Current Trends in Economical Concrete Construction

Part One: Floor Framing and Lateral Systems

By Jim Delahay, P.E. and Brad Christopher, P.E.

This is Part One of a three-part series that provides an introduction to current trends that lead to economical reinforced concrete construction. This article covers Floor Framing and Lateral-Resisting system concepts. Future issues of STRUCTURE® magazine will include Part Two, which will cover tips on formwork, and Part Three, which will include tips on reinforcement and discuss other influential factors such as building codes and project delivery systems.

Concrete is one of the most durable and readily available materials used in building construction. It is unique because it is delivered to the site in an unfinished state. There are numerous ways to mix, form, place, and reinforce concrete. As a result, designers and builders have flexibility in using reinforced concrete. Trends in concrete construction are dictated by this flexibility. As with all construction materials and systems, designers and builders are constantly looking for new ways to build with concrete for less money and in less time. This series of articles discusses current trends in economical concrete construction focusing on formwork, reinforcement, concrete, and other influential factors.

Economical Framing System Selection

The choice of the framing system is one of the earliest and most important project decisions made that affects the economy of the structure. In the age of design-build and projects with construction managers involved from the start, contractors are more often being relied on at the beginning of a project to help decide which framing system is most economical. Span length, floor framing depth, fire rating, deflection, vibration control, and potential for future modifications all influence the framing system selection process. Formwork, which can account for more than half the cost of a concrete frame, is a crucial factor in deciding what framing system to use.

Floor Framing Systems

The cost of the floors in a low- to mid-rise building can account for 90% of the total cost of the concrete frame. Therefore, choosing the right floor framing system for the given bay dimensions (or optimizing bay size) is the most crucial step. *Cost per square foot* increases considerably with increase in span.

As documented in the PCA publication, *Concrete Floor Systems – Guide to Estimating and Economizing*, flat plates and flat slabs are generally the most economical floor systems for square or nearly square bays of less than 30 feet. Flat plates and flat slabs are typically used for hotels, apartments, dormitories and condominiums. They are ideal for buildings with low floor-to-floor heights, and where tenant use and accompanying floor openings tend not to change. Flat plates can be constructed in minimum time with minimum field labor because the flat plate utilizes the simplest possible formwork and reinforcing steel layout. They lend themselves well to the use of flying forms, which in combination can produce a very economical and efficient floor framing system. The flat plate system tends to have larger column sizes due to shear requirements. For heavier loads and longer span combinations, the flat slab system will require less concrete and reinforcement and can utilize smaller columns than the flat plate for the slight added cost of forming drop panels. Flat slabs are well-suited for office, parking garage, library, storage and industrial facilities. For larger bay sizes the waffle slab system will provide increased stiffness with less dead weight for overall economy.

Fire Resistance Rating					
Concrete Type	1 hr	1½ hr	2 hr	3 hr	4 hr
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-Lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

Table 1: Minimum Slab Thickness (inches), IBC 2000 Table 720.2.1.1

Bay spacings of thirty feet or less can be framed economically with conventionally reinforced joists, beams, and girders using structural depths ranging from 19 to 21 inches. Using the new 24-inch-deep pan sections, joist spans of 35 to 40 feet are practical and economical. In order to maintain constant joist, beam and girder depths, post-tensioning should be considered for girders spanning more than 30 feet.

Thicknesses and spans for conventionally reinforced beams and slabs are frequently based on ACI 318 minimum thickness requirements. Except for unusual circumstances, these thicknesses can be used without checking member deflections. However, due to the widespread availability of computer programs that check deflection, it is becoming more common to check deflections and thereby use slab and beam depths less than the ACI default minimum values. A word of caution: Floor vibration becomes more of a concern with shallower beams and slabs.

Floor Vibrations

Vibration has predominantly been a concern in steel framed buildings. However, with today's new technology, floor

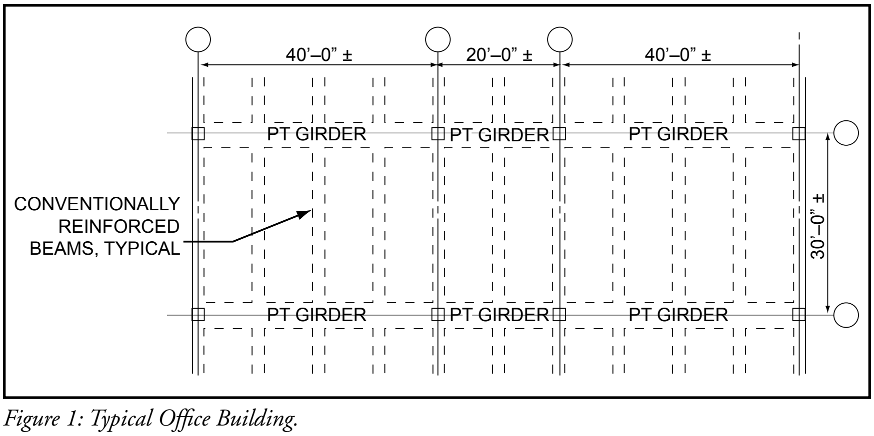

Figure 1: Typical Office Building.

