Formwork Considerations for Economical Concrete Projects

BY EMILY B. LORENZ AND AMY REINEKE TRYGESTAD

You've been assigned the task of selecting reinforcing steel for individual beams, joists, and slabs for a project. The layout was provided to you by your project manager. As you begin your task, however, you begin to wonder how she got to that point. For example, why did she specify 24-3/4 in.-deep (625 mm) joists, when a precise 22.67 in. (576 mm) dimension would have saved concrete and used about the same amount of reinforcing?

Interestingly, the key to designing an economical, reinforced concrete structure is not necessarily through optimization of the in-place materials. Rather, the key is constructibility—successful design must include consideration of the building process itself. Of course, there are many facets of constructibility; but in this article, we'll focus on formwork considerations.

WHY FOCUS ON FORMWORK?

According to the Concrete Reinforcing Steel Institute (CRSI), "formwork and its associated labor is the largest single cost segment of the concrete structural frame—generally more than 50%."[1] You are now a part of the design team—you must consider the impact of your design (and layout) on the project budget. Simplifying the structure's layout and, in particular, minimizing formwork complexity will help reduce costs (Fig. 1). To better understand how you can help, you need to be knowledgeable about how the concrete forms (molds, if you will) will be constructed. For starters, we recommend that you spend a few evenings curled up with a good book,[2] ask (beg, if you must) to spend time at job sites; and, perhaps most important, don't be shy about asking questions.

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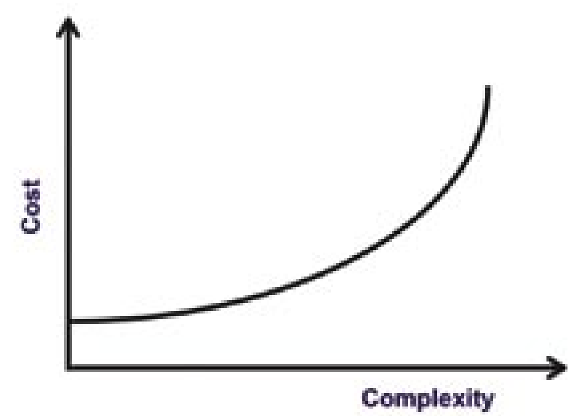
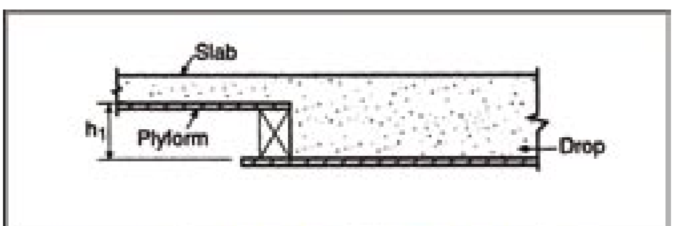


Fig. 1: Cost and complexity are not directly proportional

Fig. 2: This form of shear reinforcement is easy to install, without congestion or formwork interruption[5]



Nominal lumber size	Actual lumber size (in.)	Plyform thickness (in.)	h_1 (in.)
2X	1-1/2	¾	2-1/4
4X	3-1/2	¾	4-1/4
6X	5-1/2	¾	6-1/4
8X	7-1/4	¾	8

Fig. 3: Standard lumber dimensions used for drop-panel forming

SIMPLIFY!

Of all concrete floor systems, flat plate floors are the simplest to form. Because the soffit (bottom) of the slab is a continuous plane, the formwork comprises only a series of shores, braces, and beams that support a plane of plyform in the fields between columns. Any interruptions to the continuity of this plane can carry large cost implications.

As spans or live loads increase, however, they can reach a point where a constant-thickness slab with adequate shear capacity is no longer economical. Using larger columns or increasing the concrete compressive strength may provide marginal relief. Adding shear reinforcement (Fig. 2) can be very effective.[3] If these options don't suffice, however, the next step is to incorporate drop panels. Drop panels increase the thickness around columns and therefore increase shear capacity where it is needed without creating the weight penalty imposed by having a thickened slab throughout the entire floor plate.

Section 13.3.7 of ACI 318-05[4] defines the minimum requirements for panel dimensions, but your specified drop panel dimensions should also be a function of formwork considerations (Fig. 3).[5,6] Drop panel depths other than those dictated by standard lumber dimensions will unnecessarily increase formwork costs.

STANDARDIZE AND REPEAT

In terms of formwork complexity, joist construction is a step up from two-way slab construction. In brief, joist construction comprises a combination of closely spaced (clear spacing of 30 in. [760 mm] or less) ribs and a top slab. Because the joists are closely spaced, the joist system behaves and is essentially designed as a one-way slab (ACI 318 Sections 8.11 and 11.5.5). Joist construction is normally achieved using standard pan forms that are 30 in. (760 mm) wide and from 8 to 24 in. (200 to 600 mm) deep.

Although a 2 in. (50 mm) slab will often meet structural requirements for joist construction, fire-resistance ratings require significantly more thickness. A 2 h rating, for example, requires a 4.6 in. (120 mm) slab when carbonate aggregate concrete is used.[7] This is often rounded up to 4-3/4 in. (120 mm).

Because thicker slabs can easily span greater distances than 30 in. (760 mm), wide module pans were developed to optimize the total system while still using pans to form the ribs. Wide module pans come in 53 and 66 in. (1350 and 1680 mm) widths. The resulting floor system does not qualify as joist construction (shear reinforcement is often required), but it is still highly economical (largely because it uses standardized forming systems).

