
2. Grind surface of concrete
3. Place dish on concrete slab and cover with plastic dome
4. Wait 60 to 72 hours
5. Remove and weigh dish of calcium chloride

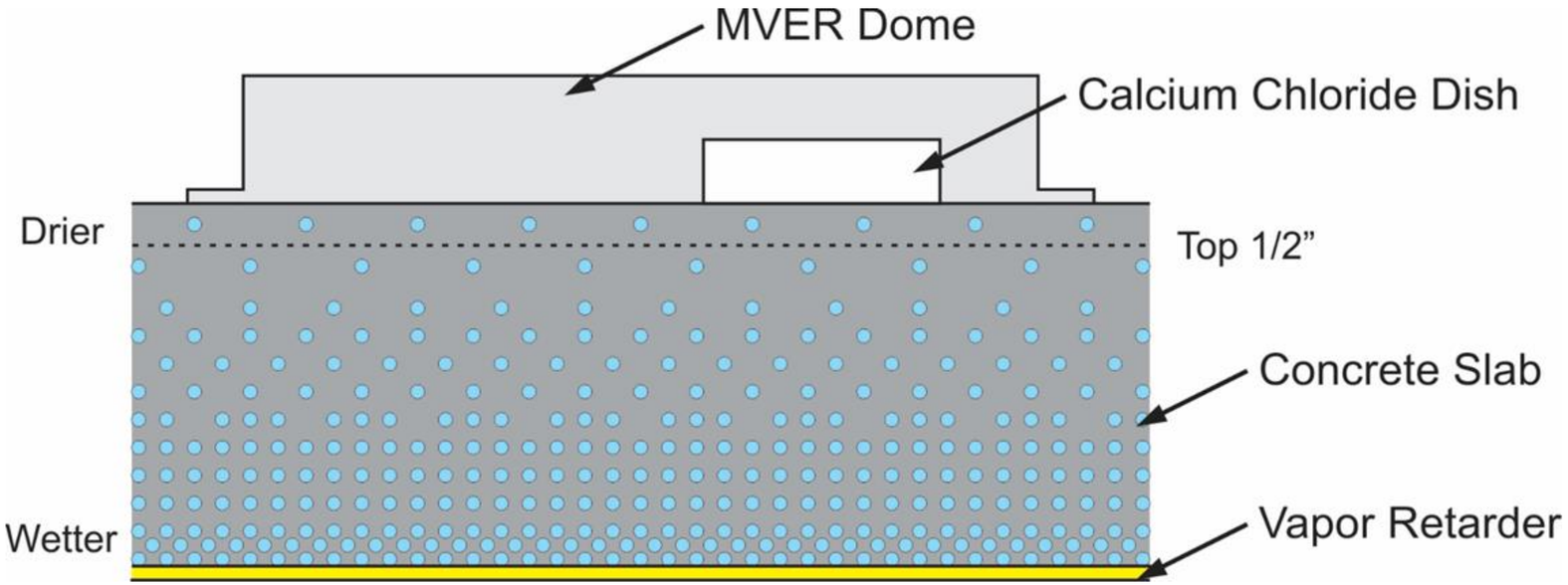
Condensation inside MVER dome

Moisture Vapor Emission Rate (ASTM F1869)

6. Calculate MVER
    a. Weight gain of calcium chloride
    b. Known area of vapor emissions
    c. Given time period
7. MVER expressed in terms of lbs/1000ft^2/24hrs

Challenges with MVER

- The test method only measures the slab surface (~ ½ in.)
- Test results are influenced by the ambient conditions
- Consequently, test results can be misleading



Schematic diagram of MVER test method

Modified MVER Test

- Procedure
  - Dry vacuum grind a 20” x 20” area of slab surface (optional, depending on circumstances)
  - Cover with a 24” x 24” low permeable material (e.g. sheet vinyl) for a two-week period
  - Conduct MVER test
- Pre-covering test area allows moisture deeper in the slab to rise and establish a state of moisture equilibrium
- When tested, more closely reflects the MVER that the mitigation system must be capable of controlling

Relative Humidity (ASTM F2170)

1. Determine slab thickness
2. Scan area for reinforcement
3. Drill ¾ in. diameter hole in slab to 40% thickness (for one-sided drying)

