HISTORIC ROOF DECKS:

[ROOF DESIGN ISSUES AND CONSIDERATIONS]

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ABSTRACT

On many older buildings, frequent water leakage into the roof assembly over the years results in deterioration of the roofing system, structural deck, and exterior walls. Evaluation of the condition of the building components that interrelate with the membrane, especially flashings, is required for the successful installation of a new system. Simply replacing the membrane and disregarding direct or indirect issues such as deteriorated parapets, structural deck deficiencies, excessive deflection, drainage line corrosion, drainage system capacity, and conformance with current code requirements eventually results in poor stewardship of the assets that a historic property affords. It also supports short-term thinking that ultimately results in future performance problems and advanced and accelerated decay.

This paper focuses on problems and issues associated with substrate conditions that are hidden by materials and flashings and some of the pitfalls associated with them. Guidelines for evaluating the condition of masonry walls, lightweight concrete, and structural clay tile roof decks and their impact on performance are provided. Selection of the proper materials, given the condition of many older underlying substrates, is also discussed. In addition, the authors (based on their experiences) present suggested practices for obtaining a successful installation of a new roof system on an older, historic building.

WHY DO A THOROUGH INVESTIGATION?

Reroofing an historic structure should begin with a carefully thought-out plan so that a successful outcome will result for the building owner, designer, contractor, and general public. A thorough investigation should be the first step in developing a replacement program. The health, safety, and welfare of the building users are maintained if detailed and reliable information about as-built conditions is obtained, particularly for the roof deck. Reroofing specifications that are prepared based upon holistic interpretation and detailed knowledge of as-built conditions indicate to all concerned that the plan of action and approach to a project are professional, knowledgeable, and responsible. A prudent doctor would not proceed with surgery on a patient without running the necessary tests first to diagnose the problem. In fact, it may be considered professionally irresponsible for designers not to perform a thorough investigation of the interrelated roof system components to formulate a proper plan of action. The time invested in a detailed investigation is almost always recovered in more complete and accurate bids from contractors.

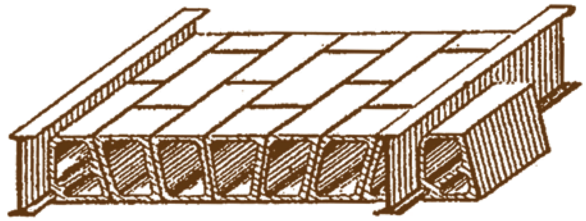
Through experience, the authors have found structural decks for historic structures to be relatively unique. When substrate conditions are properly assessed, a relatively small amount of unforeseen conditions will result in a construction project completed with relatively few change orders. Unpleasant surprises and cost extras are likely to occur if investigative activities are deferred to the construction phase.

Frequently, older structures have a history of prior leaks. The combination of deteriorated conditions at parapet walls and decks necessitates repair of these elements in conjunction with the roofing system replacement to achieve a successful project outcome. An inspection of interior spaces and attics will help to reveal areas of leakage. Water stains on wall and ceiling surfaces can be carefully recorded and superimposed with the relative position of specific areas of the roof. Focusing investigative attention on the areas of apparent deterioration increases the likelihood that worst-case scenarios will be revealed.

Inspection openings in the roofing system are necessary to identify the type and number of membrane layers, how the system is attached to the deck, whether insulation is present and what type was used, and the condition of the top surface of the structural deck. The openings should be relatively large so that a reasonable examination of the top surface of the deck can be made. Selecting an opening adjacent to a parapet wall has the benefit of revealing the condition of the wall below the flashing as well as the roof deck-to-wall interface. Conditions uncovered may substantially influence the new flashing design.

