Concrete for high-rise buildings

Ever since the industrial revolution the peoples of the world have been gravitating in huge numbers to urban areas. One result has been that land costs in preferred areas have become almost prohibitive and buildings have gone higher and higher in the quest to do as much as possible on as little land as possible.

Concrete has played an increasingly important role in the efforts of architects and engineers to find a satisfactory and economical material for high-rise multistory buildings. The first concrete skyscraper was built in 1902 in Cincinnati, Ohio. It was the 16-story, 210-foot high Ingalls Building which, incidentally, just received a face-lifting and is still in active use.

Today the highest reinforced concrete building in the world is the Banco de Estado, a 507-foot, 34-story building in Sao Paulo, Brazil. In Chicago, right across the street from the Executive House—a 38-story hotel that set a U. S. concrete building height record when it was built about three years ago-—there is now under construction a pair of apartment buildings that will be not only the highest apartment buildings but also the highest concrete frames in the world.

The reasons for this surge in the use of concrete for high-rise buildings are manifold. The continuity concrete affords a building frame provides unequaled structural interaction of its parts. Concrete floor systems, such as flat slab and flat plate, offer the smallest possible floor depths. Material costs are low. Concrete is readily adaptable to unusual plans, for example the curved and circular designs now so popular. High strength reinforcing rods are extending concrete's potential in this field. Ultimate strength design, now gaining acceptance in the United States, provides a more efficient means of designing in concrete. And finally concrete building frames are low in cost. Even in the United States, where labor costs are the highest in the world, concrete frames are notably economical.

In a recent test held by the New York City Housing Authority, competitive bids were called for on alternate concrete and steel frames for three 20-story apartment buildings. Every one of the nine contractors who bid on this contract bid concrete lower than steel; and the average concrete bid was more than half a million dollars less than the average bid for the steel frames. In addition, plumbing and electrical bids were lower. These advantages have resulted in increased use of concrete for multi-story buildings.

Modern high-rise concrete buildings are models of design skill in the use of materials. It is now a commonplace to specify high strength concrete, usually 5,000 psi, for compression members in the lower stories of multistory buildings. Concentration of reinforcing bars in these members is very high. The trend toward buildings other than rectilinear in shape is producing some unusual structural members. All of these factors spell placing problems unless a mix design is formulated that produces concrete of considerable flowability and high quality.

The problem of obtaining uniform, high-quality concrete in this work hinges mainly on two basic considerations: (1) mix design; and (2) placing and curing procedures.

Designing a concrete mix that provides the properties desirable in high-rise buildings using available materials often constitutes a real challenge. In a project as large as a high-rise building, a number of trial mixes should be made to arrive at a concrete which will satisfy the needed requirements. The major problems in this work are: maintaining economy; preventing segregation; minimizing bleeding and formation of laitance; and securing desired flowability, uniformity, durability and high strengths.

Since high-rise buildings often take a year or more to build, the mix design must take into account the radically varying ambient conditions that will be encountered during construction. In addition, more than one basic mix design might very well be needed for a high-rise building. For example, a number of buildings now make use of lightweight aggregate concrete for the floor slabs but regular concrete is specified for columns and sheer walls. Since many lightweight aggregates are angular, achieving thorough particle coating becomes a problem and special steps must be taken to insure good workability and finishing qualities. Even if regular concrete is used for the entire structure, the mix design for foundations most probably would not be the same as that for exposed columns.

In high-rise buildings where reinforcement concentration is often quite heavy, care must be exercised that the maximum coarse aggregate size used does not prevent proper consolidation of the concrete in narrow forms and around the bars. The American Concrete Institute Building Code provides that the maximum size of the aggregate shall not be larger than one-fifth of the narrowest dimension between sides of the forms nor larger than three-fourths of the minimum clear spacing between the bars.

