Practice Points NUMBER 19

Structural Hollow-Tile Flat-Arch Assemblies: A Guide for Assessment and Repair

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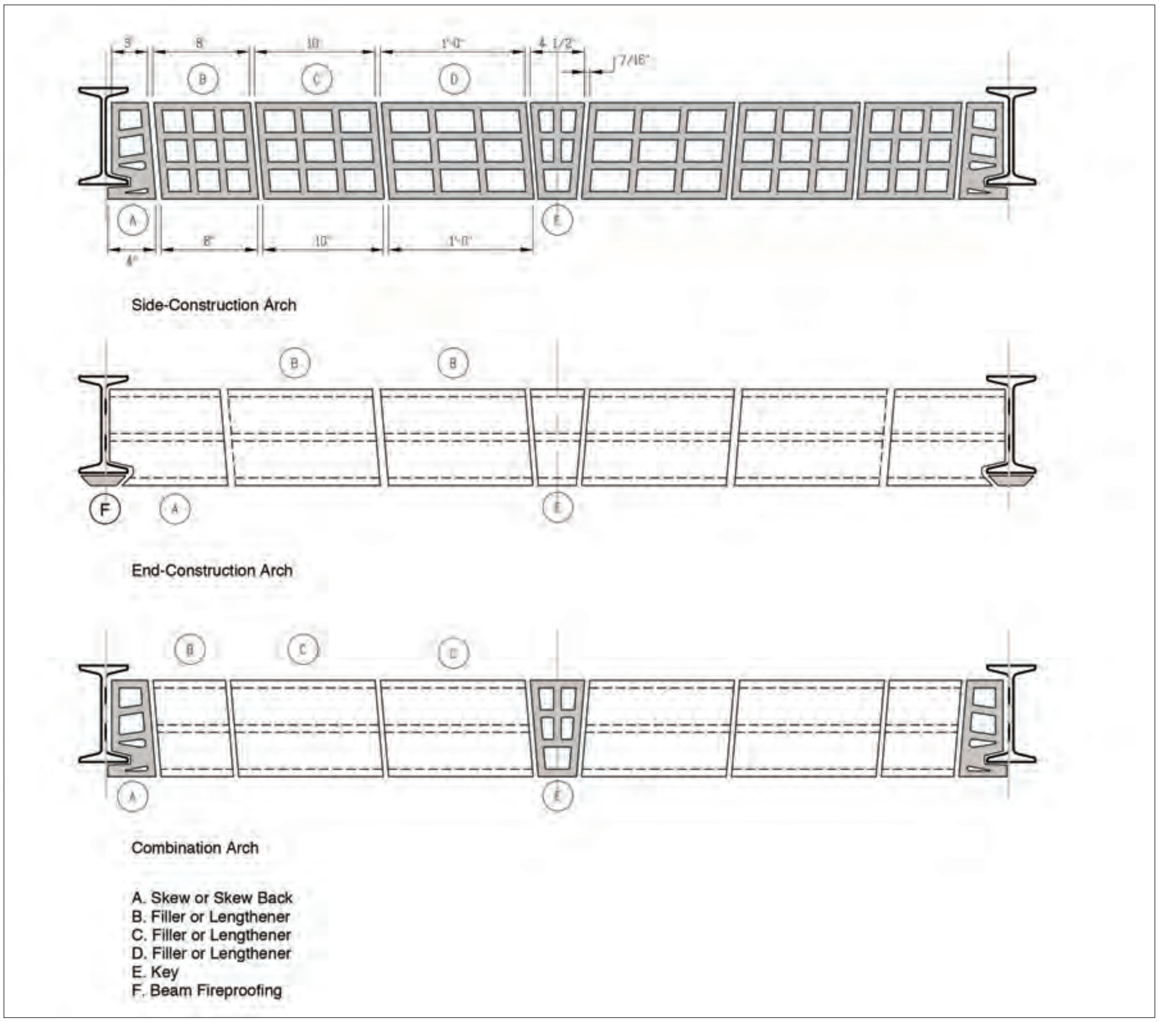


Fig. 1. *Typical flat-arch construction section through three hollow-tile flat arches. The three types of construction are, from top, side-construction, end-construction, and combination-construction. All figures by authors.*

In the late nineteenth century, as the technology and practice of construction changed, driven largely by the desire for taller and more fire-resistant buildings, a remarkable number of new products and systems emerged for constructing floor assemblies. Hollow-tile flat-arch floor systems gained popularity during this period. They were systems already familiar to builders, as they had evolved directly from traditional building technology, and they were fireproof. They were also lighter than traditional brick masonry arches but had enough structural capacity to support loads from light-duty residential floors to heavy-duty industrial floors and everything in between. Hollow-tile arches became commonly used in all types of buildings.

