Current Trends in Economical Reinforced Concrete Construction

Part 3: Reinforcement, Materials, and Other Factors

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This is the final installment of a three-part series on current trends in economical reinforced concrete construction. The first two parts covered gravity and lateral framing systems, cost savings of labor vs. materials, and tips on formwork. (STRUCTURE®, July 2007 and October 2007 issues). This article discusses reinforcement for concrete beams, walls, and columns and the advantages of high strength concrete. It also addresses how the International Building Code (IBC) has affected concrete design and construction, and notes how the use of reinforced concrete works well for design-build and fast track projects.

Economical Reinforcing Steel

The Concrete Reinforcing Steel Institute (CRSI) publishes authoritative information regarding reinforcing steel. The *Manual of Standard Practice*, for example, has been presenting the standards for the reinforcing steel industry since 1927.

Bar Strength and Grade

Although ASTM A615 reinforcing steel is available in 3 grades – Grade 40, Grade 60 and Grade 75 – Grade 60 bars continue to be the most common grade of reinforcing bars used in construction. Many steel manufacturers produce Grade 75 reinforcing bars. **The use of Grade 75 bars is an economical solution to help reduce congestion in columns and beams**. However, the availability of Grade 75 reinforcing should be verified prior to the design stage.

Grade 60 reinforcing steel is also available in a low-alloy steel, ASTM A706. For more information on the history of reinforcing bars, see CRSI Engineering Data Report 48, *Evaluation of Reinforcing Bars in Old Reinforced Concrete Structures*.

Bar Size Selection

Once calculations have been performed to determine the area of reinforcing required, bar selection is up to the discretion of the designer. **Scheduling reinforcing is more of an art than a science.**

There are various schools of thought on how best to schedule reinforcing bars for beams, columns, and walls. The following rules of thumb are agreed upon by many designers and, equally important, by rebar placers.

Beam Reinforcement

- Use fewer, larger bars rather than more, smaller bars, while still meeting the crack control requirements of the code. Installation is faster and more economical with fewer bars.
- Repetition, repetition, repetition in bar sizes and patterns speeds installation. Reducing the size of bar by one size between adjacent beams, for example, will create more problems than any savings from the reduced amount of steel.
- Where possible, space longitudinal bars at least six inches apart. This spacing allows ironworkers enough room to install and tie reinforcing bars. Closely spaced bars create congestion and tend to slow rebar installation.
- Minimum spacing values often control when designing beam stirrups, thus the smallest practical size (generally #3 stirrups for beams) will be the most economical. Where pan systems are used to form narrow joists, it is common to use welded wire fabric for shear reinforcing. See *Figure 1 (page 44)* for an example.

Column Reinforcement

- Use fewer, larger bars rather than more, smaller bars. Using fewer vertical bars can reduce the number of ties (which are labor intensive to fabricate and install) which, in turn, reduces fabrication and placement labor costs associated with preparation of column cages.
- Where sufficient spacing between adjacent interior vertical column bars is present, consider using "tangential" (straight bar) lap splices in lieu of "typical" (offset bend) lap splices.
- Consider the transition of column vertical bars between adjacent floor levels to help simplify the detailing and installation of column reinforcement. Maintaining the same number of column vertical bars for the entire height of the building, but varying bar size, is common. Where this may be impractical, transitioning from, for example, 16 bars to 8 bars is a sensible option.
- A good way to transition from a round column to a square column (or vice versa) is to use the same shaped cage throughout the entire building height. For instance, use a square cage in the lower lifts of a round column that will transition to a smaller-sized square column on an upper level.
- Using high-strength concrete makes it possible to use smaller column sizes. However, in order to adhere to ACI's maximum reinforcement requirement of 8% of the gross column area, smaller column sizes will tend to require more mechanical couplers in lieu of lap splices. Mechanical couplers can increase the cost of material and labor for column reinforcement. Higher-strength concrete may allow the use of smaller bars, which could be lapped. Increasing the specified strength of the column concrete will not add appreciable cost to the concrete price, and adds no additional labor or material to the project cost. In other situations where acceptable to the architect, increasing column sizes to allow for lap splices can be a more economical choice. The cost of additional lengths of reinforcing bar is less than the cost of material and labor for mechanical couplers.
- Where mechanical couplers are preferred, consider that compression couplers are less expensive than tension couplers and should be specified in lieu of tension couplers where possible.

