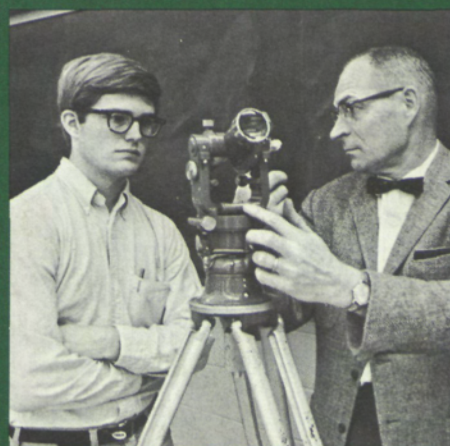
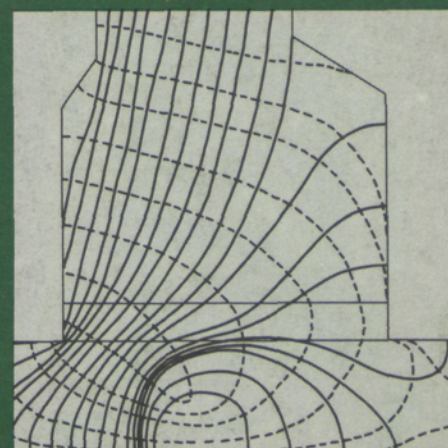
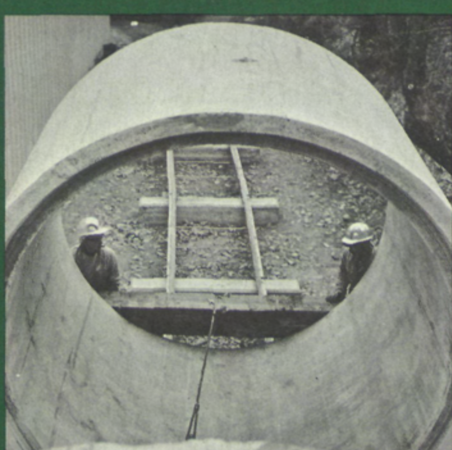
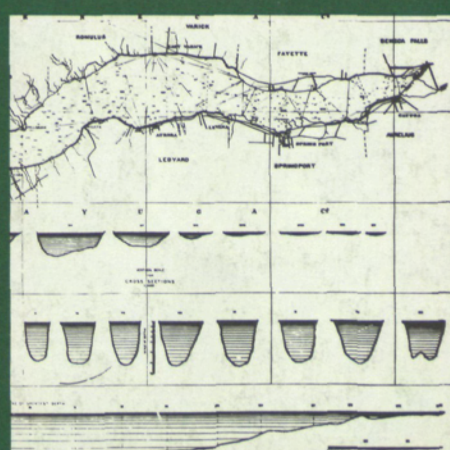
ENGINEERING

CORNELL QUARTERLY









VOLUME 2

SPRING 1967

IMPROVING
MAN'S
ENVIRONMENT

IN THIS ISSUE

ENGINEERING: Cornell Quarterly, Spring 1967, Vol. 2, No. 1. Published four times a year, in Spring, Summer, Autumn, and Winter, by the College of Engineering, Cornell University, Carpenter Hall, Campus Road, Ithaca, New York 14850. Second Class postage paid at Ithaca, New York. Subscription rate: $2.50 per year.

Opposite: Named "The Outstanding Civil Engineering Achievement for 1967" in a national competition held by the American Society of Civil Engineers, the Gateway Arch, major feature of the Jefferson National Expansion Memorial, St. Louis, Missouri, frames The Old Courthouse.

ENGINEERING FOR HUMAN NEEDS

By William McGuire

One morning last summer, a faculty colleague was grumbling about an incident of the previous afternoon. Apparently he had been matched against a summer visitor in a local golf tournament. After introducing himself to the visitor, mentioning that he taught civil engineering, he heard his opponent say, "Oh, I've always been curious about civil engineering; just what is it?" Naiveté or gamesmanship? "What is civil engineering?"—no question is more unnerving to a civil engineer, for there is no clear answer. Asking it had its effect here; my colleague didn't win a hole.

The expression "civil engineer" goes back to 1750 when John Smeaton, a British engineer, wished to distinguish his *civilian* construction work from that of the *military* engineer; this distinction, however, is of little use in explaining our contemporary activities.

Perhaps the oldest of the definitions of "civil engineering" is Thomas Tredgold's, prepared for the Institution of Civil Engineers of London in 1827:

> . . . the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters and lighthouses, and in the art of navigation by artificial power for purposes of commerce, and in the construction and application of machinery, and in the drainage of cities and towns.

Substituting modern works for those of the eighteenth century, adding *science* to the *art,* and recognizing the emergence of other engineering fields, such as mechanical engineering, that did not exist in 1827—the durability of Tredgold's statement is evident.

A contemporary theme for civil engineering proposed by J. B. Wilbur, former head of civil engineering at the Massachussetts Institute of Technology, is "the fulfillment of human needs through adaptation and control of the land-water-air environment." Or, as A. J. Fox, editor of *Engineering News-Record,* has observed, "Engineers concern themselves mostly with products. Products are produced only five ways. They are grown, mined, generated, manufactured, or constructed. The civil engineer is that engineer who is concerned basically with the constructed product."

Each of these two views is valid. Yet, they do not depict the full sweep of human endeavor which constitutes civil engineering today. I prefer to side with one of my more pragmatic associates who is indifferent to the definition game. "Civil engineering," he says, "is what a civil engineer does. We know what it is even if it can't be defined adequately, and anyway, we are too busy doing it and enjoying it to worry about defining it."

Let me approach it his way by considering some examples of what civil engineers are doing. Then, perhaps, the scope of the profession and its impact on society will be apparent. I'll be pleased rather than embarrassed if a sense of awe shows through. The combination of intellectual effort and physical activity applied on a large scale to produce some of the greatest works of our time is, to me, worthy of awe. While I've selected illustrations of major professional undertakings, there are thousands of smaller projects which are of comparable challenge, and which have an equal or greater cumulative significance.

THE INTERSTATE HIGHWAY SYSTEM

The drama of construction has always captured the public imagination. Almost all civil engineering projects terminate in or involve some act of construction. While construction itself is only part of our role, there are many different types of construction activity, each receiving varying degrees of public attention and understanding. Even the most casual urbanite is certainly aware of the current building boom that is transforming his city. Whether Americans are equally aware of the ultimate significance of the present national highway construction program, publicity and travel not withstanding, I am not so sure.

Started in the late 1950's, the Interstate Highway System is scheduled for completion in 1975. Fifty-five billion dollars will produce 40,000 miles of superhighways connecting all of our major cities.

Interstate Route 80 is, perhaps, the most spectacular highway in the system. A clear road 2,900 miles long and stretching from the Hudson River to San Francisco Bay, Interstate 80 will pass near or through Cleveland, Chicago, Omaha, Salt Lake City, and Reno. It is about as straight as an east-west road can be, lying within a few miles of the forty-first parallel from New York to central Nevada, where it dips south to cross the Sierra Nevadas via the Donner Pass. And in its path every type of construction condition has been encountered: urban and rural, flat and mountainous, arid and swampy.

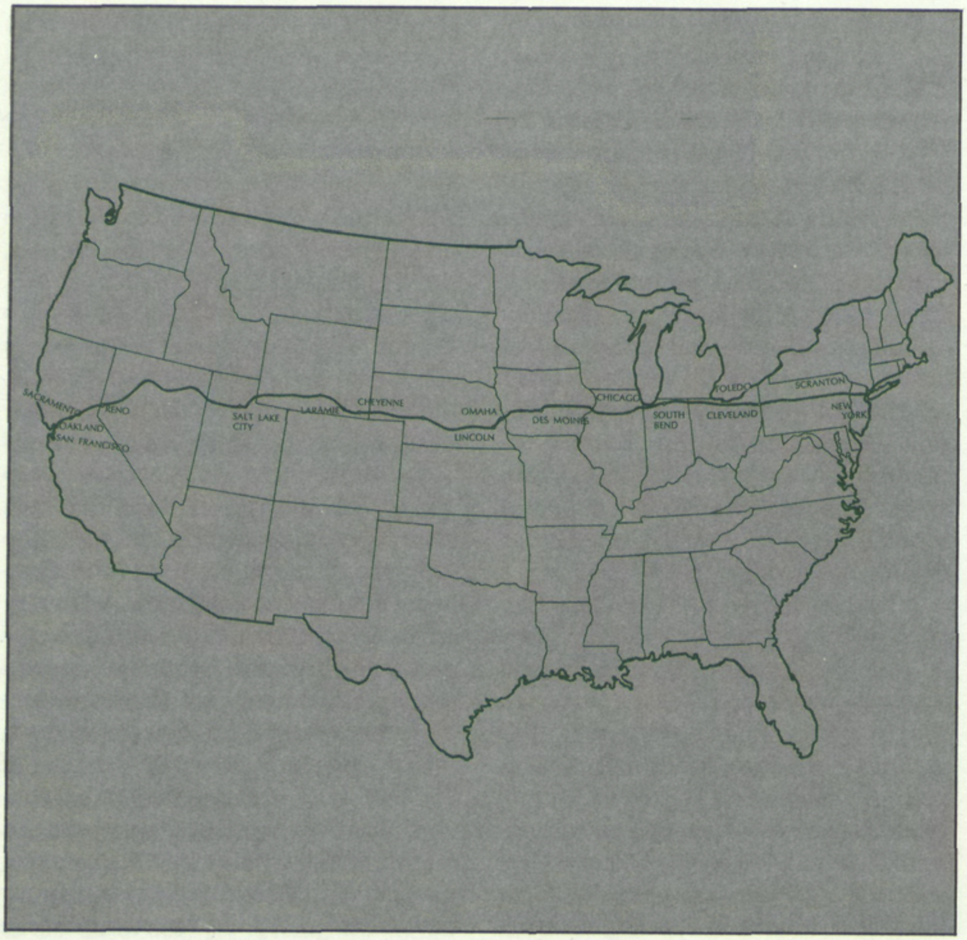
Surprisingly, one of the most difficult stretches of Interstate 80, from the standpoint of pioneering construction, was in the East rather than in the West. This is the section from Stroudsburg to Sharon in Pennsylvania, where there are mountains or hills most of the way. The chief difficulty is that the highway cuts diagonally across the corrugated ridges of the upper Appalachians. Deep rock cuts, some more than 200 feet deep, and enormous fills are needed to meet the standards for grades and alignment of a modern high-speed road.

Aside from the coal mining in the eastern half of the 350-mile strip, and some scattered industry, this north-central Pennsylvania region has never been fully developed, primarily because of its forbidding terrain. How much impact the new road will have on the region is not yet clear. At a minimum, though, it will be a shot-in-the-arm for the economically depressed anthracite

Opposite:

1. *A student, assisted by George B. Lyon, associate professor of civil engineering, obtains surveying instruction in the freshman seminar program.*
2. *William L. Hewitt, associate professor of civil engineering, and a student discuss a compression test in a laboratory fully equipped for testing asphaltic mixes.*

Below: Interstate 80, the major east-west link in the Interstate Highway System, represented a variety of large-scale road building problems.



region. Improved truck transportation to the Atlantic seaboard should attract industry to the area to take advantage of the available labor force. Interstate 80 may well be the catalyst to transform the whole northern half of Pennsylvania.

THE CHICAGO METROPOLITAN SANITARY DISTRICT

Sanitary engineering is both inside and outside of civil engineering. Its scientific fringes are in the realms of chemistry and biology. And yet, water and waste treatment systems are usually planned, designed, constructed, and managed by civil engineers.

Technologically, one of the greatest challenges to the sanitary engineer has been the waste disposal problem of greater Chicago, and it is there that he has scored one of his greatest successes.

