ARCHITECTURE

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Suffield features random specks of color that contrast with a classic background. The result is a look never before seen in a 6' vinyl sheet.
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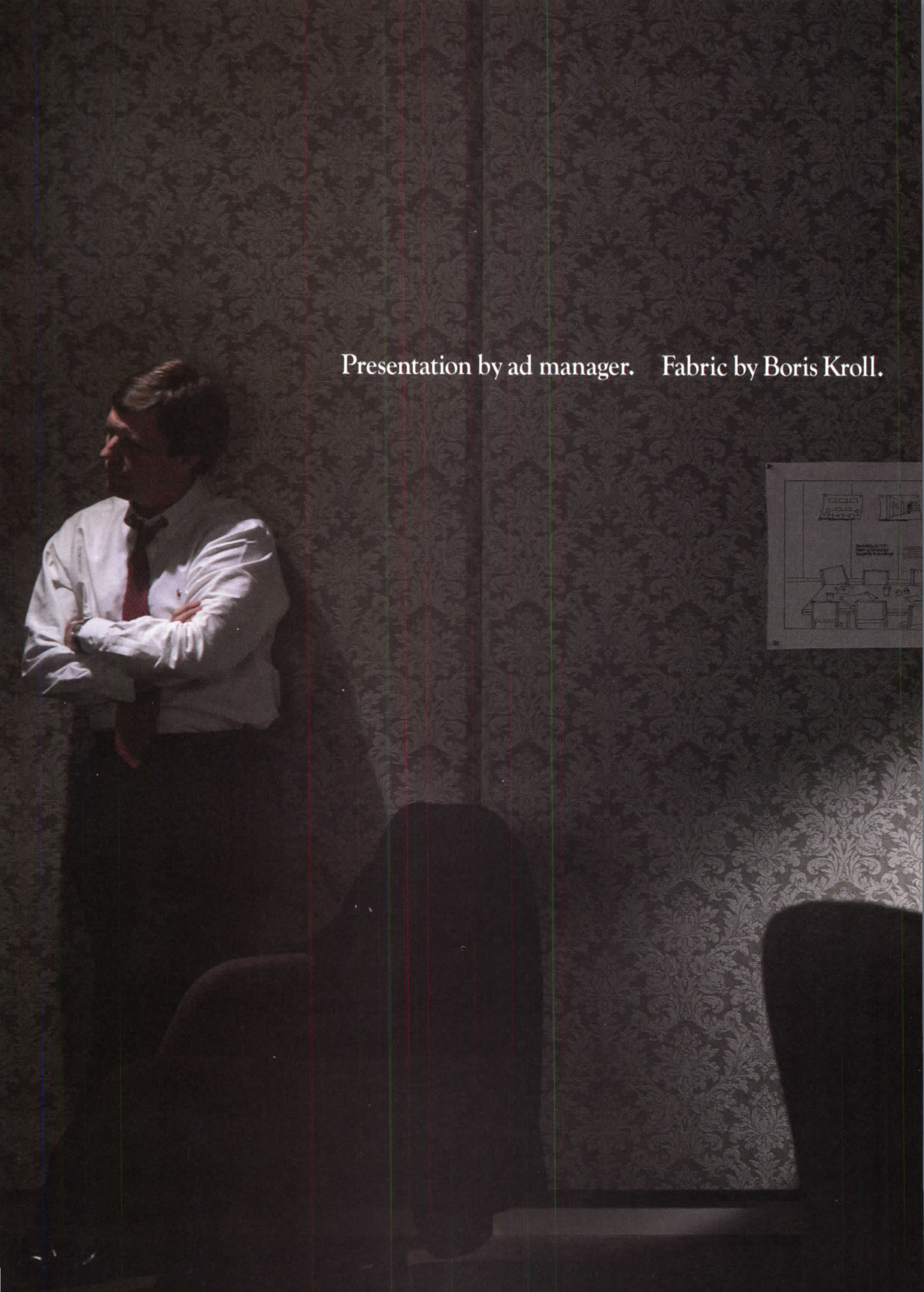
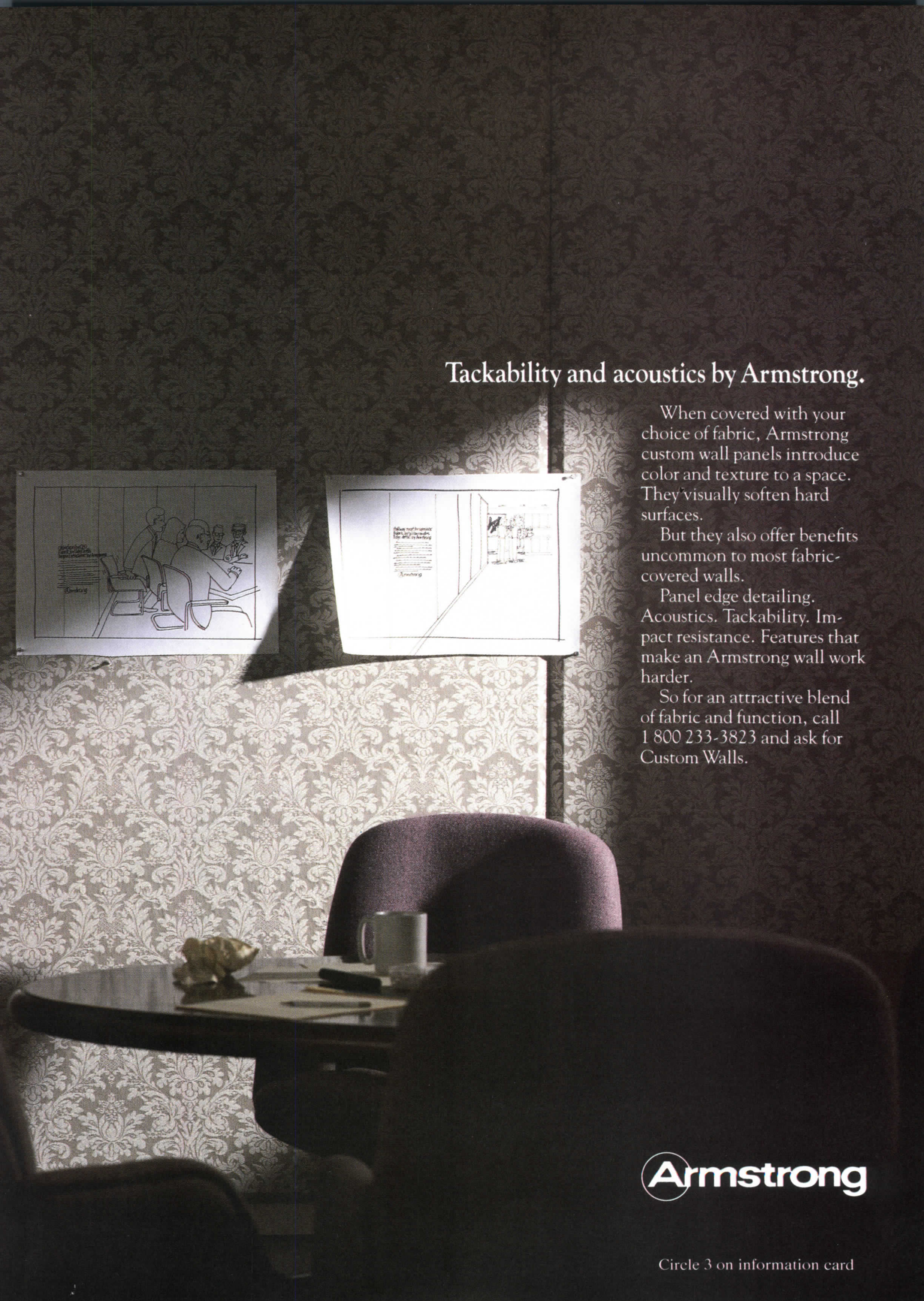

Presentation by ad manager. Fabric by Boris Kroll.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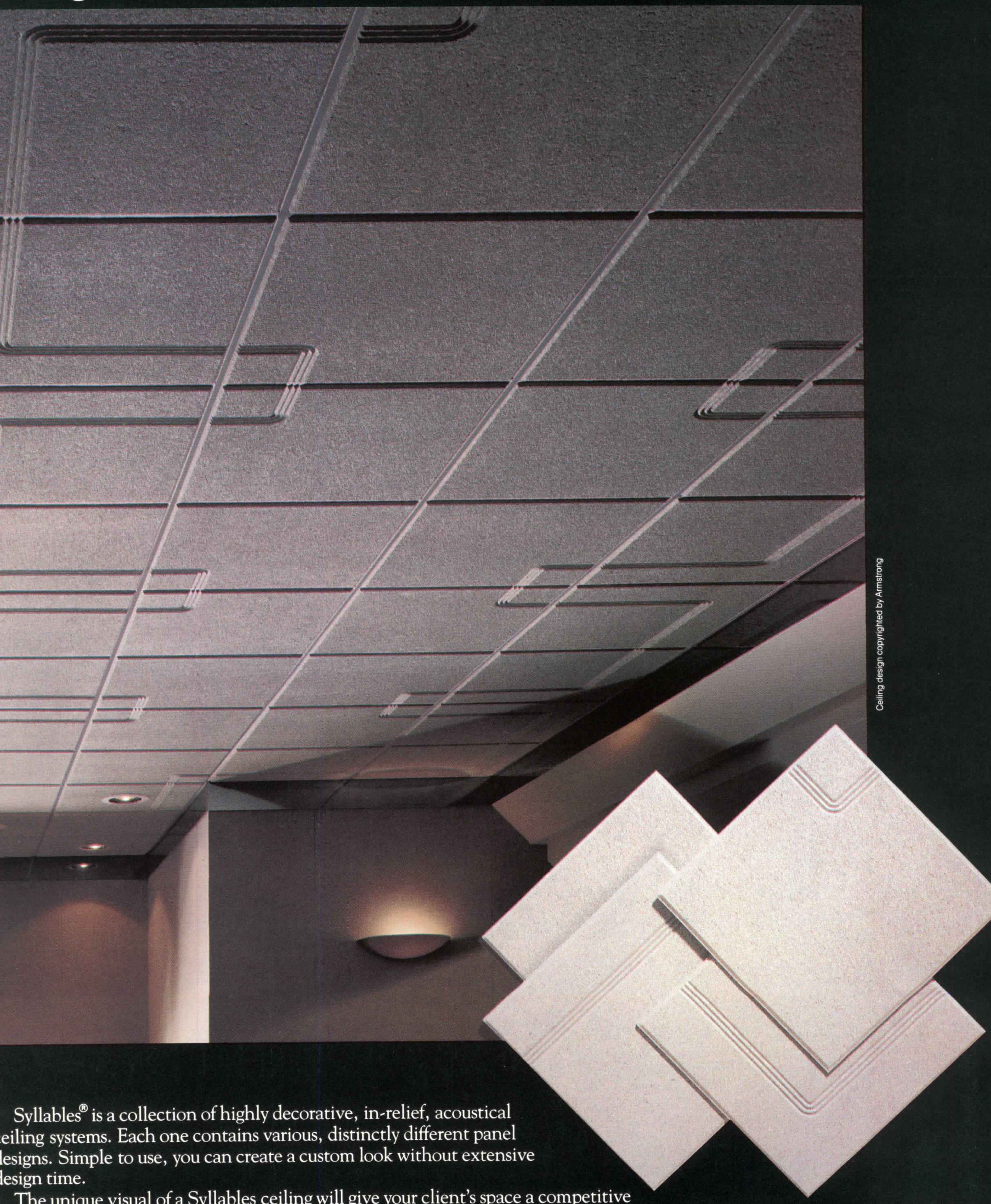

Ceiling design copyrighted by Armstrong

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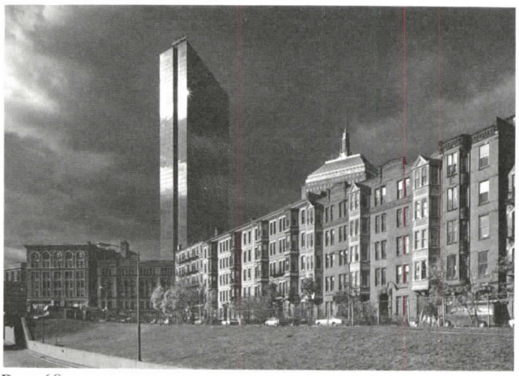
Structure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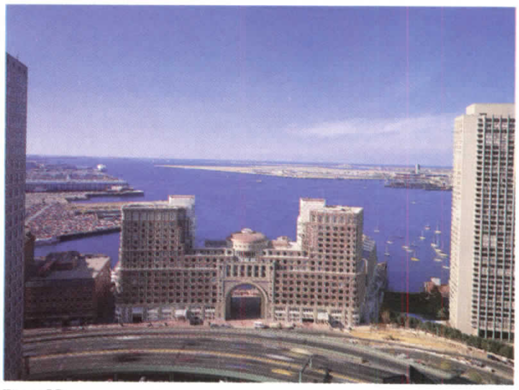
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ARCHITECTURE, publication number ISSN0746-0554, official magazine of the American Institute of Architects, is *published monthly* by the American Institute of Architects at 1735 New York Ave. N.W., Washington, D.C. 20006. **Individual subscriptions:** U.S. and its possessions: $37 for one year, $55 for two years, $72 for three years. Canada: $43 for one year, $63 for two years, $82 for three years. Foreign: $61 for one year, $103 for two years, $145 for three years. Single copies, $5 each (except for May and September issues, which are $10). Publisher reserves the right to refuse unqualified subscriptions. For subscriptions: write circulation department, ARCHITECTURE, 1735 New York Ave. N.W., Washington, D.C., 20006; allow eight weeks. Quotations on reprints of articles available. Microfilm copies available from University Microfilm, 300 N. Zeeb Road, Ann Arbor, Mich. 48106. Referenced in The Architectural Index, Architectural Periodicals Index, Art Index, Avery Index to Architectural Periodicals. Second class postage paid at Washington, D.C., and additional mailing offices.

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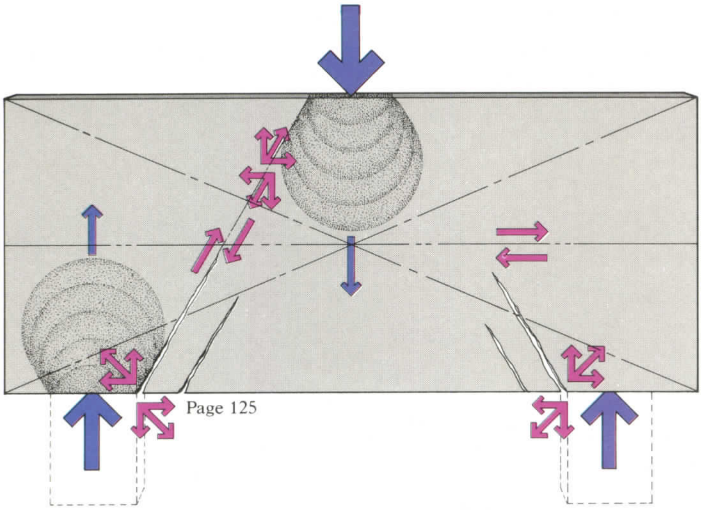

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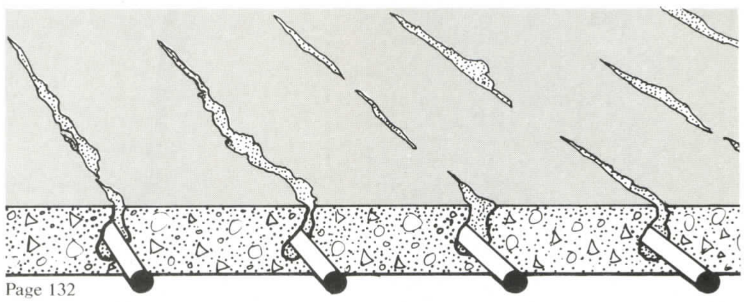

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Cover
McCormick Place expansion facility's roof suspension system with Chicago's skyline in the background (see page 100). Design by Skidmore, Owings & Merrill. Photograph © Nick Merrick Hedrich-Blessing.

News

YOU'RE LOOKING THROUG
TO DETECT HEAT & KEE

It may look like an ordinary double-pane window, but there's more to this glass than meets the eye.

What you can't see is the revolutionary, transparent coating which acts like a see-through computer designed to know the difference between heat and light. And that means you can specify a window that won't just last for years, it'll actually earn its keep.

THE ANDERSEN® HIGH-PERFORMANCE WINDOW. IT'S PROGRAMMED FOR COMFORT.

The technology behind this remarkable window is fairly complicated, but the results are easy to process.

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How? The secret is a series of microscopically thin layers of metallic coating bonded to an inner airspace surface of the glass. And while you can hardly see it, this programmed surface actually recognizes radiant heat and restricts its flow through the glass. It even filters out ultraviolet rays that fade fabrics. And all the while, it's practically invisible.

It works 365 days a year, day and night, no matter where your customers live or which direction their windows face.

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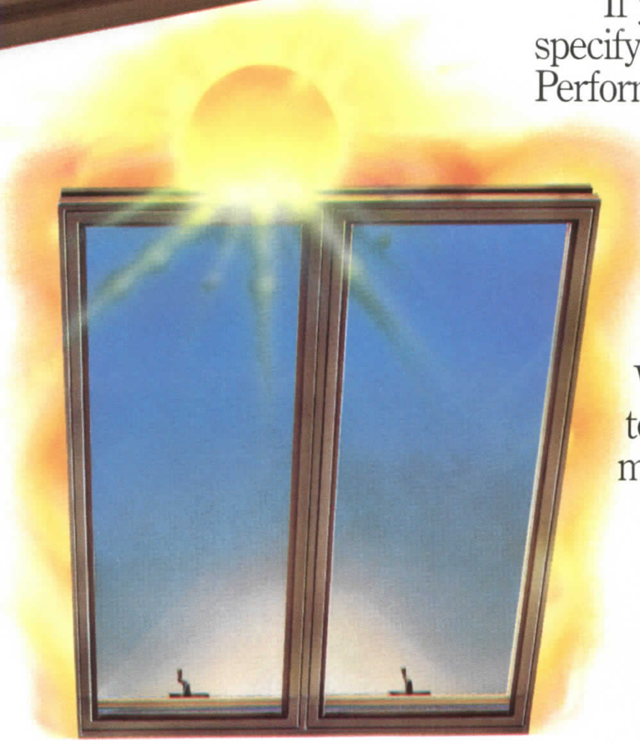
COMPUTER PROGRAMMED WHERE YOU WANT IT.

heating months, and 22% more efficient in the searing summer sun. And, as you would expect from Andersen, they look beautiful year around.

THE HIGH-PERFORMANCE SUN WINDOW. IT CONVERTS HOT SUN INTO COOL DAYLIGHT.

Andersen has taken the High-Performance window one step further for hotter climates and homes with a full western or southern exposure.



By adding a High-Performance coating to soft, bronze tinted glass, we've developed a window that reduces the sun's heat up to 2½ times better than an ordinary window. And while glare and fabric-fading rays are virtually eliminated, there's still plenty of visible light for people and plants to flourish. What's more, High-Performance Sun windows look handsome from the outside, yet colors aren't distorted when looking from the inside.

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If you're not already specifying Andersen High-Performance windows, contact your Andersen distributor, see Sweet's File 08610/AND, or write Andersen Corp., Box 12, Bayport, MN 55003. We'll show you how to make the world a more comfortable place.

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Andersen

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HOLOPHANE PARKLANE.
SHINES WITH THE LIGHTS ON OR OFF.

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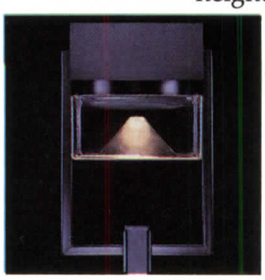
This high-powered fixture's extruded aluminum housing, with internally-welded seams, is available in either painted or anodized finish.



The seamless acrylic prismatic cone/cube helps reduce "puddles" of light at the pole base while projecting light in a wide overall pattern; one wide enough to reduce the number of fixtures and still provide up to a 6:1 spacing-to-height ratio.

The ParkLane luminaire integrates with practically any contemporary architectural theme.

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EVENTS

March 23-25: Ceramic Tile and Bathroom Furnishings Exposition, Miami. Contact: Trade Show International Inc., Italian Tile Center, 499 Park Ave., New York, N.Y. 10022.
March 27-29: International Congress on CIM Databases '88, Cambridge, Mass. Contact: Kim Takita, CAD/CIM Alert, 824 Boylston St., Chestnut Hill, Mass. 02167.
April 7-9: Conference on "The City of the 21st Century," Tempe, Ariz. Contact: Madis Pihlak, Conference Coordinator, Dept. of Planning, Arizona State University, Tempe, Ariz. 85287.
April 10-14: Solar Energy Conference, Denver. Contact: United Engineering Center, 345 E. 47th St., New York, N.Y. 10017.
April 12-14: Course on Engineering of Fire Detection and Alarm Systems, Hartford, Conn. Contact: Society of Fire Protection Engineers, 60 Batterymarch St., Boston, Mass. 02110.
April 13-14: Southwest Builds '88 Trade Show, Phoenix. Contact: Claire Kilcoyne, Practice Management Associates Ltd., 10 Midland Ave., Newton, Mass. 02158.
April 13-15: Conference on Waterfront Development, Bristol, England. Contact: Peter Arbury, C.C.W.T., 15 Colston St., Bristol BS1 5AP England.
April 13-15: Lighting World International Conference and Exposition, Los Angeles. Contact: Jacqueline Illonardo, National Expositions Co., 15 W. 39th St., New York, N.Y. 10018.
April 16-18: AIA design committee meeting entitled "18th-Century American Architecture," Annapolis, Md. Contact: Anne Howell at Institute headquarters, (202) 626-7429.
April 17-20: Manufacturing Science and Tech Program, Atlanta. Contact: Stuart Goldstein, American Society of Mechanical Engineers, 345 E. 47th St., New York, N.Y. 10017.
April 19-20: IIT/Chicago-Kent College of Law Annual Construction Seminar on Construction Documents and Disputes, Chicago. Contact: Steven Stein, Greenberger, Krauss & Jacobs, 180 N. LaSalle St., Chicago, Ill. 60601.
April 21-23: American Institute for Design and Drafting Convention and Technology Exposition, San Jose, Calif. Contact: AIDD, 966 Hungerford Dr., Suite 10-B, Rockville, Md. 20850.
April 22-24: Society of Environmental Graphic Designers Regional Meeting on Environmental Graphic Design Education, Baltimore. Contact: Sarah Speare, SEGD, 47 Third St., Cambridge, Mass. 02141.
April 27-30: Annual Convention of the National Wood Flooring Association, Kansas City, Mo. Contact: NWFA, 2714 Breckenridge Industrial Court, St. Louis, Mo. 63144.
May 15-18: AIA Annual Convention, New York City. Contact: John Gaillard at Institute headquarters, (202) 626-7396.

LETTERS

Architect as Catalyst: What a wonderful job [technical editors] M. Stephanie Stubbs and Douglas E. Gordon did in writing the case history of Liberty Center [Jan., page 108]. The writing is careful, correct, well-detailed, and wise. I don't know how they worked their way through that jungle of complexity—but they did. We are all very proud—doubly proud now.

David Lewis, FAIA
UDA Architects
Pittsburgh

'Strident Verticality': Prince Charles's forthright remarks about today's urban building designs deserve much attention [see Jan., page 22]. I hope that his courage, stature, and position will help us all to take another look, as we crowd ever closer in strident verticality.

Verticality may be here to stay, but a case in old English law is stated: "If your building casts a shadow on my land, I shall have an action against you." It may not be too late for common agreement, with some tax penalty for existing shadow monsters.

There is a strong urge for owners and designers of tall buildings on small, crowded plots, as close to city center as possible, to say: "We must make a building that will be *really* noticeable (and the tallest in town, if we can manage) and provide budget for attention-getting." This has led to urban fabrics of bunched, shadow-bound, weed buildings.

We have discussed with Sir Hubert Newton of Leeds and corresponded with Sir Desmond Heap about the concept of "density equity"—mutually agreeing to tax according to intensity of land use as well as building area and value—which could now, and probably in the days of horses, wheelbarrows, and muddy roads, diminish sheep-following overdensity.

It seems certain that thinning major centers would strengthen England's early new-town concept and, eventually, its major cities (ours, and the world's, too), using the principle of adequate urban taxes geared to relative intensity, to pay for the enormously escalating costs of servicing high density.

Urban taxes have probably always been higher than rural, but never enough to generate all the services such overdeveloped agglomerations need; and at some time long ago, the big city's asset value became a liability.

Robert E. Hansen, FAIA
Fort Lauderdale, Fla.

General Conditions: Dale Ellickson's letter to the editor in the December issue [page 12] responded to some of the issues I raised in my article "An Individual Look at the New A201" [Oct. '87, page 90]. Having been a documents committee member for 10 years, I am fully aware of the extent of discussion on issues, but there are times when the focus is on generalities rather than on the specific issue from the standpoint of real practice or on the potential exposure of the professional.

Although I will accept most of Mr. Ellickson's comments, I must continue to express grave concern over the revised definition of the term "Work" in the new edition (1.1.3). He states that the committee made a "conscious decision to include temporary facilities in the definition of 'Work.'" He appears to take the position that the contractor's obligations regarding responsibilities for construction means, methods, safety, temporary facilities, etc., under Subparagraph 3.3.1, will completely free the architect and owner from any responsibility for this portion of the revised definition of "Work."

The owner's right to stop the work (2.3.1), the architect's site visits to "determine if the Work, when completed, will be in accordance with the Contract Documents" (4.2.4), and the architect's authority to reject work (4.2.6) all do not make such a distinction that they only apply to the "permanent" portions of the work. Mr. Ellickson implies that the simple inclusion of "when completed" in 4.2.4 along with the language in 3.3.1 above will suffice. This is where we part ways.

I agree with his position that "the architect is concerned with the final result. The means of achieving it remains the responsibility of the contractor." The courts historically look not as much at the intent but at the language itself. Sooner or later, one is going to question, "Why did AIA make this revision to the definition of 'Work' but not to the architect's role in inspecting or rejecting the 'Work'? Was it an intentional desire to have the architect's responsibility broadened?" Although this truly was not the reason, can we be sure this will not increase the architect's exposure to litigation?

As I stated in the original article, I believe that the majority of the changes were very positive. I continue to caution all concerned that this particular revision to the definition of "Work" may prove to be a much more dangerous one than we can presently perceive.

Edward McCrary, FAIA
San Francisco

Corrections: The photographs of Liberty Center (Jan., pages 108-112) should have been credited to Carol M. Highsmith.

In a January news article (page 18) on an ACSA/AIA research conference, Donald Schon was erroneously listed as a professor of architecture. He is the Ford professor of urban studies and education in the department of urban studies and planning at MIT.

In the January article about Century City, the nearer building in the right-hand photograph on page 62 is the newer tower of the Century Plaza Hotel by Skidmore, Owings & Merrill/San Francisco.

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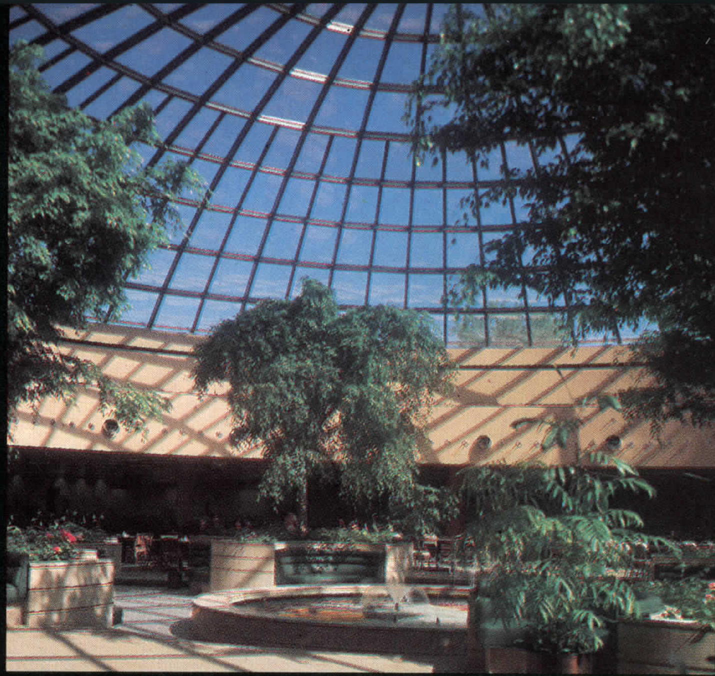

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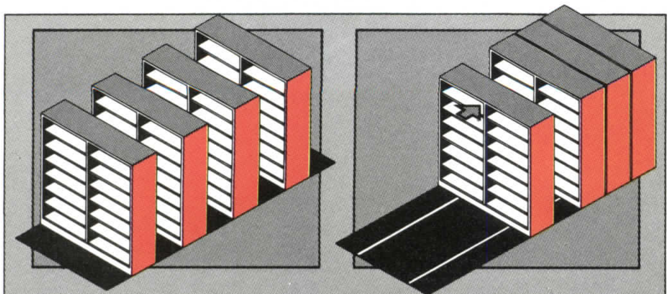

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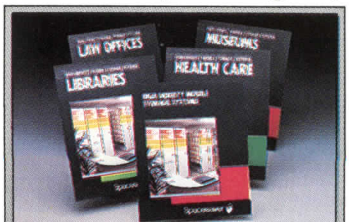

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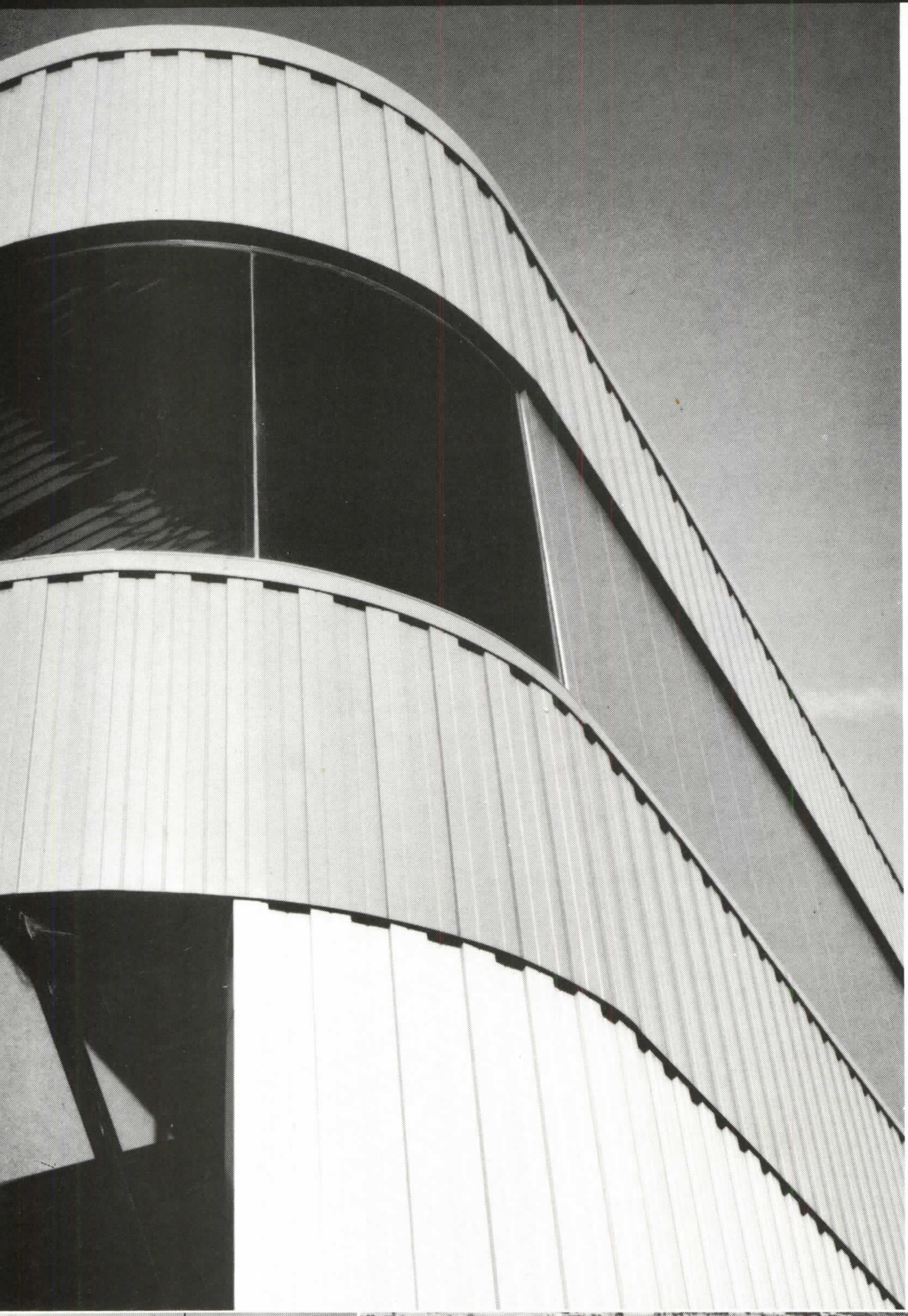

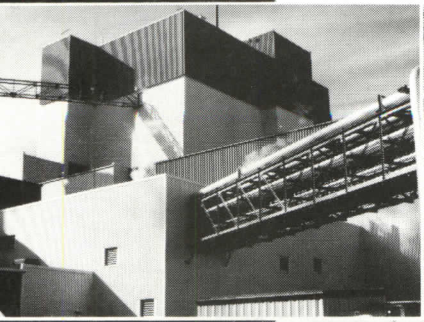

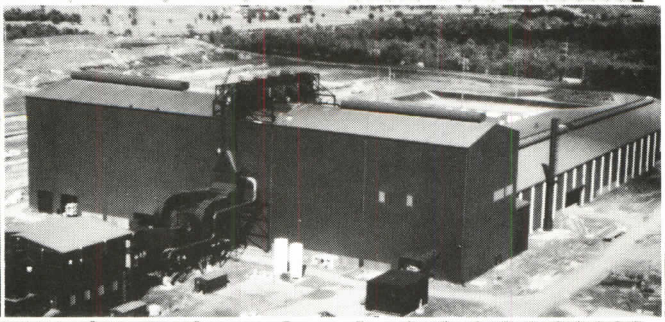

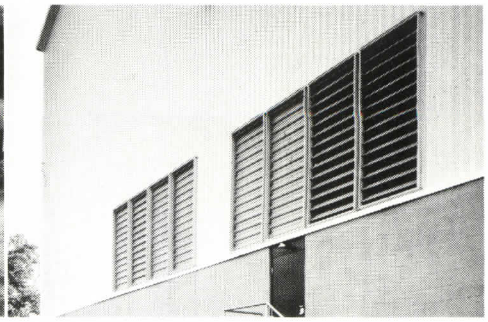

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determining the "aged" R-values of
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esign a roof that has to last 20 years
nore on a test that only evaluates six
nth's performance?

