Construction and Materials Research and Development for the Nation's Public Works

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CONSTRUCTION AND MATERIALS RESEARCH AND DEVELOPMENT FOR THE NATION'S PUBLIC WORKS

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CHAPTER ONE

INTRODUCTION AND SUMMARY

CONSTRUCTION AND MlATERIALS RESEARCH AND DEVELOPMENT FOR THE NATION'S PUBLIC WORKS

The nation's infrastructure is the physical framework that supports and sustains virtually all domestic economic activity; it is essential to maintaining international competitiveness as well. In its broadest definition, "infrastructure" includes all types of public facilities, such as highways, roads, and bridges; water resource projects and water supply and treatment systems; sewer systems and wastewater treatment plants; locks, dams, and waterways; ports; airports; railroads and mass transit facilities; public buildings; and resource recovery facilities.1 To meet the immediate concerns of the Senate Environment and Public Works Committee for a review of infrastructure research and development (R&D), this Office of Technology Assessment (OTA) Staff Paper focuses on construction technologies and materials for transportation and water-related infrastructure components --those commonly termed "public works,"2 Thus, public buildings, mass transit systems, railroads, airports, and the air traffic control system are not included, although significant Federal sums are spent on them.

OTA found that public and private expenditures for R&D related to infrastructure technologies and materials are very low--generally less than 0.3 percent of gross annual expenditures by Federal agencies or business volume for industries. Moreover, water and wastewater systems and advanced construction technologies receive virtually no Federal R&D funding. In light of

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[1] See, Public Works Improvement Act of 1984, P.L. 98-501,

2 As used in this Staff paper, "construction" refers to new construction, reconstruction, repair, and maintenance unless specifically described otherwise.

this, Congress may wish to consider increasing support for R&D programs that focus on these neglected areas.

OTA also found substantial institutional barriers and economic disincentives to nonfederal R&D, especially in the movement of new technologies and materials off the research bench and into the field. These include procurement processes and issues related to risk that impede the adoption of new technologies and materials in public works projects, and splintered private and governmental roles. In addition, investments in public works are characterized by high fixed costs, lengthy planning and construction schedules, complicated public financing arrangements, and long payback periods, which lead to uncertain economic returns on R&D investment. Consequently, OT.A concludes that simply increasing R&D expenditures without also taking steps to alleviate these barriers and disincentives will do little to advance the materials. machinery, and methods by which we design, build, and maintain our Nation's public works.

BACKGROUND

Federal, State, and local governments are responsible for building, repairing, and maintaining public works. The magnitude of public works investments by these governments is very large--S97.3 billion in 1984--accounting for about 24 percent of all new construction annually. However, the growth rate of public works investment has slowed significantly' over the past three decades compared with the growth rate of net private capital formation.[3] Two studies have associated this trend with deterioration of the nation's infrastructure.

[3] National Council on Public Works Improvement, The Nation's Public Works: Defining the Issues (September 1986), p. 47.

[4] Randall W'. Eberts, "An Assessment of the Linkage Between Public Infrastructure and Economic Development," prepared for the National Council on Public Works Improvement (July 1986); Therese J. McGuire, "On the Relationship Between Infrastructure Investment and Economic Development," prepared for the National Council on Public Works Improvement (July 1986).

Total real spending for public works increased from $60 billion in 1960 to $97 billion in 1984, but total spending as a share of GNP has declined. In 1984, total public works expenditures on construction, operations, and maintenance were 2.7 percent of GNP, down from around 3.7 percent in 1961. This decline reflects a marked drop-off in capital expenditures for new construction, and an increase in outlays for operations and maintenance. Thus the public sector has shifted its primary focus from building new stock to maintaining its existing capital base.[5] Construction of entirely new, large-scale public works projects has slowed substantially with the completion of the interstate highway system and the shift in national budget priorities toward defense-related projects.

Another important trend is the change in the types of facilities funded that occurred between 1960 and 1980. Highway projects dominated public works investment in the 1960s, with water resources and water supply systems a distant second. After 1970, highway spending began to decline as spending for other facilities--primarily wastewater treatment and mass transit--grew. In the 1980s, highway spending has continued its relative decline, while mass transit funding continues its relative increase. Expenditures for wastewater treatment, water supply, and solid waste have remained comparatively stable since 1980.[6]

Still another trend is the shift in spending by level of government. From 1960-1984, the relative role of States in funding public works declined, while the local share of infrastructure spending rose, with the greatest increase occurring since 1980. In 1984, local governments accounted for 50 percent of the total public works investments, the Federal Government 27 percent, and State governments 23 percent. While local governments have borne more of the responsibility for the construction costs for water supply, wastewater treatment, solid waste, and mass transit facilities, they also face rising costs for operating and maintaining all forms of

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[5] National Council on Public Works Improvement, supra note 3, at pp. 48-49.

[6] Ibid, p. 51.

public works. The Federal role has been characterized by periodic bursts of spending for highway, wastewater treatment plant, and mass transit facility construction.[7]

The concerns about the condition of the Nation's infrastructure that were so widely-publicized in the early 1980s prompted several recent studies[8] that attempted to define current annual infrastructure investment needs for adequate maintenance, repair, rehabilitation, and new construction. These estimates range from $52.6 billion to $118.2 billion.[9] Actual expenditures are expected to meet only 33 to 60 percent of the estimated public works construction and repair needs.

The relative decline in capital works expenditures and other concerns led the Senate Committee on Environment and Public Works to ask OTA to study a number of issues related to research and development for public works to determine the effectiveness of infrastructure R&D policy and programs. These issues include:

1. The major areas of construction, repair, and maintenance technology that could benefit from increased research and development and that are likely to yield valuable results in the short and long term;
2. The magnitude of research and development needs, and the point point at which increased funding for research and development would reach diminishing returns;
3. The present state of research and development in the private sector, and the advantages or disadvantages of government research and development programs relative to similar private sector efforts;
4. A comparison of research and development spending for infrastructure construction, maintenance, and rehabilitation and that in other major industries;
5. The research and development efforts of other countries, and the extent to which these efforts are underwritten by government agencies;

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[7] Ibid, p. 53.

[8] National Council on Public Works Improvement, supra, note 3; Congressional Budget Office, Public Works Infrastructure: Policv Considerations for the 1980's (.April 1983); The Associated General Contractors of America, America's Infrastructure: A Plan to Rebuild (May 1983).

[9] National Council on Public Works, supra, note 3, Table II-1, at p. 10. Estimates are for *ail* public works, including airports, mass transit systems, and solid waste disposal facilities.

6. The overlap between the areas of highways, water projects, sewage treatment, public buildings, and other types of construction that might warrant a more unified or coordinated research program for all of these areas;

7. The constraints on innovation caused by existing Federal contracting or administrative procedures; and

8. The adequacy and efficiency of technology transfer between government agencies and the private sector.

This OTA Staff Paper responds to the Committee's request. Part One of the Paper is this Introduction and Summary. Part Two examines R&D for construction technologies and methods, and Part Three focuses on materials-related R&D for public works. This is not an exhaustive review of all aspects of R&D for public works. OTA relied on an extensive literature survey supplemented with information obtained in meetings and telephone conversations with Federal agencies, trade associations, and companies. Several questions were impossible to address adequately within the time constraints of this survey, and would benefit from further study. In particular, we were unable to quantify the size of the R&D needs, or the point at which R&D investment reaches diminishing returns (question 2, above). Instead, we provide a brief qualitative review of the R&D areas that would deliver the "biggest bang for the buck," and discuss means of using the available research dollars more efficiently. In addition, we were unable to conduct a thorough review of the constraints introduced by Federal contracting policies and issues related to risk (question 7).

WHAT ARE THE POTENTIAL ECONOMIC BENEFITS OF R&D FOR PUBLIC WORKS?

The long-term cost savings from the development of new and improved technologies and materials for public works construction, repair, and rehabilitation, or of a better understanding of the properties and uses of currently available technologies and materials, could far exceed the short-term cost of an expanded commitment to R&D. Other benefits of public works R&D are less easy to quantify, such as the potential public health benefits of improved water and wastewater treatment, and the benefits of improved infrastructure systems for local economic development. While OTA was unable to quantify the potential R&D costs of achieving these benefits, we can offer several examples of research areas with potentially big "payoffs" that can be quantified.

The Transportation Research Board (TRB) estimates that the total cost of rehabilitating and replacing the nation's highways and bridges will be between $1 trillion and $3 trillion. According to the TRB, if research could improve the performance and durability of roads and bridges by just one percent, the direct savings would be $10 billion to $30 billion. Much of that payoff would come from advances in materials and improved understanding of materials performance, because materials absorb almost half of new construction costs.

The Federal Highway Administration estimates the repair and replacement costs for the more than 137,000 bridges rated as "deficient" at over $35 billion; an additional 85,000 bridges are in need of rehabilitation at a total of $15.5 billion.[11] Most of these repair costs are for replacement of concrete bridge decks. The decks are designed to last for 40 years, but because of weather conditions and the use of corrosive de-icing materials, they often require extensive repairs in 5-10 years and replacement at 15 years. Development of anti-corrosion protection systems that could extend the performance life of bridge decks from 15 to 20 years (only half the theoretical design life) would have a payoff in excess of $2 billion.[12]

For repair and reconstruction of *public works,* however, costs associated with redirecting traffic, site protection, and public safety are so large that the materials costs can shrink to be-

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10 Transportation Research Board, America's Hi~hwavs: Accelerating the Search for Innovation, Special Report 202, 1984, at p. 82.

11 Martin Tolchin, "$50 Billion Needed for Bridge Repair, Congress is Told by Federal Agency," New York Times, April 12, 1987, p. 24.

12 TRB, supra note 10, *at* p. 109,

tween 3 and 4 percent of the total. Thus R&D to improve the durability and lengthen the effective life span of the materials used for repair and reconstruction could bring large construction cost benefits with little increase in the total project cost.

Asphalt paving materials account for over 20 percent of total highway spending in the U.S. The Federal Government alone is projected to spend over $200 billion on asphalt pavement by 2000. Even a one percent improvement in the performance life of asphalt pavement from research could save over $100 million annually in total highway repair and construction costs. This expected savings is not unreasonable, because many highway engineers believe that an increase of 3 to 5 percent in asphalt pavement life could be achieved now simply through better quality control in pavement design, construction, and maintenance. Similarly, asphalt cement represents roughly 20 to 25 percent of the cost of asphalt paving material. Use of improved asphalt cements in initial construction or overlay could save repair and repaving costs of more than four times the cost of the cement.[13]

Studies of buried sewer and water pipes by the Environmental Protection Agency (EPA) and the American Water Works Association Research Foundation have found that external and internal corrosion are roughly equal contributors to pipe deterioration. Neither mode of corrosion is well understood, but arresting either one could almost double the performance life of sewer and water pipe systems. Internal corrosion protection systems, such as slip liners and special coatings, avoid the much higher costs of excavating and repairing or replacing buried pipe, which can run as high as $80 to $100 per installed line foot of pipe. Although cost estimates for internal protection measures were not available, the American Water Works Association says they can be significantly less than excavation and repair/replacement costs. Continued R&D would lead to lower costs and improved performance of internal protection methods .14

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13 Ibid, at pp. 66-67, 82-83.

14 Personal communication to OTA by Jack Sullivan, American Water Works Association, April 1987.

As these examples show, the benefits of even modest increases in materials R&D for highway repair, maintenance and construction alone could be $15 billion to $35 billion over the next 10 to 20 years. Compare these savings to the current Federal and nonfederal investment in materials R&D for all types of public works of $53 million to $62 million, and the value of the investment in R&D becomes even more pronounced. Still more significant, much of this benefit could be obtained with materials that are available now, but are not used because of inadequate technology transfer, the perceived financial risks of using new materials, and government procurement practices.

Of particular importance is research into methods of improving the life of drinking water systems, which has a relatively low level of support. A focused research program to increase knowledge about the factors affecting the life cycle costs of clean water systems could bring rich benefits as the country embarks on a renewed effort to upgrade such systems.

Individuals contacted by OTA during the course of this survey cited three primary areas in addition to materials where R&D could offer great opportunities for public works benefits:

-- Robotics and automation for use in construction, particularly for applications in hostile environments and for remote sensing;

-- Computer applications creating efficiencies in construction processes and improving design. Advances in computer technology and software, such as integrated knowledge systems consisting of networked expert systems, simulation models, and databases, also could be invaluable in overcoming the inadequate information exchange among researchers and public works agencies, and thus in promoting the use of the best available materials and technology; and

-- Basic research into natural water processes, such as the effects of shoreline erosion and groundwater movements and characteristics on structures. So little is known about these natural processes that public works improvements often are undertaken with insufficient understanding to ensure structural longevity.

WHO IS FUNDING R&D FOR PUBLIC WORKS?

Research and development for public works are sponsored and carried out by a number of Federal agencies, and by State and local governments, universities and research centers, trade associations, and corporations. However, despite the economic importance of public works, and the magnitude of annual investment in construction, operations, and maintenance, R&D expenditures on construction technologies and materials are relatively small. Total Federal R&D for infrastructure was $103 million in FY85, or roughly 0.3 percent of total new infrastructure construction (see table 1- 1). Of this amount, OTA estimates that Federal agencies spent around $36 million on R&D for infrastructure materials; $14 million on incremental and advanced improvements in construction technologies and methods; and the remainder to improve design, evaluations, needs analyses, management systems, feasibility studies, information dissemination, etc.

The types of, and levels of funding for, Federally-sponsored R&D programs related to public works vary widely (see tables 1-2 and 1 -3). Domestic public works projects tend to borrow technologies and materials developed for other applications (e.g., fiber-reinforced concrete). Federal research agendas reflect this in their emphases on adapting available products for specific public works applications, on analyses of public works capacity, and on management support. OTA found no significant Federal R&D expenditures for advanced construction technologies, or to support the design or development of alternative infrastructure systems, such as a totally new way of delivering water.

Although reliable data on nonfederal R&D funding are difficult to obtain, OTA found that private sector R&D for infrastructure construction technologies and materials also is minimal. Based on the figures obtained within the time constraints of this survey, OTA estimates that total nonfederal materials-related R&D for infrastructure is about $18-$25 million annually. Similar figures were not available for construction R&D, but OTA estimates R&D expenditures by construction equipment and materials manufacturers to be less than 0.3 percent of the total annual value of new construction in the United States. Construction firms come in on the low end of this estimate, spending less than 0.04 percent of their annual construction sales on R&D. Materials manufacturers and suppliers spend between 0.1 and 0.3 percent of their annual sales on R&D. Data on R&D spending by State and local governments generally were not available for this survey.

Table I-l .-federal RAD Expenditures

YEAR	Value of New Infrastructure Construction in U.S. (mllflons of dollars)	federal R6D - Incremental and Advanced: Ml I I ions of Dollars	federal R6D - Incremental and Advanced: Percentage of Total Publlc Works Expenditures	Federal R&() - Total Reported: Mlllons of Dolfars	Federal R&() - Total Reported: Percentage of Total Publlc Works Expenditures
1985	34,370	14	0.1	103	0 .
1986	38,742'	15	0.1	109	0.
1987	(unknown)	14	(unknown)	97	(unknown

[9] f'rel iminary d.dta.

SWltceb; Total v~lue of new infr~>tfucture construction ad~pted by OTA from U.S. Department of (kmmerce, Bureau of the Cen>us, v~[ue of NCW Clm~truction Put in Place, C30-86- 12, issued fetwuary 1987 (Washington, DC: U.S. Government Printing Off Ice, December 1986). ;-ederal R611 expenditures from OTA.

lable I-2.–leder~l Expenditures on R6D for All Infrastructure Types
FY 1985-87 (3-Yecir>) Spending
(in mi l l ion> of ~01 ldr>)

	For Construction Technologies					
	Adv~nced R&L)	Incremental R&D	Lhsic Rese~rch For R&D	Re~e~rch to Improve De>ign, Evaluations, And/or Needs An~ly>es	Other Rti>carch	rOt[d]l
Federal Agencies:						
Corps of Engineers	$0	$28.2	$0	%35.6	532.8	596.6
Bureau of Reclamation	0	0.3	0	4.3	2. I[b]	7.4
Federal Highway Administration	0	7.7	0	14.5	9.8	32.0
5 ate HP&R Projects[a]	0	0	0	9.8	ı30.0	I 40.4
Nell onal Bureau of Standards	0.3	0.4	1.9	4.7	2.9	10.3
1nv ronmental Protection Agency	0	0	2.0	6.0	3.0	1 I.0
rJdl onal Science Foundation	0.3	1.4	0	3.3	1. 4[b]	6.5
Organization Using Federal Funds:						
Transportation Research Board (NCHRP)	0	0.2	0	3.3	1. 7[b]	5.2
TOTAL	$0.1	$38.3	$3.9	$81.5	$184.9	$309.4
PERCENT DISTRIBUTION	0.2$	I 2.4X	1.3%	26. 3%	59.8$	100. ox

Note: Figures may not total correctly because of rounding.

[a]State Highway Planning and Research (HP&R) of the Federal Highway Administration funds also include research projects not directly related to construction technology or materials, such as studies on highway safety and traffic operations.

[b]Includes a small amount of basic research useful for R&D of construction technologies.

SOURCE: Office of Technology Assessment, from data provided by Federal agencies.

l~blc l-3.–Feder~l Ml) Expenditures for Each Infrastructure Type
tY 1985-87 (3-Years) Spending
(in mltl ions of dollars)

	(or Construction Technologies					
	Adv~nced Rl$l)	Incremental ~a~	tldslc Research For RaO	Research to Improve Design, Ev~luations, And/or Needs Analyses	Other Re>edrch	Total
l)dnb	.5	1.8	1.9	11.0	4.4	19.4
Wdlcf supply Sybtclnb	.3	.4	1.9	6.7	6.7	16.0
Sewer Sy>tem>	.3	2.9	3.9	9.4	5.6	22.1
lligtlwijy> tilld Oll)ef liu{~dways	.6	8.0	1.9	28.3	146.6	185.0
of Idgeb”	.4	3.6	1.9	12.1	5.0	23.0
lufllicl>	.3	.4	1.9	4.6	2.1	9.3
Wdlclwdyb, including i’oi t>	.5	23.7	1.9	31.7	27.0	84.1

[n] iXl-!(~tlC> dıı unkl~uwl) ~\ıııııılııl ot expc[ld i t ures lor State Hf’&R projects; however, these expenditures are not for ~oil>tructlon teclinologlc ”~.

tk) i c: t igures mdy fmt Cldd tl<)(izul~tdlly tlecdube of rounding and dre not added vertically bec~use >l 911 l f l Cdll t dlllLMlll l s (J t bpc llct i ng dpp l y 10 more t t~dn one type of i n f r db t r uc t ure. Md t er i d l s C XDClld i t uı c> df G l l lt. l 11 dc d .

SOURCL: Otfice of lechnulogy Assessmenl

Due to a number of institutional and economic constraints, research that would be considered advanced in industries such as chemicals and electronics generally is not undertaken by the infrastructure-related industries in the United States. Therefore, the low levels of private R&D funding contrast markedly with industries that sell defined products in commercial markets. For example, the chemical and electrical industries each spend about 4.3 percent of revenues for R&D, while the motor vehicle industry spends about 3.2 percent. However, R&D is proportionately lower for the electric utilities industry (0.4 percent of sales), which is a regulated monopoly but does cooperative integrated research, and for the mining and minerals industry (1.5 percent), which currently is depressed. Table 1-4 shows other comparisons.

CONSTRUCTION R&D PROGRAMS

For this analysis, OTA divided R&D on construction technologies into five categories: Advanced R&D; basic research; incremental R&D; research to improve design, evaluations, and needs (i.e., system capacity) analyses; and other research.[15] These are defined as follows:

Advanced R&D leads to a major realignment of how things are done or what product results, and brings substantial benefits in cost and quality. Two relevant examples are the introduction of tunnel-boring machines for transit construction and the use of computers in construction. These types of change make possible what would formerly have been unrealistic.[16] Of the agencies using Federal funds, only the National Bureau of Standards and the National Science Foundation (NSF) have spent substantial sums on advanced R&D. Less than 0.2 percent of all Federal infrastructure construction research dollars are spent in this category.

Incremental R&D brings about gradual and continual improvements and innovations for existing materials, processes, or pieces of machinery. The collective impact over time of these

15 Materials-related R&D was not SO easy to categorize. Frequently one project would include elements of two or more of these categories. Therefore, in tables 1-2 and 1-3, much of infrastructure materials R&D is included in "other research."

16 "Research Needs in Transportation Facilities: Guideway Technology and Materials Research," Transportation Research, vol. 19A, No. 5/6, 1985.

Table l-4.-Private Sector R&D Expenditures Per Gross Sales

Industry	R&D Expenditures (As a Percentage of Gross Revenues)
Aircraft and Missiles	4.2
Electrical Equipment	4.3
Machinery	5.2
Chemicals and Allied Products	4.3
Motor Vehicles	3.2
Metals and Mining	l.s[a]
Electric Utilities (Investor-owned)	0.42[b]
Construction	<0.33[c]

a 1985 estimate from *Business Week,* "R&D Scoreboard," June 23, 1986, pp. 139-156.

b Sherman Feher, Planning Analyst, Electric Power Research Institute, personal communication, Apr. 28, 1987.

c OTA estimate for construction expenditures in 1985. According to NSF, they receive too few responses to their annual survey from construction firms to provide reliable expenditure figures.

Source: 1984 estimate from National Science Foundation, *National Patterns of Science and Technology Resources 1986,* NSF 86-309 (Washington, DC: 1986), p. 56, except as noted.

improvements is progress in the quality and service life or costs of the technologies. The Corps of Engineers, Federal Highway Administration, and NSF are the major supporters of this type of research. About 12.4 percent of total Federal infrastructure construction research dollars are spent on this type of research.

Basic research encompasses work aimed at new techniques essential for technology development, and does not address applications. The National Bureau of Standards project on building data protocols is an example. About 1.3 percent of Federal research dollars are spent here.

Research to improve design, evaluations, and needs analyses includes construction-related research that results in choices or applications among known and available technologies. This research does not advance infrastructure construction technologies, but can lead to more efficient and cost-effective results from known construction technologies. All Federally-funded research programs support this kind of research, which accounts for roughly 26 percent of Federal infrastructure research dollars.

Other research includes projects such as management systems and administrative studies, feasibility analyses, demonstrations, and transfer or dissemination efforts. All Federally-funded research programs also support this kind of research, which receives almost 50 percent of Federal infrastructure construction R&D dollars (i.e., excluding the materials research included in this category in tables 1-2 and 1-3).

Although the activities designated "other research" are valuable, the allocation of almost half of the available Federal construction R&D resources to research that does not lead to technological advances is a fact that Congress may wish to examine carefully. They also should consider reexamining the small size of Federal expenditures--14 percent--for advanced, incremental, and basic R&D, which has the greatest potential for advances in infrastructure technologies, and therefore the largest benefits.

MATERIALS R&D PROGRAMS

Based on our brief survey, OTA estimates total materials-related R&D to be $53 million to $62 million in FY86, with around $35-$37 million coming from Federal agencies and programs and the remainder from nonfederal sources. Nearly half of the Federal materials R&D (around $17 million in FY86) is sponsored by the Department of Transportation (DOT). Within DOT, the Federal Highway Administration (FHWA) conducts research on pavement performance, and evaluates new or improved materials for highway and bridge construction, repair, and corrosion protection. FHWA also participates in two Federal-State cooperative R&D programs--the Highway Planning and Research Program and the National Cooperative Highway Research Program.

The second largest chunk of Federal materials R&D for public works comes from the Department of Defense, Army Corps of Engineers ($12 -!$13 million). The Corps' research program supports their responsibilities for construction and maintenance of water resource projects, dams, locks, waterways, ports, flood control projects, and military support facilities. The latter includes demonstration projects on energy conservation, building maintenance and repair, pavements, railroad maintenance, wastewater treatment, etc. The Corps' research is carried out at dedicated laboratories.

Other Federal research efforts include:

-- The Environmental Protection Agency funds R&D on drinking water quality and waste water treatment to support its program and regulatory responsibilities under the Safe Drinking Water Act and the Clean Water Act (less than $3 million in FY86);

-- The National Bureau of Standards conducts basic research intended to advance the fundamental understanding of materials characteristics, composition, and performance, as well as projects designed to develop standardized testing methods and equipment (around $2.4 million in FY86);

-- The National Science Foundation is a major source of funding for university and other private sector research in civil and chemical engineering, primarily under their programs related to structures and materials engineering (around $1 million);

-- The Bureau of Reclamation within the Department of the Interior researches the performance of cement and concrete in dams, canals, and line pipe; corrosion prevention for metals and concrete; and materials evaluation methods (around $1 million); and

-- The U.S. Forest Service is the central source of R&D in the US. for low-volume roads, which are a major part of the public roads system in rural areas (around **$200,000).**

Of the $18 million to $25 million spent annually on nonfederal materials R&D for public works, around 60 to 65 percent is related to highways, roads, and bridges. This is funded by State and local governments and regional transit agencies, as well as professional organizations and trade associations and their affiliated research foundations (e.g., the American Public Works Association or the Asphalt Institute). The major materials of interest in this research are cement and concrete, asphalt, steel and other structural and reinforcing materials, protective coatings, sand and gravel, surface treatments, de-icing substances, and geotextiles.[17]

Materials are an important cost component in sewer construction and maintenance, and the larger municipal sanitary districts are a significant source of funding for materials-related research for sewers and wastewater treatment systems. Other sponsors include professional and trade associations; engineering, consulting, and construction firms; and equipment and materials suppliers. Together, these groups spend approximately $3 to $5 million annually on wastewater R&D.

Another $1 million in nonfederal funds for materials R&D is devoted to water supply and treatment, primarily by local governments. The major concerns are: the mechanics of internal and external corrosion; the long-term performance of system materials for pipes (concrete, plastic, ceramics, masonry, iron, lead, steel, copper, etc.), pipe foundations and liners, and seals; maintenance requirements and technologies; methods of failure prediction; nondestructive evaluation techniques; and the effects of materials and water additives on water quality and SyS - tem durability.

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17 Geotextiles are woven and nonwover synthetic fabrics used in geotechnical applications (see chapter seven).

Finally, around $100,000 to $500,000 is spent annually on materials for water resource projects, waterways, and ports. The primary materials of interest here--concrete, stone, aggregate, pipes, coatings, geotextiles, membranes, liners, filters, and structural and reinforcing metals--are shared with other infrastructure types. Moreover, the primary responsibility for these large and costly projects rests with the Federal government.

HOW DOES DOMESTIC PUBLIC WORKS R&D COMPARE TO RESEARCH EFFORTS ABROAD?

Comparing infrastructure R&D expenditures in the United States to those abroad is difficult because the funding processes and programs are so different. Government research support in dollars is not markedly lower in the U.S. than abroad, but foreign governments play a much more active role in facilitating R&D and in bringing technical innovations into common practice.

Successful development of construction materials and technologies, and their incorporation in public works projects, require a favorable climate and appropriate incentives--both of which are lacking in the United States. Strong incentives are available in other countries to work the “bugs” out of theory and move new ideas to the marketplace. In both Japan and Europe, for example, the governments encourage innovation and development through tax incentives or matching funds, and through flexible bidding concepts. Government- industry co-funding assures a company’s willingness to commercialize results after research is completed. West Germany, for example, makes public grants available for the introduction of promising innovations into commercial markets. Also in Germany, special “linker” organizations facilitate innovation by expediting the flow of technical information and contributing to the stimulation of new ideas. The Japanese government also has agencies that coordinate research and disseminate information.

Also, relative to materials R&D, few U.S. universities have construction-related materials programs, and many civil engineers have little or no training in materials science. The opposite is true in Europe and Japan where specialty engineers receive cross-disciplinary training.[19]

An integrated approach to design, engineering, and construction would benefit infrastructure projects by identifying optimal technologies and materials for specific projects. An integrated approach also would help facilitate the transfer of information more readily. Although the U.S. is not presently pursuing this approach in any organized manner, other developed nations have established integrated research programs, such as Switzerland's efforts in concrete technology.[20]

WHAT ARE THE CONSTRAINTS ON EFFECTIVE R&D FOR PUBLIC WORKS IN THE U. S.?

The nature and effectiveness of R&D depend heavily on the environment within which new technologies and materials will be implemented. America's continuing inventive abilities are unquestionable, yet OTA found numerous institutional and economic factors that mitigate against increased R&D spending, make the available research dollars less cost-effective, and inhibit the adoption of advanced construction technologies and materials in public works projects. Over the long-term, this will mean increased construction, repair, and maintenance costs for public works agencies.

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18 Sherman Gee, Technology Transfer. Innovation and International Competitiveness, New York: J. Wiley & Sons, 1981.

19 Daniel W. Halpin, Technology in Architecture. Engineering. and Construction (Contractor Report to OTA, Tasks 1 and 2, Chapters 8 and 13, March 17, 1986.

20 Ibid., Chapter 8.

First, no national goals for public works infrastructure have been set, making it difficult to determine an optimum amount for Federal R& D expenditures. R&D has increased productivity in the past, and it is conventional wisdom that more R&D would improve productivity in the future. Within the public works context, however, productivity does not necessarily mean preparing materials or building structures more cheaply or with fewer workers, but may refer to the capacity or reliability of the system. Therefore, a redefinition of productivity goals for public works may help set public spending priorities. For example, some advances in materials and construction technologies, such as off-site road or bridge construction, simply move the time spent in materials preparation and handling to another location. However, off-site construction does shorten the time a road or bridge must be taken out of service for repairs, and thus increases the productivity of the transportation system markedly. This increase in productivity does not accrue large benefits to the industry, but it benefits the public tremendously. Thus it is probably appropriate that the public, through government expenditures, support R&D to increase the productivity of its vital systems.

Second, in order to make the limited R&D funding that is available more cost-effective, the research agenda needs to be targeted more directly to national needs. The initial step is determining what the most critical needs are. This is especially important for water supply and sewage and wastewater treatment systems, which traditionally have been local government responsibilities, and in which the R&D is more fragmented than other infrastructure types where the Federal role is larger. This would not require an exhaustive inventory of the condition of public works, but could be based on a survey of Federal, State and local agencies responsible for various types of public works about their most pressing problems. For example, the Strategic Highway Research Program (SHRP) began with a two-year planning and assessment process to further define gaps in current knowledge. A similar assessment for other infrastructure types (e.g., water supply, wastewater systems) could eliminate duplication in research efforts and facilitate coordination of projects, and thus get more “bang” out of the limited bucks available.

Innovation centers also can bean excellent means of targeting research. Examples highlighted in this survey include the NSF-funded Engineering Research Centers at Lehigh University, Carnegie-Mellon University, and the University of California at Santa Barbara; the Army Corps of Engineers' Construction Engineering Research Laboratory at the University of Illinois; the two newly-established, Army-funded Centers of Excellence in Building Construction Technology at the Massachusetts Institute of Technology and the University of Illinois; and the Air Force's Center for Cement Composite Materials, also at the University of Illinois. The SHRP also is an exemplary Federally-funded program in that it included transportation officials--the users--in the process of setting its goals and priorities. Moreover, it is the only program to focus specifically on one aspect of public works.

Although most of these programs are too new to have research results for evaluation, they share three important features:

-- they represent a specific allocation of resources over a period of time for research on construction technology and materials,

-- they require the research group to focus on advances in particular kinds of technologies and materials, and

-- they target areas of infrastructure R&D that have been identified as being likely to produce particular cost benefits and advanced or incremental technology improvements.

Third, a variety of factors combine to reduce private sector R&D. The industries that vie for public works contracts are sharply competitive and highly fragmented. Numerous small, local firms compete for every public works job. Moreover, foreign firms have begun to show an interest in the U.S. market, making the fight for market share increasingly ferocious. In this environment, and with the threat of merger or takeover hanging over even large companies, firms are forced to cut costs wherever possible to tide them over the irregular nature of public infrastructure spending. This economic climate does not support the large front end costs of developing innovations in construction technology and materials. Also important is the fact that public works construction materials generate a low rate of return and have a long payback period compared to other investments and, consequently, do not contribute much profit that can be allocated to R&D. Finally, there is a general belief in many industries that public works R&D is a governmental responsibility.

Fourth, government contracting and procurement policies place significant constraints on the amount of infrastructure R&D and the implementation of research results. The regulatory systems and procurement processes vary for different types of infrastructure. For example, highway construction standards vary according to the sponsoring government and anticipated traffic load. There is no guarantee that a generic innovation a company develops will be acceptable for all types of public works, or even all types of roads.

