Twenty-First Annual Westford Symposium on Building Science Westford, MA

Vapor Barriers In Compact Roof Assemblies

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Topics

- Problem Statements
- Concrete Basics
- Concrete and Moisture
- Field Examples
- Research
- Recommendations
- Questions

Problem Statements

- The roofing industry has seen a dramatic increase in moisture related failures from roofing over concrete roof decks, both new construction and reroofs.
  - The compressed schedules in new construction have seen General Contractors direct (demand) the installation over green concrete, after only days.
  - Most absurd report to SRI was 3 days!
  - Materials and techniques for installing roofs has changed focusing on labor efficiency and environmental friendly factors

Problem Statements

- The roofing industry has little to no guidance on the acceptance of the concrete substrate as suitable to begin installing a roof system.
  - The guidance that does exist for indirect testing of roof decks is typically legacy specification language tracing its origins to before I was born

Basics of Concrete

Basics of Concrete

- Portland Cement is not concrete
  - Portland Cement is the binding agent
  - Concrete is the composite material
    - Aggregates
      - Coarse 40%-50% by volume
      - Fine 20% - 30% by volume
    - Portland Cement 15% -20% by volume
    - Water 15% -20% by volume
    - Additional “adds” typically <1%

Basics of Concrete

- Additional components
    - Fibers
    - Accelerators
    - Retarders
    - Water reducers
    - Air entrainment
    - Fly Ash
    - Silica Fume
    - Waterproofing
    - Magic Pixie Dust

Basics of Concrete

- Production of Concrete
  - Each batch plant will have hundreds or even thousands of recipes
    - Based on local aggregates and conditions
    - Requirements of order dictate which one they use
    - Developed over time
    - Science and trial & error
- Forms for roof decks
  - Strippable forms
  - Steel form deck


CULLEN

Curing of Concrete

- **Note** we are discussing curing not drying
- Chemical process of hydration
- All about compressive strength gain
- Loss of moisture during this process can have adverse effects
  - Moist cure
  - Protect from freezing

Curing of Concrete

- Structural Engineer specified strength
  - Typically specified at 28-day compressive strength
  - i.e. 5000psi at 28 days
- **28-days has nothing to do with moisture content only compressive strength**

Moisture in Concrete

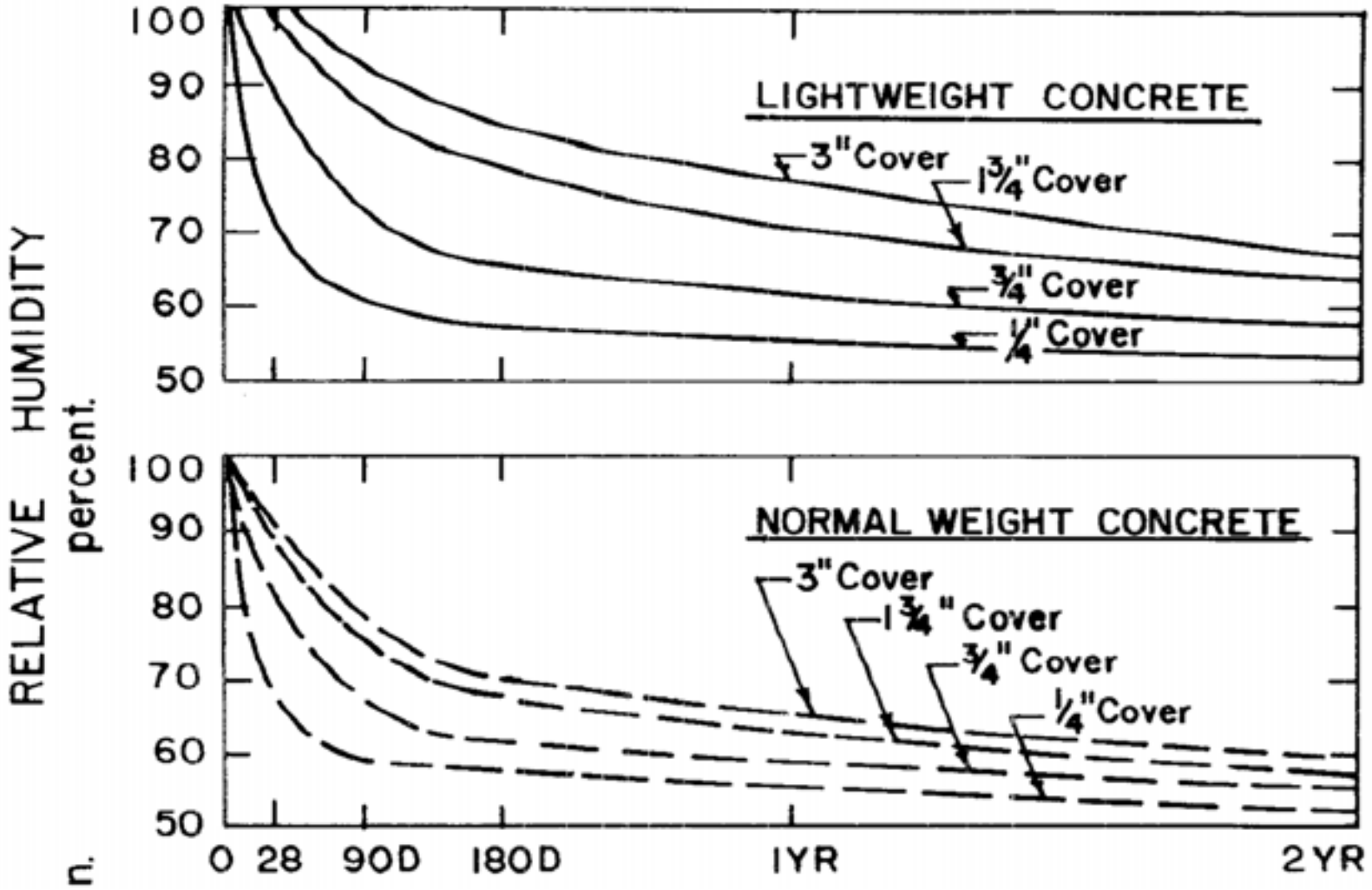
Factors That Affect Drying

- Climactic conditions
- Concrete surface condition
- Rewetting of concrete
  - Rain, snow, ice, condensate
- Capillary closure

Moisture in Concrete

- Effects of Curing and Drying Environments on Splitting and Tensile Strength of Concrete
  - J.A Hanson
  - 1968

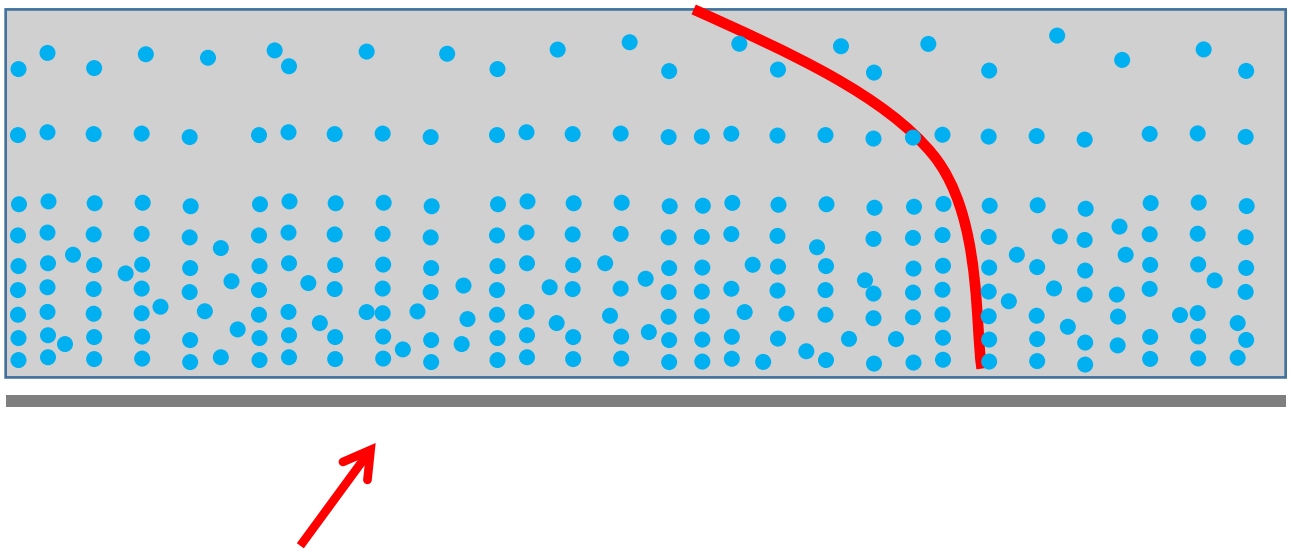
Moisture in Concrete



Effects of Curing and Drying Environments on Splitting and Tensile Strength of Concrete - Hanson

