RESEARCH & TECHNOLOGY

YOUR BUILDING IS UNDER SIEGE!!!!

UNDERSTAND THE FORCES AT WORK TO IMPROVE BUILDING DESIGN AND PERFORMANCE

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The "forces" which act upon buildings can be categorized by their magnitude, duration, and frequency.

Building codes and zoning ordinances have evolved over time to largely address high-magnitude or extreme forces. These forces include fire (extreme heat), hurricanes and tornadoes (extreme wind), flooding (extreme water levels), earthquakes (extreme mass acceleration/decelerations) and extreme snowfalls. Although extreme forces tend to be of short duration and are relatively infrequent, they are responsible for almost all catastrophic building losses.

On the opposite end of the spectrum (from the aforementioned extreme forces) are forces of lower magnitude that are present over longer periods of time and that occur with much greater frequency. This article is dedicated to a discussion of these forces, which for the purpose of this article, I am referring to as "siege" forces.

In military parlance, a siege is a form of warfare characterized by a constant, low-intensity assault on a party that holds a static, defensive position. It is a war of attrition whose outcome is influenced by the initial size and strength of both parties, and ultimately depends on how long each party can survive if not reinforced in some manner.

In the present context, your building is the defending party. Throughout its life, your building is under continual assault by siege forces. The extent to which your building succumbs to these siege forces depends on (1) how well it has been designed and constructed to defend against these forces, and (2) to what extent damage from the attacking forces are addressed during this prolonged siege.

Actual building life, which is defined as the elapsed time between the completed construction and the total destruction of a building, is almost entirely dependent on how well siege forces have been addressed in initial design and construction, and during routine building maintenance and repair. Realize that if damages due to siege forces are not addressed, the catastrophic loss of the building to extreme forces becomes more probable.

Siege Forces

1. Photodegradation
2. Wood decay fungi
3. Animals
4. Corrosion
5. Water condensation and deposition
6. Cold weather
7. Temperature fluctuations
8. Winds
9. Ventilation
10. Equipment induced vibration

Photodegradation

Photodegradation is the disruption of chemical bonds by ultraviolet (UV) radiation, which is present in sunlight. Polymeric-type materials are highly susceptible to photodegradation unless they contain polymer stabilizers or UV-absorbers. Once UV radiation disrupts chemical bonds, polymers are more likely to react with oxygen and/or water vapor causing additional changes to the material.

Polymeric materials include numerous synthetically derived plastics such as polyethylene, polypropylene, polystyrene, polyurethane, and polyvinyl chloride (PVC), and natural organic materials such as wood and other plant-based fibers, wool/hair and natural rubber.

Photodegradation results in chalking, embrittlement, cracking, discoloration, and loss of strength of sun-exposed materials (i.e., roofing, siding, exterior trim, window and door frames, exterior caulks and sealants). The slow and constant surface erosion and discoloration of unfinished exterior wood is a result of photodegradation. "Weathering" is a term commonly used to refer to the effects of photodegradation involving exposed building materials.

Figure 1 shows the roof of a building constructed in the mid 1960's. Several original fiber reinforced plastic (FRP) skylights were replaced with new FRP panels around 2007. Since that time the remainder of the original FRP panels succumbed to photodegradation leaving large holes in the roof. In 2022, the owner's insurance company refused to extend insurance on the building until the holes were properly covered. The owner met this demand using the white steel panels shown in figure 1.

For the ultimate defense against photodegradation, use stone, clay brick, cast-in-place concrete, and precast concrete units on exterior walls. Similarly, on your roof use slate, clay tile, precast concrete shingles, and materials overlaid with stones.

FIGURE 1. REPLACEMENT OF DETERIORATED FRP PANELS WITH WHITE CORRUGATED STEEL PANELS.

