# MASONRY

## MEDDLING IN ITS MYSTERIES OF MOISTURE MIGRATION

BY CRIS CRISSINGER

There has been a dramatic increase in complaints regarding water intrusion through masonry walls in recent years, according to several building envelope consultants. Has something changed to generate the deluge of problems? This treatise is intended to stimulate the thought processes relative to masonry construction's problems in general terms and not to address all possible problems. A comprehensive analysis would require a textbook.

There was a time when complaints about masonry leaks were rare. Design, manufacturing, and construction disciplines have supposedly brought technological improvements in masonry construction. However, the best of cooks knows that when trying to improve a recipe, even good intentions can spoil the dish.

### EFFECTS OF MOISTURE ON MASONRY

Weather-induced moisture is the primary ingredient for masonry deterioration and contributes to the following:

1. Creating or magnifying odors
2. Carrying harmful pollutant gases into the building envelope
3. Causing wood studs, blocking, and structural members to rot
4. Magnifying the effects of spalling caused by freeze-thaw cycles
5. Encouraging growth of biological organisms (mold, mildew, etc.)
6. Causing steel stud backup, ties, and masonry reinforcing to corrode
7. Dissolving latent salts and depositing them on the surface as efflorescence
8. Causing finishes on the inside of exterior walls to fail prematurely and to stain

### MASONRY CONSTRUCTION OF OLD

Masonry walls built prior to 1900 were usually thick and solid, consisting of multiple wythes of brick, often 20 inches or more thick, and exemplifying the rain barrier concept (*Figure 1*). The bricks in these behemoth walls absorbed water just as the brick in our modern-constructed high-tech walls do now. The wall's mass was intended to keep moisture from entering the occupied space and not just to repel critters and hostile invaders. Thus, any moisture that did enter the wall could exit the same way it got in. This is called drying out. Since it's often been said that brick absorbs moisture like a sponge, it could almost be "wringing out."

