

**TILE ROOF SYSTEMS;
ANALYSIS AND INSPECTION TECHNIQUES FOR ROOF CONSULTANTS**

By

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Known throughout the world as one of the most enduring and classic roof systems, tile has a global popularity and history that is unlike any other roofing material.

While some basic elements of tile roofing have been a part of the world's architectural legacy for thousands of years, our more recent past has seen significant growth and change within the industry.



Flat clay tile on a dome at the Pantheon, Rome, Italy.
Photo courtesy of the author.

In the United States, areas of regional popularity were established by colonial settlers and tile still predominates today. However the national use of tile roofing has been traditionally less than that of the global roofing market. For example, tile products comprise 86% of the European residential roofing market compared to 6% of the U.S. market. In the comparatively young American roof tile industry, the popularity of the material within the past two hundred years has fluctuated. The changing popularity of specific architectural styles, the development of the slate roofing industry along the east coast and competition from new roofing products that are lighter and less expensive, all have adversely affected the popularity of tile at times.

However, the U.S. tile market is again changing as the use of tile increases with its versatility. Technological improvements have combined with tile roofing's classic

aesthetics to create more versatile products with some of the longest service lives in the industry. For example, new underlayments and cold roof construction technology now make tile suitable for use in cold climates with heavy snowfall. Tile's excellent seismic performance characteristics make it useable in earthquake prone regions. Although large urban conflagrations are not the threat they were during the eighteenth and nineteenth centuries, tile's lack of combustibility makes it an ideal material in areas susceptible to wildfires. A tile roof system's excellent wind uplift resistance combined with modern attachment methods make it suitable for use in regions with frequent hurricane potential.

The increased versatility of the product and technological progress has created greater market growth potential than ever before in the U.S. roof tile market. The result of this growth is the creation of new materials, testing procedures, codes and standards. For Roof Consultants and other industry professionals, now more than ever it has become essential to obtain the specialized education and training to keep current with the changes in tile roofing.

But to understand where we are now in the industry, it is necessary to know the basic history and evolution of tile roofing.

A BRIEF HISTORY OF TILE ROOFING

The origin of clay roofing tile is linked to the development of pottery within two of the world's greatest early civilizations. First in China during the Neolithic age (the last phase of the Stone Age) at about 10,000 BC and then in the Middle East by 6,000 BC. During these periods, humans began to move from life in small groups to large tribal clan communities. For the buildings within these larger, more densely populated communities, tile roofing played a vital dual role that remains valid today. First it was an effective means to shed water from buildings and secondly it reduced the spread of fire.

From China and the Middle East the use of clay tile spread throughout Asia and Europe. Although tile roofs were used by the Assyrians, Egyptians and Babylonians, it was the Greek and Roman civilizations that elevated roofing tiles (known as Tegula) from crude, hand made objects in clay, to an art form.



Flat clay tile in the Piazza del Popolo, Rome, Italy.

Photo courtesy of the author.

We tend to think of some attributes of tile roofing, such as the ability to re-lay or re-use the material from one roof to another or the manufacture of tile in materials other

than clay as relatively modern developments. In reality, the Greek Byzes of Naxos first introduced tile made of Pentelic marble in 620 BC for use on the great temples such as the temple of Jupiter at Olympia and the Parthenon at Athens. Even more spectacular tile was created from solid bronze and gilt for the construction of the Pantheon in Rome. These tiles survived until the seventeenth century before being melted down by Pope Urban VIII to make cannon. Not the first, but certainly one of the most poorly engineered reuses of tile, as the quality of the precious metals content turned out to be too high (soft) for cannon. The first documented (and semi-legitimate) reuse of tile occurred in 231 when the Roman censor Fulvius Flaccus removed some marble roof tile from the Greek temple of the Lacinian Juno for use on another temple he was building in Rome. Hence, not all of our “modern” techniques are new. The Romans used tile roofing throughout their empire. In Europe, the popularity of clay tile grew due to an abundance of clay deposits providing the raw materials and again offering a level of protection against the spread of fire.