The Midwest Roofing Contractors
ociation has asked the same ques-
. That's why they've sponsored
dies which conclude that
se old insulation
ndards need to be changed
nore realistically reflect
g-term R-value.

We're looking forward to
government and industry
ndards. But in the meantime, isn't
ce to know that Koppers Rx is
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warranty.)

Sometimes Less Is More

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llows that it takes less of our insula-
to provide the same R-value as
isocyanurate foam insulation.

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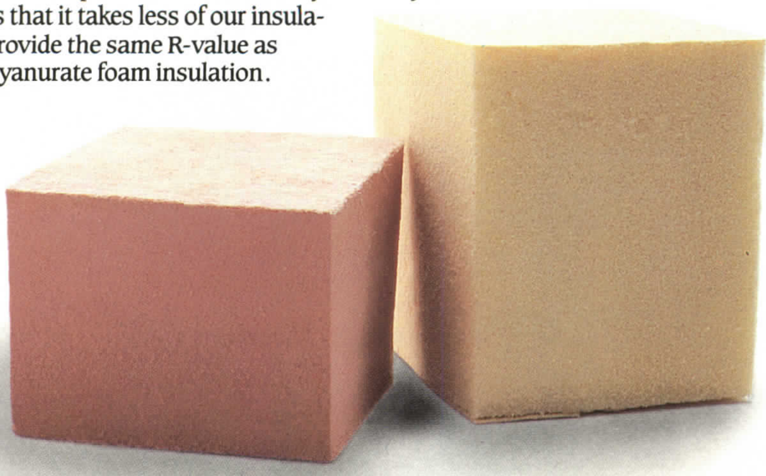
So specifying Koppers Rx will save money to start with. Then continue to save money with zero thermal drift for 20 years or more.



The Advantages Keep Piling Up

But saving money is just the beginning.

Koppers Rx offers low flame spread and smoke developed ratings. So using Rx in an hourly rated assembly could result in lower insurance costs for your building.

Rx Insulation is non-corrosive. And it's dimensional stability exceeds industry standards.

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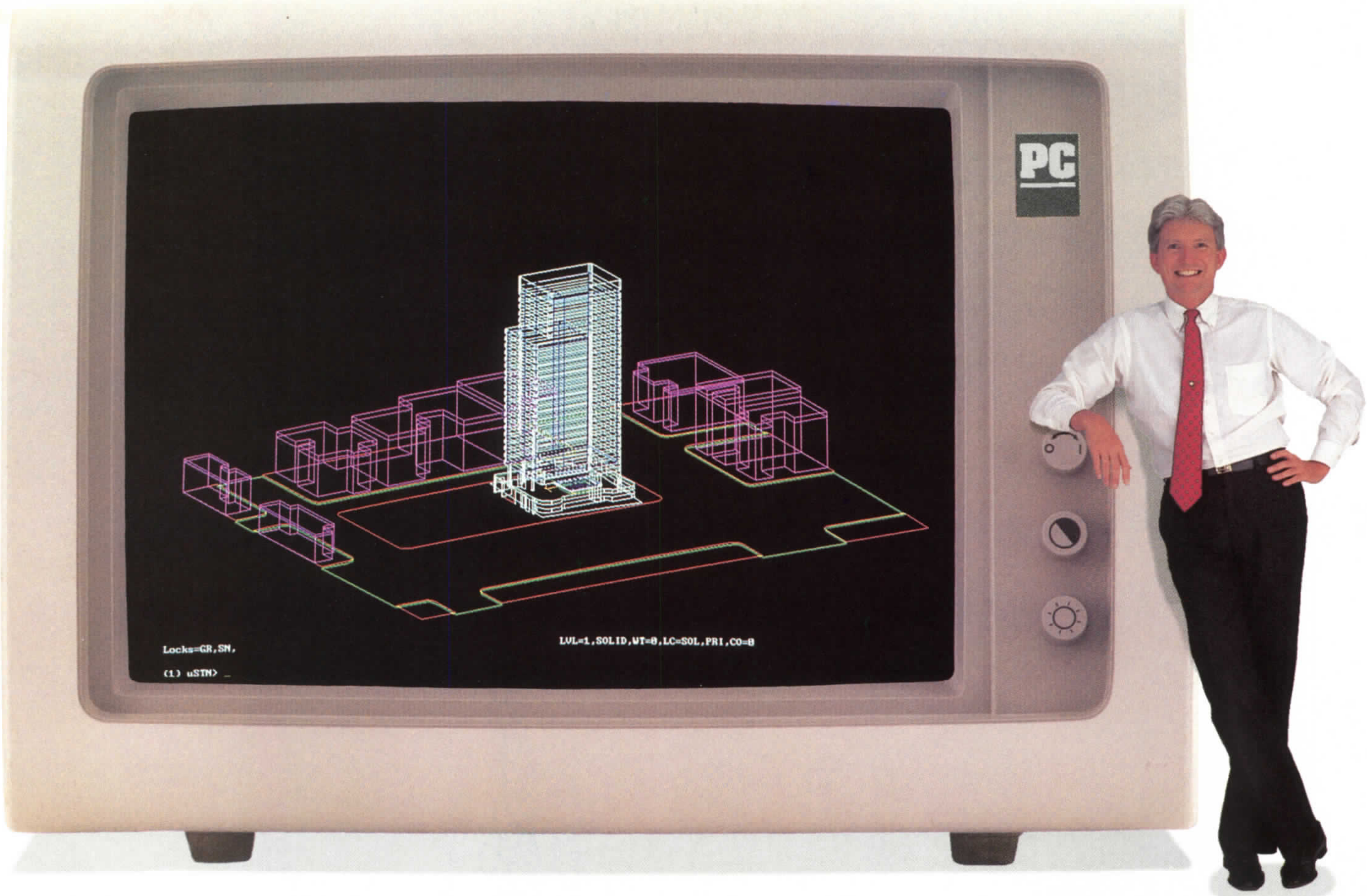

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Awards

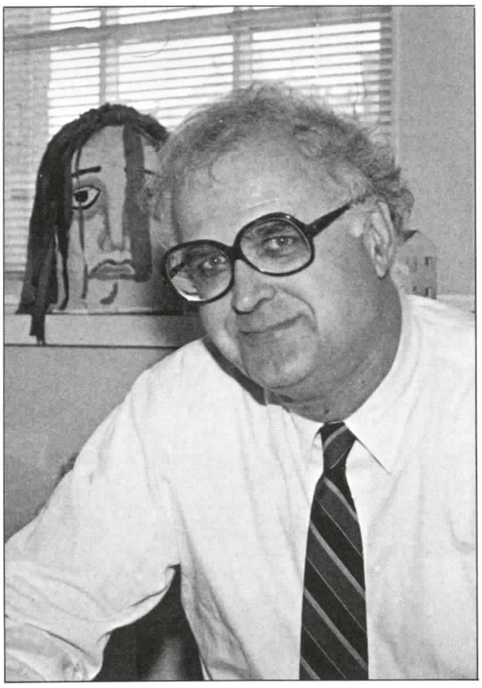
ACSA, AIA Honor John Hejduk For Excellence in Education

John Hejduk, FAIA, dean of the Irwin S. Chanin school of architecture at the Cooper Union in New York City, has been named to receive the 1988 Topaz medal for excellence in education, presented by AIA and the Association of Collegiate Schools of Architecture.

Hejduk was born in New York City in 1929 and as an undergraduate attended the Cooper Union, graduating in 1950. He received his first professional degree from the University of Cincinnati in 1952 and then a master's degree from the Harvard graduate school of design in 1953. As a Fulbright scholar he studied at the University of Rome school of architecture in 1954. While a student, he worked in various architecture offices in New York, including those of Richard Stein, FAIA, and I. M. Pei & Partners.

Hejduk began a career in teaching in the mid-1950s when he was offered a job by Harwell Hamilton Harris, who was heading the architecture school at the University of Texas at Austin and resuscitating it from stale, Beaux-Arts tradition. "Harris wanted to change the direction of the school," Hejduk remembers, and to that end hired a band of young Turks that included, along with Hejduk, Colin Rowe and painter Robert Slutsky. "We went hell or high water in introducing what we considered a fresh, new program," muses Hejduk, "and we all got fired." When the would-be Texas reformers moved back to the Northeast in search of work, says Hejduk, "our reputations preceded us and we couldn't find teaching jobs."

In 1958, after a number of years in full-time practice, Hejduk was offered a position at Cornell. He remained there for two years and then moved on to Yale, teaching under Paul Rudolph from 1961 to 1964. He returned to his first and favorite school, Cooper Union, in 1964 and was appointed dean in 1975. During his tenure he has invigorated Cooper as an architecture school where students are free to explore highly personal, intensive investigations of their discipline (see Aug. '84, page 42).



© Jose Pelaez

Hejduk resists being categorized as a teacher versus an architect or an artist. "My teaching, my writing, my drawing, and my building are all one," he says. "It's all part of my discipline and part of my practice. There are many ways to practice the discipline of architecture. I think architects have thought about practice in too narrow a way."

During his years as a student, Hejduk says he was exposed to a number of bright, dedicated teachers who left an indelible mark on his own life and work as an architect and teacher. Among them were Robert Gwathmey (father of Charles Gwathmey, FAIA), who taught freehand drawing at Cooper, and Pei, under whom Hejduk studied at Harvard. "They were good teachers," he says, "because they believed in discipline and training. And they believed in freedom, too. You knew you were in the presence of independent souls. They didn't look at their watch when they were teaching. They cared and they gave a lot."

Hejduk considers himself a member of a small and special group of people entrusted with the cultivation of new architects, drawing them out and awakening within them a passion for architecture. "I'm amazed that I can get as excited as I did when I was 17 about ideas," he says. "I consider myself fortunate and privileged that I was able to have this kind of work in my life. In this whole, great city of New York, there's only about 30 of us teaching architecture. How many people could be that fortunate?"

According to the *Oxford English Dictionary,* one of the earliest meanings of the title "dean" was a leader of 10 monks. "In a funny way it's still true," observes Hejduk. "It's the sacredness of education, the defender of the word. I think the most important thing I can give students is hope. Hope that they can change things, and they can. If they hold on to their beliefs, they can have an effect."

Hejduk's numerous books of architectural drawing and poetry and scores of international exhibits of his work have exposed students of architecture to the products of his teaching and practice. He has lectured and has been a visiting critic at schools such as Princeton, the University of Pennsylvania, McGill, Illinois Institute of Technology, UCLA, Berkeley, Cranbrook Academy, the Architectural Association in London, Zurich University, Oslo School of Architecture, and the University of Milan.

Writing on Hejduk's behalf in support of his nomination for the Topaz medal, New York City architect and Cooper Union graduate Elizabeth Diller seemed to best sum up Hejduk's contributions to his field: "John Hejduk's teaching, his architecture, and his writings have had a radical influence on my generation of architects, many of whom have had no direct relationship with him. Hejduk discourages imitators and disciples. His pedagogical strategy is deliberately indirect to foster the intellectual independence of his students. His teaching requires interpretation, his ideas surfacing, as they often do, through the riddle and parable of the raconteur. He provokes and unsettles the student, keeps him or her off balance, questions the accepted habits of thought. Hejduk wants to revive in the student that initial sense of wonder and urge to explore, which is so often lost in secondary education. Research and speculation breed within this context of questioning."

—Michael J. Crosbie

News continued on page 22


HOTEL
JEROME

Institute Honors to Six for 'Distinguished Achievements'

AIA has announced six recipients of 1988 Institute honors recognizing "distinguished achievements that enhance or influence the environment and the architectural profession." The honors will be conferred in May at AIA's annual convention in New York City.

The AIA jury on Institute honors was chaired by Adrian D. Smith, FAIA, of Skidmore, Owings & Merrill/Chicago. Other jurors were Hugh Hardy, FAIA, of Hardy Holzman Pfeiffer Associates, New York City; Carter Manny Jr., FAIA, of the Graham Foundation, Chicago; Stephen Moylan of CRS Sirrine Inc., Chicago; Shawn Sprinkel, Louisiana Technical University, Shreveport; and Pamela Tice of the Cathedral Church of St. John the Divine in New York City.

The honorees are:

• Spiro Kostof, professor of architectural history at the University of California, Berkeley, and author of *A History of Architecture.* He was cited for helping "to bring an awareness of architecture and its history to the American public," said the jury. Kostof hosted and wrote, in collaboration with Charles Guggenheim, the five-part public television series "America by Design."

• Robert Smithson, sculptor and site-oriented environmental artist. Best known for "Spiral Jetty" in the Great Salt Lake, "Amarillo Romp" in Texas, and "Broken Circle" in the Netherlands, Smithson was praised by his nominators for laying "the groundwork for current developments in site-specific public art" in the few short years of his productive life (1938-1973).

• Robert Wilson, playwright, theater designer, and director, who studied architecture at Pratt Institute and was apprenticed to Paolo Soleri before turning his talents to the theater in the mid-1960s. The jury cited Wilson for creating "monumental works that have received recognition worldwide," including operatic works based on such historical figures as Albert Einstein, Josef Stalin, and Queen Victoria. His sets (such as the Dutch production of "The Civil Wars" shown below) were cited by the jury as "universally powerful statements that have profoundly influenced the worlds of art and architecture."

• Sussman/Prejza & Co. Inc., the graphic design firm in Santa Monica, Calif., responsible (in conjunction with the Jerde Partnership) for the "successful graphic identity" of the 1984 Olympics in Los Angeles. Calling the firm a pioneer in the art of "urban enhancement," the jury said, "The elegance, care, and incredible attention to detail, in addition to their pushing back of conventional boundaries of what graphic design is, has been a true contribution to our built environment."

• The Loeb Fellowship in Advanced Environmental Studies, which gives midcareer design and planning professionals a year of independent study at Harvard University's graduate school of design. More than 200 architects, landscape architects, preservationists, photographers, artists, writers, and others have participated in the program since its founding in 1970. The jury commended the fellowship for "demonstrating in a special way that the study of design is a lifetime process in which both the academy and practitioner must continuously learn from each other and from the vast milieu of creative forces."

• The Society for the Preservation of New England Antiquities, Waltham, Mass. Founded in 1910 for the "purpose of preserving for posterity buildings, places, and objects of historical and other interest," the society maintains 45 historic buildings and operates a conservation center and an archive collection of photographs, prints, drawings, manuscripts, and other documents. Its nominators said, "The foundation has carried out this mandate with extraordinary success and has indeed become the model for preservation organizations throughout the U.S. and abroad."

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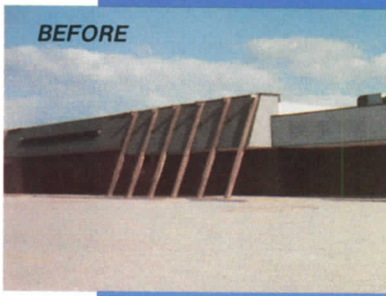

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Six Buildings Recognized by American Wood Council

The American Wood Council has recognized six buildings in its 1987 nonresidential wood design award program. In selecting the six projects out of 117 entries, the jurors noted that the diversity of wood use among the winners "underscores the versatility of wood, whether painted or stained, in rustic or formal settings."

Pinecote, an open-air pavilion set in a pine savanna at the Crosby Arboretum in Picayune, Miss., designed by Fay Jones & Maurice Jennings Architects of Fayetteville, Ark., won the top honor award. The pavilion is built of pine columns that repeat the upright forms of timbers in the surrounding landscape.

Merit awards were presented for four buildings. Whitfield Square, an elegant, clapboard-sided remodeling by Jackson & Page Architects, Guilford, Conn., was cited for its "classical styling that reflects the prevailing character of Georgian and colonial buildings in Guilford." Atwood Barn, Glen Ellen, Calif., by Dutcher & Hauf Architects of Berkeley, was praised by the jurors for its "authentic spirit" and for "coexisting gracefully with its rural setting." The other two merit-award winners are located in the planned community of Seaside, Fla.: Per-spi-cas-ity Market, a seasonal boutique of eight small plywood shops by Deborah Berke, Architect, of New York City; and Ruskin Street Beach Pavilion, built at the base of a street, by Stuart Cohen & Anders Nereim Architects, Chicago.

Shen/Glass Architects of Berkeley was honored with a citation for the Mathematical Sciences Research Institute at the University of California, Berkeley.

Jurors for the awards program were William Tillman Cannady, FAIA; Doug Kelbaugh, AIA; Melanie Taylor; and Mark Simon, AIA.—Karen Collins

Preservation

Unity Temple Granted First Easement on a Religious Building

The Unitarian Universalist Church of Oak Park, Ill., has signed an easement agreement with the Landmarks Preservation Council of Illinois to protect the exterior and historic interior spaces of Frank Lloyd Wright's Unity Temple in perpetuity and provide guidelines for future restoration work. By a unanimous vote of the congregation, it became the first church in the United States to grant a preservation easement for a historic building.

The issue of landmark designation for religious buildings has sparked controversies around the nation. Church leaders and congregations in numerous cities have fought landmark designation, arguing that it will unfairly burden them with the preservation of buildings that are costly to maintain and that the responsibility will interfere with their theological and social missions. The ongoing battle in New York City over a proposal by St. Bartholomew's Church to build an office tower on the site of its historic community house and garden has resulted in an attempt by some religious groups to declare landmark designation of a church an unconstitutional infringement on the separation of church and state. In Chicago, the city's preservation ordinance recently was amended to exempt religious properties from landmark designation if the church requests an exemption.

In announcing the Unity Temple agreement, Carol Wyant, executive director of the Landmarks Preservation Council of Illinois, said, "This easement is a breakthrough for historic preservation. It not only ensures that Unity Temple will be preserved, but also provides a model for cooperation between preservation organizations and religious bodies on the sensitive issues of preservation of religious properties."

Completed in 1906, Unity Temple is one of only two nonresidential buildings Wright designed before 1910 (the other, the Larkin Building in Buffalo, N.Y., was demolished in 1949). Unity Temple is located on a prominent site in Oak Park, near the Frank Lloyd Wright historic district and his home and studio. In addition to serving the needs of an active congregation, Unity Temple has been used for numerous Oak Park community and social activities.

Over the years the Unity Temple congregation has considered the maintenance of the building a special responsibility and has undertaken restoration and preservation as funds allowed. In 1973, a separate, not-for-profit corporation, the Unity Temple Restoration Foundation, was established to assist the congregation. The church and foundation have spent almost $500,000 to restore the Wright building. The issue of an easement has generated renewed interest in preservation of the building. "The easement is now serving as a catalyst for a more enthusiastic and aggressive restoration campaign," said Sean Murphy of the Preservation Council.

The placing of an easement on the Unity Temple legally requires the congregation to maintain the building in its historic appearance and gives the Preservation Council the authority to monitor and review the building to ensure that its architectural integrity is maintained.

The decision to grant the easement was reached after lengthy discussion and a vote by the entire congregation. Some members questioned whether the church would be able to live up to the agreement. Despite concerns that placing an easement on the building would create a financial burden and could raise legal questions, the congregation unanimously approved the agreement.

According to church member David Segal, the consensus of the congregation was that the present membership has a responsibility to both past and future congregations to ensure that the unique building is preserved and continues to serve the community. The members believe that Wright's building and his theory behind its design are integral to the mission of the church, and therefore all attempts to ensure its preservation must be made. "There was a feeling among the congregation that things just wouldn't be the same without the marvelous Wright building," Segal said.—Lynn Nesmith

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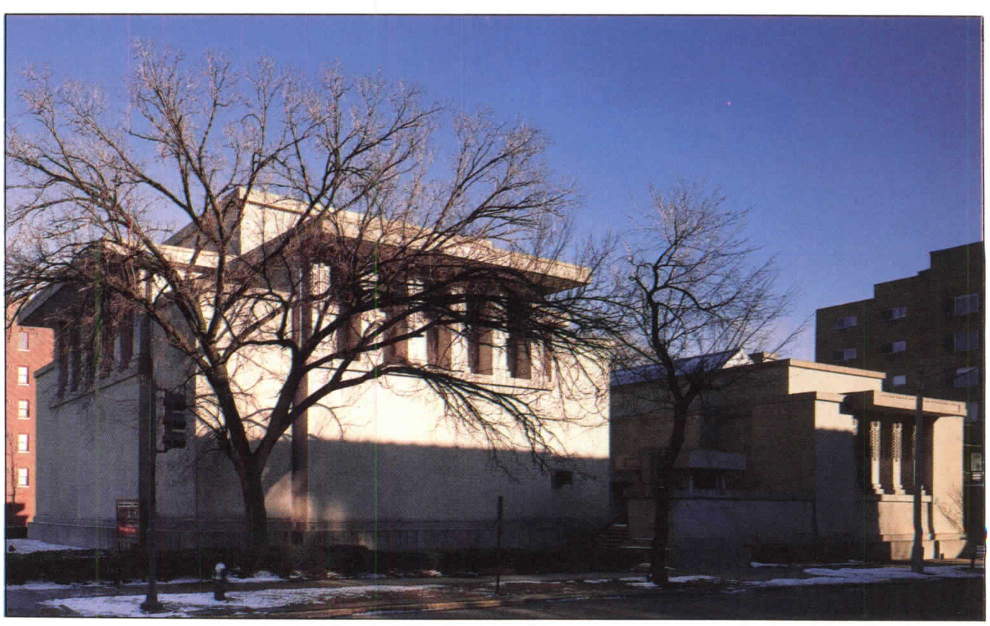

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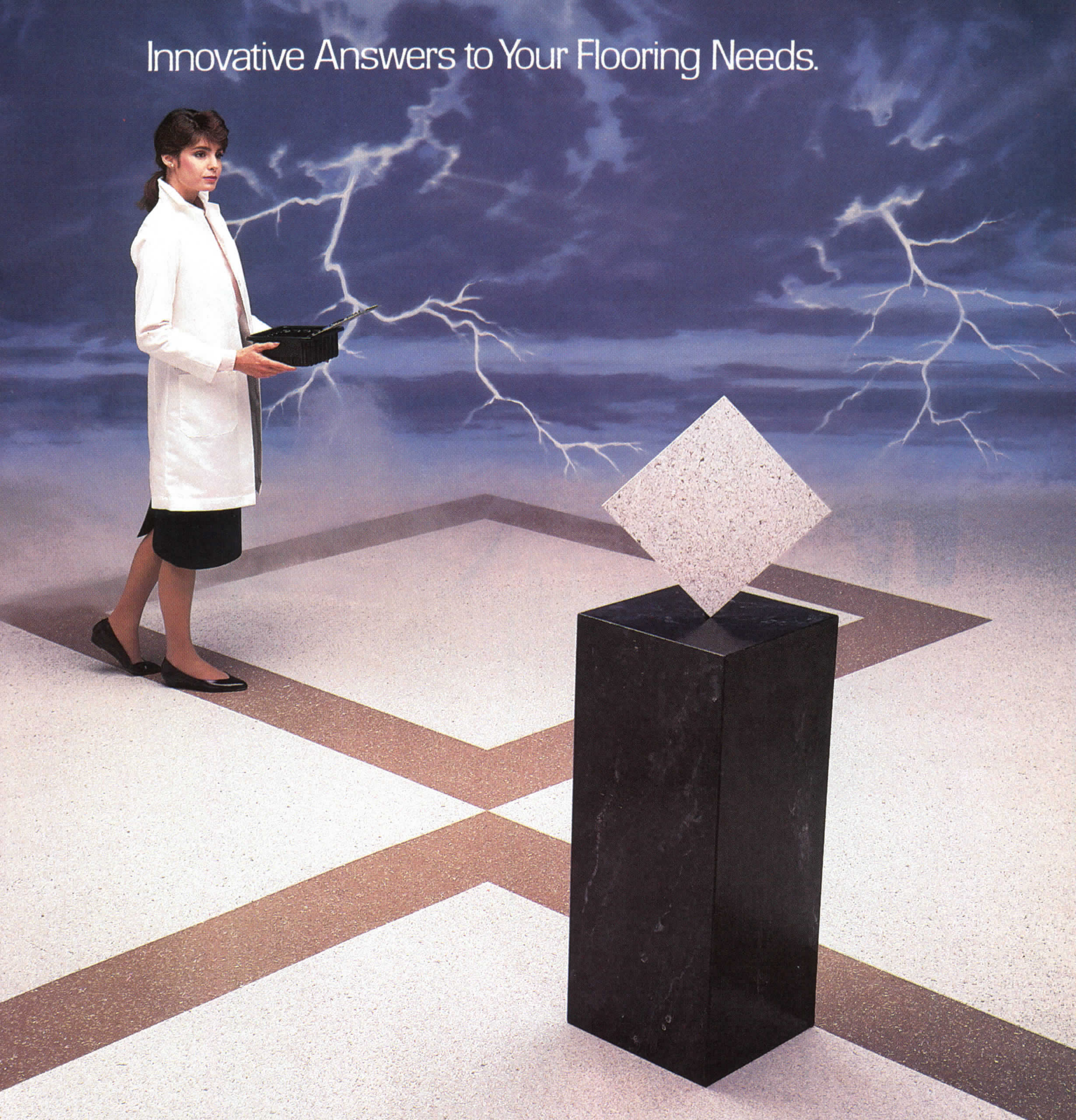

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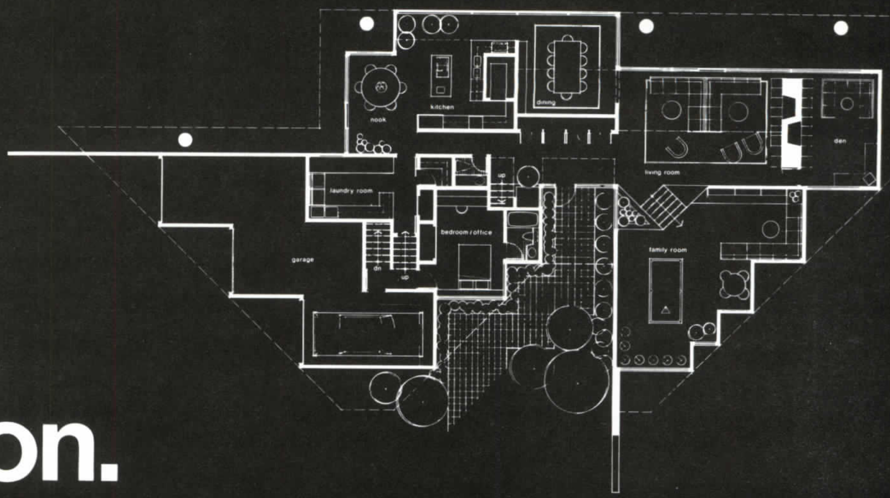

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Greene & Greene's Blacker House Fixtures Still Endangered

When last we looked in on the Blacker House (Aug. '85, page 16), the prospects of that Greene & Greene landmark were brightening in the wake of a major crisis. Texas rancher Barton English had bought the 1907 Pasadena, Calif., residence and immediately stripped it of nearly 50 integrally designed light fixtures estimated to be worth about $1 million on the antiques market. Some were put up for sale by antique dealer and English confederate Michael Carey, while others went into English's own collection at his Stonewall Ranch. The English-Carey enterprise was quickly dubbed the "Texas Chainsaw Massacre." After considerable furor in preservation circles and in the national press, English seemed open to an offer from Pasadena Heritage to remarket the house to a more sympathetic buyer after the fixtures were returned. A happy ending thus appeared possible. Furthermore, to reduce the chance of similar actions, Pasadena passed a law requiring approval of any alterations to the 40-odd Greene & Greene houses within the city limits.

