

# Bonded concrete toppings

Tips for bonding topping slabs with precast concrete construction

By Charles H. Rath, S.E., and Kurt R. Hoigard, P.E.

**S**ince the inception of precast concrete products, concrete topping slabs from 2 to 4 inches thick have been used with structural precast concrete members. Typically, the intended purpose of the additional concrete is to produce composite behavior of the topping slab with the precast member. The most common composite topping slab systems are constructed with precast concrete members, such as hollowcore, solid planks, and tees, and rely on bond only. Unfortunately, planned composite topping slabs are not always successful where bonding is the sole means used to structurally connect the topping slab to the precast concrete component.

The writers are aware of major projects where specified topping slab composite systems failed to develop the required long-term bonding, resulting in systemic disbonding throughout the project. The topping slab bond failures — on a parking garage, two stadiums, and a penal facility — required expensive remedial work to remove and replace the topping slab and could have been avoided if the designers and contractors had increased knowledge on factors influencing topping slab bonding.

Topping slab disbonding, when it occurs, it is often the result of generalized specifications, drawing notes, and plan details that do not clearly define a "composite" condition; lack of specific requirements for the precast concrete member (or substrate) top surface finish; inadequate or omitted topping slab pre-placement procedures; incomplete material specifications for the topping slab concrete; and insufficient or omitted prescriptive step-by-step methods for placing the planned composite topping slab. Also, bonding failures can result from contractors not following specifications and/or using poor construction practices. An

additional problem facing the bonded-topping-slab-precast-concrete system is the common use of divided design responsibility. The actual designer of the composite system is typically not the project architect or structural engineer but rather is the precast concrete supplier engineer, who has no control over any of the concrete topping slab requirements or integration of the topping slab and precast concrete units with other aspects of the planned construction. All of these various events too often result in the construction of a bonded topping slab system being an uncontrolled activity and will be discussed below.

## Bonded systems

Bonded topping slabs are used for both structural and functional reasons. Figure 1 illustrates bonded composite conditions. One structural reason for having a bonded system is to make the topping slab a part of the structural cross-section through composite behavior. By using a bonded composite system, additional superimposed load capacity can be developed without needing larger precast concrete members or additional

reinforcement. An added benefit of the composite system is an increase in flexural stiffness, which reduces short- and long-term deflections, and undesirable vibration responses. In addition, a bonded topping slab assists in distributing concentrated loads on a given precast concrete member to adjacent members.

Another important use of a bonded concrete floor or roof system is to act as a structural diaphragm. The topping slab, acting together with the precast concrete units, produces a stiff structural diaphragm that transmits in-plane lateral loads to shear walls or moment frames. Bonding of the topping slab diaphragm prevents localized topping slab upward buckling displacement as a result of compression or shear loading. In-situ application of the topping slab provides a convenient means to make connections between the diaphragm and other lateral load resisting elements. Commonly, inserts are cast into the lateral load resisting element into which coarsely threaded rods are placed and then encased in the topping slab concrete. Sometimes projecting rebars, instead of inserts and coarsely threaded rods, are employed for the load transfer connection.

In addition to the structural benefits, concrete topping slabs are frequently used for functional benefits such as in exterior structures exposed to the elements where the topping provides both drainage profiles and waterproofing. The use of topping slabs for waterproofing requires complete assurance that the topping slab will be composite, since disbonding would provide water with a pathway between the topping slab and the top surface of the precast concrete substrate. Moreover, if topping slab disbonding occurs, it typically leads to the development of excessive cracks in the topping slab, allowing additional water to penetrate into the open interface at the precast concrete top surface. Precast concrete substrate members are most likely to be prestressed. Prestressing causes camber that can influence the drainage profile, and it may require some of the topping slab to have a greater thickness than the nominal design value.



