Structural Rehabilitation

renovation and restoration of existing structures

Cinder Concrete Slab Construction

By Ciro Cuono, P.E.

The great fires of the 1800s in Chicago, New York, and elsewhere spurred a technology race to develop the best fireproof floor system. The years between the 1870s and 1940s represented a golden age of new technology in structural systems. Cast iron, wrought iron, structural steel and reinforced concrete framing systems, terra cotta arch construction, cinder concrete slabs, and many proprietary systems were introduced during this period. Although now known as "archaic" structural systems, as they are no longer used and have been replaced with modern methods and materials, these systems represent a large portion of our building stock.

Of these varied archaic systems, cinder concrete slab construction became one of the most dominant structural slab systems used from the 1920s to the 1940s. This article explores the origin, history, design, performance and relevance today of cinder slab construction with focus primarily on use in New York City (NYC); however, it was used in many other parts of the country as well.

Cinder concrete slab construction, also known as cinder arches, "goulash" construction, or even "short span arch construction", was a type of reinforced concrete slab system consisting of low strength concrete which used cinders as an economic substitute for stone aggregate and draped wire mesh as reinforcement.

Unlike stone aggregate concrete with reinforcing bars, these systems were not really "reinforced concrete" in the conventional sense but actually tensile structures encased in a light weight low strength concrete. This subtle but key concept can be the source of misunderstanding in dealing with these systems. The steel draped wire mesh acted as a tensile catenary system which carried all loads in tension between steel beams. The cinder concrete provided a walking service, transferring loads to the tension wires and acted as fireproofing protection for the steel wires.

Although this type of system is no longer specified, it is very relevant to engineers and architects today, not only in NYC, but in other cities as well since many of our office buildings, residential buildings, school buildings, industrial buildings etc. are made with these types of floor systems. As a result, it is important to understand their origin, history, performance, strengths and weakness when planning renovations, and repairing defects and deterioration.

History and Origin

Cinder arch construction developed as a result of economic and social forces. As the concrete industry began to develop in the United States (US) in the late 1800s and early 1900s, the key ingredients took shape to form this new type of construction.

Welded wire mesh was first patented in 1901. Although it had a variety of uses, its use took off in early concrete road construction. The early wire mesh was triangular and woven, and then rectangular in shape. From road construction it began to enter the building market where rolls of wire mesh could be easily shipped and rolled out on a job site. The "cinder" part refers to cinder and clinker, by products of coal generating plants, recycled and used to replace more expensive aggregates. The NYC empirical tables referred to "clean boiler cinders" and Anthracite or coal cinders. This incidentally provided good fire resistance which was validated in various tests.

"Draped" mesh refers to wire mesh placed over the tops of steel floor beams and then draped down at the mid-span between the beams, thus creating the "catenary" or "hung chain" which provided optimal geometry for essentially a cable system in tension.

The high load capacity, excellent fire proofing properties, light weight, and ease of construction (rolling out a wire mesh versus laying out reinforcing bars), made these floor systems the primary choice for many engineers and builders. By the 1930s, they seem to have replaced terra cotta arch construction and many other proprietary systems.

It seems most of the testing and early uses in building construction occurred in NYC where many office and residential buildings built prior to World War II are still functioning quite well, the most famous of which is probably the Empire State Building.

Testing, Analysis, and Design

Many tests were conducted in NYC, over several years, as part of the technology race for fireproof floor systems.

One such test was conducted by Professor Ira Woolen at Columbia University in conjunction with the City Building Bureau in 1907 and 1908. The test consisted of a fire, water, and load test of a cinder concrete slab with 5-foot and 8-foot spans and reinforced with triangular wire mesh. The cinder concrete contained "boiler cinders". Specimens were load tested to a compressive strength of 1,000 (pounds per square inch (psi).

The results of the testing were good, withstanding a four-hour fire at approximately 1,700 degrees Fahrenheit and sustaining a 600 psf dead load.