Wood Decay Fungi

Wood decay fungi are microorganisms that attack cellulose and, in some cases, the hemicellulose and lignin in wood. They require air, a suitable temperature, and water for survival. Optimal temperature for the growth of decay fungi varies by fungal species but is typically around 77°F (25°C), and most decay species do not grow below 41°F (5°C) nor above 104°F (40°C). Wood decay fungi require a wood moisture content at or above the wood's fiber saturation point, typically 28% to 30% on a dry basis (db) before they will start growing. Fungi responsible for brown rot (called dry rot by some in non-scientific communities) grow optimally between moisture contents of 30% and 40% db. Most other wood decay fungi grow optimally between 50% and 60% db. Decay fungi cannot continue to grow at wood moisture contents below 20% db, and water-soaked wood will not decay because it lacks the air required for fungal growth.

Preservative wood treatments take away the food source for decay fungi, typically by heavy metal toxicity with copper as the heavy metal.

Wood decay in existing structures is generally the result of (1) poor preservative treatment in a wet environment (Figure 2), or (2) water in contact with non-preservative-treated wood at a location where evaporation of the water is limited. The latter is generally the case when water gets drawn by capillary action into tight interfaces between components where there is little to no airflow. Concrete and masonry products can transmit and hold moisture at fairly high levels so wood that is not properly treated with preservative must be isolated from any concrete and/or masonry that is (1) on the building exterior, (2) not isolated from soil, (3) is routinely washed, or (4) otherwise exposed to water. Isolation is normally accomplished by placing a rigid plastic barrier between the wood and concrete/masonry (Figure 3). Where a wood support post is bearing on concrete in an exterior application, place polyurethane construction adhesive (e.g., Loctite PL Premium) between the wood post and concrete so that it squeezes out as the post is set in place. The adhesive will bond to the wood and concrete, and prevent precipitation from getting drawn (by capillary action) into the tight interface between the components. Ongoing research (Figure 4) has shown this to be very effective in preventing the decay commonly found at the base of wood posts bearing directly on exterior concrete.

FIGURE 2. SEVERE WOOD DECAY.

