History of Structural Hollow Clay Tile in the United States

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Introduction

For thousands of years, clays have been used in building construction. A notable example of an ancient clay-based building material is brick, which has enjoyed widespread appeal as a basic construction unit. A much more recent clay building material is the hollow clay tile. Made of terra cotta, these structural units were a high-technology invention in the mid-nineteenth century and continued to be widely utilized until the 1950s in the United States. Since the 1950s, hollow tile has nearly vanished from the construction arena—a victim of the widespread and cheap appeal of concrete technology.

A high percentage of late nineteenth and early twentieth century buildings employed hollow clay tile in their construction. Unlike many architectural materials, hollow clay tile was often not meant to be seen—much like the studs in a frame construction. This lack of visible prominence coupled with a dearth of modern treatises on the subject has led to a general unawareness of the origins and properties of hollow clay tile as well as of its historical manufacture and use. These subjects will be addressed in detail in this article, followed by a discussion on current trends and future directions of structural hollow clay tile in construction.

Origin

Until the twentieth century, fire was an all too common occurrence in densely-packed urban areas. Chicago, New York, Boston, Seattle, San Francisco, and countless other American cities experienced widespread destruction as a small fire grew into a rampage that jumped from one building to the next. The quest for a truly "fireproof" building was a catalyst that drove many improvements in nineteenth century building construction technology. Until well into the nineteenth century, the majority of urban structures contained significant amounts of wood. Many masonry buildings, while appearing to be fireproof on the outside, used wood floors (both as joists and planking) and wood-framed roofing systems. In essence, a building of this type was an open shell of masonry with highly flammable contents. Once the roof system ignited, fire readily gained access to neighbouring buildings.

Early methods for making a building more resistant to fire were to encase wood members in mortar or to compartmentalize the interior of a building to slow the spread of fire—the later being a system that became known as "slow burning" construction.[1] Unfortunately, to the detriment of the public, many buildings that incorporated rudimentary, or sometimes no fire-resistive features were labelled by their builders as "fireproof." Because of the abuse of this term, in the late nineteenth century, "fireproof" became obsolete and was replaced by the more accurate term "fire resistive."[2]

Until the advent of iron in building construction, the all-masonry building was considered to offer the best protection against fire. In its most extreme implementation, not only the walls and floors were of masonry construction, but the roof system was as well. Construction of this type relied heavily on compressive, load bearing masonry arches and resulted in massive buildings with cave-like interiors. Examples of these buildings are the earliest part of the Eastern State Penitentiary, constructed in the 1820s, and the Naval Home, constructed from 1827-33, both in Philadelphia.[3]

Over the first half of the nineteenth century, iron was increasingly used for building construction as a way to achieve fire-resistive construction without the cost and massiveness of all-masonry construction. By the mid-nineteenth century, the drive to increase available floor space was acute in some areas—especially in New York City—where the high cost of land drove developers to maximize floor space by incorporating iron framing systems into their buildings.[4]

Cast iron was first employed in columns for supporting compressive loads with the earliest examples dating from eighteenth century England. By the middle of the nineteenth century, cast iron was being regularly used for floor spans in the United States. In this application, it was quickly discovered that cast iron was considerably weaker under tensile stress. Because of its lower carbon content, wrought iron could take considerably more tensile stress and began to displace cast iron for floors and lintels as manufacturing methods improved in the middle of the nineteenth century. A typical flooring system would involve a span of iron joists at regular intervals spanned by flattened brick arches.[5]

Brick spans were problematic, however. They were heavy, and the arched nature of the construction required significant amounts of plaster, mortar, cement, or concrete to flatten the floors and ceilings. Hollow clay tiles provided a lightweight alternative to brick floor spans and had the advantage (in later iterations) of providing completely flat floors and ceilings. Hollow clay tile also provided a means to fireproof iron within a building—a result of the recognition that even non-combustible materials required insulation from heat.[6]

The first precedent for hollow clay tile was provided by the Romans, who used clay pots and hollow bricks in an effort to lighten vaulting. The French and English employed a similar system in the later eighteenth century. The French system used terra cotta pots while the English employed hollow clay cones.[7] The Cooper Union building in New York City, built in 1853 by Frederick A. Peterson, appears to be the first documented use of hollow clay tile in the United States. In this building, flattened ovals of tile were inserted between wrought iron beams (Fig. 1). Concrete was poured over the top and the lower surface of the tiles was plastered. This design was patented by Peterson in 1855. The tiles were constructed of "semi-fire clay" and were moulded by hand. Peterson's project, however, was an anomaly as brick segmental arches and corrugated iron continued to be used for fireproof floor construction well into the 1870s.[8]

Fig. 1. Hand molded, hollow tile floor construction used in the Cooper Union Building (from Brickbuilder, 6, 1897, 53).

Construction following the Chicago Fire spurred many architects, among them W. W. Boyington, to begin to use hollow tile for floor arches instead of brick. These designs were based on a patent by the Englishman Joseph Bunnett and used side- and end-pressure arches (Fig. 2).[9] George H. Johnson, an inventor, is credited with initiating the use of hollow tile in Chicago in 1871. Johnson used the newly designed hollow tiles in a building on the corner of Dearborn and Washington Streets. At the time, the building's tile arches "excited considerable interest among the building and architectural professions."[10]

Flat segmental arches eventually became the most popular and widespread use of hollow clay tile by the late nineteenth century. The design can be attributed to Vincent Garcin, a Frenchman who patented it in 1867 (Fig. 3). All later flat-arch designs of hollow clay tile can be directly traced to Garcin's design of projecting lugs and angled tile units with a central keystone. These units were first produced in 1872-3 and appeared in the New York post office, the Kendall Building (Chicago), and the Singer Manufacturing Building (St. Louis).[11]

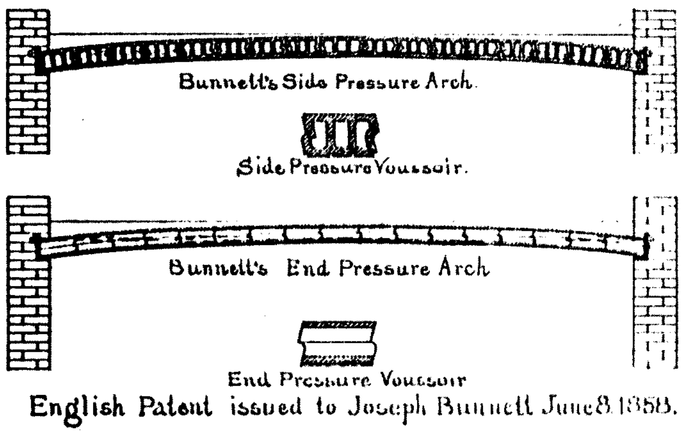

Fig.2. Early side and end pressure hollow tile arches used in the first post Chicago Fire construction (from Brickbuilder, 6, 1897, 53).

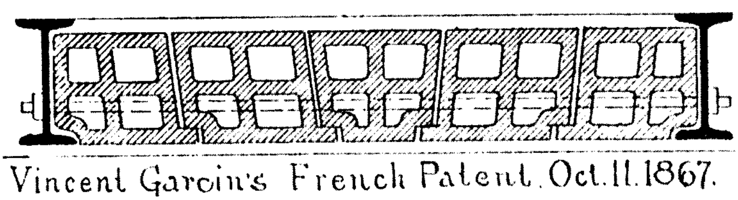

Fig.3. Predecessor of the side-pressure, flat hollow tile arch floor systems commonly used up until the twentieth century (from Brickbuilder, 6, 1897, 54).