Another significant test, in a series of many tests, was conducted in the summer of 1913 by Harold Perrine of Columbia University in Long Island City, NY. The test consisted of the construction of three types of floor systems; a cinder slab, a flat terra cotta arch, and a gypsum slab (also reinforced with welded wire mesh). The testing, funded by a

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Allowable load

The allowable load shall be determined by the following formula:

$$w = 3CAs/L^2$$

where: **w** = gross uniform load (psf)

As = cross sectional area of main reinforcement (sq. in. per ft. of slab width)

L = clear span between steel flanges in feet. (L shall not exceed ten feet in any case, and when the gross floor load exceeds two hundred psf shall not exceed eight feet)

C = the following coefficient for steel having an ultimate strength of at least fifty-five thousand psi;

1. For lightweight aggregate concrete:
   a. twenty thousand when reinforcement is continuous.
   b. fourteen thousand when reinforcement is hooked or attached to one or both supports.

(1) When the above formula is used the reinforcement shall be hooked or attached to one or both supports or be continuous.

(2) If steel of an ultimate strength in excess of fifty five thousand psi is used, the above coefficient C may be increased in the ratio of the ultimate strength to fifty five thousand but at most by thirty percent.

Figure 1. Excerpt from the 1968 New York City Building code (27-610) showing an empirical formula for cinder slab construction (carried over from earlier versions of the code).

Figure 3.

fireproofing company, was done to compare the fire resistivity of the three types of floor systems. Each was subjected to fire and test loading. The slabs were subjected to four hours of fire that was approximately 1,700 degrees Fahrenheit and then rapidly cooled with cold water, all the while carrying 150 pounds per square foot (psf) of pig iron.

After 24 hours of cooling, the slabs were loaded with further weight. The cinder slab had the best overall performance, with minimal damage from the fire and supporting 600 psf with only ½ inch deflection.

According to Frank Eugene Kidder, (a famous author of engineering handbooks in the early 1900s), some earlier tests conducted in 1902 had 4½-inch cinder slabs load tested to approximately 1,400 psf!

The successful testing and market use led to a codification of cinder floor slabs in NYC. The building code contained empirical formulas for determining slab thickness and wire mesh areas for many years (*Figure 1*).

These "empirical" formulas were essentially based on statics of a tensioned cable. The design became simply a matter of calculating a wire mesh area, or picking out the area from a load and span chart.

The cinder concrete itself was essentially unimportant. If conducting a modern compression core test on one of these slabs, a good result would be in the range of 700 psi – a result woefully unacceptable for a slab that is conventionally reinforced.

Construction

A typical cinder slab mix, often found on many old drawings, might be a 1:2:5 mix (1 part cement, 2 parts sand and 5 parts cinders) ranging in unit weight from 85 pounds per cubic foot (pcf) to 110 pcf. Touching a sample piece of cinder slab in the field feels like a piece of pumice stone. This light weight resulted in a material savings for the steel frames and foundations, making it very appealing as a floor slab system.

A typical slab was 4 inches to 5 inches thick, although 3½ inches thick can be found in many old buildings. Usually the top of the slab is at the beam elevation or just above it. The beams and slabs were then topped with a layer of loose cinder fill, which provided fireproofing to the top flanges. Within this fill layer were beveled wood sleepers, usually 16 inches on center. A hardwood floor could then be nailed to the sleepers. This fill layer was typically 2 inches to 2½ inches thick. At flat roofs, where pitch was required for drainage, the fill could be 6 inches to a 1 foot or more (*Figure 2*).

The wire mesh was draped, as mentioned above, and hooked around the flange of the end or perimeter beams.

The steel beams were encased in concrete for fireproofing. Typical spans ranged from 5 feet to 8 feet.

