Designing for Construction Productivity and Safety

Designers need to be mindful of forming, shoring, reshoring, and backshoring

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Thanks to the many outstanding software tools available today, structural engineers can efficiently and effectively design economical reinforced concrete (RC) and post-tensioned (PT) concrete structures. However, even the best computer programs do not prevent engineers from incorporating unfortunate details into their project plans. For example, many project designs require temporary movement joints to minimize cracking due to strains associated with floor movement caused by concrete volume change. However, the commonly used detail—the so-called pour strip—can be quite problematic (Fig. 1). We have observed through the years that the positioning and design of pour strips are rarely thoroughly considered, so these details are often the cause of construction delays, added costs, and safety issues.

The Main Issue

Volume change is a challenging aspect of RC and PT construction. If no measures are taken to minimize restraint to shortening (RTS) from columns, braced frames, moment frames, and shear walls, strains resulting from concrete shrinkage, creep, temperature, and elastic shortening associated with post-tensioning can result in high tensile stresses and significant cracking. In an elevated slab, the common solution is to use a pour strip—a gap between two placements of an elevated slab. A properly designed pour strip will temporarily interrupt slab continuity between the laterally stiff structural elements, thus lowering the RTS. Because creep and shrinkage strains increase with time, cracking can be reduced by keeping the pour strip open for an extended period. It is not uncommon for the design engineer to require that a project's pour strips remain open for 28 or 56 days, but we have seen project specifications calling for even longer open times.

Fig. 1: Pour strips are gaps in floor structures designed to minimize restraint of early stage volume changes of concrete: (a) backshoring and changes in elevation create logistical and scheduling issues; and (b) delayed concrete placements result in high unit costs

Location Matters

In addition to detailing and specifying the minimum open time for pour strips, the design engineer determines the locations for pour strips. Pour strips are generally located in a span that is about halfway between the stiffest elements, and often this is near the middle of the building or a section of the building, as geometry needs to be taken into account. The specific location within the selected span requires careful consideration.[1]

Quarter-span

Some engineers position the pour strip at quarter-span locations, near the point of contraflexure (zero bending moment) for uniform loads. Relatively light flexural reinforcement is required at these locations. Although the slab shear is relatively high, inexpensive concrete shear keys can be used to carry shear across the completed joint; shear friction can also be used.

Before closure of the pour strip, however, the quarter-span location results in a long cantilever that may be difficult to design as self-supporting. The loads due to slab self-weight are cumulative, so all the slab levels in the affected bay must be backshored (refer to the text box), and the shores must carry high loads. Furthermore, backshores must stay in place until the concrete structure is complete (shown in Fig. 2(a)).

The need for shoring all levels can cause significant costs for the concrete formwork contractor, but the cost of shoring is only part of the total cost. To avoid overloads, shores near the lower levels must be closely spaced, making it nearly impossible for other trades to work in the affected areas. Even if access is possible, many mechanical, electrical, plumbing, and finishing systems cannot be completed until the pour strip is closed. Furthermore, changes in elevation and exposed reinforcement in a pour strip create safety hazards for workers crossing the gap. Not only do these challenges significantly affect the schedule but they also create logistical and safety issues for everyone on the jobsite.

Definitions Provided by ACI Committee 347[2]

Backshores—shores left in place or shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area, without allowing the entire slab or member to deflect or support its self-weight and construction loads.

Reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a full bay, requiring the new slab or structural member to deflect and support its own weight and existing construction loads to be applied before installation of the reshores.

Shore—vertical or inclined support member or braced frame designed to carry the weight of the formwork, concrete, and construction loads.

Midspan

If located at the midspan (Fig. 2(b)), closure of a pour strip will require significant positive moment reinforcement. The conventional solution is to splice the reinforcement extending from both sides of the pour strip. This requires Class B lap splices per the ACI 318 Code.[3] If the cantilevers are not designed as self-supporting, loads will accumulate on the backshoring, just as they do with the quarter-span location. Thus, locating a pour strip at the midspan provides construction advantages only if the cantilevers are designed as