For materials, government agencies typically prescribe key project specifications (e.g., so many inches of a particular form of asphalt). Approval of new specifications or standards is a difficult process because it can be costly for public works suppliers and contractors to change their current materials and practices, and because testing, evaluation, and certification of new construction materials takes a long time. Standard test methods and specifications are vital for ensuring the quality of infrastructure materials and for facilitating the acceptance of new materials, but the development of good standards requires a lot of research. Federally-supported and other research to provide the basis for materials standards has been decreasing, which is a serious concern for materials innovation.[21]

Further, the contracting process itself is keyed to low bids. However, that process typically does not consider any potential long-term savings from reduced maintenance and repair costs. Because new materiaIs and construction methods often hav-e a higher capital cost than conventional ones, contractors are unlikely to propose their use for fear of losing the job. Also,

21 Personal communication t. OTA by Geoffrey Frohnsdorff, Chief, Building Materials Division, National Bureau of Standards Center for Building Technology, June 1987.

existing life-cycle costing methods are not perceived to be sufficiently accurate to support procurement based on long-term performance.

Fifth, governments and corporations also perceive a high level of risk in using new infrastructure materials and construction methods. People place a high premium on the reliability of public works. If advanced technologies or materials turn out to be less effective than anticipated, the political and economic costs of repair or replacement can be high. At the extreme, there is a risk of personal injury or property damage liability in the event of system failure.

Sixth, because of the number of agencies and organizations that conduct R&D, and the problem-oriented nature of much of the research, information flow among the researchers is limited. Trade and professional associations, journals, and conferences provide forums for the identification of research needs and priorities and the dissemination of research results. However, the processes for information exchange among and between these groups are haphazard. OTA found that, despite sporadic efforts at coordination, even Federal agencies do not share research results with each other on a systematic basis. Professional societies provide for interaction to the extent that individuals may be members of more than one group. Trade associations often do not have even that small link. Corporations often treat information on their research as proprietary and do not release it.

A related problem is the slow rate at which new or advanced materials and technology are accepted by government agencies, architects/engineers, and contractors for incorporation into public works projects. The lack of information exchange probably accounts for at least some of the snail's pace at which innovations are adopted in the United States. However, (3TA concludes that a significant increase in information dissemination would not necessarily speed the diffusion of R&D results without programs to address the economic and institutional barriers discussed previously.

AS a result of the limited funding of infrastructure materials R&D, inadequate information and technology transfer, and procurement practices and perceptions of risk, there are gaps in the R&D agenda. These take the form of mismatches between R&D projects and public works needs, and of inadequate research on particular materials and technologies and their value in individual projects, and on evaluating tradeoffs between construction, maintenance, repair, and replacement. These are all difficult and complex problems, and are not likely to be tackled by the private sector alone.

In terms of basic research, the gaps in infrastructure R&D are substantial. There is almost no research on, or expectation of profit from, research toward developing totally new methods of delivering transportation, water supply, and wastewater disposal services. There even is little basic research on new materials, such as a totally new material for building roads. Moreover, few agencies or organizations are researching the public works applications of advanced technologies and materials (e. g., ceramics and composites) that were not developed specifically for infrastructure.

OTA also identified numerous issues related to public works that need further exploration.[22] Among them are:

- Analysis of the interrelationships among design and construction and materials,
- Further study of the government procurement and contracting processes to determine the extent to which they pose barriers to technology diffusion,
- An in-depth look at the relative costs and benefits of design versus performance standards in public works procurement,
- Development of certification standards for acceptance of new construction materials and technologies to facilitate their use in public works,
- Identification of legal issues related to liability and shared risk,
- Development of improved life-cycle costing methods for use in public works procurement,
- Analysis of the tradeoffs among expenditures for maintenance versus repair versus new construction or replacement and how those trade-offs might be affected by the capital and maintenance costs of new technologies and materials,

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22 Specific research needs for construction technologies and for materials may be found in chapters five and eleven, respectively.

-- Analysis of means for facilitating the international exchange of information about construction technologies and materials R&D for all types of public works projects, and

-- Analysis of the return on investment for private sector R&D on infrastructure construction technologies and materials.

PART TWO:

CONSTRUCTION RESEARCH AND DEVELOPMENT FOR THE NATION'S PUBLIC WORKS

CONSTRUCTION RESEARCH AND DEVELOPMENT

FOR THE NATION'S PUBLIC WORKS

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CHAPTER TWO

FEDERALLY SUPPORTED RESEARCH AND DEVELOPMENT ON PUBLIC WORKS INFRASTRUCTURE CONSTRUCTION

The Nation's transportation and water resources and wastewater treatment systems are essential to the physical and economic well-being of the country. In general, public works infrastructure in the United States has stood up well, permitting us to take the smooth and safe functioning of these systems for granted until such unexpected tragedies as the collapse of the New York Thruway bridge earlier this year, We are currently faced with the need to maintain, repair, and reconstruct the existing systems to make them endure, or to develop new technologies that will enable us to replace them with more efficient and effective systems. To increase our understanding of how to meet these challenges, the Senate Committee on Environment and Public Works asked the Office of Technology Assessment (OTA) to address questions related to the magnitude and effectiveness of R&D spending in the public and private sectors. OTA has addressed these questions through a two-part staff paper, with this part focusing on infrastructure construction technologies R&D and the part following on infrastructure materials R&D.

BACKGROUND: PUBLIC WORKS INFRASTRUCTURE CONSTRUCTION

More than one million companies participate in the $400 billion construction market in the United States; public works construction accounts for 25 percent of this market. While only 1,000 of the construction companies play a major role in public works construction, even they are likely to concentrate on particular types of facilities, such as waste w at e r systems or highways and bridges, rather than on the spectrum of public works. Research and Development (R&D) funding is splintered among the numerous Federal agencies, universities, and private companies. Most of these groups do not coordinate R&D projects with other groups.[1] The environment for public works infrastructure R&D is fragmented and disparate, and the level of R&D support in each fragment is small. Such a situation speaks to the overwhelming need for addressing the multitude of institutional, economic, and industrial barriers to moving technological innovations into widespread use and enabling the Nation to enjoy the benefits.

METHODOLOGY

Early in its investigation, OTA found that no comprehensive database existed for evaluating federally or privately funded research and development (R&D) undertaken in the United States to advance construction technologies for public works infrastructure.[2] Compiling such a database thus became the first step in obtaining a "snapshot" view of federally-funded research that the administering agencies consider to be R&D on infrastructure technologies.

Five Federal agencies and one non-Federal organization relying on Federal funds were identified as having principal responsibilities and activities for public works infrastructure construction research. The five Federal agencies include the U.S. Army Corps of Engineers, the Bureau of Reclamation of the U.S. Department of the Interior, the Federal Highway Administration (FHWA) of the U.S. Department of Transportation, and the National Bureau of Standards (NBS) of the U.S. Department of Commerce, and the National Science Foundation (NSF). The non-Federal organization is the Transportation Research Board (TRB), part of the National Research Council of the National Academy of Sciences. The Environmental Protection Agency (EPA) also funds research related to materials (see chapter eight).

[1] Henry L. Michel, President and CEO, Parsons, Brinckerhoff Inc,. personal communication, May 18, 1987, and John C. Richards, M.W. Kellogg Company, personal communication, May 24, 1987.

[2] Public works infrastructure construction technologies, as used throughout this study, refers to technologies applicable to reconstruction, maintenance, and repair, as well as new construction.

OTA also contacted other Federal agencies, including the Naval Facilities Engineering Command and the Tennessee Valley Authority, and they did provide information. However, these agencies were omitted from analysis because their research on infrastructure construction was relatively small in an overall national view. Other agencies not contacted in the limited time available about their construction R&D programs include the Forest Service in the Department of Agriculture, and the Urban Mass Transportation Administration in the U.S. Department of Transportation.

In addition to creating a database to cover the above organizations, OTA investigated four other organizations: one new Federal program and new, federally-funded programs at three universities. These programs are special cases, important because of their possible future impacts and because they are examples of a different approach to infrastructure R&D and related research in the United States.

In assembling these data OTA found that federally-funded research for public works infrastructure construction is fragmented and widely dispersed within as well as outside the Federal Government. Moreover, because no central clearinghouse exists for recording what and where federally-funded infrastructure research is being done,[3] creating a comprehensive and exhaustive report was not possible. However, we are confident that we have accurately captured the bulk of Federal spending, and that our sources are representative of the allocation of Federal dollars.

The six organizations named above were requested to provide short descriptions and funding amounts of all infrastructure R&D projects completed or ongoing in fiscal years 1985, 1986, and 1987. Three years of expenditures were requested to determine whether significant recent upward or downward trends were apparent. OTA did not find such trends over the past

[3] A coordinating committee composed of the Corps of Engineers, Bureau of Reclamation, the Tennessee Valley Authority, and the Bureau of Indian Affairs does meet to discuss research programs and coordinate research among these agencies.

three years; however the past ten years, Federal research dollars have declined substantially for the types of research of interest here. The organizations were asked to list the projects applying to each infrastructure type,[4] and to include all projects they considered R&D. For doubtful cases, they were asked to include rather than omit projects.

In the absence of other reliable and comprehensive sources, OTA relied entirely on the information furnished by the six organizations. Then, using the project descriptions, OTA classified each of the projects as belonging to one of the categories defined below for each infrastructure type for new construction, reconstruction or repair, or routine maintenance. In cases of mixed activities and uncertainty about what projects consisted of, projects were assigned to their probable classification nearest to advanced R&D. A few projects reported by Federal agencies in their budget numbers were omitted by OTA, because they did not appear germane. To avoid skewed conclusions from an atypical year, OTA aggregated the data to obtain a combined 3-fiscal year snapshot.

PROJECT CLASSIFICATION

The categories of the project classification include advanced and incremental R&D; basic research for R&D; information to improve design, evaluations, and needs analysis; and other research.

Advanced and Incremental R&D

Advanced and incremental R&D may be defined in two ways. The first is on a general or conceptual basis, distinguishing evolutionary from revolutionary changes in technology. Professor Fred Moavenzadeh, Director of the Center for Construction Research and Education at Massachusetts Institute of Technology (M.l.T.), states this best:[5]

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[4] Dams, water supply systems, waste water treatment, highways, bridges, tunnels, and waterways.

[5] Fred Moavenzadeh, “Research Needs in Transportation Facilities: Guideway Technology and Materials Research,” Transportation Research, vol. 19A, No. 5/6, 1985, p. 502.

Incremental vs. quantum change. There are two types of change with respect to technology . . . One is a gradual change in which improvements and innovations are continually being made to an existing material, process, piece of machinery. . . . The collective impact of these improvements is progress in the quality or costs . . . this process of gradual improvement must be continued. The second type of change is much more dramatic: it involves a radical realignment of how things are done or what product results, and it is pervasive in that its substantial benefits in costs and quality convince entire markets of its acceptability. Some examples of this type of change include the replacement of animal-powered road construction gangs with mechanized crews in the 1920s, the introduction of tunnel-boring machines for transit construction, and the use of computers for construction . . . The impact of these types of changes is to make possible what would formerly have been unrealistic or not affordable.

The second way to distinguish the two types of R&D is to identify the areas that experts agree have potential for great advances, Improvements in the remaining areas belong in the incremental category. OTA found agreement among the sources consulted that the following areas should be considered advanced R&D for infrastructure construction technology:

- Robotics and automation in onsite construction.
- Computer applications (including knowledge-based systems and artificial intelligence) linking and improving entire processes of engineering and design, construction management, and subsequent facilities maintenance and management.
- Advanced materials, especially in the area of so-called engineered, or exotic, materials.

Examples of advanced R&D include: the NBS project on ultra-high strength concrete, applicable to all seven infrastructure types, will apply material science concepts toward ultra-high-strength concrete (compressive strength greater than 30,000 psi). The project will also investigate the feasibility of casting and of developing ultra-high-strength concrete by high -pressure compaction. A series of high-strength concretes will be designed and the factors limiting their strength will be identified. A second example is the NSF project on fiber reinforced cementitious composites technology, applicable to highways. This project will investigate the addition of small fibers to the concrete in an effort to make concrete last longer for pavements. Some fibers under consideration are: steel, glass, nylon, carbon, kevlar, and polyethylene. OTA did not find really good examples of advanced R&D in construction technologies among the Federal programs. Furthermore, while these examples of materials projects represent advanced research in the context of public works, they are not real examples of advanced materials research such as that carried out in the aerospace industries.

An example of incremental R&D is the Corps of Engineers program on repair, evaluation, maintenance, and rehabilitation, applicable to waterways and ports. In this program the Corps will “identify and where necessary develop effective and affordable technology for maintaining and where possible extending the service life of Corps of Engineers Civil Works Projects.” Another example is the FHWA project on bridge rehabilitation technology, which will focus on developing nondestructive techniques for inspecting highway bridge members during fabrication and service.

Basic Research for R&D

Basic research for R&D encompasses projects that clearly aim at new or improved knowledge or techniques that are useful or essential for infrastructure construction technology development. This category does not include research on applications. In this category are the many projects of the NBS that meet the criteria of research but not the development of infrastructure R&D, especially projects associated with advanced R&D. An example of basic research for R&D is the NBS project on building data protocols, applicable to all seven infrastructure types. According to the NBS, the project’s goal is to establish the technical basis for information exchange standards because “rational techniques for describing building practices and elements are needed to establish the technical basis for information interchange standards that will support computer integration.”

Research to Improve Desire, Evaluations, and Needs Analyses

Projects that result in choices or applications among known and available technologies of infrastructure construction are considered research to improve design, evaluation, and needs analyses. Such projects are related to infrastructure construction technology in important ways, but the research done is not developmental and does not advance these technologies. Instead, most of the projects aim at knowledge or techniques that manipulate existing and available construction technologies to obtain more appropriate, more efficient, more cost-effective, or better quality infrastructure results. Some projects aim to improve methods of analyzing when infrastructure work is needed for safety or other technical reasons. Projects in this category may include R&D, such as for nondestructive testing important for evaluations, or for expert computer systems or other computer applications for design, evaluations, or needs analyses, but they do not lead to advanced infrastructure construction technologies.

One example of such research is the Corps of Engineers program on structural engineering, applicable to dams. This program will improve (1) structural engineering practices in Computer Aided Structural Engineering (CASE); (2) the strength design of conduits, floating breakwaters, soil-structure interactions; (3) the seismic response of concrete dams; and (4) the structural behavior of sheet piles. Of particular importance will be case studies that develop new or adapt existing computer programs for design and analysis. A second example is the FHWA project on large truck safety, applicable to highways, Goals of this project are to determine the impact of increases in allowable truck size and weight limits on highway safety; to identify truck safety problems related to highway design or operation; and to develop cost-effective solutions to highway-related truck safety problems.

Other Research

"Other research" is a miscellaneous category of projects that are infrastructure-related but do not focus on construction technologies. The category includes management systems or other administration studies, feasibility studies, contract acceptance criteria studies, demonstrations, transfer or dissemination efforts, conferences and workshops, and technical assistance. An example of such research is the Corps of Engineers program on environmental impact, applicable to waterways, including ports. The program was established to develop, verify, and document user-oriented impact prediction and assessment techniques, to document and quantify environmental effects; and to develop practical engineering and resource management strategies. A second example is the FHWA project on safety and traffic control devices, applicable to highways. This project supports the Manual on Uniform Traffic Control Devices by providing R&D for signs, signals, and markings to establish and implement safety standards and to improve traffic control devices.

FEDERAL AGENCY EXPENDITURES

Five Federal agencies have responsibility for the majority of infrastructure construction R&D expenditures. EPA expenditures relate primarily to materials used in water quality and supply infrastructure (see chapter eight).

The Corm of Engineers

The Army Corps of Engineers has a military research program that focuses on buildings for the military and a civilian program. OTA examined only the latter for this study. During the three fiscal years examined for this study, the Corps of Engineers spent $96.6 million (from funds appropriated to the Corps) for infrastructure research on dams, water supply and sewer systems, waterways, and highway s-- by far the largest total amount spent for such purposes by any of the Federal agencies or non-Federal organizations (see table 2- 1). (The laboratories administered by the Corps also do reimbursable work for other Federal agencies, so total Corps spending was substantially greater than the directly appropriated funds.) The Corps spent more appropriated funds on four infrastructure types --dams, water supply systems, sewer systems, and waterways --than did any of the other organizations. Nevertheless, table 2-1 shows that Corps spending was highly concentrated. More than three-quarters of the $96,6 million was spent on waterways infrastructure research.

TABLE 2-1.-Corps of Engineers
FY 1985-87 (3-Years) Spending
(in thousands of dollars)

	For Construction Technologies Advanced R&D	Incremental R&D	Research to Improve Design, Evaluations, and/or Needs Analyses	Other Research	Total
Dams	$0	$ 1,025	$ 5,015	$ 1,410	$ 7,450
Water Supply Systems	o	0	2,565	4,370[a]	6,935
Waterway5	o	23,350	26,968	23,339[a]	73,657
Mi l itary Spending with Civil Applic~tion>:					
Sewer Sy5tems	o	2,517	0	385	2,902
Highways	0	1,351	1;393	3,629	6,373
IOIAL	$0	$28,243	$35,596[b]	$32,758[b]	$96,597[b]
PERCENT DISIRItlUlION	O.oj	29.2%	36.8%	34.0%	loo.ox

[a]Includes some bd51L I__t?Sf3df_Ch u~eful for R&D of constructive technologies.

[b]Fígure omits dupl cate spending ot projects relevant to more than one infrastructure type.

SOURCE: Office of Technology Assessment.

The Corps did no advanced R&D for any of the infrastructure types. Incremental R&D received 29 percent of Corps infrastructure research spending. Research adaptations of known and available technologies for design, evaluations, or needs analyses received about two-thirds--the largest share of Corps spending. "Other research" received a little more than one-third of Corps infrastructure research spending.

Also important is the proportion of the Corps' designated R&D spending that went for infrastructure research (see table 2-2). Corps-appropriated funds designated for R&D amounted to $263.7 million for the three fiscal years. Of this total, 36 percent was spent for infrastructure research, and OTA concludes that only about 10.6 percent can be considered spending on R&D to improve infrastructure construction technologies.

During the three fiscal years, the Corps spent $12.9 billion on actual construction. Table 2-2 shows that the Corps spent less than one percent of this sum on infrastructure research and 0.004 percent on R&D to improve infrastructure construction technologies.

Bureau of Reclamation

The Bureau of Reclamation spent $7.4 million during the three fiscal years for research on five infrastructure types--dams, water supply systems, bridges, tunnels, and waterways (see table 2-3). More than one-half of this total (57 percent) was spent for research on dams.

Like the Corps of Engineers, the Bureau did no advanced R&D for any of the infrastructure types. Table 2-3 shows that less than five percent of the bureau's spending for infrastructure research was devoted to incremental R&D. The largest proportion (59 percent) was spent for design, evaluations, and needs analyses research relying on known and available infrastructure construction technologies. The remainder (37 percent) was spent for other research.

The Bureau's line-item research programs were funded at a total of $33.3 million for the three fiscal years (see table 2-4). Spending for infrastructure research amounted to approximately 22 percent of this total, and spending for R&D on construction technologies amounted to less than one percent. Table 2-4 shows that the Bureau's spending for R&D on

Table 2-2-Corps of Engineers Comparisons
FY 1985-87 (3-Years)

	Designated as R&D Dollars (in millions)	Designated as R&D Percent	Construction Dollars (in millions)	Construction Percent[a]
Total Spending	$263.7	100.0%	$12,853.7	100.0%
Spending for Research on Included Infrastructure Types:				
On Construction Technologies:				
Advanced R&D	$0	0.0%		0.0%
Incremental R&D	28.2	10.6		0.2
Research to Improve Designs, Evaluations, and/or Needs Analyses	35.6	13.3		003
Other Research	33.8	12.7	.	0.3
Total Research	$94.8	36.6%		0.8%

Note: Figure include both civil and military spending and may not add because of rounding.

[a]Spending for research on included infrastructure types as percentages of the totals of spending in the 3 fiscal years.

SOURCE: Office of Technology Assessment.

Table 2-3. -i3ureau of Reclamation
FY 1985-87 (3-YEARS) Spending
(in thousands of dollars)

	For Construction Technologies Adv~nced R&D	Incremental R&D	Research to Improve Design, Evaluations, And/or Needs Analyses	Other Research	Total
Dams	$0	$330	$2,714	$1,128	$4,172
Walter Supp y Sys ems	o	0	430	55	485
Wdterwayb	0	0	61	0	61
Highways al d Oth r Ro~dwdys	o	0	60	0	60
Bridges	0	0	1,126	1 ,509[a]	2,635
TOTAL	$0	$330	$4,331[b]	$2,692[b]	$7,353[b]
PERCENT DISTRIBUTION	O.ox	4.5$	58.9%	36.6%	100.0%

‘Includes some basic research useful for R&D of constructive technologies.

[b]Figure omits duplicate spending of projects relevant to more than one infrastructure.

SOURCE: Office of Technology Assessment.

Table 2-4.-9ureau of Reclamation Comparisons
FY 1985-87 (3-Years) Spending

	Designated as Research		Total Agency Budgets		Construction	
	Dollars (in millions)	Percent[a]	Dollars (in millions)	Percent[a]	Dollars (in millions)	Percent[a]
Total Spending	S33.3	loo.%	$2,965.8	100.0$	$1 ,976.9	100.0%
Spending for Research on Included Infrastructure Types:						
On Construction Technologies						
Advanced R&D)	$0.0	0.0%		0.0%		0.0%
Incremental R&D	.3	0.8		0.01		0.02
Research to Improve Designs, Evaluations and/or Needs Analyses	4.3	11.0		0.14		0.2
Other Research	2.7	6.9		0.09		0.1
Total Research	$7.4	22.1%		0.3%		0.4%

Note: Figures may not add because of rounding.

‘Spending for research on included infrastructure types as percentages of the totals of spending in the 3 fiscal years.

[b]The f gure shown is for budget outlays.

SOURCE Office of Technology Assessment.

infrastructure construction technologies amounted to 0.01 one percent of the Bureau's total budgets for the three fiscal years and **0.02** percent of the Bureau's spending on actual construction.

Federal Hihway Aministration

During the three fiscal years, FHWA spent $32.0 million on infrastructure research on highways and bridges. As might be expected, FHWA spent the largest proportion (77 percent) of this total on highway research and the remaining proportion on bridge research (see table 2-5). FHWA expenditures were the largest amounts spent by any of the organizations on each of these two infrastructure types.

Like the Corps of Engineers and the Bureau of Reclamation, FHWA did no advanced R&D. Incremental R&D received about one-quarter (24 percent) of FHWA's spending for infrastructure research. Table 2-5 shows that the largest proportion (45 percent) of FHWA'S spending for infrastructure research was devoted to design, evaluations, or needs analyses contributing to uses but not advances in known and available infrastructure construction technologies. Other research not considered infrastructure construction researcher development received nearly 31 percent of the FHWA'S infrastructure research spending.

FHWA spending identified as RDT (Research, Development, and Technology) amounted to a total of $59,2 million for the three fiscal years (see table 2-6). Spending for infrastructure research accounted for more than half (54 percent) of this total. However, spending for R&D to improve construction technologies amounted to only 13 percent of the RDT spending and 1.3 percent of FHWA'S budget total for the three fiscal years.

It is estimated that total public sector spending in the United States on capital outlays for construction of highways and bridges during the three fiscal years amounted to S74.6 billion (see table 2-6). FHWA's spending for R& Dto advance construction technologies (!$7,7 million) amounted to 0.01 percent of this capital outlay total.

Table 2-5.–Federal Highway Administration
FY 1985-87 (3-Years) Spending
(in thousands of dollars)

	For Construction Technologies Advanced R&D	Incremental R&D	Research to Improve Design, Evaluations, And/or Needs Analyses	Other Research	TOTAL
Highways	$0	$5,264	$9,635	$9,777	$24,676
Bridges	o	2,469	4,887	0	7,356
IOIAL	$0	$7,733	$14,522	$9,777	$32,032
PERCENT DISrRIEkJIION	O.oi	24.?%	45.3%	30.5%	100.0%

x Excludes HP&R pfogr~m re>earch by St~tes.

SOURCE: Office of Technology Assessment.

lable 2-6.–Federal Highway Administrations Comparisons
FY 1985-87 (3-Years) Spending

	Designated as Research Development and Technology		Total Agency Budgets		Total Public Sector Spending in the U.S. on Capital Outlays for Construction of Highways and Bridges	
	Dollars (in mi II ions)	Percent[a]	Dollars (in millions)	Percent[a]	Dollars (in mill ions)	Percent[a]
Tot~l Spending	$59.2	100.0%	$604.0	100.0%	$74,600.0	loo.og
Spending for Re>c~rch on Included Infrastructure Tv~es:						
On Construction technologies:						
Advanced R&D	$ 0	0.0%		0.0%		O.ox
Incremental t&!D	7.7	13.0%		1.3%		0.01$
Research to Improve Designs, Evaluations, and/or Needs Analy5es	14.5	24.5%		2.4%		0.02%
Other Resedrch	9.8	16.6%		1.6%		0.01%
Total Rese~rch	$32.0	54.1%		5.3$		o.04g

Note Figures mtiy not add because of rounding.

* Exc udes Highwdy Pl~nning ~nd Research (HPtiR) program research by States.

[a]Spending for tk~ecrrch on Included Intrd~tructure Types as percentages of the totals of spending in the 3 fiscdl years.

SOURCE: Office of Technology Assessment.

National Bureau of Standards

NBS spent $10.3 million during the three fiscal years on research relevant to the seven infrastructure types, ranking third among the organizations in amount of total spending for infrastructure research (see table 2-7). NBS spent more than any other organization on research relevant to tunnels.

Unlike the other organizations and consistent with the NBS's emphasis on researching basic questions, a very large proportion (93 percent) of the NBS's infrastructure research spending was relevant to more than one infrastructure type and close to three-quarters (73 percent) was relevant to all seven infrastructure types.

The largest proportion (46 percent) of the Bureau's infrastructure research spending went to projects classified as design, evaluations, and/or needs analyses. "Other research" accounted for 29 percent. Construction technologies research--for advanced R&D, incremental R&D, and basic research for R&kD--amounted to 25 percent of the Bureau's infrastructure research spending. Basic research for R&D received most of this spending.

Spending for infrastructure research accounted for only 1.6 percent of the National Bureau of Standards' total budget amount of $645.2 million for the three fiscal years. Table 2-8 also shows that NBS spending relevant to infrastructure construction technologies amounted to less than half of one percent of the total of the agency's budgets for the three fiscal years.

National Science Foundation

NSF spent $6.5 million for research on the seven infrastructure types (see table 2-9). This ranked NSF fifth among the six organizations in total spending during the three fiscal years. NSF spending was distributed among six of the seven infrastructure types (no research on tunnels was funded). Nevertheless, research on highways and bridges received most of NSF's attention, accounting for 86 percent of its infrastructure research spending.

As was true of the other organizations, the largest proportion (51 percent) of NSF's infrastructure research spending went to projects classified as design, evaluations, and/or needs

Table 2-7.-National hreau of Standards
FY 1985-87 (3-Years) Spending
(in thousands of dollars)

	For Construction Technologies Advanced R&D	Incremental R&D	Basic Research For R&D	Research to Improve Design, Evaluations, and/or Needs Analyses	Other Research	Total
All 7 Infrastructure Types	$330	$396	$1,867	$3,063	$1,824	$7,480
Dams, Walter Supply dnd Sewer Systems, Tunnels, dlld Waterways only	0	0	0	225	0	255
Highways, Bridge>, Tunnels, dnd kftJtt3rWciy5 only	0	0	0	o	275	275
Highwdys, Bridges, dnd Tunnels only	0	0	o	1,204	0	1,204
Water Supply and S~wer Systems only	0	o	0	108	210	318
Bridges only	0	0	0	0	575	575
Waterways only	0	0	0	100	60	160
TOIAL	$330	S396	S1,867	S4,730	S2,944	S10,267
PERCENT DISTRIBUTION	3.2%	3.9%	18.2%	46.0%	28.7%	100.0%

SOURCE: Office ot lechllology Assessment.

Table 2-8.-NationaL Bureau of Standards Comparisons
FY 1985-87 (3-Years) Spending

	Dollars (in millions)	Percent[a]
Total Agency Budget[b]	$645.2	100.0%
Soendinz for Research on Included Infrastructure Types:		
On Construction Technologies:		
Advanced R&D	$ .3	0.05%
Incremental R&D	.4	0.06
Basic Research	1.9	0.3
Research to Improve Designs, Evaluations, and/or Needs Analyses	4.7	0.7
Other Research	2.9	0.5
Total Research	$10.3	1.6%

Notes: Figures may not add because of rounding.

[a] Spending for research on included infrastructure types as percentages of the total of agency's budgets for the 3 fiscal years.

b Includes appropriated 'Unds (56.7%), transfer from other Federal agencies (34.5%), and reimbursable funds received mainly from non-Federal sources (8.8%).

SOURCE: Office of Technology Assessment.

Table 2-9.-National Science Foundation FY 1985-87 (3-Years) Spending (in thousands of dollars)

	For Construction Technologies: Advanced RAD	For Construction Technologies: Incremental RAD	Research to Improve Design, Evaluations, and/or Needs Analyses	Other Research	Total
Dams	$0	$0	$0	$76	S76
Walter Supply Sybtemh	o	0	229	263[a]	492
Sewer Systems	0	0	0	132	132
Highwdys	273	829	972	199[a]	2,273
Bridges	67	611	1,914	727[a]	3,319
Waterways	o	0	198	0	198
TOTAL	$340	$1,440	$3,313	$1,397	$6,490
PERCENT DISTRIBUTION	5.2%	22.2$	51.1%	21.5X	100.0$

[a]Includes some bdsic research useful for RtID of construction technologies.

SOURCE: Office of Technology Assessment.

analyses. The second largest spending category R&D for construction technologies accounted for 27 percent of NSF's infrastructure research spending, although all of NSF's R&D projects pertained to highways and bridges. Other research ranked last, but accounted for nearly 22 percent of NSF's infrastructure research spending.

NSF's budgets totaled !$4.6 billion for the three fiscal years (see table 2-10). NSF's spending of !36.5 million for infrastructure research amounted to 0.1 percent of this total budget amount.

ORGANIZATIONS USING FEDERAL FUNDS

Transportation Research Board

During the three fiscal years, TRB spent $5.2 million for infrastructure research in projects of the National Cooperative Highway Research Program (see table 2-11). Spending was about equally divided for highways and bridges.

Research to improve design, evaluations, and needs analyses received close to two-thirds (63.5 percent) of the program's infrastructure research spending. The second largest spending category was for other research. Incremental R&D for construction technologies received only three percent of the program's infrastructure research spending. No funds were spent for advanced R&D on construction technologies.

Table 2-12 shows that spending for infrastructure research amounted to less than half (44 percent) of the estimated $11.7 million spent for all research in the Cooperative Highway Research Program during the three fiscal years. Spending for R&D to advance construction technologies amounted to less than two percent.

SDecial Cases and Examr)les

Several new infrastructure research programs are briefly described below. The programs are part of the snapshot of current infrastructure research activity because of what R&D they may accomplish in the future and because they are examples of a different approach to infra-

Table 2-10-National Science Foundation
FY 1985-87 (3-Years) Spending

	Dollars (in millions	Percent[a]
Total Agency Budget[b]	$4,619.0	100.0%
Spending for Research on Included Infrastructure Types:		
On Construction Technologies:		
Advanced R&D	$.3	0.01%
Incremental R&D	1.4	0.03
Research to Improve Designs, Evaluations, and/or Needs Analyses	3.3	0.07
Other Researc	1.4	0.03
Total Research	$6.5	0.1%

Notes: Figures may not add because of rounding.

[a]Spending for research on included infrastructure types as percentages of the total of the agency's budget for 3 fiscal years.

bExpenditures estimated from allOCatiOIl figures*

SOURCE: Office of Technology Assessment.

Iable 2-il.–Transportation Research Board
Fy Ig85-87 (3-Years) Spending
(in thousands of dollars)

	For Construction Technologies Advanced R&D	Incremental R&D	Research to Improve Design, Evaluations, and/or Needs Analyses	Other Research	Total
Highways	$0	$162	$2,252	$224 [a]	$2,638
Bridges	o	162	1,020	1,558 [a]	2,740
IOTAL	$0	$162 [b]	$3,272	$1,721 [b]	$5,155 [b]
PERCENT DISTRIBUTION	O.oi	3.1%	63.5X	33.4%	100.0$

‘Includes some b~s c resedrch ubeful tor R&l) of construction technologies.