Moisture in Concrete

Steel Form Deck = one way drying



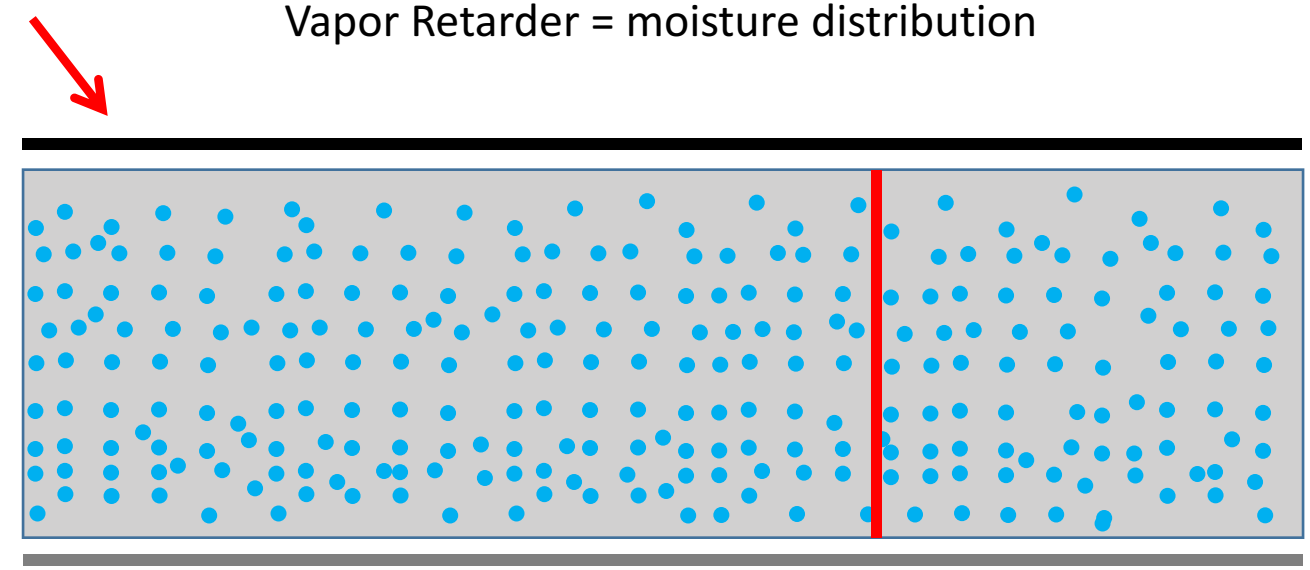
Moisture in Concrete

Steel Form Deck = one way drying

↓

Vapor Retarder = moisture distribution

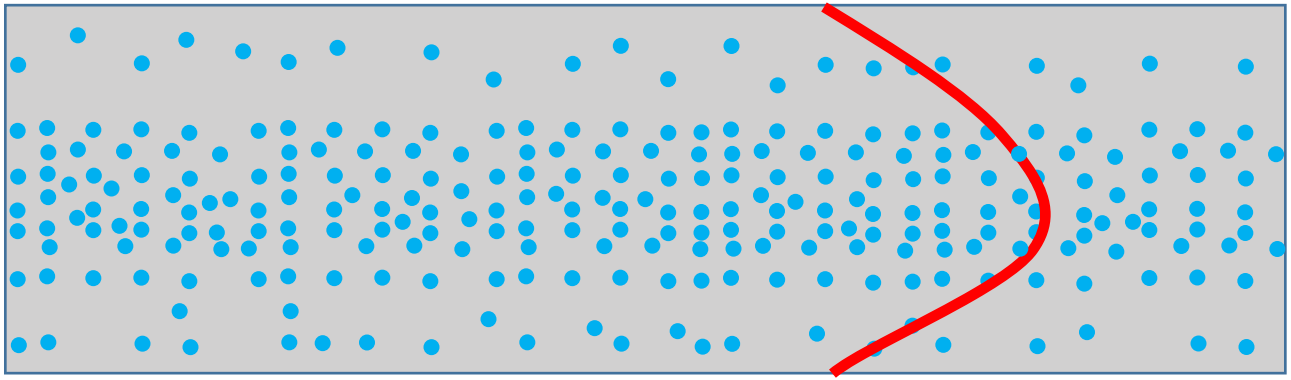
Vapor Retarder



Steel Deck

Moisture in Concrete

Stripped forms = 2 way drying

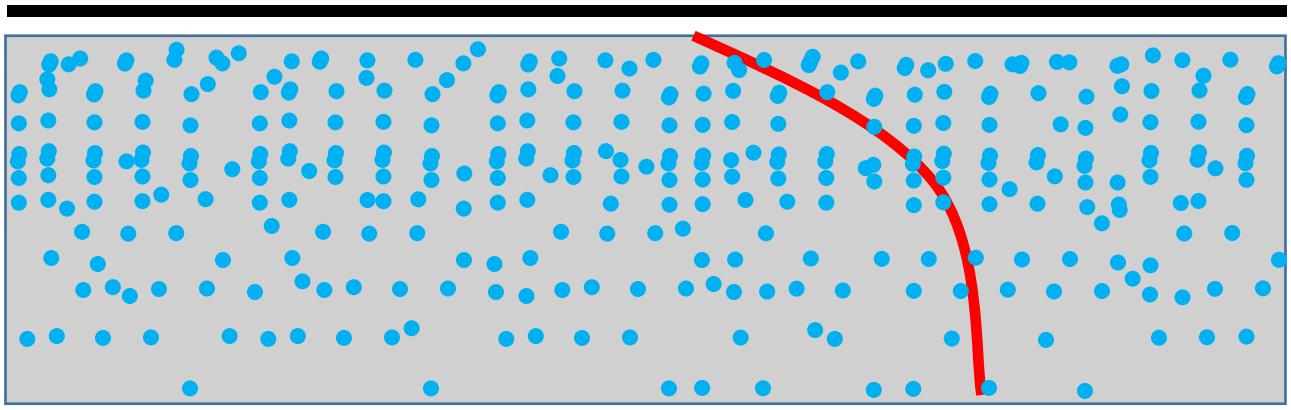


Moisture in Concrete

Stripped Forms = Two way drying

↓

Vapor Retarder = one way drying



Moisture in Concrete

- How do we measure moisture content of placed concrete?
  - Surface emission
  - Electrical resistance
  - Electrical impedance
  - Relative Humidity at depth

Moisture in Concrete

- ASTM D4263 Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method
- Very qualitative
  - Environmental conditions can greatly influence results / signal
- Easy and inexpensive
- Can give false negative