Initially, manufacturers of hollow tile were scattered across North America, producing blocks from local clay deposits. By the 1920s, most smaller manufacturers had been displaced or absorbed by larger firms, and the dominant producer became the National Fireproofing Company, or Natco. In the early decades of the twentieth century, competition among structural hollow-tile manufacturers and the growing concrete industry combined to make hollow tile a less attractive choice. Tile had to be transported as a finished product; concrete could be mixed on-site. Tile required care in handling to minimize loss from breakage; concrete was mixed from materials that could be tossed together with a shovel. As concrete technology improved and building codes were revised to accommodate concrete construction, the market for tile diminished. By the middle of the twentieth century, hollow tile had disappeared from the market.

Hollow tile proved to be a robust and durable building material. Today, there are millions of square feet of floors and roofs built of hollow tile that are still serviceable. This *Practice Point* provides a road map to approaching renovation projects with structural hollow-tile flat-arch floor and roof assemblies; it is aimed at helping practitioners avoid common pitfalls associated with this not-easily-adaptable structural element.

Building Blocks

Structural hollow-tile or terra-cotta blocks were used for many purposes in building construction in the late nineteenth century and most of the first half of the twentieth century: as fireproofing for steel structures, demising partitions, and bearing walls within larger buildings and in agricultural, detached residential, and small commercial buildings; as substrates for steep-slope roofs; and as the structure supporting floors and roofs with low slopes.[1] The R. Guastavino Company, which built arches and vaults typically from thin, solid tile, even used hollow-tile block in some of its structures. This material is often called speed tile when found in walls, book tile in steep-slope roofs, and terra-cotta or structural hollow tile when used in the construction of floors and low-slope roofs.

Blocks used in floors and low-slope roofs were fabricated from either clay or clay mixed with extending agents, such as sawdust, and then extruded and fired. Manufacturers used terms like “dense” to describe clay products and “semi-porous” and “porous” to describe products made from clay mixtures. The clay mixtures reduced the mass of the blocks, without affecting their fire resistance or structural capacity.

Putting the Blocks Together: Flat Floors and Roofs

Structural assemblies for floors and low-slope roofs of tile took two general forms: segmental and flat arches. The curve of segmental arches mimics the form of the traditional, heavier brick arch that the tile arches sought to replace. Segmental arches can still be found in service; however, the focus of this article is the more common flat arch.

Flat arches consist of three or four types of blocks. Skews, fillers, and keys are used in every arch. Some arches also include separate, trapezoidal-shaped blocks that fit below the bottom flange of the steel filler beams supporting the floor. These blocks, known as soffit tile, complete the fire protection for the steel framing (Fig. 1).[2]

The skews form the spring of the arch. Typically, they are shaped to fit above the bottom flange and against the web of the steel filler beams. In some cases, a skew includes a small tab that extends below the bottom flange of the beam; in others, it is cut to form half of a dovetail slot that accommodates a loose block of fireproofing. Fillers, which were typically supplied in several lengths, form the largest part of the arch, extending from the skews at either side of the arch toward the center. The key, like the keystone in a stone arch, fits in the middle of the span, between the fillers.

There were three types of flat arches: side-construction, end-construction, and combination-construction, which is a combination of side- and end-construction. In a side-construction arch, the cores or hollows in the extruded clay block are perpendicular to the span. End-construction arches have cores that are parallel to the span. Combination arches typically include a skew and key of side-construction and fillers of end-construction.

Advertisements in trade journals and manufacturers’ catalogs suggest that a number of geometries—some including nesting cylinders—were used in the dies that formed the extrusion from which the blocks were cut. In practice, the extrusions were typically rectilinear with rectilinear cores or hollows. The outer shell and webs between the cores were typically 5/8-inch to 3/4-inch thick. The outer shell was often grooved to facilitate a mechanical bond between the blocks and the mortar; where plaster finishes were applied directly to the block, grooves were used between the wet plaster and the block.

