REPAIR OF DRAPED MESH CONCRETE SLABS

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Draped mesh concrete slabs (supported by hot-rolled steel beams and girders) were one of the most prevalent one-way floor slab systems used in buildings constructed from the 1920s to the 1960s. These slabs consist of draped, welded wire reinforcement embedded in cinder-concrete (occasionally stone-concrete) that span between closely spaced steel beams. These slabs are not analyzed using current (modern) reinforced concrete design methods. As a result, modifications and repairs to these slabs require special knowledge of both their structural behavior and material properties.

Fig. 1: Typical method of mesh anchorage where welded wire reinforcement is bent and hooked around beam flange

Fig. 2: Perimeter of repair where existing reinforcement extends uninterrupted through repair area

HISTORY

Structural steel design had become fairly developed by the late 1880s, but reinforced concrete design was still evolving at that time. The disparity between the stages of development of the two materials became particularly acute when considering a floor system for newly developed mid-rise and high-rise steel-framed buildings. Typical early floor systems that spanned between steel beams were thick, heavy terra-cotta or brick arches covered with a relatively thin concrete topping and occasionally a layer of lighter-weight cinder fill sandwiched between the arch and the topping. These traditional, true-arch approaches slowly gave way to thinner and lighter proprietary reinforced concrete systems that acted structurally in catenary or beam action. As building heights increased (with greater knowledge and confidence in steel design), more developed concrete flooring systems became necessary.

During the 1920s through the 1960s, draped mesh cinder-concrete slabs were common because they used a lightweight, controlled-strength concrete that incorporated cinders, a readily available waste product of coal combustion. These slabs occur throughout New York City and other older urban areas where coal was burned throughout the city to provide heat and electricity. The Empire State Building, Chrysler Building, and Rockefeller Center are just a few of the many iconic buildings in Manhattan that use draped mesh cinder-concrete slabs. In the mid-1960s, however, as coal burning within cities was phased out and metal decking was becoming accepted, normalweight or lightweight concrete-on-composite-metal-deck slabs began to replace draped mesh cinder-concrete slabs as the preferred method for steel high-rise floor framing.

STRUCTURAL BEHAVIOR

Draped mesh slabs differ from modern reinforced concrete slabs because the steel welded wire reinforcement acts in one-way catenary action rather than in flexural action. At the high point in the slab, the welded wire reinforcement rests atop the steel beams (which are upset into the slab), then drapes down to a low point near the bottom of the slab at midspan. The welded wire reinforcement is placed continuously across several spans, often across the entire floor plate, and acts only in tension (behaving primarily like the main cables of a suspension bridge). To achieve the necessary structural capacity, the welded wire reinforcement needs to be continuous across all beams and anchored at the end spans (Fig. 1 and 2). As a result, any damage, deterioration, or intentional modifications to the slab must consider a means to maintain the continuity of the welded wire reinforcement, or provide alternative anchorage and/or supplemental supports. The concrete encases and bonds to the welded wire reinforcement and acts as a controlled-strength fill to transmit loads to the reinforcement. Because the concrete does not need to act fully as a structural material, its required strength is typically very low. Therefore, due to the availability of cinders to use as aggregate, cinder-concrete became the most common material used in these floor systems.

In 1896, the New York City Department of Buildings and Columbia University began a program to qualify and standardize some of the most common flooring systems. At that time, reinforced concrete design included numerous competing proprietary systems. They tested various floor systems for their load-carrying capacity and fire resistance. Specifically, tests for draped mesh cinder-concrete floor slabs took place at Columbia University between 1913 and 1914. These tests culminated in empirical formulae that were incorporated into the 1916 edition of the New York City Building Code (NYCBC). An example of the 1916 formulae for the design of concrete slabs in new construction is summarized as follows:

$$W = \frac{3CA_s}{L^2}$$

Cinder or stone concrete load-carrying capacity where W is the total load, in lb/ft^2; A_s is the area of steel, in in.^{2}/ft; L is the clear span, in ft; and C is the coefficient prescribed by the Code (varies for reinforcement, concrete type, and anchorage).

These formulae were included through the 1968 version of the NYCBC (which was in use until about 2008).

MATERIAL PROPERTIES

In addition to load-carrying capacity and fire resistance, Columbia University also evaluated the corrosion protection provided by the cinder-concrete. Their tests concluded that corrosion of the embedded welded wire reinforcement was prevented, as long as it was thoroughly coated with the cement mortar portion of the concrete. Despite the tests, other sources from the period questioned whether the acidic cinders would reduce the passive protection that concrete typically provides (through its inherently high pH) against corrosion of steel reinforcement. The literature of that time concluded that if the cinders were of good quality (typically completely combusted anthracite coal) and the concrete was proportioned and mixed properly, the cement paste should continue to passivate the corrosion reaction. The sources indicated that corrosion-related issues may exist, but they would likely be a result of the quality of the materials, mixing, or workmanship, and not with the composition of cinder concrete in general.

