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Opening the Drapes: Shedding Light on Draped-Mesh Cinder-Concrete Floor Slabs

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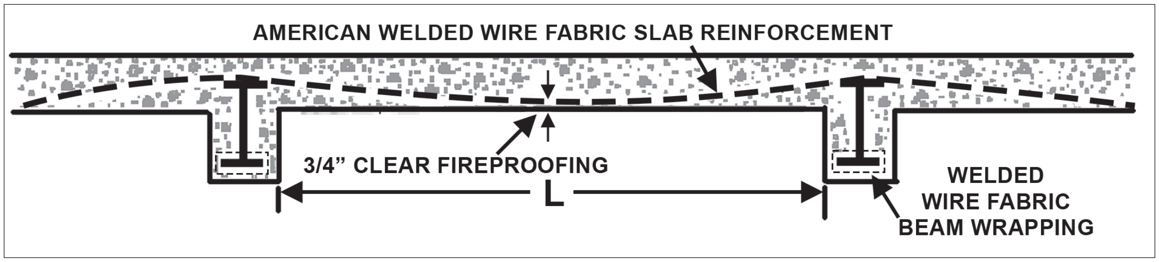

Fig. 1. *Typical draped-mesh cinder-concrete slab construction. All images and figures by the authors, unless otherwise noted.*

The advent of carbon-arc welding in the late 1880s was closely followed by the 1901 patent for welded-wire fabric, also called welded-wire mesh. Although initially used for farm fencing, it was soon used to reinforce concrete floor slabs. In 1908, the American Steel & Wire Company published the *Engineer's Handbook and Catalogue of Concrete Reinforcement*, indicating that these systems began to be used around this time. The catalog described the benefits of draped-mesh cinder-concrete floor slabs (also known as short-span construction or cinder-arch slabs), including speed and ease of placement, thinner and lighter construction, and favorable fireproofing properties. During the 1920s, this new structural floor system became an increasingly preferred alternative to flat-arch terra-cotta floor slab construction. Although initially popular in the construction of high-rise and office buildings in New York City, draped-mesh cinder-concrete floor slab systems spread to other large cities, such as Chicago and Philadelphia, and remained popular until the late 1950s, when they were replaced by concrete-on-metal deck slabs.

Today, many draped-mesh slabs are still in use in early twentieth-century buildings and, if necessary, can be repaired or upgraded during renovations. However, understanding the behavior of this structural system is critical when making modifications. This Practice Point discusses the history of these systems, along with strategies for analysis and modification of draped-mesh cinder-concrete floor slabs, as well as the evaluation and repair of structural distress in these systems.

Draped-Mesh Slab System

A draped-mesh slab is a one-way structural slab system that uses welded-wire mesh draped over the top flanges of cinder-concrete-encased steel beams to reinforce low-strength, cast-in-place cinder-concrete slabs (Fig. 1). Although stone-aggregate-concrete beams and slabs are also reinforced with welded-wire mesh (for example, in beam-and-slab or stone-arch systems), this Practice Point discusses only draped-mesh cinder-concrete slabs that span to cinder-concrete-encased steel floor framing. While the analysis of draped-mesh stone-concrete slabs is similar to the analysis of draped-mesh cinder-concrete slabs, the approach to strengthening stone-concrete systems is different because of their comparatively greater compressive strength. In draped-mesh systems, floor loads are supported in tension via catenary action of the draped mesh within the slab. The catenary action of the draped mesh resists applied vertical loads through axial tension, supporting the slab through tensile stress.

The cinder concrete provides a flat walking surface, transfers the floor loads through the mesh to the steel floor framing, and provides fire protection for the structure.

