A2E03: Committee on Properties of Concrete
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Concrete Properties

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Revolutionary developments relating to novel materials for concrete production and to modifications and improvements in the behavior of traditional materials have been taking place in the past two decades. These developments have been facilitated by increased knowledge of the atomic and molecular structure of materials; studies of long-term failures; the development of more powerful instrumentation and monitoring techniques; decreases in the cost-effectiveness of traditional materials; and the need for stronger and better-performing materials suitable for larger structures and longer spans, as well as for increased ductility. The 21st century will see the emergence of high-strength, high-performance concrete, particularly in the world's infrastructure of roads, buildings, and bridges.

New cements, techniques, and composites have already achieved very high strengths, some as high as 300 megapascals (MPa) [45,000 pounds per square inch (psi)]. Large projects already employ new and advanced construction techniques with traditional, lower strengths. This trend in new cements and techniques will continue in all phases of infrastructure constructibility and rehabilitation. In short, the last two decades of the 20th century can be described as the decades of concrete admixtures. The 21st century will be the era of high-strength, high-performance concrete.

More than 500 million tons of concrete is used annually in the United States, and many times this amount worldwide. Increasing urbanization and improvements in both developed and developing countries will only increase this demand. These same changes will also bring more industrialization and mineral byproduct wastes; for example, the world's production of fly ash was more than half a trillion tons in 1989. Some of these environmentally unfriendly by-products can be used in new concrete, given better control techniques. The versatility of concrete and its high-performance derivatives will satisfy many future needs. The 21st century will become the golden age of environmentally friendly supplementary cementing materials for high-performance concrete.

DESIGN AND REHABILITATION

As the turn of the century approaches, deteriorating infrastructure will require replacement or rehabilitation even as the increasing needs of a larger and more developed world population must be satisfied. The body of knowledge accumulated in the latter part of the

20th century can be used to achieve major improvements in concrete mixture proportioning and choice of components to help meet this challenge. More than 160,000 tests of various types have been conducted on cylinders, cubes, uniaxial and multiaxial loading, and combinations of structural components. Through analysis of the voluminous data resulting from these tests, it will be possible to determine why some structural systems built early in the 20th century still perform admirably, while other, more recent and more sophisticated systems have been failing. The lessons learned will aid in preventing the latter problems in the future.

There is a sizeable backlog of decaying infrastructure in the United States. Repair and replacement of airports and bridges, as well as mass transit, water supply, sanitary treatment, housing, and other facilities, is essential—often on an emergency basis. High-performance concrete and efficient structural designs can provide cost-effective systems with long service lives. While some design codes may be adequate, higher strengths will lead to more slender and lighter members with different behavioral characteristics. The use of these members must be justified by research into such aspects as shear, torsion, stiffness, cracking, deflection, and stability.

Buckling serves as a case in point. Even for long-span bridges and tall columns, buckling stability is rarely a consideration with the relatively massive concrete proportions necessitated by today's traditional strengths of 34 to 55 MPa (5000 to 8,000 psi), concrete covers, and sizes of reinforcing steel. However, stability will become important, for example, for very thin webs, compression flanges, and slender columns. With the less ductile behavior of concrete, stability may become critical. With thin sections, construction innovations also come into play. There are no standards at present to address many of the parameters involved.

Slender concrete elements will offer less space for traditional reinforcement. While new materials such as glass, aramid, and carbon fibers are promising, they lack sufficiently high moduli of elasticity to perform as passive (nonprestressed) reinforcement. Steel reinforcement will continue to dominate. Special stainless steels will be used increasingly, and alternative reinforcing materials will continually be sought. Nevertheless, the anticipated use of concrete strengths of 205 to 275 MPa (30,000 to 40,000 psi) and reinforcement with a yield in excess of 590 MPa (85,000 psi) will necessitate new or modified codes and design procedures.

Expanded knowledge will lead to concrete structures—whether bridges, high-rise buildings, or floating cities—that are far more immune than existing structures to seismic conditions, offering greater safety and less-costly repairs. Advances will be made in the use of both internal and external post-tensioning systems and details to facilitate resilient structures. Similarly, improved design of connections will lead to widespread use of high-strength precast members for buildings and bridges in both seismic and nonseismic regions, resulting in the universal standardization of factory-produced concrete elements.

