The Bridge Battle

New techniques form the forefront of bridge building and design

By Bob Drake

Bridge building trends generally derive from a continually shifting balance between structural design, material capabilities, and construction technologies. Materials and construction techniques are developed or adapted to meet increased structural demands; new bridge designs are created to take advantage of advances in materials and construction methods.

A strong force currently driving this interaction of design, materials, and construction is the poor condition of many bridges in the United States coupled with tight budgets and growing traffic congestion. In addition, an increased threat of terrorism brings a new aspect to bridge building and design—security.

Based on an analysis of data from FHWA’s National Bridge Inventory, the Road Information Program (TRIP) reported that 28 percent of the nation’s bridges need repair or replacement because of deterioration or failure to meet current design standards. It is not yet evident how many bridges fail to meet developing security standards.

Aside from security considerations, aging bridges are carrying increasing loads while highway budgets continually fail to fully fund maintenance needs. Of the nation’s bridges are at least 30 years old, 41 percent are at least 40 years old.

In addition to increased funding, TRIP calls for improved bridge maintenance practices and use of more high-performance materials. This mirrors the direction of bridge-building research and product development, which is focused on more cost-efficient, quick-construction methods: high-performance steel, concrete, and fiber composite applications; and improved repair and preventive maintenance techniques.

Quick construction

The emphasis on design-build projects, prefabricated bridges open to traffic today, 19 percent were built during the 1960s and about 50 percent were built from 1950 to 1980, TRIP says. (See Figure 1.) Sixty percent of the bridge elements, and modular systems at the 2002 International Bridge Conference (IBC) reflects the demands bridge builders and designers increasingly are facing—building it fast. Shortening the design and construction process saves money and reduces inconvenience and costs to businesses and the public.

Rapid bridge-replacement techniques also are important in infrastructure security plans. AASHTO’s Task Force on Land Transportation Security reported at IBC that rapid replacement of bridges was one focus of research. The nation’s most critical bridges can be hardened and protected to likely withstand terrorist attacks, but it is a costly endeavor, according to Gary Hoffman, chief engineer for Pennsylvania DOT. “We could probably spend all the money in the [highway] trust fund hardening the infrastructure, but that would not be prudent,” he said. For the majority of bridges that are less critical and unlikely to be terrorist targets, rapid replacement is a more practical approach, task force members said.

Regardless of security implications, FHWA reports that the benefits of prefabricated bridge elements and systems are gaining the attention of state transportation departments.

AASHTO’s Technology Implementation Group (TIG) last year selected prefabrication as one of its priority technologies and is developing a plan to promote its use. TIG reports at least five ways prefabricated bridge elements, manufactured on- or off-site under controlled conditions, meet public needs: minimize traffic impacts of bridge construction projects; improve construction zone safety; make construction less environmentally disruptive; make bridge designs more constructible; increase quality.
and lower construction costs.

The trend toward use of prefabricated elements is suggested by FHWA bridge inventory data. Between 1998 and 2000, the total number of prestressed concrete bridges increased about 6 percent, outpacing every other type of bridge, including steel (down 2 percent), wood (down 6 percent), and cast-in-place and other concrete (up 1 percent).

New products, such as the Nebraska Invented Tee-beam, are expanding the applications for prestressed concrete. The goal of researchers at the University of Nebraska was to build a beam that could replace diaphragms in buildings. A Tee-beam without a top flange, the Invented Tee can span up to 85 feet with a structural depth of 28.5 inches. It weighs 20 percent less than comparable standard concrete I-beams.

Not all prefabricated bridges are concrete, however. A crew from the Brinck Engineering, Inc., supplies the “Brinck” on page 20 in the May-June 2002 issue.)

High-performance materials

FRP composites is just one of an emerging class of high-performance materials that is slowly being expanded to bridge building and design capabilities while decreasing anticipated maintenance and life-cycle costs. They also may play a key role in hardening critical bridge elements against terrorist attack. These new and modified materials include high-performance concrete, high-performance steel, and FRP composites.

High-performance materials received a boost from the six-year Innovative Bridge Research and Construction (IBRC) program established in 1998 by TE-21. It is scheduled to be funded through September 2004. By its end, IBRC will have supported construction or rehabilitation of about 260 bridges using innovative materials, according to FHWA.

High-performance concrete (HPC) is characterized by its lower permeability, achieved in part by using mineral admixtures, such as silica fume, fly ash, or blast furnace slag. Low permeability inhibits corrosion of rebars and reinforcing steel, as well as deterioration of the concrete by environmental factors.