Innovations in Welded-Wire Mesh

The wires in the welded-wire mesh were produced by drawing hot-rolled rods through a die consisting of a tapered hole with a smaller diameter than the rod. The rods used in this cold-drawing process had an ultimate strength of 70 ksi and a yield strength of 40 ksi (grade 40). The drawing process increased the yield strength to 60 ksi without changing the ultimate strength, giving the wires a higher allowable stress than the rods from which they were drawn; therefore, a smaller steel cross-section could be used to resist the same load. The wires typically met ASTM A82, *Standard Specification for Cold-Drawn Steel Wire for Concrete Reinforcement*.

The mesh was assembled by laying longitudinal steel wires at a close spacing, typically ranging from 2 to 6 inches, and then laying transverse wires perpendicular to the longitudinal wires at spacings ranging from 2 to 16 inches. For the wire mesh styles used for slab reinforcement, longitudinal wire spacings of 2 to 4 inches and transverse spacings of 12 or 16 inches were common, and the size of the wires ranged from 0.135 to 0.31 inches in diameter for longitudinal wires and 0.135 to 0.192 inches in diameter for transverse wires. Note that other wire mesh configurations were produced for use in structural applications other than draped-mesh slabs.

Initially, many styles of mesh were developed, including nonwelded triangular mesh, and many means of connecting the mesh assembly were explored, such as wire staples or wrapping transverse wires around longitudinal wires. However, welding the wires in a rectangular pattern became the predominant style in the 1930s. The welded connections between the wires allowed the fabric to have some rigidity and ensured the proper spacing of wires in the slab. Closely spaced wires allowed for greater crack control in the slab than reinforcing bars with larger spacing. The mesh was often provided in long rolls fabricated to the desired width and could be easily transported and rolled out quickly on site. The long rolls allowed the mesh to be continuously draped across multiple slab bays. The final product met ASTM A185, *Standard Specification for Welded Steel Wire Fabric for Concrete Reinforcement*.

Cinder Concrete

Cinder concrete was developed as a lightweight, economical alternative to stone-aggregate concrete. The typical mix used a 1:2:5 ratio—one part Portland cement, two parts sand, and five parts cinder. In the early 1900s, cinder, or clinker, was a common byproduct of coal-burning manufacturing. By replacing coarse aggregate with widely available cinders, concrete floor systems constructed from cinder concrete became a cheap and lightweight alternative to other prevalent floor systems, such as those constructed from terra-cotta flat arches. Today, existing cinder-concrete slabs can be visually identified by the dark "ash" color of the cinders scattered throughout the concrete. The typical weight of cinder concrete ranges from 85 pcf to 110 pcf. The main disadvantage of cinder concrete is its low compressive strength. The 1938 New York City Building Code (NYCBC) required a minimum compressive strength of 700 psi, but due to variations in concrete field mixing, compressive strength testing of cinder concrete cores has shown that strengths can be as low as 250 psi and as high as 1,000 psi. Because of the variability in compressive strength, it is prudent to perform compressive strength testing of cinder concrete cores at the start of any project. Nevertheless, it was still suitable for use in draped-mesh slabs because the cinder concrete did not function as the primary load-resisting structural element; the applied floor loads were carried by the tensile strength of the wire mesh draped as a catenary within the slab. The cinder concrete's structural function was to transfer the floor loads to the mesh in the span of the slab and then transfer the loads back to the steel beams through shear at the haunches, where the slab met the concrete encasement for the steel beams. Because it was the mesh that primarily resisted the loads, engineers could be less concerned about the quality control, or lack thereof, in the mixing and placement of the cinder concrete.