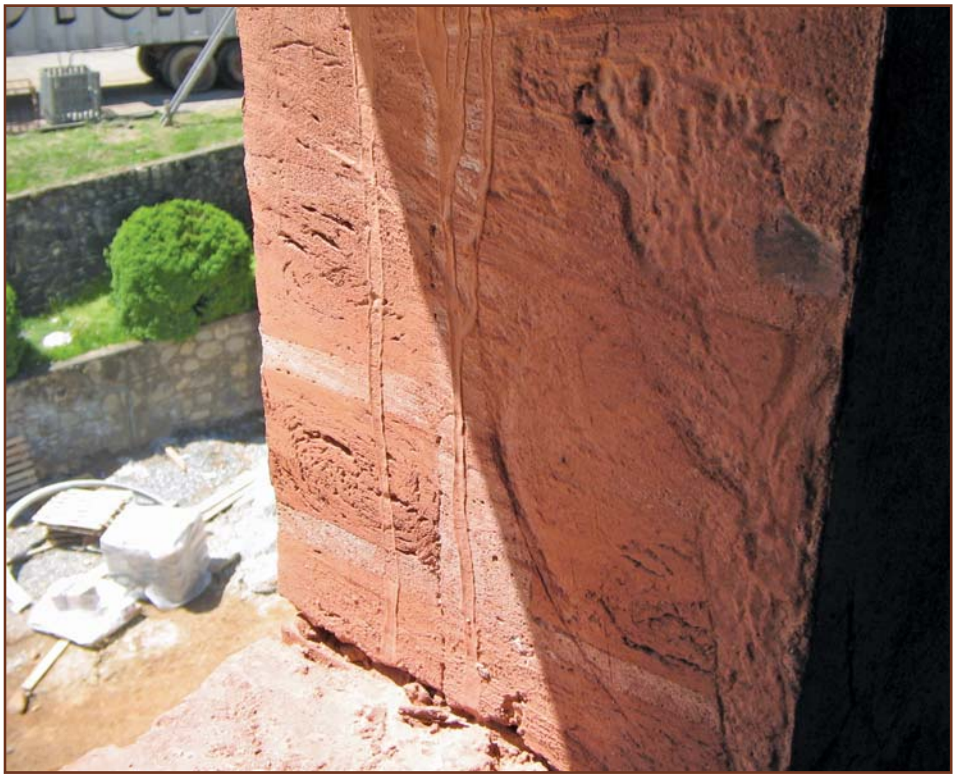

*Figure 1 – Multiple wythes of brick.*

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*Figure 2 – Umbrella.*

Older bricks were softer and more porous because they were fired at a lower temperature; consequently, they tended to take on more moisture. Modern bricks are fired in kilns with higher and more accurately controlled temperatures. This makes them harder and less permeable than the older bricks that were sometimes air-dried. At construction, bricks are as small as they will ever be. From that day forward, they will expand as they take on moisture and shrink as they lose moisture, but will never shrink smaller than when they left the kiln. This is why expansion joints are used in brick walls. Conversely, since concrete masonry units (CMU) are manufactured from a wet Portland cement mix, they are the largest that they will ever be at manufacture, and they tend to shrink thereafter. This is why control joints are used in CMU walls.

Also, the old masonry consisted of a lime mortar mix and did not contain Portland cement until the 1870s. Without the Portland cement, the mortar was softer, weaker, and more porous, all of which increases absorption. Mortar with Portland cement is stronger and more rigid than older mortars, and should not be used to repair or repoint old mortar. In other words, do *not* mix them. The incompatibility of the two types of mortar can be disappointing. No pun intended.

## WHY IT LEAKS

There is a common misconception that buildings —especially masonry—should not leak. Nevertheless, all buildings tend to leak to some extent, and some leak more than others. The secret is controlling the water that gets in and providing a quick and easy exit before it causes damage or enters the occupied space. With the exception of the Superdome and a few other stadiums, it typically rains outside of a building; unless it has a large umbrella above (*Figure 2*), the masonry is going to get wet.

The following are three basic requirements for moisture intrusion. Eliminate any one, and water will not penetrate.

1. Moisture (rain, vapor, humidity)
2. Opening (crack, pores, joints, etc.)
3. Force (gravity, wind, capillary action, pressure differential, etc.)

Masonry leaks because, as previously mentioned, brick and mortar are porous, and porous things absorb water. However, bricks in themselves do not leak. Instead, they absorb water until they become saturated and then just overflow (*Figure 3*). This is analogous to filling an empty jug with water. The jug contains the water and does not leak as it is filled. When water reaches the top of the jug, the jug becomes full or saturated and overflows or leaks if more water is added. The same is true with brick. One of the laws of physics says two bodies can't occupy the same space at the same time.

Notice the surfaces of some of the modern fancy, folksy-named bricks on the market today. Some bricks appear to have surfaces that look like they were finished with a backhoe. All these little cavities can trap and hold moisture. The unique aesthetics of disfigured bricks should not be the determining selection factor unless the project site is in an arid climate such as the desert.

Most masonry leaks seem to occur on the northern quadrant of a building. A possible explanation for this may be that bricks on the northern quadrant tend to dry more

