RoboCrane Construction of Bridges

KEN GOODWIN

The National Institute of Standards and Technology (NIST) has developed conceptual designs, laboratory scale models, and computer simulations/animation of several configurations of remotely operated cranes to assemble highway bridges. NIST's designs have been patented and trademarked as "RoboCrane." Major opportunities exist to develop full-scale cranes and demonstrate construction of temporary bridges, causeways across wetlands, and overpasses for traffic management over repair sites. Remotely operated, mobile, lightweight cranes can put modular bridge sections in place and provide better control of loads. This could result in faster assembly and less environmental disturbance. RoboCrane configurations that are well suited for bridge assembly and their potential savings in time and cost are discussed.

The National Institute of Standards and Technology (NIST) was established in 1901 as an agency of the U.S. Department of Commerce. It is the only national laboratory chartered to assist industry directly. Since 1978, when NIST's name was changed from the National Bureau of Standards to include the word "Technology," its charter has included developing new technology for industry use. Through the 1990s, NIST has made grants to encourage development of precompetitive, generic technology and regional technology transfer. The primary focus of the NIST Intelligent Systems Division (ISD) is to develop open-system, modular, hierarchical control systems architectures and demonstrations to implement and test them.

ROBOCRANE DESCRIPTION

In the last decade, ISD has developed a family of computer-controlled cranes for large-scale assembly and tool handling, trademarked "RoboCrane." RoboCrane configurations overcome the load swinging and spinning of ordinary cranes and provide six-axis control of heavy loads over large work volumes. RoboCranes are capable of manipulating tools and exerting lateral forces to accomplish operations such as cutting, grinding, drilling, welding, and finishing. These cranes are potentially capable of manipulating large parts to assemble aircraft, ships, heavy equipment, buildings, and bridges (*1*).

RoboCranes use the basic configuration of the Stewart platform parallel-link manipulator. The unique feature of RoboCranes is that they use cables as the parallel links and winches as actuators. As long as all cables are in tension, loads are kinematically constrained, and the cables resist perturbing forces and torques, such as wind acting against a suspended load.

A RoboCrane can precisely control the position, velocity, and force of tools, machinery, and loads, in all six degrees of freedom (x, y, z, roll, pitch, and yaw). Figure 1 shows the basic RoboCrane configuration: a triangular work platform suspended from an upper support structure by six cables controlled by six winches. The RoboCrane work platform supports large loads, is extremely stable, and exerts controlled forces and torques in six degrees of freedom.

Intelligent Systems Division, National Institute of Standards and Technology, Gaithersburg, Md. 20899.

The octahedron/hexapod supporting structure produces a high strength-to-weight ratio. It is made from lightweight components, based on axially loaded compression elements and high-strength cables. All structural parts are in either pure compression or pure tension (except for supporting their own weight).

To study the lifting and positioning capabilities of this design, NIST has constructed a midsize version of RoboCrane, made from 6-m lengths of aluminum tubing 10 cm in diameter. It can lift 2000 kg, even though it weighs less than 500 kg. This is an order of magnitude improvement over conventional boom cranes, which typically weigh (including counterweights) more than the loads they can lift. Figure 2 is a photograph of the 6-m RoboCrane.

The RoboCrane easily scales up to much larger sizes, such as those required for highway construction and repair. Versions with dimensions of up to 100 m, made from tubular or cross-braced triangular trusses, appear feasible.

In 1992, NIST undertook a study of automation and robotics for road construction, maintenance, and operations for FHWA's Office of Advanced Research (*2*). The study included two workshops and a series of field visits. The workshops brought together technology developers and users, as well as highway construction, maintenance, and operations experts. The resulting report recommended six promising technologies for further research and development. Expert panels established by the Civil Engineering Research Foundation of the American Society of Civil Engineers evaluated the recommendations (*3*).

One of the technologies recommended was to deploy modular temporary bridging systems by automated means. This deployment includes temporary bridging to divert traffic around bridge repairs, rapid and ecologically noninvasive bridging of wetlands, and relocatable temporary bridges to carry traffic over highway repair sites.