[b]Figure omits dupl cdte spending of projects relevant to both highways and bridges.

SOURCE: Office of Technology Assessment.

Table 2-12.-Transportation Research Board
FY 1985-87 (3-Years) Spending

	Dollars (in millions)	Percent[a]
Total Estimated Research Expenditures[b]	$11.7	100.0%
Spending for Research on Included Infrastructure Types:		
On Construction Technologies:		
Advanced R&D	$ 0	0.0%
Incremental R&D	.2	1.7
Research to Improve Designs, Evaluations, and/or Needs Analyses	3.3	27.6
Other Research	1.8	15.1
Total Research	$5.2	44.4%

Notes: Figures shown are for the National Cooperative Highway Research Program. Figures do not include funds allocated in fiscal years prior to FY 1985, but spent in FY 1985-87, and may not add because of rounding.

a Spending for research on included infrastructure types as percentages of the total of estimated research expenditures for the 3 fiscal years.

b Expenditures estimated from allocation figures.

SOURCE: Office of Technology Assessment.

structure research in the United States. Although only one applies directly to public works, the programs share three features. They specifically allocate resources for infrastructure research. They fix responsibility for technology advances, including improvements in infrastructure construction technologies. They "target" key areas of infrastructure R&D that have been identified as those that: (a) are likely to produce particular cost benefits because of current use or particular needs or (b) have the potential for the greatest technology advances.

Strategic Highwav Research Program. Four principal characteristics of the 5-year Strategic Highway Research Program (SHRP), recently underway after approval by Congress several years ago, merit attention. First, the program focuses specifically on two infrastructure types--highways and bridges--and it is the largest, indeed the only, major independent research program outside a Federal agency with an exclusive emphasis on public works. Second, the program relates spending for infrastructure research to Federal spending for new construction, reconstruction, and repair. Providing a stable income level, 0.25 percent of State-apportioned Federal monies will fund the program at $150 million over five years. Third, the program targets six priority areas for research--asphalt, long-term pavement performance, maintenance cost effectiveness, protection of concrete bridge components, cement and concrete in highway pavements and structures, and chemical control of snow and ice on highways.[6] Fourth and finally, the SHRP agenda was determined in cooperation with the users--public transportation officials. Moreover, a strong effort was made to build broad support for the program among construction trade associations.[7]

SHRP must be considered an immediately applicable technology effort. In the terms previously used, the priority areas include incremental R&D on construction technologies; re-

[6] Damian Kulagh, Executive Director, SHRP, persona communication, April 1987.

[7] Richard Mudge, Vice President, Apogee Research, Inc., personal communication, May 27, 1987.

search to improve design, evaluations, and needs analyses; and other research not considered infrastructure construction research or development. None of the work appears to be advanced R&D for construction technologies, and much of the research is related to materials. For a more complete description of the organization and structuring of SHRP see chapter eight.

Engineering Research Center for Advanced Technology for Large Structural Systems, Lehigh University. NSF awarded the Engineering Research Center for Advanced Technology for Large Structural Systems (ATLSS) to Lehigh University in 1986. There are currently eleven NSF Engineering Research Centers in the United States designated to do advanced research in different engineering areas (three more centers are expected to be selected by NSF this year). The ATLSS center at Lehigh University will focus on research to assist the construction industries.

NSF funding for ATLSS amounted to $1.4 million during the first year and will total $10.4 million over the first five years. Additional initial funding comes from other sources. The State of Pennsylvania contributed $5 million for facilities; $2 million of this was contributed by Pennsylvania's Ben Franklin Partnership Program, which will contribute an additional $1 million over the next five years.

The research plan for ATLSS identifies three "cross-disciplinary thrust areas''--advances in design concepts, innovation in fabrication and construction, and in-service monitoring and protection. Topics identified for investigation include new and better design concepts, new computer tools, high-strength and high-value materials, robotics and automation, and new sensors, coatings, and protective systems. Initial projects on which ATLSS proposed to start work in 1986 included computer-controlled testing, a large-scale multidirectional loading facility for testing, advances in connection technology, a knowledge base for steel structures, development of construction robotics technology, a knowledge-based system for designer-fabricator interface, a knowledge-based system for fatigue and fracture evaluation of steel bridges, and diagnostic corrosion sensors.

ATLSS'S purposes include all types of construction--buildings as well as infrastructure. While this is a broad focus aimed at all the construction industries, it is clear that various research will be done relevant to the infrastructure types included in this investigation. Based on the descriptions available on ATLSS'S program, advanced as well as incremental R&D on infrastructure construction technologies as well as the other types of infrastructure research can be expected to be included. However, it is important to note that no specific emphasis on public works has been stated for this center. Three other university centers funded by the NSF may also have some spin-off for construction technologies. The are the Engineering Research Center for Robotics Systems in Microelectronics at the University of California at Santa Barbara, the Center for Engineering Design at Carnegie-Mellon University, and the Earthquake Engineering Center at SUNY in Buffalo.

Centers for Advanced Construction Technology at M.I.T, and the University of Illinois. In 1986, as part of its University Research Initiative Program, the U.S. Army selected and funded from its R&D budget two university centers for advanced construction technology. One is associated with the Center for Construction Research and Education at M.I.T. and the other with the Department of Civil Engineering at the University of Illinois at Urbana-Champaign. Each of the two centers is budgeted at $15 million for a 5-year period ($9 million was authorized for the first three years including an FY 1987 appropriation of $3 million and an option of $6 million more for the remaining two years).

The research program at M.I.T. has two major components, the first, labeled "Technology," and the second, called "Methodology." The Technology component will focus on three research areas--materials and structures, computer applications, and automation and robotics. The Methodology component will focus on two research areas--performance, reliability and maintainability (as one area), and life cycle costing.

The University of Illinois program defines five areas of research--construction materials and lightweight structures, nondestructive test and evaluation techniques, explosion effects, computer-based systems, and special technologies for constructed works.

The research programs of the two centers, including preliminary project descriptions, provide the best descriptions found of areas suitable for advanced research and advanced R&D, both on construction technologies and for design and evaluations of construction. The Army considers the programs to be basic or advanced research, not development as such. The programs appear to be aimed at all types of construction and all major associated activities, but have particular relevance for infrastructure construction. While the work is directed at Army responsibilities and military applications, most of the knowledge and technology advances expected to be gained is likely to have civil applications. However, again the emphasis of these programs is not on public works infrastructure.

university Transportation Centers. The 1987 Federal highway bill contains a section authorizing grants to cover 50 percent of the cost of establishing and operating transportation centers in each of the ten Federal regions in the Standard Federal Regional Boundary System.[8] Infrastructure research is included in the types of activities for the centers. The same program was launched in previous years, but was not implemented because funds were not available.

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[8] See "Surface Transportation and Uniform Relocation Assistance Act of 1987, Conference Report," House of Representatives, Report 100-27 (March 17, 1987), Section 314.

CHAPTER THREE

CONSTRUCTION RESEARCH AND DEVELOPMENT IN THE PRIVATE SECTOR

Three major types of private sector firms are involved with infrastructure construction: construction firms, manufacturers of construction equipment, and producers of construction material. In addition, certain firms manufacture equipment used in construction, such as laser-based construction alignment equipment and data processing equipment for use at construction sites. However this equipment probably adds comparatively little to the overall cost of construction. This chapter describes infrastructure construction-related R&D programs of representative firms from each of the three major categories and summarizes other efforts made by these firms to encourage technological innovation and transfer of information about innovative ideas within the firm. The information is based primarily on interviews with knowledgeable individuals in the firms.

The results of OTA's examination are very rough because only a handful of firms involved in infrastructure construction could be contacted in the limited time available and because it was difficult to attribute research and development (R&D) efforts specifically to infrastructure construction rather than to other types of construction or design. However, the results are adequate for showing that a very small fraction of revenues for all types of construction go into privately sponsored R&D at major types of companies connected with construction (probably less than $1,088 million, or 0.33 percent of the total value of new construction in the United States for 1985) and that construction firms, in particular, do little in the way of R&D.

CONSTRUCTION FIRMS

Types of Technological Innovation

Eight large construction firms and two engineering firms that build large infrastructure projects were contacted for information about their efforts toward technological innovation. The construction firms included Bechtel Group, Inc.,[10][11] Brown and Root, Inc.,[12] Fluor Corp.,[13] the M.W. Kellogg Co.,[14] Kiewit Construction Group, Inc.,[15] Morrison-Knudsen Corp.,[16] the Parsons Corp.,[17] and Rust International Corp.[18] The engineering firms were Greiner Engineering Sciences, Inc., and Figg and Muller Engineers, Inc. R&D is important at the design level since the design process often forecloses applications of construction R&D.[19] Figg and Muller indicated that their firm undertakes project specific research, although the

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10 Tim Killen Manager of Engineering and Construction Technologies, *Bechtel National Inc;* personal communication, Mar. 27, 1987.

11 Dennis Vanderpool, Manager of Construction Technologies, Bechtel National, Inc., personal communication, Mar. 31, 1987.

12 T. L. Austin, Jr., President and Chief Executive Officer, Brown and Root, Inc., personal communication, Mar. 18, 1987.

13 Ed Dopheid, Director Of Sales, Fluor Construction, Fluor Corp., personal communication. Apr. 22, 1987.

14 Robert Levy, vice president of Technology Development, The .M.W. Kellogg Co., personal communication, Apr. 23, 1987.

15 Martin Kelley, Vice president, Kiewit Construction Group, Inc., Personal communication, Mar. 24, 1987.

16 Mike Kulchak, Morrison-Knudsen Corp., personal communication, APr. 8, 1987.

17 Otha Roddey, president, parsons Corporation, personal communication, Apr. 22, 1987”

18 David Rozendale, president, Rust International Corp., personal communication, APr ” 23, 1987.

19 Henry L. Michel, president and CEO, Parsons, Brinkerhoff Inc., Personal communication, May 18, 1987.

amount expended is confidential. OTA did not find evidence of sizeable expenditures on R&D among these engineering firms. Some of these construction firms have nominal R&D departments or budgets, while others do not.

Moreover, for both design and public works projects comprise only a small portion of each firm's business; those that have R&D programs address them to technologies applicable to other areas where the bulk of their business originates. For example, Bechtel has a 300-person R&D department, which monitors technologies developed outside the firm, conducts research and develops new technologies, and explores potential areas for new business. Bechtel does support some projects within the company to develop new technologies with potentially broad applications. Support of these projects is an effort to advance fundamentally the state of the art of construction technology and thus seems to qualify as incremental or advanced construction R&D in the sense described in chapter one. Brown and Root, Kiewit, and Kellogg have programs to monitor new technologies and to communicate information about innovative ideas within the company.

However, these programs do not actually develop new technology. Parsons, Fluor: and Rust International have software development programs for scheduling and cost control, which could possibly be classified as construction R&D, but which do not fundamentally advance the state of the art of construction technology. The source at Fluor indicated that in the past. when Fluor's clients in the petroleum and hydrocarbon industries were in better financial shape, Fluor had more cash flow to pursue technology developments, such as better rigging and heavy lifting approaches.

Some companies support R&D efforts outside the company; for example, Bechtel supports research to develop new technologies at several universities. Also, all except one of the eight firms contacted (Parsons) were listed in 1986 as members of the Construction Industry Institute (CH), a research institute dedicated to improving the cost effectiveness of the U.S. construction industry. Established in 1986, CII provides support for construction R&D at universities. The annual level of support for CII is $6 million, and much of the research is directed at data systems and management support activities, although one does support development of new construction technology. Total industry .wide expenditures for R&D efforts outside individual companies (such as for university research) do not appear to be substantial.

In general, there seem to be four categories of technological innovation by the construction firms: (1) developing new technologies in special, internally funded projects within the company, (2) applying or modifying technologies recently developed outside the firm, (3) combining already existing technologies in novel ways, and (4) providing incremental advances to existing construction techniques. Innovations from categories two, three, and four typically occur in the context of specific construction projects. Examples of innovation from each of these categories are discussed below.

Bechtel funds technology development projects within the company, including the development of an expert system to handle onsite welding engineering problems and the development of a three-dimensional design-modeling system. The design-modeling system was developed after Bechtel discovered that the systems of several outside vendors did not meet its needs. The system has infrastructure construction applications, because it can help construction engineers visualize the structure to be constructed, and Bechtel reports that it may attempt to market the system.

An example of using technology recently developed outside the firm is Kiewit's use of computer-aided drafting at certain job sites. Kiewit had no part in the development of computer-aided drafting but adopted the technology when it became commercially available. In other examples, Bechtel used robotics technology developed at Carnegie-Mellon University in

[20] Construction Industry Institute, Annual Report, 1986 (Austin, Texas)" Also, Richard L. Tucker, "Perfection of the Buggy Whip," The Construction Advancement Address, First Annual Peurifoy Construction Research Award, American Society of Civil Engineers (Boston, MA: Oct. 29, 1986).

cleaning up the Three-Mile Island nuclear power plant and also provided some support to the University of Texas to develop an automatic pipe fabrication system. (Neither of the Bechtel examples are known to have infrastructure construction applications, however.)

Kiewit combined technologies in a novel way in the construction of tunnel walls for an underground powerhouse, Here, Kiewit combined steel fiber-reinforced concrete with microsilica shotcrete technology to produce a high-strength, fast-setting concrete tunnel wall. The concrete was applied pneumatically from a hose using existing shotcrete technology. In addition, Bechtel hopes to combine computer-aided design technology for manufacturing plants with automatic pipe fabrication to simplify the design/construction interface.

An example of an incremental advance on existing construction techniques is Brown and Root's development of ways to pack water valves in structures more efficiently. This advance does not involve any new technology or fundamentally new construction procedures; instead, it appears to involve closer attention to one aspect of construction in order to do it more efficiently. The advance occurred in construction projects for the power industry and may have applications for sewer systems.

Many construction firms have programs to monitor technological developments related to construction, to encourage innovation, or to communicate innovative ideas within the company. Bechtel's R&D department does this, and Brown and Root recently formed a competitiveness committee to examine construction techniques and equipment available for construction. Brown and Root also spent several million dollars educating employees at Crosby and Associates' quality school to encourage them to find better ways of doing things and to help facilitate sharing innovative ideas in the company. So far, no major successes have resulted for Brown and Root from these programs.

Kiewit relays information about innovations in construction projects to other parts of the company at an annual meeting attended by 400-500 executives and key employees. Two days of the meeting are spent reviewing construction methods at individual projects. The microsilica/fiber -reinforced concrete wall described above was discussed at this year's annual meeting.

In summary, three of the construction firms surveyed do little internal research and development to advance fundamentally the state of the art of infrastructure construction. There is little activity to develop new technologies with potentially broad applications for construction. The firms most often innovate by applying or adapting technology developed outside the firm, by combining existing technologies in new ways, and by incrementally modifying existing construction procedures. Much of the innovation in these categories occurs at the level of individual projects. Based on informal discussions with experts in the construction field, this state of affairs is probably typical throughout the industry .[21]

Industry - wide R&D Exnenditures

The total expenditures on R&D by the eight U.S. construction firms are shown in table 3-1. These expenditure estimates are based entirely on discussions with the firms listed above and apply to construction as a whole; not just infrastructure construction. OTA analyzed information supplied by the firms and eliminated expenditures for efforts to find out about, evaluate, or use existing technologies and attempted to eliminate expenditures on research not directly related to construction itself, such as the exploration of new potential areas of business. Ambiguities arose, particularly in the area of software development for scheduling and cost control, The ambiguous expenditures were included in the total R&D expenditures. Thus, the R&D estimates probably overstate actual spending by the construction firms to develop new construction technologies.

Total 1985 contracts are also shown for each of the firms in table 3-1. "Total 1985 contracts" refers to the total value of all prime construction contracts, shares of joint ventures,

[21] For example, Frederick Krimgold, Virginia Tech, Alexandria, VA, personal communication, Mar. 17, 1987.

Table 3-1.–RllD Expenditures of Eight Major U.S. Construction Firms

Company	Total 1985 Contracts (in millions)	Total 1985* R&D Expenditures (in millions)	Total 1985 R&D Expenditures (percentage of total contracts)
The Parsons Corp.	8,620.0	0.5	0.006%
Bechtel Group, Inc.	7,364.0	<10	~o.14z
The M.W. Kellogg Co.	6,757.0	0	0
Morrison-Knudsen Corp.	5,887.7	0	0
Brown & Root, Inc.	5,578.7	0	0
Fluor Corp.	5,127.4	1.5+	0.03%+
Rust International Corp.	5,097.9	4.0	0.08%
Peter Kiewet Sons', Inc.**	1,322.5	0	0

*: OTA estimates based on criteria described on preceding page.

** This company is now known as Kiewet Construction Group, Inc.

SOURCES: Total 1985 contracts from Engineering News Record, "The Top 400 Contractors," Apr. 17, 1986, pp. 58-99. R&D expenditures from OTA, based on discussions with the construction firms.

design/construct contracts, and construction management contracts where the firm is exposed to financial liability similar to that for a general contractor.[22]

Many construction firms, including Parsons, Morrison-Knudsen, and Fluor, had over one-half their total 1985 contracts in construction management. Discussions with firms indicate that the quoted total contract amounts are very inexact measures of the amount of construction work done by the firms. However, according to this reckoning, the 1985 contracts for the eight firms totalled $45,752.2 million, and the R&D expenditures totalled less than $16.0 million. Thus, the firms devoted less than 0.04 percent of total contract volume to R&D. Since the firms contacted included the seven largest construction firms in the United States in terms of 1985 contracts, 0.04 percent is a reasonable upper-bound estimate for the fraction of total contract volume devoted to R&D for all construction firms.

The total contract volume for the top 400 construction firms in 1985 was !$136.. billion. Assuming that firms outside the top 400 do not spend significant amounts on R&D and that the 0.04 percent is an upper bound to the fraction of total contract volume devoted to R&D, the total expenditures on R&D performed within all construction firms was probably no greater than about $48 million in 1985. This approximate upper limit is consistent with the National Research Council's estimate of $54 million for the total R&D funding level for construction contractors.[23]

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22 The figures for total contracts are from Engineering News Record, "The Top 400 Contractors," Apr. 17, 1986, pp. 58-99.

23 National Research Council, Construction Productivity: Proposed Actions by the Federal Government to Promote Increased Efficiency in Construction, (Washington, DC: National Academy Press, 1986).

PRODUCERS OF CONSTRUCTION MATERIALS

Total R&D expenditures by major building materials producers for 1985 was $202.9 million. It is not known how much of this amount was expended On evaluative research as oPposed to incremental or advanced R&D to improve construction materials. The figure is used here as an estimated upper bound to the amount spent by manufacturers of construction materials on incremental or advanced R&D for construction.

MANUFACTURERS OF CONSTRUCTION EQUIPMENT

Manufacturers of construction equipment typically spend a few percent of sales on R&D activities. Three such manufacturers were contacted about their R&D efforts. One, CMI Corporation,[25] is a relatively small firm ($ 135.2 million in sales during 1985) M that specializes ‘n grading and paving equipment, asphalt recycling equipment, and a few other related types of equipment. *7 The others, Caterpillar Inc.[28] and Deere and Company*[g] are much larger firms ($6,725 million and $4,060.6 million in sales during 1985, respectively)30 that manufacture a wider variety of equipment types. Deere, for example, manufactures farm equipment as well as

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24 Business Week, Op. cit. Note that this category includes afl types of building materials, not just the construction materials relevant to the kinds of public works discussed in this Staff Paper. Therefore, this estimate is an order of magnitude greater than that in table 9-1 and the accompanying text.

25 Tom Steele, vice president for Engineering Research and Development, CM I Corporation, personal communication, Mar. 24, 1987.

26 Businesweek, “R&D score board,” Jun. 23, 1986, PP. 139-156.

27 Standard and poor’s Register of Corporations, Directors and Executives, Volume 1 (New York: Standard and Poor’s Corp., 1987).

28 chuck Grawey, Director of Research, c~terpill~r, Inc., personal communication, ~~ar. ~4T 1987,

29 R Ussel Sutherland, v ice president for Engineering and Technology, Deere and Corn Pan}’> personal communication, Mar. 20, 1987.

30 Businesweek, oP. cit.

construction equipment. A summary of the total R&D budgets of the three firms appears in table 3-2.

Based on discussions with the firms, it appears that all three spend most of their R&D dollars on developing incremental changes to existing products and improving manufacturing efficiency. Examples of incremental changes are improvements in engine efficiency to produce more power and improvements in the reliability of equipment. These changes reduce the time and expense required to do construction but do not change the way construction is done by introducing new technologies or processes.

CMI and Deere reported working in several specific areas of R&D to develop new technologies or processes for construction. CMI is doing R&D to improve processes and equipment for asphalt recycling (about $1 million per year) and to improve processes and equipment for concrete paving (about $600,000 per year). Deere is developing high-pressure water jets for renovation of bridges (about $100,000 per year) and is doing R&D on applications of electronics, such as electronic control of gearshift mechanisms in scrapers and remote control of construction equipment. The source at Deere estimated that Deere spends about $5-!$6 million per year to develop new construction technology.[31] The source at Caterpillar reported that Caterpillar is also doing R&D on applications of electronics to construction, but declined to comment further on its efforts to develop new technologies. He estimated that Caterpillar spends less than five percent of its R&D funds on advanced R&D.

Table 3-2 summarizes the estimated expenditures of the three firms to develop new technologies or processes for construction. These expenditures are for R&D activities that could in some cases correspond to advanced R&D related to some type of construction (not necessarily infrastructure construction). Because none of the firms could supply exact figures for these types of expenditure, and because the distinction between a new technology and an improve-

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31 Sutherland, oP. cit.

Table 3-2.-RAD Budgets For Selected Manufacturers of tinstruction Equipment, 1985
(in mill iOnS of dollars)

		Tot~l R&D Budget		Approximate R&D Budget for New Technologies or Processes	
MdnufaCtuCer	Sdles in Mi l l ions of Dol ldrs	Mi l l ions of Dol ldrs	Percentage of Sales	MILLIONS OF DOLLARS	PERCENTAGE OF SALES
CMI	135	5.6	4.1	1.6	1.20
l)eefe*	4,061	223	5.5	6	0.14
Cdtcrpi l ldr	6,725	326**	4.8**	<16	<0.24

x Mdnutdcturers fdrm equipment db well as construction equipment.

IID Excludes R&D expenditures for mdnufdcturing processes.

Sources: 1985 sales figures for all firms and total R&D budgets for 041 and Deere from Business Week, 'RAD Scoreboard," June 23, 1986, pp. 134-156. [otal IUD Budget for Caterpi l lar from Chuck Grawey.

gests an upper bound only to the order of magnitude for private expenditures on infrastructure construction R&D. Indeed, some reviewers of this paper contend the amount is overstated.

The level of spending by major Federal agencies and agencies that use Federal funds on incremental or advanced R&D for infrastructure construction in 1985 was estimated in chapter two to be $14 million. This corresponds to an upper bound to total (Federal plus private) spending on infrastructure construction R&D of !5129 million, or 0.4 percent of the total value of new infrastructure construction put in place in the United States during 1985. The level of spending by major Federal agencies and agencies that use Federal funds for activities classified by the agencies as infrastructure construction-related R&D for 1985 (which includes management, design, and evaluation research) was found in chapter two to be $103 million. This corresponds to an upper bound to total (Federal plus private) R&D expenditures of !5218 million, or 0.63 percent of the total value of new infrastructure construction put in place during 1985. This upper bound is a very optimistic estimate, and the actual percentage of the total value of new construction spent on R&D is probably much less.

CASE STUDY

The Complex Process of Implementing an Infrastructure Innovation

BRIDGE RECONSTRUCTION USING PRECAST, PRESTRESSED CONCRETE PANELS

Precast, prestressed concrete panels have been used to replace aging highway bridge decks in the United States since the 1970s.[33] (The technology had been known and used in Europe for 30 years previously.) The main benefit of using the panels, compared to the conventional method of pouring concrete directly on the bridge's superstructure, is that the panels do

33 Mrinmay Biswas, "Precast Bridge Deck Design Systems," reprinted from the Journal of the Prestressed Concrete Institute 31, vol. 2, March-April 1986.

not require a long curing time. This permits installation of the panels at times of day when traffic levels are low and use of the entire bridge deck when levels are high. It also shortens the total time required to do the deck reconstruction, Thus, precast, prestressed concrete panels are most useful in crowded urban areas where loss of a few lanes on an important bridge during rush hours can cause serious traffic congestion problems.

Precast, prestressed concrete panels are made by stretching high-strength steel wires with hydraulic jacks to high tension. Then, high-strength concrete is cast in a form around the wires and allowed to harden. The result is that the tensile load of the panel is carried by the steel wires, so the panel combines the tensile strength of steel with the compressive strength and rigidity of concrete. The process of forming the panels in this way is called “pretensioning.” The panels can be joined together with steel wires passed through the panels and stretched to high tension. This process is called “post-t ensioning. ”[34]

The Frenchman Eugene Freysinnet is generally credited with developing modern concrete prestressing methods. He began work on these methods in the 1920s.[35] In the late 19QOs, bridge construction using precast prestressed elements proved to be an efficient and economical way to replace the bridges destroyed in Europe during World War 11.[36] Prestressed concrete was not used in the United States until the 1950s and 1960s, when it was utilized for bridge construction, primarily for bridges with spans of about 100 feet or less. Use of precast, prestressed concrete members for construction of longer-span bridges (with a method called segmental con-

3A The Encyclopedia Americana, International Edition, vO]. 4, Birmingham to Burlington (Danbury, CT: Grolier, Inc., 1986), p. 529.

35 Walter Podolnov, Jr and Jean M. LMUher, Construction and Design of prestressed Concrete Segmental Bridges “(New York: .John Wiley and Sons, 1982), p. 4,

36 BiSwaS, OP. cit.

ment to an existing product can be fuzzy, the quoted amounts should be understood as only suggesting the order of magnitude of expenditures by the firms to develop new technologies and processes for construction. The figures do show that while the fraction of total sales revenues spent to develop new technologies or processes for construction is small, the actual amount of money spent is not trivial.

The total R&D expenditure for major farm and construction equipment manufacturers in 1985 was approximately $837.3 million.[32] Since this figure includes R&D to develop farm machinery as well as construction machinery, it is an upper limit to expenditures on incremental or advanced construction R&D by equipment manufacturers.

TOTAL PRIVATE EXPENDITURES FOR CONSTRUCTION R&D

Table 3-3 shows the estimated upper limits to construction R&D by construction firms, construction equipment manufacturers, and construction materials producers. The upper limit to the total private spending on construction R&D for 1985 is $1,088 million. This amount represents 0.33 percent of the total value of new construction in the United States for 1985.

Table 3-4 shows estimates of the total value of new infrastructure construction for the United States in 1985. It is impossible to determine from the available information the total expenditure by private firms on infrastructure construction R&D. Indeed, since many technologies apply to different types of construction, it may not make sense to attempt to separate infrastructure construction R&D from other types of construction R&D. Nevertheless, if the level of private infrastructure construction R&D is assumed to be in the same proportion to the level of total private R&D for construction as the total value of infrastructure construction in the United States is to total construction in the United States, then the level of private infrastructure construction R&D for 1985 has an upper bound of $115 million. Clearly, this figure sug-

S2 This was obtained from data in Business Week, oP. cit., with the Caterpillar R&D budget corrected according to information from Chuck Grawey, op. cit.

Table 3-3.-Upper Limit to R&D Expenditures by Private Firms For All Types of Construction

	MilLions of Dollars
Construction Firms	48
Construction Equipment Manufacturers	837
Building Materials Manufacturers	203
TOTAL	$1,088

Source: Office of Technology Assessment.

Table 3-4.–Approximate Infrastructure Construction Expenditures Based on Data From the Census Bureau for 1985

Type of Public Construction	Expenditure (in millions of ciOllars)*
Highways and Streets	$19,998
Sewer Systems	7,196
Water Supply Facilities	2,664
Miscellaneous	4,512
Total	$34,370

* 1986 dollars.

Source: Adapted from U.S. Department of Commerce, Bureau of the Census, Value of New Construction Put in Place, C30-86-12, February 1987, (Washington, DC: U.S. Government Printing Office, December 1986).

struction) did not begin until later--the first such bridge was completed in the United States in 1973.[37]

The use of precast, prestressed panels for bridge deck reconstruction began as a response to a need in bridge reconstruction, not as a result of any particular technological development. During the 1950s and 1960s, a great deal of highway and bridge construction took place, including work on the interstate highway system. Structures were often built quickly, and the builders did not always anticipate the level of use they would eventually enjoy. Moreover, structures were not always maintained in top condition. Since the 1970s, these bridges have begun toshow significant signs of aging, and many have needed rehabilitation. Furthermore, in many areas no good alternate traffic routes exist for bridges, which are used to capacity during rush hours. Thus, precast prestressed concrete panels have been attractive in many cases because they cause less traffic disruption than conventional redecking approaches.[38]

Three basic factors must be weighed when deciding whether to use precast prestressed panels for bridge redecking. The first factor is cost, which depends partly on the size of the job and the uniformity of the bridge panels required for redecking. If only a few panels are needed or if the bridge has variable width or curvature, then panels may be very costly relative to poured concrete because the forms needed to manufacture the panels would be used only a few times. On the other hand, if the bridge is very long and has uniform width and curvature, the forms can be used repeatedly for many panels. The availability of local facilities for manufacturing panels is an additional cost consideration. Finally, the cost of maintaining traffic levels during rush hours by opening and closing lanes on the bridge can also be high.

The second factor is traffic disruption. Precast prestressed panels generally offer a big advantage here since traffic can pass over them shortly after they are laid, permitting construc -

37 podolnoy and ,~~uller, opt cit., p. vii.

38 James Lutz, project Director, Greiner Engineering sciences, Inc., 13althnore, ~D, Personal communication, May 6, 1987.

tion during the night and traffic flow during the day. Also, bridges can generally be redecked in a shorter total time using panels than by using poured concrete.

The third factor is performance of the completed bridge deck. Poured concrete has an advantage in that it bends somewhat in response to the bridge superstructure below it, thereby reducing stresses on the structure. This phenomenon is known as "participation." The riding surface of poured concrete is potentially better than that of panels because it can be adjusted very accurately to form a nearly perfect flat surface. Imperfections in a panelled surface can be compensated for to some extent by overlaying asphalt on top of the panels, but long-term problems can result because of water and salt seepage through the asphalt layer. Precast prestressed concrete is generally of higher quality than poured concrete because it is prepared under more controlled conditions.[39]

Precast, prestressed concrete panels were used during 1982 and 1983 on the Woodrow Wilson Memorial Bridge across the Potomac River near Washington, DC. Traffic across the bridge is extremely heavy, so safe maintenance of all six lanes of traffic during peak hours, four or five lanes during off-peak hours, and one lane in each direction at night were mandatory during the reconstruction period. The entire concrete deck of the 5,900-foot bridge needed to be redecked and widened.[40] Since maintenance of traffic was an overriding concern and the bridge was long, of uniform width, and without curvature, use of prefabricated deck segments was the clear choice of reconstruction method.

A bonus clause in the contract for redecking the Wilson Bridge rewarded the contractor, Cianbro Corporation, for each day the contract was completed ahead of schedule, up to 120 days. The contract required completion of the work within 575 calendar days. The reward was

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39 Ibid.

40 James G. Lutz and Dino J. Scalia, "Deck Widening and Replacement of Woodrow Wilson Memorial Bridge," reprinted from the Journal of the Prestressed Concrete Institute, vol. 29, No. 3, May-June, 1984.

based on a Federal Highway Administration estimate of the cost of traffic disruption due to construction, reportedly about $10,000 per day, even though six lanes were generally open during rush hours. About 15 percent of the way through the project, Cianbro offered to complete the deck work within 350 calendar days, or 225 days earlier than required by the contract, if paid for the additional costs of hiring more work crews and supervisors and the costs of making more forms for manufacturing panels at the fabrication plant. This additional cost was reportedly about $3,000 per day for the 105 days saved above the 120 days rewarded in the contract. The offer was accepted. Cianbro completed the bridge redecking within 350 calendar days, as promised.[41] According to a confidential source, if conventional construction methods were used, the project would have taken three years and only three lanes would have been open to traffic throughout the day.