Chicago has always drawn its water from Lake Michigan. By the late nineteenth century, most of its sewage was being returned, untreated, to the lake through the Chicago River. To correct the serious contamination which resulted, a drainage canal was constructed

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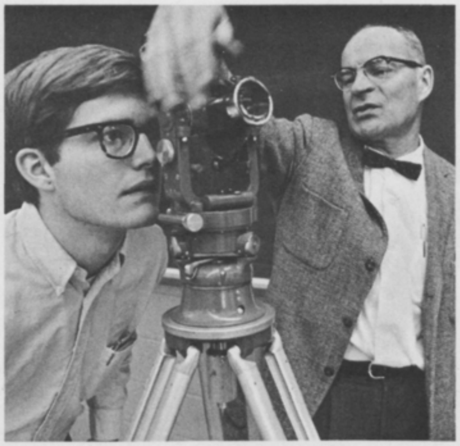

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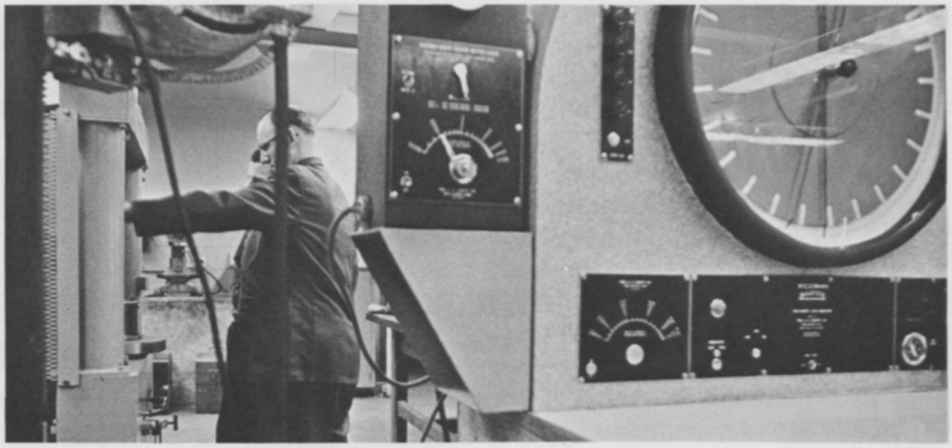


connecting the Chicago River to the Illinois River, a tributary of the Mississippi. When the canal was completed around 1900, the flow of the Chicago River was reversed, and the city's immediate problem was solved. Shortly, however, the Illinois River became polluted. Also, the canal drew off an amount of Lake Michigan's water that eventually proved unacceptable because of the growing demand for the power generated hydraulically at Niagara Falls. In the late 1930's, the city of Chicago constructed plants for the complete treatment of all of its sewage and greatly reduced the amount of water diverted from Lake Michigan through the gates at the mouth of the Chicago River.

One of the Chicago plants is the largest of its kind in the world. It treats almost a billion gallons of sewage a day using highly sophisticated, automatically controlled mechanical and biological processes. Its managing body, the Metropolitan Sanitary District (MSD), is responsible for protecting the water quality of Lake Michigan and for assuring that the effluent discharged to the drainage canal is acceptable. The MSD has jurisdiction over most of Cook County, 848 square miles of a highly urbanized and industrialized area. The total capital investment in this project has been about $625 million; another $700 million will be needed between now and the year 2000 to meet minimum demands. The latter figure may well run to $1.7 billion if problems such as flooding and storm water overflow are to be solved.

The technological achievements of the MSD have been marred by some of the greatest scandals in the history of American public administration. How this situation is being corrected brings to mind the managerial role of the civil engineer. In this instance, Mr. Vinton Bacon, a civil engineer, was appointed general manager in 1962 with the charge of restoring orderly, honest management to a corrupt enterprise. Mr. Bacon still has problems, but one measure of his effectiveness to date is this: the annual operating budget has been reduced from $78 million to $67 million, while all necessary services have been maintained.

THE CALIFORNIA STATE WATER PROJECT

While Chicago's major problem is getting rid of its waste water, California's is to supply fresh water to the right place at the right time.

Southern California is an arid region. Its annual rainfall is about 15 inches; it has lots of sun and consequently lots of people. It has about 2 percent of California's fresh water, but some 60 percent of the state's population.

As a result, Southern California has long had to reach out to other regions to meet its water needs. In 1913, Los Angeles completed a 250-mile aqueduct to draw 300 million gallons a day from the Owens Valley region. In 1939, another aqueduct was built almost an equal distance to the Colorado River. By a decision of the United States Supreme Court, the city is presently limited to a draft of approximately 500 million gallons a day from this latter source. To compound the problem, California's population is expected to have tripled by the year 2020; water demand will increase 60 percent and the electric power demand, tenfold.

The Department of Geotechnical Engineering conducts research studies on soils behavior including the use of electric current for soil stabilization. Here a student adjusts the traxial soil testing apparatus before testing a special soil sample.

To meet its water needs of the next fifty years, California has embarked on a breathtaking venture. The State Water Project, as it is called, will collect water in the richly endowed Sierra Nevadas in the northern part of the state and transport it to the south. Water supply to the San Francisco Bay area, flood control, power generation, and the creation of recreational areas are also included in the project. Present plans call for the construction of 17 dams, 676 miles of aqueduct and pipeline, 9 power plants, and 18 pumping plants. Cost estimates have run as high as $15 billion.

One of the major storage works, the Oroville Dam on the Feather River, was begun in 1962 and will be completed this year. A mile-long earth fill dam, it has an embankment 770 feet high, making it the highest dam of its kind in the world. The total volume is 80 million cubic yards, the equivalent of twenty-five Great Pyramids.

The layman is apt to think of an earth fill dam as just a pile of dirt. Actually, an earth fill dam is as carefully designed and built as any structure. The central core is constructed of a fine soil carefully tamped in place so as to be as nearly impervious as possible. Since some seepage is inevitable, it must be controlled by bounding the central core with a more coarsely graded drainage layer. Other interior layers are required for over-all stability and strength, and, finally, the exposed areas must be paved with rock. Also, allowance must be made for the vagaries of the natural material where only a limited amount of refinement is practicable. All in all, the combined talents of the structural engineer, the geologist, the hydraulic engineer, the soil mechanics engineer, and the construction man are required to design and construct a sound earth fill dam.

Another link in the State Water Project is the California Aqueduct, a huge concrete lined open canal which will run 444 miles from the San Francisco Bay region to a spot just east of Los Angeles. Among the many technical problems that will be encountered is the design and construction of a crossing in which as much as 4,100 cubic feet of water per second will be pumped from the floor of the San Joaquin Valley over the Tehachapi Mountains, a vertical lift of nearly 2,000 feet. To get some feeling for the magnitude of 4,100 cfs, it is about one-fifth of the average discharge of the Hudson River. Then, too, the Tehachapi crossing traverses the Garlock and San Andreas geologic faults. Since earthquakes are almost a certainty in this region, the Aqueduct must be designed to remain operable in the event of a quake.

THE ST. LOUIS ARCH

Just as some see the civil engineer as a constructor, others think of him as a structural engineer: the designer of bridges and buildings. But structural engineering embraces much more than bridges and buildings; within its purview is just about everything that is called upon to resist loads and forces—transmission towers, pressure vessels, penstocks, containment vessels, tunnels, and ship hulls. While mechanical engineers do most of the design of machine elements, it is to the civil engineering schools that the aircraft and aerospace industries turn for their structures specialists.

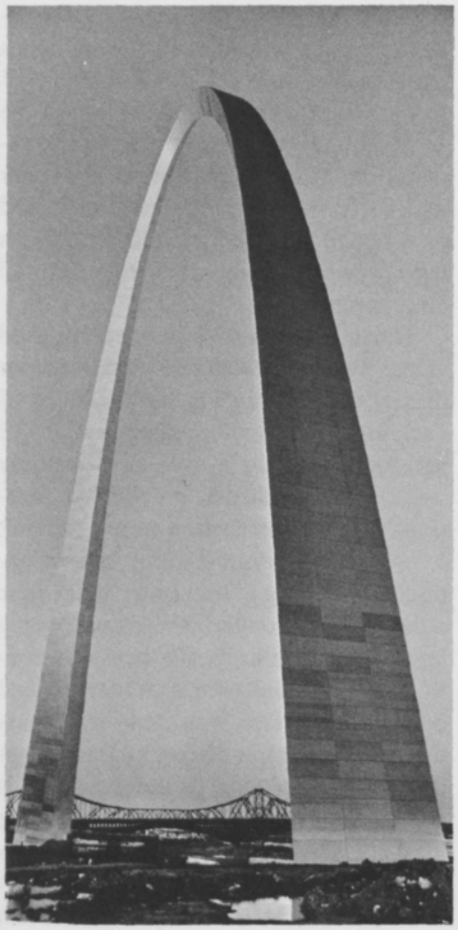
One of the most interesting recent structural accomplishments is not a functional device at all, it is a monument: the St. Louis Gateway Arch. Located on the west bank of the Mississippi in downtown St. Louis, it commemorates the Louisiana Purchase and symbolizes St. Louis' historic role as the gateway to the West. Perhaps more importantly, the Arch symbolizes the spirit of hope and dignity of a reborn city.

The beauty of the Arch is its simplicity. Proportioned by the late architect, Eero Saarinen, it is a stainless steel inverted catenary, 630 feet wide and 630 feet high. The legs are triangular in cross-section and taper down from 54 feet on a side at the base to 17 feet at the crown. The hollow legs of the Arch are of cellular, double-wall construction. The spaces between the inner and outer walls are concrete filled and prestressed for the first 300 feet. Each leg springs from massive underground abutments.

The construction was accomplished using two one-hundred ton creeper derricks that, crawling up the sides of each leg, erected succeeding sections of the Arch and their own rails as they went. Careful checks on the leg positions during construction were essential; to avoid the complications of sun-induced inflections, surveying was done at night. To convert the cantilevering legs into a true arch, the keystone section was inserted with a predetermined compression. This was done by prying the two legs from two feet apart to eight and a half feet apart at the top. At this point, the properly tailored keystone was inserted and the pressure was released from two 300-ton jacks.

A monument is hardly a monument

"Society has a heavy stake in civil engineering."



if it looks like somebody's old washboard. The design had to consider how the stainless steel skin would avoid wrinkling, either permanently during welding or transiently under changing intensity of sunlight. Wind loading and the vibration characteristics of this unusual structure also had to be carefully considered.

CHARACTERISTICS OF PRESENT DAY CIVIL ENGINEERING

Out of this sampling of projects, some impression of modern civil engineering can be formed. Through these examples we can sense the link to the tradition of Smeaton and Tredgold. At the same time, I hope it is clear that there is a world of difference, both in diversity and complexity, between these twentieth century works and those of the eighteenth and nineteenth centuries.

To say that each of my illustrations is purely a civil engineering creation would be a blatant exaggeration. In each, a great or lesser share of credit belongs to businessmen, politicians, industrialists, architects, scientists, and other engineers. The key point is, however, that the major burden of planning, design, construction and, in many cases, management, has been and is being borne by civil engineers.

The diversity of civil engineering works which I have already mentioned requires men of diverse skills. We have, for example, civil engineering generalists who can coordinate and direct complex projects because of their broad understanding of several areas of the profession. On the other hand, the profession requires that anyone desiring to be a true expert can be one over only a limited range of the spectrum. Sanitary engineering and structural engineering, for example, have distinctly different scientific bases, and a mastery of the technology of either is a significant achievement—all that one man can hope for in a lifetime. For most of us, specialization within civil engineering is inevitable and necessary if we are to make a distinct and worthwhile contribution to the whole.

The other common characteristics of current projects is the trend toward bigness or complexity. There are still many small projects involving only one

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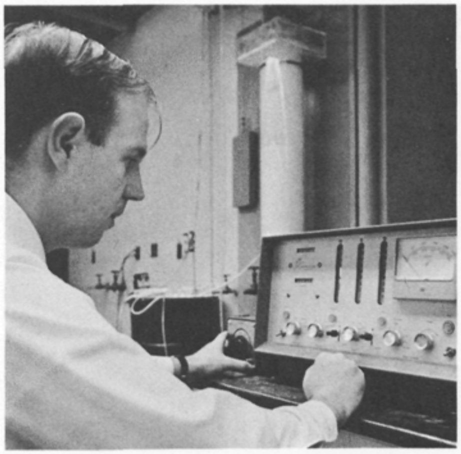

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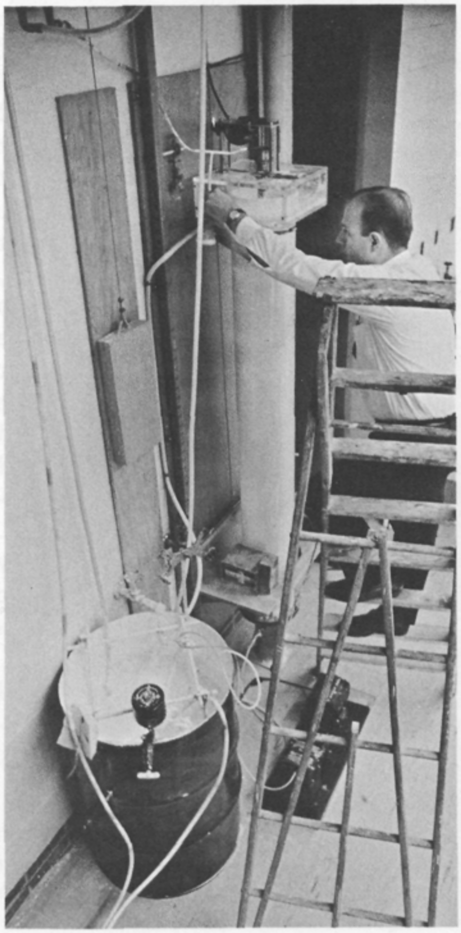


Opposite: The St. Louis Gateway Arch with the Eads Bridge in the background.

Left: The use of radiological measuring techniques to determine variations in density in a column of calcium carbonate slurry, a simulator of sludge.