The keys to optimizing a pan-formed floor system are to specify standard form sizes, maintain a constant soffit elevation whenever possible, and to use repetition, repetition, repetition. Obviously, standard pan forms will be less expensive than custom forms. Further, a wide flat beam soffit (congruent with the joist soffit) is more economical (Fig. 4) than a dropped soffit.[8] Maintaining a constant soffit elevation is most feasible when the joists span in the long direction and the supporting beams span in the short direction (the member with the heavier load thus has the shortest span). If necessary, increase joist or beam depth only as a last resort. Finally, don't forget that repetition benefits everyone. If you can maintain a consistent system from bay to bay as well as from floor to floor, you will enhance the productivity of everyone: the contractor, the reinforcing detailer, the reinforcing fabricator, laborers, carpenters, iron workers, inspectors, and yourself.

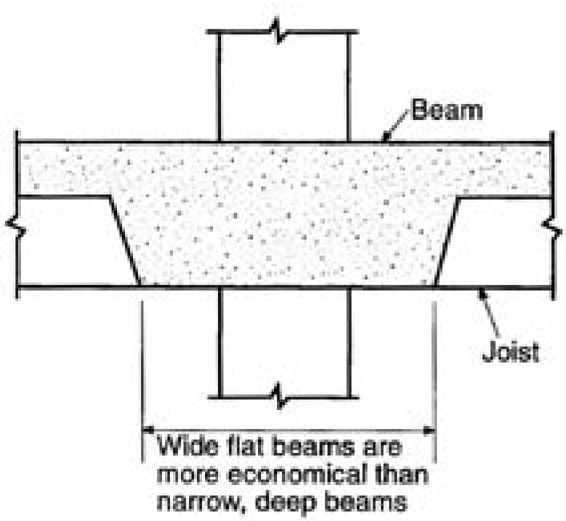


Fig. 4: Matching beam and joists depths is important, too

FITTING IT ALL TOGETHER

When determining beam sizes, wider and shallower is typically better. This is counterintuitive to the academic approach to member sizing (that is, estimating the beam depth to be two times the beam width). Although a narrower, deeper beam may have greater material efficiency, the framing of the beam-column connection has an impact on forming costs. The top of the column is placed to the bottom beam soffit, but the column size/shape must be retained through the beam depth. Less labor is required for forming beams with widths equal to or wider than the supporting column (Fig. 5). Wider beams also help minimize reinforcement congestion at the beam-column joint, where vertical column bars and a large amount of beam top steel must pass. Give yourself some construction room….keep the beams wider. The cost of a little more concrete will be greatly offset by the forming savings.

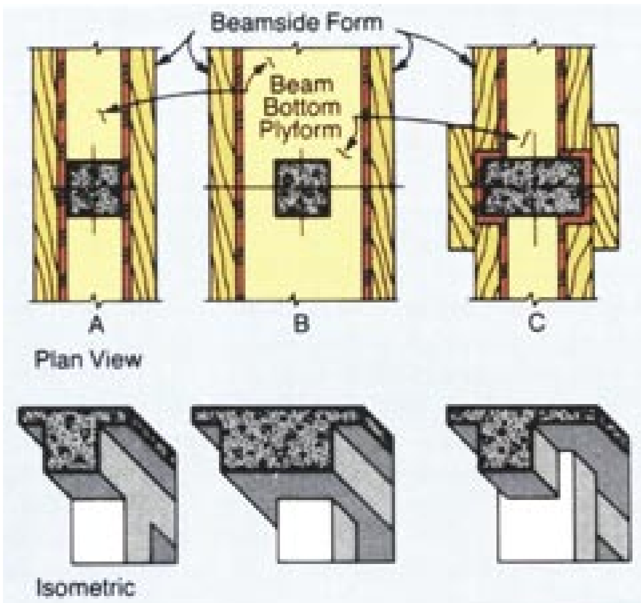


Fig. 5: The extra steps it takes to form out the column with a narrower beam[5]

For buildings of low and moderate size and height, the column dimensions should remain uniform from floor to floor.[9] This reduces the number of column forms required for the job site, repeats the sizes for faster floor-to-floor construction, and eliminates misalignment of offset reinforcement to accommodate different column sizes. The number of forms should also be reduced by selecting only one to three column sizes for a project, depending on the floor plate size.

NOT MEANS AND METHODS

Now you can work on becoming formwork savvy (by the way, does the 24-3/4 in. depth make sense now?). Remember, you are now a team player and your design decisions *will* have an impact. We're not trying to venture into the realm of means and methods. Instead, we're trying to give an overview of how a concrete structure is put together. As we said previously, make sure to visit construction sites. Whether you see a contractor struggling to form an unconventional geometry with custom forms or rapidly erecting a well-planned system, your appreciation of formwork optimization will grow.

Do you have another topic that might be worthy of an article? As a young engineer, is there something that you find confusing? Seasoned engineers—do you remember back when you were a new designer—the problems you had? Please send in your ideas—we welcome ideas for additional topics.

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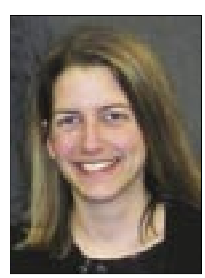

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