AUTOMATED BRIDGE CONSTRUCTION

The Department of Defense has developed high-strength lightweight tactical bridges and causeways for military traffic, including tanks. These systems appear to be well suited to civilian construction projects.

NIST worked with 10-A Inc., a designer of military bridges, to use a lightweight modular bridging system along with the RoboCrane in highway and bridge construction. The combination of modular bridges with automated RoboCrane assembly has potentially significant economic benefits. NIST and 10-A Inc. have obtained a patent on the automated bridge construction system and are prepared to grant exclusive licenses, if needed, for commercial development. (*4*)

Figure 3shows the basic elements of the 10-A Inc. modular highway bridging system. It has numerous attributes making it particularly viable for

- Rapid construction of temporary bridges to handle traffic during bridge repair,

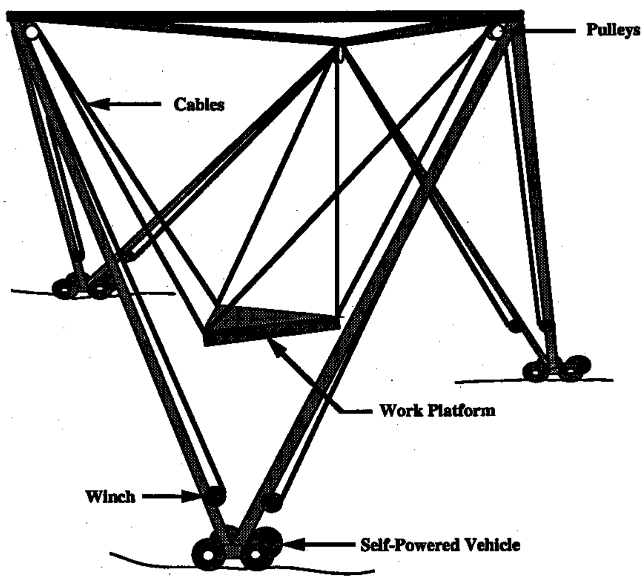

FIGURE 1 NIST RoboCrane.

- Construction of bridges over wetlands with minimum environmental impact, and
- Construction of bridges to respond to emergency situations.

The weight of the bridge sections, designed for HS-20 loads (*5*), is significantly less than any other style of highway bridge. Bridge sections are transported as fully assembled large sections, typically the size of standard ISO 9.9-m (40-ft) containers. These are stored in a nested configuration for easy transport.

Due to the significantly reduced weight of the bridge components, and the lightweight RoboCrane, the combined weight of the bridge section and the RoboCrane is within the standard capacity of the bridge section load rating.

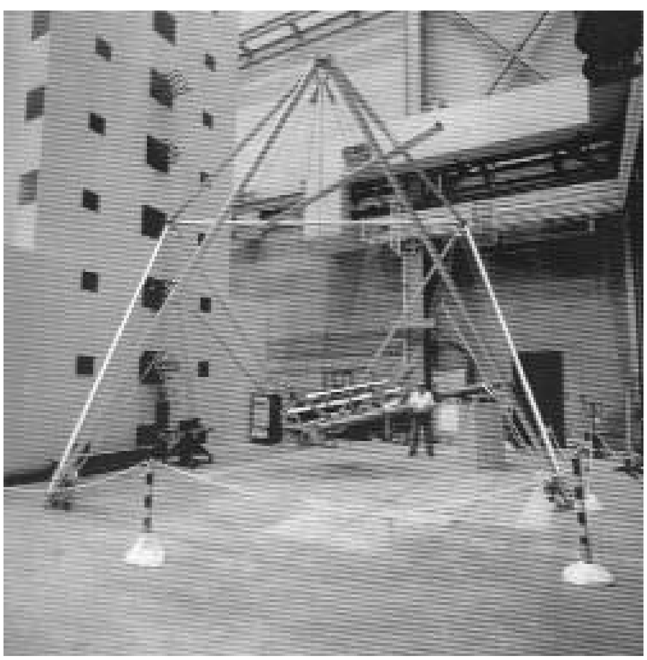

FIGURE 2 Photograph of 6-m RoboCrane.