1. The scintillation counter.

2. Adjusting the slurry feed rate into the columns.

or a few engineers, but nevertheless, we are moving in the direction of larger undertakings—projects that involve more money, more land, and more people.

One clear feature of today's projects is the speed with which new technology is incorporated. A California Aqueduct is not built as the Erie Canal was—with picks and shovels and Irishmen. While the Irish endure, they have new "picks" and "shovels," huge semiautomatic and fully automatic equipment for excavating, grading, and paving. Similarly, the alignment of Interstate 80 is not controlled with the surveying instruments of a hundred years ago or even of ten years ago. Geodimeters, electronic instruments employing principles similar to those of radar, are used for precise measurements over long distances. Lasers are entering the same field. Survey notes are processed immediately for electronic computer interpretation.

The electronic computer itself has long since lost its novelty in the civil engineering office or on the job site. Its use ranges from systems planning, structural analysis, bridge design, data interpretation and processing, and plant control to the logistical problems of regulating the flow of equipment and material on construction projects.

By far the *most significant characteristic* of the output of civil engineers today is its influence on society. While I may have selected as my illustrations projects financed by public funds for which some public return is clearly intended, many, perhaps most engineering projects are privately financed. And most of these, too, have at least an indirect effect on our daily lives. Society has a heavy stake in civil engineering.

If we civil engineers influence society, it is fair to inquire as to our sense of social responsibility. Here, I think, we deserve credit for being more conscious of our mission than just about any other segment of technology. This does not mean that what we have done has always resulted in an improvement of the human condition. Thoreau once said, "We are in great haste to construct a magnetic telegraph from Maine to Texas; but Maine and Texas, it may be, have nothing important to communicate." None of us is wise enough to predict whether Maine and Texas—or New York and California—will have anything to "say" to each other.

Since I have been asserting civil engineering's share of the credit for man's successes in his encounter with the environment, we need to be reminded of those areas of our responsibility where the struggle continues. We cannot, for instance, feel complacent about driving smoothly from the Atlantic to the Pacific until we can resolve the transporation problems of our cities. Chicago's water supply is pure, but its air is filthy. Southern California is assured of adequate water for the next fifty years, but after that, what? The spirit of the St. Louis Arch will not be fulfilled until all of the people of the city are adequately housed. It is in problems such as these that much of the future challenge to civil engineering will rest.

THE FUTURE

Many of our tasks are cut out for us. The quest for water will continue, not only in Southern California, but throughout the country. Water use planning will be done on a regional rather than a local basis. Importation of water from Canada will have to be considered. Desalinization of sea water and reuse of treated waste water will receive increasing attention.

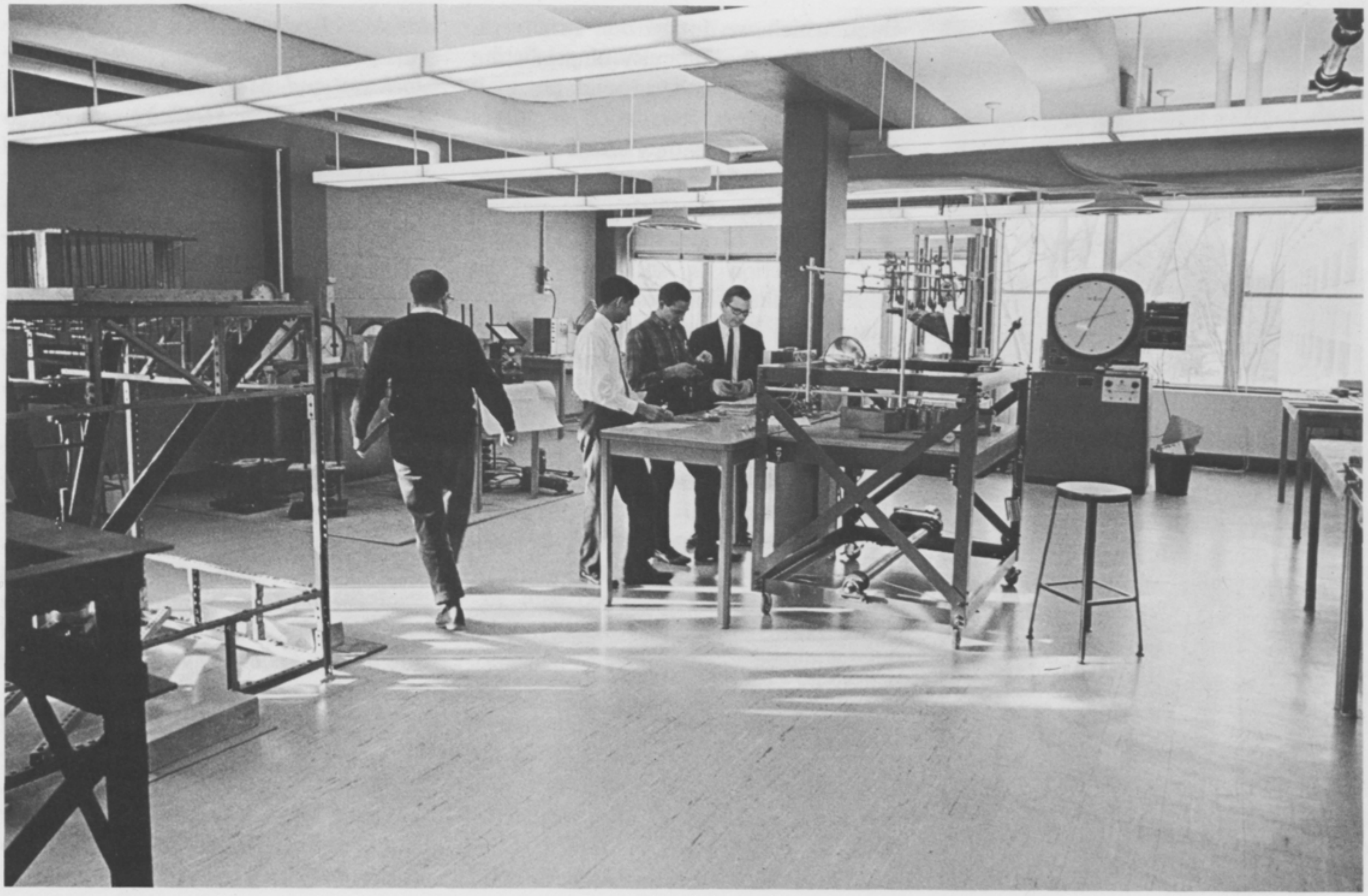
Techniques of systems analysis must be brought to bear on our transporation problems if we are to stand any chance of reducing the congestion that is strangling our cities. It is apparent that such techniques—spawned in mathematics and operations research—must be adapted and then applied by civil engineers.

In structures, the thrust will be in several directions. The development of new structural forms and materials will continue. Methods of analyzing and proportioning structures will be further refined. For instance, at the present time, the steel or reinforced concrete frame in a building is designed to resist all of the load. In some cases it may, in actuality, receive considerable help from its cladding and infilling—the walls, floors, or stairwells. The manner in which such elements can participate in load sharing is just beginning to lend itself to reliable analysis. Mathematical techniques for optimizing the proportions of structures will be developed. The margin of safety of structures may eventually be calculated on a realistic probabalistic basis rather than on a stress or load ratio basis as it is today.

One of the greatest problems in civil engineering construction is the perversity of the behavior of the soil and rock

Professor Richard N. White and students in the structural models laboratory where special configurations are pretested before being used in large-scale facilities.

"...specialization within civil engineering is inevitable and necessary if we are to make a distinct and worthwhile contribution to the whole."



Hollister Hall, named in honor of S. C. Hollister, Dean of Engineering at Cornell from 1937 to 1959, houses the facilities of the School of Civil Engineering.

upon which we found our structures. Considering the difficulty of predicting precisely what is underground, one may well wonder how foundation engineers are as successful as they are. To reduce the incidence of failure and to find more effective ways of utilizing the natural soil is another of our greatest challenges.

Construction is still one of the most speculative businesses in existence. Lump sum bidding on large complex jobs requires that more scientific bidding techniques be developed. Further, more precise methods of job control must be instituted. Developments of this sort in construction management are sure to come.

In the following articles my colleagues examine more closely some of the problems just reviewed and explore the stimulating opportunities ahead in civil engineering.

William McGuire is the Director of the School of Civil Engineering in Cornell's College of Engineering. He received his B.S.C.E. degree from Bucknell University in 1942, and in 1947 he received his M.C.E. degree from Cornell. After two years as a structural designer for Jackson and Moreland, Engineers in Boston, Professor McGuire returned to Cornell as a professor of structural engineering, teaching structural theory; steel, timber, and reinforced concrete design; and foundations. He became Director of the School in 1966.

In addition to teaching, Professor McGuire has done independent consulting on such projects as the Museum of Modern Art in New York, the Enrico Fermi Reactor Plant in Monroe, Michigan, and Cornell's Arecibo Ionospheric Observatory in Puerto Rico. He is the author of several articles and books in the field of structural engineering, and in 1962 was the co-winner with Professor Gordon Fisher of the Norman Medal of the American Society of Civil Engineers, for a paper on containment studies for an atomic power plant.

Professor McGuire is a member of the American Society of Civil Engineers, the American Concrete Institute, the International Association for Bridge and Structural Engineering, Chi Epsilon, and Sigma Xi.

NEW CONCEPT IN NUCLEAR REACTOR HOUSING

By Richard N. White

Nearly all engineered facilities either need a supporting or enclosing structure or are structures in themselves. The bridges and subways for transportation, the locks, dams, and water supply facilities for water resources utilization, the industrial and metropolitan buildings we live and work in, the jetports, the spacecraft and space centers, the auditoriums, and the hundreds of other constructed facilities that we take for granted—all have one very important common denominator, that of a load-carrying engineered structure.

Structural engineering, and structural design in particular, is a combination of science and art requiring a successful merger of materials, mechanics, and geometry. While the Verrazano Narrows Bridge or the St. Louis Arch are spectacular examples of one-of-a-kind designs perfected by structural engineers, they also serve to illustrate that the necessity for uniqueness in design is a situation which is faced daily by structural designers and by other civil engineers. These engineers must "solve" a structural design problem without the benefit of building a laboratory prototype and testing performance. Sophisticated analysis techniques using digital computers must be supplemented by an intimate knowledge of structural behavior to arrive at the best possible structure. Public safety and economics are paramount considerations in the design process. There is no second chance!

THE STRUCTURAL ENGINEER AND NUCLEAR ENERGY

A good illustration of how the structural engineer aids in providing for human needs is furnished by his satisfying of the new structural requirements in nuclear power generation. An almost exponential rise in the demand for power has led to great increases in generation by nuclear reactors. Although a case may be made for using nuclear energy to generate power because it does not add to air pollution (as Dr. Edward Teller maintains), economics alone provides the strongest argument for using it. During the first nine months of 1966, for example, more generating capacity was ordered in new nuclear plants than in conventional or fossil fuel plants. Twenty-one nuclear central power station generating units were ordered in 1966; at present, a total of thirty-four such units are either under construction or in a signed-contract phase in the United States. Utility companies are commited to providing at least another six units. A projection of *installed* nuclear power capacity is: by 1970, 11,000 Mwe; by 1980, 95,000 Mwe; and by the year 2000, 734,000 Mwe.

