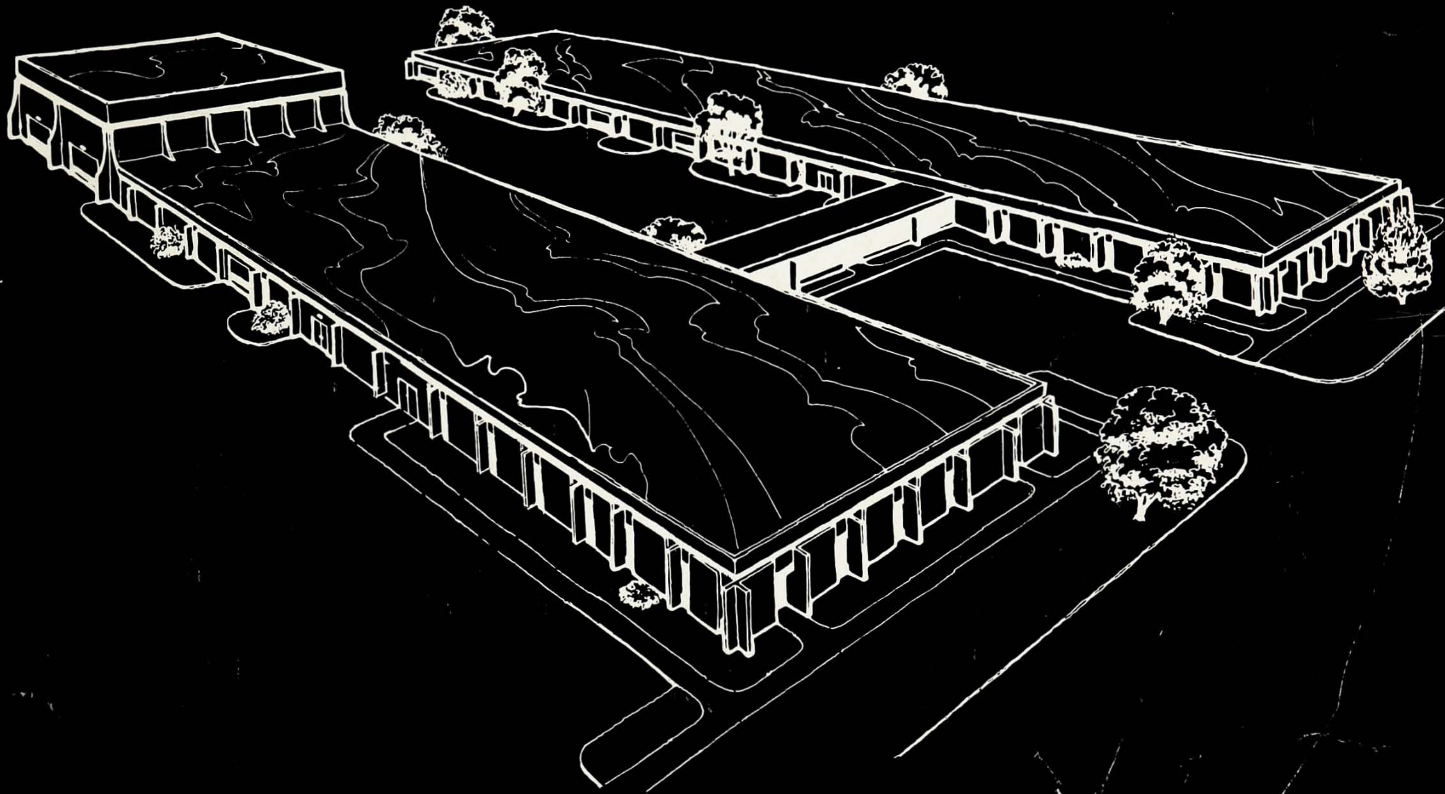

CERL: A HISTORY OF THE U.S. A
CONSTRUCTION ENGINEERING RESEARCH LABORATORY

1968—1974

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CERL: A History of the U.S. Army Construction Engineering Research Laboratory 1968-1974

FOREWORD

It is always appropriate to dedicate a history to some person or group instrumental in the development of the organization. I would like to dedicate CERL's first history to the founding researchers, many of whom were transferred from the Ohio River Division Laboratories in Cincinnati, Ohio, and from the Office, Chief of Engineers, to our new location in Champaign, Illinois. Many of these researchers are still with the laboratory and have been the cornerstone of its existence and progress throughout these first critical years. They can be justly proud of their efforts as CERL begins to achieve national recognition.

In my mind two individuals stand out over the first half dozen years of CERL's existence. They are COL Edwin S. Townsley, the Director from 1969 to 1972, and Dr. Louis R. Shaffer, the laboratory's Deputy Director since it was established in Champaign in 1969. The stamp of their presence is on almost every facet of laboratory life.

I would also like to thank Gary A. Steller, a doctoral student in the University of Illinois Department of History, who did an outstanding job of researching this history.

I hope this document does justice to the prodigious efforts that our founding researchers have put into shaping today's CERL.

Colonel Melvyn Remus
Commander and Director, CERL

PREFACE

One of the objectives of this history is to demonstrate that construction research, although not as dramatic as space research, is indeed an interesting and important area of scientific inquiry. Effective construction research can and has saved the government millions of dollars; it is producing data that will help prevent the building you may be in five years from today from collapsing during an earthquake.

The history of the Construction Engineering Research Laboratory (CERL) is a very recent story, yet even in its first six years of existence, CERL can point to some impressive achievements. In its own way the laboratory has reflected an Army response to the particular demands placed on it by a changing American society. For this and other reasons the complex and fascinating process of establishing a modern research institution is of genuine interest to the scientist and historian alike. In describing this process the history will first deal with the factors that led the Army Corps of Engineers to establish a construction research laboratory and to seek affiliation with a university. The organization of the laboratory will be explained in direct relation to its mission of construction research; CERL's research accomplishments will be described and directly related to specific Army problems. Finally, CERL's present level of development will be evaluated in terms of the potential future needs of the Army.

This will not be a highly technical history with intricate and arcane descriptions of laboratory experiments. The lay reader should find it quite easy to understand; at the same time the technical specialist should be able to gain an accurate understanding of just what CERL is doing.

The research for this history began in December 1974 at CERL, where the bulk of the information was obtained. Most of the sources consisted of CERL publications and internal records, with the addition of questionnaires and oral interviews. Of the people whom I talked with at CERL, Colonel Melvyn Remus, the present director, was especially helpful in providing useful documents and his personal views about the overall development of the laboratory. I would also like to thank Dr. Walter Arnstein, chairman of the Department of History at the University of Illinois, who was instrumental in giving me the opportunity to write this history.

Gary A. Steller

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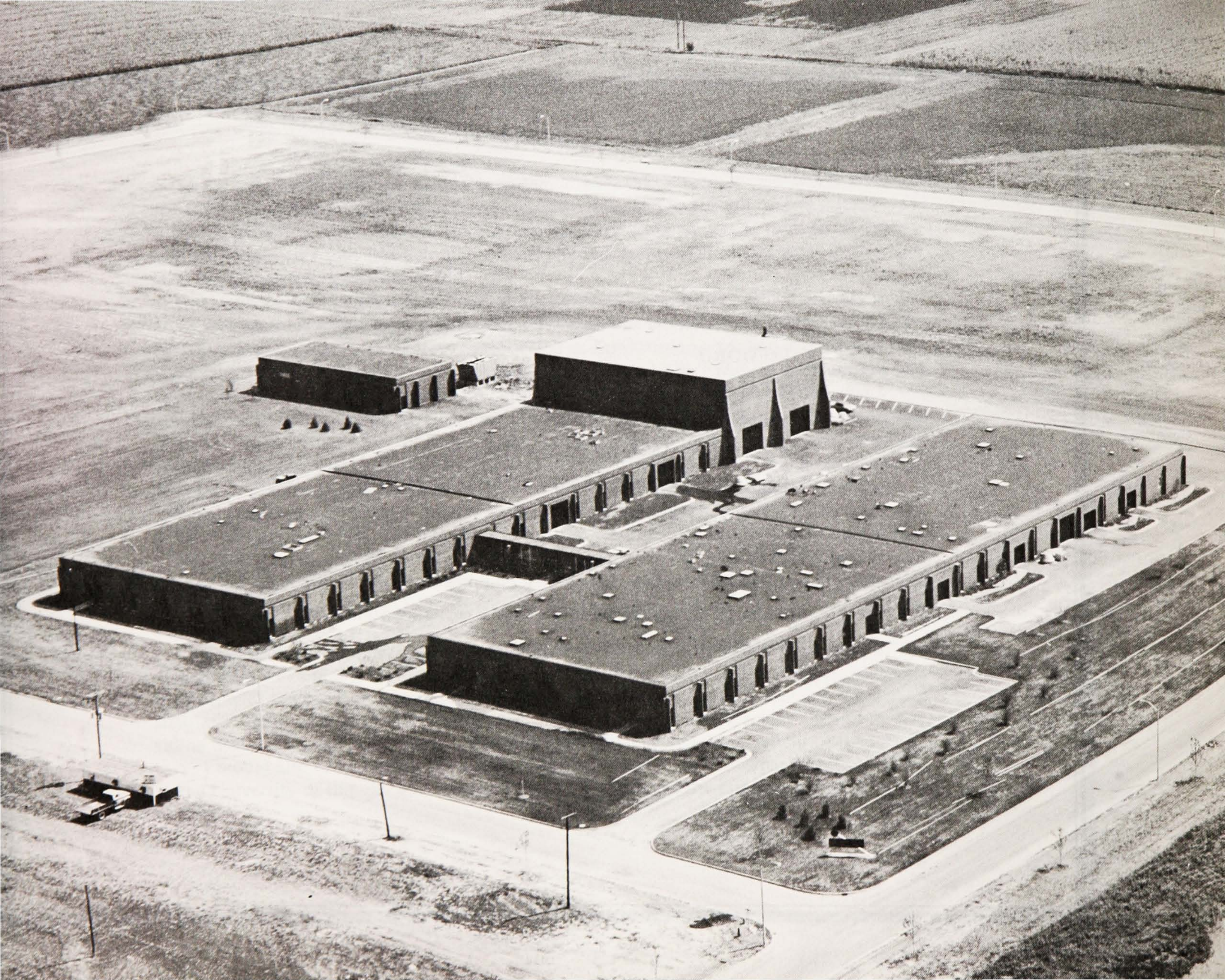


