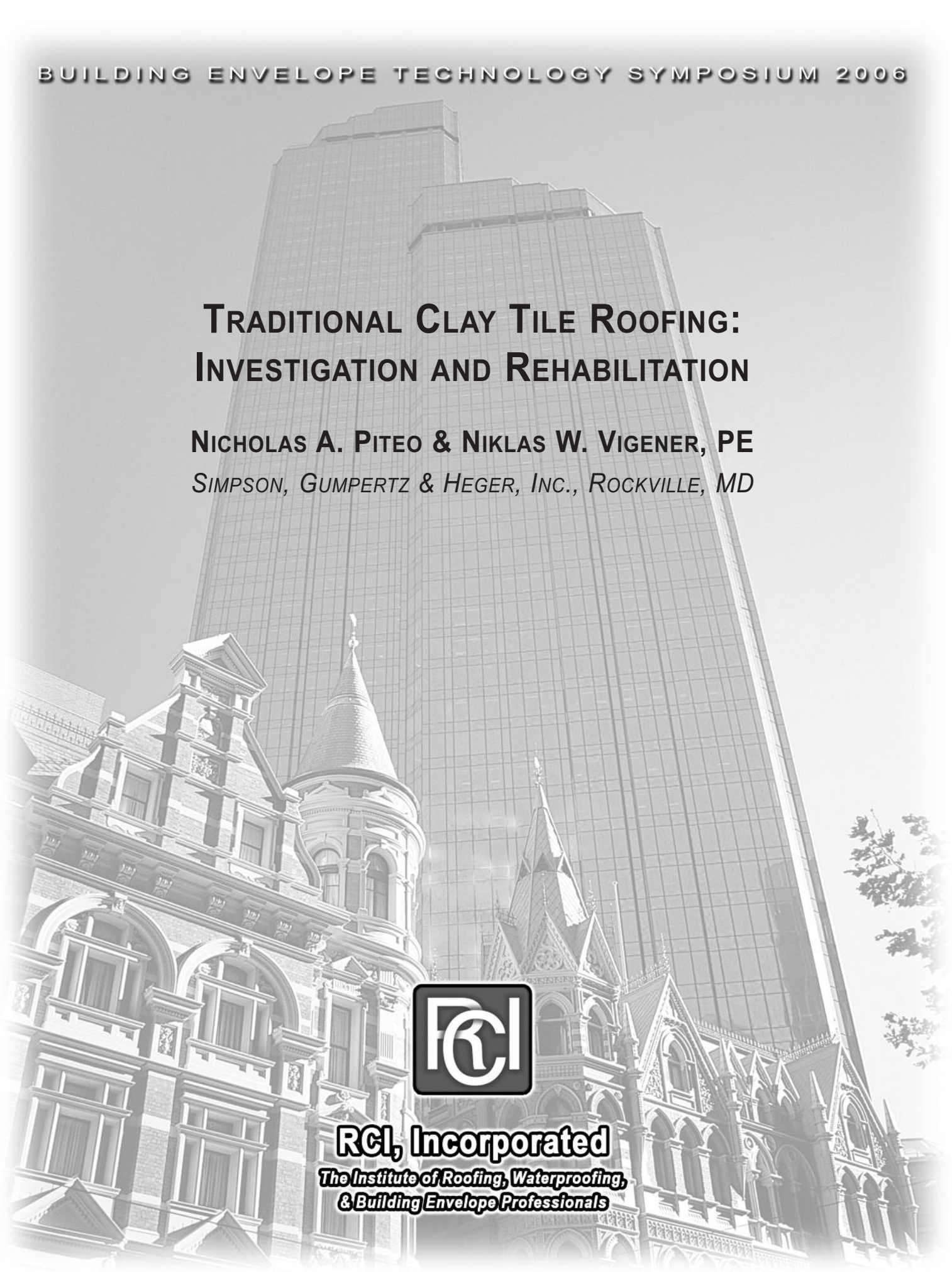
TRADITIONAL CLAY TILE ROOFING: INVESTIGATION AND REHABILITATION

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ABSTRACT

Achieving maximum durability with clay tile roofing requires careful material selection, meticulous detailing, and construction by knowledgeable and diligent craftsmen. This presentation provides practical advice to help designers and builders conceive, design, and construct durable clay tile roofs. Using several case studies and detailing examples from the presenters' experience, the presentation covers aspects of clay tile roofing applicable to both new construction and restoration projects. These include investigation of existing clay tile roofs to determine causes of failure; selection of tile materials, geometries, and finishes; selection and detailing of flashing and underlayment; and review of attachment methods.

SPEAKER

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Nicholas A. Piteo is a senior engineer with Simpson Gumpertz & Heger Inc. (SGH), a national design and consulting engineering firm that designs, investigates, and rehabilitates structures and building enclosures. Mr. Piteo has a breadth of experience in the investigation, repair, design, and rehabilitation of building envelopes, with a specialization in masonry. He has performed numerous façade and roof investigations, including clay tile roofing, for which he also provided new designs. He received his Masters of Architectural Engineering degree from Pennsylvania State University, where he won an award for best structural thesis for his presentation on blast-resistant design of buildings.

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Niklas W. Vigener, PE, received his B.S. in civil engineering from Clarkson University and his M.S. in structural engineering from the University of California at Berkeley. He has been the project manager on many of his firm's most notable building technology and historic preservation projects. Vigener led the historic consultation, investigation, and remedial design of building envelope issues at Yale University's Sterling Memorial Library. He also spearheaded the master plan condition assessment, historic consultation, and design of the building envelope rehabilitation at the New York State Capitol Building. Vigener is a lecturer in the Department of Civil Engineering at Johns Hopkins University.