Preliminary work on the Browns Ferry Nuclear Plant, to be constructed by the Tennessee Valley Authority on the Tennessee River near Decatur, Alabama, showed that in this particular location a nuclear-powered plant would cost twenty percent less to operate than a coal-fired plant. Rated capacity for this $250 million plant will be 2,304,000 kw, placing it on a power generating scale with the Grand Coulee in Washington State. Today, this power output is adequate for a city of two million people. The building of large-scale nuclear power plants leads to one conclusion: nuclear power has arrived. With it, however, there has come a host of engineering problems ranging from the application of nuclear physics to the

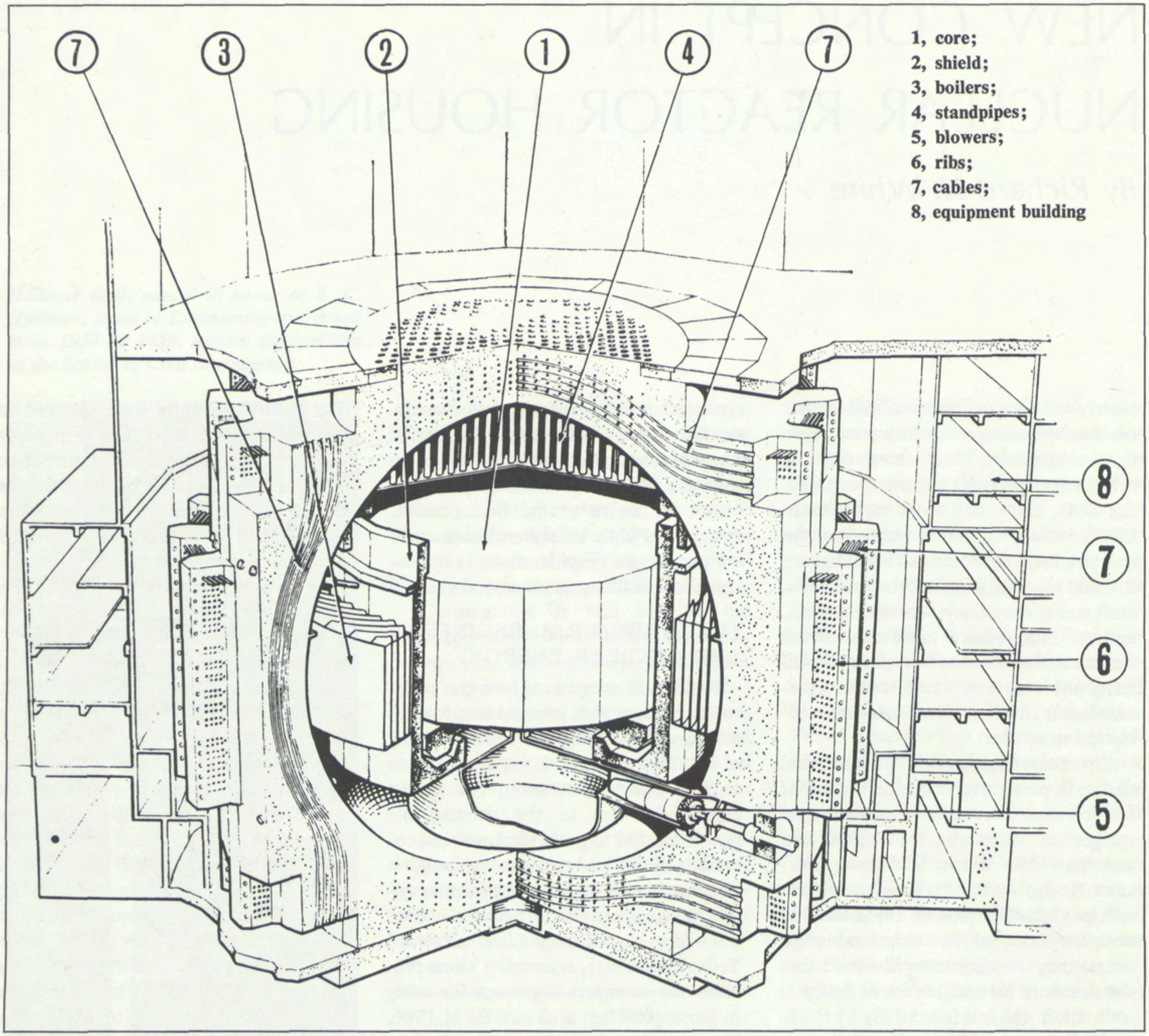
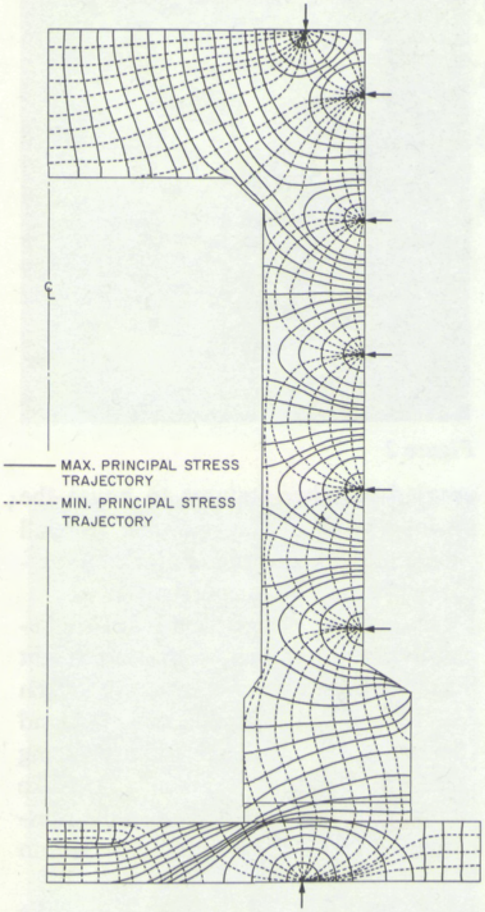


Figure 1. The Wylfa Prestressed Concrete Reactor Vessel. Photo courtesy of Taylor Woodrow Construction Limited, Middlesex, England.



A schematic model of the stress patterns set up in the PCRV showing the effects of force points using the proposed prestressed configuration.

construction and operation of nuclear generators.

The structural problems associated with housing a reactor are critical. Absolute containment of radiation is the prime requirement; there can be no margin of error in engineering a reactor structure. A high-temperature, high-pressure, radioactive process must be safely and economically contained over a long period of time, and this requires the construction of a rather large and expensive pressure vessel, usually cylindrical or spherical in shape.

As reactors increase in size, and particularly as large volume, gas-cooled reactors become more attractive for generating power, the use of conventional steel pressure vessels becomes unrealistic. Large volume requirements and/or high operating pressures, may call for wall thicknesses of ten inches or more in steel vessels; yet to field fabricate steel plates of more than about five inches is not feasible.

PRESTRESSED CONCRETE REACTOR VESSELS

A new concept for reactor pressure vessels was developed for a number of low-power-density, gas-cooled reactors by the British and the French in the early 1960's. It makes use of concrete vessels precompressed by locking in high compression forces during construction. Termed "prestressed concrete reactor vessel" or "PCRV," the structure is prestressed with hundreds of high-strength steel cables. By itself, concrete in tension is weak and certainly not suited for containing a large volume under high pressure. However, concrete can be utilized effectively in a PCRV because the steel cables always hold it in compression. Internal pressurization merely reduces the amount of precompression afforded by the prestressing steel. As long as the concrete does not go into tension, which the steel cables within the concrete prevent, the structure remains sound and tight. Concrete wall thicknesses of from ten to fifteen feet provide adequate radiation shielding. This thickness also protects against internal "missile" penetration of vessel walls should a malfunction of mechanical equipment occur inside the reactor.

Each of the two reactors of the British Wylfa station, scheduled to go into service in 1969 in Wales, will be enclosed in a PCRV (See Figure 1). The vessel is spherical inside, with an interior diameter of 96 feet, and it has a minimum wall thickness of 11 feet. Design pressure is 423 psi. Each vessel contains some 28,000 cubic yards of concrete and 5,000 tons of steel, and produces a load of about 80,000 tons on the foundations.

The first United States reactor to use the PCRV concept will be the Colorado high-temperature gas-cooled reactor which is being built for the Public Service Company of Colorado. This plant will be able to attain very high efficiencies by operating with a steam pressure of 2,400 psig at 1000° F. In addition to the reactor, the prestressed vessel will house the reflector, steam generators, and helium circulators. The compact and efficient plant design enables elimination of primary coolant piping. Also, it is felt that the PCRV design will provide an additional measure of inherent safety as compared with more conventional structure design.

PCRV DESIGN PROBLEMS

Prestressed concrete reactor vessels with interior dimensions on the order of 100 feet (equivalent in strength to a ten inch thick steel vessel) are now structurally feasible. Although major emphasis on PCRVs has been for use in gas-cooled reactors, there seems to be no reason why the same concept cannot be applied successfully to higher pressure water-cooled reactor systems with very large generating capacity.

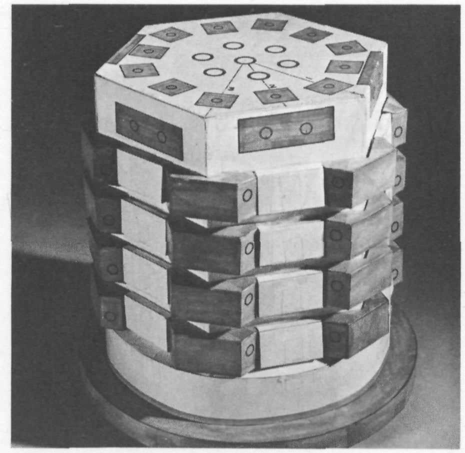


Figure 2

Figure 2 shows mock-up of the Cornell PCRV model. The scale models being constructed, (1) and (2) on opposite page, will be pressurized to failure to determine their overall structural response and mode of failure.

Never before has prestressed concrete been used in such massive structures, in such intricate shapes, and under such extreme combinations of pressure, temperature, and irradiation. And, never before, with the possible exception of high dams upstream from large population centers, has concern for public safety been as great as in reactor structure design.

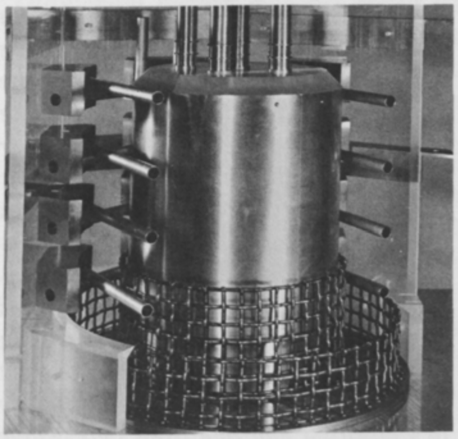
Design requirements go far beyond those of providing a simple, safe pressure vessel; openings and nozzles must be provided for maintenance, refueling, exit of power or power fluids, instrumentation, and other equipment. The vessel must also have internal equipment supports and foundations and a myriad of other features to house the reactor system. The optimum over-all shape must be determined for each particular reactor design and capacity.

Foundation design itself is critical because of the extremely high dead weight of the complete reactor structure, which can be as much as 80,000 tons. If sound bedrock is not available for supporting these high loads, a massive raft-like foundation is required to keep the pressures which the soil must bear within permissible limits.

The behavior of the vessel must be determined when it is subjected to overpressures. Prestressing systems and configurations must be designed and assessed. And since the service life of such nuclear stations is considered in terms of decades, the long-term performance of concrete under the rather severe conditions of high three-dimensional stresses, high temperature levels and thermal gradients, and radiation fields must be understood in order to provide safe, yet economical, designs. Better analysis techniques for these thick-walled, inelastic, unsymmetrical structures are needed to determine how

"Never before has prestressed concrete been used in such massive structures, in such intricate shapes, and under such extreme combinations of pressure, temperature, and irradiation."

1



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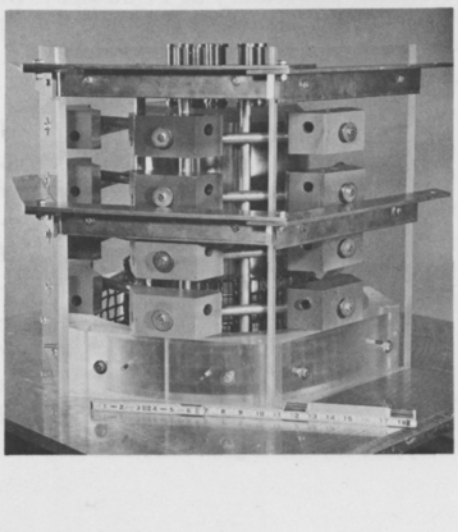

they will respond to basic reactor loadings and to such dynamic loadings as earthquakes.

The long-term effects of exposure to high temperatures and radiation on the steel in the system must be studied further, as must the interaction of the PCRVs thin internal liner (generally steel plate) and its thick concrete walls. (The liner is used to give additional protection against leakage.) More study of new construction techniques, and of the fundamental behavior and cracking characteristics of concrete under load is also needed.

CORNELL PCRV RESEARCH

Several faculty members in Cornell's Department of Structural Engineering are currently engaged in the broad PCRV development program which is now being undertaken in the United States. The Atomic Energy Commission (AEC) Advisory Committee on Reactor Safeguards recently heard an invited presentation by Professor George Winter on fatigue and crack growth in prestressed concrete structures. This meeting was scheduled as part of the AEC commitment to investigate and expand the technology of the PCRV concept.

The AEC is sponsoring an extensive PCRV research and development program through the Oak Ridge National Laboratory in Tennessee and through commercial laboratories. As part of this program, Professor Peter Gergely and I are conducting research projects in two different areas.

Professor Gergely is studying and evaluating the performance of prestressing systems, paying particular attention to the complex stress conditions which are found near the anchorages at the ends of the prestressing cables in the PCRV. Previously, Professor Gergely has done extensive work on concrete anchorage and cracking problems in more conventional concrete and prestressed concrete structures.

My research project involves studying the basic behavior of PCRVs under design and overload conditions. Scale models (See Figure 2) will be pressurized to failure, and overall structural response and mode of failure will be determined. These findings will be compared to analytical predictions and test

The author, Richard. N. White, winner of the 1965 Cornell Society of Engineers' Award for Excellence in Engineering Teaching.

results on a larger, but similar PCRV to be tested by Oak Ridge personnel.