The National Concrete Bridge Council, a coalition of associations representing concrete, steel reinforcing, lightweight aggregate, and admixture producers, recently led development of a strategic plan for HPC. The plan includes a number of specific objectives that, if achieved, could significantly affect bridge building in the United States. These include the following:

- Construct entire short-span bridges within one week
- Reduce the average user delay by 20 percent for typical travel
urban bridge reconstruction projects:
- Transfer HPC technologies to all 50 states by building several HPC bridges in each state;
- Train 500 bridge engineers per year in HPC technology;
- Train 2,000 construction personnel per year in HPC bridge technology;
- Add HPC technology courses to the curricula at 10 engineering universities;
- Collect cost data on various conventional bridge systems;
- Develop tools to perform life-cycle cost analyses; and
- Develop reliable material tests.

FHWA currently is testing a new addition to the HPC class of materials called ultra-
high-performance concrete (UHPC). UHPC is steel-fiber reinforced and contains finely
ground reactive powders and no coarse aggregates. FHWA's Turner-Fairbank Highway
Research Center (TFHRC), reports that TFHRC displays twice the compressive strength
of any HPC used to date in a U.S. bridge. The steel-fiber reinforcement provides tensile
strength that in FHWA tests allowed more than 19 inches of deflection at the midpoint
of an 80-foot long girder before failure. Additional tests indicate that the shear capacity
of UHPC girders, without shear reinforcement, is two to three times greater than that
of conventionally reinforced prestressed concrete girders, according to TFHRC.
Not to be outdone by the cement and concrete industry, in the early 1990s the American
Iron and Steel Institute (AISI) joined with FHWA and the U.S. Navy to develop
high-performance steel (HPS). It was first used in a highway bridge in the United
States in 1997. Since then, HPS has been used in more than 150 bridges across the
country, according to FHWA. Currently, 33 states have HPS bridges in service, fabrication
or construction, or planning or design. (See "HPS Cost Savers" on page P2 of the
March-April 2002 issue.)
HPS contains less than 60 percent of the carbon and 15 percent of the sulfur that conven-
tional steel does. Available in grades HPS-70W and HPS-50W, it is stronger, tougher,
and more resistant to cracking and corrosion. A 40 percent higher yield strength allows
design of longer, shallower bridge spans.

HPS is classified as weathering steel, meaning that it is suitable for use in an un-
painted condition. This reduces maintenance and life-cycle costs for HPS bridges. Although HPS is
more expensive than conventional steel, initial bridge costs can be less because its
greater strength allows use of significantly less steel, cutting fabrication and erection costs.
It also allows longer spans, reducing the number of bridge piers in some applications.
FHWA released an HPS Designer's Guide last year with details on using HPS for
bridges and sources for more information. It is available online at the AISI website,
www.steel.org/infrastructure.

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To provide an additional option in HPS, researchers at Northwestern University’s Infrastructure Technology Institute are working toward commercialization of NUCu steel.

NUCu steel — a hot-rolled, air-cooled, 70ksi copper-precipitation-hardened product — has better weldability, fracture toughness (especially at low temperatures), and corrosion resistance than even HPS-70W, researchers claim. The Illinois DOT specified NUCu steel for a bridge to be built this year; and NUCu is included in the latest revision of ASTM Standard A710.

Although generally not labeled “high performance,” FRP composites are innovative materials that are increasingly grabbing the attention of bridge engineers and owners. Their lightweight, high-strength, and non-corrosive properties make them suitable for a number of applications, such as prefabricated bridge decks and girders, rebar and reinforcing rods, and seismic and structural strengthening.

FRP composites are available in various compositions, including glass and carbon fibers. Cost remains a significant barrier to its widespread use. But given its expected performance and improved life-cycle cost analyses, coupled with increased emphasis on asset management, FRP composites could become more competitive in an increasing number of applications. (See Getting a Handle on Life-Cycle Costs, p. 18).

**Repair and maintenance**

One bridge application where carbon FRP composites are already gaining wide acceptance is seismic and structural strengthening. FRP strips and flexible fabrics are attached to the surfaces of bridge girders or wrapped around support columns using an epoxy adhesive. Researchers at Georgia Tech indicate that carbon FRP can increase bridge strength 30 to 40 percent. Sika Corp.’s CarboDur strips and SikaWrap fabrics can increase shear and flexural strength and decrease deflection and cracking in bridge beams, slabs, and columns, according to the Swiss company. Sika says its carbon fiber fabric has a tensile strength of 159,000 psi, and carbon fiber strips develop up to 406,000 psi.

