Considerations for Precast Concrete Panels Tied to Slabs-on-Ground

Forces induced in slabs increase the risk of cracking

by Scott M. Tarr, Matthew J. Sheehan, and Eric J. Van Duyne

In what is commonly called "big-box" building construction, the floors are industrial concrete slabs-on-ground that must accommodate continual pounding of warehouse traffic. These concrete floors are typically designed to minimize random cracking, as cracking results in greater maintenance needs for both the floors and the product-moving equipment. The potential for cracking is influenced by many factors, including loading, slab thickness, joint spacing, concrete shrinkage potential, and restraint conditions, but the floor serviceability and perceived retail value are commonly impacted by the presence of random cracks.

Conventional concrete slab designs include regularly spaced joints to control the location of the cracking beneath saw cuts or include reinforcement to control the width of the cracks. Less common systems like post-tensioned or shrinkage-compensating concrete slab-on-ground designs are intended to eliminate most joints while still preventing tensile cracking.

We have observed an increasingly more common practice of detailing precast concrete wall panels, whether plant-cast or site-cast (tilt-up), to be tied to the building's slab-on-ground (Fig. 1), especially along loading dock areas where the interior finished floor elevation is higher than the exterior final grade. ACI 360R-10[1] includes a recommended detail for lateral ties between walls and slabs-on-ground in which each deformed bar extends a limited distance into the concrete floor and is partially isolated from the slab using a pliable foam sleeve (Fig. 2). The sleeve allows the bar to elongate over a specified unbonded length, and it reduces vertical and horizontal restraints at the wall panel to slab connection. This type of connection thus provides a restraining force normal to the wall panel at the slab elevation, and this force serves to resist out-of-plane panel deformations due to soil pressure or thermal differential through the panel thickness. The magnitude of the force is a function of the unit weight of the concrete slab and interface friction with the subbase, and it varies depending on the distance the steel reinforcing extends into the concrete slab.

Fig. 1: Steel threaded coil rods anchored into concrete wall panels and positioned for embedment along the slab-on-ground perimeter

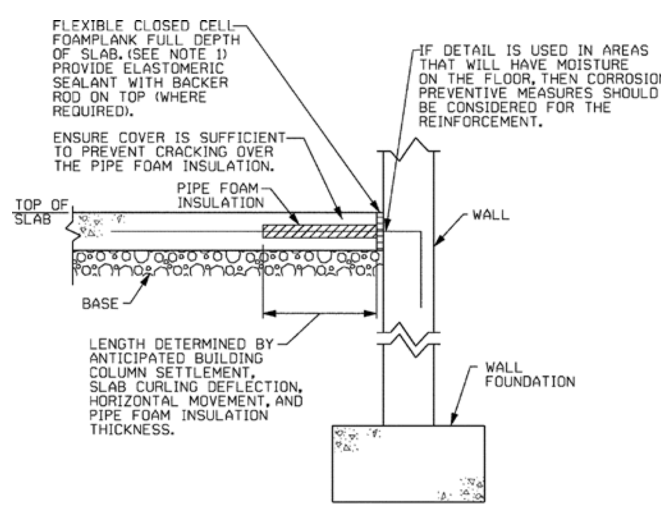

Fig. 2: Lateral tie to slab-on-ground for walls (per A7.3.4 in ACI 360R-10[1])

Fig. 3: Slab-on-ground steel reinforcing quantities and details redesigned to be within ACI 360R recommendations while still providing restraint for the concrete wall panels

We have observed designs that required steel reinforcing to extend as little as 4 ft (1.2 m) (Fig. 1) or up to approximately 50 ft (15.2 m) into the slab. In the latter case, the extension spanned the entire first building column bay (Fig. 3). The restraint force is normal to the wall panel at the slab elevation, serving to resist out-of-plane panel deformations due to soil pressures or thermal differentials. Sometimes tying the wall panels to the slab is required to transmit vertical or lateral loads from adjacent building components to the soil. However, this detail is commonly used with the intent to restrain outward thermal bowing of the precast wall panels, rather than being related to carrying building structural design loads.

