BACKGROUND

If you are a building envelope consultant or are familiar with exterior wall design, you have likely heard of the Four Ds of exterior wall design. Each “D” stands for an important feature of the design that is needed to reduce problems with elevated moisture and to improve durability. The Four Ds of exterior wall design are described in Figure 1.

While we have the technology and knowledge in the construction industry to accomplish the Four Ds, construction budgets and schedules often limit our ability to deliver robust and long-lasting walls that include all four. In some cases, the designer may have good intentions to provide the Four Ds, but some details are simply value-engineered (VE’d) out of the project. As a forensic engineer who investigates wall failures, this is a commonly encountered theme. Unfortunately, in most cases, the VE’d details or product substitutions fail to meet the true definition of value engineering, which generally includes a cost savings to the owner without compromising the performance of the delivered product. We seem to always get the first part (cost savings) right, but we routinely compromise the performance of the delivered product.

Often, the VE’d wall assembly will eliminate and/or compromise one or more of the Four Ds. When one or more of the Ds are not provided, failure of the exterior wall assembly can result. Failure could range from corroded fasteners and stained wall sheathing to rotten framing and structural collapse, with many variations in between. Based on many years of forensic experience, it has been observed that in every wall failure, not only is one of the Four Ds of wall design not accomplished, but an opposite and harmful “D” may exist in its place. Specifically, for every one of the Four Ds of good wall design, there exists an opposing “D” that can cause or contribute to wall failure. This paper presents the Four Ds of wall failure.

THE FOUR DS OF EXTERIOR WALL FAILURE

From a forensic engineering standpoint, it seems that every wall failure that has been investigated is associated with one or more of the following Ds:

**D1 – Direction** (vs. Deflection) – concentrated flow of water into the building envelope at specific points of discontinuity such as roof/wall intersections, windows, balconies, cladding transitions, etc.

**D2 – Dam** (vs. Drainage) – places in the drainage path of the wall assembly

**D3 – Deflection** (balanced by Corrosion Control)

**D4 – Durable Materials for the Conditions**

![Figure 1 – The Four Ds of wall design.](image-url)
where water gets trapped or dammed, such as lapped siding intimately attached to exterior wall sheathing, improper sealant joints, etc.

**D3 – Damp** (vs. Drying)  – absorptive materials that stay wet and cause migration of water into the wall assembly, such as mortar slop, conventional stucco, and cement board products

**D4 – Distress** (vs. Durable) – the use of materials that are susceptible to damage caused by elevated moisture, such as wood, oriented strand board (OSB), medium-density fiberboard (MDF), steel fasteners, etc.

The Four D’s are described in more detail below, along with photos showing the consequences of each.

**Direction**

Unlike deflection that keeps water off of exterior walls, direction concentrates water intrusion at locations where the building envelope is interrupted. The most common areas of water intrusion are roof/wall intersections, windows (*Figure 2*), doors, and balcony/walkway intersections. These are locations with potential for concentrated water intrusion. This concept is also supported by the 90:1 principle, which suggests that 90 percent of water intrusion happens through 1 percent of the building envelope. The locations of the 1 percent are typically those areas described above.

Even when otherwise code-compliant wall assemblies are constructed, these areas of concentrated water intrusion are sometimes too much for the wall to handle, and the assembly is simply overwhelmed with moisture. Even products that perform in a satisfactory manner elsewhere are challenged to resist moisture when it is funneled into the wall at concentrated points.

While roof/wall intersections, windows, and doors have been known areas of water intrusion for years, balconies and walkways have become a more common problem since the introduction of mid-rise wood-framed buildings. Specifically, the construction methods of mid-rise wood-framed buildings are considered to be susceptible to more exaggerated vertical movements associated with frame compression and shrinkage.
Even when balconies and walkways are designed with a slope to drain water from the surface, this slope can quickly be eliminated or reversed as the wood-framed wall compresses and shrinks. These areas have become so problematic that many newer mid-rise wood-framed building designs do not include balconies or exterior walkways.

The 2018 International Building Code (IBC) has recognized the problems with improperly sloped balconies, and includes new requirements that are intended to improve the chances for satisfactory performance. While the code revisions are expected to be helpful, caution should still be exercised. Specifically, the code does not require drainage mats at the bottom of windows, which represent a “best practice.” Additionally, the design and construction details need to consider potential areas of water accumulation, such as columns and intersecting walls.

**Dam**

In the absence of clear and efficient drainage paths, water can get trapped in walls due to dams that are created in the wall assembly. The most common dams observed in wall failures are improperly installed sealant at window head flashing or the base of a wall, self-adhered flashing (SAF) tape over windowsill nailing flanges, and tightly attached cladding components (typically cement board products) over a weather-resistant barrier (WRB). Another common dam is created when metal trim (typically white aluminum coil stock) is used to encapsulate beams on residential structures, typically clad with vinyl siding. Because this detail can result in the storage of water in a large horizontal reservoir, it is sometimes referred to as a trough.

Dams typically hold water in the wall assembly and/or direct the water to other places in a concentrated manner. For instance, when window head flashing is improperly sealed, water is forced to migrate laterally on top of the flashing. In the absence of end dams (not required by the building code), the water falls off the ends of the flashing and migrates due to gravity to the bottom corners of the window. In this case, the dam condition results in direction of water intrusion at the bottom of the windows, as described above.