Moisture in Concrete

- ASTM F-1869 Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride
- Dish of Calcium Chloride is weighed before and after 24hr exposure under a clear lid
- Returns pounds of water emitted per 1000ft² per 24 hours
- Very old test

Moisture in Concrete

- Calcium Chloride test

http://www.duraamen.com/images/mv_pic_01_test_kit_01.jpg

Moisture in Concrete

- ASTM F-2420 Determining Relative Humidity on the Surface of Concrete Floor Slabs Using Relative Humidity Probe Measurement and Insulated Hood
- Uncommon test
- Uses a relative humidity probe placed on top of slab inside a small insulated box
- Gives indication of moisture at surface not what is in the slab
- Uncommon test

Moisture in Concrete

- Humidity Probe Measurement and Insulated Hood

http://www.esellersolutions.com/eSellerManager/images/upload/item/Southsurvey/itemImage_111_7_12_11_48_35.gif

Moisture in Concrete

- Electrical resistance measurement
- Drill two holes in concrete
- “brush” probes inserted and resistance between probes correlated to moisture content
- Not seen in the US currently

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FOR PROFESSIONAL APPLICATIONS

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Laserline

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Moisture in Concrete

- Impedance measurement of concrete surface
- Electric field is passed through concrete
- Instrument reads out moisture content percentage.
- Only reads top 1.5 inches of slab

Moisture in Concrete

- Tramex CMEX II

http://i.ytimg.com/vi/JJjEJyK4ia8/0.jpg

http://www.i-sells.co.uk/images/Resize%20of%20Electrodes.JPG

Moisture in Concrete

- ASTM F-2170 Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes
- Drill hole in concrete deck
  - 40% of depth
- Relative humidity probe inserted into hole
  - Sealed
  - Recovered / read after 72 hours
    - (24 hours works just fine)

Moisture in Concrete

- ASTM F-2170 (Continued)
- Flooring manufacturers require minimum RH reading delivered via F-2170 before floor is allowed to be installed
- Wide acceptance
- Lots of Research

http://www.southsurvey.co.uk/img/gi_20_38_466_700.jpg

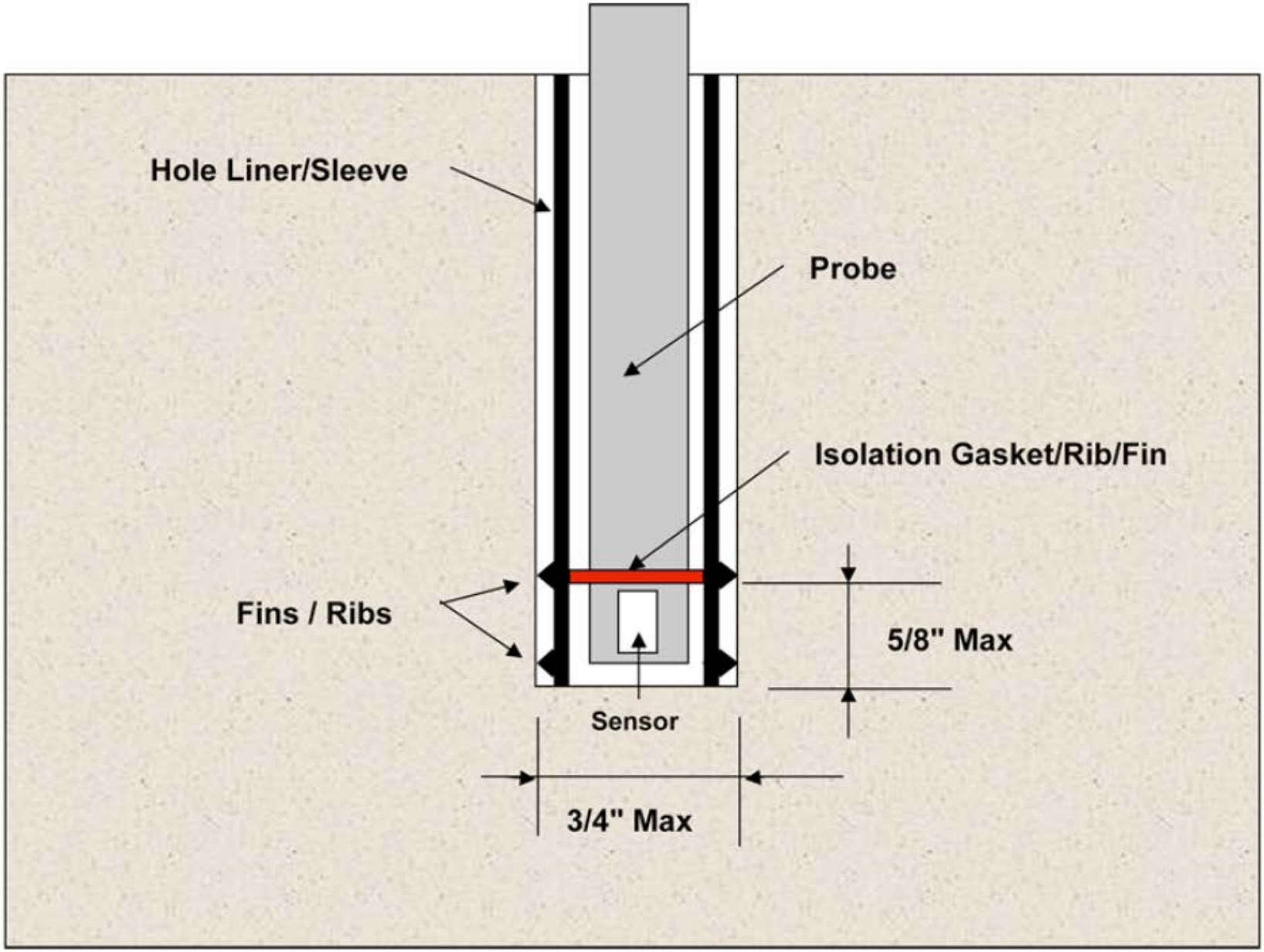


FIG. 2 Example % RH - Probe Element Position

Moisture in Concrete

- Flooring industry struggled with the issue concrete floors and failures at the turn of the century
- Flooring manufacturers specify at what test values (moisture content) their products can be installed over concrete
  - Typical values range from 80% to 90% RH via F2170

