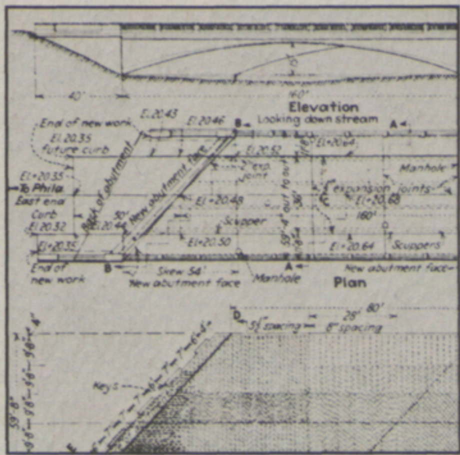
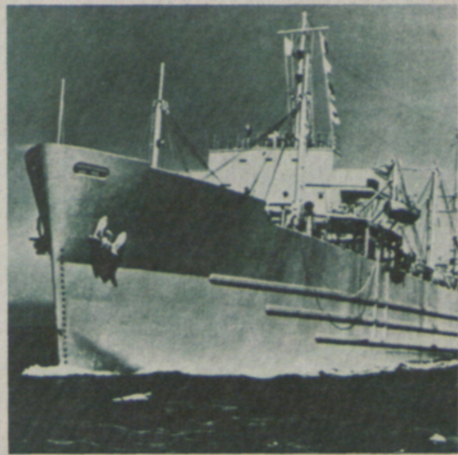
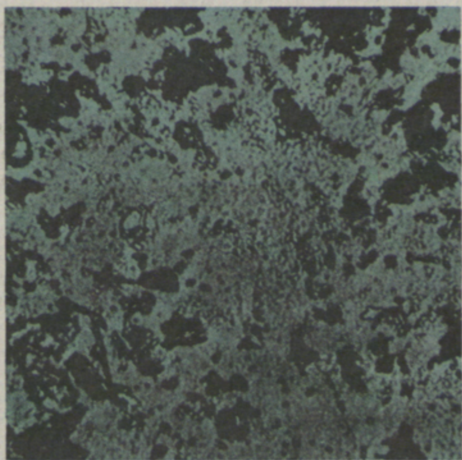
ENGINEERING

CORNELL QUARTERLY







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PIONEERING
IN
CONCRETE

IN THIS ISSUE

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Opposite: The famous skew arch bridge over the Chester River in Pennsylvania, designed and built by S. C. Hollister in the 1920s.

About the Colloquium

The Solomon Cady Hollister Colloquium was organized as the third National Conference on Civil Engineering: History, Heritage, and the Humanities, and was convened on June 2, 1980, at Princeton University. The statement of purpose included the comment, "Since reinforced concrete has emerged as the major building material of this century, it is extremely appropriate that we now honor a man whose career spans [its] development. . . . Each paper will focus on one aspect of Dean Hollister's remarkably varied career, and at the same time treat each topic in the broader context of concurrent development. . . ."

The colloquium was jointly sponsored by the National Endowment for the Humanities, the American Concrete Institute, the American Society of Civil Engineers, the Society for the History of Technology, and Princeton and Cornell Universities. The meeting director was Professor David P. Billington of Princeton, and the steering committee included Professors John F. Abel and Richard N. White of Cornell.

The published proceedings include, in addition to the complete texts of papers that are the basis of the articles presented here, several other papers of interest and documentary importance. These are by Robert Wilde, deputy executive director of the American Concrete Institute, on the growth of the institute before and during Hollister's presidency; by George Winter, Class of 1912 Professor of Engineering, emeritus, at Cornell, on the development up to 1941 of a national code for reinforced concrete design; and by Neal FitzSimons, a 1950 Cornell graduate who is now a consulting engineer, on Hollister's consulting activities. Other commentaries and reminiscences are also included. The proceedings are available, at ten dollars a copy, from William O'Brien, Jr., Princeton University Conference, 5 Ivy Lane, Princeton, New Jersey 08544.

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Photographed at the Hollister colloquium during intermissions between papers and at the reception that followed were (1) Hollister with (at left) Marie-Claire Blumer-Maillart, daughter of the well-known Swiss bridge designer Robert Maillart, and (at right) emeritus Professor and Mrs. George Winter from Cornell; (2) Ada and S. C. Hollister; (3) Professor John F. Abel and President Frank H. T. Rhodes of Cornell; and (4) Thomas E. Everhart, dean of Cornell's College of Engineering (at left) and Joseph deFrees '29, president of the Allegheny Valve Company. Many of the participants were former students of Hollister's.

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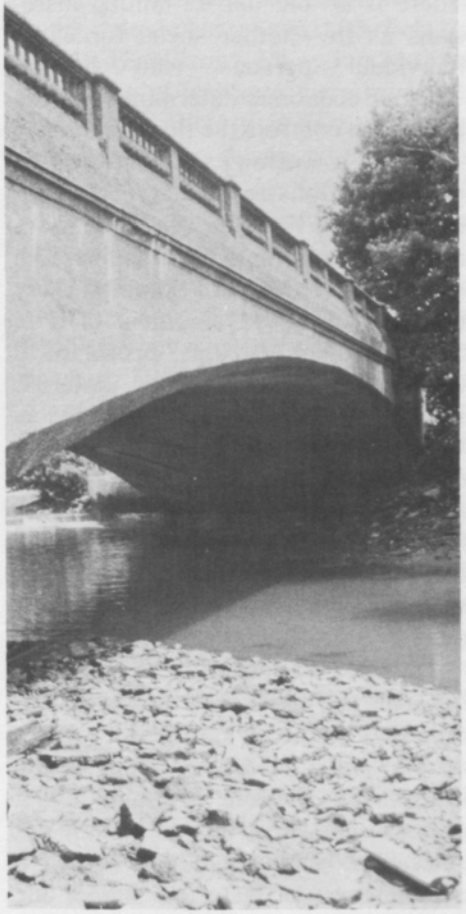
Pioneering in Concrete

The Solomon Cady Hollister Colloquium on "Perspectives on the History of Reinforced Concrete in the United States, 1904–1941," which convened this spring at Princeton University, holds special interest for Cornell engineers. Much of that history was shaped by Hollister, who spent most of his career at Cornell as professor and director of the civil engineering school and, for more than two decades, as dean of the College of Engineering. Because of his notable achievements as dean, which included educational innovations and the building of an entire new College facility, Cornellians may be less aware of his stature in the structural engineering areas in which he worked professionally. His contributions included (but were not restricted to) pioneer work in the development of reinforced concrete as a structural material, a contribution that has been appropriately recognized through the colloquium. We at Cornell are proud of Hollister and are pleased to join in this special tribute.

A second reason for our interest is the continuing strength of Cornell research in concrete. Actually, this is a related reason, for the present concentration of faculty members accomplished in this field stems from Hollister's early development of faculty and programs. Most of the papers for the colloquium were written by members of Cornell's Department of Structural Engineering, who had the experience needed to write about Hollister's work in the context of developments in the field. The articles presented here are based on those prepared (at much greater length) for the colloquium proceedings; a future issue of the *Quarterly* will feature articles about current Cornell research in structural concrete. For the perspective afforded by the Hollister colloquium looks forward as well as backward in time. In Hollister's words, spoken in 1934 when he assumed the presidency of the American Concrete Institute: "The achievement of today was the goal of yesterday. It cannot be the goal for tomorrow. Great as have been the achievements in the field of concrete today, they are only the dreams of yesterday come true."

With this issue, the *Quarterly* is pleased to contribute to the recognition of the place of technological history—even, or especially, of such a basic, workaday material as concrete—in social history, and of the effect of individual ideas—technical as well as philosophical, political, and cultural—on the shaping of our world.—G.McC.



PROFESSION AND PERSONALITY

Perspective in a View of S. C. Hollister and his Work in Reinforced Concrete

by David P. Billington

There is an old debate among historians as to whether social forces or individual persons lead events: whether economic determinism or the great man controls the flow of history. Actually, a tension exists between individual actions and social forces and, congruently, between engineering innovators and their professions. An example is the work of Solomon Cady Hollister in the development of reinforced concrete, that prototypical twentieth-century building material. Because of its general implications as well as its intrinsic interest, this story of a man and a field has been the subject of a detailed inquiry that formed the basis of a special colloquium at Princeton University in the spring of 1980, and is highlighted in this *Quarterly* issue.

The time was right for such a study because the field of reinforced concrete has matured, yet the documents are still available. An important source is Hollister himself, the only living professional whose career, like the development of the field, has gained a completeness of historical shape; our account follows his progress from study to practice to professional leadership and, finally, to educational statesmanship. An additional reason for the timeliness of this project is the recent formation of two major institutions: the Society for the History of Technology and the National Endowment for the Humanities. The former, founded in 1958, just as Hollister neared retirement as engineering dean at Cornell, has put the study of engineering history onto a firm academic base. The National Endowment not only supports historical scholarship in engineering (it provided funds to help support this colloquium), but encourages the bringing of a humanistic perspective directly into engineering education, a goal that Hollister endorsed thirty years ago when he served as president of the American Society for Engineering Education.

Viewing a specific technological development through the works of one man illustrates how a humanistic perspective can illuminate the history of technology and relate it to the larger history of a society. One individual's significant contributions are seen as characteristic of general ideas of the times. The central cultural themes of twentieth-century American society that become evident in this consideration of the works of Hollister are: the influence of European ideas on American developments, practice as the source of innovation, and the educational tension between general ideas and technical methods.

INTRODUCING NEW IDEAS FROM EUROPE

Hollister characterizes American mobility and initiative. His crucial move, as a young man, from Washington State to the University of Wisconsin reflected an awareness of pioneering ideas in his area of interest. No one told him to go to Wisconsin; he decided on the basis of his self-directed study of new text books.

It was at Wisconsin (as described by Richard N. White elsewhere in this issue) that Hollister first began serious study of European works, especially the comprehensive German-language works on structures and reinforced concrete that had been published before World War I. His first important study was of the Swiss works on graphic statics coming from Carl Culmann and his student Wilhelm Ritter. Hollister made an analytical study of this subject for his baccalaureate thesis, demonstrating his talent for attacking difficult questions of mechanics on his own. A second significant European influence was the monumental *Handbuch für Eisenbetonbau*, the single most important pre-World War I work on reinforced concrete, which had been compiled by the Austrian engineer Fritz von Emperger. Unlike much of the modern writing on this subject, the *Handbuch* emphasized completed structures and was documented by photographs, plans, calculations, and construction procedures; it showed the astounding variety of forms already built by 1914 and detailed the methods by which they were analyzed and built. A third major European influence on Hollister was the work of the Frenchman Eugene Freyssinet in the design of huge concrete structures. When Hollister became aware of this work in the late 1920s, he translated Freyssinet's article on the long-span arch design at Plougastel, thus introducing to American engineers new ideas on design and construction from France. Freyssinet's novel studies, stimulated by the Plougastel arches and focused on creep and concrete arch behavior, led to his invention of prestressing.

It was never Hollister's idea to copy European works directly; rather, he sought to bring new ideas to the attention of American practitioners, most of whom could read no foreign language. One major result of Hollister's openness to European ideas was his support for the Austrian George Winter, who would play a formative role in reinforced concrete developments after Hollister himself had turned his attention more toward engineering education. Winter arrived at Cornell in 1938 as a graduate student supported on a fellowship arranged by Hollister, who subsequently became Winter's doctoral thesis adviser.

ENGINEERING PRACTICE: THE BASIS OF INNOVATION

Though influences from Europe were significant, United States innovation in structural engineering was soundly based on engineering practice. The idea that innovation arises primarily from practice and only secondarily from laboratory research was not shared by some prestigious scientists and engineers, who argued for and gained massive support for academic and laboratory scientific research following World War II. In the 1960s, however, the government undertook a study called Project Hindsight, which produced staggering results: almost none of the defense technology developed during the war could be traced to basic scientific research. Project Hindsight showed that engineering is not merely applied science, but something else. It is to the end of defining that "something else" that historical scholarship has immediate and enduring value to the profession.

Examples from Hollister's career illustrate how technical innovations came primarily from practice. In his first work requiring major design responsibility, Hollister designed thin concrete walls and shells for ships of unprecedented size (see the article by Arthur H. Nilson). Many innovations in the use of concrete were required, and all arose directly in the service of a design problem. A second example is Hollister's 1925 design for the skewed arch bridge in Chester, Pennsylvania (discussed in some detail by John F. Abel and Peter Gergely). This bridge problem forced Hollister to think freshly about arch analysis, and for his resulting treatise he was awarded the American Concrete Institute's first Wason Medal, an award established to recognize outstanding *research* papers. Significantly, the paper centered on both design and construction; he commented in the discussion section that "one must sit as a student before the performance of the structure itself." A third innovation of Hollister's was his work on transit-mix concrete, which was very important economically (see the article by Floyd O. Slate). The 1932 paper describing this technique grew directly out of Hollister's consulting work with a machine company.

Hollister's research parallels that of other major figures in the history of reinforced concrete whose innovations arose from practice. One thinks of the 1900 hollow-box, concrete bridge of Robert Maillart; the 1928 invention of prestressing with high-strength steel by Freyssinet; the first consistent basis for thin-shell, concrete roof design originated in the middle 1920s by F. Dischinger and U. Finsterwalder, both working for a construction company; the 1908 mushroom slabs of Maillart; the 1905 flat slabs of C. A. P. Turner. All these inventions arose under pressures of design, and many came from building firms.

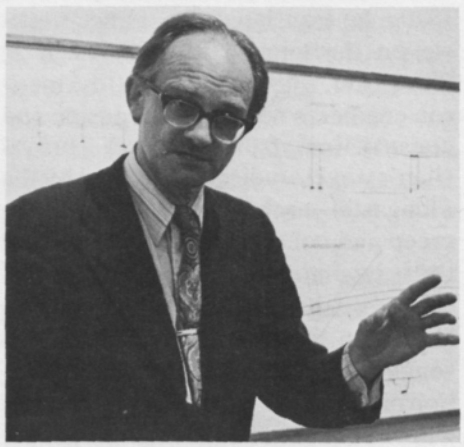
THE TENSION BETWEEN DESIGN AND ANALYSIS

The observation that innovation in reinforced concrete structures occurred primarily as a result of design practice points up a central issue in engineering education: the tension between general ideas and technical methods—between ideas as centered on overall design and methods as used in detailed analysis—in short, between design and analysis. This tension is expressed today in the competing educational claims of practice and of theory, or of practicing professionals and research-oriented teachers.

Hollister understood that theory and practice are inseparable in the best engineering works. As a student at Wisconsin (see White's article), he had been influenced by Turneaure in the view that design should incorporate theory, careful execution, and beauty of form and detail; and Hollister's career reflected that attitude from the start. As an educator, he sought to maintain a proper balance between science and engineering practice (see the article by Walter R. Lynn), and the principal reason for his success in introducing more basic studies was his professional background. In the mid-thirties he could argue for more theory because he had already, as a young man, had more experience in practice than most educators. But implicit in his drive for more academic rigor in analysis was his strong motivation for design. Here he followed the same route as the great Swiss academics, Culmann and Ritter, who had stimulated him during his student years. Both those Zurich professors had had long and intimate experience with built objects and their urge to systematize structural analysis cannot be separated from their basic motivation, which was to encourage better design, not to develop more sophisticated analyses. The heavy scientific emphasis in engineering that followed Sputnik and that seemed to overwhelm the practice-oriented side of the profession has worried seasoned educators like Hollister for the past two decades.

Hollister learned early two basic and still-valid lessons—that there is need for scientific discipline, but that the best stimulus for new ideas is actual design practice. His career richly demonstrates that discipline comes from a scientifically based profession, and that ideas come from individual experience and resources. Ideas without discipline cannot be translated into satisfactorily built objects; discipline without ideas cannot rise above the accepted and mundane to the innovative and inspirational.

David P. Billington, professor of civil engineering at Princeton University, served as conference director for the Hollister Colloquium and as an editor (with John F. Abel) of the conference proceedings. After graduating from Princeton in 1950, he studied prestressed concrete in Belgium as a Fulbright fellow and practiced structural design before joining the Princeton faculty in 1960. He has written books on thin shell concrete structures and on the art of engineering in the bridges of Robert Maillart, and he teaches structural engineering to both engineers and architects.



