TAKE CAUTION WITH CONTINUOUS INSULATION:

Account for Differential Expansion and Contraction in the Design Phase

By J. Lawrence Elkin, PE, CCT

Figure 1 – Hard Rock Café in Myrtle Beach, South Carolina.

The 2009 International Energy Conservation Code (IECC) and ANSI/ASHRAE/IESNA 90.1-2007, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, both include requirements for continuous exterior wall insulation (ASHRAE 2007 and ICC 2009). When I first reviewed this code, I was immediately reminded of problems that developed at the Hard Rock Café as a result of the well-intentioned use of continuous insulation in the building envelope (Elkin 2004). My purpose is not to condemn the use of exterior insulation; it is merely a reminder that practitioners need to thoughtfully consider all aspects of design changes.

During my investigation of the Hard Rock Café facility in Myrtle Beach, South Carolina, I arrived before sunrise one morning to measure movements in the cladding as the sun warmed the surface. The custodian met me outside and asked what I was doing. "I'm just making some measurements to see how the building was built," I replied. He looked as me very seriously, then looked at the building and then back at me again. Very slowly he stated, "It's built like a pyramid." True enough! (See *Figure 1*.)

The restaurant, built in 1995, was indeed constructed to appear like the stone pyramids in Egypt. However, this modern incarnation of the classic structure included a wide-flanged steel frame that supported steel purlins, steel decking, and a cladding system. The geometry of the restaurant dictates that the building envelope perform the dual function of acting as both walls and roofing.

Destructive testing revealed that the cladding consisted of (beginning at the steel deck) 3½ in. of expanded polystyrene (EPS) insulation, ¾-in. plywood nail base, an adhered bituthene membrane, ⅜-in. air space, and 5⁄16-in.-thick synthetic stone panels (see *Figure 2*). The plywood was attached with self-drilling screws that penetrated through the EPS and into the steel deck. The exterior panels were adhered to aluminum cleats that were screwed into the plywood nail base. To complete the appearance that the building was comprised of large, stacked stones, ⅜-in.-wide silicone sealant

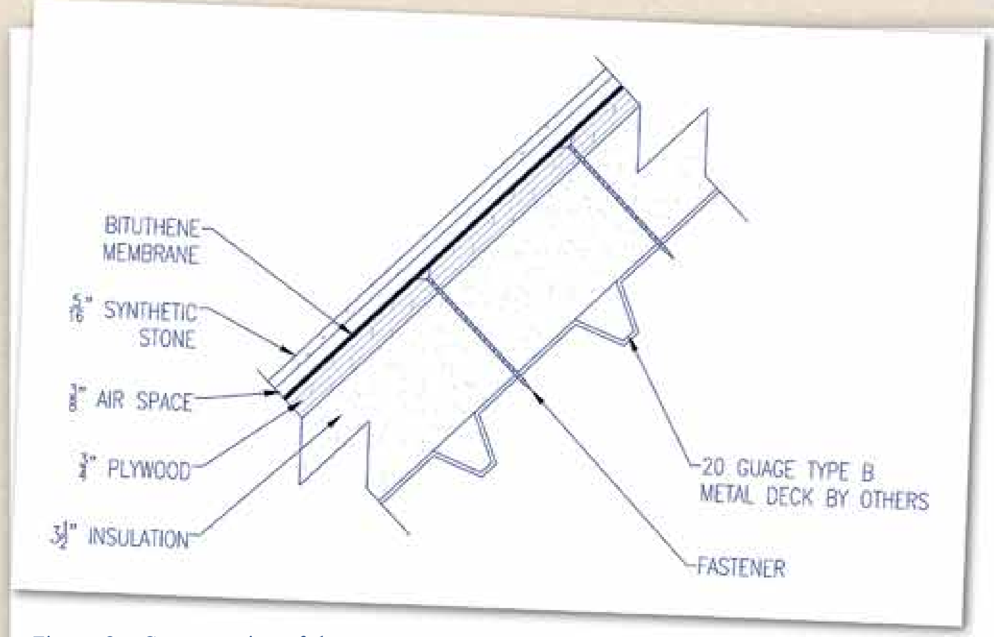


Figure 2 – Cross section of the as-designed and constructed wall/roof assembly.

