VIEWPOINT

Albert A. Grant, who was employed by the government of the District of Columbia from 1949 to 1966, supervised the design of urban bridges and highway structures until he became the Chief Engineer, Office of Planning and Programming, where he directed the planning and programming of the Interstate system for the District. Between 1966 and 1987, he was Director of Transportation Planning for the Metropolitan Washington Council of Governments and supervised the transportation planning for the highway, public transportation, and aviation systems in the national capital region. He was president of the American Society of Civil Engineers (1987–88); chair of the Board of Governors of the American Association of Engineering Societies (1991); chair of the Transportation Research Board Committee on Intergovernmental Relations for 6 years; and chairman of the Committee on Infrastructure of the Building Research Board, National Research Council (NRC), which examines new technologies for infrastructure applications. He is currently president of the Mid-Atlantic Telecommuting Advisory Council, and serves on the NRC's Board on Infrastructure and the Constructed Environment and the Board of the Renewable Natural Resources Foundation.

CIVIL INFRASTRUCTURE SYSTEMS: THE BIG PICTURE

By Albert A. Grant, Mid-Atlantic Telecommuting Advisory Council

To plan, design, and build civil infrastructure systems successfully today, the civil engineer must negotiate a minefield of potentially explosive obstacles: political, legal, environmental, economic, cultural, education, and communication to name a few. In other words, the successful civil engineer must be able to see, understand, and work within "the big picture."

Almost 50 years ago, Samuel C. Florman, a civil engineer with amazing foresight described the engineer as follows (The Civilized Engineer, St. Martin's Press):

Someone must step forward to say, "We can afford to make that automobile a little safer." "Let us consider the possible harmful effects of that insecticide before we market it," "Let us develop a plant process that will not pollute the water we use," "Let us make that machine a little quieter," "Let us not demolish that historically precious old building," "Let us locate that dam, not only where it will generate the most power but also where it will serve the interests of the community—aesthetically and socially . . .

This "someone" cannot be an ordinary citizen of good will. He must be able to bolster his arguments with facts—technical, scientific, and economic. Hunches and sentiments will not be sufficient. His recommendations, in order to be persuasive, must be founded in a knowledge of resources, materials, and energy conversion; statistics, probabilities, and decision theory; computers, controls, and systems engineering. Moreover, this "someone" must be concerned. He must be articulate. He must be esteemed. And he must have a highly developed moral and aesthetic sensibility. In short, he must be a liberally educated engineer.

In my view, this description has remarkable currency and validity for civil engineers developing civil infrastructure systems today. It is worth reading and rereading from time to time to keep the role of the engineer in perspective.

This Viewpoint is intended to provide some broad insight and understanding of the big-picture elements of civil infrastructure systems by: (1) Briefly reviewing the issues and obstacles in the civil infrastructure minefield; (2) identifying a number of developments and opportunities to address and remove these obstacles; and (3) offering a series of recommendations that can help to enhance the vision, ability, and options of civil engineers in implementing civil infrastructure systems as we move into the 21st century.

ISSUES AND OBSTACLES

State of the System

The deteriorating condition of our physical infrastructure poses an enormous challenge to civil infrastructure system planners and managers in terms of financing, logistics, and catch up. To illustrate:

Highways: Some 234,500 mi of U.S. roads are rated poor or mediocre. In addition, according to the Federal Highway Administration more than 70% of peak-hour travel on urban interstates occurs under congested or severely congested conditions.

Bridges: One out of three bridges in America is rated structurally deficient or functionally obsolete and needs major improvements ranging from deck replacements to complete reconstruction. More than a fourth of all bridges are more than 50 years of age (source: Federal Highway Administration).

Mass transit: The average age of transit buses now exceeds recommended usable age by 20–35%, and between 20% and 30% of rail-transit facilities and maintenance yards are in poor condition (source: American Public Transit Association).

Aviation: The number of enplanements is expected to increase 57% over the next decade due to globalisation of the airline industry. The number of severely congested major airports will grow from 7 to 17 if no new runways are added (source: FAA).

Water resources: More than 10,000 dams are classified as high hazard in the United States; 13,549 are classified as being of significant hazard (source: U.S. Army Corps of Engineers and Federal Emergency Management Agency).