Assembling the System

After ironworkers erected the steel skeleton, with beams spaced typically at a maximum of 8 feet on center, concrete contractors suspended formwork from the steel beams. The formwork allowed for open space below without the use of shores. This accelerated the pace of construction compared to terra-cotta flat arches, which required temporary shoring below the terra-cotta. Next, workers loosely rolled the welded-wire mesh over the top flanges of steel beams that were upset into the slab, and

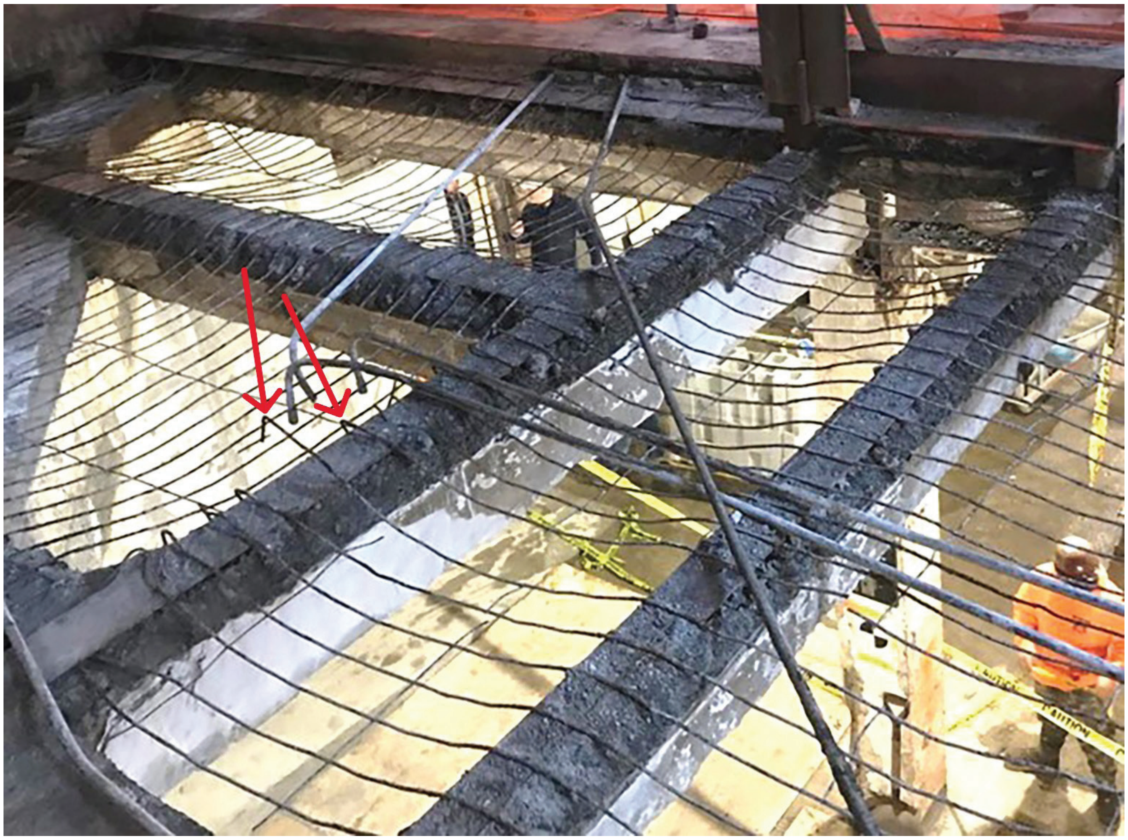

Fig. 2.
Welded-wire fabric mesh, comprising longitudinal and transverse wires, draped over steel beams and hooked around the top flange of a steel beam (see arrows).

the wires draped at a low point at the midspan of the slab with a ¾-inch clear distance from the formwork. To anchor the mesh at the ends of spans, workers hooked the mesh to the edge of the top flange of the steel beam or, sometimes, wrapped the mesh around the steel beam and hooked it to the bottom flange (Fig. 2). Where the mesh was continuous on both sides of steel beams, there was no mechanical connection between the mesh and the steel. The top of the steel floor framing was typically set 1½ to 2 inches below the top of the cinder concrete slab.