## Slab disbonding

Disbonding of the topping slab from the precast concrete member can lead to a variety of unwanted problems, which can create the need for expensive and inconvenient remedial work. Some of the problems resulting from disbonding include the following:

- loss of flexural capacity due to the decrease in the cross-section depth;
- creation of hollow sounds from footsteps or traffic from the interface gap between the topping slab and the precast concrete;
- development of excessive topping slab shrinkage cracks;
- curling of the topping slab at cracks (particularly at crack locations above precast-to-precast member joints);
- development of reflective cracks in flooring materials that are adhered to the topping slab;
- loss of rebar or mesh engagement within the topping slab where the reinforcement has little or no concrete cover at the topping slab bottom (particularly where reinforcement is placed too close to or directly upon the precast concrete unit top surface);
- leakage through the topping slab cracks, which permits water migration via the disbonded interface to areas below the floor or roof system;
- corrosion of topping slab reinforcement (resulting from improper cover at the topping slab bottom and water leakage);
- corrosion of precast concrete embeds (when water is present in the disbonded interface); and
- damage from freeze-thaw to the topping slab bottom and the precast concrete top surface (which can occur when water is within the disbonded interface). This is a serious problem for non-air-entrained topping slab and precast concrete members.

## Substrate surfaces

Surfaces of the bonded topping slab substrate can be made smooth or have a purposely roughened profile. Smooth surfaces are most often produced by a precast concrete fabricator as part of its normal finishing methods. In fact, the extruded manufacturing process for most hollowcore slab units results in a smooth surface. Smooth finishes for other precast concrete members are typically created by screeding and floating the precast concrete's top surface at the time of its production. A roughened top finish can be fashioned by mechanically raking the surface during fabrication, scoring or grooving

the precast concrete member top surface at the time of extrusion, or sometime later by mechanically scarifying the already hardened top surface.

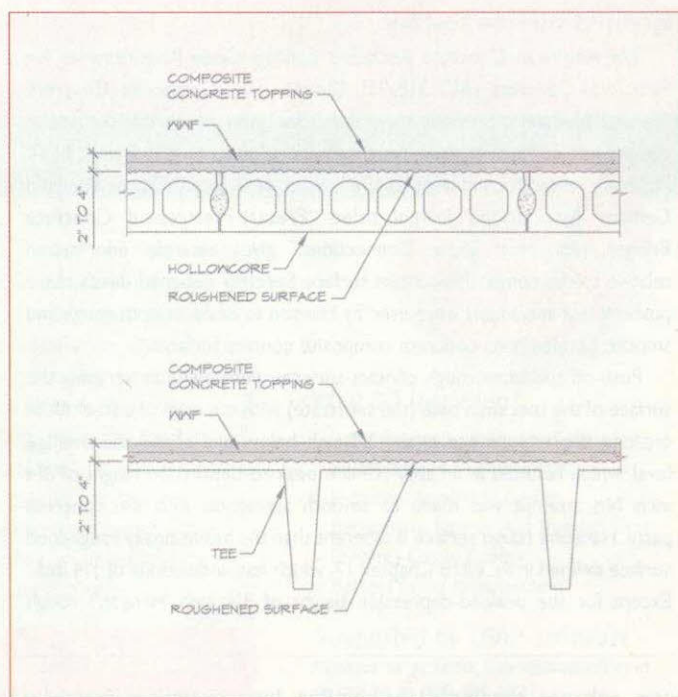
Photo 1 illustrates the smooth top surface of an extruded precast-prestressed concrete hollowcore member. Usually precast concrete members with smooth surfaces do not have open pores since the surface is closed by the cement paste laitance.

A purposely roughened surface is shown in Photo 2.

