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# Journal

## Restoring and Maintaining Archaic Concrete Floor Systems

J. Christopher Clements, AIA

For a building owner, contractor, or design professional, encountering an unfamiliar material can be a terrifying prospect, especially if that material makes up something as fundamental as the floor slab. When we think of a floor slab in modern construction we think of reinforced concrete, ubiquitous and reliable. However, it was not always so. Prior to the ascendancy of reinforced concrete, a number of different materials were used to construct floor slabs: brick, terra cotta, and a group of materials and methods we will call alternative concrete systems.

Hidden in plain sight, archaic floor systems predominated in the late 19th and early 20th centuries, and many are still in service today. This 1910 building, nestled between glass towers, has a cinder concrete roof.

It is this last group that can often be the most puzzling to deal with, as it represents a myriad of approaches without clear modern parallels. Frustratingly, these systems can appear to be a more standard concrete deck until their true nature is revealed through damage or alteration, leaving bewildered contractors and upended schedules. Knowing how to recognize and approach these systems can be invaluable if one is encountered.

### History and Background: Cities Under Threat

Throughout the 1800s, America's increasingly dense cities lived under the threat of fire. While we are used to thinking of fire as a localized issue that threatens at most a few adjacent structures, for these 19th century cities, fires could be a widespread catastrophe, burning huge swaths of the city. Moreover, they were frequent. Major fires occurred in Boston (1872), Chicago (1871 and 1874), and New York (1835 and 1845). San Francisco was the site of seven major fires between 1849 and 1851.

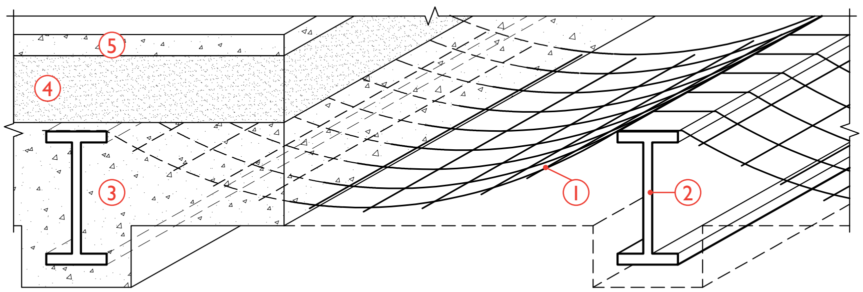
The destruction wrought in this period presented an incredible demand for "fireproof" construction materials. In 1885, New York added a requirement to its building code that any building over 70 feet tall should be "fireproof," and similar language was added to other building codes throughout the U.S. during the 1880s and 1890s. While reinforced concrete would eventually come to dominate as the material for slab construction, it was not yet available. At the time, concrete was thought of as a material for foundations, not structural elements. That concrete was not considered a

*J. Christopher Clements, AIA is Senior Staff Architect with Hoffmann Architects in Virginia. With a background in chemistry and fine arts, as well as an advanced degree in architecture, he brings an understanding of material science and aesthetic harmony to rehabilitation projects at historic and landmark structures.*