Later, as European settlers came to America, they brought their historic roofing trades with them. Clay tile have been found in the ruins of the 1585 settlement of Sir Walter Raleigh on Roanoke Island, North Carolina. This was England’s first settlement to the new world. The Spanish used tile in their early settlements at St. Augustine Florida and New Orleans. At first Dutch settlers on the East Coast imported clay tiles from Holland. By 1650 however, they had established a production facility in the upper Hudson River valley, shipping tile down the Hudson to “New Amsterdam”. By the beginning of the Revolutionary War, there were several tile manufacturers in the New York City area offering colored, glazed and terra-cotta tile. On the West Coast tile was being produced by 1780 at Mission San Antonio de Padua in California by Spanish Missionaries. In Colonial America tile were popular for the same reasons that were relevant during the Neolithic period. The materials were readily available and they were fire proof. The latter helped address a near hysteria about fire in Colonial American cities. After devastating fires in London in 1666 and Boston in 1679, the first building and fire codes were established in New York and Boston. These codes encouraged the use of tile roofs and remained in effect for almost two hundred years. By the 1830s however, clay tile was temporarily out of fashion. Competition with slate along the East Coast and new metal products that looked like tile became significant.



Process of replacing original Ludowici Celadon clay Spanish tile (initially installed at the turn of the 20th century) with new tile by the same manufacturer on a historic hotel in upstate New York (the original tile came from Celadon’s plant in Alfred, NY).

Photo courtesy of the author.

But the mid 19th century brought the popular new architectural style of "Italianate Villa" and with it new popularity for clay tile. New production facilities sprang up. Gladding, McBean and Co. in California in 1875, the Celadon Roofing Tile Co. in Alfred, New York in 1888 and Heinz Co. in 1911 to name a few of the larger, enduring producers.

The Industrial age brought a flurry of new patents and industry changes. In 1870 the first tile making machines were patented along with the first of the interlocking tiles by J.G. Hughes in 1871 and refinements were being made in production of metal "tile". But by far the most significant development in the tile industry since the Greeks and Romans, occurred in 1848 when a German farmer named Adolph Kroher introduced concrete tile. Commercial production began in Bavaria shortly after. Concrete tile were introduced to England, Holland and other European countries by the early 1900s. Automated production began, along with the practice of adding coloring pigments to imitate clay tile. By the late 1920's concrete tile was a permanent part of the American tile industry competing as a product that was lighter and less expensive than clay.

Today, both concrete and clay constitute the roof tile market. Our current technologies, new products, codes, and standards continue to be developed with both products in mind.

These relatively recent developments within the industry have created a changing and increasingly complex environment, creating new challenges for the consultants and others who will be evaluating tile roof systems.

THE ROLE OF THE ROOF CONSULTANT

Roof consultants may become involved with tile systems in a number of ways. A client may request an inspection to locate current leakage or to evaluate remaining service life of a tile system. Owners of larger tile roofs may require maintenance planning or project management. Problems that occur in tile systems prior to the end of their service life may be the result of installation errors or extreme environmental occurrences. In many cases involving construction defects, the consultant may testify as an expert witness in arbitration or litigation.

In all of these scenarios, the consultant must fulfill two primary responsibilities. First, he or she must understand the system and product involved. Secondly, all of the facts must be gathered correctly and objectively. In conducting any tile roof inspection, there are four essential questions that, when answered will provide the basis for our observations and opinions;

- 1.) What is the problem and how did it happen? (i.e. installation errors, material defects, design flaws, lack of maintenance, etc.)
- 2.) When were the tiles installed? (age of the building is a good but not an absolute indicator)
- 3.) How was the roof installed? (which method(s) and materials were utilized?)
- 4.) What are the applicable codes and manufacture's installation instructions?