The mating surfaces of the blocks perpendicular to the span were typically formed or cut with a taper or batter of 1 inch to 1 $^{1}/_{2}$ inches; the adjacent surfaces of blocks, or those parallel to the span, were typically straight or plumb (Fig. 1). While manufacturers advertised that blocks were available in a range of depths of 1-inch increments from 4 inches to 15 inches, in practice, arches were typically between 8 and 12 inches deep.

In addition to the steel framing and the tile arches, floor assemblies typically included tie-rods between the steel beams. Above the arch, wood sleepers were typically placed within a lightweight, often cementitious, cinder fill, covered with wood subflooring and a finished wood floor or with a mortar bed covered with stone or decorative tile finishes.

Loading up the Blocks

Unlike today's concrete-on-metal deck-floor assemblies that are assembled from largely interchangeable components that can be sourced from many suppliers, the components of hollow-tile arches were often proprietary and peculiar to each hollow-tile arch manufacturer. While manufacturers published catalogs with tabulated total-load capacities for various spans and arch depths and made this data available for inclusion in design manuals, such as those published by Carnegie Steel and Bethlehem Steel, the design of hollow-tile arches was handled in-house. Each company would design, fabricate, and install the tile arches.

The tabulated data available in historic literature is valuable as a guide for the design professional charged with making alterations to a tile arch-floor assembly. However, the data needs to be reviewed with an understanding that there are some limitations to its utility. Ensuring the load-carrying capacity of hollow-tile arches is a critical challenge to today's engineer. In addition, other aspects of hollow-tile arch construction present numerous limitations to its ability to be repaired and reused.

The flat-arch assembly actually allows a shallow arch or arched thrust line to form, within the depth of the block, spanning to adjacent steel beams. Thrust from the arches, which is equal and opposite in adjacent bays within the core of the building, is effectively neutralized where the arches are continuous. To resist the thrust loads that are developed from the arch at the building perimeter and at the edges of openings, steel tie-rods are installed along the length of the steel beams. While ties are particularly critical at edge conditions, they are also commonly found throughout the floor assembly.

Hollow-tile floor systems are not as easily adaptable as modern reinforced-concrete slabs because of the way that the tile carries load. Seemingly simple renovations, such as adding mechanical penetrations or stair openings, will disrupt the continuity of the arch structure. In buildings that have been renovated previously or are subject to repair by building staff and/or contractors who do not understand the limitations of tile arches, it is not uncommon to encounter large trenches, pipe penetrations, and openings in the terra-cotta flat-arch systems once finishes are removed. These existing alterations can significantly reduce or disrupt the load-carrying ability of the arch.

Rearranging the Blocks

Even the more "standard" aspects of renovations—such as new floor finishes; additional point loads from heavy equipment or sculptures; wall relocations, additions, or removals; and new stair or mechanical, electrical, and plumbing (MEP) openings—need to be assessed in relation to the tile arches to determine whether repairs are needed; the scope must be accurate for the cost estimates and pricing to be reliable. On every project, there will be a question of whether it is more economical to save and repair the tiles or to simply remove and replace them. However, if armed with an understanding of the structural capacities, typical load distributions, and a sense of limits to which hollow-tile assemblies can be modified, the design team can make informed decisions.

During the information-gathering phase of predesign, it is important to obtain as full a picture as possible of the construction and condition of the tile arches. A robust program of documentation and probes is recommended. While establishing the general condition of many existing floor assemblies, a few probes are often sufficient, along with some prior experience. However, establishing the types of repairs necessary and developing an allowance for the overall quantities of repair can prove to be costly in structural hollow-tile floor assemblies. Some conditions can be difficult to document, making it hard to establish an accurate scope; for example, even when they are visible, prior repairs may not have been executed correctly and hollow-tile blocks may have been damaged to install hung ceilings in some spaces but not others. The scope of repairs and/or floor replacement can expand significantly where conditions like these go unnoticed before construction begins.

Fig. 2.
Damage to underside or soffit of tile arches may include missing blocks (a), holes in blocks (b), and missing mortar between blocks (c).