[41] James Lutz, Projects Director, Greiner Engineering Sciences, Inc., Baltimore, Maryland, personal communication, May 6, 1987; and Lutz and Scalia, op. cit.

CHAPTER FOUR

CONSTRUCTION R&D PROGRAMS IN OTHER INDUSTRIES AND IN FOREIGN COUNTRIES

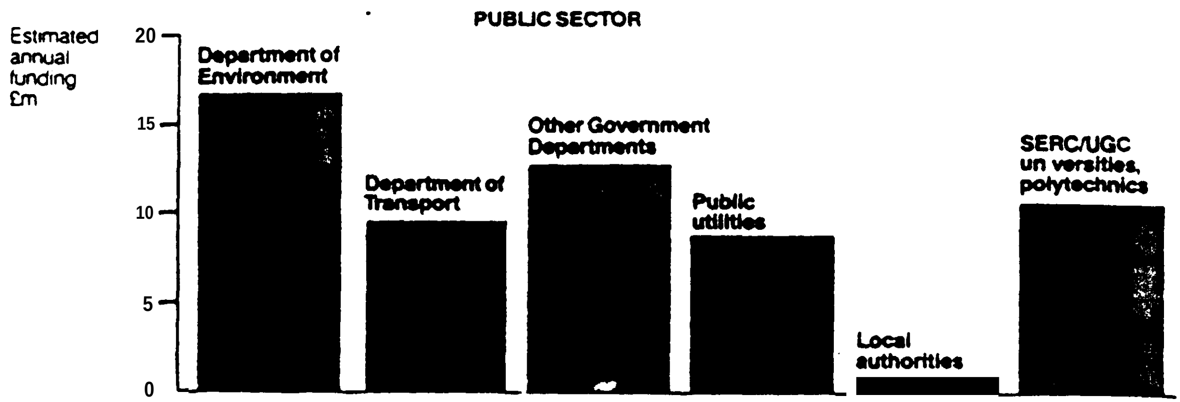
American firms have been preeminent in the world in large-scale construction for many years. Recently, however, smaller-scale construction is becoming increasingly internationalized, and American firms find themselves competing with foreign construction firms even for domestic work. R&D efforts in other industries and in foreign countries provide comparisons and potential alternatives for infrastructure construction R&D programs in the United States.

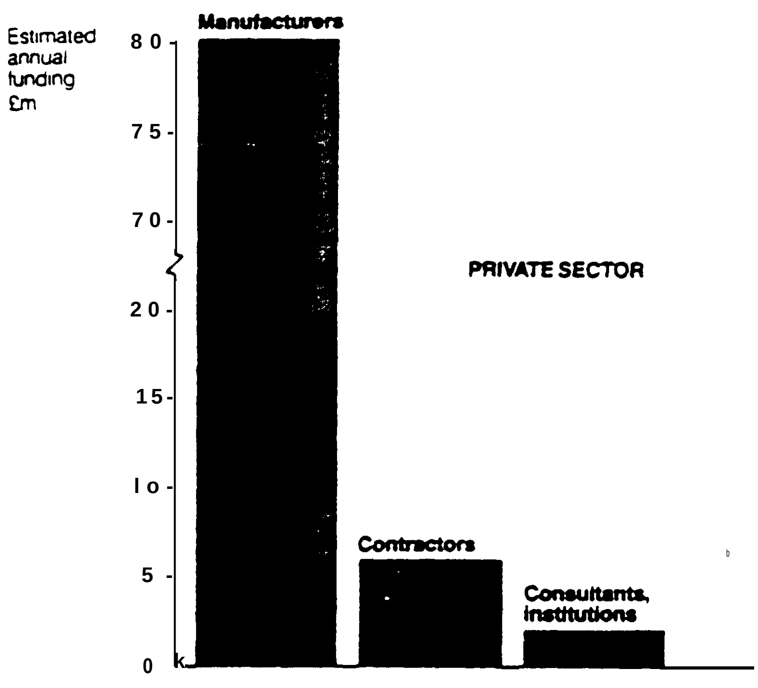
The competitiveness of U.S. firms in international markets or against foreign-based firms in U.S. domestic markets is not a primary concern of this study. Nevertheless, foreign competition has become a major driving force for new and improved technologies in many industries, and could become so for construction. This chapter presents a brief comparison of R&D and innovation of public works construction technology support in the United States with examples from other countries. That comparison highlights some institutional strengths and weaknesses of the U.S. system as well as describing alternatives.

RELATIVE EXPENDITLTRES FOR R&D IN OTHER U.S. INDUSTRIES

Privately funded R&D expenditures for several major industries are listed in figure 4-1. Electric utilities and construction have markedly lower R&D expenditure percentages than the other industries. In addition to this private support on R&D, many manufacturing industries also perform in-house, federally-supported R&D funded primarily by the Department of Defense. These expenditures are not included in figure 4-1. For example, the aircraft and mk - sdes industry received Federal funds equivalent to 12.9 percent of sales volume for R&D, while the electrical equipment industry received 2.6 percent; the machinery industry, 0.75 percent; the

Figure 4-l,-Estimated Funding for Construction related RGD in the United Kingdom





SOURCE: Daniel W. iialpin, Construction Management Consultant to OTA, “Final Report, Task I, Technology in Architecture, Engineering and Construction,” Mar. 17, 1986.

chemicals and allied products industry, 1.2 percent; and the motor vehicles industry, 0.40 percent.[42]

INFRASTRUCTURE R&D PROGRAMS IN FOREIGN COUNTRIES

OTA examined construction R&D programs in two foreign countries--Japan and the United Kingdom--comparing to the extent possible the expenditures of these countries for construction R&D with those in the United States. One European Community research program, Basic Research in Industrial Technologies for Europe (BRITE), was also examined, since several projects in the BRITE program are relevant to infrastructure construction.

Janan

In Japan, the Ministry of Construction funds nonmarketable basic research at institutes such as the Public Works Research Institute and the Building Economics Research Institute. The institutes are not connected with universities, but they employ full-time researchers as well as faculty from universities on a temporary barn.[43] The Ministry of International Trade and Industry (MITI) funds similar research for transportation.

The level of government support for construction research programs is unknown but is reportedly small compared with the amount invested by Japanese construction company laboratories.[44] The Japanese Government indirectly supports R&D Programs in the construction cOmpany laboratories through tax breaks and other institutional means.[45] For example, if a com-

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42 Adapted by OTA from National Science Foundation, National patterns of Science and Technology Resources 1986, NSF 86-309 (Washington, DC: 1986), p. 55.

43 Neil M Hawkins, Associate Dean for Research, University Of Washington, Personal communication, May 28, 1987.

44 Daniel W Halpin, construction Management Consultant to the Office of Technology Assessment, "Final Report, Task 3, Technology in Architecture, Engineering and Construction, " Mar. 17, 1986.

45 Ibid.

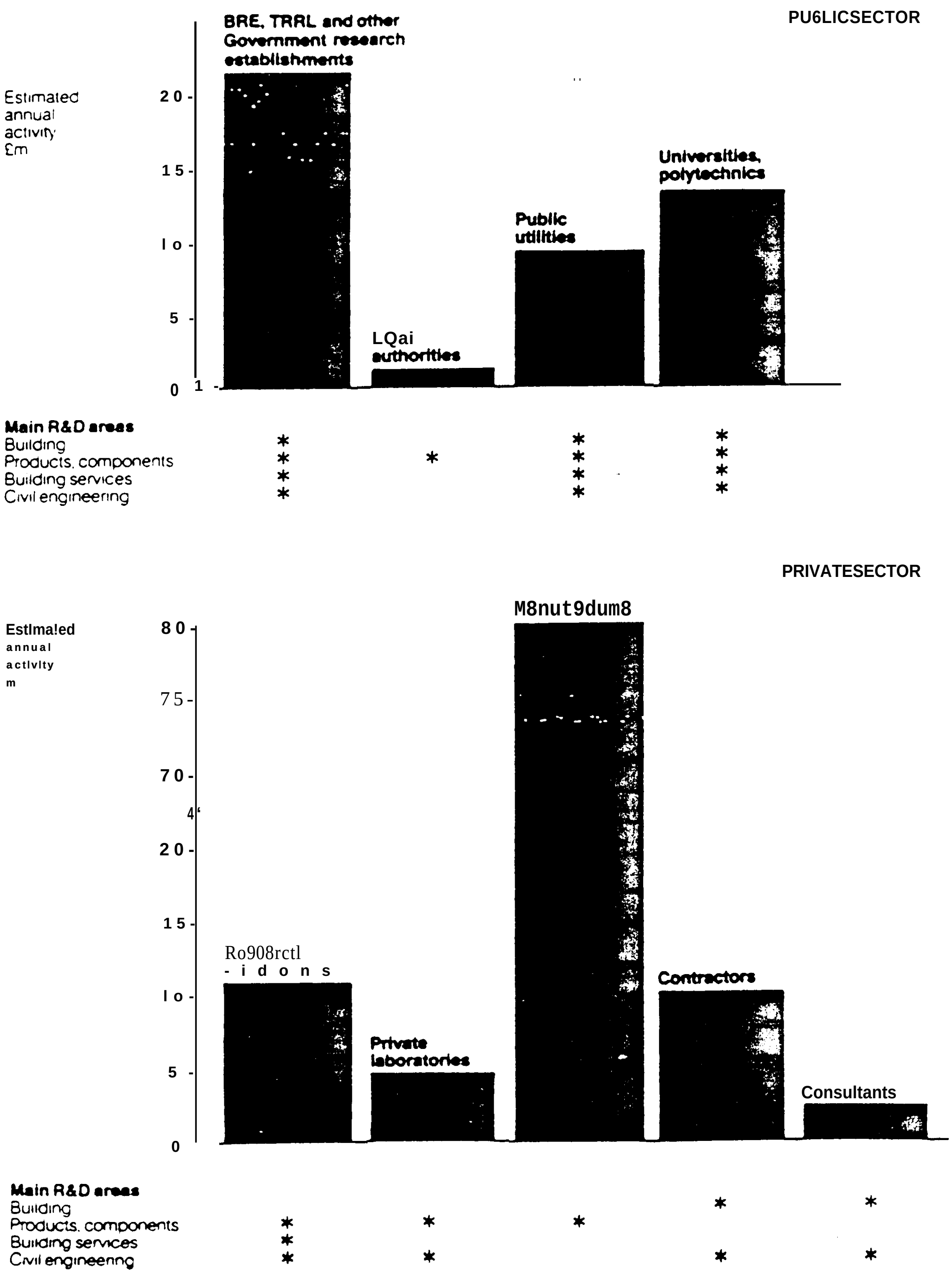
pany invests more in a given year in research than its largest R&D investment over the past ten years, it gets a tax deduction of up to ten percent of its total tax. If the R&D investments less than 15 percent higher than the largest R&D investment over the past ten years, 25 percent of the increased portion is deducted from its annual tax. If the annual increase is over 15 percent, the deduction is 50 percent of the increased amount. For further discussion of institutional support for R&D in Japan, see chapter five.

R&D expenditures are shown in figure 4-2 for eleven out of the 18 construction firms (worldwide) that enjoyed at least $3 billion in total contracts and at least $16.5 million in foreign business for 1985. The list includes seven Japanese firms; R&D expenditures are known for five of these firms. The five firms spend a little less than one percent of their total contract volume on R&D, in decided contrast to large U.S. firms, whose much smaller expenditures are also shown in figure 4-2. All of the largest Japanese firms have smaller total contract volume than the seven largest U.S. firms, but R&D expenditures for each of the five Japanese firms whose R&D expenditures are known are greater than for any of the U.S. firms.

Many of the types of R&D pursued by Japanese firms in recent years were "invited" by the Japanese government, and they are impressive.[46] KajimaJs R&D has included a concrete finishing robot, a rebar placing robot, wall tile inspection machine, and a five-boom crawler for tunnel work. Taisei's R&D program has included pioneering developments in abrasive waterjet methods for cutting steel, rock and concrete; new tunneling techniques based on the New Austrian Tunneling Method; microcomputer systems for shield tunnel boring machines; an underwater T.V. inspection system; robots for spraying concrete, inspecting wall tiles, and spraying paint on building exteriors; as well as development of computer software for concrete-laying robots. Takenaka has worked on robotic systems for concrete placement and finishing, a paint spraying robot, a robot tower crane fox lifting and positioning steel reinforcing bars for concrete

46 Neil M. Hawkins, op. cit.

Figure 4-2--Estimated construction related R&D Activity in R&D Facilities in the United Kingdom



Source : Daniel W. Halpin, Construction Management Consultant to OTA, "Final Report, Task 3, Technology in Architecture, Engineering and Construction," Mar. 17, 1986.

buildings, and a combination crane and concrete placement machine. Shimizu's R&D program has included earthquake-resistant walls; clean room technology; processing and disposal of nuclear wastes; automatic installation of ocean platforms; and robots for spraying fireproofing on structural steel in high-rise buildings, and for industrial cleaning, concrete cutting, painting with rollers, and lifting and positioning steel beams. Kumagai Gumi has worked on liquid natural gas storage, new shields and techniques for tunnel boring, novel methods for driving piling, novel methods for building walls by applying hardeners to soil, and robotics for automatic assembly of segments of tunnel lining. A smaller company, Hazama Gumi, Ltd., specializes to a greater extent in infrastructure construction, such as dams, tunnels, railways, highways, subways, airports, waterways and shipyards. Hazama Gumi has an R&D department which has developed an automatic control system for a tunnel boring machine shield using laser and computer technology. Hazama Gumi's researchers are interested in acoustic and other sensors for measuring soil properties in real time in front of the shield to allow them to optimize control of rate of material extraction and shield velocity .47

The research programs of the Japanese construction firms contrast markedly with the research programs of U.S. firms. Of the eight U.S. construction firms contacted in this study (see chapter three for details), only Bechtel appears to be doing R&D at a level of sophistication approaching that of the Japanese firms. Even at Bechtel, the amount of such research is less than at the Japanese firms. Much of what could be considered R&D at U.S. firms is software development for scheduling, cost control and other management functions. Enhancements in management functions are important, but do not fundamentally advance construction technology. From discussions to gather information for chapter three, OTA estimates that R&D at U.S. construction equipment manufacturers probably approaches the sophistication of Japanese construction R&D in some cases.

47 James S. Albus, Chief, Robot Systems Division, National Bureau of Standards, Summary Trip Report, July 7, 1985.

United Kingdom

Public sector funding in the United Kingdom for R&D for construction in general (not just infrastructure construction) comes from a variety of sources, as shown in figure 4-1. The research is performed at several types of facilities, as shown in figure 4-2. It is not known how much of this research is evaluative or design-oriented, and how much is oriented toward development of construction technologies. According to one estimate, the British Government spends about 60 million pounds, or 0.28 percent, of the total construction turnover in the United Kingdom, on R&D for construction.[48]

According to a study of construction R&D in the United Kingdom, manufacturers fund most of the R&D in the private sector (see figure 4-1).[49] Organizations that do R&D in the private sector are shown in figure 4-2.

Total private expenditures on R&D for construction in the United Kingdom is about 90 million pounds, or 0.42 percent of the total construction turnover, according to one estimate. The same analysis estimates that the total expenditure (public plus private) for construction R&D in the United Kingdom is about 0.7 percent of the total construction turnover. Another analysis estimates 0.5 percent. [50]

The overall pattern of construction R&D in the United Kingdom seems similar to that in the United States: most of the private-sector R&D is done by the manufacturers, with construction firms doing very little. It was impossible to do an indepth comparison of United States and United Kingdom efforts in the short time span for this project.

48 Halpin, op. cit.

49 Ibid.

50 Ibid.

The BRITE Program

BRITE is a European Community (EC) program that provides one-half of the funding for 103 research projects in a variety of technological areas. Industrialists from EC that participate in the research provide the other half of the funding. The funding level provided by BRITE is 125 million ECU (approximately $125 million U.S.) for a four-year period (1985-1988).[51]

The focus of BRITE is broad, but nine major technological areas are given priority: (1) problems of reliability, wear, and deterioration of materials and systems, (2) laser technology and powder metallurgy, (3) joining techniques, (4) new testing methods, (5) computer-aided design and manufacturing, (6) polymers, composites, and other new materials, (7) membrane science and technology, (8) catalysis and particle technology, and (9) new technologies applied to articles made from flexible materials.[52]

Three of the 103 BRITE projects appear to apply directly to infrastructure construction, reconstruction, repair, or routine maintenance. Two of these are in the area of reliability, wear, and deterioration. The titles of these projects are: (1) Electrochemically-based Techniques for Assessing and Preventing Corrosion of Steel in Concrete, and (2) Deterioration Prevention in Reinforced Concrete Structures Subject to Hostile Environments. The other infrastructure construction-related projects are entitled, (1) Improvement of the Lifetime of Woven and Non-woven Synthetic Materials for Geotextiles, Packaging and Agriculture, (2) Applications in Civil Engineering. W 5A OTA was unable to determine actual funding levek for these Projects.

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51 Commission of the European Communities, "BRITE The Community Programme of Research in Industrial Technologies Gets Under Way," Press Release (Brussels: Feb. 4, 1986).

52 Ibid.

53 "Complete List of Projects under the First Tranche of the BRITE Programmed," BRITE, European Community (no date).

54 Commission of the European Communities, "BRITE: Eight More Projects Selected for Community Support," Press Release (Brussels: June 19, 1986).

POTENTIAL R&D MODELS FROM OTHER INDUSTRIES AND COUNTRIES

R&D in other industries and countries suggests models which could potentially be applied to infrastructure construction in the United States. Several models are described here, but further study is needed to examine the models in more detail.

The first model is support by the Federal Government for R&D within private construction firms for public works construction. As described earlier in this chapter, many manufacturing industries have substantial R&D efforts funded by the government, primarily the Department of Defense. The problem with this approach as it applies to construction firms is that the firms currently do very little R&D and so would probably not have the facilities or experience to perform much federally-supported R&D, at least for a number of years. Another version of this approach is further support of projects using innovative approaches to construction, perhaps in a format similar to that in the 1982 Surface Transportation Assistance Act, described earlier. A problem here would be the definition of "innovative" and how to determine if a construction project is really innovative.

Japanese construction firms reportedly receive tax breaks for increasing their R&D expenditures, although the main incentive is in the profit margin on jobs within Japan that involve advanced technologies or processes that can then be used on the world market.[55] The same approach could be followed in the United States for its construction firms. Of course, tax breaks for U.S. firms need not follow the Japanese format exactly.

The European Community program, BRITE, is an example of a combined government industry research program, which could potentially be applied in the United States. The industries that actually participate in the research contribute half of the money, with the expectation

55 Neil M. Hawkins, op. cit.

CHAPTER FIVE

INSTITUTIONAL AND POLICY ISSUES

The nature and effectiveness of R&D depends to a large extent on the institutional environment in which it is carried out. In the case of public works infrastructure R&D, this environment is characterized by:

- Governmental Decentralization-- over 38,000 government have a role.
- Monopoly-like characteristics --each governmental unit has sole jurisdiction.
- Inflexible Procurement Systems
- Fragmented Sellers -- with the exception of large structures, such as bridges, tunnels, and large dams, most construction is done by a large number of small local firms.
- Nature of the Operations-- much construction work involves large tonnages of low cost materials; the training and skill levels of construction labor inhibits the use of sophisticated technologies.[56]

These factors universally point to the tremendous difficulties in funding, completing R&D on, and disseminating new and worthwhile technologies-- particularly where both information and skills are involved.

OTA found that America's traditional inventive abilities and achievements remain unquestioned. A recent article states:

> The fact remains that the United States is still a creative hothouse. Its laboratories churn out important advances and whole new technologies from biotechnology and fiber optics to superconductivity. And foreign

[56] Alan E. Pisarski, "The Role of Technology," unpublished draft chapter of a report to the National Council of Public Works, May 1987.

> students flock to U.S. universities, where they now account for 20 percent of all students and a staggering 55 percent of those studying engineering. So the failure is not American technology--it is American manufacturing. U.S. industry has big trouble when it comes to transforming ideas into products that can be sold on world markets. That's the missing link in the innovation process.[57]

Although U.S. manufacturing firms have difficulties translating invention into innovations and saleable products, the problems and failures are much greater in construction. Technologically, construction has primarily been and is likely to continue to be largely a "borrowing" industry. Most technological advances originate from or are shared with other industries--little has been invented that is used solely in construction. The "invention" problem for construction is what technologies to borrow and how to adapt them to construction applications.

However, OTA concludes that key elements of the Nation's institutional and industrial structures have become incompatible with an ability to capitalize on the benefits of R&D. As examples--the United States has no Federal agency responsible for construction matters comparable to the Japanese Ministry of Construction. Research funding is fragmented and in many cases insufficient to accomplish very much. Construction firms rely for R&D on government, universities, and manufacturing firms that develop and sell the technologies. Little accountability has been required for practical results or benefits in applications obtained from government-funded R&D. Tax incentives for R&D in the private construction sector have been largely ineffective; apparently they have been insufficient to offset the disincentives.

Regulatory and procurement practices, and the lack of risk sharing, economic incentives, and industrial and intergovernmental cooperation, are powerful disincentives to R&D for many construction companies. Remedies for the institutional impediments to the effective application of public works R&D are as essential for technological progress in infrastructure construction as the R&D itself. With appropriate changes in public institutions and strategies, the private sector

57 Business Week, Apr. 20, 1987, p. 56.

might be able to remedy many R&D problems with little government help, Moreover, it will be extremely difficult for the Federal Government to remedy the problems of infrastructure R&D without changes in the institutional environment and greater attention to economic incentives.

Accordingly, this chapter describes the institutional and policy issues that need to be addressed if the United States is to develop a stronger national effort for public works infrastructure R&D. The discussion also identifies other institutional issues that need further investigation and study before it is possible to develop a sound basis for determining public policy alternatives. Finally, while the subject is not addressed in this paper, OTA recognizes that a detailed examination of the economic impacts of R&D in public works infrastructure is necessary for full understanding of the institutional framework.

REGULATORY AND PROCUREMENT SYSTEMS

Regulatory systems in the United States differ among types of infrastructure. For certain types or categories of infrastructure, government procurement systems are the regulatory systems.

As an example of the complexity of the procurement and standard systems, the States set construction standards for water and sewer systems. Pursuant to the Clean Water Act, the Environmental Protection Agency establishes performance standards for water purity. The States consider and may utilize other construction guidelines or standards adopted or recommended by the American Society of Testing Materials, the National Sanitation Foundation, and the American Water Works Association. Other organizations such as the Occupational Safety and Health Administration, the American Society of Civil Engineers, and the Corps of Engineers may become involved. In the case of highways and bridges, the American Association of Highway and Transportation Officials (AASHTO), has a formal process for review, adoption, and amendment of standards, which individual States may then adopt or use. The Federal Highway .Administration sets standards in cases where Federal funds are used.

The Bureau of Reclamation applies a concept of "sound and accepted engineering practice" in design and construction of small dams and waterways, without a formal process. Some States require licensing for construction of privately owned small dams, which are reviewed and approved on a case-by-case basis.

The Corps of Engineers has a rigorous internal review process for setting and revising what are referred to as "acceptable engineering standards" applying to the public works for which they are responsible. Technical reviews for standard-setting are linked to their R&D projects. While the Corps standards are keyed to accepted commercial and industry standards, they also must meet the Corps' own criteria.

Each of these groups is concerned with one or perhaps two or three types of public works. Yet a large construction firm may bid on numerous public works projects in different public works segments as well as pursue private sector contracts, often in a different area. Realizing economic payback for the heavy front end costs of developing a sustained R&D program is possible only with economies of scale unavailable to all but the very largest firms, The need to meet different sets of standards poses a formidable obstacle to achieving those economies. Other related problems include the fact that contractors for public works are generally not prequalified, reducing opportunities for R&D investment recovery .58

Moreover, most contracts for infrastructure construction are awarded on a low-bid basis with specifications that are heavily weighted toward existing technologies and experience-based methods. Further analysis is needed to ascertain whether this type of public works infrastructure procurement achieves real economies. It may, in fact, impede technology innovations that could be cost effective, especially if they reduce life cycle costs.

Various agencies have included "value engineering" clauses in contracts for some years. These clauses, effective after contracts are awarded, are intended to provide contractors with an

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58 Henry L Michel, president and Chief Executive Officer, parsons Brinckerhoff, Inc, Personal communication, May 18, 1987.

incentive to develop new designs or technologies. The usual incentive offered is that the government shares with the contractor any cost savings that result. The Bureau of Reclamation, for example, offers contractors 50 percent of cost savings realized through value engineering. However, OTA was able to identify few new or improved infrastructure construction technologies that have resulted from the value engineering. The one significant technology development attributable directly to value engineering is the use of roller-compacted concrete in the Corps of Engineers' gravity dam on Willow Creek in northeastern Oregon. This innovation uses roller-compacted concrete in place of pouring concrete in the normal manner, creating a net saving for the dam of $11.6 million and reducing construction time for the dam by 25 percent.[59]

Nor did OTA find examples in the United States of a European technique, design competition. In a design competition, contractors bid and are selected on the basis of alternative designs and methods to those of government specifications. This approach is related to value engineering, but applies before, rather than after, contracts are awarded.

Recognized problems with building construction regulations are probably analogous and can be used to illustrate the impediments that regulation and procurement systems provide for public works infrastructure construction. Technology innovations in building construction are impeded by a number of factors. First, a wide variance exists in State and local building codes and inspections across the United States, complicating product and construction requirements and adding significant costs for large producers and builders. Secondly, taking a new building product or technology through the model code and State and local code approval processes typically requires considerable time and money, Moreover, code approval processes favor existing producers and technologies in various ways, making it difficult to obtain approvals for new products and technologies. Finally, "performance" standards, which might encourage inventive-

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59 Paul V. Do brous, Chief of Value Engineering Office, Corps of Engineers, personal communication, April 1987. Also see: "Rolled Concrete Triumphs," Engineering News Record, Oct. 21, 1982. Other applications for roller-compacted concrete are discussed in chapter seven.

ness and innovation and lower costs, are much more difficult to administer from a regulatory perspective than commonly used design or prescriptive standards.

The extent to which the numerous and varied regulatory and procurement systems for infrastructure construction inhibit R&D and technology innovation remains unclear. Additional research to identify changes in regulatory and procurement systems that might encourage or provide incentives for infrastructure R&D and technology innovation could be useful. A Public Works Management Program funded by the State of Ohio and located at the Cleveland State University is just beginning and may illustrate one method of addressing some of these issues. The "program will train civil engineers to understand the economic, political, and social, as well as technical aspects of providing public works."[60] The course was developed through consulting with public works officials to determine their needs.

SAFETY, QUALITY, AND LIABILITY CONCERNS

OTA found that liability issues are serious impediments to construction technology innovation as well as to R&D. U.S. construction firms are understandably reluctant to take the risks associated with new or different construction methods and materials that are not common practice or in general use. Undertaking R&D is pointless if a firm believes it may not use resulting technologies because of fears of litigation. Thus, to industry, the prospect of litigation often outweighs the possible advantages of new or improved technologies.

Liability is not a stand-alone problem. It is linked to and reflects other mutually reinforcing problems, inside and outside the legal system, which adversely affect technology innovations in the construction industries. The nature and extent of these problems are not fully understood and need to be researched to provide a basis for considering solutions. Among the

60 Cleveland State University, "Public Works Management Program," unpublished program description prepared for the National Workshop on the Role of the University in Public Works Management, Apr. 28-29, 1987.

problems are accidents, which are more prevalent on U.S. construction sites than is generally realized. Insurance costs are high, reflecting the risks of liability and litigation.

At the same time, public safety concerns related to inspections and quality control are frequently justified. To a greater or lesser extent, each construction project is unique. Large construction sites in particular pose problems of quality control that are much more difficult to address than problems of quality control on factory production lines. Construction is still a “craft-based” industry; it has never been a “high tech” industry; and training of workers, especially for maintenance and repair of increasingly advanced systems, is usually minimal. Consequently, cost and performance benefits from more advanced technologies are difficult or impossible to retain. In many cases, as more advanced technologies are used, inspection problems are compounded. For example, to protect themselves, some owners and developers employ private engineering firms to do independent inspections, as they lack confidence in public building inspectors who have neither the knowledge nor experience to keep pace with new or different technologies. The United States does not have a credible, institutional “authoritative voice” to test and approve new or different construction technologies in a timely and cost effective manner, as some foreign countries do. Moreover, the United States has not institutionalized arrangements for sharing risks of new or more advanced technologies, as have some other countries.

The failure and consequences of using new technologies without R&D are cited by the director of one of NSF Engineering Research Centers:

> ". . . both industry and government often implement construction technology without any significant research and development. This in turn has resulted in substantial costs in repairs and corrective measures when these construction technologies fail to perform. In most cases, the research and development is only done after this lack of performance. The cost of subsequent study, repair and litigation is an enormous expense and ineffective way to achieve economy and performance of the infrastructure. A case in point is the utilization of electroslag welds in bridges. Very little research and development was carried out on this process before it was extensively put into use in the 1960’s. Failure of the I-79 bridge at Neville Island near Pittsburgh led to banning the use of the method in

bridge tension members in 1977 by the Federal Highway Administration. The process is still not accepted for use, and many of the structures with these welds have had costly repairs and retrofits installed. This same experience is repeated often in both private and public sector applications."6[1]

While tort reform is tempting as a way to mitigate some of the risks of new or different technologies, it will not remedy the underlying technology-related problems associated with liability.

EFFECTIVENESS OF TECHNOLOGY TRANSFER AND INNOVATION DIFFUSION

Movements of technologies from the R&D phase into construction application fall into two categories. The first is technology transfer--moving new or improved technologies from laboratories to innovative firms that can utilize it. The second is innovation diffusion--creating widespread uses of new or improved technologies across infrastructure segment lines. As an example, innovations in dredging equipment developed for the mining industry also are applicable for dredging waterways, ports, etc., but these research efforts are uncoordinated. City public works departments may not use new or improved technologies either because they do not know about them or have other personnel limitations. Moreover, the city may receive bids from numerous small, less sophisticated firms that are similarly uninformed, rather than from large-scale infrastructure construction firms with staffs of professional architects and engineers.

Research is needed to determine whether or not there are problems different from those already identified. It is also important to explore positive methods, such as incentives, which might be created to improve or speed-up innovations in infrastructure construction. Some new or improved construction technologies appear to be implemented quickly with good results, while others are not. Because of the nature and size of projects, the types of firms and profes-

G1 John w Fisher, Director of the Engineering Research Center for Advanced Technology for Large Structural Systems at Lehigh University, personal communication, May 22, 1987.

sionals involved, and the contracting procedures used, problems of technology transfer or innovation diffusion may differ among sectors of the industry. A systematic analysis and case studies that explore these issues could be very useful in identifying the factors involved.

PROTECTING TECHNOLOGY DEVELOPMENT

The role and importance of protecting technologies to provide incentives for R&D need further examination. According to one source, the advantage that a company receives from developing a new or different construction technology lasts, at most, for only two projects. At that point, the technology is known and available to other companies. While OTA did not examine procurement or contracting procedures in detail, it was told that specifications for construction contracts written by public agencies for large projects frequently specify the construction technologies to be used. While such specifications provide equality for bidders, they discourage innovative methods. T'his manner of procurement also provides a disincentive for companies to incur costs for R&D from which they may not benefit financially very much nor for very long. On the other hand, the specifications can help diffuse technologies, as procurement or contracting procedures become a vehicle for innovation diffusion.

OTA determined that U.S. construction firms infrequently seek patents. The lack of advantage may explain why U.S. firms spend money for "environmental scanning" (continuously searching the global environment to see what is being used or developed that they may wish to use). They obviously consider such scanning to be more cost and profit effective than R&D and seeking patents. (See chapter 3 for examples.) This may also relate to the periodic fluctuations in U.S. construction markets, which make financial commitments to R&D difficult or unwise. According to some, the human technical and organizational skills of applying a technology in large-scale construction are far more important than the proprietary advantages of construction technologies themselves which are difficult or impossible to protect.

It appears that Japan offers a contrasting case.[62] Japanese construction firms obtain patents numbering literally in the thousands, which may fit their longer time horizon and other differences in strategies for obtaining domestic and international business.