Cover-meter to detect reinforcement

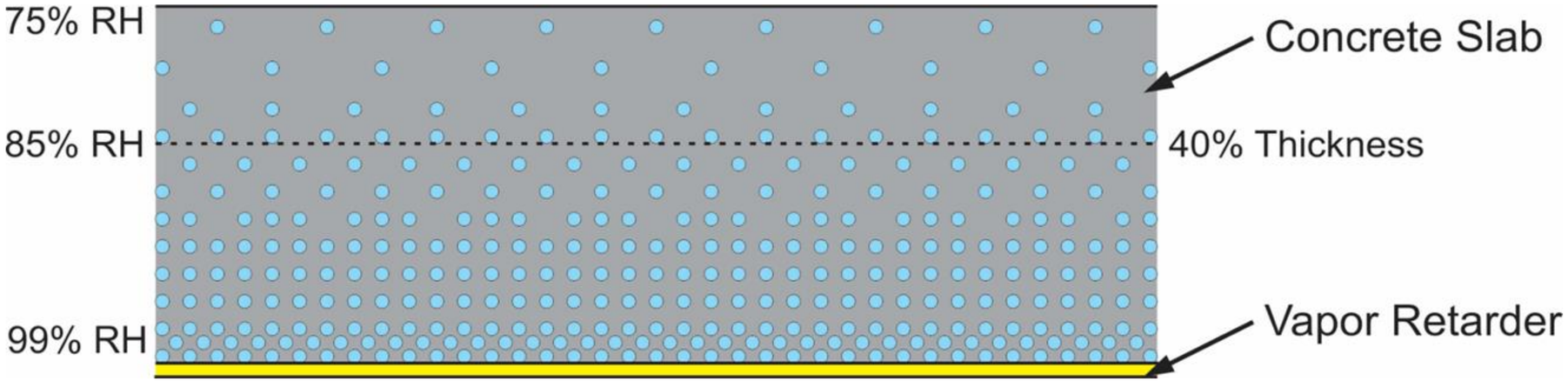
Relative Humidity (ASTM F2170)

4. Install RH sleeve/probe into concrete slab
5. Wait 24 hours (previously 72 hours)
6. Measure relative humidity

Installation of RH probes

Why are RH Probes Installed at 40% Thickness?

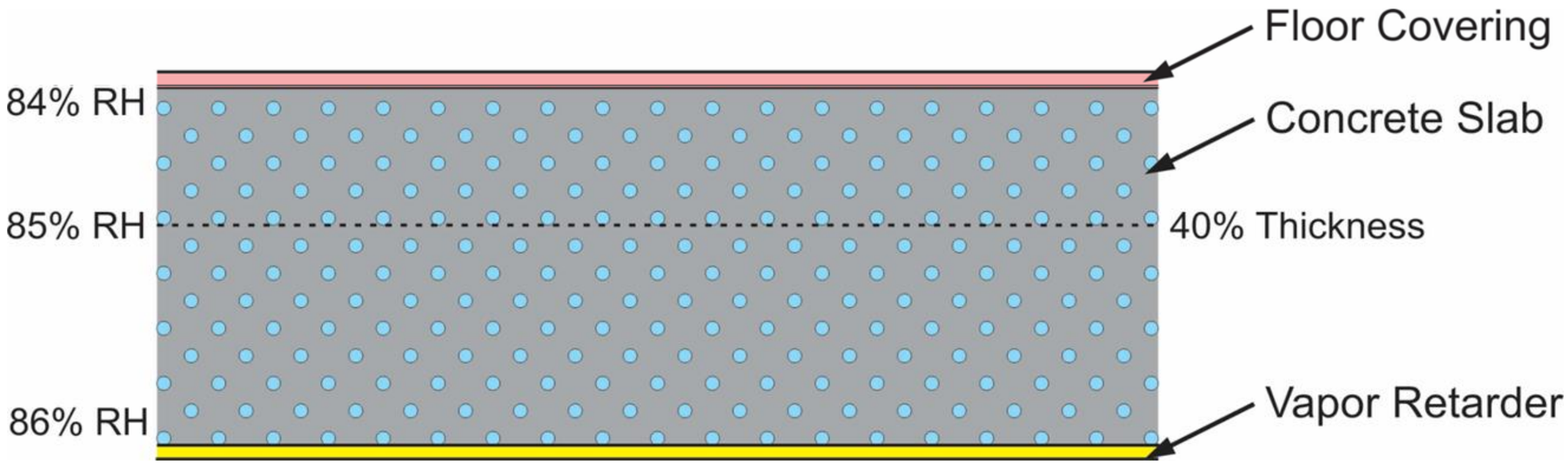
- For 1-sided drying
- Prior to installation of floor covering
  - Bottom of slab has higher RH
  - Top of slab has lower RH



Schematic diagram of concrete slab prior to installation of floor covering

Moisture Stabilizes in Slab After Covering

- After installation of floor covering
  - Concrete slab reaches a stable RH
  - RH stabilizes to the value obtained at 40% thickness prior to installation of floor covering



Schematic diagram of concrete slab after installation of floor covering

Advantages of RH Measurements

- Provides good indication of future slab performance
- Measures the moisture content within the concrete
- RH probes can be installed and checked weeks/months later

Measurement of concrete RH

Correlation Between RH and MVER?