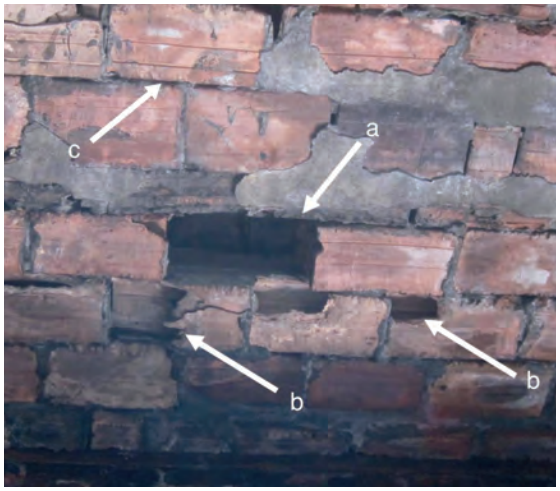


Fig. 3.
Missing soffit blocks on a steel beam and pockets cut into tiles for beam clamp hangers are a common condition of systemic damage.

Fig. 4.
Damage to tiles at a pipe penetration is frequently caused by prior chopping, rather than cutting cleanly through the arches.

As with most floor assemblies, areas of hollow tile susceptible to water damage, such as below bathrooms and mechanical rooms, near an exterior wall, and at the roof, need particular attention. Plaster and other existing ceilings may look sound and undisturbed, but well-executed repairs can hide damage to tiles, which may not be just small, discrete holes. Plumbers and electricians sometimes install piping and conduit in trenches cut into the top or bottom of the hollow-tile assembly; a smooth ceiling can, for example, conceal a 6-inch-wide trench until the ceilings are removed. When plaster finishes are applied directly to the surface of the tile, a program of sounding and/or non-destructive evaluation may be warranted, in order to locate areas that are deteriorated and/or have been previously repaired.

Existing original design drawings, shop drawings, and even documents from prior renovations, if available, can be extremely useful to help determine probe locations and establish locations of existing steel beams. If no drawings can be found, surface-penetrating radar surveys can be used to establish beam locations, as well as approximate floor buildup. Removing samples to document the density of the tile can also help in the assessment of original capacity. All of the information gathered should be used to develop a tile-repair scope and to price out the scope of the renovation.

Common existing conditions that are uncovered in projects with tile arches include damage to the tiles, missing mortar between blocks, missing blocks, openings cut for pipes or ducts, pockets for beam clamps chopped into the terra-cotta along the length of existing beams, and trenching through terra-cotta for installation of cabling, pipes, and/or conduit (Figs. 2–7). Effective communication is the single most important part of the design phases of construction projects, and projects with tile arches are no different. A lack of communication among design consultants can lead to significant change orders during construction, and the limitations of tile arches increase the importance of making sure the design team has established a clear, coordinated scope and program for repairs.

Local repairs. Part of the design phase is designing repairs for tile arches that have been damaged in past renovations or have deteriorated. The goal is to maintain the tile economically so that the arches can function properly for the remaining life of the building. Recommended repairs typically involve patches of an overhead repair mortar for small holes in the tiles, repointing mortar between tiles, and more extensive mortar or shotcrete repairs reinforced with steel for larger openings or voids. Mortar is preferred because it can be pushed into the cells of existing blocks to provide engagement with the existing blocks; it can also be completed from below to avoid disturbing finishes and tenants on floors above (Fig. 8).[3] Having standard repair details and estimates of quantities for each detail on the construction drawings greatly facilitates receiving accurate bids, minimizes delay in producing sketches, and reduces the impact of change orders during construction. That is not to say that new conditions will not be uncovered during construction, but reducing surprises helps to obtain a more accurate scope for construction.

Framed openings. New openings in the tile arches are a critical coordination challenge. Typical tile-arch spans are approximately 5 feet, so any opening that is longer than that will necessitate alteration of the steel framing in the floor, requiring expensive temporary shoring, as well as the possibility of replacing portions of the floor assembly adjacent to the proposed opening (Fig. 9). If an opening is smaller than the span, full spans of tiles (i.e., from beam to beam for the width of the proposed opening) must be removed; the need for shoring and accommodating the battered geometry of the tile blocks generally precludes the practical and economical retention of partial arches. An opening shorter than the span will require new framing installed on the sides of the opening, as well as a section of concrete slab, to replace the tiles that have been removed.