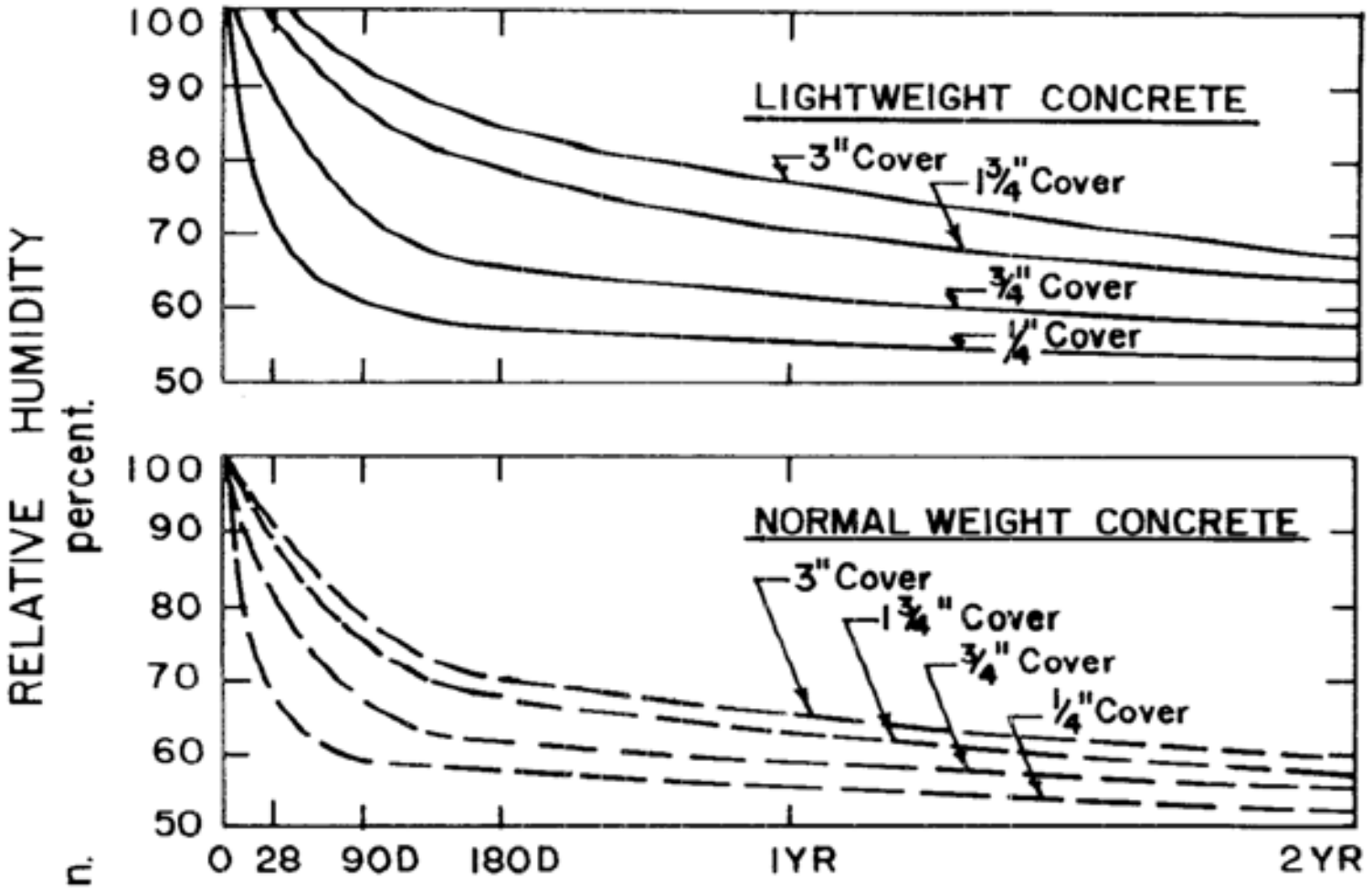
Moisture in Concrete

- However floors and roofs exist in drastically different environments
  - Floors can be left till near the end of the construction cycle
  - Roof needs to go on very early
  - Floor typically has conditioned air
    - Temperature and humidity
  - Roof is exposed to weather
    - Rewetting

Bad and Worse

- So the flooring contractor has it easy right?
- Remember the Hanson graphs?

Bad and Worse



Effects of Curing and Drying Environments on Splitting and Tensile Strength of Concrete - Hanson

Bad and Worse

- Differences between Regular Weight Concrete (RWC) and Light Weight Structural Concrete (LWSC)
- Mass (approximate)
  - RWC 150 lb/ft^3
  - LWSC 110 lb/ft^3
- Starting water content
  - Regular weight aggregates have 8 - 15 lb/yd^3 of concrete
  - Light weight aggregates have 150 – 200 lb/yd^3 of concrete
- Both can achieve the same compressive strengths
  - LWSC does it with less weight

Bad and Worse

- Light weight aggregates
  - Expanded shales and clays
  - Alternately referred to as “pre-wetted aggregates”
  - Need to be ponded or soaked for days to months before being batched into a concrete mix
    - Water fills pores and prevents light weight aggregates from interfering with mix properties and performance
- Lightweight structural concrete has repeatedly been shown to take much longer than regular weight concrete to dry.

Recommended Reading

- Engineering Bulletin 119 : Concrete Floors and Moisture
  - Howard M. Kanare
  - 2008, Portland Cement Association

Field examples (Train Wrecks)

Field Example #1

- Plaza deck on corporate campus
- Light weight structural concrete over steel deck
  - Too late in design to switch to regular weight concrete
- IRMA design with fluid applied and self-adhesive waterproofing sheets
- Deck allowed to cure / “dry” in summer heat for just over 3 months


Empire
STAINLESS STEEL

Field Example #2

- East coast hospital
- Roof deck designed to be floor for future vertical expansion
  - Operating suites below roof deck
- Light Weight Structural Concrete on metal deck
- Fully adhered EPDM with tapered ISO
  - Low rise foam adhesive in ribbons
- In place for 3 years


48 in


12

Field Example #3

- Hospital in the upper Midwest
- Roof deck intended to be a floor for future vertical expansion
- Light Weight Structural Concrete on metal deck
- Fully adhered EPDM with tapered ISO
  - Low rise foam adhesive ribbon

Field Example #3

- Top floor unoccupied
- No leaks reported
- First indication was fully adhered membrane billowing in wind
  - Below design winds
  - 9 months after occupancy
- Manufacturer denied warranty coverage due to trapped moisture (interior moisture)
- Insurance company denied claim as defective construction

Research
Phase 1

Research Sponsors

Research Goals

- Primary Goal
  - Determine what moisture level in concrete decks is appropriate for roofing operations
    - New construction and reroof
- Secondary Goals
  - Study instrumentation capabilities for speed and accuracy in the determination of moisture levels in concrete roof decks
  - Study impact of weather and the phenomena of “rewetting” on moisture levels in concrete roof decks

Research Plan

- 4 Modules of the Phase 1
- Began preparation and planning Spring 2016
- Concrete pours occurred July 11, 2016
- Study is ongoing
  - New information learned reshapes hypotheses and direction of research
  - Phase 2 starting August-September 2017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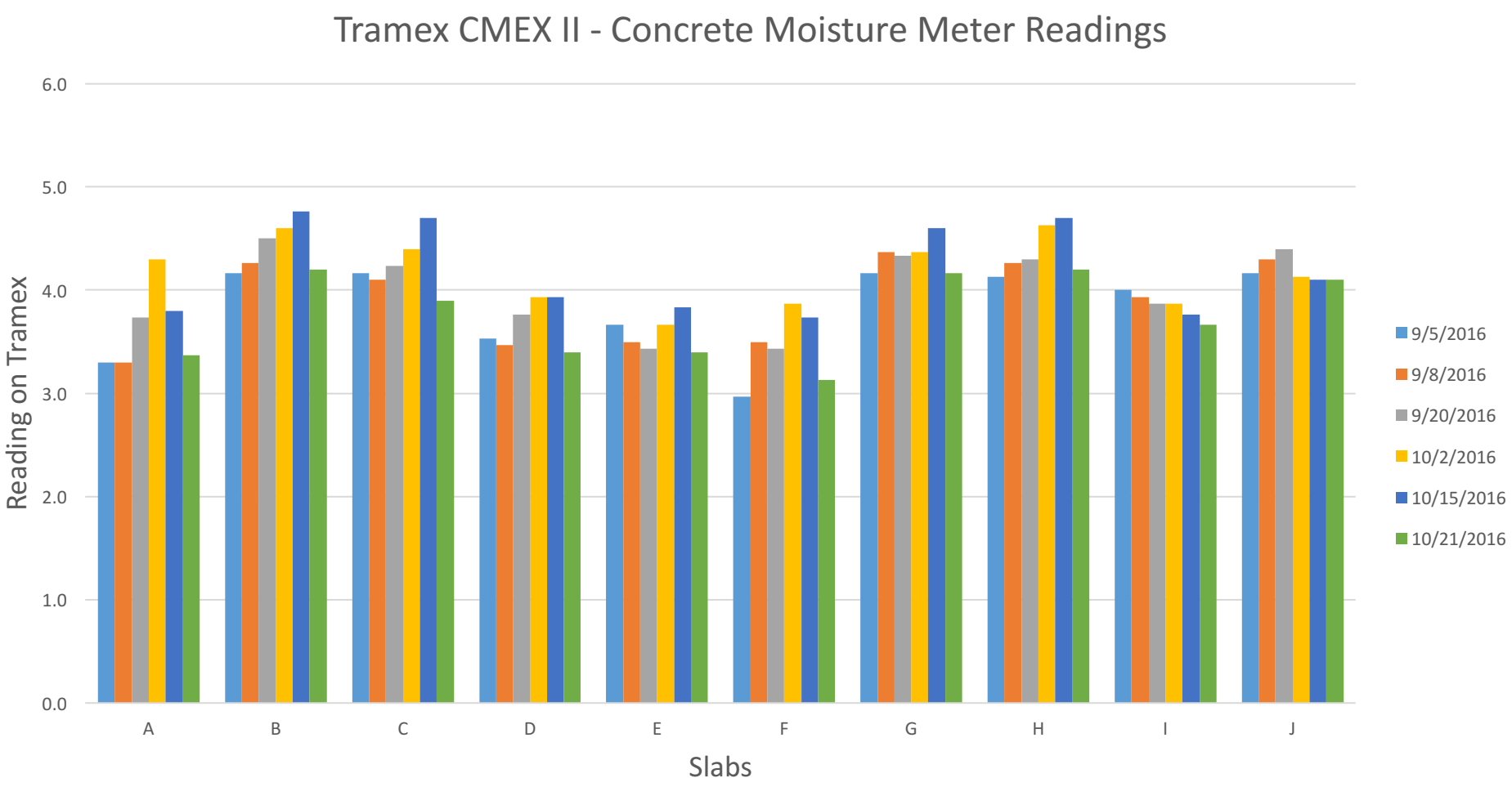
BLACK MAX