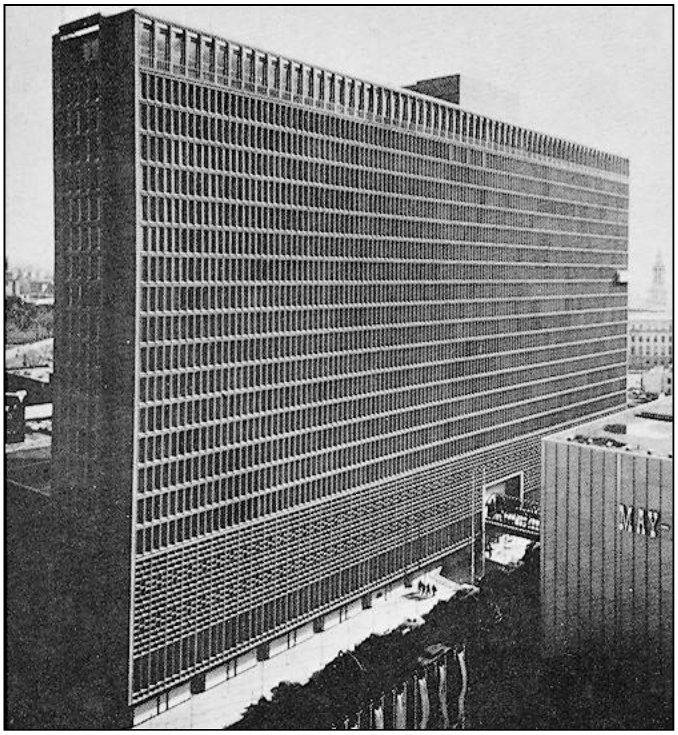
The narrow, high forms often used for columns and shear walls aggravate the tendency of mixes to bleed and produce laitance. These problems are quite common in the tall building construction field, but they can be prevented by close attention to two aspects of the mix design: (1) cement paste consistency and physical composition; and (2) characteristics of the aggregates.

The major points with respect to the latter in preventing bleeding are avoiding harsh or smooth non-absorbent aggregates and poor gradation. Harsh aggregates of poor particle shape usually result in the need for more cement paste and invite addition of extra placing water by workers on the job site. Watering concrete aggravates bleeding and makes segregation more likely, which in turn causes water gain.

Air entrainment and minimum water content can play an important role in halting bleeding, formation of laitance and segregation. As has been mentioned, the height and narrowness of columns and shear wall forms render these problems particularly troublesome. When the unit water content can be lowered by proper proportioning of the mix and the use of an air-entraining water reducing agent, water gain, naturally, will be reduced. In addition, air entrainment results in a fatty, more cohesive concrete that resists segregation better than a non-air entrained mix. Besides lowering water content and bleeding, compounded water reducing and air entraining agents result in higher strengths and better workability —both highly desirable in placing concrete for high-rise buildings.

Without proper placing procedures, however, even the

Shown below in an early stage of construction and at the right as they will look when completed, the 60-story group of buildings in Chicago to be known as Marina City typify the new freedom which modern concrete construction has brought to the design of high-rise structures. A self-lifting crane which can revolve 360 degrees is being used to hoist forms, reinforcement and concrete. When completed the 588-foot towers will be the tallest reinforced concrete buildings in the world.



The reinforced concrete frame of the Denver-Hilton, another example of an all concrete high-rise structure, was faced with more than 450,000 square feet of concrete curtain wall.

best designed concrete will segregate and bleed, resulting in honeycombing, poor bond to steel and other woes. In general the usual desirable placing procedures apply to concreting tall building members. However special care must be taken with respect to some aspects of placing.

Because column and wall forms are usually rather high and reinforcing bars are often spaced quite closely, workmen must be careful in depositing and vibrating concrete in this work. Concrete should be dropped in a true vertical plane and have a free fall of no more than four feet. For deep forms, concrete should be discharged into a hopper to which is attached a flexible drop chute extending to within four feet of the bottom of the form. If this is not done, the coarse aggregate will ricochet through the network of bars and against the sides of the forms, causing separation. In addition the bars and forms will be coated with mortar which will dry out before concrete is placed over it. The result is mottled surface appearance, dusting and poor bond strength.