continued on page: 14

continued from page: 13

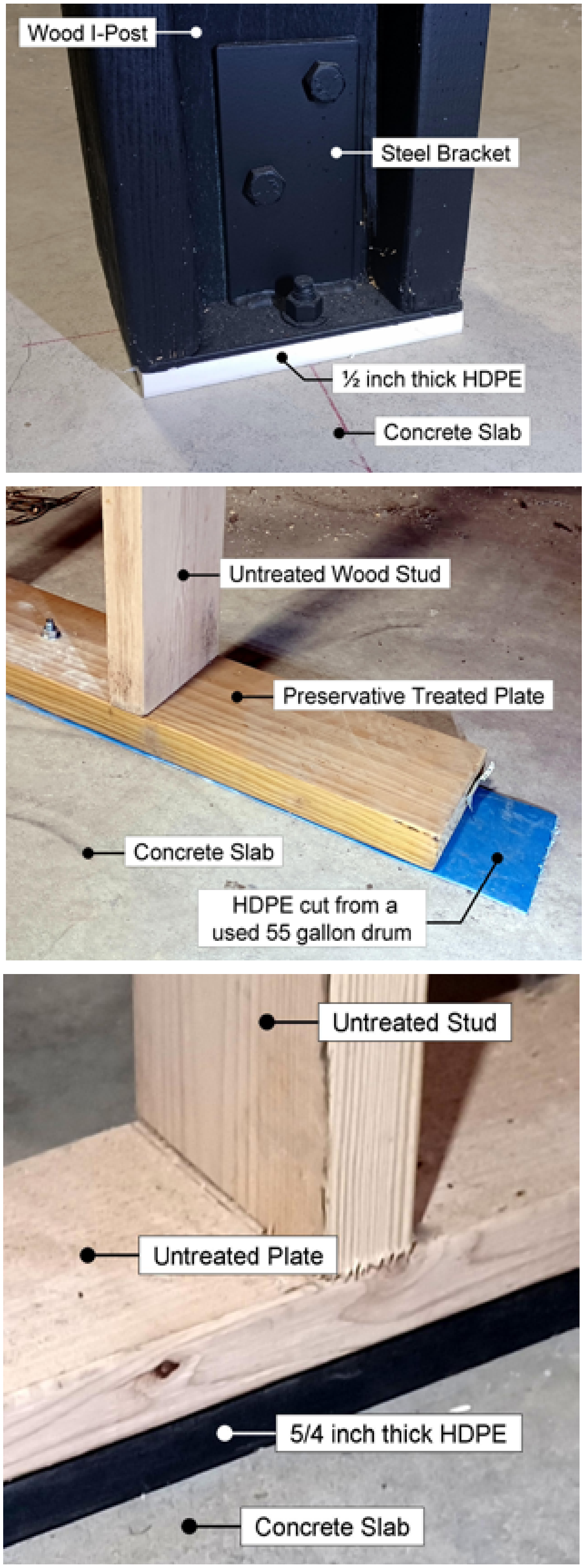

FIGURE 3. ISOLATING WOOD COMPONENTS FROM A CONCRETE FLOOR WITH HDPE COMPONENTS TO LIMIT WOOD DECAY IN A FOOD PROCESSING FACILITY.

FIGURE 4. POLYURETHANE CONSTRUCTION ADHESIVE USED TO PREVENT PRECIPITATION FROM GETTING DRAWN INTO THE INTERFACE BETWEEN AN UNTREATED WOOD POST AND A CONCRETE PIPE PIER. THIS CONNECTION IS ONE OF SEVERAL SIMILAR CONNECTIONS MADE IN MAY, 2011 AS PART OF AN ONGOING RESEARCH PROJECT BEING CONDUCTED BY THIS AUTHOR ON WOOD DECAY PREVENTION. AN EXAMINATION OF THIS POST DURING JANUARY, 2023 (WHEN THIS PICTURE WAS TAKEN) DID NOT REVEAL WOOD DECAY. NOTE THAT THIS CONNECTION IS LOCATED IN A HEAVILY SHADED AREA.

Animals

Wood is susceptible to attack by many types of insects, especially termites (for which wood is a food source) and carpenter ants (for which wood serves as a nesting area). Other problematic insects include power post beetles, roundheaded and flatheaded borers and carpenter bees.

Rodents can cause damage and spread disease. With sharp, continuously growing teeth, they can chew through most non-masonry-type building materials. Rodents frequently create large holes through building assemblies which serve as pathways for other pests, water, and unwanted air transfer. Rodents commonly nest in insulation and saturate numerous areas with feces and urine. They can create fire hazards when they gnaw off electrical wire insulation and chew completely through smaller wires inside walls.

Non-poultry birds are common (but unwelcome) residents in any building with a wall opening or a window or door that is open for extended periods of time. This occurs in most animal confinement buildings and many large commercial and industrial buildings. Bird droppings, especially around HVAC components, can create health issues. Birds are notorious for pecking holes through vapor retarders and insulations that are reachable from a roosting location (Figure 5). Such holes generally increase condensation and unwanted air movement, which in turn tends to boost decay and corrosion in the surrounding region

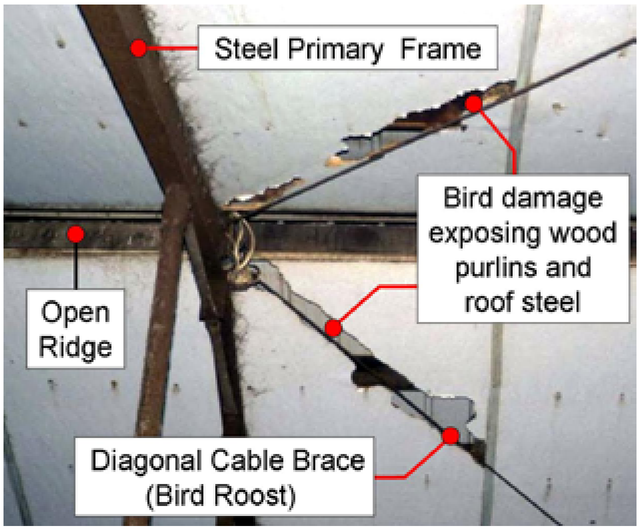

FIGURE 5. BIRD DAMAGE.

Corrosion

After their manufacture, all metals have a propensity to revert back to their more natural and stable state of ore (e.g., iron ore). This naturally occurring, spontaneous and irreversible redox reaction is called corrosion, and the product of this process is generally an oxide, hydroxide or sulfide.