Fig.4 and 5. Side pressure, flat hollow tile arch with "tile shoe" detail to protect iron beams (from Brickbuilder, 6, 1897, 98).

An important fireproofing deficiency with these early flat arches was that the ends of the iron beams were not protected. In a fire, the iron would soften due to the heat leading to possible structural failure. One of the first proponents of insulation of structural materials was the architect, Peter Bonnett Wight. In 1881, Wight started the Wight Fireproofing Company, specializing in hollow clay tile materials. In all, Wight patented five methods for improving the fire resistance of a building with hollow clay tile, including a ceiling clay tile system for protecting wooden floor joists.[12] In 1883, Wight came up with a "tile shoe" that could be placed over the exposed end of an iron beam to provide insulation from the heat of a fire (Figs. 4 and 5).

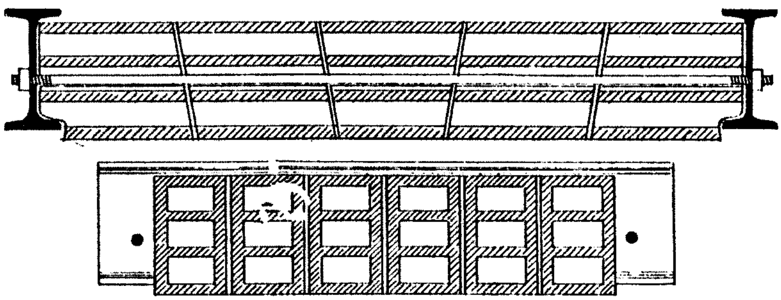
Cross and Longitudinal Sections of Thomas A. Lee's End Pressure Porous Terra-Cotta Arch, Tested at Denver, December 1890.

Fig.6. Predecessor of the end pressure, flat hollow tile arch commonly used from about 1900 onwards (from Brickbuilder, 6, 1897, 99).

The last major design innovation in hollow clay tile occurred in the 1890s with the introduction of the "end pressure" arch (Fig. 6).[13] Up until this point, side pressure arches had the tile units laid parallel to the I-beams. End-pressure systems instead laid the tile units perpendicular to the beams. The chief advantage of the end-pressure system was its capacity to carry 50 per cent more weight than the side-pressure system. By the early twentieth century, the end-pressure system had almost entirely supplanted the earlier side-pressure system.[14] A 1906 advertisement in Sweet's Indexed Catalog of Building Construction mentioned that side-pressure construction "is now but little used" and that the newer end-pressure construction is "now generally used for all ordinary purposes, being lighter and much stronger than [side-pressure construction]."[15]

Hollow clay tile before the 1880s was compositionally closer to brick than to terra cotta. More often than not, a variety of low quality mixed clays was used, sometimes with the addition of fire clay. Fire clay, described in a contemporary treatise, is aptly named as it "fires to a buff colour, and owing to its lower content of fluxes, is more resistant to higher temperatures than the red burning clays."[16] The construction of the Montauk Block in Chicago in 1882 was the first use of hollow tiles made exclusively of fire clay and ushered in the era of lightweight floor construction.[17] Porous terra cotta was introduced in the 1870s for general fireproofing and was first employed for floor arches in the Washington, D.C. Patent Office in the mid-1880s.[18] The term terra cotta is somewhat of a misnomer, as these early hollow clay tiles apparently did not have added grog (previously fired clay), but rather used sawdust or coal as a filler which burned out upon firing.[19]

An amazing variety of hollow clay tile products was introduced in the decades immediately following the Chicago Fire of 1871. Spurred primarily by the need to fireproof, new types of hollow tile were designed for interior partitions, false floors and ceilings, chimneys, and exterior walls. The 1888 catalogue of the Pioneer Fire-Proof Construction Company lists all of these products in addition to hollow clay tile for floor arches. The catalogue features an "ideal fire-proof building," complete with hollow tile used in the floor, walls, and even on the roof (Fig. 7).[20] The use of structural hollow clay tile for the exterior and interior walls of buildings reached its highest popularity from about 1910 to 1950. During this period, entire buildings and houses were built with structural clay tile—in some cases without the use of any brick. Of all the manufacturers, the National Fireproofing Company (NATCO) assumed the highest prominence. During these years, NATCO produced a large variety of catalogues and building manuals featuring thousands of varieties of hollow building tile for walls, lintels, sills, floors, and ceilings. Later hollow tile blocks for walls (such as NATCO's products) usually featured dovetailed grooves for holding plaster, while earlier blocks were completely smooth.

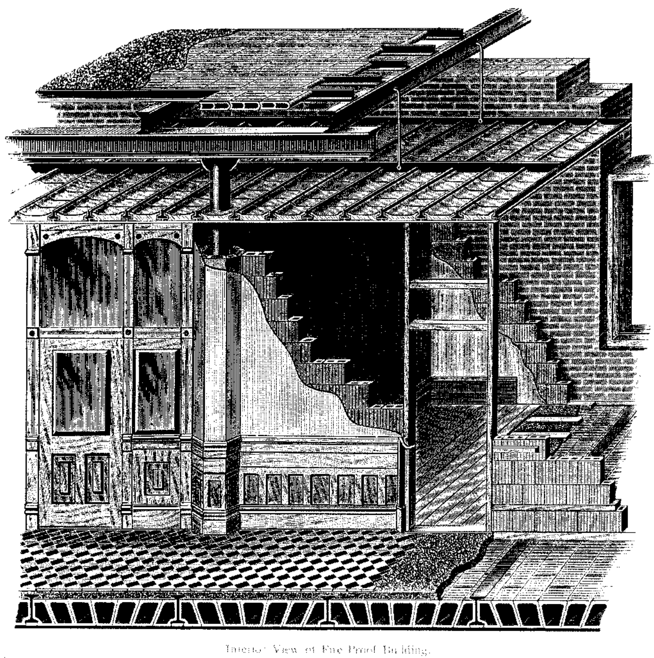

Fig.7. Section view of a fireproof building published in 1888 (from Pioneer Fire-Proof Construction Co., Hollow, Solid and Porous Tile for Fire-Proofing Buildings, 7).

Because of wood shortages during World War II, structural hollow tile was used extensively for the construction of mobilization structures, war housing, defence plants, and administration buildings.[21] Other building technologies were evolving at the same time as hollow clay tiles were changing. By the 1950s, cheaper and faster building methods that supplanted hollow tile were being used. Reinforced concrete and composite metal decks replaced tile arches and interior partitions were easier and cheaper to build with wood and steel studs faced with gypsum board and plywood. Even though tile construction was lighter, and in some cases more fire-resistant than the newer methods, economic considerations eventually extinguished the building tile industry.[22]

Manufacture

The manufacture of hollow clay tiles began with the excavation of clay from pits. In the eastern United States, the most famous of these clay-pits was found in Perth Amboy, New Jersey (Fig. 8). Carts were filled with clay from the pit which was then dumped into bins in a central receiving area. Lumps of clay were shovelled from the bins onto a conveyer which then entered a grinder where the ground clay was mixed with previously fired clay, known as grog, or with sawdust or other organic material as a filler. Grog controlled shrinkage and was only added to clays destined to make dense and non-porous hollow tile. The addition of sawdust made porous terra cotta as the sawdust burned away upon firing, leaving voids in the clay body. The mixed clay was then combined with water (typically 12 – 15 per cent), making a "stiff mud." Early manufacturing systems before 1900 used a steam press to push the clay in a large plunger through a die (Fig. 9). Later systems used an auger to push the clay through a die in a continuous stream. At periodic intervals, the stream, called a "column," was cut into individual blocks (Fig. 10). The clay blocks were then moved to a drier where excess moisture was removed. The last step was to burn the clay at about 1800 degrees Fahrenheit in a kiln for sixty to one hundred hours (Fig. 11). During this process the clay shrank approximately one inch per foot. If the tile was to be glazed, sodium chloride or other salts were introduced near the end of the burn. Alternatively, a spray glaze of various combinations of feldspar, flint, zinc oxide, lead oxide, calcium carbonate, barium carbonate, and borax was applied to unfired blocks. The end result was complete vitrification of the outer surface of the block, producing a glass-like surface.[23]