STRUCTURAL RESEARCH IN OTHER AREAS

The Cornell research program on the PCRV concept is one aspect of the broad research activity under way in the Department of Structural Engineering. The fundamental behavior of concrete under short-term and long-term loading, a continuing study of the basic interaction of steel and concrete in reinforced concrete elements, and the development of techniques for small scale modeling of complicated structural configurations are among studies closely related to those in the PCRV program. Other concrete-oriented research includes computer analysis of the non-linear behavior of reinforced concrete, a study of the behavior of reinforced concrete structures under repeated loads, and the determination of the ultimate strength of frames and shells.

Considerable research in steel structures is also in progress which will enable us to utilize new materials and new structural forms better. For example, some current research on steel structures covers such diverse topics as: (a) the effects of cold-forming on basic strength properties of light gage steel, (b) the development of specifications for the structural use of light gage stainless steel, (c) damping characteristics of structural joints, (d) improved analysis techniques for cable roof structures, and (e) steel shell structures.

Today, structural engineers must continually plan new structural designs for changing environmental needs. Our brief examination of the structural design problems for nuclear power reactor housings merely touches upon the range of important and interesting problems that our structural engineers face daily.

Richard N. White, Associate Professor of Civil Engineering, joined the Cornell faculty in 1961. He attended the University of Wisconsin where he received the B.S. degree in 1956, the M.S.C.E. degree in 1957, and the Ph.D. degree in 1961.

Professor White was an instructor at the University of Wisconsin, and has worked as a structural designer for John A. Strand in Madison, Wisconsin. He has done research at the Bell Telephone Laboratories, Inc., on modeling of the cutting and rupture of soils. His other research activities include the study of: the modeling of concrete structures (under two National Science Foundation research contracts), structural connections (under a United States Steel grant), and the structural problems in reactors (under one research contract from Los Alamos Scientific Laboratory in California and one from Oak Ridge National Laboratory in Tennessee). In 1965, Professor White won the Cornell Society of Engineers' Award for Excellence in Engineering Teaching.

A member of the faculty of the Department of Structural Engineering, Professor White is the author of several publications in this field. He is a member of the American Society of Civil Engineers, the American Concrete Institute, the American Society for Engineering Education, the Society for Experimental Stress Analysis, Phi Eta Sigma, Chi Epsilon, Tau Beta Pi, Phi Kappa Phi, and Sigma Xi.

LAND RESOURCE UTILIZATION AND PLANNING

By David J. Henkel

Throughout history man has relied on the soils and rocks of the earth's crust to support a wide variety of structures. He has also used these materials for the construction of roads, dams, canals, harbors, and many buildings. The pressure to extend man's use of the earth's surface has been intensified by a rapid increase in population and by the quickened pace of the growth of technology and production. The population increase has created an almost insatiable demand for land for shelter, transportation, production, and recreation.

In many parts of the world, the more desirable land sites with relatively simple foundation problems have all been used, and further developments require that marginal land, such as swamp or landslide areas, be reclaimed. The growing demand for land has emphasized our need for greater knowledge of those materials which occur near the earth's surface, as well as our need for a more rational approach to land utilization and planning.

Generally, the materials which make up the earth's crust are in dynamic equilibrium with their environment. Changes in this environment, either natural or man-made, may cause movements in the earth's surface or in deeper layers of the crust that can have adverse effects on any structures near these movements. For example, changes in the ground water regime following the construction of a dam may trigger large-scale landslides. Pumping water from wells may lead to substantial settlements of the ground surface in surrounding areas.

ACTIVITIES OF THE GEOTECHNICAL ENGINEER

Geotechnical engineering deals with the basic components of sites and structures: soil mechanics, surveying, engineering geology, ground water, construction materials, and the functional demands of the structure on the site. The following areas of interaction among these components must be thoughtfully considered:

- Methods of construction relating to the site.
- The costs of site preparation as affected by various positionings of units.
- Design characteristics related to site foundations, rock quality, and earthquake shock.
- Soil strength as influenced by ground water changes; rocks as affected by weathering and solution; landslides as caused by construction surcharge.
- Tie-in of a site to its adjacent area: its feeder roads, its water supply, its waste disposal.

THE ARECIBO TELESCOPE

The intracacies of modern, complex structural designs and site developments can be illustrated by Cornell's Arecibo

The 125-acre site for the Ionospheric Observatory met these conditions: (a) location where solar objects pass most directly overhead; (b) economical construction facilitated by natural topographical features; (c) climate where temperature variations, wind velocities are low.

Sinkholes in a flat terrain, characteristic of Karst topography, dominate this area. The solution of limestone in water caused the formation of large caves and later caused the collapse of the cave roofs, thus creating sinkholes. Tropical weathering has left only the nubs of hills upon which the feed support towers were constructed.

The site is well-drained, the area under the reflector base being much above the permanent water table. The porous limestone is easily worked, winds are usually light, and major tropical storms are rare. The maximum temperature variation is only 30 degrees.

1. Topographic layout with circular excavation contours superimposed, showing the conformity of the terrain to the design requirements of the reflector surface.
2. The completed facility. Note the service road leading to the bottom of the bowl.
3. An aerial photo showing the site selected from the twenty-eight considered with its unusual sinkhole topography.

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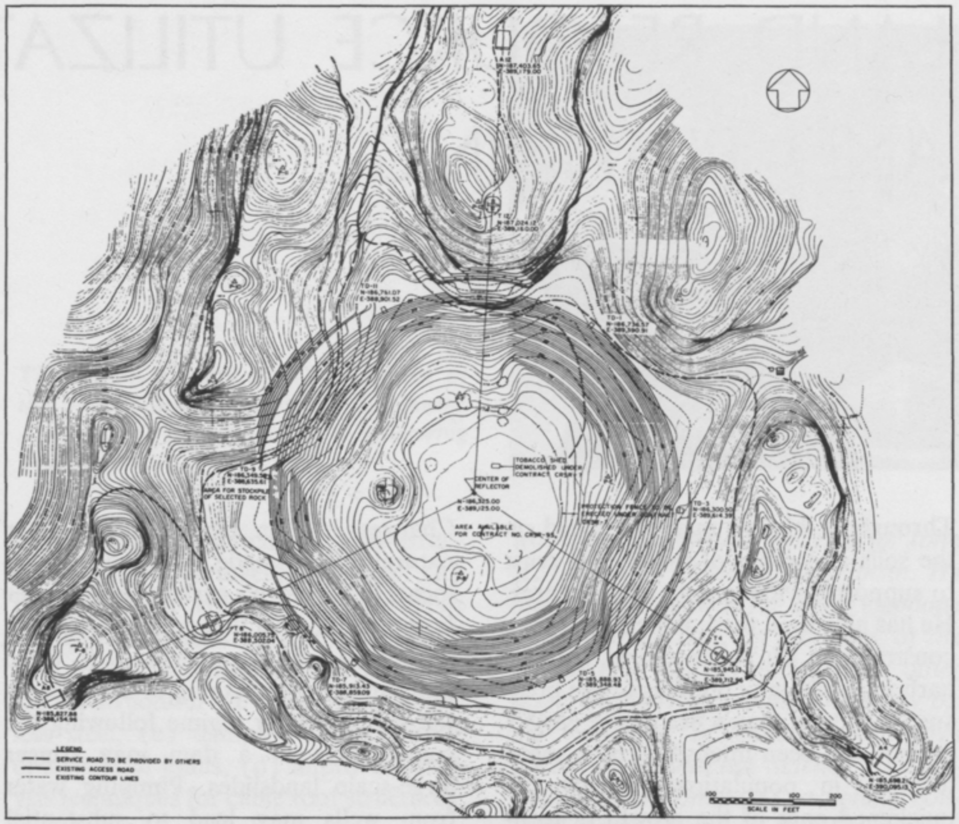

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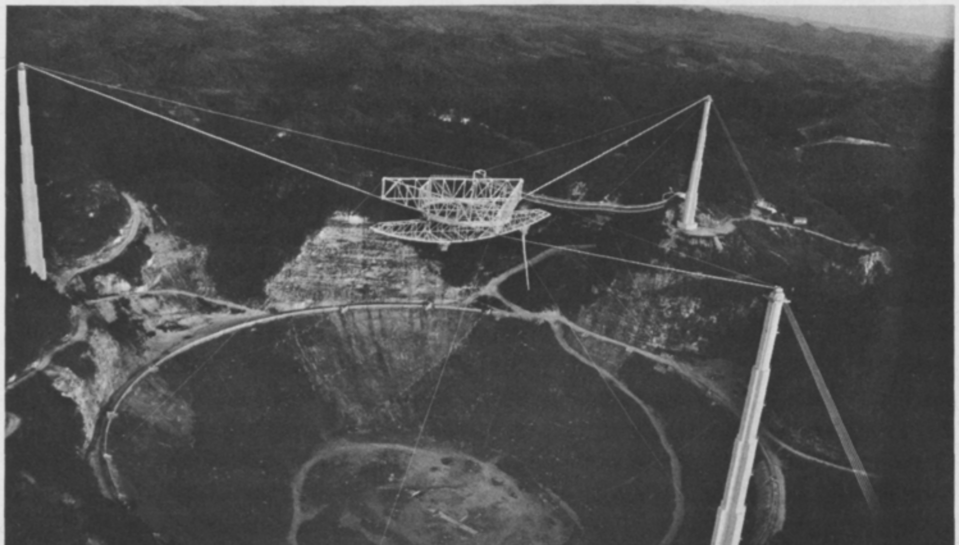

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radio-radar telescope. This telescope is the largest known radio "ear" and "camera lens" in the world, with a 1,000 foot span across the rim of the spherical reflector. It is set into an earth "bowl" about 350 feet deep at its center, and is located on a 125-acre site some 11 miles from Arecibo, Puerto Rico, and the coast.

Several requirements were critical to the consideration of the site. First, it had to be located where solar system objects pass more directly overhead (which placed it in the tropics) and where there would be moderate temperature fluctuations so that problems of structural expansion and contraction would be minimal. The site had to be well removed from the electrical interferences of metropolitan areas or airline routes.

Beginning with the problems of the physical site itself, to excavate a site of such magnitude would not only be costly but also impossible to maintain: excavated in soil, it would fill with water or the sides would slide in, or both. Steel framing combined with a more manageable, shallow depression would take on the proportions and costs of a large stadium. Geotechnical staff experience and course materials from our files pointed the way to an optimum solution: look to the natural bowl-shaped depressions found in tropical limestones. With the use of aerial photographs analyzed in Ithaca, the most suitable site was pinpointed in an area of 700 square miles of incredibly rough terrain in the remote highlands of Puerto Rico.

Now the structural project had to be tailored to the site. Before the site was chosen, the telescope had been conceived of as a reflector dish and signal "feed" tower 500 feet above it. With a naturally formed bowl and the surrounding peaks at the chosen site, the signal "feed" could be suspended above the reflector dish using lateral support towers on the adjacent peaks. This concept formed the basis for the final design that stands today, showing the influence of site characteristics in producing a less costly and more electronically efficient radio telescope.

Finally, the geometric shape and positioning of the mesh of the reflector surface of the telescope with respect to the feed mechanism had to be calibrated. This is analogous to testing the grinding of the lens and prisms in an optical telescope. The shape of this mammoth reflector was determined photogrammetrically to a precision of plus or minus one centimeter. This was accomplished from precise measurements of aerial film by methods of analytic aerotriangulation, a technique that was recently developed by the Department of Geotechnical Engineering at Cornell.

ADVANCES IN SURVEYING AND MAPPING

One prerequisite essential for planning and for construction is having accurate maps of both large and small areas. Recent developments in aerotriangulation and electronic distance measuring devices have produced faster and more accurate mapping. While the advent of earth and moon satellites and space vehicles has raised new problems of position fixing and navigation, it has also provided new tools which can be used to give more accurate geodetic

data on the shape of the earth and on the relative distances between widely spaced points on the earth's surface.

The use of space vehicles for photographing the surface of the moon has provided valuable new information on the surface conditions to be expected when a manned spacecraft lands on the moon. Of all the instruments to be carried aloft in such vehicles, the aerial camera appears to offer more possibilities than any other for yielding valuable information about the physical universe. As mentioned earlier, such information led to the location of the Arecibo telescope. Through aerial photography, knowledge of far greater detail is available concerning surface soils and rock, vegetation, drainage patterns, geological structure, and ground water conditions. With such information, transportation routes, water supply basins, and sources of construction materials (e.g., gravels) can be located and can be developed at a fraction of the cost of alternative methods.

Much has been said about the potential military capabilities of photoreconnaissance satellites, but the nonmilitary uses of satellites bearing aerial cameras and other related remote sensing instruments are only now being considered.

Aerial photographs are of great value in locating areas of instability on the earth's surface, and using them has simplified the identification and location of areas where landslide problems are likely to be encountered. The use of sequential series of photographs that cover a span of time relate environmental changes to their consequences. Our Geotechnical Engineering Department is carrying out research on potential peaceful uses of photography and other remote sensing imagery from orbiting satellites, particularly for making natural resource surveys. Because the quantities of information being sent back to earth will be so staggering, we are devising ways to automate the extraction of data as much as possible. Recent advances in the field of computer graphics make it possible to present up-to-date data in the form of distribution maps. Results of all this research are in turn being integrated into engineering education at both the graduate and the undergraduate level.