Chapter I
THE CREATION OF CERL

In the mid-1960s the U.S. Army Corps of Engineers determined that to successfully meet the challenge of its huge and increasingly complex construction program a new research laboratory was required. This decision led to the creation of the Construction Engineering Research Laboratory (CERL) in 1968, and increased the Corps' major laboratory inventory to five: Waterways Experiment Station, Engineer Topographic Laboratories, Coastal Engineering Research Center, and Cold Regions Research and Engineering Laboratory. Each of these laboratories supported a different facet of the Corps mission, but none addressed that assigned to CERL.

The Army went to the National Academy of Sciences and asked its Building Research Advisory Board (BRAB) to study the Corps' construction program to discover what new ideas the Army should try to implement in order to fulfill its construction requirements. In two reports, issued in 1967 and 1968, BRAB arrived at some general conclusions which became the basis for the Army's proposal to Congress to set up a construction research facility. The 1967 report pointed out first of all that the Army's construction program was often based on technological processes and products that were the result of research sponsored by private industry or university research programs. The challenge to the Army was to get this advanced knowledge into the Corps military construction program so that the Army could take the greatest possible advantage of progress being made in the construction industry. The study also stated that:

> The present DMC (Directorate of Military Construction) construction research effort follows traditional engineering research concepts and is essentially *ad hoc* with respect to scope and funding of projects.[1]

An *ad hoc* approach meant that each building project was considered separately, with research limited to the specific project funding the work. A unified approach was required to attack the spectrum of problems of military construction.

What should the Army do? BRAB emphasized that it was essential to develop a "coordinated construction research program." The major goal of this program would be to improve "...the planning, design, construction, operation, maintenance and retirement of structures that fall within its purview."[2] Some construction problems encountered by the Corps were unique to the Army's mission, so that in these areas the coordinated research program would be responsible for research which private industry would not undertake. The results of this original research would go in two directions. First, the findings would be transmitted directly to the engineer in the field to help him solve his specific problem. The results would also be transmitted to private industry and the university engineering community to stimulate further research by these sectors on different aspects of the research re-

[1] Building Research Advisory Board, *Final Report on Evaluation of Corps of Engineers Construction Research Program* (National Academy of Sciences, 1967), p 5.

[2] *BRAB*, p 6.

← Aerial View of CERL, 1969

sults. It was essential that the Army research program develop strong ties with the other components of the construction industry, so that information would flow freely back and forth, thus strengthening the combined construction research effort. Since technological discoveries often would not be directly related to what the Army had to accomplish, the Army research program would develop practical applications of these discoveries which the Army engineer could use. BRAB stated that the building process was being greatly affected by developments such as widely expanded use of computers; without a centralized construction program the Army was likely to miss the advantages of such innovations.

A major feature of the proposed research program was its emphasis on long-term research. A really effective plan of attack meant that the Corps should be looking five and ten years into the future and anticipating the new trends in Army building. Certainly the immediate difficulties in construction should be dealt with, but the most efficient way to ensure quality building while at the same time saving money would be to conduct research and provide solutions on a long-term basis.

The Corps of Engineers determined that the needed research effort would be most successful if conducted at a new laboratory dedicated to construction research. In a written statement prepared for Congress in 1967, Major General F.J. Clarke, then Deputy Chief of Engineers, presented the Corps' proposal for a new construction engineering laboratory. His statement detailed the reasons why the new research effort made it "essential that the Corps laboratory facilities be enlarged."[3]

[3]Major General F.J. Clarke, *Statement on Proposed Leasing of Facilities for Construction Research Laboratory* (1967), p 2.

General Clarke first described the Army's continuing construction research program. Most of this research took place either at the Ohio River Division Laboratories (ORDL) or at the Waterways Experiment Station; each Corps division also had the facilities to undertake research to help solve specific construction difficulties.

The Corps of Engineers had decided, said General Clarke, that in view of its immense construction responsibilities it should take a more active role in construction research. First of all, echoing the conclusion of the BRAB report, the Army felt that its construction program should be built on the basis of long-term research to solve long-range problems.

> Up to this time much of our laboratory work has been of an *ad hoc* nature (investigations and research which are responsive to problems of the moment, and usually of a short-term nature). Such a program quite obviously does not provide the means for addressing long-term problems or projected requirements on a systematic basis for improvement of capabilities in design and construction. Further the *ad hoc* handling of unique problems on a crash basis is inefficient, costly, and not necessarily satisfactory.[4]

Of course, the new laboratory would be capable of responding to immediate short-term problems, but the essential goal was low-cost construction that would meet "unique and stringent performance requirements for military facilities." Only a laboratory dedicated to long-term research would make that goal a reality. The problems involved in achieving quality construction were becoming more complex and were demanding solutions based on fresh research.

Because of the particular requirements for the new laboratory, the Army decided that it should not simply

[4]Clarke, p 3.

renovate surplus facilities. Moreover the Army decided that this laboratory should be located near a university with a superior engineering program. Champaign, Illinois, home of the University of Illinois, was the Army's choice.

The proposal to build a new laboratory had no difficulty getting through Congress. On February 1, 1968 Congressman William L. Springer of Illinois was able to report the signing of the initial contracts for building the Construction Engineering Research Laboratory. Congressman Springer saw the laboratory as the potential base for an extensive research system, as private research institutions would decide to locate in Champaign-Urbana in order to work closely with CERL.[5] Also at this time, other Corps personnel attempted to bring CERL into the public eye. This was not just a matter of seeking favorable publicity. CERL was never seen as a secret laboratory hidden from view; an essential aspect of CERL's mission was for it to become a nationally recognized source of construction knowledge.

Colonel Rodney Cox, the laboratory's first director, was an eager proponent of the basic concepts behind CERL. The Corps of Engineers, he said, has a tremendously complex construction task, and this task costs the nation nearly $2 billion a year. Enough reason certainly for the Corps to have a modern research program to guide that great effort. "Instead it has built by precedent, doing minimal research on an *ad hoc*, project-by-project basis,"[6] he declared. CERL would mark a clean break from this procedure. Harry B. Zackrison, Chief of the Engineering Division of the Corps of Engineers and an instrumental figure behind the CERL proposal, explained the concept of long-term research.

> For example, instead of looking at a crowded barracks and deciding it needs another barracks, the Army ought to find out how many men will need housing over the next five to ten years, and program its construction accordingly. It also needs to redefine housing criteria. For example, we've always put windows in barracks, but do barracks really need windows? We haven't asked, we've assumed. We also need to examine construction materials. Maybe we should build everything with plastic—it's durable, easy to maintain. We've got to define our user needs, not repeat solutions because we don't know where to look for new ones.[7]

The official Army order establishing the new construction laboratory was dated September 9, 1968. Until the laboratory was moved to its new facility in Champaign, the initial staff of 62 was based at ORDL. The transfer took place in July 1969, at which time the new facility was officially named the Construction Engineering Research Laboratory. At CERL's official dedication on July 25, 1969, Major General Clarke amplified that there could be no compromise on the quality of Army construction; if anything that quality had to improve. This state of affairs demanded efficient construction research and analysis, and that was the essence of CERL's goal.

President David D. Henry of the University of Illinois also spoke at the dedication.