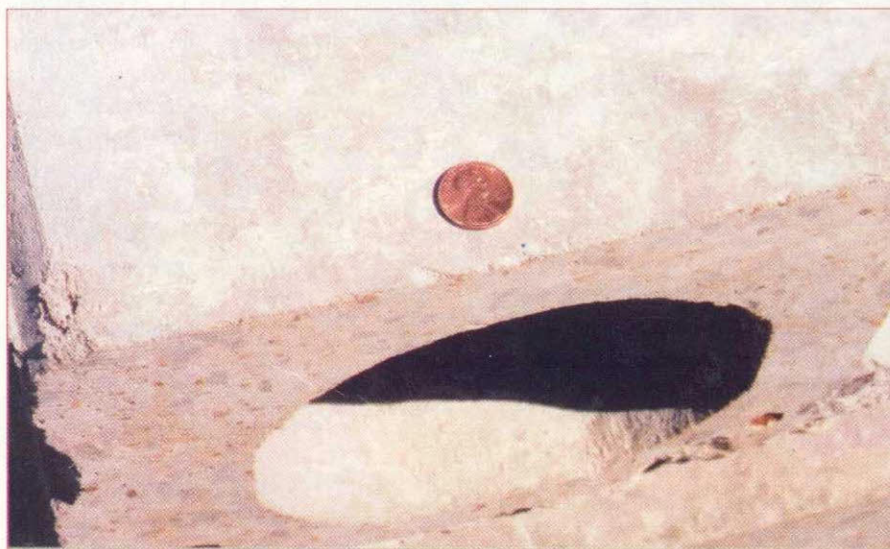
This surface was produced with a common steel garden rake after the surface was slightly stiffened, but before the concrete hardened. The roughened surface shown in Photo 2 is similar to that produced for specimen testing of bond strength (see "Bonded surface testing" on page 46 for more information on testing procedures), except for the depth of the grooves, which is approximately 5/8-inch peak-to-valley maximum. Critics of the purposely roughened surface argue that some of the aggregate and paste projections will come loose and lessen the degree of topping slab bond. A key aspect of the

roughened substrate surface is that it allows the topping slab concrete to mechanically interlock with the substrate to prevent disbonding. Also, the interlock negates the loose surface particle effect. Roughening the substrate as shown in Photo 2 increases the area of the topping slab contact surface by about one-half.

Scarifying a surface to provide a roughened top finish is shown in Photo 3. Scarifying increases the topping slab surface bonding area by one-quarter. Sandblasting the scarified surface exposes the surface's pores as well as removes scarifying dust. Open substrate surface



**Figure 1: Common precast concrete construction with slab topping.**



**Photo 1: The typical smooth surface finish of an extruded precast concrete hollowcore slab.**





## Bonded surface testing

The American Concrete Institute's Building Code Requirements for Structural Concrete (ACI 318-02), Chapter 17 - Composite Concrete Flexural Members, provides the references upon which the composite design and contact surface roughness requirements are based. N.W. Hanson's research conducted in 1960, which was detailed in the Portland Cement Association's *Journal* titled "Precast-Prestressed Concrete Bridges: Horizontal Shear Connections," gives essential information relative to the composite contact surface. Specially designed direct shear push-off test specimens were used by Hanson to evaluate both rough and smooth bonded plain concrete composite contact surfaces.

Push-off specimen rough contact surfaces were made by scraping the surface of the specimen base (the substrate) with the edge of a steel sheet creating depressions and peaks 3/8-inch below and above the average level, which resulted in an approximate peak-to-depression height of 3/4 inch. No attempt was made to smooth aggregates into the concrete paste. Hanson's rough surface is different than the intentionally roughened surface defined in ACI 318 Chapter 17, which has undulations of 1/4 inch. Except for the peak-to-depression height of 3/4 inch, Hanson's rough

surface is similar to Figure 2. The smooth surface of the push-off specimens was created by troweling the base to a relatively smooth condition. Bond, or adhesion, of the test specimen's two parts was achieved by casting the upper part of the specimen to the base's dry hardened surface. Specimen concrete was normal weight and had compressive strengths of 3,500 to 5,000 pounds per square inch (psi).

Eight rough and smooth bonded plain concrete specimens were tested. The ultimate direct shear strength of the rough contact surface varied from 350 to 555 psi. Considering these eight tests as a small sample of a large test population, the fifth percentile rough surface bonded shear strength capacity (meaning that 95 percent of the sample have a greater test value) is 300 psi using a student T distribution. Tests on eight plain concrete smooth bonded specimens had shear test ultimate values ranging from 90 to 230 psi, with a student T distribution fifth percentile smooth and bonded direct shear capacity of 40 psi.