Slab-on-Ground Design

As explained in ACI 318-14[2] and ACI 318-19,[3] industrial concrete slabs-on-ground are not commonly relied upon to transfer horizontal or vertical loads from the structure, so the slab designs are not governed by ACI 318 Code requirements. As indicated in ACI 318-14 Provision 1.4.7 and ACI 318-19 Provision 1.4.8:

"This Code does not apply to design and construction of slabs-on-ground, unless the slab transmits vertical loads or lateral forces from other portions of the structure to the soil."

ACI 318-14 Commentary Section R1.4.7 and ACI 318-19 Commentary Section R1.4.8 further refer designers to ACI 360R-10 for "Detailed recommendations for design and construction of slabs-on-ground and floors that do not transmit vertical loads or lateral forces from other portions of the structure to the soil…" Per Provision 1.4.7 in ACI 318-14 (Provision 1.4.8 in ACI 318-19) and ACI 360R-10, when the slab-on-ground is not required to be part of the seismic-force-resisting system of the structure or transmit other vertical or horizontal loads, it is not recommended to tie concrete wall panels into it and unnecessarily increase the risk of out-of-joint floor cracking.

As also discussed in ACI 318-14 and ACI 318-19, Commentary Section R13.2.4, there are instances where the slab-on-ground must act as a structural diaphragm to hold the building together at the ground level and transmit vertical or lateral loads through the floor slab-on-ground to the soil. In addition to providing restraint against soil or thermal effects, such connections transfer wind and seismic shear forces from the panels into the slab-on-ground and subsequently to the soil. Because this function is critical to lateral stability of the panels and the structure as a whole, in those instances the ACI 318 Code requires the slab-on-ground to be designed as a structural slab. However, when this is necessary the designer and project team should be aware that designing and constructing the slab-on-ground in accordance with ACI 318 structural reinforcing requirements will typically increase the risk of out-of-joint floor cracking.

Reinforcement Requirements

For structural slabs, the minimum shrinkage and temperature reinforcement required by ACI 318-14 is between 0.14 and 0.20% of the cross-sectional area of the slab (ACI 318-19 Provision 24.4.3.2 requires 0.18% in all cases). However, if this level of reinforcement is continued through saw cut contraction joints in slabs-on-ground, there is a significant risk of random cracking in the slab panels rather than, or in addition to, beneath the saw cut joints.

ACI 360R-10, Section 6.2, states that the continuation of a small percentage of deformed reinforcement (0.1% of the slab cross-sectional area) through saw cut contraction joints in combination with a joint spacing determined for unreinforced slabs based on the magnitude of the concrete shrinkage potential has been used successfully as a way to enhance aggregate interlock and provide adequate load transfer and joint stability. This can be a very effective design detail when the concrete shrinkage potential causes the saw cut contraction joints to widen beyond the capacity for effective aggregate interlock to develop. However, ACI 360R-10, Section 6.2, also includes the following statement:

"As a general rule, the continuation of larger percentages of deformed reinforcing bars should not be used across saw cut contraction joints or construction joints because they restrain joints from opening as the slab shrinks during drying, and this increases the probability of out-of-joint random cracking."

ACI 360R does not recommend providing reinforcing levels between 0.1 and 0.5% due to the risk of visible random cracking. Typically, the design intent for a slab-on-ground is to minimize the occurrence of visible out-of-joint random cracking by specifying saw cut contraction joints at the spacing recommended by ACI 360R. However, it is unrealistic to expect a slab without any random cracks. Section 5.2.9.3 in ACI 302.1R-15[4] includes the following statement:

"Some random cracking should always be expected, even with sufficiently close joint spacing. It is reasonable to expect random visible cracks to occur in 0 to 3 percent of the surface area floor slab panels formed by saw cutting, construction joints, or a combination of both. If slab curl is of greater concern than usual, joint spacing, mixture proportion, and joint details should be carefully analyzed. Reinforcement will not prevent cracking. If the reinforcement is properly sized and located, cracks should remain tightly closed."

