CONCRETE SLABS AND MOISTURE ISSUES

Prepared for

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INTRODUCTION

Modern buildings would not be practical without concrete floors. Annual construction of new floor area for public and commercial buildings in the United States is approximately 140 million square meters (1.5 billion sq ft), most of which is concrete. This figure includes schools, hospitals, recreational facilities, stores, restaurants, offices, warehouses, terminals, and industrial buildings (Dodge 2001). Concrete floors in residential buildings raise the total area even higher. The amount of remodeling or adaptive reuse of buildings with concrete floors is unknown but is undoubtedly substantial. The vast majority of concrete floors are constructed without problems and provide a long and useful service life for building occupants.

If a concrete floor is maintained relatively dry while in use, many types of potential problems are avoided. However, water is a necessary ingredient in concrete, and floors are sometimes exposed to water accidentally during construction and later during the life of the building. Deficiencies in design as well as construction factors such as costs and schedules can influence how dry a floor remains during its life. Moisture in concrete floors causes billions of dollars in damage to buildings annually in the United States. Problems caused by excessive moisture in concrete floors include:

- dimensional changes of floor coverings such as expansion of wood
- discoloration of floor coverings and coatings producing unacceptable appearance
- debonding of floor coverings leading to trip-and-fall hazards
- growth of microbials leading to reduced indoor air quality, odors, and allergic reactions in some individuals
- deterioration of adjacent construction materials such as walls and wall coverings
- corrosion of items embedded in, or attached to, the concrete floor
- accumulation of moisture on the working surface creating a safety hazard

These types of problems often occur with concrete slabs in direct contact with the underlying earth that are not effectively isolated from ground moisture with a vapor retarder. Slabs above ground, also called elevated or supported slabs, sometimes have these problems if they have not dried sufficiently before flooring installation, or if they get wet unexpectedly, for example, from water spills, fire sprinkler system use, excessive humidity from building uses, or improper floor maintenance.

Elevated floor slabs in ribbed steel deck often are made with lightweight aggregate concrete. This lightweight concrete reduces the total load on the structural elements of a building, reducing costs and increasing useable floor area. Lightweight aggregates have higher water absorption than normal aggregates; concrete made with lightweight aggregate can take considerably longer to dry than ordinary concrete and must be carefully tested for moisture before proceeding with flooring installation.

A concrete floor slab is just one component in the entire floor system. Other parts of the system that influence how the finished floor performs over time include subgrade soil, capillary break, subbase, vapor retarders, patching and leveling compounds, primers, adhesives, penetrations and seals, connections to walls and columns, finish floor coverings and coatings, maintenance chemicals, and the building environment. Each of these items plays a role in the moisture condition of the floor, and many of these items are affected by moisture in the floor system.

Concrete in the floor is often changing:

- Cement in the concrete continues to hydrate as long as sufficient moisture is present, even for years after the concrete is placed.
- The surface of a concrete floor slab chemically reacts with carbon dioxide in the air, changing pH at the surface millimeter by millimeter.
- Moisture is taken up, given off, and transmitted through concrete.
- Chemicals in floor coverings, adhesives, and coatings can react with concrete alkalies.
- Changing moisture levels can cause concrete floor slabs to shrink, crack, and warp.
- Incompatible flooring materials can react with moisture over time causing floor

finishes to “grow” or separate from the substrate concrete slab.

SOURCES OF MOISTURE

Moisture sources can be classified as *natural* or *artificial*. Natural sources of moisture include the following:

- Precipitation
- Dewpoint (condensation)
- Ambient humidity
- Subslab vapor
- Hydrostatic pressure
- Capillary rise
- Osmotic pressure

These natural sources must be considered during building design; design details must be provided to eliminate entry of unwanted moisture during occupancy and use of the building. Installation of an adequate vapor retarder directly below the concrete floor slab should eliminate entry of moisture from below the slab; design details should prevent unwanted moisture infiltration at the perimeter of the building. Vapor retarders should meet the requirements of E1745-97, *Standard Specification for Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs*. This standard requires permeance not more than 0.3 perms and sets three levels of tear and puncture resistance. Ordinary 6-mil polyethylene sheet may meet the permeance requirement but likely will not meet the physical strength requirements of this standard; 10-mil polyethylene is the minimum that should be used under floor slabs and there are many products available with lower permeance and higher strength.

