Technology of the Future

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As the 21st century approaches, it is appropriate to contemplate the bridge technology of the future. Research is already under way on improved materials that may have dramatic impact in the bridge industry, and the application of new systems to existing bridge types, as well as new and improved types of bridge structures, is being attempted. Many of the improved materials and new concepts will reach practical application, while others will be abandoned for technical or economic reasons. Improved materials and new types of bridge structures as yet unenvisioned are also certain to emerge in the next century.

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Materials

New materials are evolving. However, many of the "new" materials of current interest, such as high-performance concrete (HPC) and steel (HPS), are really enhanced versions of familiar materials.

Aluminum is beginning to make a comeback. High-performance aluminum alloys can offer significant advantages, such as light weight, high strength, superior corrosion resistance, ready fabrication, recyclability, workability, and toughness and strength at subzero temperatures. The use of high-performance aluminum can result in virtually maintenance-free components for bridges. Because of its relatively light weight, aluminum provides proportionally less inertial momentum to the destructive energy of earthquakes, and therefore has the potential to reduce earthquake damage significantly. Use of aluminum as a replacement bridge deck can upgrade the load-carrying capacity of posted bridges. Moreover, an aluminum bridge system can be erected within days, rather than weeks or months, reducing erection, traffic control, and public inconvenience costs.

HPC is all too often associated simply with high strength. Its other desirable qualities include improved constructibility, greater durability, and enhanced mechanical properties. Typical concrete strengths currently range from 27.5 to 41 megapascals (MPa) (4 to 6 ksi). Increasing these strength levels by a factor of 2 or 3 (103 MPa [15 ksi], for example) will reduce the volume of concrete required and open up significant design possibilities.

Improvements in structural steel materials, production processes, fabrication methods, joining techniques, and protective treatments are now or will be emerging. HPS will provide enhancements in weldability, toughness, corrosion resistance, ductility, fatigue resistance, fire resistance, formability, and strength. Higher-strength steels with good weldability are likely to reduce structure costs dramatically. Improved welding electrodes and processes are being or will be developed as well. These two developments, along with improved confidence levels, may allow the use of one-sided and field welding, which would lead to lower erection times and decreased costs. The improved ductility and toughness of HPS will result in its greater utilization in bridges when seismic design is of concern. In addition, improved corrosion resistance will reduce life-cycle costs and further contribute to increased use of HPS in bridges. To maximize this potential, however, innovative structural forms of HPS will have to be developed. These new forms will allow greater use of new product lines, such as corrugated sheet, as well as existing products, such as square, rectangular, or circular tubes, in bridge construction. Together with other materials and techniques, such as polymers, concrete, and prestressing tendons, these new steels will give bridges improved aesthetic qualities and reduced construction costs.

High-Performance Steel: New Horizon in Steel Bridge Construction

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The Snyder South Bridge in Nebraska is the first U.S. bridge constructed from high-performance steel.

As a result of a cooperative research program carried out among the U.S. Navy, the Federal Highway Administration, and the American Iron and Steel Institute (AISI), a new grade of high-performance steel (HPS)—70 ksi—is now commercially available. The Navy, AISI, and FHWA received the Civil Engineering Research Foundation's Charles Pankow Award for Innovative Applications for the development of this steel. This new HPS, referred to as HPS-70W, has superior weldability and toughness characteristics. Although 70-ksi steel has been available for years, potential problems during fabrication prevented its use. The new HPS-70W is a weathering steel and has much higher toughness (as much as three times higher) than the old 70-ksi steel. Additionally, HPS-70W may require no preheat at all during welding, a characteristic that makes field welding a real possibility.

Nebraska and Tennessee have taken the lead in the application of HPS to bridge construction. Construction of the Snyder South Bridge was initiated in Nebraska in May 1997. This bridge was opened to traffic in October 1997, making it the first HPS bridge in the United States. The Snyder South Bridge is a simple span—150 feet long with five I-girders constructed from HPS-70W steel.

A two-span continuous HPS bridge in Tennessee with a total length of 573 feet is scheduled to be open to traffic in the near future. The use of HPS-70W steel in the design of the plate girders for this major bridge has resulted in at least a 20 percent savings in material by weight. The construction of plate girders for both this and the Snyder South Bridge proceeded without a problem.

The state of Nebraska is moving ahead with a three-phase project to implement HPS-70W steel in bridge construction. This project is a cooperative effort with FHWA, the Nebraska Department of Roads, and the University of Nebraska-Lincoln. Phase I of the project, which is nearing completion, consisted of construction of the Snyder South Bridge and research studies to remove current limitations in the American Association of State Highway and Transportation Officials' bridge design manuals that prevent full utilization of HPS-70W steel in bridge construction. The bridge site for Phase II of the project has been selected in an urban area. This bridge will be a major structure and will be two-span continuous, each span being approximately 250 feet long. The preliminary plan is to use hybrid plate girders, employing HPS-70W steel for the superstructure.