COMPETITIVE ENVIRONMENT OF THE U.S. PRIVATE SECTOR

During recent years, the competitive environment in the United States has become less hospitable for private companies to undertake R&D for the construction industries generally, As firms have sought to avoid takeovers and be more competitive domestically and internationally, they have focused on short-term profitability. In some cases, an immediate improvement in cash flow and earnings has become a company's primary objective. Often the easiest way to improve short-term profitability is to cut costs by reducing or eliminating operations that do not immediately contribute to profits. R&D operations often fall into this category as such operations. A noteworthy example is Owens-Corning Fiberglass which, faced by a takeover attempt, cut its annual R&D budget in 1986 from approximately $94 million to $48 million and cut its research staff from about 1,000 to 500 employees. Although no data were available on manufacturing firms specifically supporting infrastructure construction, some manufacturers (including Manville Corporation, Owens Illinois, Libby Owens Ford, and U.S. Gypsum) have drastically cut back their R&D efforts supporting other types of construction.[63]

The Owens-Corning Fiberglass experience is instructive in showing some of the effects of financial pressures. The company's large exploratory research program, aimed at developing new product lines, was eliminated entirely. Research supporting product lines that the company

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62 Information and discussion in this chapter of Japanese Construction activities is based, in part, on information obtained at a meeting of the Committee on the International Construction Industry of the Building Research Board, Commission on Engineering and Technical Systems, National Research Council, April 21, 1987, Representatives of the Japanese Government and four of the largest Japanese construction firms made presentations at the meeting.

63 Dr Robert C. Doban, Senior Vice President for Science and Technology, Owens-Corning Fiberglass Corporation, OTA interview, Apr. 24, 1987.

sold as part of restructuring was also halted. The company narrowed and focused its remaining R&D on short-range objectives supporting business lines that the company retained.

It appears that the push for bottom-line profitability to avoid takeovers has had a chilling effect on R&D carried on within many private companies, both those directly threatened, and those fearing a possible take over. This factor may provide a powerful new disincentive for private companies in the United States to undertake R&D activities for the construction industries broadly, including infrastructure construction. And the commitment to competition makes cooperative research efforts difficult even among firms with common needs and limited resources.

Many questions remain to be answered about the effects on competition of further internationalization of construction in general, and the effects on the American economy of Japanese and European companies entering U.S. domestic construction markets in particular. In the context of technology however, Japanese entries into American construction markets may have positive effects. Increased competition could heighten interest in R&D for construction technologies to gain competitive advantage. In consequence, technology innovations in the United States could be accelerated, and construction productivity and quality could be enhanced.

ISSUES NEEDING FURTHER STUDY

U.S. federally-funded infrastructure research emphasizes design techniques, evaluations, and other topics pertaining to domestic infrastructure projects. Although essential for good management, these types of research do not advance or support infrastructure construction technologies. Furthermore the amounts of advanced, basic, and incremental R&D for construction technologies being funded by the Federal Government are minimal. The emphasis and priorities as well as organization and magnitudes of infrastructure research pose important issues for Congress to consider. After this initial look at public works construction R&D in the United States, OTA finds a number of issues warranting further study. Among them are:

- the complex interrelationships between design and construction processes and materials choice,

- the impact of legal issues, such as risk and liability,

- identification and analysis of legal issues related to shared risk,

- alternative standards setting processes more conducive to innovation,

- an in-depth study of the economic framework for industrial and public works R&D, and innovation, and

- development of performance and certification standards for acceptance of new technologies to facilitate their use in public works.

CASE STUDY

Japanese Institutions-- A Contrast and A Challenge

Although Japan differs from the United States socially and institutionally, an examination of construction technologies R&D in that country shows both similarities and contrasts with the United States. In particular Japan has institutions that employ a strategy of using R&D to create advances in construction technologies that are then used to gain advantages in international markets.

Large Japanese construction companies operate in an institutional environment that may enable them both to enter U.S. construction markets and to compete effectively against U.S. companies in foreign markets. This institutional structure includes the establishment of significant R&D capabilities and a market strategy in which R&D and technology innovation play important roles.

Construction R&D was observed as a practice of some Japanese construction firms as early as the 1950s, and significant laboratory work was being done by the late 1960s. Around 1974, large Japanese construction companies apparently planned more extensive R&D activities leading to current levels of spending and laboratory-based research, which were achieved by the early 1980's. All this was unlike large U.S. construction firms that continued to do little, if any, R&D.

Japanese institutional support for R&D includes: (1) The Japanese Government funds feasibility studies giving initial entrance, intelligence, and influence affecting contract awards.[64] (~) Loan mechanisms from Japanese sources for financing projects in the United States often

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64 The U.S. Government has a similar funding mechanism for overseas work, but not for domestic work.

specify that monies are available only with the choice of a Japanese construction firm and not otherwise. OTA was told that U.S. construction firms may enter into joint ventures with Japanese companies to participate in this advantage. (3) Japanese manufacturers have factories built in the United States by the Japanese construction firms they are allied with in Japan. (4) Japanese real estate investments in the United States are large and growing. When construction is planned as part of a real estate deal, Japanese construction firms may be used. (5) A Japanese banking mechanism has been established in the United States useful for handling construction financing. (6) Significant R&D capabilities located in Japan in large Japanese construction firms focus on specific technologies and applications with some undetermined amount of generic or basic R&D research being done by the Japanese Ministry of Construction. (7) Construction projects in Japan are used to develop technologies. U.S. construction firms are not permitted to participate in these projects. (8) Relationships developed in the United States are used to tap into U.S. technology advances, especially in advanced areas. (9) Subsidiaries and offices of at least five of the six largest Japanese construction firms are now located in the United States with "localization" or blending efforts by the Japanese companies--for example, Shimizu Construction Co., Ltd. now has offices in 13 cities across the United States. Some projects in the United States have been built by Japanese construction firms, probably drawing on several elements of this structure.

AMOUNTS. TYPES. AND STRATEGIES OF R&D

Data on private sector R&D expenditures by large American and Japanese construction companies, presented in chapter 4, indicate that company size does not explain why Japanese construction firms do significant amounts of R&D and American firms do not. Measured by dollar or dollar-equivalent value of contracts, six U.S. construction firms led the world in size among the firms doing over !$3 billion in total contract work in 1985. Each US. company did contract work valued at more than $5 billion. Six Japanese companies followed these U.S. firms in rank order of size, each doing between $4 to $5 billion in contract work. The gap between the largest U.S. company and the largest Japanese company in the lineup was S4 billion--considerable difference.

Each of the Japanese construction firms spent roughly 1 percent annually (amounting to an average of 8 billion yen, or about $34 million using the 1985 exchange rate) of its contract revenues and employed between 900 and 1,000 people in R&D work. Comparable data for the U.S. companies are incomplete. Moreover, it is uncertain exactly what R&D activities are included in the data available for either the Japanese or American companies. Nevertheless, OTA is certain that American firms spent smaller amounts and undertook less R&D than their Japanese counterparts.

American construction firms also appear to do far more “environmental scanning” than R&D--that is, they look for new or different technologies that others are already developing or using that they might also utilize, rather than creating their own new or different methods, machinery, materials, or components. Japanese construction firms also look at what others are doing; however, their greater emphasis on and expenditures for R&D for innovation appear to be parts of their market strategy.

INSTITUTIONALIZED R&D

It appears that the Japanese have institutionalized R&D by organizing and integrating operations of large construction firms in a manner that recognizes exactly what technologies to borrow and how to adapt them to construction. It appears that Japanese construction project managers can call for R&D support when they believe it can be useful, and R&D projects may originate from field experience. Design/build contracting arrangements are frequently used, facilitating some of the integrated work, and R&D appears to be connected to specific projects and applications even in large companies. Furthermore, construction projects are planned in a manner that identifies problems on which R&D should focus, often several years in advance. For example, it required at least 8 years to develop or refine technologies to stabilize the seabed for the new Kansai Airport in Osaka Bay. One firm undertook the necessary R&D with reasonable assurance it would receive contract for that portion of the job. The Japanese thus use domestic projects requiring R&D to develop both technologies and the labor skills to apply the technologies. Both are later marketed in competitions for other projects within Japan and in foreign countries.

The manner in which the Japanese have institutionalized R&D makes it eminently suitable for translating U.S. inventiveness into construction technologies--something U.S. companies are not doing and are not organized to do. Given the present institutional mechanisms, benefits for the construction industries originating from U.S. inventiveness may be captured more by Japanese companies than by U.S. companies.

PART THREE

MATERIALS RESEARCH AND DEVELOPMENT

FOR THE NATION'S PUBLIC WORKS

TABLE OF CONTENTS

CHAPTER SIX

INTRODUCTION TO MATERIALS R&D FOR PUBLIC WORKS

The 1986 report of the National Council on Public Works Improvement (NCPW) noted that, although the basic technology of public works has changed very little in the past 50 years, "current developments in science and engineering are capable of making significant contributions to the improvement of every major infrastructure sector in the foreseeable future."[1] The Council's report concluded that new or improved materials can significantly improve the condition of our Nation's infrastructure and even minimal efforts could yield substantial benefits, However, they also found that a number of formidable institutional constraints inhibit the application of new technology in the construction industry generally, and especially in public works.

Th s part of the OTA Staff Paper evaluates the importance of materials R&D efforts to rebuilding and maintaining our Nation's public works, and identifies some of the most recent developments in materials for infrastructure, These include cement and concrete, asphalt, plastics and other synthetics, geotextiles, and paints and coatings (see chapter seven). In addition, it describes current Federal and nonfederal programs supporting materials R&D for public works (chapters eight and nine). The Federal agencies examined include the Departments of Transportation, Commerce, Defense, and the Interior; the Environmental Protection Agency; and the National Science Foundation. Federally-supported highway materials research programs of the

[1] National Council on Public Works Improvement, The Nation's Public Works: Defining the Issues (September 1986),

National Research Council also are discussed. This part also briefly describes foreign R&D programs for infrastructure materials (chapter ten). Finally, it outlines institutional issues and materials research needs that OTA staff identified during the course of preparing the paper, and discusses options for resolving those issues (chapter eleven).

This is not an exhaustive review of all aspects of materials R&D for public works. OTA Energy and Materials Program staff relied on an extensive literature survey supplemented with information obtained in meetings and telephone conversations with Federal agencies, trade associations, and companies. Several questions were impossible to address adequately within the time constraints of this survey. In particular, we were unable to quantify the size of the materials R&D needs, or the point at which R&D investment reaches diminishing returns. Instead, we provide a qualitative discussion of the materials R&D areas that would deliver the "biggest bang for the buck," and discuss ways of targeting the available R&D to make it more effective. In addition, we were unable to conduct thorough reviews of foreign R&D and of the constraints introduced by Federal contracting policies.

WHAT ARE INFRASTRUCTURE MATERIALS?

Materials may be defined as "the 'stuff' that things are made of." There are two basic classes of infrastructure materials: 1) natural or construction materials, which derive their properties in the field or in use (e.g., asphalt, concrete, cement, stone, sand and gravel, coatings); and 2) manufactured products that are fabricated from materials in a controlled environment and tend to have more consistent properties (such as pipes, gaskets, liners, membranes, filters, hoses, and precast concrete items). OTA*S primary focus in this Staff Paper is on natural and construction materials (see chapter seven).

WHAT IS INFRASTRUCTURE MATERIALS R&D?

The materials industry and its R&D projects vary widely--from “high tech” ceramics and composites to such basic materials as sand and gravel.[2] Infrastructure materials R&D includes both basic and applied research. The basic research focuses on the scientific understanding of the characteristics and properties of different materials, their performance in use, their modes of failure (e. g., fracture, deformation, delamination, rutting, slumping, corrosion, etc.), and their interaction with the environment. Applied infrastructure materials R&D examines methods of prolonging and enhancing the performance of materials in place, and of predicting and preventing failure, including the development of nondestructive testing methods. In addition, the materials industry frequently evaluates and adapts technologies or materials developed for other uses to infrastructure needs or to specific local infrastructure problems. In this latter sense, infrastructure materials R&D includes some work that in other fields might be dismissed as neither advanced nor incremental, or perhaps not even research.

Research and development on infrastructure materials currently is sponsored and carried out by a number of Federal agencies, and by State and local governments, universities and research centers, trade associations, and corporations. Based on our brief survey, OTA estimates total materials-related R&D to be $53 million to $62 million in FY86, with around $35-!$37 million coming from Federal agencies and programs (see chapter eight) and the remainder from nonfederal sources (chapter nine). Nearly half of the Federal R&D (around $17 million in FY86) is sponsored by the Department of Transportation (DOT). The second largest chunk of

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[2] The materials industry can be characterized as a “mid-day” industry--one that is essential to the basics of life, food, shelter, and transportation. At the same time, much of Federally-funded materials R&D is directed toward academic “big physics” and “high tech” projects with little application to the needs of the domestic materials industry. Statement of Dr. Rustum Roy, Pennsylvania State University, Hearings on Materials Research and Development Policy, Subcommittee on Transportation, Aviation and Materials, House Committee on Science and Technology, 98th Cong., 1st Sess., 1983, at pp. 258-67.

Federal materials R&D for public works comes from the Department of Defense, Army Corps of Engineers ($12-$13 million). Other Federal research efforts are conducted by the Environmental Protection Agency; the National Bureau of Standards, the National Science Foundation; the Department of the Interior, Bureau of Reclamation; and the Department of Agriculture, Forest Service.

Of the $18 million to $25 million spent annually on nonfederal materials R&D for public works, around 60 to 65 percent is related to highways, roads, and bridges. This is funded by State and local governments and regional transit agencies, as well as professional organizations and trade associations and their affiliated research foundations (e. g., the Asphalt Institute, American Public Works Association).

Materials are an important cost component in sewer construction and maintenance, and the larger municipal sanitary districts are a significant source of funding for materials-related research for sewers and wastewater treatment systems. Other sponsors include professional and trade associations; engineering, consulting, and construction firms; and equipment and materials suppliers. Together, these groups spend approximately $3 to $5 million annually on wastewater R&D. Another $1 million in nonfederal funds for materials R&D is devoted to water supply and treatment, primarily by local governments. Finally, around $100,000 to $500,000 in nonfederal R&D is spent annually on materials for water resource projects, waterways, and ports.

HOW DOES DOMESTIC MATERIALS RESEARCH FOR PUBLIC WORKS COMPARE TO R&D EFFORTS ABROAD?

Successful development of materials and their incorporation in public works projects require a favorable climate and appropriate incentives-- both of which are lacking in the United States. Strong incentives are available in other countries to work the “bugs” out of theory and move new ideas to the marketplace (see chapter ten). In both Japan and Europe, for example, the governments encourage innovation and development through tax incentives or matching funds, and through flexible bidding concepts. Government-industry co-funding assures a company's willingness to commercialize results after research is completed. West Germany, for example, makes public grants available for the introduction of promising innovations into commercial markets. Also in Germany, special "linker" organizations facilitate innovation by expediting the flow of technical information and contributing to the stimulation of new ideas.[3]

In the U. S., industrial materials research and development are product-oriented, and aimed at maintaining a competitive edge.[4] However, the numerous materials programs and researchers, and the inadequate information flow among them result not only in duplication of efforts, but also in gaps in the materials R&D agenda. In comparison, both the Japanese and German governments have agencies that coordinate research and disseminate information.

Also, few U.S. universities have construction-related materials programs, and many civil engineers have little or no training in materials science. The opposite is true in Europe and Japan where specialty engineers receive cross-disciplinary trainings

An integrated approach to design, engineering, and construction would benefit infrastructure projects by identifying optimal materials for specific projects. An integrated approach also would help facilitate the transfer of information more readily. Although the U.S. is not presently pursuing this approach in any organized manner, other developed nations have established integrated research programs, such as Switzerland's efforts in concrete technology.[6]

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[3] Sherman Gee, Technology Transfer. Innovation and International Competitiveness, New York: J. Wiley & Sons, 1981.

[4] Nonproduct-oriented research generally focuses on software and management systems.

[5] Daniel W, Halpin, Technology in Architecture, Engineering, and Construction (Contractor Report to OTA, Tasks 1 and 2, chapters 8 and 13, March 17, 1986.

[6] Ibid., Chapter 8.

CHAPTER SEVEN

RECENT MATERIALS DEVELOPMENTS

INTRODUCTION

Research and development for new materials and improvements in existing materials are of vital importance to our Nation's infrastructure, yet U.S. efforts lag far behind needs. This has not always been the case. In the first half of the 20th century, for example, U.S. research in cement and concrete provided the basis for developments in concrete technology throughout the world. Today, Europe and Japan have assumed the leadership role in some areas of cement and concrete research and development (e. g., kiln technology and concrete admixtures), and the U.S. has taken the "back seat." A brief description of some of the more recent developments in R&D for cement and concrete, asphalt, and plastics and other synthetics follows. Potential economic and performance benefits of using these new and improved materials could not be quantified within the scope of this brief survey, However, a few examples of research areas with potentially big "payoffs" are given in chapter one.

CEMENT AND CONCRETE

Cement[7] is the "glue" in the most widely used composite material--concretes Concrete is used in larger quantities than any other man-made material, and is the preferred material for civil engineering construction.

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[7] Portland cement is a dry powder composed of compounds of silica, alumina, lime, and iron oxide, which forms a hardened paste when mixed with water; it generally is used as a binder with aggregate to form mortar or concrete, but also may be used in its paste form as a structural material.

[8] Concrete is a mixture of aggregate, water, and a binder (usually portland cement) which hardens to a stone-like condition. The more water used in mixing, the higher the porosity of the hardened concrete. Pores act as crack nuclei, the consequence of which is that the tensile strength and fracture toughness of concrete are usually low. To improve its usefulness, concrete must be reinforced with steel and/or its porosity reduced.

The primary advantages of using cement and concrete are that they are durable, versatile, inexpensive and easy to produce. Despite the importance of these materials and their advantages, however, U.S. investments in cement and concrete research have been minimal. According to a 1980 report on the Status of Cement and Concrete R&D in the U.S., Federal and private funding for basic research are inadequate, and only a few universities are involved in R&D efforts. Furthermore, research efforts are fragmented, and the flow of scientific and technological information among cement producers and users and the related governmental, academic and industrial establishments is inadequate.[g]

The same report recommended that government agencies with responsibilities for energy, materials, the environment, and construction should increase their support of long-range fundamental research on the manufacture and use of cement and concrete. It also recommended that efforts should be made to devise an improved mechanism for transferring research results to development and practice. The report further suggested that special attention be paid to studies of: a) basic mechanisms, such as hydration and crystal-phase development in cement, and hardening and strength development in concrete; b) long-term behavior and durability in extreme environments; c) use of energy and resources in producing cement and utilizing concrete products; and d) the interaction of experiment, theory and modeling.

Perhaps one of the greatest challenges facing the cement and concrete industry is to produce materials that are both highly durable and economical. Some of the latest developments in cement and concrete materials used for infrastructure are cement-based composites, concrete admixtures, fiber-reinforced concrete, polymer concretes, and high-strength concrete.

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[9] Frohnsdorff, G. and J. Skalny, Cement in the 1990s: Challenges and OD Dortunities, Phil. Trans. R. Soc. Lend., Volume 310, 1983, p. 18.

Blended Cements

Blended cements, which have been introduced within the last decade, combine portland cements with one or more different types of reactive byproducts, such as blast-furnace slag, fly ash, or silica fume. The addition of these particulate to portland cement can enhance its strength and increase the durability of steel-containing cement composites used in highways and bridges. Use of these materials, however, depends on local availability. For example, silica fume is a byproduct of the metallurgical operations in the production of silicon metal or ferro-silicon alloys and is available only in limited quantities. The Bureau of Reclamation has conducted field tests of silica fume concrete at American Falls Dam; and the Army Corps of Engineers, Concrete Technology Division, has evaluated and tested concrete containing silica fume and fly ash.

Fiber-Reinforced Concrete

Fiber-reinforced concrete is concrete made of hydraulic cements containing fine, or fine and coarse, aggregate and discontinuous discrete fibers. Some of the fibers used to reinforce concrete include steel, glass, carbon, nylon, polyethylene, and polypropylene, Fiber-reinforced concrete has the potential to improve the strength and durability of pavements, bridges, dams, and buildings. Also, fiber-reinforced concrete has been used to stabilize rock slopes, armor jetties, and line mine tunnels. Several examples of field applications of fiber-reinforced concrete include: paving applications of steel fiber-reinforced concrete at McCarran International Airport (aircraft parking area), Cannon International Airport (new taxiway), and Fallen Naval Air Station (aircraft apron); dam repair to stop erosion of plunge pool bedrock at May field and Alder Dams, and construction of spillway deflectors on Lower Nionumental Dam and Little Goose Dam on the Snake River.[10]

10 ACI Committee 544, "State-of-the-Art Report on Fiber Reinforced Con Crete, Con Crete International, May 1982.

The addition of small fibers to concrete continues to be researched by both the Federal and private sectors. The National Science Foundation (NSF) is currently funding work in this area, and the Portland Cement Association is doing some R&D on glass fiber-reinforced concrete for use in parking lots to control cracking.

Polymer Concretes

Polymer concrete is a composite material formed by incorporating a polymer[11] as a binder in a mixture of fine and coarse aggregate; no other cement is used. Many different polymers can be used: acrylics, polyesters, vinyl esters, polyurethane, styrene-butadiene, and polyvinyl acetate and epoxy resin. Current polymer concrete uses include patching and reconstruction of concrete structures; rehabilitation of pre-cast panels on bridges; and application of thin, waterproof, and saltproof overlays on roads. One of the main advantages of using polymer concrete is that traffic is disrupted for shorter periods of time during construction.

Thus far, polymer concretes have not found extensive application because the technology has not been perfected and production is costly. Consequently, the polymer concrete industry has not grown in recent years. DuPont, for example, stopped manufacturing this material because the concrete was cracking. Companies like duPont are watching the industry closely so that if a sufficient market develops, they could restart their operations.[12] On the Federal side, the Army Corps of Engineers, through its Repair, Evaluation, Maintenance and Rehabilitation Research Program (REMRR) and its Waterways Experiment Station, has conducted demonstrations of polymer concrete use in repairing concrete structures (e.g., dams). The Bureau of Reclamation also is funding a "concrete materials systems" research project, that will include polymer concrete development and evaluation.

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11 A polymer is a substance made of giant molecules formed by the union of simple molecules (monomers); for example, polymerization of ethylene forms a polyethylene chain.

12 Business Communications Company, Inc., Strategies of Advanced Materials Suppliers and Users, Contractor Report to OTA, 1986.

Roller Compacted Concrete

Roller compacted concrete (RCC) requires less cement and lower quality aggregates than conventional concrete. Compaction is used to reduce pore space, thereby decreasing permeability and enhancing durability,[13] The in-place cost of RCC is about one-third 1ower than that of conventional concrete. Also, RCC pavement takes less time to spread than conventional concrete. Roller compacted concrete is suitable for dams and pavements. The Army Corps of Engineers built the world's first RCC dam (Willow Creek) in the early 1980s; now there are RCC dams under construction all over the world. The first commercial RCC pavement was built in Houston in 1985 for the Burlington Northern Railroad's intermodal hub facility .[14] The NSF, Army Corps of Engineers, Bureau of Reclamation and the Portland Cement Association have funded research and demonstration projects on RCC technology.

ASPHALT

Asphalt[15] is most commonly used as a paving material. Of the 32 million short tons of asphalt produced in 1986, about 70 percent was used for paving. Generally, asphalt R&D efforts have concentrated on improving the performance and workability of the material. According to the Asphalt Institute, some of the activities undertaken by the private sector have focused on several areas:

- o development and evaluation of asphalt additives to control pavement rutting, thermal cracking, and load-associated fatigue;
- o improvements in asphalt cement specifications for low temperature behavior, oxidative hardening, and compatibility with aggregates, and environmental and safety concerns;

13 Halpin, supra note 5, at p. 12.

14 "New Ways With Concrete," Civil Engineering, May 1985.

15 Asphalt is a brown t. black bituminous substance found in natural beds and, more importantly, obtained as a residue in petroleum refining. It consists chiefly of hydrocarbons.

- refinements in production processes at refinery;
- development of mix design methods for aspha t concrete under various climate and traffic conditions;
- evaluation of the effect of changes in external ~actors (truck weights, new types of hot mix production, compaction equipment and techniques, etc.) on the asphalt concrete;
- field performance evaluation of asphalt pavements;
- development of new uses for asphalt cement, such as in construction of asphalt concrete roadbeds for railroads; and
- investigation of the chemistry of asphalts.[16]

On the Federal level, the Strategic Highway Research Program (described in chapter eight) proposes to investigate asphalt as it relates to pavement performance, qnd ultimately will develop performance-based specifications for asphalt and asphalt-aggregate mixtures.

PL,4STICS

Radically different pipe production methods provide the greatest potential for plastics use in infrastructure. Up until recently, polyvinyl chloride (PVC) pipe has only modestly penetrated the sewer and water supply pipe market, because it is costly to manufacture and has not met American Society for the Testing of Materials (ASTM) specifications for compression resistance, flexural strength, and other loading parameters. Two recent major breakthroughs in pipe production methods have made it possible to manufacture heavy-duty PVC pipe in bores from 27-60 inches and larger-- big enough to compete with concrete in sewer and water pipes. One of the new production methods was developed in Greece by A.G. Petzetakis S.A. and is marketed in the U.S. by Aim International. The pipes manufactured using this process are

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16 OTA staff meeting with Asphalt Institute executives, March 17,1987.

equivalent in compressive strength and stiffness to solid-wall pipe. The Petzetakis system also cuts materials use by as much as 50 percent.[17]

The Ultra-Rib system is the other new breakthrough for making heavy-duty large-bore, vinyl pipe. This system was developed by Corma, Inc., a Canadian pipe corrugation equipment manufacturer, and Oy Uponor AB, a Finnish pipemaking and equipment company. In the Ultra-Rib system, the pipe is extruded from a specialized die, and then enters a forming unit developed by Corma that puts radial stiffening ribs in the pipe at rates more than twice as fast as for solid pipe. Extrusion Technologies Inc. has entered into the first Uponor process license agreement in the U. S.; they plan to make and sell Ultra-Rib sewer pipe up to 18 inches in diameter by Spring 1987.[18]

GE OTEXTILES

Geotextiles[19] are woven and nonwoven fabrics used in drainage, erosion control, materials separation, and soil reinforcement. The Pennsylvania Department of Transportation (DOT) was one of the first agencies to use geotextiles, and to evaluate their strength and permeability after one-, two- and six-year intervals. Their test results showed that, while fabric permeability and strength decreased somewhat over time, the geotextiles were still performing satisfactorily after six years. These test results in part influenced the Pennsylvania DOT to include geotextiles as a standard part of drainage system design in locations where open-graded aggregate

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17 "The Pipe Business Gets a New Shake from Advanced Technology," Modern Plastics, February 1987, pp. 42-43.

18 Ibid p 42. and personal communication to OTA from Mr. Eckstein, Uni-Bell, March Lo, 1987.

19 Geotextiles consist of long chain polvmeric filaments or yarns, such as ProPY1ene, PolYethJ'~-ene, polyester, polyamide, or polyviny]idene- chlor ide formed into a stable network such that filaments or yarns retain their relative position to each other. The fabrics are inert to commonly encountered chemicals.

backfill requires protection from adjacent, low-plasticity fine soils that transport easily .20 The Texas State Department of Highways also evaluated the use of geotextiles as a separator between pavement base and subgrade. The evaluation showed that geotextiles are cost-effective in stabilizing lightly-traveled, thin pavements over difficult subgrade.

Geotextiles can also be used in drainage systems and wastewater treatment facilities. For example, in Muskogee, Oklahoma, geotextile liner panels were used to repair concrete walls at a water treatment plant.

In addition, the Army Corps of Engineers, Waterways Experiment Station, has used geotextiles for streambank protection, and the Bureau of Reclamation has funded a multi-year program to line all of its canals with geotextiles. The fabric linings are used to prevent water loss, erosion, and contamination in arid areas.

The geotextile industry has shown tremendous growth. Sales increased from $10 million in 1980 to $250 million in 1985.[21] In 1985, the amount of geotextiles used in Europe and North American reached about 300 million square meters.

ANTICORROS1ON METHODS[22]

The deterioration of steel-reinforced concrete bridge decks and structural steel members is a serious national problem. A major cause of the concrete deterioration is the corrosion of embedded black steel reinforcing bars by chloride ions that permeate the concrete cover. These chloride ions are derived from de-icing salts applied directly to the bridge decks, or from marine environments.

ZO Materials and Testing Division, Bureau of Construction Quality Control, Pennsylvania Department of Transportation, Lone-Term Insitu Prot)erties of Geotextile~, January 1983, pp. 22-23.

21 “Engineering with Fabric,” Civil En~ineerinq, December 1985.

22 This section is based on infornlation received from the Federal Highway Administration, Office of Research, Development and Technology, May 22, 1987.

New construction provides the best opportunity to protect bridges against corrosion. According to the Federal Highway Administration (FHWA), a number of protective systems have proven effective. These include epoxy-coated rebars, corrosion inhibitors incorporated in the steel, and concrete coatings such as epoxies, polymer overlays, and sealers. Epoxy-coated rebars are the most effective bridge corrosion protection, followed by corrosion inhibitors and coatings. Two methods commonly used to rehabilitate older salt-contaminated concrete bridges are overlays and cathodic protection.

EDox~-Coated Rebars

Epoxy-coated rebars, first used in 1973, became a FHWA-approved protective system in 1976. Forty-six States use epoxy-coated rebars for new bridge deck construction. The fusion-bonded epoxy coating forms a protective barrier against the corrosive action of chloride ions. The FHWA is funding research to evaluate epoxy-coated rebars for substructure and superstructure members, as well as epoxy-coated seven-wire strands for prestressed concrete bridge components.

Corrosion Inhibitors

Corrosion inhibitors such as calcium nitrite are being considered for use in concrete bridge components that cannot be built with epoxy-coated rebars. The FHWA reported that, in the laboratory, these materials effectively reduced corrosion of black steel rebars when chlorides were present in the concrete. A number of structures currently are using this system,

CoatinPs

A number of States coat non-traffic, non-abrading concrete surfaces with either sealers, penetrants, epoxies, or polymer overlays. These coatings reduce the penetration of chloride ions and water, protect the embedded reinforcing steel, improve the properties of hardened concrete against freeze-thaw deterioration, seal cracks, and strengthen concrete. When used in combination with quartz aggregate, these types of coatings also can reduce slipperiness on wet or icy surfaces.

Overlays

According to FHWA, a relatively large number of bridge decks have no built- n protective systems, but still contain sufficiently few chloride ions that they do not yet need to be replaced. These bridges can be rehabilitated effectively with a good quality overlay that is impermeable to, and thus will prevent additional contamination by, chloride ions and water. A variety of overlay materials, such as latex-modified concrete, high-density low-slump concrete, silica fume concrete, and polymer concrete, can provide 15-20 years of additional bridge deck life with a smooth riding surface.

Cathodic Protection

Cathodic protection is another technique that has been used to stop corrosion of reinforced concrete components if the concrete is durable and has not already deteriorated significantly. The technique involves forcing a low-level electric current through the concrete to the rebars to counteract the corrosive current that flows naturally between steel and salt contaminated concrete. Cathodic protection technologies require regular monitoring and maintenance. The Federal Highway Administration recommended the use of cathodic protection in 1982, and this technology now is gaining acceptance by transportation officials, engineers, contractors, etc.

The technology for cathodic protection of bridge *decks* has matured enough that a number of durable systems are available today. About 150 systems have been installed, most of which are on bridge decks. Systems for *substructure* bridge components are still under intense development. None of the available cathodic protection technologies has been installed for a sufficient period to evaluate long-term durability, however.

As part of its research on cost-effective methods for combating corrosion, the Construction Engineering Research Lab, Army Corps of Engineers, developed a breakthrough in cathodic protection -- the ceramic anode. This anode makes corrosion protection available at one-fourth the cost of previous technologies, and in a size that permits installation in areas previously considered too small. One ampere of current supplied to the ceramic anode will stop corrosion on 500 square feet of uncoated steel. An exclusive license for the ceramic anode patent was awarded to APS Materials, Inc., of Dayton, Ohio, in May 1984.[23]

23 Telephone conversation with Paul Howdyshell, Construction Engineering Research Laboratory (CERL), Army Corps of Engineers, March '16, 1987; and CERL Fact Sheet, September 1986.