Cores. Cores through tile floor assemblies for mechanical systems also require close coordination among the members of the design team. Tile arches span a single direction, and groups of closely spaced cores can pose a significant risk of destabilizing the arch if they are perpendicular to the span (Fig. 10). Cores in this orientation must be spaced far enough apart to maintain enough tile between and around the cores; keeping the proper spacing often poses a problem when fitting the mechanical systems in shorter lengths of wall. If the cores can be oriented in a strip parallel to the arch span, the small strip of blocks can simply be removed from beam to beam, and the cores run through the new opening. For any proposed cores, a structural engineer must assess the condition and construction of the tile arch, the design loading, and the existing safety factors and then establish guidelines for where cores can be accommodated and where a span must simply be removed (Fig. 11).

Fig. 5.
Trenching through the bottom shell and webs of blocks can significantly affect the capacity of arches, as in this case, where a network of trenches was uncovered in the tiles after a plaster ceiling was removed.

Fig. 6.
Prior repairs (the light-colored mortar on the surface of the block) can be difficult to discern from "mortar slop" (dark-colored mortar) when tile arches are viewed through small probes.

Fig. 7.
Damage to the tile assembly, indicated by the white arrow, that may cause hinging in the arch may also be difficult to document where probes are limited in number.

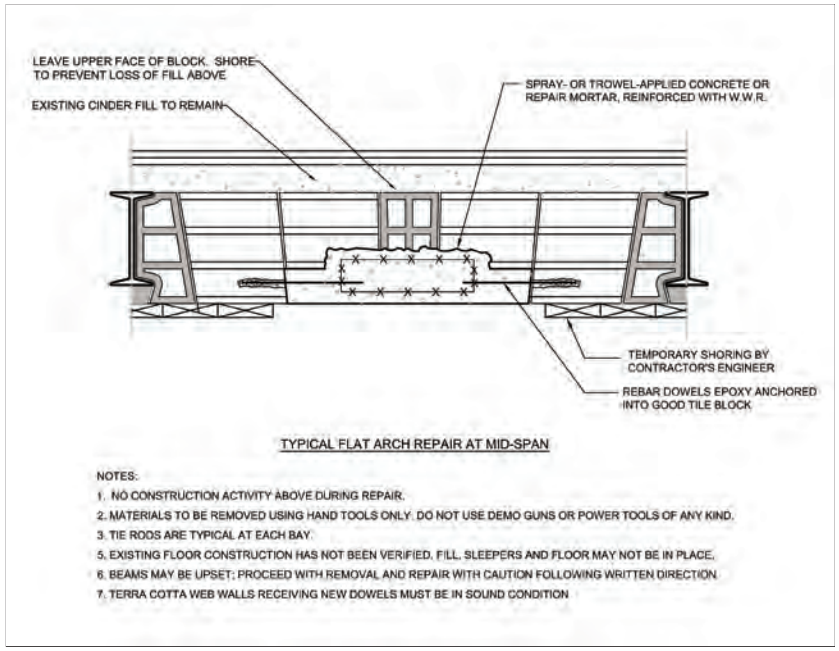
Tie-rods. While coordinating openings in tile arches, it is important to keep in mind that tie-rods exist within the tile depth, and they play an important part in maintaining the stability of the arch. The tie-rods are generally spaced between 5 and 8 feet on center, and frequently, a proposed opening will overlap a tie-rod. When this happens, the tie-rod can be removed only after a new load path has been established—by means of a new tie on one side (if the new opening is relatively small) or with new ties on each side of the opening. The new tension elements—actual tie-rods, angles, or steel plates—will be above and/or below the level of the tiles, and any torsion induced from moving the tie-rod elevation should be assessed by a structural engineer. Any existing tie-rods at the edges of new openings must also be assessed structurally to verify that their capacity is sufficient to resist the thrust from the tile arch at the perimeter of the new opening.

