The United States Government's Role in High-Performance Materials for Infrastructure

by T.J. Pasko, Jr., and G.J. Frohnsdorff

Synopsis:

Sixteen agencies of the United States Federal Government have developed an interagency proposal for promoting the use of high performance concrete and other materials for use in the Nation's Infrastructure. They are working jointly with the Civil Engineering Research Foundation (CERF) to enlist private sector support for sponsoring a research and development program aimed at getting the materials into use. CERF is drawing upon the technical community, such as that in ACI to define the various research needs and studies which will lead to materials acceptance. Materials other than concrete are addressed in other parts of the total program. Workshops were held in the spring and fall of 1993 to develop schedules and priorities. A tentative cost for the concrete program is approximately $200 million over 10 years, which includes some technology transfer and which would be expected to be matched by some private sector funding.

Keywords: Civil Engineering Research Foundation; high-performance concretes; high-strength concretes; infrastructure; United States Government

Thomas J. Pasko, Jr., P.E., is the Director of the Office of Advanced Research in the U.S. Department of Transportation, Federal Highway Administration and is the chairman of an interagency task group on infrastructure and construction under a larger committee on materials. He has been involved in concrete research since 1959 and has served on numerous ACI committees.

Geoffrey J. Frohnsdorff, Ph.D., is the Chief of the Building Materials Division of the Building and Fire Research Laboratory in the National Institute of Standards and Technology. He is the secretary of the interagency task group on these activities and is active in numerous related activities in American Society for Testing and Materials (ASTM) and the American Concrete Institute (ACI).

INTRODUCTION

Background

In January 1991, the Civil Engineering Foundation (CERF), an affiliate of the American Society of Civil Engineers (112,000 members), conducted a workshop for approximately 350 persons in Washington, D.C. The attendants discussed the problems of the Nation and subsequently published "Setting a National Research Agenda for the Civil Engineering Profession" (Ref. 1). One of the resultant thrusts was a need for the "Revitalization of the Public Works Infrastructure." This challenge was further defined as a need to develop a plan for the use of High Performance Concrete and Steel, the materials which form the backbone of the Nation's infrastructure.

While CERF was rallying the profession, there was a relatively unrelated effort taking place within the government to get the various agencies doing similar research to coordinate their work. The Federal Coordinating Council for Science, Engineering and Technology (FCCSET) reports to the Science Advisor to the President and it was successful in developing major interagency programs in global warming, high performance computing, and others. In 1991 one of the subcommittees of the coordinating council, the Committee on Materials (COMAT) developed a new interagency program on Advanced Materials and Processing (AMPP). Ten agencies budgeted to spend $1.6 billion on advanced materials (superconductivity, fiber optics, etc.) in 1992. They were successful in obtaining an increase of 10 percent ($162 million) for 1993 (Ref. 2).

In January 1992, a Task Group was established under COMAT to develop a program on infrastructure and construction materials, partially in response to the challenge set forth by CERF and the private sector. This report presents the deliberations of that Task Group. In February 1994 the committees were reorganized and the work continues under a task group of the National Science and Technology Council.

Status

As of April 1994, the following efforts are noted. CERF held a workshop on April 29, 1993, to draw attention to the National Needs and produced a report (Ref. 3). Experts from approximately 12 different materials areas (concrete, steel, aluminum, composites, etc.) and their representative associations met on November 2-3, 1993 in workshops to delineate the research needs of their industries to participate in the construction of the infrastructure of the next generation. The total program is to be unveiled in about August 1994 in a final combined report and presented at a special national conference.