Metals such as magnesium, zinc, aluminum and some aluminum alloys have a high oxidation potential and typically undergo corrosion as soon as they are exposed to air. This "dry" corrosion results in the formation of an oxide layer/coating on the metal surface. As the oxide coating thickens, corrosion slows and eventually stops. If the oxide coating is not physically or chemically disturbed, it will serve as an effective barrier against further corrosion. Since dry corrosion seldom results in a significant loss of base metal and provides some protection against further corrosion, it can be considered beneficial.

For most other metals, corrosion reactions typically require an electrolyte (i.e., ionized liquid or gel). Such "wet" corrosion reactions can significantly deteriorate metal. Bi-metallic corrosion (a.k.a. galvanic corrosion) is wet corrosion involving two dissimilar metals. When joined together by an electrolyte, the metal with the higher oxidation potential will corrode. Table 1 lists the electrical potential of metals in saltwater where the more negative the electrical potential of the metal, the greater the oxidation potential. Thus, metals in Table 1 are listed from highest (top) to lowest (bottom) oxidation potential.

In bi-metallic corrosion parlance, the metal with the higher oxidation potential becomes the anode, and the other metal the cathode as electrons begin to flow between them. The greater the difference in the oxidation potentials of the two metals (i.e., the further they are apart in Table 1), the more rapid will be the deterioration of the anode. The relative sizes of the anode and cathode also impact the rate of corrosion. If the metal comprising the cathode is large and surrounds a relatively small anode, the rate of corrosion will be rapid. Conversely if the surface area of the anode is large relative to the cathode, the corrosion rate will be slow.

Table 1 – Galvanic Series (in Flowing Seawater)
(Source: Stephen Dexter, University of Delaware Sea Grant Marine Advisory Service)

	Metal or Metal Alloy	Electrical Potential Range of Alloy vs. Reference Electrode, Volts*
	Magnesium	-1.60 to -1.63
Anodic or Active End	Zinc	-0.98 to -1.03
	Aluminum Alloys	-0.70 to -0.90
	Cadmium	-0.70 to -0.76
	Cast Irons	-0.60 to -0.72
	Steel	-0.60 to -0.70
	Aluminum Bronze	-0.30 to -0.40
	Red Brass, Yellow Brass, Naval Brass	-0.30 to -0.40
	Tin	-0.29 to -0.31
	Copper	-0.28 to -0.36
	Lead-Tin Solder (50/50)	-0.26 to -0.35
	Admiralty Brass, Aluminum Brass	-0.25 to -0.34
	Manganese Bronze	-0.25 to -0.33
	Silicon Bronze	-0.24 to -0.27
	Stainless Steel – Type 410, 416**	-0.25 to -0.36
	90-10 Copper-Nickel	-0.21 to -0.28
	80-20 Copper-Nickel	-0.20 to -0.27
	Stainless Steel – Type 430	-0.20 to -0.32
	Lead	-0.19 to -0.25
	70-30 Copper-Nickel	-0.13 to -0.22
	Silver	-0.09 to -0.14
	Stainless Steel – Types 302, 304, 321, 347	-0.05 to -0.10
	Stainless Steel – Type 316, 317 **	-0.00 to -0.10
	Titanium and Titanium Alloys	+0.06 to -0.05
Cathodic or Noble End	Platinum	+0.25 to +0.18
	Graphite	+0.30 to +0.20

* These numbers refer to a Saturated Calomel Electrode. Measured in seawater with flow rates between 8 ft/sec and13 ft/sec and temperatures between 50 and 80°F (10 and 27°C)
** Values listed are for a passive state. In low-velocity or poorly aerated water, or inside crevices, these alloys may start to corrode and exhibit potentials near -0.5 V

SEE PAGE 20 FOR FULL CHART

Preventing wet corrosion in existing buildings is largely about excluding or removing electrolytes from metals. In short, keeping metals dry. This is not an option for HVAC and plumbing systems which involve water and other solutions. For an overview of some of the unique corrosion

continued on page 16

continued from page: 15

RESEARCH & TECHNOLOGY

problems associated with HVAC and plumbing systems, read "The Top Ten Corrosion Threats" at www.corrosionpedia.com/2/2031/corrosion/top-10-corrosion-threats