Since then, however, the situation has deteriorated badly. After his initial interest, English rejected the offer to resell the house. And late last year he applied for permission to remove three doors and seven windows, even though, according to Pasadena City Director Rick Cole, he had long ago promised that nothing more would be removed. (Similarly, Randall Makinson, curator of the Greenes' Gamble House, has said that Carey assured him that the Blacker House would be kept intact after English took title.)

Acting through a San Diego attorney, English sought approval to replace the doors (estimated to be worth $330,000) and windows "with nearly identical reproductions . . . virtually indistinguishable from the originals." The city's Cultural Heritage Commission denied permission for a 45-day period and is expected to do so on seven more occasions, thereby providing 360 days' protection. After that, English is free to do whatever he wishes with the artifacts.

By all accounts, the reproductions will be of high quality. Glass artisan Paul Crist, who has completed the doors and is under contract to do the windows, is well regarded as a technician. But to many Pasadenans this is not the significant issue. Local artisans experienced in craftsman-period restorations, while acknowledging Crist's skills, assert that they would not do such work themselves. Woodworker Tom Gardner says he "wouldn't take anything out. I want to see those things stay in Pasadena." Glassworker Bob Tatosian would be willing to work with new owners in restoring the Blacker House but says, "I couldn't live with myself—I wouldn't feel right" about making reproductions that would enable a Greene & Greene owner to remove original artifacts. "They would never look right in any other home."

Makinson, who often is asked to recommend craftspersons, says: "I wouldn't leave Paul Crist out, but I would also say that I was unhappy that he did the work for Barton English." Clare Bogaard of Pasadena Heritage says she "would never recommend anyone who worked on Blacker House reproductions."

Based within greater Los Angeles but well outside Pasadena, Crist acknowledges that local feelings have run high over the issue, but he dimisses the reaction as "just local politics—wishful thinking." He says, "I don't like seeing [the removal of integral artifacts] any more than anyone else, but it's a fait accompli. . . . There's not that large a group conscience. Collectors get pretty rabid." Makinson endorses that last statement, opining that "Michael Carey would like to sell fireplaces, stairwells, and even whole rooms."

Makinson feels that Pasadena's so-called Greene & Greene law "is absolutely useless—it doesn't protect a thing." He would like to see the city adopt "an unbuilding code—if it can regulate what people build, it should also regulate what they un-build." Carey, on the other hand, reportedly has said that the present law is an unconstitutional abridgment of property rights. That law replaced a much tougher emergency measure that had been deemed too restrictive, and Makinson is not alone in feeling that 360 days of protection, limited to roughly 40 Greene & Greene residences, is not adequate for Pasadena's rich lode of turn-of-the-century domestic architecture. But local officials and preservationists also point out that Makinson was conspicuously absent from the debate at public hearings concerning the legislation.

Clearly, the present law is only as strong as the scruples of historic property owners. In the past, English has paradoxically claimed to be a better preservationist than those who were attempting to negotiate with him for the return of the light fixtures. One Pasadenan is now wondering why he doesn't take the reproduction doors and windows, "constructed with uncompromising faithfulness to the originals," back to Texas and leave the authentic ones in place. Moreover, if the copies resemble the originals as closely as claimed, can anyone be sure the intended substitution hasn't already taken place? In January, English declined to discuss the Blacker House with ARCHITECTURE, saying he was too busy. Many preservationists no doubt would agree.—JOHN PASTIER

Blacker House original main entry doors, which English seeks to replace.

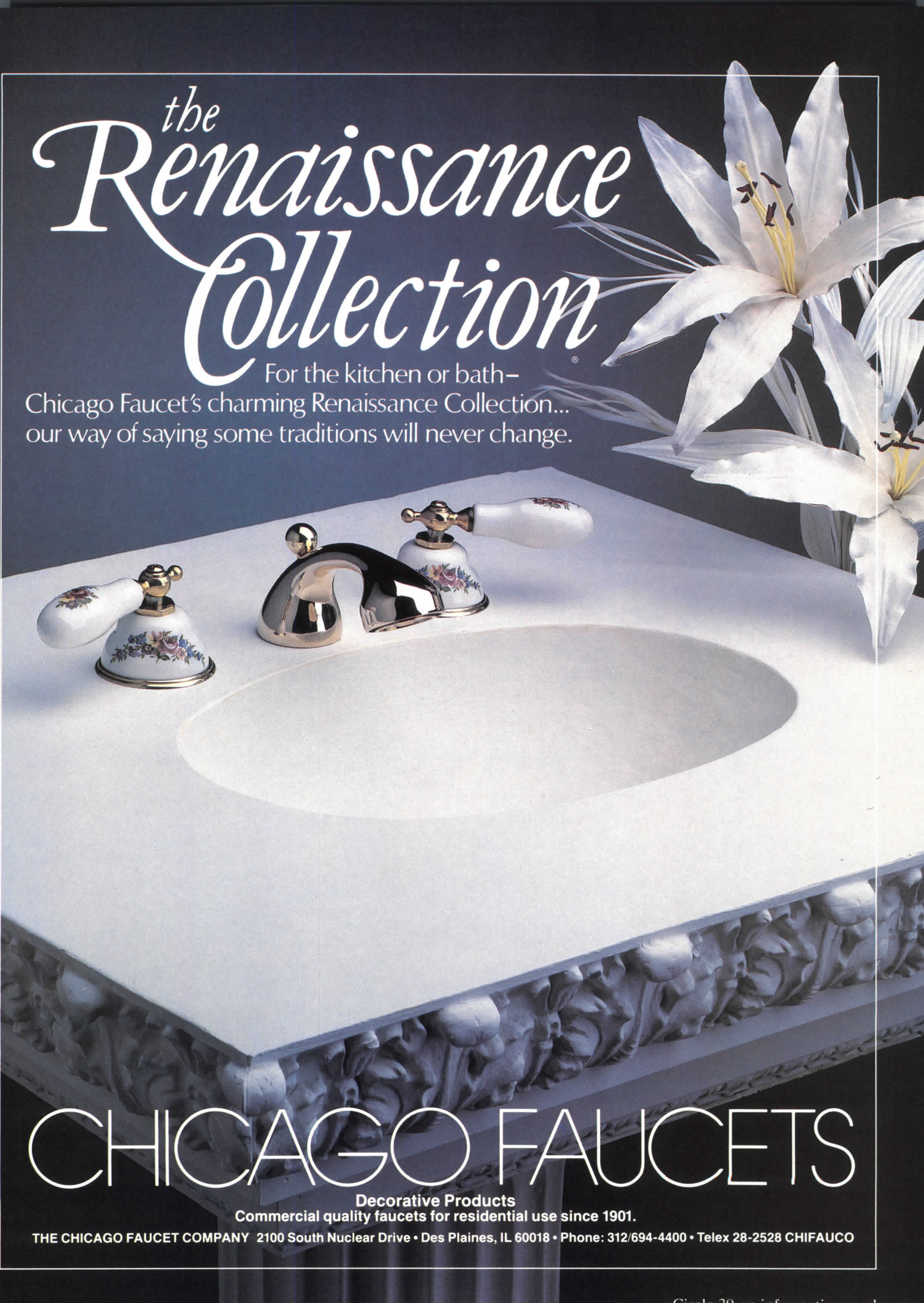
© Marvin Rand

Usonian House Anchors Disjointed Wright Exhibit

"Frank Lloyd Wright: In the Realm of Ideas" is an exhibition of parts rather than wholes, peculiar circumstances in which to meet the high priest of organic architecture. The most compelling item by far is the Usonian Automatic House erected in front of the Dallas Museum of Art. The remainder of the exhibition, located across the street in the Trammell Crow Center Pavilion, is a jumble of images, artifacts, and rhapsodic statements from the master, often fascinating in themselves but adding up to a disjointed introduction to the most astonishing career in American architecture.

The confusion is a product partly of miscalculation and partly of unfortunate circumstances. The exhibition was organized by the Scottsdale Art Center and the Frank Lloyd Wright Foundation "to convey an understanding of Frank Lloyd Wright's major ideas." It is directed at laymen rather than scholars, depending heavily on models, drawings, and large color photographs, and dispensing almost entirely with plans and elevations. However, the foundation has been criticized so often for deifying

continued on page 34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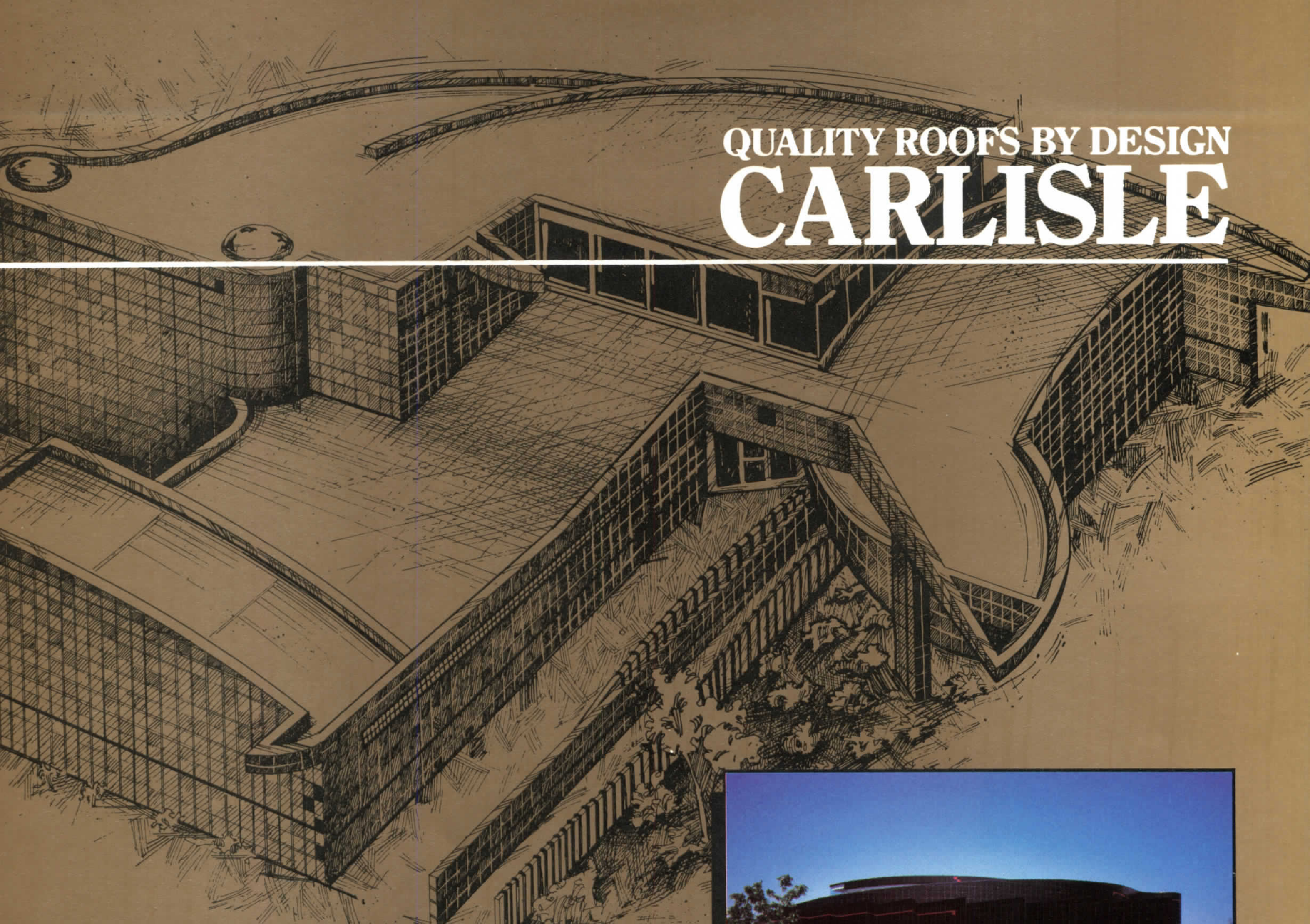

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Preservation *from page 30*
Wright that this time out it chose to forgo interpretative commentary altogether. Wright's is the only point of view expressed, served up in pithy quotations from his writings. There is not even a chronology to remind us of the simple yet awesome fact that Wright was born a few years before the Great Chicago Fire and lived until the eve of the Vietnam War.

However sensible this approach may have seemed in the abstract, it is dismaying to the general audience for whom the exhibition is intended. Of its four thematic units—"The Destruction of the Box, The Nature of the Site, Materials and Methods, Building for Democracy"—only the first hangs together. Images of the Coonley House, the Larkin Building, Fallingwater, and other pivotal projects illustrate Wright's continual struggle to escape from the foursquare, rectilinear plans of the 19th century into a free-flowing interior space, where walls become screens and corners give way to cantilevers. The message is reinforced by curvilinear wall panels and large arcing baffles suspended like mobiles from the ceiling.

But if the packaging is impressive, the contents frequently are not. The show is essentially a reiteration of familiar Wrightian ideas rather than a fresh interpretation of them. More problematic is that they are served up in a vacuum. Breaking the box was a major achievement of modern architecture, yet one could leave the exhibit convinced that Wright hit on the idea all by himself, without assistance from contemporary developments in Europe or earlier experiments by arts-and-crafts architects here and abroad. A brief historical overview would provide a glimpse of the context in which Wright's ideas developed without diminishing his extraordinary achievements.

The section called "Materials and Methods" is even more disappointing because the collection of models, original drawings, furniture, and decorative objects promises so much. The model of the Arizona State Capitol project deserves a room to itself. Wright was the supreme materialist whose work reads like a history of modern construction. Yet most of this must be intuited in this exhibition. There is no indication of how his experiments with wood and concrete were related to later innovations in the use of glass and sheet metal, or how all of these come together under the broader heading of organic architecture. We search in vain for clues to the methodology that produced such extraordinary buildings.

One reason the Usonian Automatic House is so appealing may be that it explains itself. The original 1955 design called for concrete block, laid up without mortar and tied together with steel rods. To make disassembly and transportation easier, the exhibition version consists of a polystyrene core sandwiched between laminated board and covered with Dryvit. It is visually convincing, despite some last-minute compromises in construction because of bad weather.

The organizers of the exhibition make it clear that they are not presenting the Usonian Automatic House as an answer to contemporary housing problems, but only as an illustration of the untapped potential of modular construction. It is certainly a splendid essay in economy of means, feeling far grander than its 1,800 square feet because of Wright's deft manipulation of ceilings and walls and his masterful handling of light. Complex effects are created by the rearrangement of simple elements. A corner block, turned upside down or on its side, becomes a roofline ornament or part of a pergola. One thinks of the ingenuity of today's average home builder and sighs.

After Dallas, the exhibition travels to six more cities, including Washington and Chicago. Changes are already under way, starting with the addition of text panels to summarize the four main themes of the show and to place Wright's work in historical perspective. Labels will be added to distinguish built from unbuilt work, a matter of much confusion to viewers at the moment.

Because of scheduling conflicts, the Dallas Museum of Art could accommodate only the Usonian House. Everything else had to be displayed in a pavilion across the street, which consisted of three discrete galleries on two levels. For an exhibition that was already conceptually frayed, this physical fragmentation was nearly a coup de grace. Future locations should be kinder.

"Frank Lloyd Wright: In the Realm of Ideas" doesn't pretend to be the major retrospective its subject deserves and has yet to receive. It is an amiable primer directed primarily at the person on the street, an attempt to invest powerful ideas with contemporary meaning. With work, it may yet accomplish that modest goal and set the stage for a more intellectually ambitious exhibition.—David Dillon

Interior view of the exhibition's re-created Usonian Automatic House.

Barth Tillotson

Government

Congress Approves First Major Housing Bill in Seven Years

One month after defeating a major housing bill, the U.S. Senate reversed its decision and passed the first independent housing and community development authorization bill since 1980.

In late November the Senate had rejected a bill that had been passed with strong bipartisan support in the House of Representatives. To revive the bill and gain the necessary Senate votes, House and Senate negotiators made several technical modifications and reduced some authorization levels to assure that overall funding did not exceed $15 billion. These changes met administration recommendations, and the President was expected to sign the legislation in February.

The approved bill authorizes $15 billion for housing and community development in fiscal 1988 and $15.6 billion in fiscal 1989. The two-year measure provides $7 billion annually for low-income housing assistance, $1.5 billion for public housing operating subsidies, and $225 million for urban development action grants (UDAGs).

The bill also authorizes $3 billion for community development block grants (CDBGs). Within this $3 billion, $5 million is allocated for public housing child care demonstration. This bill also requires that 60 percent of the block grant funds be spent for low- and moderate-income persons. Communities that receive these revenues are also required to assess the housing needs of the homeless and to develop housing assistance plans. Authorized block grant activities were expanded

continued on page 39

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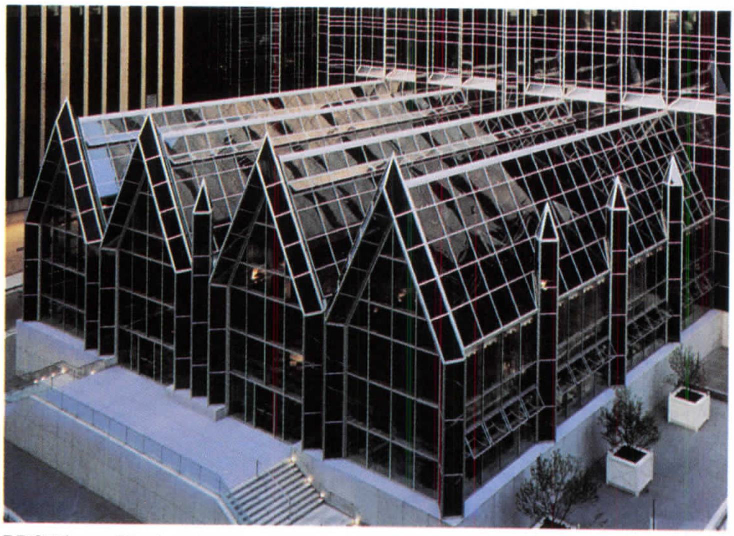


PPG Place, Pittsburgh

Trump Tower, New York

Collin Creek Mall, Dallas

Government *from page 34*
to include housing rehabilitation and the establishment and operation of 911 emergency telephone systems for two years.

Current levels of funding would remain constant, but the approved measure would terminate the housing development grant program at the end of 1989.

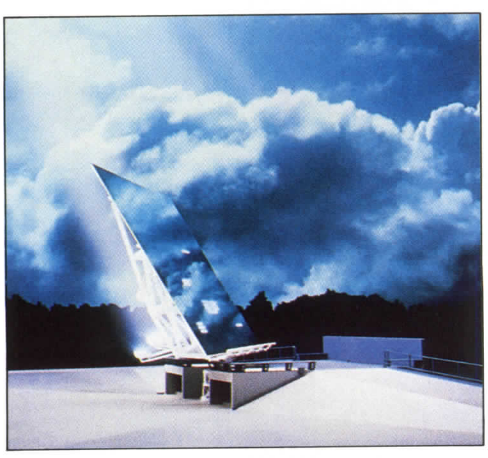
A provision authorizes replacement housing and relocation assistance for persons displaced by CDBG and UDAG projects, although implementation of this provision was delayed until fiscal 1989. Low-income direct displacees would be guaranteed affordable replacement housing for 10 years, and five years of rental assistance payments would be required for other direct displacees.

San Francisco Firm to Design Astronauts Memorial

The San Franciso firm Holt Hinshaw Pfau Jones was selected as the winner in a national design competition for a memorial to honor the astronauts who have lost their lives in the pursuit of space exploration. The memorial will be constructed on a six-acre site near the entrance to the visitors center at the Kennedy Space Center in Florida. The competition was sponsored by the Astronauts Memorial Foundation, a nonprofit organization founded after the space shuttle Challenger tragedy to construct a memorial.

Holt Hinshaw Pfau Jones was awarded $25,000 for its proposal, entitled "Space Mirror." The winning scheme has a 50-foot-wide and 40-foot-high wall of mirror-finished granite. The names of the 14 honored astronauts, grouped together by the final mission on which they flew, are cut through the granite. In making their selection, the jury cited the winning design as a "very poetic use of technology."

The other finalists were Donald C. Paine of Summerville, Mass. (second place), and John P. Blood and Craig D. Newick of New Haven, Conn. (third place). Honorable mentions were also presented to Karl Ermanis and Brad Vokes; Darell Fields; Keith and Kathryn Rabuse; Khanh Ba Nguyen; and Pablo Diaz, Bruce Gemmell, Ludmilla Pavlova, and Gwendolyn Butler of Michele Bertomen Architects.



© Holt Hinshaw Pfau Jones

The Institute

Asimov and Harris to Speak At AIA's New York Convention

Science fiction author and biochemist Isaac Asimov and pollster Louis Harris are scheduled to speak at the national AIA convention to be held May 15-18 in New York City. In addition, a number of presentations and panel discussions are planned that will address the convention's theme, art in architecture.

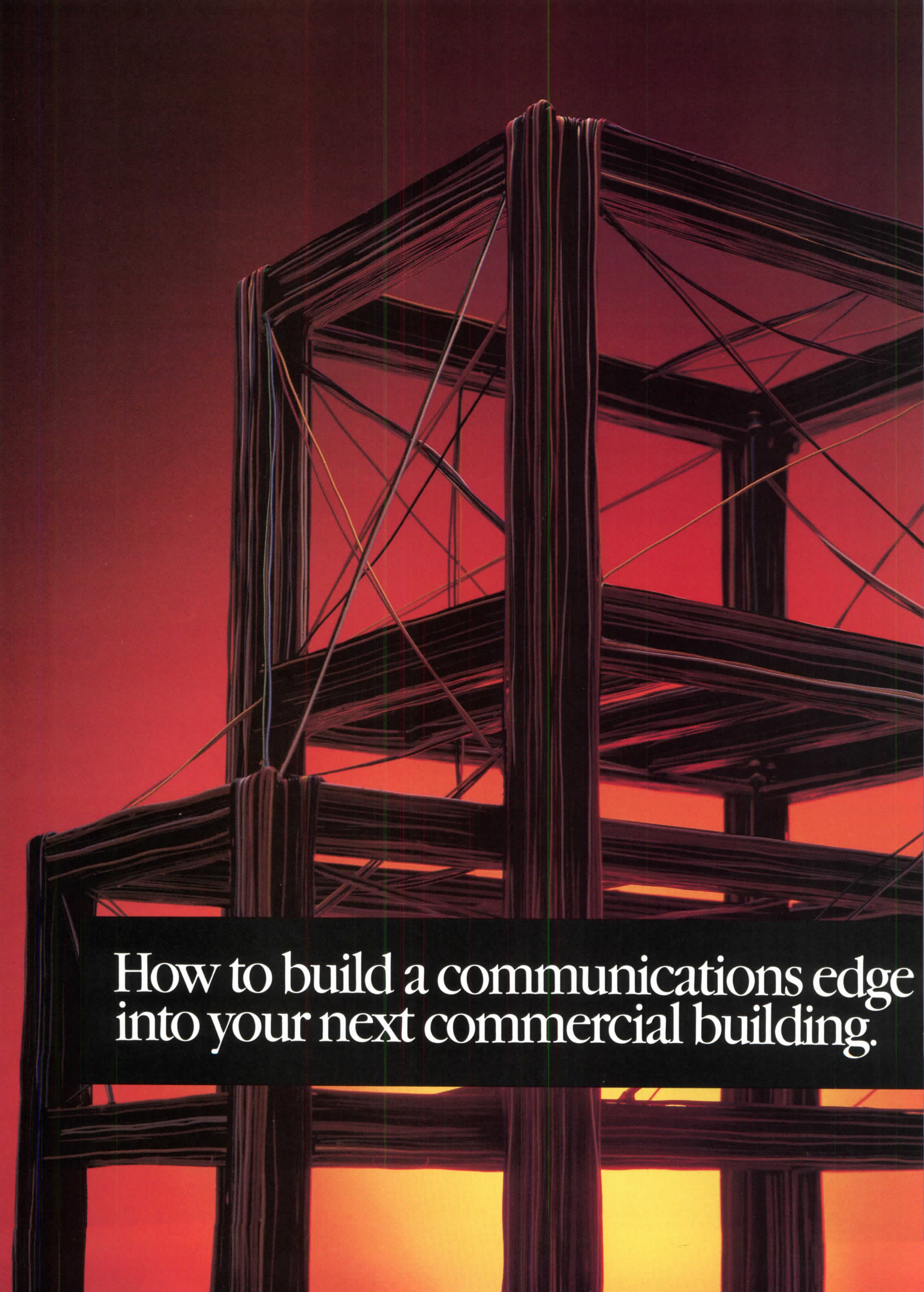
As the convention keynote speaker, Asimov will explore how architecture affects and reflects our culture and will share his vision of the future of architecture. Asimov is the author of more than 375 books ranging from science fiction to scholarly studies of Shakespearean dramas.

Harris, the convention's second major speaker, is one of the country's leading analysts of public opinion, and his polls have charted the trends of American political and social life for more than 30 years. He is expected to discuss the trends that foretell the future of American society and the architecture our culture will require, as well as give his predictions for the future direction of architecture.

As part of AIA's Vision 2000 program, Louis Harris & Associates will survey 200 people—government officials, developers, educators, architects, and other related professionals—to project where architecture is heading and how architects should prepare for the future. In his speech, Harris is expected to relate the preliminary findings of this survey.

In the first of a series of design forums, Thomas Hine, architecture critic for the Philadelphia *Inquirer,* will moderate a program entitled "Design: Star Architects and

continued on page 42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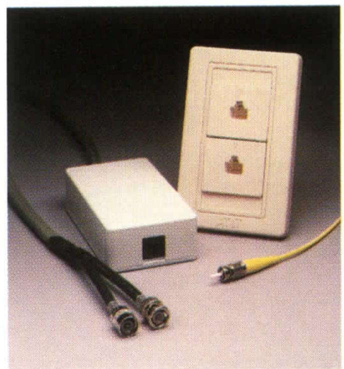

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The Institute *from page 39*

Designer Buildings." Hine and a panel of design critics will discuss the mechanics and morality of fashion setting in architecture. In a second design program, Robert Campbell, AIA, will talk about several of the 1988 honor award projects and lead a discussion between selected winning architects and the jurors.

Urban design case studies also are planned. New York *Times* architecture critic Paul Goldberger will discuss Donald Trump's massive Television City proposal for the West Side, and *New York* magazine design critic Carter Wiseman will moderate a discussion on the controversial Times Square redevelopment plan.

During the four-day convention a number of theme programs will address the relationship between art and architecture. Design critic Suzanne Stephens will preview museum projects and moderate a panel discussion among several New York architects who are working on art museums and galleries. In a second theme program, Robert H. Landsman, AIA, will explore urban design and development guidelines that require a percentage of the construction budget be set aside for public art and will describe the design collaboration of several artist/architect teams.

In addition, painters, sculptors, writers, and performing artists are scheduled to give their opinions on the influence of architecture on the arts and to discuss the future of the arts and the role of architects.

AIA has also planned more than 100 hours of workshops and professional development consultations and seminars. More than 500 exhibits, including new products, building materials, furnishings, services, and technologies, will be on view on the exhibit floor of the new convention center designed by I.M. Pei & Partners.

BRIEFS

Glass-block Design Competition

Pittsburgh Corning Corp. is seeking entries in a glass-block products design competition. The open competition has no entry fee and the deadline is March 31. The top prizes will include $6,000 for the best conceptual project; $3,500 for the best planned or pending project; and $2,500 for the winning completed entry. The second-prize winners will receive $4,000 for conceptual; $2,500 for planned or pending; and $1,500 for completed. For more information, contact James H. Coleman, Pittsburgh Corning Corp., 800 Presque Isle Dr., Pittsburgh, Pa. 15239.

San Diego Art Competition

The city of San Diego is sponsoring a competition to establish art in public places. The multiyear program, called "City Gates," is designed to strengthen San Diego's cultural identity and enrich the collective urban experience. The entry deadline is March 22. For entry requirements, contact Public Arts Administration, Conference Building, Room 10, Balboa Park, San Diego, Calif. 92101.

Illinois Achievement Award

Ray Ovresat, FAIA, of Vickrey/Ovresat/Awsumb in Chicago was awarded the distinguished achievement award by the Illinois Council/AIA.

Construction Management Winners

A five-person team from California Polytechnic State University, San Luis Obispo, won the Tishman Trophy in a construction management competition for university students of construction management. Members of the winning team are Dave Eichten, Jon Foad, Alan Laurlund, Keith Parsons, and Dave Rogers.

Registration Exam Preparation Seminar

The Registration Institute is sponsoring a three-day seminar for those preparing for the 1988 NCARB Architect Registration Exam. The seminar covers nine parts of the exam and will be given in May in Miami, Washington, D.C., and Atlanta. For more information contact the Registration Institute Inc., 2600 Bantry Bays Dr., Tallahassee, Fla. 32308.

Brubaker Named

C. William Brubaker, FAIA, of Perkins & Will in Chicago recently was invested as chancellor of the AIA College of Fellows. Brubaker is a past president of the Chicago Chapter/AIA and received its 1987 distinguished service award.

Engineering Achievements

Six projects ranging from a salt substitute for de-icing roads and bridges to a revolutionary new aircraft engine won awards for outstanding engineering achievement in a competition sponsored by the National

continued on page 45

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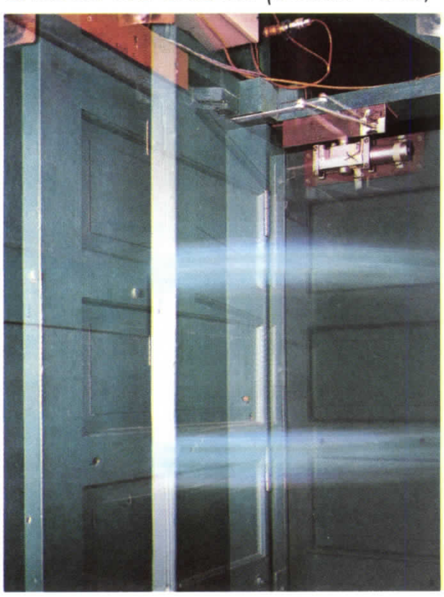
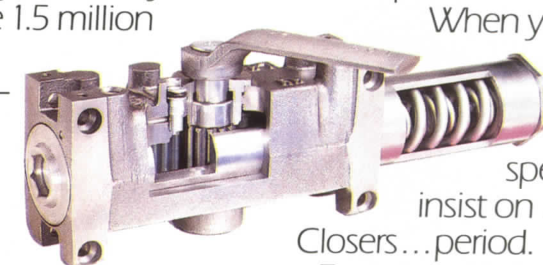


The Test Goes On!



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Six major reasons to specify Sloan...

At first glance, it's difficult to imagine how these six different buildings are related. But if you take a closer look at their histories, you'll find they all share a common theme: the washrooms in all six buildings have been refitted with Sloan flushometers.

True, these buildings don't look old enough to need major plumbing repairs. But the fact is, the original flushometers that were installed just didn't hold up. Even after repeated servicing, they continued to malfunction. They didn't shut off properly. They leaked at the stops. In some cases, they even flooded the washrooms. In short, they weren't Sloan flushometers.

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the first time.