Water supply: Annual compliance costs to water systems to meet the mandates of the Safe Drinking Water Act will reach $3 billion per year for the next two decades (source: Environmental Protection Agency).

Wastewater: It will take $137 billion to meet requirements of the Clean Water Act by the year 2012. By that year, the
nation will need to increase the number of facilities providing wastewater treatment by 3,353 (source: Environmental Protection Agency).

Solid waste: Even with significant source-reduction efforts, total annual municipal solid waste will increase from 207,000,000 to 218,000,000 tons by the end of this century (source: Environmental Protection Agency).

Hazardous waste: Current data indicates that more than 300,000,000 tons of hazardous waste are generated annually in this country, and there are more than 1,300 Superfund cleanup sites that have been targeted (source: Environmental Protection Agency).

Public schools: 31% of America’s public schools were built before World War II. The national cost of deferred school repairs is now estimated at over $100 billion (source: American Association of School Administrators).

State of the U.S. Construction Industry

Compounding this challenge is the current state of the U.S. construction industry. While it is the nation’s second largest economic activity, accounting for approximately 13% of the gross domestic product (GDP), it is also the most fragmented, with over 1,000,000 firms employing an estimated 10,000,000 professionals and skilled and semiskilled workers. The industry lags behind other industries in productivity gains and in resources related to research and development. While non-defense-related R&D investment in other U.S. industries, such as telecommunications, aerospace, chemicals, and automotive, runs between 3% and 4%, the construction industry investment is less than 0.5%. As a result, this industry, which is so vital to the success of civil infrastructure systems, has suffered from weakness in leadership, productivity, and innovation.

Financial Constraints

Over the past decade, the public infrastructure stock has fallen without interruption, from nearly 55% of GDP in 1982 to less than 40% in 1992. Federal spending on investment in additions to the public infrastructure stock fell from 1.15% of GDP in 1980 to 0.8% in 1993. The present climate of budget austerity makes the problem even more acute. Federal spending for capital investment is financed almost entirely from the discretionary category of the U.S. government’s budget, and caps have been placed on this discretionary spending as a deficit-reduction strategy.

Regulatory Barriers

Federal, state, and local regulations that are intended to achieve admirable goals individually often have a combined negative effect on the development or rehabilitation of the nation’s public-works infrastructure. There are continuing public management problems with uncoordinated restrictions, redundant laws and regulations, and contradictory requirements.

Risk and Litigation

A continuing barrier to innovation and productivity in civil infrastructure systems is the fact that in our litigious society, tort liability has become a strong disincentive to the introduction of new technology and processes into practice. As a result, U.S. competitiveness in a global market continues to deteriorate, since technological innovation forms the basis for productivity growth. Risk and liability concerns generally lead to low-risk designs, which reward practitioners for stability rather than innovation.

Sustainable Development

Emerging concepts and principles of sustainable development add another dimension and challenge to the planning and development of civil infrastructure systems. Civil engineers will play a critical leadership role as facilitators of sustainable development, and will need to expand their skills, knowledge and understanding in such areas as environmental economic analysis, the creation of sustainable technologies and processes, integrated systems thinking and synthesis, and expanded multidisciplinary partnerships that can address cultural and social issues and differences.

DEVELOPMENTS AND OPPORTUNITIES

National Construction Goals

To address the many challenges that confront the U.S. construction industry, the White House—Construction Industry Workshop on National Construction Goals was held in Washington, D.C., in December 1994. The workshop was organized by the Civil Engineering Research Foundation (CERF) for the Construction & Building Subcommittee, Committee on Civilian Industrial Technology, National Science and Technology Council. The workshop addressed the following national construction goals proposed by the Construction & Building Subcommittee:

- 50% reduction in delivery time
- 50% reduction in operation, maintenance, and energy costs
- 30% increase in productivity and comfort
- 50% fewer occupant-related illnesses and injuries
- 50% less waste and pollution
- 50% more durability and flexibility
- 50% reduction in construction work illnesses and injuries

I prepared a white paper on the relationship of these goals to public-works infrastructure: I found that by and large, their achievement could contribute significantly to the efficiency, cost-effectiveness, and productivity of civil infrastructure systems. Major conclusions of the workshop were that: (1) National construction goals make sense and should be further developed; (2) implementation requires a hitherto lacking industry vision and focused leadership; (3) benchmarking industry performance is essential for measuring current status and future performance; (4) industry’s initial emphasis should be to reduce/eliminate barriers; and (5) close industry/public sector/academia coordination and partnering is essential for success.