L-13-A
L-14-A

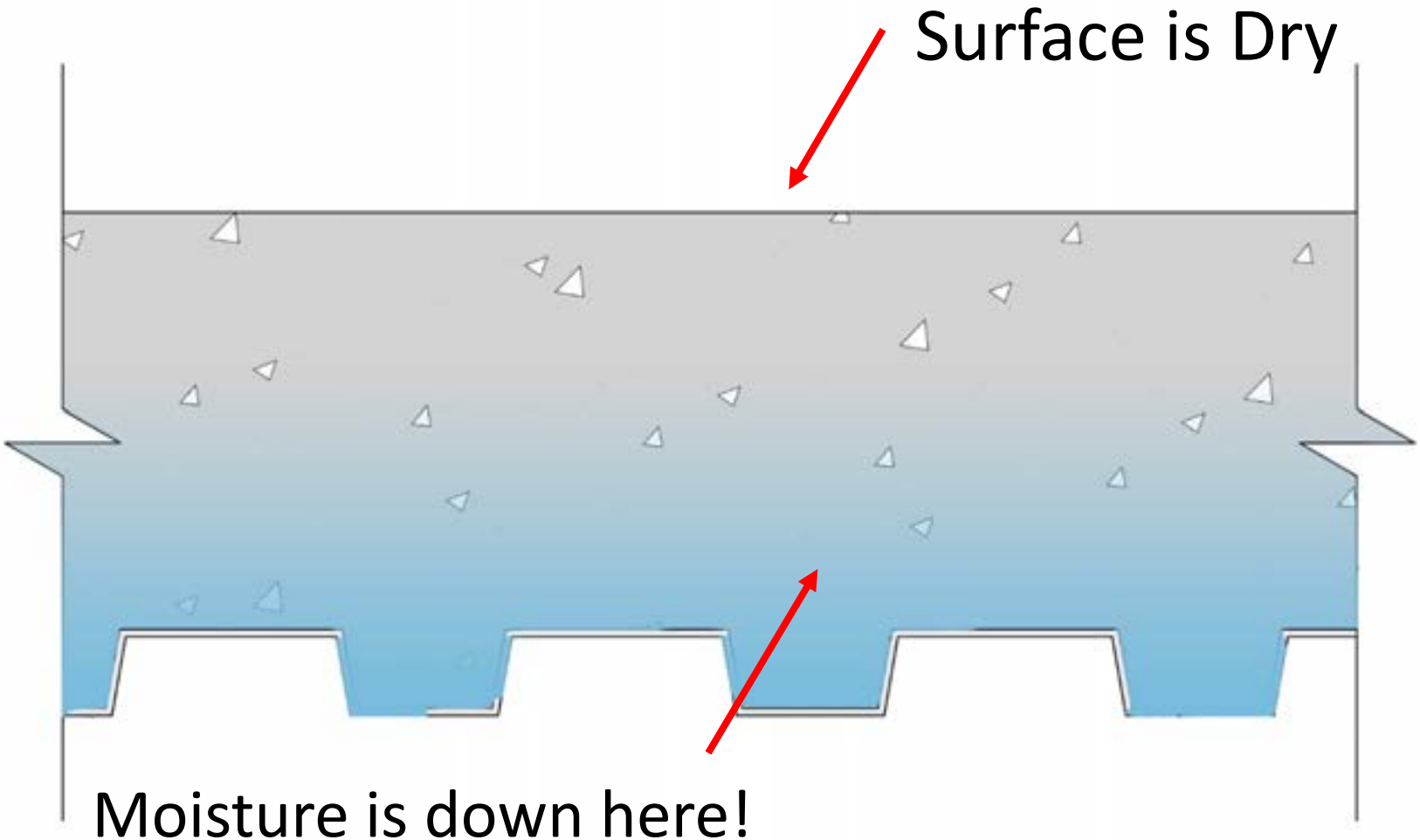
Research Progress

- Phase 1 Full scale concrete weathering farm and lab samples
  - Received 20.43 inches of rain during the 16 week period
  - Tramex CMEX II - Concrete Moisture Meter used
    - No discernable difference between inside, outside, normal weight, light weight
    - Only was an indicator of recent rain

Research Progress




3.2
5.1

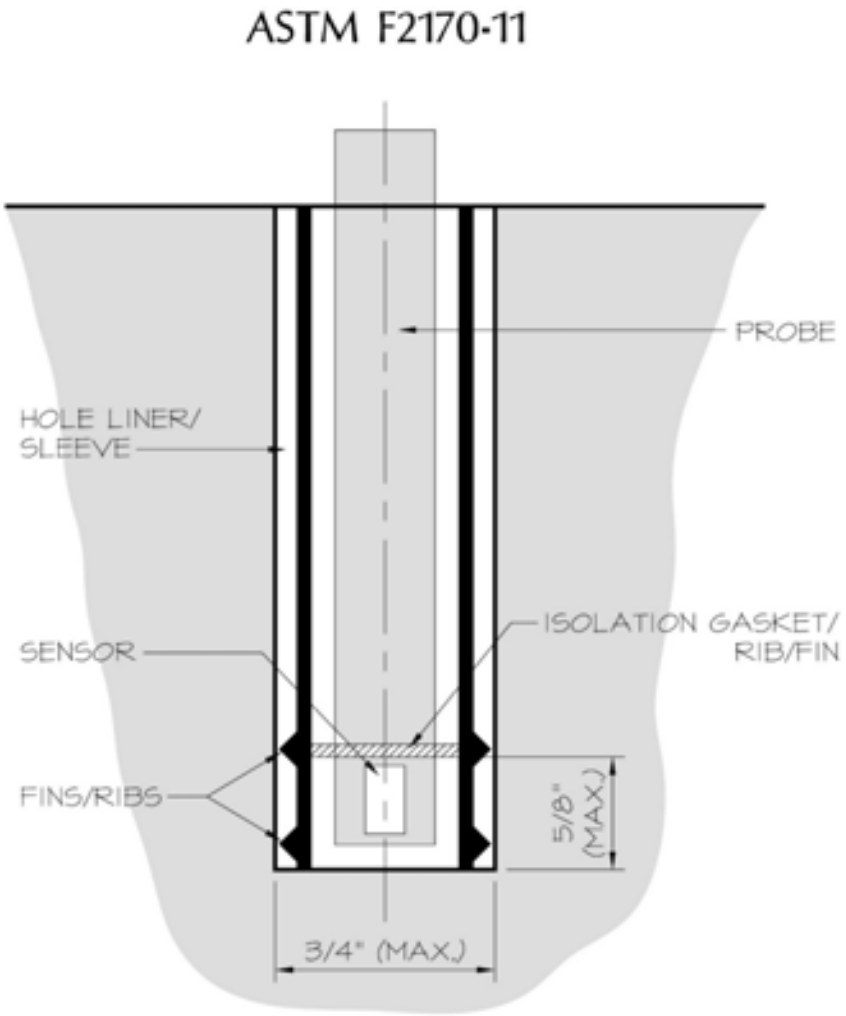

Surface is Dry
Moisture is down here!