Phase III of the Nebraska project involves the design and construction of an innovative steel bridge system that will exploit the advantages of HPS-70W steel. Several innovative bridge systems have been developed by J. Muller International and Modjeski and Masters, Inc. In Phase III, one of these innovative systems (or a modified version) will be used in the construction of a continuous steel bridge.

The effort to remove current limitations in AASHTO bridge design manuals involves the conduct of full-scale tests at the University of Nebraska-Lincoln, FHWA, and Lehigh University. In addition, analytical studies are being conducted at Georgia Institute of Technology. It should be noted that these limitations in the AASHTO manuals are merely the reflection of a lack of test data. The main thrust of these ongoing research activities is to assess the inelastic rotational capacity of steel plate girders constructed from HPS-70W and HPS-100W (steel with 100-ksi yield strength). Preliminary results obtained from testing I-girders constructed with HPS-70W have been very encouraging.

The state of Pennsylvania will also be constructing a steel bridge using HPS-70W steel and an innovative superstructure system. FHWA is organizing several regional workshops to share knowledge gained in using HPS in bridge construction.

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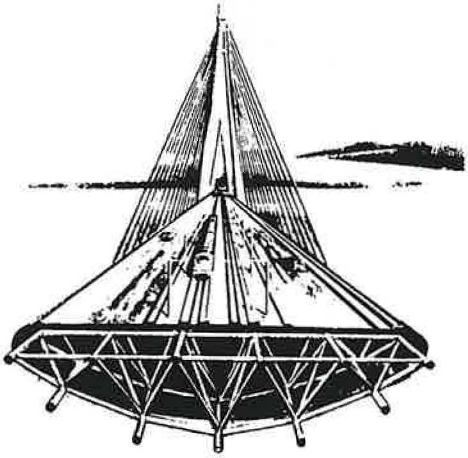

FIGURE 1 Proposal for tubular highway with high-performance concrete deck and fiber composite enveloping enclosure.

Advanced fiber reinforced polymer composites (FRPs) offer the potential to eliminate the problem of excessive dead load of long span bridges, as well as the adverse environmental effects that result in corrosion of metals and concrete reinforcement. The primary advantages of an FRP composite deck or superstructure are its lighter weight, corrosion resistance, and potential for prefabrication in modular units that allow rapid erection without the need for shoring or formwork. Modular composite FRP units could be shop- or field-fabricated in sections, allowing rapid assembly that would result in reduced construction time and traffic control costs. An FRP deck could reduce the weight of conventional construction by about 70 to 80 percent. Its properties also make FRP a desirable material for the repair and retrofit of damaged structural steel or concrete bridge components.

New Structural Concepts

In 1972, more than 25 years ago, a paper (*1*) was published in Finland that addressed the feasibility of elevated tubular tunnel highways utilizing advanced materials such as high-strength steel, high-strength concrete, and plastics, materials that are currently available or being developed. A plastic tube bridge would protect the environment from traffic and traffic from the environment (see Figure 1). Roadway surfaces would be protected from the climate, and the roadway would be dry and free of fog and ice at all times, increasing safety. Maintenance would be reduced because snowplowing and deicing chemicals would not be required.

The tubular monocoque bridge girder would have greater stiffness as a result of its large moment of inertia. Its elliptical cross section would be reasonably aerodynamically advantageous. Traffic within the envelope of the tube would be unaffected by direct action of wind on the vehicles. A tubular highway could be constructed of successive suspension spans of 1000 to 1500 meters (3,000 to 5,000 feet).

Another tubular highway concept that has been advanced in recent years is that of the submerged floating tunnel, or "underwater bridge." A number of proposals have been made for environmentally sensitive projects applying this concept in Norway, Italy, Japan, and Switzerland. The concept is simply a tubular superstructure that is sufficiently submerged under water to provide adequate clearance for marine vessels to pass over the structure. Support for the superstructure would be provided by underwater piers at appropriate spacing, or alternatively, the superstructure could be anchored to the bottom of the lake or sea by cables.

In the United Kingdom a new structural form called SPACES is emerging (see Figure 2). The system consists of a tubular three-dimensional space frame acting compositely with a lightweight deck slab. When necessary, the structure can be post-tensioned. The space frame is enclosed by a participating aerodynamically profiled shell of advanced composite material.

A proposed typical application for the SPACES system is multispan viaducts with optimum spans of approximately 100 meters (330 feet). SPACES would provide a superstructure weight of about 60 percent that of a comparable concrete solution. Whole span space frames could be erected in a single lift.