The Task Group has produced a draft internal report which identifies who is doing what within the U.S. Government and sets forth some general guidance about how the program might operate and interface with the private sector. The Clinton Administration has reorganized the effort to give greater emphasis to infrastructure renewal. The Task Group continues to gather information and collaborate on research of common interest. Several agencies such as the National Institute of Standards and Technology (NIST) and the Corps of Engineers (COE), have proposed picking up portions of the proposed program in their annual budgets. Also, the Federal Highway Administration (FHWA) has provided significant support to Texas to build a bridge during 1994 with high strength concrete of about 90 Mpa (13,000 psi) (Ref. 4), and has raised pooled funds for high strength bridge research and fatigue testing. The National Science Foundation (NSF) has initiated the establishment of new infrastructure research centers. Additionally, some elements of the proposed needed research are competing for funding under the grant programs of the Technology Reinvestment Program (TRP) of the Department of Defense and the Advanced Technology Program (ATP) of the Department of Commerce.

Definition: Infrastructure

The infrastructure considered in this report is defined as all constructed facilities that form the basis of our society, such as buildings, waterworks and transportation. Some examples of elements of the infrastructure are given in Table 1.

State of the Art

Independent research on high performance materials, such as concrete and steel, has been underway for many years in many different agencies to support their missions. As an example from the highway field, the Strategic Highway Research Program (SHRP) is concluding five years of research and development (R&D) on the overall improvement of portland cement concrete at a cost of $12 million -- a significant amount by highway standards. Over $2 million was specifically designated for high performance concrete, as defined in the program. Also, the COE recently completed the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Program, a $36 million study to develop improved technology for evaluation and repair of civil works structures. Approximately $1.5 million was devoted to development of high-performance concrete. The results of both programs will be added to the vast knowledge base on concrete and related materials, such as that resulting from research funded by the NSF in which compressive strengths of over 690 MPa (100,000 psi) have been attained in small laboratory specimens. By itself, and in the short term, this uncoordinated research will not bring about much change in the construction community where only limited amounts of high-strength concrete are presently being used.

Many definitions have been proposed for "high performance concrete." High performance could mean high quality and highly durable concrete with little reference to strength, however, it is difficult to quantify the durability aspects. Hence, this report emphasizes the more easily quantifiable comparisons which can be made based on the high strength aspects of improved concretes. However, if it can be shown that, as is believed to be the case, high-strength concretes can be high-durability concretes, there will be an additional incentive to use them. For example, the REMR Program demonstrated that 95 MPa (13,500 psi) high-strength concrete exhibits significantly improved resistance to erosion, particularly in hydraulic structures where the concrete is subjected to the abrasive action of waterborne debris.

In practice, to date, 160 MPa (23,000 psi) concrete has been used experimentally in Norway to "armor" pavements subjected to studded tires and 130 MPa (19,000 psi) concrete has been used to reduce column sizes in tall buildings in Seattle. In the bridge technology area, the East Huntington Bridge in West Virginia was constructed with 55 MPa (8,000 psi) design strength concrete, the highest strength concrete used in U.S. bridges to date. Some experimentation is presently underway in the U.S. with 70 MPa (10,000 psi) concrete in bridge girders, as reported in this conference and in the *PCI Journal* (Ref. 5).

One reason higher strengths have not been used in bridges is that the present design criteria, which are based on the properties of conventional strength concrete, may limit the economic benefits that can be obtained from using thinner cover over reinforcing steel. Knowledge of the expected durability of efficiently designed high-strength concrete members is needed before full exploitation of high-performance concrete is possible. Also, because high-strength concrete is quite brittle and tends to fail suddenly, research is needed to assure adequate ductility in the structural system.

A major deficiency of high performance materials (especially referring to concrete and steel) has been the limited scope and lack of vision in setting the goals of the R&D programs. In particular, because the R&D activities have been set to match the limited funds available, they have tended to focus on the search for solutions to existing operational problems and, therefore, lack innovation. Few projects have been carried out with the goal of building and testing prototype structures for demonstrating the inherent economies and the safety of an integrated design/construction package or system. Most research studies compare one structural member to another, often on a one-to-one basis, supplemented by a theoretical study and, sometimes, verification by a small model study. Few studies have been done to analyze a structure from materials selection to final concept testing such as was done for the proposed Three Sisters Island Bridge for Washington, D.C., which was never built.