> At a time when there are many unthoughtful and uncritical and uninformed observations upon the *so-called* military-industrial complex, it is good to have emphasized that the benefits of this laboratory will reach into the lives of people and make a contribution to the enhancement of the quality of life.[8]

[5] "$3.25 Million Contract Signed for Army Corps Lab," *Champaign-Urbana News Gazette*, February 1, 1968.

[6] "Corps Builds New Lab for Systems Research," Engineering *News-Record*, Vol 182 (February 6, 1969), p 22.

[7] *Ibid.*, p 23.

[8] David D. Henry, Transcript of remarks on the occasion of the dedication of CERL, July 25, 1969, p 1.

No one factor is more important to an understanding of the creation of CERL than its affiliation with the University of Illinois. General Clarke in his Congressional statement said that "one of the first decisions made, once the need for a new laboratory became apparent, was to locate the facility near an outstanding engineering school . . .[9] According to him the advantages for CERL of such an affiliation would be highly instrumental in ensuring the success of the laboratory. There would be access to the university's laboratory, library, and computer resources. In effect the two institutions would pool their laboratory facilities. CERL could draw upon the services of the faculty and graduate students of the engineering college for help with various research projects, and the CERL professional staff would be able to study and even teach at the university. That would be very helpful in enabling CERL to retain a good staff; the option of further advanced academic study while at the same time working at CERL would be a potent combination for encouraging highly competent men and women to come to CERL.

In 1966 the Corps of Engineers had sent out letters to 46 universities presenting the Corps' laboratory proposal and asking each university to present its own proposal for a working relationship with the laboratory. Twenty schools replied and the Chief of Engineers, Lieutenant General William Cassidy, evaluated these proposals with the aid of an advisory board from the Division of Engineering of the National Research Council in Washington, D.C. This group of construction experts was impressed by the proposals from Purdue University, Cornell University, and the University of Cincinnati, but their unanimous recommendation was the University of Illinois.[10]

The University of Illinois proposal for the construction laboratory was prepared by the college of engineering with the support of the university administration, the owners of the Interstate Research Park (the location of the proposed laboratory), and the twin cities of Champaign and Urbana. The bulk of the proposal concentrated on a detailed exposition of the research activities and facilities of the college of engineering. As of 1966, there were 1,400 academic staff personnel, 3,600 undergraduates and 1,300 graduate students; the research budget was close to $15 million a year. The American Council on Education was quoted as ranking the college of engineering fifth in the nation in quality. Of particular interest to the Army in this case was the civil engineering research.

> The Department of Civil Engineering at Illinois has the most extensive research program of any civil engineering department in the country—nearly 10 percent of the entire research effort in the country in civil engineering is conducted at the University of Illinois. The annual research budget has been increasing steadily and has been approximately $1.7 million for the past two years, leading all other schools by a good margin.[11]

The proposal makes especially clear that the college of engineering saw no problems in cooperating with the Corps. Individual professors from the University of Illinois had helped the Army deal with earthquake landslides in Alaska, engineering geology in Nevada, and foundations for dams and locks on the Arkansas River.

[9] Clarke, p 5.

[10] Clarke, Appendix E.

At the Waterways Experiment Station, U. of I. researchers had engaged in foundation testing; at ORDL they had studied airfield pavements, radar towers, and lunar soil behavior. The Corps had another good reason for knowing the caliber of the Illinois program; the University of Illinois had seen a remarkably large number of its engineering graduates go to the Corps of Engineers. Over the years strong personal ties had developed; Nathan Newmark, head of the Department of Civil Engineering at the U. of I., was a good friend of Harry

General Clarke and U. of I. President Henry at CERL's Dedication, July 25, 1969

[11] *Proposal to the Office of the Chief of Engineers for an Engineering Laboratory for Construction Research* (June, 1966), p 76.

Zackrison. Indeed, according to the associate head of the civil engineering department at that time, there were some worries within the Army that the Corps was becoming too involved with one school, perhaps to the detriment of the Army research effort.[12]

CERL's affiliation with the University of Illinois has fulfilled General Clarke's expectations, however. The mutual exchange of staff and use of equipment has strengthened the engineering programs of both institutions. Colonel Remus, CERL's present commander and director, describes the relationship as "very cordial" and very productive for CERL.

> For example, 25 percent of the CERL staff is comprised of highly qualified temporary and part-time employees—most of whom are available only because of the pursuit of higher education being undertaken by the employee or a member of the employee's family.[13]

At the beginning, there had been doubts within the university community about the relationship with CERL. Some people within the administration were worried about CERL's leasing arrangements with the University of Illinois Foundation, which actually owned the laboratory buildings. Under the terms of the lease the Army could pack up and depart in 90 days, leaving the university with large, empty laboratory buildings. It should be mentioned, however, that the Army pays a high price in rent for the short termination privilege, and that CERL's history of growth and expansion makes it unlikely that the Army will use the 90-day option.

[12]Interview February 21, 1975 with Jack Briscoe, presently Vice Chancellor for Administration Affairs of the University of Illinois.

[13]Colonel Melvyn Remus, *Semi Annual Program Review of CERL Program* (October 1974), p 12.

At first there was doubt about CERL within the university. Some faculty members questioned the wisdom of apparent influence the Army would gain over the university's research efforts. This opinion, which was expressed at a time when Vietnam was an issue of primary concern, came not from the engineering faculty, but from the liberal arts faculty. The engineering people connected with the university's proposal discounted this fear. It was further believed that CERL's relationship with the university would be a healthy example of civilian influence on the military's research program and goals rather than vice-versa. Nonetheless, the idea of the university helping the Army did not sit well with many professors and students; this feeling was expressed with greatest vehemence in 1972 during the last of the major Vietnam War protests. During a student strike at the University of Illinois, a newsletter printed by the striking students said of CERL:

> **War Criminals on Campus Dept.**
>
> Who designs the reinforced concrete runways that land those C-5A's and other heavy aircraft bringing anti-personnel weapons to Vietnam? . . It's Champaign's very own Construction Engineering Research Laboratory . . . They have over a hundred employees including department heads, associate deans, and professors from the university helping them do the engineering and computer work for Vietnamization.
>
> OFF CERL! Demand that the University end all ties with the military NOW![14]

This impassioned moral outrage has largely subsided, and although discussions with students and professors in liberal arts reveal lingering suspicion, such concerns have proven unfounded.

[14]*The Striker,* April 20, 1972.

Chapter II
FACILITIES AND ORGANIZATION

Location

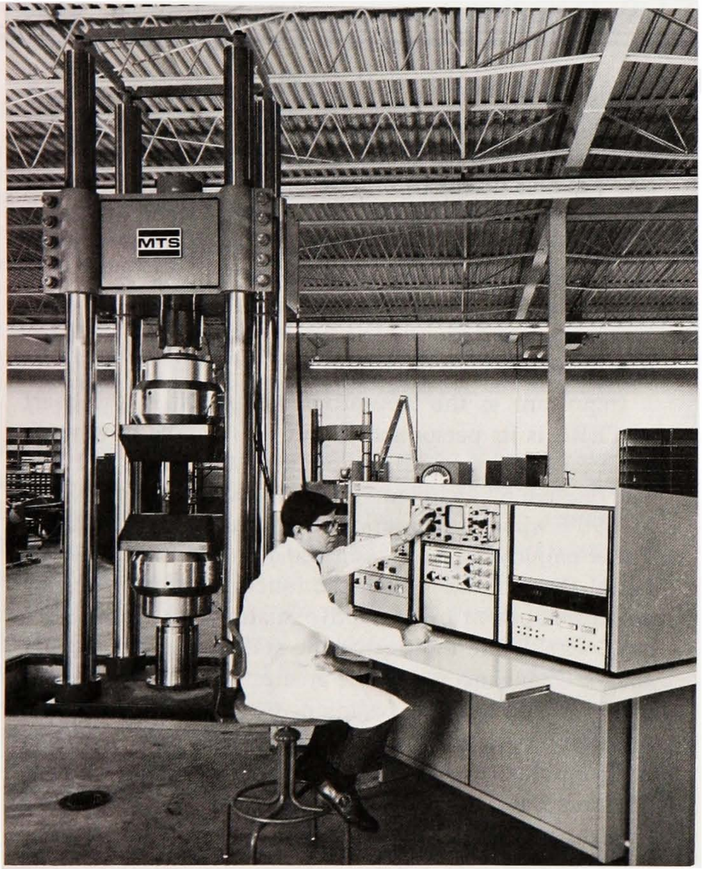
The Construction Engineering Research Laboratory, which is located on a 30-acre site in the Interstate Research Park of Champaign, began in 1969 with two laboratory buildings, each having a surface area of 48,000 sq ft, and a utilities building. From the beginning there were plans for further expansion of CERL, including two more laboratory buildings, a warehouse, administration building, and a snack bar. The warehouse is in the planning stage and a snack bar has been added.