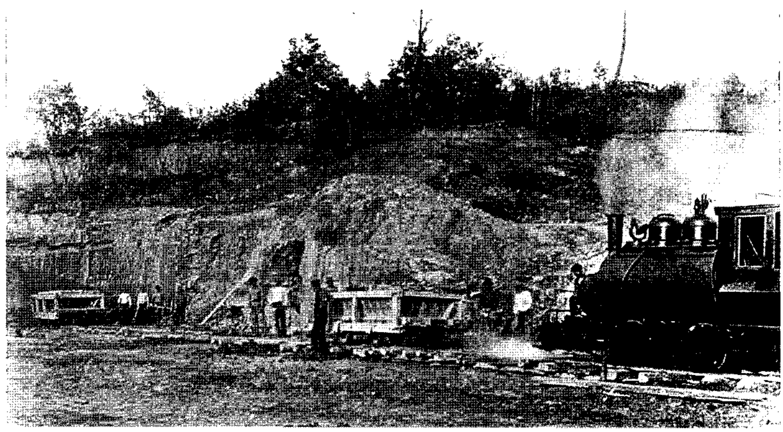

Fig.8. Perth Amboy clay pit (from Squires, The Hollow-Tile House, 26).

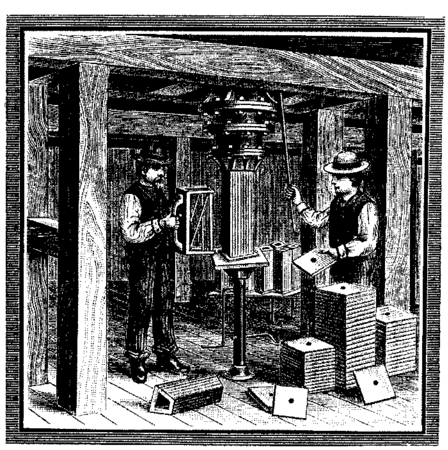

Fig.9. Early method of using a steam press to create extruded clay tiles (from Pioneer Fire-Proof Construction Co., Hollow, Solid and Porous Tile for Fire-Proofing Buildings, 10).

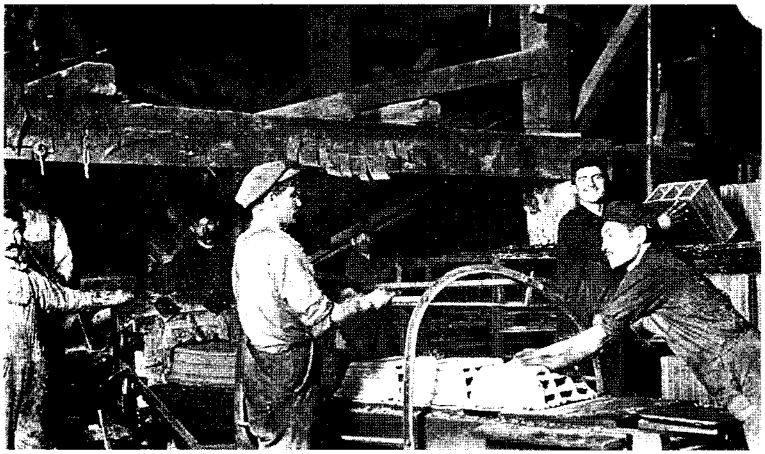

Fig.10. Workers cutting a column of auger extruded clay into individual blocks (from Squires, The Hollow-Tile House, 27).

Fig.11. Kiln with previously fired hollow tile blocks (from Squires, The Hollow-Tile House, 5).

The clay used for hollow tile manufacture was usually fire clay—especially if the end product was porous and meant to be used for fireproofing. The pressure used in moulding the tile helped force the individual particles closer together, making a more durable product.[24] Undoubtedly, the pressure also helped remove water and controlled shrinkage. After World War II, a "de-airing chamber" was added to the auger machine. The wet clay was exposed to a vacuum of 15 to 20 inches of mercury before it entered the auger. The purported advantage of this process was an increase in strength of both the green (wet) and fired body, an increase in plasticity, and "better utilization of inferior clays."[25] The entire process was designed for maximum economy. The clays could be extracted from the ground, mixed with water and formed into blocks ready to be fired all in the same day. The clay-water mixture was not allowed to sit and "sour" for a period of time as with ornamental terra cotta manufacture. Apparently, the cost of storing and waiting for clay to sour seemed to produce negligible advantages.

One of the earliest manufacturers of structural hollow tile was the Pioneer Fire-Proof Construction Company of Chicago. The post-Chicago Fire building boom provided much of their business. In the twentieth century, the National Fireproofing Company of Pittsburgh, Pennsylvania became one of the largest nationwide suppliers of hollow tile under the NATCO brand name. The National Fireproofing Company along with the Hollow Building Tile association of Chicago (manufacturers of Master Tile) published a series of promotional and educational books on hollow tile installation and use. The following manufacturers also produced hollow tile on the East Coast: Henry Maurer and Son (New York City), O. W. Ketcham (Philadelphia), Pennsylvania Fireproofing Company (Erie, Pennsylvania), Atlantic Terra Cotta Company (New York City), and the Federal Seaboard Terra Cotta Corporation (New York City). Further inland were the Chattanooga Sewer Pipe and Fire Brick Company (Chattanooga, Tennessee), Denison Fireproofing Company (Mason City, Iowa), American Terra Cotta Corporation (Chicago), Kalamazoo Tank and Silo Company (Kalamazoo, Michigan), Indianapolis Terra Cotta Company, Inc. (Indianapolis, Indiana), and the Northwestern Terra Cotta Corporation (Chicago). The West Coast was represented by the Kraftile Company (Niles, California) and the Heath Cube Service (Tacoma, Washington).

Properties

Most hollow tiles manufactured after 1880 were made of fire clay. Compared with other clays, fire clay contained a low percentage of metallic oxides (from 9.25 to 1.39 per cent) and a high percentage of silica (70 per cent or more). Fire clays also had a lower "softening point," or the point at which the clay particles begin to fuse. The end result was more complete vitrification than with other clays.[26]

Hollow tiles were graded based on their porosity and permeability. "Very hard burned or vitreous" tile had less than 8 per cent water absorption, and was very hard and particularly dense with low porosity and permeability. Hard burned hollow tile was used primarily in foundation work or exterior walls that were not rendered. Its low-porosity and permeability was well suited for ground contact or direct weather exposure. Often, tile that was referred to as "vitreous" was simply glazed. The body of the tile may have in fact been quite porous. Standard "hard burned" or "dense" tile had a 12 per cent water absorption, a low degree of porosity and permeability, and was used extensively for load bearing walls that were covered with a plaster or brick veneer. "Ordinary," "medium burned," or "semiporous" tile also had a water absorption of 12 per cent but had a greater degree of permeability than hard burned tile. This characteristic was desirable to interior plasterers because the tile would create a "suction" that would make plaster adhere better. Ordinary tile was not usually used for renders (stucco) because of the increased permeability of the tile. Ordinary tile had a wide range of porosity—with the lighter and more porous examples being used extensively for fireproofing. "Soft" or "porous" tile was under-burned and had physical properties somewhat similar to brick. It was very porous and permeable. When sawdust or organic matter was added to the clay and then burned, the result was a very light and porous product sometimes referred to as "terra cotta lumber" because of the ability to hammer nails into it. (The term "terra cotta" is a misnomer as no grog is usually added to the clays and it has very different physical properties to true terra cotta.) The last type of hollow tile is "glazed" or "salt-glazed" tile. The body or biscuit of the tile may have very different properties, but regardless is covered with a layer of vitreous glaze.[27]