This statement by ACI Committee 302 indicates that random visible cracking can be expected to occur in up to 3% of the panels on a project. Our experience has shown that this is a very reasonable expectation when the design includes contraction joints spaced in accordance with ACI 360R recommendations.

While not considered "architectural concrete," industrial floors must still meet an industry-standard appearance, and visible cracking is often perceived as a defect. Therefore, cracking should be minimized to avoid diminution of value. However, if visible cracking is acceptable in certain instances, the contraction joint spacing can be increased or eliminated. Section 8.1 in ACI 360R-10 states: "Reinforcement will not prevent cracking, but will actually increase crack frequency while reducing crack widths." Therefore, the number of cracks would be expected to increase with the percentage of steel in the slab. If reinforcement exceeds 0.1% of the slab cross-sectional area, cracks may occur more frequently than at the recommended contraction joint spacing, so out-of-joint random cracks would be expected.

However, in addition to creating visible random cracks, the level of reinforcing may not be sufficient to hold cracks tight enough to resist deterioration without filling or maintenance similar to that required at saw cut joints. Filling/maintaining random cracks can be substantially more troublesome than filling/maintaining saw cut joints. If crack-width control is important, such as when the slab will be exposed to small, hard wheels as are commonly used on material-handling equipment, ACI 360R-10, Section 8.3, includes the following guidance:

"To eliminate saw cut contraction joints, a continuous amount of reinforcement with a minimum steel ratio of 0.5% (PCA 2001)[5] of the slab cross-sectional area in the direction where the contraction joints are eliminated is recommended."

Reinforcement in a slab-on-ground adds restraint to normal concrete drying shrinkage and temperature reduction. At a percentage above 0.1%, it is likely that cracking will occur more frequently than the recommended maximum joint spacing.

Tying Wall Panels

Anchoring concrete wall panels to floor slabs-on-ground should only be done with the understanding that the risk of random cracking in the floor slab is increased. It is the responsibility of the design team to acknowledge and verify with the facility owner that this increased risk of cracking in the floor is acceptable. Unfortunately, the increased cracking may also occur in the area of the slab expected to carry the highest amount of traffic—the loading dock or “speed bay” aisle, which is often directly adjacent to the wall panels. Even a limited number of cracks can be a troublesome maintenance issue if they occur in the highest traffic area.

In many buildings, concrete wall panels are tied to slabs-on-ground to limit wall-panel bowing caused by, for example, differentials in temperature, relative humidity, or degree of curing through the wall thickness. Depending on solar exposure, wall panels can deform substantially daily. Most wall-panel bowing observed in existing structures is outward and permanent. However, this bowing can become an issue if backfill material adjacent to the panels and beneath the slab sloughs into the void created by the deflecting wall panel. If the backfill material used along the wall panels is sand or other material relatively susceptible to sloughing, the wall cannot return to its original position and the floor slab can crack or settle due to a lack of base support. If anchoring the wall panels to the slab is necessary along portions of building elevations, embedded slab reinforcing details and quantities should be modified to be consistent with ACI 360R-10 recommendations for slabs-on-ground (Fig. 3). However, if the ACI 360R-10 recommendations are not adequate for providing the slab-on-ground performance characteristics required for a project, anchoring the wall panels to the slab-on-ground is not the only design option available to address this issue. The following alternatives have been used successfully:

- Backfill along the concrete wall panels using a granular material with a large maximum size and well-graded particle distribution. Such material is less subject to sloughing than other materials, particularly compared to sand backfill;
- Wrap the granular backfill with a geotextile fabric that prevents fill material from sloughing into any void created by bowing of the wall panel;
- Backfill using a controlled low-strength concrete mixture (CLSM) or flowable fill;
- Tie the wall panels to a separate bulkhead or pourstrip isolated from the floor slab; or
- Design the wall-panel foundation to eliminate backfilling against the bottom portion of the wall panel.