Equipment

Some of CERL's laboratory equipment came from ORDL when the laboratory was transferred to Champaign and new equipment has been purchased. Among the most important items of equipment are the scanning electron microscope and the closed loop materials testing system. (See Appendix I for a list of major laboratory equipment.) Probably the single most impressive piece of laboratory hardware is the Biaxial Shock Test Machine (BSTM), for which a separate building was completed in 1973. This $3 million facility was a joint project of CERL and the U.S. Army Engineer Division in Huntsville, Alabama. Although the BSTM was built to test facility support equipment for the SAFEGUARD antiballistic missile system for resistance to nuclear shock effects, it was also designed to be used to test structures and equipment for earthquake forces. The BSTM is one of the largest such machines in the world. It has a 12 x 12 ft aluminum table upon which test items are placed; motion of the table is produced by hydraulic actuators operating both horizontally and vertically to reproduce the effects of a nuclear blast or an earthquake. The BSTM can produce forces up to 810,000 lbs vertically and 450,000 lbs horizontally. Dr. Walter Fisher of CERL received an Army Research and Development Award for his work in developing the BSTM.

Personnel

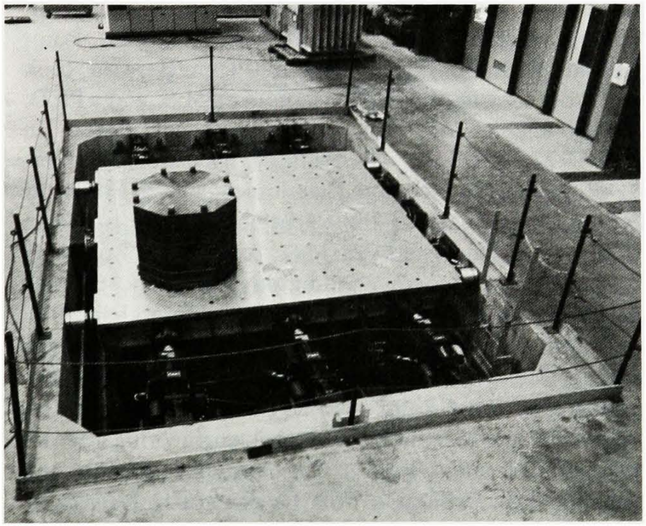
Important as the laboratory equipment is, the heart of CERL is its personnel. About 300 people now work at CERL, compared to the original staff of 62 in 1969. The original 62 included 35 who transferred from ORDL in 1969 when its function was transferred to CERL. Three employees have been transferred from the Rock Island District, along with the functions of paint testing and development of protective coatings for Corps dams and locks. While the size of the staff has grown rapidly since CERL's inception, the greatest increase took place in 1972-1973 with the beginning of a new environmental research program. At the end of 1974 the staff consisted of 192 permanent and 85 temporary employees; of the 85 temporary people, 16 were experts and consultants brought in for particular projects and 31 were graduate research assistants from the U. of I. Besides the temporary and permanent workers there is a separate category of staff member called IPA. This refers to the Intergovernmental Personnel Act of 1970 that provides



1 Million lb Loading System With Programmed Control Unit

Metal Fatigue in Steel as Seen Through Scanning Electron Microscope the opportunity for an individual from a nonprofit civilian organization to accomplish tasks at a federal research installation that will help both the installation and the individual. This opens up a wide pool of research talent to the laboratory and greatly increases CERL's capability to react to program requirements. IPA's with specific talents can be brought from the academic community (or occasionally other organizations) to help meet new research objectives.

One interesting fact about CERL is that of its 300 employees only five are military personnel. Also noteworthy is the fact that the researchers outnumber the administrative support staff. A glance at the organizational charts in Appendix III might suggest that the support offices and research divisions are about equal in strength, but such is not the case. The support staff is only half as large as that of the research divisions, since support services in personnel, finance and accounting, real estate, and procurement are furnished by other Army installations.



Biaxial Shock Test Machine With 12,000 lb Weight

Four offices within the CERL organization provide different types of administrative and advisory support for the research divisions. **The Plans and Programs Office** helps the director and deputy director formulate the actual research program. The plans and programs officer has tasks such as interpreting Army regulations on research and development for application to the CERL program.[1] **The Comptroller Office** is in charge of budgeting, accounting, auditing and general management affairs. **The Administrative Office** has a wide variety of duties, including liaison with the University of Illinois, maintenance of laboratory buildings and equipment, security and safety arrangements, and the processing of new staff members. The three branches of the **Information Systems Center** provide the researchers with the necessary nontechnical support for research and report preparation: the Computer Services Branch assists laboratory personnel with all aspects of computer use; the Technical Information Branch is responsible for technical report publication; and the Library contains 4,000 books and 6,000 technical reports as well as current subscriptions to 500 periodicals. Of special importance is the direct contact that the CERL Library maintains with the University of Illinois Library, one of the largest libraries in the United States.

[1] *CERL: Statement of Missions and Functions*, February 1, 1974, p 4.

Executive Office

Then there are the executive officers who guide the overall research program. The two key figures here are the commander/director and deputy director, who share the ultimate responsibility of assuring that CERL meets its research objectives. The position of deputy director was designed to be held by a civilian as opposed to the director's position which would always be a military post. With the Army procedure of rotating commanding officers, CERL has a new director at least every three to four years; this hopefully provides new perspectives on the CERL program from each incoming director. The deputy director's position is as much as possible a permanent assignment, assuring a certain degree of leadership continuity as directors are rotated. In its first five years CERL had three directors but only one deputy director, Dr. Louis R. Shaffer. Dr. Shaffer is a living example of CERL's attempt to tie in with the rest of the construction world, since he has been active both in private industry and the academic world. At one time he was assistant director of engineering at the Sharon Steel Corporation in Sharon, Pennsylvania. He has an M.S. and a Ph.D. in civil engineering from the University of Illinois, where he taught from 1957 until he was appointed deputy director in 1969. He was a member of the Building Research Advisory Board which drafted the 1967 and 1968 Army construction reports, so he finds himself working within the organization that resulted from that committee's recommendations.

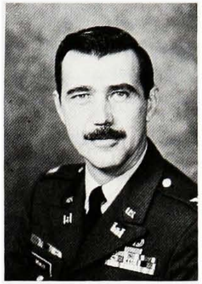
The Corps of Engineers has sent to CERL four directors with very impressive practical and academic experience in engineering. Colonel Rodney E. Cox, the first director, had a B.S. in civil engineering from Virginia Polytechnic Institute, an M.S. in highway engineering

Col. Cox

Col. Townsley

from Iowa State University, and a Ph.D. from that school in transportation engineering. He also was graduated from the Army Engineer School at Fort Belvoir, Virginia. Colonel Edwin S. Townsley, a West Point graduate with an M.S. in economics from Harvard, took over from Cox in 1969. He also held an M.S. and a Ph.D. in civil engineering from the University of Illinois. In July 1972, Townsley was replaced by Colonel Robert W. Reisacher, a registered architect and a Fulbright Fellow. A graduate of the Carnegie Institute of Technology, Reisacher held an M.S. from both Princeton University and George Washington University. Colonel Reisacher retired from the Army in November 1973 and, until July of 1974, Dr. Shaffer was acting director. Colonel Melvyn D. Remus, the present director, is a graduate of West Point and of Iowa State University, where he received an M.S. in civil engineering. He has both studied and taught at the Army's Command and General Staff College at Fort Leavenworth, Kansas; he has been directly involved with engineering research and development for the Department of the Army. All of

Col. Reisacher



Col. Remus

Dr. Shaffer

CERL's directors have obviously had substantial academic experience; all of them also had one common experience in practical Army construction: at least one tour of duty in Vietnam. Colonel Remus, for example, was involved with the development of the huge Army supply center at Cam Rahn Bay.

Besides being responsible for the overall research program, the director also has two responsibilities which are interconnected. First, as would be expected, he has a clear duty to see that the CERL staff, whether researchers or support personnel, are rewarded for good work. Morale at a laboratory like CERL is as real a performance factor as in any military command situation. Second, the director must endeavor to see that CERL's achievements are given proper recognition by the Army, the construction industry, and the public. This is a particularly crucial task in a new laboratory which often feels great pressure to show results for the money that has been allocated to it. The deputy director is responsible for the technical management of the research program.