If the concrete slab is placed under cover, after the roof and walls are erected, precipitation should be kept off of the slab. Ambient humidity (along with temperature and air movement) controls the drying rate of the concrete. If the ambient humidity is lower (drier) than the concrete, moisture will move outward from the concrete and the slab will be drying. If ambient humidity is higher (damper) than the concrete, moisture will be absorbed by the concrete. Thus, depending on the weather, daily cycles can exist of the floor alternately drying and re-absorbing moisture from the air.

Artificial sources of moisture include the following:

- Building uses
- Ventilation
- Maintenance
- Spills
- Concrete batch water
- Curing water
- Irrigation
- Broken pipes

Probably the most important source of moisture in concrete floor slabs is the original batch water, more specifically, the water-cement ratio. Drying rate and ultimate permeability of the concrete depend mostly on water-cement ratio. After the floor slab has dried sufficiently and finish flooring has been installed, unexpected spills, broken pipes, or overzealous cleaning can introduce unwanted water from above or below the floor slab. (For more information on this subject, see *Understanding Concrete Floors and Moisture Issues*, an informational CD-ROM available from the Portland Cement Association.)

A concrete floor slab is part of the building envelope. Just as we do not accept leaks in a roof or at windows or walls, we must design to eliminate moisture vapor intrusion through every floor slab. Adequate design followed by construction that meets the designer’s intent can produce a dry floor that will provide many years of service without moisture problems.

OVERVIEW OF CEMENT AND CONCRETE CHEMISTRY AND TECHNOLOGY

What are cement and concrete?

Concrete is a mixture of cement, sand, stone, and water. The cement and water form *cement paste*, which glues together the sand and stone, known as *aggregates*. Chemicals known as admixtures are often incorporated in concrete to develop special properties of the batch such as controlling setting time, increasing workability, and improving strength development or freeze-thaw resistance. Proportions of concrete batch ingredients and chemical reactions between cement and water determine the behavior of fresh concrete properties including strength development, permeability, and moisture content of the hardened concrete at later ages.

Portland cement is the most common type of hydraulic cement used for general construction. Cement is made by an industrial process that involves grinding a mixture of limestone and clay, or other raw materials of similar overall chemical composition, and then heating the mixture to about 1500°C in a large rotary kiln. Partial melting occurs and various chemical reactions take place in this burning process. The product at this stage, called *clinker*, consists of nodules up to about 25 mm (1 inch) in diameter. Clinker is mixed with several percent *gypsum* and finely ground to produce the gray powder we know as *portland cement*. The size of individual cement particles is of the order 10 µm, about one-tenth the diameter of a human hair.

During the burning process, limestone and clay react to form several cement components including *calcium silicates* and *calcium aluminates*. These components are hydraulic in the sense they react chemically when mixed with water. During these reactions, called *hydration*, the paste sets and hardens to form a rock-like mass even when submerged under water. Concrete does not harden because of drying. The apparent drying we see at the surface of concrete is the result of consumption of water due to the chemical reactions. (For more information, see PCA (1988), Taylor (1990), Lea (1998), or Neville (1998).)

How does concrete get strong?

Hydration. *Hydration* starts immediately upon contact between cement and mix water. Among the cement components, calcium aluminate is the most reactive towards water. Gypsum is added to clinker during the cement manufacturing process to control this rapid initial hydration reaction and permit sufficient time for placing, consolidating, and finishing the concrete before hardening.

During hydration, the calcium silicates form a gel-like calcium silicate hydrate, which cement scientists call C-S-H. The C-S-H gel is the most important cementing component of concrete. It is responsible for the engineering properties of concrete such as setting and hardening, and strength development; the structure of the C-S-H gel on a microscopic scale is important for the behavior of water and water vapor in concrete.

Water-cement ratio. Water-cement ratio is perhaps the most important parameter in concrete technology. It is simply the weight of water divided by the weight of cement in a concrete batch. For example, a cubic yard of concrete that has 282 lb of water and 564 lb of cement has a water-cement ratio of 0.50. Theoretically, there is sufficient water to fully hydrate all the cement particles in concrete batches with water-cement ratio about 0.38. But for such a concrete mixture the workability (that is, as the ease of placing, consolidating and finishing fresh concrete) would be poor—the mix would be too stiff to be practical. Therefore, chemicals known as water-reducing admixtures are needed to make the mix workable. In practice concrete mixtures with higher water-cement ratio are often used. In such cases there is more than sufficient water for the hydration as long as drying out is prevented during the period of curing. However, this extra water, which is needed to ensure workability of the concrete, must be dried out later.