Properties of Synthetic Stone Veneer	
Property	**Value**
Weight	3.2 lb./ft² (5⁄16-in. thick)
Moisture absorption (ASTM D570)	0.08% (by weight short duration) 0.20% (by weight 24-hr. immersion)
Thermal conductivity (ASTM C177)	4.862 Btu in./hr. ft² °F
Thermal expansion (ASTM D696)	10.8x10^{-6} in./in. °F
Permeability (ASTM E96)	0.02 perm
Apparent porosity	1%

Table 1

(±50% movement) was used in the joints between the panels.

The synthetic stone panels were composite sheets made by incorporating natural slate and stone fillers in a resin binder with chopped glass fibers for reinforcement (Petrarch 1994). As installed at the site, the panels measured approximately 10 x 4 ft. A summary of the synthetic stone's properties is provided in *Table 1*.

The exterior wall cladding assembly was completed in early April 1995. However, reports that the panels were visibly deformed arose by October of 1995. The panels exhibited upward curling of the panel edges and "pillowing" of the middle portions of the panels. In other words, the panels remained tight to the structure at the cleats but deflected away from the structure between the cleats (see *Figure 3*). By spring of 1996, the panels had flattened, but the sealant joints were at the lower limit of their allowable widths. As summer progressed, the panels began to deflect and the sealant joints began to rupture as they became excessively small (Elkin 2004).

Figure 3 – View of deformations.

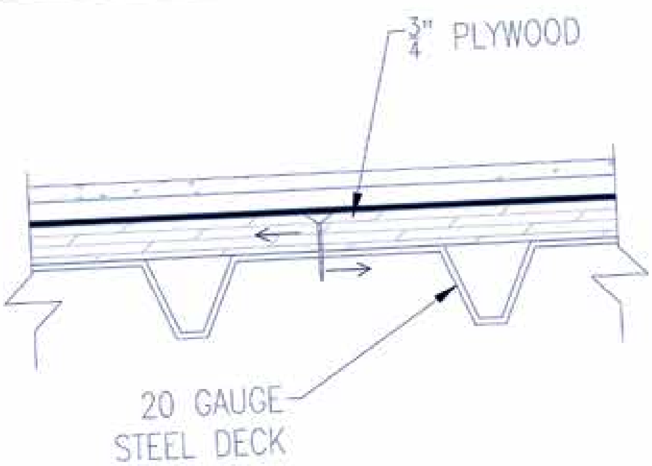
At the time of the investigation, two hypotheses were considered. The first was that the synthetic stone panels had expanded excessively. A battery of testing was conducted that ultimately determined the panels performed per the manufacturer's specifications (Elkin 2004).

The second hypothesis was that the cladding assembly was experiencing unanticipated differential movement across its various layers (*Figure 4*). The genesis of this theory resided in the manufacturer's requirement that plywood substrate be fastened directly to the structure. The as-designed/as-built assembly included 3½ in. of EPS between the plywood and the structural steel deck. Had the plywood been screwed directly to the steel, the fasteners would have been placed primarily in shear when the steel and wood expanded differentially. As such, the fasteners would have limited the relative movement of the wood and steel. However, the long screws that extended through the EPS would have been subjected to unrestrained bending when the wood and steel expanded differentially. *Figures 5A* and *5B* depict the differences in the fastener loadings created by the installation of the EPS layer.

Figure 4 – Differential movement of the wall assembly resulted in excessive compression of the sealant joints and interferences between adjacent panels. Ultimately, this panel fractured as a result.

Testing this hypothesis would have proven challenging. Recreating the assembly, along with its exposure to both interior and exterior conditions, would have required constructing a sophisticated test hut. In addition, many months would have been needed to collect the data. As an alternative, I chose to develop a computer simulation of the expansion and contraction of each layer to assess the relative movement within the cladding assembly. The simulation consisted of two phases. First, heat and moisture transport effects were calculated using a commercially available software package. Temperature, humidity, and moisture content values were analyzed on a per-hour basis for the materials that comprised the building envelope. The results from this routine were exported to a spreadsheet so that coefficients of thermal and hygroscopic expansion could be applied to predict the expansion/contraction in each layer.