When SAF tape is installed over a windowsill nailing flange, the SAF serves to trap water when the window leaks, and all windows (eventually) leak. While installing the SAF at this location has been forensically determined to be a bad idea, this detail was shown in print by manufacturers of building components, including SAF, windows, WRB, and stucco. This detail was also published in industry magazines as a “best practice” back in the early 2000s. Many contractors followed these instructions, only to later be named as defendants in construction defect cases when water intrusion damages were discovered.
When metal trim is used to finish the bottom of wooden beams (typically at porches, balconies, and walkways), water can collect and be held against the beams if proper details are not followed. Damages can be significant, sometimes requiring complete replacement of damaged structural beams, if proper waterproofing and drainage details are not incorporated into the design and construction (Figure 4). The most common failure includes a partially or completely unprotected wood beam (laminated veneer lumber [LVL], parallel strand lumber [parallelam], or an assembly of 2x members) with painted aluminum coil stock used to trim out (i.e., enclose/encapsulate) the bottom of the beam, with no provision for drainage. The water simply collects in the metal and wicks into the wood beam, causing rot and deflection. Depending on the extent of damage, this condition can quickly develop into a life-safety issue.

Damp

Dampness can develop in the wall assembly if drying is not provided (typically by a drainage mat or an air cavity). Brick veneer cavities filled with mortar slop are the most common areas for dampness to develop and stay in the wall. When an adequate drainage path and flashing are not provided, water may try to exit the wall through the face of the brick, sometimes resulting in efflorescence (Figure 5). Similar conditions can develop in hard-coat (a.k.a. conventional) portland cement stucco.

When damp conditions remain in the wall assembly, the water can migrate slowly toward the interior, damaging wall sheathing and framing members along the way. This migration of moisture from the wall cavity toward the interior is most pronounced in the hot/humid Southeast, particularly in the summertime when differences between inside and outside temperatures are most significant. A summer afternoon rain event serves to feed moisture into the wall, while the cool, conditioned, low-pressure interior serves to draw the moisture through the wall, away from the hot, humid, high-pressure conditions of the exterior. This cyclical exposure to elevated moisture can wreak havoc on OSB wall sheathing, which is particularly susceptible to moisture damage, even when covered by a code-compliant WRB.

The process that allows moisture to pass through the WRB is called capillary continuity. The best example of this process
is waking up in a tent when camping and touching your finger to the side of the tent and getting wet. The moisture on the outside of the tent passes through to your finger due to capillary continuity.

**Distress**

When building components are exposed to elevated moisture conditions, various types of distress can develop. Distress caused by elevated moisture conditions has been documented to range from corroded fasteners, swelling, and/or delamination of wall components (Figure 6), to rotten wall/floor framing (Figure 7) and structural collapse. Of course, if water intrusion is significant enough, interior damages—including water-damaged finishes and mold—can develop, which can become a health concern for the occupants.

For this reason, it is important to understand all of the components that could be exposed to elevated moisture within the wall assembly. Each component should be durable and resistant to damage and/or dimensional changes when exposed to moisture. Many wood-based components, such as OSB wall sheathing and MDF siding and trim, are particularly sensitive to swelling. As these components swell, the exterior protection layers—typically consisting of caulk and paint—are compromised. Once these layers are compromised, the extent of water intrusion increases, and the rate of damage is increased.

**CONCLUSIONS**

While we should all be familiar with the Four Ds of exterior wall design, we should also be equally or more familiar with the Four Ds of exterior wall failure. Each exterior wall that we design and/or evaluate needs to incorporate proper design concepts. However, these walls should also be reviewed, on paper and in the field, to determine if any of the Four Ds of exterior wall failure may exist or develop over time.

The intent of the building code is to provide reasonably durable and safe buildings, with no definition of what “reasonable” is. In order to meet the intent of the building code, we need to construct exterior walls that are functional and durable. Given the host of products and technology that we have available in the construction industry, this should be a reasonable and attainable goal. Following the Four Ds of wall design and avoiding the Four Ds of wall failure will help us accomplish this goal.
REFERENCES
5. 2304.12.2.5 Supporting members for permeable floors and roofs. Wood structural members that support moisture-permeable floors or roofs that are exposed to the weather, such as concrete or masonry slabs, shall be of naturally durable or preservative-treated wood unless separated from such floors or roofs by an impervious moisture barrier. The impervious moisture barrier system protecting the structure supporting floors shall provide positive drainage of water that infiltrates the moisture-permeable floor topping.

According to the United States’ Centers for Disease Control, workers in the construction industry have the second-highest suicide rate of all occupational groups. Researchers examined 12,000 suicides in 17 states from 2012 and found that farming, fishing, and forestry workers had the highest rate (84.5 per 100,000 workers), followed by construction and extraction (53.3) and installation, maintenance, and repair (47.9).

In the United Kingdom, the Office for National Statistics released an in-depth report on suicide by occupation between 2011 and 2015. Those statistics showed the risk of suicide for those working in the construction trades was 1.6 times higher than the national average, and the risk in the roofing industry was a staggering 2.7 times higher than the UK average. Unskilled workers were most at risk.

— CDC & www.nfrc.co.uk