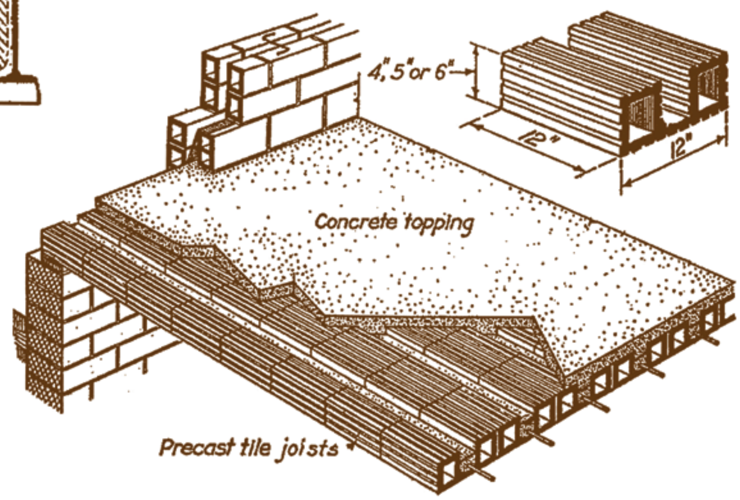
In many older buildings, the original architects designed the roof structure with liberal slope for drainage. Typically, low-slope decks employing masonry or cementitious materials were protected by built-up

Figure 1 – Typical assembly of flat and segmental clay tile arch systems.



View of 12½-in tile arch between 15-in I beams. Weight, 45 lbs per sq ft.

Figure 2 – Typical combination clay tile and integral concrete topping roof-deck system.



coverings or sheet metal. A common practice was to utilize an organic felt bituminous-membrane system adhered directly to the deck, without rigid insulation. In our experience – and depending on the age of the structure – it is not unusual to discover several membrane layers applied one over the other, sometimes with rigid insulation installed between some of the layers, as well. Also, older building designs often include attic spaces. Attic spaces have the benefit of accommodating access to mechanical, plumbing, and electrical services.

In our experience, roof drainage was given careful attention and consideration in many older buildings. The manner in which slope was achieved was either through sloping the structural system or by adding slope. Frequently, loose cinders were used as sloped fill over the structural deck, similar to today's factory-tapered insulation. Saddles and crickets were often made from wood and/or cementitious fills.

TYPICAL SUBSTRATES CIRCA 1900

Common materials used for roof substrates in older historic buildings included structural clay tile, lightweight concrete decks, precast gypsum planks, and masonry parapets. This paper focuses on structural clay tile and lightweight concrete decks and the interaction of these decks with masonry walls.

Structural clay tile is characterized by machine-made hollow units with parallel spaces. These units were available in a variety of shapes and sizes. Tiles were first manufactured around 1875. Several floor and roof designs were patented during this time. In 1903, the National Fireproofing Corporation of Pittsburgh published a handbook and catalogue illustrating products and presenting data for use in the design of segmental and flat-arch floors. The dead weight of structural clay tile systems often ranged from 35 to 45 lbs/sq ft. The main advantages provided by these floor and roof systems were ease and speed of erection (independent of temperature limitations), and fireproofing for structural steel framing. Structural clay tile may be classified into four groups:

- Flat arch
- Segmental arch
- Combination tile and concrete
- Book tile

Flat-arch and segmental-arch systems rely upon arch action for strength and rigidity. For these arches, tiles are placed between steel beams, forming a flat arch. *Figure 1* illustrates both of these.

Combination systems rely upon the composite interaction of clay tile units, concrete, and steel reinforcing bars to carry tensile and bending stresses, as shown in *Figure 2*. These decks often utilized a 2-in-thick plain or cinder concrete topping over the clay tile as a composite component of the roof-deck system. The combination system is analogous to a modern-day concrete pan joist or waffle slab structural system.

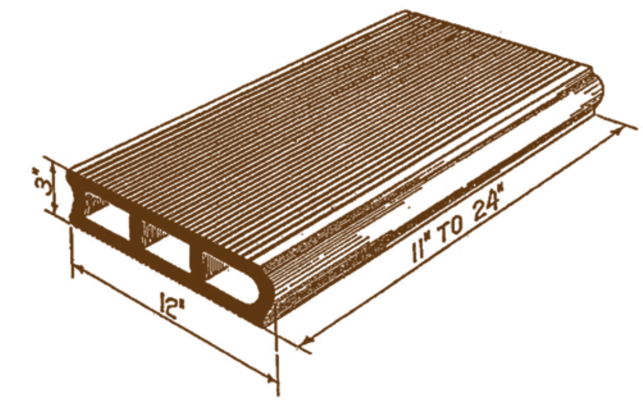
Book tiles are relatively large structural tile units that are supported by steel purlins with the sides held in place with steel T-bracing, as shown in *Figure 3*. Book tile was primarily intended for use on steep roofs, but they may be found on flat roofs, also. The name "book tile" refers to the shape of the tile, in that it resembles a closed book. The strength of the tile unit resists tensile and bending stresses.