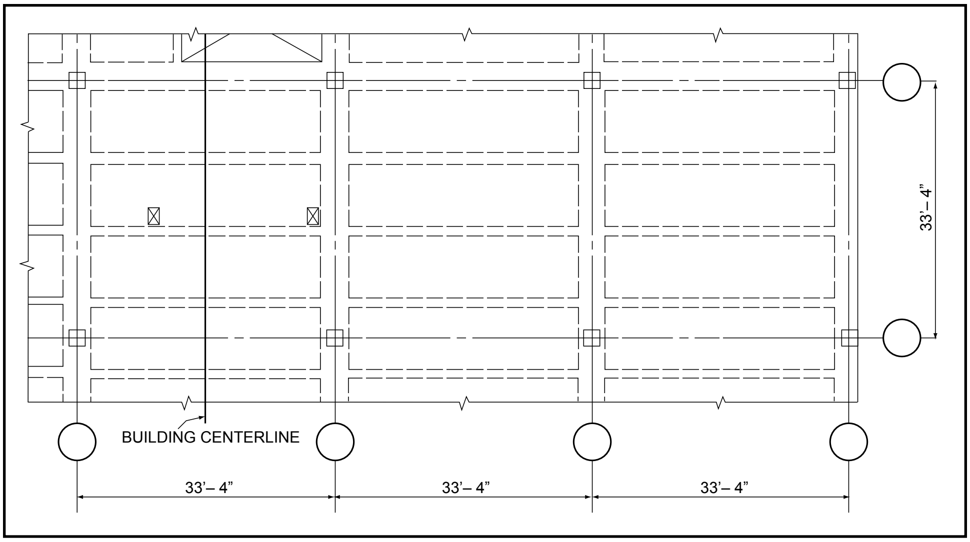

Figure 2: Square Bays with Conventionally Reinforced Beams and Girders.

vibration is becoming more of a concern even in concrete buildings. Hospitals, laboratory/research buildings, and any other structures that will house high-powered sensitive microscopes, laser equipment, surgical suites, etc. should be investigated for floor vibration characteristics. Previously, vibration analysis was limited to those structures with rhythmic excitation, such as dancing or aerobics, and rarely was any analysis done for concrete structures. Current vibration requirements can make it imperative that vibration analysis of concrete frames be part of the design process. ATC Design Guide 1, *Minimizing Floor Vibration*, provides some guidelines.

Fire Rating

Fire ratings play an important role in selecting the framing system for a project. Concrete structures can meet required building code fire ratings with no additional cost because they are inherently fireproof – connections, such as beam-column joints, are not vulnerable to fire and do not require specially constructed additional protection.

The International Building Code (IBC) specifies minimum slab thicknesses for various fire- resistance ratings (*see Table 1, page 19*).

Slab thicknesses are chosen based on fire rating and slab spans set as far as the minimum reinforcement and deflection criteria will allow. For example, a carbonate aggregate concrete slab requiring a two hour fire rating would likely be 5 inches thick (based on the required minimum thickness of 4.6 inches per IBC Table 720.2.1.1). A 5-inch thickness is sufficient for spans up to 10 feet, based on ACI 318 Table 9.5(a). For analysis and design considerations, see CRSI Engineering Data Report 52, *Fire Resistance of Reinforced Concrete Buildings*.

Building Geometry and Layout

A typical office building layout consists of a 3 bay, 100-foot wide floor plate (40-foot office space bay, 20-foot core area, 40-foot office space bay). This framing system typically utilizes post-tensioned girders parallel to the 100-foot building width with conventionally reinforced slabs and joists or beams spanning between girders (*Figure 1, see page 19*). Square bays with spans of 30 feet or more are also common for office buildings. Conventionally reinforced joist or beam construction is economical for these span ranges (*Figure 2*). To minimize formwork costs, a key to the economy of all these systems is to have the same depth beams and girders.

Future Expansions or Modifications

Another factor that can affect the framing system selection is the capability to accommodate future expansion and modification. It is not unusual for owners to pre-plan for future floors or future wings. The framing system can be affected by these future plans. The roof of a building may serve as a future floor. In order to avoid undue disruption to the interior operations of the building during a future expansion, the roof should be designed for future construction conditions due to the load imposed by shoring as well as wet concrete and possibly higher live load. These higher design loads may result in the framing system for the roof being different from the typical floors.

Lateral Systems

Wind and earthquake forces are resisted by a building's lateral system. Lateral forces on concrete buildings are normally resisted by moment frames or shear walls. The lateral system members should fit within the architectural and mechanical aspects of the building. A lateral system is considered to be efficient if the system does not increase the column or floor framing member size beyond that required for gravity loads.