TRADITIONAL CLAY TILE ROOFING: INVESTIGATION AND REHABILITATION

1. INTRODUCTION

Traditional clay tile roofs combine both modern and time-proven materials with traditional craftsmanship to produce what can be one of the most durable, aesthetically pleasing, and architecturally distinct steep-slope roofing systems. On the downside, designing and constructing clay tile roofs present technical and aesthetic pitfalls that can defeat the most durable materials. For example, an inappropriately selected tile color or finish can unacceptably alter the appearance of a building, and a poorly designed or constructed roofing system can be quickly destroyed by material failure, leakage, or wind uplift.

Achieving maximum durability requires careful material selection, meticulous detailing, and construction by knowledgeable and diligent craftsmen. This paper presents practical advice to help designers and builders conceive, design, and construct durable clay tile roofs. Several aspects of clay tile roofing are covered in a restoration and rehabilitation context, including investigation of existing clay tile roofs to determine causes of failure; selection of tile materials, geometries and finishes; selection and detailing of flashing and membrane underlayment; and review of attachment methods. Advice and recommendations based on the authors' experience are also included to illustrate successful design and building practices for clay tile roofs.

2. INVESTIGATION

Prior to beginning rehabilitation design, a careful investigation of the clay tile roof is required. The purpose of this step is to document the condition and performance of the roof and collect necessary material and dimensional information for the design. Field investigations typically include an interior condition survey to locate roof leaks; followed by water testing to track leakage paths into the building; and sample openings in the roof to document the configuration and condition of its components. We discuss the critical steps for a field investigation below.

2.1 Document Review and Preparation for Field Work

In preparation for the field work, the designer should collect and review existing documentation, such as original construction documents, photographs, maintenance logs, and repair histories pertaining to the roof. Pre-planning for field work is a comprehensive process involving multiple tasks:

- identification and coordination of appropriate access equipment;
- selection of sample opening locations;
- selection of water test locations;
- coordination with a skilled roofing contractor to assist with access and make and repair sample openings;
- review of building plans, photographs, and
- a pre-investigation visit.

Information shown on existing building drawings (such as details, roof slope, tile manufacturer, or prior repairs and modifications) is helpful for preliminary planning, but must be verified during the field investigation.

2.2 Field Investigation

Once the pre-planning work is complete, the first step of the field investigation is an interior building survey, starting with interviews of building occupants to locate roof leaks. The information collected during this survey will serve as a "road map" to help plan water tests and sample openings of exterior roof features.

Exploratory or sample openings are required to document the roof's as-built construction and will make up the bulk of the field investigation. Documentation of sample openings must include necessary information to design and detail roof repairs and should include photographs, notes, and sketches. The designer should make sample openings at all typical roof locations, including roof eaves, rakes, valleys, hips, ridges, roof penetrations, and rising walls, as well as at unique roofing features that will require special detailing. Generally, the larger an exploratory opening is, the more information it reveals and the easier it is to view the detail configuration. In areas that have been subject to water leakage, sample openings will reveal concealed damage, such as deteriorated deck, that must be accounted for during design.

During the investigation, clay tile samples should be removed for identification of tile type and configuration, manufacturer, exterior finish, and color range. Preparation of custom tile finishes and geometries to match existing tiles requires considerable lead times, so starting this process early in the rehabilitation design is prudent. Tile samples can also be tested to determine relevant material properties (see below). This step is necessary to evaluate the tiles' in-service performance and their potential for reuse in repairs or re-roofing.

Although a discussion of the requirements for re-using tiles is beyond the scope of this paper, we note that, as a result of the significant market for finding matching replacement tiles and relative ease of salvage, a large cottage industry has arisen for salvaged re-used clay tile. Advertisements for used tile brokers can be found in restoration magazines and Web sites. We recommend laboratory testing of any salvaged tile, prior to bulk purchase, to assess its anticipated residual durability. If the tile tests well, it may provide an economical approach to finding durable, well-matched replacements to tile that are no longer available.

In some cases, water tests that track existing leakage paths to the interior are required in order to determine the causes of premature roofing failures and pinpoint roof details that have failed and must be reconfigured during the rehabilitation design.

3. COMPONENTS OF CLAY TILE ROOFING SYSTEMS

Multiple individual components make up clay tile roofing systems, including slope, deck, underlayment, flashings, and attachments. Each component can impact the overall performance of the roofing system and it is important to understand the role that each plays.

3.1 Roof Slope

All clay tile roofs must have sufficient slope to shed rainwater off of the roof assembly. Minimum slope requirements vary by manufacturer and tile geometry, but generally range from 3:12 to 5:12. While the 2003 edition of the International Building Code (IBC 2003) requires a minimum slope of 2-1/2:12, we recommend a minimum roof slope of 4:12, consistent with National Roofing Contractors Association (NRCA) tile slope recommendations, to promote drainage and improve the reliability of the assembly in regions that are subject to snow accumulation. At lower slopes, water does not drain as promptly, more water is prone to bypass the outermost surface of the tile and reach the underlayment, and thus, the performance of the roofing assembly becomes more heavily reliant on the performance and reliability of the underlayment, particularly at fastener locations. Consequently, where existing roof slopes are 4:12 or less, providing self-adhered membrane underlayment is especially important to limit the risk of leakage.

Most tiles do not have maximum slope limits. However, tiles installed over very steep slopes – 18:12 or greater – are prone to "chatter" (i.e., they rattle in windy conditions) unless special attachment provisions, such as wind clips and adhesives at the nose of the tiles, are included in the design to restrain movement. Chatter may also occur due to local wind conditions on roofs with smaller slopes.