Another possible use for continuously orbiting satellites equipped to provide coverage of the entire surface of the earth would be to monitor the food production schedules of the world. Timely warnings of the likelihood of crop failure could be given, particularly in the critical food producing areas, and with such warning arrangements, redistribution of food supplies and extra plantings might be made in time to moderate the consequences of such failures.

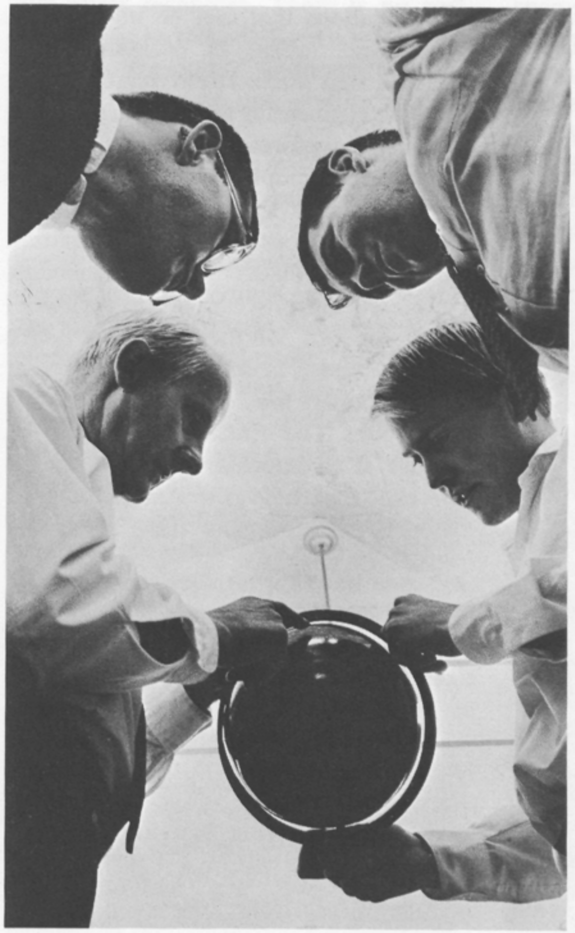
FOUNDATION ENGINEERING

The importance of the overall environment has already been emphasized in the earlier illustrations of geotechnical activity, but the successful implementation of plans for new developments also requires a detailed knowledge of the engineering behavior of the soils and rocks involved in construction operations. Many of the new structures which arise as a result of our increased sophistication in technology require extremely close tolerances on the relative settlement between various portions of the structure. While ingenious structural

"The central problem for the future is to educate engineers to appreciate the whole as well as the detailed aspects of using any unique site for structural purposes."

design can alleviate the consequences of excessive differential settlement, there is, nevertheless, a demand for the refinement of methods for estimating the deformations which will take place as a result of changes in the weight bearing on the ground surface.

Such refined methods were used in the planning of Cornell's 10 billion electron volt accelerator which is under construction on the campus beneath Upper Alumni Field. In this instance, a buried facility was needed, one within walking distance of the Newman Laboratory of Nuclear Studies. Additionally, a concrete-lined tunnel 10 feet in diameter, and approximately 2,500 feet in circumference, sited to reduce potential settlement to a 2mm tolerance, was desired. As in many other types of structures, the depth-to-rock factor was critical. Needed was "Sufficient soil cover to avoid rock excavation, rock close enough to provide solid foundations," and, added to this, there was a hope for "no ground water." These are typical of the prepared statements frequently presented to geotechnical engineers. The Cornell Synchrotron is



Opposite: Donald J. Belcher, professor of civil engineering, widely known for his contributions to photogrammetry, examines an air photo strip of a small village.

Left: Arthur J. McNair, professor of civil engineering, a major contributor to surveying techniques now used in space, reviews triangulation methods for surveying celestial bodies.

"Riding to work" through Cornell's nearly completed circular synchrotron. The tunnel, which is a half-mile around, is set more than 40 feet beneath the surface of Upper Alumni Field. Powered by 10 billion electron volts, the Synchrotron's electron beam will be guided into orbit and held there by magnets.

being built at a depth of 40 feet, achieving most of the desired conditions. The ground water could not be dispelled, but at least geotechnical studies showed in advance that ground water was present and was in a serious state of interaction with the silty soils of the site; this made it possible for structural designers to compensate for the ground water situation.

These exacting demands on the foundation engineer call for advances in our ability to define the field stratification of soils and rocks as well as their deformation properties. The problems are complex. Natural materials vary in both the horizontal and vertical directions and the expense of subsurface exploration limits the range of investigations that can be undertaken. Soils and rocks, in addition, have complicated stress-strain relationships, and the engineering solution to practical problems requires the ability to reach appropriate simplifications of both the environmental and the detailed deformation properties of the natural materials involved. While refinements in theoretical procedures are desirable, they will not, of themselves, produce improvements in our ability to predict with accuracy the field behavior of soils and rocks. The central problem for the future is to educate engineers to appreciate the whole as well as the detailed aspects of using any unique site for structural purposes.

OUTLOOK

In the future, how well we make use of the earth's surface for the construction and planning of new facilities will depend upon a clearer appreciation of the overall environmental factors, and the relationships of soils and rocks to planned construction. We need to remind ourselves that underdeveloped countries are facing critical periods in their history. Their future and our's will depend on better water and food supplies, better transportation routes, and the location, planning, and careful use of natural resources. Concern with both the environmental factors and the detailed problems of mechanical behavior of soils and rocks suggests that geotechnical engineering can look forward to substantial and important contributions to society in the years ahead.

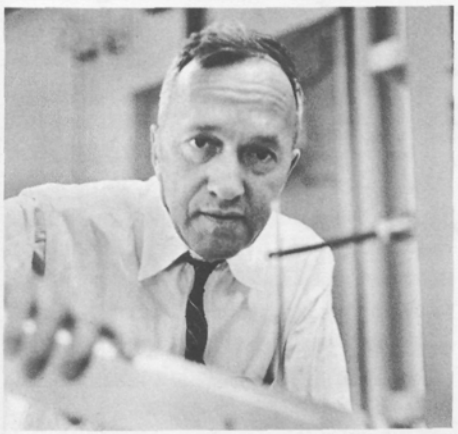
David J. Henkel is Chairman of the Department of Geotechnical Engineering. In 1941 he received the degree of Bachelor of Science in Civil Engineering from the University of Natal in Durban, South Africa, and in 1958 he received the Doctor of Philosophy degree from the University of London and the Diploma of the Imperial College of Science and Technology, London. Professor Henkel came to Cornell in 1965 as a professor of civil engineering.

Following his graduation from the University of Natal, Professor Henkel was head of the Soil Mechanics Division of the National Building Research Institute in Pretoria, South Africa. He has also been a lecturer in soil mechanics at the Imperial College, a visiting lecturer at the University of Illinois, and a professor of soil mechanics at the Indian Institute of Technology in New Delhi.

Professor Henkel is the author of many publications dealing with foundations, shear strength of soils and clays, and the stability of natural slopes. He is a member of the Institute of Civil Engineers, London, and the American Society of Civil Engineers. He is also a fellow of the Geologic Society.

WATER SHORTAGE, NO... SOUND MANAGEMENT SHORTAGE, YES

By Charles D. Gates



There is no nationwide water shortage nor any imminent danger of there being one. Regional and local quantity and quality problems exist owing to an inequitable natural distribution of water over space and time and because of society's inability or reluctance to manage available water resources effectively. In the future, weather modification may help to correct the inequitable distribution, but for a nation that will be using water at an estimated rate of 560 billion gallons per day in 1980, even weather modification will not be enough. We must also have sound management of our water resources. There is no real alternative to this, and once we accept the fact, acceptable solutions to problems of allocation and quality control appear possible.

Effective planning and management of water resources depends on our gaining more and better knowledge of pertinent physical, biological, and social phenomena. We must systematically and simultaneously consider many interrelated variables and make the decision-making process reflective of the most recent advances in water science and technology and more responsive to the public interest.

Finding solutions to the complex problems in water resources planning, development, and management requires the collaborative efforts of individuals with a sound background in one of the biological, physical, or social sciences, or in a profession such as engineering or law. Through experience and advanced study, such specialists can also improve communications with individuals in related disciplines.

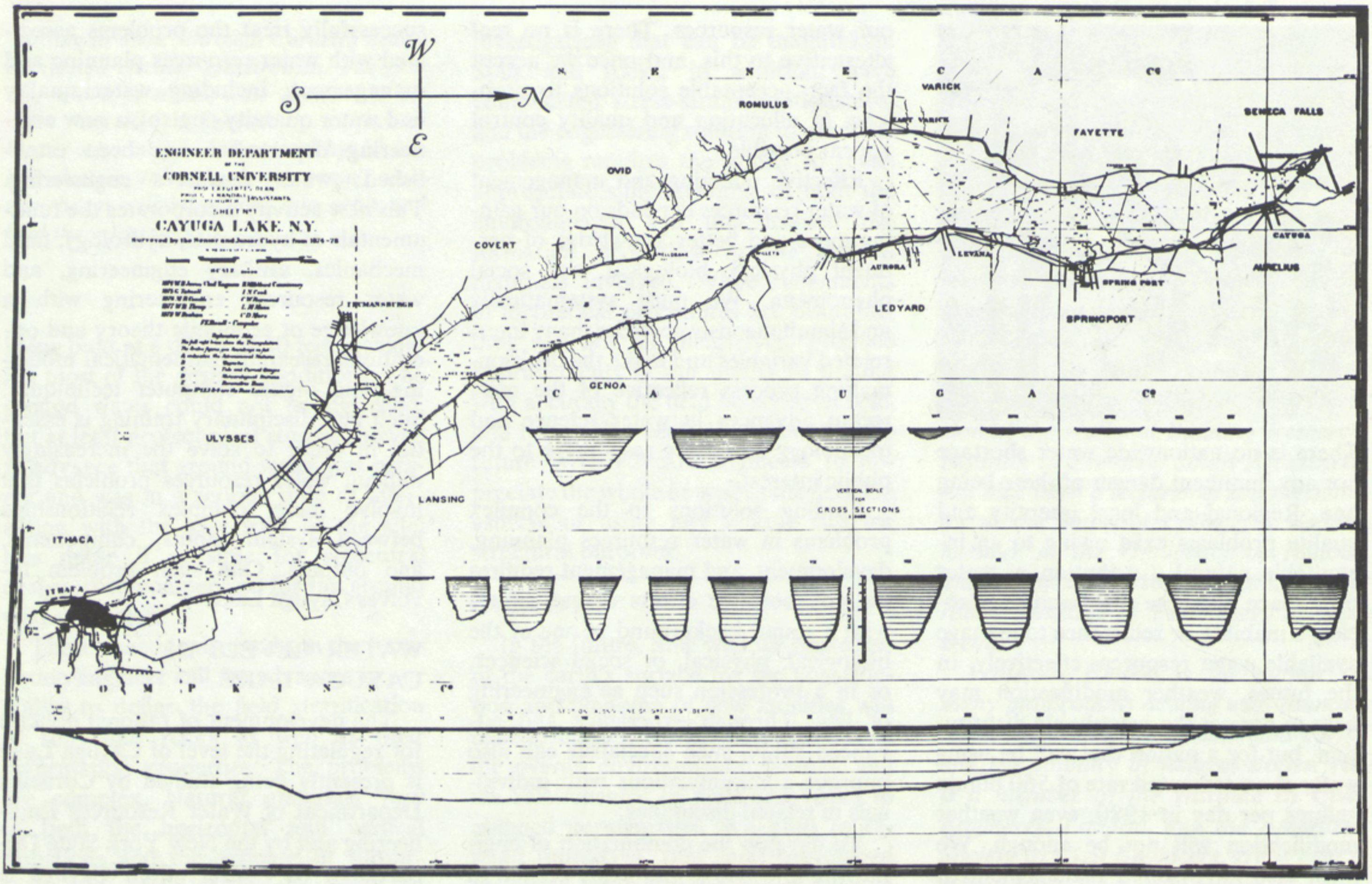
To develop the combination of engineering knowledge and skills needed to successfully treat the problems associated with water resources planning and management, including water quality and water quantity control, a new engineering department has been established: water resources engineering. This new activity incorporates the fundamentals of hydraulics, hydrology, fluid mechanics, sanitary engineering, and water resources engineering with a knowledge of economic theory and operations research, mathematical modeling, and digital computer techniques. Such interdisciplinary training is essential in order to solve the increasingly difficult water resources problems that involve many complex relationships between system inputs, components, and outputs. One such problem involves Cayuga Lake.

WATER LEVELS IN CAYUGA LAKE

The development of rational policies for regulating the level of Cayuga Lake is presently being studied by Cornell's Department of Water Resources Engineering and by the New York State Department of Conservation. Cayuga is

Opposite: A view of Cayuga Lake, one of the famous Finger Lakes of central New York State.