Research Divisions

At present the research at CERL is divided among five operating research divisions, each divided into two to four branches. Each division, which consists of personnel from a variety of disciplines, probes a specific aspect of the construction process. For example, many kinds of Army construction activity have a direct effect on the environment, and that effect is a major concern of the **Environmental and Energy Systems Division.** The division's research centers around reducing air, water, and even noise pollution that may be caused by Army construction and normal operation of facilities. Another goal of this division is to take a thorough look at the Army's energy requirements in order to help the Army make the most economical use of fuel resources in its fixed installations. **The Facilities Habitability and Planning Division** deals mainly with the planning for and architecture of Army facilities since the Army wants to produce buildings that are not only functional and economical but also pleasant to work and live in. **The Facilities Engineering and Construction Division** develops the most efficient type of structure for a particular purpose, and then the way to most efficiently build that structure. At the same time the **Materials Systems and Science Division** is investigating the characteristics and response of various types of construction materials including metals, composites and plastics; as well as fracture, failure, seismic design and the response of structures to earthquakes, blasts and other harsh environments. Finally, the **Facilities Operations and Maintenance Division** takes the completed structure and tries to develop methods of operation and maintenance that will best preserve the structure during its life cycle.

Reorganizations

This structure of five research divisions is not what CERL began with; the laboratory has gone through one major and several minor reorganizations of its research work. The major reorganization resulted in the present research structure, which was developed in November 1973 during Colonel Reisacher's tour of duty. (See Appendix III for present and previous organizational charts.) The reorganizations reveal an inherent problem in the expanding research program of a new organization. Though the various divisions work together on projects, it gives the researchers a clear sense of just what projects are their responsibility if particular research problems are assigned to particular divisions. But under any kind of divisional structure there will be some research where the necessary expertise exists in two or more divisions. In these cases the director must resolve jurisdictional disputes. On October 16, 1973, Colonel Reisacher sent a memorandum outlining the difficulty to the chiefs of the research divisions.

> During the past six months, and particularly since the beginning of this fiscal year, it has become more difficult to clearly place research work that is received into the existing categories assigned to the various operating divisions . . . It is obvious that these jurisdictional issues arise because of the close correspondence in certain missions and functions among the operating divisions.[2]

A group formed at CERL to study reorganization concluded that, given the nature of the laboratory's mission, no one organizational plan could solve all jurisdictional difficulties. Yet, given the nature of CERL's constantly changing research program, it seemed an obvious mistake to try to stick with existing organization. A reorganization could at least reduce, if not eliminate, the number of jurisdictional disputes between divisions. It also seemed clear that CERL would have to show itself adaptable enough to deal with new issues such as the environmental avalanche of the early 1970's if it was to become a truly effective part of the Corps laboratory system. Important new research thrusts might not fit well into the old organizational pattern.

Yet a new laboratory does not want to spend too much time organizing and reorganizing itself. One of the research division chiefs pointed out one risk of reorganization for CERL.

> Reorganization will cause disruption of work and delays in meeting milestones (research objectives)—a result which could be most detrimental to CERL at this point in its history.[3]

Most of the division chiefs have been with CERL since 1969. As a result the rapid growth of the CERL program and the reorganizations of the CERL research structure have especially affected them. One division chief "started as a one-man laboratory dealing with electrical power."[4]

[2]Colonel Robert W. Reisacher, Memorandum to Division Chiefs, October 16, 1973.

[3]R.M. Dinnat, Chief of Facilities Habitability and Planning Division, Memorandum sent to CERL reorganization study group, October 1973.

[4]Richard G. Donaghy, Chief of Environmental and Energy Systems Division, written response to questionnaire, January 1975.

His present position is more complicated; a division chief is directly responsible to the executive branch for the implementation of his division's portion of the research program. This means the supervision of 50 or more researchers and assistants. For the division chief the reorganization of the laboratory is a major concern, since it is not easy "to meet constantly changing requirements while providing personnel with a clear growth and development pattern."[5] The division chiefs generally agree, however, that reorganization has resulted in greater efficiency in meeting research goals.

There is real pressure on a new laboratory to get substantial results produced quickly. Yet on the other hand, as Colonel Remus observed, a new laboratory can more easily adjust to changing conditions than an older laboratory with firmly established procedures. Reorganizations in a new laboratory should be expected; to expect the original organization to serve a program that has changed its substance dramatically would be overly optimistic.

[5] *Ibid.*

Chapter III
RESEARCH THEMES AND ACCOMPLISHMENTS

Research Categories

There are three broad categories of research at CERL. First is research involved in the fulfillment of the Army's long-range investigational program in construction. Then there is the intensive research involved in solving problems for which the Corps has to have immediate solutions; it is common for other Corps organizations to come to CERL with such immediate problems. Third is a program of reimbursable research sponsored by other agencies, particularly those agencies with which the Corps has worked on building projects. The reimbursable research is limited to projects which are in accordance with the other two goals of the laboratory's program. This is a necessary restriction to keep the research effort focused on the mission assignment.

CERL was first conceived as a laboratory devoted to long-term research.[1] In that regard an interesting situation soon developed as people at CERL and the Corps of Engineers noticed that the research program was becoming dominated by short-range problems which demanded a quick response. The reason for this development is fairly straightforward. The one convenient aspect of an immediate problem is that its dimensions are readily apparent and its solution can often be seen to have an immediate impact. This, especially for a new laboratory, can give more of a sense of achievement than working out the details of a five-year plan where results will often not be evident for years. It was never intended that CERL should ignore emergency construction problems in favor of concentrating totally on problems anticipated in 1980. Yet the basis of CERL's creation was the premise that effective research meant long-term research. This premise was re-emphasized in 1974 with the establishment of long-range planning.

Five-Year Plans

A central aspect of the emphasis on long-range planning is the requirement that the research programs be structured in terms of a five-year plan of stated objectives. Each major area of research, such as the environment, will thus be developed in terms of a five-year prospectus of what the program will attempt to achieve.

A brief look at one of the Corps of Engineers' current five-year plans will give the reader some indication of what is involved in long-range research planning. The five-year plan for the environment involves several laboratories; CERL is the leading laboratory for the military program in environmental investigation. The plan presently in force divides the environment theme into five major projects–environmental quality management, pollution control technology, environmental impact analysis, water quality, and fisheries engineering. Each major project is then broken down into various specific research projects, each of which is given a projected completion date up to the year 1980. Each major project is given a funding profile which describes just how much is expected to be spent.

[1] Clarke

The five-year plan also explains why the Army is embarking on these environmental projects. The plan lists over three pages of federal and state environmental laws with which the Army must comply. It reveals that current technology is not developed highly enough to meet many of the Army's objectives and that the Army will be developing new techniques. These new techniques are necessary since many environmental problems are unique to the Army—for example, noise from artillery blasting and helicopters. Finally, the plan specifies what the actual research results will be and how they will be used.

The five-year environmental plan also reveals one significant change that has occurred at CERL. The basic outlines of the research program that General Clarke described to Congress in 1967 have remained essentially unchanged except for the fields of energy and the environment. In 1967 there was no mention of the need to save energy; the main problem was how to supply more power to the Army. The planned environmental projects were "to provide economical and functional means of protecting structures and men, machines and systems from the effects of hostile environments."[2] There was no mention of how the Army might control pollution and protect the environment. But by 1973 an environmental studies project based on a very different premise had been established at CERL, with steadily increasing appropriations planned for the future. The nation had suddenly awakened to the twin threats of a decreasing energy supply and a devastated environment. Now part of CERL's mission is to develop techniques that will save energy and help the Army protect the environment.

[2]Clarke, p 5.

A complete description of all aspects of CERL's research program would go far beyond the scope of this history; the remainder of this chapter will outline the major thrusts of the CERL effort. One such thrust is included in the following quote:

> It is also of importance to note that in materials technology, the research and investigation is not often for the invention of basic raw materials such as new plastics or metals. Materials R & I is focused toward the development and application of material systems to take maximum advantage of progress in industry and not towards reinventing the wheel. It has been estimated that 10,000 firms exist which are developing materials applicable to vertical construction; CERL's program is to tie into this capability and evaluate the applicability in the pay-off of these materials to Military Construction, Army. We do extend material development where required to make them more appropriate to Army facilities.[3]

Not surprisingly for a construction laboratory, the research theme of facilities and structures has the highest funding level (see Table 1). No one CERL research division has charge of the projects included under this

Table 1

Summary of Funding Per Theme, FY 1974

Theme	$ Million
Facilities & structures	3.7
Operations & maintenance	0.6
Real estate	0.0
Environment	1.6
Energy	1.0
Military operations	0.6
Water resources	0.0
TOTAL	7.5

[3]Remus, p 6.