3.2 Roof Deck

Proper selection of the roof deck is critical to the installation and performance of a clay tile roof assembly. The deck must support construction loads along with code-required dead and live loads, provide a continuous substrate for the membrane underlayment, supply adequate structural capacity for the tile attachment, and meet code-required fire resistance. Fire code considerations are not discussed in this paper. In historic buildings, we commonly encounter lightweight cinder concrete decks, pre-cast lightweight concrete deck planks with or without lightweight cinder topping, continuous wood plank decks, discontinuous wood "skip" sheathing, or discrete metal or wood bars.

3.2.1 Concrete Decks

Poured-in-place lightweight concrete decks and pre-cast concrete deck planks provide both continuous underlayment support and a stable work platform, and may even add some insulation value to the roof assembly. Unfortunately, while lightweight concrete readily accepts nails, it provides little resistance against nail withdrawal, and frequently cannot provide code-specified wind uplift resistance without more complex fastening arrangements such as screws or adhesive anchors.

We have seen other instances where the concrete deck was too hard to accept roofing nails, or fractured during nail driving. Because of these limitations, we prefer to cover existing concrete roof decks with plywood decking to take advantage of the plywood's better nail pull-out resistance.

3.2.2 Wood Decks

In older buildings, wood decks commonly consist of tongue–and-groove decking. For new design, plywood is typically used. Both make for an excellent roof deck.

- Plywood must be rated for structural use as roof sheathing by the Engineered Wood Association, formerly the American Plywood Association (APA), and conform to standard PRP-108. Other panelized wood products, such as oriented strand board (OSB), are much less durable than plywood and are not appropriate for use in heritage buildings. Even though designers intend sheathing to remain dry in service, we recommend kiln-dried, preservative-treated plywood to provide protection against unintended leakage or exposure. Use of preservative-treated wood requires additional fastener considerations; see the attachment section below. The plywood attachment, span, and thickness must be designed to withstand wind uplift and accommodate service loads. Traditional rules for plywood installation still apply, including providing slight gaps between adjacent sheets to accommodate wood expansion and avoid buckling of the sheathing. Plywood also requires special considerations when installed below vapor-impermeable substrates, such as self-adhered membrane underlayment, and should be kiln-dried to avoid trapping moisture within the roof assembly. See also our discussion of self-adhered membrane underlayment below.
- Wood plank decking and/or tongue-and-groove wood decking must accommodate many of the design considerations discussed above for plywood. Historic tongue-and-groove decking ranges from 3/4-inch thick on many residential applications, up to between 2 and 3 inches thick on some mill buildings and other industrial buildings. Tongue-and-groove sheathing tends to have narrow, shallow gaps between individual boards, whereas plank or skip sheathing often has wide gaps (often up to 1 inch wide) between boards. Large gaps and "skip sheathing" are not acceptable substrates for new or rebuilt roof assemblies because the membrane underlayment sags into these voids and causes membrane seams to open, which leaves the membrane vulnerable to leakage. Further, out-of-plane irregularities and sharp edges of boards can cut or stress and prematurely wear membrane underlayments over time. In cases of skip sheathing or plank sheathing with wide gaps, we recommend covering with plywood to provide a smooth, clean, uniform substrate for membrane underlayment. For optimum adhesion of the membrane, prime the plywood and seal gaps between boards to prevent bridging and provide for continuous adhesion. Similarly, clean, prime, and seal gaps in tongue-and-groove sheathing prior to membrane installation for optimum membrane adhesion and performance.

3.2.3 Other Decking Systems

In some historic buildings, clay tiles are wired directly to horizontal metal or wood bars that span continuously between roof trusses or rafters. These traditional systems, which have no continuous substrate sheathing or underlayment membrane, are inherently less reliable in their waterproofing performance than similar systems with continuous underlayment and sheathing. In some cases, depending upon the interlocking geometry and watertightness of the particular tile, they can provide sufficient waterproofing performance over unoccupied and unfinished areas, such as attics, which have some tolerance for water leakage. However, they are vulnerable to wind-driven rain, particularly at flashing transitions. In rehabilitation work, it is advisable to add continuous sheathing and mem-

brane underlayment to improve the reliability of the system; however, the additional weight of the sheathing and underlayment must be considered during the design.

3.3 Underlayment

Clay tile roofs are water-shedding systems. The tiles interlock and/or overlap to intercept and shed most water off of the roof assembly. However, most clay tile installations alone are far from watertight and inevitably allow some water to pass through the tile joints, particularly at roof perimeter conditions, such as hips, valleys, ridges, and eaves, and at roof penetrations. Membrane underlayment is typically needed to collect this water and conduct it to the exterior along the roof eaves and valleys.

When evaluating roof underlayment, durability of the membrane is an important design consideration. Good quality clay tiles have a typical service life of 75 years or longer; ideally, the quality of the membrane underlayment must match this life expectancy. We have seen instances where nondurable or poorly detailed and installed membrane underlayment resulted in leakage and required reconstruction of the entire roof well before the clay tile reached the end of its service life.

3.3.1 Asphalt-saturated Felt

Asphalt-saturated felt is a traditional choice for clay tile roof underlayment and has a long track record of performance. Felt is straightforward to roll out, install in shingle-lap fashion, and attach to the roof deck. For attachment, we prefer button cap nails over staples because staples penetrate the waterproofing membrane in two places and frequently tear the felt at fastener locations, which reduces the reliability of the membrane underlayment.

