building blocks

Preservation Engineering

Early Reinforced Concrete and Designed Masonry

By Donald Friedman, P.E.

For engineers reviewing old buildings, the beginning of the twentieth century marks significant changes. Steel framing was nearly mature, new local fire codes (particularly after the Baltimore fire of 1904 and the San Francisco fire following the 1906 earthquake) made the use of wood in large buildings less common, masonry construction began to change from empirical use to calculated design, and reinforced concrete in a recognizable modern form began to be used for complete building frames. Among these changes, the details of early reinforced concrete are least well known and the changes in masonry analysis often misunderstood.

One fact clearly distinguishes the historical development of reinforced concrete from that of steel: from the 1870s onward, engineers in the United States were among the leaders in advancing the technology of iron and steel construction, in bridges and buildings, especially long-span roofs; on the other hand, reinforced concrete was a maturing technology in Europe before any large-scale use in the U.S.

Many of the oddities of early reinforced-concrete construction in the United States – defined here as that used before 1930 – are the result of the forms of an imported technology being used by engineers and contractors with limited experience in it and by the experience of the years immediately proceeding, when they had developed floor systems by empirical testing rather than by analysis. (See *Preservation Engineering: Floor Systems*, in **STRUCTURE**, September 2004.) Theory for a composite material was readily available for simple beams but not for columns; even worse from the 1910 standpoint was that the new material introduced an entirely new structural form: the flat slab.

Structural masonry has obviously continued in use – low-rise bearing wall buildings are common today – but the forms of use have changed. Increased use of reinforced concrete slabs coincided with the decline of tile-arch floors, and increased use of skeleton frames created the need for thin masonry curtain walls. The development of curtain walls after 1900 influenced later masonry bearing-wall design, as calculated design replaced empirical rules.

Materials

Because admixtures were not used before World War II, early concrete was simply the basic mixture of cement, water, and aggregate; various grades of steel have been used for reinforcing, but no other material.

Early rebars were often part of patented systems, such as the Kahn and Columbian systems, which were installed by the manufacturers. Even when more generic reinforcing systems were used, the bars are often oddly shaped: before the use of deformed bars became standard in the late 1920s, many bar types depended on friction and chemical bond for development, and therefore had complicated cross-sections to provide additional surface area. (*See Figure 1*) Early deformation types varied widely and were less effective than the current requirements until the late 1940s. Obviously, hooked rebar was developed in the same manner then as now, but the bond strength of unhooked rebar from before 1950 must be examined before load analysis can be performed.

Before the creation of the American Society for Testing and Materials (ASTM) in the early 1900s, the term "portland cement" was used to describe a wide range of artificially-created cements of varying quality. ASTM's Committee C, responsible for cement standards, produced the first national cement standard in 1904, after which an acceptable quality of cement became common.

The most general construction- or materials-related problem with old concrete is gross segregation. The vibration used in placing concrete – if any – was not adequate, and it is common to see beams, slabs, and even columns with areas of large voids resulting from a near lack of fine material during placement. Any investigation of a concrete structure built before 1950 should check whether segregation and voids significantly reduce the load capacity.

Masonry materials have changed relatively little. Concrete block in its most basic form – precast units meant to be built in with other masonry – was first created in the nineteenth century, but was not often used for structural purposes or facades until after World War II. Before then, it was sometimes used as a substitute for terra cotta tile or gypsum block in the construction of fire-resistant interior partitions, a use that can be seen in the occasional references to it as "concrete tile." Clay brick has gradually increased in compressive