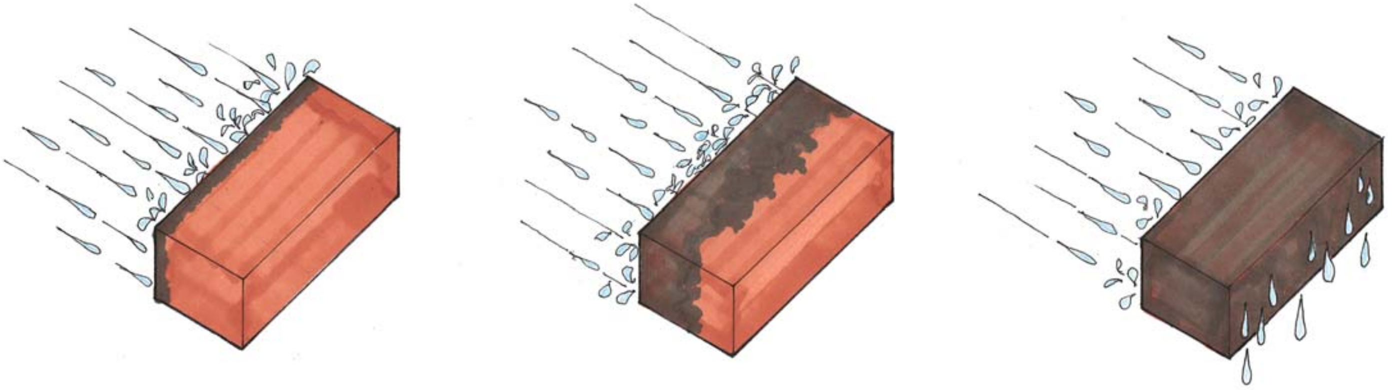

*Figure 3 – Progression of moisture absorption.*

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slowly because they are exposed to less of the available direct sun and heat. Also, the prevailing winds tend to be from directions other than the north. These factors could cause the brick to retain more moisture for longer periods, which would result in requiring less water to bring the brick to the saturation point.

How much a structure gets wet depends on how long and how hard it rains and the direction of the rain. Rain usually falls vertically (*Figure 4*) because of gravity unless it is deflected by the wind. Horizontal wind forces that exceed vertical gravity forces make rain move at some angle between vertical and horizontal (*Figure 3*). Let's call it a "rain blizzard." This phenomenon is explained by another law of physics: things in motion tend to remain in motion in the same direction unless acted on by an outside force.

Moisture accumulation occurs when more moisture moves in than moves out. Fewer raindrops strike the face of the masonry walls when raindrops fall vertically because the wall gets some protection from any roof overhang, window sills, and any other projections extending horizontally from the vertical plane (mini umbrellas). This is probably why fewer walls leak during a vertical rain. When the wind pushes raindrops against the masonry wall, the drops spread out and become a thin sheet of water as shown in *Figure 5*; then kinetic energy takes over, driving the sheets of water into the masonry. It is easier for the wall to absorb water that is thin and flat than fat and round. Surface tension allows the cohesion of water droplets to defy gravity and cross small openings and cracks, allowing the moisture to be pulled into the wall. Many may recall the demonstrations of surface tension in physics class, where water is carefully filled above the rim of a glass without overflowing, or a thin piece of metal floats when carefully placed in a pan of water. However, break the surface tension by gently touching the water, and the water will overflow the glass rim, and the piece of metal will sink.

The physical characteristics of the masonry make it rather hospitable to the rain and invite it to come on in. The flattened raindrops make their grand entry, and it is not an unannounced or sneaky entry. Sometimes they can actually be heard knocking on the wall. The moisture moves through the porosity of the masonry and mortar, through open mortar joints, and through normal gaps and joints in the building construction. Each raindrop seems to have the innate ability to find its way through the building envelope. Additionally, when the rain is intense or prolonged, moisture can find its way up from the ground, into the foundation, and up the wall into the structure. These antigravity actions are called capillary action and vapor diffusion.

Cracks in the masonry (*Figures 6A and 6B*) are common and can be caused by mortar shrinkage during curing, by brick units expanding as they absorb moisture, or by wind generating lateral forces. These cracks can range from 0.004 in to 0.040 in wide. Stress cracks in the masonry units can be much wider. Tests by independent laboratories show that wind-driven rain can enter openings as narrow as 0.004 in. However, representatives from the Brick Institute of the Carolinas have said that aesthetically, cracks 0.010 to 0.015 in are often consid-