IBC 2003 requires that underlayment conform with ASTM D226, Type II (No. 30 asphalt-saturated felt), ASTM D2626, or ASTM D249 Type I mineral-surfaced roll roofing. Furthermore, IBC 2003 requires two layers of underlayment for low-slope applications; low slope is defined as between 2-1/2:12 and 4:12. We prefer two layers of ASTM D226, Type II membrane underlayment for increased durability and redundancy against leakage. Asphalt-saturated felts will embrittle with age, particularly if they have been exposed for an extended time prior to clay tile installation, and are prone to tearing, especially at ridge, hips, and other details where the membrane is creased; see *Photo 1*.



Photo 1 – Torn felt membrane underlayment. Asphalt-saturated felt embrittles with age and becomes prone to tearing.

For roof slopes of 3:12 and greater, IBC 2003 also requires an additional layer of 36-in.-wide [ASTM D226] Type I membrane underlayment at valley locations. This additional layer of felt is intended to provide added protection from leakage and membrane erosion. We prefer to provide self-adhered membrane underlayment, regardless of the roof slope, below roof perimeter conditions and areas that conduct large volumes of water, such as valley flashings. Self-adhered membrane underlayment, when properly lapped and installed, provides a more reliable continuous waterproofing layer than loose-laid felt, and also resists erosion of asphalt oils from frequent runoff or standing water that contribute to premature, asphalt-saturated, felt degradation.

3.3.2 Self-Adhered Membrane

Self-adhered membrane underlayments (typically rubberized asphalt on a polyethylene or fiberglass carrier) for roofing applications may include features such as slip- or abrasion-resistant surfaces, reinforcement to resist tearing, or formulations to resist ultraviolet degradation. Due to the wide variety of available self-adhered membranes, we limit our discussion to general principles applicable to most self-adhered membranes.

Self-adhered membranes provide improved weather resistance over felt underlayments, mainly because they provide some self-sealing capabilities at fastener penetrations, have reasonably watertight membrane-to-membrane seams, and fully adhere to the deck (creating isolation of any small leak). Together, these characteristics provide greater protection against leakage in low-slope applications in all climates, and from water ponding behind ice dams in cold climates, than shingle-lapped felt underlayment. In cold climates, self-adhered membrane underlayments should be used, and may be required by code, for ice dam protection. Felt membrane underlayment must overlap the self-adhered membrane underlayment if the latter is used for ice dam protection. A full discussion of ice dams and ice dam protection is beyond the scope of this paper. For maximum waterproofing performance, self-adhered membrane underlayment must be installed without gaps, wrinkles, or fish mouths (small, tunnel-like openings in lap seams at wrinkled membranes).

Most membrane underlayments, and particularly self-adhered membranes with polyethylene carrier sheets and their release paper, are slippery to walk on. Wet membrane underlayment frequently occurs due to rain, dew, or frost. Under slippery conditions, foot traffic should be prohibited and release paper should always be promptly removed from the roof during installation. Many self-adhered membrane manufacturers also make products with textured facers to improve slip resistance. In hot conditions, we have seen instances where the modified asphalt melted and caused the

carrier sheet to slip when stepped on.

Self-adhered membrane must also be protected from exposure to sunlight and must not be used in permanently exposed locations since most membranes will degrade in sunlight. Allowable exposure is generally limited to about 30 days, although limitations vary by manufacturer and membrane type.

Additionally, self-adhered membranes form an effective vapor retarder and may cause condensation unless the roof assembly is properly vented. Although a discussion of vapor retarders in roof assemblies is beyond the scope of this paper, we note that potential applications where a significant proportion of the roof deck is covered with self-adhered membrane should be analyzed during the design phase to assess their condensation potential.

3.3.3 Hybrid Underlayment

Where the potential for condensation does not preclude the installation of self-adhered membrane over the entire deck, we recommend providing a layer of self-adhered membrane installed over the roof deck and covering it with a layer of asphalt-saturated felt. This arrangement provides the advantages of both systems, including tighter seals at fasteners and ice-dam protection provided by the self-adhered membrane. The felt, on the other hand, has a longer allowable exposure time and protects the self-adhered membrane from UV exposure and, to a limited degree, from wear and tear during roofing installation (e.g., protection from dropped nails and tools), can provide a more slip-resistant work surface, and provides waterproofing redundancy.

3.4 Flashings

Flashings provide durable waterproofing in exposed locations and avenues that conduct high volumes of water such as open valley flashings, eave flashings, exposed counterflashings, and roofing transitions. Flashings are typically exposed and must be UV-resistant. Flashings must also be carefully integrated with the underlayment to provide continuous waterproofing while resisting corrosion and premature wear. Flashings are made almost exclusively from metals and must be carefully selected and detailed for durability.

While IBC 2003 allows a minimum flashing thickness of 0.019 inches, we find that more robust flashings are required to match the expected service life of a clay tile roof. Typically, 16- or 20-oz. copper is sufficient for most flashing areas that are not subjected to concentrated water run-off. High-flow areas, such as valleys, require thicker flashings to provide a reasonable service life.

To be durable and reliable over the long-term, metal flashings should be solderable and non-corroding. Aluminum is not solderable, and galvanized steel flashings readily corrode at cut edges, and thus, do not meet these criteria. Copper (including coated coppers such as zinc-tin, alloy-coated copper) or stainless steel are two metals that meet these criteria, and that we recommend and use for flashings.