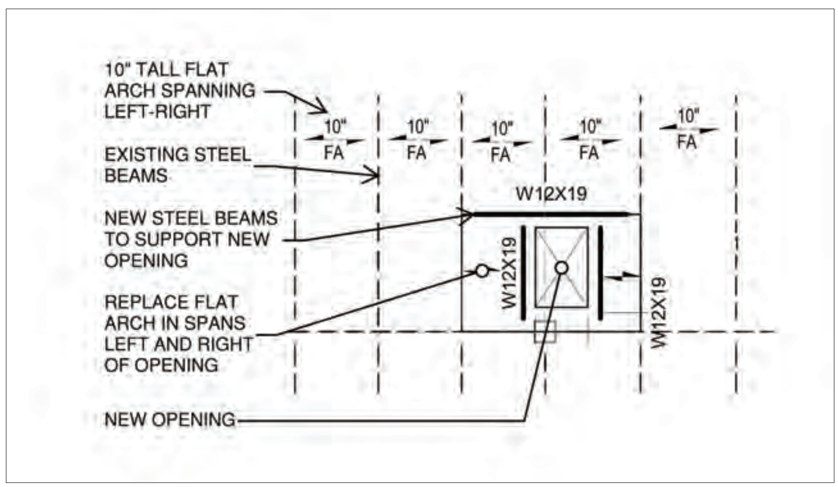
Anchoring to tile and hangers. Installing anchors in tile and/or hanging secondary structures (black iron for ceilings, conduit, piping, etc.) from tile arches is also an important coordination item for the entire design team. In an ideal world, contractors would be able to hang whatever they need wherever they want, but the brittle nature of tile makes it difficult to impossible to reliably install anchors and/or hangers to support loads from heavy pipes and equipment. The structural engineer, architect, and MEP engineer need to work together to determine a range of allowable loads that can be hung from the tile assembly.

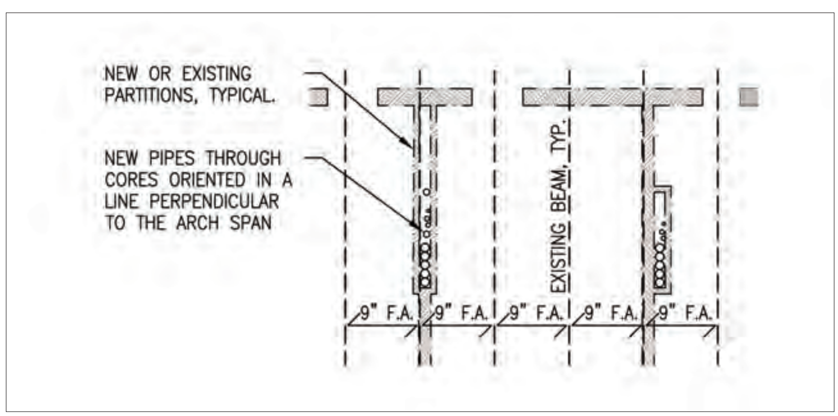
Establishing the maximum loads that can be accommodated by a given tile assembly frequently starts with an estimate based on prior experience and wraps up with pull tests in the field. Toggle-like anchors that employ a flat plate or cold-formed channels as the concealed nut can be used for lighter loads. Stainless-steel rods set in epoxy with screens or sleeves or grout-filled socks that engage both the lower shell and at least one of the internal webs of a block are recommended for heavier loads (Fig. 12). Depending on the condition and strength of the tile arch, however, heavier loads might not be possible. If hanging from the tiles is not feasible, a grid of Unistrut or a similar system secured directly from the existing steel beams can be used to support ceilings and mechanical systems (Fig. 13).

Getting It Built

Once the construction phase is reached, the coordination does not stop. Now the design team must coordinate effectively with the contractor to ensure that all the carefully laid plans are completed safely, economically, and fully. This effort starts with







Opposite:

Fig. 8.
Section through an arch showing typical detail of a schematic repair for damage to a hollow-tile arch.

Fig. 9.
Plan showing a new opening in a floor framed with hollow-tile arches that overlaps an existing steel beam. Significant structural modifications to the arches will be required.

Fig. 10.
Plan showing cores aligned perpendicularly to an arch span, which must be spaced to minimize removal of terra-cotta. Where tight spacing is required, the arch must be removed from beam to beam.