The floor slabs typically consisted of a structural slab, a layer of cinder fill, and a concrete topping. The structural slabs were typically 4 inches thick, which is also the minimum thickness generally encountered in the field. Often, lightweight nonstructural cinder fill was placed over the cinder concrete slab. The fill provided a layer of protection for the structural slab, increased soundproofing, and allowed for the placement of nonstructural items such as piping, conduit, and wood sleepers to support the finished flooring. The cinder fill layer was typically 3 to 4 inches thick, although some construction has shown up to 6 inches of fill. A 1-inch cement topping was placed on top of either the fill layer or, in slabs without cinder fill, directly on top of the cinder concrete floor slab. The cinder fill did not contribute to the strength of the slab.

The whole assembly is an example of integral-concrete fireproofing, meaning additional fireproofing assemblies were not required. In New York City at the turn of the twentieth century, draped-mesh cinder-concrete slabs passed fire tests conducted for the Department of Buildings.

Analysis of Draped-Mesh Slabs

In 1913, Columbia University conducted full-scale load testing of draped-mesh cinder-concrete floor slabs. The test results and established formulas for the design of catenaries were synthesized into empirical formulas, which could be used to calculate allowable uniform floor loads in pounds per square foot. The formulas from the load tests were similar to the formulas for catenaries based on statics, in that they are directly proportional to the area of the catenary and inversely proportional to the square of the span. The NYCBC adopted the empirically derived formulas for draped-mesh cinder-concrete slabs in 1916, and they were referenced by the American Steel & Wire publication *Wire Reinforcing Fabric in Buildings* in 1928. As such, the reinforced concrete formulas in the *American Concrete Institute Building Code Requirements for Structural Concrete* (ACI 318) are not applicable in determining the capacity of draped-mesh cinder-concrete slabs.

Over time, these formulas were simplified and incorporated into subsequent versions of the NYCBC, through the 1968 version, as shown below:

$W = 3CA_s/L^2$

Where W is the allowable uniform floor load (lb/ft^2); A_s is the cross-sectional area of wire mesh reinforcement (in^2 per foot width of slab); L is the clear span between steel flanges (ft); and C is a unitless coefficient that varies based on slab composition (i.e., cinder versus stone-aggregate concrete) and reinforcement continuity (i.e., continuous versus hooked or attached to one or both ends). This coefficient can be increased if the strength of the wire mesh exceeds 55,000 ksi. For cinder concrete in which the reinforcement is continuous (i.e., middle bays), C = 20,000; and for cinder concrete in which the reinforcement is hooked or attached at one end (i.e., end bays), C = 14,000.

Due to the reduced strength of the slab at end bays, designers typically specified a double layer of wire mesh to provide similar load-carrying capacity in those areas. While partial-width openings in the adjacent slab bays may allow for continuity of the mesh due to the bearing of the transverse steel wires against the concrete, engineering judgment should be used to determine whether the wires are sufficiently developed into the remaining slab beyond the beam. A conservative approach is to ignore continuity from the bearing of the transverse steel wires, as there is no related code guidance, and to consider the adjacent slab as an end bay with a structural capacity reduced by 30 percent. If the wire mesh becomes discontinuous due to full removal of an adjacent slab bay, large slab openings, or mesh corrosion, the adjacent bay should be considered an end bay.

Floor Openings

Since the American Steel & Wire Company refers to the NYCBC for slab capacity formulas, it is reasonable to look at the NYCBC for guidance on allowable floor opening sizes. In the initial versions of the NYCBC, unframed floor openings were limited in size to 2 square feet. In the 1968 version of the NYCBC, this provision was modified to read: "Openings more than 1'-6" on a side shall be framed. All areas encompassing multiple openings aggregating more than 1'-6" in any 10'-0" width or span of floor or roof slab shall be framed." Cutting the wire mesh at an opening releases the tension in the wires responsible for the catenary action, and the ability of the reinforcement to support the load in the bay of the opening is lost. Within the bay of the opening, additional slab strengthening—beyond that needed to frame the opening—in the form of new, closely spaced (approximately 2 feet on center) steel beams or channels may be required if the remaining slab on either side of the opening cannot span the distance between steel framing when analyzed using provisions for plain concrete.