In general, hollow clay tile is a very strong material in compression and very weak (brittle) in tension. When used in a wall, it will support five to twenty times its own weight. The strength of the mortar is usually the most important factor rather than the strength of the tile. Most publications during the heyday of hollow clay tile emphasized the use of a very rich Portland cement mortar.[28] The following table shows typical specifications for several kinds of hollow clay tile:

Tile	Description	Absorption, lhr. boil, percent	Compressive strength, PSI	Modulus of rupture, PSI	Tensile strength, PSI	Modulus of elasticity in compression, million PSI	Modulus of elasticity in tension, million PSI
A	Buff colour, dense, very uniform, no pits or cracks	5.7	12,440	2,630	818	3.0	3.0
B	Red colour, light, not very uniform, numerous pits and cracks	12.2	4,160	1,190	566	2.1	2.7
C	Dark red colour, dense, uniform, few pits and cracks	12.7	12,110	1,210	656	2.6	2.3
D	Medium red colour, medium weight, non-uniform, number of small rocks and clay balls in the makeup	8.3	9,900	1,665	604	3.0	3.2

From: Harry Custer Plummer, *Brick and Tile Engineering; Handbook of Design* (Washington, 1950), p.92

The Department of Commerce published a specification for hollow clay tile in 1927. This document prescribed the allowable properties of hollow tiles that were to be used in the construction of homes and buildings. For medium burned tile, the maximum allowable water absorption was 16 per cent over an average of five blocks. Water absorption was calculated by first drying the tile in an oven between 212 and 220 degrees Fahrenheit until a constant weight was achieved. The tiles were then immersed in room-temperature deionized water (specified as "soft," "distilled," or "rain water") and then boiled for a minimum of one hour. The tiles were then removed and the surface water was wiped off with a damp cloth. The per cent absorption was calculated by dividing the weight of the water absorbed by the dry weight of the tile and then multiplying by 100. This document also specified the minimum compression strength for floor arch tile at 3,000 PSI for end construction and 1,500 PSI for side construction. Wall tile specifications were not indicated. Medium burned tile was recommended in all cases over soft burned tile.[29]

According to an article published by ASTM (American Society for Testing and Materials) in *The Standards for Preservation and Rehabilitation*, "many of the floor systems that were used in the past have a reserve strength that is well beyond what is predicated by typical calculations. One type of floor system in particular, the clay-tile arch, has a true strength that is significantly stronger than what ordinary calculations would predict."[30] While hollow clay tile construction systems are exceptionally rigid and strong, they do not perform well under seismic load. Existing information on the performance of unreinforced hollow clay tile during a seismic event is very sparse, but some studies have been published. A national workshop on unreinforced hollow clay tile in 1992 provides useful information on the performance of hollow tile and recommendations for improving the performance of hollow tile under seismic load.[31] The conclusion is that buildings built with structural hollow clay tile in areas prone to seismic disturbance be retrofitted with tensile reinforcement—typically steel embedded in mortar or in some cases, wood. Microwave probing and in situ performance tests were recommended methods for assaying the need for reinforcement. The Department of Civil and Architectural Engineering at Drexel University in Philadelphia, Pennsylvania studied unreinforced hollow clay tile construction from 1979 to 1992. A recommended reinforcement procedure was to insert No. 4 reinforced plastic rebars at four foot intervals in the wall and inject additional grout through drilled holes. This technique has been successfully applied in basements in the Philadelphia area. Fiberglass composite laminates were also studied as a possible method for resisting seismic loads.[32]

Hollow clay tile, both in structural and non-structural configurations, was used extensively for fireproofing. In 1950, it was noted that "structural clay tile covering is particularly desirable for the fire protection of structural steel beams, girders and columns, and it has been recognized as a standard fireproofing material for over fifty years."[33] In tests of steel columns, hollow tile offered a fire resistance period of over four hours—a result exceeded only by a four inch covering of solid gypsum.[34] In the twentieth century, hollow tile construction was especially recommended for garages, both for its fire resistant quality and its durability.[35]

Use and installation in floors

The earliest application for structural hollow tile was in floor arches. By the 1880s, designs were standardized, with the flat arch systems predominating (refer to Figs. 12 and 13 for examples). Makers of these early systems recommended a mortar composed of lime, coarse sand, and hydraulic cement. Typically, concrete was poured on top of the hollow tiles with wood cleats and furring strips embedded in the concrete for attaching wood flooring. Marble or tile, if used, was cemented to the concrete with grout. Plaster was applied directly to the underside of the tiles, forming a flat ceiling.[36] More modern versions of the flat hollow tile arch were used well into the twentieth century. End pressure, combination end and side pressure, and segmental arch systems used in the 1920s looked remarkably like the designs used decades earlier (Figs. 14 - 15). One major difference was the mortar. By this time, mortars for use with hollow tile had a much higher proportion of Portland cement. A typical ratio was one part cement to three parts sand. The addition of hydrated lime of not more than 15 per cent was permissible and was added mainly for improved workability of the mortar. The use of a pure lime mortar was strongly discouraged as being too weak.[37]

By the turn of the twentieth century, reinforced concrete construction was becoming more common for floor construction. Hollow tile was embedded between the reinforced concrete beams. Concrete could completely cover the block or, in some cases, was only poured on the top and sides (Fig. 16).[38] This type of construction was commonly called the "combination floor system." It was constructed by placing planks on scaffolding and bridging each with a series of hollow clay tiles. Steel reinforcement was laid in the channel thus created and concrete was poured over the rebar until it eventually covered the tops of the tiles. The hollow tiles were grooved with a dovetail shape that engaged the concrete and held the assembly in place. The "Johnson system" was an alternate design that placed an uninterrupted series of hollow tile on top of a wire mesh reinforcement embedded in concrete (Fig. 17). The book tile, a flat hollow tile with a tongue and groove, was frequently used for roofs and for raised floors. In high rise buildings, plumbing was often run above the existing floor as little space was available inside the floor for pipes. The floor surface was raised with partition and book tiles in order to accommodate the pipes (Fig. 18).