Shortly after concrete is placed, consolidated, and struck off to a level plane, some of the excess water will rise to the surface. This “bleedwater,” must be allowed to recede so the sheen disappears from the surface before finishing operations called floating and troweling. If bleedwater is excessive, it can cause a weak, dusty surface to form sometimes called “laitance.”

POROSITY AND PERMEABILITY

Capillary pores

Water in a concrete batch is mostly displaced by solid hydration products as the cement hydrates. However, some of the original batch water forms a system of capillary pores.

Permeability of concrete with respect to moisture movement depends on the connectivity of the pore system. At the beginning of hydration the capillary pore system is continuous throughout the paste and permeability is high; as cement hydration proceeds, the capillary porosity decreases and the pores become smaller in size. At a certain point, depending on the degree of hydration and the value of the original water-cement ratio, the capillary pore system is no longer continuous. For water-cement ratios greater than approximately 0.6 to 0.7, the capillary pores are connected even at full hydration of the cement. With lower water-cement ratios, the pore system develops into isolated clusters of pores and the permeability is decreased.

Practical implications

For a concrete slab on ground made with high water-cement ratio, the continuous pore system will transport moisture from the ground by capillary action and diffusion to the surface of the concrete slab. As long as there is a source of water or water vapor below the slab, moisture will be transmitted through the slab at a rate depending on the temperature and the humidity at the surface of the concrete slab. Obviously, this process can lead to moisture-induced failures of finish flooring. For concrete made with low water-cement ratio, the pores in the interior of the concrete become isolated from the top and bottom surfaces, and transport of moisture through the slab will be greatly reduced. Low water-cement ratio, high-quality concrete slabs will transmit less moisture from below the slab to the finished surface and, therefore, are more likely to tolerate occasional moisture intrusion, while high water-cement ratio, lower quality slabs are more often likely to fail. Even the best quality, low-permeability concrete needs a proper vapor retarder directly below the slab for long-term, moisture-proof performance (see below).

CURING AND DRYING

Curing

Strength development of concrete is directly related to the degree of hydration of the cement, and inversely related to the water-cement ratio: for a given set of concrete batch ingredients, lower water-cement ratio produces higher strength. Hydration of cement is greatly reduced when the internal relative humidity of the concrete falls below approximately 80%. Therefore, concrete must be kept moist and protected against drying during the curing period. Curing is accomplished by using moisture-retaining curing covers (damp burlap, plastic sheets), ponding or fog-spray, or use of spray-applied curing compounds. At least a few days curing are necessary to provide a concrete floor slab with sufficient surface integrity for applied floor coverings or coatings.

Curing compounds meet ASTM C309-98a *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete*, or C1315-03 *Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete*. Many curing compounds do not permit adhesives to bond well with the concrete substrate. Therefore, it is very important that the concrete contractor not use a curing compound where floor coverings will be adhered, unless it is known that the specific curing compound is compatible with the anticipated flooring adhesive.

Because curing compounds retain moisture in concrete, they will slow the initial rate of drying at the concrete surface. However, it is not known precisely how much these curing compounds retard the total drying time of concrete.

Drying

Concrete to receive flooring material must be dry enough to permit the adhesive to bond properly and to prevent damage to the flooring. The surface may look dry but the slab can contain sufficient moisture to cause problems when covered. The following factors affect the time needed for drying concrete slabs to a desired moisture level:

- Type of cement
- Type and amount of aggregates
- Thickness of the concrete slab
- Water-cement ratio (or water-cementitious ratio when mineral admixtures are present such as fly ash or silica fume)
- Curing conditions
- Drying conditions

- Desired moisture condition specified by the flooring/adhesive manufacturer

Of these factors, the water-cement ratio (or water-cementitious ratio) is the single most important parameter for the drying of the concrete.

An often-quoted rule of thumb for estimating the time for drying concrete floors to an acceptable moisture content is about one month per inch of concrete thickness. This rule applies to concrete made with a moderate water-cement ratio, drying from the top only, assuming no moisture intrusion from below, and applies from the time that the concrete is under cover and the building is mostly closed in (when the concrete is no longer exposed to precipitation or high humidity). But concrete with a high initial free water content (such as lightweight concrete made with expanded lightweight aggregates having high absorption) may require longer time to dry than normal-weight concrete.