NIST is currently seeking new partners among bridge-contracting and crane companies to develop full-scale prototype cranes and demonstrate them in a practical field applications. To illustrate the technical potential for automated bridge construction, NIST has produced a short (12-min) videotape. Copies are available on request from the author (*6*).

The purpose of this paper is to make decision makers aware of the availability of RoboCrane configurations, which appear well suited for bridge assembly, and their potential savings in time and cost.

NEED FOR AUTOMATED SYSTEM

Erecting highway bridges requires heavy truck, crawler, or barge-supported boom cranes. Sometimes there may be insufficient room for a shoulder or a temporary lane to maintain traffic flow during highway or bridge repairs. In such cases, the repair contractor must stop operations and clear a lane, at least for commuting hours. This disrupts repair operations and greatly increases project costs.

Traffic management for bridge and road repair work involves closing lanes and roads to conduct the repair work. The lane shifting and exposure of construction workers to passing traffic is hazardous. Lane closing slows traffic and may burden local businesses. The FHWA has quantified losses to the public due to traffic disturbance during road and bridge repair. As a result, highway and bridge reconstruction, rehabilitation, and construction projects have incentive clauses for contractors to reduce completion time. These often amount to $10,000 or more per day for large projects.

Serious traffic delays may be caused by bridge and highway repairs where there is a restricted right-of-way width or a restricted width due to topographical barriers (mountains, wetlands, or buildings). Managing traffic by closing lanes is sometimes unacceptable and the repair work is postponed, resulting in continuing hazards to the public.

In the process of bridge erection on wetlands, where environmental disturbance caused by construction equipment is highly undesirable, the crane may have to be transported over the bridge. For commercially available cranes, the AASHTO HS-20 loading capacity is insufficient, and the bridge must be upgraded to support the weight of a crane, which requires a heavier bridge, at greater cost. The RoboCrane weighs less than the allowed AASHTO HS-20 loading and thus eliminates the need to overdesign bridges.

For bridging streams, rivers, and wetlands, the Construction of temporary coffer dams and islands supported on piles is often required to support boom cranes. A cantilevered RoboCrane can travel on the previously completed portion of the bridge, thus eliminating the need for such dams and islands. A common construction practice to get around this problem is to launch trusses by cantilevering, particularly for military bridges (e.g., the heavy dry support bridge). The use of a cantilevered RoboCrane will provide more accurate and faster placement of trusses or subassemblies.

DEVELOPMENT OF SYSTEMS

The approach that NIST has taken to develop automated bridging systems suitable for highway construction and repair applications is to combine military-developed lightweight bridge and causeway