REPAIR METHODOLOGIES

Draped mesh cinder-concrete slabs have been repaired or strengthened due to deterioration (corrosion of the reinforcement and deterioration of the concrete resulting from exposure to water/moisture over time) (Fig. 3 and 4); due to damage (physical

Fig. 3: Deterioration of slab due to corroded reinforcement at slab underside

Fig. 4: Close-up view of corroded reinforcement at slab underside

Fig. 5: Partial-depth and full-depth slab damage from finish removal during a tenant fit-out

Fig. 6: Existing poorly executed repair made at a full-depth penetration

Fig. 7: Partial-depth slab damage where a wire of the reinforcement was exposed and used for supporting a hanger

damage revealed during tenant fit-outs) (Fig. 5 through 7); and for change of use (alterations due to change in occupancy or change in loading). Several typical and often-encountered repair methodologies are discussed in the following sections .

Note that this discussion of repairs to one-way draped mesh slabs will employ the terms "end span" and "adjacent span." In this context, an end span is the last span of a repair area that is directly adjacent to an existing, unmodified draped-mesh span. An adjacent span refers to an existing, unmodified draped mesh span that is adjacent to a repaired span.

PARTIAL-DEPTH REPAIR

Partial-depth repairs are the simplest type of draped mesh slab repairs and are commonly required when the reinforcement corrodes near its low point (at the middle of the span) or from shallow concrete damage that occurs during tenant fit-out renovations. Partial-depth repairs are relatively simple as long as the reinforcement has limited section loss, it remains anchored, and the required depth of repair into the slab cross section is limited. This type of approach usually involves repairing a small area, sometimes less than 3 in. (75 mm) diameter. Yet, in some instances, these repairs can include replacing the bottom cover of an entire span or infilling an area at the slab topside (Fig. 8). Other special instances of partial-depth repair can involve forming and pumping repair material in a localized area of deterioration at the underside of finished floors in occupied space.

Partial-depth repairs typically start with carefully removing the compromised cinder concrete, using hand methods, to expose the welded wire reinforcement and prepare the substrate. Power tools are not recommended for this work because of the brittle and unpredictable nature of cinder concrete. Furthermore, care should be taken during selective demolition to avoid loosening the reinforcement from the underside of the cinder concrete, and to avoid disturbing the bearing of cinder concrete onto the reinforcement. In every case, exposed reinforcement should be cleaned, examined for section loss, and coated with a corrosion inhibitor. In smaller areas where an individual wire of the reinforcement is exposed locally, the most common approach is to repair the area with a suitable trowel-applied overhead repair material. At locations where the corrosion of the reinforcement is widespread but the remaining cross section is still sufficient and the bearing of the cinder concrete on the reinforcement is not compromised, a new layer of expanded metal lath can be mechanically anchored to the underside of the slab and a new layer of repair material (troweled, shot, or formed and pumped), for fire and corrosion protection, can be applied. At locations where the cross section of the reinforcement is significantly reduced, full-depth, topping slab, or supplemental support repairs are required.

TOPPING SLAB REPAIR

Topping slab repairs can either be bonded (act compositely with the existing draped mesh cinder-concrete slab) or unbonded (where an independently supported slab is installed over the existing slab). Whenever a topping slab is added, or other significant changes are made to the permanent dead loads, the steel framing supporting the slabs should be evaluated.

For bonded topping slab repairs, the existing slab remains intact, and the continuity and anchoring of the draped reinforcement is usually not affected. Bonded topping slab repairs can supplement the strength of the existing slab for additional loading, or can be used to supplement the stiffness of the existing slab for new finishes that require low deflection (such as large floor tiles). To start a topping slab repair, the existing finishes, previous toppings, cinder fill, or other layers placed over the existing slab are removed. This is often beneficial because it removes the excess dead load from the system, and may achieve the desired ceiling heights. Next, the top surface of the cinder concrete of the existing slab is prepared to act as a substrate for the new repair material. Other than surface preparation, there is very little selective demolition of the existing slab, and exposed reinforcement is typically treated in a manner similar to a partial-depth repair.

Because bonded topping slab repair relies on composite action between the topping and the existing slab, and due to the low strength of the cinder-concrete slabs, direct-tension pulloff tests should be performed after the topping slabs have achieved sufficient strength. The results of these direct tension pulloff tests that evaluate the bond strength between the existing slab (substrate) and new topping slab can be used to correlate the available shear strength at the bond line between the topping and existing slabs. Without a proper bond, the needed composite action cannot be achieved.