- RH of slab provides indication of moisture within the concrete
- MVER provides indication of moisture emitting from concrete
- Quite simply… there is no correlation between the test methods

Comparison of MVER vs RH testing

Typical Concrete Moisture Specification

Moisture Testing: Proceed with installation only after substrates pass testing.

A. Perform anhydrous calcium chloride test, ASTM F 1869. Proceed with installation only after substrates have maximum moisture vapor emission rate of 3 lb of water/1000 sq. ft. in 24 hours.

B. Perform relative humidity test using in situ probes, ASTM F 2170. Proceed with installation only after substrates have a maximum 75% relative humidity level measurement.

Drying of Concrete

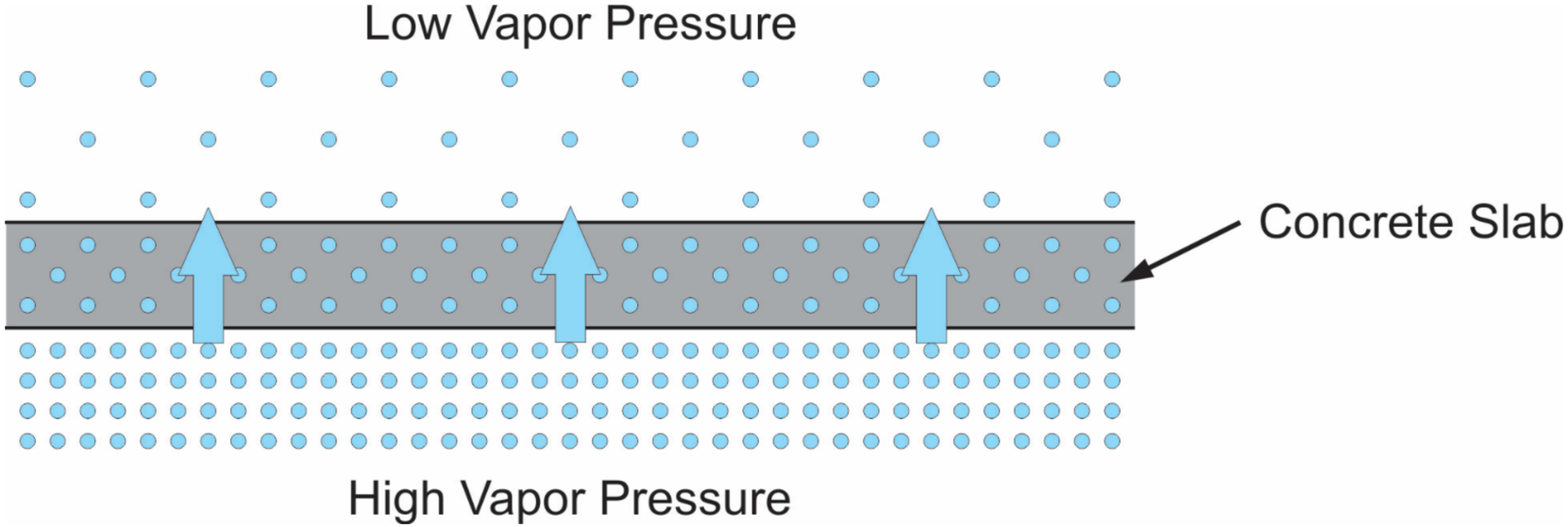
How Long Does Concrete Take to Dry?

- Concrete drying rate depends on…
  - Installation of (working) HVAC
  - Concrete slab thickness
  - Water-cement ratio
  - Concrete finish

When is Day 1?