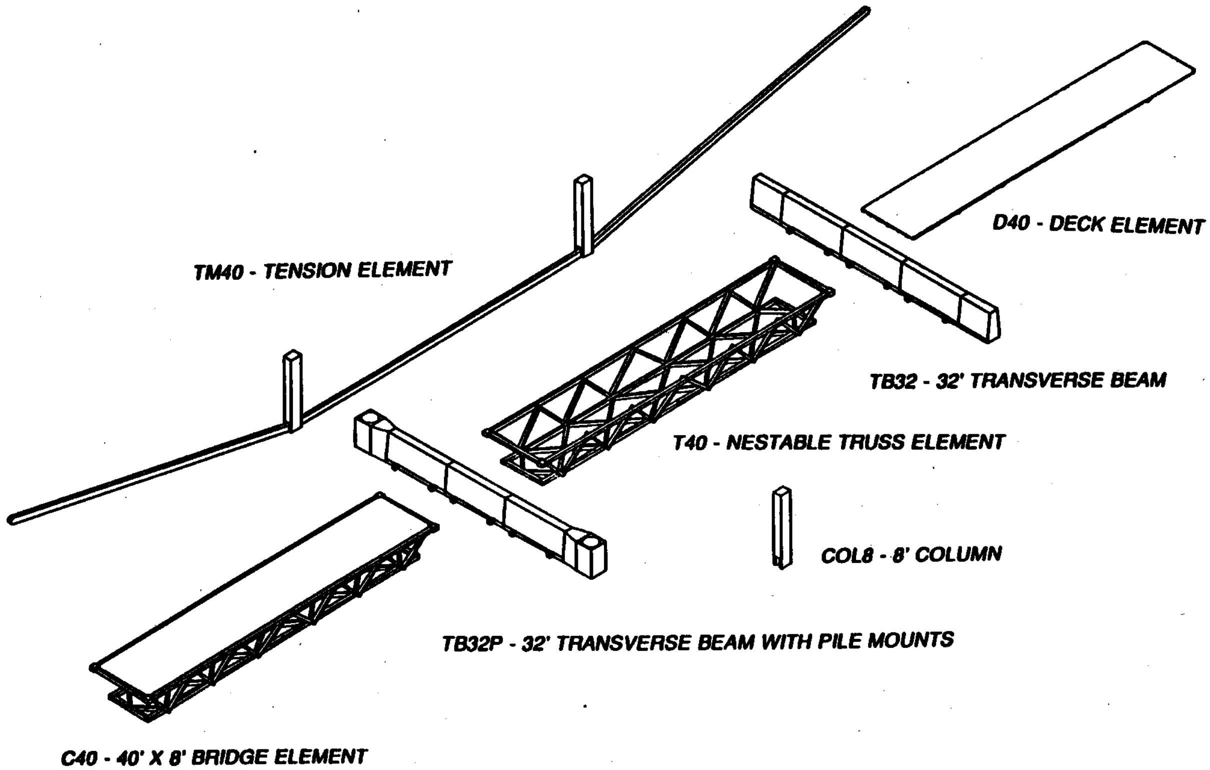

FIGURE 3 Basic elements of 10-A Inc. modular bridging system.

systems with NIST crane developments. NIST has created conceptual designs, static scale models, working laboratory scale models, computer models, and animations to illustrate possible scenarios for bridge assembly.

Figure 4 shows a concept for a cantilevered RoboCrane with a spine that can position modular bridge sections beside an existing roadway, while the traffic continues unimpeded under the crane. This concept is suitable for a repair site where no suitable locations exist for positioning conventional cranes. For example, a mud flat under a bridge will not support a mobile crane or allow a crane to be brought in on a barge. However, an existing bridge can support a RoboCrane that straddles the traffic and can manipulate modular bridge components to be assembled into a bypass.

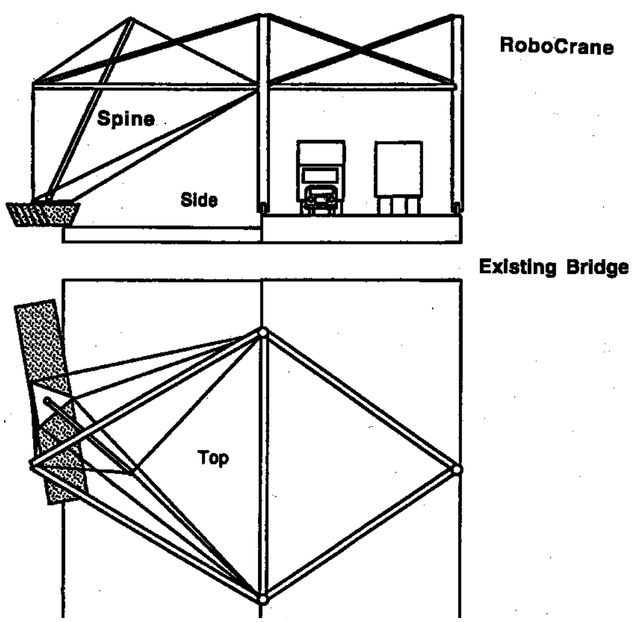

FIGURE 4 Cantilevered Stewart platform crane with spine.