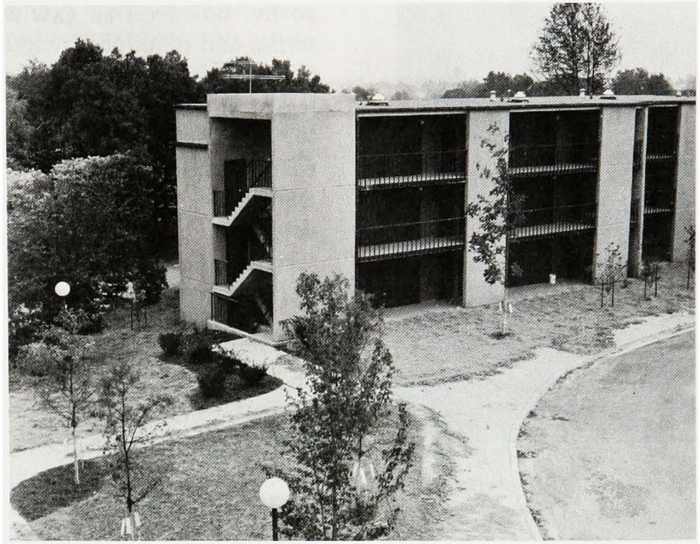
theme; the scope of the program involves a wide variety of construction problems. The basic task is the deceptively simple one of building better structures and facilities while keeping costs as low as possible. Then there is the additional factor of human acceptance; an economical structure is not successful if the users are unhappy with it.

As the BRAB report predicted, much of CERL's research has been based on the computer. The laboratory has developed several programs to help simplify the work of the individual Army engineer. AMPRS, Automated Military Progress Reporting System, greatly reduces the effort the district engineer must expend in fulfilling his reporting requirements. The Army has literally thousands of miles of pavement to maintain; LIFE1, a life-cycle cost analysis computer program, has been developed to help the engineer decide on the best method for repaving and maintaining the pavements under his care. Dr. Edward Murphree, Jr., received the Army Research and Development Award in 1971 for his work on the planning and design of airfield pavements. AEADS, Automated Engineering and Architectural Design System, will help the engineer faced with specific construction choices such as the optimum type of roofing material for a particular situation. The computer can even tell the engineer what is wrong with specific roofing materials for a specific construction task. AEADS is still in its initial phase of development by the Facilities Operations and Maintenance Division; in future years it should become a comprehensive system capable of assisting the engineer with almost any aspect of the construction process.

The laboratory has also developed several guides and

Pavement Distress

manuals for Corps engineers. *The Construction Plant and Equipment Cost Guide* will help the engineer determine how much he should expect to pay a contractor for the use of equipment needed for a given job. With the data the engineer will be able to arrive at a fair and equitable agreement with the local contractor. Another "best seller" developed at CERL has been the Equipment Selection Card, devised to help construction managers in the Theater of Operations efficiently select construction machinery for a given job. The Facilities Habitability and Planning Division has produced an *Interim Guide for Industrialized Building*, which enables the engineer to decide when he might cut costs significantly by using industrialized buildings. The bachelor



Fort Knox Bachelor Officer Quarters

officer quarters at Ft. Knox, Kentucky were built with the aid of CERL expertise on industrialized buildings. As a result the quarters were completed much more quickly than if conventional methods had been used, and at a cost $120,000 below the original government estimate.

In another area, the Army noted that at many of its bases soldiers often chose to spend their own money to eat at civilian restaurants rather than at free on-base dining facilities. To help make on-base dining facilities more attractive to the soldier, a branch of the present Facilities Habitability and Planning Division produced the *Decor Guide for Enlisted Personnel Dining Facilities,* which is meant to help the officers in charge of a dining hall make the facilities more appealing. The *Decor Guide* offers advice on everything from choosing pleasant color schemes to methods of noise reduction. There is also the *Dining Facility Evaluation and Improvement Guide* which gives advice on how to survey soldiers to discover their preferences for dining conditions.

CERL also has done some very interesting work in the area of investigating material and equipment performance. For many years concrete mattresses with copper-clad steel wire reinforcement have been used by the Corps of Engineers as flood control revetments along the Mississippi River. The copper-clad wire has been getting more expensive, making the revetments more

NORAD Spring, Showing Corrosion Effects

Inflation Forming of a Dome

costly. Based on an extensive study of alternative materials and required strength, the Materials Systems and Science Division came up with a proposal for using stainless steel wire and reducing the amount of reinforcing in the revetments by 30 percent, thus achieving substantial cost savings. The huge NORAD (North American Air Defense) complex in Colorado is built on a system of very large steel springs. After less than 10 years of service a few of the springs began to crack and fail. Because many of the springs were suspected of potential for failure and would require replacement, CERL was requested to investigate the problem. CERL research identified the main cause of the problem and suggested a repair program which cut the estimated repair and replacement bill by about $750,000. When the Apollo moon program was completed, one of the pieces of equipment that appeared to have an application on earth was a drill designed to work in the lunar environment in which cooling water is non-existent. The Corps of Engineers inherited the lunar drill, and CERL has been quite successful in modifying the system for more earthbound tasks.

In the area of concrete research, the Materials Systems and Science Division has done much work with refining the Kelly-Vail technique for testing the quality of concrete before it is poured. CERL's work with fiber-reinforced concrete is a fine example of successful long-range research. Fibrous concrete is a material to which short fibers of steel or other materials have been added. Following the lead of Professor Romualdi at the Carnegie-Mellon University, ORDL, seeing the potential for pavement construction of this concrete, initiated a fibrous concrete research program. General Clarke mentioned it in his Congressional statement. "Still in its infancy, this study may produce a material which will provide an economical reinforced concrete for structures subject to shock loadings."[4] General Clarke's prediction was given substance by CERL research; its work has proven that a fibrous concrete pavement half as thick as a regular concrete pavement will last many times as long as regular pavement when subjected to heavy vehicular traffic. This was dramatically demonstrated by testing which simulated the effects of heavy traffic such as the jumbo-jet C-5A aircraft. CERL has acted as a consultant for many Corps construction jobs which used fibrous concrete. One CERL researcher, Bobby Gray, received the Army's Research and Development Award in 1972 for his fibrous concrete investigations. Furthermore, CERL has made a real effort to share its knowledge with the rest of the construction industry. In 1972 the laboratory convened the first fibrous concrete conference, with over 250 attendees from 38 states, England, Canada, ten federal agencies, and 20 Corps of Engineers Districts. The conference was designed to cover all factors involved in the use of fibrous concrete; the featured speakers were from CERL, private industry, and universities. Included in the agenda was a visit to CERL where the conference participants observed laboratory and field demonstrations of various aspects of fibrous concrete. In this case CERL was directly following the BRAB report recommendation to establish fruitful communications with the rest of the construction world.

Environmental Research

After facilities and structures the research theme with the highest funding is the environment. Activities at an Army base can affect the surrounding environment in many ways. One of the most useful activities of CERL is helping Army commanders and engineers cope with increasingly stringent environmental laws and regulations. When a Corps engineer contemplates a job today, he must have an accurate idea of how it will affect the environment. Will it violate any environmental laws? The Environmental and Energy Systems Division has developed a *Handbook on Environmental Impact Assessments* to help the Corps engineer accurately predict the effects of what he plans to do. The division has also produced the Environmental Impact Computer System for predicting the impact of various Army activities on the environment. This program can provide the engineer with reliable factual data with which to write an environmental impact assessment or statement. In other environmental research, the division has developed a computer-aided method to help Army personnel determine the impact of noise at Army installations. When the Concorde SST first landed at the Dallas-Ft. Worth airport, CERL engineers and technicians were there measuring noise for the Environmental Protection Agency. CERL has also helped develop techniques for reducing air and water pollution caused by boilers, incinerators, and other sources of pollution found on many Army bases.

Probably the most controversial environmental issue that CERL has been involved with concerns a problem of rather unusual dimensions—13 million blackbirds. In late 1974 CERL was asked to prepare an environmental impact statement on the proposed destruction of

[4] Clarke, p 7.

blackbirds plaguing Ft. Campbell, Kentucky. This was a situation where CERL was required to produce a quick response to an immediate problem; the time span in this case was a matter of days rather than weeks.

Energy Research

Energy is the research theme with the third highest funding level. Here the Army situation duplicates the national situation of 1974. The cost levels of energy sources and systems are getting higher, and there is constant pressure to keep costs as low as possible. Part of CERL's energy work has involved study of the possibilities of solar energy and the increased use of insulation in existing Army barracks. CERL has recently begun work on instrumentation and data analysis systems designed to help the Army correctly predict levels of energy consumption at its installations. Perhaps the most innovative work has been with the use of solid waste. In a series of studies for the Naval Facilities Engineering Command, the Environmental and Energy Systems Division has investigated the use of solid waste as fuel to produce energy. This research includes analysis of the various components of solid waste in order to predict its energy potential and studies of the best method of converting the waste to energy at a particular installation.

Operations and Maintenance Research

The next research theme in terms of funding is operations and maintenance. The principle behind this research is that effective construction practice does not stop when the building is completed. If a building is given the best kind of maintenance, it will better fulfill its function and will last longer. The Facilities Operations and Maintenance Division has developed systems which provide the facilities engineer with the data needed to formulate the best maintenance policies for Army buildings and to determine when a building becomes too expensive to maintain and should be replaced. HEMS (Hospital Equipment Maintenance System) is an automated system designed to give the facility engineer reliable data for setting up a schedule of repair and maintenance for hospital equipment.