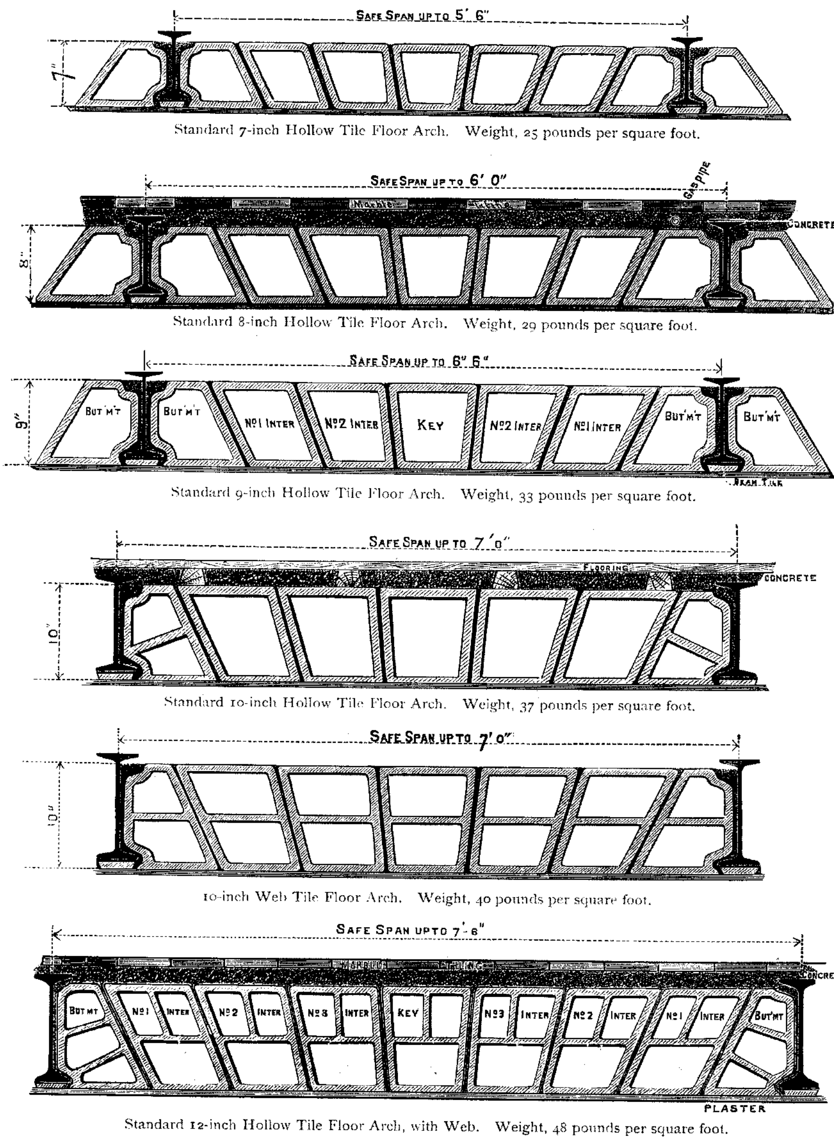

Fig.12. Late nineteenth century flat hollow tile floor arches (from Pioneer Fire-Proof Construction Co., Hollow, Solid and Porous Tile for Fire-Proofing Buildings, 18).

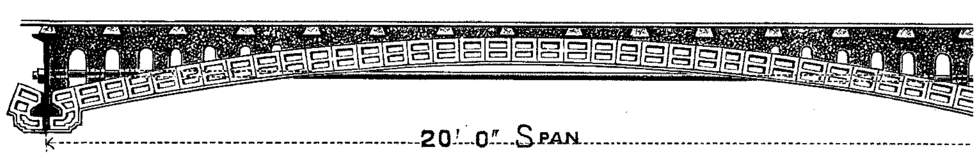

Fig.13. Late nineteenth century hollow tile floor arch (from Pioneer Fire-Proof Construction Co., Hollow, Solid and Porous Tile for Fire-Proofing Buildings, 19).

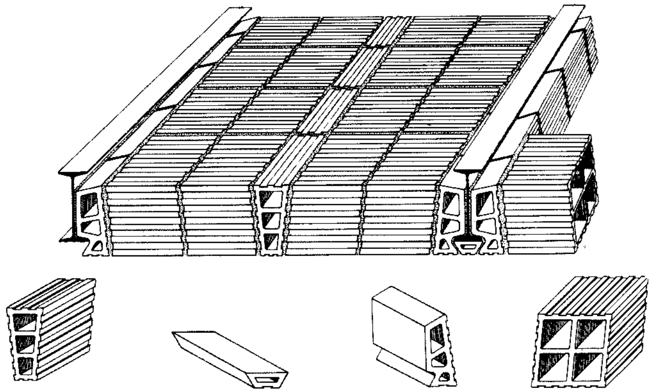

Fig.14. Early twentieth century side pressure, hollow tile floor arch which was rapidly becoming obsolete (from Hollow Building Tile Association, Handbook of Hollow Building Tile Construction, 78)

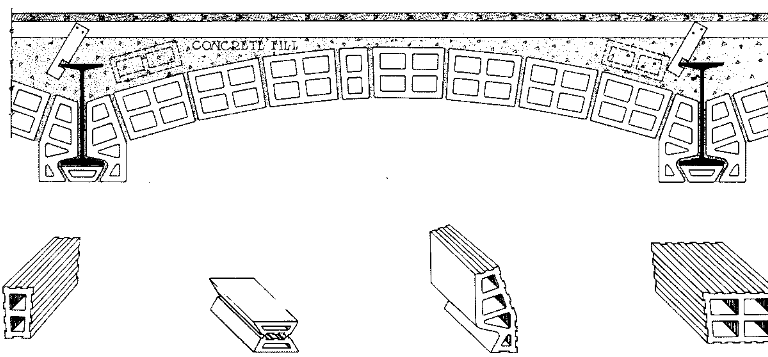

Fig.15. Early twentieth century end pressure, hollow tile floor arch (from Hollow Building Tile Association, Handbook of Hollow Building Tile Construction, 79).

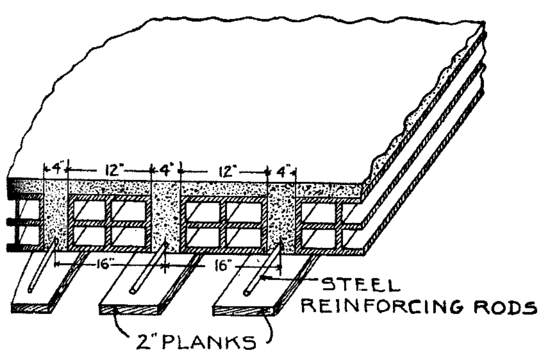

Fig.16. Combination floor system of reinforced concrete and hollow tiles (from Cosgrove, Hollow Tile Construction, 79).

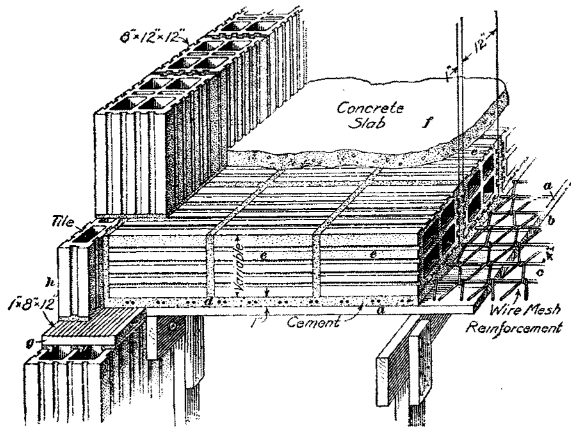

Fig.17. The "Johnson" system of floor construction (from White and Lowndes, Hollow Tile Construction, 59).

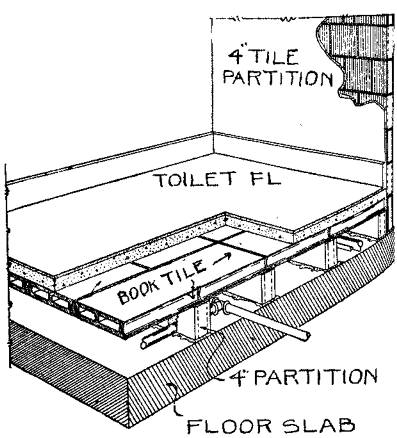

Fig.18. Book tile used for a raised floor (from Cosgrove, Hollow Tile Construction, 76).