In finding the answers to these basic questions, other relevant information is often

discovered that creates a complete assessment. The result should be a thorough, accurate, well-documented opinion or report.

Next we'll discuss some tile basics for background information as well as identifying sources for specific and detailed information.

TILE TYPES AND SYSTEMS

Knowing the type, the manufacturer and the age of the tile are among the most critical pieces of information you can obtain from your inspection. Determining the type and manufacturer can be as simple as reading the inscription on the underside of the tile or it can be as frustrating as trying to identify a small regional manufacturer that went out of business seventy-five years ago.

Predominantly there are two types of roofing tiles, overlapping and interlocking. Interlocking tiles are designed to be installed in pairs with an extrusion on one tile that is designed to "lock" over the other tile securing both. Overlapping tiles don't have a locking side and are generally nailed in place. There are a number of tiles shapes and profiles, but most fall into two categories, pantiles and flat tiles. Pantiles consist of two half cylinders, where one is attached to the roof deck or battens and the second is inverted and overlaps the upturned edge of the first. These comprise the most common profiles associated with tile roofing i.e.; Spanish, mission or barrel tile. Flat tile can be either completely flat (no extrusion or lock) or they can be interlocking on the top and one side.



Clay overlapping (flat shingle) tile exhibiting signs of water absorption.
Photo courtesy of the author.

These standard shapes may be known by different names in a different part of the country or the world.

Over the past one hundred years, roof tile have been made from a variety of materials, including clay, concrete, sheet metal, fiber cement and composites. Of these, clay and concrete are the most popular and predominately used materials.

All this information about tile types, shapes, materials and manufacturers can be confusing. Remember that there are few individuals who can correctly identify all tile manufacturers at a glance. The important concept here is to use all these individual tile characteristics in our forensic investigation to correctly identify tile type, condition and

manufacturer. While the significance of type and condition are obvious, why is identifying the manufacturer important? Almost every manufacturer has historically published installation instructions for their product. In cases of problematic tile systems where installation errors are suspected, these guides provide documentation of recommended or published procedures. In addition, tile manufacturers can help determine the approximate age of a particular tile, based on their production records. Manufacturers also provide a key piece of information for maintenance planning when they publish the service life for their products. Knowing the service life of the tile is critical for maintenance cost projections and determining repair or replace options.

When identifying tile and tile manufacturers, look at the obvious first. Is this a tile that is familiar to you? Are there other tile roofs in the area that look the same and may be well documented? In the case of newer concrete and clay tile, construction records may be available. If not, consider your geographic location. Tiles are heavy and expensive to ship, consider the manufacturers and distributors closest to the building. Most tile manufacturers will evaluate a sample tile or identify with close up photos. In the case of older or historic tile, one of the best references available is the book “Historic and Obsolete Roofing Tile” by Vincent Hobson and Melvin Mann. The book contains histories of all the early major tile manufacturers in the U.S. as well as hundreds of scaled, color photographs of individual tile.

By determining tile type, condition and manufacturer, we should have sufficient information to answer three of the essential inspection questions. The remaining question is “what are the applicable codes and manufacturers installation instructions?”

INDUSTRY STANDARDS AND INSTALLATION METHODS

Industry standards and installation guidelines are the tools consultants use to evaluate the integrity, quality and code compliance of a tile roof installation. The purpose of these guidelines is to provide a level of quality and standardization for the manufacture, testing and installation of tile. They are also critical elements in construction litigation, often validating the consultant’s position and observations. Roofing tile has more than its share of acronyms for the myriad codes, standards and organizations representing the industry. While addressing all of the standards organizations that include tile roofing would be overwhelming, a chronology of some of the more relevant organizations is as follows.

The ASTM International (American Society for Testing and Materials) is one of the oldest and largest voluntary standard development organizations in the world. Founded in 1898, ASTM over the years developed ASTM C1167 standards for clay tile roofing and ASTM C1492 for concrete tile. The written standards for both include standard specification for materials and manufacture, tests for wind uplift and standards for terminology. In addition a grading system is established for “resistance to frost”.