THE EDUCATION OF A PIONEER

by Richard N. White

Solomon Cady Hollister's college education spanned the years just prior to the opening of a new era in reinforced concrete technology, a development in which he pioneered and in which he is still making major contributions some sixty-five years later.

The new era, signalled by World War I, found Hollister well prepared, but in a singular manner. Because of the course of his undergraduate education—he switched majors and also interrupted his on-campus studies with periods of employment—he turned to a remarkable level of self-study of structural engineering and related topics. The only course in reinforced concrete that he ever took was a single correspondence course.

The story of how he made his way in the early years is an account of individual achievement in a rapidly changing environment. Its fascination for us today lies partly in the interplay between Hollister's personal qualities—including resourcefulness, inventiveness, and thoroughness—and the educational constraints and challenges he encountered.

THE STUDENT YEARS ON THE WEST COAST

Hollister started college at Washington State University with a double major in economics and history, but after a year, he transferred into civil engineering. These studies included surveying, trigonometry, analytical geometry, calculus, statics, dynamics, and strength of materials, but no structural engineering. His first study of reinforced concrete and structural analysis came during a two-year period of work with a surveying crew after his sophomore year; he enrolled in a University of Wisconsin correspondence course and studied a series of books, many by Wisconsin professors, that had a great impact on his career. These books included the 1908 edition of *Principles of Reinforced Concrete Construction* by Turneaure and Maurer; the 1909 edition of *Concrete, Plain and Reinforced* by Taylor and Thompson; the 1904 version of *The Theory and Practice of Modern Framed Structures* by Johnson, Bryan, and Turneaure; and *Reinforced Concrete Construction* by Hool (1913).

Having saved some money to continue his education, Hollister returned to Washington State in 1913 and received his first formal training in concrete as a material in the materials laboratory class, which included experimental work in concrete as well as steel and timber. (During this year, he also worked four afternoons a week teaching descriptive geometry, earning the grand total of one hundred dollars, a sum that covered nearly half his costs of attending school. It is worth noting that he had no previous training in descriptive geometry and that he taught in the mechanical engineering department; Hollister's willingness to take on a challenging new assignment with relatively little formal background was repeated many times during his career.)

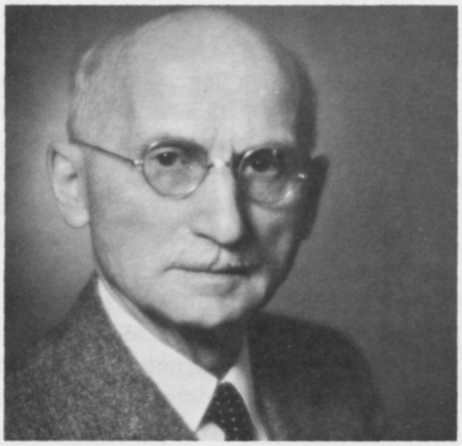
Instead of returning to Washington State for his senior year in 1914, Hollister took a job with the consulting engineering firm of Stannard and Richardson in Portland, and applied his new design skills to the complete design of a rather complicated reinforced concrete reservoir. The reservoir was never built, but Hollister made good use of the design calculations and sketches after he transferred in early 1915 to the University of Wisconsin, where he concentrated his attention on reinforced concrete and structural theory.

WISCONSIN AND ITS INFLUENCE ON HOLLISTER

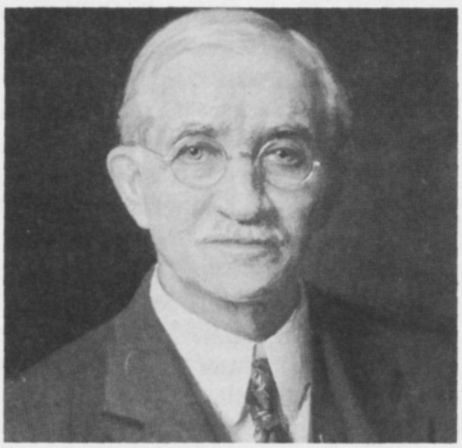
The move to Wisconsin brought Hollister into direct association with the professors, particularly Frederick E. Turneaure (a Cornell graduate) and Edward R. Maurer, who had written the books Hollister had studied on his own. He took Turneaure's course in advanced structures, which he especially appreciated for its rigor and reliance on calculus, and with Maurer he did independent work in structural theory, primarily through the study of German-language texts (though when he began, he read German only hesitantly). This reading covered material that constituted a graduate-degree program in Germany or Switzerland, and it gave Hollister a base in structural theory and indeterminate anal-

Turneaure

Maurer



Talbot



Professors who had a great influence on Hollister during his student years, first through their books and then as mentors at the University of Wisconsin, were Frederick E. Turneaure and Edward R. Maurer. They were among the pioneers in the United States in structural engineering education, and the teaching of reinforced concrete technology was given substantial impetus in 1907 with the publication of the first edition of their book, Principles of Reinforced Concrete Construction.

Maurer was a Wisconsin graduate; Turneaure studied at Cornell for an 1889 degree in civil engineering. Instruction in structural engineering at Cornell in the late 1880s was focused on applications of mechanics, statics, and descriptive geometry to the construction of the various kinds of arches, trusses, and bridges, especially bridges of iron, wood, and stone. There was no formal instruction in reinforced concrete, since the technology was still in its infancy.

A major influence on Hollister was Arthur Newell Talbot, a leader in the development of reinforced concrete as a structural material in the United States. Talbot was a faculty member at the University of Illinois for forty-one years and chairman of the Theoretical and Applied Mechanics Department there for thirty-six years. He brought Hollister to Illinois as an instructor in 1916-17.

Young faculty colleagues who interacted with Hollister were Frank Richart, who held an M.S. degree from Illinois, and Harald M. Westergaard, who had both a Ph.D. from Illinois and a Doctor of Engineering degree from Munich. (Hollister's salary was $1,100 for the year; because of their advanced degrees, Richart received an additional $100 and Westergaard an additional $200.)

ysis that few Americans were able to achieve prior to the 1930s.

At Wisconsin Hollister's academic program, certainly not typical, was arranged to provide instruction he had not already received, formally or through independent study. Wisconsin's standard four-year curriculum in civil engineering included ten hours in statics and mechanics of materials, four hours in materials of construction, and fifteen hours in structural engineering. Some of these courses covered reinforced concrete, but Hollister was exempted from them on the basis of a qualifying examination. In addition to his valuable work with Turneaure and Maurer, Hollister took course work in the metallurgy of iron and steel that he came to regard as crucial to his education as a structural engineer. To fulfill the requirements for two comprehensive design projects, he obtained permission to substitute for the standard designs two ambitious projects of his own choice: a three-hinged steel arch for a railway station, and a reinforced concrete dome with a steeple opening into it. His B.S. thesis, "The Ellipse of Elasticity and its Application to the Analysis of the Elastic Arch," was a model of clarity and thoroughness, written on a very difficult analytical topic.

SEEKING OPPORTUNITIES IN GRADUATE STUDY

Civil engineering education at the time Hollister was a student was very practice-oriented. An analysis of the employment of Wisconsin graduates at that time showed that 23 percent worked for government agencies, 20 percent were consultants and contractors, 12 percent worked in manufacturing, 12 percent worked for railway companies, 6 percent were teachers, 7 percent were in nonengineering work, and the remaining 20 percent were in unclassified occupations. Hollister estimates that only about one in forty Wisconsin civil engineering graduates continued in graduate school, and this small number was mainly in physics or mathematics. Cornell records show a similar trend: from 1871 to 1917, Cornell granted 1,888 four-year degrees in civil engineering and only 72 master's degrees (forty of these between 1904 and 1917). It would be another thirty-five years before graduate education in civil engineering began to move into a position of strength.

When Hollister graduated from Wisconsin, Turneaure helped him secure a job with McClintock-Marshall, a Pittsburgh firm that fabricated structural steel. His first task with this company was to detail, on sketch sheets, beam-to-girder and girder-to-column connections for a ten-story structural-steel department store to be built in Columbus, Ohio. He was told that after a certain amount of detailing experience, he would be permitted to do some drafting, but design would come only much later. Unwilling to wait until his mid-forties to become a designer, he decided to accept the offer of a teaching position in theoretical and applied mechanics at the University of Illinois in the fall of 1916.

He spent a profitable year at Illinois, working under Arthur Newell Talbot, the department chairman, whose aggressive leadership and pioneering work in experimental research in rein-

"The only course in reinforced concrete that he ever took was a single correspondence course."

CORNELL CURRICULA IN CIVIL ENGINEERING*

1904

Freshman Year:
Analysis (4)
Calculus (6)
Chemistry (6)
Physics (10)
Drawing, Lettering, Topography (6)
Land Surveying (3)

Sophomore Year:
Dendrology (2)
Geology (6)
Descriptive Geometry (5)
Mechanics (10)
Engineering Laboratory (5)
Materials of Construction (5)
Lettering, Tinting, Shading (2)
City Surveying (2)

Junior Year:
Political Economy (6)
Railroad Engineering (8)
Structural Design (9)
Hydraulics (with Laboratory) (6)
Municipal Engineering (7)
Field Construction (1)
Geodetic and Topographic Surveys** (4)

Senior Year:
Stereotomy and the Masonry Arch (3)
Geodesy (with Laboratory) and Astronomy (6)
Cartography (2)
Electrical Engineering (4)
Steam Machinery (4)
Engineering Problems (3)
Specifications and Contracts (2)
Electives (16)
Thesis

*Hours of credit are in parentheses
**During vacation

1911

Freshman Year:
Analytics (4)
Calculus (7)
Chemistry (6)
Physics (8)
Descriptive Geometry and Drawing (7)
Elementary Surveying (3)

Sophomore Year:
Geology (6)
Mechanics of Engineering (10)
Engineering Laboratory (4)
Materials of Construction (3)
Chemistry (5)
Drawing (4)
Advanced Surveying (3)
Geodetic and Topographical Surveys** (6)

Upperclass Years:
A general set of courses, or one of five engineering specialties:
Geodetics
Hydraulics
Sanitary Engineering
Railroad Engineering
Bridge Engineering

These curricula illustrate the content of civil engineering educational programs in the United States prior to World War I. The study of reinforced concrete as a building material developed rapidly toward the end of this period: in 1917 the offerings included Concrete Construction, a requirement; two elective courses in Concrete Design; and a number of courses that covered reinforced concrete as part of the subject matter.

1917

Freshman Year:
Analytics (5)
Calculus (5)
Chemistry (6)
Physics (8)
Descriptive Geometry (4)
Drawing (2)
Elementary Surveying (3)
Introductory Lectures (1)
Military Drill (6)

Sophomore Year:
Practical Geology (6)
Mechanics of Engineering (10)
Materials Laboratory (2)
Materials of Construction (3)
Physics (2)
Drawing (4)
Advanced Surveying (5)
Technical Reports (3)
Military Drill (6)
Summer Survey** (3)

Junior Year:
Elements of Economics (4)
Railroads (5)
Engineering Construction (3)
Bridges (7)
Hydraulics (3)
Municipal Sanitation (3)
Engineering Problems (2)
Survey Computations and Mapping (1)
Electives (6)

Senior Year:
Public Speaking (3)
Heat Engines and Auxiliaries (3)
Elements of Electrical Engineering (4)
Water Supply (3)
Concrete Construction (3)
Specifications and Contracts (2)
Engineering Design (3)
Electives (12)

forced concrete structures had helped create a strong graduate program in structures. Hollister had "the run of Talbot's lab," and enjoyed the availability of talented young teaching colleagues (such as Harald M. Westergaard and Frank Richart) as "intellectual sparring partners." His feeling that the university offered a better avenue to opportunity in structural engineering than did the steel-fabricating business proved correct, and in the spring of 1917 he was ready to enter into practice.

REINFORCED CONCRETE IN THE CURRICULUM

The introduction of the study of reinforced concrete into undergraduate programs in civil engineering can be traced by examining the Cornell curricula for three different years between 1904 and 1917 (see the chart).

The 1904 curriculum covered a broad array of topics intended to prepare the graduate for general work in planning, designing, and constructing roads, railways, bridges, buildings, foundations, water works, hydraulic structures, municipal facilities, and the like. Reinforced concrete had not yet found its way into the program as a separate subject. Cements and sands were treated in Engineering Laboratory, cement was included in Materials of Construction, and cements and concrete with and without reinforcement were considered in an elective course, Testing Materials. The structural design course, however, focused on metal and timber structures, particularly bridges, with no mention of concrete. The courses Stereometry and the Masonry Arch, and Masonry and Foundations, and probably some of the other elective courses, included some discussion of concrete. In 1904 thirty-seven students received the degree of Civil Engineer.

By 1911 all upperclassmen were required to take a course in concrete construction. And of the five specialty options they could choose from, the one in bridges had specific course work in reinforced concrete arches, higher structures, and masonry and foundations. Also, concrete was considered to a greater extent in the general structures and materials courses. Instruction in the fundamentals of reinforced concrete had clearly emerged into a highly visible position in the curriculum. The field of civil engineering as a whole was becoming more popular—there were 92 graduates at Cornell in 1911; in 1912 there were 123.

The rapid evolution during the next six years may be appreciated by considering the 1917 curriculum. The program still required only a single course in concrete construction, but new electives were available and concrete was mentioned in a widening array of course descriptions. (The 1911 multipath option system for upperclassmen had been dropped in favor of a fixed set of courses plus six electives.) Concrete Construction, a required course, considered properties and use of plain concrete, and also elementary theory and laboratory work pertaining to reinforced concrete as applied to columns, slabs, and beams. The required Materials Laboratory included study of tests for cement, mortar, and concrete aggregate. Two courses in Concrete Design—one in buildings and one in bridges—could be elected. Some at-

TYPICAL CORNELL CURRICULUM IN CIVIL AND ENVIRONMENTAL ENGINEERING*

1980

Freshman Year:
Calculus (8)
Physics (4)
Chemistry (4)
Computer Programming (3)
Engineering Perspectives (3)
Natural or Social Science Electives (6)
Liberal Studies Seminars (6)

Sophomore Year:
Engineering Mathematics (7)
Physics (8)
Engineering Probability (3)
Mechanics of Solids (3)
Dynamics (3)
Engineering Core Science Elective (3)
Liberal Studies Electives (6)

Junior Year:
Fluid Mechanics (4)
Mechanical Properties of Materials (3)
Structural Engineering (4)
Environmental Quality Engineering (4)
Soil Mechanics (3)
Engineering Economics and Systems Analysis (3)
Technical Electives (6)
Liberal Studies Electives (6)

Senior Year:
Civil Engineering Electives (12)
Technical Electives (6)
Free Electives (6)
Liberal Studies Electives (6)

*Hours of credit are in parentheses

"He was a keen student not only of the rigorous mathematical side of structures, but also of the behavior of actual structures."

tention was paid to concrete pavements in Highway Engineering. Masonry and Foundations treated concrete piles, cofferdams, caissons, piers, bridge abutments, and spread footings for building foundations.

This brief survey of civil engineering curricular development at Cornell reveals that reinforced concrete instruction developed rapidly in the decade prior to 1917, with the evolution of course coverage that was not too different from modern treatments. Extensive laboratory work was included (unfortunately, this highly desirable mode of instruction has been eroded in many civil engineering curricula). Analysis of indeterminate structures was not particularly well developed, however, with the result that proper attention was not given to the inherent continuity in reinforced concrete structures.

ASPECTS OF AMERICAN AND EUROPEAN EDUCATION

Several different approaches to educating engineers were followed in the United States and Europe in the late nineteenth and early twentieth centuries.

A unique feature of the American educational system was the operation of extension divisions of the state universities, which offered evening and weekend instruction at various large cities and also by correspondence. The fact that Hollister's career in concrete construction began through a correspondence course is a good illustration of the extremely important educational role played by these extension divisions, a role that continues to this day, particularly in the field of agriculture. By 1910 the University of Wisconsin (which offered the course Hollister took) had the most comprehensive extension program in the nation. Nineteen courses in structural engineering, including a series of four courses in reinforced concrete construction and three in masonry construction, were offered by correspondence. A short news item in *The Wisconsin Engineer* in 1911 noted that many of the students enrolled in the structural engineering courses already held civil engineering degrees from leading universities, and that there were a number of architects and employees of structural firms. It is evident that many engineers learned about reinforced concrete in this self-study mode.