- Copper is the traditional flashing material of choice for its exceptional workability, durability, and in-service performance record. Unlike aluminum, copper can be soldered to provide watertight and durable flashing connections. "Red" or uncoated copper will turn brown, then greenish blue and eventually green with patina due to oxidation and natural weathering. (Refer to Revere Copper's *Copper and Common Sense*, listed under the references section below, for a more complete discussion of the patination process.) This process varies by region and exposure, and occurs at different rates for different copper surfaces. The green patina can also bleed onto walls or other building components and stain them green. Effective management of copper runoff is essential to prevent such staining. Lead- or zinc-coated copper resists patina formation and staining as long as the coating remains intact. Environmental and health concerns about lead runoff preclude the use of lead-coated copper in most applications. Zinc-coated copper does not have the lengthy performance history of lead-coated copper, but provides a similar appearance, supposedly without environmental concerns.
- Stainless steel is another durable flashing material because of its exceptional corrosion resistance, including resistance to the more corrosive wood preservative treatments used today. Unlike galvanized steel flashings, stainless steel is equally durable at all cut edges, and at scratches. Stainless steel can be soldered watertight, but is tougher to work with than copper, and some consider its shiny appearance aesthetically objectionable. However, it may be aesthetically appropriate and desirable for modern/contemporary buildings.

IBC 2003 and the NRCA *Roofing and Waterproofing Manual* permit other metals, such as aluminum and galvanized steel, but these lack the durability of copper or stainless steel and we consider them inappropriate for use in monumental buildings.

We recommend that flashing design include provisions to facilitate maintenance and eventual roof replacement, such as removable skirt components on through-wall base flashings.

3.5 Attachment

Clay tile attachment is critical to the overall roof performance and must account for wind loads while maintaining a durable and weather-tight roofing system. IBC 2003 offers a methodology to determine the aerodynamic uplift moment acting to raise the nose of the tile and describes limitations for its use, which may be used to determine adequate attachment provisions. Two common methods of clay-tile attachment permitted by IBC 2003 are adhesives and mechanical fasteners. In some traditional applications, clay tiles were simply hung from horizontal battens; in other installations, tile were fastened or wired to battens.

3.5.1 Battens

Some clay tiles, such as pan and cover tiles, require wood battens (i.e., strips of wood set on or over the structural deck used to elevate and/or attach the tile roof covering) to attach the cover tiles. Wood battens are typically outboard of the roof underlayment, i.e., they are expected to endure some moisture exposure and must be preservative-treated to resist deterioration in service. Today's commonly available wood preservatives are more corrosive than their predecessors and require special fastener considerations; see the attachment discussion below. Toe-nailing to the deck is the traditional way to secure battens, but we have found that metal angle brackets provide for more reliable attachment because they avoid splitting the wood batten, a common problem where toe nails are installed with little edge distance.

3.5.2 Adhesive Attachment

We have seen mortar, aphaltic mastics,

and spray foam used as clay tile adhesives. One drawback of all adhesives is that they inhibit drainage by reducing or eliminating the "drainage plane" free space between the underside of the tile and the underlayment. Spray foams can provide tenacious adhesion to many substrates; many are "Dade County Approved" for use in Florida's high wind hurricane zones. Some foam manufacturers have training programs that address typical challenges of spray-foam adhesive, including a "blind" installation procedure that does not allow a visual review of the adhesive after tile installation, code limitations on the permitted adhesive contact area, unpredictable expansion patterns, and proper clean up of overspray. Spray foams have a limited performance history and are not yet proven to match the expected service life of clay tile roofs. Additionally, most spray foams cannot be installed in cold temperatures, which limits their use to a short construction season in cold climates, and they have a limited track record in freeze/thaw exposure. They do not adhere to some underlayments, especially membranes with a polyethylene carrier sheet.

Because of their limited track record and the aforementioned difficulties, we recommend using mechanical fasteners to provide adequate tile restraint, and using spray foam only as a supplemental measure to reduce "chatter" of the tiles in strong winds.

On the other hand, mortars and mastics are traditional materials. Their traditional use was typically not as a primary means of attachment, but rather as a "hole filler" for edge tiles at rakes and valleys; to provide a closed, finished appearance; and to reduce nesting of insects beneath open tile edges. Mortars tend to have very limited adhesion to clay tiles. Mortar should not be used as primary clay tile attachment, but can be used as a supplement to mechanical fasteners to reduce chatter and reduce nesting of nuisance insects (e.g. hornets, wasps) in edge voids. If left exposed or subject to water run-off, mortar may also produce unsightly white efflorescence staining. Mortar is also susceptible to freeze/thaw damage under these conditions and must be evaluated for durability when exposed to such conditions in service.

3.5.3 Mechanical Attachment

Mechanical fasteners, such as nails, screws, wire ties, and nose clips, have a long performance history with clay tile roofing and they remain the most reliable attachment method. Mechanical fasteners must be installed to achieve sufficient deck penetration, but should not strain the tile, which can cause breakage. Clay tiles should "hang" from the fasteners to allow some movement.

Two fastener materials meet the corrosion resistance and durability required with clay tile roofs: copper and stainless steel. Galvanized fasteners typically do not provide similarly reliable corrosion resistance over the anticipated life of the tile (e.g., 75 years), especially when in contact with commonly available, corrosive wood preservative treatments. A full discussion of corrosive wood preservative treatments is beyond the scope of this paper.

Traditionally, clay tiles are held in place with one or two fasteners at the head or along the edge of rake tiles. IBC 2003 has numerous prescriptive fastener requirements, including minimum of 11-gauge fasteners, 5/16-inch diameter head, and sufficient length to penetrate the deck a minimum of 3/4-inch or through the thickness of the deck. IBC 2003 also provides a table to describe the minimum fastener requirements to simplify design efforts at some basic wind speeds and roof heights.