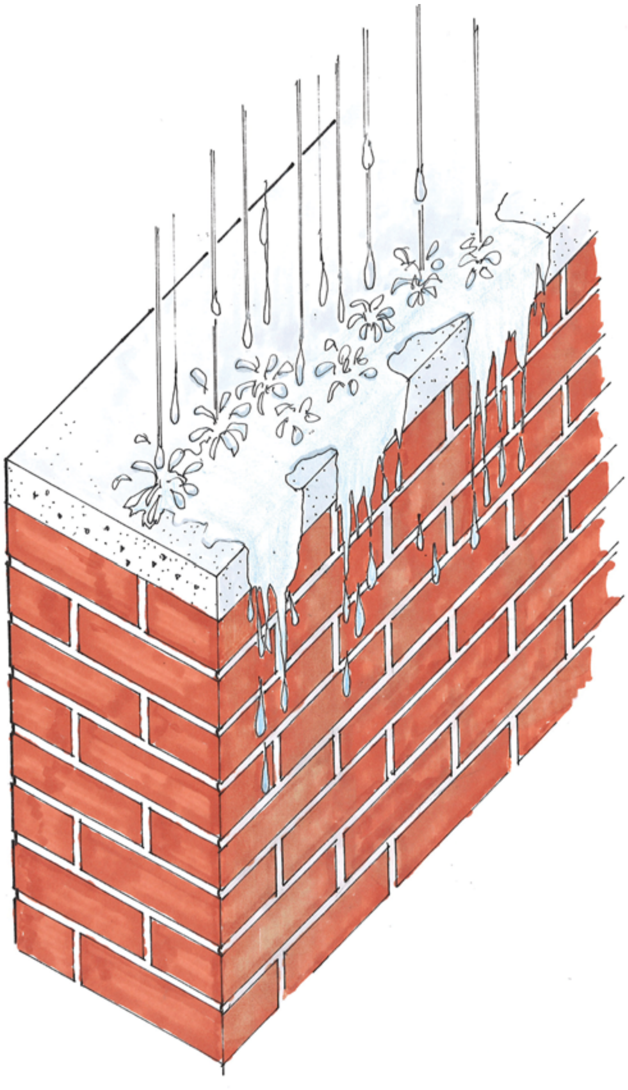

*Figure 4 – Water sheeting.*

*Figure 5 – Sheeting water created by water test.*

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*Figures 6A – Shrinkage cracks in mortar joints.*

*Figure 6B – Weak Bond in mortar joints.*

ered acceptable because they are not usually visible or noticed at distances greater than 10 ft. In comparison, a Kleenex is approximately 0.003 in thick, a new dollar bill is approximately 0.005 in thick, and a typical business card is approximately 0.010 in thick. So, taking this to its logical conclusion, wind-driven rain may enter a crack equal to the thickness of a Kleenex and will enter a crack equal to the thickness of a dollar bill.

After reviewing some mortar mixes, there seems to have been a shift from Type N mortar to Type S mortar for exterior non-load-bearing masonry veneer. Type S is much stronger and more rigid with less flexibility, meaning the mortar is more brittle. It is possible that the rigidity of the Type S causes the joints to crack during building movement. The Brick Institute says that substituting Type S for Type N in non-load-bearing masonry

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*Figure 7A –Tooled concave joint.*

*Figure 7B – Tooled flush joint, old construction.*

*Figure 7C – Tooled raked joint.*

veneer is acceptable, and designers seem to be making this substitution.

Tooling is paramount for watertight integrity. Proper tooling creates a matrix of mortar that encapsulates the sand to prevent it from being exposed to weather that reduces capillary action. The most effective joints are concave and flush (*see Figures 7A, 7B, and 7C*). Raked joints should not be used because the important mortar matrix may not be achieved, and raking creates a ledge that holds water.

Before exploring possible reasons for our perplexing problems, we need to review some of the various ways that moisture can move in and take up residence in a masonry structure, or for that matter, other types of structures. Moisture, in this context, means water in any one of its three physical states: (1) solid, such as ice; (2) liquid, such as water; and (3) gas, such as water vapor. It would be difficult for moisture in the solid state to enter a structure, so the liquid and vapor states seem to have the most dramatic effect on masonry. However, moisture as liquid or vapor that is trapped in a structure can freeze and inflict significant structural damage.