## Typical Alternative Concrete Floor Systems

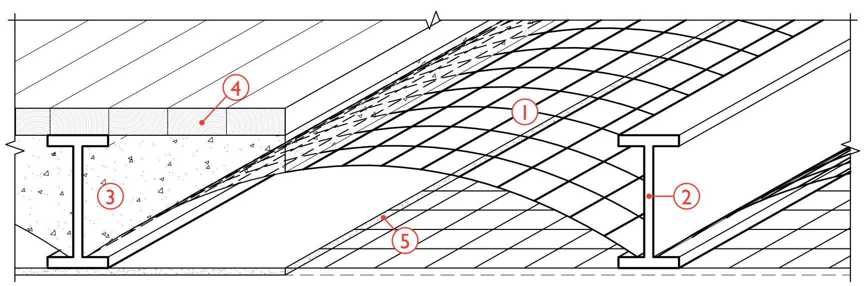
*Late 1800s - Early 1900s*

### Cinder Concrete



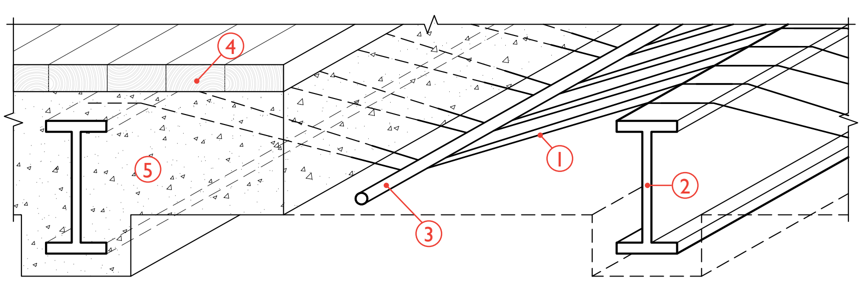

1 Wire mesh
2 Support beam
3 Cinder concrete slab
4 Cinder fill
5 Cinder concrete topping slab

### Roebling System A




1 Stiffened wire mesh
2 Support beam
3 Cinder concrete slab
4 Wooden sleepers
5 Plaster ceiling on wire mesh

### Metropolitan




1 Twisted wire pairs
2 Support beam
3 Hold-down bar
4 Wooden sleepers
5 Plaster of Paris and wood chip slab

suitable material for floor slabs was primarily due to the lack of adequate reinforcement. The twisted steel bars that would eventually develop into modern rebar were only patented in 1884, and it would be several more years before they were used outside of bridges and other engineering works. Without reinforced concrete, there was no easy answer to the challenge of creating a fireproof building material for floors.

This gap in building technology drew in the inventors of the late 1800s in droves, and they developed numerous patented flooring systems, designed to resist fire while carrying the increasingly heavy floor loads brought by industrialization. These systems included terra cotta and brick arches, "filled joist" systems where timbers were paired with fire-resistant materials, and alternative concrete systems. Terra cotta and brick arches, both flat and vaulted, were already in use at the time, but had significant disadvantages. These systems were heavy and thick, taking up a large amount of headroom and adding a lot of weight to the structure. Construction was laborious and intensive, first requiring the construction of a wooden centering, on top of which the arches would then be carefully constructed. Filled joist systems had all the structural downsides of wooden joists, with the added weight of the fill material. The arrival of alternative concrete systems provided far better alternatives, even if the various systems each came with their own challenges and limitations.

## Alternative Concrete Systems: Cinder Concrete

Cinder concrete is one of the most commonly encountered alternative concrete systems and can be one of the most troublesome, due to the unpredictable chemical properties of the coal cinders used in its construction. Patented in 1906 by the engineers A.W. Buel and C. S. Hill, it became one of the dominant structural slab systems from the 1920s to the 1940s, and surviving examples can be found extensively throughout New York City. Cinder concrete had a number of advantages over other systems of the day: high load capacity, excellent fire resistance, low material cost, and ease of assembly.

As indicated by its name, a cinder concrete system is comprised of a cinder fill layer encased on either side by low-strength concrete. This cinder fill was made from the cinder and clinker left over from the burning of coal, an abundant waste product at the turn of the century. Anywhere from four to eight inches thick, this loose cinder layer provided lightweight fire protection.

Cinders would also be used as an aggregate in the concrete itself, a typical mix being one part concrete and two parts sand mixed with five parts cinders. The resultant concrete weighed between 85 and 110 pounds per cubic foot and had a rough, pumice-like texture.

Tensile strength in this system was provided by wire mesh draped between light gauge steel beams. Laid in this way, this arrangement provides tensile support by means of a catenary system, the strength of which is the basis of many of the various alternative floor systems.

Taken together, the cinder fill provides fire resistance and helps distribute the load, the draped wire mesh provides tensile strength, and the concrete topping provides the walking surface, transfers loads to the mesh, and protects the system from water intrusion. In typical installations, the floor would be covered over with wood sleepers and hardwood floors or, in the case of rooftops, with a loose cinder fill sloped to provide drainage.

## Alternative Concrete Systems: Roebling Floors

Introduced in 1892, Roebling floors were one of the earliest concrete floor systems used in the U.S. The various Roebling models were defined by a series of patents held by William Orr for John A. Roebling's Sons corporation, a producer of wire and wire rope. The genesis of these floors came out of a desire to find new markets for wire cloth, one of the products the company produced. By adding small gauge rods into the wire mesh at intervals, Orr produced the stiffened wire cloth that would serve as the basis for the Roebling floor. On its introduction, it was marketed as a lighter and cheaper alternative to the then commonly used brick and terra cotta arches. Two systems were used, System A and System B, with variations made for different building types.

Typically 1 part cement, 2 parts sand, and 5 parts cinders, cinder concrete slabs are structurally unstressed, relying on wires to carry loads.

System A was comprised of the company's stiffened wire cloth arched between I-beams, providing a formwork onto which lightweight concrete was poured. Oftentimes this would be a cinder concrete of the same type used in the floor systems discussed previously. Above this, wood sleepers and fill material provided the base for wooden flooring. Depending on the situation, the arches could be covered by another layer of stiffened wire cloth stretched between the I-beams and covered with an applied plaster coating or left open with the beams themselves coated in concrete. While this might appear to be a reinforced concrete system, it is not and was not intended to be so, as the wire mesh is positioned distinctly outside of the concrete.