Wall Reinforcement

- The keys to economical concrete wall construction include maintaining constant wall thickness, providing sufficient thickness to permit proper placing of vertical bars and splices to allow for proper vibrating, and specifying fewer different bar sizes and spacings.

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- Many times, minimum reinforcing is required in concrete shear walls. The same reinforcing bar size and spacing can be used on numerous lifts, if not the entire wall height.
- One of the most expensive items in wall construction can be "bump outs" or pilasters. If possible, column cages at wall ends or corners should be designed and detailed to fit with in the boundary of the wall.

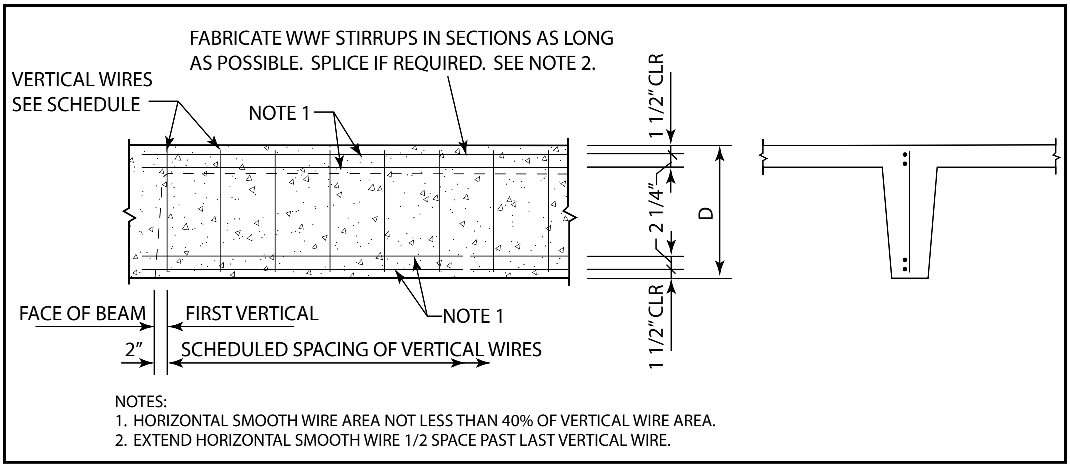

Figure 1: WWF Stirrups.

Concrete

High-strength concrete (i.e., compressive strengths greater than 6,000 psi) is readily available at economical prices. The convenience of obtaining **high-strength concrete has led to several trends in economical concrete construction, including earlier form stripping times, less post-tensioning required in floors, and columns with less rebar congestion**.

A growing trend in concrete construction is to use high-early-strength concrete for early form stripping purposes. Because formwork and labor are major cost items, any time saved by stripping forms early can make a noticeable difference in overall construction time and cost. Formwork that does not support the weight of concrete, such as beam sides and columns, can typically be removed after 12 to 24 hours of normal curing. Formwork supporting the weight of concrete, such as soffits of beams, joists, and slabs, should not be removed until after these structural members are strong enough to support their own weight plus any superimposed loads. A rule of thumb is to strip forms after the concrete has reached two-thirds to three-fourths of the specified design strength. However, other factors should be considered: Early form stripping can cause damage to concrete corners and edges, and can lead to excessive creep deflections. Creep (long term deflection under load) can be accelerated by removing forms while concrete is still "green". The most common method of measuring concrete strength for form removal purposes is compressive strength tests of field-cured cylinders. Many Engineers will allow form stripping of horizontal members to occur after 3 or 4 days and after 75% of the specified strength is reached. For this reason, some contractors will schedule concrete placement on Thursday or Friday and begin stripping the forms on Monday.

Another growing trend is to use higher-strength concrete for post-tensioned floors. Contractors have indicated that using 5,000-psi concrete for post-tensioned floors instead of the typical 4,000-psi concrete can be more economical. The added cost of higher-strength concrete is more than offset by savings from supplying and placing fewer post-tensioning cables.

In post-tensioned structures, high-early-strength, 4,000-psi mixes regularly achieve 5,000 psi by 28 or 56 days. Collaboration between the structural engineer and the contractor can capture the best of both worlds. The framing system can be designed to allow tendon stressing, form stripping, and reshoring based on a design 4,000-psi concrete, while simultaneous design for service conditions can be based on 5,000-psi concrete. If this situation can be negotiated, it can potentially eliminate much of the premium for 5,000-psi concrete while capturing the benefits of a 5,000-psi design.