### THE RULES

To appreciate what goes on inside a brick wall, several rules of movement need to be reviewed. Moisture movement occurs when it changes from one state or point to another.

1. Moisture looks for an opening.
2. Gravity makes moisture flow downhill.
3. Warm air holds more moisture than cool air.
4. Moisture follows the path of least resistance.
5. Moisture moves from a higher humidity to a lower humidity.
6. Moisture moves from warm temperatures to cooler temperatures.
7. Moisture moves from higher vapor pressures to lower vapor pressures.

In other words, think high to low, like the evening television meteorologist who shows a high pressure moving to a low pressure. This whole moisture movement is mostly related to heat. Beginning with moisture in the solid state, if enough heat is added to the ice, it changes to a liquid state. If even more heat is added to the water, it changes to a gaseous state. Removing heat causes the reverse to occur. Therefore, it can be said that heat, whether added or subtracted, is the mechanism that allows water to change states.

### METHODS OF MOVEMENT

Moisture has four means for making an appearance in masonry. Besides cascading down the face of a structure as a liquid torrent, it has three other more subtle ways of making its entry, and any one of them can dampen spirits. Following are the other three methods:

1. Catching a ride in moving air.
2. Hiding as invisible moisture in vapor diffusion.
3. Sneaking up concrete foundation as capillary action.

Generally, moisture will move through masonry or any

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other building material that is porous or fibrous. However, it does tend to move through some porous materials faster than others. The cell structure of the building material determines which state of moisture will move through a material and how easily it will move. Remember, moisture can exit the same way that it enters. For a more detailed discussion on the methods of moisture movement, refer to this author's article, "The Great Moisture Movement," published in the July 2005 edition of *Interface* journal. Drying is achieved in three ways: draining, ventilation, and vapor diffusion. Drainage is probably the quickest way to remove moisture because it is removed in bulk (liquid) form. However, drainage cannot remove moisture that is stored in the brick because drainage does not begin until the brick is saturated. Thus, until drainage begins, drying is done by ventilation and, to a lesser degree, by vapor diffusion.

## EFFLORESCENCE

One of the first signs of a moisture problem is efflorescence. Efflorescence is a white powdery substance (*Figures 8A and 8B*) that the author sometimes calls "masonry makeup," except that it does not add beauty to the wall. Its sole purpose in life is to sound the moisture alarm. On discovering efflorescence, the designer can proclaim, "There appears to be moisture in those walls." Efflorescence is another complex topic that deserves its own article, so be on the lookout. It forms on cementitious construction when internal restless moisture dissolves free water-soluble salt deposits in the masonry and carries these deposits to the surface. When the moisture containing the dissolved salts evaporates, the masonry makeup appears.

The simple equation for visible efflorescence is:

**Efflorescence = salt deposits + moisture + moisture path to the surface + evaporation.**

Eliminate any one component of the equation, and the efflorescence problem is solved. Hidden efflorescence can be present in masonry when the salts are dissolved by moisture but the moisture has not migrated to the surface. Efflorescence is not just a cosmetic problem. During freeze/thaw conditions, efflorescence can cause the brick to weaken, spall, or crumble. It can be a slow process, but it does occur.

There are two kinds of efflorescence: powdery and crystalline.

*Figure 8A – Powdery efflorescence.*

*Figure 8B – Crystallized efflorescence.*

**Powdery efflorescence**, as described above, can usually be brushed away.

**Crystalline efflorescence** forms when powdery efflorescence goes through cycles of being deposited on the surface, then dissolved from rain, and ultimately redries. Eventually, tightly bonded crystals form that cannot be brushed away.