One of the largest bridge model tests to date was a 0.4 scale model, 34.4 m long x 6.1 m wide (113 ft. x 20 ft.), built in the FHWA laboratories to demonstrate alternative load factor design of a composite structure. Total study costs from 1985 to 1990, including model construction and loading to destruction, were about $2.5 million. Such research is costly in both time and money.

In 1990-92, the NSF, in collaboration with the FHWA and the Ohio Department of Transportation, supported a progressively destructive field test of a full-size decommissioned bridge to validate modeling and analysis. The project was conducted by the University of Cincinnati and the total cost was $760,000. Another planned destruction test is underway in New Mexico.

In the future, it is imperative that the research and development be planned on a scale commensurate with the problems faced, if innovation is to be achieved.

THE GOAL

The goal of this effort is to optimize the design of infrastructure systems using high performance materials, demonstrate the construction and testing of prototypes, and provide assistance in implementing the technology. Along the way, appropriate R&D will be done to solve associated materials/construction detailing problems and deficiencies and to make it possible to use high performance materials to extend the limits of design. A coordinated interagency program leveraged with the private sector will produce major breakthroughs and economies of scale that will save dollars for investment in reducing the backlog of needed improvements in the infrastructure.

Impediments to Meeting the Goal

There are a number of problems which must be overcome:

a. The cost of the needed technical program, from research through demonstration, will be great compared with the costs of earlier, less ambitious efforts.

b. The available funds are presently divided among many agencies, thus making the efficient management of any program difficult.

c. The money now being used for studies of high performance materials is, for the most part, distributed among many researchers doing relatively small, uncoordinated studies. These researchers may have to be mollified if the funds are diverted to the few organizations capable of undertaking the larger programs which must include the construction and testing of prototypes.

d. The existing design codes and standards are usually conservative to protect the public, and tend to restrict the use of new materials until, and unless, a substantial database about them has been established. Related to this is the need to adopt life-cycle costing principles in the bidding process.

e. The use of designs based on the higher strengths attainable with high performance materials must place greater emphasis on quality control so as to avoid deficiencies that could lead to catastrophes. Is the construction industry ready for this? Is the labor force adequately educated?

f. When strength is the issue, savings will result only if less of the higher-quality, higher-strength materials is used in place of the volumes of normal materials. Among major challenges that can be foreseen are the proper connection of smaller members, protection of the members from deterioration by the environment, prevention of failures from localized buckling or impact, improvement of ductility and fracture toughness, coping with handling stresses, and overcoming problems associated with increased deformations resulting from higher working stresses and smaller members.

g. The use of less massive structures may require "smart" technology so that they may monitor themselves to assure public safety. The question of liability exposure must be overcome.

h. Implementation of the new technologies will take much time because of the need to develop new codes and standards and to disseminate the new knowledge to about 39,000 local governmental entities.

Opportunities

The need for establishing a new construction-oriented R&D effort is apparent from the growing recognition that the United States must:

a. Restore its infrastructure.

b. Become a world leader by being more competitive and productive so as to be able to compete in the European community and with Pacific Rim countries.

c. Gain a share of the market in developing countries, including those of the former Soviet Union.

d. Do more to conserve natural resources by using them more efficiently.

These concerns have led to a new interest in infrastructure research, as demonstrated by:

a. The completion of the $150 million Strategic Highway Research Program and emphasis placed on implementation.

b. The completion of the $36 million REMR Research Program and initiation of the REMR-II Program at a similar funding level.

c. The passage of the 1991 Intermodal Surface Transportation Efficiency Act which addresses new technologies (such as magnetic-levitation) and encourages research and technology transfer in many new ways.

d. The proposed shift from a national defense mode to emphasizing the rebuilding the Nation's infrastructure to stimulate economic growth.

e. The institution of new incentives to encourage private sector involvement in R&D, such as the newly-formed private research foundations for concrete, aggregates, asphalt and specifications. Similarly, initiatives on the government side are the Corps of Engineers' cost-shared R&D Program with the private sector, (the Construction Productivity Advancement Research Program, CPAR), and the Department of Commerce's Advanced Technology Program (ATP).