Several new products have been developed to address another major problem plaguing the nation’s bridges: corrosion. GalvashieldXP, developed in the late 1990s and marketed in North America by Vector Corrosion Technologies, Winnipeg, Manitoba, is a palm-sized anode consisting of a galvanic zinc core in a cementitious matrix. It is designed to reduce localized ring anode corrosion of reinforcing steel that occurs in areas surrounding concrete patch repairs. Accelerated corrosion of steel reinforcement can develop in the old concrete adjacent to the patch because of differences in corrosion potential.

GalvashieldXP anodes, attached to the reinforcing steel around the perimeter of the patch and fully embedded

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**ONLINE:** FHWA developed a website to encourage the exchange of knowledge and information about high-performance concrete. The High Performance Concrete Exchange (http://knowledge.fhwa.dot.gov/cpox/htpcn.summ) has a number of specific topic areas for public participation.

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FH - DEC 2002 | 17
Getting a Handle on Life-Cycle Costs

Accurately comparing the costs of alternative construction methods and materials can be difficult, particularly with new high-performance or prefabricated materials that may have higher initial costs but perform longer with lower maintenance costs.

To help bridge engineers compare costs of conventional and newer materials, researchers at the National Institute of Standards and Technology (NIST) released a life-cycle costing software program called BridgeLCC 1.0 in 1999. The free software has registered users in 38 states and 16 countries, according to NIST.

The Windows program is based on ASTM Practice E-917 for measuring the life-cycle costs of buildings and building systems. It is designed to accommodate new, as well as conventional, construction materials, and incorporates estimated operating, maintenance, repair, disposal, user, and third-party costs. Users are considered car and truck drivers; third parties are businesses or other entities near the bridge that are affected by construction activities.

BridgeLCC 2.0, an expanded version of the software, is in development and expected to be released next year. Improvements from version 1.0 include the ability to analyze as many as six alternatives at a time; create life-cycle events that include more than one agency, user, or third-party cost; and create and use multiple work zones (with driver delay, vehicle-operating costs, and accident costs).

Version 2.0 also has an improved Monte Carlo simulation for modeling most parameters with probability distributions. A preview release of BridgeLCC 2.0 is available for download at www.bfrl.nist.gov/bridgelcc/welcome.html.

in the new concrete, corrode in preference to the reinforcing steel, according to the manufacturer. Service life depends on steel density, concrete conductivity, chloride concentration, humidity, number of anodes installed, and anode spacing. The company claims 10 to 20 years of life under normal conditions.

New on the market this year is a fully embedded corrosion-monitoring device with wireless communication. Virginia Technologies, Charlottesville, Va., developed a system of networked sensors that are attached to the reinforcing steel and wired together before the concrete is poured. Each sensor monitors changes in salinity, moisture, temperature, and conductivity that can indicate corrosion. Sensor readings travel by wire to a communications module that reports the information through a wireless link to a data logger. Virginia Technologies' embedded corrosion instrument (ECI-1) is contained in a molded plastic enclosure measuring 3.2"x3.7"x4.8".

Another bridge-maintenance product just entering the commercialization stage is called ElectroStrip. Developed by ElectroStrip Corp., New Kensington, Pa., the system uses an electrochemical process to debond lead-based paint from steel surfaces. Absorbent pack containing electrode screens and wetted with a sodium sulfate solution are attached to the steel surface with magnets or mechanical devices. After connection to a DC power supply (10-15 volts) for 45 to 90 minutes, the pads and debonded paint are removed and the surface washed.

Following tests of a prototype system on a Virginia bridge in 1998, FHWA researchers concluded that the ElectroStrip system required minimal equipment, set-up time, and containment: and it generated less debris than traditional abrasive and water-jetting paint-removal techniques. The cleaned steel surface also exhibited no flash rusting. ElectroStrip says it is focusing application on small- to mid-sized repair and maintenance jobs.

Unfortunately, as numerous products and technologies focus on niches within the bridge building industry, selecting the appropriate structural design materials, and construction or repair method becomes a more complex process. The advantage of this technology over lead, however — if you can sort it out — is the greater likelihood of finding an affordable strategy to win the bridge battle. ■