proach traditionally taken in the design of such installations.

The design of modern nuclear power reactors, as well as other critical facilities such as major dams, bridges, and hospitals, is more sophisticated than that of the El Centro Steam Plant, but these designs have not yet been severely tested by an earthquake. Engineers using modern dynamic analysis recognize that each structure or piece of machinery, once set in motion, will vibrate at its own natural frequency the way a crystal goblet gives off its own tone when struck. Because seismic waves come in a whole range of frequencies, only certain waves can shake a particular structure. For example, seismic waves with a relatively high frequency of 15 hertz have little effect on a ten-story building, but they might vibrate piping or machinery. In the same way, the buildings of Imperial County College, which suffered no significant damage, did not "see" the exceptional 1.74*g* peak acceleration recorded there because it was at too high a frequency.

By using dynamic analysis, an engineer can decide if certain parts of the spectrum of seismic waves from an earthquake, such as the peak acceleration, can be de-emphasized in the design of a particular structure. For example, most structural engineers suspect that the high peak vertical accelerations of the Imperial Valley earthquake would have little effect on plant design because they were so brief and of such high frequency.

The delicate part of dynamic analysis is choosing an appropriate replacement, called the effective acceleration, for the observed peak acceleration. Numerous factors that might affect how hard a structure shakes, such as the underlying soil, the type of foundation, and the duration of the quake, must be considered, but such decisions are not entirely objective. "Only a handful of people in the world can do it," says John Blume of URS/John A. Blume & Associates in San Francisco. "A part of it is still judgment, although there is a lot of theory." Thomas Wosser of H. J. Degenkolb & Associates in San Francisco adds that "this earthquake design business is more an art than a science. Effective acceleration is a difficult thing to rationalize—it's a judgment call at best."

The NRC's Advisory Committee on Reactor Safeguards has made similar observations. When designers made modifications in the Diablo Canyon plant to accommodate the additional shaking expected from any earthquake on a newly discovered fault several kilometers away, the committee noted that "for want of better data, certain calculations were necessarily accepted largely on [expert] judgment and experience rather than on extensive observations or analyses, judgments not previously applied in approving power plant design."

Engineering judgment has provided the only guide so far as to why the Imperial Valley earthquake did not do more damage than it did. Many masonry buildings, which are usually the most susceptible, suffered little damage. Possible explanations remain qualitative and vague. Perhaps the shaking did not last long enough or was not violent enough; or, perhaps most of the masonry buildings had been tested by the 1940 Imperial Valley earthquake. Christopher Rojahn of the USGS in Menlo Park suspects, from inspecting the strong-motion record, that the shaking was not violent enough at the right frequency. It appeared to be strongest at the lower frequencies, which affect taller buildings such as the six-story County Services Building more than the typical one- to three-story masonry building. The quake would perhaps have done more damage, Rojahn says, if there were more buildings in the county taller than a few stories.

While noting that insufficient data have probably led to wasteful overdesign more often than dangerous construction, the National Research Council's Panel on Earthquake Problems Related to the Siting of Critical Facilities recently observed that "estimates [of ground motion] are subject to considerable uncertainties, reflecting the limited historical data base and the lack of detailed, quantitative knowledge of the influence of physical factors on ground motions. Data are particularly limited for near-field [close in] and large-magnitude earthquakes; unfortunately, such events pose the greatest hazard to structures." The Imperial Valley earthquake helped extend detailed observations to moderate earthquakes. The large quakes that may test structures such as the Diablo Canyon plant remain largely unobserved.—RICHARD A. KERR

Additional Reading

1. *Earthquake Research for the Safer Siting of Critical Facilities* (National Research Council, National Academy of Sciences, Washington, D.C., 1980), $8.50.
2. D. M. Boore *et al.*, *Estimation of Ground Motion Parameters* [U.S. Geological Survey Circular 795 (1978)].
3. *Architects and Earthquakes* (AIA Research Corporation, Superindent of Documents, Government Printing Office, Washington, D.C., Stock No. 038-000-00331-3), $2.20.

Lens Biophysics and Cataract Formation

Biophysical methods prove highly applicable to the lens

Most lens research centers on the problem of explaining cataract formation and of finding unifying theories to explain the many kinds of cataracts that can be induced to form in experimental animals. In general, the theories have had a biochemical basis and have applied to particular cataracts, such as those that develop in mice fed a high-galactose diet or those induced by ultraviolet light.

Only a handful of researchers have used biophysical techniques to study the lens, according to Oscar Candia, a biophysicist at Mount Sinai Medical School in New York. But the lens, it seems, is ideal for biophysical study because of its nearly spherical shape, which facilitates work with mathematical models, and because of its transparency. Among those taking a biophysical approach to lens research are James Rae, Richard Mathias, and Robert Eisenberg, who are physiologists at Rush University in Chicago. The three have used methods of biophysics and obtained results that suggest to them a new and functional theory of how the lens can maintain its volume and its transparency.

The Rush University group reported its results in June at a symposium entitled the Lens as a Biophysical Preparation, which was held during the combined meeting of the Biophysical Society

0036-8075/80/0829-1007$00.50/0

and the American Society of Biological Chemists in New Orleans. According to Eisenberg, who chaired the symposium, its purpose was to bring the lens to the attention of the biophysical community and to demonstrate that it is a useful and interesting tissue for biophysicists to study.

The theory of lens transparency is based on the Rush University group's finding that the lens has a highly unusual structure—the fiber cells in its interior have extremely impermeable membranes. These membranes, the researchers propose, must be impermeable to small ions if the lens is to remain transparent. Anything that disrupts this impermeability should cause cataracts.