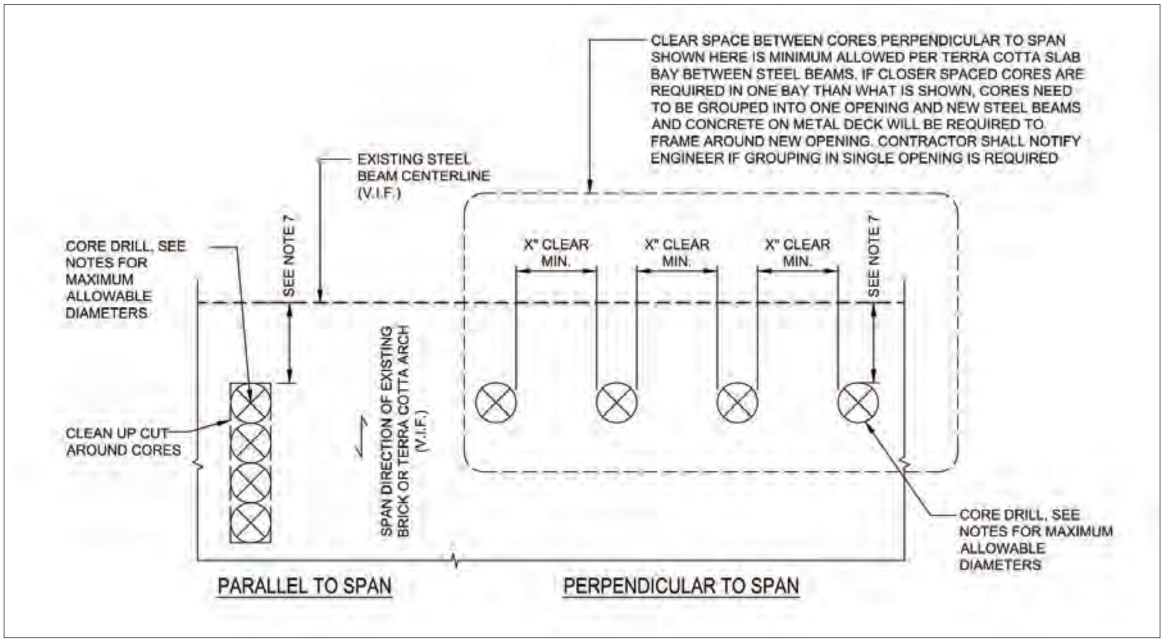
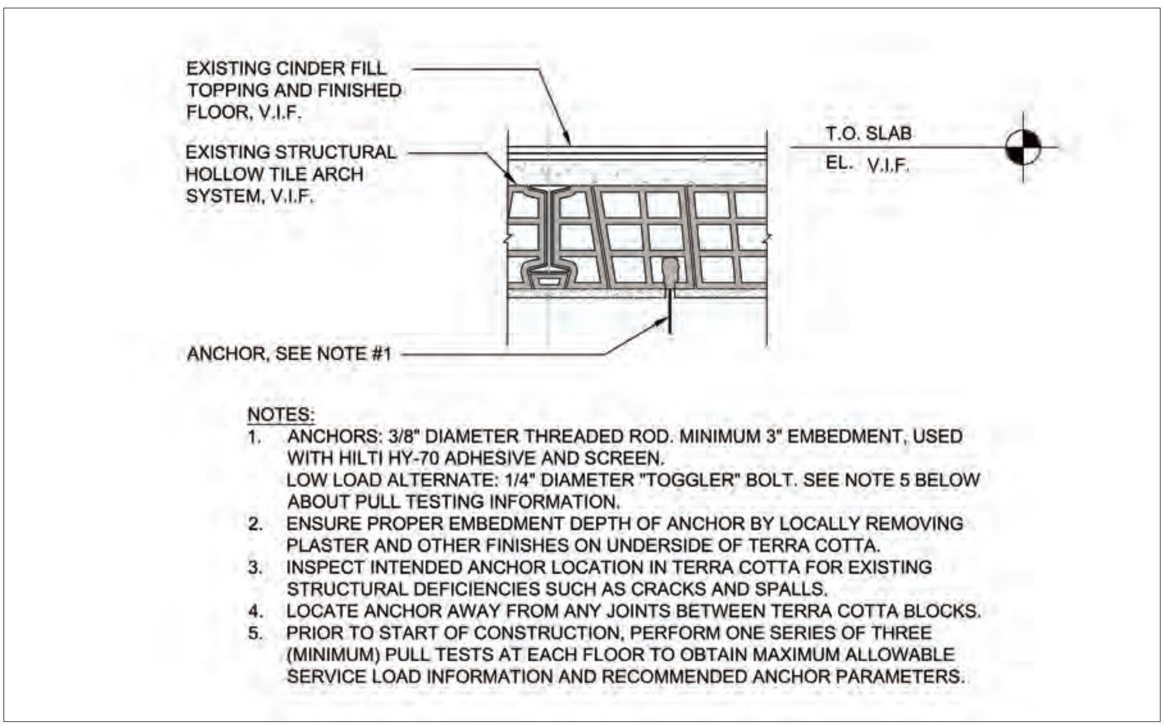