Use and installation in walls and foundations

One of the earliest uses of hollow tile in walls was for non-load bearing partitions (Fig. 19). The use of hollow tile partitions was primarily driven by the need to fireproof. In 1883, a lawyer working in a Montauk Block office in Chicago (completed 1882) lauded the fire protection offered by hollow tile partitions in a letter to the Pioneer Fire-Proof Construction Company:

> "Gentlemen—The work done by you on the Montauk Block has, I am glad to say, proved most satisfactory. The building was exposed to a most severe test in the fire which occurred on Saturday afternoon, December 30th, 1883, and for some hours was surrounded on the north and west sides by flames, only twelve to fifteen feet away. The fire forced an entrance through

the windows, and if it had not been for the thoroughly good qualities of your tile partitions would have soon spread over the building. As it was, it was confined to only the rooms where it gained an entrance. It did not spread, and the damage was but trifling. I am convinced that if it had not been for the resistance given by your tile partitions, the loss would have been very great, perhaps imperiling the whole building. I am, therefore, greatly pleased with the fire-resisting qualities of your tile partitions."[39]

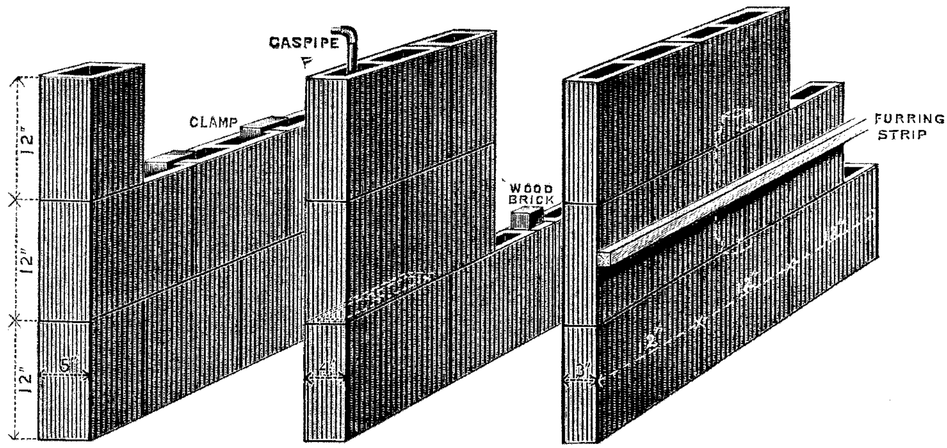

Fig.19. Early wall partition of hollow tile (from Pioneer Fire-Proof Construction Co., Hollow, Solid and Porous Tile for Fire-Proofing Buildings, 22).

As all masonry, iron, and steel buildings proliferated at the end of the nineteenth century, a method for constructing interior walls without wooden studs was needed. Hollow tile fit the bill perfectly. These walls were advertised as being vermin and rat proof with superior hygienic qualities. The tile was laid in much the same manner as brick. An early mortar of "rich lime and coarse sharp sand" was recommended for laying such tile.[40]

In the late 1880s, the idea of constructing a building entirely of tile was fairly novel. Even at this early date, however, many types of tile from basic wall units to window sills and lintels were readily available (Fig. 20). By the 1920s, such construction was commonplace and the lime mortar used earlier was supplanted with a one part Portland cement to three parts sand. Quite complex assemblies of concrete and hollow tile were used extensively throughout a building in the walls (both interior and exterior), floors, and even the roof and foundation (Fig. 21).

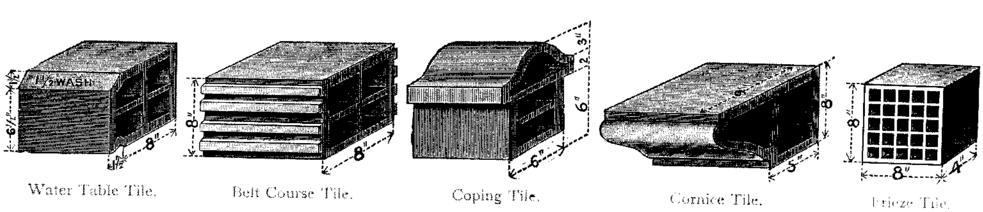

Fig.20. Various styles of structural hollow tile wall units available in the late nineteenth century (from Pioneer Fire-Proof Construction Co., Hollow, Solid and Porous Tile for Fire-Proofing Buildings, 38).

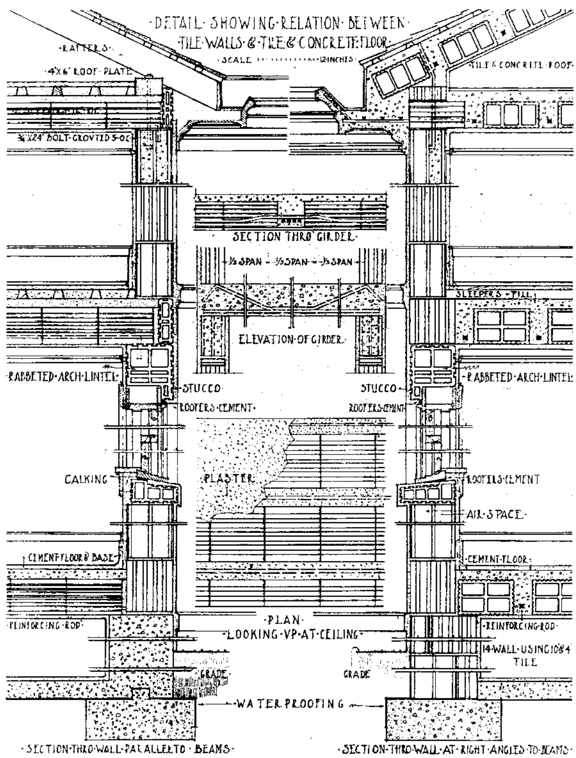

Fig.21. Example of the combination of hollow tile and cement for structural purposes (from National Fire Proofing Co., Builders Handbook of Natco Hollow Tile Construction, 23).

Typical wall finishes on a hollow tile wall were plaster on the inside and a cement render or brick veneer on the outside. Most wall tiles had vertical dovetail shaped grooves that were designed to hold the plaster and render as well as the mortar in place (Fig. 22). Cement stuccos became very popular in the early decades of the twentieth century. Typically, the stucco contained Portland cement, sand, and a small quantity of hydrated lime for workability. The tile surface was first wetted and then two coats of cement were applied: a scratch coat to bond to the tile and then a finish coat that was then waterproofed.[41] From the perspective of the twenty-first century, failure of cement stuccoes through cracking and water infiltration is well known. In 1921, however, manufacturers were quite confident of the endurance of the new cement stuccoes. According to one source, "stucco cannot crack or come off of a Hollow Tile wall once it has been properly applied. There is a genuine bond between these materials and any attempt to separate them will demonstrate this, as the line of cleavage will not fail in the joint between the materials."[42]

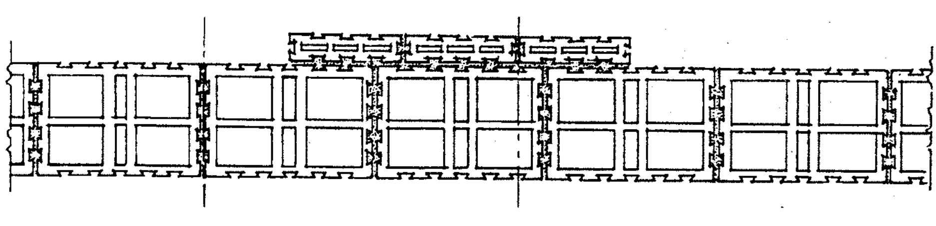

Fig.22. Section plan of a hollow tile wall revealing the dovetails integrated into each unit (from National Fire Proofing Co., Builders Handbook of Natco Hollow Tile Construction, 11).

