PART TWO:

CONSTRUCTION RESEARCH AND DEVELOPMENT

FOR THE NATION'S PUBLIC WORKS

CONSTRUCTION RESEARCH AND DEVELOPMENT

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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 water 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).

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[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 DISIRItIUIION	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.

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

[b]The figure 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 DISrRIEkJIlON	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 ll 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 lg85-87 (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.

[b]Expenditures estimated from allocation 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&I) 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-

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[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.

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