Performance

The performance of cinder slabs is rather amazing when one considers some of the inherent weaknesses of their design. The demonstrated analytical and historical strength of steel cables is well documented. As an essentially pure tensile structure, there seems to be a robust capacity for overloading. However, the small diameters of the cables or mesh result in a small robustness once there is the susceptibility to corrosion. Roof slabs and slabs near plumbing lines or below wet areas of construction (for example a restaurant kitchen floor) are

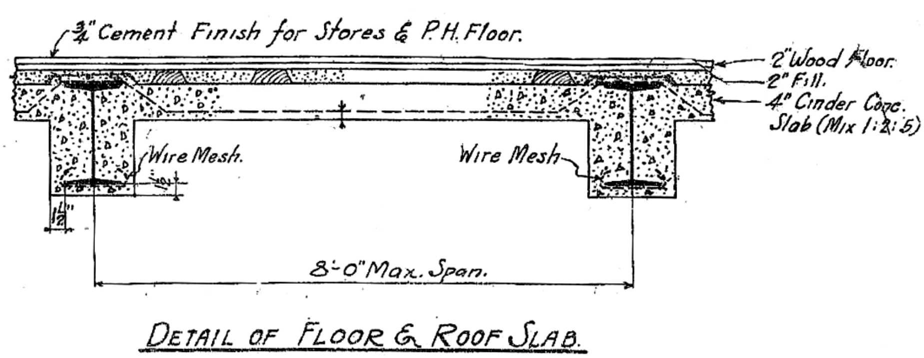

Figure 2.

common sources of leaks. The author has personally observed the underside of slabs that were subjected to long term corrosive environments, resulting in severely spalled slabs. From the floor one may observe the exposed mesh with an obvious rust color; however, upon close inspection one may find the wires severely corroded, snapped, or even completely disintegrated leaving behind a streak of rusting that almost looks like a partially corroded wire (*Figure 3*). One can only wonder how a condition like this has not resulted in a collapse. Perhaps a combination of redistributions at adjacent more fully intact areas, conservative loading requirements, friction, and other "ignorance factors" has prevented more disastrous results. To this author's knowledge, there is no significant documented major failure of these types of floor systems.

The ductility of steel mesh and the obvious signs of spalling have perhaps helped as well, as these signs of impending disaster usually signal a building owner to call in an engineer and provide some type of repair.

Figure 4.

Modern Issues

Since cinder concrete arches are no longer used, it would seem an "archaic" structure. In NYC, however, they are so ubiquitous that a working knowledge of their design and construction is a prerequisite to engaging in renovation work.

The usual issues have to do with either planned renovations, where loading changes and opening or closing of stair, mechanical or elevator shafts occur (*Figure 4*), or repairs due to rusting and corrosion.

Their long history of good use and tremendous load capacity from testing generally makes analysis fairly easy. Armed with a tape measure and a caliper, an engineer can take a few spot field measurements of the wire size and spacing and, in conjunction with the empirical formulas from decades ago, quickly arrive at a safe loading capacity.

Reframing openings can be tricky, since loss of anchorage or continuity of the mesh could theoretically relax the mesh. Many engineers often require contractors to tack weld any exposed mesh to the steel beams, especially adjacent to newly cut slabs.

Repairs are more complicated. Cinder concrete is extremely porous and lightweight. Water from leaks, from old steam lines, or roofs and parapets gets absorbed by the cinder concrete and can stay there for years, slowly corroding the wire mesh. The combination of the cinder aggregates and water can react to create sulfuric acid which, along with poor resistivity of the cinder concrete, can lead to severe corrosion.

The expansion from corroding wire mesh can crack and spall the underside of cinder slabs. Often a small spall is noticed and upon a few "whacks" of a sounding hammer, the entire underside can quickly spall off leaving the rusting wire mesh completely exposed. Caliper measurements can be used to recalculate a remaining capacity, assuming further corrosion is arrested. However, this can be impractical since conditions can vary greatly even in a few bays; thus, a few spot measurements may not give a reliable result.

An overhead repair mortar could be applied to patch the underside of a spalled slab; however, this cosmetic repair will not restore any lost capacity. New low profile steel beams (such as channels, angles, or tubes) can be installed below a defunct slab to reduce the span in lieu of a total demolition and replacement.

On a roof, where the loose fill may be quite thick, this fill can be removed and replaced with a new modern reinforced concrete slab spanning between the tops of the existing steel beams, thus abandoning the old slab in place and using it as form work only.

The creative engineer can find ways of working around a deteriorated slab. Understanding the limits of cinder slab construction is important to this process.