Hanson's tests did not consider inherent in-place structural shear forces acting at the concrete bond surface caused by long-term differential concrete shrinkage nor cyclic-temperature differences between the concretes. These shear forces may exceed the smooth bonded shear strength. ■

pores enhance topping slab bonding by drawing the topping slab concrete paste tentacles into the pores.

## Construction practices

Many construction factors and procedures can have a meaningful effect upon topping slab-to-substrate bonding including proper cleaning and preparation of the precast member substrate and placing and curing of the topping slab. For example, substrate surface

cleaning is essential if topping slab bond is to be achieved. All loose debris, saw dust, and dirt require removal. Cleaning can be accomplished by sweeping and vacuuming followed by the use of oil-free blown compressed air. In addition, surface contamination resulting from spills of construction materials, grease, oils, paints, and similar substances must be fully removed using appropriate chemicals or abrasive blasting.

Bonded topping systems using hollowcore-

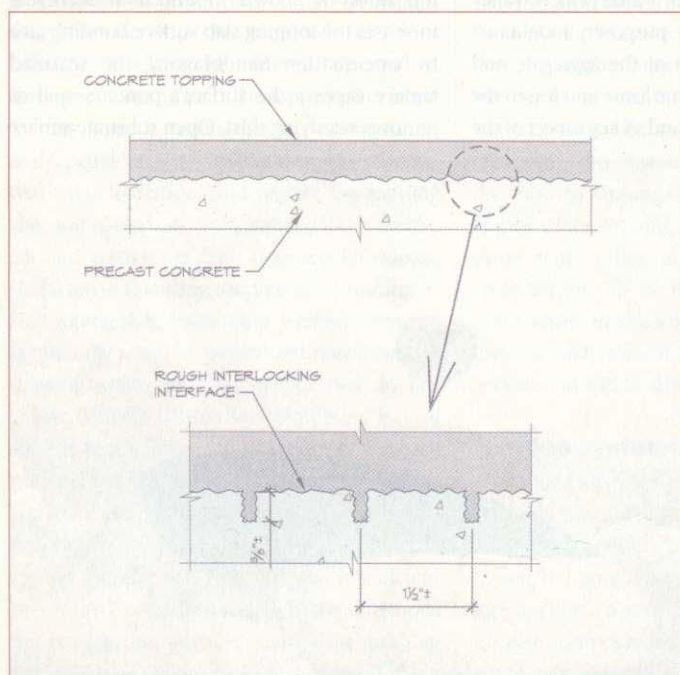
type members should have joints about any individual slab grouted, and the grout should be level with the member's top surface. This decreases the occurrence of topping slab cracking at each slab keyway joint.

Mesh and other reinforcements embedded in the topping slab should be supported on continuous chairs or slab bolsters to ensure that the reinforcing will be located at the planned positions with required top

and bottom concrete cover. Topping slabs should always contain mesh reinforcement, at a minimum, to control topping slab crack widths above or just adjacent to side and end joints of the precast concrete substrate. Further, properly placed mesh, between the mid-point and upper-third of the topping slab thickness, counteracts curling (which can occur at topping slab cracks) by providing moment resistance to the curling deformation.

The substrate surface receiving the topping slab needs to be correctly pre-wetted prior to placing the slab. This wetting should pre-saturate the concrete and keep it continuously wet for at least 12 hours prior to slab placement. Immediately before topping slab placement, the substrate should be in a saturated surface dry condition, with no standing water. Bonding of the topping slab can be improved by the use of a grout scrub coat. When the topping slab contains mesh reinforcing, use of shotcrete is a more practical method of applying the grout scrub coat. Regardless of the scrub coat application, it is critical that the scrub coat not be allowed to prematurely dry out, which would inhibit bonding of the topping slab.