CHAPTER EIGHT

FEDERAL PROGRAMS SUPPORTING RESEARCH ON MATERIALS FOR PUBLIC WORKS

The Federal Government directly and indirectly funds a wide range of materials-related R&D for public works, including improved materials for highways, water supply and waste-water treatment systems, dams, airports, and public buildings. Table 8-1 shows the approximate Federal expenditures on materials-related infrastructure R&D in FY86; detailed breakdowns and project lists may be found in the Appendix.

DEPARTMENT OF TRANSPORTATION

Within the Department of Transportation, the Federal Highway Administration (FHWA) is the primary sponsor of Federal R&D on highways, roads, and bridges. Directly-funded FHWA research includes both internal staff research and external contract research. Total funding for *all* types of FHWA direct R&D activities was about $30 million in FY86, including administrative expenses (employees' salaries and overhead). FHWA estimates that total highway and bridge construction, maintenance and repair R&D was $11.6 million in FY86.[24] Of this, around $2.5 million, or 22 percent, was materials-related. FHWA staff research accounts for about 15-20 percent of FHWA staff time. FHWA administrative contract research is conducted by outside engineering firms, consultants, universities, industry research organizations, and the National Bureau of Standards.

Most of FHWA'S directly-funded R&D on highway design, construction, operations, and maintenance is performed by the Office of Engineering and Highway Operations Research and

24 The FHWA also conducts research on highway safety and traffic operations.

Table 8-1

FEDERAL INFRASTRUTURE MATERIALS RESEARCH AND DEVELOPMENT EXPENDITURES
FY1986

Federal Agencies	Millions of Dollars
Department of Transportation	
Federal Highway Administration	2,5
State HP&R Program	9.5 (est.)
NCHRP	3.2
Other DOT agencies	2.0
Department of Defense	
Army Corps of Engineers	
Civil Works	9.9
Military Facilities	2.0-3,0
Other DOD	N/A*
Environmental Protection Agency	
Drinking Water	<2.0
Municipal Wastewater	<1.0
Department of Commerce	
National Bureau of Standards	
Center for Building Technology	2.4
Materials Sciences & Engineering	N/A*
National Science Foundation	
Systems Engineering	1.0-1.2
Other	N/A*
Department of the Interior	
Bureau of Reclamation	1,0
Other DOI	N/A*
Department of Agriculture	
Forest Service & other	0.2
TOTAL	35.0 - 37.0**

* No estimate provided for infrastructure-related materials R&D.

** Excludes Federal funding of Strategic Highway Research Program in the National Academy of Sciences, which could add $30-50 million annually over five years.

Development. Their major project areas include research on rigid pavements (concrete and cement) and flexible pavements (asphaltic materials), on protection of steel and other metal reinforcement and structural components from corrosion, and on protection of concrete and asphalt pavements and structures from corrosion and deterioration. Other materials R&D concentrates on the evaluation of new or different commercially available materials for construction, repair, and corrosion protection. Basic research aimed at developing new materials and materials applications for highway use is now probably less than $200,000 per year. The Office of Highway Operations also supports some experimental highway construction and pavement demonstration projects with materials components, but the approximate level of funding is not available.

Internal FHWA funding for research on paving materials, including asphalt and concrete, has been cut considerably in recent years in anticipation of the relatively high funding levels for pavement research under the Strategic Highway Research Program (described later in this chapter), and because FHWA believes that State work under the Highway Planning and Research Program (see below) is sufficient.[25] Based on project summaries provided by FHWA, OTA estimates that materials-related research within the FHWA declined from $2.7 million in FY85 to about $1.9 million in FY87. In contrast, in the mid-late 1970s FHWA direct contract research on asphalt alone was several million dollars per year. In addition, the number of FHWA staff engaged part-time in research has been declining, although there has been an increase in the number of contract research personnel at the FHWA facility in McLean, Virginia.

FHWA also oversees the distribution of Federal research funds to the States under the Highway Planning and Research Program and the National Cooperative Highway Research Program. The Highway Planning and Research Program (HP&R) is a cooperative Federal-State research program that finances State highway planning and research efforts under general FHWA

25 See for example, Federal Highway Administration, FC'P Annual Progress Report for Year Endin~ September 30, 1985, Project No: 4D, "Improved Flexible Binders".

oversight and coordination. HP&R funds are 1.5 percent of each State's share of Federal-aid highway funds, with an optional 0.5 percent available for urban highway research and planning.

Each State decides on the relative allocation of its HP&R funds to planning and research. The average distribution of HP&R funds nationwide is 20 percent for research and 80 percent for planning, with individual State research allocations ranging between 5 percent and 55 percent of State HP&R funds. However, States' definitions of "research" are very broad and often include evaluation of commercially available materials and processes for road construction specifications. FHWA figures indicate that total HP&R funds were $178 million *in* FY86 and $165 million in FY85. About 30 percent, or $47.3 million was spent on research in FY86, slightly more than the $46.1 million spent in FY85.[26] Based on Hp&R project information, OTA estimates that materials-related research probably absorbed 10 to 20 percent of that $47.3 million.

The National Cooperative Highway Research Program (NCHRP) is coordinated by the American Association of State Highway and Transportation Officials (AASHTO), the FHWA, and the Transportation Research Board (TRB). The respective roles are: the States finance NCHRP by contributing 4.5 percent of their HP&R funds; the Transportation Research Board (TRB) administers the program with the approval of State officials; AASHTO'S Select Committee on Research chooses the research activities; and FHWA provides general oversight, and reviews contracts and the technical content of research projects. The NCHRP relies extensively on universities, research foundations, and private firms to conduct research, although there are some contracts with State personnel.

The Transportation Research Board estimates that NCHRP funds actually available for research (i.e., excluding TRB-AASHTO administrative expenses) are between $3.5 and $5.5

26 The FHWA estimates of actual State research spending exclude State funds passed through to the National Cooperative Highway Research Program, which were $7.4 million in FY85 and $8 million in FY86.

million annually.[27] Estimates of the portion of this allocated to materials-related research vary. One TRB project manager suggested that materials research should include materials characterization as well as materials aspects of pavement performance, construction, design, maintenance, and repair. Based on this definition, he estimated that, on the average, 25 to 30 percent of NCHRP work is materials-related. Actual project figures provided by TRB to OTA suggest that materials-related projects may have totaled as much as 45 percent of total NCHRP research spending for FY85-FY87. These projects include research on: corrosion protection; the evaluation of materials additives; the performance of pavements and structures; and the development of pavement management systems, of techniques for predicting materials performance and failure, and of nondestructive evaluation methods.

The Federally Coordinated Program of Highway Research & Development (FCP) was set up in 1971 to coordinate State and Federal activities. FCP covers virtually all of the FHWA staff and contract research, and about 70 percent of State HP&R and NCHRP work.[28] The FCP categorizes State and Federal projects according to overall research goals and reports on progress and publications; it has no separate research budget.

OTA estimates that research on infrastructure materials conducted by other DOT agencies and programs probably totals around $2 million per year:[29]

o The National Highway Traffic Safety Administration (NHTSA) researches the relation of vehicle characteristics and roadway design and construction to aGcident prevention;

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27 Funds actually allocated to research vary from year tO year because of multi-Year and "phased" projects. Of $10.1 million in actual NCHRP project expenditures for FY85-87 reported to OTA by the Transportation Research Board, about $4.6 million was dedicated to materials-related projects.

28 Most of the remaining 30 percent of Hp&R work focuses On SIXCkil local needs or n~tional problems selected independently by h'CHRP committee.

29 Transportation Research Board, A mer *ica's H i ~h wQvs:* Accelerating the Search for Innovation, Special Report 202, 1984, at pp. 36-37,

- The Urban Mass Transportation Administration (UMTA) supports some research that directly relates to street design and operation;
- The Transportation Systems Research program in Cambridge, Massachusetts conducts some materials research as part of studies funded by other DOT agencies, such as an evaluation of high-strength concretes for mass transit tunnels and structural support systems;
- The Federal Aviation Administration (FAA) sponsors some pavement-related research on airport runways that also could be applicable to highway problems; and
- The DOT Office of University Research funds highway transportation research projects through a special grant program.

DEPARTMENT OF DEFENSE

The Department of the Army-Corps of Engineers manages the second largest Federal R&D effort on infrastructure materials. This R&D supports the Corps' responsibilities for construction and maintenance of water resource projects, dams, locks, waterways, ports, flood control projects, and military facilities. The Corps spends approximately $1.6 billion annually on civil works construction, and an additional $1.4 billion on operations and maintenance. The Corps also spends about $1.5-$2 billion per year for new construction on Army installations, and around $1.8-$2 billion annually in maintenance and repair. Their annual R&D budget for *civil* works is about $30-$35 million, of which about $9.9 million is materials-related. The Corps also spends at least $2-$3 million annually on *military* R&D projects relevant to infrastructure materials.

The Army Corps of Engineers maintains a broad range of materials science and engineering R&D and technology transfer activities to support its civil and military missions. Their generic materials-related research involves materials characterization, performance evaluation of materials in use, corrosion prevention, and development of maintenance management systems and nondestructive testing methods and equipment,

Of particular interest to this survey are the Corps' special research and demonstration programs that promote the application of innovative technologies to infrastructure problems.

The Repair, Evaluation, Maintenance, and Rehabilitation Research (REMRR) Program is a six-year, $35 million effort set up to meet the need for research to meet the growing demands of the Corps' civil works. The Facilities Technology Applications Test (FTAT) Program--a five-year, $29 million effort-- focuses on transferring advances in operations, maintenance, and rehabilitation technologies from the Corps' research laboratories (see below) to Army installations through demonstration projects on energy conservation, building maintenance and repair, pavements, railroad maintenance, and environmental quality. Many of the technologies and methods selected for demonstration in the FTAT Program are derived from the Corps' military-related Base/Facility Development and Installation Support Research Programs.[30] In FY87, the Corps initiated a companion program to FTAT, the Technology Transfer Test Bed Program, to promote the application of their R&D resu ts in new construction at military installations. According to Corps' researchers, the multiple military technology transfer programs in part refleet the separate appropriations for Corps' mi itary R&D and military construction.

The Corps maintains four major research laboratories to conduct its R&D and to provide technical assistance, testing, and other analytical services for its civil and military operations. Eight smaller laboratories provide quality control, as well as detailed testing and analyses of construction and other materials, for investigations, design, and construction of specific civil and military projects. The three major laboratories that carry out infrastructure-related R&D are: the Construction Engineering Research Laboratory in Champaign, Illinois; the Waterways Experiment Station in Vicksburg, Mississippi; and the Cold Regions Research and Engineering Laboratory near Hanover, New Hampshire.

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30 The Corps did not provide project lists or estimates Of FY84-FY86 funding for materials-related research with potential application to civilian public works under the military-funded Base/Facility Development and Installation Support Research Programs. Therefore, these efforts are not reflected in OTA's estimates of total R&D expenditures for those years in Table 1 and else where. OTA estimates that, in FY87, the Corps may spend from $3-$4 million on materials-related R&D under these programs in three areas: construction materials, maintenance management systems, and pavements and foundations.

The Construction Engineering Research Laboratory (CERL), which is associated with the University of Illinois, has primary responsibility for the Corps' R&D on buildings and structures and on life-cycle management of Army installations. CERL'S major materials-related research emphases are on the performance characteristics of metallic construction components (especially welding technology), and on the evaluation of coatings and other corrosion preventives. One product of CERL'S facilities management R&D was the PAVER system--a computerized pavement maintenance and management system for roads and airport runways. PAVER later was adapted for civilian use in cooperation with the American Public Works Association. CERL also does work on water and waste water treatment systems for military facilities. CERL'S research budget is approximately $40 million per year, of which about 10 percent or $4 million involves materials-related research relevant to public works.

The Waterways Experiment Station (WES) is the largest of the Corps' research laboratories. Its research activities encompass materials and techniques for construction, maintenance, and repair of pavements, waterways, dams, ports, and concrete structures, including some work on geotextiles. WES also investigates the effects of coastal and riverine processes on navigation, flood and erosion control, and coastal and offshore structures and their component materials. WES' concrete research alone is estimated at $1.2 million in FY87.

The Cold Regions Research and Engineering Lab (CRREL) focuses on the special materials, engineering, and construction problems of cold environments. CRREL'S work on pavement performance and subsoil characteristics under extreme cold and temperature variations is useful to the military services as well as to northern State highway agencies. No estimate of CRREL'S infrastructure materials R&D budget is currently available, but it is much smaller than programs at other Corps laboratories.

iMuch of The Corps' materials research is intended to support its construction and maintenance functions and is not directed primarily at the development of new materials. However, if commercially available products are not adequate for, or cannot be adapted to solve the unique problems often encountered in Corps' facilities, researchers will develop a new product or technology. As a result of such original problem-oriented research on corrosion prevention, for example, CERL developed ceramic anodes for cathodic protection systems. These anodes are smaller, last longer, and cost less than current silicon- iron and graphite anodes. CERL licensed its discovery to a private manufacturer for use on bridges and other structures.

The Army, Navy, and Air Force fund other materials research with potential application to public works. For example, both the Navy and the Air Force operate smaller versions of the Corps' research laboratories to support their own facilities construction and maintenance programs. No estimates of total or materials-related infrastructure R&D for these programs were provided. In addition, the services have been expanding their support for materials, construction and engineering R&D at university research centers. For example, the Army funds two newly-established Centers of Excellence in Building Construction Technology at the Massachusetts Institute of Technology and the University of Illinois. These Centers may conduct research on building construction materials that are also suitable for other categories of public works. Similarly, the Air Force is funding a Center for Cement Composite Materials at the University of Illinois with a 3-year grant totaling nearly $3 million.[31] Detailed information on research at these Centers is not yet available, but they probably will represent a very small portion of DOD's research expenditures.

Finally, there is probably some spinoff potential for infrastructure materials from R&D on ultra-high-strength concretes and advanced ceramics and composites from the strategic defense initiative program and other military research. For example, work for the Air Force at the National Bureau of Standards' Center for Building Technology and elsewhere examines means of reducing porosity in concrete to improve its strength and its resistance to cracking and

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[31] Chemical and Engineering News, March 30, 1987, p. 16.

to corrosive materials. The characteristics of these concretes for defense purposes (hardened structures, runways) are not sufficiently different from those of interest to highway agencies.

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) funds R&D on drinking water quality and wastewater treatment to support its program and regulatory responsibilities under the Safe Drinking Water Act and Clean Water Act. Research funds are split between EPA's Office of Research and Development (ORD) and the regulatory programs. EPA budget figures indicate that total R&D funds for drinking water are about $13 million per year, and for wastewater treatment, about $8 million.[32] Research budgets under both programs are projected to increase slightly due to additional efforts arising from reauthorization and amendment of the Safe Drinking Water Act in 1986 and the Clean Water Act in 1987.

Under both the regulatory and ORD drinking water programs, EPA has sponsored research projects directly related to the construction, maintenance, repair, and rehabilitation of water supply systems, such as the corrosion of water pipes and ways to prevent or slow their deterioration. EPA also has studied how pipe deterioration contributes to the contamination of drinking water supplies (through leaching and erosion of contaminants such as copper, lead, lead solder, and asbestos fibers from pipes and joints), and means of prevention.

Most of EPA's water supply R&D is conducted at the EPA water research facilities in Cincinnati, Ohio. Their total FY86 drinking water research budget is about $5 million (including salaries, overhead, and extramural research). OTA estimates that expenditures for materials and infrastructure-related drinking water research were less than $2 million, including a $1 million "seed money" grant to the American Water Works Association Research Foundation. However, R&D directly related to infrastructure construction and repair has now largely been

32 These figures exclude salaries and overhead.

discontinued, leaving only a few projects with minor materials components. According to EPA research staff in Cincinnati, total infrastructure and materials-related R&D in FY87 is probably less than $0,2 million. Future research on drinking water will be directed heavily toward new rulemaking to set maximum contaminant levels or specified treatment techniques for some 80 different substances as required by the 1986 amendments to the Safe Drinking Water Act.

EPA conducts research on sewers and municipal wastewater treatment systems to support its regulatory and grant programs under the Clean Water Act. During the 1970s, EPA's Cincinnati Water Research Laboratories were extensively involved in R&D on innovative waste water treatment processes and maintenance, repair, and rehabilitation technologies. Changing Federal policies on R&D have largely transformed the municipal wastewater research program into a regulatory support organization that monitors technology developments in the private sector and overseas. Although EPA provides about $2.4 billion annually for new municipal treatment plant construction, their R&D on construction, maintenance, management, and rehabilitation of sewers and wastewater treatment systems has averaged less than !31 million annually in recent years. According to EPA research staff, almost all infrastructure and materials-related R&D projects in the municipal wastewater treatment program have now been zeroed out.

Materials-related research under EPA's wastewater programs largely arose out of work on solving specific problems, such as how to prevent corrosion and inflow and infiltration of

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33 personal communications t. OTA from Robert M. Clark, Director, Drinking Water Research Division, EPA Water Engineering Research Laboratory, Cincinnati, Ohio. Detailed information on materials-related research was unavailable. Therefore, OTA's estimates of materials and infrastructure-related research include various EPA/ORD projects on water supply systems and drinking water problems that include aspects of system integrity, rehabilitation, materials, or hardware-related water contamination problems.

sewers. R&D in this area included basic research on the long-term performance of materials and the mechanisms of corrosion in order to formulate appropriate corrective strategies. Past materials-related research included work on methods for repair and rehabilitation of sewer pipes, and the evaluation of new synthetic and natural fiber filters to remove contaminants during sewage treatment. However, R&D is increasingly being redirected to deal with the growing problems of toxic contaminants in wastewater treatment plants and treatment and disposal methods for sewage sludge. Moreover, both staffing and research funding are now less than half of what they were six years ago.

The Innovative/Alternative (1/A) Technology incentive set-asides under the construction grants program[35] of the Clean Water Act offer a potential market of several hundred million dollars per year for new sewage treatment technologies, but provide no funding for actual research and development. As a result, many new wastewater treatment processes are now being tested at the full plant scale rather than at bench or pilot project scale.

In addition to research done under the Clean Water Act and Safe Drinking Water Act, expanded EPA efforts in the area of hazardous wastes and toxic pollutants may have some relevance to technologies for both drinking water and wastewater treatment. EPA researchers and others noted that development of treatment technologies for removal of contaminants from leachate at Superfund sites may prove useful for water supply and wastewater treatment systerns.

M Corrosion, a severe problem in some areas, can lead to deterioration of sewers and their eventual collapse. Infiltration refers to the permeation of rainwater, as groundwater, into a sewerage system. Infiltration occurs through cracks in pipes, at pipe joints as settling and other movement occur, and where side-branches ("laterals") meet the pipe. Inflow is the entry of water from sources such as illegal storm drain connections, or excessive storm water entry at manhole covers. Inflow and infiltration can increase the amount (and costs) of sewage treated by as much as one third, and pose materials-related research problems that can be quite different from those presented by corrosion.

35 Innovative technologies are narrowly defined as new processes not Yet widely accepted in practice that achieve the required sewage treatment levels at lower costs than conventional technologies, and/or save energy.

DEPARTMENT OF COMMERCE

Within the Department of Commerce, the National Bureau of Standards (NBS) conducts research on infrastructure materials at the Center for Building Technology and the Institute for Materials Sciences and Engineering. Their research is directed primarily toward advancing the fundamental understanding of materials characteristics, composition, and performance; and developing standardized testing methods and equipment.

The Center for Building Technology (CBT) in Gaithersburg, Maryland focuses primarily on the study of materials that "derive their properties in the field," such as concretes, cements, and paints, as opposed to those that are fabricated off site and thus can be standardized more easily. Although direct appropriations for CBT are !$3-$4 million, they currently spend a total of about $13-$14 million annually. Over sixty percent of their funding comes from other Federal agencies (such as the Department of Energy, Federal Highway Administration, General Services Administration, the Corps of Engineers, and the Air Force). A small percentage comes from outside the Federal Government. CBT estimates that it spends about $2.4 million per year on generic materials research relevant to public works infrastructure and other aspects of construction. Their work has, in the past, made significant contributions to infrastructure construction. For example, research they conducted for the Federal Highway Administration in the early 1970s led to the development of epoxy-coated steel reinforcing bars for highway construction.

Much of CBT'S current work on concrete is aimed at deriving basic information on the interrelationships between the composition and structure of cements and concretes and their performance in the field, and at developing standardized mathematical descriptions for this information. The results of these efforts will make it possible to conduct more systematic research on concrete and cement, to develop predictive models of performance, and to communicate the results of the research more effectively.

In addition, CBT is evaluating the performance of various anti-corrosive surface coatings (mostly paints, but also epoxies and polyurethanes), and the relationship of substrate condition and preparation to service life. Other R&D activities at the Center include earthquake resistance of materials and structures, performance of concrete structures in hostile environments, and development of nondestructive evaluation methods for new and existing structures. The Construction Materials Reference Laboratory, part of the CBT Building Materials Division, is supported and staffed by the American Society for Testing and Materials (ASTM) and AASHTO. It provides a voluntary service to assist construction materials laboratories throughout the nation in evaluating and improving the quality of standard testing procedures for primary construction materials, such as cement, asphalt, aggregates, and soils.

The Institute for Materials Sciences and Engineering (IMSE), also in Gaithersburg, houses other NBS research on infrastructure materials. The Metallurgy Division develops methods of measuring the corrosion rates of steel and other metals used in construction. The Polymer Division handles research on plastics, including polymer blends and composites; its work on plastic pipes is especially relevant for public works. The Fracture and Deformation Division provides basic engineering data needed for design through its studies of fracture and deformation strengthening of steel and other structural alloys and its failure analyses of other materials. Estimates of the level of funding of infrastructure-related materials R&D at IMSE were not available, but their total funding is about $22 million annually.

The Economic Development Administration of the Department of Commerce funds construction of local public works projects including streets, water supply systems, and wastewater treatment facilities. EDA has a modest research and technical assistance budget, but most of that is spent on planning and socioeconomic studies about economic development.

NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) is a major source of funding for university and other private sector research in civil and chemical engineering. Research on infrastructure materials is funded under several NSF programs. The most direct infrastructure research is carried out under the NSF Engineering Directorate's Mechanics, Structures, and Materials Engineering

Division, and Emerging and Critical Systems Engineering Division. Additional materials research is sponsored by the Mathematical and Physical Sciences Directorate's programs in ceramics, metallurgy, and polymers, and by the Materials Research Labs and Research Groups. Some water-resources research is funded within the Engineering Sciences programs on Chemical, Biochemical and Thermal Engineering, and Environmental Engineering.

Total FY87 funding for the Engineering Program is $162 million, and for mathematical and physical sciences, $464 million. Information provided by NSF indicates that materials-related infrastructure research received $1,8 million in FY85 and $0.9 million in FY86. However, OTA has only received a partial listing of the infrastructure-related research under the Engineering Program.

DEPARTMENT OF THE INTERIOR

Within the Department of the Interior, the Bureau of Reclamation constructs, operates, and maintains dams for reclaiming arid and semi-arid kinds in the Western United States. The Bureau's projects often serve multiple purposes, including municipal and industrial water supply, hydroelectric power, irrigation, water quality improvement, flood control, navigation, recreation, and fish and wildlife enhancement. The Bureau spends $600 to $700 million annually for construction and another $260 million for operations and maintenance (O&M). About 81 percent of construction and O&M costs are reimbursable through contracts with project beneficiaries, although the repayment periods may be very long.

Based on a program review document provided by the Bureau, OTA estimates that total materials-related research funding in FY86 was slightly over $1 million. The Division of Research and Laboratory services conducts most of the Bureau's public works R&D; they have an annual budget of approximately $3 million ($825,000 in materials research) and about 130 ongoing projects. Most materials projects are funded for around $100,000 over a multi-year period. Some additional materials research on concrete structures and materials, totaling about $200,000 in FY86, was conducted in the Division of Water and Land Technical Services. Research sponsored by the Program Related Engineering and Scientific Studies program (PRESS), within the Bureau's Denver Engineering and Research Center, includes the performance of cement and concrete in dams and canals, corrosion prevention for metals and concrete, and materials evaluation methods. In addition, the Bureau and the Corps of Engineers have cooperated in several areas of research. The Bureau's R&D program undertakes some original and problem-oriented research, but, as with the Corps of Engineers, a significant share of the effort is devoted to the evaluation of available products and the development of materials specifications for Bureau projects.

Also within the Department of the Interior, both the U.S. Geological Survey (USGS) and the Bureau of Mines conduct some materials research relevant to infrastructure. The USGS maintains a research and assessment program on water resources, water quality, and water availability for surface and groundwater, which can assist in the planning and design of water resource and water supply projects. The USGS also studies the occurrence and characteristics of minerals used in construction materials. The Bureau of Mines tracks domestic and international ‘mineral production and consumption. The Bureau discontinued support for its asphalt research center in Laramie, Wyoming as part of a privatization initiative; the laboratory now conducts contract research under private ownership. For many years, they also supported a modest research effort in the characteristics and uses of construction and clay materials. With their recent switch in emphasis to strategic and critical materials, however, their support for research on construction materials has been reduced substantially. Estimates of USGS and Bureau of Mines materials R&D are not available.

THE DEPARTMENT OF AGRICULTURE

The U.S. Department of Agriculture (USDA) finances construction of roads and water supply and wastewater treatment facilities under several programs. The most notable is the National Forest roads program, which builds and maintains a 320,000 mile road system and adds about 10,000 miles per year, making it the fourth largest road system in the world. Annual Forest Service road-related expenditures are about $750 million. The Transportation Research Board reports that the USFS has funded a "small but productive R&D program to reduce its construct ion and maintenance costs and to improve the performance of its road system."[36] USFS expenditures for road-related R&D have been around $0.2 -$0.3 million per year. The TRB report categorized the USFS as the "central source of R&D in the U.S. for low volume roads, which are a major part of the public roads system in rural areas."

The Farmers Home Administration (FmHA) finances construction of rural water supply and wastewater treatment systems through grant and loan programs, but has no supporting research program. The Soil Conservation Service (SCS) conducts research on water and soil conservation and constructs small flood and erosion control projects. Some SCS projects may have materials components but OTA has not yet been able to identify them.

OTHER FEDERAL AGENCIES

There are a number of other Federal agencies that fund materials research that may be applicable to infrastructure, but these agencies generally do not segregate their programs or expenditures in such a way that infrastructure-related research can be identified easily. For example, the Department of Energy's Basic Energy Sciences Program is a major sponsor of advanced materials research in the U.S. Over $150 million was allocated to materials sciences research under this program in FY87. Some DOE-funded research on advanced ceramics (including cements and concretes) and on composites clearly has some potential application to construction of public works projects. Research in the area of energy conservation may prove extremely useful in reducing energy costs for wastewater treatment plants and for production of cements, concretes, and asphalts. OTA does not have estimates of the level of research at DOE or other agencies (such as TVA, NASA, HUD) that might be relevant to infrastructure materi-

36 Transportation Research Board, supra note 29, at p. 37.

als. However, two special short-term projects of note are worth describing here: the National Council on Public Works Improvements and the Strategic Highway Research Program.

OTHER FEDERALLY-FUNDED RESEARCH PROGRAMS

National Council on Public Works Improvement

The Public Works Improvement Act of 1984 (Public Law 98-501) created the National Council on Public Works Improvement as a Federal Advisory Commission to report to the President and the Congress on the state of the nation's infrastructure. The legislation directed the Council to analyze: the age and condition of public works; the capacity of public works to meet current and anticipated economic development; and methods used to finance the construction, rehabilitation, and maintenance of public works. While the Council initially is focusing on transportation, water resources, and waste management, the Act defines public works to include all types of infrastructure.[37] In future reports, the council may include hospitals, schools, jails, courthouses, and space travel and telecommunications facilities.

The Council's' first report, published in September 1986, presented the results of a broad survey of public works issues and analyses in the categories of decisionmaking, technology, and economics and finance.[38] The report's preliminary conclusions On technology emphasize the promise that new materials, construction technologies, and information and communication systems hold for improving the productivity, performance, and durability of public works.

The Council will produce two additional reports by 1988 that will analyze the issues identified in the first report and suggest practical approaches to meeting future infrastructure

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37 This includes highways; streets; bridges; mass transportation facilities and equipment; resource recovery facilities; airports; airway facilities; water supply and distribution systems; waste water collection, treatment and related facilities; dams; Federally-owned buildings; docks and ports; waterways; and other facilities critical to economic development.

38 National Council on Public Works Improvement, supra note 1.

needs. In addition, the Council has commissioned a series of background papers on topics relevant to their legislative mandate. The Council is doing no research of its own on infrastructure materials.

The Strategic Highway Research Program

The recently-enacted highway bill (P.L. 100- 17) established the Strategic Highway Research Program (SHRP) as an intensive 5-year program of Federally-funded research on problems affecting the nation's highways and bridges. SHRP is administered by the National Research Council.[39] Materials-related research is the major focus Of this Program. Full funding for the program has been authorized by the Congress.

Using start-up funds, SHRP has completed a two year planning and assessment process to further define projects under the six primary research areas originally identified in the Transportation Research Board report, America's Hiqhwavs: Accelerating the Search for Innovation. The TRB criteria for selection of research areas included gaps in current knowledge, lack of a previous coordinated research effort, and potential for high short-term payoff from new advances. The research areas and approximate levels of funding are:

1) asphaltic materials--!$5O million,
2) pavement performance--$5O million,
3) maintenance cost-effectiveness--!$20 million,
4) concrete bridge component protection systems--$l O million,
5) cement and concrete --$ 12 million, and
6) chemical control of ice and snow--$8 million.

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39 The National Research Council is the operational arm of the Federally-chartered National Academy of Science (NAS) and National Academy of Engineering (NAE).

40 Transportation Research Board, supra, note 29.

SHRP is administered by an executive committee, and four separate advisory committees oversee the six research areas. The four advisory committees are Asphalt, Long-term Pavement Performance, Maintenance and Snow Control, and Concrete and Bridge Components. SHRP projects will be carried out by both public and private bodies, including Federal agencies, States, universities, trade associations, and private contractors and consultants. Some research may even be conducted overseas.

CHAPTER NINE

NONFEDERAL PROGRAMS FOR INFRASTRUCTURE MATERIALS RESEARCH

INTRODUCTION

Nonfederal infrastructure research and development is supported and conducted by both public and private entities. Within the public sector, States, counties, municipalities, regional agencies, and quasi-governmental bodies, such as water districts and turnpike or port authorities, fund R&D projects on materials for public works. Within the private sector, materials research is conducted by investor-owned utilities; universities and other research groups; trade and professional associations; engineering, consulting, and construction firms; materials suppliers; and product and equipment manufacturers,

This chapter discusses the types and amount of nonfederal funding of materials research by major infrastructure category: highways, roads, bridges, and tunnels; sewers and wastewater treatment systems; water supply and treatment systems; and water resources projects, including waterways, ports, dams, locks, canals, and irrigation systems. It should be noted, however, that some research is relevant to more than one type of infrastructure, particularly in concrete and cement research.

Reliable estimates of total nonfederal spending on either materials-related or general infrastructure R&D are generally lacking. No single group collects data on all public and private infrastructure areas. What estimates of nonfederal infrastructure-related R&D exist were developed for individual reports, such as the estimates derived for the National Materials

Advisory Board's study of R&D in the cement and concrete industries, and the Transportation Research Board's estimates of highway research.[41]

Based on published estimates of nonfederal governmental spending and on interviews with industry associations, OTA estimates that between $18 million and !$25 million is spent annually on nonfederal materials R&D for public works, primarily for highways and bridges (see table 9-1).[42] This level of investment in R&D is very low compared with the tens of billions of dollars spent annually on infrastructure construction, maintenance, repair, and rehabilitation.

Nonfederal support for public works R&D also has been declining steadily. Although some new trade associations and university research institutes have been created recently (see below and in chapter eight), the overall level of R&D funding is still very low compared with identified research needs. Moreover, continuity of funding remains a problem for some private research institutes, which are increasingly dependent on Federal grants and contracts as a primary means of support.

HIGHWAYS. ROADS. AND BRIDGES

Research on materials used in the construction, maintenance, and repair of the nation's highways, roads, bridges, and tunnels receives around $11 million to $15 million annually, or almost two-thirds of nonfederal R&D. The primary materials of interest here are cement, concrete, asphalt, steel and other structural and reinforcing materials, protective coatings, sand, gravel, surface treatments, de-icing substances, and geotextiles.