The ICC (International Code Council) was established in 1994 as a non-profit organization that develops comprehensive national model construction codes. It was founded by BOCA (Building Officials and Code Administrators International), the ICBO (International Conference of Building Officials) and SBCCI (Southern Building Code Congress International). These three organizations had been operating independently since the early part of the last century, developing regional codes. The formation of the ICC combined their expertise into one source. The consultant and other industry

professionals benefit by working with one set of codes (ICC) as opposed to three different sets of standards prior to 1994. One of the most relevant ICC services is their evaluation report (ICC-ES). The ES reports objectively evaluate code compliant materials and installation methods and are available on the ICC web site.

In 1987 the Roof Tile Committee of the Florida Roofing, Sheet Metal and Air Conditioning Contractors Association (FRSA) and the National Tile Roofing Manufacturers Association (NTRMA) co-wrote consensus standards for the installation of concrete and clay roof tiles. This effort over the course of ten years, produced the “Concrete and Clay Roof Tile Installation Manual”, one of the most comprehensive sets of tile standards. Prior to 2001, individual manufacturers wrote their own installation standards. At that time there were fifty-eight separate standards. The NTRMA manuals consolidate them into one source. The NTRMA also produced the manuals “Concrete and Clay Tile Roof Design Criteria Manual for Cold and Snow Regions” in conjunction with the Western States Roofing Contractors Association (WSRCA) and also the “Moderate Climate Installation Guide”. In addition NTRMA teamed up with the University of Southern California to conduct studies and tests of the seismic performance of concrete and clay roofing tile. In the only study of its kind, earthquake conditions were reproduced on four of the most commonly used tile systems. The results revealed that when installed in accordance with current code, these systems can not only meet UBC (Uniform Building Code) standards for seismic load requirements of tile, but they are capable of withstanding a quake almost double the intensity of the 1994 Northridge quake, which measure 6.7 on the Richter Scale. The NTRMA has recently changed its name to the Roof Tile Institute (RTI) and it continues to be one of the best sources for tile information and technical support. No discussion of tile standards would be complete without mentioning the SBC (Standard Building Code) and the FBC (Florida Building Code). The SBC has been the fundamental basis for tile installation for quite some time, and because of the hurricane exposure the FBC has some of the most stringent “wind uplift” requirements in the nation.

The number and quality of standards and code organizations provide an excellent benchmark for materials, manufacture and installation and are valuable technical and documentation resources for the consultant.

THE INSPECTION PROCESS

Tile roof systems are unique and as a result, the inspection process presents challenges and characteristics unlike any other roof system. All roofing tile are not created equally nor do they fail equally. One of the most critical challenges before the tile expert is the accurate determination of the reasons behind tile system’s failure. In other words, “what is the problem and how did it happen?”

As with most forensic roof investigations, the inspection begins by accessing the roof in order to evaluate its components. Again we need to answer the questions, what type of tile is it? What point has the system reached within its’ service life? Are there problems and if so are they normally occurring, the result of environmental factors or pre-mature failure. One of the more common misunderstandings about tiles is how various systems age. For the most part, this is a direct result of the hardness of the tile. Both concrete and clay tile are porous in varying degrees. It is porosity and the resulting water absorption that weakens the tile over time. Water saturation in concrete tile