## THINGS THAT HAVE CHANGED

Most modern bricks seem to be the same (rough, rectangular, and red), are fired in the same electric furnaces, and have approximately the same 3500-psi compressive strength. Perhaps the clays have changed, but brick manufacturers say that the same standards are met. Brick manufacturers claim that porosity, which governs absorption, is still virtually the same. However, depending on its composition and how the brick is fired, porosity can vary somewhat among brick manufacturers. Shop drawings submitted for brick should include the initial absorption rate and coefficient of absorption. A simple onsite initial rate-of-absorption test can be conducted. Absorption is defined as the weight of water absorbed by a brick unit under laboratory conditions and is expressed as a percentage. ASTM C216 limits Type SW (severe-weather) face brick to 17% and Type MW (moderate-weather) to 22%. However, the absorption of most bricks produced in the U.S. is 4% to 10%.

The initial rate of absorption (IRA) of brick is an important factor in predicting bond strength. Laboratory tests have determined that ideal bond strength and maximum water resistance are produced with IRA of from 5 to 25 grams/minute/30 sq in at the time bricks are laid. The 30 square inches is based on the bed surface area of a modular brick. Brick with an IRA greater than 30 should be wetted prior to laying.

The saturation coefficient of brick (C/B ratio) indicates the amount of easily absorbed water by immersing the brick in cold water for 24 hours and the amount absorbed under pressure by immersing the same unit after drying into boiling water for five hours. This ratio measures the amount of open pores remaining in the brick after free absorption that will accommodate expansion during freeze/thaw cycles. Type SW brick must have a ratio equal to or less than 0.78.

Another possible change is the mortar. Many years ago, lime putty was made on site, and all proportions (sand, Portland cement, lime, and water) were carefully measured before being added to the mixer, and the mixing was timed. Site visits now often reveal sand being measured by the shovel full instead of in a 1-cu-yd box, with much of the shovel's contents missing the mixer entirely. Modern Portland cement and lime are premeasured and prebagged, and often, part of the bag winds up on the ground. Instead of being measured, water is added directly to the mixer by hose until the mix "looks about right." The mixer runs until the attendant remembers to stop it. Masons repeatedly retemper mortar, which can increase the water/cement ratio and reduce mortar strength.

## CAVITY WALLS

There are two basic approaches to prevent water from entering a structure: barrier systems and drainage systems. A barrier system is simple compared to a drainage system. A barrier system consists of an exterior weather-resistant cladding, such as brick, that is exposed directly to the weather and relies on exterior cladding, flashing, and sealed joints to prevent water intrusion. The old multiwythe construction is an excellent example of a rain-barrier system. A drainage system (such as a cavity wall) assumes that some water intrusion through the exterior cladding is inevitable and makes provisions for it to drain out.

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*Figure 9 – Cavity impacted with mortar droppings.*

One of the most dramatic changes was the advent of the cavity wall that replaced multiwythe construction. The cavity wall is a complex and misunderstood design and deserves a separate article. However, it will be briefly discussed here.

After first appearing in ancient construction, the British reintroduced the cavity wall concept in the late 1800s, and it started to gain popularity in the mid 1900s. Cavity walls in masonry can be like tooth cavities—they can cause a lot of grief if they are not treated promptly and properly. However, a masonry cavity can be a desirable thing and should not be filled as is done for a tooth cavity. If a masonry cavity is filled or cluttered (*as shown in Figure 9*), it is no longer a cavity, and that may not be a good thing. Reasons will become obvious in the following paragraphs. *Figure 10* shows a cavity partially blocked with insulation.

In its simplest form, a cavity wall provides the following three lines of defense:

1. An exterior cladding such as brick to protect the cavity and drainage plane.
2. An air space consisting of a 1- to 2-in-wide drained cavity to break the moisture train. This dimension is measured from the back of the brick to the drainage plane.
3. A drainage plane consisting of a backup of CMU or steel studs with sheathing and both types of backups covered with an air barrier/water-resistant barrier to drain water to the bottom of the cavity. Insulation can also be added to the exterior face of the drainage plane as long as the air space is maintained.