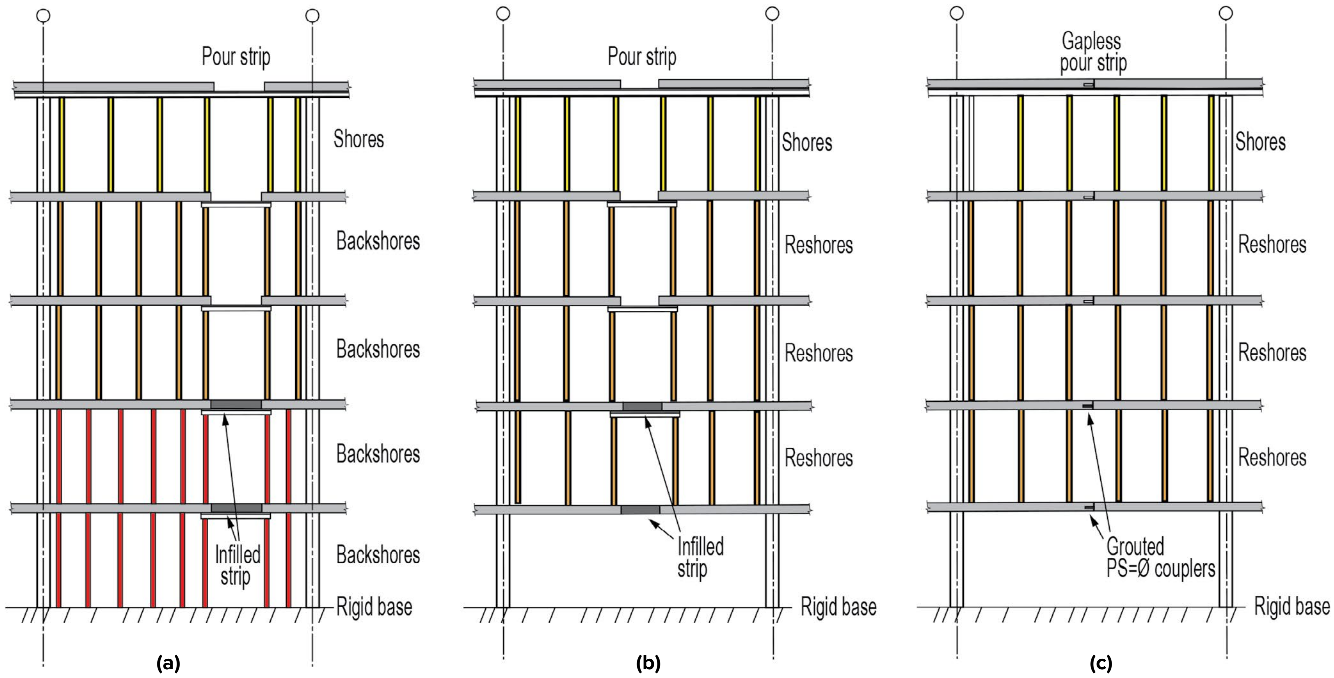

Fig. 2: Pour strips can significantly impact formwork and shoring: (a) conventional pour strips can result in cantilevered slabs that require heavily loaded backshores extending to the base of the structure; (b) if the cantilevers can be designed to be self-supporting, conventional pour strips can reduce the need for backshoring; and (c) gapless pour strips can provide similar advantages, combined with a safer working surface at all levels

self-supporting (with a small premium for added reinforcement). Reshoring is required, but only to support the self-weight of the next slab to be cast and its associated construction loads. Backshoring is not required, and loads are not cumulative. Furthermore, the reshoring can be terminated when the floor structure below can support one level of self-weight and construction loads.

Due to these advantages, most contractors prefer the midspan location for pour strips, with each cantilever designed as self-supporting. This system allows for the reshoring solution rather than the higher-capacity (that is, many more shores), multistory backshoring solution that needs to stay in place until the completion of the concrete structure.

Alternative Solutions

A recent article provides a formwork designer's insights regarding backshoring and reshoring,[4] proposing that a wide pour strip will facilitate the creation of self-supporting cantilever slabs, thereby allowing reshoring in lieu of backshoring. Another option is what we call a "gapless pour strip" (Fig. 2(c)).

While the term gapless pour strip could be considered an oxymoron, it provides a good description of this form of strain-relief joint. A gapless pour strip does not require a gaping opening in the floor structure, so it can greatly enhance jobsite safety by eliminating openings and changes in elevation. Also, a gapless pour strip eliminates what most concrete contractors say is the most expensive concrete (per unit) on a project—the closure placement (Fig. 1(b)). Even more significantly, however, the gapless pour strip eliminates the hassles, delays, and safety hazards associated with moving equipment, materials, and personnel over a gap and through the dense shoring required for many standard pour strips (Fig. 1(a)).

A gapless pour strip will also necessitate a change in normal operations for PT construction. The lack of a gap will mean the tendons in the second slab cannot be tensioned at the joint. In other words, dead-end anchors will be needed at that location. Fortunately, the contractor can determine placement and tensioning sequences without affecting the structural design.