As previously mentioned, high-strength columns are also common. Concrete strength in excess of 6,000 psi, and up to 10,000 psi, is economical to achieve. The downside to high-strength concrete columns is the interface with the floor slab. Section 10.15 of ACI 318 requires that,, where the column strength exceeds 1.4 times the slab strength, measures must be taken to address the strength difference. High-strength column concrete can be "puddled" in the slab at the column locations. Although the practice does not meet the exact wording of section 10.15, many engineers will design a column at exactly 1.4 times the slab strength, still specify a multiple of 1,000 psi for the column strength, but not require puddling. Example: A 6,000-psi column mix could be used with a 4,000-psi slab if the column design was based on a column concrete strength of 5,600 psi.

Column in slab.

Other Influential Factors

New building codes

With the ever-growing adoption of the International Building Code (IBC), designers need to be increasingly aware of code changes that have an effect on concrete construction. One of the biggest changes in the IBC from older codes is in the seismic force calculations. The IBC, with a few exceptions, requires all new construction to be designed to resist earthquake-induced lateral forces. Because of the changes in seismic force calculations required by the IBC from older codes, areas of the country that were previously areas of lower seismic risk may now be areas of moderate to high seismic risk.

Seismic force calculations take into account the seismicity of the region, site soil characteristics and occupant use. Structures located in moderate to high seismic regions, on bad soils, or classified as essential facilities can easily fall into Seismic Design Category C or D. A Seismic Design Category of C or greater requires the use of intermediate or special moment frames and/or shear walls, and requires the designer use the provisions of ACI 318 Chapter 21 *Special Provisions for Seismic Design*. The prescriptive detailing and analysis requirements of Chapter 21 for the seismic-force-resisting system (and members not identified to be in the lateral-force-resisting system) can significantly increase the required amount of reinforcement. This is particularly true at beam-column joints.

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Hooked Rebar.

Additionally, expansion joints in concrete structures may be governed by seismic drift requirements and can be larger than typically anticipated. IBC seismic effects on the concrete structure can have significant impact on costs. Engineers and contractors should try to determine early in the design process what these impacts of the new IBC seismic provisions will be.

Design-build versus traditional bid

Design-build and traditional design-bid-build are the two most common methods to award a project. More and more owners are selecting the design-build method. One reason is that general contractors are not waiting to bid projects. They are marketing directly to owners and letting them know the advantages of having the contractor on board from the start. Contractors are performing the work on a "cost plus" or a "guaranteed maximum price" (GMP) basis. Advantages include contractor input on project scheduling, budgeting, and structural system selection, plus the design team can consult with the contractor throughout the design process. Design-build has led to another trend called "fast track".

Fast track

Fast track means beginning construction before the construction documents are complete. Fast track can be used on many types of projects, but is most common on projects involving reinforced concrete. The idea behind fast track is to complete the overall project sooner by having portions of construction and design proceeding simultaneously. Reinforced concrete works well with this method because it is so readily available and requires minimal pre-ordering.

A typical scenario for a multi-story concrete building being constructed "fast-track" is for site work to begin while foundations are being designed, construction of foundations to occur while upper floors are being designed, and upper floors to beconstructed while final interior decisions are being made. The fast track project causes the structural engineer to design a building in reverse of how design is normally done. Structures are usually designed from the top down. Upper floors are designed first and gravity loads are tabulated from the roof down to the foundations. However, foundations are the first things to be constructed so they must be issued first, and probably well before final designs are complete for the balance of the structure. Many times structural packages are issued weeks or months before any architectural, mechanical, electrical, or plumbing drawings are issued. Generally, there is a premium in the structural engineer's fee due to the nature of fast track.

One of the keys to the success of a fast track project is to educate the owner. The owner should be made aware that there are going to be changes, discrepancies, errors, etc. during construction because of the speed of design and construction, and the less-than-normal coordination between design disciplines. This is the premium the owner may have to pay for having the project completed so quickly.

Conclusion

The inherent flexibility of reinforced concrete construction lends itself to finding new and innovative ways to mix, form, place, and reinforce concrete. Project schedules have become one of the most important considerations in construction today and play a major role in influencing trends in concrete construction. Reinforced concrete structures can be built on tight schedules because the major components – concrete, reinforcing steel, and formwork – are locally supplied and readily available. Framing systems and floor layouts are being guided by contractors who are involved in projects from conception. Other factors such as high-early-strength concrete, formwork repetition, and reinforcement repetition contribute heavily toward expediting the construction process. Balancing economics with speed of construction is a key to the success of today's projects.▪

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