Below: Survey of Cayuga Lake made by Cornell engineering students of Dean E. A. Fuertes between 1874 and 1878. Top: Surface map showing lake tributaries. Middle: V-shaped patterns showing selected east-west cross-sections. Bottom: North-south cross-section showing comparative depth and shallowness.

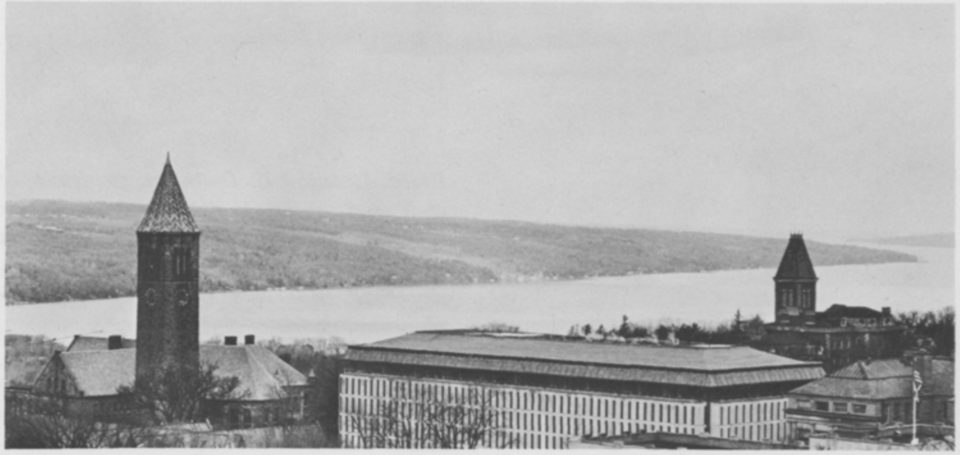


the second largest of the Finger Lakes, 37 miles in length and varying from 1 to 3 miles in width; its maximum depth is about 425 feet. The Lake flows into the Cayuga-Seneca section of the New York State Barge Canal System.

Current legislation requires that the water level of the Lake be regulated to provide favorable navigation conditions for the Barge Canal. Other important legal requirements are that adequate waste dilution water be provided downstream from the Lake, that flood damage be prevented whenever possible, and that adequate water supplies be allocated to a variety of municipal, industrial, agricultural, and recreational users.

For the last forty years, the elevation of water surface in Cayuga Lake has been controlled at between 379 and 386 feet above mean sea level. Fluctuations in the Lake level occur when the quantity that must be released is less or greater than the net amount flowing into the Lake. An attempt is made to keep the level between 380 and 384 feet, depending on the season.

Flooding occurs in the city of Ithaca when the water surface rises above 385 feet. At 386 feet, furnace fires are extinguished in several hundred homes, and flow in many of the city's sewers stops. Below 384 feet, small boat navigation is no longer possible on tributary streams flowing through Ithaca into the Lake. Cottage owners along the Lake naturally want a uniform water level maintained throughout the summer so that they can easily dock their boats, and landowners along the outlet streams expect clean flowing water at all times. To satisfy these requirements, water must be released from Cayuga Lake during the summer



months, usually an amount in excess of the flow into the Lake.

Even if the future streamflows into Cayuga Lake and the future evaporation rates could be predicted with certainty, it is obvious that no single operating policy for regulating the Lake level would satisfy everyone. The unpredictability of future inflows, release or discharge requirements, and the economics associated with various Lake levels is a further complication.

ANALYTICAL STUDIES UNDER WAY

To gain additional insight into how best to regulate the Lake, the water resources engineer must initiate and integrate a series of separate studies. One study must be directed toward developing a technique for predicting the probability of possible net inflows.

Flows have been measured on very few of the many streams that flow into Cayuga Lake; records on overland runoff or evaporation are not even available. With such sketchy information, only the data on daily Lake levels and gate openings at the Barge Canal can be used to compute needed inflow-outflow relationships. Applying hydraulic engineering principles, engineers and computer experts have been able to write a computer program which has calculated daily discharges during the forty years of record. From an analysis of these Lake levels and discharges, a matrix of serially correlated net inflow probabilities for each hydrologic season of the year can be specified.

How to predict the probabilities of various releases that will be required to insure navigation on the Barge Canal is another of our tasks. This depends upon the amount of water already available in the Canal, as well as upon the releases into the Canal from both the upstream and downstream reservoirs, the number of lockages for barge traffic on the Canal, and the amounts withdrawn by various users. Thus to develop an adequate operating policy for Cayuga Lake, this study must encompass all of the reservoirs and water users within the 92-mile Cayuga-Seneca section of the Barge Canal system.

Each water user in this system has already planned his activities expecting

Right: Leonard B. Dworsky, professor of civil engineering, is director of Cornell's Water Resources Center which promotes and coordinates comprehensive University-wide programs in water resources planning, development, and management.

Below: The computation corner of the hydraulics laboratory located in Hollister Hall.

a certain quantity and quality of water to be available each day. These expected quantities, qualities, and Lake levels are termed "targets." Deviations from any of these targets, e.g., Cayuga Lake's rising above 385 feet or dropping below a level of 384 feet in the summer season, can result in substantial economic losses as well as personal inconvenience.

Accurately determining the dollar losses resulting from deviations from a given user's target is an extremely difficult task. If it can be done, and if the future water inflows and releases can be determined accurately, then an optimum operating policy can be formulated using a deterministic mathematical model. Such a model would include all reservoirs and water users within the system. A solution obtained from the model would then indicate when and how much water to release so as to *minimize* losses associated with any deviation.

Net inflows, however, are not determinable, and economic losses are not completely predictable; hence, probability must enter into both the model and the solution. While we may not be able to predict exactly what the inflows and economic losses will be for a particular user, the probability of these can be estimated.

Probabilistic mathematical models written for solution on modern high-speed electronic computers can aid water resources engineers in arriving at improved operating policies by simultaneously and systematically combining and examining many complex and interrelated components of a particular problem. Alternative designs or policies that satisfy various objectives can then be explored. This approach is an attempt to show the relationships of the individual targets to the whole reservoir-canal system. To achieve the maximum system performance, trade-offs among the various parts are often required to resolve conflicting or competing targets.

Using the principles of probability, one reasonable policy might be to minimize the over-all expected dollar losses. If the economic information is not available, a policy could be formulated that simply minimizes the expected total deviation from all of the users' targets within the reservoir-canal system. Such a policy would treat every water user equally, regardless of the benefits or losses associated with various allocations to each one.

DECISION MAKING

When all possible analyses have been made, all probabilities considered, and all possible solutions identified, then someone must decide which alternative is the best. Often this task is the politician's—final responsibility is his—but usually he is not technically qualified to make such a decision. Consequently, he must frequently rely on the recommendation of the water resources engineer. In such cases, the engineer, using his judgment, experience, education, and even his intuition, must decide among seemingly reasonable alternatives how best to serve the public interest.

Charles D. Gates, Chairman of the Department of Water Resources Engineering, received the degree of Bachelor of Arts from Williams College in 1937, and the Master of Science in sanitary engineering from Harvard University in 1939. He joined Cornell's faculty as an assistant professor of civil engineering in 1947.

Before coming to Cornell, Professor Gates taught and conducted research in the detection and removal of chemical warfare agents from water at the Army Chemical Center in Maryland. He was also head of the Distillation Test Section of the Engineer Research and Development Laboratories at Ft. Belvoir, Virginia, where he did research on methods and equipment for the desalination of sea water. Professor Gates has worked as a civil engineer on flood control projects in New Hampshire and Vermont.

In addition to his teaching duties, he was responsible for a graduate training grant at Cornell that initiated a program of the application of systems analysis to sanitary engineering. Professor Gates is a consultant to the New York State Department of Health, the United States Public Health Service, and the New York State Office for Local Government. His current research deals with the reactions and subsequent results of organic wastes in water.

Professor Gates is the author of many publications on sanitary engineering, water quality control, and waste management. He is a member of the American Water Works Association, the Water Pollution Control Federation, the Cayuga Lake Basin Regional Water Resources Planning Board, the American Society for Engineering Education, Phi Beta Kappa, Chi Epsilon, and Sigma Xi.

SYSTEMS ENGINEERING AND THE HUMAN ENVIRONMENT

By Gordon P. Fisher

Man's struggle with his environment is not new. He has always modified his environment, and, in turn, has been forced to respond to the very changes he has caused. Accommodation between man and his environment has always taken place by a process of evolutionary adaptation. But today environmental alterations are too dramatic and man's interaction with his surroundings is of far too great a scope and intensity for him to tolerate such accommodation without rational planning. Increasing population, increasing urbanization, increasing technology and industrialization: all have accelerated the rate at which man alters his environment, and all have introduced new and serious stresses which affect man's health and well-being. Limited air, water, and land resources must be exploited to support man's increasing numbers and sharply growing demands at the same time that they are expected to assimilate the steadily expanding spectrum of wastes that he generates. How to control this assault of man upon himself—to protect him against biological, physical, and social hazards arising from his altering his environment, and to preserve the values of a wholesome life—is one of the greatest challenges of our era.

Many aspects of man's conflict with his environment are already apparent. Most of them arise from the concentration of people in urban areas: the transportation of people and commodities in and between cities; the preservation, allocation, and distribution of resources (land, air, water, power, space); the collection, treatment, and disposal of a variety of wastes; the preservation of residential values; and the rehabilitation of slum blight.

The stresses of extreme urbanization are clearly apparent. They can be seen, for example, in the Northeast Corridor, the great megalopolitan area stretching 600 miles along the East Coast from Boston to Washington. Forty million people live there—20 percent of our national population on 2 percent of the land! How can we preserve such an area as a pleasant place in which to live and work? How can we provide efficient and economical movement within it? Should further urbanization be discouraged? Should steps be taken now to induce people to move into the hinterland?

Furthermore, we can now perceive the development of four large urban complexes in this country: the Northeast Corridor, the Western Corridor (Seattle-San Francisco-Los Angeles), the North Central Complex (Buffalo-Detroit-Toledo-Cleveland-Chicago), and a South Central Complex (New Orleans-Houston-Dallas-Fort Worth). What does this mean for the future national transportation system? Should these large centers be served exclusively by jet air transport? What happens to land values, the mercantile interests, the quality of living in the great areas between these megalopolitan centers? What regional and national goals should be set for the future? When and at what cost can these goals be achieved? What is the risk of the individual's losing control over his own destiny in a process of central social planning?

Decisions that affect society now are being made at every level of government, most often with insufficient in-

formation, insufficient understanding of alternatives and consequences, insufficient insight into the nature of the problems, and insufficient sympathy for individual preferences. What is so disquieting is that these decisions taken on behalf of the public are massive, expensive, and nearly irreversible in their impact. And these decisions will continue to be made whether or not we improve our ability to attack the problems that they are supposed to resolve.

Too often in the past, we have used a piecemeal approach, concentrating on limited and unconnected objectives, such as air quality control, water quality control, sanitation, and transportation, each for its own sake. Consequently, we have had limited successes because we have been both unwilling and unable to take into account the *interdependence* of these environmental factors. If we are to enlarge our successes, we must deal with *systems* rather than collections of components. We need an integrated approach to problems that permits simultaneous consideration of an aggregation of effects.

Systems analysis can be applied, and with great profit, even to the several parts or subsystems of the total environment such as transportation and water. Individual components of some of these subsystems have been impeccably engineered, but the subsystem as an entity has not been treated with a comparable degree of sophistication. For example, the modern truck and automobile are well-engineered vehicles, the highways over which they move are designed to high standards, bridges and tunnels are constructed using the best modern materials and techniques. Yet, in combination, these elements will not necessarily guarantee the most satisfactory transport of people and goods. Similarly, sanitary engineers design very effective waste-disposal plants and water supplies, but how much attention have they given to the balance and integration of facilities which might be shared, physically and economically, within an entire region?

The problems we are dealing with have several general characteristics:

a) They are multicomponent, multivariable problems.

b) The interactions between components are more important than the components themselves.

c) Variation with time is a dominating factor.

d) Decisions must be made under a high degree of uncertainty about the future, placing great dependence on statistical inference and probability.

e) They require the allocation of limited or scarce resources, and economic efficiency is an important consideration.

f) Their solution depends heavily upon quantification of the elements of a system and on optimization of the response of the system.

Fortunately, a whole new body of knowledge has emerged that promises much more powerful and lasting solutions to our environmental problems. These are the methods of management science, including systems analysis and operations research, that have proved so effective in defense in dealing with weapons systems effectiveness, optimal distribution of search and combat forces, and budget allocations among various weapons alternatives. They have been applied also to many industrial management situations with equal effectiveness. The development of this new methodology, the experience gained in applying it to defense and industrial situations, and the introduction of electronic digital computers have given us new ability to deal with environmental problems. Environmental problems, of course, are enormously more complex than those in the defense and industrial sectors, but these new analytical tools are already being used to provide more rational bases for establishing environmental quality goals, and for allocating scarce resources. An unusual illustration of the application of systems engineering skills to a public health system, the regional management of tuberculosis, is given in "Engineering and Medical Science" (See page 33).