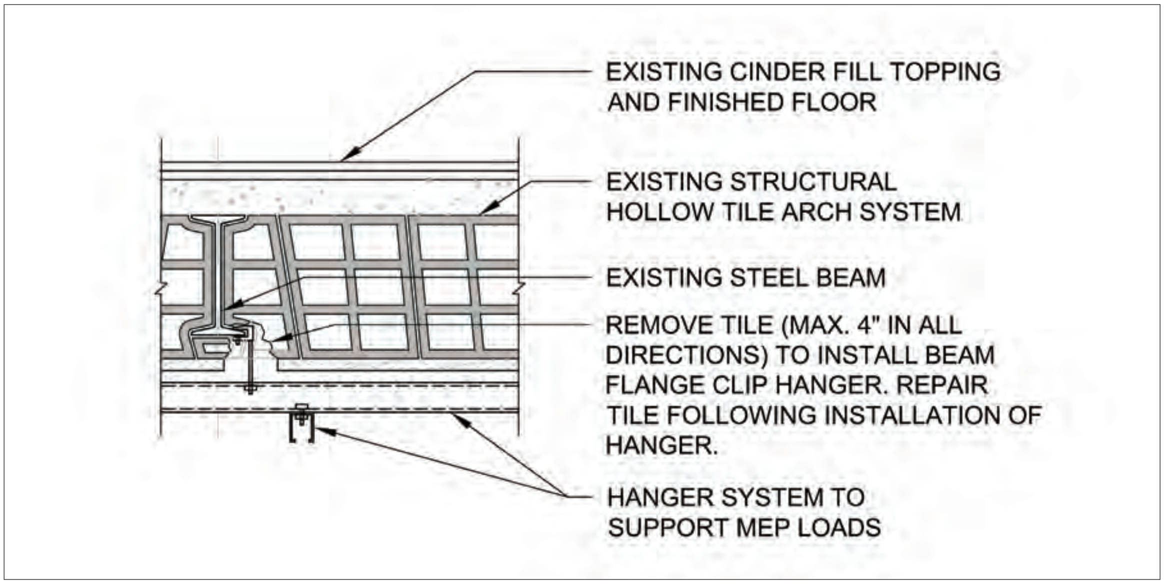
Fig. 11.
Schematic plan of a typical detail for coring through arches provides guidelines for a contractor to manage coordination of installation of services in pipes and conduits.

Fig. 12.
Section showing a typical detail for hanging low loads directly from the tile arch using an epoxy or mechanical anchor.



evaluating the cost estimates and contractors' bids to ensure that the full scope of work is understood by all parties. Tile arches are frequently a novel system to contractors, so it may be useful to have a page-by-page review of the drawings with prospective bidders or the contractor. It is essential that the contractor understand how tile arches function structurally (to avoid destabilizing them), where typical details are applicable, what extent of repairs will be required, and what to do if a different condition is uncovered in the field. Although tile floors look more like slabs than arches, they truly act as arches. When compromised, little but friction and the integrity of mortar between rows of blocks keep the arches from falling.

Fig. 13.
Section with a detail for support of heavy loads from tile arch-floor assemblies, which is recommended to directly support heavy loads from existing steel beams.



Conclusion

Although it is impossible to list every condition that may be encountered on renovation projects with structural hollow-tile flat-arch floor assemblies or to fully reduce the complexity of repairing these assemblies, it is hoped that this *Practice Point* has laid the groundwork for running a successful project. New challenges are uncovered on every project; a strong understanding of the fundamentals of how the hollow-tile arches work and their basic characteristics can help design professionals tackle new challenges.

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Notes

1. Historically, the terms "tile" (short for "structural hollow tile") and "terra-cotta" were used interchangeably to described building materials of fired clay. The term "tile" is used in this paper.
2. Other tile shapes were used to fireproof girders, which were often deeper than adjacent floor beams. Soffits built out around girders often include shapes such as clip tiles, hollow bricks, and/or speed-tile blocks often used in partitions.
3. As in any masonry project, the mortar used for repairs should be specified to be compatible with the materials in the original construction.

Practice Points present essential information on technical topics related to preservation practice for both new and experienced professionals.

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