In Germany a successful system of "technical high schools" was firmly established. Turneaure, who was dean at Wisconsin, studied this system at first hand, visiting a number of the schools in 1895-96 and again in 1912-13. The course coverage was essentially the same as in American universities, although the students entered with a generally higher level of preparation, especially in languages and general studies. The methods of teaching and giving examinations were more formal, and there was little contact between students and faculty. Turneaure noted that in 1895 there were practically no engineering laboratories for students, and although this situation changed drastically over the next two decades after German educators visited American schools, there was still only limited opportunity for the individual hands-on laboratory experience that American students enjoyed.

Reinforced concrete was one of the few new studies added to the German curricula in the years between Turneaure's visits, although the number of engineering students had increased sharply.

The changes in British engineering education between 1895 and 1912, also observed by Turneaure, were even more pronounced than those in Germany. The number of institutions offering the equivalent of an American civil engineering education had doubled to at least a dozen. Laboratory work resembled that in American schools, although there was more reliance on a lecture system for theoretical studies. Engineering enrollment was comparatively light, however, since job opportunities were meager; many of those who did graduate emigrated to Canada or the colonies. Turneaure pointed out that engineering schools in England had evolved *after* major industrial development, whereas in Germany the industries were "created largely by technically trained men."

Turneaure rated the French engineering schools below those of Germany. In general, he concluded that American schools were best adapted to American students, even for graduate study. He did recommend that young American engineers travel to Europe, preferably after a few years of experience, to get a better appreciation of European engineering practice.

A CRITICAL TIME, AN IMPORTANT INDIVIDUAL

Solomon Cady Hollister, as we have seen, received his engineering education in an era that saw the birth of instruction in reinforced concrete. Inspired and encouraged by several of America's greatest engineering educators, he put himself "ahead of the crowd" through an intensive program of independent and regular study of American and German-language technical books. He was a keen student not only of the rigorous mathematical side of structures, but also of the behavior of actual structures made of "less than perfect" materials. His critical and thorough approach to each new subject he faced was to bear great dividends throughout his long and distinguished career in reinforced concrete, structural engineering, and engineering education.

In addition to tracing Hollister's early years, I have touched on the rapid evolution of instruction in reinforced concrete from the turn of the century to 1917. The coverage is, of course, incomplete; more might well have been written about developments at Illinois and other schools, and even in the consideration of Wisconsin and Cornell, more attention might have been paid to the contributions of Johnson, Withey, Hool, Urquhart, and others. Still, even a limited survey of the period demonstrates the challenge and opportunity inherent in a developing technology and in the educational programs that foster it. The widespread adoption of reinforced concrete as a building material is an important part of our heritage in structural engineering. And the civil engineering practitioners and educators who brought this about are modern pioneers.

Richard N. White, director of Cornell's School of Civil and Environmental Engineering, specializes in model analysis, earthquake engineering, and concrete structures, including nuclear structures, framed structures, and shells. Educated at the University of Wisconsin, he taught there before coming to Cornell in 1961. He has also had experience as a practicing engineer and consultant, and is a coauthor of a series of texts on structural engineering. White was a co-recipient of the Collingwood Prize of the American Society of Civil Engineers, and is a fellow of the American Concrete Institute.

REINFORCED CONCRETE FOR SHIPS

by Arthur H. Nilson

For engineering innovation and daring, structures must rank high on any list. Imagine having a mandate to design a monolithic concrete vessel as long as a thirty-five-story building is high, and with walls thirty-five feet high but merely five inches thick. Consider that the ship must be able to withstand all the forces the sea can exert, and must be not only watertight, but capable of containing cargoes of oil and gasoline in integral tanks without leakage. A solid-cargo version of the vessel must be able to transport goods to destinations more than thirty-five hundred miles away. And the entire project, including design, construction, and commissioning, must be carried out in a wartime emergency, with launchings scheduled less than two years after the start of the design work.

That such a project was carried out successfully is a matter of historic record. The achievement, which would be remarkable even with today's technology, is particularly noteworthy in that it took place in the period from 1918 to 1920, when reinforced concrete was in its infancy, construction standards poor, and workmanship on the job typically crude. This was only a quarter century after reinforced concrete engineering in the United States had begun in earnest.

The chief design engineer for the work was S. C. Hollister, twenty-six years old, with a still-new degree from the University of Wisconsin.

THE WORLD WAR I SHIPPING EMERGENCY

In the opening months of United States participation in World War I, estimates of the size of the merchant fleet needed for Army transport and supply gave a very gloomy picture. It appeared that at least three million men would be needed in Europe—some estimates ran as high as five million—and goods and equipment to support this force were estimated as close to six tons per man. Consequently, the needed shipping capacity would be at least eighteen million tons and possibly much higher. The available tonnage in June of 1918 was less than three million. To provide for the required shipping, and also to replace ships lost to the highly effective German submarine fleet in the Atlantic, it was estimated that no less than nine million tons a year of new shipping would be needed.

Consideration was given to the possibility of accelerating the production of steel for ships. It was found that this would require an increase in the production of coal, which was already in short supply because of the lack of railroad cars in which to ship it. The manufacture of additional railroad cars would, in turn, require the diversion of steel plate needed for the production of the ships. Accelerated building of wooden ships was attempted, but failed because of the impracticality of using unseasoned timber. The only alternative appeared to be ships made of concrete.

The Concrete Ship Section was established on January 1, 1918, as part of the Emergency Fleet Corporation. R. J. Wig, then of the Bureau of Standards, was named chief engineer and head of the section, and Hollister was named chief designing engineer. Professor W. A. Slater of the University of Illinois was retained as consultant, and

"The building program was proceeding at full speed at the time of the armistice. . . . In all, twelve concrete ships were launched."

J. L. Bates, the chief civilian naval architect of the Navy, was assigned to the work, at first on a part-time basis. An ambitious program of design and construction was initiated. It was planned to produce one 3,000-ton, three 3,500-ton, and thirty-eight 7,500-ton ships, some to carry dry cargo and some to transport gasoline and oil.*

PREWAR USE OF CONCRETE FOR SMALLER VESSELS

Although a project of the proposed scale was unprecedented, the notion of building small boats, barges, and ships of concrete was not new. The famous rowboat constructed in 1849 at Carces in France by M. Lambot was the first concrete boat on record, and probably was the first structure of any kind to be built of reinforced concrete. It was patented and exhibited at the World's Fair in Paris in 1855.

The next attempt came in 1887, some thirty-eight years later, when the Fabriek van Cement-Ijzer Werken in Holland built a small boat to be used for duck shooting. The same firm later built concrete barges, with capacities up to 55 tons, that were virtually unsinkable because of a cellular construction.

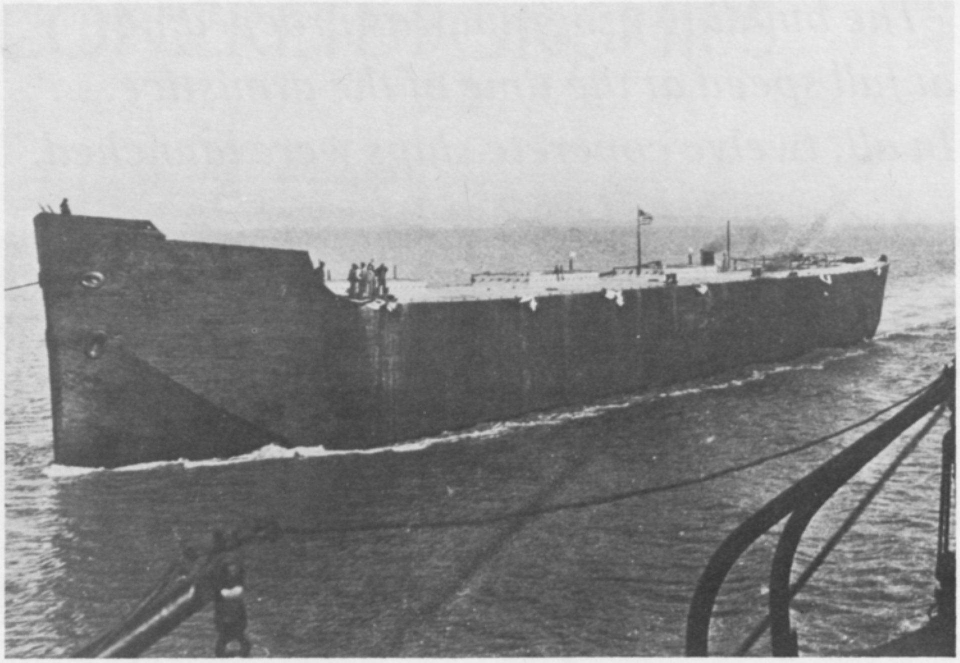
A motorboat, built for recreational purposes by R. Last and Sons in Holland, is interesting in that it anticipated the "ferrocement" method of construction developed more fully in Italy in the 1930s. A framework of steel ribs and longitudinal rods was attached to wire mesh and covered with mortar to make a finished shell about one-half inch thick.

In 1897 Carlos Gabellini of Rome began the construction of concrete scows, barges, rowboats, and bridge pontoons by a new method. The procedure began with the placement of reinforcement—usually round steel rods—for the keel and ribs. This reinforcement was covered on the outside with ¼-inch wire mesh and a one-inch coat of mortar, and on the inside by a somewhat thinner coat of mortar. Forms for the ribs and keel were then put in place and these units cast; ribs ran both longitudinally and transversely, creating a checkerboard pattern with ten-inch pockets. A ⅛-inch wire mesh was placed over the ribs, a thin mortar covering was plastered on, and finally a third and coarser wire mesh was pressed into the soft mortar. The hull was completed by troweling over the entire surface.

In 1909 German shipbuilders in Frankfurt constructed a 220-ton concrete freighter formed in the manner of a conventional concrete structure. The main hull had parallel sides, but it is said that the lines were quite good elsewhere. In 1912 a concrete sailboat was built in Dresden.

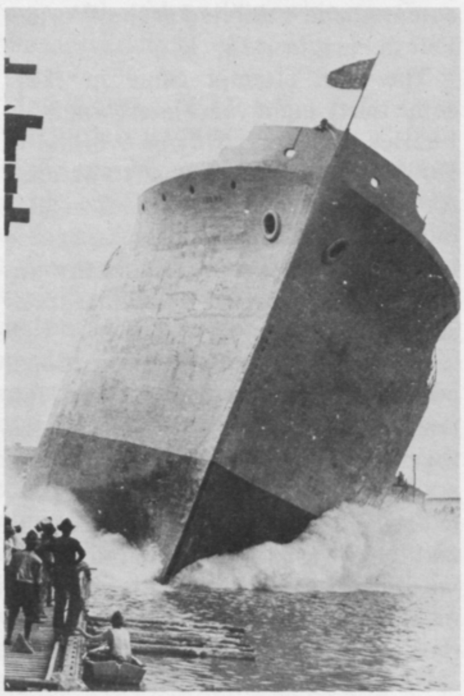
**The relation between cargo capacity and displacement should be noted. The displacement of a ship is the weight of the water she displaces, and is therefore the sum of the self-weight of the vessel and its cargo capacity. The cargo capacity is referred to by naval architects as the "dead weight," although in the usual structural engineering vocabulary the self-weight is the dead weight. Whether it refers to displacement, dead weight, or self-weight, the unit is the "long ton" of 2,240 pounds, which is the weight of 35 cubic feet of sea water.*

The Faith



The Faith, *the only large concrete ship built prior to the World War I emergency program, is shown shortly after launching on March 14, 1918, before the installation of the superstructure. Rated at 5,000 tons, she carried 4,300 tons of rock salt and copper ore from San Francisco to Vancouver on her maiden voyage in May of 1918. Her straight-sided, hard-chined lines are considerably more primitive than later designs. She performed well in service, however: in 1920 she was reported still in good condition, in service in the South American trade.*

The Selma



The Selma *was one of eight 7,500-ton tankers built in the World War I concrete-ship program. This photograph shows her launching in Mobile in the fall of 1919. The launching is being accomplished sidewise, a method that was preferred to the endwise launching required in some yards. (Some difficulty, because of settlement of piles supporting the ways, was experienced during the end launching of one of the concrete ships.)*

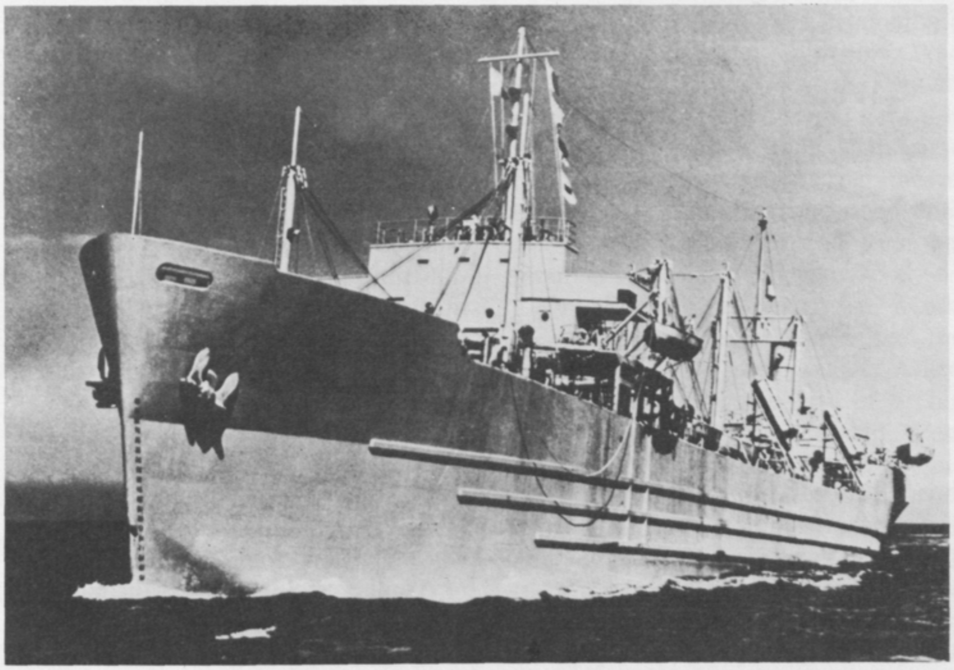
In commenting on this photograph, Hollister noted that despite his warnings, the persons in the foreground were engulfed by the back wave from the launching and narrowly escaped drowning.

Two other 7,500-ton tankers, the Palo Alto *and the* Latham, *were in service by February, 1920, and five more were launched before the program ended. Also in service by February, 1920, were four smaller concrete cargo ships: the 3,500-ton* Polias, Cape Fear *and* Sapona, *and the 3,000-ton* Atlantus.

In the period from 1912 to 1917, a large number of concrete barges, some with a capacity of 1,400 tons, were built in England for use on canals. Twenty-four tugboats were also built in England prior to and during World War I.

The Sydney Harbor Trust Company in Australia constructed a pontoon 110 feet long and 53 to 57 feet wide with a draft of approximately eight feet and a total displacement of 783 tons. This pontoon withstood severe treatment in its use as a landing stage for ferries.

In about 1914 the Fougners Stall-Beton Skibsbygnings Compani of Christiania, Norway, began construction of a number of small concrete pontoons and barges. In 1917 they built a boat about 200 tons in capacity that made at least one round-trip voyage to the English coast. This was in all prob-



This clean-lined vessel was one of one hundred concrete ships built during World War II. All these ships had the same external dimensions: a length of 375 feet and a beam of 54 feet. The hull thickness of 6.5 inches was somewhat greater than for the World War I generation of concrete ships. Longitudinal fenders or rub strips were incorporated below the load waterline to reduce the ship's vulnerability to impact, a problem that had proved troublesome with the earlier ships.

ability the first sea-going concrete vessel. The company followed this success with a number of small yachts and commercial vessels, as well as a floating dry dock.

In the United States, the first concrete boats were a 525-ton scow built for the San Francisco harbor traffic, and some barges built in 1910 for use in the Panama Canal. Other barges were built in the next few years.