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41 National Materials Advisory Board, ConCrete Durabilitv: A Multibillion-Dollar Opportunitv, NMAB-437 (1987), estimated R&D expenses at 0.3 percent of sales for cement producers and 0.1 percent of sales for concrete producers. The Transportation Research Board, supra note 29, estimated R&D spending for the highway construction and equipment industry at 0.15 percent of sales. These R&D investments are among the lowest of any U.S. industries.

42 This total generally excludes Federal grants and contract funds. Federally-funded '&D by nonfederal entities is included in the totals for the source agencies.

Table 9-1

ESTIMATED ANNUAL NONFEDERAL INFRASTUCTURE MATERIALS

RESEARCH AND DEVELOPMENT EXPENDITURES

Infrastructure	Millions of Dollars
Highways, Roads, and Bridges	11,6 - 15.2
Municipal Sewers and Wastewater Treatment	3.0 - 5.0
Warter supply and Treatment	1.1 ‘
water Resources, Waterways, and Ports	0,1 - 0.5
General Materials Research	2.0 - 3.0
TOTAL	17.8 - 24.8

Highway materials R&D is the most coordinated area of nonfederal infrastructure materials research. The integrated structure of the programs overseen by the American Association of State Highway and Transportation Officials (AASHTO), the National Cooperative Highway Research Program, the Federally Coordinated Program of Highway Research & Development, and the materials industry institutes provides mechanisms for joint research and diffusion of results. Moreover, the technical expertise and research framework underwritten by the Federal Highway program make the limited amount of State-funded research more effective.

Nonfederal Government R&D

Construction, maintenance and rehabilitation of highways, streets and bridges is primarily a governmental function carried out by States, counties, and municipalities. The modest research programs of nonfederal governments generally are directed at solving local infrastructure problems and at evaluating and testing commercially available products for local use.

According to the Transportation Research Board (TRB), States annually spend about $10 million of their own funds on *afl* highway research. Assuming that State-funded *materials* research is approximately the same portion of State-funded R&D as in Federal-State cooperative research programs (see chapter eight), OTA estimates that States spend about $2 million annually on highway materials-related projects. State highway departments typically have one or more professionals on staff with responsibility for materials engineering and research.

The TRB and the American Public Works Association (APWA) report that some larger county or city public works or roads departments also support independent research on paving materials and corrosion. The TRB estimates that cities and other local government units spend $1 million to $2 million annually on highway research. Materials-related research is probably no more than $100,000-$200,000 of this.

Quasi-governmental agencies, such as those that administer Statewide tollways or interstate bridges and tunnels, also maintain research programs. For example, the New Jersey Turnpike Authority has contracted with the Asphalt Institute to assess the reasons for the sudden "rutting" of asphalt pavement on large sections of the turnpike. The Port Authority of New York and New Jersey research program also includes a materials group, but OTA was unable to obtain specific project descriptions within the timeframe of this survey. Estimates of how much such agencies spend on R&D also were not available. Generally, their research is funded out of revenues and user fees which are not subject to the same political exigencies as State and local government research budgets.

Professional and Trade Associations

A significant share of nonfederal highway materials R&D is supported and coordinated through professional organizations, trade associations, and their affiliated research foundations. However, the primary emphases of these groups is on member services, publications, standards development, and technology diffusion.

The largest share of nonfederal materials R&D for roads and bridges comes from technical societies and trade associations representing materials producers and suppliers. These include: the Asphalt Institute, the National Asphalt Pavement Association (NAPA) and its Research Foundation, the Portland Cement Association, the American Concrete Institute, and the Steel Structures Painting Council. Most industry trade associations have small staffs and very modest research budgets, but the Asphalt Institute, NAPA, and PCA support a total of $2 million per year in research on the characteristics, performance, and evaluation of materials. Materials-related work in iron and steel, other structural and reinforcing materials, and coatings and other anti-corrosives probably also is on the order of no more than $ 1 -!$2 million annually.

Associations of government transportation officials and agencies provide a forum for identification of research needs and priorities and coordinated research efforts, but provide little direct funding for R&D, The two major groups in this area are AASHTO, which represents State officials, and the American Public Works Association (A PWA), which represents State and local governments. Almost all of AASHTO materials research is funded through contracts from States or Federal government agencies. The APWA Research Foundation has a total annual

R&D budget of between $100,000 and $500,000. The primary focus is improving transportation management and maintenance through professional educational and research programs for its members, although it has sponsored some materials-related contract research.

The National Governors' Association, National League of Cities, National Conference of Mayors, National Association of Counties, and National Conference of State Legislatures all have transportation subcommittees and occasionally underwrite research efforts on behalf of their members, but fund very little materials research.

Universities and Other Research Centers

Many universities have materials or highway transportation research centers. There are no independent estimates of the level of funding for research carried out in materials science and civil engineering programs, but the major source is the Federal government--either directly through contracts and grants or indirectly from State agencies, HP&R funds, or NCHRP contracts. Therefore, the amount spent on research is reflected in those budgets (see chapter eight). At some public institutions, there may be additional funding of research centers by State legislatures. For example, the State of Alabama is providing $600,000 to help support the National Center for Asphalt Research, which is jointly sponsored by Auburn University and the NAPA Research Foundation.

Materials Manufacturers and Suppliers

Many materials manufacturers and suppliers maintain R&D departments. According to industry representatives, the asphalt, cement, and concrete industries combined probably spend a total of $6-$8 million annually on R&D, in addition to that sponsored by industry research groups, such as the Asphalt Institute. Industry expenditures for materials R&D are significantly lower now than they were six years ago. According to the National Materials Advisory Board, many private cement and concrete companies have closed their research laboratories. There is no estimate of the private R&D budgets for other materials manufacturers and suppliers, but the

TRB and other sources estimate that average R&D expenditures in the transportation segment are about 0.15 percent of sales.[43]

SEWERS AND WASTEWATER TREATMENT SYSTEMS

Sewers and wastewater treatment systems use a wide range of construction materials and manufactured products: sewer pipes (concrete, masonry, plastic, iron, steel), seals, liners, gaskets, and pumps in sewer collection systems; and screens, filters, membranes, liners, pipes, pumps, additives, and monitors for treatment plants. Materials are not a major consideration in waste water treatment processes, but are an important cost component of sewer and treatment plant construction and maintenance.

Nonfederal research efforts in sewers and wastewater treatment systems have been underwritten by local governments and sewage authorities; professional and trade associations; engineering, consulting, and construction firms; and equipment and materials manufacturers. Large municipal sanitary districts sponsor a lot of R&D, but their efforts are largely problem-oriented or focused on evaluation of commercial products, rather than on materials development. The Metropolitan Sanitary District of Greater Chicago, the Los Angeles County Sanitary District, and Seattle Metro funded a total of about $3.5 million in support of R&D in 1983,[44] OTA was unable to find more recent estimates of the level of research funded by local agencies.

The American Public Works Association, Association of State and InterState Water Pollution Control officials, Association of Municipal Sewerage Agencies, the Water Pollution Control Federation, and the American Society of Civil Engineers are among the major technical groups involved in wastewater treatment. They probably spend a total of $1 m. llion to S2 mil-

43 Transportation Research Board, supra, note 29, at p.1.

44 American Public Works Association, Defining the Role Of Federal and pri'ate Sec'or Activities in Solving Munici Dal Environmental Problems, Workshop Proceedings prepared for EPA, August 11-13, 1983.

lion annually on research on wastewater systems management and identification of research needs. A significant portion of these funds come from contracts with EPA and with local water and sewer utilities. The Water and Wastewater Equipment Manufacturers Association represents many wastewater equipment suppliers. They were unable to provide estimates of either total sales or R&D expenditures for their members.

University research centers also conduct some research on various aspects of sewers and wastewater treatment with Federal funds from sources such as EPA and NSF.

Municipal wastewater treatment systems have made significant progress in dealing with conventional pollutants, but now face new pollution control requirements and increasing demands on their systems. This will present new challenges in repairing and replacing aging systems, and in upgrading and expanding facilities to meet Federal regulations and to deal with changes in inflow characteristics from residential-commercial toxic wastes. Rehabilitation of sewers to control infiltration still remains a significant problem.

WATER SUPPLY AND TREATMENT SYSTEMS

A total of about $14 billion was spent for construction, operation, maintenance, and repair of drinking water supply and delivery systems in 1984, primarily by local governments and water utilities. The major cost components are the underground pipe plus excavation and placement. Materials and products include: pipes (concrete, plastic, ceramic, masonry, iron, lead, steel, copper), pipe foundations and liners; seals, pumps and treatment equipment; nondestructive evaluation techniques; and technologies for inplace repair, maintenance, and rehabilitation. Materials-related research areas include the mechanics of internal and external corrosion, the long-term performance of system materials, maintenance requirements and technologies, rehabilitation technologies, failure prediction, and the effects of materials and water additive? on water quality and system life.

Nonfederal R&D on materials for water supply systems is primarily conducted by local water utilities, professional and trade associations, engineering, consulting and construction companies, and equipment and supply manufacturers. State agencies' R&D efforts are generally aimed at the health effects of pollutants and identifying the source of contaminants.

Large public and private water utilities fund some R&D which focuses on solving local water system problems or on evaluating available technology for local use. Any openness to innovation in water supply technology that might be fostered by local financial responsibility for water systems is countered by the strong emphasis placed on the reliability of those systems.

Two professional organizations sponsor and coordinate a large share of nonfederal water supply R&D by local water utilities: the American Water Works Association Research Foundation (A WWARF), and the American Public Works Association (A PWA).[45] The AWWARF Research Foundation supports approximately !$ 1 million annually in R&D on materials-related aspects of water systems; current efforts focus on corrosion and rehabilitation of water lines. APWA support for water systems research is probably under $100,000 per year. Its most recent research emphasis is on system management, but some past projects have included materials components. Neither group **could** provide dollar estimates of the R&D activities of their members, but noted that many of the large municipal water systems and investor-owned water utilities sponsor extensive research efforts, including some materials R&D. Examples include utilities in Los Angeles, San Francisco, Chicago, the District of Columbia, Atlanta, St. Louis, Boston, and New York City.

The construction and engineering firms that design and build water systems do little independent R&D, according to a representative of an industry association. There is probably some private investment in new materials-oriented technologies for repair and rehabilitation, but these figures are likely to be proprietary.

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[45] AWWARF was founded as a separate research entity by the American Water Works Association, which represents public and private utilities that supply about 60 percent of the drinking water in the U.S. and Canada. Congress provided $3 million in FY84-FY86, through EPA, as "seed" money for AWWARF. The foundation is now funded by subscription fees paid by member water utilities.

WATER RESOURCES PROJECTS

Water resources projects--waterways, ports, dams, locks, irrigation and flood control facilities, reservoirs, and other multipurpose facilities--probably receive the lowest level of non-federal R&D support because of the high level of Federal responsibility. Also, the primary materials and products of interest --concrete, stone, aggregate, pipes, coatings, geotextiles, membranes, liners, filters, and structural and reinforcing metals and substances--are shared with other infrastructure types. The special materials-related problems in water resources include channel erosion and infill, embankment stabilization, and corrosion and deterioration of locks, dams, pilings, and other structures. OTA was able to identify about $100,000 in annual non-federal expenditures on materials R&D for water resources projects.

There are a number of municipal agencies and quasi-governmental authorities that administer ports and waterways, and there are some privately-owned dams and flood control facilities associated with industrial or recreation developments and electric power projects. Some of these nonfederal entities undoubtedly sponsor some materials research, but the level of funding is not known.

Many of the larger trade and professional organizations have divisions that are dedicated to advancing design, engineering, and materials in construction and maintenance of water resources projects. However, their work generally draws on generic research by materials suppliers, and on work by architecture/engineering and construction firms.

CHAPTER TEN

INTERNATIONAL RESEARCH AND DEVELOPMENT FOR INFRASTRUCTURE MATERIALS

In the past decade, international competition in construction technologies and materials has become more intense. During this same period, U.S. industry began to lose its competitive edge in a number of domestic and international markets. The U.S. also became a "foreign" market for some industrialized countries marketing advanced technologies and materials here. More and more countries will penetrate U.S. technology and materials markets, and our reliance on imports will increase, unless a national commitment is made to change our approach to materials R&D. The following discussion characterizes the orientation and funding of infrastructure materials R&D in Japan, Britain, and Germany, and identifies whatever differences exist. Also, a brief description of specific materials R&D efforts in Europe and Japan is given.

JAPAN

In Japan, materials R&D is user- and applications-oriented. R&D efforts focus on clients' needs, and research is done accordingly. Japanese construction and trade industries conduct construction-specific research, and maintain large laboratory facilities. This is in stark contrast to the U.S. where construction companies do little or no R&D, and the designer knows better than the client what is best. Japanese universities also conduct R&D that is separate from, but complementary to, the work being done at construction company laboratories. Duplication of effort usually is avoided.[46]

46 Halpin, supra note 5, task 3, chapter 2.

New materials are a primary focus of Japanese construction R&D. These include materials used for subsurface ground stabilization and for the construction of bridges and buildings. Because ocean development is important for future land expansion in Japan, the Ministry of International Trade and Industry (MITI) identified advanced construction materials as an integral part of the country's future "marine community program" and overall infrastructure.[47]

One of the keys to the success of Japanese innovation is government support of private sector R&D. Government support comprises a host of government measures that have an important bearing on private sector investment decisions. Prominent among these measures are a policy designed to improve a firm's accessibility to technological information, and fiscal incentives designed to encourage R&D investment, modernization of plants, and technology exports. The MITI and the Science Technology Agency (STA) coordinate R&D efforts, and compile and disseminate data on world economic trends, trade, and industrial developments. Other government agencies set up to facilitate the flow of technical information are the Japan Patent Information Center (JAPATIC) and the Japanese Industrial Technology Association (JITA). JAPATIC was formed in 1971 to serve as a clearinghouse for patent information of both Japanese and foreign origin. The access to this information fosters the transfer of licensing of inventions and helps expedite the innovation process.[48]

Although the Japanese government's information policy certainly helps encourage innovation, perhaps the most far-reaching measures enacted are the fiscal incentives. These include tax credits on a firm's R&D expenditures, accelerated depreciation of plant and equipment, and tax exemptions on sales of technology products overseas.[49]

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47 Strategic Analysis, Inc., New Structural Materials Technologies: Opportunities for the Use of Advanced Ceramics and Composites (Contractor Report to OTA, December 31, 1986), p. 177.

48 Gee, supra note 3, at pp. 148-152.

49 Ibid., pp. 153-154.

Another key to Japanese success in technological innovation is their willingness to assimilate, adapt, and improve on R&D conducted elsewhere. In the course of adapting and perfecting other countries' technologies, the Japanese develop new innovations and new markets. For example, the Japanese are producing innovative egg-shaped concrete waste treatment digesters using design methods based on prestressed concrete technology developed by a West German firm. Also, the Japanese have been very successful in moving technologies quickly from the research stage to the marketplace. This is due, in part, to the fact that in many cases the basic research was done elsewhere; development simply involves adapting the technology to Japanese standards. In contrast, the U.S. is not normally so well informed about R&D efforts abroad.[50]

EUROPE

Each European country has its own approach to conducting and funding R&D. The British and German approaches are described here.

Britain

As in the United States, British R&D efforts tend to be product oriented. Also, a variety of public and private institutions, including government, universities, associations, materials suppliers, and private commercial laboratories conduct materials R&D. Approximately 60 percent of British R&D is funded by the private sector, and 40 percent by the public sector. Materials and component manufacturers finance the majority of private sector R&D efforts, which are aimed at securing a competitive advantage. sl Consequently, the fragmented nature of the

50 Halpin, supra note 5, task 3, chapter 2.

51 "Strategy for Construction R& D," building and Civil Engineering EDCs, United Kingdom, no date.

British research community is similar to that found in the U.S. There is no organization in Britain that carries out the function of the MITI in Japan.[52]

Much of the research in Britain is driven by the fact that infrastructure is in need of repair, and actual funding levels have been declining over the past several years. Areas of great R&D interest include waste disposal, sewage treatment, and public transportation. Improvements in materials and better nondestructive testing techniques will support R&D advances in these areas, and enhance Britain's competitive position in the international construction market. Materials R&D will focus on improving durability and ease of construction and maintenance.[53]

Germany

The German government does not operate its own research laboratories but depends on a number of private, nonprofit research institutions and associations for R&D. However, the government, through the Federal Ministry for Education and Science, is the main funding source and as such controls the direction of R&D activity for these nonprofit organizations. The key organizations are the Germany Research Society, the Max Planck Society for the Advancement of Sciences (the largest research establishment in Germany), the Fraunhofer Society for the Advancement of Applied Research, and the Confederation of Industrial Research Associations. These nonprofit institutes often operate as intermediaries between the government and industry, aggregate needs of the private sector, and disseminate R&D results to industrial firms.[54]

Most engineering and construction research is conducted in the private sector by either manufacturers, large contractors, or institutes receiving support from the public or private see- ,

52 Halpin, supra note 5, task 3, chapter 3.

53 Ibid.

54 Gee, supra note 3, at p. 158s

tor. The role of government ministries, such as the Construction Ministry, the Transportation Ministry, and the Ministry of Research and Technology, is to coordinate and identify national research needs and disseminate research results. For example, a 1981 German government report, "The Future Tasks in Construction Research," identified primary research areas for the construction industry. These included development and improvement of construction materials and methods for industry, bridges, tunnels, water resources, and transportation systems. Specific projects included waterproof concrete, corrosion reduction of reinforced concrete, and improved post-tensioning methods.[55]

A unique aspect of the German engineering and construction industry is the "Gutachten" (expertise) system. This system requires that third-party experts (often, university professors who reside in the German State in which a project is designed or built) verify various aspects of the engineering and construction process. Sometimes, large materials testing facilities are used to evaluate the quality of materials and design concepts. These "Materialprufungs Anstalten" are a source of interface between industry and university faculty. The system encourages a special relationship in which conceptual ideas initially generated at the university are advanced and perfected by industry. Furthermore, university professors act as entrepreneurs and participate as individuals in the patenting process. As a full partner in the patent, a professor can receive large financial rewards and enhance her reputation. Both factors motivate university faculties to conduct R&D.[56] In contrast, U.S. patents from university research often belong to the institution (depending on local policy) rather than to the faculty members who did the work.

Like the Japanese government, the German government plays an active role in coordinating and directing R&D efforts. Both countries employ a wide participative system for R&D planning. Representatives from government, industry, and nonprofit institutions become

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55 Halpin, supra note 5, chapter 4.

56 Ibid.

involved in the planning process through numerous advisory groups and committees.[57] Also like the Japanese, the Germans survey international R&D efforts and disseminate this information to the private sector. Furthermore, considerable attention is devoted to facilitating innovation at all stages of the process. Special linker organizations, such as the Garching Instrument Company, and the Arbeitsgruppe fur Patentverwertung (A RPAT), act to narrow information gaps between research and commercialization. Garching, a for-profit organization, is the primary link between the Max Planck Society and industry. It negotiates agreements with industry, acts as licenser for patents, engages in prototype development, and sometimes performs marketing. ARPAT, which is one of the Fraunhofer Society institutes, acts as a licensing and patent rights broker but does not participate in negotiations between principal parties. The activities of the Garching Instrument Company and ARPAT have no equivalents in the U.S.[58]

Besides these activities, the German government stimulates innovation through fiscal measures, which include a variety of tax benefits, such as credits, allowances, and accelerated depreciation, for R&D investments and expenditures. In addition, the government offers public grants to assist companies in introducing innovations into the commercial market. The innovation may be either a product or a process, and, in addition to being technologically new, it must have good commercial promise. Furthermore, the government has made risk capital more easily available to small- and medium-sized companies. One approach used is to provide credits and guarantees to equity investment companies in order to encourage them to invest in technological innovation projects of small- and medium-sized firms. Another approach is to share risks with a private venture capital company for a limited period of time. [59]

57 Gee, supra nOte 3, at p. 157.

58 Gee, supra note 3, at p. 158.

59 Ibid.

European community

While each European country has its own approach for conducting and funding R&D, the European Community (EC) realizes that maintaining international competitiveness will depend on cooperation among member countries. Accordingly, in 1985, EC created the Basic Research in Industrial Technologies for Europe (B RITE) program. The central objective of the program is to provide an incentive toward the creation of a technological base that Community industries can draw on to maintain international competitiveness over the next decade. Nine major technological areas are given priority: 1) problems of reliability, wear, and deterioration of materials and systems; 2) laser technology and powder metallurgy; 3) joining techniques; 4) new testing methods, including nondestructive, on-line, and computer-aided testing; 5) computer-aided design and manufacturing and mathematical modeling; 6) polymers, composites and other new materials; 7) membrane science and technology; 8) catalysis and particle technology ogy; and 9) new technologies applied to articles made from flexible materials.[GO] Total funding for the 103 selected research projects is 120 million ECU, 50 percent of which is provided by the EC and 50 percent by the industrial companies participating in the program .61 Several of the selected projects will address infrastructure-related issues. They include Electrochemically - based Techniques for Assessing and Preventing Corrosion of Steel in Concrete; Deterioration Prevention in Reinforced Concrete Structures Subject to Hostile Environments; and Improvements of the Lifetime of Woven and Nonwoven Synthetic Materials for Geotextiles, Packaging and Agriculture.[62] Funding levels for these projects are not known at this time.

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60 commission of the European Communities, “Basic Research in Industrial Technologies for Europe,” information package, no date.

[61] Commission of the European Communities, "BRITE - The Community Programme of Research in Industrial Technologies - Gets Under Way,” Press Release, Bruxelles, February 4, 1986.

[62] Complete List of projects Under the First Tranche of the BRITE program me, European Community, no date.

EUREKA is another European initiative to improve productivity and competitiveness of Europe's industries and economies through closer cooperation among enterprises and research institutes in the field of advanced technologies. It was created in 1985 at the European technology conference. To date, 19 European countries, including the Commission of the European Communities, participate in this initiative. Seventy-two cooperation proposals were adopted as EUREKA projects, which cover a wide range of advanced technologies. These technologies include manufacturing, computing, communications, materials, biotechnology, and advanced forms of transport. Implementation of the projects will cost ECU $3.2 billion over a period of 2-10 years. Two advanced materials projects approved *in* 1986 are CARMAT 2000 and Light Materials for Transport Systems. The $60 million CARMAT 2000 project will evaluate new materials for car structures over a four-year period. The other approved project, Light Materials for Transportation Systems, is funded at $15 million and will last four years. Little information is available on this project.[63]

CEMENT AND CONCRETE

According to the National Materials Advisory Board (NMAB), cement and concrete research and development are declining worldwide, except for Japan. A 1980 NMAB report states that cement and concrete R&D efforts in the U.S. suffer from a lack of intellectual and financial support from pertinent industries and government agencies. In Britain and France, the status of cement and concrete R&D is similar to that in the U.S. In Britain, the Cement and Concrete Association will be cut to one-third of its size, and redirected towards contract research. And, in France, the primary cement industry research institute, CERILH, is closing. In contrast, Japanese building contractors have substantial R&D budgets, and are given

63 Strategic Analysis, Inc., supra note 47, at pp. 32-33.

additional support from the Japan Building Contractors Society, the central coordinating agency, and the Japanese government.[64]

The U.S. cement industry is plagued by obsolete manufacturing facilities, and lags far behind many industrialized nations in the design of efficient plants. Consequently, the U.S. has to rely on new technologies developed primarily in Europe and Japan to modernize existing plants. For example, Germany and Japan are leaders in developing new types of cement kilns.

Another recent trend in the cement industry is the increasing number of acquisitions of U.S. cement companies by foreign companies. In 1986, two U.S. companies, Gifford-Hill and Ideal Basic Industries, were purchased by European companies. Also, Martin Marietta phased out all of their cement operations in 1983. Blue Circle Industries Group of Great Britain bought some of Martin Marietta's plants. About 60 percent of U.S. cement production Plants in 'he U.S. are now owned or controlled by foreign companies.

Developments in improving concrete have taken place both here and abroad. The Europeans and Japanese have done substantial work on concrete admixtures, particularly super-p1asticizers[66] and high range water reducers. U.S. efforts have focused on polymers in concrete, computer applications in modeling and design, and special concrete applications (e. g., earthquake resistance), as well as compliance with environmental regulations.[67]

Japan has done considerable work on polymer concrete, which was first developed by Nippon Telephone and Telegraph (NTT) in the late 1960s. Since then, polymer concrete has

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64 Frohnsdorff and Skalny, supra note 9.

65 Business communications Company, Inc., supra note 12.

66 Superplasticizers are small organic molecules (no more than 20-25 atoms) used to improve the workability of concrete. The molecules help to disperse water in the concrete so that less *water* is needed.

67 Frohnsdorff and Skalny, supra note 9.

been used to make manholes for telephone lines and now accounts for over 80 percent of block manholes used by NTT. Polymer concrete is also used to make manholes for sewer systems.[68]

Underwater concrete is attracting much attention in Japan. Mitsui Petrochemical first introduced underwater concrete in 1979. Use is increasing in applications such as bridge supports and other structures exposed constantly to water. Because of the increasing demand for this material, the Japanese government formed an *ad hoc* committee (consisting of ten construction companies and auxiliary organizations of the Transportation Ministry and Ministry of Agriculture, Forestry and Fisheries) to establish product standards and create an instruction manual. The Ministries also are actively promoting the use of underwater concrete.[69]

ASPHALT[70]

The U.S. asphalt industry is confronted with a wider variety of problems caused by climate, terrain, traffic loads, and crude oil qualities, than their European counterparts. Consequently, according to the Asphalt Institute, U.S. asphalt R&D efforts are a valuable source of information to the Europeans in addressing their roadway problems.

Pavement rutting is a pronounced problem in Europe. Although there are many ways to solve the problem, the Europeans are focusing on asphalt additives. Two additives that the U.S. Asphalt Institute currently is examining are Styryl (French process) and polyethylene (Austrian process).

Finally, the Asphalt Institute mentioned that Germany, France and Holland have government organizations that support asphalt R&D.

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68 Strategic Analysis, Inc., supra, note 47.

69 Ibid., p. 172-77.

70 This section is based on information received from the Asphalt Institute, March 17, 1987.

PLASTICS

Two of the most recent technological breakthroughs in pipe production systems were developed abroad. The system developed by A.G. Petzetakis S.A. of Athens, Greece, reportedly can produce 60-inch plastic (polyvinyl chloride) pipe that is equivalent in compressive strength and stiffness to solid-wall concrete or cast-iron pipe. Aim International is marketing the Petzetakis system in the U.S. The other pipemaking system was developed by Corma, Inc., a Canadian pipe-corrugation equipment manufacturer, and Oy Uponor AB, a Finnish pipemaking and equipment company. Extrusion Technologies, Inc., has entered into the first Uponor process licensing agreement in the U.S. Both of these processes enable polyvinyl chloride pipe to compete with concrete and cast iron pipes for infrastructure applications. ’l

GEOTEXTILES

Geotextiles (synthetic fiber fabrics used in geotechnical applications) were first developed in the Netherlands in the 1950s as a result of an ambitious civil engineering construction program--Delta Works. Delta Works was initiated after the catastrophic flood of 1953, which inundated 150,000 hectares of land and killed 2,000 people. Since that time, European and U.S. interests in geotextiles have grown. Today, about 38 U.S. and at least as many European companies manufacture and/or distribute geotextiles. Some of the largest U.S. companies include Amoco Fabrics Company, Dow Chemical, du Pent and Exxon Chemicals Americas.

WASTEW.ATER TREATMENT

In the United Kingdom, 13 regional water districts have been established to conduct waste water treatment research. These water districts and a limited number of private companies contribute to the operation of the Water Research Centre, which has a staff of over 255 and

71 Modern Plastics, supra note 17, at pp. 42-44.

about 78 major studies underway. Although most of the Centre's budget comes from the 13 water districts, the national government also contributes 12 percent of the funding. The Water Research Council of Great Britain recently opened an office in Philadelphia to market British sewer and wastewater management systems and technology to U.S. waste water agencies.

A number of large U.S. municipal wastewater treatment authorities fund appreciable R&D on their own (see chapter nine). For example, the Metropolitan Sanitary District of Greater Chicago, the Los Angeles County Sanitary District, and Seattle Metro funded a total of about $3.5 million in support of R&D in 1983. However, the public pays for that R&D via user fees, and the type of R&D funded is generally limited to satisfying local needs.[72]

The Japanese rely heavily on the central government for sewer and wastewater research, planning, and design, and the government has increased its investment in municipal wastewater R&D significantly in the past six to eight years. The Japan Sewage Works Agency (JSWA) has expanded its total staff from 30 to over 900 employees, and considers municipal wastewater treatment a major focus of the Agency's research program. Unlike its U.S. counterpart, the Environmental Protection Agency (EPA), the JSWA also designs treatment works for municipalities through contract arrangements. In the U. S., design and engineering work is performed largely by private sector firms.

The Japanese also have launched a five-year, $30 million collaborative research program involving MITI, JSWA, the Japan Ministry of Construction, universities, and private companies. The goal of the program is to develop a new class of wastewater treatment technology, which, if successful, would meet pressing local needs as well as become a possible new export to the U.S. and Europe. The program supports two simultaneous research efforts: one in biotechnology for waste treatment; and the other, dubbed "renaissance, " examines a wide range of treatment approaches, including various membrane technologies. U.S. experts note that the prospects for a

72 American Public Works Association, supra note 44.

breakthrough in wastewater treatment technology are far from certain, and that any Japanese advances likely would have to be adapted and modified for U.S. conditions. Currently, exports comprise no more than 1-2 percent of Japan's wastewater treatment equipment sales.[73]

73 Personal communication with John Convery, U.S. Environmental protection Agency, Municipal Wastewater Research Division, Cincinnati, Ohio.

CHAPTER ELEVEN

INSTITUTIONAL ISSUES, RESEARCH NEEDS, AND POLICY OPTIONS

In conducting this brief survey of infrastructure materials R&D, OTA identified two sets of issues: those related to the quantity and quality of data about the Federal and nonfederal R&D budgets, and those related to the amount and scope of the R&D itself. The latter include reduced funding for R&D at all levels, insufficient information exchange about R&D projects and programs, mismatches between R&D projects and needs, and government policies and perceptions of risk that inhibit the application of materials research results in public works projects. Together, these limit the amount of research conducted, make the research less comprehensive in scope than it might be, and impair the cost-effectiveness of public works improvements.

This chapter discusses these issues and the constraints they place on materials R&D, and identifies options for addressing them. This should not be considered a complete list of policy options, but a brief discussion of those that are most apparent given the limited scope of this survey. Because calling for additional R&D funding is a relatively simplistic solution in the face of massive budget deficits, and because OTA was unable to quantify the R&D funding needs, the options discussed below focus primarily on means of making the limited funding that is available more effective. Specific materials areas that could benefit from increased research funding are discussed at the end of this chapter.

BUTDGET' DATA~ PROBLEMS

While Federal agencies were extremely cooperative (sometimes eager) in providing us with their budget figures for R&D, we are unsure about the accuracy and comprehensiveness of some of those figures for the purposes of this survey. Agencies whose primary mission is not infrastructure-related typically do not segregate their programs or expenditures in such a way that research relevant to public works can be identified easily. For example, the Department of Energy's Basic Energy Sciences Program is a major sponsor of advanced materials research in the U.S. Some DOE-funded research on advanced ceramics (including cements and concretes) and on composites clearly has potential applications in public works construction. However, that is not the defined goal of the research, and the precise amount that is relevant cannot be identified easily. Other organizations categorize their research by type of infrastructure (e.g., wastewater treatment). When materials R&D is a component of a general infrastructure research effort, its level of funding is not easily separated from a total project budget. In addition, some agencies include administrative expenses (salaries and overhead) in their R&D budgets; others do not. We have identified these reporting differences in the text to the extent possible.

Accurate and comprehensive budget data are hard to find for nonfederal infrastructure R&D. No single institution collects data on all nonfederal infrastructure research. Even within relevant industries or infrastructure categories, there is little independent data collection on R&D. Furthermore, companies often treat information on research efforts and funding as proprietary and do not release it. Options for addressing this problem are discussed further in the section on "Information Exchange," below.