On some structural clay tile roofs, a mortar or concrete topping, typically 1 to 2 in thick, was often field-applied over the tiles as a leveling and bedding layer. This was done to provide a smooth, uniform, and monolithic surface on which to install the roof membrane. During demolition of a roofing membrane from this deck, care needs to be taken during chipping or sawing to avoid potentially damaging the clay tile units and compromising the combined tile/arch integrity.

LIGHTWEIGHT CONCRETE

Lightweight concrete for roof decks can be characterized either by cast-in-place or precast material that can be classified into the following three groups:

- Cinder concrete
- Nailing concrete



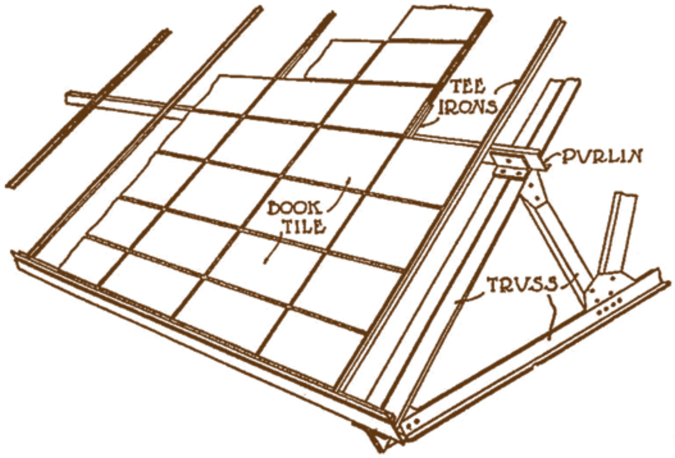


Figure 3 – Typical steep-slope application of clay book tiles.

- Sloped cinder fill and cementitious topping

Cinder concrete is a low-quality, lightweight, structural concrete that utilizes cinders as the primary aggregate. A commonly employed mix is one part cement, two parts sand, and five parts cinder. Cinder aggregate is a by-product of coal combustion and it is highly porous and cellular in nature. Cinder concretes have also been used as sloped fills over normal-weight concrete. Some cinder concretes have high sulfur contents, which are deleterious to steel. A nonstructural application for roofs utilizes loose cinders graded in a sloped configuration for drainage and then capped by a thin concrete or mortar topping, which provides a smooth surface for the roof membrane.

Proprietary lightweight concretes have been available under the trade names of "Federal nailing concrete," "Haydite concrete," and "Porete slabs." These systems were either poured in place or precast, with their chief benefits including speed of installation and nail-holding ability for attaching built-up membrane on low slopes and slate and clay tile on steep slopes. In precast systems, joints were grouted, and a thin cementitious topping may or may not have been installed, depending upon requirements. The precast systems were made in a channel configuration and had untopped thicknesses typically varying from 2¾ to 3½ inches.

Sloped cinder fill systems are nonstructural, field-made substrates for flat roofs that were placed over structural concrete slabs to provide slope for drainage. Cinders were loosely placed and graded to the required configurations and then topped by concrete or mortar, usually 1½ to 2 in thick. The topping would normally have a built-up membrane applied directly to its surface. A cinder-fill deck provides limited insulating capacity for the roof system. A drawback with sloped cinder fills is that water can collect within the cinder fill layer. When making an inspection opening, beware that the thin, poured concrete or mortar layer over the cinders may visually appear as though the deck is structural concrete. If a cementitious surface is observed at an inspection opening, it may or may not be the actual structural surface of the deck. Rather, it may be a nonstructural concrete or mortar topping. Chipping the cementitious surface should be done because it may help reveal if the surface onto which the membrane is applied is structural or nonstructural.