increases over the life of the tile, accelerated by erosion of the cement and exposure of the mix aggregate. Toward the end of the concrete tile's service life, efflorescence can form on the underside of the tile prior to complete saturation. After saturation, water then drips off of the underside of the tile. In the latter portion of this process, most concrete tiles are too soft to walk on. Clay tile exhibit different characteristics toward the end of their service life. Clay tile also absorb water, however their porosity is a function of the density of the clay used in their manufacture and the vitrification process. Vitrification is the process that turns clay to glass by applying heat (firing). Clay tile that are not thoroughly vitrified are softer and consequently possess a shorter service life. Freeze/thaw cycles in colder climates cause spalling when moisture expands as it freezes. Spalling and flaking are the result of normal water absorption and wear process. Flaking begins on the surface of the tile and continues throughout the life of the tile until the flaking wears completely through. The presence of these elements are sometimes incorrectly diagnosed as tile failure. During examination of a representative number of tiles, the flaking should be dislodged. If algae or lichen are present under the flaking, the process is a slow, natural one. If bright, clean clay is exposed, the process is accelerated and newer. This could be the result of environmental factors i.e.; hail damage, excessive hot and cold temperature variation, or it could indicate premature tile failure.

Another common "normal" failure peculiar to clay tile is cracking in older tiles. Occasionally the clay may not have been properly worked prior to firing. During firing, the clay would then shrink, causing small cracks, some barely visible. As these tiles age the cracks can become pronounced, providing sources of increased water absorption and possibly breakage. A key point of misunderstanding in diagnosing a clay or concrete tile system, is that any of the potential reasons of failure we have discussed thus far do not necessarily represent a system failure. Too often an inspector will encounter one or more of these conditions in a single test area or small section of the roof. The erroneous assumption is made that the entire system has failed, when in fact the problems may be isolated. Examples of isolated failures could be the result of improper aggregate/mortar mixes in a single batch of concrete tile, improper vitrification in a single batch of clay tile or repairs to a roof section using older salvaged tile. This underscores the importance of testing multiple areas of the roof system upon discovery of these problems, to verify whether they are systemic or isolated issues. This could mean the difference between recommendations of spot repairs versus an entire roof replacement, a particularly important consideration on historically significant buildings.

Tile systems overall have excellent resistance to environmental effects. However, severe environments can affect tile in varying degrees. For example, small hail doesn't affect most tiles. However, large hail has different effects on various types of tile. Both concrete and clay tile in the latter portions of their service life, are softer and large hail can pass entirely through or knock out large sections of the tile. Hard clay tile are normally completely shattered or cracked, hail will seldom pass through them. Newer concrete tile may exhibit chipped edges or broken corners from medium to large hail.

Wind damage to a tile roof is fairly evident. Tile that have shifted out of place or have blown completely off are an indication. The Consultant should verify proper exposure of the tile courses in the case of wind uplift damage as excessive exposure increases the "over turning" moment of the tile. Proper fastening methods in compliance with RTI and applicable regional standards should also be verified.

Certain environmental factors that adversely affect other roof systems have only aesthetic effects on tile. For example, algae or moss growth can be pressure washed off the tile. Efflorescence of soluble salts is fairly common on concrete tile. It is the result of lime and water reactions in the material that release calcium hydroxide. Carbon dioxide and rain eventually wash it away.

Other significant components included in our inspection are the methods of tile attachment, type of underlayments and flashing details. Our focus should again be on obvious indications of age and condition, viewing these components through multiple test areas. Although there are regional variations in methods and materials for these components they should be compliant with RTI or Manufacturer's specific installation guidelines as well as any applicable regional codes or standards.

Having discussed potential problems and proper diagnosis of tile roof systems, how do we physically access the roof to perform our forensic testing? As mentioned earlier, some tile roofs can be walked on and some can't. But as in any roof inspection, personal safety is our first priority. Persons inspecting any steep slope system should utilize a body harness and a properly secured lifeline. Once on the tile however, proper weight distribution is key to minimizing damage. Walk as little as possible on the tile themselves. When walking on tile becomes necessary, step only on the butts or lower three inches of the tile. This is the "headlap" area with the most supporting material. To access the roof system for test areas, some sort of scaffold or work area is often required. On lower roof pitches, sand bags supporting secured plywood can provide a stable work area. On steeper pitches, roof brackets designed for slate roofing work well, providing a continuous 1"x10" or 1"x12" is placed under the metal brackets to distribute the weight.