Flashing and associated weeps are also a vital part of a simple cavity wall and provide an exit for moisture. In theory, moisture that penetrates the brick will enter the cavity as a liquid or vapor. The liquid runs down the backside of the brick to the bottom of the cavity. The vapor condenses on the drainage plane and drains to the bottom of the cavity. Because of forces produced by varying exterior wind and internal HVAC, air pressure in the cavity can be either negative or positive, relative to the exterior. When the cavity pressure is negative, it sucks, and that is not good because it pulls in moisture in vapor and sheet forms from the exterior. Ideally, the cavity pressure should be equal to or slightly positive compared to exterior pressure, and that can be accomplished with cavity vents and venting weeps. Depending on cavity size, it may have to be partitioned to achieve complete venting. This is usually referred to as cavity equalization, but the pressure within the cavity probably does not actually equalize. A more appropriate term mentioned by the Brick Institute might be "cavity pressure compensation."

## WHAT TO DO

Since moisture will invariably invade a structure, it is best to make provisions for the unwelcome intrusion. In that regard, gravity and circulation can be a designer's best friend. By allowing moisture to run freely down the inside of a cavity and then weep to the exterior, gravity can keep accumulation to a minimum. Venting the cavity to allow circulation allows the cavity to exchange damp air for dryer air; to neutralize the cavity air pressure; and to prevent a negative air pressure within the cavity, which reduces moisture migration from wind-driven rain. Wringing out the wall will eliminate moisture. Weeping and venting are also a designer's friends. If venting is a means of reducing water penetration into the cavity, why haven't all of those unvented cavities been leaking? Careless construction may have generated unintended openings that achieved sufficient venting; but now, tighter walls are being constructed.

Weeps, flashing, and vents work in unison. Weeps must be of the proper type and

*Figure 10 – Loose insulation blocking cavity.*

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*Figure 11 – Improperly located weeps.*

properly located. Weeps should be directly above the sill on the flashing and not as shown in *Figure 11*. Cluttered cavities, as previously shown, can obstruct the downward flow of water and interfere with exiting water at the weeps.

Provisions must be made to prevent moisture entry, and additional provisions must be made for a prompt exit when it does enter, before damage is done. Through-wall flashing and weeps are a vital part of the drainage system. The flashing should be a durable material such as copper or stainless steel, and weeps should occupy a full head joint and be spaced a maximum 24 inches oc. Brick bats and mortar droppings can puncture some flexible sheet plastic flashing material. Although frequently used, rope weeps should be discouraged because, short of keeping bugs and vermin out of the cavity, they become encrusted with mortar droppings, making them ineffective and interfering with cavity ventilation.

*Figure 12 – Flashing properly located behind sheathing and joints overlapped but*

## MASONRY CLEANING

Proper tooling causes the mortar to form a paste that encapsulates the sand and forms a protective water-resistant matrix. Ideally, masonry should be cleaned regularly and gently with a bucket of water and a soft brush during construction to protect the joints. Pressure washing can damage that matrix and expose the sand or even remove some of the mortar and destroy waterproofing capabilities. If pressure washing is permitted, maximum pressure should be 300 psi to avoid damage to the brick and mortar.

## SUMMARY

Flashing location is just as important as the material and its installation. It should be installed as shown in *Figure 12*. Flashing must be installed correctly with the seams sealed. Flashing should extend behind the sheathing and have overlapped corners; preformed corners are even better.

Masonry is going to leak some water, but there is no industry standard for an acceptable amount of leakage. Based on what is known, it only seems reasonable to expect a masonry structure to be able to withstand wind-driven rain produced by expected wind velocities and associated pressure as depicted in the wind tables applicable to the geographic location of the structure. Designers must ensure that cav-


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ity spaces are clearly detailed to show air space, drainage plane, compartments, flashing, vents, and weeps, and that proper materials are specified. The challenge is to get the various components installed correctly. When this author served on submarines, a frequent question asked during a candidate's qualification examination was "What is the difference between a leak and a flood?" Of course, the correct answer was, "If I find the water, it's a leak. If the water finds me, it's a flood." Let's find the water to avoid the flood.

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