Appendix C of "NFBA Metal Panel and Trim Installation Tolerances" is titled "Galvanic Corrosion" and contains several recommendations for reducing corrosion through building design and component selection. For a good overview of the chemistry associated with corrosion, readers are referred to an article by Mike Sondalini found at https://accendoreliability.com/metal-corrosion-basics-controls

Water Condensation and Deposition

Condensation is the conversion of a vapor to a liquid. Deposition is the conversion of a vapor to a solid. Water vapor will condense onto any surface that is below the dew point temperature of the air, and water vapor will form frost or hoarfrost on any surface that is below the frost point temperature of the air.

Due to radiation related heat loss from exterior surfaces at night, most exterior surfaces will be covered with early morning dew and/or frost when the relative humidity of the air is high. Condensation and deposition moisture that does not immediately run off these surfaces, normally evaporates as the morning progresses and the surface warms. Condensation on exterior surfaces tends only to be problematic when drawn or forced into cracks and crevices by wind and/or negative pressure ventilation systems.

Condensation and deposition tend to be most problematic on interior surfaces since many interior components are not designed to get wet or remain wet for an extended time.

Some of the worst interior condensation and deposition conditions occur in uninsulated animal confinement facilities that lack supplemental heat. During periods of extreme cold, operators often reduce building ventilation to curtail heat loss. This action invariably drives up interior relative humidity, and the amount of water condensing and freezing on exterior cladding (Figure 6). While decreasing ventilation may initially warm animals, it has the opposite effect when it literally starts to rain in the facility, and animals lose much of the insulating qualities of their coat. Whereas water condensing on an outside surface will simply run off the structure or quickly evaporate, this is not the case inside the building. Inside surfaces are seldom designed to facilitate water drainage, and moisture evaporation occurs more slowly indoors because of lower air flow rates and less direct sunlight. During warmer weather, indoor condensation enhances decay, corrosion, and mold growth.

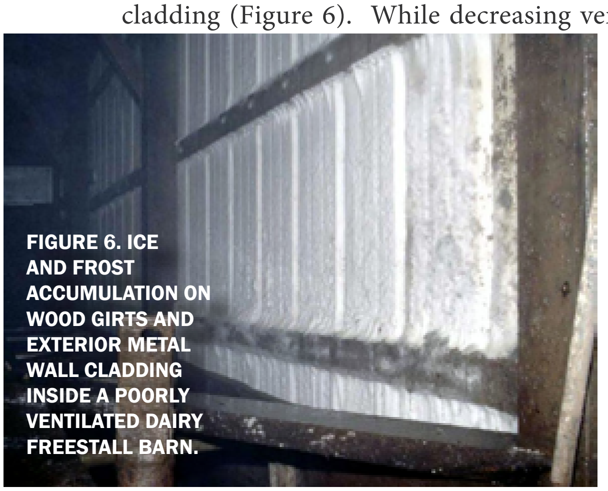

FIGURE 6. ICE AND FROST ACCUMULATION ON WOOD GIRTS AND EXTERIOR METAL WALL CLADDING INSIDE A POORLY VENTILATED DAIRY FREESTALL BARN.

Condensation in animal confinement buildings is often reduced by installing faced fiberglass (Figure 7) or rigid board insulation directly under the roof cladding, or by spraying foam insulation against the underside of the cladding. To function properly (and not cause more problems than they solve), these insulations must be properly installed and maintained. Insulations have the added effect of reducing radiant heat gain during hot and sunny weather and reducing heat loss during cold weather. Interior dripping due to condensation can be reduced by adhering anti-drip liners to the underside of roof sheathing. These liners hold condensation until it can re-evaporate into interior air.

FIGURE 7. INSTALLATION OF VINYL-FACED FIBERGLASS INSULATION BETWEEN WOOD FRAMING AND CORRUGATED METAL ROOFING.

Cold Weather

Cold weather, particularly freezing weather in northern climates, can have specific and pronounced effects on buildings, including differential movement of building components and systems due to frost heave, water infiltration due to ice dams along building eaves, accumulation of moisture in building thermal envelopes, truss uplift, and disintegration of concrete.