Should this placing procedure be impossible because of type or concentration of reinforcement, a duct should be built at each third space between studs. The hopper that feeds these ducts should be built with a pocket below the duct opening so that the concrete flows smoothly into the form. If the concrete is discharged at an angle to the sides of the form, it will bounce off the sides and against the bars, thereby resulting in separation despite the use of the duct system.

In deep, narrow forms consistency of the concrete must be varied. A mix of higher slump (say from 4 to 6 inches) should be used at the bottom of the form with mixes of progressively lower slumps towards the top. Water gain will help equalize the over-all quality of the concrete and settlement shrinkage will be kept to a minimum.

Vibration can be a great help in concreting high-rise buildings because it permits use of lower water contents. However vibration can be misused. If it is employed with wet mixes or continued for too long, separation will result. Also, if vibration is used to move concrete horizontally, rather than to compact it, the surface will be torn and poorly consolidated .

In vibrating lifts, especially those containing concretes of different slumps, uniform angle of penetration of the vibrator head should be maintained. Also make sure that the vibrator head penetrates a few inches into the previous layer of concrete to effect thorough consolidation of the two lifts. If some time must elapse between casting of successive lifts, a retarder should be used to insure plasticity of the previous lift when the next layer is to be cast.

Placing and finishing practices also have an important bearing on the quality of concrete flatwork. Concrete should be dumped into the face of the concrete already cast—not away from it. If concrete is to be placed on a slope, always start at the low point and work toward the high point—never the reverse. If a chute is used to place concrete on a slope, a baffle should be positioned at the end of the chute to break the velocity of the concrete flow.

These desirable proportioning and placing practices will also largely hold true for lightweight concrete, now so popular for floor and roof slabs in tall buildings. However there are some differences due to the unit weight and absorption characteristics of lightweight aggregates.

Lightweight aggregates are broadly divided into two classes: extra-light (such as vermiculites and expanded perlites), and medium-light (for example, expanded clays and shales). Only the latter are capable of developing the high compressive strengths for the structural members of high-rise buildings.

These medium-lightweight, high-strength aggregates may be further divided into two types: coated aggregates—those generally rounded in shape and with a hard, relatively impervious coating over a porous core; and crushed aggregates— usually angular, irregular-shaped particles produced by grinding to size large lumps of material exploded, so to speak, from the parent material. As might be expected, coated aggregates are preferable because they absorb less moisture and produce a more workable concrete.

Uniform workability of the mix is more difficult to maintain with lightweight aggregates due to their general high absorption and the wide variation in rate of absorption from particle to particle. Because the coarse aggregates are lighter than the concrete mass, they tend to float to the surface when improperly placed.

Air entraining and water reducing agents are of special value in lightweight concrete because they improve workability markedly and reduce water requirements. Higher air contents—up to about 7 percent—should be used than are normally specified for regular concrete.

In measuring air content of lightweight concrete it is important that the volumetric method be used. It is virtually impossible to obtain the specific gravity of lightweight aggregates to the degree of accuracy required by the gravimetric test, and the pressure method is unsuitable for highly porous aggregates.

Slump is not a wholly reliable gauge of workability in normal weight concretes and in lightweight work its dependability is further reduced. If the slump test is used to help measure workability, it should be remembered that the slump for a given degree of workability will be less with lightweight aggregate concrete than with a normal sand-and-gravel mix. Roughly speaking, lightweight concrete with three to seven percent entrained air of two- or three-inch slump will have approximately the same placing characteristics as normal weight concrete of four- or five-inch slump. A more reliable gauge of workability in lightweight concrete work is obtained by use of the V-B Consistometer. A workable lightweight plastic mix would give a reading of from two to five V. B. degrees.

Lightweight mixes should be handled as little as possible. Lightweight mixes tend to entrap air and honeycomb more than normal weight concretes. Although vibration is quite helpful in preventing these defects, careful supervision is needed to prevent over-vibration which would aggravate water gain and segregation. It is easier to notice segregation in working with lightweight concrete because the coarse aggregates, being lighter rather than heavier than the mass, float to the surface when segregation takes place.

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