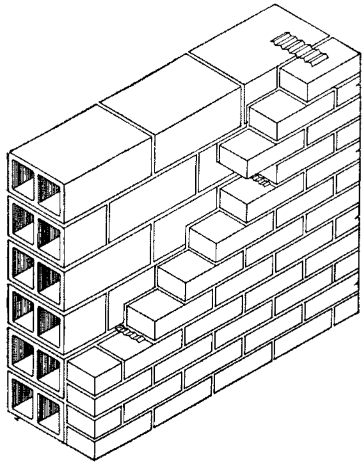

Fig.23. Brick veneer construction (from National Fire Proofing Co., Builders Handbook of Natco Hollow Tile Construction, 20).

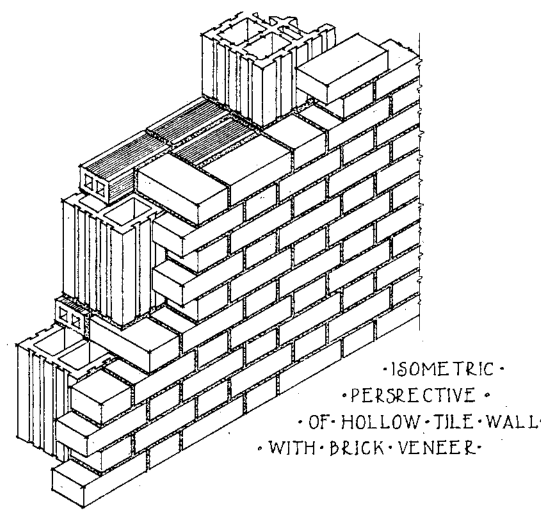

Fig.24. Bricks integrated into the tile units (from National Fire Proofing Co., Builders Handbook of Natco Hollow Tile Construction, 19).

Brick veneers were also very popular for exterior finish materials over a hollow tile wall. A single wythe (or leaf) of non-load bearing brick was attached to the hollow tile with metal ties (Fig. 23) or was bonded into the wall as part of the load-bearing structure of the wall (Fig. 24). It should be noted that the metal ties were often galvanized (or even plain) steel and tended to corrode over time. There are many brick veneer walls constructed in this manner that have entirely lost any cohesion to the underlying wall and may fail catastrophically. From a structural standpoint, bonding the brick into the tile was a preferential construction technique.

With traditional wood frame construction, it is quite easy to attach items to the wall such as furring strips, mouldings, and hooks. A simple nail driven into the wood stud within the wall affords a very firm attachment point. Nails and screws cannot be easily driven into a masonry wall, such as one made of hollow tile. With earlier brick construction methods, a wood nailing block was inserted into the wall to create an attachment point. This method was not recommended for hollow tile walls.[43] Some authorities recommended highly porous tile, known as terra cotta lumber, for its ability to withstand having a nail driven into it without cracking. As early as the 1880s, however, the use of terra cotta lumber was discouraged because of its dubious efficacy in securing attachments.[44] Instead, a whole range of fasteners were used to attach items to a hollow tile wall such as expansion bolts, toggle bolts, collapsible steel screw sockets, and self-clinching nails (Fig. 25).

Hollow tile was also used for foundations. For this purpose, dense vitrified or glazed tile was highly recommended. Telephone conduit tile, designed to protect telephone wiring buried in the ground, was also used. The tile units tended to be rather long and rectangular with internal webbing running horizontally lengthwise (Fig. 26). After the tile was installed in place, the exterior of the wall was coated with waterproofing compound such as asphaltum or coal tar pitch. Alternately, a stucco of enriched (1:1) Portland cement also served as waterproofing.[45] These same types of hollow tile were also recommended for retaining walls.[46]

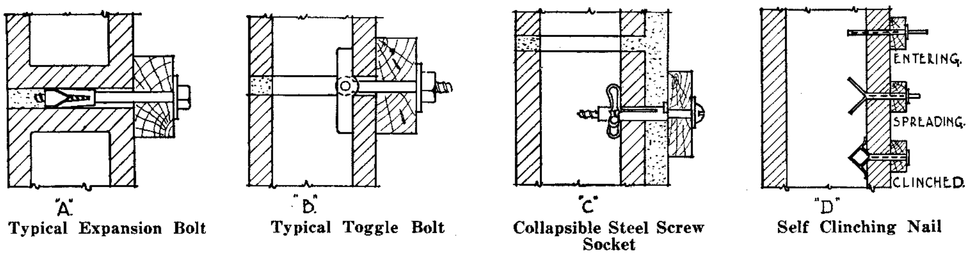

Fig.25. Fasteners used with hollow tile wall construction (from Hollow Building Tile Association, Handbook of Hollow Building Construction, 42).

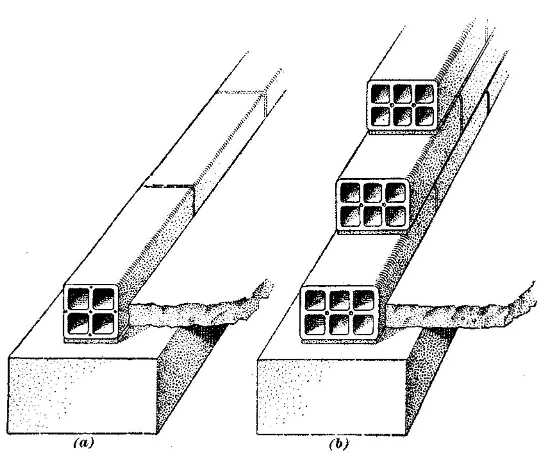

Fig.26. Hollow tile used in foundations (from White and Lowndes, Hollow Tile Construction, 31).

One of the last developments in hollow tile construction was wall ashlar. Until the 1930s, it was commonplace to cover most hollow tiles with stucco or brick. After this time, as the modern movement grew, it became acceptable to expose core structural building materials such as concrete without any surface adornment. In a similar fashion, complete walls of glazed hollow tile, ground to a uniform size, were used for both interior and exterior walls without any additional surface finish. Not only did this produce a hygienic and easy-to-clean surface, but it cut down on labour and material costs. The American Terra Cotta Corporation's wall ashlar was advertised as being "particularly well adapted for store fronts, service stations, lobbies, stair halls, corridors, laboratories, etc. where appearance, permanence and sanitation are essential."[47] These wall units were available in a variety of colours. A 1937 advertisement for the Atlantic Terra Cotta Company explained: "the use of color is one of the tenets of modern architecture and Atlantic Terra Cotta can be obtained in any color that may be desired—pastel shades, brilliant faience and rich mottled abbochromes."[48]

Current trends

Outside the United States, the production of hollow clay tile, similar to that used before World War II, has continued. Inside the United States, the use of hollow clay tiles has also survived, albeit in a diminutive form commonly referred to as hollow clay masonry. With nominal dimensions of 11 to 15 inches, a height of up to 4 inches, and a depth of 4 to 12 inches, hollow clay masonry is essentially the same as the wall ashlar used from the 1930s onward. It is most often employed in a glazed form usually referred to as structural glazed facing tiles and used in public corridors, toilet rooms, institutional kitchens, locker and shower rooms, and industrial plants.[49] The same advantages are touted for hollow clay masonry as were touted for hollow clay tiles: good strength, quick construction, design flexibility, low maintenance, high water resistance, and a variety of surface appearances.[50] Structurally, hollow clay masonry is still a vitrified clay product with hollow cells and is made in much the same manner as hollow tiles were. Unlike earlier hollow tile installations, current building codes require hollow masonry construction to be reinforced with steel rebar and grouting filling the voids of the blocks.[51] As the current revival in terra cotta production continues, the use of hollow clay tile may also see a revival.