Problems caused by frost heave can be expensive to repair depending on their location, cause, and impacts on the building. It's best to eliminate frost heave problems before they start through proper design and construction of the building foundation, with proper attention given to foundation insulation, backfill materials, and above and below grade water drainage.

Ice dams form on roofs covered with snow or ice when surface temperatures at the eave are below freezing and temperatures further up the roof are above freezing. In this situation, water running down the roof will form a buildup of ice (i.e., an ice dam) at the eave. As water pools behind this dam, the ice dam grows leading to a larger pool of water. This can result in leaks through the roof into areas where the water can cause wood decay and mold growth. Alternatively, a decrease in temperature also freezes the water behind the dam, and as it expands, it forces apart building components above the eave. Ice dams form in buildings with poor attic ventilation or where a measurable quantity of heat is escaping into the space under the roof. Ice dams can be largely prevented by (1) ensuring that the entire underside of the roof surface is properly ventilated so that the temperature above and below the roof surface are similar, and (2) installing ceiling insulation and foaming/sealing around ceiling fixtures and ducts to prevent building heat from reaching the underside of the roof. Alternatively, a building owner can remove roof snow shortly after a snowfall, de-ice eave ice with calcium chloride, install heating tapes on the eave, and/or blow outside air into the attic.

In cold climates, vapor retarders are installed on the inside of thermal envelopes to prevent building moisture from diffusing into exterior wall and roof cavities during colder weather. When vapor retarders are incomplete or have been compromised, moisture diffuses into exterior cavities and condenses on exterior insulation and sheathing or cladding. During prolonged periods of subfreezing temperatures, ice crystals will form and grow, remaining until outdoor temperatures move back above freezing at which time the melt water will trickle into other areas where it can enhance decay and mold growth.

Truss uplift occurs when the moisture content (MC) of the truss's bottom chord is driven to a lower level than its top chord. A decrease in moisture content shortens the bottom chord, and as with any beam (and a truss is a very narrow and deep beam), when you shorten the bottom of the beam, the beam arches upward. Truss uplift is largely confined to trusses in attic spaces that: (1) are well ventilated with outside air, (2) are isolated from a heated building interior with a properly installed vapor retarder that prevents moisture from entering the attic space, and (3) has insulation covering the bottom chords. In well ventilated attics in cooler climates, the moisture content of top chords typically reaches its maximum in December and its minimum in April. In the upper Midwest, the maximum MC ranges between 14.5% and 16% db, and the minimum between 12% and 13% db (USDA Forest Service, FPL-RN-0268 Equilibrium Moisture Content of Wood in Outdoor Locations in the United States and Worldwide by William T. Simpson). When isolated from the indoor environment via a vapor retarder, lower chords in the attic space will be at the same absolute humidity as the upper chords. However, if covered with insulation and in direct contact with the finish ceiling, the lower chords will be measurably warmer than the upper chords throughout the late fall and winter months. This means that the relative humidity of the space surrounding the lower chords will be significantly lower than the relative humidity of the air in contact with the upper chords. And it is the relative humidity (not the absolute humidity) that largely dictates the equilibrium moisture content (EMC) of wood. In fact, between 30°F and 80°F, and between 20% and 60% relative humidity, wood EMC can be approximated within 0.2% by the equation:

$$\text{EMC (\%, d.b.)} = 0.16 \times (\%\text{RH}) + 1.3\%$$

During cold winter months, a difference in air relative humidity may occur between top and bottom chords of 60%, which for most conditions translates into an EMC difference around 10%.

The impact of truss uplift increases as the distance between truss bearing points increases. The most significant truss uplift I have encountered was in a hog finishing building. Due to significant uplift, interior partitions dropped out of the U-shaped plastic extrusions that held them in place at the ceiling. In smaller structures, problems associated with truss uplift are mostly cosmetic (e.g., nail pops, open seams in drywall) and can be eliminated through proper attachment of drywall and interior walls to trusses.