Then, in 1917, the San Francisco Shipbuilding Company constructed the 5,000-ton *Faith*, the only concrete ship of a size even remotely comparable to the largest of those proposed for the emergency wartime fleet. A cargo ship with a length of 330 feet and a beam of 46 feet, the *Faith* represented a pioneering effort in the use of reinforced concrete for large, seagoing vessels.

UNPRECEDENTED CHALLENGE IN THE WARTIME EMERGENCY

When the Concrete Section of the Emergency Fleet Corporation proposed its program in 1918, there was no design technology and no construction industry skilled in concrete shipbuilding techniques. A joint committee of the American Concrete Institute and the Portland Cement Association had studied the prospects, but its accomplishments were meager. It finally decided to recommend the trial building of a 2,000-ton barge, and made a total of five "specific" recommendations typified by the first: "Both cement and aggregates should be selected with great care to insure a concrete of maximum efficiency." Meanwhile, events were galloping by the committee. In Washington, Wig, Hollister, and Bates were laying plans for a large fleet of vessels, all self-propelled, with capacities up to 7,500 tons. And despite the difficulties, the first of these concrete ships was actually launched less than two years after the land needed for shipyards had been acquired.

ACHIEVING GOOD LINES IN CONCRETE SHIPS

One of the basic problems confronted by the emergency team was how to establish the overall geometry of the proposed ships. A prevalent notion was that in order to keep the formwork manageable, concrete ships should have extremely simple lines: hard-chined construction with square knuckles and bilges, and surfaces curved in only one direction. The first large concrete vessel, the *Faith*, did have extremely simple lines. How-

"The chief design engineer for the work was S. C. Hollister, twenty-six years old, with a still-new degree. . ."

ever, Bates (who had received his degree in naval architecture from Cornell in 1903) held out for the more seakindly shapes produced by double-curved surfaces, and after consultation with Hollister, he concluded that there should be no particular difficulty in constructing them. In fact, the placement of steel reinforcement and concrete might even be facilitated by the smooth transitions possible with long, easy curves.

The resulting shape of the concrete vessels was not substantially different from that of steel ships. Cross-sectional drawings show round bilges with small deadrise, nearly vertical sides, and a crowned deck surface. The flared bow and stern sections were likewise similar to those of steel ships of that era.

DESIGN PROBLEMS INVOLVING MATERIALS

In considering materials, the prime factor was weight. This could be reduced by decreasing the density of the material and by minimizing the thickness of the concrete shell and bulkheads; both means were employed in the concrete-ship construction.

For the concrete, it was decided to use light-weight aggregate made by vitrifying a clay slurry in a kiln and then crushing the product. Such a material had been developed by the brick-making industry in the southwest United States. These manufacturers had found that a porous aggregate (to be used in the brick slurry) could be formed by burning certain clays. These clays tended to swell on heating because of the formation of organic-gas bubbles, which remained as voids in the structure of the vitrified material. It was found, though, that steam introduced into a slurry of the clay would accomplish the same purpose and afford a means of control. After burning the slurry, the clinker could be crushed to make a hard, glass-like, light-weight aggregate characterized by nonconnecting voids. The government researchers who had developed the process patented it and made it generally available. The concrete-ship designers found that concrete made with this new aggregate had a density of 106 pounds per cubic foot, about two-thirds that of normal concrete.

Another requirement of the material was high strength, so that wall thickness could be kept to a minimum. Concrete with a compressive strength of 2,000 to 3,000 pounds per square inch was generally used for buildings at that time, but for the ships it was decided to try for a strength of 5,000 pounds per square inch at age twenty-eight days. Wig, a specialist in cement technology, worked closely with Hollister on this part of the program. It was known that in the standard mixing process, not all the ground Portland cement became hydrated when water was added; there was a residuum that did not contribute to the binding process. Experiments showed that reburning and regrinding yielded finer cement that exhibited greater hydration, producing a more plastic mixture and a higher-strength material.

Higher-strength concrete further required richer mixes with lower water-cement ratios. Such concrete was more brittle than the ordinary variety, and therefore more dependent on reinforcement for ductility and impact resistance, but it was found to have not only greater strength, but an additional advantage: it was impervious to leakage of stored liquids such as oil and kerosene, as well as to seawater intrusion. This was because the vesicular structure did not contain communicating cells. To the shipbuilders, it meant that waterproofing agents would not be required.

The use of this high-strength, lightweight concrete permitted thinner sections and resulted in ships with a ratio of dead weight (in ships this means cargo capacity) to total displacement of 62 percent, compared with 65 to 68 percent for steel ships at that time, and 53 percent for wood ships.

The other crucial material was steel for reinforcement. Billet steel conforming to ASTM standards was specified.

ACHIEVING THE REQUIRED STRUCTURAL STRENGTH

A ship in a seaway encounters severe stress situations. When a ship spans a trough between two wave crests, it sags a certain amount, depending on the depth to which it settles before it acquires enough buoyancy to equilibrate the weight. Then, as the ship travels a half length, it becomes supported by the wave at its midlength, with its two ends hanging over troughs. This produces a tendency to break the ship's back, an action known as hogging. The amount of hogging, too, depends on how deeply the ship settles. As the vessel progresses through the sea, it alternately sags and hogs, tending to bend first in one direction and then the other, and thus producing a reversal of stresses amidships. And when the ship crosses the waves diagonally, stress is exerted as a torsional moment on the hull. At the time the wartime construction program was begun, the effects on reinforced concrete of load reversal and torsional moment were not well understood.

Dr. H. M. Westergaard had joined the Concrete Ship Section for the summer of 1918, and Hollister asked him to attack the problem of a ship crossing waves on the diagonal. Westergaard produced a solution to this difficult problem, and it was incorporated into the design. The problem of analyzing bending stresses in the hull resulting from the perpendicular force of the water was studied by Hollister. Using plate theory modified to suit conditions of continuity and edge restrain, he set up a method of analysis which he applied to the rectangular components at the midsection of the ships and to the triangular portions at the ends. The required concrete thicknesses were determined and the appropriate reinforcement specified.

The structural design proceeded on the basis of the requirement that under any foreseeable service condition, stresses in the materials should be kept within stated limits. Such stress-based design was the rule throughout the construction industry at that time. An allowable flexural stress in the concrete of 1,500 pounds per square inch was selected, and bond stress of 200 pounds per square inch was permitted for the reinforcement. Both round and square reinforcing bars were used; plain round bars were considered easier to fabricate, but deformed bars were used to provide positive mechanical interlocking in critical regions. The largest bars, 1.25 inches square, had a maximum length of 50 feet. Anticipating present-day procedures for the control of concrete cracking, reinforcing bar stresses were limited to 12,000 pounds per square inch in places where the formation of cracks would lead to seepage, and to 16,000 and 20,000 pounds per square inch in places not exposed to the water.

In laying out the arrangement of structural members and in the detailed design, Hollister noted: "In every phase of the design of the concrete ship, the principle of continuity cannot be overemphasized. The path of stress should be as direct as possible, and there is ample evidence that sudden change of section of the member carrying the stress results in failure of varying magnitude. The transfer of stresses around openings in the deck must require far more attention than would similar ones in the floor of a building. The design of the connection of either end of any deck erection likewise requires the greatest care."

BUILDING AND LAUNCHING THE CONCRETE SHIPS

Construction of the concrete ships was no less difficult than the design. In effect, construction work of laboratory quality was carried out on a field scale. Walls five inches thick, thirty-five feet high, and more than four hundred feet long were to be built without defect of any kind.

Strict specifications were developed to avoid segregation of the mix, honeycombing, or places of weakness. A rule was established that concrete was not to be introduced into the forms farther than eighteen inches above the resting place, and in no case was concrete to be dropped through a screen of reinforcement. Shutters were built into the walls of the formwork to permit the concrete to be chuted directly in place without dropping from above. A vibrator was introduced to assure fluidity in the mix during placement. Originally it was specified that no cold joints were to be permitted; when this proved impractical, techniques were developed for thoroughly cleaning laitance from the hardened concrete, after which a high-strength cement grout was placed before pouring with the normal mix was resumed. Construction using these techniques and restraints produced a concrete structure superior to any that had ever before been produced commercially.

On the first hull, a 3,000-ton cargo vessel, the reinforcing bars were placed against the outside forms. After the forms had been concreted and stripped, a layer of gunite concrete ¾ inch thick was sprayed in place and troweled smooth to form the outer surface of the hull and to provide protection for the bars. On the second hull the steel was blocked out from the forms. Great care was taken to position the reinforcement accurately to guarantee the desired concrete cover. This procedure was followed for all subsequent construction, as it provided a smooth surface that was integral with the structure. No minor consideration was the accurate positioning, prior to casting the concrete, of all the necessary inserts, fittings, and anchorages for engines, boilers, and other machinery and equipment.

The amount of concrete required for a 7,500-ton tanker, for example, was 2,660 cubic yards, and 1,550 tons of steel bars were required for reinforcement. Construction time was shorter than for a comparable steel ship.

The building program was proceeding at full speed at the time of the armistice, when it was severely cut back. In all, twelve concrete ships were launched: four small cargo ships with capacities of 3,000 or 3,500 tons, and eight 7,500-ton tankers. Thirty-eight of the large ships had been planned.

THE RECORD OF HONORABLE SERVICE

The concrete ships proved to be good sea boats. They behaved admirably in heavy weather and won praise from previously skeptical officers and crew.

Because their surfaces were smoother than those of steel ships with riveted joints, the concrete ships were faster in the water by several knots, and because of the relatively larger moment of inertia about the longitudinal axis, the concrete ships, loaded or unloaded, had a greater period of roll and therefore an easier motion. Some concern had been expressed about the effect that vibrations of the propulsion machinery would have on the concrete hulls and on the people aboard. There was, in fact, less vibration than in steel vessels, and in some cases almost none. It is said that one ship's captain, upon coming aboard, was unaware that his engines were turning. In none of the vessels was any leakage reported. A few shear cracks were noted in the shell and bulkheads of all the ships, but these had no apparent effect on strength or serviceability.

One undesirable characteristic of the concrete ships was recorded: the vessels were apparently unable to withstand concentrated blows on the shell without some shattering of the concrete. In docking, for example, impact that would merely cause indentation of the plates of a steel ship would cause considerable damage to a concrete ship. The problem was more serious for barges on inland waters than for seagoing ships; it was found necessary to install oak fender strips for the barges. Such fenders were not used on the seagoing ships, and it was found that any impact damage that did occur could be repaired easily and inexpensively.

An eloquent testimonial to the performance of a concrete ship was provided by the captain of the *Cape Fear*, one of the cargo ships of 3,500-ton capacity. His comments, written upon the conclusion of a trip from Wilmington to Jacksonville, are reproduced here in his own words:

My expearence on the cement ship Cape Fear I feel it my duty to say something of our most delightful trip on that beautiful ship. Wee left Wilmington, N.C. August 26th with a very neat and powerful iron tug belonging to Government and as she crossed the bar raising her beautiful bow high up as if to give farewell bow to her name sake wee diserpared down the cost and there never was a more gracefull ship has never been seen. I myself has bin going to sea this 40 years and abeerlutely I would rather take my chances on one of concrate. Well now wee sighted Jacksonville bar. I believe it is 24 miles up river but never the less wee were soon at the city when the tug droped us comeing up our starboard side and noticed she was comeing head on wide open think she was going to sink us I steped back and my god what a ram and I sware I never felt it I was standing directly over it and I was sure wee were ruined that was some lick and I tell right here if it had bin an steal or woden ship I am sure it would sunk her but it did not hurt us much they tell mee it can be repaired at a very little cost or delay and I do know aney sort of ship sure would have to go on the dock. . .

CONCRETE SHIPS AFTER WORLD WAR I

At the end of the war the twelve concrete ships were to be put up for sale, but there was also a fleet of several hundred surplus steel ships to be sold by their owners. Under pressure from these owners and from the steel industry, the Emergency Fleet Corporation agreed that the engines would be removed permanently from the concrete ships and they would be sold only for service as towed barges or longshore storage facilities.

Records are not available as to the eventual fate of most of the ships. It is known that one was sunk in shallow water off Cat Cay in the Bahamas; although used by the United States Navy as a target for bombing practice during World War II, the hull survived and may still be seen, barely awash. A 3,500-ton ship was sunk in Narragansett Bay as a result of a piloting error. Two of the 7,500-ton tankers ran onto a breakwater at Tampico, Mexico; it is reported that one was salvaged and returned to service. Similarly, a 3,500-ton cargo vessel that was put on the rocks at 11 knots speed near Rockland, Maine, was salvaged, although nearly the entire length of the bottom of the hull was damaged. Still another vessel was sunk off Cape May, New Jersey. (Cores taken from that hull some years later indicated that the compressive strength of the concrete was 13,000 pounds per square inch; even allowing for the usual gain of strength with age, it is evident that the quality of the concrete was significantly better than specified at the time of construction.)

Between the two World Wars the commercial situation was such that there was no opportunity for further trials with concrete ships. The approach of World War II, however, created a new emergency situation, and just before war was declared, the United States Maritime Commission decided to establish another concrete ship program. Bates, now retired as chief civilian naval architect, was appointed technical director of the Commission and charged, among other things, with the development of the concrete ship program. Hollister was asked to serve as consultant and accepted that appointment.

Under this second wartime program, one hundred concrete ships with a total shipping capacity of about one million tons were built. All had the same outside form, with a length of 375 feet, a 54-foot beam, and a 28-foot draft. About half were dry-cargo vessels, and the remainder were tankers for transporting fresh drinking water and aviation gasoline, both desperately needed for the war effort in the Pacific. Sometimes the water and fuel were carried on the same ship, in tanks separated by a 3.5-inch bulkhead.

In unpublished notes, Hollister recounts some of the interesting experiences with the concrete vessels in the Pacific:

A small Japanese submarine attacked a ship loaded with aviation gasoline and set one tank afire. That tank burned dry, calcining the hatch coaming, but the fire did not spread to the next tank, which was full of gasoline. On another attack, a depth charge was released from a tug accidentally, and exploded close to the concrete vessel without setting it afire. That one was also loaded with gasoline. These two experiences did much to build respect for concrete as a material.

Some of the concrete ships of the fleet were used to establish the beachhead at Normandy during the Allied invasion of the European mainland. These ships were deliberately sunk just off the beach to establish bulkheads extending out into the water, in this way providing shelter for the landing craft which followed.

Since World War II, a bifurcation has taken place in the methods of construction used for concrete vessels. The method known as "ferrocement," derived from the Gabellini method and later refined by Nervi and others, has been used extensively for the construction of commercial fishing craft and yachts. Precast, prestressed concrete has been adopted for larger vessels, such as a remarkable floating facility for the storage of liquefied petroleum gas. This structure, which has a capacity of 375,000 barrels, was built in Tacoma, Washington, and towed 10,000 miles across the Pacific to the Java Sea.

IS THERE A FUTURE FOR CONCRETE SHIPS?

Given current energy shortages and the need for shipment of oil and other goods great distances at sea, together with improved technology and changing economic circumstances, is it possible that our times may see further development of the concrete ship? When questioned recently about this, Hollister's response was enthusiastic. He emphasized that he would not do it the same way this time, however. Planning in his mind the new directions, he spoke of newly developed concrete with three times the compressive strength of the concrete available during the wartime programs, and of new construction methods. Hulls would be precast segmentally, much as for present-day construction of long-span concrete bridges, and the segments would be post-tensioned after assembly, using high-tensile steel cables. Flexural and shear cracking of the hulls would be avoided by precompression of the concrete, a process that would also improve the resistance to impact. Smaller steel-to-concrete ratios permitted by the use of high-tensile steel would reduce congestion of the steel reinforcement and facilitate placement of the concrete. Dividing bulkheads would be precast in the flat position to avoid forming, and they would be biaxially pretensioned to provide strength and control cracking.

These forward-looking comments from Hollister provide insight into the man and his career. The concrete ship program, a fascinating story in itself, serves to illustrate how Hollister drew on his unique education in the basic and engineering sciences, and on his well-developed sense of design, to attack new problems with confidence.