Intelligent Bridges

Intelligent structures or bridges have been referred to in the literature as "active," "adaptive," or "smart." Such structures appear to offer the poten-

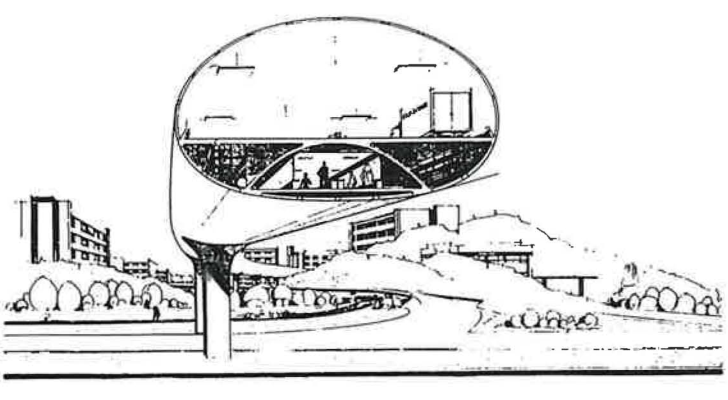

FIGURE 2 SPACES system with tubular space frame enclosed by a structurally participating fiber composite skin.

tial for dramatically modifying the technology of bridge engineering in the future. An intelligent bridge system includes sensors, which receive information about the bridge's behavior or the external action being applied to it; a controller, which determines the counteractions to be applied; and actuators, which apply counteractions to the bridge. An analogy can be made to living creatures, with the sensors being comparable to sense organs; the controller being comparable to the nervous system; and the actuators being comparable, for example, to the muscles executing a countermeasure.

An example related to bridge aerodynamics is offered by the Danish firm of COWIConsult, which has recently patented an actively controlled aerodynamic surface that it is believed will allow unlimited span length with regard to aerodynamic stability. The system is, to borrow from the wing flaps of aircraft technology, a controllable airfoil bridge deck.

A series of accelerometers mounted in the deck monitors vertical movements and sends a signal to an on-board mounted computer. The computer in turn responds by instructing a hydraulic servo mechanism to change the pitch of the flaps, creating either a positive or a negative lift to counteract the effect measured by the accelerometer.

Concluding Remarks

New materials and structural concepts are emerging that will extend the boundaries of technology limitations. As promising as emerging materials are in providing increased strength and durability and reduced weight, however, there is a price to be paid for these advantages in the form of reduced stiffness. Designers must be aware of the potential for global and local instabilities resulting from decreased stiffness. Undoubtedly it will be impractical at some point to realize the full advantages of increased strength and reduced weight because of resulting inherent instability or because service limit states are exceeded. It may be necessary to deal with new limit states, such as user sensitivity to vibration or claustrophobic reaction to long tubular structures or tunnels, and to partner with the medical profession for solutions. The result will in turn be the need for innovative structural solutions to overcome the problems that emerge with the use of new technologies.

Reference

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High-Performance Concrete: A Superior Solution

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As part of the implementation of Strategic Highway Research Program high-performance concrete (HPC) products, several states have started to use HPC for bridge construction. Applications include all bridge components: decks, superstructures, and substructures.

HPC meets performance requirements that cannot always be met with conventional constituents and normal mixing, placing, and curing practices. These requirements may involve the enhancement of ease of placement and compaction, long-term mechanical properties, early-age strength, and durability and service life.

Because of its lower water-to-cementitious-materials ratio (w/cm), HPC is typically stronger than conventional-strength concrete. However, high strength is not always the primary requirement. HPC is valuable where any of the following properties are required: high strength, high early strength, low permeability, resistance to freeze-thaw damage, resistance to chemical (e.g., sulfate) attach, abrasion resistance, low absorption, high resistivity, high modulus of elasticity, and volume stability.

Given its improved material characteristics, bridge decks built with HPC can be expected to last much longer than those built with conventional concrete. High-strength concrete girders can span longer distances and be used at wider spacings than conventional concrete girders, thus reducing the number of girders required and lowering costs. Alternatively, bridge designers have the option of selecting shallower girders to increase clearances without changing grades. Again, the net result is economy. Therefore, HPC can be used both to reduce the size and to extend the service life of superstructure and substructure elements, particularly in severe environments. It also allows for more graceful structures; aesthetics, although difficult to measure, can represent an important benefit.

Twelve states are participating in the Federal Highway Administration-sponsored HPC Bridge Showcase program. The intent of this program is to give the states an opportunity to see how they can benefit from the use of HPC. So far, the program appears to be a success. Virginia, for example, has completed two additional HPC bridges on its own; it has another under construction and five in design. A number of other states, including New York and Delaware, are not participating in the FHWA program, but are using HPC, particularly in their decks.

In summary, HPC is an improvement over previous formulations of high-quality concrete, made possible by the use of modern admixtures and supplementary cementitious materials. In almost all forms of construction, HPC offers a superior solution that should have lower service-life costs than conventional concrete. The superior qualities of HPC will result in its increased acceptance on the basis of reduced life-cycle costs. In some instances, initial economies will result even though the material itself may be slightly more expensive. Information about the use of HPC can be found at FHWA's HPC Web site: http://hpc.fhwa.dot.gov.

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