CORNELL ACTIVITIES

Clearly, educational institutions as well as practicing engineers have a role to play in enhancing the quality of our environment. Too often engineers and engineering colleges have left the solution of these problems to the artistic prejudice of urban and regional planners when, in fact, many of the problems of environment are centered on technological considerations that engineers are better equipped to handle. At Cornell University we have begun to meet these massive socio-technical problems by establishing a new department and program: *Environmental Systems Engineering*. Environmental systems engineering is an interdisciplinary activity having as its main thrust the application of systems analysis and operations research principles to problems of both man-made and natural environment. It deals with operational and managerial aspects of transporta-

The effect of various additives on the strength and wear properties of asphaltic mixes is being studied by these students in the transportation laboratory in Hollister Hall.

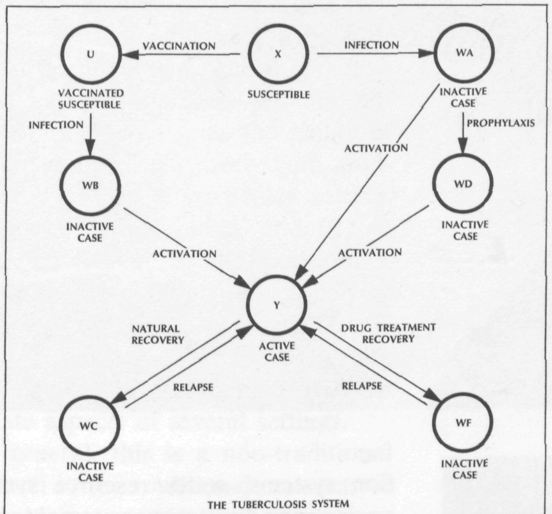
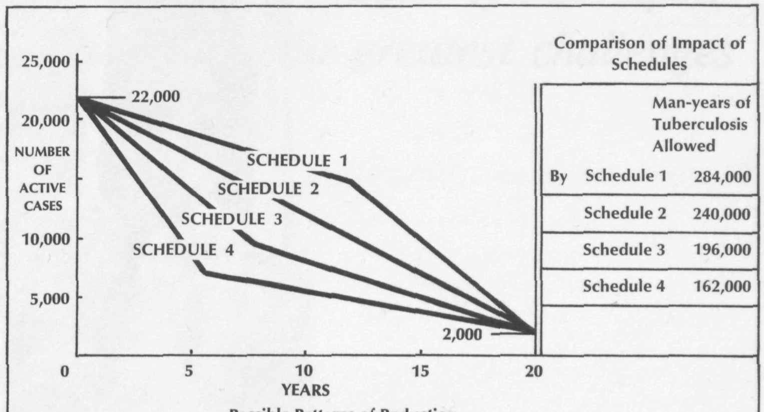


Figure 1



Possible Patterns of Reduction of Active Cases of Tuberculosis (Begins With a Hypothetical Population of One Million in Which There are Initially 22,000 Active Cases.)

Figure 2

ENGINEERING AND MEDICAL SCIENCE

Poverty, malnutrition, and disease hamper the progress of developing nations. While there are various methods of dealing with any one of these problems, funds to implement them are limited. Decisions must be made on which method to use, and systems analysis can be an important aid in reaching that decision.

Tuberculosis is one example of a problem to which systems analysis may be applied. The World Health Organization currently estimates that there are some 15 million individuals with active (infectious) tuberculosis in the world. In regions of India, 1 to 5 percent of the population may be active cases, while another 25 to 30 percent may be inactive (infected but not yet infectious).

Alternative solutions to reducing the level of tuberculosis may be analyzed by using a mathematical model. The disease system is described by eight interrelated categories (circles in Figure 1). The infection of a susceptible individual (X) by an active case (Y) creates an inactive case (WA). The inactive case has a given risk of becoming an active case. That risk may be decreased by providing prophylaxis in the form of drug treatment. Prophylaxis is one of three methods of tuberculosis control. The inactive case who has been given drugs moves to a new inactive category (WD) in which his rate of activation is diminished.

An individual who becomes an active case can also be treated with drugs which may cure him or render him noninfectious. This is a second form of control. The cured individual is transferred to another inactive category (WF) from which he may relapse back to the active state. Alternatively, an active case may recover naturally (without drug treatment); this condition is represented on the diagram by WC. Here, too, relapse to the active state is possible.

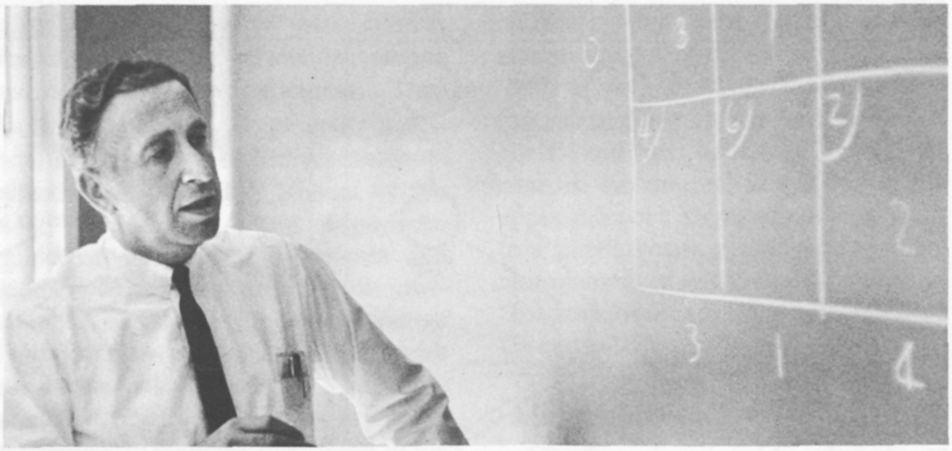
A third approach is the vaccination of susceptibles, moving them to category U. Vaccination does not prevent infection, but if the vaccinated individual becomes infected (category WB), the risk of his becoming an active case is reduced.

This descriptive mathematical model can be used to predict the future course of the disease. Once the natural trend of the disease is known, a decision maker can specify several patterns of active case reduction that might be acceptable. Then, the systems analyst determines the alternatives — the methods of control, intensities of treatment, and timing — to achieve the desired results at the least cost. The decision maker must now balance the "man-years of tuberculosis" resulting from the several patterns (see Figure 2) against the cost of those patterns.

The development and extension of these techniques to describe alternatives and to predict effects reflect the interests of environmental systems engineering.

The development of the tuberculosis model is part of a study supported by the Center for Environmental Quality Management, and conducted by Dr. Charles ReVelle, a research associate in the Department of Environmental Systems Engineering who will join its faculty as an assistant professor in the fall.

1



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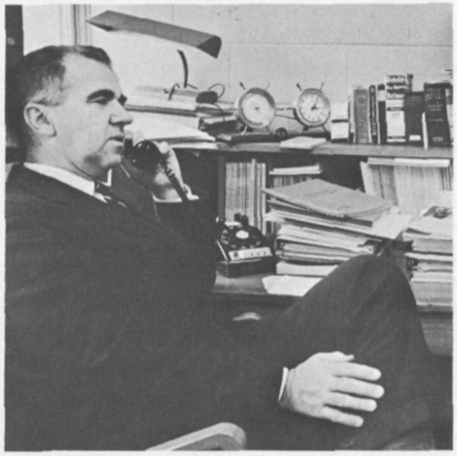

Professional diversity strengthens the staff in environmental engineering:

1. *Walter R. Lynn, director of the Cornell Center for Environmental Quality Management, holds a doctorate in sanitary engineering from Northwestern University. His major area of interest is the application of systems analysis to the techniques of sanitary engineering.*
2. *With a doctorate in economics from Harvard University, Louis M. Falkson is concerned with the economic aspects of water supply, pollution control, and related environmental health activities.*
3. *George H. Blessis had over fifteen years of professional experience in the construction industry after receiving his professional civil engineering degree from Yale University. At Cornell he is Coordinator of the Construction Engineering Management Program.*

tion systems, water resource systems, engineering project management, structural optimization and reliability, and other problems in public decision making that are amenable to a systems approach. An ultimate concern, of course, is the integration of these several areas and the rational allocation of public resources among them. The program takes a particular interest in the interwoven problems arising from urbanization. Through systematic analysis, the program presumes to be an agent of planned change and to provide greater insights which can lead to rational decision making and economic efficiency in the realm of complex multi-component problems. Primary emphasis is placed on the solution of real world problems of the human environment, not on the mere extension of mathematical theory.

The traditional interests of civil engineering assure that certain specific application areas are likely to be emphasized. Transportation is one area that is receiving early attention; water resources and construction project management are others. Environmental systems engineering is not limited to these areas alone, however. Each substantive application area will be pursued with a view to a central emphasis on the systems approach with the objectives: (1) to enhance the ability of a student to deal effectively with modern problems in a particular setting, e.g., urban transportation, and (2) to bring the student to the position of attaining a general problem-solving ability that will permit him to contribute in a number of different problem settings, and also to integrate and interrelate aspects of several settings.

In general, this is a non-traditional approach to the traditional concerns of civil engineering, which offers a promise of adding new dimension and power to an engineering discipline which has always spoken directly to the needs of society.

The Department is a key element in another new organization at Cornell, the Center for Environmental Quality Management. The center is a nondepartmental agency which crosses many disciplines in the University, coordinating and encouraging interdisciplinary training and research in environmental analysis and control. It has a much broader scope than the Department, and is a device for maintaining strong liaisons with supporting areas, such as sociology, biology, medicine, and urban and regional planning.

OUTLOOK

In short, man must learn to *manage* the quality of his environment. It is dangerous to rely on purely evolutionary development. The nation simply cannot risk trial-and-error engineering in situations for which the cost of error, in terms of both dollars and human satisfaction, may be disastrous. Certainly, the best of our technology and the best of our minds should be addressed to these situations, rather than abandoning the decisions to casual and uninformed analysis. The problems are complex, the tools are yet incomplete, the competent practitioner is still rare, but the promise of early success is great and exciting. The best hope for the preservation of our environment and for lasting solutions in its management lies in the area of systems analysis and engineering.

"How to control this assault of man upon himself... is one of the greatest challenges of our era."

Gordon P. Fisher, Chairman of the Department of Environmental Systems Engineering, came to Cornell in 1948 as an assistant professor of civil engineering after receiving the Doctor of Engineering degree from the Johns Hopkins University. He had received from there the degree of Bachelor of Engineering in 1942. Professor Fisher had varied experience as a structural engineer before coming to Ithaca and he continues his association with industry through consulting. While at Cornell he has been Associate Dean of Engineering and Director of the University's Water Resources Center.

Professor Fisher is the author of many publications on structural engineering and environmental control, and in 1962 was co-winner with Professor William McGuire of the Norman Medal of the American Society of Civil Engineers, for a paper on containment studies for an atomic power plant.

A fellow of the American Society of Civil Engineers and the American Association for the Advancement of Science, Professor Fisher is an expert member of the Comité Européen du Beton, Commission V (Paris). He is a member of the American Concrete Institute, the International Association for Bridge and Structural Engineering, the Column Research Council, Sigma Xi, Tau Beta Pi, and Chi Epsilon. He was recently elected to membership in the New York Academy of Sciences. Professor Fisher is a registered Professional Engineer in New York and Maryland.

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Perhaps President Theodore Roosevelt, through the strength of his personality and his position, was the first to arouse national interest in our environment. It was easy for the pioneers to assume that the natural resources and beauty of our lands were limitless. Not until the great influx of people and the growing industrialization and urbanization at the beginning of this century did Americans begin to see that there was a limit to such assets. As an outdoorsman and a conservationist, President Roosevelt sensed how important the quality of our environment would be in determining the quality of life in the future.

Enhancing the quality of our environment and making the best use of it are not new activities to civil engineers, the builders of much of our physical environment. They have traditionally been responsive to meeting many of our needs for shelter, water supplies, and transportation networks. But because their works are such accepted and essential parts of our environment, we have taken civil engineers for granted. Only when a bridge collapses, a dam fails, or a water supply dwindles do we realize the importance of their profession to our daily lives.

Civil engineering is an appealing profession to young people because they and the public now recognize that the problems of our physical environment are important and challenging. William McGuire puts it best in our lead article, ". . . the most significant characteristic of the output of civil engineers today is its influence on society." If we consider just a few of the major problems facing much of the world's population—land shortage, air and water pollution, urbanization, mass transportation, malnutrition—we begin to realize that the civil engineering profession will be expected to play an essential role in their solution.

The five articles that form this issue, *Improving Man's Environment,* describe the interests and concern of each author in the quest for a better and more productive environment. The authors touch upon many of the current activities in the profession in general, and in Cornell's School of Civil Engineering in particular.

THE EDITOR