1. Angelina County Exposition Center, Lufkin, TX **2.** Linpro Company, Berwyn, PA **3.** Northwood Jr. High School, Meade, WA **4.** Barnett Plaza, Orlando, FL **5.** Cow Town Colosseum, Fort Worth, TX **6.** CNA Tower, Orlando FL

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Briefs *from page 42*

Society of Professional Engineers. The winning projects are:

- Big Hill Storage Facility, part of the U.S. Strategic Petroleum Reserve, Winnie, Tex.
- Arizona Nuclear Power Project, Palo Verde Nuclear Generating Station, Wintersburg, Ariz.
- Voyager Aircraft, Mojave, Calif.
- Salt-Substitute De-icer, Pierre, S.D.
- Unducted Fan Engine, GE Aircraft Engines, Evendale, Ohio.
- High Sulfur Test Center (HSTC), Somerset Station of New York State Electric & Gas, Barker, N.Y.

Waterfront Design Competition

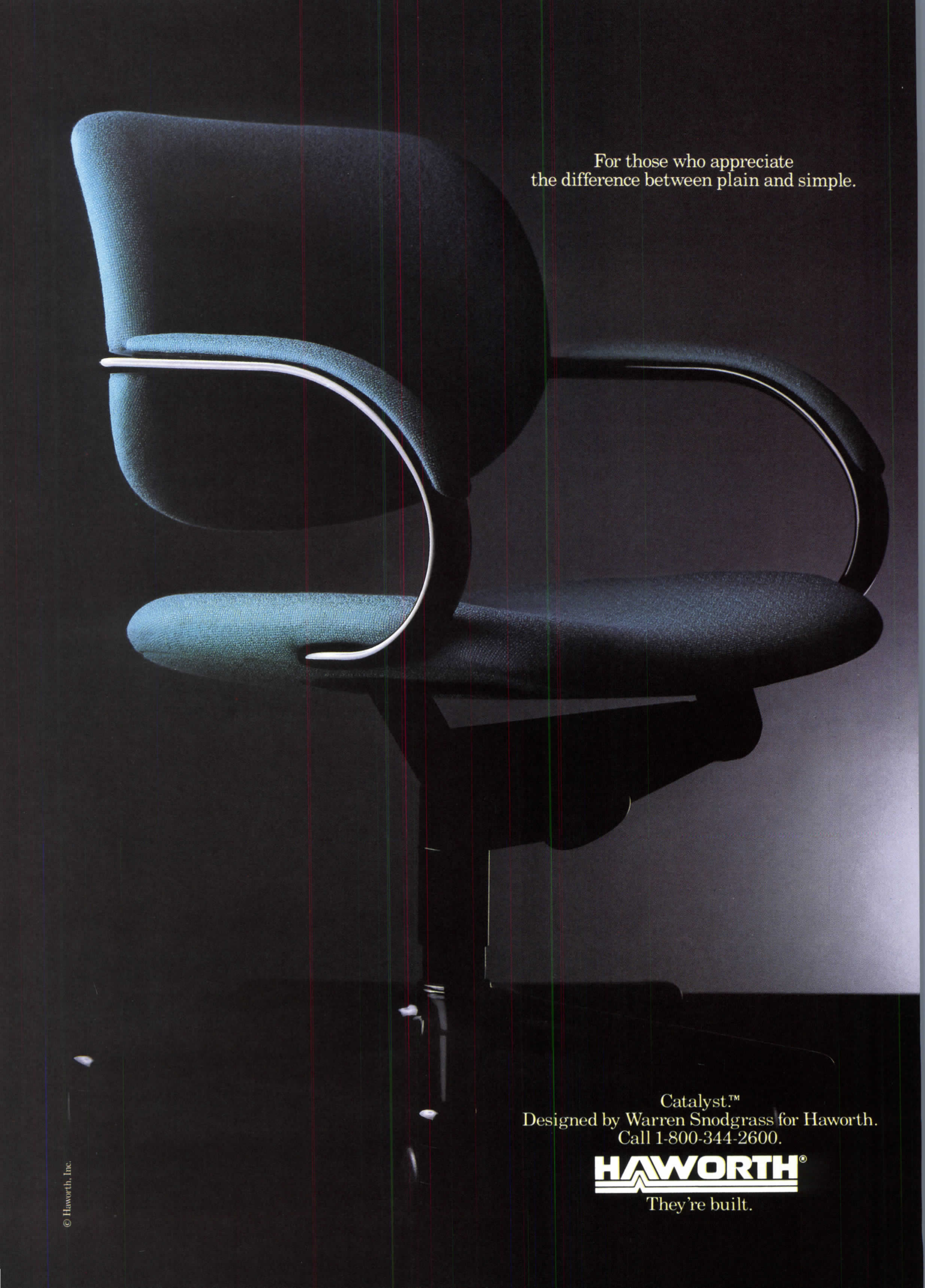
The Waterfront Center is sponsoring its second "excellence on the waterfront" project competition, to be held June 23-24, in Washington, D.C. The deadline for submissions is June 1. For more information contact the Waterfront Center, 1536 44th St. N.W., Washington, D.C. 20007.

Design Award Winners

Eighteen projects recently received awards from the Society of American Registered Architects:

- Private Duck Club, Colusa County, Calif., Wilson Peterson Associates.
- Sante Fe Lots 3 and 4, Anaheim, Calif., Gilbert Aja & Associates.
- Oppenheimer Corporate Headquarters, Oppenheimer Tower, New York City, Planned Expansion Group.
- Harbour Landing, New Haven, Conn., Nadler Philopena & Associates.
- Laughlin Residence, Indian Wells, Calif., Holden & Johnson Architects.
- The Arts Center, College of DuPage, Glen Ellyn, Ill., Wight & Co.
- Bell Community Center, Bell, Calif., Wolff-Lang-Christopher/Architects.
- Two Corporate Park, Irvine, Calif., Gilbert Aja & Associates.
- 7th & Montana, Santa Monica, Calif., Rothenberg Sawasy Architects.
- Park Plaza Retirement Residences, Orange, Calif., Leason Pomeroy Associates.
- Southridge Middle School, Fontana, Calif., Wolff-Lang-Christopher/Architects.
- Brea Fire Station No. 3, Brea, Calif., Wolff-Lang-Christopher/Architects.
- Crystal Court Mall, Costa Mesa, Calif., Architects Pacifica Ltd.
- Griffin Towers, Santa Ana, Calif., The Nadel Partnership.
- Greenway ShopRite Plaza, Yonkers, N.Y., Planned Expansion Group.
- Terryville Branch of Connecticut National Bank, Terryville, Conn., Hunter Smith & Associates.
- Clocktower Close, Norwalk, Conn., Nadler Philopena & Associates.
- Charlie Trotter's Restaurant, Chicago, Bernheim + Kahn Ltd.

Jury members were Jerrold L. Brim, chairman, Bertrand Goldberg, Mary Jean Kamin, Phillip Kupritz, Duane E. Linden, Sheldon A. Schlegman, and Phil Schreiner. □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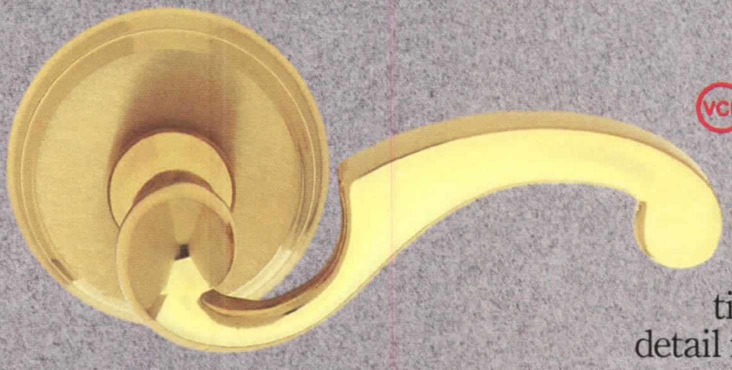

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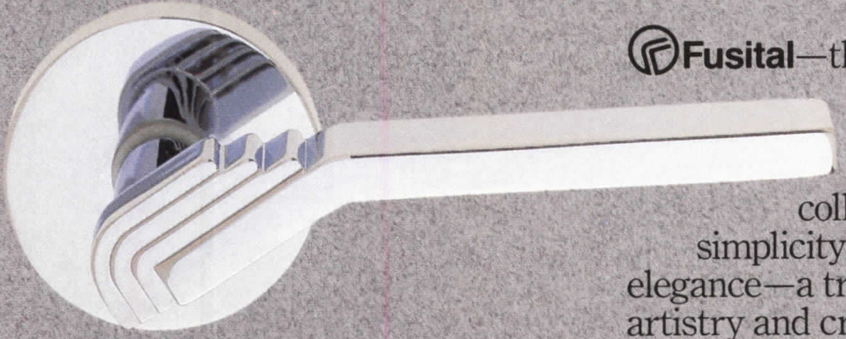

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Forges—the outstanding value in sparkling contemporary design, combines excellence in workmanship with imagination in concept—altogether a beautiful and practical solution for today.

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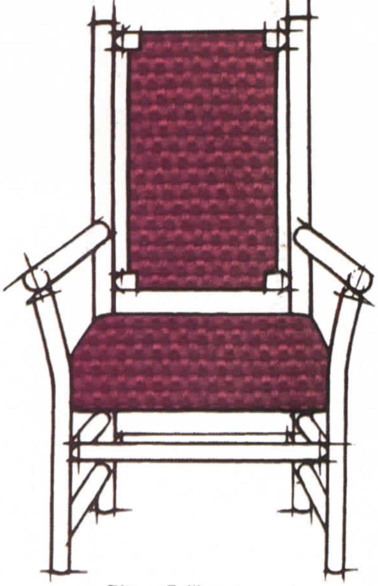
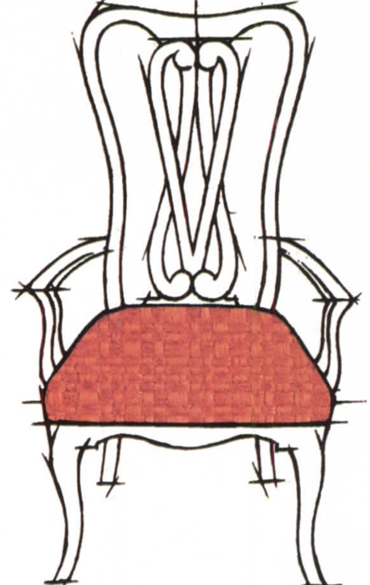
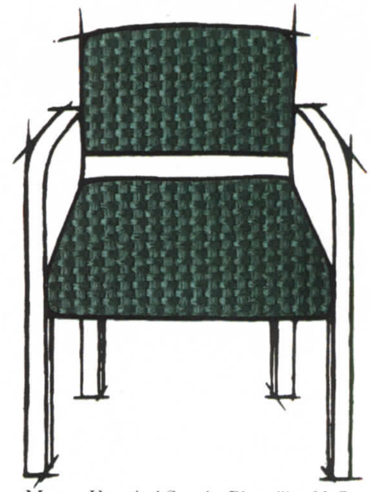


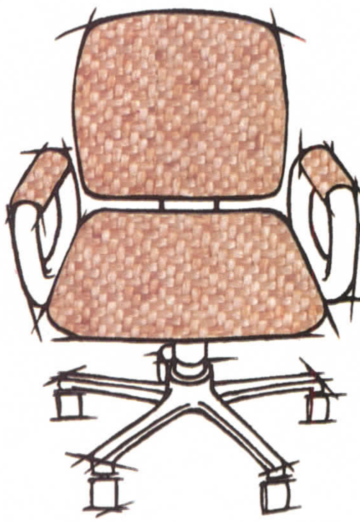
Piñon Grill restaurant,
Hilton of Santa Fe, Santa Fe, N.M.
Manufacturer: Old Hickory Furniture Co. Inc.
Designer: Joyce K. Wynn Inc.



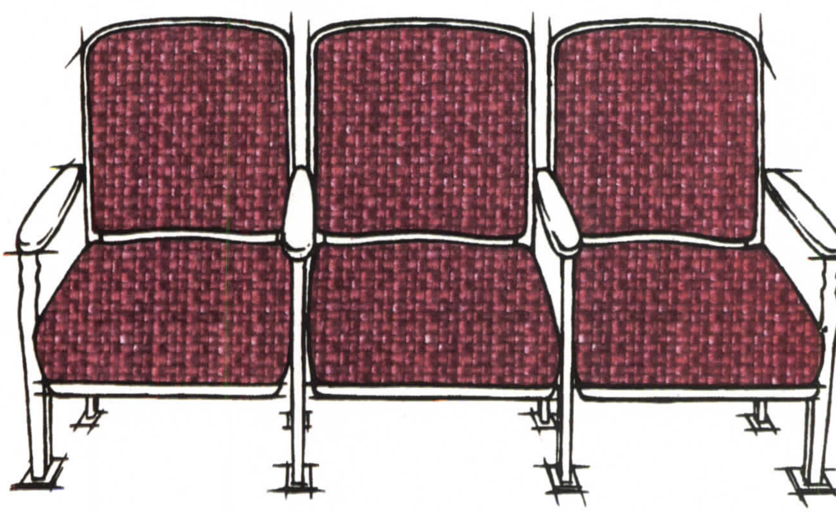
Lawson Enterprises Inc., Lansdale, Pa.
Designer: Bert Laudenslager,
Whitemarsh Interiors Inc.



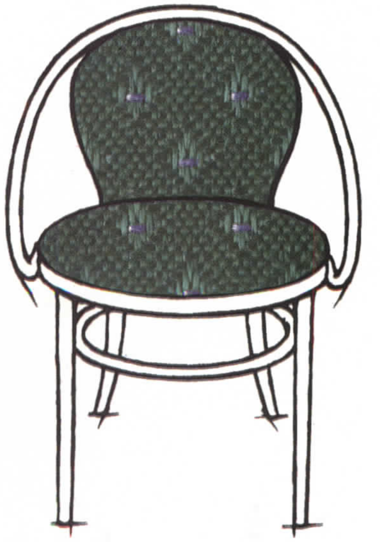
Mercy Hospital South, Pineville, N.C.
Manufacturer: Nemschoff Chairs Inc.
Designer: Lisa Harris, Mitchell Assoc.



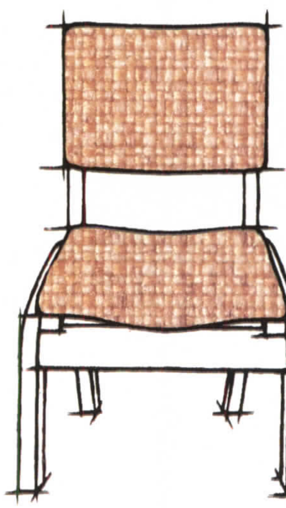
DuPont Company, Wilmington, Del.
Manufacturer: Steelcase, Stow & Davis
Designer: Beverly Thomes,
Contract Environments



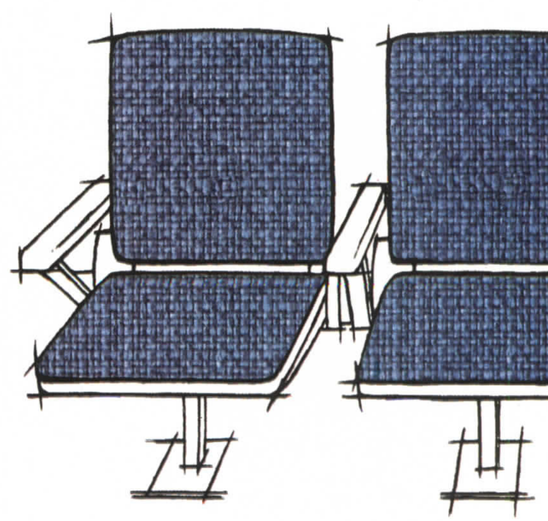
The Alice Busch Opera Theatre,
Glimmerglass Opera, Cooperstown, N.Y.
Manufacturer: Country Roads
Designer: Hardy Holtzman Pfieffer Assoc.



Garden Café restaurant,
Sheraton Smithtown, Smithtown, N.Y.
Manufacturer: Shelby Williams Industries Inc.
Designer: Corbusier



Central Michigan University cafeteria,
Mt. Pleasant, Mich.
Manufacturer: Sauder Manufacturing



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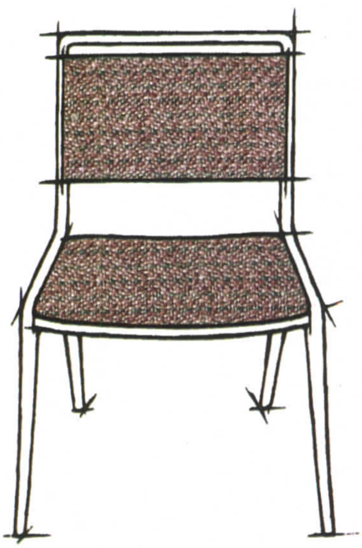

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Architects as Seen Through The Eyes of an Engineer

The Art in Structural Design: An Introduction and Sourcebook. Alan Hogate. (Clarendon Press, $49.95 hardcover, $24.95 paperback.)

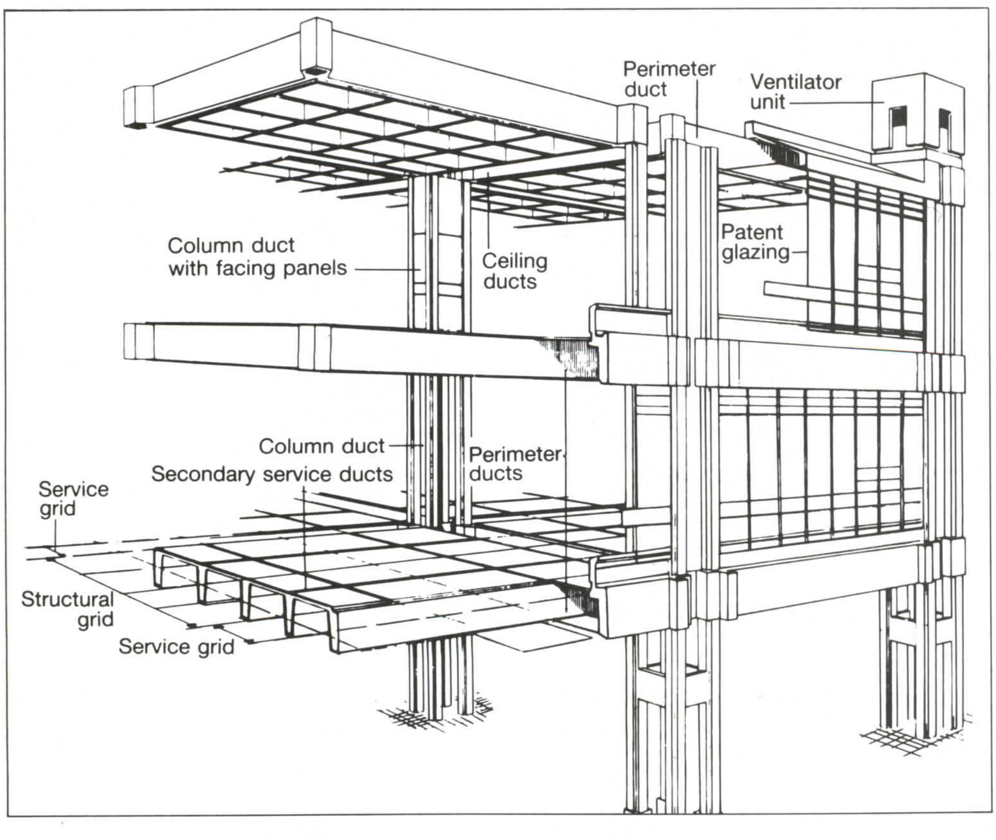
Alan Hogate, structural engineer and professor at Monash University in Victoria, Australia, has taken on a formidable task—presentation of the noncomputational aspects of structural design. In this new book he works with a broad brush, choosing as topics the nature of the design process and its relation to creativity, the formal organization of design, functional requirements, and economic criteria.

Interestingly, the author presents architects as models for explaining these topics. He states in the preface, "A large part of this book is devoted to studying the architect: his modus operandi and his philosophies, since in many projects he is the single most important influence on the work of the structural engineer." This is a book architects will want structural engineers to read; it outlines those soft-edged, barely tangible areas of design work that are recognized at once as all-important and yet extremely difficult to articulate.

For architects reading the book, the information is neither new nor earth-shattering, but it is structured and presented well and is easy to read. Neat line sketches, pencil renderings, and black and white photos of the greatest and the latest architecture abound. Selection of building examples represents an international range; Hogate is not cowed by Aussie chauvinism, although the only building presented as a chapter-length case study is, justifiably, the Sydney Opera House.

The reader never loses the feeling that the book was written as a text; Hogate continually is teaching, presenting basic principles in a clear and straightforward manner. This style might have turned out to be annoying to the general reader, except for the fact that the prose doesn't cross the border into preaching. It is fair in approach by deliberately creating space for personal philosophies and questioning. The questions, essay topics, and subjects for debate presented at the back of the book are excellent: "Is Modern Architecture dead? Should it be?" "Compare your impression of the philosophy of Nervi or Torroja with that given in Chapter 18." "Does art for art's sake have a legitimate place in the built environment?" "Is it good to describe an engineer as a person who can do for one dollar what any fool can do for two dollars?" These are a sampling of the 50 exercises. Professors should crib them for their classes, and practitioners should answer them for their own edification.

Illustration of how service runs influenced structural design of a university building.



Perhaps the major fault of *The Art in Structural Design* is that it tries to cover too much and as a result covers everything too thinly. The history of architecture is sketched in a mere 36 pages. Hogate admits in the text that it is indeed a daunting task to present the scope of material he tries to cover within the space given. But the building examples—Saarinen's TWA Terminal, Le Corbusier's Villa Stein, Johnson's PPG Building, Mendelsohn's Einstein Tower—seem well chosen for the points they were selected to illustrate. The presentation generates a hunger to know more—the kind of desire one hopes is sparked in structural engineering and architecture students early in their academic pursuits.

Hogate has created, in tone and format, a structural engineering counterpart to Mario Salvadori's gentle and informative *Why Buildings Stand Up*, a book architects seem to love, even if they would rather clients not see it on their shelves. It might be fun for architects to see a definition and criticism of their roles and work through the eyes of an articulate engineer. Architects may already have learned the lessons of *The Art in Structural Design*, but the book is, at least, a pleasant memory-jog of their importance. So pleasant that Hogate may be forgiven for referring to the architect throughout the text as "he."—M. Stephanie Stubbs

Wall Systems Analysis by Detail. Herman Sands. (McGraw-Hill, $35.50.)

Whether the reader is a student learning the basics of cladding or an old hand interested in a thorough analysis of some fun buildings, this book will entertain and inform for days—or weeks.

Herman Sands selected for study 10 buildings that represent a cross section

continued on page 52

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Books *from page 49*
of metal, glass, concrete, and brick wall-panel systems on steel or concrete structures. Case studies integrate photos, details, and explanatory text on each two-page spread, so the reader is able to grasp the concepts both visually and verbally.

Sands drew the sections and details freehand, which imparts a welcome, friendly feeling to the book (not to mention an admiration of Sands's artistic inclinations). Each case study begins with photos and follows with sections, giving the reader two visual perspectives on the building: one the external illusion, the other an X-ray view of the working wall complete with structural backing, connections, fasteners, expansion joints, sealants, and finishes.

This is an architect's picture book, and one can easily lose 15 minutes while poring over a single, detail-packed section. The text supplements the illustrations—not the other way around—with explanation that serves mostly to tie the photos and drawings together (although Sands also often finds the opportunity in his descriptive narrative to convey his admiration for modernism).

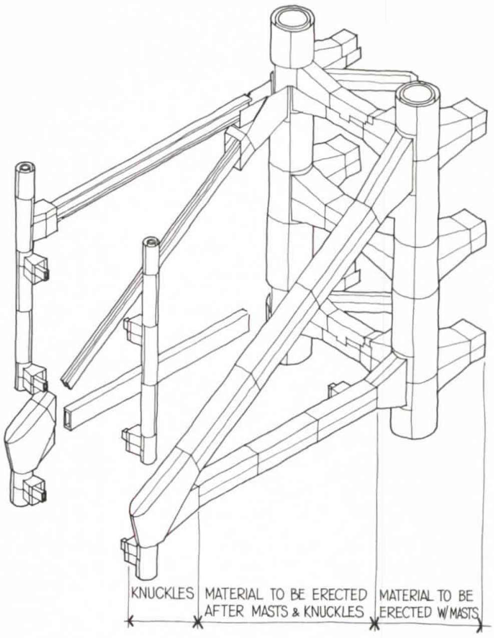
Sands begins with one of the more interesting cladding systems and structures in recent memory, the Hong Kong and Shanghai Bank Building. Structural elements protrude through the glass and aluminum cladding and must themselves be clad in a protective aluminum coat. Details show how the cladding and steel structure interact to stay watertight throughout normal thermal cycling as well as wind loads up to 100 miles per hour.

The Family Court Building in New York City is a concrete structure clad in black granite and glass. Steel bracing also is employed to achieve what Sands calls "an intricate bas-relief containing angled setbacks, loggias, bridges, and other articulated sections sculpted from the building's mass." As a case study, this building demonstrates thoughtful attachment of stone paneling to concrete and steel with anchors, angles, clips, and dowels, including hanging stone soffit and stone-clad parapet and windowsills.

For glass cladding, Sands takes us to the Corning Glass Works in Corning, N.Y., for a look at the W. C. Decker Engineering Building. This steel-framed building is covered with structural glazing, both vision glass and opaque spandrel glass.

As an example of structural glass curtain wall with a minimum of apparent spandrel and mullion, Sands selected a building in New York City, 2 Hammarskjold Plaza, which meets the city's strict fire code.

The Gilbane Building in New Haven, Conn., is an example of hanging precast concrete panels on a steel frame. Spellman Halls in Princeton, N.J., exemplifies precast concrete panels on a concrete structure. For those interested in custom-cast concrete cladding of unusual shape that requires metal bracing on a simple steel structure, Sands details Sibley's



Isometric shows cladding at the outer truss assembly of the Hong Kong and Shanghai Bank.

Department Store, Fayetteville, N.Y.

Sands also shows a metal-clad, steel-frame low-rise (RCA factory, Circleville, Ohio); an example of brick cavity wall and steel-and-glass curtain wall attached to concrete slabs (3 Park Avenue and Central Manhattan High School); and a building that takes energy-conscious advantage of its aluminum and glass skin (the Tower Building, Philadelphia).

—Douglas E. Gordon

Sunlighting as Formgiver for Architecture. William M. C. Lam. (Van Nostrand Reinhold, $74.95.) **Bringing Interiors to Light.** Fran Kellog Smith and Fred J. Bertolone. (Whitney, $39.95.)

"Throughout history, throughout the world, the sun has been worshipped by mankind. Its benefits have been recognized, praised, and prayed for and the potential problems of its presence adapted to," writes William M. C. Lam in his recent book, *Sunlighting as Formgiver for Architecture.* This is a master's folio, a notebook crammed with data, problems solved and still unsolved, lessons learned, case studies of personal works, examples of admired work of others, and dreams of what can be. It will be a valuable reference for anyone interested in the application of daylight in architectural spaces.

Part one contains principles of light, typical design solutions, and lighting concepts. Lam's work on perception from *Perception and Lighting as Formgivers for Architecture,* his first book, is incorporated with data from more recent research on aperture design. Here, basic principles are conveyed with unconvincing repetition, a lack of order, and a layout apparently designed to minimize pages.

Part two documents, in case studies, representative work from Lam's practice. The case study is a traditional educational method in the medical and legal professions, used to teach the application of basic principles in real situations. Lam, in his roles as speaker, educator, and author, has used detailed case studies extensively, contributing to the evolution of the architectural case documentation. Lam uses cases to relate the complexities of the building process and to introduce the application of design tools, such as scale models, full-scale mock-ups, and testing, and to document the incorporation of design research in the projects. Nine building types, including offices, schools, and museums, are identified with outlines of typical lighting conditions indicative of each type. Specific design solutions, such as the design for top-lighted museum gallery spaces, are repeated as variations on a theme.

Lam stresses the importance of intuition in design with light but leaves the question open as to how the designer develops intuition. One way is through repeated experience of applying basic principles to specific cases. Another is to learn from the experience of a master. Two components are missing from *Sunlighting:* first, a map, to guide the reader in the leap from basic principles to building design; and second, a key, to reveal value beyond the important, but currently insufficient, goal of saving energy.

"Every designer is commissioned to create an intuitive and practical design solution for a particular client—a solution devised to meet the needs of a unique program," begin Fran Kellog Smith and Fred J. Bertolone in *Bringing Interiors to Light.* The value of this book lies less in the information it contains, much of it available from other sources, than in the structure it outlines for the reader to manage manufacturers' literature and other publications.

Part one introduces basic principles of light and lighting. The authors advocate a linear design process. "[B]y exploring the factors of analysis that affect lighting design decisions in sequence, their interaction will become apparent." A series of photographs compares subjective impressions of a single room selectively illuminated with uniform and nonuniform light patterns, demonstrating the impact lighting can achieve and the versatility a designer can provide through lighting.

The case studies in part two illustrate examples of lighting designs documenting data/physical specifications, analysis/program, concept/strategy, constraints, and tactics.

Part three includes miscellaneous information, such as lighting for barrier-free environments and "light as art."

—Jacquelin Spangler McBride

Ms. McBride who is senior architect for the public facilities department of Boston, also teaches at Roger Williams College in Bristol, R.I.