MASONRY PARAPETS AND WALLS

Parapet walls were often built as multi-wythe masonry without cavities, frequently three to four brick wythes thick. Stone masonry and terra cotta were also used on parapets. Typically, the interior surfaces incorporated common brick masonry or rubble fill. Stone coping units or terra cotta tile were selected to cap the top of the parapet walls. The interface of the horizontal surface of the roof membrane with the vertical flashing surfaces of parapet walls often included a through-wall metal flashing system. This system is intended to prevent moisture within the wall system from entering the roof system or the building and is a good detail that is not utilized in today's construction as often as it should be.

Concealing or covering the through-wall flashing with roofing material is a common problem that leads to the early deterioration of both the roof system and masonry. In order to keep the roof system dry, the flashing terminations must be below the line of the through-wall flashing so that water within the wall does not drain into the roof system. Many older structures have the through-wall flashing positioned such that the minimum contemporary industry standard flashing clearance of eight inches cannot be achieved without terminating the flashing above the line of the existing through-wall flashing.

An evaluation of the condition of the parapet walls is critical when designing a roof-replacement project. Good roofing practice dictates that any reroof flashing should never be terminated above the line of a masonry through-wall flashing. A new through-wall flashing assembly could be installed at a higher position in the wall by reconstructing the wall. Another problem is encapsulating the entire inside surface of a tall parapet with roofing material. Covering the entire surface of the masonry with roof membrane flashing is contrary to good masonry practices and, in northern climates, can accelerate deterioration of the masonry. Over time, water infiltration, cyclic freeze-thaw damage, and efflorescence cause corrosion of embedded steel. (See *Figure 4*.)

Stair stepping the flashing along the parapet keeps the height within recommended industry standards, while allowing the masonry above the flashing to breathe. It may be necessary to locally remove sections of the masonry parapet and install a stair step design to maintain sufficient vertical height for membrane base flashings.

TYPICAL PROBLEMS ASSOCIATED WITH SUBSTRATES

Deterioration of the structural deck and parapet wall or corrosion of embedded steel components is usually attributable to moisture infiltration. Other causes may include building movement from either expansion/contraction or settling over time, or interior conditions that may contribute to

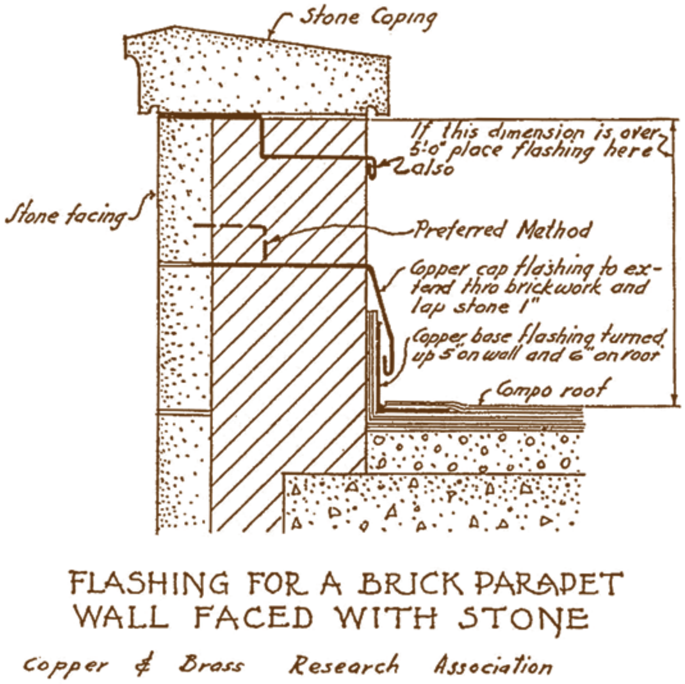


Figure 4 – A typical lightweight concrete topping course applied on a concrete structural slab.

condensation. Often, because of the type of construction, water leakage into the building may go unnoticed for an extended period of time. *Figure 5* highlights the many paths water can travel before it leaks into the interior spaces.