Installation of (Working) HVAC

- HVAC system needs to lower the relative humidity of the building space
- The lower the relative humidity, the faster the slab will dry



Moisture travels from areas of high RH to areas of low RH

Concrete Thickness and Water-Cement Ratio

Summary of concrete drying times based on literature

w/cm	Thickness	Time to 3 lb	Time to 85% RH	Source
0.45	4 in.	90 to 120 days	--	ASTM F710 (2008)
0.40	4 in.	46 days	--	Brewer (1965)
0.50	4 in.	82 days	--	Brewer (1965)
0.60	4 in.	117 days	--	Brewer (1965)
0.40	4 in.	49 days	--	Suprenant & Malisch (1998)
0.50	6.5 in.	> 7 months	223 days	Craig & Wolfe (2012)

Power Float and Trowel

- Troweling of concrete creates a hard dense surface
- Transition to smaller blades as concrete hardens
- Increase angle of blades to decrease surface area contact

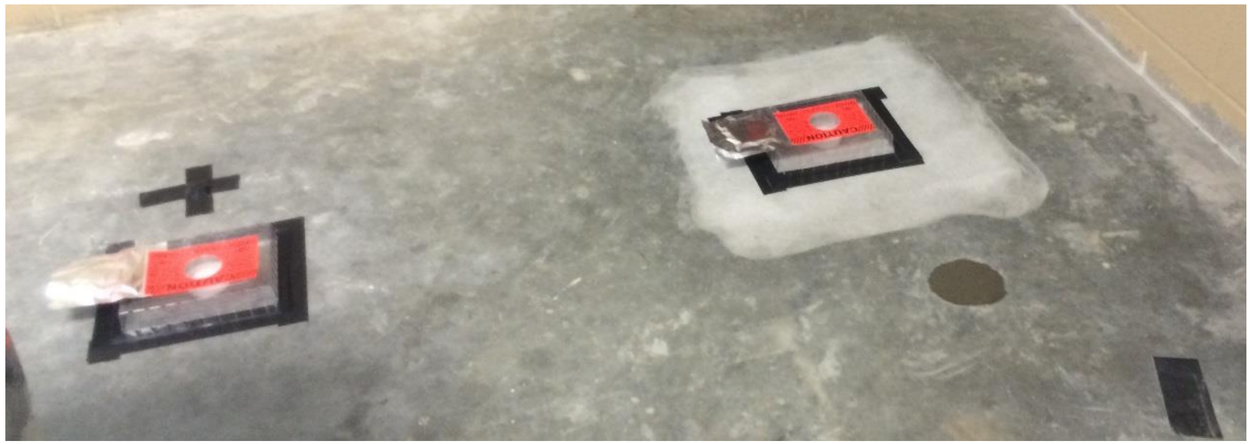
Pan float

Combination blade

Finish blade

Concrete Finish Impacts Evaporation Rate

- Hard trowel finish densifies surface of concrete slab
- Concrete finish can retard moisture evaporation rate by 25% to 30%
- Evaluate the need for a burnished slab finish



Comparison of MVER testing with and without hard trowel finish

Slab Moisture Mitigation

Moisture Mitigation (end of project)

- Schedule meetings with construction team that provide no resolution
- Let concrete naturally dry and continue to test concrete daily (hoping results will change)
- Approve $100,000 to $2,000,000 change order for:
  - Topical moisture control system
  - Accelerated dehumidification techniques