Books continued on page 56

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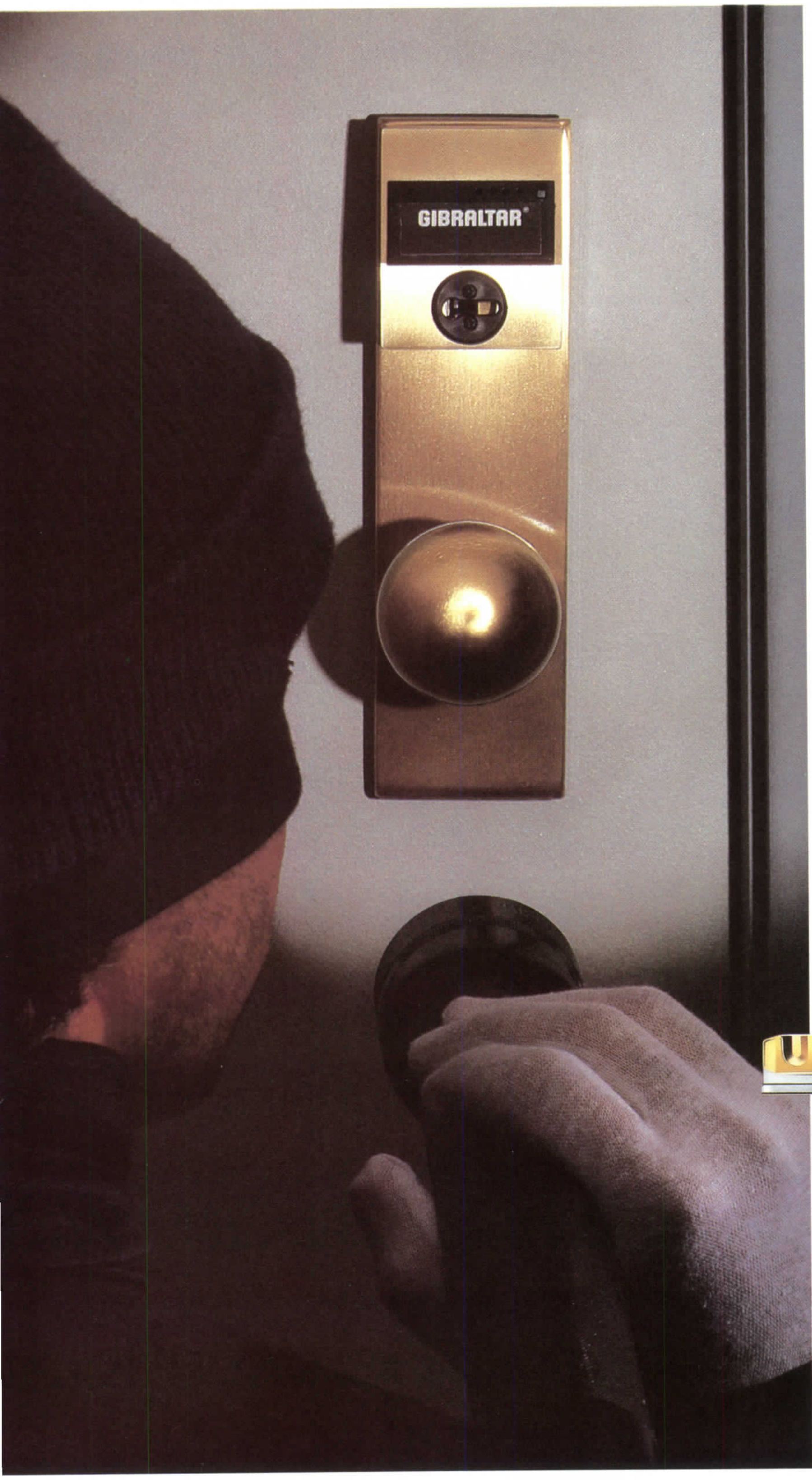

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Energy Efficiency in Buildings: Progress and Promise. Eric Hirst, et al. (American Council for an Energy-Efficient Economy, 1001 Connecticut Ave. N.W., Suite 535, Washington, D.C. 20036, $19.50.)

The preface of this book defines its audience as, first, policy makers and program managers responsible for research and development funding and, second, building design professionals including architects. Since architects don't normally lead research and development policy and funding efforts, and since the topic of energy efficiency is not now given the priority it was even a few short years ago, this book is likely to be ignored by the architectural profession.

My view is that both of these circumstances are regrettable and that, accordingly, *Energy Efficiency in Buildings* deserves review and circulation.

The book summarizes successful energy-efficient building and engineering innovations achieved in the past 10 years, carried out largely through federal involvement in research, development, and demonstration of solar and energy-efficient buildings since the mid-1970s. It documents combined architectural and engineering strategies that have achieved up to 80 percent reductions in energy required in new housing and commercial buildings and up to 50 percent reductions in energy required for existing buildings. These savings are not conjectural but the documented performance of occupied energy-efficient building designs, achieved by investments that are repaid within conventional life-cycle investment limits.

The architect who does not know that energy-efficient goals can be achieved with reasonable design choices and economic limits is uninformed, a condition of professional ignorance for which this book presents itself as an antidote.

Early steps in the process of architectural design—siting, massing, fenestration design—are the least costly means of achieving economic energy performance. If energy-efficiency concerns are introduced only late in the design stages, the choices are fewer and the mechanical engineer might already "begin behind the eight ball," as it were, having to overcome the disadvantages of an energy-wasteful architectural schematic. Energy concerns are best handled before a design solution is conceptualized by a consulting team that considers these and other technical concerns, including construction materials and economies.

The team approach to system design can make up for added professional "predesign" time and fees by substantial design and construction cost savings that result when all components of a building are integrated in the early design stage. The need for such teamwork should be especially evident today in daylighting design and its integration with efficient electric lighting, which is still an urgent cost reduction goal in large buildings and infrastructure design, aimed at leveling utility plant loads and optimizing their capacity.

Energy efficiency is one aspect of building design that, in the 1970s period of high-energy cost escalation, pressed itself upon building designers and owners as an unwelcome and nagging concern, aggravated all the more because it had so thoroughly been ignored in the previous decade. Since that time, much has been learned and accomplished, as is ably summarized in this book. The lessons learned can be easily incorporated into conventional design practice and be the source of improved architect/engineer teamwork as well as improved comfort and reduced life-cycle building costs.

What occurred between 1975 and 1985 was a concerted national effort made possible by federal government support of research and development of energy-related building innovations, in partnership with architects, engineers, home builders, and the building industrial community. It would be a pity if the successes from this experience are not carried into the next decade, an outcome that will result from complacency and a "let's get back to where we used to be" modus operandi in architectural practice and education. If the U.S. building industry is to continue its world-leading record of innovation into the next century, in response to international business competition and raised expectations of building quality and performance, the record reported in this volume will be essential reference material.

—Donald Watson, FAIA

Mr. Watson, author of Energy Conservation in Building Design *(1979) and* Climatic Design *(1983), is also a practicing architect and visiting professor at Yale University's school of architecture.*

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Solving Problems in Structures. P.C.L. Croxton and L.H. Martin. (John Wiley & Sons, $28.95.)

This is a book of basics in structures aimed at engineering students studying the topic for the first time, the authors state in their preface. For architects looking to brush up on some fundamentals or architecture graduates facing registration examinations, it is a textbook of theory, problems, and solutions devised to accommodate the solo student as well.

Concentrating mostly on plane structures, Croxton and Martin touch on space statics and space frames in the last chapter. The preceding chapters take the reader progressively through statics; geometrical properties of sections and types of load; reactions, free-body diagrams, cables, and friction; stress and strain; stress resultants in beams and arches; stresses in beams; and plane pin-jointed frameworks.

Familiarity with mathematics is a requisite, and comprehension requires practice in solving problems, of course, but the authors are quite helpful in providing sample problems that derive solutions mathematically and with diagrammatic aids. Still, for full comprehension, this book almost certainly requires a mentor if not a tutor or teacher.

—Douglas E. Gordon

Reinforced Concrete Fundamentals. Phil M. Ferguson, John E. Breen, and James O. Jirsa. (John Wiley & Sons, $58.18.)

The fifth edition of a series that began in 1958, *Reinforced Concrete Fundamentals* bills itself as an "ideal reference, refresher, and desk top resource for civil engineers needing a clear, modern approach to concrete design." This sounds like a book any architect should avoid like the plague, right?

Wrong. The book is interesting, clearly written, and has enough diagrams and illustrative drawings to keep an architect moving through it. Better yet, it contains some construction shots and photos of sad-looking concrete where some engineer (or architect?) went wrong.

Although a fifth edition, the book contains enough new material to make it worthwhile, especially for architects who don't happen to have the first four at hand. The updated material presented in the new edition tells a brief history of the latest developments in concrete reinforcement. For example, a chapter on shear wall design discusses location of shear walls within a building, design considerations, failure modes, and placement of reinforcement. Additionally, this edition wraps up with a brand new chapter entitled "Detailing for Seismic Resistance" that explains general objectives for seismic design, building configuration, and reinforcement for flexural members and columns. The context then widens to include seismic frame design.

Much of the rest of the text is meat-and-potatoes design of concrete members, flexural analysis of beams, shear and torsion, short columns, slender columns, retaining walls, and footings. It also discusses flat plates and slabs, two-way slabs, and detailing of joints. Perhaps the most intriguing chapter title is "Distribution of Concentrated Loads and Other Special Problems," which tells, among other things, how to design for openings in slabs. All material throughout the book has been updated to requirements in the 1983 and 1986 editions of the American Concrete Institute building code. Appropriate code sections are referenced and presented right in the text—a useful addition to any structural design manual.

The book was designed as a text for civil engineering students; following each chapter are references for further reading and sample problems, good for those who can't resist the temptation to prove to themselves they can do numbers. It is disconcerting that the answers to the problems are not printed, although samples are worked out in the text occasionally, not so often as to be burdensome. The detailed and well organized index is an immense help. You wouldn't cuddle up with it for a rainy evening's reading pleasure, but that's all the more evidence that it is a useful reference document.

The late Phil Ferguson, professor of civil engineering at the University of Texas at Austin, was sole author of the first four editions of *Reinforced Concrete Fundamentals.* Breen and Jirsa, the other authors, are currently professors of civil engineering at that university.

—M. Stephanie Stubbs

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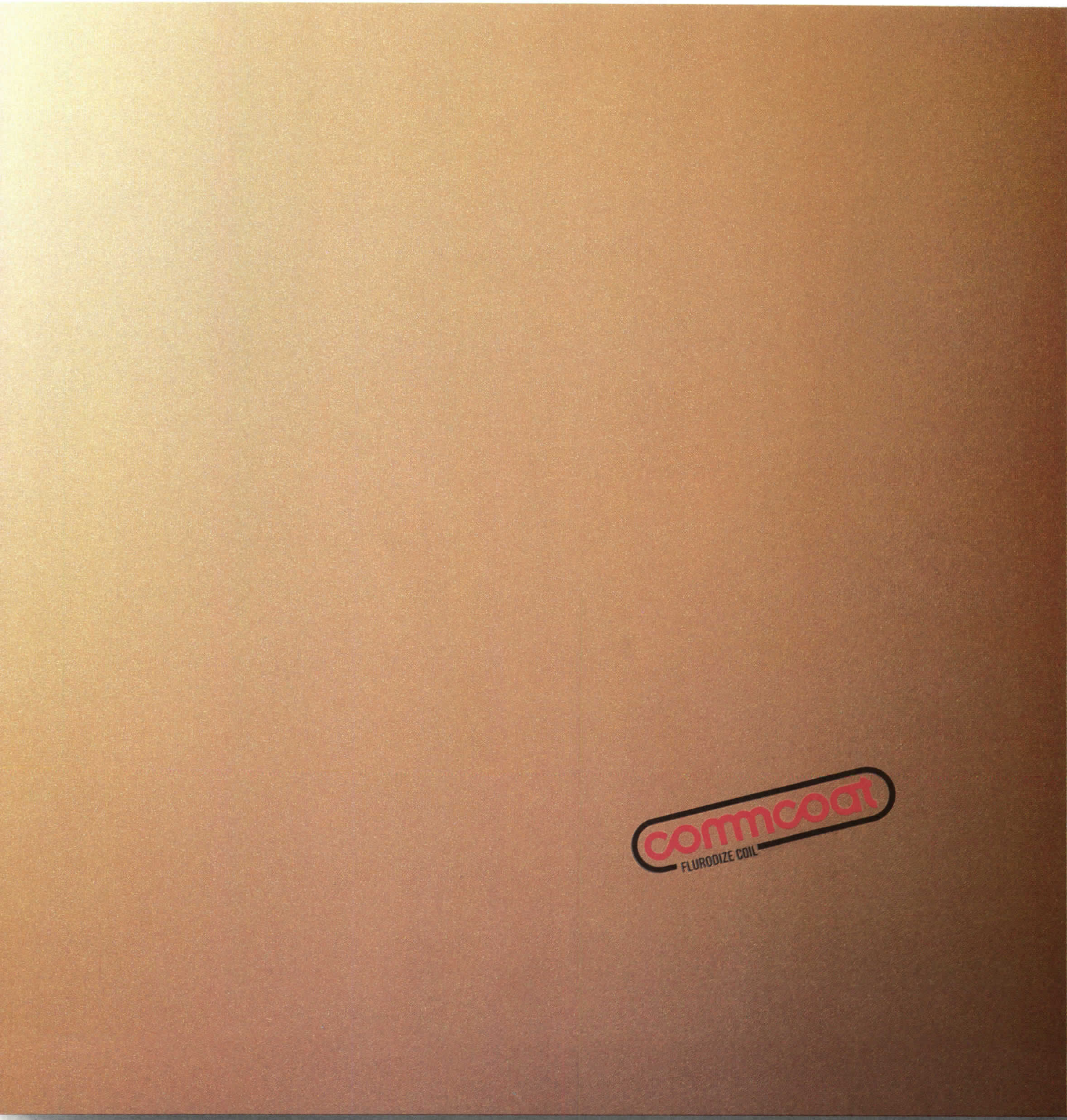

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ARCHITECTURE

Part of our planning for the merger of ARCHITECTURE and ARCHITECTURAL TECHNOLOGY was to do a special issue each year on a technical subject. This is the second such issue. It begins with a highly instructive history of a very celebrated and very troubled building, then goes on to a series of articles on structure. The subject is examined from a variety of viewpoints in a variety of ways: technical treatises, interviews, case studies of innovations in individual building projects. A common thread is the relation of structure to design, or more precisely, structure as an integral aspect of design. This issue thus exemplifies the kind of architectural-technical integration that the merger was about. Editors in charge of its planning and execution were M. Stephanie Stubbs and Douglas E. Gordon, with important contributions from Forrest Wilson, Elena Marcheso Moreno, Amy Gray Light, and Timothy B. McDonald.—*D.C.*

Learning from The Hancock

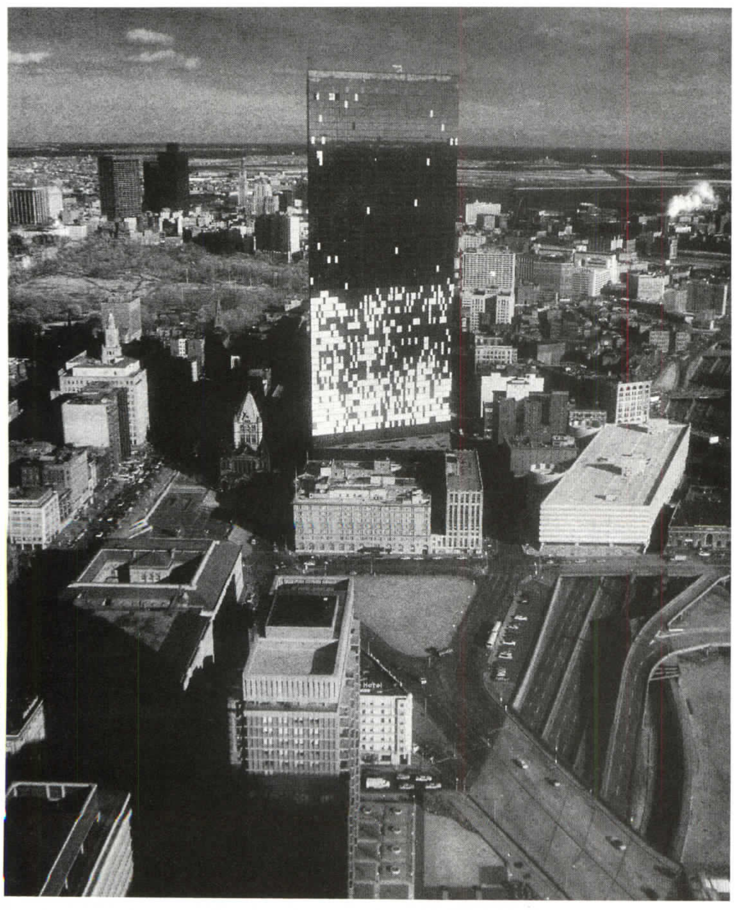
Two accounts of the failures and averted failures involving the famed Boston tower. By Robert Campbell, AIA

A high wind blew in Boston on the night of Jan. 20, 1973, 15 years ago. By the next morning the John Hancock Tower, then under construction, had become perhaps the most celebrated American building failure of its decade.

The Hancock was clad almost entirely in a single element that was repeated 10,344 times. This element was a double-glazed window unit measuring about $4\frac{1}{2}$x$11\frac{1}{2}$ feet. In the storm, dozens of these units failed, some shattering. Eventually, about a third of the Hancock's glass was removed and replaced with plywood. Finally the entire tower was reglazed with a different type of glass.

There was talk, too, of other problems. Buildings and subsurface utilities near the Hancock experienced damaging settlement. It was reported that the Hancock's structural core was being stiffened with new steel. A so-called tuned mass damper was installed on an upper floor.

The Hancock survived its problems to win a worldwide reputation for cool beauty, as well as a national AIA honor award for its architect, I.M. Pei & Partners (Henry Cobb, FAIA, design partner), and the Harleston Parker medal from the Boston Society of Architects for the year's "most beautiful piece of architecture" in Boston. Gradually its problems faded from memory. Little was revealed to the public or to the architectural community. A legal nondisclosure agreement among the parties to the incident banned them "in perpetuity" from public comment on the Hancock's technical problems. As a result, even among architects there is general ignorance and confusion about the causes of the Hancock's problems. One continually hears explanations that are entirely false. Architects have not been given a chance to learn from the Hancock.



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Two persons who are knowledgeable about the Hancock were not directly involved in litigation or in the nondisclosure agreement. One is William LeMessurier of Boston, the noted structural engineer; the other is Victor Mahler, AIA, a former member of the Pei firm who is now a consultant on curtain-wall technology in New York City. Between them, LeMessurier and Mahler know a great deal about the Hancock. What follows is an edited transcript of interviews with them. The interviews grew out of a seminar, organized by Peter Blake, FAIA, in which LeMessurier participated at the Aspen Design Conference last June.

Until the day comes—if it ever does—when the Hancock nondisclosure agreement is voided, there can be no pretense of perfection in a report such as this. Much of the truth remains unavailable. But the basic outlines of an astonishing and significant story seem clear in the recollections of these two professionals.

To help readers follow the interviews, I must give one clue in advance. The Hancock, as things finally turned out, suffered not one but four technical failures or potential failures, *and none of them had anything to do, in principle, with any of the others.* The first was a cave-in of the excavation for the building, causing the foundation settlements in the neighborhood. The second was excessive movement of the building in the wind, solved by the tuned mass dampers. The third—and most remarkable—was the danger that the building might topple over on its long axis, solved by the stiffening of the core. The fourth was the breaking of the glass, solved by reglazing.

The Hancock Tower is a 60-story, 790-foot, mirror-glazed office tower structured with conventional steel framing. Its physical form is unusual in only one regard—but this, as will be seen, turned out to be critical: its floor plan is exceptionally long in its longer dimension.

The edited interviews follow.

Interview with William LeMessurier

Campbell: How did you get involved with the Hancock?

LeMessurier: I got involved at the time the architect had completed the design of the building. The building commissioner in Boston had the right under the law to require an independent review if he thought a project was sufficiently important. Hancock engaged us at Harry Cobb's recommendation to review the design.

We did not consider any aspect of the foundation design. The exam was on the building frame. We made extensive, independent computations using computers. We reported that the building followed the Boston building code.

Campbell: Did you have any worries or concerns at the time of that review?

LeMessurier: I had none, although the practice of my own office would have been to design the building 20 percent stiffer

Left, the Hancock in 1973 with patchwork of plywood panels. Right, a 1980 portrait. Richardson's Trinity Church is in center of photo; Copley Plaza Hotel is immediately in front of Hancock.


The Lenox

than it was. Stiffness is not determined by code but by the designer's judgment. We scored the building O.K. and signed our affidavits and then we went home and forgot about it. And then they started building the building.

Campbell: What happened then?

LeMessurier: The next involvement that we had was with [H.H. Richardson's] Trinity Church. At the time, the Hancock foundation was under construction right across the street. The church—this is before I got there—had already engaged a foundation engineer. He set up a careful monitoring survey of the church before the Hancock started any excavation and took readings every week. As the excavation for the Hancock proceeded, he could see that the church was settling. The church people began to worry and brought us in to look at the building.

At that time there were effects beginning to show up, such as a distortion in one of the leaded glass windows in the transept facing the Hancock. This motion kept up until the transept was literally tilting away from the church's central tower. My partner made a personal investigation by getting up under the roof. He found that where the roof timbers framed into the masonry of the tower, these timbers had been pulled out of their seats. The transept wall, tilting outward at the other end of the timbers, had pulled them out from the tower.

Campbell: How much bearing was left?

LeMessurier: You'd have to ask my partner. The timber was pulling its brick support out from the wall. Immediate correction was undertaken to prevent disaster. Later I saw the plotted graphs of the settlement of Trinity and simultaneous plots of the rate of the Hancock excavation. The correlation between the settlement and the rate of excavation was perfect.

Campbell: Was there any visible evidence of a fault in the Hancock excavation?

LeMessurier: I did not pay a great deal of attention to that because it really wasn't my prime responsibility. However, there is lots of information that I gleaned from talking to various people. The sheet piling and its lateral braces, which were supposed to keep the street from falling into the excavation hole, actually moved very substantial amounts—perhaps three feet.

Campbell: Which side of the excavation was the movement on?

LeMessurier: Generally all around, on the side right across from the church, but also on the street between the Hancock and Copley Plaza Hotel.

Campbell: As far as you can judge, how would the collapsing inward of the foundation wall cause settlement of the church? Did it relieve pressure on the church's friction piles, or what?

LeMessurier: It was presumably very deep-seated lateral and rotational motion of the whole block of earth, which included the piles. It was not just a surface effect—it was a very deep-seated effect.

Campbell: Was change in the water table a factor at all?

LeMessurier: I don't think change in the water table had anything to do with it.

Campbell: This may be asking you for hearsay, but there were also settlement problems, weren't there, with the Copley Plaza and in the underground utilities?

LeMessurier: Oh yes. I heard that the steam pipes broke in the streets because of distortion, and water pipes and so forth. I also remember learning that the church was being paid money for their clear damage without any argument from very early on.

Campbell: So much for the settlement problem. What happened to the Hancock next?

LeMessurier: The building frame went up without any unusual effects until the glass started to go up and started to break. The glass breakage, and this is what I remember from scuttlebutt at the time, was first not presumed to be serious. It took a while for people to wake up to the fact that maybe there was something more serious going on.

A firm of three MIT professors called Hanson, Holley & Biggs was engaged when people finally decided that this glass breakage was getting out of hand and maybe there was something wrong. And Hanson, Holley & Biggs became important players.

It's common among civil engineers, when they hear about glass breaking, to assume the problem must be in the building frame, or settlement of the building may be going on, or wind may be moving the building. None of these turned out to be causing the glass problem, but no one knew that then.

Well, there was no likelihood of settlement of the building going on because the piles all went into rock. But it was a perfectly reasonable thing to say that maybe the cracking of the glass was being caused by building motion. So there was a large effort undertaken by Hanson, Holley & Biggs to instrument the building, putting an anemometer on the roof, installing measuring devices to see if they could measure the racking across the sheets of glass. Ultimately they also measured acceleration, that is to say, the degree of change in velocity of the building as it moves.

I'd had [Myle J.] Holley and [John M.] Biggs both as teachers when I did my graduate work at MIT. I never had [Robert J.] Hanson as a teacher. But I did meet him from time to time during this affair and he clearly had his mind made up that the building was in trouble in terms of wind motion, whether that was causing the glass to fail or not. I'm sure he thought the motion was causing the glass breakage in the beginning. But the main point is that questions were raised by Hanson about the building motion and the building's strength in the wind.

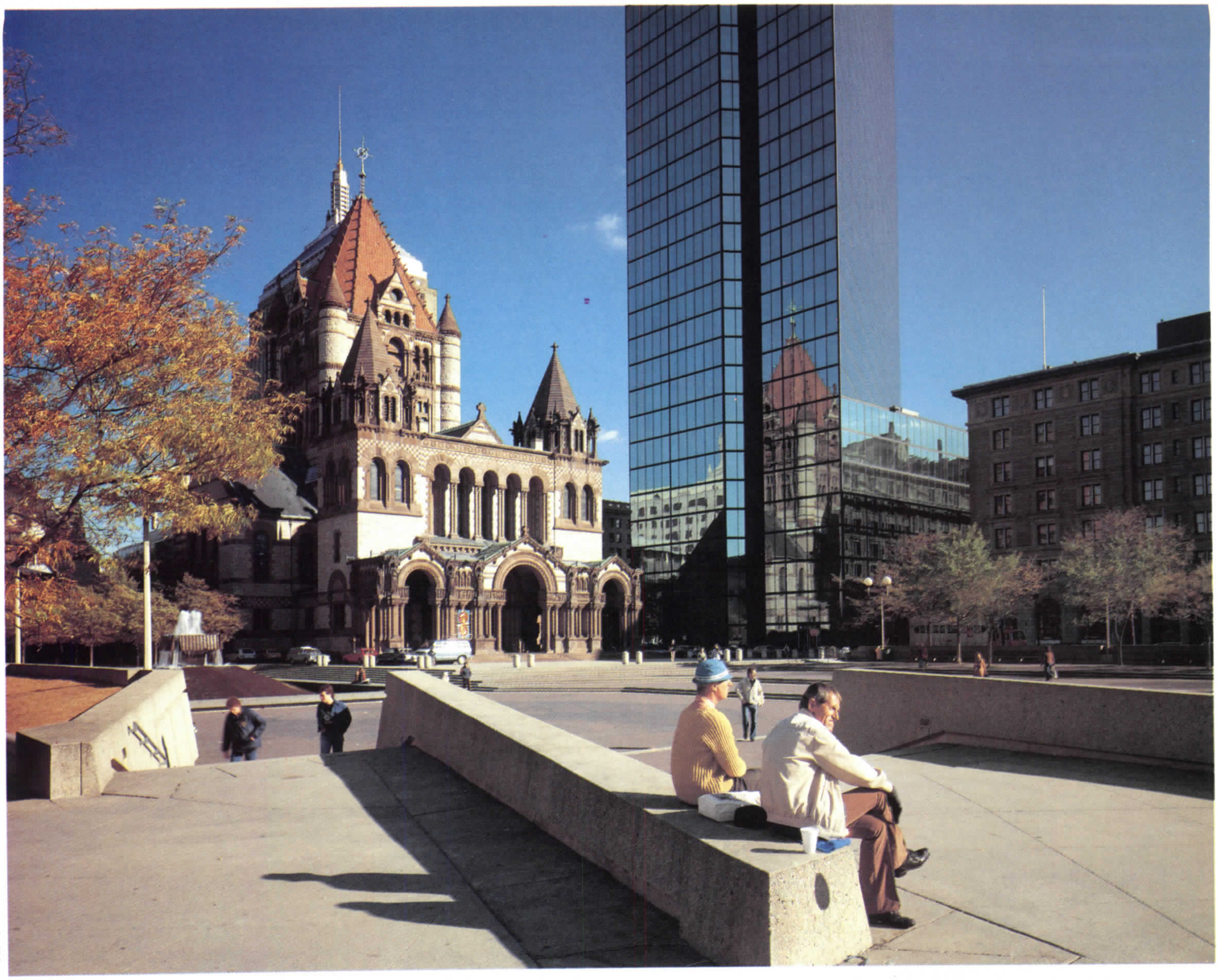
Campbell: Let's leave the glass problem out of this because we'll be hearing more about that from Mr. Mahler. But it's true, isn't it, that the investigation inspired by the glass problem is what eventually led to the discovery of other concerns?

LeMessurier: Right. The first thing that came up from Hanson that was a source of real concern was that the measurements of the building's performance in windstorms with accelerometers indicated that it was highly probable that people would find the building quite uncomfortable. It's a building's acceleration, of course, not its mere movement, that can cause discomfort to the inhabitants.

You have to realize that, at the time the Hancock was being designed, nobody really had any standard for deciding whether people were going to be comfortable or not when a tower moved in the wind. Everyone knew that people were sometimes uncomfortable when windstorms came, but there was never any quantitative basis for writing a recommendation of what you do or how you predict discomfort. It can't be predicted by calculation. It can only be predicted by measuring models in a wind tunnel. And the model has to include the entire neighborhood and all the other buildings and objects other than the building you're interested in.

While the Hancock was being designed, however, this state of ignorance was changing. There was a man named John Reed who did his doctoral dissertation at MIT. He worked for us in our office for one summer. He did the first studies correlating people's actual experience in a building with rigorously measured physical data on the actual performance of the building. The question he really wanted an answer to was this: how often would you put up with this experience? His paper—"Human Response to Wind-Induced Motion of Buildings"—appeared well after the Hancock had been designed.

Now, some background. The way you relieve the discomfort of people who are occupying a building that is moving in the wind is, obviously, to reduce the building's motion, that is to say, its acceleration. Our office got involved in this problem of damping wind motion in the Federal Reserve in New York by Kevin Roche, which never was built, and later the Citicorp in New York. The Fed was 750 feet tall and very slender. In order to fix it Professor Alan Davenport, who was doing the wind tunnel tests, said, "Bill, you've got to attack damping directly; there's no way you can do it by simply putting in more steel." We worked out the idea of a mass of weight, maybe 400 tons, that would be attached to the building frame by springs and connected to a shock absorber, but otherwise would be free to slide on the floor, and would damp the building motion. And so we installed that at Citicorp. We called it a "tuned mass damper."



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Above, a view diagonally across Copley Plaza, with Trinity Church mirrored in Hancock's glass and the Copley Plaza Hotel at right. The church and the hotel, built on wood piles in filled land, suffered settlement damage during excavation for the tower.

While that was actually under way at Citicorp, Harry Cobb was getting statements about wind movements from Hanson, and it seemed that the Hancock problems would be very similar to those we had predicted for Citicorp. Harry became convinced that we were the only ones doing something in a real building. So I was brought in once again to develop a system in principle like the one we were doing in Citicorp—although it ended up different because, at Hancock, the twisting of the building in the wind was part of the comfort problem, as well as the back and forth motion in the short direction. By the way, there was no measured motion in the long direction, no measured acceleration that would raise any doubts about anything—this is a very important statement because that fact turned out to be very misleading.

At Hancock you had a structural system such that the natural period of vibration of the building in the side-to-side mode matches, very closely, the natural period of vibration in the torsional mode. You got close correlations between these movements so they reinforced each other. Because the torsional motion was so important, we used two of the dampers, and by putting them at a considerable distance apart down the length of the building, one could move in one direction and the other in the other direction, and they could deal with the torsional component as well as the translational component.

Campbell: Why do you call it a tuned mass damper?

LeMessurier: The word "tuning" means that, say, if I hang a mass from a spring and I pluck the mass, the mass and spring will go up and down at an interval that is predictable from the combination of the spring and the mass. So you match that interval to the natural period of the building, the time it takes to oscillate through one complete cycle from here to there and back, which in the case of the Hancock in the short direction would be about seven seconds.

Campbell: So the tuned mass damper consists of two huge weights, roughly at opposite ends of the 58th floor, free to slide back and forth in the short direction but attached to a spring?

LeMessurier: To a spring and shock absorbers—the shock absorbers are essential. Each weight is about 300 tons of lead and slides on a thin layer of oil over a steel plate. As the building sways or twists one way, the damper's inertia pulls it the other way—as long as the period of vibration of the system is tuned to the period of vibration of the building.

Campbell: So you retrofitted the Hancock with these tuned mass dampers, and that solved the problem of the building swaying too much for the comfort of its future inhabitants.

LeMessurier: But meanwhile, Mr. Hanson was still carping away at the ultimate safety of the building. They did wind tunnel tests and they worried about motion—motion in the short direction, twisting motion. The situation was getting out of hand, and finally Harry Cobb decided that he would get a high-level opinion from somebody of impeccable credentials, outside of the usual consultants in this business in this country.

Campbell: And this is when the totally unexpected problem, the problem that the building might actually fall over, began to emerge?