System B, while also considered a Roebling floor, was a much different system. In this case, the concrete was reinforced by flat iron bars laid overtop of the supporting steel beams, with the wire cloth again providing formwork; though, in this case, the cloth was not arched but rather laid flat underneath the reinforcing bars. This system could accommodate wider spans than System A, by virtue of its tensile reinforcement.

## Alternative Concrete Systems: The Metropolitan System

The metropolitan system was patented in 1899 by Conrad Freitag. What distinguishes it from other alternative concrete systems is that the binder is gypsum rather than Portland cement. In the metropolitan system, gypsum plaster is mixed with treated wood chips and sawdust as aggregate, then poured between steel beams. As with

## Testing of Archaic Floor Systems

*One of the chief concerns of anyone encountering an alternative concrete floor will always be:* ***"Is it safe?"***

Under intense heat and load for an 1897 empirical test, the Roebling floor, at left, remained intact, while the tile arch collapsed.

To best answer this question, we need to look at the testing carried out at the time these floors were introduced, in itself an informative look back at the history of building codes in the United States.

The most influential battery of tests was carried out by the New York City Bureau of Buildings in 1913, working with Columbia University. Fourteen different types of flooring systems were tested against each other: in the same conditions, using the same methods, and under the supervision of impartial observers. The test involved both traditional brick and terra cotta flooring against novel systems. At the time, there were no standardized tests for material assemblies. These would be the first and would form the basis for testing regimes to follow.

The test protocol was designed to judge fire resistance and was as direct as it was thorough. First, a sample of the floor system was built across four brick walls. The floor was loaded to 150 PSF and, with that load in place, the assembly was subjected to increasing temperatures over a period of five hours, with more than three hours spent at over 2,000°F. After this, the underside of the floor was hosed down with cool water to simulate the action of extinguishing a fire, and additional load was placed on the floor to bring it up to a total loading of 600 PSF. The floors were monitored during testing, and measurements of deflection made at the final stage. The results of these tests proved these new systems superior to established brick and terra cotta floors and spurred their acceptance. ■

Interior of test chamber shows the concrete arch intact and the tile arch after rupture.

PHOTOS: *THE ENGINEERING RECORD*, VOL. XXXV, NO. 1, JANUARY 2, 1897

cinder concrete, tensile strength is provided by wire reinforcement in a catenary arch, though in this case the structural support is provided not by wire mesh but by twisted pairs of wires individually secured and strung between the beams. These wires carry almost all of the load; the thick but lightweight plaster slab predominantly serves as a base for the walking surface and provides fire resistance.

### Alternative Concrete Systems: Other Systems

While these three systems may be the most common of the alternative concrete floor systems, they are by no means the only ones. These systems were typically produced and sold under patent, and this drove diversity of design along with innovation. Many systems exist as slight variations of one another; as an example, one cinder concrete deck was observed to have iron bars laid across the beams in the same fashion as a Roebling System B. General themes are often present: the use of wire reinforcement to provide tensile strength, short spanning distances, and the use of thick slabs to impart fire resistance. Aggregate materials are very diverse, and nonstructural materials are often present solely to impart fire resistance.

### Problems and Solutions

It is important for an owner or building professional to know about the presence of an alternative concrete system, preferably prior to any construction work or even design. While cutting into a slab is the surest way to verify the presence of an alternative concrete system, it is probably the least convenient – or desirable. Severing the wires in these systems can seriously compromise their structural capacity.

Fortunately, there are some markers

to look for that suggest the presence of an alternative concrete system. Building age is perhaps the key initial indicator; any building constructed between 1880 and 1920 has a very good chance of having one of these systems in place, though examples can be found as late as 1950. When looking at the slab itself, the presence of unusual aggregate materials such as sawdust, wood chips, or cinders suggests archaic concrete construction. Damaged areas of the slab may expose reinforcing wires or mesh atypical for modern reinforced concrete, particularly on the underside of the slab where the curvature of the catenary may be visible. Less definitive but easier to observe is slab thickness: an unusually thick slab can be evidence for an alternative system.

These systems can present a number of problems. Relatively thin layers of concrete, like those used in cinder fill decks, can crack easily, and even without cracks the relatively porous concrete mixes used often admit water. Once inside, water can traverse cavities present in the design and saturate areas of loose fill, which then may remain wet for years, conducting water throughout the slab.