Research Progress

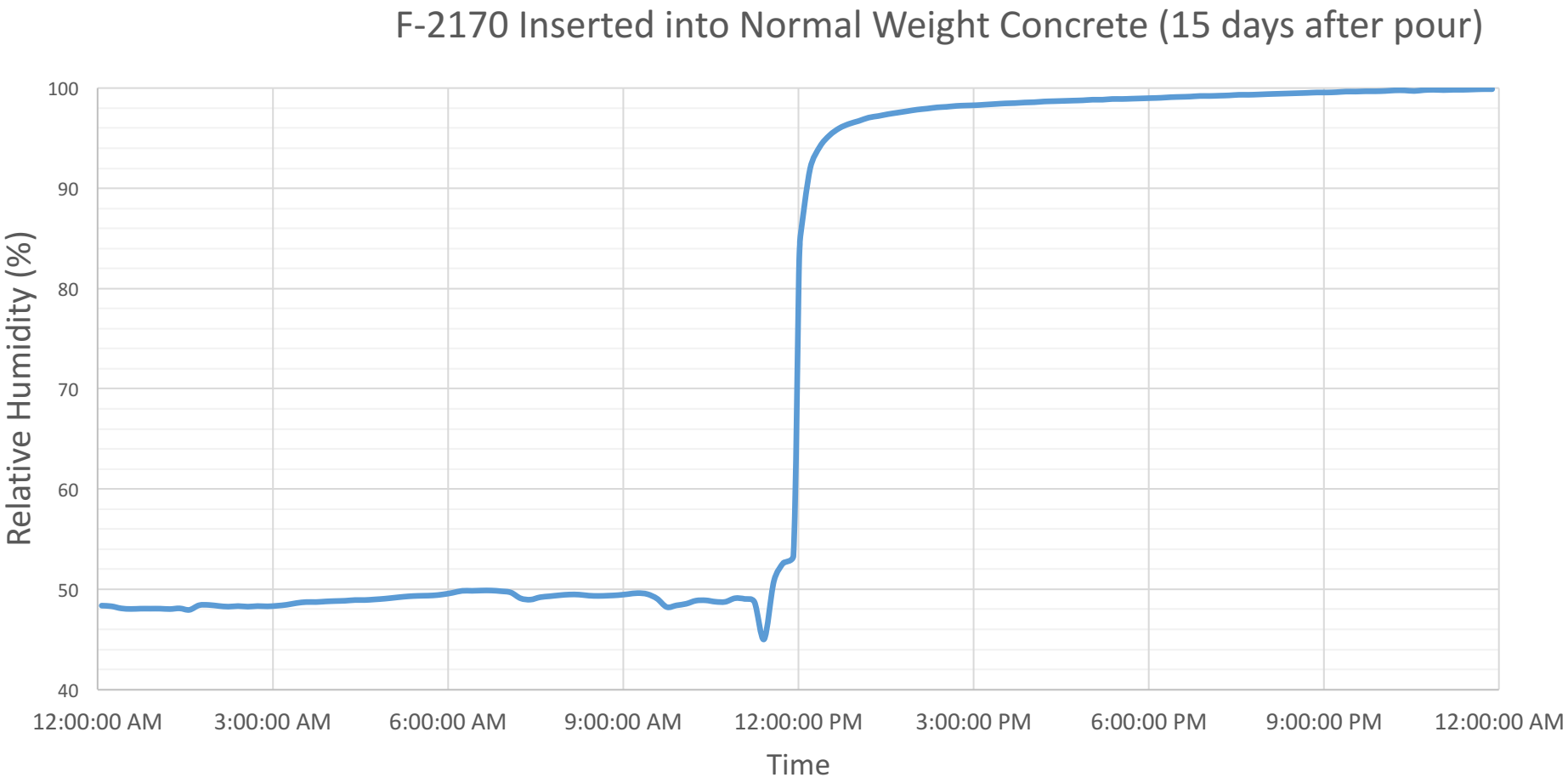
- Phase 1
  - Use of F-2170 probes
  - Wagner Meters in Rogue River, Oregon provided hundreds of probes and accessories for this study.
    - Calibrated before use
    - Readings typically taken 1,2,3,6, and 24 hours after placement weekly
      - Pans
      - Slabs
      - Replicates
      - Exterior pans brought in lab and probe again
    - Thousands of readings with confounding variables
    - Promising data need more time to study

WAGNER METERS

Research Progress



Research Progress



Research Progress

- Phase 2 Hygrothermal characterization of concrete
  - E96 Vapor Permeability
  - C1794 Water Absorption Coefficient
  - C1498 Hygroscopic Isotherm
  - C1699 Moisture Retention

Research Progress

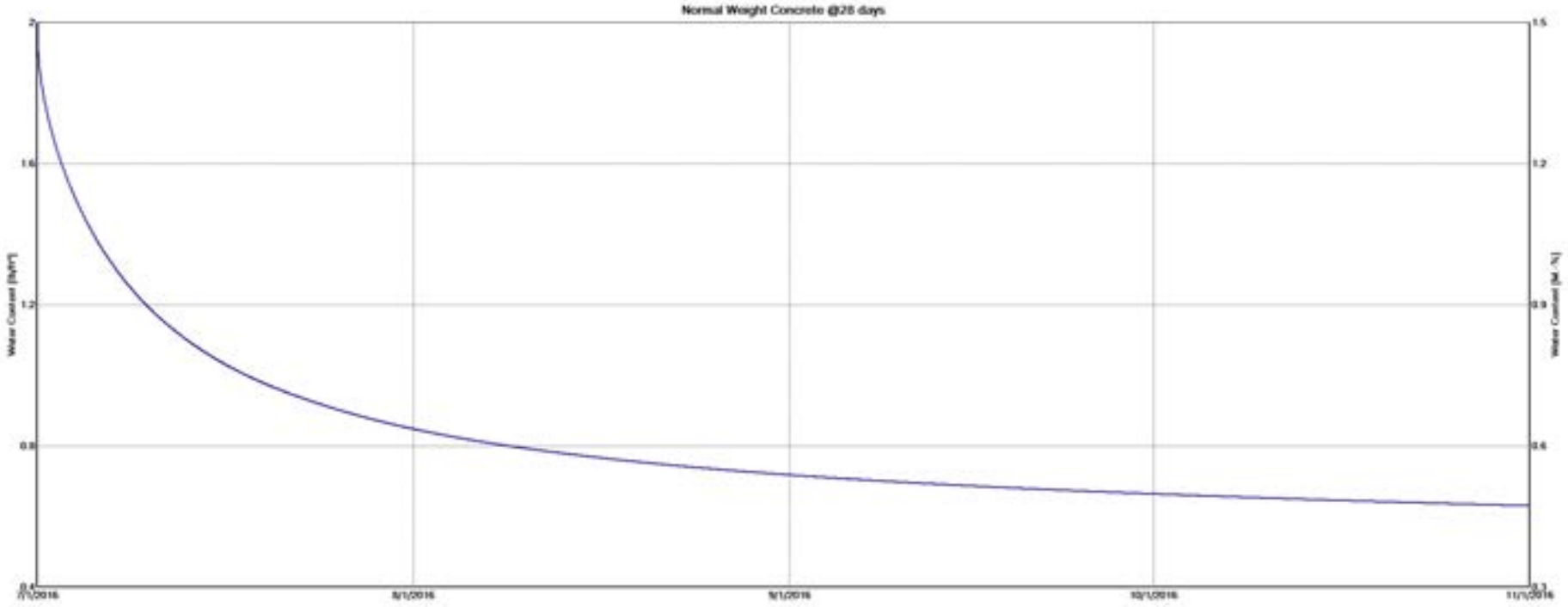
- Module 2 Hygrothermal characterization of concrete

