by Henry G. Russell, P.E.

Why use high-performance concrete?

For many years, high-strength, high-performance concrete has been used in the columns of high-rise buildings. However, in recent years, there has been increased use of high-performance concrete (HPC) in bridges where both strength and durability are important considerations. The primary reasons for selecting HPC are to produce a more economical product, provide a feasible technical solution, or a combination of both.

At the present time, a cubic yard of HPC generally costs more than a cubic yard of conventional concrete. HPC requires additional quantities of materials such as cement, fly ash, silica fume, high-range water-reducers and retarders to ensure that the concrete meets the specified performance. However, concrete is only one component in construction, and the total cost of the finished product is more important than the cost of an individual material. On the other hand, HPC should not be specified if there are no economical or technical advantages to be gained from its use. Here, TECHNICAL TALK explains why HPC is used in buildings and bridges.

With column mixes carrying design strengths in excess of 10,000 psi, Chicago's 225 West Wacker Drive was among a wave of late 1980s-early 1990s buildings to incorporate high-strength concrete.

Favorable experience with high-strength concrete prompted Washington DOT engineers to specify 7,000 psi compressive strength mixes for the cable-stay bearing piers of Tacoma's Theo Foss Waterway Bridge.

PHOTOS: *Concrete Products*

Buildings

The economic advantages of using high-strength, high-performance concrete in the columns of high-rise buildings have been known for many years. In simple terms, high-strength concrete provides the most economical way to carry a vertical load to the building foundation. The three major components contributing to the cost of a column are concrete, steel reinforcement and formwork. By utilizing high-strength concrete, the column size is reduced. Consequently, less concrete and less formwork are needed. At the same time, the amount of vertical reinforcement can be reduced to the minimum amount allowed by the code. The net result is that the least expensive column is achieved with the smallest size column, the least amount of reinforcement and the highest readily available concrete strength.

According to a study by Moreno (1), the use of 6,000 psi (41 MPa) compressive strength concrete in the lower columns of a 23-story commercial building requires a 34-in. (865-mm) square column at a cost of \$0.92/ft^2 (\$9.90/m^2). The use of 12,000 psi (83 MPa) concrete allows a reduction in column size to 24-in. (610 mm) square at a cost of \$0.52/ft^2 (\$5.60/m^2). In addition to the reduction in initial cost, a smaller column size results in less intrusion in the lower stories of commercial space and, thereby, more rentable floor space. Yet the use of high-strength concrete in columns has not been limited to tall buildings: Parking garages have also used the material to reduce column sizes. Since columns intrude into the layout for parking spaces, a small column is advantageous.

In addition to specifying concrete compressive strength, modulus of elasticity has been specified for the concrete in several high-rise buildings. The most notable building is Two Union Square in Seattle where a modulus of elasticity of 7.2 million psi (50 GPa) was required in addition to a compressive strength of 14,000 psi (97 MPa). To achieve this modulus of elasticity, a compressive strength of 19,000 psi (131 MPa) was required. A higher modulus of elasticity provides a stiffer structure which has less lateral deflection under wind loads.

Bridges

In 1993, the Federal Highway Administration (FHWA) initiated a national program to implement the greater use of HPC in bridges. Applications include bridge decks, girders, piers and abutments. Nine bridges had been completed under the national program by the end of 1998. In addition, a number of other states are using HPC under their own programs. The use of high-strength concrete in prestressed concrete girders allows for longer span lengths (Figure 1), wider girder spacings or shallower sections (Figure 2).

The use of concrete with a specified compressive strength of 14,700 psi (101 MPa) at 56 days permitted the use of AASHTO Type IV girders for a span of 157 ft. (47.9 m) on the North Concho River, U.S. 87, and South Orient Railroad Overpass in San Angelo, Texas. A simple span length of 157 ft. is impossible to achieve with normal strength concretes and a 54-in. (1,372-mm) deep girder. On multi-span bridges, the use of longer girders results in fewer spans and fewer substructures.