3.5.3.1 Nails and Screws

Nails are generally the most straightforward type of fastener to install. We recommend the use of ring-shank or spiral-shank nails, as they provide additional withdrawal ("pull-out") resistance, at minimal increase in material cost. Copper nails have long been a traditional fastener choice due to their corrosion resistance and ease of installation. Copper nails are also easy to cut to accommodate later tile removal and replacement. Unfortunately, thin copper nails may bend during installation into hard substrates, such as concrete and plywood decks. Stainless steel nails are a stiffer and more corrosion-resistant alternative to copper and they rarely bend. However, stainless steel fasteners are tough to remove to allow later piecemeal tile replacement; they usually must be cut off with a hacksaw. Screw fasteners typically provide better pull-out resistance than nails, but take longer to install and make later repair or replacement much more difficult and time consuming.

3.5.3.2 Wire Ties

Eave tiles and tiles adjacent to valley flashings are frequently wired into place, i.e., corrosion-resistant wire is fastened to the deck beyond the flashing and the tiles are hung into position (*Photo 2*). This configuration avoids fastening through flashings, which compromises their water tightness.

3.5.3.3 Nose Clips

Supplemental clips to hold down the front edge of the tile, commonly called nose clips, are particularly important in high wind regions because they provide two points of tile attachment, one at the head and one at the nose, to resist uplift force. IBC 2003 requires nose clips at eave tiles under some circumstances. While not required by IBC 2003, we recommend the use of nose clips in the field of the roof to



Photo 2 – Fastening eave and valley tiles (not shown) with wire ties can avoid penetrations through metal flashings, which would result in less reliable waterproofing performance.

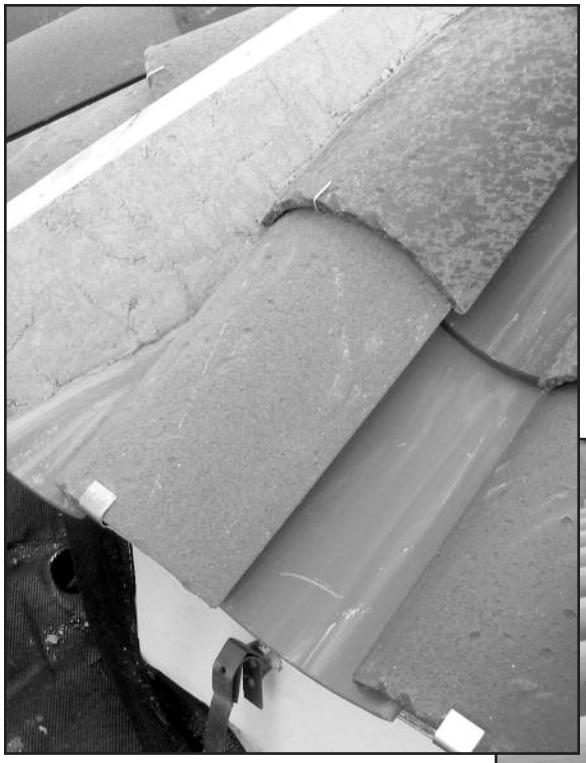


Photo 3 – Nose clips are used to resist uplift forces on tiles. The photo shows both a wire nose clip in the field of the roof (top) and a custom-manufactured nose clip along the roof eave (bottom). Custom-manufactured nose clips may be required to provide adequate stiffness and length to fasten above, rather than through, metal flashing along roof eaves.

Photo 4 – Delamination in clay tile as a result of freeze-thaw damage. Testing of clay tiles prior to selection and installation can help avoid such damage.



provide greater resistance to tile uplift in high-wind regions. Numerous proprietary nose clip products are available. Designers must select nose clips with adequate stiffness to hold the tile nose in place; long, thin wires or sheet-metal clips are often too flexible for this purpose.

Nose clips along eaves frequently present additional problems because adequate clip stiffness and the desire to fasten the clip away from the eave flashing generally oppose each other. In these cases, we have successfully used custom-manufactured, heavy-gauge stainless steel or copper nose straps to provide tile restraint along eaves (*Photo 3*).

3.6 Clay Tiles

Durability is the most important quality for clay tile selection. The tiles must be appropriate for their intended geographical location and use. Proven performance in similar climates and applications is one way to gauge tile quality and designers should visit such installations if possible. In addition to a review of in-service performance, ASTM C 1167, the Standard Specification for Clay Tile Roofs, includes tests to help gauge the expected durability of tiles. We discuss some of these tests below (*Photo 4*).

3.6.1 Testing

ASTM C 1167 classifies clay tiles into grades for durability, based on their resistance to frost action. Tile grades range from Grade 1, representing significant resistance to severe frost action; to Grade 3, with only negligible resistance to any frost action. A map in ASTM C 1167 recommends tile grade by region. At a minimum, designers should adhere to the grade recommendations of ASTM C1167. We recommend only specifying and using Grade 1 tile in northern climates, and whenever possible, we prefer to use Grade 1 tiles for increased durability in less severe climates.

The "gateway" grade requirements of ASTM C1167 are based on the tile's cold-water absorption and saturation coefficient, which compares cold-water absorption to boiling-water absorption and is used to gauge the freeze/thaw resistance of the tiles. Gateway requirements for the performance grades were established to limit the need for freeze/thaw tests, which may take ten weeks or longer to complete, and are often too long to allow testing of the actual batch of tiles intended for the project, while still meeting construction schedules. We have found that these gateway absorption and saturation coefficient requirements provide a good indicator of long-term clay tile durability under freeze/thaw weathering and general exposure. We have conducted laboratory tests on existing clay tile that have failed, and existing clay tile that have performed well for over 100 years, and found the absorption results to correlate well with tile durability.