Figure 5shows a relatively lightweight cantilevered crane system that can assemble and place bridge sections to build a causeway. This is done without the use of conventional heavy cranes and the need to construct islands to support them in wetlands. The cantilevered crane can also position spud wells, piles, and pile drivers to provide load-bearing support for the causeway.

Figure 6 shows a temporary overpass bridge to carry traffic over a bridge repair site. The columns of the temporary bridge are aligned with the columns of the existing bridge. For relatively weak bridges, some strengthening of the existing column may be required.

After the first section of an overpass has been completely decked, the section provides an assembly site to construct a RoboCrane and a second overpass section. When the overpass is completed, traffic can continue with the same number of lanes while the bridge is being repaired. The temporary overpass bridge can be disassembled and moved to a new site after repairs have been completed.

As shown in Figure 7,a rectangular gantry structure provides the mechanical support for the RoboCrane suspension system. The top plane of the structure provides the support points for one or more Stewart platforms. Simultaneous control of the six winches for each platform allows precise placement of bridge sections.

Multiple RoboCranes can speed the construction sequence. For example, one RoboCrane can be used to assemble components,

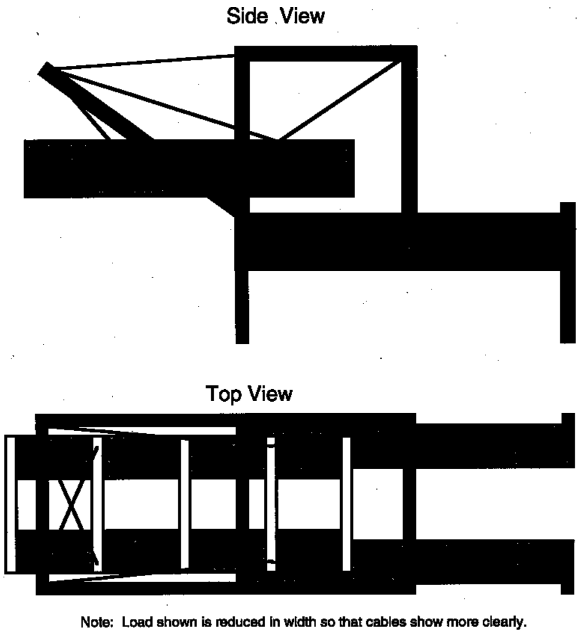

FIGURE 5 NIST RoboCrane lifting skeleton section of bridge.

while a second can be used to install completed subassemblies. For mobility, the gantry frame can be mounted on wheels, providing gross horizontal motion to straddle loads such as modular-bridge sections. The gantry moves from one section to another on wheels that traverse from one section of a causeway to another. In addition, the length of the gantry frame is sized to match the column spacing of the existing bridge or causeway. Many existing bridges are overdesigned and are capable of supporting the original bridge dead load, the RoboCrane, and the temporary bridge.

POTENTIAL BENEFITS

The RoboCrane configuration is well suited for a wide variety of applications. It offers potential advantages in weight, cost, and speed of operation. The benefits that accrue from automated bridge assembly are economy, efficiency, safety, and environmental protection. A modular bridging system, combined with the RoboCrane, may reduce construction time and cost. Because it takes full advantage of the lightweight bridge sections and crane, the system can yield minimum combined cost, fast erection, and a high degree of safety and reliability.

For highway or bridge repair operations, temporary bridging can provide a new lane beside a repair lane so that traffic flow is not interrupted. This benefits both the motorist—who will experience less delay from construction—and the repair contractor—who can carry on activities without interrupting repair work. (Several states have reported that in many bridge repair contracts, traffic management accounts for more than half the total project cost.)

The use of a temporary bridge—which can be readily transported to the site, quickly erected to carry all traffic during the bridge repair, and then removed to another site—improves the rehabilitation process. Building a detour or bypass using a temporary bridge can save 20 percent to 50 percent of the normal repair time. In a recent project proposal, using a temporary bridge reduced the estimated project duration from 3 to 2 years and made the work zone safer, the quality of the finished repair better, and the total cost of the project significantly lower.