LeMessurier: Yes. I don't know how Cobb had first heard of or met Bruno Thürlimann, a Swiss who came to the United States and worked here and studied for a few years at Lehigh University. He eventually became uniquely qualified, above anybody else in the world, to study the real ultimate strength of steel structures, including those effects that normally are left out of practice and out of codes. Whether Cobb understood that about him I don't know. But for whatever reason, Cobb made the best possible choice. At this time—it would be late 1974—Thürlimann was a professor in Zurich. The proposal was made by Cobb to Hancock that they engage him.

Thürlimann knew he was no great authority on wind, so he insisted that an equivalent expert in wind engineering be engaged to help him. This was A.G. Davenport, whom I mentioned before, at the University of Western Ontario. They went to work in late '74, wind tunnel analysis going on in Canada, calculation going on in Zurich, and back and forth. I became aware of this because Davenport's and Thürlimann's input became part of this damper design that we were doing. It was helpful to have, for the first time, real, first-class wind tunnel tests being done in order to pin down the performance requirements of the damper.

Campbell: At first, if I recall, Thürlimann thought everything was going to be O.K.

LeMessurier: Over the winter of '74 to '75, Thürlimann was giving reports back to Cobb and beginning to say that everything was hunky-dory until he was about ready to come to the United States and give a final report. He studied the building in the short direction and in the torsional mode very carefully, and he came to the conclusion that it really had a very large factor of safety against failure, much larger than anybody had a right to expect.

Then, at the last minute, he decided to look into the frames in the long direction—just as a matter of thoroughness. No one thinks of a long, thin building like the Hancock falling over in the long direction. But when he did, he realized there was a grave problem there. And after having almost gotten to the point of saying everything was all right, he had to call at the last minute and say, well, I'm terribly sorry to say it looks as though we have something very questionable in the long direction.

There was a meeting in New York in March 1975 to which Thürlimann came. Harry invited me and the other engineers who had been involved. Thürlimann stunned us by arguing that there was a real danger the Hancock could fall over in the long direction. He was convincing. As a result the building was stiffened—and so was the building code. The Hancock, you will remember, had fully met all applicable codes.

Campbell: Can you explain in layman's terms what the problem was?

LeMessurier: It all has to do with the incremental force when gravity acts on a building that has already been pushed by the wind. If you push on a weightless structure that is perfectly straight, you can calculate the overturning moment by simple mechanics. But if you realize that a gravity load is sitting there, and if the motion from the wind is great, then the gravity load will tend to push the building out of line still further. It's called the "second order effect."

Campbell: You're saying that the lateral wind load pushes the building out of plumb, and then a gravity load comes into play.

LeMessurier: Right. And adds an incremental amount of overturning. But it's really much more complicated than that. Thürlimann found that the second order effect in the long direction was critical not only from the point of view of strength. It also meant that the building became more flexible. The gravity effect gave the tower a longer natural period of calculated vibration—18 seconds instead of 14, if I recall. And then when this longer natural period was coupled with the analysis of the wind tunnel results, it turned out that the wind forces went up, too.

Campbell: How could the wind forces go up?

LeMessurier: Because wind comes in pulses, gustily, not steadily. And it is characteristic of the wind to have more energy at time intervals of 18 seconds than of 14 seconds.

Far right, a detail of a double-glazed window unit similar to the type used in the Hancock building. Note the reflective coating on the inside surface of the outside light.

So you have an exceedingly long period of vibration, including this correction due to the second order gravity effects. You've got wind forces that were very much bigger than any code would specify. You put those together and you could conceive of a scenario of failure. That was the conclusion—it was very firmly stated by Thürlimann and supported by Davenport, and there was really no choice but to do something about it.

Campbell: Can I ask a speculative question? What were the odds, if you hadn't strengthened the building, that it would really ever have fallen down?

LeMessurier: It's an impossible question. The reason is that Thürlimann was measuring only the steel frame. Other things were adding uncalculated stiffness to the building, actually tripling its stiffness. That was enough so that, instead of the calculated period of 14 seconds (not counting gravity), the building's actual period in the long direction was really eight seconds by physical measurement. Thürlimann showed that most of the extra stiffness came from the interior concrete block walls of the core, plus a little from the glass skin. Well, obviously, you don't count on glass for stiffness when the forces get high. And Thürlimann asked, are those block walls still going to be there even when this thing really gets stressed? Or are they going to collapse? The block was not wedged into the steel frame, and there was no way any responsible person could assume that it was always going to stay perfect.

So, to answer your question, would the building have fallen down? I don't know. I know that if you took half of the engineers in that room that night who heard the report, they would have been absolutely baffled by the paradox that a building would fall down because it had an 18-second period but when you actually measured it, it had an eight-second period.

But no engineer would take personal responsibility for saying this building was all right, not after Thürlimann's presentation. So it was decided rather rapidly that the building would be strengthened. The steel frame was doubled in stiffness in the long direction, with new diagonal steel bracing placed next to the block walls.

Campbell: Does the Hancock story mean that other skyscrapers may be at risk?

LeMessurier: It's a possibility, because all the codes ignored this problem. The big thing that was missed and had always been missed was the action of these second order effects due to gravity producing increases in the forces in the beams and in the beam-column connections. So I wrote a report for Harry and then went to bat—very, very hard I must say, working behind the scenes—with people on the specifications committee of the American Institute of Steel Construction, who write the code that underlies all the public codes. We finally did amend the code.

Campbell: The Hancock in plan has a very unusual, asymmetrical shape. A sort of long, skinny rhomboid. Was the shape a factor at all?

LeMessurier: The length was a factor, but not the odd angles.

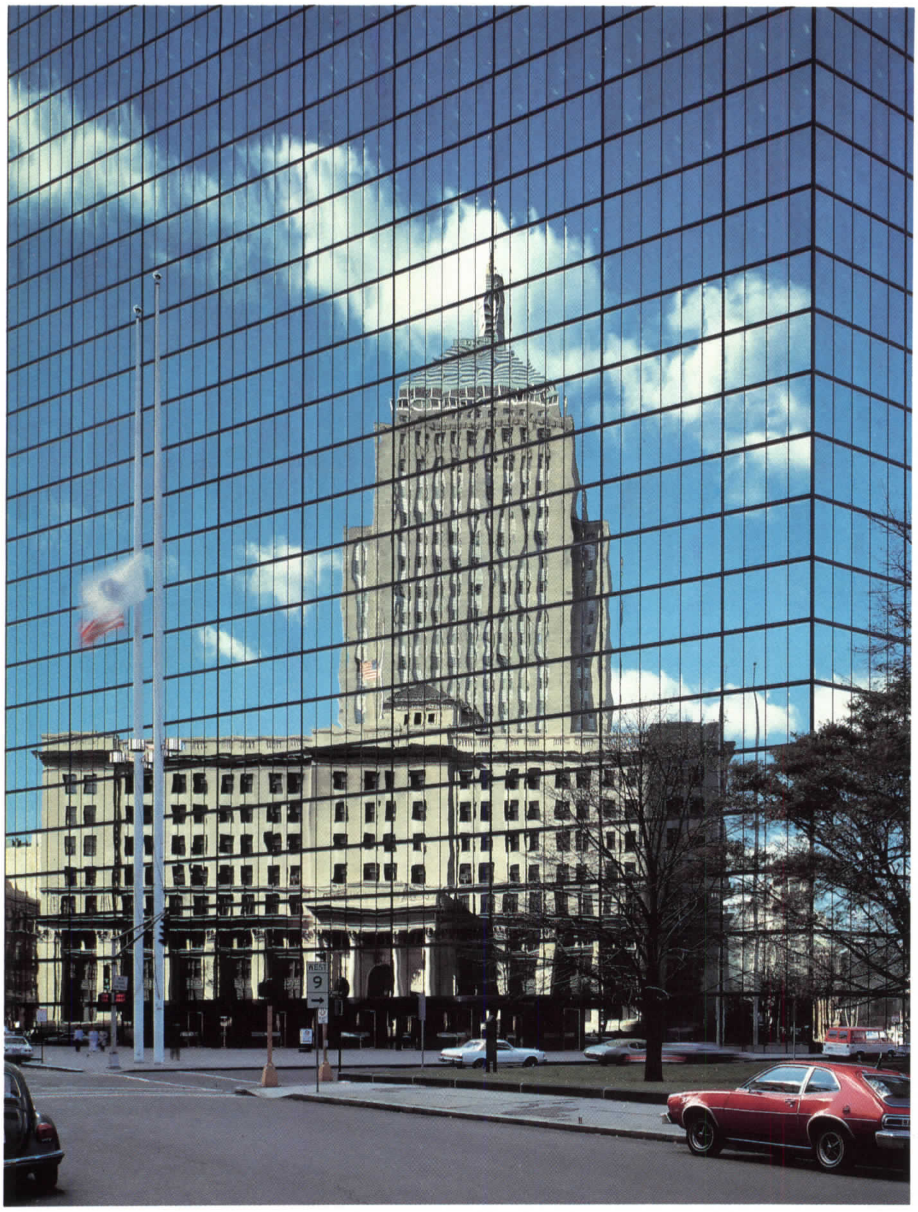
Campbell: Why does the risk come in the long direction? Why doesn't the building fall over the short way, as you'd expect?

LeMessurier: The wind load is much greater in the short direction, of course, where the building presents its widest surface to the wind. So the building is designed to be stiffer—about three times as stiff in the short direction as in the long one. It doesn't move enough in the short direction for gravity to take hold on the building frame. Gravity is acting on a much less stiff structure in the long direction.

It makes all the difference just how long the building is. It makes a geometrically increasing difference. I've worked out the formula.

Campbell: In your opinion, is the Hancock safe today?

LeMessurier: After all the study and testing it's been through, it is certainly one of the safest buildings in the world.



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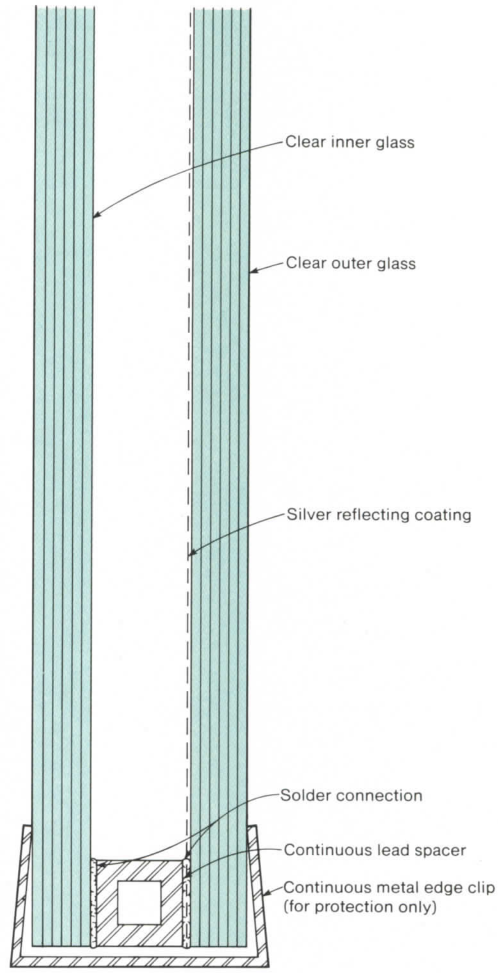

Interview with Victor Mahler

Campbell: Victor, how did you first hear there was a problem with the windows at the Hancock?

Mahler: I was in Pei's office from the mid-'60s to the latter '70s, during the entire evolution of the project. When the problems arose, I was in Toronto and got a call from Mr. Cobb's secretary, asking me to drop everything and come to Boston that evening, immediately. What happened was the January 1973 windstorm, the first big winter storm, which did the first big damage. Before that there was an odd window here and there that would go, but that was treated as normal construction damage.

We arrived in Boston at an event that was pretty powerful. There was a lot of breakage. Glass broke and was sucked out and fell in the turbulent wind stream, and it was blown against other glass on its way down.

We made a very detailed inspection, myself and a staff of younger architects from I.M. Pei. We went through the entire project, window by window, and we performed analysis looking for some pattern in the data. But we could find no clear correlations.

Campbell: Can you describe the window units?

Mahler: It was an old, classic, soldered construction. Double-glazing units have been around since the 1930s, and this is how they were made. There are newer technologies now. There was a continuous lead spacer all around the edge between the two glass pieces, and this lead spacer was soldered with hot lead to both the front and rear pieces of glass to form the sealed unit, with, of course, air in between. The solder forms a strong chemical bond with the glass.

Campbell: Where was the reflective coating?

Mahler: The inside layer of the outside glass had the coating. So the lead seal was soldered to the glass on one side and to the coating on the other. This glass—this reflective glass—was a new architectural material. It started to become available in the 1960s. The glass was coated with a very thin layer of silver-colored material including chrome. This was an exciting material then, not only because it looked exciting but because it rejects some light and much heat. The glass companies were very interested in creating a market for this new product and they wanted a large building, one that would be prominent and well received, as a showpiece.

The other thing that was unusual at Hancock was the size of the units, about 4½x11½ feet. They went from floor to floor, and that was a new departure. In the past there had been fire code requirements to have a spandrel between the floors with insulation to prevent flames from going out and breaking the glass on the floor above. Now, with sprinklers and other life-safety advances, it is possible not to have that. So these were larger pieces of glass of this type than had been used in this way before.

Campbell: What at first seemed to explain the breakage?

Mahler: There were a number of theories. We asked ourselves, had the glass been fabricated and installed properly? Yes, it had. When the steel structure flexed in the wind, did it force the wall out of position in such a way as to damage the glass? No, it didn't. So, we set aside fabrication, installation, and building movement as being unlikely causes. We began to look at the glass itself. How were the glass lights and their aluminum frames responding to wind loading and to the stress that is caused by thermal expansion and contraction?

Campbell: During all this, did glass continue to fall out?


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Mahler: Yes, and in June of 1973 Harry Cobb felt that there was enough evidence from all the observations, analyses, and tests that had been made to show that the glass wasn't doing its job as specified. Harry wrote a letter to the building department here indicating that it was necessary to condemn the glass and that it should be removed. That was a very powerful step. And in fact it was removed and replaced with plywood—not the whole building, because we had different thicknesses of glass at different heights.

Campbell: The investigation now was focused in on the glass?

Mahler: Yes, although it was not so simple to conclude at the time. There was continuing investigation on the skin itself, the metal, the anchorage, with the initiation of detailed analysis of wind tunnel data by Professor Davenport up in the University of Western Ontario, who is probably the pre-eminent wind engineering contributor in the last 20 years. Our earlier testing had demonstrated amply that there never would be enough deformation of the facade from wind force to put stresses on the glass, as I said before. Thus, there is no connection whatsoever, to the best of my knowledge, between building movement and damage to the facade. Wind tunnel tests were now being performed in which the building model was rotated in one-degree increments. Until that time, 15 or 20 degrees had been standard, and that is how the building had originally been tested in the design phase. The one-degree increments showed us some hot spots on the facade, and this was really a surprise. We didn't see any correlations between the breakage pattern and these hot spots. But they did indicate a possible problem, and, as a result, just to be sure, we did reinforce the anchorage in some places when we later reglazed the building.

Campbell: What led you to the final breakthrough in understanding the cause?

Mahler: You have to understand that, besides the wind tunnel tests on the building as a whole, an independent lab was testing the glass units themselves, looking at oscillation and vibration. Every piece of glass in a tall building has to go through tens of thousands of cycles of oscillation—back and forth in the wind—per day. By now the question in our minds was, are the stresses—this cycling plus the thermal stress—doing something to the edge construction of the glass?

All along we'd noticed something in the reports of glass damage. A double-glazing unit is designed to divide the load evenly between the inside and outside lights. But at the Hancock, in most cases, the outside light would break first. Or, when we saw cracks, they would be in the outside light. We wondered why this should be. When the lab tests were made for oscillation and vibration, we looked at the failures and, again, they were in the outside lights.

And on the building itself, sometimes we would catch a crack, and later look at that unit when it failed. We'd look at the edge, and we would see that the edge of the lead seal had little chips of glass in it. You could feel them, you could see them. The glass would break away from the lead seal, leaving tiny fragments of glass in the remaining lead spacer.

It was the testing lab that eventually found an answer. It was discovered that the lead edge assembly developed fatigue. No one knows where it started, whether it was in the lead spacer or in the solder that bonded the lead to the reflective chrome coating and the glass. Fatigue took the form of microscopic cracks in the lead or the solder. And because the bonds—between the lead and the coating, and also between the coating and the glass—were such strong ones, when the fatigue cracks occurred, the cracks would telegraph through to the glass. Microscopic cracks would form in the glass and begin the destruction.

You have to remember that all double glazing for years had been done with *clear glass.* The problem at Hancock was precipitated by the excellence of the bond between the solder and the reflective coating, and between the coating and the glass. If the bond hadn't been so good, the cracks in the solder might not have telegraphed through to the glass. It's ironic. People worked for years to get a reflective coating that would adhere properly. Their very success contributed to the problem.

Campbell: What exactly do you mean by fatigue failure?

Mahler: Well, the glass is continually moving in and out of the wind. There's air between the two pieces of glass and, as they move, the air compresses and expands. That transmits stress to the bonding edge, which is the lead seal. Over many, many cycles the lead and the solder showed fatigue.

Campbell: So the only answer was to reglaze?

Mahler: All of the lights had to be replaced. It's too bad, perhaps, from an esthetic point of view. The original glass was plate glass, and a tremendous effort was made by Pei and the manufacturer to keep it absolutely flat. It was plate glass using the old process of polishing with rouge. The present glass is tempered float. It's wigglier. Harry Cobb wanted a very, very flat-looking glass facade.

Campbell: Have any of the new windows fallen out?

Mahler: You expect a few. The last I heard, the rate had become very, very small.

Campbell: Hadn't anyone had problems with glass of the Hancock type before?

Mahler: We felt, if we're having problems, someone else should be, too. So I reviewed and visited many projects throughout the United States. And I found that the same double-glazed reflective units seemed to have a history of continuing breakage. I photographed units that were showing small cracks and about to break. I learned to recognize a certain kind of a crack, a J-shaped crack at the edge.

Campbell: Was the large size of the glass units at Hancock a problem?

Mahler: The large size increased the stresses and made the problem more intense.

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Lessons from the Hancock

Campbell: What are the lessons for architects from this whole experience?

Mahler: I think that a classic problem in any manufacturing industry is when you have designers who are reaching really to the edge of the the state of the art, that even with all due care and a tremendous amount of professional responsibility there is a chance that you will have found the edge of the state of the art. And it's not only from the technical aspect. It has to do with the organization and responsibilities of the building trades and the building laws.

We had a situation where really everybody reached to the edge. It was like the Gothic cathedrals in the old days, and you know Beauvais—it fell down once, it fell down twice, O.K., now let's try a third time. Finally they got it. It would be hard to do that today under the building laws.

I don't think the codes, I don't think the legal system, I don't think the network of contracts nor the network of professional responsibilities are really set up to face this kind of situation. And all of the wrangling and legal problems simply showed that.

Campbell: Bill, I'll try the same question on you. What can an architect learn?

Opposite, the Hancock as backdrop. Its glazing comprises an unvarying 4.5x11.5-foot grid, unbroken by spandrels, from sidewalk to roof, so that each row expresses a floor. Above, the Back Bay's second and third John Hancock buildings from the Massachusetts Turnpike. The older Hancock (1947), with stepped pyramid top and needle spire, is by Cram & Ferguson.

LeMessurier: Any time you depart from established practice, make 10 times the effort, 10 times the investigation. Especially on a very large-scale project.

Campbell: What about the good things? What do we do better as a result of the Hancock?

LeMessurier: Well, we've spawned a whole new profession of skin consultants. The science of wind tunnel investigation and surface forces has certainly grown. And there has been an enormous amount of academic interest in more refined structural analysis than was used at the time of the design of Hancock.

Campbell: How do you feel about the Pei office and its performance in the design of the Hancock?

Mahler: The people who worked on this project used more than the necessary professional care. They spent far greater effort designing that building and that facade than any commercial architecture firm would do.

Campbell: How about the Pei firm's performance when the crisis came?

LeMessurier: Harry Cobb's performance was not only responsible, it was inspiring. I can't, except off the record, tell you how important it was in my own life to be familiar with his management of this problem. But because I learned how to behave while watching him, whenever I have had some problems in my own professional life that made me have to stand up and be responsible for my client's interest, I said I will have to behave like Harry. I've seen other people who run and hide when these things happen. They call their lawyers, they batten down the hatches, and end up not solving the problem. I think Harry Cobb was an absolute model of how a professional should behave in this kind of situation. □

The Intuition of the Structural Engineer

Interviews with five distinguished practitioners. By Forrest Wilson

Illustration by Brian McCall

Philosophers have held engineers in contempt since the time of Socrates, and perhaps before. Plato stated that no educated man would want his daughter to marry one. As an engineer, Leonardo da Vinci was despised by the literati of his time, and Leonardo returned their contempt with interest.

Similarly, much is made of the differences between engineers and architects. Architects are men and women of letters and imagination, so the truism goes, while engineers live in a world of numbers where each problem logically has a single solution.

There is a gulf between the literary intellectual and the technologist that C. P. Snow termed "the two cultures." He wrote in *The Two Cultures*: "[Architects and engineers are] two groups comparable in intelligence, identical in race, not grossly different in social origin, earning about the same incomes, who do not communicate at all, and have so little in common that instead of going from Burlington House or South Kensington [London's shrines to science] to Chelsea [London's home of the arts] one might have crossed an ocean . . . because after a few thousand Atlantic miles one found Greenwich Villagers talking precisely the same language as Chelsea and both having about as much communication with MIT as though the scientists spoke nothing but Tibetan."

So how can these two camps coexist, much less work closely together, on the same design team? Possibly because even while their tools, thought processes, and sometimes even their goals differ, their principles are the same. The following thumbnail sketches of internationally famous engineers indicate the ideas and attitudes of four contemporary "engine makers." The similarity of their attitudes to those of many architects may come as a surprise. The thumbnail sketches tell us that some engineers trust their intuition as much as their mathematics and theories. And maybe more importantly, they tell us that adhering to accepted professional practice may be the safest way around incurring liability, but it is not the surest way to avoid building failure.

But first, as a reminder, we begin with some prevailing stereotypes of architects versus "engine makers."

- Engineers solve technical problems, leaving architects to solve the problems of esthetics and the humanities.
- Engineers are practical number crunchers, while architects are romantic dreamers.
- Phlegmatic engineers derive solutions by mathematical analysis. Architects' solutions come in flashes of intuition.

Have these statements always been true? Were they ever true?

Mario Salvadori: A love of beauty

Mario Salvadori, Hon. AIA, self-described as a "humble engineer," is renowned in the architectural community, perhaps most widely through his books on structures. His first book, *Structure in Architecture: The Building of Buildings,* published in 1963, contained not a single mathematical formula. With its release, a man at MIT sent word that Salvadori would certainly lose his job, because one cannot teach structures without mathematics (and for that reason the book is not a popular one with engineers). But, as Leo Levi of the University of Milan said, to teach structures by mathematics is easy. One puts a number in, turns the crank, and the correct answer comes out at the other end of the equation. To explain in words why a building does what it does, one must truly understand structures. That the book is in its third edition and has been translated into 16 languages indicates that, indeed, Salvadori understands structures.

By inclination, training, and intellectual interest, Salvadori is a mathematical physicist. He has a deep interest in architecture—acquired by osmosis, he says, from contacts with Gropius, Breuer, Saarinen, Bunshaft, Pei, and Barnes—which is evident in his many accomplishments. He is professor emeritus of architecture at Columbia University.

An engineer with a tremendous influence over the education of a generation of architecture students, Salvadori calls himself a "modest servant of architects" and has a well-developed opinion of the respective roles of architects and engineers during design. For instance, he won't accept a job unless he is assured he will work closely with the architect on integration of structure and design intent.

Still, Salvadori claims engineers and architects are different kinds of human beings. Architects, psychologically and by disposition and training, are generalists, he says, among the last humanists left in our technological culture. They must know more and more about everything and end by knowing very little about everything. On the other hand, the engineer typically is a specialist in a particular branch of engineering, and consequently knows everything about very little. Is there any wonder they differ? he asks.

When asked to describe an ideal structural engineer, however, Salvadori gives an answer that, without substantial alteration, could be applied to architects. Good structural engineers must be capable of explaining subtle structural principles in elementary terms, he says. There are no "difficult" structural concepts. They all can be explained to a 10-year-old child (as Salvadori has done for the past 12 years to minority students in New York City schools).

Structural engineers should be exceptionally proficient in their field and cannot be limited to what they learned in school, Salvadori says. They must refine their theories and include the nuts and bolts of technology. They must be intimately familiar with the infinite variety of detail involved because many of the most horrifying construction disasters have been due to lack of detailing knowledge.

Salvadori does identify some fundamental differences, of course. Engineers must know mathematics and have a clear comprehension of the simplifying assumptions mathematics must indulge to translate practical problems to solutions, Salvadori says. The computer facilitates this task enormously but adds the danger of unquestioning use of structural computer codes. Even the best programs have bugs, some of which appear only after years of use. The engineer should be daring and cautious, innovative and conservative. His or her mental makeup and training are not conducive to wild conceptions. This is understandable because change implies chance and a structural chance unsupported by solid theoretical and practical knowledge can lead to disaster. Most architects could empathize with that.

Also on Salvadori's list of engineer requisites is a love for beauty. This is possessed by all to a certain extent, he says. But he speculates that, because engineers may not feel this is part and parcel of their profession, they may discourage their own creative impulses. A similarity is found in the way some architects view structural engineering. Maybe the mutual, though not entirely founded, feeling of inexpertise is the basis of the traditional animosity.

Concentrating on architects, Salvadori believes they should be intimately familiar with the technologies at their disposal. Architects must gain a thorough qualitative understanding of technology to communicate with engineers, and shouldn't be awed by them, Salvadori says. The architect needs to know the limits of structure, such as that, at the present time, a mile-high skyscraper or a span much longer than a mile cannot be built. These limits will be exceeded, but through improvements in the properties of materials rather than through "new structural systems," he contends.

Salvadori says that architecture students should know by the time they enter their second year in school that they are wasting their time trying to invent new structural systems. Nonetheless, he says, most architecture students live in a pre-Newtonian world in which gravity is yet to be discovered. Furthermore, all their buildings seem to require a site on a Pacific atoll where the temperature is constant day and night throughout the year, where winds are eternally pleasant breezes, and where earthquakes would not dare disturb the peace of the happy inhabitants, he says. And, although it's true that a mathematical approach to structures is the easiest to adopt, Salvadori claims that architecture students, by mental makeup, are allergic to mathematics.

Lev Zetlin: Creativity, analysis, intuition

But engineering itself is not an exact science, according to Lev Zetlin, an internationally recognized engineer and building forensics expert. Science is a record of observed and interpreted natural relationships, and accuracy of measurement, instruments, calibration, and mathematics determines the reliability of the science. But engineers venture one step beyond these findings to extrapolate to phenomena that have not been measured and to make predictions, Zetlin points out. For this reason, Zetlin feels that engineering intuition, not blind faith in calculations and margins of safety, is the keystone to sound structure.

Zetlin gained much of his feeling for the intuition behind structural design as commanding civil engineering officer of the Israeli Air Force in 1947, after serving as an officer in the British army in World War II. Under wartime restrictions, following the establishment of Israel, he designed and supervised construction of transmission towers and related war structures with the materials and knowledge at hand, often under strict schedules and battle conditions. He later refined his formal knowledge in the United States, when he earned a doctoral degree in engineering at Cornell University.

Zetlin explains that our structural design formulas are based on simplified assumptions concerning the properties of materials, loads, and other conditions. As an example, he posits that, while there may be 80 parameters to consider in an analysis, only two are responsible for 98 percent of building deformation—the modulus of elasticity is responsible for nearly 80 percent and Poisson's ratio for nearly 20 percent. Engineers therefore concentrate their attention on the modulus of elasticity. Furthermore, a fixed number is assigned to the modulus although in reality it changes with temperature and stress. Actual deflection varies—it may be 1.32, 1.31, or 1.33 inches—yet, for the sake of convenient calculation, only one number is considered in the structural calculations.

Then the engineer uses differential equations with variable coefficients, which have no precise mathematical solution, Zetlin continues. Values are established without empirical basis, differential equations are solved by assumption and luck, and measurements are eliminated to simplify theory. The engineer then use statistics and a bell curve to derive a standard deviation, which may vary by 10 percent.

Traditionally, the acceptable deviations have worked fine. If an engineer specifies 28 nails and 22 are used, the structure will probably stand. But with standard deviation, acceptability is a matter of relativity. For instance, in astronomy, a 0.1 percent error could easily mean an error of 2 million light-years. So, as new materials, techniques, and components create a greater margin of error, use by engineers of traditionally acceptable deviations could result in structural collapse. An engineer who predicts a 30 percent error and introduces a 70 percent factor of safety is making a mistake if error has crept to 110 percent, even if the error predicted is in keeping with the standards of the engineering profession.

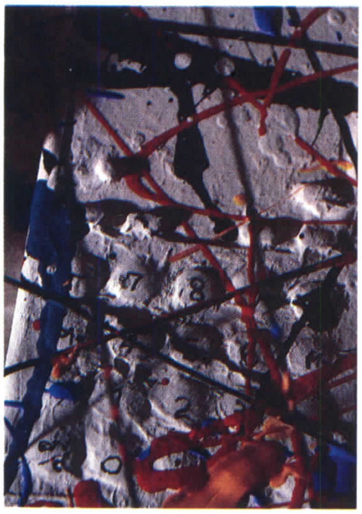


Illustration by Brian McCall

The point is that there has been an increase in construction problems and failures that are not due to professional incompetence on the part of the engineer. New materials with different properties, sophisticated structural connections, prefabricated components, improved design methodologies, and changes in construction field skill have proliferated. The result sometimes proves disastrous. As an example, Zetlin cites the relatively new principle of structural continuity, which has reduced the amount of needed building material but introduced a new phenomenon of total structural collapse. If a column failed in a post-and-beam structure, part of the building gave way but the remainder stayed intact because each element in the building was an independent system. When a portion of a continuous structure fails, the entire building collapses like a house of cards.

Collapse mechanism analysis is a new mathematical tool to determine the failure geometry to warn of possible collapse. But fear breeds caution, and there is a fear of building innovation, new materials, and techniques. Engineering imagination is stifled, Zetlin says, especially when engineers adhere strictly to handbooks and manuals. Formulas in most engineering handbooks and manuals are based on the theories of approximation and cannot be extrapolated to predict, within safe boundaries, the behavior of structures constructed with materials, connections, or geometry different from those within the envelope of past experience.

Zetlin believes that an understanding of analytic tools and their limitations is of extreme importance to creativity. If designers know the limitations of the envelope of experience and understand when a structure is beyond that range they can formulate new techniques. Such knowledge aids in the development of an intuitive approach to innovative structural systems. If an engineer knows that the formula for a 60-foot stone bridge cannot be extrapolated to one that is 300 feet long, then intuitively he or she will seek another solution. Innovative, efficient, economic, and esthetically pleasing structures employing advances in materials and technology and imaginative uses of labor, construction equipment, and design methodology usually fall outside the envelope of experience. Therefore, knowing the limitations is a prompt to innovation.