While not required by ASTM C 1167, freeze/thaw testing according to ASTM C 67, Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile, as modified per ASTM C 1167, subjects tiles to freeze/thaw cycles similar to those expected in service in northern climates. Freeze/thaw testing is allowed by the standard as a means to "prove" tile resistance to severe weathering conditions, if they fail to meet the specified gateway absorption grade requirements described above. However, the

50 freeze/thaw cycles may represent only 1-2 years of actual exposure in many northern climates in the U.S.; thus, the passing of this test is not "proof" of long-term durability.

Transverse breaking strength of tiles (i.e., bending strength) offers the best indicator of resistance of the tile to breaking due to impact (e.g., tree branches or ice falling onto the tile), and point loading (e.g., foot loads from workers walking on the roof). The importance of breaking strength data in selecting and specifying tile for a roof should be assessed by the designer on a case-by-case basis. On roofs with overhanging trees, large roofs above that shed ice to lower roofs, and rooftop elements (e.g., painted dormers, chimneys, etc.) that require frequent maintenance, the roof will be subjected to more frequent and severe field conditions that promote breakage than roofs not having any of these characteristics.

While breaking strength is not a direct indicator of durability due to freeze/thaw weathering, on some tests of existing clay tile we have noted an indirect correlation between the two. Tile that are dense and well-fired (highly vitrified) tend to test better in terms of both their breaking strength (creating greater resistance to breakage), and their absorption (creating greater resistance to freeze/thaw deterioration).

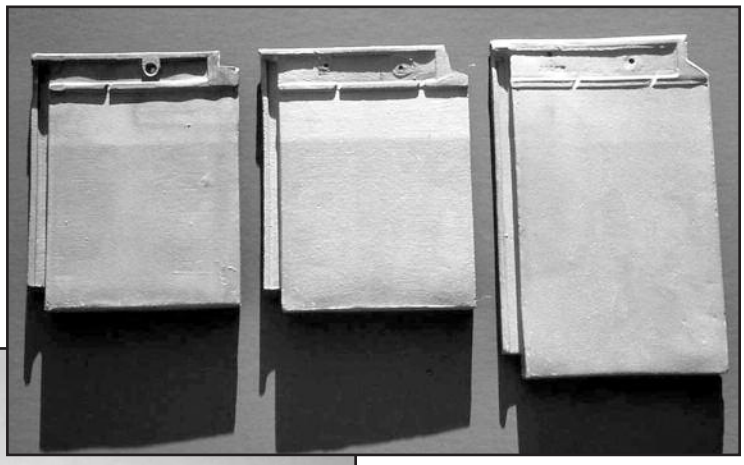
3.6.2 Tile Profile

The shape and surface profile of an individual tile also affect its durability and waterproofing performance. Many different stock tile shapes are commonly available, some of which are shown in *Photo 5*. Consult tile manufacturers' literature for descriptions and illustrations of available shapes.

Traditionally, many tiles included intricate features to channel water out of the roof assembly and limit fastener exposure to the weather. Such features include ridges to shield fastener holes and drainage channels with weep slots to collect water and direct it downward. Many modern tile shapes either lack these traditional tile surface features altogether, or have muted versions that are less effective at protecting tiles and fasteners than their traditional counterparts. *Photo 6* shows several generations of clay tiles that illustrate the devolution of these surface features.

3.6.3 Reproduction Tiles

Reproduction of traditional tiles to match specific existing tiles for restoration projects frequently presents significant challenges. Traditionally, clay tile manufacturers often used labor-intensive fabrication methods to produce intricate and irregular tile shapes and finishes. While these techniques can still be replicated, high initial set-up costs and labor costs make large-scale production of custom tiles too costly for most jobs. Today, custom, hand-formed tiles are considerably more expensive and take much longer to procure than mass-produced production line tiles, which may be stockpiled for rapid distribution. For commonly available field tiles, some manu-



Above: Photo 6 – The devolution of tile surface features: Three generations of tile from the same manufacturer show loss of surface articulation from a circa 1951 roof tile (left) to its later (center) and contemporary (right) counterparts. On the earliest tile (left), note raised hub at fastener hole to protect fastener holes from leakage and deeper drainage channel (indicated by longer shadow from back leg of top channel). These features are muted or eliminated on later tiles to right.