On the latter point, note that concrete wall panels must be designed and reinforced for stresses imposed during handling, shipping, or erection. In prestressed concrete panels, the prestressing level is normally sufficient to avoid cracking during handling of the panels, and that may be sufficient to resist out-of-plane loads when the panels are in place. Therefore, tying the panels back at the floor slab level is not generally critical to the design of the panels.

Lifetime Connections

Connection of wall panels to a slab-on-ground, whether for seismic requirements or to prevent panel bowing, increases the risk of random cracking in the slab. This risk should be discussed in predesign and preconstruction meetings, and alternative details should be considered. Other topics that should be discussed include the amount of slab that must be mobilized and the long-term implications of requiring slab reinforcing to remain in place.

Even when the wall-panel connection is made only to restrain out-of-plane movement of the wall panel, the area of the slab requiring reinforcing bars may become excessive. As previously noted, the area of slab that must be mobilized to transfer the force will be a function of the coefficient of friction between the slab and underlying base. This may become a significant cost consideration if a subslab vapor-retarder sheet is required to avoid damage to moisture-sensitive flooring, to avoid moisture damage to goods stored directly on the floor, or to lower the risk of slab sweating. Because a vapor-retarder or slip sheet reduces the coefficient of friction between the slab and base, some engineers have required the reinforcement to extend several bays into the slab interior, impacting cost as well as increasing the risk of cracking.

It also must be communicated that the tie reinforcement and the reinforcement in the slab-on-ground cannot be cut or removed during the life of the structure. As discussed by PCI,[6] this is a significant consideration as it is very common to remove and replace deteriorated portions of slabs-on-ground, especially in high-traffic areas. Further, slab-on-ground repairs are generally doweled into the existing slab with smooth dowels that minimize restraint of the replacement concrete shrinkage after setting. If the tie-back reinforcement is required to be maintained, this can substantially change the repair detail and associated risk of cracking in the replacement concrete. For this reason, ACI 318-14 and ACI 318-19, Provision 26.5.7.2(d), requires:

"Saw cutting in slabs-on-ground identified in the construction documents as structural diaphragms or part of the seismic-force-resisting system shall not be permitted unless specifically indicated or approved by the licensed design professional."

Early discussion of these issues may allow the introduction of alternative details that will provide more economical means of ensuring the long-term performance of the wall panels, the floor slab-on-ground, and the complete structural system.

References

1. ACI Committee 360, "Guide to Design of Slabs-on-Ground (ACI 360R-10)," American Concrete Institute, Farmington Hills, MI, 2010, 72 pp.

2. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 519 pp.

3. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)," American Concrete Institute, Farmington Hills, MI, 2019, 629 pp.

4. ACI Committee 302, "Guide to Concrete Floor and Slab Construction (ACI 302.1R-15)," American Concrete Institute, Farmington Hills, MI, 2015, 76 pp.

5. "Concrete Floors on Ground," EB075, third edition, Portland Cement Association (PCA), Skokie, IL, 2001, 136 pp.

6. PCI Committee on Precast Sandwich Panels, "State of the Art of Precast/Prestressed Concrete Sandwich Wall Panels," second edition, *PCI Journal*, V. 56, No. 2, Mar. 2011, pp. 131-176.

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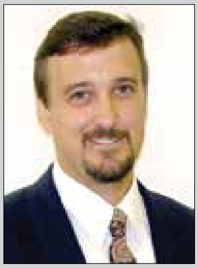

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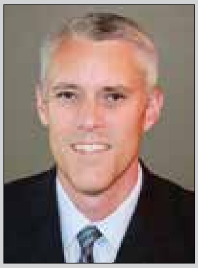

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