For heat and moisture transport modeling, WUFI Pro was used. WUFI considers the effects of vapor diffusion and capillary suction in one dimension through an assembly (Kuenzel et al., 2001). Several aspects of the as-built construction make the use of this simulation tool particularly effective. The presence of the continuous bituthene membrane minimized the potential for air leakage across the assembly. Including air-leakage effects is difficult in hygrothermal modeling; the construction allowed me to negate these effects. In addition, the structure's design included large areas of opaque envelope without interruptions by windows, doors, or other penetrants. The homogeneity of the cladding omitted the need to consider multidimensional effects at these penetrations.



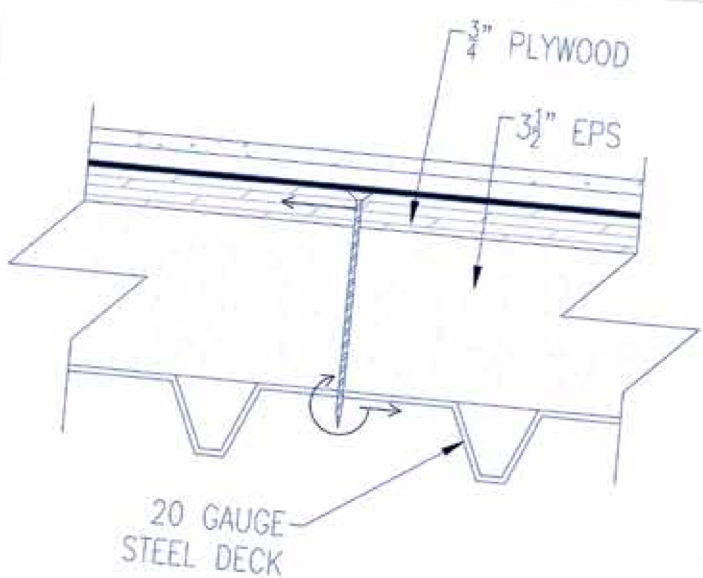


Figure 5 – Deck and fastener configurations.

$$Representative\ Property = \frac{(Area_{air} \times Property_{air}) + (Area_{steel} \times Property_{steel})}{Area_{air} + Area_{steel}}$$

Equation 1

WUFI utilizes moisture-dependent property data to enhance the accuracy of its solutions. A library of material properties is included with the software, and most of the cladding assembly materials were included. However, no data files were provided for the synthetic stone panels or the structural steel deck.

The synthetic stone panels had low moisture absorption and low vapor permeability. These characteristics indicate that the material property data would be nearly constant and not subject to significant changes based on moisture content. This condition is similar to behavior of polyethylene—a material that was in the property data library. Using polyethylene as a starting point, the remaining required data could be derived from the manufacturer's literature.

Properties for the steel deck required a more complicated solution. At first, steel would appear to be a continuous and impermeable layer. However, corrugated steel decking becomes porous when one considers the effects of laps and fastener penetrations. The sizes and number of the holes were estimated from field measurements for a typical sheet of decking. Then I created a synthetic steel-air layer by using an area-weighted averaging of the properties for each material. *Equation 1* depicts this method.

When performing a simulation, it is important to estimate the starting conditions to a reasonable degree of accuracy. For design purposes, providing a "lead time" in the simulation can offset the need for this accuracy. That is, additional simulation time can be built in before the actual period for analysis. The lead time diminishes the effects of the initial conditions. In a diagnostic simulation, the period for analysis should be close to the actual period of performance, and the initial conditions will have a significant influence. As such, I researched local historical weather data for Myrtle Beach for the time when the cladding was being installed (USAF 2000). Based on a mean dry-bulb temperature of 55°F (13°C) and mean dew point temperature of 45°F (7°C), I estimated that the moisture content of the plywood would have been approximately 12% as an initial condition (FPL 1987).

I simulated the cladding's performance for two years. This time frame allowed for the effects of seasonal changes, as well as year-to-year wetting/drying of the assembly. Upon completion of the calculations, I used the output data to assess how the width of a typical sealant joint would vary with time.