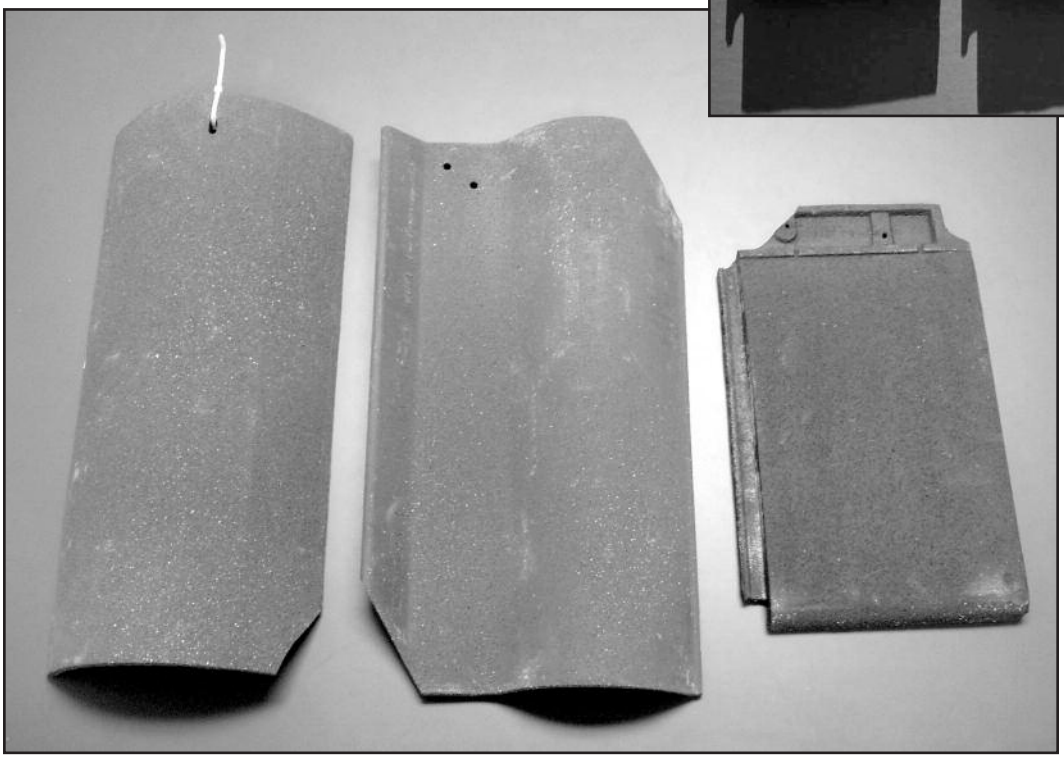


Photo 5 – Some common tile shapes include Pan and Cover or Straight Barrel Mission Tile (left), Spanish or "S" Tile (center) and Flat Interlocking Tile (right). Mission tile are also available with a tapered profile. Numerous other tile shapes are available; contact tile manufacturers for information on available shapes.



Photo 7 – Accessory tiles, such as the rounded hip closure tile shown above (or tiles for ridges, rakes, and starter courses), are often available from manufacturers for various tile shapes and styles. In some cases, these require special order and have considerably longer lead times than typical field tile shapes. Identify and order accessory or custom tile shapes early to avoid delays during construction.

facturers offer "accessory" pieces, specially shaped for common non-field conditions such as hips, ridges, rake closures, etc. The rounded hip closure tile in *Photo 7* is one example of an accessory tile shape. Where custom-shaped tiles are required, plan ahead and allow considerable lead time and additional cost compared to standard tiles to allow for their production and delivery.

Tiles are often available in many color options and with numerous finishes. Some variations in the finish texture are even available, such as the depth and degree of scored surface textures. Unfortunately, these modern variations do not approach the almost limitless variations available to craftsmen of hand-formed and pressed tiles of the past. As a result, matching traditional tile finishes, while keeping to reasonable production costs and schedules, is often difficult. Existing clay tiles may include formed edges, tile color variations due to antiquated firing techniques, or surface finishes that are no longer commonly used.

Manufacturers are often willing to vary surface textures within the limits of their production equipment, blend different tile colors, or use special firing techniques that introduce trace gasses or mists to produce variation in finishes in an attempt to mimic existing tile roofs. Some other features of existing tiles, such as "battered" edges and custom surface finishes, are more difficult to procure in a cost-effective manner. Generally, appearance options are limited by budget, schedule, and the willingness and capability of the manufacturer to modify its production equipment and process to replicate traditional tile features with reproduction tiles.

4. OTHER CONSIDERATIONS

4.1 Hazardous Materials

Older clay tile roof installations frequently include roofing cements or mastics containing asbestos fibers. Susceptible locations include hips, ridges, and eaves where roofers relied on roofing cement to adhere tiles or to provide a "finished" appearance to the roofing. Similarly, some roofing felts may include asbestos. A discussion of hazardous materials is beyond the scope of this paper. The roof designer should consult a qualified industrial hygienist and the building official for the jurisdiction to specify appropriate precautions and abatement procedures.

4.2 Insect Infestation

Clay tile roofs, which typically include large dry and concealed spaces, are notorious as ideal habitats for many insect species, including yellow jackets and hornets. If the re-roofing project is undertaken in the spring and summer, when wasps are most active, large swarms of wasps can injure workers. If necessary, clay tile roof restoration projects should include procedures for handling wasp infestations. One proactive wasp-management strategy entails baiting for wasps in the early spring to limit the number of "foundress queens," wasps that go on to establish nests and large colonies. Another strategy is to seek out the "clusters" of displaced wasps after roof removal during periods of inactivity between evening and morning to spray and eliminate them. Workers should be prepared to encounter wasps throughout the work and must make appropriate preparations for personal protection.

USEFUL REFERENCES

The following references are useful when designing and installing clay tile roofs:

- **Copper and Common Sense**, published by Revere Copper Products, Inc. This reference provides descriptions and illustrations for many metal flashing conditions, including eave flashings, expansion joints, valley flashings, and gutters.
- **The Clay Tile Installation Manual**, published by Ludowici Roof Tile. This reference provides descriptions and illustrations of clay tile installations for many common tile types and includes recommendations related to decking, underlayments, and fastening.
- **The NRCA Roofing and Waterproofing Manual**, published by the National Roofing Contractors Association. This reference provides descriptions of tile roofing components, including clay tiles, with installation recommendations and illustrative figures.
- **Concrete and Clay Tile Installation Manual for Moderate Climate Regions** and **Concrete and Clay Tile Design Criteria for Cold and Snow Regions**, both published by the Tile Roofing Institute (www.tileroofing.org).