Conclusion

Conflagrations served as an impetus to develop new construction technology. The first fire-resistant construction relied on all-masonry construction, but produced overly-massive buildings with insufficient floor space. The introduction of structural iron allowed for the maximization of floor space while still being fire resistant. These early structural iron systems relied on brick arches to span the distance between beams, but were neither flat nor lightweight. Hollow clay tile was a superior material in its ability to make flat floors and ceilings while being lightweight and fire resistant.

The manufacture of hollow clay tile was similar to terra cotta and brick; early hollow clay tile used mixed clays while later hollow clay tile employed fire clay. In an effort to make the unit lighter, organic materials were mixed with the clay which burned out upon firing, leaving voids. In its extreme, these voids allowed for nails and fasteners to be driven through the unit without significant damage.

Hollow clay tile was initially used in just floor construction, spanning the spaces between iron beams, but quickly grew to be used in many other applications including walls, foundations, and ceilings. Its role in insulating structural iron, and later steel, was a major reason for its adoption in construction. By the early twentieth century, it became possible to construct a building of almost nothing but steel and hollow clay tile.

Structural hollow clay tile was extremely common from the 1870s to the 1950s. Since its demise, little attention has been paid to this once popular building material until recently. Driven primarily by fears of seismic instability, more research is being conducted into hollow tile construction. In the future, hollow clay tiles may see a revival as their properties are better appreciated in order to complement current construction methods.

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References

1. Sara E. Wermiel, *The Fireproof Building* (Baltimore, MD, 2000), p.105.
2. ibid., p.8.
3. ibid., pp.11-36.
4. Sarah Bradford Landau & Carl W. Condit, *Rise of the New York Skyscraper* (New Haven, 1996), p.19.
5. Wermiel, *Fireproof Building*, pp.12-37.
6. Landau & Condit, *Rise of the New York Skyscraper*, p.29.
7. ibid., p.26.
8. Wermiel, *Fireproof Building*, p.84; Peter Bonnett Wight, 'Origin and History of Hollow Tile Fireproof Floor Construction', *The Brickbuilder*, 6 (1897), p.54.
9. Landau & Condit, *Rise of the New York Skyscraper*, p.27; Wight, 'Origin and History'.
10. Pioneer Fire-Proof Construction Co., *Hollow, Solid and Porous Tile for Fire-Proofing Buildings* (Chicago, 1888), p.8.
11. Wight, 'Origin and History', p.55.
12. Sarah Bradford Landau, *P. B. Wight: Architect, Contractor, and Critic, 1838-1925* (Chicago, 1981), pp.47-8.
13. Wight, 'Origin and History', pp.74, 98-9.
14. John Joseph Cosgrove, *Hollow Tile Construction: A Practical Explanation of Modern Methods of Designing and Building Fireproof Residences of Hollow Tile* (New York, 1921), pp.85-7.
15. Architectural Record Company, *Sweet's Indexed Catalog of Building Construction* (New York & Chicago, 1906), p.90.
16. Hollow Building Tile Association, *Handbook of Hollow Building Tile Construction* (Chicago, 1921), p.4.
17. 'Skeleton Construction. Fireproofing. Foundations', *The Brickbuilder*, 4 (1895), p.13.
18. Wight, 'Origin and History', p.75.
19. Harry Custer Plummer, *Brick and Tile Engineering; Handbook of Design* (Washington, 1950), p.3.
20. Pioneer Fire-Proof Construction, *Hollow, Solid and Porous Tile*, p.7.
21. Plummer, *Brick and Tile Engineering*, p.7.
22. Conrad Paulson, 'Structural Clay Tile' in Thomas C. Jester, ed., *Twentieth-Century Building Materials : History and Conservation*, (New York, 1995), p.155.
23. Frederick Squires, *The Hollow-Tile House* (New York, 1913), pp.23-4; Pioneer Fire-Proof Construction, *Hollow, Solid and Porous Tile*, pp.9-11; Plummer, *Brick and Tile Engineering*, pp.14, 18, 20. Specific problems related to auger and die design are discussed in 'Problems Relating to the Design of Hollow Tile and Brick Extrusion Machines', *The Ceramist*, 8, no. 5 (1926).
24. Pioneer Fire-Proof Construction, Hollow, Solid and Porous Tile, p.10.
25. Plummer, *Brick and Tile Engineering*, p.16.
26. ibid., pp.11-3.
27. Hollow Building Tile Association, Handbook of Hollow Building Tile, p.5; Charles Elmer White & William S. Lowndes, *Hollow Tile Construction* (Philadelphia, 1924), p.4.
28. Hollow Building Tile Association, *Handbook of Hollow Building Tile*, pp.5-6.
29. United States National Bureau of Standards, *United States Government Master Specification for Tile, Hollow, Clay, Load-Bearing Wall. Federal Specifications Board Specification No. 506* (Washington, 1927), pp.2-4.

30. John P. Stecich, 'Analysis and Testing of Archaic Floor Construction', in Stehen B. Kelley, ed., *Standards for Preservation and Rehabilitation*, (West Conshohocken, Pa, 1996), pp.208-9.
31. Martin Marietta Energy Systems Inc. & Structural Engineers Association of Northern California, *Proceedings National Workshop on Unreinforced Hollow Clay Tile: September 21-22, 1992, San Francisco, California* (Washington, 1993).
32. Ahmad A. Hamid, 'Summary of a Decade of Unreinforced Masonry Research at Drexel University', in Martin Marietta, *Proceedings National Workshop,* p.122.
33 Quoted from Plummer, *Brick and Tile Engineering,* p.303.
34. ibid., p.308.
35. White and Lowndes, *Hollow Tile Construction*, p.2.
36. Pioneer Fire-Proof Construction Co., *Hollow, Solid and Porous Tile for Fire-Proofing Buildings*, pp.14-9.
37. Hollow Building Tile Association, *Handbook of Hollow Building Tile Construction*, p.58.
38. Cosgrove, *Hollow Tile Construction*, p.79.
39. Pioneer Fire-Proof Construction, *Hollow, Solid and Porous Tile*, p.48.
40. ibid., pp.22-3.
41. National Fire Proofing Co., *Builders Handbook of Natco Hollow Tile Construction* (Pittsburgh, 1916), p.3.
42. Hollow Building Tile Association, *Handbook of Hollow Building Tile Construction*, p.56.
43. ibid., p.42.
44. Pioneer Fire-Proof Construction, *Hollow, Solid and Porous Tile*, p.23.
45. White and Lowndes, *Hollow Tile Construction*, p.59.
46. Hollow Building Tile Association, *Handbook of Hollow Building Tile Construction*, p.25.
47. Sweet's Catalog Service, *Sweet's Catalog File*, vol. 3 (New York, 1937), p.18.
48. ibid., p.8.
49. Edward Allen, *Fundamentals of Building Construction* (New York, 1999), pp.308-9.
50. KPFF Consulting Engineers & Western States Clay Products Association, *Notes on the Selection, Design and Construction of Reinforced Hollow Clay Masonry* (Seattle, 1997), p.13.
51. ibid., pp.24-6.