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CONCRETE STRUCTURES FOR AMERICA

A Glimpse of Design Practice in the 1920s

by John F. Abel and Peter Gergely

In 1924 S. C. Hollister, a Philadelphia consultant in concrete construction, was recruited to take over the job of engineer for Delaware County, Pennsylvania, when the incumbent suddenly died. Although he had no specific experience with the kind of engineering required, Hollister undertook the assignment with confidence, as he had accepted responsibility several years earlier in the wartime emergency program to build an entirely new kind of transport ship of reinforced concrete. He began the county engineer's job by supervising the completion of a six-span arched viaduct over the Brandywine River, and then proceeded to build some thirty additional reinforced-concrete arch bridges in the county. The culmination of this work was the famous Ninth Street Bridge in the city of Chester, a 160-foot span that crosses the Chester River at a skew of about 42 degrees. Hollister's work on this bridge, which was notable for its competent and imaginative structural design and detail, and the paper in which he described it, won him, in 1929, the

Left: A commemoration of Hollister's bridge-building in Delaware County, Pennsylvania, is this plaque on the Ninth Street Bridge in the city of Chester. The bridge, which crosses the Chester River at a skew of 42 degrees, is renowned for its structural design and durability.

Below: The first bridge Hollister worked on while he was county engineer was this six-span arched viaduct over the Brandywine River. It is still in use.

". . .individual qualities and experiences can give character to an engineering work."

first Wason Research Medal of the American Concrete Institute (ACI).

Hollister, who developed a singular career as both practitioner and educator, was hardly typical of his time. Yet because of his professional accomplishments and influence, his career gives an insight into the status and development of civil engineering design, particularly in reinforced concrete, during the nascent third decade of this century.

THE CONTEXT FOR CONCRETE DESIGN IN THE TWENTIES

In the early part of the twentieth century, the principal large-scale use of reinforced concrete in the United States was for flat-slab floor construction. Most American designers still preferred to work with steel, and the use of concrete did not expand as rapidly in this country as it did in Europe. Yet there was a steady increase; in particular, the railroads' dramatic use of concrete for viaducts and bridges in the Middle Atlantic states contributed to wider acceptance of the material for bridge-building. By 1920 there was considerable diversification: concrete was being used not only for floors and bridges, but for foundations, retaining walls, hydraulic structures (dams, culverts, and tanks), bins, chimneys, and entire buildings. Simultaneously, there was a movement away from the patented "systems" prevalent in Europe, toward individually designed structures. Professional societies, including the ACI, facilitated this development by organizing efforts to develop codes and standards for various kinds of construction. (The papers by Robert Wilde and George Winter in the 1980 Hollister Colloquium proceedings document these activities.)

Seen in retrospect sixty years later, the most striking aspect of this early period of concrete design in the United States is the richness of the literature. In addition to the construction codes and standards, the available material included textbooks, handbooks, and journals. As compared with most of today's publications, these early ones were full of detailed examples of design and construction, and they placed much greater emphasis on esthetics and workmanship. English-language descriptions of European designs were included in some texts.

Part of the motivation for this thoroughness in reporting was that the average designer had little empirical information about the new material, and only rudimentary analytical methods. Structural behavior was not well understood. The strength design concept was not well developed and failure modes were not all recognized; for example, little was known about the anchorage of steel bars, especially stirrups. The available material was low in strength and methods for designing concrete mixes had not yet been developed. Analytical methods for indeterminate structures such as concrete arches were limited, mostly to graphical approaches; short arch bridges were often not analyzed at all. And there was no practical way to determine the moments in large monolithic concrete frames.

In bridge construction, the arch was almost always used because that form had served well for many centuries in masonry construction. The design of concrete arches developed almost independently in Europe and in the United States, however, and it is interesting to compare the results. In the United States, engineers were generally slower to realize the potentials and special characteristics of concrete; initially, American arch bridges were massive, hingeless, and rather conservative. European engineers often used hinged arches to allow for the settlement of supports and to accommodate shrinkage, and they were innovative in the use of ribbed arches, open-spandrel columns, floating foundations, and precast block arches. Because of careful attention to design, they were able to build structures lighter in weight than the contemporary American ones, which relied on massiveness to avoid tension and limit compression stresses. American designers often took temperature and shrinkage into account, though, and they made advances in scaffolding and centering systems.

HOLLISTER'S CONTRIBUTIONS THROUGH HIS PRACTICE

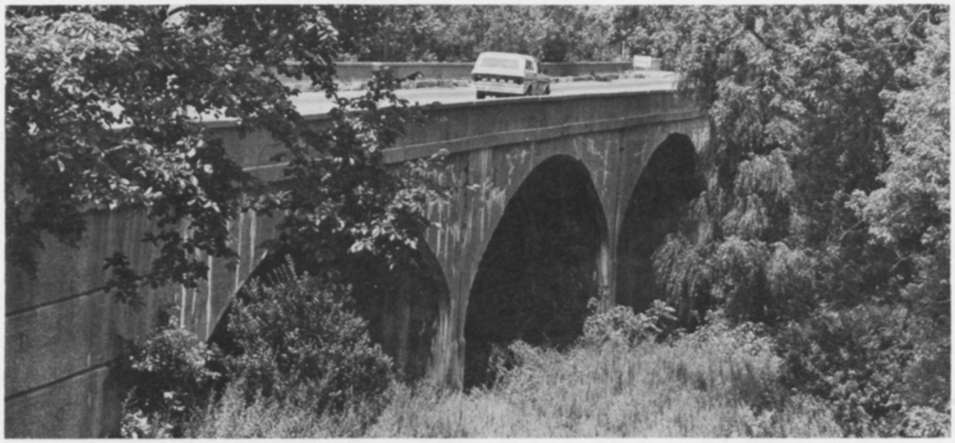
Hollister was well prepared to participate in the development of reinforced concrete technology in the 1920s. Even as a student, he had acquainted himself with the European literature. He had acquired diverse experience as a professional civil engineer and had risen rapidly to responsible design positions. He had written a handbook (*Useful Data*, 1918) about concrete construction. Above all, he had successfully undertaken the design of a large-scale construction program requiring new techniques, tight quality control, and an accelerated schedule: the World War I program for building concrete ships.

This shipbuilding project led directly to the formation, in early 1920, of the consulting firm of Wig and Hollister in Philadelphia. Wig had been the chief engineer of the concrete ship program; previously he had been head of the cement section of the National Bureau of Standards. In 1921, a third principal engineer was added, and the firm became Wig, Hollister and Ferguson. In 1922 Wig left to become manager of a California company, and later in the decade the firm expanded its management consulting activities with the addition of an attorney; the firm became Light, Hollister and Ferguson.

The consulting company worked mainly in concrete construction and in construction management, although it also handled some structural design. The major client was the John H. McClatchy Company of Philadelphia, builder of three to four thousand units of row housing each year. For McClatchy, Hollister devised methods of waterproofing the concrete-block houses (see the article by Floyd O. Slate). He also set up a system of staged construction of groups of row houses. Not only were the excavation, foundation construction, and superstructure fabrication arranged in an assembly-line manner, but the material was prepared in advance—lumber was precut, for example, and stair units were prefabricated. Design work for McClatchy included a railroad trestle with a bunker for unloading, and a tunnel to carry a creek under and parallel to a Philadelphia street. This culvert was built as a cast-in-place concrete elliptical arch with a separate, curved concrete invert, and the forms were made in moveable sections for repeated utilization.

Another client during those years was the National Floor Tile Company of Mobile, Alabama. Hollister helped this company develop a line of colored cement tiles and provided advice on architectural designs that could utilize the product. The technical problem was to find mineral coloring agents that would not be affected by lime.

Hollister carried on a part-time consulting practice after his appointment as county engineer in 1924, continuing as a principal in the firm until he began teaching at Purdue in 1930. During these years in practice, he became very active in professional societies, especially the ACI, which he served as president in 1932-33, and he came to know many of the foremost designers of the time. Particularly important to Hollister were his associations with Henry C. Turner, president of the Turner Construction Company and president of ACI, and John J. Earley, an architectural engineer and artist.



The Shoemakerville Bridge, designed in June of 1925, is one of the approximately thirty bridges built by Hollister for Delaware County, Pennsylvania. It is a viaduct located on Providence Road over Ridley Creek between the city of Chester and the township of Upper Providence. The six spans are 63 to 80 feet long, and the width of the bridge is 48 feet. Each span consists of six arch ribs supporting a flat-slab deck, and the spans are separated by full transverse expansion joints at each pier. The piers themselves arch between two footings. The abutment ramps (not visible here) are 70 and 140 feet long.

THE BRIDGE BUILDING IN DELAWARE COUNTY

All thirty or so bridges that Hollister built while he was county engineer were of concrete. The initial cost of a concrete bridge was comparable to that of a steel one, and it had the advantage of being easier and cheaper to maintain. Most of these bridges were small, designed for grade separations or creek crossings, and most were earth-filled arches, although a few had beam-and-slab construction. Several bridges, of somewhat longer span, were closed-spandrel, earth-filled arches. At least five of the total number are still in use.

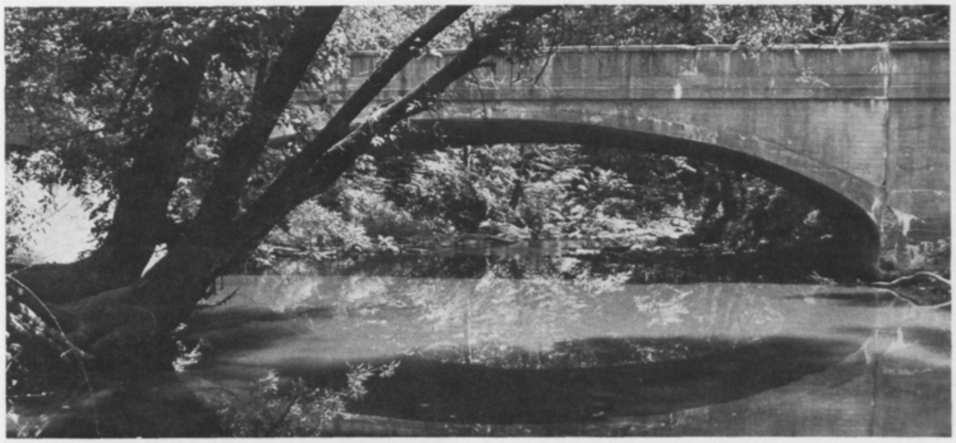
As county engineer, Hollister supervised all design and construction. For the ordinary road design and engineering work, and for calculations and checking, he hired a professor from Villanova as an assistant, but he took on the arch designs for the bridges himself. He was also particular about quality control and insisted that a resident engineer be present during all phases of bridge construction.

Hollister was highly aware of contemporary design modes in this country and in Europe, but he also relied on his own experience and ideas. For example, although he knew about the use of hinges in arch construction, he never used them himself because he had "always had trouble with joints." And although he was aware of patented reinforced-concrete arch systems that employed single reinforcing specified for various sections of an arch according to the expected moments, Hollister always used double reinforcing to accommodate all possible combinations of loads and shifting of abutments.

These characteristics of thoroughness and care are evident in Hollister's prize-winning work and descriptive paper (*Proceedings of the American Concrete Institute* 24: 371-400) on the skew arch bridge over the Chester River. The paper begins with a consideration of the theory of behavior of skew arches and proceeds to a discussion of the design of this particular bridge. Then there is an account of the actual construction, and a summary of the measurements made to evaluate its performance. The highly mathematical analysis is covered in an appendix.

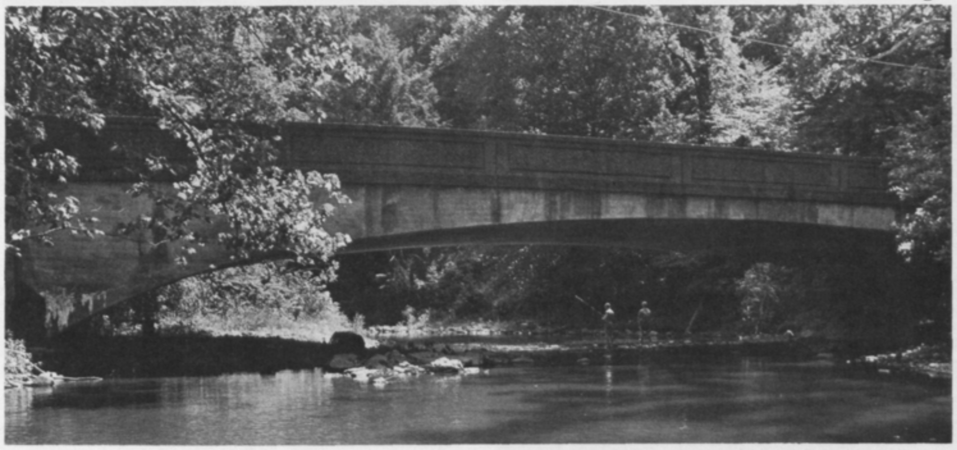
A major consideration in designing skew arches, Hollister pointed out in this paper, is that the force on the abutments is not uniform: on the side where the bridge forms an obtuse angle with the abutment face, the compressive force on the end of the abutment is more than twice its average value; at the other end of the same abutment, tension can occur. An additional problem is that the arch barrel experiences torsion and tends to bend transversely, even under uniform loading. In the Ninth Street Bridge, a number of design features reflect the three-dimensional behavior of the skew arch. The arch configuration selected as most appropriate for the torsional and transverse-bending conditions was a barrel with a tubular box section. The bottom slab was thickened at one end because of the higher compressive thrust. The longitudinal steel in the high-tension zone was embedded in the abutment to resist uplift. The abutment seats themselves were designed with keyways to resist possible

Fox's Branch Bridge



The Fox's Bank Bridge is a closed-spandrel, earth-filled arch with a 70-foot span. Located in a lovely country setting on Manchester Road, it crosses Ridley Creek between the townships of Middletown and Upper Providence. The rise of the fixed arch is 10 feet, 7½ inches, the total width of the bridge is 32 feet, and the barrel is 10 inches thick at the crown and 18 inches thick near the springing. The railings were built with rectangular spindles, but these were replaced in 1936 with the solid railing shown. The abutment walls are closed concrete parapets, designed to complement the original open railings of the span.

Mount Alverno Bridge



The Mount Alverno Bridge is similar in style, design, and setting to the Fox's Bank Bridge, except that it is longer—its span is 120 feet. It crosses the Chester between the townships of Middletown and Aston. The rise is 13 feet, 4¾ inches, the width is 34 feet, 4 inches, and the thickness of the barrel ranges from 15 inches at the crown to 43 inches near the springing. The closed parapets with their exposed-aggregate, inset panels are the same for the abutment and the span. This smooth transition, together with the low rise-to-span ratio and the slight but noticeable convex vertical curvature, gives a graceful appearance.

slip of the bridge parallel to the abutment. The transverse steel in the arch slabs was designed to withstand diagonal tension caused by the torsion.

One feature of the design not mentioned in the paper is the chamfer or *corne de vache* along the edge of the soffit (the inside surface of the arch). The practical purpose of this curvature—which can be seen in the photograph on page 29—is to ensure the smooth flow of water past the barrel during periods of high water, but in the Ninth Street Bridge it serves an esthetic function as well. The continuation of the *corne de vache* to the crown with diminution, combined with the skewed curvature of the soffit, creates a simple but elegant visual effect. Hollister adapted this feature from the shallow masonry arches designed a century and a half earlier by the French master of the stone arch, Jean-Rodolphe Perronet.