When the wire mesh is cut, the continuity or anchorage of the wire mesh reinforcing may no longer be considered continuous for the bays adjacent to the bay of the opening. When there is a change in continuity, engineers need to analyze the strength of adjacent bays, applying a 30 percent reduction in strength, and determine if supplemental slab reinforcement is required in those bays. If the slabs do not have sufficient strength, it is often adequate to add a steel beam at the midspan of the bay (Fig. 3). This beam can be designed to augment the strength of the floor system by relying on both the catenary action of the draped mesh and the capacity of the cinder concrete to span as plain concrete between the concrete-encased existing beams and the new beams at the midspan of the slab. Strengthening the slab from below can be accomplished with relatively shallow beams, making it a lightweight solution. However, installing the steel

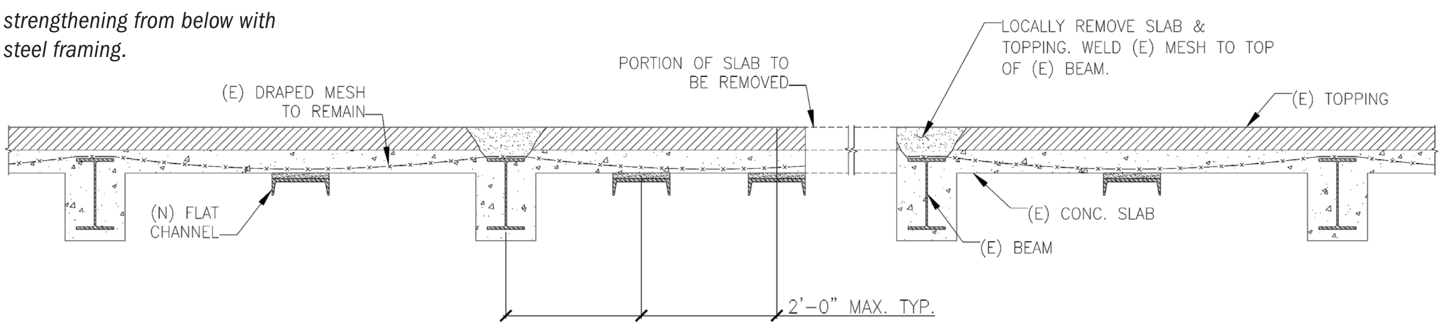

Fig. 3.
Schematic detail for slab strengthening from below with steel framing.

connections can be challenging if the existing steel has a high carbon content and is not suitable for welding, even with preheating.

Prior to creating any new slab openings, it is good practice to install temporary shoring beneath the adjacent slab bays due to the loss of reinforcement continuity. Additionally, before creating the openings, the contractor should remove the cinder fill and cinder concrete over the top flanges of the existing steel beams on both sides of the opening, for the full width of the opening (Fig. 4). The mesh should then be welded to the existing steel beams, using welded steel shims as needed to fill any gaps between the existing steel and the mesh. Welding the mesh anchors it so that the adjacent bays retain catenary action despite cutting wires to make the new opening. Since the weldability of the mesh and the steel may vary, it is important to test their chemical compositions prior to making new openings. It is critical that, prior to the start of the job, the contractor understands the steps that are required for the creation of new floor openings so that additional supplemental slab reinforcement or additional slab demolition is avoided.

It is also worth discussing the 1968 NYCBC provisions related to openings early in the design process with the architect and mechanical engineer, as a thoughtful layout of openings can greatly reduce the need for supplemental steel and slab reinforcement. If many openings are required, grouping them together allows them to be framed together rather than separately. Sometimes, by shifting an opening into an adjacent bay, the required supplemental steel can be greatly reduced.