Innovative Financing

New developments in innovative infrastructure finance options hold promise for increasing investment in civil infrastructure systems. The Congress, working with the nation’s governors and mayors, is exploring ways to increase the ability of states and localities to use tax-exempt financing. Municipal bonds play a major role in financing the public-works needs of communities. Among the innovative legislative initiatives proposed are:

- Creating a new class of tax-exempt bonds to be known as Mandated Infrastructure Facility (MIF) bonds
- Repeal of market-discount rules enacted in 1993
- Enacting volume-cap legislation to provide flexibility and financing options to states and localities
- Increasing commercial bank purchases of governmental bonds by expanding the definition of “small user” to
include communities that sell no more than $25,000,000 in bonds annually.

- Encouraging creation of “public-benefit bonds” to allow self-directed pension plans to invest in infrastructure.

Civil engineers looking at the big picture need to be aware of, and lend their support to, these innovative financing concepts in their local communities.

Infrastructure Investment and Productivity

There is growing evidence that public investment in infrastructure is a crucial ingredient for productivity growth, and without continuous investment in infrastructure, a modern society cannot function. At a roundtable discussion called “Investment for the 21st Century,” sponsored by the Economic Policy Institute, in January 1995, the participants were presented with a statement signed by over 400 prominent economists warning of the economic dangers of neglecting the public infrastructure. Economists differ in their precise estimates, but they all generally agree that public investment has a substantial impact on productivity and private investment. The big-picture civil engineer needs to keep abreast of these relationships in making the case for investment in civil infrastructure systems.

High-Performance Materials and Systems

CERF, the research affiliate of ASCE, has demonstrated strong leadership in the promotion of high-performance materials and systems. In 1993, CERF presented a blueprint, entitled “High-Performance Construction Materials and Systems: An Essential Program for America and Its Infrastructure,” that called for a historic partnership between the construction industry and the federal government, to culminate in a 10-year national program of research and development. CERF, in cooperation with the Federal Highway Administration, has established the Highway Innovative Technology Evaluation Center (HITEC). HITEC began accepting applications in January 1994 for a wide range of technologies aimed at the highway market, including products, materials, services, equipment, and systems. By providing nationally recognized evaluations of innovative technologies that cannot be measured against existing standards or specifications, HITEC aims to minimize duplication in evaluating new products. HITEC may be the forerunner of similar centers for other infrastructure areas such as mass transit and environmental technologies.

CONCLUSION AND RECOMMENDATIONS

The purpose of this Viewpoint has been to broaden the big-picture perspective of civil engineers who plan, design, build, and maintain civil infrastructure systems. It has been wide-ranging to illustrate the kinds of skills, knowledge, and understanding that civil engineers must add to their basic technical abilities to operate successfully in today’s complex and challenging infrastructure environment.

The following is intended to capture the spirit of the foregoing issues and developments in the form of a set of recommendations along with their relationship to the infrastructure aspects of the proposed national construction goals and the potential roles of government, industry, and academia in meeting the infrastructure challenges of the future.

Promote and encourage innovative alternative contract and procurement practices, such as design-build, for major public works projects: Design-build contracts and related variations can contribute significantly to the goal of reducing delivery time by allowing construction work to begin before final design details are completed, and by eliminating potential external conflicts between the designer and the builder. Design-build contracts permit the use of innovative designs, materials, and construction systems to maximize efficiency, reduce costs, and increase durability.

Government should broaden contracting requirements and specifications to allow and encourage alternative procurement procedures. Industry should document and share experience with design-build and other innovative procurement practices to improve understanding and broaden use of these practices. Academia should introduce knowledge of these alternative practices into the engineering curriculum.

Implement federal capital budgeting for public works by establishing a public-works investment section in the president’s budget: This recommendation would provide for a series of broad, flexible infrastructure trust funds, each funding a category of interrelated public-works activities and supported by appropriate dedicated sources of revenue. It is designed to encourage multiyear stability in planning long-term investments and maintaining facilities cost-effectively. This would contribute to the goals of reducing delivery time and operation and maintenance costs for multiyear public-works construction projects by assuring adequate continuous funding for construction and maintenance. Government (the president) should introduce legislation for this recommendation.