Drying of concrete progresses when the relative humidity in the air over the slab is less than the relative humidity within the surface of the concrete. In temperate climates found throughout much of the United States, concretes experience daily cycles of drying and re-absorbing moisture as the relative humidity in the air changes. For example, during a warm, relatively dry summer afternoon, concrete will give up moisture; overnight when the temperature drops and the relative humidity increases, concrete will actually gain moisture. The net effect over many weeks is that the interior of the concrete slab will continually dry while the surface will emit and then absorb moisture if the air space over the slab is not conditioned. We can see from this explanation that drying will be most efficient if the air space is conditioned or at least closed against outdoor weather.

Brewer's Study of Slab Drying Times

Working at the laboratories of the Portland Cement Association in Skokie, Illinois, Harold Brewer researched and published in 1965 a study on drying of four-inch concrete slabs. He studied the drying rates of slabs made with water-cement ratios ranging from 0.4 to 1.0. The graph shows the results for some of his slabs, converted to units of lb moisture/1000 sq ft/24 hr. As can be seen, the drying time to reduce the flow to 3 lb / 1000 sq ft / 24 hr can range from a little more than one month all the way up to six months depending on the water-cement ratio of the concrete. (Note: These rates are true moisture vapor transmission, measured by determining the mass of water evaporating through his concrete specimens; they are not measuring the same thing as calcium chloride kit values we obtain today by placing test kits on top of a concrete slab.)

The trends seen in Brewer's extensive work have been confirmed over the past decades through research in Europe and many jobsite measurements made in the U.S. High water-cement ratio concretes initially emit moisture at a high rate, but take longer to achieve the desired final moisture condition, compared to concretes of lower water-cement ratio.

Estimating Drying Times

Based on experimental work summarized by Hedenblad (1997) and work performed in Finland and Denmark, The Swedish Concrete Association Report No 6 (1977) describes a method for estimation of drying times for concrete slabs under standard conditions. Correction factors make it possible to adjust for deviations from the standard conditions. The purpose is to enable the project engineer and the contractor to estimate *minimum* drying times for concrete slabs already during the planning stage, since drying is on the critical path to installing floor finishes, and therefore, to occupancy.

A computer program to estimate drying times for various concrete mixes and drying conditions called TorkaS is available from the Center for Building Material Research, Lund University, Lund, Sweden at their website: (http://www.fuktcentrum.lth.se/torkas.htm). Contractors and planners can use the program to see what effect changes in concrete mix designs and ambient conditions will have on drying times. It can be a useful tool for general construction scheduling. However, this program should be considered a guide only and not used to predict absolute drying times.

MEASURING MOISTURE IN CONCRETE

Introduction

Test methods used to measure moisture in concrete can be classified as qualitative or quantitative. Qualitative tests provide a general indication of moisture while quantitative tests produce a numerical result. Both types of tests can provide useful information; however, do not rely on a qualitative test to determine if a floor moisture level is acceptable. A qualitative test result that indicates excessive moisture is a strong indication that the floor is not ready to receive adhesive and floor covering. On the other hand, a qualitative test result that does not indicate excessive moisture must be followed by a quantitative test to assure that the floor is in fact acceptably dry. Stated another way, these qualitative tests usually do not give false positive results but can give misleading negative results.

Rooms and floors must be at service temperature and relative humidity for at least 48 hr before performing any moisture test. If the room air and floor are not at service conditions, test results can be misleading. Moisture vapor emission from a concrete surface, and relative humidity within the slab, are strongly dependent on the relative humidity and temperature of the ambient air over the concrete surface.

Qualitative Moisture Tests

Plastic Sheet Test (Mat Test)

ASTM D4263, *Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method*, involves taping a 18 x 18-in. square of 4-mil polyethylene onto a concrete surface and allowing it to rest for at least 16 hours, then examining the underside of the sheet and the concrete for signs of moisture. If condensed moisture is present under the sheet, or if the concrete has darkened noticeably, then excessive moisture is present and the concrete is not ready to receive a moisture-sensitive covering. Some flooring manufacturers specify a 24-hr test period using a heavy-duty polyethylene sheet.

The presence of observable moisture below the plastic sheet depends on dewpoint, that is, there must be enough moisture to condense at the surface temperature of the concrete. However, it is possible to get a negative result, that is, no apparent moisture, simply because the temperature of the slab surface is above the dewpoint temperature for the amount of moisture in the slab.

Some flooring installers place a heat lamp over the plastic sheet in an attempt to “draw out” moisture from the concrete. This variation of the test is not recognized in the

ASTM method and is not likely to provide reproducible results. In fact, moisture flows from warm to cold, so heating the surface of the concrete would have the unintended effect of driving moisture away from the surface, producing a false negative result.