GOVERNMENT POLICIES AND RISKS

Government contracting and procurement policies, and public and private sector perceptions of risk may place significant constraints on the amount of infrastructure materials R&D and the implementation of research results. As a result of these practices that impede innovation, and of the extremely high premium placed on the reliability of infrastructure systems, the gap between materials research and practice is more likely to be bridged through gradual adaptation of new methods and improvements, with elaborate testing and hesitant modification of existing specifications and acceptance criteria.[74]

Government construction standards, procurement specifications, and regulatory requirements shape the environment for research and innovation in public works. The U.S. contracting process divides public works projects into design and construction phases. Construction firms often must bid on projects for which the specifications and materials have been prescribed in regulations and/or selected in advance by design-engineering firms. Design-engineering firms may be unwilling to experiment with new materials because of high liability risks if the material does not perform as expected, or because government agencies may have already established key project specifications by prescription (e.g. so many inches of asphalt) instead of as performance specifications.

This division between designer and builder has, in some instances, led to an adversary relationship. Drawing upon a musical analogy, one specialist in engineering and construction technology compared the designer to the musical composer who said, "I only compose; it's not my fault if the note cannot be played on the tuba. You as a player must solve the problem." In some cases, the architect/engineer has taken a similar position by designing something that is either "unplayable" or inefficient from a construction and materials point of view.[75]

There is a general bureaucratic inertia in continuing to use established procurement specifications and materials testing and construction standards. Development and approval of new specifications or standards can be a lengthy and difficult process that requires substantial research. However, government and private research that might provide the basis for new standards has been declining. Furthermore, it can be costly for established public works personnel,

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74 Committee on National Urban Policy, Commission on Behavioral and Social Sciences and Education, National Research Counc ii, (Royce Hanson, cd.) Perspectives on Urban Infrastructure, National Academy Press, 1984, at 206-207.

75 Halpin, supra note j, Tasks 1 and 2, Chapter 4.

suppliers, and contractors to alter current materials and practices, and any proposed change in procurement specifications and construction standards may become politically charged depending on whose ox will be gored by the change. For example, although granitic or basaltic aggregate may perform better and last longer in road construction than limestone aggregate, a State with a large limestone industry is unlikely to include out-of-state materials in their specifications.

The extent to which government contracting and procurement processes actually deter the use of new or improved materials needs to be determined. If significant disincentives are found, means for removing or mitigating them should be developed. The relative costs and benefits of design versus performance standards in public works procurement also merits further analysis. The lack of good performance standards hinders development of new materials because there is no reliable way of evaluating the materials' long-term service life and reliability. Because of the complexity of the problem, development of the needed standards requires a large investment in research.[76]

In addition, contracts usually are awarded to the lowest bidder, and new materials often have a higher capital cost than conventional ones. While over the long-term these materials might reduce repair and maintenance costs, few analyses of the trade-offs between front-end and life-cycle costs are available. Without some mechanism for considering potentially lower life-cycle costs in the procurement process, bidders proposing the use of improved, but potentially more expensive materials would place themselves at a competitive disadvantage. However, the accuracy of life-cycle costing systems is suspect, and needs additional research.

Governments and corporations also perceive a high level of risk in using new materials in public works. First, people place a high premium on the reliability of public works. When you turn on your water faucet you expect water to come out at a reliable pressure, you expect it to be of a consistently potable and healthful quality, and you expect to receive it at a reasonable

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76 National Materials Advisory Board, supra note 41.

cost. Local governments and their public works contractors are reluctant to use new materials in case the reliability of the system is in some way impaired, and either the quality or the cost of the service is adversely affected.

Any openness to innovative technologies that might be fostered by local financial responsibility for water or wastewater systems is countered by the strong emphasis placed on the reliability of those systems. It is easier for public works utilities to justify rate increases for repair and maintenance to preserve the immediate reliability of a system than for the use of innovative materials in construction that might prolong reliability at some time in the future. Moreover, if advanced materials turned out to be less effective than anticipated, the political and economic costs of repair or replacement can be high.

Public works agencies and their contractors also are very sensitive to liability risks. If people are injured or property is damaged as a result of materials failure in a public works project (at the extreme, the collapse of a bridge or dam), the liability costs for the materials producer and tester, the construction firm, and the public agency can be financially crippling. Although this risk is probably not so great a deterrent in the use of advanced materials as the possibility of having to bear greater repair costs, it is still a consideration.

Some form of incentive is needed to overcome the perceived risks of using new or improved materials in public works. These could take the form of the tax incentives and government co-funding used in Japan, or the grants used in West Germany, or simply some form of guaranteed "repair insurance" in the event the materials did not perform as well as expected. For example, the Environmental Protection Agency's Innovative/Alternative Technology Program has a 100 percent modification or replacement provision to prevent communities from having to bear the costs of failure of new waste treatment technologies.

Better quality control in project design and maintenance and better education for project architects and engineers also are necessary to address conflicts between materials designers and construction contractors, and to alleviate the perceived risks in using new materials. While these are difficult to legislate, relatively simple options such as requiring materials science for civil engineer certification and continuing engineering education would help. The German "Getachten" (expertise) system described in chapter ten also provides a model for improving quality control.

FUNDING FOR INFRASTRUCTURE MATERIALS R&D

Infrastructure materials R&D--whether Federal or nonfederal--generally is underfunded compared to the research priorities (based on perceived needs for better materials performance) and to the probable level of investment needed to meet current and anticipated future infrastructure maintenance, repair, and construction needs. There has been a general decline in all Federal civilian R&D during the 1980s due to the budget deficit and the administration's philosophy that civilian R&D is a private sector or State government responsibility. For example, internal FHWA funding for research on paving materials, including asphalt and concrete, has been cut considerably in the past eight years because FHWA believes that State work under the Highway Planning and Research Program (HP&R; see below) is sufficient, and in anticipation of the Strategic Highway Research Program's (SHRP) intensive efforts on pavement performance. Based on project summaries provided by FHWA, OTA estimates that FHWA materials-related research declined from $2.6 million in FY85 to about $0.9 million in FY87. In contrast, in the 1970s, FHWA direct contract research on asphalt alone was several million dollars per year.

Also, the Administration has repeatedly proposed the elimination of the National Bureau of Standards' Center for Building Technology (CBT). For FY88, the Administration proposes that CBT be combined with the NBS Center for Fire Research, and that the combined budgets be reduced by 40 percent. Congress has previously rejected efforts to cut or eliminate the CBT.

Moreover, Federal R&D funding often is tied to the need to evaluate available products for use in Federal projects or to solve particular problems. The Army Corps of Engineers and the Bureau of Reclamation have been somewhat insulated from this trend because of their continuing mission-related R&D responsibilities. In other Federal agencies, however, once a project has been completed or a solution for a problem has been found, continuing R&D in that area is more difficult to justify.

Nonfederal support for public works R&D by State and local governments and the private sector, also has been declining steadily. Beyond the general economic conditions in many industries today, the low level of nonfederal R&D funding can be attributed either to the lack of Federal support, or to the procurement and liability issues discussed previously, or to corporate perceptions about the low level of return from materials R&D for public works.

Although the relatively new trade association and university sponsored research institutes described in chapters eight and nine mark a small reversal in the overall trend, the level of nonfederal infrastructure R&D funding is still very low compared with identified research needs. Also, continuity of funding remains a problem for some private research institutes, which are increasingly dependent on declining Federal grants and contracts as their primary means of support. For example, the primary focus of trade associations historically has been on member services, publications, standards development, and, in a few cases, technology diffusion. Now that declining profit margins have led many companies to cut their contributions to trade associations, research efforts have been cut back.

Lack of Federal support is especially a problem for State and local governments. While Federal, State and local government research priorities and policies largely determine the materials and infrastructure needs to be examined, Federal priorities often differ markedly from those of the State and local governments who have to implement the Federal programs. There is little Federal R&D to support State and local programs in the areas of water supply and wastewater treatment, for example. Local governments bear the primary responsibility for drinking water supply, and contribute the bulk of the $6 billion spent annually on the construction, maintenance, repair, and rehabilitation of drinking water systems. Although the Federal Government (primarily the Bureau of Reclamation, Corps of Engineers, and Environmental Protec -

tion Agency) historically has conducted R&D on water supply systems and treatment processes and equipment, little Federal money flows to State or local research efforts. Local government officials have stated that they have refocused their waste water efforts from R&D to construction in order to capture Federal funding under the Clean Water Act's Construction Grants Program.[77] This lack of support for local R&D is compounded by the information exchange and technology transfer constraints discussed below.

In addition, as noted previously, internal FHWA funding for research on paving materials, including asphalt and concrete, has been cut considerably in the past eight years in anticipation of the SHRP research on pavement performance, and because FHWA believes that State work under the Highway Planning and Research Program (HP&R) is sufficient. Yet the States' commitments to research under HP&R varies widely, with individual State research allocations ranging between 5 and 55 percent of State HP&R funds (the remainder goes to planning). Moreover, States' definitions of "research" are very broad and often center on evaluative studies, such as the suitability of available materials and processes for road construction specifications.

The low level of private sector R&D on infrastructure materials is due more to corporate perceptions of the costs and benefits of R&D than the lack of government support. Infrastructure materials R&D, even more than most other materials R&D, does not fit the classic industrial or engineering pattern of integrated R&D management, in which process and product development precede a total technological and marketing effort. In the classical, idealized pattern, universities and government research laboratories perform basic research that serves as the foundation for goal-oriented R&D in industrial laboratories. In contrast, materials R&D efforts

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77 See, for example, remarks of Robert P. Miele, Los Angeles County Sanitation District, in American Public Works Association Research Foundation, Proceeding of Workshop: Defining the Role of Federal and Private Sector Activities in Solving Municipal Environmental Problems, Airlie House, Va., Aug. 11-13, 1983, at pp 50-52.

are highly fragmented and tend to be heavily problem-oriented, especially for infrastructure materials. Much of the necessary basic and systematic research that could lead to advances in materials properties and behavior has been neglected and underfunded. There are many small firms involved which do not have adequate resources to support extensive R&D, and the bulk of the effort is devoted to the evaluation of available products.

Further, the public works construction industry traditionally has had a low level of R&D because construction companies typically view themselves as brokers of services; they tend to believe that R&D investments will not confer any significant competitive advantage. They also tend to view these materials as commodities, which implies that any proprietary products resulting from R&D efforts will not have much market penetration (even if they are patented). This is compounded by the fact that public works construction materials, such as cement and concrete, generate a low return and have a long payback period compared to other investments and, consequently, not much profit to allocate to R&D. These are high-volume, low-value products, so that even low-cost materials substitutes or additives can add enough to costs to make them uncompetitive. In addition, as discussed previously, the slow certification process and potential liability risks for new materials are significant constraints on private sector R&D.

Finally, the construction materials industry does not sponsor much R&D because of local variations in the materials. Because constituent materials (sand, gravel, lime, asphalt, aggregate, etc.) are obtained from local sources and are highly variable in composition and quality, research often will have only limited geographic applicability, further limiting potential gain from R&D,

There is slightly more investment in R&D among equipment companies and materials suppliers associated with chemical companies, which traditionally have been more supportive of research. However, even these companies are deterred by the potential for a low return on investment. For example, as noted in chapter seven, du Pent has deferred further development of polymer concretes until a sufficient market develops.

A good start on making the limited R&D funding that is available more effective is to target the research agenda more directly to national needs. The initial step is determining what the most critical needs are. This is especially important for water supply and sewage and waste water treatment systems, which traditionally have been local government responsibilities, and in which the R&D is more fragmented than other infrastructure types with a major Federal role. This would not require an exhaustive inventory of the condition of public works, but could be based on a survey of Federal, State and local agencies responsible for various types of public works about their most pressing problems. For example, SHRP is a targeted program that began with a two-year planning and assessment process to further define gaps in current knowledge (see chapter eight). A similar assessment for other infrastructure types (e.g., wastewater facilities, water supply systems) could eliminate duplication in research efforts and facilitate coordination of projects, and thus get more "bang" out of the limited bucks available.

Innovation centers also can be an excellent means of targeting research. Examples highlighted in this survey include the Army Corps of Engineers' Construction Engineering Research Laboratory at the University of Illinois; the two newly-established, Army-funded Centers of Excellence in Building Construction Technology at the Massachusetts Institute of Technology and the University of Illinois; and the Air Force's Center for Cement Composite Materials, also at the University of Illinois. The funding for such centers requires that they focus on particular kinds of research, and thus helps to ensure that the research meets national needs.

Incentives also are needed to address the corporate perception that they will receive a low return on investment from infrastructure materials R&D. These could be introduced through tax incentives or the contracting process (e. g., waive the low bidder requirement for companies willing to demonstrate improved materials). Also, governments could co-fund the R&D with some form of guarantee that it would actually be used in projects and/or approved for procurement specifications.

INFORMATION EXCHANGE AND TECHNOLOGY TRANSFER

One consequence of the highly fragmented nature of the infrastructure materials R&D industries, and of their limited R&D funding, is that the exchange of information about ongoing and completed R&D efforts is inadequate. Trade and professional associations, journals, and conferences provide forums for the identification of research needs and priorities and the publication of research results. However, these forums usually are organized by type of infrastructure or material. Because the research itself tends to be problem-oriented, there may be little cross-over of information between research groups about new developments in particular types of materials.

Information exchange is even more difficult from non-infrastructure research. Thus, an improved form of concrete developed for a purpose not related to public works may be equally useful in dams, or pipes, or other infrastructure applications, yet the infrastructure materials researchers may be unaware of it. Further, corporations often treat information on research efforts and funding as proprietary and do not release it. Finally, local governments--the primary purchasers of infrastructure materials--often lack the resources to participate in trade associations and conferences, or subscribe to journals.

As with other issues discussed in this chapter, the lack of information exchange and research coordination is most pressing for water supply, and sewage and waste water systems. At present, highway materials R&D is the most coordinated area of research in the U. S., because of the cooperative nature of Federal and State programs. However, even this coordination is limited to highways, roads, and bridges; communication of the results of materials research for another infrastructure type that may be relevant to highways (e. g., concrete for dams, airport runway pavements) is haphazard.

A second problem is the slow rate at which new or advanced materials are accepted by government agencies, architects/engineers, and contractors for incorporation into public works projects. This slow rate of commercialization (or "technology transfer" from R&D program to public works project) is primarily attributable to the procurement and liability issues discussed previously. It also derives, however, from a lack of knowledge about the materials and how to design for and use them. The annual costs of not using the very best available materials could not be quantified, but must be very large (i.e., billions of dollars) for increased future repair and maintenance.

These problems with information and technology transfer result in an inefficient use of what R&D resources are available. Some materials research efforts may be unnecessarily repetitive. In other cases, research funds could be used more effectively in cooperative efforts.

At the extreme, a national clearinghouse on R&D for public works, would be most useful.[78] This should include information on planned, ongoing, and completed R&D projects, as well as on the results of using advanced materials and construction technologies in public works systems, both in the U.S. and abroad. Advances in computer technology and software, such as integrated knowledge systems consisting of networked expert systems, simulation models, and databases, could be invaluable in overcoming the inadequate information exchange, and thus in promoting the use of the best available materials. However, development and adaptation of these systems for public works R&D applications, and their acquisition by users, will be expensive.

At least, individual agencies or trade associations could provide information exchange and research coordination. Organizations such as the International Union of Research and Testing Laboratories for Materials and Structures (RILEM) and the International Council for Building Research and Documentation (CIB) are becoming increasingly important in facilitating the international exchange of information. including research *plans*. In the U. S., the National Bureau of Standards and the Army Corps of Engineers Construction Engineering Research Laboratory are particularly active in RILEM and CIB.

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78 Compare the Japanese and German governments, which have agencies that coordinate research and disseminate information.

Domestic programs that provide information exchange include the Federally Coordinated Program of Highway Research & Development (FCP), which was set up in 1971 to coordinate State-Federal activities (see chapter eight), and the American Concrete Institute Committee 123. However, as noted previously, programs oriented toward either a specific infrastructure or material type cannot always capture advances in another area.

GAPS IN INFRASTRUCTURE MATERIALS R&D

As a result of the limited funding of infrastructure materials R&D, inadequate information exchange and materials commercialization, and procurement practices and perceptions of risk, there are gaps in the R&D agenda. These take the form of mismatches between R&D projects and public works materials needs, for particular materials and their value in individual projects, and for making decisions about maintenance versus repair versus replacement.

As the primary purchasers of infrastructure materials, Federal, State and local governments' research priorities and policies largely determine the materials and infrastructure R&D agenda. Their priorities typically are set by the need to solve specific local infrastructure problems. Yet, the fragmentation of the R&D efforts means that research aimed at special local problems is not coordinated, and limits application of the research results in public works projects.

Private sector R&D is stimulated by the existence or perception of a market for new infrastructure materials due to government investment in public works and the availability of funds. But, as discussed previously, infrastructure materials typically generate a low return on investment. Therefore, private infrastructure research has focused on new construction methods and technologies, and largely ignored research on maintenance and repair methods and materials that could prolong the useful life of materials and public works.[79] Although the long-term

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[79] This is, in part, because public spending programs favored new construction. For example, road and bridge repairs did not qualify for much Federal or State assistance until recently.

market for these methods and materials could eventually be more profitable, new construction carries a higher short-term profit for suppliers and contractors. Moreover, deferring R&D until a sufficient market develops is a vicious circle, because the State and local governments, who are the primary purchasers of infrastructure materials, have a high sensitivity to risk and will not consider using a material until it is fully developed.

The differences in cost effectiveness between repair and maintenance versus new construction or replacement (e.g., filling potholes or resurfacing) also is a critical consideration in infrastructure investment. In assessing such tradeoffs, public works utilities need to be aware of the full range of materials and technologies and their costs. For example, new materials applied to road surfaces or used in sewer pipes could substantially prolong their lives and reduce maintenance and repair costs. This might make it much easier to amortize high-cost projects over considerably longer periods. Yet, few studies have analyzed the tradeoffs among expenditures for maintenance versus repair versus new construction or replacement, even for well-established materials. Information on how these trade-offs might be affected by the capital and maintenance costs of new materials-related technologies is not available. As noted previously, improved life-cycle costing methods would help to bridge this gap.

In terms of more basic research, the gaps in materials-related infrastructure R&D are substantial. There is almost no research on, or expectation of profit from, research toward developing totally new methods of delivering transportation, water supply, and wastewater disposal services.[80] There even is little basic research on new materials, such as a totally new material for building roads. Many of the most important research areas are closely related and apply to all materials for public works--concrete, cement, steel, paints and coatings, asphalt, plastics, and organic matrix composites. These research gaps can be narrowed through a better understanding

80 A possible exception here might be the application Of superconductivity to mag-lev transportation.

of mechanisms of degradation and corrosion of materials in service, and development of methods for predicting material service life and the performance of materials under use. These are all difficult and complex problems, and are not likely to be tackled by the private sector alone.

For both asphalts and cements, there is now a renewed effort aimed at understanding what these materials are; how they derive their properties; and how variations in composition, additives, applications, or environmental conditions can influence their performance in use. However, a critical need continues to be funding of cooperative research efforts on developing international conventions for better standards and measurement for testing and describing asphalt and concrete. This would allow differing properties and compositions to be noted, research results communicated, and materials recreated.

Moreover, few agencies or organizations are researching the public works applications of advanced materials (e. g., ceramics and composites) that were not developed specifically for infrastructure. In part, this is because advanced structural materials typically are too costly to be considered for use in most public works applications.[81] Yet, as noted previously, virtually ‘0 analytical studies have quantified the tradeoff between the front-end costs of these materials and their potential long-term savings in maintenance and repair costs, and service life.

Other public works materials R&D needs include:

-- basic research on the mechanisms of corrosion in underground pipes to reduce repair requirements and the potential for water contamination;

-- basic research on correcting inflow and infiltration of water and sewer systems;

-- improved de- icing and anti-corrosion methods for highways and bridges;

-- the development of certification standards for acceptance of new construction materials and technologies to facilitate their use in public works;

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[81] See U.S. Congress, Office of Technology Assessment, New Structural Materials Technologies: Opportunities for the Use of Advanced Ceramics and Composites, Technical Memorandum, Sept. 1986.

- further analysis of the fieasibility of incorporating performance standards in public works contracting and procurement specifications;

- development of reliable methods, including nondestructive testing of materials, for assessing the quality or condition of materials in both new and old construction;

- testing methods to monitor the properties and quality of materials during construction and repair (e.g., asphalt or concrete as they set);

- cooperative research efforts on developing international conventions for better standards and measurement for testing and describing asphalt and concrete.

- research on the effects of materials on water quality (for example, the problems associated with solvent migration through certain types of plastic pipes and gaskets, toxicological problems from the interaction of direct and indirect additives to drinking water with materials in the water distribution system); and

- development of integrated computer systems (networked expert systems, simulation models, and databases) for improving the usefulness of materials research and facilitating the selection of materials for public works construction, maintenance, and rehabilitation.

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PART THREE APPENDICES

ABLE A-1

FEDERAL SPENDING FOR INFRASTRUCTURE-MATERIALS R&D:

DEPARTMENT OF TRANSPORTATION, FEDERAL × GHWAY ADMINISTRATION

Program	FY 85	FY86	FY87
H ghway Operation			
Highway Maintenance - materials for	°0,°°°	149,174	0
Calcium Magnesium Acetate De-icer	248,240	10,257	0
Subtotal	348,240	159,431	0
Pavement Design, Construction & Management			
Rigid Pavement Design/rehabilitation (Concrete)	744,340	758,031	225,673
Flexible Pavement Design/Rehabilitation (asphalt)	211,307	551,659	450,000
Improved Flexible Binders (asphalt & synthetics)	227,052	0	15,000
Construction Control & Management (Test methods-quality)	36,558	0	250,000
Vehicle Surface Interactions (Pavement behavior data)	368,593	273,659	0
Subtotal	1,587,850	1,583,349	940,673
Structural Design and Hydraulics			
Bridge Rehabilitation Technology (NDE, asessment, guidelines)	384,685	337,165	623,535
Bridge Maintenance & Corrosion Protection	437,383	436,950	249,015
Subtotal	822,068	774,115	872,550
Total FHWA Research Spend ng Ma eria s Related	2,758,158	[illegible]5 6,895	1,813,223
Direct materials work	2, 6,562	1,767, 54	939,688

TABLE A-2

ARMY CORPS OF ENGINEERS INFRASTRUCTURE MATERIALS R&D

CONSTRUCTION ENGINEERING RESEARCH LABORATORY

Selected Projects	Prior Years	FY '86	FY '87	FY '88	FY '89
Nondestructive Evaluation of Deteriorated Metal Structures	$200,000	$[illegible]0,000	$0	$0	$0
Structure Damage Index to Determine the Remaining Life & Reliability of Metal Structures	$50,000	$100,000	$50,000	$0	$0
Corrosion Assessment of Reinforcing Wires & Tendons	$40,000	($80,000)*	($80,000)*	($50,000)*	($50,000)*
Corrosion-Resistant Materials for Civil Works Structures	$100,000	$100,000	$[illegible]0,000	$0	$0
Civil Works Corrosion Mitigation and Management System	$0	$100,000	$150,000	$100,000	$50,000
Painting of Submerged Surfaces	$0	$100,000	$50,000	$0	$0
Development of High-Solid Coatings	$0	$0	$100,000	$50,000	$40,000

* To be funded from slippages and savings within the REMR Program.

TABLE A-2, CONTINUED

ARMY CORPS OF ENGINEERS, WATERWAYS EXPERIMENT STATION

REPAIR, EVALUATION, MAINTENANCE AND
REHABILITATION RESEARCH PROGRAM (REMR)

Selected Projects	Prior Years	FY '86	FY '87	FY '88	FY '89
Evaluation of Existing Maintenance Materials & Methods	$280,000	$175,000	$150,000	$150,000	$150,000
Surface Treatments to Minimize Concrete Deterioration	$175,000	$175 000	$150,000	$100,000	$50,000
Techniques for Underwater Concrete Repairs	$250,000	$200'000	$100,000	$100,000	$80,000
Techniques for Joint Repair & Rehabilitation	$145,000	$175,000	$200,000	$150,000	$120,000
In-Situ Repair of Deteriorated Concrete	$120,000	$150,000	$125,000	$125,000	$100,000
Grouting Practices for Repair & Rehabilitation of Rock Foundations	$375,000	$275,000	$150,000	$50,000	$75,000
Assessment of Long-Term Performance Characteristics of Resin Grout Rock Bolts	N.A.	N.A.	$150,000	$150,000	$150,000
Field Exposure Durability Studies	N.A.	N.A.	$45,000	$50,000	$55,000
Use of Cementitious Materials Other Than Portland Cement	N.A.	N.A.	$60,000	$0	$0
Unsolved Problems Related to Alkali-Silica Reaction (ASR) in Concrete	N.A.	N.A.	$60,000	$60,000	$55,000
Curing Compound for Concrete	N.A.	N.A.	$10,000	$0	$0
Winter Concreting	N.A.	N.A.	$0	$0	$50,000
Effect of Fly Ash & Other Pozzolans on Concrete Durability	N.A.	N.A.	$0	$55,000	$70,000
Optimizing Pozzolan/Portland Cement Quantities in Concrete	N.A.	N.A.	$0	$50,000	$50,000
Improved Nondestructive Techniques for Concrete Structures	$50,000	$150,000	$150,000	$150,000	$100,000
Techniques for Removal of Deteriorated Concrete	$0	$0	$50,000	$100,000	$200,000
Methods for Assessing the Condition of Deteriorated Structures	$0	$0	$100,000	$100,000	$100,000

TABLE A-3

NATIONAL BUREAU OF STANDARDS INFRASTRUCTURE MATERIALS R&D

Center for Building Technology	FY '85	FY '86	FY '87
Polymer Concrete Set Time		$[illegible]0,000	$125,000
Preliminary Minimum Strength Levels for the Bond of Repair Materials to Existing Concrete Pavements		$55,000	$55,000
Expert System for Durable Concrete	$45,000	$81,000	$40,000
AASHTO Materials Reference Laboratory	$170,000	$160,000	$140,000
Cement & Concrete Reference Laboratory	$163,000	$160,000	$128,000
Performance Requirement Tests & Criteria for Materials Used to Repair Portland Cement Concrete	$50,000	$[illegible]0,000	
Ultra-High Strength Concrete		$[illegible]0,000	$[illegible]70,000
Quantitative X-Ray Diffraction Analysis of Portland Cement Concrete		$25,000	
Influence of Pore Solution Chemistry on Alkali-Silica Reaction		$[illegible]0,000	
The Influence of Interfacial Microstructure on Bonding in Concrete		$96,000	
Representation of Concrete Microstructure	$65,000	$54,000	$6[illegible],000
Nondestructive Test Methods for Concrete	$175,000	$116,000	$15[illegible],000
Cement Hydration	$336,000	$327,000	$32[illegible],000
Quantitative Characterization of the Surface Properties of Building Materials Via Computer Image Processing		$96,000	$[illegible]
Improved Characterization of Coating System Performance	$80,000	$50,000	
Organic Coatings		$110,000	$110,000
Degradation of Organic Protective Coatings	$90,000	$96,000	$115,000
Development of Performance Tests & Criteria for Coatings		$200,000	$15[illegible],000
Volatile Organic Content Compliant Coatings			$50,000
Cyclic Loading of Masonry Building Components		$2[illegible]8,000	$210,000
Technical & Scientific Support	$22,000	$20,000	$25,000
TOTAL	$1,196,000	$2,214,000	$1,82[illegible],000

TABLE A-4

NATIONAL SCIENCE FOUNDATION INFRASTRUCTURE MATERIALS R&D*

Materials-related only Systems Engineering for arge Structures & Division of Critical Engineering Systems	FY85	FY86	(To date) FY87
Dams:			
Dam Failure Workshop	45,500		
Subtotal	45,500		
Water Supply Systems:			
Assessment of aging wa er supply systems	174,321		
Engineering methods to assess system upgrades - model		54,953	
Decision methods based on assessment of line pip[illegible] failure modes			174,971
Subtotal	174,321	54,953	174,971
Sewers - Wastewater Treatment Systems:			
Workshop - research needs on buried line pipe		51,685	
Subtotal	0	51,685	0
Highways/Roadways:			
Microadditives for Asphalt Mixtures	110,000		
Reinforced Concrete Degradation	390,110		
Variability of asphalt cements	37,500	35,000	
Electrohydraulic Paving Materials Investigation	55,220		
NDE of Building Materials Contamination	140,970		
Model of Layered Aggregate Pavements	59,993		
Cathodic Protection - Alkali-aggregate reaction deteriora[illegible]	67,186		
Subsurface materials to prevent frostheaves		114,6[illegible]0	
Porous Materials durability - equipment		42,0[illegible]0	
Fracture healing in asphalt concrete		142,5[illegible]3	
Fly ash cement for recycling seal coat pavement material		169,9[illegible]8	
Plastic Fiber Reinforced Concrete for Large Structures			120,179
Fiber reinforced cementitious composites			206,690
Steel fiber reinforced roller compacted concrete pavement			49,723
Methods/materials for pavement ice control			30,000
Subtotal	860,979	504,071	406,592
Bridges:			
Prestressed Concrete Steel Girders	145,688		
Epoxy Mortar - Highway Bridges	121,343		
Prestressed Concrete Steel Box Girders -seismic eva	161,049		
Deteriorated Steel deck - remaining life	90,000		
Alloy Steel Microcracks - equipment	34,145		
Polymer Construction Materials - equipment	67,000		
Epoxy bonded concrete overlays for seismic reinforcement	141,877		
Shock treatment for weld metal joints to enhance ductility		186,903	
Robotic manufacture of steel deck replacement panels		30,000	
Fatigue life of prestressed composite steel concrete girders		107,725	
Workshop - US-Europe bridge evaluation, repair & rehab		36,194	
Performance evaluation joints in precast concrete segment bridges			94,531
Bond of Epoxy-coated rein orcing steel to concrete			223,444
Workshop US-Japan - Strengthening of Bridges			32,900
Subtotal	761,102	360,822	350,875
O AL - Ma er a s	1,841,902	971,531	932,438

*Many of these are 2- or 3 year projec s

TABLE A 5

BUREAU OF RECLAMAT ON FUNDI FOR INFRASTRUCTURE MATERIALS R&D CENTER

NGINEERING & MATERIALS DIVISION OF RESEARCH & ABORATORY SERVICES	FY '85 & PRIOR YEARS	FY '86	FY '87
Concrete & Structura			
Concrete Materials Systems Research	$1,134,000	$70,000	$100,000
Superplastizers & Flowable Concrete	$71,000	$30,000	
Verification of Deleterious Levels o Calcium Sulfate Concentration	$87,000	$[illegible]	$10,000
Repair of Concrete Affected by Alkal Aggregate Reaction	$81,000	$30,000	$35,000
Fly-Ash Cements	$60,000	$20,000	$30,000
Development of Bond Strength Between Lifts of Roller - Compacted Concrete, Concrete & Structural	$84,000	$50,000	$20,000
Concrete and Structural Total	$1,517,000	$215,000	$195,000
Hydraulics			
Prevention of Cavetation to Flow Surfaces (materials performance)	$496,000	$100,000	$80,000
Drain Envelopes	$284,000	$25,000	
Gravel Packs & Well Screens	$560,000	$80,000	$ [illegible]
Hydraulics Total	$1,340,000	$205,000	$ 8[illegible]
echnical			
S Cement Research	$96,000	$4[illegible]	$45,000

TABLE A-5, CONTINUED

Other Mater als & Instrumentation	FY '85	FY '86	FY '87
Mechanical Properties of Well Screens and Casings (Use of New Materials, i.e., Plastics	$43,000	$20,000	$1[illegible],000
Open & Closed Conduit Systems (Includes materials R&D)	$1,834	$120,000	$110,000
Coating Research & Technology	$214,000	[illegible]	[illegible]
Plastic Pipe & Tubing Research	$220,000	10,000	$22,000
Seepage & Erosion Control Materials	$316,000	[illegible]	$25,000
Corrosion Control Methods & Materia =	$111,000	[illegible]	$12,000
Elastomeric Sealers for Joints in Concrete Structures	$20,000	$10,000	$ 0,000
Coatings Performance Survey	$10,000	$10,000	
Other Materia s Total	$935,834	$2[illegible]00	$199,000
Dam Safety Research			
Dynamic Properties of Concrete	$335,000	$50,000	
Research of Long-Time Concrete Studies & NDT Systems for In Situ Evaluation of Concrete	$333,000	$60,000	$60,000
Behavior of Concrete Dams and Their Foundations During Extreme Seismic Events	$96,000	$40,000	$40,000
Portland Cement Grouting Research	$323,000	$50,000	$30,000
Chemical Grouts for Dam Foundation Seepage Control	$89,000	$15,000	
Dam Safety Research otal	$1,176,000	$215,000	$130,000
TO AL	$5,064,834	$885,000	$749,000