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Figure 1 Longer Span Lengths with High-Strength Concrete
(72, 63, 54-ft. girder depths)

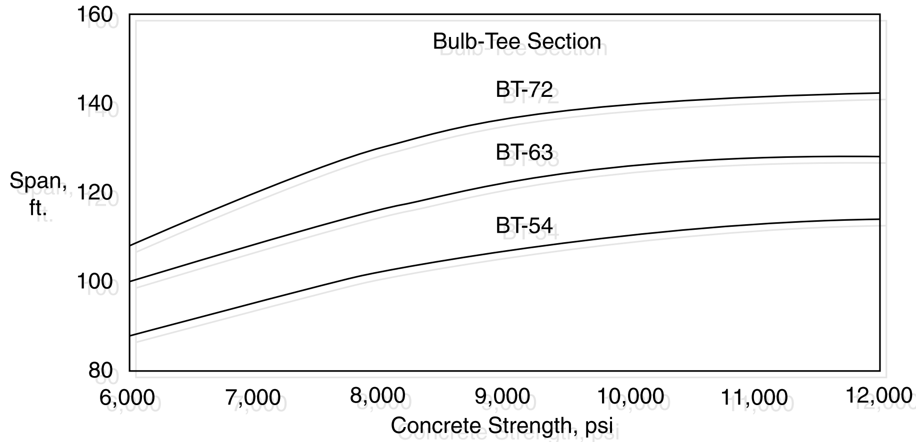
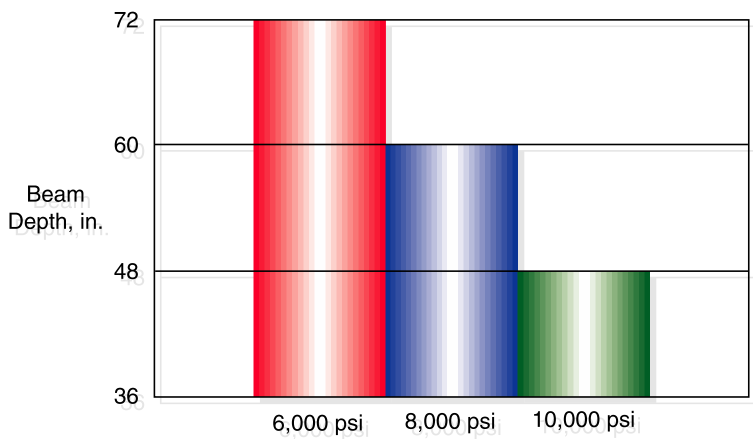


Figure 2 Girder Depths for 100-ft. Span



High-performance concrete is also being used in bridge decks where durability is far more important than compressive strength. Consequently, performance requirements other than strength are being specified. For durability, performance can be measured using freeze-thaw resistance, deicer scaling resistance, abrasion resistance or chloride permeability. At the present time, most states are specifying a limit on chloride permeability for their HPC decks.

The goal is to specify quantifiable performance to match the intended application. However, selecting durability performance requirements can be difficult, and specifications are usually a combination of prescriptive and performance requirements.

In Virginia, moist curing of HPC bridge decks is required for a minimum of seven days and until 70 percent of the specified 28-day strength is obtained. Protection by fogging to prevent rapid drying of the concrete surface prior to application of wet burlap and plastic sheeting is required. After moist curing, a curing compound is applied to the deck surface. Most states with HPC bridge decks require at least seven days of wet curing for the concrete. At least one state requires 14 days of wet curing.

Unlike high-strength concrete in buildings, the use of high-performance concrete in bridges is more difficult to justify based on initial costs only. The economic advantage of HPC varies depending of the premium cost for the HPC product. In many of the HPC bridges built to date, the premium costs for the HPC have not been entirely offset by savings in materials. However, as more contractors and producers develop experience with HPC, it is anticipated that the premium will decrease and initial costs will compare more closely with costs for conventional concrete bridges.

With bridges, there are additional costs associated with maintenance and repair. The use of HPC with its greater durability is likely to result in less maintenance and longer life. With the introduction of life-cycle costing, the long-term economic benefits are likely to more than offset the premium costs for initial construction. Further information about the use of HPC in bridges is provided at the FHWA's web site: http://hpc.fhwa.dot.gov.

High-performance concrete was used on a bridge on S.R. 516 near Auburn, Wash. The use of concrete with a specified strength of 10,000 psi (69 MPa) for the prestressed concrete girders resulted in five lines of girders compared to seven lines that would have been required with normal strength concrete. In addition to strength, the concrete was required to have a rapid chloride permeability not exceeding 2,000 coulombs and a freeze-thaw resistance greater than 80 percent.

In Colorado, an HPC bridge was used to replace a previous structure that carried Interstate 25 over Yale Avenue in Denver. The previous structure consisted of a four-span, cast-in-place T-girder bridge with piers located in the median of Yale Avenue and at each side of the roadway. The HPC bridge used 10,000 psi (69 MPa) concrete and consisted of two spans in place of the original four spans. The use of HPC, in combination with adjacent box beams, met the requirements for longer spans while maintaining a shallow superstructure depth.

References

1. Moreno, J., "High-Performance Concrete: Economic Considerations," *Concrete International*, Vol. 20, No. 3, Mar