Unbonded topping slab repairs can be installed over a damaged existing slab but are not always feasible if an increase of overall strength of the system, including the steel framing, is needed. The unbonded topping slab acts as an independent structural member that either replaces or upgrades the capacity of the existing slab and bears on the existing steel beams through the existing cinder-concrete slab. The existing slab is used only as a permanent formwork, and it is not relied upon for strength (other than the bearing stresses from the topping slab at the beams). If the cinder-concrete is in good condition but the welded wire reinforcement is severely corroded, the existing slab can remain in place below the new topping slab, provided that it can support its self-weight unreinforced. Less-deteriorated slabs can typically remain in place. In most instances, existing finishes, previous toppings, and cinder fill are removed for an unbonded topping slab. If the thickness of cinder fill is greater than the thickness of the topping slab, layers of rigid polystyrene can be installed to act as lightweight filler and to achieve the desirable finished-floor elevation (Fig. 9).

Fig. 8: Selectively demolished partial-depth repair area at top of slab

Fig. 9: Unbonded topping slab repair area (with foam filler) adjacent to full-depth repair area on composite metal deck

Topping slab repairs typically incorporate additional reinforcement. Unbonded topping slab repairs must be reinforced to provide the required flexural strength. However, it is possible for bonded topping slab repairs to be reinforced for shrinkage and crack control only. After installing reinforcement, either prepackaged repair materials (typically extended with aggregate) or ready mixed concrete can be used to place the topping slab.

FULL-DEPTH REPAIR

Full-depth repairs are required when the existing slab is severely deteriorated and can no longer support the required loading. To maintain the catenary action, the existing draped mesh must either be continuous, without modification throughout the repair span, or be anchored to the steel beams at the adjacent spans (Fig. 10). Usually, the welded wire reinforcement in the repair span is highly corroded, and continuity through the repair span is not possible. Thus, welding of the wire reinforcement to the steel beams at the edge of the repair span may be the only option, and new reinforcing is required for the design of the full-depth repair.

The procedure for a full-depth repair often starts with installation of temporary shoring in adjacent bays, placed as a precaution until the wire reinforcement can be properly anchored. Additional shoring, placed in the bays designated for replacement, is used as a work platform for demolition and to assist with formwork installation. Demolition proceeds with a saw cut at the repair perimeter, typically located over the centerlines of beams and girders. The depth of saw cut should not cut or damage the welded wire reinforcement and/or beam flange. Initially, demolition with small electric rotary or pneumatic hammers can remove the bulk of the cinder concrete at the center of the slab. Finally, selective demolition with hand tools is performed to remove the remaining cinder concrete within about one foot of the saw-cut perimeter. The extent of demolition and condition of the remaining cinder concrete, beams, and reinforcement are reviewed, and further action taken if necessary, prior to proceeding with installation of the new slab reinforcement. Once the new reinforcement is installed, ready mixed concrete or prepackaged repair material (typically extended with aggregate) is placed.

Fig. 10: Full-depth repair area with existing reinforcement and new additional reinforcement placed on wood formwork

Fig. 11: Closely spaced channels of supplemental support repair (shown after spray-on fireproofing was applied)

SUPPLEMENTAL SUPPORT REPAIR

At locations where a full-depth repair is performed but the reinforcement in an adjacent span cannot be properly anchored, it may be necessary to support the adjacent spans by providing supplemental supports (Fig. 11). In situations where the reinforcement's ability to carry load in tension through catenary action is interrupted due to lack of anchorage, closely spaced steel channels can be installed at the underside of the slab, parallel to its span, and connected to the existing steel beams. These new channels are sized and spaced to carry the self-weight of the slab and any superimposed loads. The slab can then be analyzed to span as plain concrete perpendicular to the new channels (parallel to the beams) using conservative material strength assumptions. In some cases, steel plates can be installed directly below that slab to act as a deck between the new channels. After the new steel is installed, the space between the underside of the slab and the top of the new steel is pumped or dry-packed with a nonshrink grout.

CONCLUSIONS

When working in major cities with steel-framed buildings built in the first half of the 20th century (1920s through 1960s), it is important to understand and consider the type of concrete floor system (and concrete material), as well as its limitations and available remedial options, before embarking on implementation of any repair or strengthening work. If the existing floor slab is a draped mesh system, it is important to work with a structural engineer and a contractor who are experienced with this type of floor system. Remedial options are often limited and are governed by the behavior and material characteristics of the system. Even the smallest modifications (such as removing a small portion of a span for a new opening), if not planned and executed properly, can compromise the structural integrity of the floor over many bays. Providing adequate protection or shoring, and avoiding additional, unintentional damage, are equally important during the repair of these fragile systems. Proper experience and knowledge of cinder-concrete material characteristics and draped mesh concrete slab design are paramount to the repair of these floor systems.

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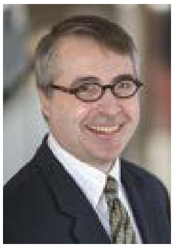

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