Internal Tolerance Conflicts in Concrete Construction

Beware of risks associated with splitting of work packages among subcontractors

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ACI Committee 117, Tolerances, is developing a document titled “Guide for Tolerance Compatibility in Concrete Construction.” It will list standard tolerances for materials and products that commonly interface with concrete construction and include suggestions for accommodating individual material and product tolerances with concrete construction tolerances. This document will be a great asset in handling troublesome tolerance incompatibility between concrete members and elevators, stairs, finish floor coverings, cladding and infill walls, and embedded items.

The new document won’t, however, deal with tolerance compatibility issues within concrete construction itself. Tolerances associated with layout, formwork elevation and alignment, reinforcement fabrication and placement, surface elevation, and levelness can cause internal tolerance compatibility issues—conflicts within concrete construction. Coordination of the internal tolerances in ACI 117-10 is difficult, even when a single concrete contractor controls the total work package, including layout. But these contractors can usually complete the work to the satisfaction of the Owner and Architect/Engineer because they control the total work package.

To reduce costs, owners, construction managers (CMs), and general contractors (GCs) have begun to split up the work packages by using different subcontractors to erect formwork, install reinforcement, and place concrete. The CM or GC (CM/GC) may also provide layout control for all of the subcontractors but may not have the same experience as the concrete subcontractor in dealing with the internal tolerance compatibility challenges of the formwork, reinforcement, and concrete. The CM/GC often assumes that the concrete placing and finishing contractor will be responsible for the coordination of the other subcontractors’ work. But this is not possible when the work packages are separated with individual contracts. When the work packages are separated, the CM/GC should be responsible for ensuring internal tolerance compatibility.

EXAMPLE OF INTERNAL TOLERANCE COMPATIBILITY

Tolerances for formwork, reinforcing steel, and concrete were developed independently before being combined into one document, ACI 117, in 1981. Because of this, the combination of separate tolerances is not always internally consistent. This is demonstrated in the following example.

Figure 1 is a schematic of a reinforced concrete canopy slab supported by a reinforced concrete spandrel beam. The formwork subcontractor can place the forms within ±3/4 in. (±19 mm) of the design elevation and still be within ACI 117-10 tolerances.1 But the concrete top surface elevation requirement prior to removal of supporting shores is also ±3/4 in. (±19 mm). Thus, if the formwork contractor places the forms at either tolerance extreme, the concrete contractor must place the slabs at the exact design thickness values, perfectly flat and level, to meet the surface elevation tolerance. In this case, the formwork subcontractor would have used up the concrete placing subcontractor’s tolerance.

The canopy is reinforced with Z-shaped bars. ACI 117-10 requires a fabrication tolerance of ±1 in. (±25 mm) for each bar, and it specifies placement tolerances that vary with the depth of the member in which the bar is placed. In this case, the tails of the Z-bar are placed in the 6 in. (150 mm) thick slab and the 24 in. (600 mm) deep beam. Per ACI 117-10, when the member depth is between 4 and 12 in. (100 and 300 mm), the placement tolerance is ±3/8 in. (±10 mm). Also per ACI 117-10, when the member depth is greater than 12 in. (300 mm), the placement tolerance is ±1/2 in. (±13 mm).
If the Z-bars were fabricated 1 in. (25 mm) short of the design length, they would still meet ACI 117-10 requirements. But, even if the bottom tail of the bar was placed within tolerance (±1/2 in. [±13 mm]) when tied to the tension steel in the spandrel beam, the ±3/4 in. (±10 mm) tolerance plus the ±1/2 in. (±13 mm) tolerance (7/8 in. [22 mm] total) can’t make up for the exact 1 in. (25 mm) fabrication shortfall. In this case, the fabrication subcontractor would have used up the bar placement subcontractor’s tolerance.

This is an extreme example. Generally, no single subcontractor uses all of an associated tolerance. But even if a single contractor uses some of an assigned tolerance, the available tolerance for the follow-up trade is reduced.

**CONSTRUCTION ISSUES**

Three unfortunate misconceptions regarding construction tolerances are often voiced:

- A single subcontractor can use the entire tolerance such that other follow-up trades have no tolerance and thus must perform perfectly;
- Separate subcontractors all understand tolerances for their own work and how they affect subsequent trades; and
- Subcontractors building on another contractor’s work automatically assume responsibility for the other trade’s work as part of their execution.