Recall that the panel joints were initially ⅜ in. (0.375 in.) wide. The dashed lines show the maximum and minimum allowable widths of the joint, based on the ±50% movement limit for the sealant material. The hourly data for joint movement result-

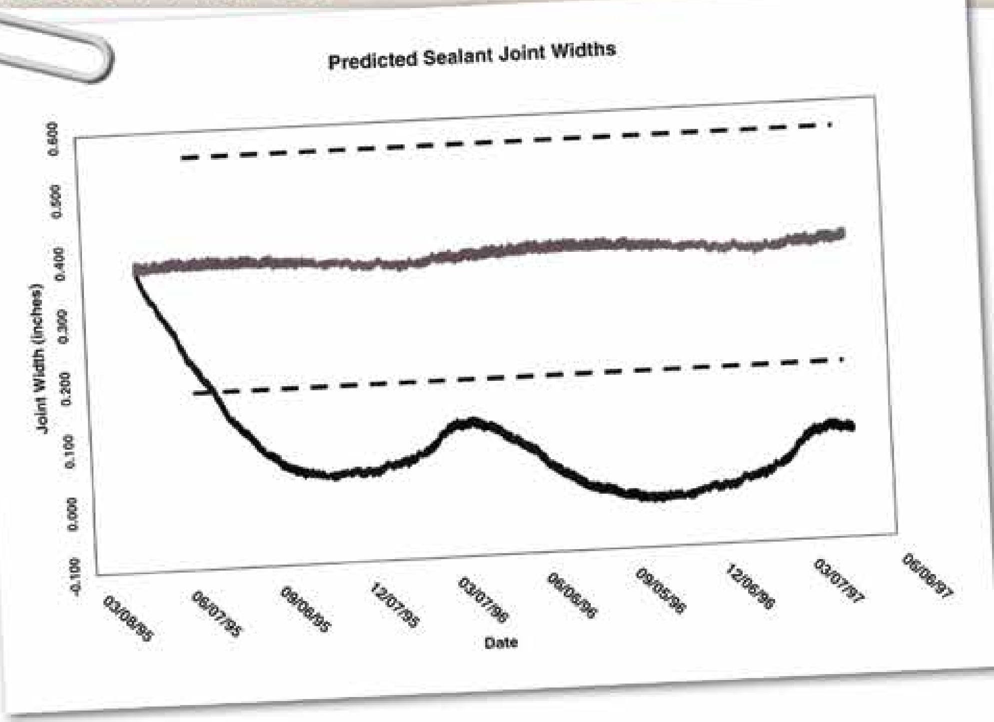


Figure 6 – The expected performance with consideration of only thermal movements as compared to the performance considering both thermal and moisture-related movements. The dashed lines represent ±50% acceptable movement range.

ing from thermal expansion/contraction only are shown by the line that oscillates about ⅜ in. for the entire two-year period. However, the decaying sinusoidal data pattern also includes the effects of moisture-related movements; in this case, it is primarily drying of the plywood layer.

Figure 6 shows how the joints would have been if the layers were free to slide with respect to each other as they expanded and contracted. In reality, the screws that fastened the plywood to the steel deck provided some resistance to the differential expansion. I reduced the moisture expansion coefficient to reflect the reported condition that the sealant joints had reached the lower limit of acceptable width in the spring of 1996. *Figure 7* shows the revised output using the modified expansion coefficient.

Several conclusions are readily apparent from the data:

1. The building movement is cyclical with the seasons. Drying-related shrinkage occurs during the spring, summer, and early fall as heat and moisture flow is directed inward. The impermeable bituthene layer inhibits wetting from the exterior. Conversely, wetting-related expansion occurs in the late fall and winter, during the short period when heat and moisture flows reverse to the exterior.
2. There is year-over-year drying of the structure. The wood sheathing did not take on as much water as it lost in either year. However, the drying appears to be reaching an asymptote. Expansion and contraction cycles after year two appear to be within the allowable movement range of the sealant by then.
3. A thermal expansion/contraction analysis alone is not sufficient to predict the movement in some building envelope assemblies. Assemblies that contain hygroscopic materials may experience movement dominated by wetting and drying.
4. Hygrothermal modeling has historically been used to predict the risk of condensation within assemblies. Such modeling can be a valuable tool to predict thermal and moisture-related movements in building envelopes.