Moisture Control System

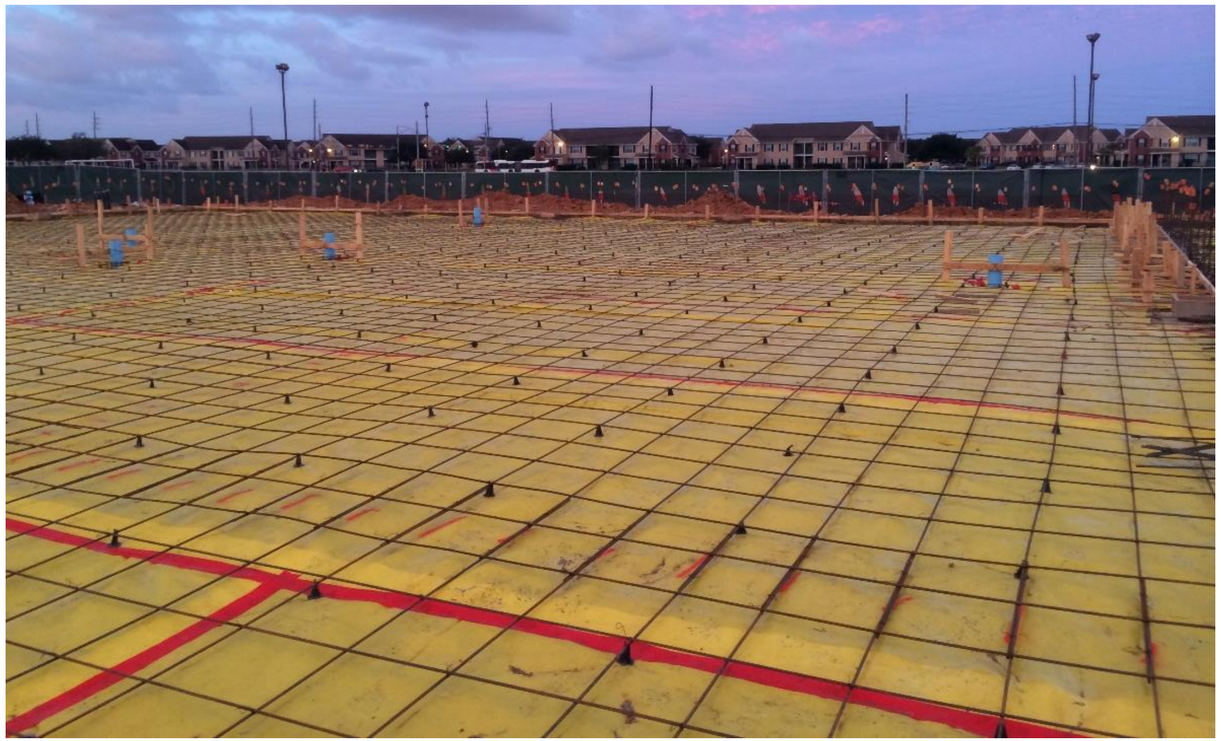
Moisture Mitigation (In the Beginning…)

- Properly install vapor retarder
- Apply a “fuzz” finish to slab
- Use a low w/c concrete mixture
- Install HVAC early!
- Moisture mitigation system

Improper installation of vapor retarder

Installation of Vapor Retarder

- Vapor retarder should overlap 6” at seams and be taped



Installation of vapor retarder

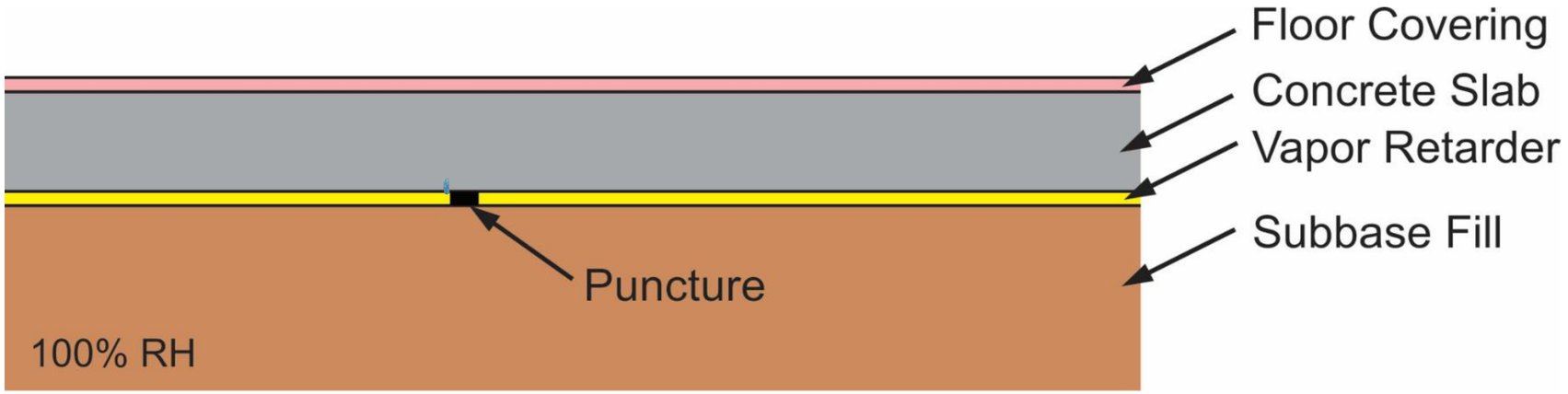
Puncture or Tear of Vapor Retarder

- Laborers may puncture vapor retarder with stakes
- Vehicular traffic can rip plastic
- Underlying sharp aggregates may puncture through