CONSTRUCTIBILITY CONSIDERATIONS

Many long-span concrete bridges have already been built using traditional materials and technology. Advances are being achieved with methods such as precast segmental construction. Lighter members facilitated by high-strength concrete and new reinforcing and prestressing techniques and materials will not only enable very-long-span systems, but also permit broader application of lightweight concrete in the production of lighter precast components for many routine structures. Quality-controlled factory production is perfectly suited to higher-strength concrete components. Increased concrete strength and precise batching, mixing, and curing of new materials and admixtures will necessitate good quality control and quality assurance. Advances in computerized production and control systems will provide excellent quality to precise geometric tolerances. In addition, lighter members will lower transportation and erection costs. Artificial fibers will be applied increasingly to prestressed members and cable-stayed systems. Longer spans, lighter members, and advanced erection techniques will permit fewer or smaller foundations with less environmental impact and reduced cost.

LONG-TERM DURABILITY

Significant improvements in durability through the use of such materials as granulated blast-furnace slag, fly ash, silica fume, and densified cements will result in structures with longer life and lower maintenance costs. Instrumentation and monitoring of structural performance for corrosion deflection and cracking will lead to improved and intelligent materials and methods with predictable long lives.

EDUCATION AND TRAINING

High-performance, high-strength concrete involves many ingredients that must be properly proportioned and mixed if the desired benefits are to be obtained. Mixture proportioning is a complex process requiring knowledge of the interaction of cements, natural pozzolans, slag, fly ash, silica fume, air-entraining admixtures, and high-range water-reducing admixtures; for the desired workability, strength and finish must also be considered. Designers and constructors will have to be trained in the choice, applications, production techniques, site sampling, and laboratory testing of these materials if they are to be used correctly. New and expanded curricula at universities and other educational institutions will be required for this purpose. Such training at both the undergraduate and graduate levels will inevitably lead to more specialization in such areas as materials science, corrosion engineering, and methods of concrete production and site control. In addition, standards, specifications, guidelines, and certification processes will be needed to implement the new technology. There will also be increased emphasis on environmentally friendly concrete structures that require fewer binding materials so as to reduce the heat of hydration and achieve energy savings.

Equally important are the knowledge and training of field inspectors. Inspectors will need to be able to interpret laboratory test data correctly, and understand the effect of the loading rate on the test results and the errors induced by testing the machine loading pattern.

MONITORING AND COST EVALUATION

With longevity of systems becoming increasingly important, long-term cost-benefit analyses, accounting for all costs throughout the life cycle, will become a yardstick for alternative designs and materials. For example, the American Segmental Bridge Institute has already committed to attaining life spans of more than 100 years. Remote, real-time, and long-term instrumentation monitoring and feedback will enable engineers to evaluate performance and maintenance, and the resulting information will support refined and realistic cost evaluations. It will become possible to evaluate entire facilities, including megaprojects, using proven methods, calibrated against scientifically established results and performance.

EXPECTATIONS AND CONCLUSIONS

High-performance, durable concrete will dominate the new and rehabilitated infrastructure of the next millennium. The new concrete will contain pozzolanic materials, new admixtures, and new cements. Fiber-reinforced concrete and artificial high-strength fibers and prestressing will see wider application. Advanced, precast production and erection systems will be widely adopted, along with computerized production and monitoring. Projects will routinely be instrumented to provide reliable feedback and information to design and maintenance organizations. New education, training, codes, standards, guidelines, and certification processes will be needed at all levels of the industry. Long-term cost-benefit analyses will become routine for comparison of solutions.

The major infrastructure projects of the new millennium will place increasing demands on engineers, necessitating more environmental awareness, public participation, meetings, and design convocations. The engineer, as well as the technologist, will have to be an entrepreneur, a scientist, an architect, an artist, a draftsman, a constructor, a materials technologist, an economist, an environmentalist, and a communicator.

RESOURCE

Nawy, E. G. *Fundamentals of High-Performance Concrete*, 1st ed., Ch. 12. Longman, United Kingdom, 1996. [2nd ed., John Wiley & Sons, New York, 2000.]