T. Y. Lin: Inspiration of classical poetry

Another renowned engineer (who also is a philosopher) also believes his profession faces trouble, but for different reasons than Zetlin gives. T.Y. Lin sounds an argument architects tend to associate more with themselves than with engineers. The pay is low and engineers have not learned to manipulate the society as have politicians, financiers, and bureaucrats, Lin says. Engineers seldom advertise, and they work with little overhead, profit, or recognition, he continues. Moreover, engineers pay too much attention to the technological issues and too little to social and human problems. They ignore legislation, so others—most notably lawyers—have a legislative edge. Overall, however, Lin agrees with Zetlin that intuition is the key to good engineering.

Lin cites a love of literature and a knowledge of the Confucian theory of classical poetry as major inspirations in his life. He was graduated from the University of California in 1933 and returned to China to build for 13 years, in a time of war and turmoil. His experiences were not all that different from Zetlin's. He was forced to return to basic engineering, understand its essential nature, and work with unspecified materials using empirical rules. This developed and honed his intuitive feeling for structure.

After returning from China, Lin taught for 30 years at the University of California at Berkeley, experimenting and developing theories. Challenges proved simpler to him after 13 years of intuitive engineering. In China he had designed with primitive materials rigid frames that stood more than a hundred feet tall while successfully sustaining the moving loads of heavy trains. Many of these bridges remain in use to this day.

Of course, there were no computers—Lin worked with soul and instinct. Once the basic theory was understood, the design could be over- or underdesigned, but it was optimized. This is not possible with a computer, and Lin worries that computer learning separates students from basic theory. The belief in numbers puts too much trust in the computer, and there is no experience with which to detect wrong numbers. Commonsense understanding of physical behavior becomes less and less common.

Lin feels that bridges especially express the elegance of natural forces. The three arches of the Formosa Bridge are a perfect moment diagram for a continuous span found in every basic book of engineering. The hangers are almost invisible, and all nonessentials are minimized. The Ruck-A-Chucky Bridge in Auburn, Calif., done by Lin with Myron Goldsmith, FAIA, was not designed "artistically"—it expresses natural forces as the solution to a scientific problem. The cables are spread, forming a hyperbolic parabola as the forces run along the curve. There is no shear, no torsion. Moments are eliminated. The solution required six months of analysis and a moment of insight.

The basic concept of the Ruck-A-Chucky Bridge was to cross 1,300 feet of water 500 feet deep. Using a curve meant tunnels did not have to be dug through bordering mountains. An arch didn't look right. They then tried a suspension bridge, and then a cable-stayed bridge with four piers. One day Lin asked Ken Low, an associate in his firm, for an idea. The piers should be a little longer, said Low. Then the idea came—lay the piers down. But the end solution would have been impossible without the entire analytic process.

Lin says that instinct extends beyond calculations and that numbers should support engineering instincts, not substitute for them. For instance, connections should look right, he says. An ugly connection or structure is probably unsafe, nonfunctional, uneconomical, and unoptimized. Equally important is consideration of human response to structure. For example, if a bridge is three miles long and a car is driven over it, will the driver become dizzy?

Because structural engineering must satisfy the demands of human behavior, the environment, politics, and economics, Lin says it isn't a pure science. Furthermore, compared with disciplines such as electronics, the development of building structure has not progressed appreciably. With relatively little change over the last 2,000 years, there is small difference between structural developments of 1,000 and even 3,000 years ago.

But Lin does see the roles of the architect and engineer, as well as their relationship, currently in a state of flux. For instance, he says, in the 1960s an architect would go to an engineer with an unusual form and say, "Build it!" and the engineer had to change the design to calculate the structure. Today, the opposite occurs—engineers discover unusual forms and say to the architect, "Find a use for it." Lin thinks both approaches are extremes that ignore optimization. And optimization, he says, is the goal toward which the architect and the engineer should proceed together. He points out that optimization as balance in life is a Chinese philosophical concept. Unlike compromise, optimization achieves more than the sum of the parts. Lin believes that if all concerned are reasonable, extreme points of view may be reconciled for an optimum solution.

Another role change Lin has noted during his career is that, while architects were involved in science and technology in the '60s, today it is engineers who appear to be the design professionals most responsible for technical innovation. For example, ASHRAE appears more interested in the quality of interior environments than architects, and it spends more money on research. But, with modern technical developments, each discipline—mechanical, electrical, and structural—has a contribution to make. If each is optimized, none forces itself at the expense of the others, and all are combined for the most satisfactory whole.

When Zetlin and Lin speak of the importance of intuition to structural engineering, they draw their conclusions from earlier experiences in the field in other countries. But both developed their conclusions while working in the United States. A question still remains, then: do the basic laws of intuitive structural design transcend geography as well as time? To appreciate the effect of trends on engineering intuition, one should step outside the United States to get a different perspective. Australia, where design concepts are readily imported and just as quickly domesticated, serves as a good vantage point from which to observe the effects of structural developments in recent history.

Henry Cowan: A social conscience

Australian Henry Cowan is an internationally famous engineer who organized the architectural science department at the University of Sydney in 1954, the year of the Sydney Opera House competition. Both experiences made it clear to Cowen that, although architects are fascinated with structural forms, without the intuition derived from knowledge and experience the projects they visualize cannot always be built as planned and may have serious social and economic ramifications. In the case of the opera house, the jury perceived the winning design as a thin-shell structure. As such, the jury, its chairman Eero Saarinen, and its government architect thought the design was economical. In his cost estimate, a quantity surveyor assumed a four-inch shell, and even with expensive formwork the project continued to look economical. As it turned out, the cost of the finished opera house proved to be 1,800 percent greater than estimated, in large part because of construction complications stemming from an unbuildable design.

Such mistakes are not as likely today in Australia, Cowan says, since experience and improved technology mean structural forms can be accurately determined and calculated. He still sees designs that can't be built, but generally they aren't building designs, he says. Shell structures didn't generate much interest beyond the opera house, Cowan says. But a structural trend that did pique the curiosity of Australian architects and engineers was high-rise design. Structural problems for tall buildings generated some interest in Australia when height limitations were lifted in cities like Sydney and Melbourne in 1957. Suddenly Australians had an interesting new structural problem for a time, Cowan says. It took a decade, but by the late 1960s, architects and engineers had developed an intuitive feel for tall building structure and were designing tall buildings as a matter of course.

Cowan cites a number of other structural developments that have occurred during his career with unanticipated results. For example, he says, the dream that prefabrication held in the '50s and '60s was a mistake. Prefabrication works extraordinarily well in emergency conditions. But the design of aluminum houses following World War II demonstrated that it was impossible to exercise factory precision under site conditions and that once a margin for fitting is allowed the advantages of prefabrication are lost. Expensive joints must be added and, under normal conditions, prefabrication becomes more expensive than traditional building methods. However, industrialized building is arriving in less dramatic but more practical ways—there are packaged bricks, prefabricated roof trusses, prefabricated bathrooms, plumbing, and nail guns.

Likewise, while the energy crisis in the '70s shifted economic attention from structure to energy, what was saved on energy was often lost on expensive buildings. We were also wrong in believing houses had to be terribly light; there is more sense in building with massive materials because the structure is not easily damaged, is easy to alter, and has good thermal inertia.

During the 1980s, the important development in architecture has been computers. The Australian government has switched to computerized drafting, but the use of computers in design is still under consideration. Cowan says that the computer is useful for modeling effects, such as shade and shadows, and in that way it is not a design tool but rather a design guide that enables architects to exercise their creativity within practical limits. He doubts that architects have the patience to mix intuitive judgments with computer accuracy. Computing is totally different from design because when something new is drawn on a computer, what existed before is lost. Nonetheless, Cowan feels that if the computer finds a significant place in Australian design it will revolutionize architecture as it has structural engineering.

Cowan also stresses the importance of the social aspects of the high-rise building trend. Australians currently are concerned foremost with housing instead of acoustics, thermal conditions, or structure. Cowan says that Australians have a bad conscience regarding treatment of the aborigines and also are concerned about providing housing for the elderly. Both issues demand the collection of social and economic data and the use of statistics, which engineers have not learned to do very well, he contends. Past solutions of placing poor people into high-rise housing, with the thought that they would be better off, were gross errors of judgment in Cowan's opinion. Open office planning is the same kind of social mistake, although on a smaller scale than high-rise housing, he says. These mistakes could have been predicted by responding to human opinion, and human preference is an area of research that Cowan feels is important.

Cowan says that engineering itself has always been a reasonably precise discipline—there is a right solution, and some solutions are more right than others. Wrong solutions fall down. Architects can make even greater mistakes, such as the social error of high-rise housing or the economic error of the Sydney Opera House. And politicians can make the gravest mistakes of all. But successful architects get greater rewards than engineers, and, of course, successful politicians get the greatest rewards of the three.

Working together in the swamp

During the last two decades, professionals have become increasingly aware of what Donald Schon, a professor at MIT, terms "indeterminate zones of uncertainty in practice." A problem is not given, and the difficulty lies in discovering what is to be solved. These are areas of uncertainty, uniqueness, and conflict that cannot be handled through technical rationality. The professional must get from "mess" to "problem" before technology can be applied. Schon's analogy is a topology of practice that consists of a high ground and a swamp. On the high, hard ground, technical rationality can be practiced. In the swamp below lie the messy, difficult, and crucially important problems that professionals must solve. The dilemma of today's professional is whether to work on high-ground, purely technical problems or on illusive human issues down in the swamp, in which they cannot describe their work as rigorous.

We see in the thumbnail sketches of Salvadori, Zetlin, Lin, and Cowan that the great "engine makers" are increasingly willing to jump into the unique situations that cannot be handled through technical rationality alone. Are the "two cultures" described by Snow becoming one? When architect and engineer both muck about in the swamp of human idiosyncrasy, trying to solve the vital undefined problems of our time, where is the difference between them?

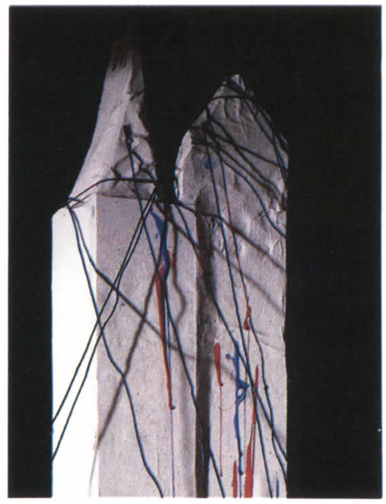


Illustration by Brian McCall

Konrad Wachsmann: 19 years ago

This previously unpublished personal interview by the author was conducted in California in 1969.

"People continually ask why we cannot use space technology for housing. This is naive. We need more money for building research than the billions spent on space technology. Building is the key economic problem, of all national economies, but if you ask to do basic research on housing products, there are never sufficient funds available.

"Building product manufacturers of concrete, steel, and wood are geared to improving their products in terms of houses built today. This is not the problem. We lack housing education and it is a national problem. The university is obsolete and no longer conforms to our requirements. Better education for students is impossible because there is no teaching education. The training of teachers is more important than the training of students.

"Architecture as an art is less important than other things. The Renaissance could have survived without science but not without art. There is no general conviction today concerning the importance of art as there is about the importance of technology. Although educated and sophisticated people have definite opinions about art, there is no general, accepted opinion or conviction. But everyone understands technology. Without it we could not exist. How things are changed from raw materials into something useful is a technological, social, economic phenomenon and therefore a political phenomenon.

"It is easy to talk about art and architecture, but what is needed is work on technology to create a new environment. Rather than writing a book one should work on the problem. There is no point in writing a book about architecture for there is nothing to be said. Thousands of people should be working on the housing problem, not a few artistic prima donnas.

"People ask about the intention of technology and its use and the young's widespread turning away from it. I think they turn away before they touch it and prefer to make programs. If one makes programs, he or she never has to make a statement.

"The most important things today are those bearing on technology. For example, the building of a house is not determined by design but by production problems. Each building is built as the solution to an individual problem. The wall is reinvented with each design. These are not particular problems but are instead generalized universal problems.

"Designers want to survive. They must make money and cannot possibly solve problems using the amount of money they receive in design fees. Only a limited time can be spent. The objective is to sell the product. Typically the client is asked to be a guinea pig and finance experiments. Money for the solution of real problems is lacking. Problems cannot be solved for 5 percent or 6 percent of the cost of a building.

"I do have a fantastic client who said, 'I do not care how long it takes or how you do it. I have a grant to do anything I want. They do not ask questions or require a product or a report.' This condition does exist, but on too small a scale." □

Exploring Composite Structures

They exploit the best qualities of concrete and steel. By Matthys P. Levy

In the basements of many houses in the United States there stands an early example of composite construction: the concrete-filled pipe column. In that application, concrete provides the rigidifying element that stiffens the steel shell, preventing oil-canning and thereby increasing the allowable load on the steel column. When first used more than 50 years ago, the concrete-filled pipe column symbolized an attitude about the relative merits of concrete and steel. At that time the useful strength of concrete was about one-tenth that of steel. Today, concrete strength is approaching one-half that of steel, a dramatic fivefold increase. Concrete, which was relegated to use as a stiffening material with no credit given for its strength, is now the structural material for 75-story buildings. Of course, reinforced concrete, by definition, recognizes the specific strength of concrete in compression. Composite structures take advantage of the compressive strength of concrete as well as its inherent stiffness.

Composite structures exist in many forms. Shear studs welded to the top flange of a steel beam provide the bonding element tying a poured concrete slab to the beam. Similarly, deformations in a metal deck bond the deck to the poured concrete topping. These are examples of composite construction. It is, however the type of construction more properly called *mixed steel-concrete systems* that is explored in this article.

A mixed system generally starts with a steel structure for the horizontal framing: beams, girders, metal deck, and usually a composite concrete topping. The vertical gravity system often consists of steel columns encased in concrete or concrete-filled tubular columns. Lateral load-resisting capability may be provided in a number of ways; for example, a vertical truss system, either cross-braced or vierendeel (really, a rigid frame), provides shear rigidity transferring axial bending loads to exterior concrete or composite columns. Alternatively, a perimeter tube is developed by encasing steel columns and beams in cast-in-place concrete or by attaching precast concrete panels to a steel frame.

There have been two objectives in the continuing exploration of mixed systems: (1) seeking an economic balance in the optimum use of both steel and concrete by exploiting the best properties of each material and (2) providing the requisite stiffness for stability and resistance to lateral deformation. In a high-rise building, the total steel tonnage for the structure includes that required for the floor, the columns, and wind resistance. Expressed as pounds of steel per square foot of floor area, the floor steel is a constant, while the steel required for columns increases linearly with height, and that required for wind resistance increases as the square of the height (see Figure 1).

Mr. Levy is a principal of Weidlinger Associates, an international structural and civil engineering research firm headquartered in New York City.

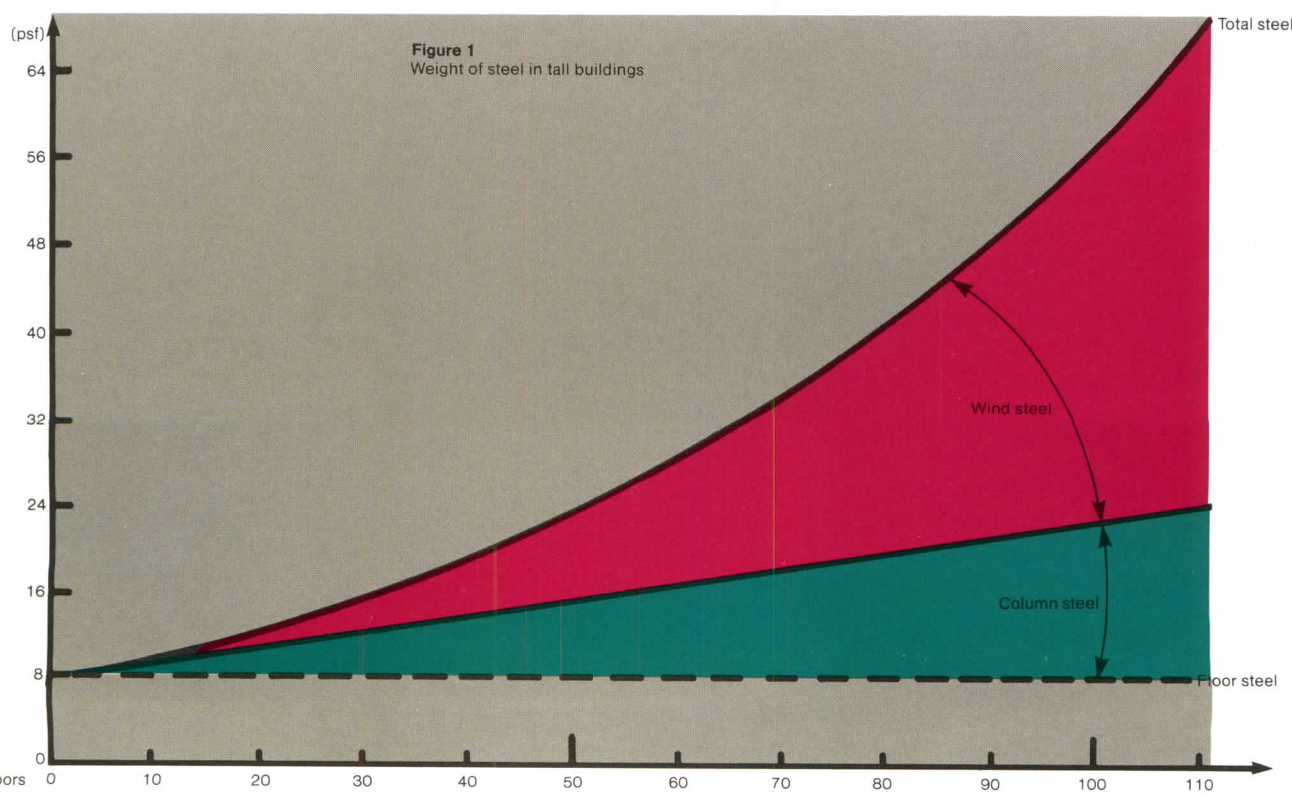


Figure 1
Weight of steel in tall buildings

Fazlur Khan of Skidmore, Owings & Merrill/Chicago developed tube-type building structures to reduce the so-called wind penalty, devising both trussed and framed systems that contained the increase in steel quantities to reasonable levels in buildings such as the John Hancock and Sears towers in Chicago. Khan also used the tube concept in concrete buildings (DeWitt-Chestnut and Brunswick buildings in Chicago), while Paul Weidlinger earlier had used the concept for Saarinen's CBS Building in New York City. In each of these cases, economies of the structure resulted and the stiffness of the building was enhanced.

The 52-story One Shell Square Building in New Orleans by Skidmore, Owings & Merrill was one of the first to use a true mixed system. The perimeter tube in that building consists of spandrel beams and columns, 10 feet on center, of travertine-clad, poured concrete. All interim framing and erection columns along the perimeter are of steel. It is common in mixed systems to use erection columns to permit the steel frame to proceed about 10 stories ahead of the concrete construction. These erection columns then are incorporated into the final composite concrete columns. The separation between the steel and concrete construction is dictated by stability considerations: the steel frame without the concrete frame is not stable and requires temporary bracing using steel cables or cross-bracing. The temporary bracing becomes uneconomical if it is required to stabilize more than about 10 stories of construction.

Composite tubular systems such as that used in One Shell Square, ideal for stiffness in the 50- to 80-story range, demonstrate the following characteristics:
- Use of an efficient perimeter frame with short spans and columns spaced five to 15 feet on center.
- Speed of construction similar to an all-steel building.
- Unimpeded interior space with no shear walls or cross-bracing.

From a technical standpoint, a framed tube is obviously not as rigid as a windowless tube. The principal difference is the effect called shear lag: as a frame deflects laterally, beams and columns develop bending forces, which have the effect of shifting large axial forces to the corner columns. Furthermore, on the two faces perpendicular to the wind direction, instead of a uniform resistance, which would be characteristic of a solid, rigid wall, more force is concentrated at the corners. This

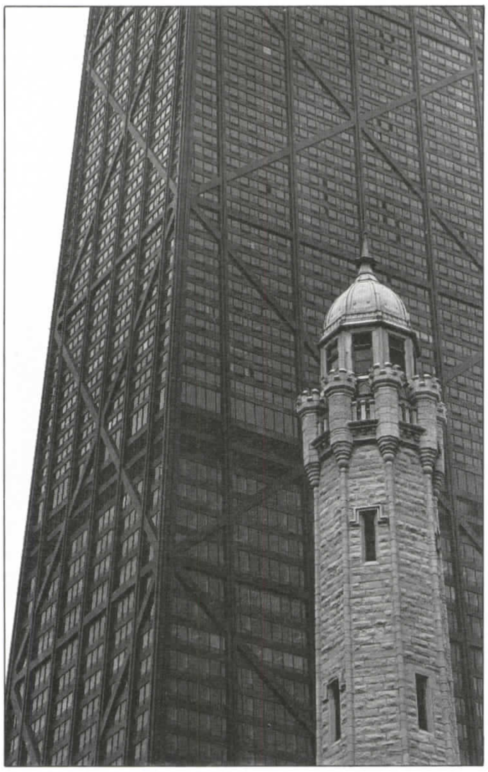


Figure 1, left, graphs the weights per square foot of steel needed for floors, columns, and wind versus number of floors in a building. Chicago's Hancock tower, above, was designed to keep these steel requirements to a reasonable level. Figure 2, below, compares actual stress due to shear lag versus true cantilever stress.

shear lag effect, which is illustrated in Figure 2, reduces the efficiency of a cantilevered tube. The greatest benefit in terms of distribution of materials between columns and beams to reduce this effect is usually obtained by making the beams deeper and therefore stiffer, keeping in mind that columns must also carry gravity loads. With today's computers it is a relatively simple exercise to parametrically examine different proportions of beam and column stiffness to arrive at an optimum configuration (measured in terms of material utilization).

In a mixed system, differential shortening of columns is an important consideration. Consider two columns, one steel and the other concrete, carrying the same gravity loads. The concrete column is subject to creep and shrinkage, which have the effect of shortening the column. Columns on the perimeter of the building (composite and concrete) are sized for both gravity and wind loads and operate at a lower stress under gravity loads alone as compared with interior columns (usually steel), which carry only gravity loads and therefore can be more highly stressed. In this case the steel column will shorten more than the concrete column. The combined effect of creep, shrinkage, and differential axial shortening in a tall building can be substantial—measured in inches rather than fractions of an inch.

The Texas Commerce Tower in Hous-

Figure 2
Shear lag

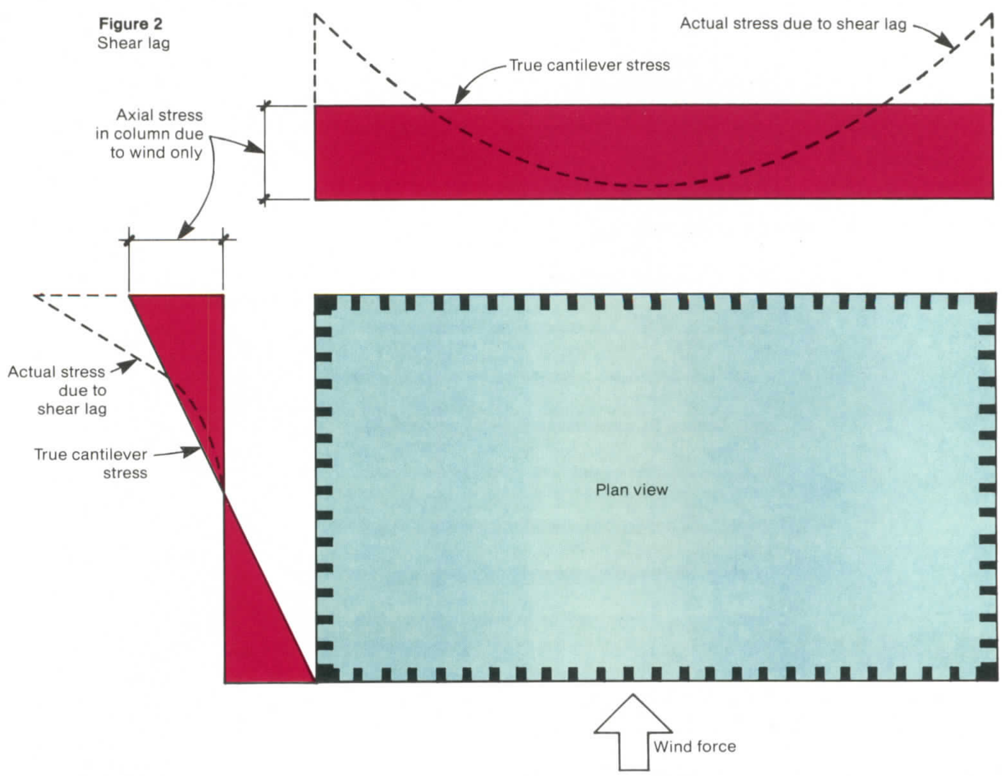


Figure 3
Texas Commerce plan

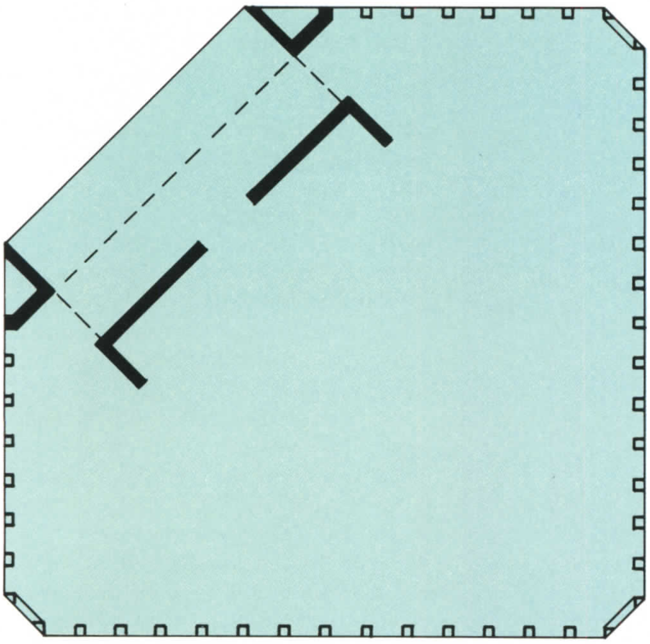
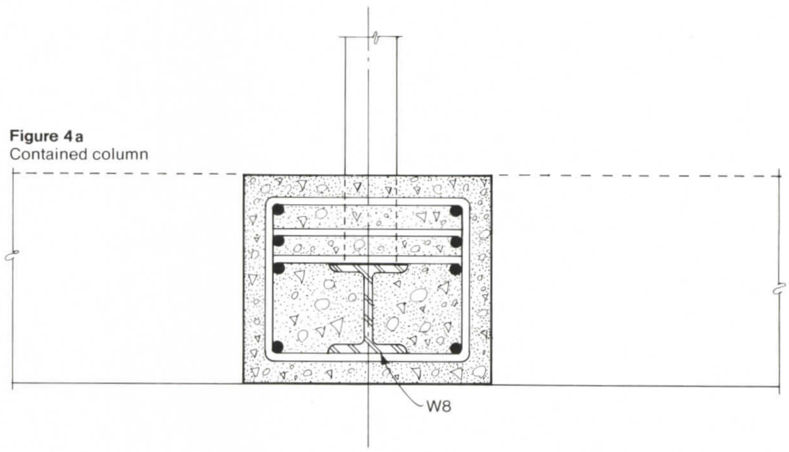


Figure 4a
Contained column



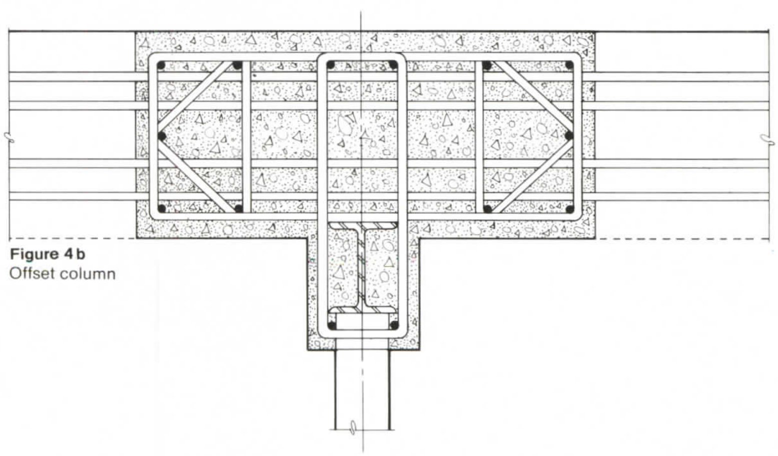


Figure 4b
Offset column

Above left, Figure 3 shows a plan of the Texas Commerce Tower with composite columns and linked shear wall. The drawings above contrast an integral erection column (Figure 4a) with a separate erection column inside the spandrel (Figure 4b). Below left, the erection sequence of the tower is shown in Figure 5.

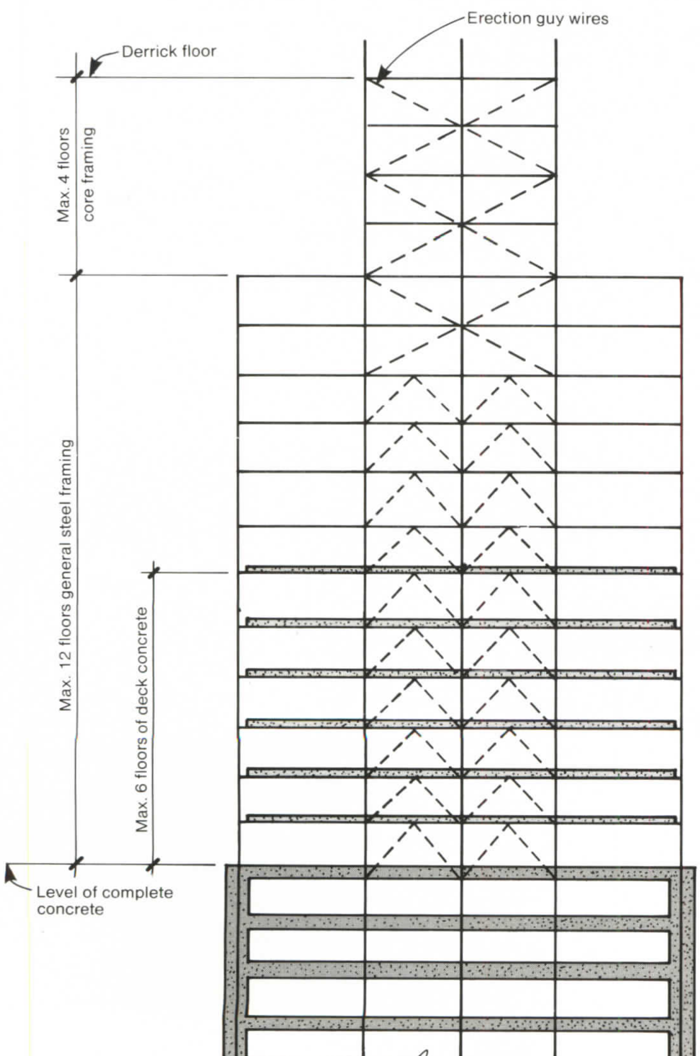


Figure 5
Bracing and limitation on construction sequence

ton is a 75-story, granite-clad building engineered by Joe Colaco. Designed by I. M. Pei & Partners with 3D International, the building is 161 feet square with a large, 85-foot chamfer on one corner and a structural frame consisting of beams and composite columns 10 feet on center with a linked shear wall and beams across the chamfered side (see Figure 3). Floors are steel-framed and the erection columns are buried in the spandrel columns (Figure 4a). This contrasts with earlier composite structures where the erection columns were placed to the inside of the spandrel (Figure 4b). It is easier to form and place reinforcing in this latter configuration, but the projecting post hinders interior space planning. Erection followed the classic approach of allowing the steel frame to proceed ahead of pouring the exterior composite frame. In this case, 12 stories plus an additional four stories of the core proceeded in advance of the composite frame (Figure 5).