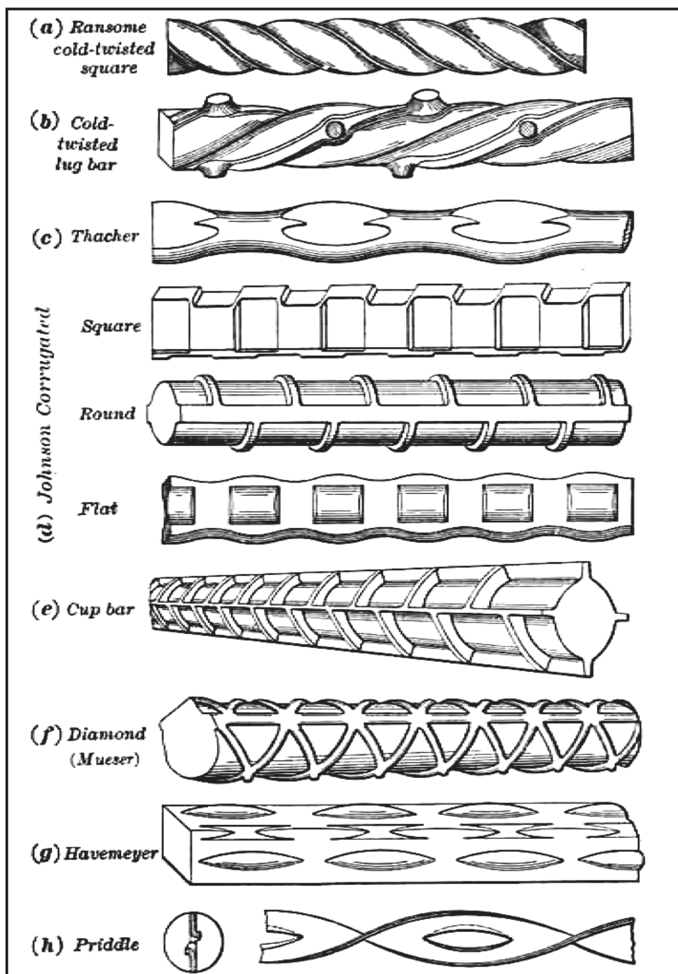

Figure 1

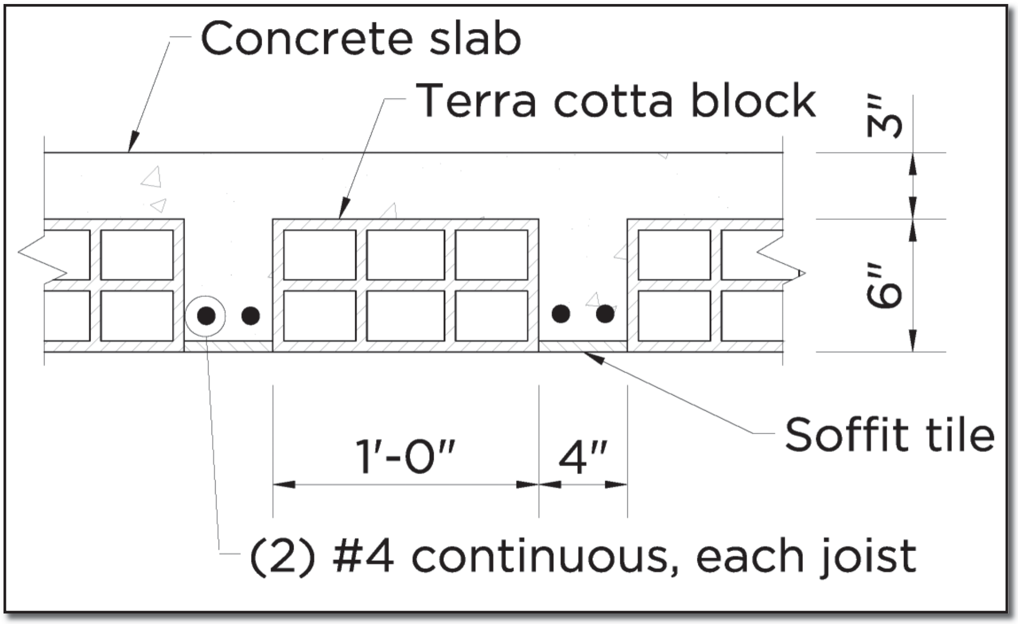

Figure 2

strength from improvements in manufacturing techniques, but is basically the same product it was in 1850. Older, softer bricks are usually taken to have an allowable compressive stress of 200 or 250 pounds per square inch (psi).

Concrete Codes

Shortly after the first large all-concrete buildings were constructed in the United States, existing professional organizations began to form committees to study reinforced-concrete design and new organizations were formed specific to the material: the American Society of Civil Engineers (ASCE) committee was formed in 1903, the American Concrete Institute (ACI), as an organization, was formed in 1904, and so on. The ASCE, the ACI, the ASTM, and the American Railway Engineering Association created the "Joint Committee" before 1910 to ensure uniform analysis and design techniques. When the Portland Cement Association was formed in 1916, it joined the Joint Committee. The Committee issued a series of reports, which were, effectively, versions of a basic code that could be adopted and modified by the member organizations. Until the late 1920s, when code-writing for building use became the responsibility of the ACI, concrete buildings were designed to the standards of the Joint Committee reports or to city or state building codes, which were often based on more conservative allowable stresses than the committee reports.

Beams and Slabs

By the time the Joint Committee was created, standards for elastic analysis of flexure in reinforced concrete had been established in a form similar to standards that formed the basis of the ACI code until 1963; these standards were allowed as an alternate method until 1999. One-way slabs and beams can therefore be analyzed for moment using the current code with little difficulty, assuming that there is no problem with bar development.