Again, the key premise to any roof inspection is personal safety as the first priority.

HURRICANE CHARLEY

As we discussed, tile roof systems have one of the best performance records in the industry. This is also one consultant's opinion after an extensive inspection of tile systems following an extreme weather event.

On Friday August 13th, 2004 at 3:45 PM, Hurricane Charley made landfall at Cayo Costa Florida (just west of Cape Coral) as a category 4 storm. Its winds were estimated at 145 mph and measured at 111 mph before an equipment failure at Punta Gorda airport. Charley continued its' northeast track across De Soto, Hardee, Polk and Osceola counties. The storm emerged off the Volusia County coast and back into the Atlantic on Saturday August 14th. Taking just nine hours to traverse the Florida peninsula, it was the strongest hurricane to make landfall in the state since Hurricane Andrew in 1992.

Shortly after the storm, RCI member Warren French of French Engineering retraced the path of the storm to study tile performance during the hurricane. As part of the RICOWI (Roof Industry Committee on Weather Issues) team, Warren began his assessments in the Port Charlotte/Punta Gorda areas and provided the following information. The most destruction to buildings from Charley, occurred within a narrow band following the storm track from Punta Gorda northeasterly across the state to Daytona Beach. One to two miles from the center of the storm track, most damage went

from heavy to moderate. Virtually all of the tile encountered was concrete with only one clay tile roof examined. Of particular interest was how the various attachment methods of the tile performed in such a severe wind event. Because Punta Gorda is an older community, most tile roofs were older, mortar set concrete tile. Overall, system performances of the older mortar set tiles were the poorest. Mortar deterioration and subsequent loss of adhesion resulted in either substantial numbers of tile blown from the roof deck, to completely missing rakes and ridges.



Example of a ridge tile failure in a concrete tile roof system.
Photo courtesy of Mr. Warren French of French Engineering, Inc.

Mechanically fastened tile systems fared better than the older mortar set. They performed well, up to 105 mph to 110 mph. However above those wind speeds, wind uplift failure occurred with the resulting impact damage (damage caused by airborne tile and tile debris impacting the roof). On one four story building inspected, the tile lost to wind uplift blew over the ridge and broke tile on the opposite side of the roof. As the hurricane passed and the wind direction changed, the debris was blown back over the ridge, further damaging the tile on the roof elevation they originated from.

Overall, new “foam set” tile systems performed well. Most properly installed systems only received impact damage from other flying debris. Exceptions in this system’s performance occurred for two reasons.

Failure of the ridge tile occurred on roofs that did not use a ridge nailer board but relied on mortar without fasteners.

The second failure source was an installation error occurring when the two part foam mix was improperly mixed, resulting in the foam being either “part A rich” or “part B rich”.



Upper concrete tile roof exhibiting partial failure of the “foam set” system possibly due to an improper foam mix. Lower roof exhibiting damage from flying debris.
Photo courtesy of Mr. Warren French of French Engineering, Inc.

For the most part on the roofs inspected, installation problems were minimal. In addition to the problems described above, the other significant installation error occurred when exposure of the tile courses was stretched. This resulted in an excessive over-turning moment with the resulting uplift loss.

Observations of the surviving tile were made in comparison with ASCE (American Society of Civil Engineers) standard 7-02. The wind load provision within this standard addresses “corner conditions” damage to tile as well as wind force and wind uplift moment effects on ridges, rakes and eaves.

Overall, while tile systems did sustain damage, they outperformed most other roof systems within the path of one of the fiercest hurricanes in Florida’s recent weather history. Extreme weather events like Hurricane Charley highlight some of the best characteristics of tile roofing. Excellent performance and versatility combined with classic aesthetics separates tile as a truly unique roof system.

The inspection and reporting process for tile roof systems can be challenging and interesting. A working knowledge of the product and its qualities as well as the effects of age, weather and other factors will allow us as professionals to accurately diagnose the issues involved in tile roof system failures.