When water comes into contact with metal reinforcing materials, corrosion can occur, quickly weakening the slab.

Since damage to wire-reinforced floors may compromise load capacity, invasive probes require experience and planning.

Due to their thin gauge, wire- and wire-mesh-based systems are especially susceptible to corrosion damage, which can quickly impact their strength. To make matters worse, chemicals present in cinder fill or aggregate can produce corrosive compounds, such as sulfuric acid, when mixed with water, accelerating deterioration. It is not uncommon to find wires in compromised slabs that have completely disintegrated, leaving only rust. Even in the absence of corrosive failure, cracking can cause the embedding concrete to lose enough integrity that the individual wires are subject to ductile failure, as loads are not effectively distributed.

One question that can arise when encountering a slab is with widespread failure of tensile wire is: how was it able to continue standing? The answers to this are varied. In many cases, loads are transferred to intact areas of the slab. The large number of tension members (wires) present means that even a failure of numerous wires, provided they are not all localized, need not cause collapse. In many cases, even if a wire has failed at a given point, friction between the wire and the surrounding matrix allows it still to provide some structural function along the rest of its length. Perhaps most crucial to the survival of these floors is that they were designed very conservatively with respect to loads, even by the standards of today, so the loss of some capacity does not necessarily leave them deficient.

While on the subject of structural capacity, it is also important to know how these floor systems are regarded by modern building codes. While not prohibited, these systems stand outside of modern code requirements. Perhaps the best passage to reference in regard to these is systems is the International Building Code (IBC) 1604.4: "Any system or method of construction to be used shall be based

With a pumice-like texture that is rough and porous, cinder concrete uses byproducts of coal as economical, lightweight, fire-resistant aggregate *(left)*. Often, a surface of wire lath was suspended below the beams and coated with plaster to provide a finished ceiling *(right)*.

on a rational analysis in accordance with well-established principles of mechanics." While archaic, these systems are still based in sound empirical design and were subjected to testing equivalent to our standards today.

If code analysis needs to be performed, there are methods available to engineers. In particular, any systems based on catenary action can use well-established statics along with spot measurements to determine wire size and spacing in order to calculate loading capacity. Simplified formulas for this analysis remain part of the building code in New York City today.

Still, there are limitations to the accuracy of these assessments. Damage to the floors can reduce load capacity or fire resistance. Seismic analysis and testing were not part of the original test protocols for these floor systems and may not be possible to evaluate due to the lack of data for particular floor types.

## Restoration and Conservation

Thousands of buildings with these floor systems are still in service today, many over a hundred years after they came into service. Overall, alternative concrete floor systems are best left undisturbed - if in good repair there is no reason to assume that they require replacement. Any repairs or alterations should be made in consultation with a structural engineer, who should undertake a detailed examination of the floor system and its condition.

Localized damage to the slab can simply be patched if supporting wires or other reinforcement is intact. This type of repair will not restore the concrete's structural capacity, but this is not crucial as the wires are the structural elements.

If an area has been weakened through the corrosion or cutting of the tension elements, then restoration will require replacement of the entire span between the supporting beams. As the structure relies on continuous tension from beam to beam, the spanning area of the slab cannot be partially replaced and still function. Additionally, since tension elements may run continuously from one span to the next, the tops of the beams must be fully exposed, and any wires must be tack welded to the beams before they are cut to maintain the integrity of the adjacent spans.

A test cut into this concrete ceiling reveals wire mesh compromised by corrosion.

Alterations to alternative concrete slabs should be made very carefully and will require special details. As cutting into a catenary support system will destroy its load capacity, alternative measures must be taken to support the load between the opening and the adjacent steel beams.

In the case of an alternative concrete system as a roof deck, the existing slab may be abandoned in place if found to be compromised and more limited repairs are impossible. For this procedure, the construction team carefully removes the topping slab and cinder fill, then pours a lightweight reinforced slab into the cavity, spanning between the existing steel beams. As the existing cinder layer can be quite thick and heavy, such a repair can have the ancillary benefit of removing up to 50psf of dead load from the floor.