During construction, the abutments were a major concern. The excavation revealed that the underlying rock fell away on one side of the river; the abutment there had to be redesigned with dowels anchored in the rock. The arch was constructed by casting the soffit slab and ribs in five segments to avoid oblique thrusts on the scaffolding and to postpone the development of skew action until the concrete had acquired strength. After the concrete had cured, the narrow openings between the segments were concreted, and then the complete soffit slab and ribs served to help support the concrete subsequently placed for the spandrel walls, the top slab, and the

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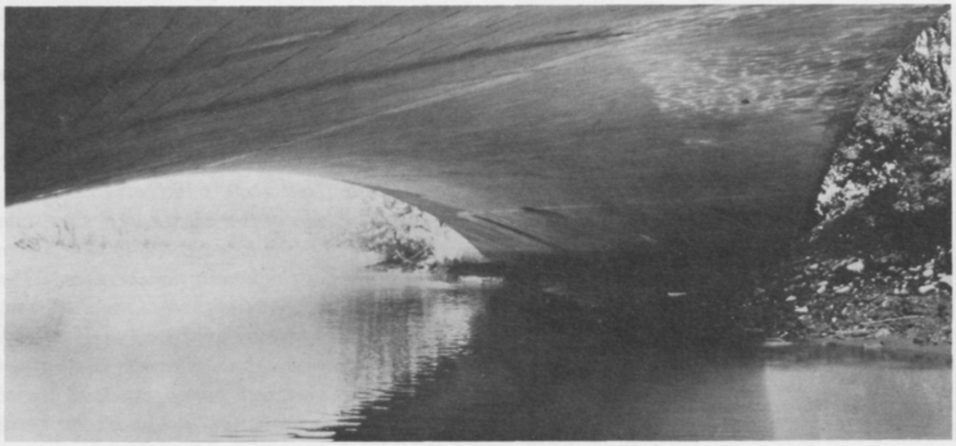

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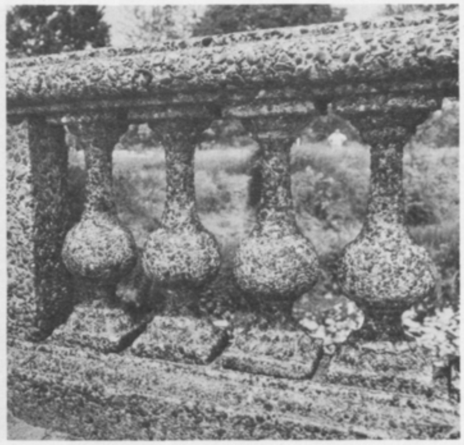

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The culmination of Hollister's work as a designer of reinforced concrete arch bridges is the Ninth Street Bridge in the city of Chester, Pennsylvania. It was designed in July, 1925, and completed in October, 1926. This 160-foot span crosses the Chester River at a skew of about 42 degrees. The combination of the extreme skew, the relatively long span, and the low rise presented a challenging design problem.

1. The three-dimensional configuration of the skew arch is apparent in this view of the underside of the span.

2. The angle at which the bridge crosses the river can be discerned in this recent photograph. The large skew angle, together with the width of the bridge (59 feet, 4 inches perpendicular to the roadway) and the width of the river, required that the abutments be offset by about 107 feet; no part of one abutment lies directly opposite any part of the other. The soffit profile is circular, with a radius of about 221 feet.

3. Careful detail is evident in the ballustrade with its individually field-cast concrete spindles.

4. A graceful as well as practical design feature is the corne de vache, *or chamfer, along the edge of the inside surface of the arch.*

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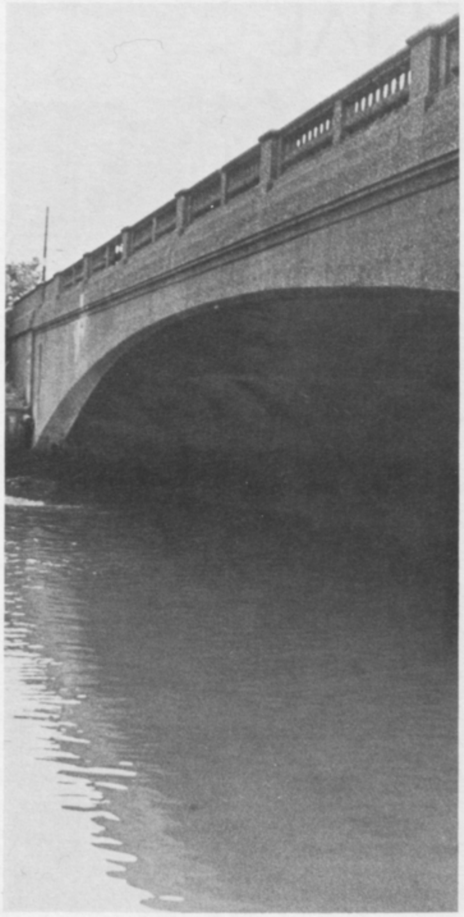


deck. Throughout the construction, care was taken to maintain uniform quality of the concrete mix and placement. Special attention was paid to details, such as the finishing of the concrete surfaces and the molding of balustrade parts, that affected the appearance of the bridge.

An incident that occurred soon after completion of the bridge is indicative of the quality of design and construction. A water main carried by the bridge leaked into the tubular barrel, filling it with water, but as the arch remained watertight, the leak was not discovered until nearly a year later. Even with the extra weight of water, the bridge had continued to function without distress.

The story of Hollister as a designer of arch bridges seems remarkable particularly because of its revelation that individual qualities and experiences can give character to an engineering work. Left largely to himself, this man drew on his earlier study and experience to produce designs that were functionally successful, economical to build, and beautiful in form and detail. The Ninth Street Bridge, still in service after more than half a century, is not only a useful structure, but an example for today's engineers.

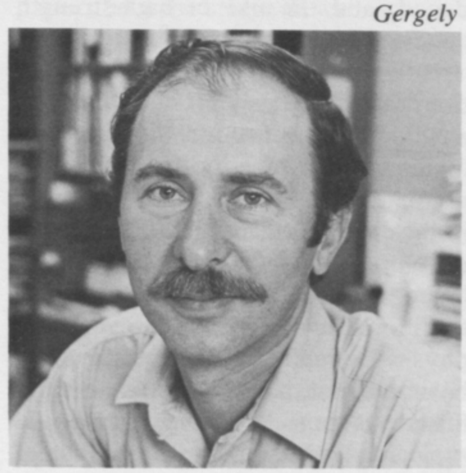
John F. Abel and Peter Gergely are members of Cornell's Department of Structural Engineering.

Abel, a specialist in finite element analysis and computer graphics, studied at Cornell for the B.S. degree, at Stanford University for the M.S., and at the University of California, Berkeley, for the Ph.D. He joined the Cornell faculty in 1974 after four years at Princeton University, and is now an associate professor.

Gergely came to the University in 1963 after receiving the Ph.D. degree from the University of Illinois, and was promoted to professor in 1975. He took his undergraduate work at McGill University. His research specialties are structural mechanics, shells, dynamics, earthquake engineering, and reinforced concrete. He is a registered professional engineer in New York State and has worked as a structural engineer in Montreal and Pittsburgh. In 1974 he was co-recipient of the State-of-the-Art Paper Award of the American Society of Civil Engineers.

Abel

Gergely



THE MAJOR BUILDING MATERIAL OF THE TWENTIETH CENTURY

Concrete and Hollister's Role in its Development

by Floyd O. Slate

When S. C. Hollister started his professional career in 1916, the whole field of concrete was in its infancy. The understanding of material behavior was very limited, and specification codes were at an early stage of development. Architectural uses of concrete were just beginning—concrete houses were a novelty. Techniques now familiar, such as mixing in transit and using vibrators and centrifugal force for compacting, had not been thought of. Light-weight artificial aggregates had not yet been introduced, and the use of high-strength concrete was far in the future.

Hollister made substantial contributions in all these aspects of concrete as a material in connection with his work in the design of structures. His approach to construction problems was, in fact, crucial to his influence in the development of concrete. He combined the empiricism characteristic of traditional civil engineering with the physical scientist's search for a more basic understanding of *how* and *why*. (This is a stance that is perhaps more typical of giants of the past than of many modern professionals with high degrees of specialization.)

SHIPS, POTS, HOUSES, AND PIPES OF CONCRETE

One of the earliest of Hollister's contributions occurred in the course of his important work on concrete ships during the World War I period. As discussed elsewhere in this issue by Arthur H. Nilson, the project entailed the introduction of a new material—light-weight artificial aggregate—and a new technique—use of a vibrator for placing the concrete. Hollister was able to produce a concrete of very high and consistent quality by insisting on new standards of workmanship, inspection, and quality control. As he pointed out in commenting on the shipbuilding program, "Concrete differs from all other building materials in that it is manufactured on the job. Its integrity as a structural material is in the hands of the builder."

During the twenties and early thirties, when he worked as a consulting engineer and was active in the American Concrete Institute (ACI), Hollister continued to influence the development of materials. For example, Babcock and Wilcox needed a new type of pot, about eight cubic feet in capacity, for melting metal for castings. To make the pots light in weight, Hollister specified a Haydite expanded aggregate; to make them suitable for electrical heating, he used nonmagnetic phosphor-bronze for reinforcement; and to avoid problems involving heat, he lined them with fire brick. The pots solved the problems the company had been experiencing and started a new trend in the industry.

During the 1920s, Hollister also worked extensively on concrete houses, particularly in finding effective ways of waterproofing and dampproofing. He used bituminous materials and foamed plastics at joints, and made provisions to stop capillary water. Of particular interest is his scheme of spraying a water solution of soft soap on the outer surface of the concrete; the calcium ions from free lime in the concrete would react with the soluble sodium salts of fatty acids in the soap, and relatively insoluble cal-

The concrete ballustrade on this bridge over the Chester River in Delaware County, Pennsylvania, is notable for its durability and detail. The bridge is one of about thirty Hollister designed while he was county engineer in the 1920s. This photograph of Hollister on the bridge was taken last spring during a tour of the area by several members of Cornell's structural engineering faculty.

cium salts of fatty acids would be precipitated in the pores of the concrete, greatly reducing permeability. To enhance the attractiveness of the houses, he sometimes used colored pea gravel as exposed aggregate on concrete blocks; the technique involved using a molasses-like retarder on the form face, and brushing and washing the green concrete after early removal of the form. Many of these houses still stand, in use, in Philadelphia.

In about 1950, Hollister pioneered in centrifugal placing and compacting of concrete for pipe. The project was for Raymond Concrete Pile, a company that had contracted to lay a bell-and-spigot pressure pipe, six and one-half feet in diameter, for a water supply line to Lubbock, Texas. The use of spinning has since become a major method of manufacture for high-quality concrete pipe.

MATERIALS IN THE FAMOUS SKEW ARCH BRIDGE

Hollister's famous skew arch bridge in Chester, Pennsylvania (described in the article by John F. Abel and Peter Gergely) was notable not only for its structural features, but for the materials aspects of the concrete. Hollister's insistence on proper choice and use of materials and on careful quality control resulted in a bridge of remarkable durability. Built well before designers and engineers knew about air entrainment, this concrete bridge—and even its balustrade—has survived even though it is situated in a severe freeze-thaw environment.

Interesting sections of Hollister's paper about the bridge describe the use of exposed aggregate as a touch of beautification, and the use of an original field-precasting technique for forming the balustrade spindles. (The paper, published in 1928 in *Proceedings of the American Concrete Institute* 24:371-400, earned him the first Wason Research Medal awarded by the ACI.)

To obtain an attractive surface, colored aggregate was selected and the concrete was handled so as to leave the aggregate exposed. The gravel was obtained locally and, as Hollister charac-

Figure 1a

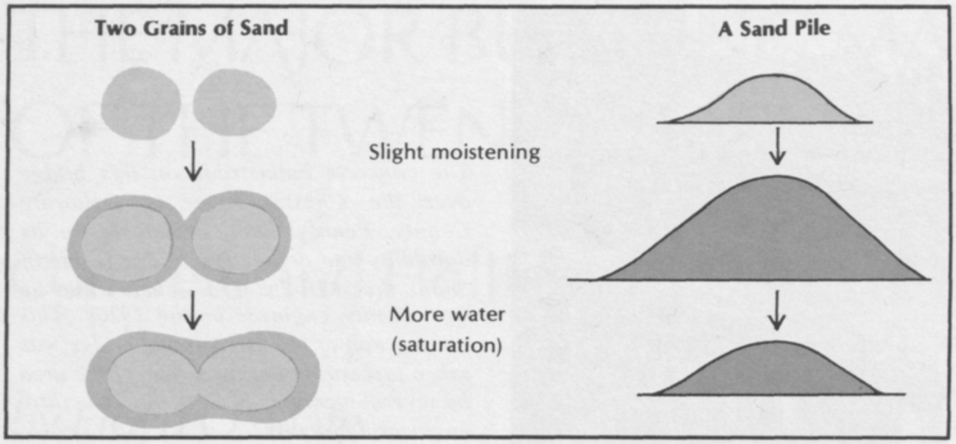


Figure 1a. Representation of the bulking of dry sand when it is gradually moistened, and its subsequent decrease in volume as more water is gradually added. An explanation of this phenomenon was given by Hollister in his 1931 article on concrete mixtures. Two representative grains of sand, slightly moistened, are kept apart by a thin film of water that surrounds each particle and is held in position by surface tension. Effectively, the water film increases the size of the total bulk, represented in the figure by the sand pile. As water is added gradually, a point of maximum bulking is reached. Then, as further water is added, it collects in the neck between the two sand particles, the water surface tends to form a "peanut" shape surrounding both grains, and surface tension is sufficient to pull them together. The sand pile accordingly shrinks nearly to its original bulk. Hollister pointed out that the amount of moisture required to produce maximum bulking, and the amount of the bulking, are functions of the surface area of the sand.

Figure 1b

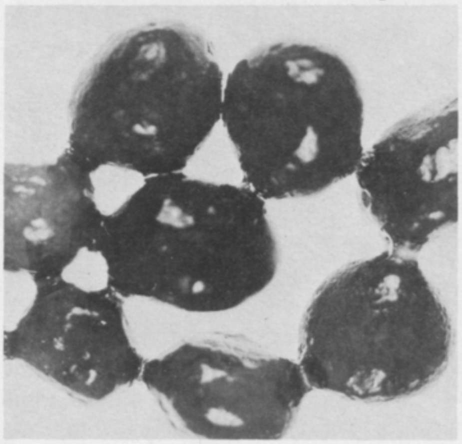


Figure 1b. Liquid films on grains of sand, from a photograph in Hollister's paper. (Prepared by Stanley Olsefski.)

teristically noted, did not add any extra cost. "In appearance it was predominantly buff," he wrote, "with shades of color interspersed, running out to deep purple, dark red, brown and black." On the basis of preliminary tests, the mix proportion that would yield the highest strength was determined for the arch sections. A somewhat drier mixture was used for the abutments, which included a slope "formed by laying up stone in layers as the concrete proceeded." Sound clean stone from the old masonry abutment was also incorporated in the concrete mass.

The balustrade spindles were produced a few at a time throughout the period of construction, using a set of iron molds for casting the concrete. Each day the molds were filled, and on the following day the green spindles were removed and the molds refilled. The process was described in Hollister's paper:

The molds were filled with concrete mixed quite wet so as to insure the thorough filling of all portions of the mold. Dry coarse aggregate was then rammed into the mold a little at a time and any excess water or grout was allowed to overflow the top of the mold. This continued until no additional coarse aggregate could be rammed into it. The top of the mold was then struck off and several thicknesses of newspaper were laid over the top on which was piled previously dried sand. Moisture began to be drawn by the capillarity of the paper, the sand serving as a reservoir for moisture thus drawn. When the sand became quite wet it was scrapped [sic] *off without disturbing the newspaper and replaced by dry sand. This continued until the drawing of the moisture practically ceased. This is a method the writer learned from John J. Earley.* The concrete resulting from*

(continued on page 34)

**John J. Earley, an architectural engineer and sculptor from Washington, D.C., is regarded by Hollister as an important influence during his early career.*

Figure 2. Dispersion of cement in water, from a photograph magnified 275 times. This is a copy of the photograph that appeared in Hollister's 1931 paper on concrete mixtures.

Hollister noted that cement particles, which are much smaller than the sand grains, tend to cluster, and that when water is added, these clusters become surrounded by water films. In a concrete mix, sand grains fill the interstices between particles of gravel, forcing them somewhat apart; the clusters of cement adhere to the particles of sand and gravel; and water forms a film around each of these constituents. Additional "free" water provides for the needed amount of workability.

In the case of cement, a complicated hydrating process, the most important factor in concrete strength, occurs both before and after solidification. Hollister described the formation, important for the manipulation of wet concrete, of a jelly-like colloid on the surface of the cement particles. The more water that is present for a given amount of colloid, the weaker the colloid becomes and the greater the tendency for shrinkage and possible cracking.