Moment frames consist of horizontal members (beams) connected to vertical members (columns) with monolithic rigid joints. Moment frames may be placed along interior column lines or along the exterior of the building. The strength and stiffness of the

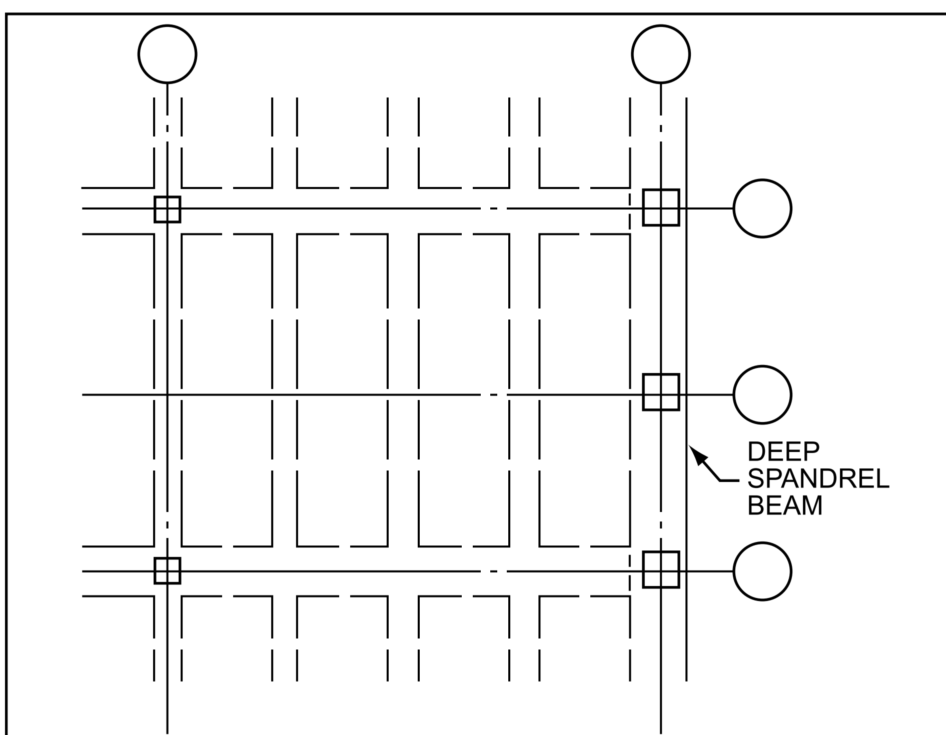

Figure 3: Deep Perimeter Beams with Closely Spaced Columns.

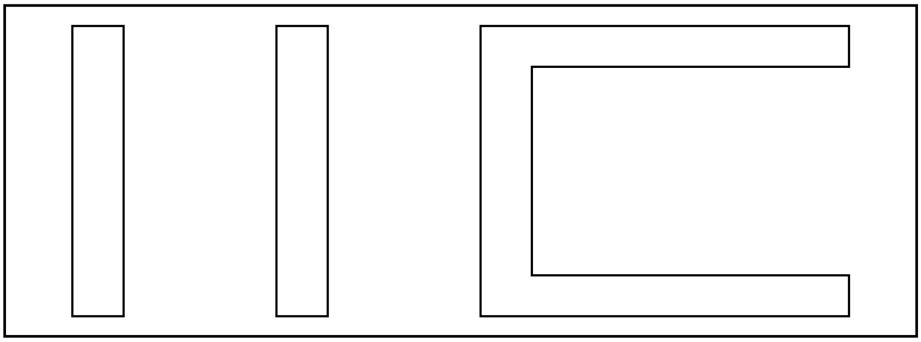

Figure 4: Two and Three Sided Shear Walls.

moment frame is proportional to the column and beam size, and inversely proportional to the floor-to-floor height and column spacing. Where member sizes must be increased in order to resist lateral forces adequately, an efficient approach is to provide closely spaced perimeter columns and deep spandrel beams, as shown in *Figure 3*.

Shear walls are designed as thin slender beams that cantilever vertically to resist lateral forces. Where possible, shear walls should extend all the way to the foundation. Shear walls, like flanges of a steel beam, are more effective on the outside of a building, but are more commonly used in the core area for architectural reasons. They are typically placed around stairs, elevators, or other shafts. For ease in forming, contractors prefer shear walls on two sides of a rectangular pattern rather than a C-shaped pattern (*Figure 4*).

Both moment frame and shear wall designs can be economical solutions. Generally, shear walls are a more economical lateral system when buildings exceed 8 stories, when architectural constraints limit the column size or beam depth, when column layouts are not on a uniform grid, or when stair and elevator shafts are conveniently located. Having a contractor included during the design stage can help in selecting the most economical system (i.e. larger columns vs. shear walls).

High seismic loads require special detailing of the reinforcing to achieve the code designated level of ductility. Where seismic loads are a consideration, a significant increase in design, detailing, and total reinforcing steel cost should be expected. For a more comprehensive treatment of seismic detailing requirements see the PCA publication, *Seismic Detailing of Concrete Buildings*.▪

Jim Delahay, P.E., was the president of LBYD Civil and Structural Engineers until he passed away unexpectedly in April 2005. Delahay served on the Structural Committee of the International Building Code, the NCSEA Code Advisory Committee, and the Applied Technology Board of Directors. He was also Vice Chairman of the ASCE 7 Wind Load Task Committee.

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