Cut through vapor retarder

Vapor Retarder Puncture or Tear

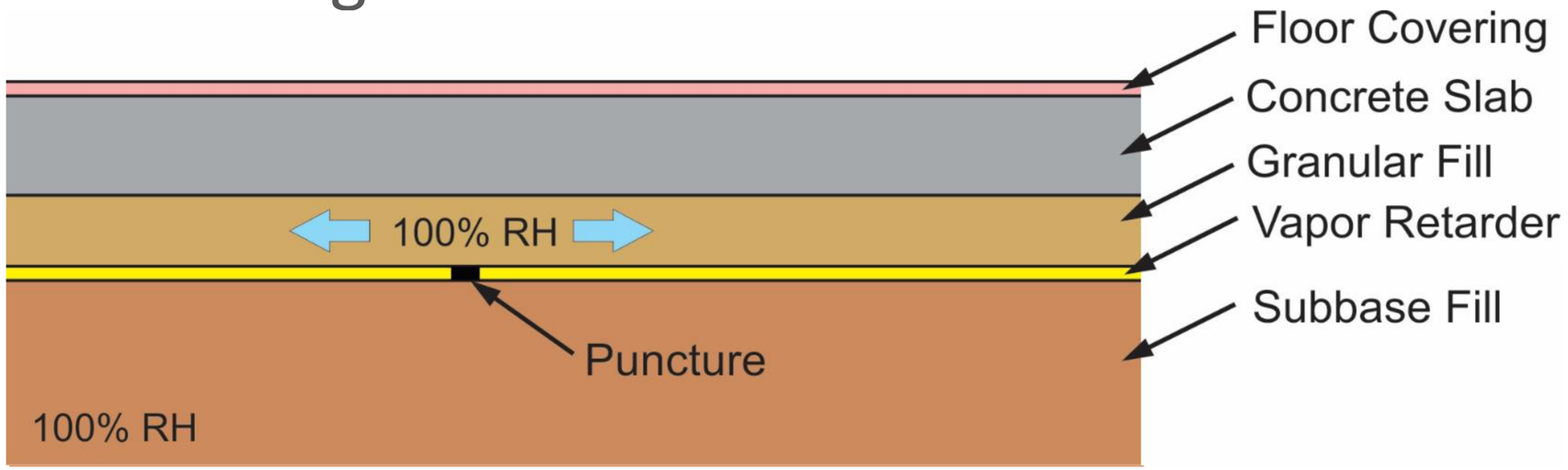
- If vapor retarder is in direct contact with concrete slab, affected area of small tear or puncture is minor
- Vapor retarder must be in **direct contact** with underside of slab



Small puncture in vapor retarder

Puncture Beneath Granular Fill

- Vapor retarder placed below granular fill (i.e., sand)
  - Water vapor will enter fill layer and free to travel
  - Fill layer will achieve high moisture content
  - Fill moisture will migrate to concrete slab