Promote the development and use of life-cycle cost analysis for public-works investments, including standard methodologies and application: Life-cycle cost analysis is a valuable economic analysis technique for evaluating public-works programs that require long-term capital and maintenance expenditures. The benefits and costs of infrastructure investment are measured and appropriately discounted over the full life cycle of each project. Life-cycle analysis can contribute to the goals of reducing operation, maintenance, and energy costs and increasing durability and flexibility by showing the cost-effectiveness of higher initial investment in quality when measured over the full project life.

Government should establish policies that include life-cycle costing as an element of infrastructure investment analysis. (For example, the Federal Highway Administration has issued a temporary policy based on Executive Order 12893, “Principles of Federal Infrastructure Investment,” calling for life-cycle analysis.) Industry should include life-cycle analysis in evaluating public-works project design alternatives, and educate clients on the benefits of investment decisions based on such analysis. Academia should integrate life-cycle analysis into the engineering curriculum.

Reduce regulatory barriers to public-works infrastructure development at all levels of government: This recommendation can contribute significantly to the goal of reducing delivery time of public-works projects, particularly in the planning, design, and preconstruction permit phases. As an example, Presidential Executive Order 12873 is designed to reduce the imposition of unfunded mandates upon state and local governments, and to streamline the application process and increase the availability of waivers to such governments. Governments (at all levels) should require all agencies to consolidate, streamline, and integrate their multiple regulatory responsibilities. A single administrative processing/permitting agency should be established to shorten and improve the approval process for public-works infrastructure projects.

Promote the development and application of high-performance construction materials and systems for public-works infrastructure through incentives for innovative R&D, use of performance standards, and limiting and sharing of risk and liability in the use of such materials: This recommendation can contribute significantly to the goals of increased durability.
and reduced operation, maintenance, and energy costs for public-works infrastructure. Benefits include improved performance and lower costs from materials with such characteristics as superior strength, toughness, and ductility; enhanced durability and service life; resistance to abrasion, corrosion, chemicals, and fatigue; and initial and life-cycle cost-efficiencies.

Government should authorize the establishment of a national coordinating council to provide industry leadership in planning and executing comprehensive research on high-performance construction materials, and expediting the commercialization of these new technologies; create tax incentives that encourage private-sector investment in innovative R&D and its application; propose legislation that will promote construction innovation by limiting liability and sharing risk; and work with industry to develop and promote the use of performance standards that facilitate the application of high-performance construction materials and systems. Industry should unite through the national coordinating council and make a strong commitment to participating actively in and supporting the goals of the National High-Performance Construction Materials and Systems Program. Academia should join with government and industry in a true partnership under the program.

Incorporate evolving developments in quality, sustainability, and partnering into public-works infrastructure planning, design, and construction: This recommendation will contribute to the goals of reduction in delivery time and reduction in waste and pollution. Because of their size and impact, major public-works infrastructure projects are highly vulnerable to socioenvironmental criticism and criticism due to lack of quality. Sustainable development requires conceptually new manufacturing processes and equipment, expanding use of recyclable materials, the development of regenerative/recyclable products, and reduced use of nonrenewable resources. It requires focus on upstream pollution prevention rather than end-of-the-pipe cleanup technologies.

Total quality management (TQM) concepts and applications are receiving increasing attention and application in the design and construction industry here and abroad. The ASCE manual entitled *Quality in the Constructed Project* provided a milestone in this area in the United States, and the International Standards Organization (ISO) has published a series of five international standards on quality systems (ISO 9000–9004).

Evolving partnering concepts and practices apply to both sustainable development and quality. Expanded multidisciplinary partnerships are critical to ensuring that sustainable technologies; processes, systems, and human needs; and concerns are reflected in the design and construction of the built environment. Partnerships between the owner, designer, and builder are critical to the achievement of quality in the constructed project.

Successful public-works infrastructure development now and in the future will require increasing understanding and application of the principles of sustainability, quality, and partnering.

Government, industry, and academia should work together to provide education and training on the purpose and application of these concepts and strategies for all people working in the construction and building industry. They should also work together to inform the public of the benefits of these developments and the commitment of the industry to their increasing utilization in meeting the future construction and building needs of the nation.