The main benefit of rapid, cantilevered bridge construction over wetlands is environmental. The bridge can be built from one end with pilings driven from the erected bridge without touching the ground (except for the pile locations). There is no need to move construction equipment and crew into the wetland area itself, thus reducing the environmental impact. This approach to bridging projects over wetlands hastens the approval process, which has become a time-consuming activity that delays large economic development projects. Robotic construction enables faster bridge assembly, with minimum environmental impact on wetlands and other nearby terrain.

CONCERNS

In February 1996, NIST held a workshop on automated bridge construction to explore the question, What would it take for your organization to participate in bringing automated bridge construction technology into practical use? The participants discussed numerous technology application barriers and problems, such as risk sharing, incentives, liability, and financing.

A practical problem with developing a prototype crane for temporary-traffic management bridging is that the savings for a single

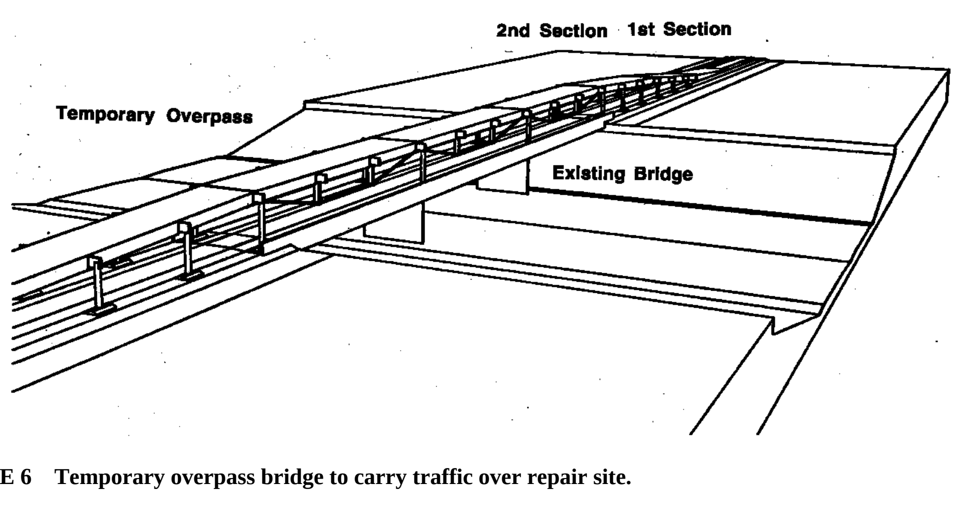

FIGURE 6 Temporary overpass bridge to carry traffic over repair site.

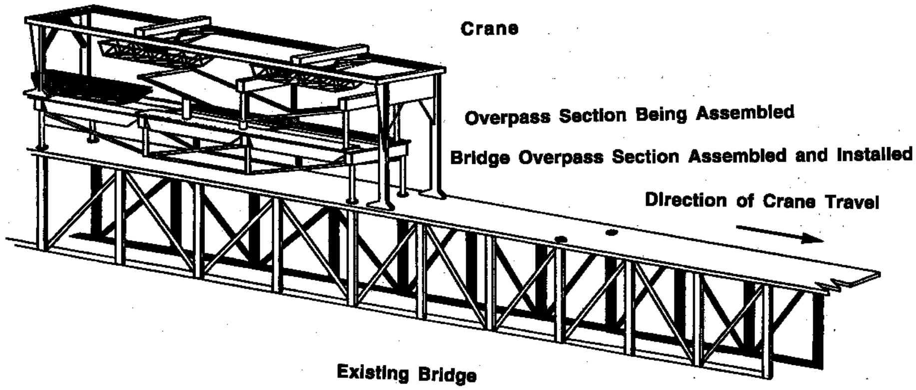

FIGURE 7 RoboCrane assembly of overpass on bridge.

job will not cover the development costs. The crane might be used for only a week to install the bypass and another week at the end of the job to remove the bypass. In the meantime, the crane would be idle. Like conventional cranes, which are generally leased for short terms, using a RoboCrane becomes economical only if it can be moved to different jobs and used a high percentage of the time. A project with only a single bridge repair would not achieve sufficient benefits to offset initial development costs.