Buildings in cold climates are subjected to freeze-thaw cycles that can deteriorate concrete, masonry products, and mortars. This deterioration is significantly reduced with proper air entrainment and surface sealing to limit intrusion of moisture. Be aware that ordering properly air-entrained concrete will not result in improved freeze-thaw resistance unless the concrete is properly placed. Figure 8 shows a concrete surface one year after placement. Although this concrete had a very low water/cement ratio and was ordered with 6% air entrainment, it was over-worked after placement (i.e., excessively power-floated and power-troweled) which removed surface air entrainment.

FIGURE 8. OVER-FINISHED AIR-ENTRAINED CONCRETE AFTER ONE YEAR OF WINTER EXPOSURE.

continued on page 18

continued from page: 17

RESEARCH & TECHNOLOGY

Temperature Fluctuations

Temperatures are constantly changing. In addition to being the driving force for cycles of moisture condensation and evaporation, it also produces cycles of thermal expansion and contraction.

All common building materials expand and contract when heated and cooled, respectively. The magnitude of this change in length is calculated using the material's coefficient of linear thermal expansion (CLTE, or α). Specifically, the change in length of a material is equal to its original length multiplied by its CLTE and the change in temperature. When the Greek letter delta (Δ) is used to indicate the difference or change, the equation is:

$$\Delta \text{ Length} = \text{Length} \times \text{CLTE} \times \Delta \text{ Temperature}$$

The CLTE for steel and concrete are both approximately 12×10^{-6} (°C)$^{-1}$. Wood has a parallel-to-grain CLTE ranging from 3.1×10^{-6} to 4.5×10^{-6} (°C)$^{-1}$ (Wood Handbook, USDA Forest Service), glass has a CLTE around 8.5×10^{-6} (°C)$^{-1}$, and most unreinforced plastics a CLTE between 50×10^{-6} and 150×10^{-6} (°C)$^{-1}$. With a CLTE for steel of 12x10-6 (°C)$^{-1}$ (=s 6.67×10^{-6} (°F)$^{-1}$), a 30 ft long sheet of steel when warmed by 50°F would increase in length by 0.01 ft or 1/8 inch.

$$30 \text{ ft} \times 6.67\times10^{-6}(°\text{F})^{-1} \times 50°\text{F} = 0.01 \text{ ft}$$

$$0.01 \text{ ft} \times 12 \text{ in/ft} = 0.12 \text{ in}$$

A building component that can freely expand and contract is generally no concern from a durability perspective. Conversely, attention must be paid to any component that is restricted from freely changing length as this typically means that when heated and/or cooled it will induce forces in other components. Such is the case when there is differential expansion and contraction between two or more mechanically connected components. Of greatest concern in this regard are the localized forces associated with the "through-fastening" of metal roof panels to underlying roof framing. Metal roofing is thin and thus has a low heat capacity per unit surface area. This means it will heat up and expand relatively quickly when exposed to direct sunlight. Underlying framing will neither expand as much nor as quickly as thin metal roofing because of its greater heat capacity, protection from direct sunlight, and in the case of wood roof framing, because of its lower CLTE. This results in differential thermal expansion between panels and framing and a build up of forces in and around through fasteners. Over time, the forces and differential movement will tend to loosen up through-fasteners or form slots in the metal panels; actions that increase the likelihood of roof leaks.

There are two factors that significantly impact differential thermal expansion between roof panels and underlying framing because they directly impact temperature differences between panels and framing. First is the presence of thermal insulation between the panels and framing -- the more insulation, the greater the temperature difference. Second is panel surface finish. On a sunny 90 F day, the temperature on an unpainted metal roof can be upward to 145 F. While this is less than many darker colored roofs, it is 30 to 40 F more than white roofs and roofs with paint coatings infused with materials that selectively reflect infrared radiation.

The thermal expansion of roof panels that takes place under sudden sun exposure (breaking clouds) may be associated with audible popping sounds as components grow and slide past each other. These sounds should be a reminder of the cyclic movements that can loosen fasteners and slot roofing panels.

The longer a metal roof panel, the greater will be its overall change in length for a given temperature change. To avoid problems with differential movements between long panels and underlying framing it is best to avoid through-fastening of the panels. Instead, switch to a floating roof system – a system with metal panels that are held down with clips that allow for the unrestricted expansion and contraction of the panels. One drawback of floating roof systems is that they do not contribute to diaphragm action (i.e., the distribution lateral building forces induced by wind and earthquake) to any significant degree.