On the "pull" side of R&D, several organizations now in place can help strengthen Federal technology development. Examples of actions being taken are:

a. The American Society of Civil Engineers (112,000 members), through its Civil Engineering Research Foundation (CERF), with the support of the private sector, is using a forum of national experts to develop a strategic plan of action for civil engineering R&D.

b. The CERF, together with the American Concrete Institute (20,000 members), the American Iron and Steel Institute (1,200 members), and others, is planning research to improve the country's ability to exploit high-performance concrete and steel technologies.

c. The Federal agencies have been encouraged to be active in organizations such as these mentioned in (a) and (b) to promote synergism between the private and public sectors.

d. The use of Cooperative Research and Development Agreements, CRADA's, such as the Corps of Engineers' CPAR (Construction Productivity Advancement Research) Program are developing partnerships with industry.

e. The CERF, the COE, AASHTO, and FHWA are launching a center for evaluating new technologies to help promote their implementation in the 39,000 local governmental organizations. This Highway Innovation Technology Evaluation Center (HITEC) started operation in February 1994 and is initially funded for 4 years (Ref. 6). CERF is presently negotiating with government agencies to establish similar centers for environmental technologies and building innovations.

APPROACH

Because about one-third of new construction receives some Federal support, the U.S. Government is in a unique position, by virtue of its property ownership and its influence on new construction, to be a leader in the development and transfer to practice of new infrastructure technology. Similarly, it has the capability, by virtue of its technical resources and expertise, to work with the private sector to improve engineering/ construction technology. It also provides funding to Federal-aid projects.

Ways in which the U.S. Government can lead in the development and demonstration of new construction technology is by building with high performance materials and improved structural systems. This is because the Government can obtain exemptions from codes and standards, particularly in pilot programs; in part, this is because it is self-insuring. Of course, final designs must be shown to be safe for public use before they are adopted by the private sector. Examples of ways in which the Government might lead in the introduction of new construction technology are:

a. The DOT agencies and the Corps of Engineers might test innovative designs or processes by using them in the building of bridges, and in water supply, flood control and other transportation facilities.

b. The General Services Administration, the Postal Service, the Bureau of Prisons, and the Department of Veterans Affairs might demonstrate new concepts in structural design and automated construction.

c. The Environmental Protection Agency (EPA) might build prototype structures for water supply, sewage treatment, and solid waste handling. They might also further the development of nonhazardous protective systems (such as paints).

d. The NSF, the National Institute for Standards and Technology, the Department of Energy (DOE) and other agencies, might continue to expand the horizons of research into the design and use of new materials, and assist in the improvement of codes and standards, while the Federal Emergency Management Administration might assist in the development of new protective systems for structures and lifelines.

e. The Department of Housing and Urban Development and the DOE might exert a greater influence on the use of high performance materials in residential housing and urban applications.

f. The Departments of Education and Labor might help provide training in the proper and safe use of the new technologies.

Presently, in the construction industry, the U.S. Government has the reputation of being a very conservative designer and builder. It is very traditional in its approach to infrastructure projects. This could be changed through the interagency activities of this program. It could be further enhanced through the issuance of an executive order that charges the agencies to design/build on the leading edges of the technology and to promote "show-and-tell" aspects of the prototypical features.

The inherent features which would make it possible for the U.S. Government to influence the design and construction industry in the United States are the vast amounts of government ownership which exists. Some items of government ownership or influence are shown in Table 2.

<u>Interagency Cooperation</u>

Table 3 shows how the various agencies might coordinate their activities on a concrete program which covers basic research through demonstration prototypes and education. More user agencies would be added later. The complexity is more apparent when one considers the U.S. Government has 14 departments (each