Unlike a regular slab, loads cannot be hung from an alternative concrete system without careful consideration, as

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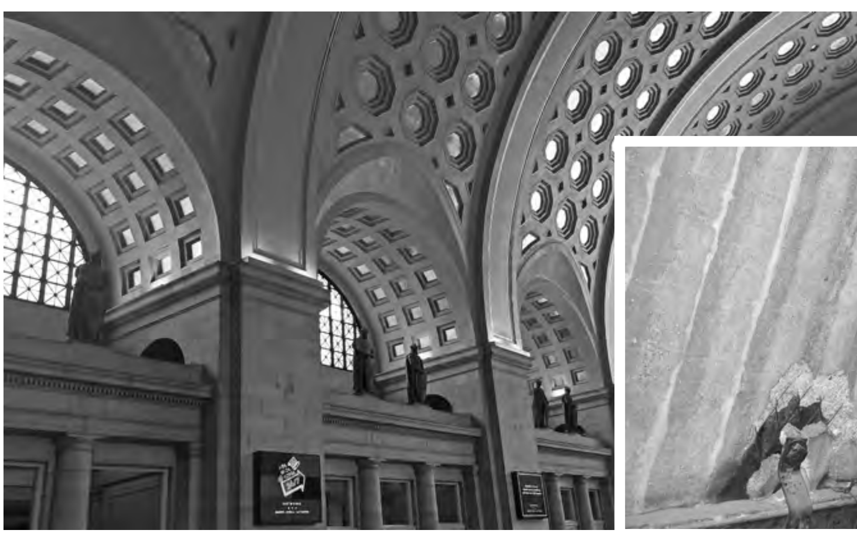

Within this soaring vaulted ceiling lurks an archaic concrete system that has been covered over, making it challenging to access and repair. Note the exposed structural wire mesh where fasteners for the roof were added in the 1980s.

# representative projects

## Archaic Floor Systems

For building owners and property managers, encountering an unfamiliar floor system can raise important questions. What is the best approach to maintain and repair the structure? How should distress and failure be resolved? And above all else: is it safe?

Hoffmann Architects has experience with cinder concrete, metropolitan systems, Roebling floors, terra cotta and brick arches, and many other variations of historic floor assemblies. Our design professionals know how best to assess and restore these archaic systems without compromising structural integrity or historic profiles.

Hoffmann Architects' projects involving the unique floor systems of the turn of the century include:

**Union Station (1907),** Washington, District of Columbia, *Roof and Arch Investigations, Including Cinder Concrete Vault.*

**Columbia University**
**Watson Hall (1905)**
New York, New York
*Roof Replacement and Structural Repairs for Cinder Concrete Floor/Roof System*

**Pfizer World Headquarters (1935)**
New York, New York
*Building Enclosure Investigations and Repairs, Including Flat Arch Concrete Floor System*

**Plaza District Building (Bergdorf Goodman Men's Store) (1930)**
745 Fifth Avenue
New York, New York
*Cinder Concrete Roof Replacement*

**Columbia University**
**Butler Hall (1924)**
New York, New York
*Roof Replacement, with Repairs to Cinder Concrete/Terra Cotta Deck*

**High School for Health Professions & Human Services (1906)**
New York, New York
*Repair of Brick Flat Arch Floor System*

**The George Washington University Corcoran School of the Arts & Design, Flagg Building (1897)**
Washington, District of Columbia
*Building Envelope Rehabilitation, Including Metropolitan Floor System*

**State University of New York Maritime College**
**Fort Schuyler (1856)**
Bronx, New York
*Roof Replacement for Mixed Cementitious Roof Deck*

**Scholastic Headquarters (1890),** New York, New York, *Building Enclosure Restoration, Including Terra Cotta and Cast-Iron Floor System.*

**Open Society Foundations (1910),** New York, New York, *Building Enclosure Peer Review and Rehabilitation, Including Cinder Concrete Roof.*

**Hoffmann Architects, Inc.**
2321 Whitney Avenue
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the slab itself does not have the strength to resist pullout. Existing hangers attached to wire reinforcement may be used with caution. If new hangers are to be installed, they should be attached directly to the steel floor beams. If an element must be placed between beams, a rod can be drilled through the entirety of the slab and the load distributed by a wide flange on the top; however, this should be avoided if possible as it risks damaging tension elements during drilling.

Cinder concrete decks were favored in the 1920s-40s for their load capacity, fire protection, light weight, low cost, and ease of construction.

## Still in Service

As a part of the living history of construction, archaic floor systems exist in many buildings despite having been supplanted by modern construction methods. As a building manager or design professional, it is important to be aware that these systems are in use today, and to recognize if one is in place before attempting repairs, alterations, or construction, to avoid inadvertently damaging the integrity of the structure. However, these historic systems are proven to be safe and durable, and with knowledgeable stewardship will be able to prove themselves reliable well into the future. ■

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2321 Whitney Avenue
Hamden, CT 06518
203-239-6660

462 Seventh Avenue
New York, NY 10018
212-789-9915

2711 Richmond Highway, Ste. 333
Arlington, VA 22202
703-253-9800

www.hoffarch.com

Editor/Production: Alison Hoffmann