Slab Strengthening

If the existing draped-mesh cinder-concrete slab does not have sufficient capacity to support increased floor loading, strengthening from below with steel framing is an

Fig. 4.
Exposed mesh at the top flange of an existing beam after removal of cinder fill.

option for localized areas. If large areas of the slab are affected, if head height is an issue, or if the existing steel is not weldable, topping slab strengthening should be considered. For this approach, a new lightweight concrete slab typically replaces the layer of cinder fill, which typically has depths between 3 and 6 inches (Fig. 5). Since cinder fill can vary in consistency—from loose to hardened depending on the amount of cementitious material mixed with the cinders—removal can be quick and easy or laborious. In either case, the contractor should carefully remove the fill to avoid damaging the existing slab. The new topping slab, placed directly on top of the existing slab, is usually designed to support all superimposed loads and span from beam to beam, essentially bypassing the cinder-concrete slab, which serves only as a permanent form. Cinder fill has a lower density than lightweight concrete, and replacement of the fill with a concrete topping slab will generally increase the floor dead loads. For any increases in dead and live loads,

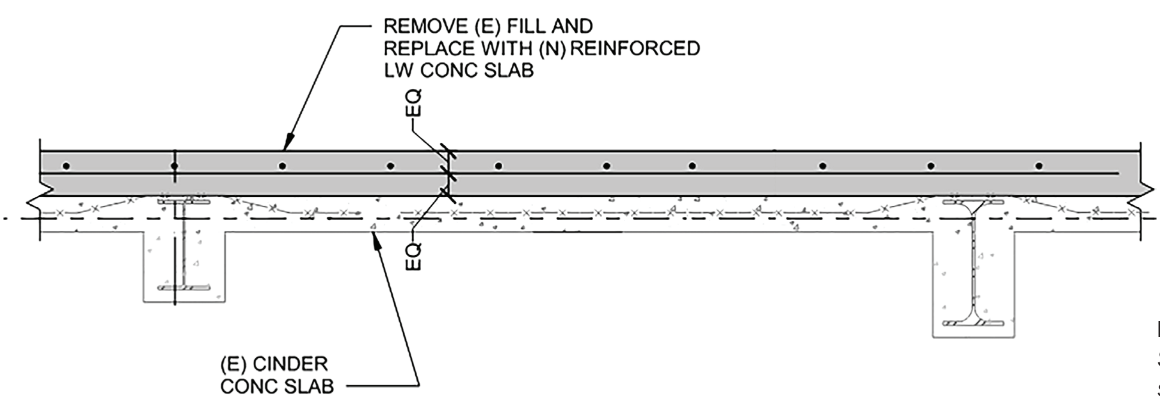

Fig. 5.
Schematic detail for topping slab strengthening.