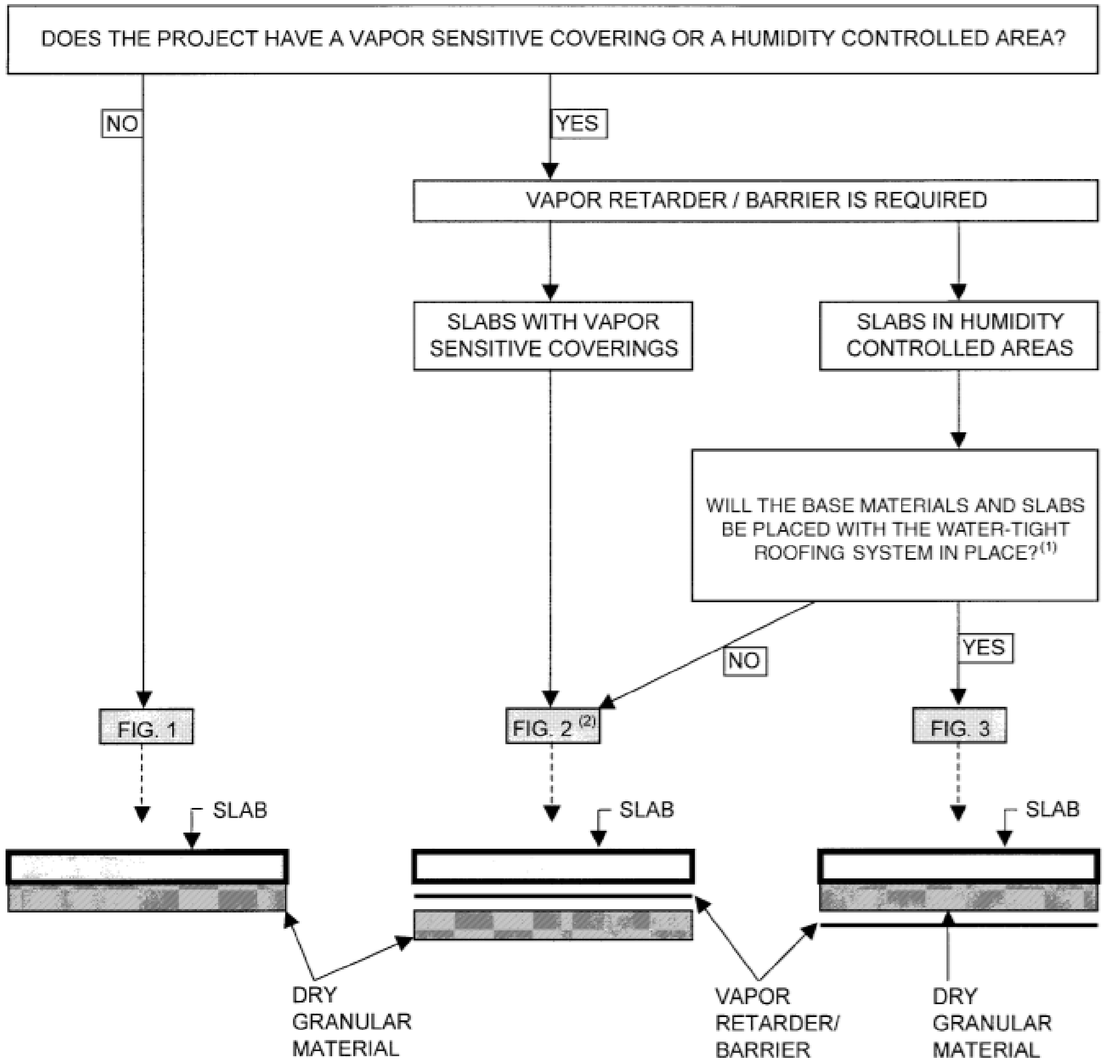
Small puncture in vapor retarder

Vapor Retarder Placement (ACI 302.1R-96)

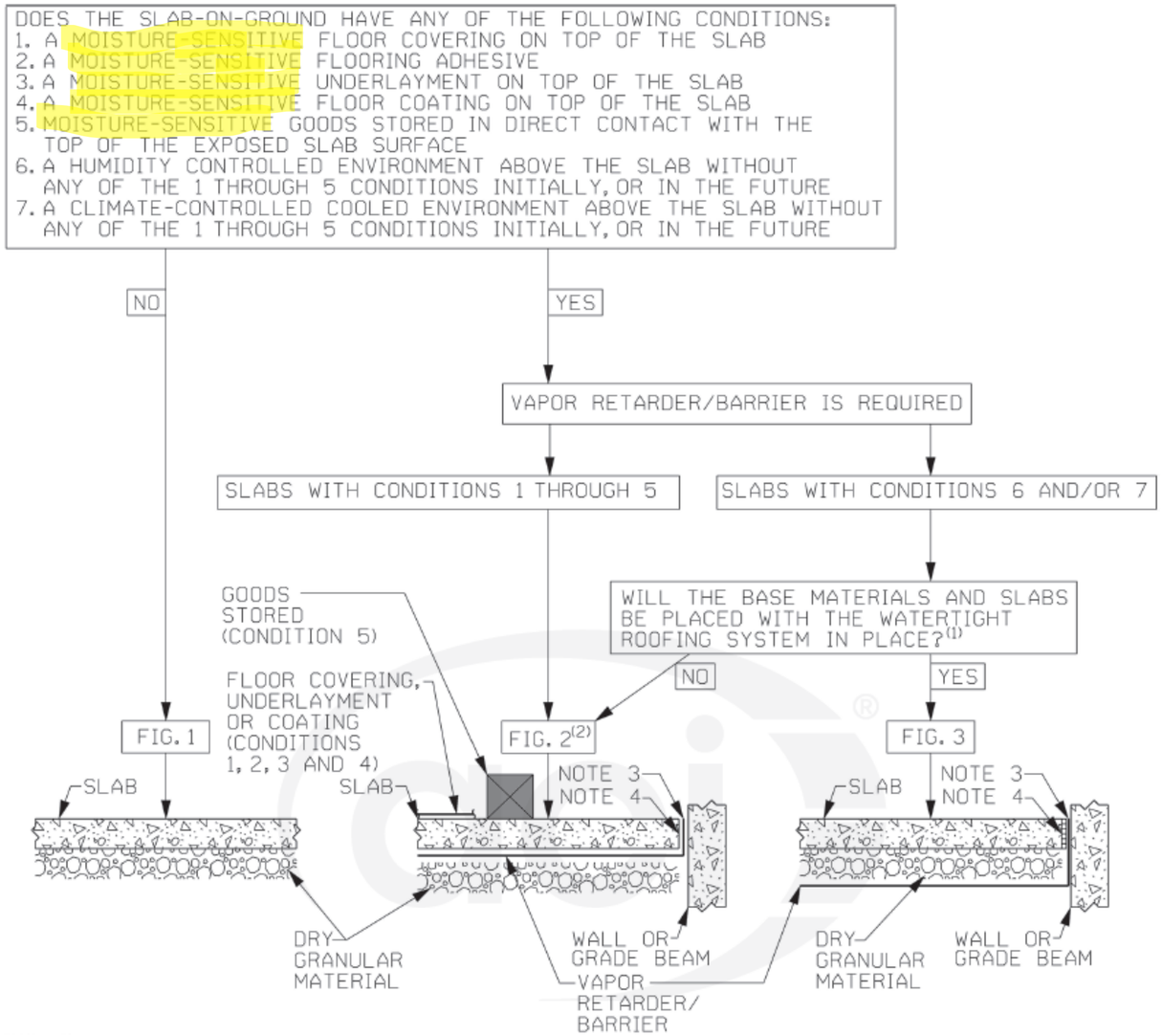
4.1.5 *Vapor barrier/vapor retarder*—If a vapor barrier or vapor retarder is required due to local conditions, these products should be placed under a minimum of 4 in. (100 mm) of trimable, compactible, granular fill *(not sand)*. A so-called "crusher run" material, usually graded from $1^1/_2$ in. to 2 in. (38 mm to 50 mm) down to rock dust, is suitable. Following compaction, the surface can be choked off with a fine-grade material (Section 4.1.4) to reduce friction between the base material and the slab.