Beam shear stresses were addressed in various ways before 1930. Many of the patented reinforcing systems provided pre-fabricated cages of rebar that included stirrups. The Joint Committee gave preference to "web reinforcing" stirrups or closed ties by providing a high "shear stress" computed using the concrete sectional area. However, beams with no shear reinforcing were allowed at a reduced shear stress and beams with only bent-up bottom bars were allowed at an intermediate shear stress.

Two-way slabs of this era, by contrast, were typically qualified by empirical testing programs. There was a recommended Joint Committee flat-slab design, with "four-way" reinforcing (following both primary bay axes and the crossing diagonal axes), but there were also many odd designs involving some combination of diagonal, curved, continuous, and intermittent bars. It is not possible to analyze these systems using modern codes, but they have often performed well and, if their condition is maintained and their loading unchanged, should continue to perform well.

Modern concrete slabs and, after the mid-1950s, concrete on metal deck gradually displaced earlier floor systems. Terra-cotta tile-arch floors were displaced in the 1900s and 1910s by draped-mesh, cinder-concrete slabs (as described in *Floor Systems* in the September 2004 issue of **STRUCTURE**), but some masonry use in floors continued. Some early concrete joist systems in the 1920s used terra-cotta blocks rather than forms to create the voids between joists: the blocks and concrete rib bottoms provided a continuous surface for the application of ceiling plaster. (*See Figure 2*) Later this idea was extended to waffle systems, but both types of floor fell out of use after the introduction of composite metal deck in the 1950s.

Columns and Piers

The exteriors of old reinforced columns look much like those of modern columns. The columns tend to be stockier than steel columns of their era and tend to be square, round, or octagonal in section if located in a building interior, and rectangular if located at an exterior wall. Only the common use of flared capitals provides visual distinction. Capitals, which have never officially fallen out of use as a method of reducing punching shear, have become far less common as the design shear strength of concrete has risen over the course of the twentieth century (both from stronger materials and code changes) and as concrete flat-slab use has spread from industrial occupancies, with wide column spacing and high live loads, to office and residential occupancies, with closer spacing, lower loads and, therefore, lower shear stresses.

Codes in the early 1900s encouraged designers to treat concrete columns in a similar manner to masonry piers, by defining the allowable loads in terms of slenderness and overall compressive stress only. The requirement for stocky columns (for example, the second Joint Committee report limited columns to an unbraced height of 12 times their diameter) reduced the likelihood of moment-magnification effects; the interaction equation for bending and axial compression simply added the actual-to-allowable ratios without interaction effects.

The element of column design that differs most from current practice was the use of reinforcing. Experimental data had proven the ability of lateral ties to increase column capacity, but this was treated as an issue of strength and not one of toughness or ductility. The second Joint Committee report gave three different allowable compressive stresses for concrete columns: a base allowable stress for columns reinforced with longitudinal bars, an allowable stress 20 percent higher than the base for columns reinforced with "bands, hoops, or spirals," and an allowable stress 45 percent higher than the base for columns with both types of reinforcing. In analyzing such structures now, it is typically not possible to justify alterations to or increased loads on columns that lack either longitudinal or lateral reinforcing.

Obviously, if engineers were allowing unreinforced concrete piers, they were also allowing unreinforced masonry piers and walls. Reinforced masonry was first developed in the nineteenth century as a method of constructing fire-resistant beams and slabs, but remained relatively rare until after the 1933 Long Beach earthquake. The earthquake-resistant construction adopted (first in California) after 1933 included vertical rebar in walls for continuity and the substitution of metal ties for brick headers. This form of construction only gradually spread to areas of lower seismic risk; as late as the 1990s, there were portions of the country that did not use model codes that included nationwide seismic risk maps. Every locality, therefore, has a transition date or period which separates unreinforced-masonry construction chronologically from reinforced-masonry construction.

Walls

Building codes in the nineteenth century used prescribed thicknesses and details for walls rather than stress design. Based on a wall's total height and distance between bracing elements (pilasters, floors, or intersecting walls), the codes provided a required minimum thickness. In some cases, the total cross-sectional area of walls derived from the code thicknesses could be rearranged into thicker piers and gaps to create large windows. This system was adequate for the relatively low buildings and thick walls of that era, but was not a realistic method of dealing with the taller buildings and thinner walls of the steel- and concrete-frame era after 1900. In the early twentieth century, wall design for wind pressure was governed by unreinforced elastic design, governed by allowable tensile stresses in the codes.

Summary

Structural evaluation of existing reinforced concrete and masonry buildings may hinge on an understanding of changes in the materials, design methods, and design codes since 1900.▪

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