	ASTM E96 calculated Perm·in			
	Light Weight Structural Concrete		Normal Weight Concrete	
Age	**Wet Cup**	**Dry Cup**	**Wet Cup**	**Dry Cup**
28 Day	1.48	0.78	3.42	1.05
60 Day	1.45	0.47	2.03	1.13

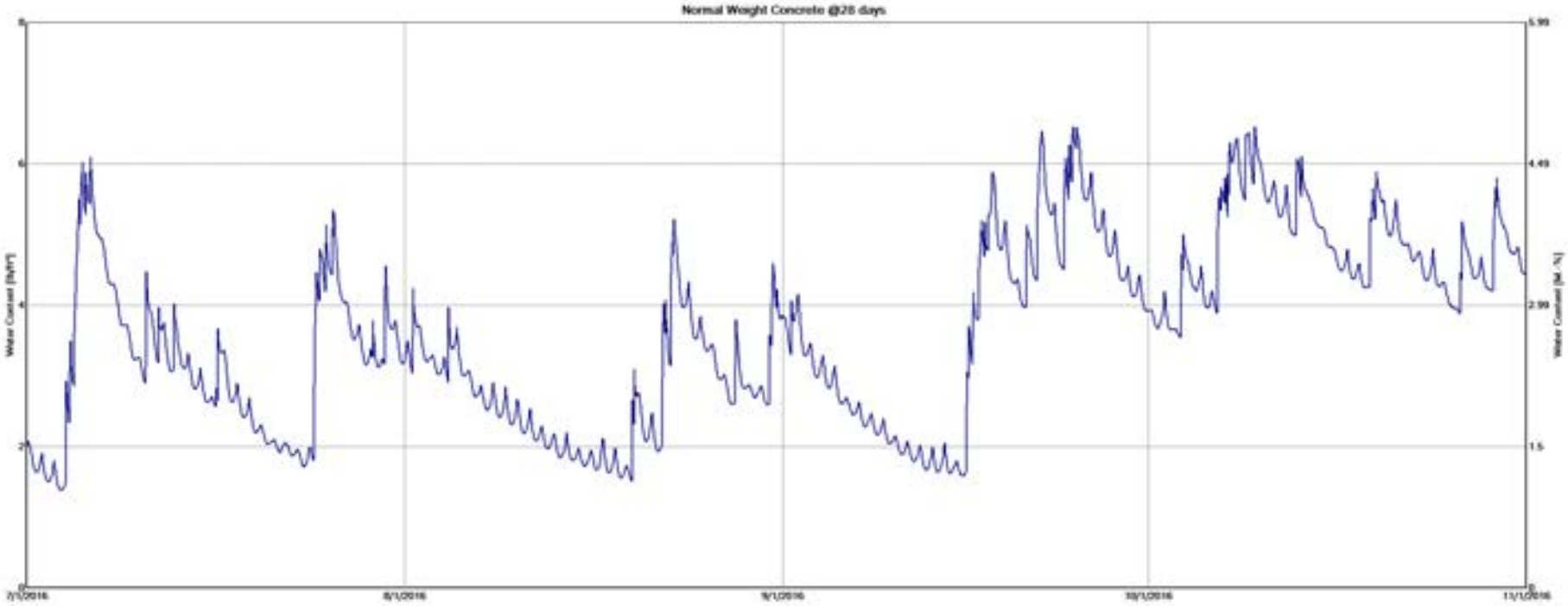
Research Progress

- Module 3 Hygrothermal modeling
  - WUFI 5.3 Pro Hygrothermal program utilized
- Consulting with justSmartSolutions the U.S. partner of the German software vendor
- The data output from the modeling has been validated with Module 1 data
- Let us look at some of the thing we can opine from just the simple graphs!

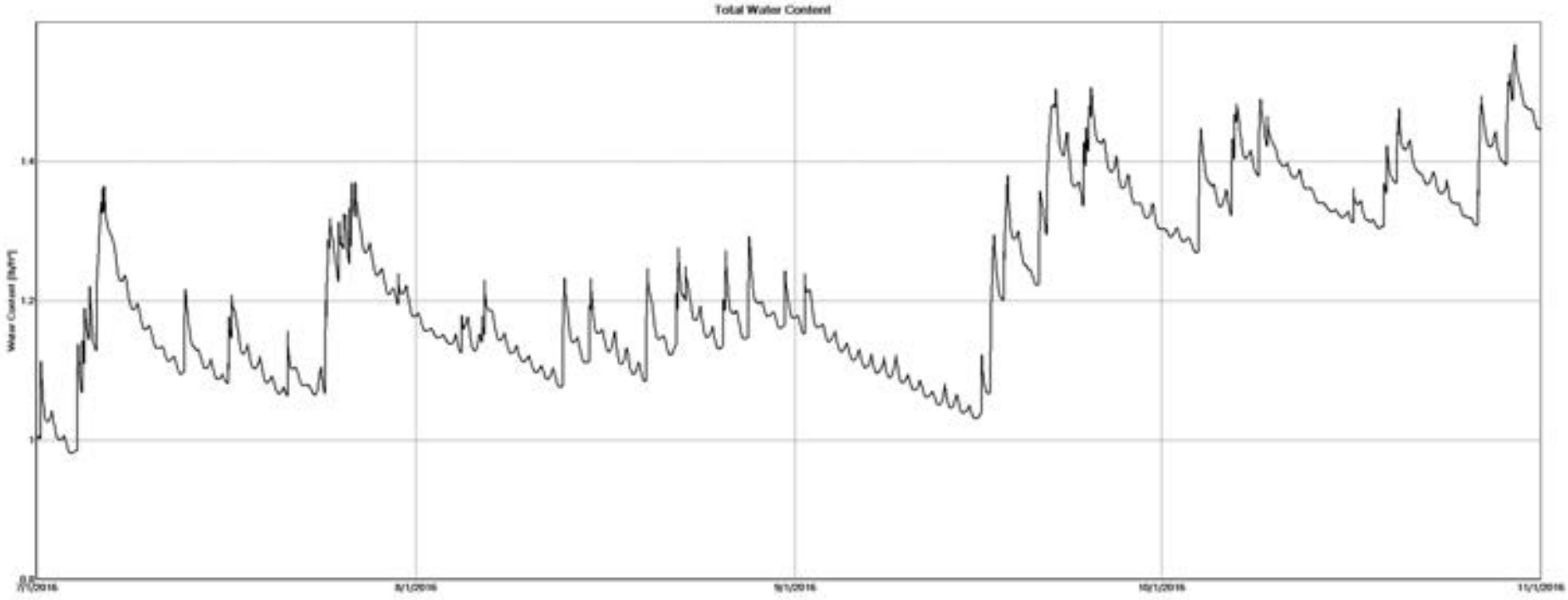
Normal Weight Concrete – Lab Dry Down (4 Months)
Top 1 inch of slab