Deterioration of the mortar joints is a common problem in masonry parapets. Identifying the quantity and location where repointing work or brick replacement is needed will often avoid potentially costly change orders. If a through-wall flashing system is deteriorated or if flashing height is insufficient, some parapet repairs should be anticipated. Through-wall flashing in a two-piece configuration allows the counterflashing to be removed to allow maintenance of the membrane flashing, as well as future reuse of the counterflashing when reroofing occurs.

Stone parapet walls may be very porous. The porosity of the stone may allow water to travel through the wall, thus bypassing any surface-mounted roof flashings. A good detail is to provide a through-wall flashing to manage water that will eventually infiltrate the wall.

The bearing conditions of the structural framing members may be affected by moisture infiltration. This is a serious problem that should be examined thoroughly. Temporary shoring of the framing while masonry repairs are undertaken may be needed if deterioration is advanced.

Deterioration of the top shell in a clay tile unit within an arch system may reduce structural capacity and compromise the integrity of the arch. Similarly, concrete or mortar toppings may have delaminated and may conceal damaged top shells. A structural engineer familiar with clay-tile arch systems should be consulted to assess these issues.

Several attachment options must be evaluated to determine how the new roof system will be attached to the substrate. For flat roofs, the attachment options include fully or partially adhered, mechanically fastened, and ballasted systems. The condition of the deck will influence decisions for roof-replacement systems.

Wood saddles and cants should be inspected to determine their condition. Replacement should probably be anticipated unless their condition is exceptionally good. If the roof was re-covered in the past, perhaps new cants and saddles were installed, but no deck repairs were performed beneath the saddles.

During construction, damage can occur to the roof substrate from the equipment used to remove the old system. Storage of materials and construction traffic across the deck while removing the old roof and installing the new one may also weaken it and cause further damage. Stockpiling roofing material may overload already weakened areas of structural deck.

All of the above conditions and hypotheses should be evaluated prior to the start of the repair work to determine if the substrate for the new roof system is capable of providing continued safe performance.

DESIGN CONSIDERATIONS FOR MATCHING THE ROOF SYSTEM TO THE SUBSTRATE

Following are some of the design issues that should be considered and incorporated in a roof-replacement plan.

Consider Existing Conversions and Additions

Additions or conversions of space may have resulted in additional mechanical equipment on the roof and offsets between areas that create snowdrifting issues where none existed prior to the revision. A significant change in interior humidity and/or temperature may require a different amount and type of insulation as well as vapor retarder location. Expansion joints separating building additions need to be incorporated into the roof design. Removal and replacement of mechanical equipment may be necessary, which will add complexity to the overall renovation plan.

Provide Required Fire Protection

Clay tile provides an excellent source of fire protection for steel framing. *Figure 6* shows how the clay tile typically protected structural steel members. If there is significant deterioration of the existing clay tile deck and selected removal and replacement of tile units is necessary, the replacement materials need to provide the same or better fire protection of structural steel, should

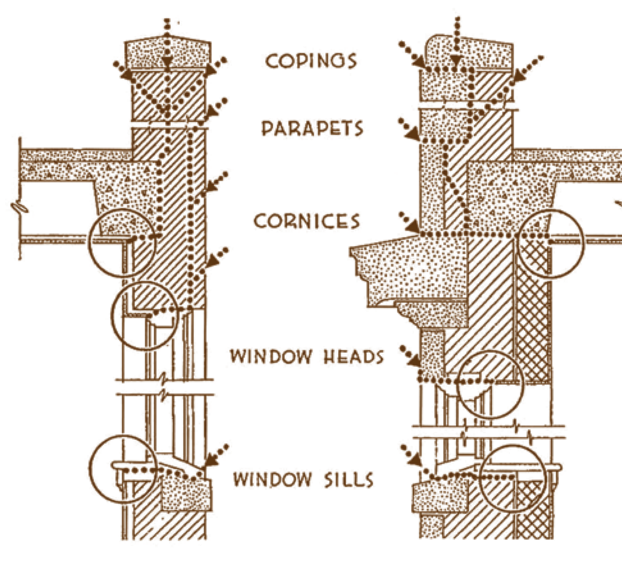


Figure 5 – Some of the paths water can follow before leakage is discovered in the interior spaces.

any be uncovered. The building code, local officials, and insurance company representatives should be consulted to make sure the repair design satisfies local fire-resistance protection requirements.