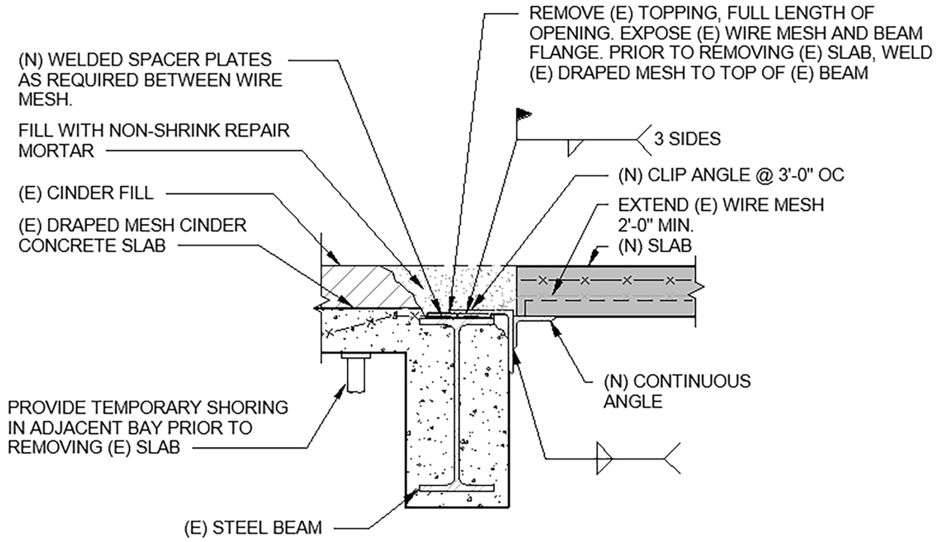

Fig. 6.
Schematic detail for supporting new concrete-on-metal deck slab at existing steel beam

the existing steel beams and their connections must be analyzed and strengthened if necessary.

Sometimes, the fastest and easiest option will be demolition of the structural slab and replacement with a new concrete-on-metal deck slab (Fig. 6). This option can often provide increased slab capacity without increasing the weight on the existing steel framing. The upset elevation of the existing steel should be considered, and deck-support angles can be used to adjust the top-of-slab elevation. It is important to consider the slabs in the adjacent bays at the edges of the demolition. This option is best suited for situations where demolition does not create new end bays (i.e., the slab spans in adjacent bays change direction or the adjacent bay is already an end bay). When a new end bay is created, the demolition sequence outlined above should be followed, and adjacent bays may still require strengthening.

Deterioration: Repair or Replace?

While many damaged draped-mesh cinder-concrete slabs can be salvaged, exposure to moisture over time can lead to severe deterioration. Visual condition surveys typically identify widespread spalling and cracking of the concrete and exposed mesh, and hammer sounding of the slab can be used to identify concrete delamination (Fig. 7). In addition to a visual survey, exposed mesh should be observed up close and measured to determine whether it has lost substantial cross section (Fig. 8). Sometimes the wires become embrittled and weakened to the point that they can be easily snapped by hand. Other times, signs of corrosion of the wires from afar may actually be staining left on the slab as a byproduct of corrosion where complete section loss of the wire has occurred (Fig. 9). In that case, the unreinforced concrete slab will likely require strengthening or replacement. Again, adjacent bays must also be analyzed for their reduced capacity as end bays and strengthened if needed. In many cases where the slab is substantially deteriorated, it will make most sense to demolish and replace it.

In cases where there is concrete spalling at the underside of the slab and no deterioration of the mesh is observed, the slab can be repaired with a partial-depth repair detail. Helical anchors can be set into the existing slab at the spall, and formwork can be installed. A repair mortar can either be placed from a core at the topside of the slab or pumped into the spall from the underside.

Fig. 7.
Delaminated and spalled concrete and exposed, corroded wire mesh at underside of slab prior to hammer sounding.

Fig. 8.
Close-up view of corroded and snapped mesh at slab underside.

Fig. 9.
Corrosion staining and complete section loss of mesh at slab underside.

For repair of deeper concrete spalls or the infill of slab penetrations (both typically limited to 1 foot 6 inches by 1 foot 6 inches unless additional analysis is performed), the slab can be repaired with a full-depth repair detail. This repair detail can only be used when there is an existing cinder fill that can be removed to an area 3 inches wider than that of the opening on all sides, creating a "shelf." Deformed bars can then be placed on the shelf, and repair mortar can be placed to fill the void. The described detail relies on the bearing of the deformed bars and concrete infill on the existing structural slab around the perimeter of the opening. Note that while this detail reestablishes the concrete slab, it does not repair the loss of catenary action in the slab.

Conclusion

While the conditions on each project may vary, understanding the history and behavior of the draped-mesh cinder-concrete floor system will enable designers to strengthen and preserve existing draped-mesh slabs that remain in good condition. Disseminating this information on slab behavior and the implications of slab demolition and modification at the start of the project can allow for thoughtful and strategic modifications that minimize the amount of slab strengthening required on a project. Further research could determine the timeline and extent of this system's spread beyond New York City.

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