The first misconception is irrational. If a subcontractor could perform perfectly, tolerances wouldn’t be needed. In addition, when bidding the project, if contractors did know they would not get a tolerance because another contractor already used it up, they would submit a higher bid. Each subcontractor must have a known tolerance prior to bidding, and that tolerance should be available when their portion of the work package begins.

The second misconception can become the root of a tolerance problem. Having separate subcontractors installing individual work packages risks tolerance incompatibility issues because splitting up work packages drives the price charged by each subcontractor. This increases the chance of using less experienced or skilled subcontractors who may not understand tolerances and the compatibility of each activity’s tolerance needed for the work to be installed properly.

The third misconception causes bidding problems for subcontractors. Follow-up contractors do not have the cost in their bid or time in their schedule to measure and verify previous contractors’ work. That should be the responsibility of the CM/GC. Because this is often a source of contention, subcontractors should include in their bid, as an alternate, both a cost and schedule impact for measuring and verifying previous contractors’ work. Even if the alternate is removed by the CM/GC, this will establish a paper trail of communication about the responsibility and risk.

**LAYOUT**

The CM/GC sometimes provides field engineering services that set “control” lines to all contractors. This can be problematic when the field engineers don’t understand how the separate contractors view their work packages. Formwork contractors perform their layouts with respect to the design elevation, whereas the follow-up trades typically perform their layouts with respect to the formwork elevation and location.

**Control vs. Layout**: The CM/GC should always set control lines at each floor of a building. How the control lines are used should be a decision made by the subcontractor. Because of liability issues, the CM/GC should not be involved in each subcontractor’s layout procedures. We recommend that the CM/GC provide control lines at each floor, with the contract for each subcontractor specifically stating that this only sets control at each floor, leaving the subcontractors responsible for their own layout.

The control line should not conform to any plan elevation. It’s particularly important to avoid setting the control line at the finished floor elevation, as the subcontractor may believe that the finished floor elevation was chosen by the CM/GC. On a recent project, the CM/GC set control lines at 5 ft (1.5 m) above the finished floor elevation and marked them on a concrete wall—this was a good practice.

Unfortunately, some CMs/GCs set control elevations as layout for subcontractors. We know of subcontractors that have put $10,000 to $300,000 in their bids for layout,
only to have the CM/GC remove it and tell them that they would provide layout. We also know of lawsuits in which the CM/GC provided incorrect layout to the subcontractor. Providing subcontractor layout involves too much liability for the CM/GC and, as discussed in this article, the CM/GC does not always understand each trades’ layout requirements.

**Formwork:** It’s considered good practice for formwork subcontractors to set the supporting formwork about 1/4 to 1/2 in. (6 to 13 mm) higher than the design elevation. This allows for some form settlement, take-up between members, and form deflection. The formwork can be set even higher when it’s supported by mussels. The formwork contractor can use the entire ±3/4 in. (±19 mm) ACI 117-10 tolerance for formed surfaces (Section 4.8.2), before removal of shores, as long as the formed surface slope doesn’t exceed ±3/8 in. in 10 ft (±10 mm in 3 m) (Section 4.8.2). For the suspended slab example (refer to the sidebar on p. 34), these two tolerances would apply to the formed bottom surface of the slab.

**Reinforcement:** Reinforcement installers set the reinforcing steel using standard height wire, precast concrete, or plastic supports placed on the forms, or carrier bars that are positioned by measuring from the form surface. Thus, the steel location is fixed by the support height and formwork elevation, which may change slightly during concrete placement. That is, the steel is always positioned off the formwork regardless of where the formwork is located with respect to the design elevation.

The reinforcement installer can use the entire ACI 117-10 tolerances for both steel placement and concrete cover. Note that ACI 117-10 states that the steel location is “measured from the form surface” (Section 2.6.6) and that concrete cover is “measured perpendicular to the concrete surface” (Section 2.2.2). There is no “concrete surface” until after placement, so design concrete cover is also measured from the form surface during inspection. Why is this important? After concrete placement, it could be measured from the concrete surface but, either way, it’s not measured from the design elevation. Thus, both steel placement and cover are not measured from the design elevation but from the form surface.

**Concrete:** Concrete subcontractors typically set their elevation control for the top of the concrete slab based on the form surface elevation. Thus, any temporary screeds that determine the concrete thickness are set based on the formwork regardless of where the formwork is located with respect to the design elevation. If a laser level is used to control elevation during strike off, the laser must be set based on the formwork location plus the nominal slab thickness. The concrete subcontractor can then use the entire –1/4 in. (–6 mm) tolerance for slab thickness. Note that ACI 117-10 does not have a plus tolerance on suspended slab thickness. The thickness tolerance is not based on the design top surface elevation but on the as-built concrete thickness.