Consider Dead- and Live-Load Limitations, New Code Requirements, Uplift Design

New roofs should be designed to conform to the current building code requirements for dead, live, and wind loading. Particular attention should be paid to the condition of the structural slab for the load-carrying capacity and uplift resistance of the new roof covering. If the uplift resistance of the roof system over an historic deck substrate is not strong enough to overcome the imposed wind loading, the roof will not last long and can potentially blow off.

Achieve Proper Slope to Drain

Saddles built between drains may have been originally constructed of wood or mortar. The condition of these saddles needs to be evaluated, and they may need to be replaced or repaired. If a sloped cinder-fill system on sloped concrete topping exists and it is then removed, a new system should be provided that achieves adequate drainage slope.

Verify Plumbing Code Requirements

It is wise to add overflow drains or scuppers for roofs surrounded by parapet walls, and this is likely to be a building code requirement. Drains can become clogged and allow water to accumulate on the roof surface. Emergency overflows are designed and installed to prevent collapse from occurring. Often, the condition of the drainheads and drain leader lines is poor, necessitating replacement of a portion of the plumbing system itself. Existing drain lines may be potentially undersized and may require plumbing repairs in order to bring the drainage system up to current code.

Address Electrical Repairs

Electrical conduits may be buried in concrete toppings or insulation, and their existence can influence the repair approach to be taken. Conduits can be identified using a metal detector or by careful observation from the underside of the deck.

Structural Engineering

If the structural deck requires extensive repair, a qualified structural engineer should be consulted to evaluate the need for shoring and to recommend repair options.

Provide for Special Removal and Disposal Procedures for Asbestos Felts and Flashings

Testing of the existing roofing membrane and flashings should include a check to verify whether either of these materials contains asbestos. Special removal techniques and waste disposal procedures are regulated by government agencies.

Evaluate the Existing Bituminous Membrane if Well Adhered to the Structural Deck

If an existing bituminous membrane is present, is found to be tenaciously adhered to the deck, and is in good condition, one option may be to retain it rather than remove it. This membrane may provide a reasonable temporary protection, but it needs to be evaluated in terms of its interface with a new roof assembly. If a well-adhered bituminous membrane needs to be removed for any reason, major deck repair is almost certain to be required. In all likelihood, the condition of the bituminous membrane relates directly to the condition of the structural deck.

Consider Code and Insurance Requirements

Building code provisions for roofs need to be carefully reviewed on older buildings. The codes have established wind-resistance and fire-rating classifications. Applicable specifications should be followed based upon code- and insurance-prescribed ratings. Roof replacement normally deals with external fire exposure, but if the deck is included in the repairs, then the overall ceiling, deck, and membrane systems need to be considered together.

Consider Warranty Issues: What Is Not Warranted?

Roofing manufacturers will warranty the performance of products they manufacture and supply. However, they normally do not warranty the condition of the existing structural deck or how roofing materials are adhered to the deck. The design professional is required to verify the condition of the deck and method of attachment of the roof assembly.