To create a gapless pour strip, some type of device is required at the strain-relief joint. This device must be capable of transferring forces across the joint after the second slab at the joint has been placed and sufficient time has passed for most of the volume change to occur. We classify these devices

Fig. 3: The PS=Ø Mechanical Rebar Splicing System can ensure ductile continuity and a gapless pour strip

Fig. 4: The PS=Ø mechanical coupler allows contractors to produce gapless pour strips: (a) the couplers are attached to formwork at a construction joint prior to placement of the first slab at the joint (here, shown on a wide-module joist placement); and (b) after the specified time has passed after placement of the second slab at the joint, workers place very high-strength grout in PS=Ø mechanical couplers. The red arrows indicate the open joint that will be filled with concrete matching the slab strength

as lockable dowels and mechanical couplers. The former is designed to transfer shear forces, and the latter is designed to transfer both shear and tensile forces across the joint.

Lockable dowels

The lockable dowel is designed to transfer shear forces yet allow for horizontal movement until it is locked using an epoxy filler. This type of device does not provide the required ductile diaphragm chord continuity of the reinforcing bars. Furthermore, because diaphragm chord continuity will be interrupted at the pour strip, the designer may need to add lateral force-resisting elements to compensate for the interruption. In other words, a gapless pour strip created using lockable dowels will behave like an expansion joint, creating two independent structures. As a result, the device must be accommodated in the original structural design.

Mechanical couplers

Our company has developed the PS=Ø® Mechanical Rebar Splicing System (Fig. 2(c) and Fig. 3), which allows for free movement at the strain-relief joint until the coupler is grouted with a very high-strength concrete grout (Fig. 4). The PS=Ø system uses proven coupler technologies that have been used worldwide for decades. With a threaded end and a grout-filled sleeve, this system is listed in ICC ESR-4213[5] as meeting ACI 318 Type 1 and Type 2 mechanical splice requirements for deformed reinforcing bars, and it complies with both the Florida and California building codes. The PS=Ø system continues a long, successful coupler history of mechanically splicing reinforcing bars, providing ductile continuity in countless seismic applications all over the world.

When used with formed shear keys in the concrete and/or using shear friction, this mechanical coupler results in both shear and moment continuity across a strain-relief joint. The coupler also provides the required ductile diaphragm chord continuity of reinforcing bars. Furthermore, because the PS=Ø coupler is ductile cast-iron steel filled with concrete grout, and the gap is filled with concrete, all fire ratings are maintained simply by using the same cover as required for steel reinforcing bars by the International Building Code.

The system allows flexibility regarding the location of the strain-relief joint. If the joint is located at a quarter-span location (where a self-supporting cantilever is usually too long to be practical), backshoring is traditionally necessary. With the PS=Ø system, dowel action prior to grouting creates a propped cantilever, which is self-supporting and requires only reshoring. If the joint is located at the midspan, however, there is also an opportunity to create self-supporting cantilevers and thus eliminate the need for backshoring in lower levels (Fig. 2(c)). Fortunately, in typical PT construction, it is relatively easy to design a self-supporting cantilever, with the pour strip (strain-relief joint) located at the midspan. Furthermore, when a pour strip is needed for stressing (at an interior location), with PS=Ø, the pour strip can be placed back immediately after stressing the second slab, again achieving the gapless pour strip. A similar application is available at walls below grade with a slotted hole in the PS=Ø coupler that allows for longitudinal as well as transverse movement.

Regarding installation timing, because no redesign is required, many PS=Ø couplers have been installed late in the project to improve the schedule. So, while a single level remains to be cast, it is never too late to incorporate the PS=Ø system in that level.

With the pour strip located at the midspan, the PS=Ø system has all the same behavior and engineering characteristics of the traditional midspan pour strip (with lap slicing for continuity) but without the gap. The only required flexural reinforcement at the midspan location is the bottom reinforcing bars needed to be coupled to provide the required midspan positive moment capacity.

The general conclusion with the PS=Ø system is to place the pour strip at either the quarter-span or the midspan. The quarter-span location has the advantage of no additional PT tendons and fewer PS=Ø couplers, whereas if the original design called for a midspan pour strip (as is most economical for the traditional pour strip), no redesign is required even though there may be a slight premium for some additional post-tensioning. In neither case is backshoring required, and significant cost, schedule, and safety benefits are achieved with either location.

—PS=Ø, **www.pourstrip0.com**

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Selected for reader interest by the editors.

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