ACI 117-10 requires the top surface of the concrete slab, before removal of supporting shores, to be within ±3/4 in. (±19 mm) of the design elevation. Note that the formwork elevation tolerance is the same as that for the top surface of slabs. If the formwork contractor sets the forms at either of the tolerance extremes, the concrete contractor’s elevation tolerance can be reduced to zero, thus requiring an exact design thickness and a perfectly flat and level surface. The total-package contractor typically sets the formwork within ±1/2 in. (±13 mm) or less of the design elevation to allow the placing crew the entire minus thickness tolerance and most of the flatness and levelness tolerance (depending on what F_F and F_L values are specified) to meet the elevation tolerance. For a project with separate formwork and concrete contracts, the CM/GC should coordinate the elevation tolerance between the formwork and concrete subcontractors.

Setting the screed location based on the formwork elevation aids in complying with the thickness tolerance, but the screed heights may need to be adjusted relative to one another. Because ACI 117-10 allows the formwork to slope ±3/8 in. in 10 ft (±10 mm in 3 m), setting the screed height at a fixed slab thickness incorporates any formwork slope into the concrete surface slab during the concrete strikeoff. This slope may affect the concrete subcontractor’s ability to obtain the specified F_L (refer to the sidebar on p. 34).

**Other trades:** Mechanical and electrical contractors set sleeves and conduit based on the formwork elevation. In addition, specialty equipment installers set embedded plates, anchors, and other items with respect to the formwork.

**Layout confusion:** Some CMs/GCs provide the concrete subcontractor with elevation control for the top of the concrete slab that is not set off the formwork but from the design elevation. When the concrete subcontractor works from the design elevation provided by the CM/GC and the formwork subcontractor places the formwork 1/2 in. (13 mm) high, the concrete subcontractor, even though performing perfectly, can’t be within the ACI 117-10 slab thickness tolerance of –1/4 in. (–6 mm).

When the CM/GC performs layout and requires all subcontractors to use the layout lines, the CM/GC should be responsible for making sure that this layout doesn’t reduce tolerances for the subcontractors performing work after the layout lines have been set.
**F_L: EFFECT OF SETTING SCREED HEIGHT OR LASER CONTROL FROM FORMWORK**

Form surfaces are allowed to slope to ±3/8 in. in 10 ft (±10 mm in 3 m). If the screed heights are set at a constant thickness above the formwork, strikeoff during concrete placement will incorporate that formwork slope into the concrete surface (Fig. A). Thus, the floor levelness, as defined by the elevation change over a 10 ft (3 m) distance, is affected by the formwork. If the concrete surface slopes 3/8 in. in 10 ft, the maximum achievable levelness is about \( F_L = 35 \). If the concrete surface slopes 1/4 in. in 10 ft (6 mm in 3 m), the maximum achievable levelness is about \( F_L = 50 \).

ACI 302.1R-04, “Guide for Concrete Floor and Slab Construction,” recommends a maximum composite overall levelness for suspended slabs of 20. Typically, the concrete contractor can set the screed heights accurately enough and perform strikeoff well enough to obtain \( F_L = 20 \) when the screed heights are constant (formwork slope incorporated into concrete surface).

If the concrete contractor needs to achieve higher \( F_L \) values, the screed height may need to be adjusted to account for the formwork slope. It’s best to adjust the individual screed heights higher; this increases the concrete thickness, but ACI does not have a plus tolerance on slab thickness. The responsibility for adjusting the screed heights to ensure that the \( F_L \) can be met is that of the concrete contractor. If, however, the CM/GC provides elevation control for the concrete contractor, it should then be their responsibility.

**FUNDAMENTAL RIGHTS FOR SUBCONTRACTORS**

When work packages are split among several concrete-related subcontractors, all of these subcontractors should have the right to:

- Know their tolerances prior to bid and expect that those tolerances will be available when their work package begins;
- Expect that the CM/GC will provide an experienced and knowledgeable person responsible for coordination of the work between trades;
- Anticipate that the CM/GC will measure and verify the work of prior trades before their work package begins. If the CM/GC does not perform this task, the follow-up subcontractors should not be held responsible for the results of prior contractors’ work packages; and
- Assume that when the CM/GC provides layout, it will be done to allow each work package to be accomplished within the tolerances stated at bid.

**References**


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