The plastic sheet test on concrete is a good example of a qualitative test that can be misleading. If the floor looks damp below the plastic sheet, excessive moisture indeed is present. But, if the floor looks dry under the plastic sheet, moisture might be lurking below the surface and the floor might not be dry enough to proceed with installation of flooring. This test does not reveal whether moisture might be entering the slab from below, for example, if no vapor retarder is present under the slab.

Mat Bond Test

A 1-yd. square sample of resilient sheet flooring is adhered to the concrete floor using the manufacturer's recommended adhesive and installation procedure, and the edges of the flooring are taped to the concrete. After 72 hours the flooring is pulled up by hand. The force required to remove the flooring is judged and the condition of the adhesive is examined. If the adhesive is emulsified or obviously wet, or if the bond is unacceptably weak, then the floor is not dry enough to receive flooring. This technique obviously requires judgment and experience to evaluate the quality of adhesive bond. A well-bonded sample suggests that the floor is suitable for installation of the flooring.

This procedure is described in some floor covering installation manuals and really is a short-term test installation. There are two variations of the test: in one variation, the adhesive is allowed sufficient open time to develop tack, and a piece of flooring is then installed just as it would be for the actual installation. In a second variation, suitable only for water-based adhesive, the adhesive is spread on the surface of the concrete and covered immediately with a piece of low-permeability resilient sheet flooring (vinyl or rubber) and the edges are then sealed with tape. Moisture in the adhesive is initially trapped between the flooring and the concrete. If the concrete has a curing compound, sealer, or dense surface, then the moisture from the adhesive will move into the concrete very slowly or not at all. When examined, the adhesive may still be wet, indicating that the concrete surface must be treated to remove the moisture-resistant substance. This is one method to check for a sealer on the concrete that might not be visible to the naked eye.

Like the plastic sheet test, the mat bond test indicates moisture problems that might occur within the first few days after installation due to moisture near the concrete surface. Problems that might develop over a longer period, for example, moisture vapor migration from subbase into the slab, will not be detected by this test.

Electronic Instruments

The following tests produce numerical results but are listed here as being qualitative rather than quantitative because they provide indirect, comparative indications of moisture in the concrete. These instruments generally are not recognized by standards setting bodies or flooring manufacturers for the purpose of accepting or rejecting a floor. They can be useful as survey tools to broadly evaluate the relative moisture conditions across a floor and to select locations for quantitative moisture tests.

Electrical Resistance Test. Handheld meters with sensing pins or probes are placed in contact with the concrete surface and the meter reading is noted. This type of meter was developed for moisture in wood and is widely used for that purpose. These meters are delivered from the manufacturers calibrated for various wood species and read directly in percent moisture content. While these instruments can be accurate and useful for wood, the electrical resistivity of concrete depends on many factors beside moisture content, such as the extent of hydration, composition of hydration products, and the presence of alkalies, carbonation, and chlorides. Pin-type meters that only contact the concrete surface cannot assess the moisture deep within a slab.

Electrical Impedance Test. Electrical impedance meters are handheld devices placed on a concrete surface. A transmitting antenna on the meter emits a radio-frequency field that is received by another antenna on the meter. The electrical field created by the instrument is attenuated by the dielectric nature of the concrete and moisture in the concrete. Such instruments can provide useful information on *relative differences* in moisture conditions to a depth of as much as 50 mm (2-in.). They are subject to interference from metal in the slab such as rebar or welded wire fabric (wire mesh).

Quantitative Moisture Tests

Gravimetric Moisture Content

The weight percent of free moisture in concrete can be determined from a representative sample of the floor slab. The best sample is a full-depth core with diameter at least three times the aggregate top size. The core should be dry-cut to avoid introducing additional water from the coring operation. Alternatively, pieces of concrete can be stitch-drilled and chiseled from the floor, being sure to go deep enough to represent the bulk of the slab, not just the top surface. The sample must be wrapped immediately in impermeable foil so its moisture content does not change during transport and storage. In a laboratory, the concrete is weighed and then heated at 105º C for 24 hr (Fig. 6-8), cooled to constant weight in a desiccator and re-weighed. The weight loss is calculated and expressed as percent of the dry weight. This technique can produce a very accurate measure of the weight percent of free moisture in the concrete. However, there are several reasons not to use this test: 1) free moisture determined by this method does not correlate well with field performance of adhesives and floor coverings; 2) most concrete cores are wet-drilled and cannot be used for this test; 3) obtaining sufficiently large and dry samples is labor intensive and time-consuming. While gravimetric moisture measurement is an indispensable tool for assessing the moisture content of aggregates, soil, and subbase materials, it is not very useful for assessing the readiness of a concrete floor to receive floor covering.