Figure 2

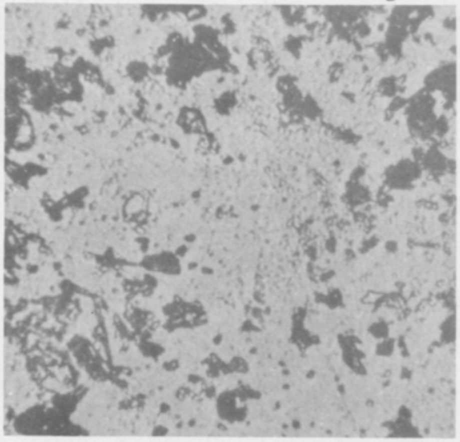


Figure 3. Illustrations showing the effect of excess water on the cracking of cement paste after drying. The sample at left had a normal water-to-cement ratio and the one at right had a considerably higher ratio. In Hollister's 1931 paper, he noted the significant relation between concrete shrinkage and excessively wetted cement. When excess water is present, the colloid formed by the action of water on cement tends to float to the top, especially when the concrete is agitated. Hollister observed that overworking of the top surface of poured concrete, as on a floor or sidewalk, promotes this accumulation of "fatty" mortar, and cracking or crazing can result if the concrete is dried too rapidly. (Illustrations prepared by Stanley Olsefski.)

Figure 3

"He combined the empiricism characteristic of traditional civil engineering with the physical scientist's search for a more basic understanding of how *and* why."

such a procedure has a maximum of coarse aggregate and sufficiency of binding material and at the moment of final set of the concrete has a minimum of water present in the mass. It develops a surprisingly strong concrete, equivalent to that obtained at the high point of the Abrams water-ratio curve. The process insures a rapidly acquired strength at the end of the first day and since there is a maximum of coarse aggregate there is practically no shrinkage, hence no cracking of the spindles at the minimum cross-sections.

SIX DECADES OF WORK IN CONCRETE

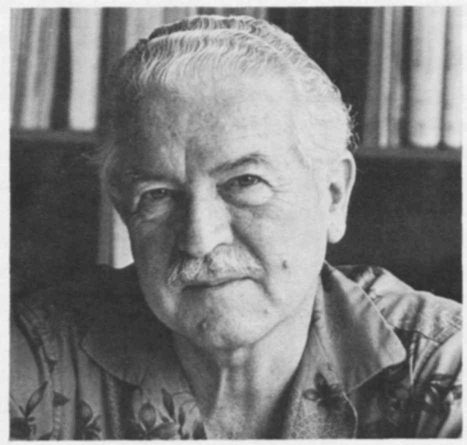
Hollister's most important contribution to the materials field was probably a landmark paper on concrete mixtures that he published in 1931 (*Proceedings of the American Concrete Institute* 27:959-73).

The paper included a mechanism proposed to explain the bulking of sand, a vital consideration when batching by volume (see Figure 1). It also discussed the absorption of water by the cement and by the aggregate, and how these factors in combination affect the workability of fresh concrete. The paper also provided what was probably the first explanation from an engineer for the well-known law of Abrams relating the strength of a mixture to the water-cement ratio (see Figure 2).

Another major contribution was Hollister's work on the transit concrete mixer, which has become so vastly important to the industry. This work was initiated by a problem involving the degradation of stone during the process of mixing concrete. Hollister's meticulous research, undertaken as a consultant to the Jaeger Machine Company and published in 1932 (*Proceedings of the American Concrete Institute* 28:405-17), gave a shot in the arm to the infant concrete construction industry. He investigated practical details of the mixing, such as the optimum number of revolutions of the drum under different loading conditions, the speed of rotation, and the effect of the water-cement ratio on concrete strength.

Throughout his remarkably productive career, Hollister has had a forward-looking attitude. In 1934, for example, at the end of his term as president of the ACI, he forecast future developments in concrete as a material. "Imagine, for example," he said in his concluding address, "concrete with an available strength of 10,000 pounds per square inch. Smaller columns, thinner and lighter beams and slabs would at once result. Precast units, easy to handle, would be available. The present limiting heights of buildings, of spans of bridges, would be at least double. A new basis of design, new codes and specifications would be required."

Hollister is currently serving as a consultant for a Cornell research project on high-strength concrete, and he is preparing a paper on the durability of concrete, an aspect he feels needs more study. More than six decades after he began his work on structural concrete, he is still active and looking ahead.



Floyd O. Slate, professor in Cornell's Department of Structural Engineering, has been a co-winner of the Wason Medal for Materials Research by the American Concrete Institute three times. (In 1974 the medal was in recognition of joint research on concrete by Slate, his Cornell colleague Arthur H. Nilson, and Tony C. Y. Liu.) He is active as a consultant, not only in the United States, but in many foreign countries, primarily in the field of low-cost housing for developing nations. He holds three degrees from Purdue University, and worked at Columbia University and Purdue before coming to Cornell in 1949.

HOW TO EDUCATE AN ENGINEER

Ideas of an Influential Innovator

by Walter R. Lynn

To Solomon Cady Hollister, an engineer is a man for all seasons: a practitioner, a researcher, and a responsive and responsible human being. An engineering educator, in addition, must be effective in preparing young people for productive careers in a continually changing profession. It is these views that have shaped Hollister's work and attitudes for almost seven decades.

When Hollister first came to Cornell in 1934 as director of the School of Civil Engineering, the faculty was in a condition best described as moribund—wrapped in an academic cocoon that insulated it from the real world of engineering. Into this environment came a man who insisted, as a condition of employment, that he be permitted to continue his work as a consultant (he was then designing the penstocks for Hoover Dam). In the mid-thirties academic institutions did not encourage engineering faculty members to do professional consulting, but Hollister was hired and proceeded to shake up the School and, when he became dean three years later, the entire College.

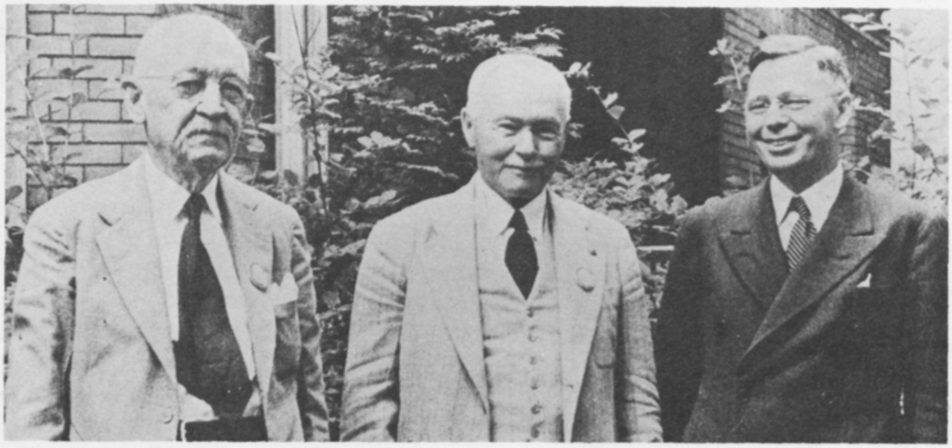
In reminiscing about those days, Hollister recalled a revealing incident. He received a complaint from the University comptroller about the rising utility bills for Lincoln Hall, the main civil engineering building. The rule had been to shut off the heat at 4 p.m. Hollister replied that he was glad to see some evidence of stimulation in the civil engineering school, and that much more could be expected. The issue was evidently taken to President Farrand, who ran into Hollister at a party a few days later and remarked, "I understand that the heating and lighting bills are increasing in Lincoln Hall. Well, keep them going!"

A SCIENTIFIC BASE FOR ENGINEERING EDUCATION

One of the current issues was the need for continuing education, a situation that disturbed Hollister because he felt that graduates of a properly conducted educational program should be able to find their way through the literature as it changed and thus keep abreast of developments in their fields. He believed that many practitioners couldn't do this because schools often limited the instruction in mathematics and its applications.

When he became dean, Hollister recognized that he had an opportunity to effect change at Cornell and that Cornell's problems were common to all of engineering education. He was a master strategist. He recruited technically and scientifically competent faculty members who had also demonstrated their ability to solve practical engineering problems, and slowly the complexion of the College faculty changed.

A notable innovation was the development of a five-year undergraduate program that provided enough time for strengthening the instructional base. In the first two years, the emphasis was on general courses in physics, chemistry, mathematics, engineering sciences, and liberal studies. More specialized course work, including practical applications, was undertaken during the following three years. The intent was to educate engineers who, because of their preparation in both basic and practical studies, would be



Three engineering deans photographed in 1939 are, left to right, Frederick E. Turneaure of the University of Wisconsin; Anson Marston of Iowa State College; and S. C. Hollister of Cornell.

Both Turneaure and Marston were Cornell civil engineering graduates of the class of 1889. Both had scholarships in mathematics; they were roommates and wrote their thesis together. Turneaure was Hollister's chief mentor during Hollister's years as a student at Wisconsin (see the article in this issue by Richard N. White.)

"Should professional education consist of training in a series of techniques, or in scientific principles?"

able to function effectively throughout their careers. Few other educational institutions were willing to lengthen their undergraduate curricula in this way, however, and in the 1960s the faculty modified the program by establishing a four-year course of study augmented by an optional fifth-year Master of Engineering degree program. All engineering underclassmen were enrolled in a common Basic Studies curriculum before they entered a chosen specialty field. The M.Eng. program was intended primarily for students headed for professional practice, and provided an alternative to the educational path leading to careers in teaching or in theoretical and applied research.

CLARIFYING PURPOSES AND EDUCATIONAL MEANS

Hollister's educational influence extended far beyond Cornell. As incoming president of the American Society for Engineering Education in 1952, for instance, he called for studies that would constitute a fundamental examination of the education of engineers. The result was the so-called Grinter Report, which continues today to provide challenges to engineering education. The charge to the appointed committee posed the questions:

1. What is required for the education of an engineer who will be competent to serve the needs of the engineering profession over the next quarter or half century? What are these needs?
2. Where is the line of demarcation between science and engineering?
3. To what extent shall the expanding sciences be reflected in engineering education?

4. To what extent is specialization appropriate to the education of the engineer of the future?
5. How far should proliferation into nontechnical borders be carried, and where is the line beyond which such a program of education ceases to be engineering?
6. Should professional education consist of training in a series of techniques, or in scientific principles?
7. Should the educational focus be upon courses, or on the progress of the individual student?
8. As the only medium, for most students, for higher education, what roles should engineering educational programs adopt?

HAS THE PENDULUM SWUNG TOO FAR?

Hollister can claim considerable responsibility for the initiation of the scientific-theoretical movement in engineering education. The question in his mind now is whether the pendulum has swung too far. In a recent interview transcribed for this paper, he commented:

We are suffering a downturn in the product of the University in terms of the students' practical abilities. There is a distinct reduction in the attention given to the practicum, which has been replaced with more academic theoretical content. We have eliminated many laboratory courses that used to furnish a considerable amount of skill and the technical rationale to help the student comprehend what the theory was really all about.

Questions important to engineering education arise:

- Have we become so involved and enamored with theoretical questions and subspecializations that we have lost sight of our interest in the profession we are expected to serve?
- Do we still serve a profession?
- Does engineering (without a qualifying adjective) have any meaning any longer, and if it does, do we convey that meaning to our students?

These questions recurred often during a series of interviews I held with Hollister in the fall of 1979; they are questions he wants his colleagues to ask themselves. Innovators never stop trying to change things: Solomon Cady Hollister continues to stimulate us to actively consider the changes to come in engineering education.

Walter R. Lynn, Cornell professor and former director of the University's School of Civil and Environmental Engineering and of the Center for Environmental Management, has just begun a term as director of Cornell's Program on Science, Technology, and Society. He is a specialist in environmental systems analysis, public health, and water quality management models. Lynn who joined the Cornell faculty in 1961, received the Ph.D. in civil engineering and systems analysis from Northwestern University. He also holds a bachelor's degree in civil engineering from the University of Miami and a master's in sanitary engineering from the University of North Carolina. In addition to teaching and research at Miami, his experience includes employment as a professional civil engineer and as a consultant.

SOLOMON CADY HOLLISTER

Notes on an Engineering Leader

The colloquium papers abstracted in this issue show essentially only one aspect of S. C. Hollister: his professional career in the field of reinforced concrete. The Holly known to his Cornell associates is considerably more complex. We know him as a former dean who instituted important changes in engineering education, developed a strong faculty and research program, increased the size and quality of the student body, and spearheaded the building of a new campus for the College of Engineering. Many of us know also about some of his other achievements in engineering practice: his design of the steel penstocks at Hoover Dam, for example, and his many other substantial contributions to the study and use of metals in engineering. We are aware of his work on the classification of certain fossil shells (he spent part of this past summer working on a paleontological research paper). We know of his lifelong interest in architecture and we recall how carefully he oversaw the design of the engineering buildings at Cornell to ensure economy and versatility.

Yet there are still other facets of this man's life and personality that emerge as one talks with him or with others who have known him. Reminiscences collected in the colloquium proceedings give glimpses of Holly's personal and professional influence at various points in his long career.

A sketch by Arthur R. Lord, who succeeded Hollister as president of the American Concrete Institute (ACI) in 1933-34, was reprinted from a 1932 issue of the Institute's newsletter. Lord wrote:

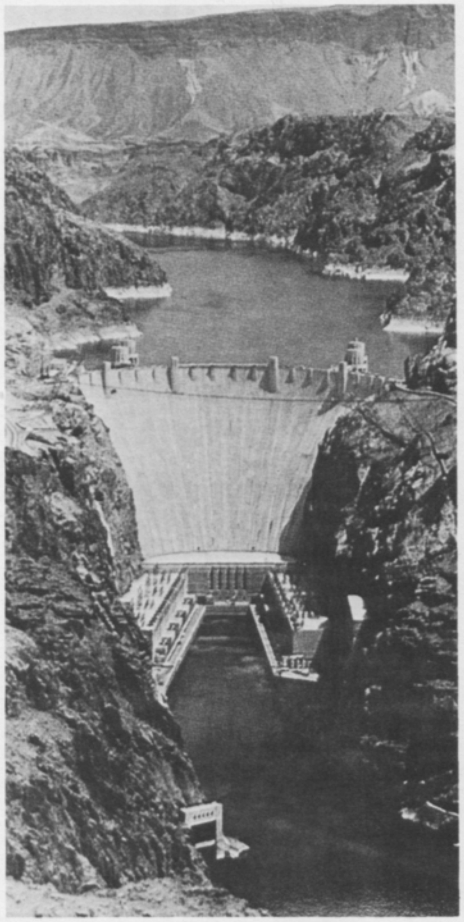
The most disconcerting thing about S. C. Hollister is his youth. Destined next month to become the Institute's tenth and youngest president, he brings to his new responsibilities not only youth in the mere matter of years, but corollary attributes which may be especially valuable to the society in these times–the animation and spirit of youth and a warm and contagious interest in a wide range of subjects. . . . He comes into my office and starts to disclose his latest mathematical "shortcut" (his expression, not mine) in structural design, using a jargon of mixed Greek, Roman and Hindu symbols, the prelude to aspirin. In a few minutes he has switched to "liveable" concrete houses, of which he has architected not a few, and thence to his latest concept of the essentially colloidal action of hydrating cement; to tests of transit mixers and to studies of wind torques and pressures on models in wind tunnels. . . . He's a mental intoxicant. . . . He has climbed all over and through and around the Institute, fitting himself into every conceivable niche, like a small boy turned loose in a strange attic.

Another remembrance was contributed by Fritz Leonhardt, who was a foreign exchange student at Purdue when Hollister was a professor there, and who practiced as a consulting engineer in Germany and is now professor, emeritus, of Stuttgart University. Leonhardt recalled his gratitude for finding in Hollister "a professor not only of high professional qualities, but with so much warmheartedness in receiving and helping a foreign student."

A close professional relationship developed, and a friendship as well.

Quite often I was asked to his home where his wife Ada radiated so much warmth and fine hospitality. Usually there were interesting guests and a very thoughtful conversation on diverse problems. Sometimes Holly took me along on his Sunday trips with Ada and his children. I was surprised by his deep knowledge of nature. He knew the names of all the trees and flowers and birds which we found. I had a folding boat with me, developed in my home country, in which two people could paddle even on wild rivers. Holly came along with me several times and we made exciting trips on the Wild Cat River, a tributary of Wabash River near Lafayette. I left this boat to him and his children; they used it quite often for many years.