This theory is the culmination of more than a decade of work, which began when Rae, who was then at the University of Texas Medical Branch at Galveston, used microelectrodes to determine that the lens consists of many electrically coupled cells. Similar results were reported in England at about the same time by George Duncan of the University of East Anglia.

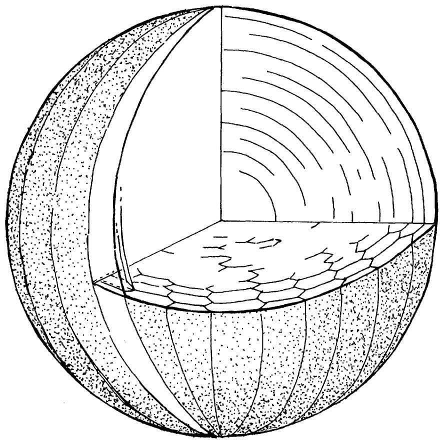
When Rae began his work, most physiologists analyzed the lens as though it was essentially one huge cell. This was not unreasonable because when the lens is probed with an electrode, it acts like a single cell—the voltage is the same at every location.

Rae began questioning the single-cell analysis of lens structure when he found that on moving an electrode in minute steps within a frog lens he saw widely different voltages. "It was as though the electrode was popping out of one cell and into another," he recalls. Rae then tried using two electrodes and discovered that when they were close together in the lens, the induced voltage was different than when they were far apart. It was as if the current was damped by passage through internal membranes.

Eisenberg met Rae in 1973 and the two began to work together. In 1976, they published a paper stating that their electrophysiological experiments indicated that the lens must be analyzed as a multicellular tissue.

Around the mid-1970's, Mathias joined the group, which subsequently moved to Rush, and the three researchers worked on a mathematical model of the electrical properties of the lens. Arthur Peskoff of the University of California at Los Angeles has since independently developed a similar model.

The problem in deriving a mathematical model of the lens, Eisenberg explains, is to describe a tissue consisting of many cells coupled together and having extracellular space, or cracks, between them. Such tissues, called syncytial, are typical not only of the lens but of the rest of the body, with the exception of nerve and skeletal muscle, which are the focus of most electrophysiological research. Nerve and skeletal muscle, Eisenberg explains, were chosen for study because they are large and of obvious importance. But theories of these tissues do not apply to syncytial tissues.



The lens has two kinds of cells: epithelial cells on the outer surface and fiber cells on the interior. [Drawing by Jane Walsh]

Working with Victor Barcilon, an applied mathematician at the University of Chicago, the Rush University group derived field equations—partial differential equations that describe the flux of currents in any syncytial tissue. To solve the equations, they made use of the fact that the lens, being spherical, is highly symmetrical.

The method these researchers used to solve the field equations, singular perturbation theory, is a way to expand the solution in terms of a parameter of the equations. The solution is approximated by the first few terms of the expansion. "When this method works," Eisenberg says, "the resulting solutions have direct and obvious physical meaning." The first approximation to the solution, for example, describes a uniformly charged syncytial tissue. The second approximation shows point source effects—a precipitous drop in intracellular current density outside the immediate neighborhood of a microelectrode. The sequence of approximations shows the spatial dependence of point source effects and is the real measure of cell-to-cell coupling.

This mathematical model of the lens was designed to describe a structure with one sort of membrane on the surface cells and another sort on interior cells. It is now known that the surface epithelial cells of the lens are very different from the fibrous cells inside. As the lens grows, new surface cells are added and the old equatorial epithelial cells enlarge, lengthen, and become fiber cells. The lens never sheds any cells. What was not known, however, was the different electrical properties of the membranes of the two kinds of lens cells. By passing currents through lenses and seeing how they are dissipated, the Rush University group was able to use its mathematical model to determine that the internal membranes are extremely insulating or, equivalently, that they are impermeable to ions. This led them to their working hypothesis concerning lens volume regulation.

The question that immediately came to mind, says Eisenberg, is "Why are the inner membranes so impermeable?" He proposes that if the membranes allowed free passage of sodium ions, sodium would enter the cells because there is more of it in the fluid surrounding the lens than in the lens itself. If more sodium flowed in, so would water, and the lens would swell and become cloudy as it does when cataracts form, according to Eisenberg. And, he says, when researchers experimentally alter lens cell volumes, the lenses become cloudy.

The membranes of most cells are far more permeable to sodium than are lens fiber cell membranes, but these more permeable cells actively extrude much of the sodium that enters through a mechanism called a sodium "pump." But sodium pumps require so much energy that they could not be supported by the low metabolic activity of lens fiber cells. The fiber cells have few mitochondria—the organelles involved in energy production. If the lens had large numbers of organelles it would lose much of its transparency. The lens has no blood vessels, which would also disrupt its transparency. Thus if glucose were a source of energy, it and its waste products would have to diffuse over long distances in the lens, which would be an extraordinarily slow process. Since the lens cannot support a sodium pump, the only expedient left is to keep sodium ions out by impermeable membranes, Eisenberg says.

The hypothesis that cataracts form when the impermeability of the lens membranes is disrupted is testable, according to Eisenberg. The biophysical experiments, the Rush University group believes, highlight some of the difficulties the lens has as a tissue. They also demonstrate the feasibility of using biophysical methods to study the lens and may inspire more biophysicists to turn to this tissue.—GINA BARI KOLATA