Moisture Vapor Emission Rate (Calcium chloride kit test)

This test, ASTM F1869-98, is the most commonly used quantitative test in the United States and is recommended by the Resilient Floor Covering Institute and the Carpet and Rug Institute. More than 300,000 of these tests are performed annually. The Rubber Manufacturers Association first publicized the test in the early 1960s. Most flooring and adhesive manufacturers specify maximum limits for moisture vapor emission from concrete floors based on this test expressed as pounds of moisture emitted from one thousand square feet in twenty-four hours. Specification limits vary by flooring manufacturer and material type. Some published requirements for wood flooring products are shown here:

Type Of Product	Recommend Test Procedure	Requirements	Source
Wood Flooring	ASTM F1869	<3 lbs/24 hrs/1000 ft^2	Alloc
Planks	ASTM F1869	<3 lbs/24 hrs/1000 ft^2	Anderson
Oak Planks, Maple	Moisture Content	<3% Moisture	Green Mountain
Strips	ASTM F1869	<3 lbs/24 hrs/1000 ft^2	Kahrs

Oak, Maple	Moisture Content	< 2.0 % (CM Method)	Witex
Laminate Flooring	Moisture Content	<2.5 % (CM Method)	BHK of America
Laminate Flooring	ASTM F1869	<3 lbs/24 hrs/1000 ft^2	Edelweiss Flooring
Solid Wood	Moisture Content	None Listed	Wood Flooring International
Bamboo	ASTM F1869	None Listed	Plyboo
Hardwood Floors	Appropriate Test Method	None Listed	Bruce
Maple	Polyethylene Film Test Phenolphthalein Test Calcium Chloride Test	No Condensation No Red Color <4.5 lbs/24 hrs/1000 ft^2	Maple Flooring Manufacturers Association
Hardwood Flooring	Polyethylene Film Test Phenolphthalein Test Calcium Chloride Test Rubber Mat Test	No Condensation No Red Color Crystals After 12 Hrs No Water Marks - 24 Hrs	NOFMA
Wood Flooring	Polyethylene Film Test Phenolphthalein Test Calcium Chloride Test	No Condensation No Red Color <3 lbs/24 hrs/1000 ft^2	NWFA
Planks	Moisture Test Phenolphthalein Test	<4.5% (CM Method) No Red Color	Hartco
Oak Parquet	Phenolphthalein Test Calcium Chloride Test	No Red Color <3 lbs/24 hrs/1000 ft^2	Robbins

MVER test kits are available from several vendors in the U.S. Each kit consists of:

- A plastic dish with lid approximately 3-in. diameter containing 16 grams anhydrous calcium chloride; pressure sensitive adhesive (PSA) tape to seal the lid around its circumference; paper label to record data on the top of the lid; moisture-resistant, heat-sealable bag to contain the dish during storage until needed for use.
- A flanged, clear plastic cover, called the “dome” 1.5-in. height by 0.5 ft^2 inside the flanges (made of low permeability plastic such as polyethylene terephthalate, the same plastic used for soda pop bottles); caution label fixed inside the cover.
- Preformed sealant strip used to form a hermetic seal between the flanges of the dome and the concrete floor.

The building must be enclosed with its HVAC system operating and the room and floor of interest must be at anticipated service conditions 48 hr before performing the test. Ambient relative humidity and temperature can significantly affect test results. Test areas should be selected that represent the entire floor, including the center and perimeter of the floor. The test area is prepared by scraping or brushing to provide a clean surface slightly larger than the area of the dome. A calcium chloride dish is weighed to the nearest 0.1 g including the lid, label, and sealing tape. Note on the label the starting date, time, weight, and test location. The dish is opened and placed on the floor, the sealing tape is temporarily secured against the inner side of the plastic dome, and the dome is fastened to the floor using the sealant strip. After 72 hr, the dome is cut open to remove the dish; the lid is replaced on top of the dish and sealed with the tape. Weigh the dish and calculate the net weight gain in grams. Calculate the moisture vapor emission rate in lb/1000 ft^2/24 hr as shown in the kit manufacturer's instructions. Because ambient air humidity and slab temperature can significantly affect the reported MVER, it is useful to measure and report these data along with the MVER results.