The topping slab concrete should have a low water-cement ratio to minimize topping-slab-to-substrate differential shrinkage. A low water-cement ratio, in the range of 0.32 to 0.35, can be best achieved by using high-range water reducers. Also, proper curing of the topping slab minimizes the effects of topping-slab-to-substrate differential shrinkage. The best curing is to cover the topping slab with a wet burlap-



**Figure 2: Sketch of an intentionally roughened composite concrete interface.**



type material and a moisture retaining cover. Wet curing should preferably be maintained for a seven-day period.


### Building code requirements

The American Concrete Institute's Building Code Requirements for Structural Concrete (ACI 318-02) and the International Codes Council's International Building Code (2003 IBC) have specific requirements for composite structural systems, which are not typically adhered to in actual practice. Most hollowcore slabs using a composite, bonded-only, topping slab do not have an intentionally roughened top surface as required by ACI 318-02. Instead the top surface is smooth.

However, a smooth precast concrete member top surface is sanctioned by the Precast/Prestressed Concrete Institute's Design Handbook - Precast and Prestressed Concrete, which states, "Experience and tests indicate that normal finishing methods used for precast concrete structural members will qualify as intentionally roughened." This conflicts with the writers' experience and knowledge of concrete topping disbonding. Chapter 17 of the 2003 IBC requires verification and inspection of concrete construction (Table 1704.4) for proper placement of concrete (including topping slabs), however these inspections are not commonly made. In fact, special inspections for concrete construction are dictated by the 2003 IBC Sections 1704.1 (Exception 2.), 1704.1.1, and 1704.1.2.

A general summary of the ACI 318-02 requirements for precast concrete structural members having a bonded composite topping slab without reinforcing ties, as understood by the authors, include the following:


- The substrate concrete members are required to have an intentionally roughened composite contact surface.
- Elastic section properties for the centroid and moment-of-inertia,  $I_g$ , should be based upon the gross composite cross-section for ultimate strength designs.
- The controlling ultimate horizontal shear at the contact interface occurs at the point of maximum vertical shear. Use  $V_u Q / I_{gb} v$  to find the applied ultimate composite horizontal shear stress, where  $Q$  is the static moment of the topping slab area (which is  $b_v t$  times the distance between topping slab center,  $t/2$ , and the composite cross-section centroid), and  $b_v$  is the width of the topping slab acting with the precast concrete member. The




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**Photo 2: A raked surface produces a desirable, intentionally rough finish.**

maximum applied ultimate horizontal shear stress for bond-only composite members is limited to  $\phi 80 \text{ psi} = 68 \text{ psi}$ , where  $\phi$  is 0.85 for shear.

- Concrete cover for reinforcement within the topping slab at interior applications is not to be less than 3/4 inch and at exterior conditions exposed to the weather is not to be less than 1-1/2 inches for #5 bars and smaller. If the topping slab is exposed to chlorides, the minimum cover is not to be less than 2 inches. A #5 bar in a topping slab exposed to de-icing salts at an outdoor athletic stadium would require a minimum thickness of 3-3/8 inches using 3/4 inch bottom cover. Considering reinforcement placement variations and concrete thickness tolerance, a minimum topping slab thickness greater than this 3-3/8 inches may be required.

## Related design considerations

Other construction aspects can impact the topping slab thickness and its design. When selecting the topping slab thickness, consideration should be given to ease of construction and practicality of the design including the precast concrete member camber or deflection immediately after topping slab placement, the position of reinforcement within the topping slab, and specified concrete covers at both the top and bottom of the topping slab. In addition, consider the required concrete cover and vertical dimension of beam projecting composite ties, if present, as well as surface drainage profiles and dimensions of the selected surface drain assemblage. Embedded conduits (electrical or other) and their sizes must be accommodated and consideration must be given to conduit grouping and clear spacing between conduits so that topping slab bond is

not adversely affected. Also, remember the depth of tooled or saw-cut topping slab control joints is controlled by the concrete cover.