The most serious concern about using modular bridges over wetlands appears to be material selection. Concrete is greatly favored in wetland situations. Lightweight aluminum bridges may be economically viable, but they have yet to gain wide acceptance.

FUTURE STEPS

More studies are needed to evaluate the technical feasibility and viability of constructing temporary bridges, causeways across wetlands, and traffic management bypasses. To confirm expected benefits, development and demonstration projects should be conducted.

Criteria for selecting a suitable demonstration site might include high-volume traffic areas where lengthy lane closures are unacceptable, alternative routes for traffic detours are lacking, buildings and water obstacles restrict placement of conventional boom cranes, and multiple bridges need to be repaired in sequence so that the modular bridge sections could be used more than once.

Each demonstration project would involve a team consisting of staff from NIST, a state highway department, and a financing organization; a bridge designer; and a general contractor. Additional team members would include staff from a modular bridge company, a steel bridge fabricator, and a crane fabricator.

For demonstration projects to be useful for the larger community, there will need to be much more extensive testing, analysis, and evaluation than would be required just to build the demonstration structure. Extensive external input and advice will be needed to ensure that the project fulfills its specific performance requirements and the generic performance requirements of a class of such projects.

Recent commercial developments in modular bridges may offer additional opportunities to apply RoboCrane technology to bridge assembly. For example, the extruded aluminum bridge sections developed by Reynolds Aluminum, Inc., could be put into place by RoboCranes (*7*).

The Channel Bridge precast concrete sections recently demonstrated by J. Miller International and evaluated by the Highway Innovative Technology Evaluation Center could be placed by suitable RoboCrane configurations, while eliminating the sliding operation (*8*).

Additional efforts will be required for each project to determine what the experiment design will be, what alternative designs and methods will be tried, how the project will be monitored, evaluated, and documented, and how broad dissemination and technology transfer of the results will be provided. Follow-up evaluations will be required to ascertain the durability of the components, their resistance to weathering, load cycles, and crack propagation. Finally, economic evaluations will be needed to determine the actual cost savings and other benefits that may be realized.

REFERENCES

1. Bostelman, R.V., J.S. Albus, N.G. Dagalakis. A Robotic Crane System Utilizing the Stewart Platform Configuration. *Proc., ISRAM 1992 Conference*, Santa Fe, N.M., Nov. 10–12, 1992.
2. Ernest, K. *A Study of Potential Applications of Automation and Robotics Technology in Construction, Maintenance and Operation of Highway Systems: A Final Report.* NISTIR 5667V1. Gaithersburg, Md., June 1995.
3. *CERF Cost/Benefits Analysis of Technology Proposals.* NISTIR 5667V2, Section 8. Civil Engineering Research Foundation, Gaithersburg, Md., June 1995.
4. Albus, J. S., K. Goodwin, Y. Tene. *Construction of Large Structures By Robotic Crane Placement of Modular Bridge Sections.* U.S. Patent 5,511,268.
5. American Association of State Highway and Transportation Officials (AASHTO). Standard Specifications for Highway Bridges, 15th ed., 1992, as amended by the Interim Specifications—Bridges—1993.
6. Albus, J.S. *The RoboCrane Applied to Bridge Construction* (Videotape). NIST, Gaithersburg, Md., March 1995.
7. Reynolds Metals Company. *Reynolds Aluminum Bridge Decks*. Feb. 1996.
8. *Evaluation Findings: The Segmental Concrete Channel Bridge System.* CERF Report: HITEC 96-01, Product 04. Highway Innovative Technology Evaluation Center, March 1996.

The National Institute of Standards and Technology does not endorse the products mentioned in this paper. These products are used for illustrative purposes only and are not mentioned because they are necessarily better than another product.

Publication of this paper sponsored by Committee on Construction of Bridges and Structures.