Glen J. Schoessow, professor of nuclear engineering at the University of Florida, reminisced about the Hoover Dam penstock project, which he worked on with Hollister for four years, designing and testing the huge, two-inch-thick steel structures.



Hoover Dam's steel penstocks, thirty feet in diameter and two inches thick, were designed and tested under the supervision of Hollister in the early 1930s. Penstocks of this size were well beyond the state-of-the-art at the time. The dam itself rises 726 feet above bedrock in the Colorado River.

The $10,800,000 contract for the penstocks was awarded to Babcock and Wilson, a firm that hired Hollister as consultant. The plans called for four of the thirty-foot-diameter pipes, each eight hundred feet long, which would each branch to four thirteen-foot-diameter penstocks to feed sixteen turbines. All components were to be designed to withstand 18,000 psi hoop stress and 19,000 psi total stress. Problems involved in the design included devising a method for welding plate into rings, providing manhole reinforcements, and designing support for sections and pinned joints between sections.

This project was still in progress at the time Hollister left Purdue to become head of Cornell's civil engineering school; he accepted the Cornell post on the condition that he be allowed to complete work on the penstocks.

Finally, in 1936, two years after completion of the designs, the great day arrived: the penstocks were in place, and were hydro tested to prove the design. Among much speculation and some apprehension, Hollister kept his hand on the throttle, kept his cool, helped others to do likewise, and all tests were 100 percent O.K. Thirty-four thousand tons of penstocks had been completed to stiff specifications: designed, tested, approved, built, erected, and tested, all in four years. This indeed was a great accomplishment. Only a few engineers can point to such success. All those who worked with Hollister were not working for him but with him; he had the ability to motivate with confidence, and his credibility was 100 percent. . . . Specification 534 was just the beginning. From that point forward, Hollister. . . was not involved in "routine" design, but instead almost always in innovative design and improvements.

Hollister's enthusiasm and willingness to tackle any problem were captured in this photograph taken in the fall of 1917 at Purdue University, where he was performing tests for the Corrugated Bar Company. At this time, at the age of twenty-six, he was taking trips to Washington to discuss the wartime emergency concrete-ship program, for which he was to serve as chief designer.

SOME DETAILS OF A FULL AND VARIED CAREER

How did Hollister develop his potential for innovation in both practice and education? The papers prepared for the colloquium—largely by Cornell colleagues—illuminate the process. The basic biographical chronology only outlines and sketchily documents it. But the essential facts are these:

Hollister was born in 1891 in Crystal Falls, Michigan, the only son in a family of five children. His father became a lumberman in the Northwest, and Hollister grew up in the state of Washington.

He was educated at Washington State College, in Pullman, and at the University of Wisconsin, where he earned the B.S. degree in civil engineering in 1916. Some years later—in 1932—he received the professional degree of Civil Engineer from Wisconsin. (His thesis was titled, "A Method of Wind-Stress Determination in Tall Buildings"; almost forty years later, he did an evaluation of wind forces on tall buildings that was tested last year in Denver.)

He met his wife, Ada, during his undergraduate years at Wisconsin; she was an arts major in the same class. They were married in 1919 (their sixty-first wedding anniversary was the day of the Hollister Colloquium) and reared a family of four.

Hollister began his professional activities before he had graduated from college. He worked as a surveyor for municipal projects in Portland, Oregon, and on transmission-line surveys through rugged terrain along the Columbia River before transferring to Wisconsin. Work he did for engineering consulting firms in Portland included designs for a dike to protect Puget Island, an automatic municipal lighting system, an underground reservoir, and a 100-foot pony-train highway bridge.

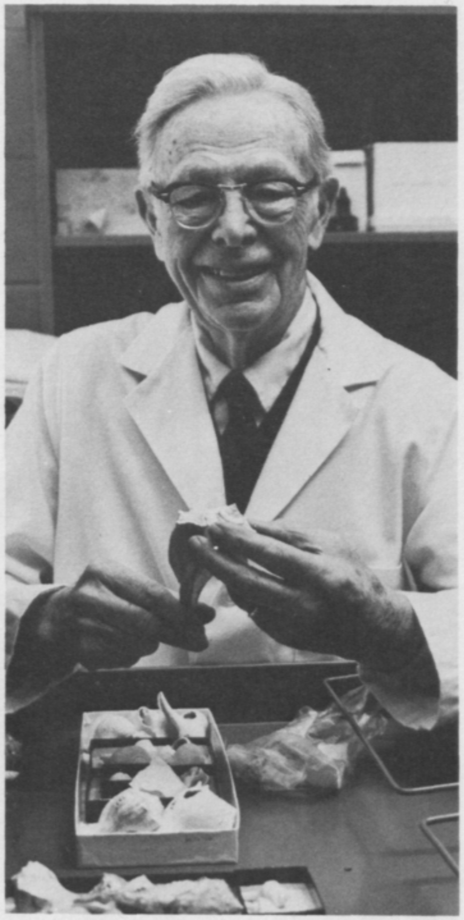
After graduating from Wisconsin and before undertaking the World War I concrete ship design assignment (described in one of the colloquium papers), Hollister worked as an engineer at McClintock and Marshall in Pittsburgh, and monitored concrete-slab tests at Purdue University. His professional practice in Philadelphia after the war, particularly his design of bridges in Delaware County, is also described in a colloquium paper. In 1930 Hollister joined the faculty at Purdue and in 1934 he came to Cornell as professor and director of the School of Civil Engineering (on the condition that he be allowed to complete work on the Hoover Dam penstocks). He became associate dean and then, in 1937, dean of the College of Engineering, a position he held until his academic retirement in 1959. He continued to serve the University as a trustee until 1964.

Throughout his career, Hollister has maintained a consulting practice and participated in the activities of professional societies. He joined the ACI during his early years in Philadelphia and served as president of that society in 1932-33. He was also active in the American Society of Civil Engineers (ASCE), the American Society for Engineering Education (ASEE)—which he served as president in 1951-52—and the Engineers' Council for Professional Development. He was a found-

Left: Hollister was president of the American Concrete Institute in 1921-33.

Left below: In 1959, the year he retired as dean of the College of Engineering, Hollister was honored by the dedication of the new civil engineering building as Hollister Hall.

Right: A long-standing interest of Hollister's is paleontology. He has worked especially on the classification of two genera of fossil shells; he published a monograph on living species in 1958 and is currently preparing another paper on extinct species.



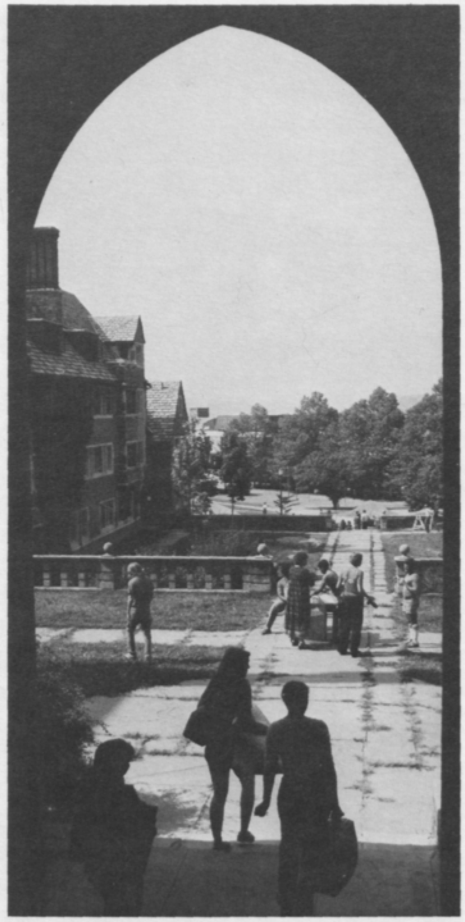
ing member of the Engineering Manpower Commission of the Engineers' Joint Council. He is a fellow of the American Association for the Advancement of Science and an honorary member of a half-dozen other professional societies. In addition, he served on numerous government commissions and advisory committees, including the Second Hoover Commission on the Reorganization of the Federal Government.

A TIME FOR HONORS AND CONTINUING WORK

Awards he has received include the Wason Research Medal of the ACI, the Lamme Medal of the ASEE, and the Henry C. Turner Medal of the ACI (awarded in 1979). Hollister Hall on the Cornell campus was named in his honor, and he received the Cornell Engineering Award on the occasion of the college's centennial. He was elected to the National Academy of Engineering and named to the 75th Anniversary American Hall of Fame of the ASEE. Although he never earned a doctorate in a formal program, he has received honorary degrees from four institutions: Stevens, Wisconsin, Lehigh, and Purdue.

Today, at the age of eighty-nine, Hollister is still active as a consultant and frequently shows up at Hollister Hall to confer with students and faculty members on research and design problems, or to discuss the future of engineering education. The educational criterion, he says, is that engineers must learn what they need to know to be able to make things work. He should know. —G. McC.

Freshmen Take Over During Orientation Week



■ Cornell freshmen got a head start on their college experience by arriving on campus in late August for a special orientation program. They (and their parents) were met by a contingent of four hundred student orientation counselors and welcomed at the President's Convocation. Serious matters such as placement tests and registration took up part of the week, but there was also a full program of special events, including a barbeque, the New Student Offbeat Olympics, and musical entertainment at Cornell Night.

FACULTY PUBLICATIONS

The following publications and conference papers by faculty and staff members and graduate students at the Cornell University College of Engineering were published or presented during the period March through May 1980. Earlier entries inadvertently omitted from previous listings are included here in parentheses. The names of Cornell personnel are in italics.

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LETTERS

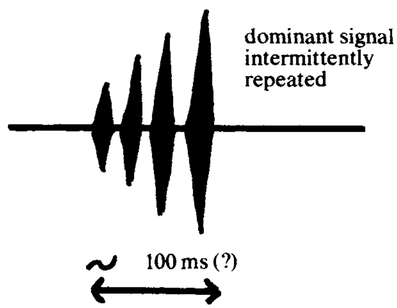
Sound and the Science of Listening

Editor: You will be interested in the enclosed letter from Dr. Pollock, and his letter to Ronald R. Hoy.

Y.-H. Pao
Department of Theoretical and Applied Mechanics
Cornell University
Ithaca, N.Y.

Dear Professor Pao: I much enjoyed your article in *Engineering: Cornell Quarterly,* and I thought that the Quarterly itself was an unusually well conceived and well produced publication. Another article in the same issue led to an unexpected diversion into another area of study, as described in the attached letter which might amuse you.

Dear Professor Hoy: I was interested by the description of your work which appeared in *Engineering: Cornell Quarterly* 14(4), 1980, and when a cricket strayed into my office yesterday and started chirping, I could not resist the temptation to take a look at the sounds on an oscilloscope and see how they compared with Figure 6 of the article. I passed the sounds through a crystal microphone and a 20-kHz high-pass acoustic emission preamplifer and signal conditioner to an oscilloscope. I was interested to see that although the cricket looked superficially similar to your *Telegryllus oceanicus,* the dominant signal was distinctly different from the one shown in the article, consisting of a train of three or four pulses of definitely increasing amplitude. Unfortunately, in the limited time available, we could not get a photograph or transient recording of the signal, but I am making a rough sketch below in case you are interested. I conjecture we may be dealing with an inter-species difference and it is interesting to try to imagine how the receptor neurons would be differently wired to respond to the different signal characteristics.



Adrian A. Pollock
Director of Research and Application
Dunegan/Endevco
San Juan Capistrano, Calif.

Noise: the Fourth Pollutant

Editor: When this issue of the Cornell Quarterly arrived, I read it with more than my usual avidity because industrial noise control has been my endeavor for the past eleven years. It has been a fascinating and rewarding experience. . . . I would be grateful if you could provide us with fifteen additional copies.

Frank Ptacek, ME '35
William Paul Company
Philadelphia, Pa.

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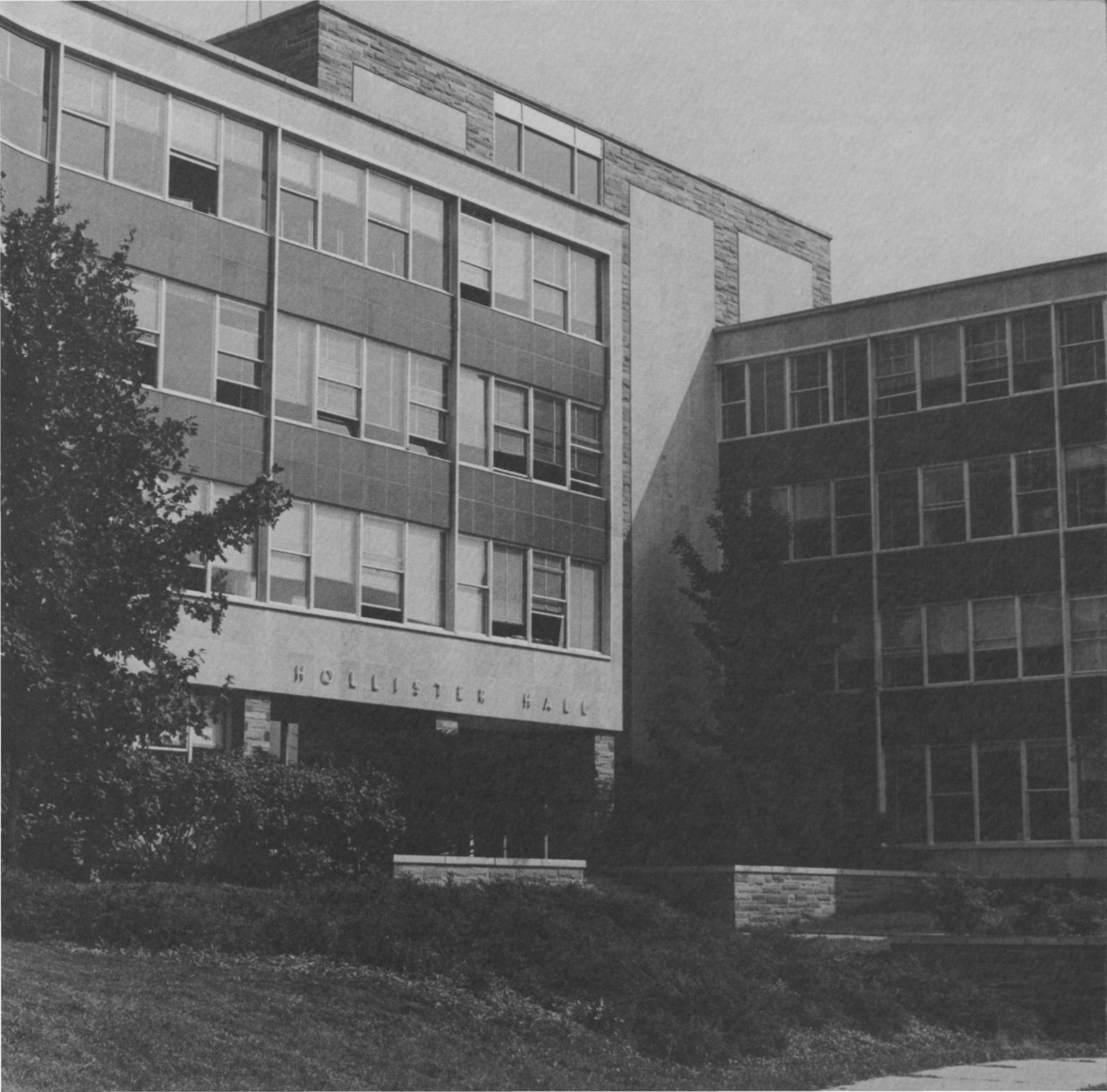
Opposite: Hollister Hall, home of Cornell's School of Civil and Environmental Engineering, was designed under the supervision of Dean S. C. Hollister and was named in his honor upon its completion in 1959. Hollister served as director of the School of Civil Engineering from 1934 to 1937 and as dean of the College of Engineering from 1937 to 1959. The building was one of ten constructed as part of Hollister's program to provide an entire new facility for the College. Hollister Hall was given by Spencer T. Olin '21 in memory of his father, Franklin W. Olin '86.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