The MVER test determines moisture emitted from the upper ¾-in. of a concrete slab and is not a good indicator of moisture deep in the slab. The MVER test yields just a snapshot-in-time of moisture emission from the upper portion of the concrete and cannot predict the long-term performance of a floor, especially if there is no vapor retarder below the slab. As with the qualitative tests discussed previously, a high MVER result indicates a floor is not ready to receive flooring, but a low MVER result only indicates that the moisture level in the upper portion of the concrete may be acceptable.

Relative Humidity Measurement

In several countries outside the U.S., standards for floor moisture are based on measuring relative humidity within, or in equilibrium with, the concrete floor slab. This practice has several advantages over other concrete moisture measurement techniques:

1. RH probes can be placed at precise depths in a concrete slab to determine the relative humidity below the surface or to determine the RH profile as a function of depth.
2. RH probes actually measure the relative humidity within the slab and are less sensitive to short-term fluctuations in ambient air humidity and temperature above the slab.
3. Moisture moves through concrete in a partially adsorbed or condensed state by diffusion, not simply as unbound, free water vapor or liquid. The rate of moisture transmission depends on the degree of saturation, which is a function of the relative humidity on each side of the concrete. Therefore, the driving force for water vapor movement through a slab is the relative humidity differential through the slab's depth, not simply vapor pressure differential (Powers, 1958; BRAB-FHA, 1958). RH probes are a method of directly measuring this property.

4. Relative humidity is a measure of equilibrium moisture level. When a floor covering is placed on top of a slab it restricts evaporation from the top surface of the slab; moisture within the slab then distributes itself to achieve an equilibrium due to temperature and chemical interactions from top to bottom of the slab. In the long run, adhesive and flooring are then exposed to the equilibrium moisture level at the top of the slab. Tests such as the calcium chloride kit artificially pull moisture out of the top few centimeters of the slab and do not reflect the long-term moisture situation that will be established by equilibration. RH probes can measure the relative humidity that will exist well after the floor is covered.
5. RH probes can be connected to electronic data loggers to record changes in relative humidity within a slab over time. Such measurements can be very useful to determine whether a floor is getting wetter or drier, and how long it might take to reach an acceptable level of moisture.

In 2002, ASTM International approved a new test method modeled on the Scandinavian Nordtest method, titled ASTM F2170-02, *Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes.*

Acceptable RH levels.

Acceptable RH levels using *in situ* probes have been established and published in Finland and Sweden. These maximum permissible values are given in the following tables:

The Finnish SisaRYL 2000 Code of Building Practice

Table 75:T3 – maximum value of relative humidity in concrete

Max. %RH	**Cover material**
85%	plastic carpet with felt or cellular plastic base Rubberised carpet cork tile with plastic film barrier to exclude damp textile carpet with rubber, PVC or rubber-latex coated textile carpet made of natural fibres
90%	plastic tiles plastic carpet with no felt or cellular plastic base

	Linoleum
60%	parquet board with no plastic film between wood and Concrete
80%	mosaic parquet on concrete

Swedish HusAMA83, General Material and Workmanship Specifications for Buildings

Max. %RH	Cover Material
80%	Wood and wood-based materials
80%	Vinyl floor coverings with a backing which may provide nutrients for mycological growth
	Bonded floor coverings which do not tolerate degradation of floor adhesive by alkali in the concrete
90%	Layered products
85%	Homogeneous vinyl materials
	Cork tiles
80%	Without vinyl layer on the underside
85%	With a vinyl layer on the underside

These tables indicate, for example, that vinyl tile can be installed according to the Swedish standard if the relative humidity is less than 85% since it is considered a homogeneous vinyl product, but the Finnish standard permits vinyl ("plastic") tile to be installed if the relative humidity is as high as 90%. The Swedish standard permits wood installations over concrete with 80% relative humidity, while the Finnish standard only provides requirements for "mosaic parquet" products. A potential shortcoming of these tables is that they do not differentiate among various types of installation systems (mechanical or direct glue-down) or among various types of adhesive.

APPROACHES TO REMEDIATION OF PROBLEM SLABS WITH HIGH MOISTURE CONTENTS

First, determine if the moisture problem is due to moisture from within the slab, such as original batch water, or from an external source. If the floor slab is on ground, has an intact vapor retarder, and moisture is not entering from the perimeter, the floor can be dried. Elevated slabs can be handled the same way. Drying can be accelerated using industrial dehumidifiers that provide low-humidity, warm air, circulated with fans over the floor. Monitor the moisture in the floor using relative humidity probes until an acceptable level of dryness is achieved.