CERL is also in the process of investigating materials-handling procedures in Army commissaries. Initial findings suggest that the most commonly used equipment, the forklift, is not always the most efficient for a given situation, and that a conveyor belt system would often be more efficient and quicker. It is also expected that studies will establish the possibility that proper maintenance procedures can be designed as a building is being constructed, so that the building can be properly maintained from its first day of use. As part of its operations and maintenance mission, CERL considers it important to communicate directly with the Corps engineers in charge of operations and maintenance.

> In this regard, for instance, we have just recently concluded a corrosion course for facilities engineers, where we had field personnel attend a course at CERL lasting two weeks. In addition to discussing the subject of corrosion and anticorrosion materials, these field personnel were given an introduction to the capabilities that they might expect from CERL as both a consultant and as a contractor to help solve their problems.[5]

This corrosion course is an annual event at CERL.

[5] Remus, p 32.

Col. Remus Addressing Facilities Engineer Corrosion Course

Military Operations Research

The research theme with the lowest level of funding is military operations. In this theme modern technology is being used to enable necessary structures to be built quickly in a theater of operations. The Facilities Engineering and Construction Division has developed a computer program, NONTAC-80, which assists Army personnel confronted with a bridging situation under battle conditions. This system will give reliable information on the best bridge type in a particular terrain. Work is also being accomplished on a unique method for providing basic shelters in a combat area–the use of shipping containers as structural elements. For frontline battle conditions, CERL is experimenting with the use of inflation-formed concrete structures. There is also the PRESTO system–Preformed Expandable Structures for Theater of Operations. Such structures, built of polyethylene foam and wooden frames, are very cheap and easily erected. Another development in this area is TOBSEP, an automated and manual process for evaluating the potential use of a broad spectrum of temporary and semipermanent buildings in a specified military situation. On a more massive scale, the Facilities Engineering and Construction Division is working on a computerized Army Functional Components System (AFCS). When fully operational this system will help Army strategic planners meet the many problems involved in erecting a military installation in any area of the world.

Chapter IV
A LOOK INTO THE FUTURE

In 1967, General Clarke told Congress that the new laboratory should be approved as soon as possible. "Because most worthwhile research efforts require four to five years to produce useful and meaningful information, time becomes a critical element in our research planning."[1] An essential part of a look into CERL's future must be an overall estimation of these first five years of existence.

An overall estimation could with very good reason conclude that CERL has made excellent use of those first critical years. Whether considering short-term or long-term research, the catalogue of accomplishments is impressive in its variety and quantity. The response to these accomplishments is a further indication that CERL is doing a good job for the Army. There are constant requests from military agencies and private concerns for CERL publications. Significantly, former customers are returning to have work done on other problems where CERL expertise can be used. Army engineers are beginning to rely on CERL as a valuable source of guidance in their work; for example, the *Decor Guide for Enlisted Personnel Dining Facilities* has been extensively used by facility engineers in Europe.[2]

Certainly the laboratory seems to be on the right track. Yet a completely valid assessment of CERL's overall achievement cannot be made at this point in its history. Yes, CERL has already saved the Army some impressive sums of money on various projects, but it is too soon to say whether CERL or any research effort will cut Army construction costs five percent by 1980. Much important research has been only partially completed. Computer systems such as AEADS and LIFE1 are in the process of being completed or expanded. The value of fibrous concrete has been conclusively demonstrated, but all of its physical properties have not been explored. Thus, CERL will soon initiate tests of the resistance of fibrous concrete to corrosion. Other projects have been finished but have not been tested. CERL is just now beginning a study of the reactions of the inhabitants to the officer's quarters at Ft. Knox. To paraphrase General Clarke, the Army needs time to fully implement the useful and meaningful results that CERL is producing.

Looking now into the future, there are no definite plans for a significant expansion of the CERL physical plant. More space is needed, especially warehouse space, and there are tentative plans to rent part of a nearby building in the Industrial Research Park. But it appears that the laboratory will have to manage with its present facilities for at least the next two or three years. In the initial period of its history, the laboratory staff expanded quite rapidly; the next few years will probably see the staff remain at its present numerical strength. There is, of course, no space available to accommodate a signif-

[1]Clarke, p 4.
[2]Remus, p 14.

icant increase. In addition, the Department of Defense has recently put stricter limitations on the number of permanent and temporary employees a laboratory may have. This is a new situation facing CERL, which has in its past been accustomed to higher and higher personnel levels. Since the laboratory research budget is still gradually growing, this may mean, for example, the laboratory will have to contract more of its work to other laboratories. According to the CERL *Five Year Research and Investigation Plan for FY 74 through FY 78,* there are plans to increase the number of Army personnel to perhaps ten or fifteen; in part it is felt that the presence of more Army personnel will ensure that CERL researchers will be more aware of the exact nature of some of the construction problems the Army encounters.

And what of the future of the research program? In this initial period, the research budget went from less than $1 million to over $8 million. The next few years will see a much slower rate of growth, but there are no plans for reductions. In a time of tight funds, the Army is not making significant cuts anywhere in the CERL program. It is expected that the themes of facilities and structures and the environment will continue to receive the bulk of the research money.

There has to be a strong element of the "probable" when discussing the future of the research program. The massive expansion of the environmental program was a sudden development, and other surprises are always possible. The laboratory already expects that there may be a surge in funding for energy investigation. The national emphasis is now on energy conservation and self-sufficiency. Perhaps this might be reflected in the near future in reduction in funding for environmental protection, as environmental standards are relaxed to meet energy goals. Military operations are now at a low level of financial support; that could change dramatically if the Army becomes involved in a major military operation somewhere in the world. This surprise factor will always make the future direction of CERL research difficult to predict precisely. The basic mission of construction research is not likely to change, but the advent of new research areas or a sharpened emphasis on old areas is a constant possibility. CERL perhaps has not seen the last of its reorganizations; flexibility of response will continue to be a requirement. From the record of its first few years, CERL gives every indication of being able to respond effectively to the future tasks assigned to the laboratory by the Army.

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Appendix I
MAJOR LABORATORY EQUIPMENT

automatic GMA, GTA and plasma welding facilities: the only automated welding facilities in the Corps of Engineers.

biaxial shock test machine: used for shock and vibration testing of equipment. Built in 1973, it is one of the largest machines of its type in the world.

closed loop materials analysis system: used for conventional stress strain relationship tests; through-zero tension compression testing; short-term, long-term creep testing; conventional constant amplitude fatigue testing; low cycle fatigue testing; crack propagation studies in stress, corrosion, or fatigue; service simulation; fracture mechanics studies; environmental testing.

dynamic tension analysis system: used to determine the minimum dynamic tensional stress required to rupture materials.

heated rolling mill and pole figure device: used in metallurgy studies to control crystal orientation in metals.

scanning electron microscope: used for metallurgy studies, air pollution research, and in materials failure and analysis.

structural test floor loading system: used to test structural systems and subsystems. It has the capacity for testing a two-story building.

vacuum induction melting furnace: used for close composition control melting to obtain desired alloys.

X-ray defraction and vacuum spectroscopy system: used to analyze the crystal structure and elemental composition of materials.

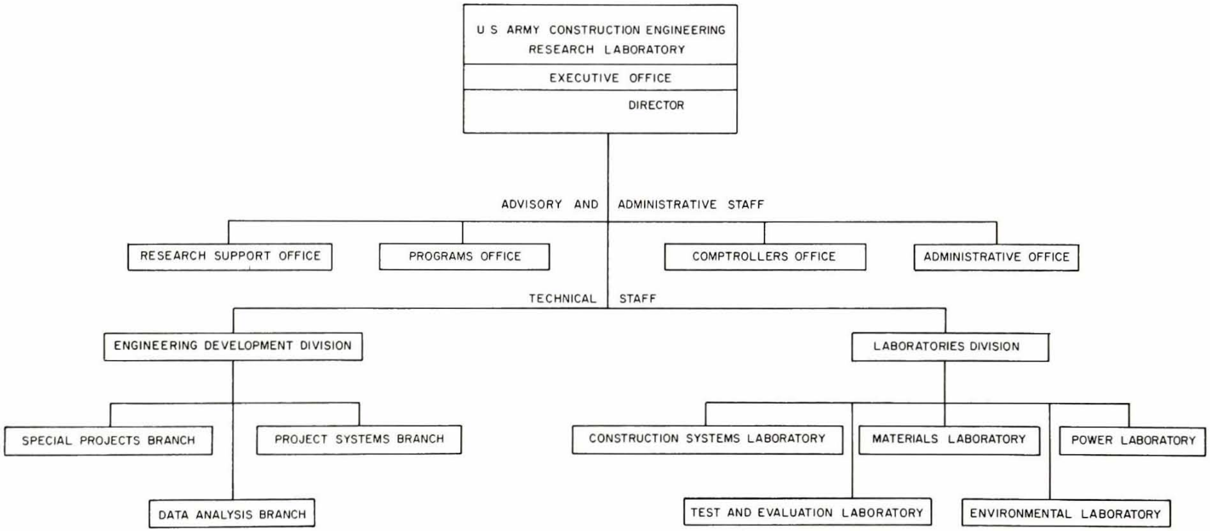
X-ray unit 400, KV: used for the analysis of material crystalline structure.