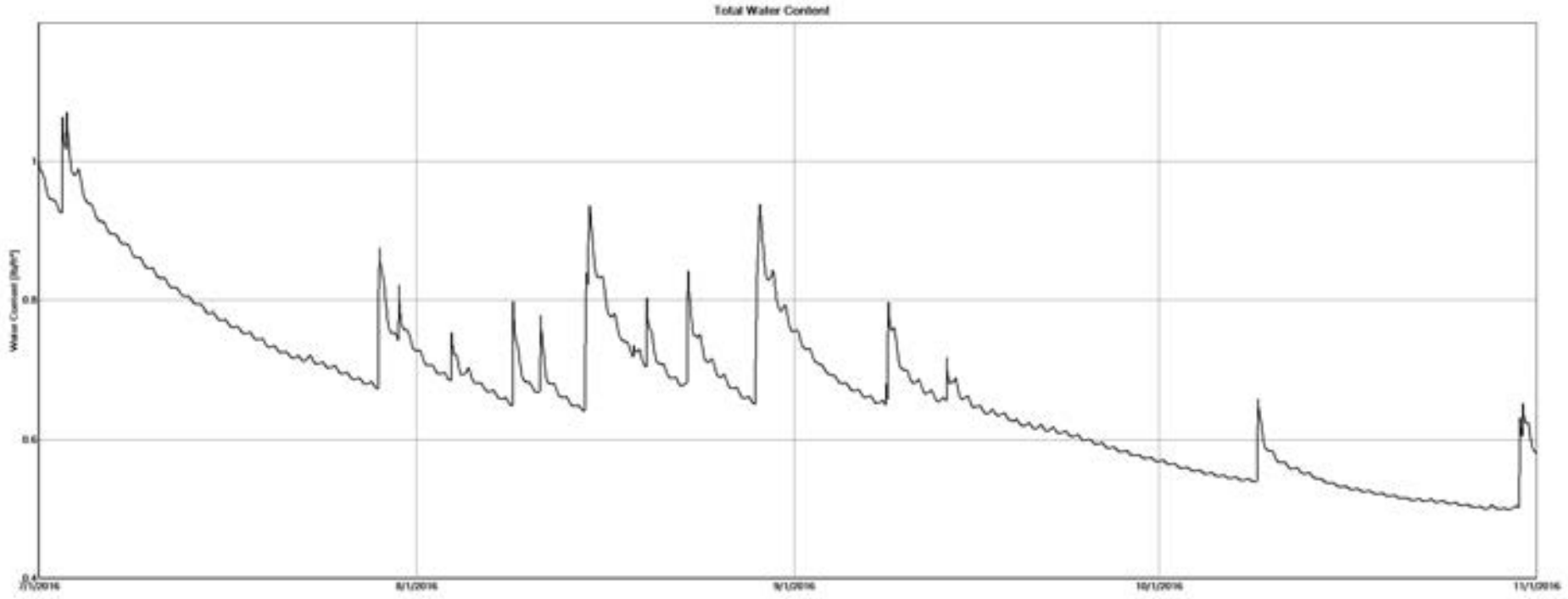
Normal Weight Concrete – Outdoor Dry Down (4 Months)
Top 1 inch of slab



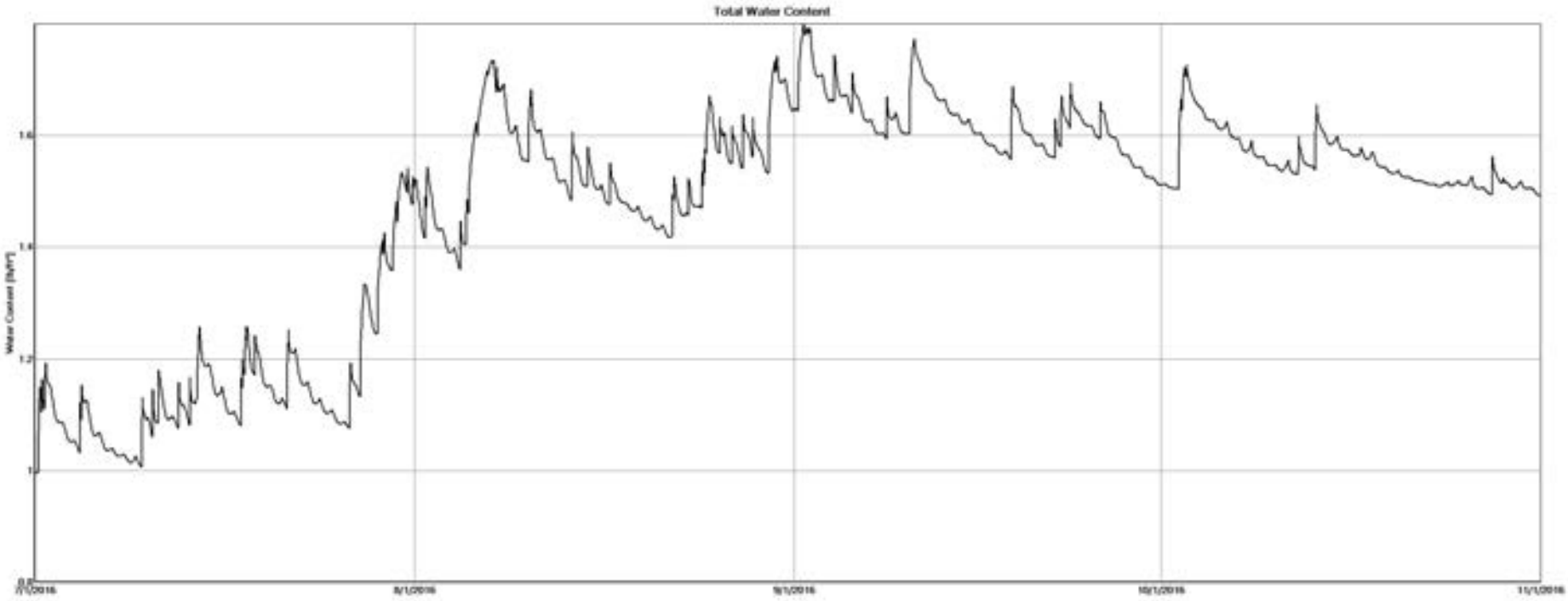
Total Water Content per Ft^2 of slab Regular Weight Concrete Chicago, IL (4 Mo.)



Total Water Content per Ft^2 of slab Regular Weight Concrete Phoenix, AZ (4 Mo.)



Total Water Content per Ft^2 of slab Regular Weight Concrete Edmonton, CAN (4 Mo.)



Research

- Used hygrothermal data for current generation roofing materials
- Simulated roof slabs outdoors for 28 days then roofed
- With and with out vapor retarders
- 100’s of combinations

Research

- Desert southwest generally ok without a vapor retarder
- Canada…just plan on a vapor retarder
- Southern tier states…maybe
  - Atlanta slab goes down July 1 = ok with no vapor retarder
  - Atlanta slab goes down December 1 = fail without a vapor retarder
- So…do I need a vapor retarder…it depends

Recommendations

- Preliminary findings of concrete research program point to a distinct issue with slabs in northern and humid climates.
- Work on hygrothermal simulations and their validation is ongoing (Phase 2).
- But given the currently available research data and observations from it, this researcher is recommending that:
  - **Unless the Designer of Record approves in writing otherwise, a vapor retarder of less than 0.01 perm is necessary over <u>new</u> concrete roof decks.**
- The impact of rewetting on existing concrete decks (reroof) and moisture laden roof systems is being determined.

Thank You

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