If time will not permit drying the floor, then the finish flooring must not be installed unless some means is provided to isolate the finish flooring from the moist concrete. Liquid-applied vapor suppression systems can be installed to limit moisture movement from within the floor slab up into the finish flooring system. For directly adhered finish flooring, the adhesive must be compatible with the sealer system. Be sure that the flooring and adhesive manufacturers recognize and approve the vapor suppression system before installation. The process of installing a vapor suppression system can be expensive and time consuming. Floors often must be shotblasted and installation of sealers can take several days.

Preformed vapor suppression membranes are available that can be placed directly on the concrete surface and then flooring is installed directly on top. These can be mechanically fastened or floating systems. Mechanically fastened systems require great care to be sure that fasteners are driven and then well-sealed against moisture. Some systems require ventilation at the perimeter of the room for moisture to escape; these may not be suitable for large contiguous areas since water vapor may condense and not be able to travel to evaporation points. Check to determine if a vapor suppression membrane is rated for use with the particular type of flooring to be installed on the specific job.

Instead of direct glue-down, the job may have to be changed to a mechanically fastened wood floor system and a different finish flooring material may have to be chosen.

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GLOSSARY OF MOISTURE-RELATED TERMS FOR CONCRETE

Absorption—The process by which water is drawn into permeable pores in a porous solid. Also used to indicate the *amount* of water absorbed by a material as percent by weight of a test specimen

Alkalies—potassium or sodium, usually in the form of water-soluble hydroxides, which increase the pH of concrete

Alkali-aggregate reactivity—reaction between certain silica or carbonate aggregates and alkali hydroxides in concrete, producing undesirable expansion and cracking.

Capillary break—layer of no-fines coarse aggregate placed on subgrade soil to stop capillary rise

Capillary rise—action of certain fine-grained soils that can draw water upward from the natural water table

Carbonation—reaction between atmospheric carbon dioxide and calcium hydroxide in cement paste to form calcium carbonate

Cement— portland cement is a calcium silicate hydraulic cement produced by pulverizing manufactured clinker and calcium sulfate

Concrete—mixture of portland cement, water, fine and coarse aggregates; cement and water form *paste* that acts as the binding material; concrete also may contain mineral and chemical admixtures

Curing—act of maintaining liquid water on a concrete surface to facilitate hydration of the portland cement; curing is the opposite of *drying*

Dampproofing—surface treatment of concrete to reduce the passage or absorption of moisture

Dewpoint—temperature at which moisture will condense on a surface

Drying—removal of moisture from concrete usually through evaporation at the surface; drying is the opposite of *curing*

Efflorescence— powdery deposit of soluble salts formed by evaporation of water at a concrete surface

Hydration—chemical reaction between water and cement compounds that produces a hard, rock-like mass and develops strength in concrete; curing aids hydration whereas drying stops hydration

Hydrostatic—fluid pressure that develops when liquid water level is above a specified location

Lightweight aggregate—manufactured aggregate such as expanded or sintered clay, slate, or shale, having low density and used to produce lightweight concrete; lightweight aggregate often has significantly higher absorption and therefore holds more water in a concrete mix than does normal weight aggregate

Osmosis—movement of water through a semipermeable membrane into a solution of higher salt concentration that tends to equalize the concentrations of salt on the two sides of the membrane; blisters under some floor coatings can form due to osmosis where concrete can act as a semipermeable membrane

Porosity—voids in a solid substance, often expressed as volume percent; the connectedness of voids, along with other properties of the substance, determines permeability

Permeability—rate of water vapor transmission through a flat material, expressed in units of mass per area per thickness per vapor pressure difference across the material

Permeance—rate of water vapor transmission through a flat material under specified conditions of specimen thickness, area, and vapor pressure difference; *perm ratings* of materials are actually permeance values for a product of specified thickness, while permeability is a numerical value per unit of material thickness

pH—logarithm of the reciprocal of hydrogen ion concentration in moles per liter, used to express the acidity or basicity of a solution on a scale of 0 to 14, where less than 7 represents acidity, 7 is neutral, and more than 7 is basic

Relative humidity—Ratio of the amount of water vapor actually present in a given volume of air compared to the amount of water vapor that could be present in saturated air at the same temperature, expressed as a percentage

Vapor Retarder—A sheet of material, either preformed or liquid applied, that reduces the rate of moisture movement past a given location; vapor retarder sheets are commonly used under floor slabs to inhibit moisture from the earth moving into a floor slab

Water-cement ratio —mass of water to mass of cement in a concrete mix, expressed as a ratio, for example, 0.45