If it is not practical to install a crusher-run material, the vapor barrier/retarder should be covered with at least 3 in. (75 mm) of fine-graded material, such as crusher fines or manufactured sand (Section 4.1.4). The granular fill, as well as the fine-graded material, should have sufficient moisture content to be compactible, but still be dry enough at the time of concrete placement to act as a "blotter" (Section 4.1).

Vapor Retarder Placement (ACI 302.1R-04)



Vapor Retarder Placement (ACI 302.1R-15)



Finishing Operations

- Troweling of concrete creates a hard dense surface
- Apply a “fuzz” finish (light trowel) to the slab
- If floor will be covered with floor covering, it likely doesn’t need a burnished finish
- Densified surface layer can be removed via scarifying

Trowel machine with pan floats

Low w/c concrete mixtures

- Concrete with lower w/c will have less free water
- Use of a high-range water reducer may be more economical than a moisture mitigation system
- This approach can be easier to implement for design-build projects versus design-bid

Fresh concrete

Early Installation of HVAC

- Ambient environment needs to be conducive to drying
- Slab doesn’t start drying until:
  - Building is totally enclosed
  - Slab is free of curing compounds
  - HVAC is running (and working correctly)
- Alternatively, air space can be dehumidified

HVAC needs to be on!

Moisture Mitigation System

- Two-part epoxy resin systems
- For RH readings up to 100%
- Concrete surface is typically required to be a minimum ICRI concrete surface profile of 3
- Material is applied using paint rollers and/or a notched squeegee

Concrete surface preparation

Moisture Mitigation System

- Two-part epoxy resin systems
- For RH readings up to 100%
- Concrete surface is typically required to be a minimum ICRI concrete surface profile of 3
- Material is applied using paint rollers and/or a notched squeegee

Application of moisture control system

In Summary… We Have Problems…

- We are seeing an increase in slab moisture-related failures due to
  - Aggressive construction schedules
  - Alternative (kind of new) test methods
  - New adhesive formulations
  - Litigious environment

Managing Risk of Concrete Slab Moisture

- Specify (correct) use of a vapor retarder
- Consider concrete mixture design and concrete placement/finishing techniques
- Specify concrete moisture measured per RH test method (ASTM F2170)
- Include options (i.e., moisture control system) when concrete does not meet moisture level requirements
- Require slab moisture testing to be performed by an ICRI Certified Concrete Slab Moisture Testing Technician

Concrete Slab Moisture

Why isn’t my slab dry yet?!

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