Consider Insulation Requirements

The addition of insulation to the roof assembly may be desired but it may not be necessary if an attic space exists. Then, the choice to insulate the attic rather than the roof system is a more viable option in order to meet energy code requirements. Insulation can also be used in the roof assembly

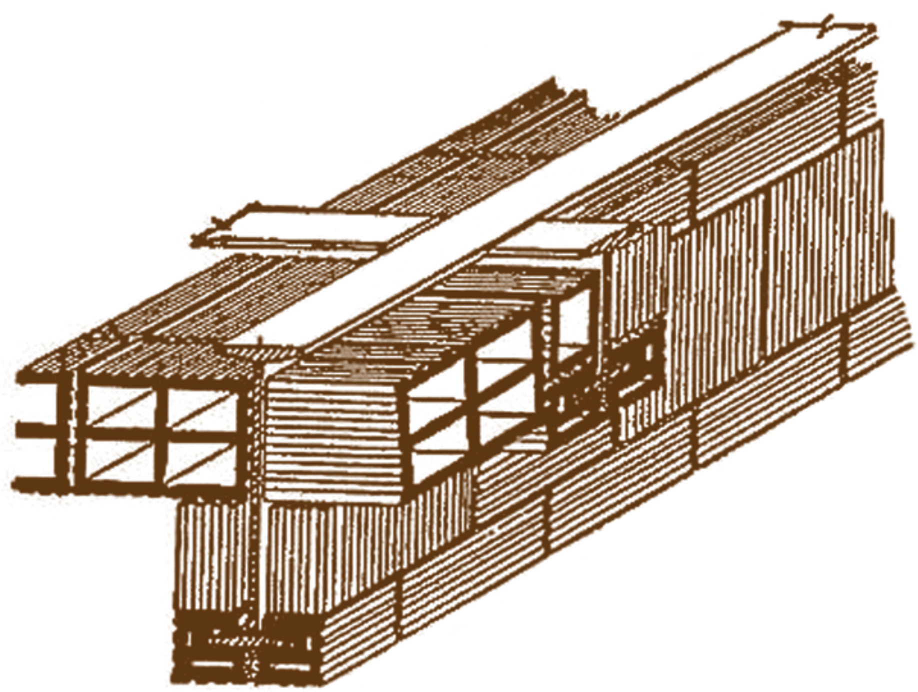


Figure 6 – How clay tile was used to cover structural steel members to provide fire protection.

where the substrate is uneven and irregular to provide a smooth, uniform surface for the roof membrane.

Perform a Dew Point Analysis of the Roof Assembly

A dew point and thermal analysis should be performed to determine if condensation would form within or on the underside of the structural deck, as is possible with a roof membrane in a cold climate.

Consider Mechanical Fastener Types Carefully

Withdrawal or pullout tests are useful to verify the holding strength and load capacity of mechanical fasteners. These tests assist in evaluating potential problems with anchorage of components such as wood blocking or prefabricated curbs to the substrate. Usually, conventional expansion anchors do not work well in cinder concrete or older lightweight concrete because of marginal concrete strength. Drilling into clay tile often results in spalling or cracking of the interior face of the top shell. The material the fastener is made from, along with the coating, if present, can greatly affect the long-term performance of the fastener. Including a fastener manufacturer early in the process is recommended to help identify which type of anchors will work. Not knowing in advance of construction whether special fasteners are needed can easily increase costs significantly.

CONCLUSIONS AND SUMMARY

The substrates of older structures need to be carefully examined in order to formulate a successful reroofing design. This plan will be significantly influenced by the type and condition of the roof deck and by the nature and condition of adjoining parapet wall systems. The roof of every building is unique, and a project-specific, holistic assessment of conditions is necessary to predict the manner in which to implement repairs as well as to make an informed selection of roofing system type.

Repair concepts on historic buildings often have structural performance implications. This necessitates involvement of a qualified structural engineer during the design phase to check the feasibility and constructability of those repairs. This step is important because the means and methods of repair are variable and are often limited by site and time constraints and by potential variability in workmanship. Trial repairs or mock-ups should be initiated, as this will help reveal problems and conditions that can only be identified during the physical act of construction and will also permit evaluation and refinement of proposed repair details.

The reroofing design plan should be guided by investigative findings and proper evaluation of all of the required design considerations. Economic constraints are often imposed on the designer. However, those constraints should not compromise professional opinions or technically appropriate decisions reached when proper analysis has been performed. The success of a new roofing system on an older historic building will ultimately be determined by the thoroughness of the investigation and care taken in selection and implementation of an appropriate repair or reroofing solution.

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