Figure 9 shows an asphalt shingled roof 20 years after original installation. This was a black roof and hence frequently subjected to extreme temperature swings. The resulting expansion and contraction produced the cracking shown. It is important to note that cracking exposes asphalt below the granular surface making it much more susceptible to photodegradation.

FIGURE 9. BADLY DETERIORATED BLACK ASPHALT SHINGLE ROOF AFTER ONLY 20 YEARS OF SERVICE.

Winds

Wind forces tend to be the most destructive environmental load for most buildings. This is largely due to their cyclic nature, directional variability, and frequent (daily) presence. To this end, rural America is replete with old timber frame barns which have succumbed to wind forces. In many of these buildings, the joints in timber frame bents become loose after years of moisture content cycling and racking by wind. A telltale sign of loose joints is a barn noticeably out-of-plumb. Unfortunately, even when the visible signs of distress become obvious, many owners do not take steps to brace, reinforce and repair the frames, which inevitably results in partial or total building collapse.

Ventilation

While ventilation is essential for indoor air quality, it can result in the unwanted transport of moist air and water into areas where it can enhance decay, corrosion, and mold growth.

Ventilation systems in cold weather regions are generally negative pressure systems. This prevents moist indoor air from entering cracks in the exterior envelope, where it will form ice during sub-freezing weather, and freeze shut doors and windows. One downside of negative pressure systems is that they may draw exterior water into unsealed joints between cladding components and around doors and windows – a problem that can be compounded by positive exterior wind pressures.

Natural ventilation systems in animal confinement facilities are characterized by large wall openings and frequently by ridge openings which expose indoor components to precipitation that will shorten their functional life. Particularly problematic is the complete exposure of metal truss plates at the ridge of animal confinement buildings. Not only are the plates subjected to repeated moisture cycling and extreme temperature swings, but they are also exposed to the corrosive effects of manure gases (i.e., hydrogen sulfide (H_2S) and ammonia (NH_3)) as they vent out of the facility. Figure 10 shows metal connector plate deterioration at a building ridge. Many designers avoid this problem by using engineered lumber rafters in place of metal-plate-connected trusses.

FIGURE 10. CORRODED METAL TRUSS PLATE UNDER AN OPEN RIDGE IN A DAIRY FREESTALL BARN.

Equipment Induced Vibration

Structural integrity can be compromised by vibrations that cause material fatigue and also loosen bolts, screws, nails, and other mechanical connections. Such vibrations are induced by power equipment (e.g., HVAC systems) in direct contact with building components, or by equipment that generates fluctuating air pressures (i.e., sounds) that in turn vibrate surrounding components. Vibrations are minimized by using passive and active vibration isolation mountings, attaching equipment directly to concrete slabs or other large masses, and by surrounding noisy equipment with sound absorbing materials.

Summary

To varying degrees, all buildings are under continual assault by the damaging effects of photodegradation, wood decay fungi, animals, corrosion, water condensation and deposition, cold weather, temperature fluctuations, winds, ventilation, and equipment induced vibrations. With an acute awareness of how these siege forces damage buildings, architects and engineers can improve building designs. This in turn can lower repair and maintenance costs, reduce the likelihood of a catastrophic building loss, enhance building resale value, and extend building life.

About the author: David R. Bohnhoff is a registered professional engineer and emeritus professor of Biological Systems Engineering at the University of Wisconsin-Madison.

This article was subjected to a peer review process conducted by the NFBA Editorial Committee, which consists of at least 10 members from engineering and academic organizations throughout the United States who are each knowledgeable about Post-Frame construction.

RESEARCH & TECHNOLOGY

Table 1 – Galvanic Series (in Flowing Seawater)
(Source: Stephen Dexter, University of Delaware Sea Grant Marine Advisory Service)

	Metal or Metal Alloy	Electrical Potential Range of Alloy vs. Reference Electrode, Volts*
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	Steel	-0.60 to -0.70
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** Values listed are for a passive state. In low-velocity or poorly aerated water, or inside crevices, these alloys may start to corrode and exhibit potentials near -0.5 V