In summary, this case study shows that unanticipated consequences can develop when a seemingly beneficial layer of continuous insulation was added to a building envelope. Our industry has a history of resisting enhancing thermal performance, as it appears to cause other problems. For instance:

1. Painters blamed peeling exterior paint on the use of wall cavity insulation until it was later determined that a vapor retarder was needed.
2. Early efforts at making buildings airtight resulted in sick building syndrome.

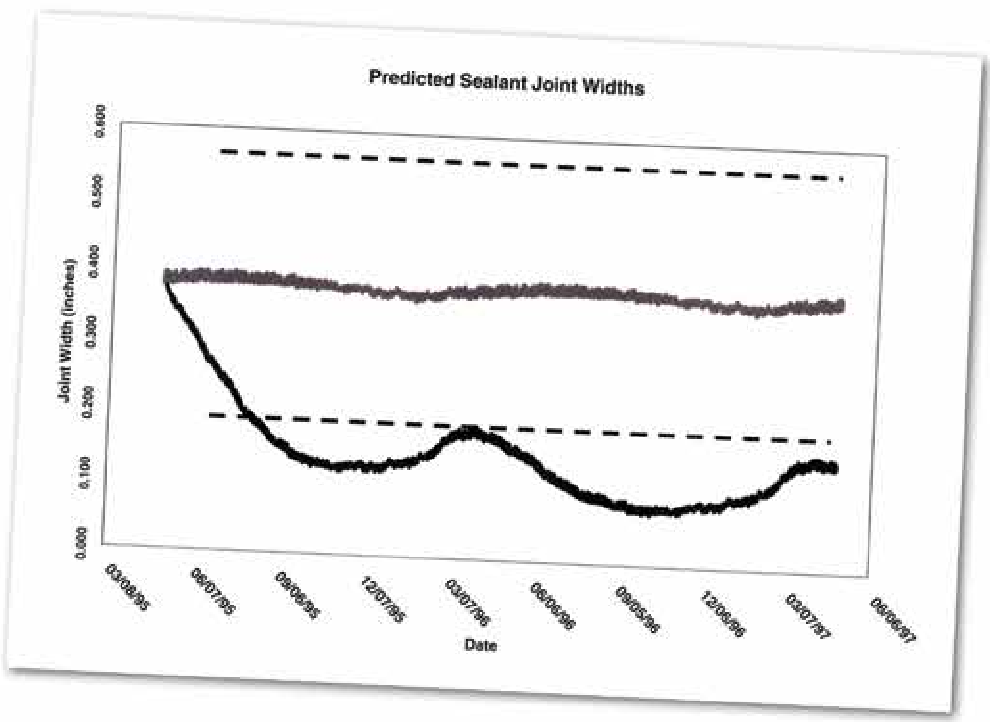


Figure 7 – Sketch showing estimated actual movement considering both thermal and moisture-related movement based on a reduced coefficient of hygroscopic expansion. The reduction of the coefficient accounts for fastening between the wall layers.

We need to provide robust designs when seeking to achieve superior thermal performance. The subject building used 3½ in. of EPS, which is more than most designs will require under the current IECC. However, it's foreseeable that the IECC requirements will become more stringent in the future as we seek even greater levels of efficiency. Designers should consider the potential for excessive differential expansion and contraction in building envelopes that incorporate continuous insulation. Let's not create opportunities to disparage the benefits of high-performance building envelopes.

POSTSCRIPT

The underlying causes of the excessive movements in the building were never corrected. Observations of the exterior indicate that some retrofit fasteners and sealant were installed over the years to maintain the structure. In researching this article, I was informed that the building has reached the end of its lifecycle and is scheduled to be demolished and replaced.

EDITOR'S NOTE: *See information on a new ASTM standard for hygrothermal models to manage moisture in buildings on page 47.*

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