Appendix II
CERL EDUCATION AND EXPERIENCE SUMMARY

Discipline	Education: BS	MS	PHD	Experience—Cumulative Years: Teaching	Research	Design	Construction
Acoustics			1				
Architecture	3	3		3	12	17	2
Business Administration		1			5		
Chemical Engineer	3	2		4	47		2
Chemistry	1	1		4	22		
Civil Engineer	13	11	10	67	203	123	84
Computer Science	2		1	1	14		
Economics	2	1		3	11		1
Electrical Engineer	5	5	1	6	99	57	8
Environmental Engineer		3	4	13	21	3	4
Geology			1	3	9		2
Geography		1		1	6		2
Industrial Engineer	1	4	2	2	30	12	19
Library Sciences		1					
Mathematics	2	2			5		
Mechanical Engineer	4	1	3	7	56	11	16
Metallurgy	1	1	3	5	33	3	1
Nuclear Engineer			1	3	5		
Operations Research		1			12		1
Physics	2	1			10	2	
Psychology	1	1		2	11	12	
Statistics		1		1	15		
Structural Engineer			2	2	14	11	
Technical Writing	2			1			
Transportation Engr.			1	5	6	1	1
Urban Planning		1	2	9	11	7	1
Total	42	42	31	141	657	259	140

6 May 1975

Appendix III
ORGANIZATION CHARTS



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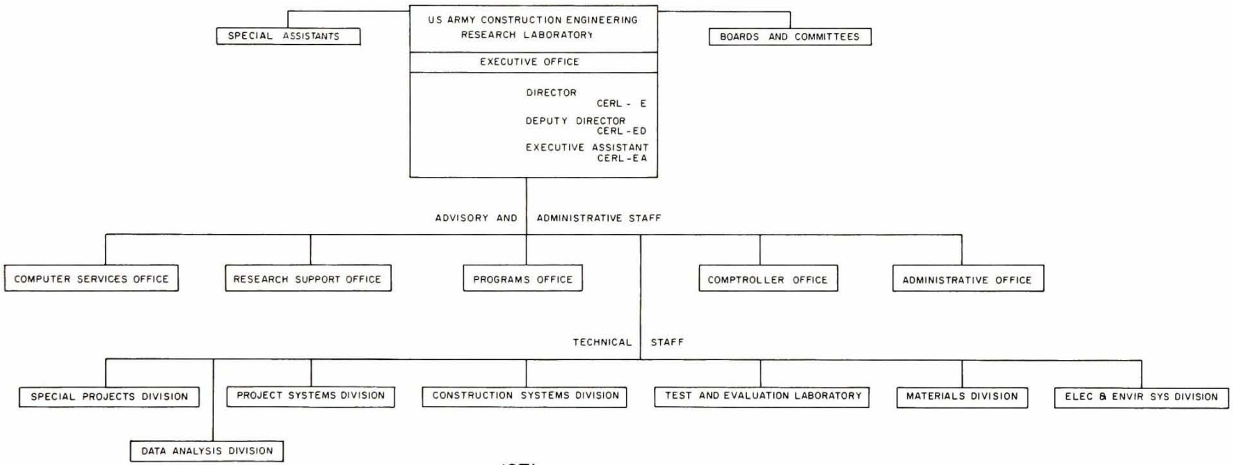
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DIRECTOR CERL - E
DEPUTY DIRECTOR CERL-ED
EXECUTIVE ASSISTANT CERL-EA
SPECIAL ASSISTANTS
BOARDS AND COMMITTEES
ADVISORY AND ADMINISTRATIVE STAFF
COMPUTER SERVICES OFFICE
RESEARCH SUPPORT OFFICE
PROGRAMS OFFICE
COMPTROLLER OFFICE
ADMINISTRATIVE OFFICE
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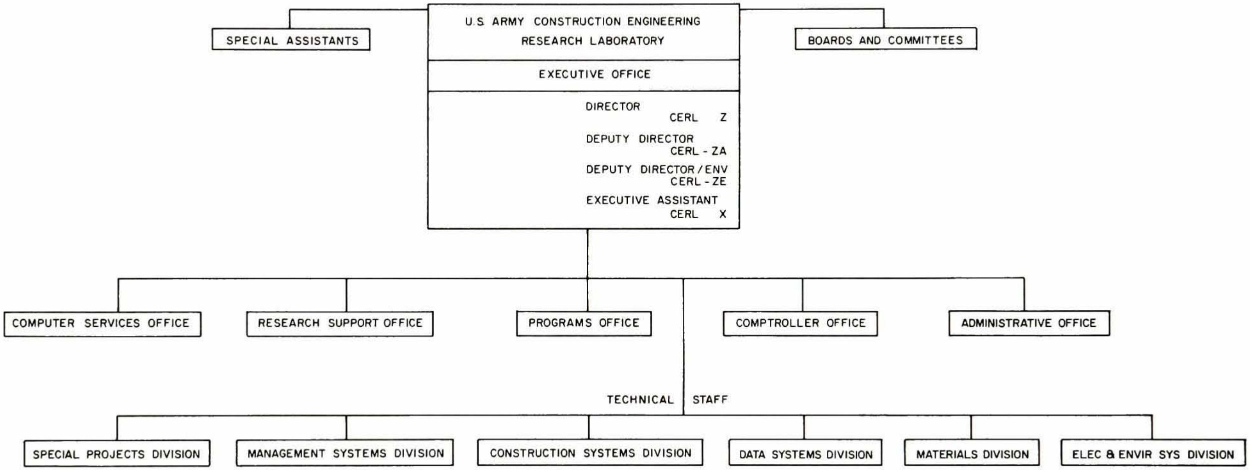
PROJECT SYSTEMS DIVISION
CONSTRUCTION SYSTEMS DIVISION
TEST AND EVALUATION LABORATORY
MATERIALS DIVISION
ELEC & ENVIR SYS DIVISION
DATA ANALYSIS DIVISION

1971



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DEPUTY DIRECTOR CERL - ZA
DEPUTY DIRECTOR / ENV CERL - ZE
EXECUTIVE ASSISTANT CERL X
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DATA SYSTEMS DIVISION
MATERIALS DIVISION
ELEC & ENVIR SYS DIVISION

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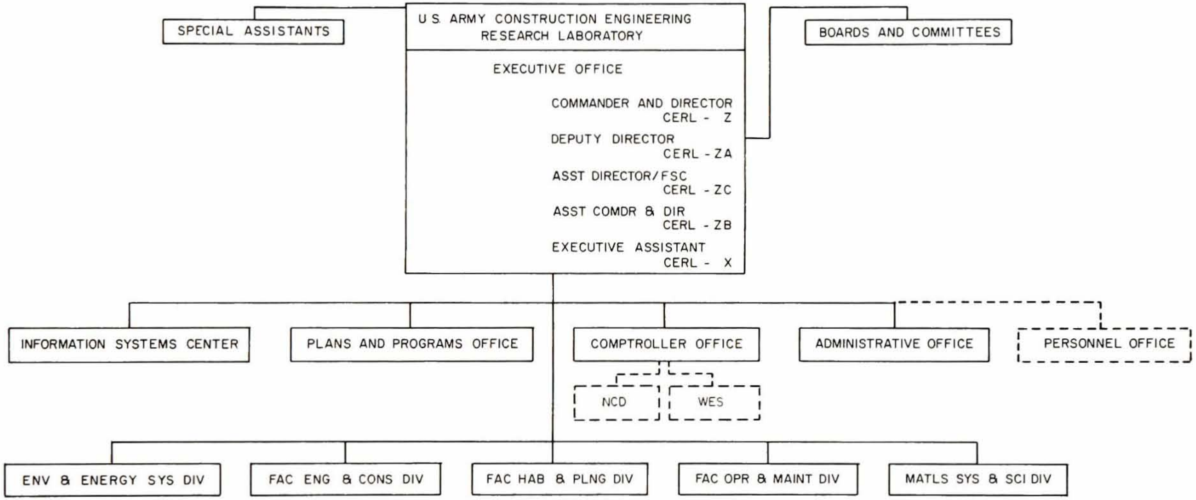
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PERSONNEL OFFICE
NCD
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FAC ENG & CONS DIV
FAC HAB & PLNG DIV
FAC OPR & MAINT DIV
MATLS SYS & SCI DIV

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