## Plan and specification requirements

Specifications and plan notes need to be very clear on bonded topping slab requirements. Since a composite structural precast concrete system involves more than one trade, it is good practice to make all specifications related to the composite system prescriptive and not performance based. To clearly communicate the design intent and to ensure proper construction of the precast concrete bonded topping slab system, specifications should address the following items (section numbers refer to the Construction Specification Institute's numerical designations):

- 1) Section 03410 - Structural Precast Concrete - This section must be specific in stating the topping slab will be structurally bonded with the precast concrete.
- 2) Section 03410 - Structural Precast Concrete - In addition, this section requires a definitive description of the precast concrete

top surface roughness concerning grooves and their orientation, groove spacing, and amplitude of roughness. Also, requirements for submittal of surface finish samples are necessary to ensure the precast concrete supplier fully understands the specified surface roughness.

3) Section 03300 - Cast-Place-Concrete - This section needs to specify the topping slab material requirements including a maximum water-cement ratio of 0.32 to 0.35.

4) Section 03300 - Cast-Place-Concrete - Additionally, this section must define in detail the precast concrete top surface preparation relative to cleaning, pre-wetting, and absence of standing water.

5) Section 03300 - Cast-Place-Concrete - This section should provide explicit wording on placement position of all reinforcements, the lapping of topping slab mesh and bars, and the use of chair or bolster supports. Top and bottom topping slab concrete reinforcement clear cover need to be stated.

6) Section 03300 - Cast-Place-Concrete - This section should also address all related requirements associated with the use of a grout scrub coat, or shotcrete application if one is to be used, to improve slab bonding.

7) Section 03300 - Cast-Place-Concrete - Lastly, this section needs to define the wet curing methods to be employed.

8) Electrical and plumbing specification sections must have requirements for positioning embedded items and clear spacings between individual units of any grouping so that topping slab bonding is not adversely affected at any area.

9) Architectural and structural drawings need to have complete dimensional information on topping slab thickness throughout the project. Required topping slab thicknesses are dependent upon: reinforcing concrete cover; topping slab reinforcement sizes; composite



**Photo 3: A machine scarified surface results in a roughened finish profile.**



beam projecting ties (if present); drain embeds; topping slab surface drainage profiles; precast concrete camber or deflections at topping slab placement; and, embedded electrical and plumbing components. Sufficiently large-scale details are required to graphically define the various interrelated conditions.

10) Concrete notes on the drawings should provide a concise summary of the topping slab requirements specified by Section 03300 - Cast-Place-Concrete, especially those listed above in Items 3 through 8.

11) Precast concrete notes on the drawings should provide clear directions, including Items 1 and 2.

12) Both the specifications and plans should clearly define the responsible design engineer for the composite precast concrete structural system. Providing a precast concrete design is not the same as being an in-charge engineer for the project.

## Conclusion

This article presented a summary of the various design and construction issues associated with precast concrete bonded topping slabs. Based upon the authors' experience with concrete topping slabs used with precast concrete members, and observations of actual project topping slab disbondings, it is clear that the construction industry cannot predictably rely upon smooth precast concrete surfaces to achieve long-term bonding with a concrete topping slab. Proper design and construction of precast concrete composite topping slabs require that the contact surface have an intentionally roughened surface as mandated by the ACI 318-02, or specified for the project, and that all the important material and construction requirements affecting topping slab bonding be specified. ■

**Charles H. Rath, S.E.**, is a consultant to and founder of Rath, Rath & Johnson, Inc., Structural Engineers, based in Willowbrook, Ill. Rath is an experienced designer and investigator with particular knowledge in precast concrete structures. He can be reached at [RATHSIL@cs.com](mailto:RATHSIL@cs.com). **Kurt R. Hoigard, P.E.**, is a principal at Rath, Rath & Johnson, Inc., Structural Engineers, and also located in the Willowbrook office. He is experienced in structural investigations, all types of structural testing, and repairs of concrete structures. He can be reached at [krhoigard@rrj.com](mailto:krhoigard@rrj.com).

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