Another issue in modern renovations is hanging ceilings and mechanical units. Cinder concrete is notoriously unreliable with epoxy and mechanical anchors in tension. The original ceilings were often hung with wire that was hooked into an exposed portion of the slab wire mesh. Regular spots of chipped out concrete, exposing the wire mesh, can provide opportunities for easy field measurements. Load testing of anchors for light loads like a gypsum ceiling (say for 4 to 5 times the load) can be used; however, conditions could vary over short distances, making this method somewhat unreliable. The more conservative approach is to hang off the original steel beams, especially for anything heavier than a ceiling.

Renovation and Repair Examples

One example of a renovation of cinder slabs that has been successful is to take advantage of the loose cinder fill atop the structural slab to gain valuable space for new structure. As mentioned, the fill layer on roof slabs (of apartment buildings with flat roofs) was often quite thick; six inches to twelve inches was not uncommon. The removal of 10 inches of loose cinder fill is equivalent to almost 50 pounds per square foot (psf) of dead load. Removal of this dead load could be used to justify new additional dead and live loads, such as pavers for a roof deck. This "load balancing method" is quite convenient, especially if analysis of the existing framing cannot be done due to lack of original drawings and the inability to make destructive probes of the framing. Pitfalls to this method include the lack of an actual engineering analysis (what if the original framing was undersized?) or overestimation of the actual weight as the loose fill could be lighter than historic load tables may indicate. Also, consideration has to be given to fireproofing, as the top flanges of the steel beams were often fireproofed by the loose cinder.

A repair example, also at a roof slab, involved the removal of the loose fill to create a newer stronger conventional reinforced concrete slab that spans between the new beams. This is a convenient methodology where the existing slab is deteriorated. Rather than complete demolition and replacement (which could be more costly, and expose the interior to increased risk from temporary instabilities and the elements), the loose fill could be removed and then a new slab poured atop a thin layer of rigid insulation (to prevent bonding) (*Figure 5*). In an extreme case, where the existing slab was severely corroded, steel plates could be hung from the new slab to "lock-in" the old slab or prevent localized pieces from falling onto the occupants below.

In summary, the dominance of cinder slab systems from the 1920s to the 1940s and their continued successful performance in so many buildings today, despite some pitfalls that have been mostly related to corrosion issues, is a testament to their strength and versatility.▪

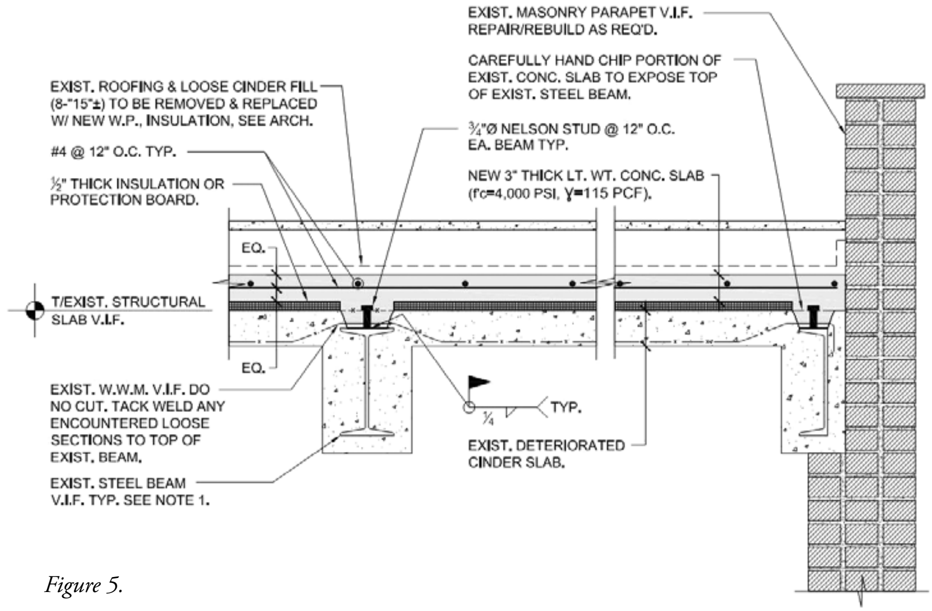

Figure 5.

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