Because of the unusual configuration of the tower and the need to "heal" the slashed corner by introducing link beams to the offset core wall, warping of the tube due to wind loading was significant. Another problem was caused by the exposed exterior surface of the building. Differential temperature movement between interior columns kept at a relatively constant temperature and exterior columns subject to ambient effects meant that, at the top floor, a two-inch thermal displacement could result between the core and the perimeter. Additional slab reinforcing was introduced in the slab around the core for the top 20 floors to mitigate the visual impact of such a movement.

For the 73-story (920-foot) Interfirst Plaza Building in Dallas, engineer William LeMessurier took a different approach. In plan, the building looks like a stretched hexagon with serrated edges. Sixteen columns are distributed inside the edge of the building on a 30-foot grid (Figure 6). Instead of shear walls or exterior frames, rigidity is provided by vierendeel frames in a two-way grid (in plan) spanning between the outside columns. In order to obtain sufficient stiffness in the vierendeel frames, beams are 42 inches deep. As a result, no interior columns, including those in the core, go to the ground, and all gravity loads are carried by 16 high-strength concrete columns. These same columns carry all the wind shear through a transfer system at the grade and concourse levels. In this tower, steel erection proceeded nine stories ahead of concrete placement.

The detail below depicts a concrete column attached to a shear wall. The plan below in Figure 6 is the Interfirst Commerce Building. The structure contains 16 high-strength perimeter columns and vierendeel frames in a two-way plan grid.

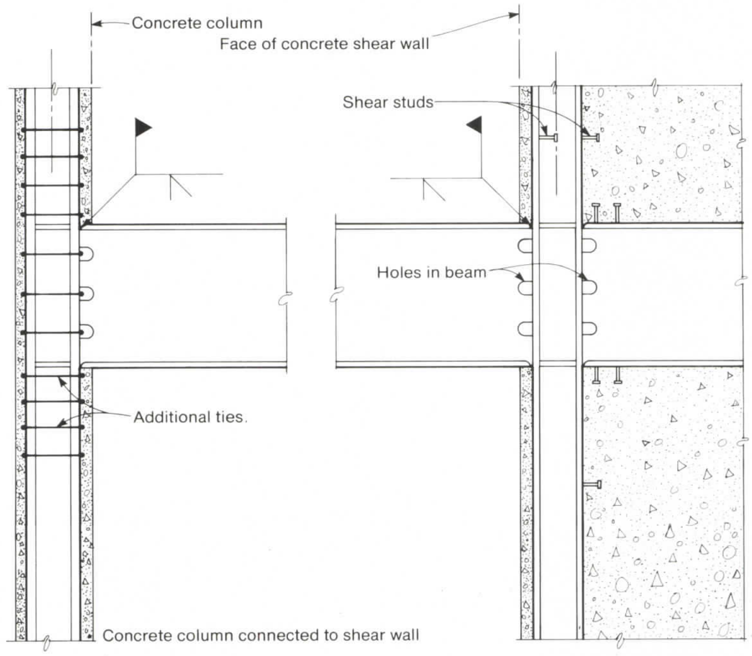


Figure 6
Interfirst Plaza plan

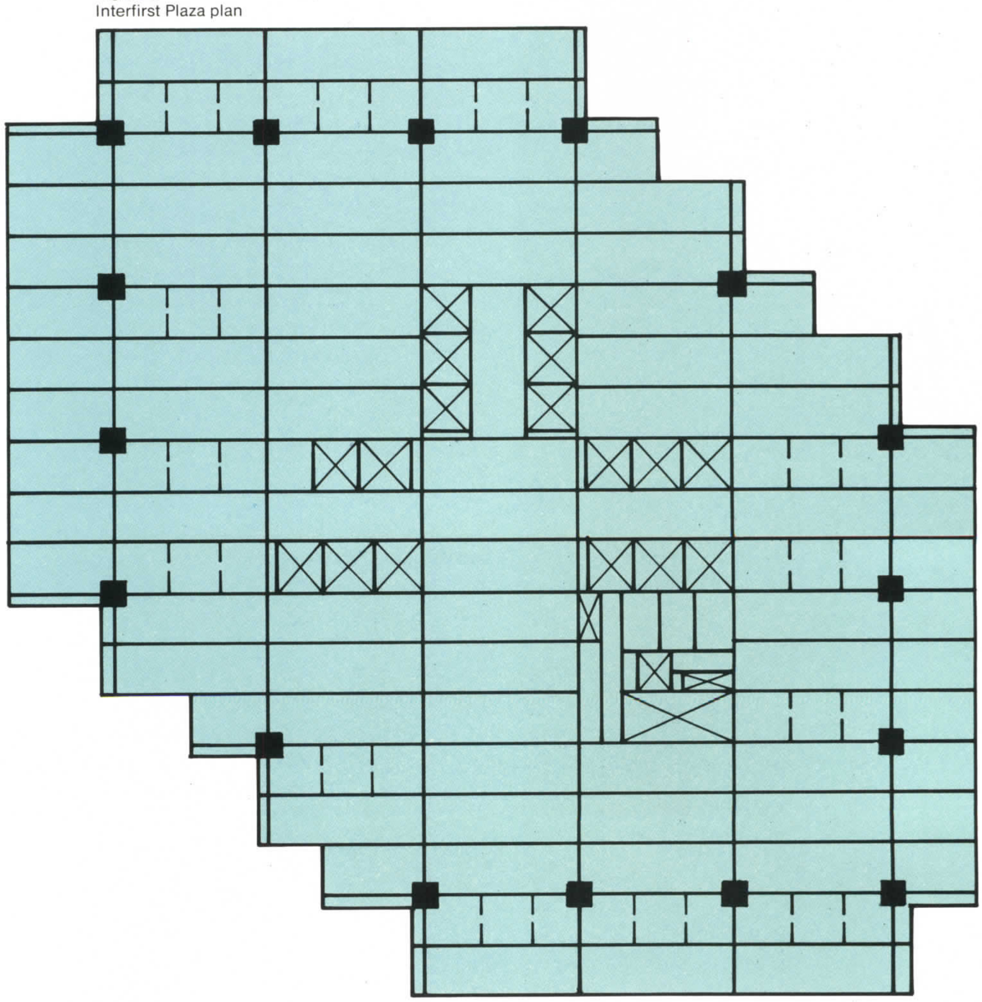
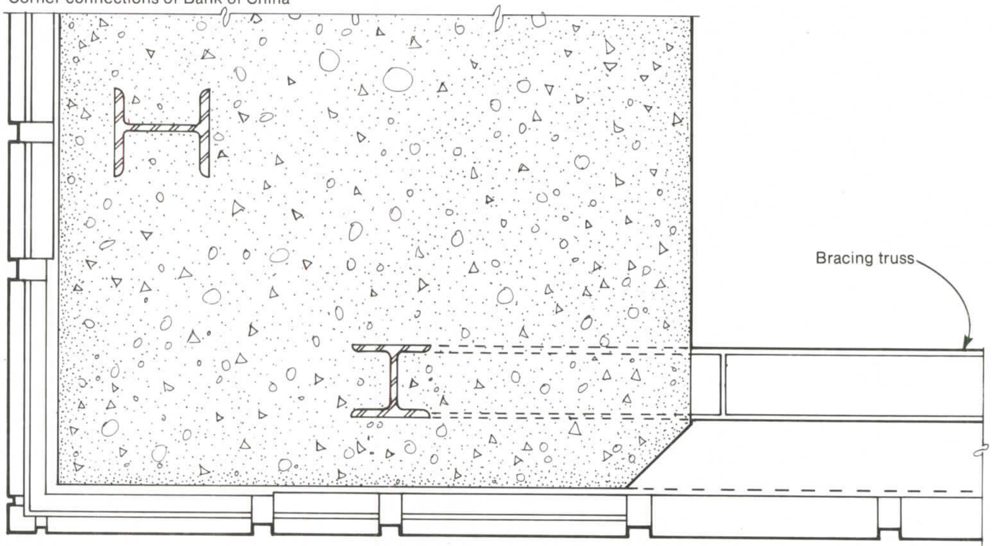
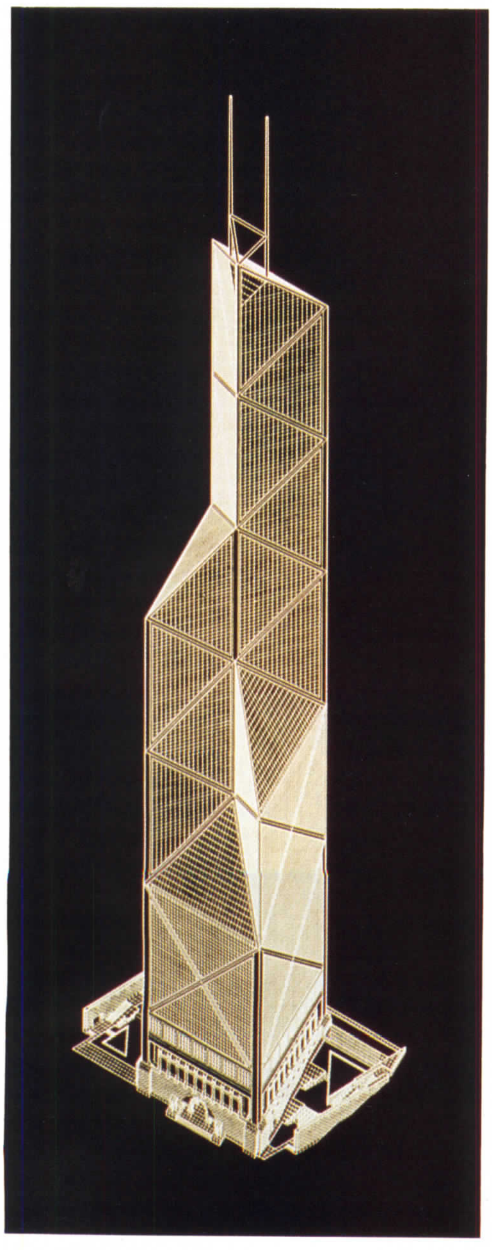


Figure 7
Corner connections of Bank of China



The photo below and Figure 7 at right show the structure of the 76-story Bank of China Building in Hong Kong.



Although a windowless tube provides the most effective way to resist shear forces, a close second consists of a web of diagonals on the faces of the tower. This concept was used in an ingenious manner by engineer Les Robertson in his structural solution to the 76-story (1,028-foot) Bank of China Building in Hong Kong, designed by Foster Associates. A prismatic structure rises from a 170-foot-square base, divided into four triangular quadrants along the diagonals. Each quadrant is topped out in sequence until the tower condenses to a single triangular pinnacle. Each successive condensation follows the geometry of the triangulated facade truss in a supremely elegant execution. Instead of ending up with a large, three-dimensional, welded connection at the intersection of the diagonals and columns, as was the case in the Hancock building, Robertson disjointed each plane truss and buried the erection columns in a sea of concrete. The resulting composite column at each corner of the tower (Figure 7) provides numerous benefits:

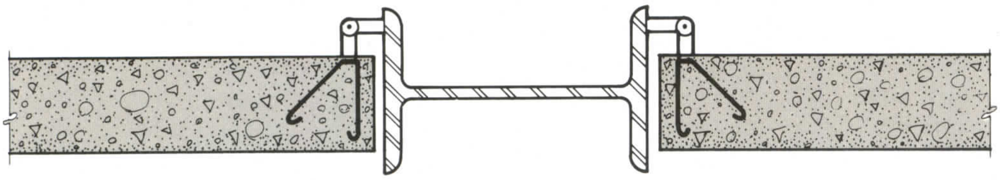
- It is a shear transfer mechanism countering the eccentricities resulting from nonconvergence of all the truss members.
- It permits large tolerance in the steel frame.
- It greatly simplifies steel details and number of welds.

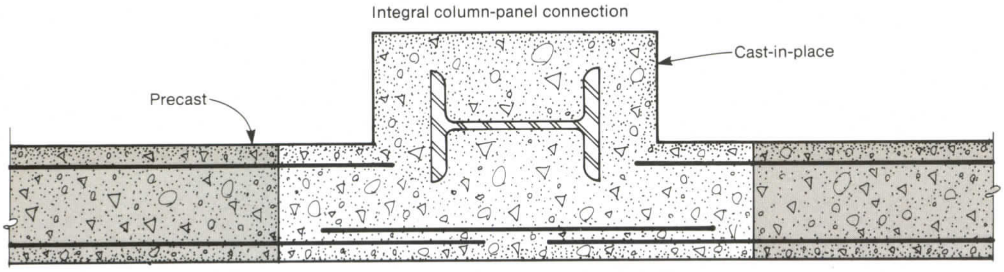
The truss system ends at the fourth floor of the building; from there to the foundation, shear forces are transferred to steel-plated core walls while the four corner columns carry most of the gravity loads. Belt trusses (which are suppressed in the building elevation) pick up intermediate columns along the facade and transfer loads to the four columns. The structure is in every sense a megastructure.

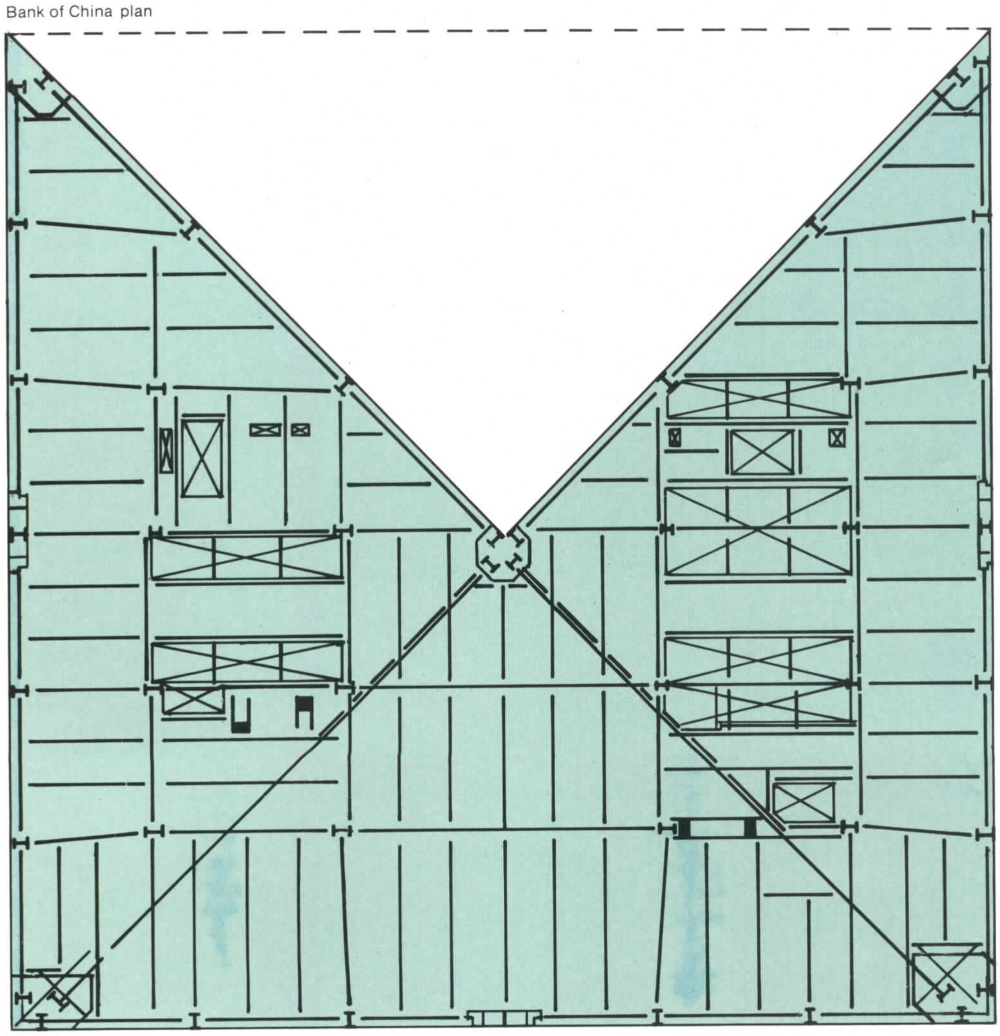
In Seattle, the use of 19,000 psi concrete steel shells brings the pipe column once again to the edge of technology (see page 92). The firm of Skilling Ward Magnusson Barkshire is using these high-tech columns in diameters of three to 10 feet to support the 62-story (759-foot) Two Union Square building designed by the NBBJ Group. The steel pipes serve as the formwork for the concrete (resulting in a level of economy) and are the total reinforcing with internally welded shear studs providing the requisite bond between steel and concrete. The floors of the building have conventional steel framing with metal deck and composite concrete slab. As a result of the mixed system, the total steel weight in this building is 12.5 psf—about 50 percent of that in an all-steel building. In general, mixed-system buildings have steel quantities on the order of 40 to 60 percent of the steel in all-steel buildings.

What can we expect in the future? One little-explored concept for mixed-system buildings is the precast building panel. Proposed by Weidlinger Associates in 1972 as "shear field panel bracing," before the advent of energy regulations, such panels now fit into the trend toward masonry facades with smaller window openings. Such panels, which can be either mechanically connected to columns and beams or, more likely, bonded to cast columns, provide perimeter tubes for buildings in the 40- to 60-story range. This is a range of heights greater than that served by core bracing systems and less than that requiring some of the more exotic structural solutions described above.

The pipe column, as a modern coat for a super-strength concrete core, has only begun to be fully explored. □







In the details shown above, an integral composite column to precast panel connection is compared with a more traditional steel-column to panel connection. The plan of the Bank of China Building, designed by Foster Associates and engineered by Les Robertson, indicates the origin of its prismatic structure. The 170-foot-square plan is divided into four triangular quadrants along its diagonals. The four corner composite columns have steel erection columns surrounded by concrete.

Case Studies of Structural Innovation

By Douglas E. Gordon and M. Stephanie Stubbs

As structural engineer Mario Salvadori says, architecture students know by their second year that they are wasting their time trying to invent new structural systems (page 77). However, there is much structural innovation on the drawing board and in the field. New materials and methods are pushing out the limits of structure and, therefore, architecture. For example, Seattle now boasts a 58-story composite-structure office tower, in which the concrete has an unprecedented strength of 19,000 psi.

Architectural innovation also draws inspiration from other industries. A luxury hotel floats in a lagoon off the Australian coast thanks to techniques derived from barge building and offshore oil rigging practices. A baseball stadium's huge, post-tensioned concrete members are joined using bridge construction technologies. A mixed-use complex skirting the edge of Boston Harbor was constructed skyward and excavated simultaneously, borrowing equipment and practices from the mining industry. And, with more sophisticated systems and materials comes greater complexity. Architects increasingly look to their computers for help in designing and calculating structures.

Not only architects but also clients seem fascinated by the esthetics of structure, as evidenced by a six-block-long convention center that loudly and cheerfully shows off its structural systems. And, of course, all the projects are done within tightly constrained construction scheduling and budgeting.

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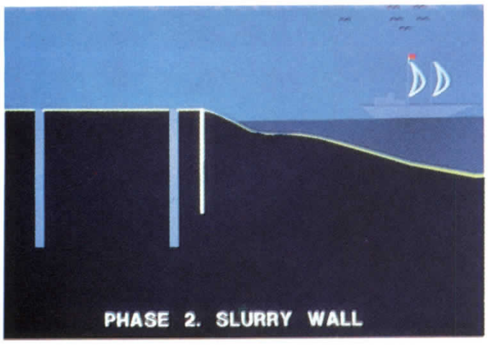
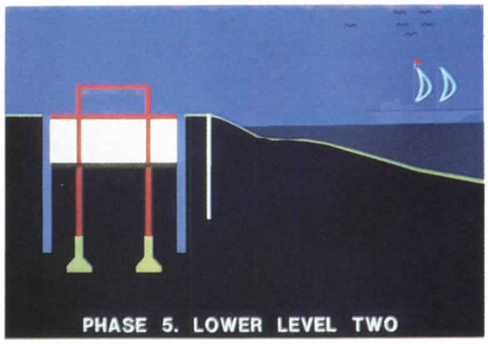
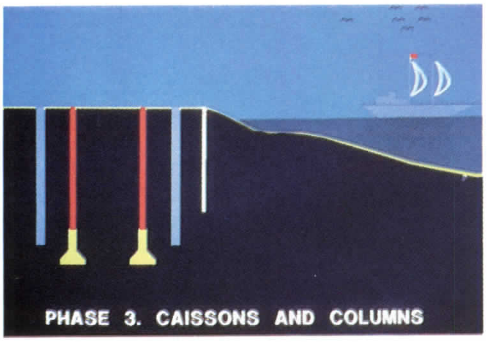
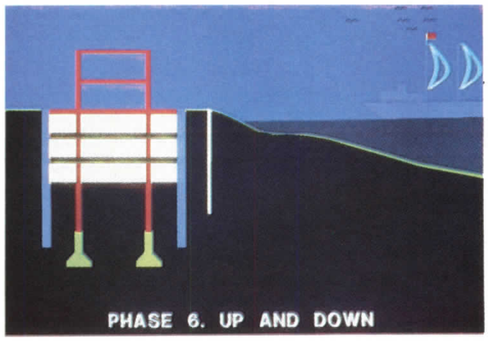
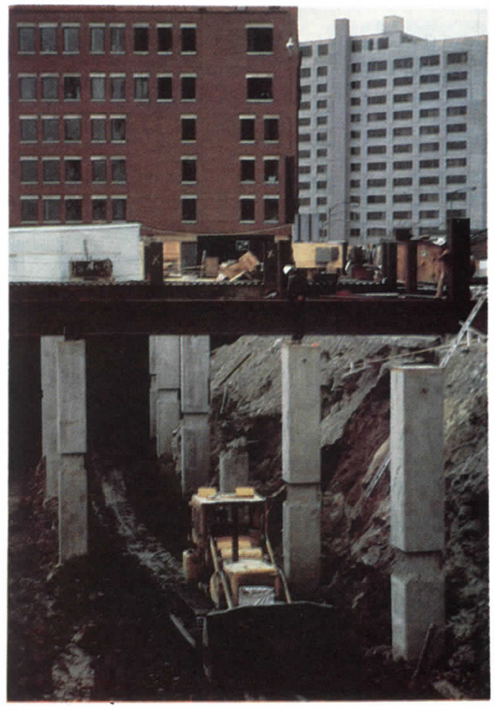










Courtesy of SOM

Photo, opposite page, shows the water side of Rowes Wharf. Drawing sequence above shows steps of up/down technique. Not shown are Phase 1, bulkhead, and Phase 4, ground-level steel. Photo above depicts excavation.

Rowes Wharf, Boston, by Skidmore, Owings & Merrill

Rowes Wharf on Boston Harbor was designed by Skidmore, Owings & Merrill of Chicago (Adrian Smith, FAIA, design partner) to accommodate a complex program of offices, condominiums, a hotel, restaurants, parking, shops, and facilities for private and commuter boats. The complex, totaling 665,000 square feet, is located on 5.38 acres of land and water, two-thirds of which is open space.

Site conditions and the proximity of Rowes Wharf to the water prompted the architects to use up/down construction, which derives its name from the practice of constructing the above-ground superstructure simultaneously with below-ground excavation. This technique was ideally suited to the project, which is so close to the tidal water that a conventionally constructed basement, without a significantly heavy superstructure on top, would not have had enough weight to counterbalance the hydrostatic pressure of high tide.

The architects also had to accommodate the city's wish to provide public access to the waterfront and to discourage above-ground parking. Providing above-ground parking for 575 cars as well as truck loading docks and other services for the hotel on the tight site was simply out of the question, bolstering the argument for some sort of underground construction.

Up/down construction was the solution. A method relatively new to this country, it also offered the opportunity to provide a watertight bulkhead without preconstruction tiebacks. For Rowes Wharf, this proved essential because the tiebacks that would have been used in conventional construction might have destroyed the integrity of an indispensable bulkhead.

Before construction on land began, the Perini Corp. of Framingham, Mass., the contractor responsible for below-grade and marine construction, cleared tons of rubble and construction debris from the harbor and then built the sheet-pile bulkhead to the water side of the construction site. The contractor backfilled the bulkhead on its building side and constructed a temporary earth berm on its water side to provide enough stability to allow the bulkhead to stand on its own until it could be permanently tied back to the plaza-level slab when the slab was in place.

An added advantage of up/down construction was the time saved by allowing the above-ground steel frame to be constructed simultaneously with the excavation of five levels for underground parking. The method, sometimes referred to as top/down construction, also saves time by minimizing weather delays, since below-grade work is protected from the elements.

Up/down technology for the building itself introduces a combination of foundation and mining techniques. Construction begins with installation of foundation perimeter walls using the slurry diaphragm wall process. The Rowes Wharf complex used a concrete slurry wall extending 1,300 feet around the land portion of the site. Using conventional drilled shaft techniques, 111 load-bearing caissons were then drilled through existing landfill and into the site's glacial till 75 feet below grade. Sixty-foot-long composite precast concrete and structural steel columns were placed on bell-shaped piers poured at the bottom of each caisson. When the columns were in place, a street-level steel floor was erected. Concrete was then cast on the floor, allowing it to serve as a diaphragm to resist the lateral thrust against the perimeter wall during excavation.

The first below-grade slab contained a 30-foot-square hole to allow access for digging down to the appropriate depth for the next level. The ten-foot headroom between floors required mining techniques and tools, including a coal-mining shovel, for almost 100,000 cubic yards of excavation. A mud mat was then poured, which became the bottom form for the next below-grade slab. A 30-foot-square access hole was left in this slab, and the process was repeated down to the fifth level. Each floor in turn acts as bracing for the perimeter wall system, eliminating the need for temporary bracing or tiebacks, while the slurry diaphragm wall acts as a retaining wall to minimize the need for de-watering.

At the same time, the composite columns provided the necessary substructure for erection of the steel frame by conventional methods. Above-ground construction started just nine months after ground-breaking. The main structures include two 15-story towers (their height limited by the Boston Redevelopment Authority) connected by an eight-story central section built around a vaulted, open public way. Three wharves, supported by 288 H-piles, 90 feet long, accommodate an eight-story apartment building, a six-story commercial building, and a public ferry terminal including docks for excursion boats and a marina. Buildings on the wharves step down in height toward the water, matching the massing of the surrounding city. The client/developer, Beacon Construction Co., estimates that four to six months of construction time were saved on the above-ground portion.

Originally a European technique, up/down construction was first used in the United States in 1986 by SOM on the 63-story Olympia Centre in Chicago. The technique was imported by the Case International Co. of Roselle, Ill.

Courtesy of Baskervill & Sons Architects

Don Eiler

The Diamond, Richmond, by Baskervill & Sons, Architects

Richmond's new baseball stadium, the Diamond, designed by the local firm Baskervill & Sons, Architects, is a replacement facility for the Atlanta Braves farm team, the Richmond Braves. Its structure employs prestressed, cast-in-place, and post-tensioned concrete and uses a type of concrete forming called match casting, a technique used frequently in bridge construction. According to the project structural engineer, Thomas A. Hanson of Thomas A. Hanson & Associates in Richmond, the Diamond may be the first instance of match casting used in construction of a building.

Designed to seat 12,500 fans, the Diamond will also accommodate thermal expansion and contraction at temperatures up to 140 degrees Fahrenheit, winds up to 150 miles per hour, and a six-foot snow load. Computer modeling allowed scenarios of various combinations of these loads to be explored.

Reinforced concrete was chosen because the Richmond Metropolitan Authority mandated that the structure be maintenance-free. Sixteen concrete Y-shaped elements, 55 tons each, in the back of the stadium and concrete pillars in the front form the vertical support. The 32 ribs supporting the seating and roof are constructed of prestressed concrete, match cast on the site.

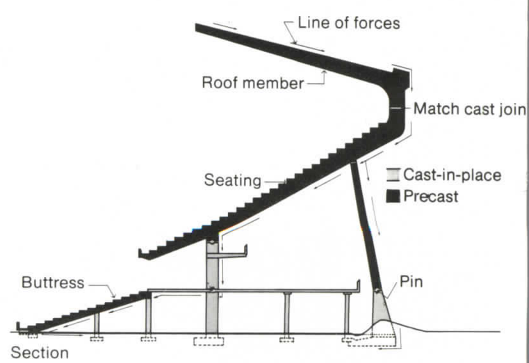
In match casting, components that will abut one another are cast together in a single form, separated by a steel plate. Once the forms are stripped, crews install the components separately. For the Diamond, each rib was cast with two pieces—a seat and roof unit—in a form, the steel plate separating the roof arm from the upper part of its seat section. Because the components are matched during casting, immediate imperfections at the end of one component have a mirror-image counterpart at the end of the other. "If you break a cookie," Hanson explained, "the two halves will fit together with a good fit. If you break two cookies and try to align unmatched halves, the fit will not be so good."

Though he had not used the technique before, Hanson was familiar with the match casting concept from having seen it in bridge construction. "The stresses were similar, and the concrete doesn't know the stadium isn't a bridge, so we were confident the concept would translate well to this application," he said. The stadium frame was so large that the alternative to precasting would have involved shoring a cast-in-place rib structure. Casting each arm in two pieces on the ground meant the bottom sections could be put in place, the seats installed, and the upper arms hoisted into place by crane and then posttensioned together, which resulted in considerable savings, Hanson said. Each of the roof arms is secured to its seat section by eight steel bars capable of supporting 1 million pounds.

The roof arms are tapered, thick and wide at the back and thin and narrow at the front. Each rib's center of gravity, where 35 tons are concentrated, is toward the back of the stadium. The entire structure is tied to the front main supporting pillar.

The construction company, McDevitt & Street of Richmond, which also was the contractor for Three Rivers Stadium in Pittsburgh, worked around the clock to meet the seven-month design/build construction schedule.

Local press reviews indicate that the Diamond, since its opening last April, has been well received by Richmond residents. The project is one of seven buildings chosen to receive the Concrete Reinforcing Steel Institute's 1987 design award.



The upper photo shows several of the 16 precast Y-shaped supports in the back of the stadium under erection, with lower portion of ribs in place, ready for seat installation. Lower photo shows a view of the completed stadium from across the field. The section above is cut through the match-cast roof and seat sections.

Four Seasons Great Barrier Reef Hotel, Australia, by Consafe Engineering

The self-proclaimed "first and only man-made 'island' resort" recently was anchored into its permanent home in a lagoon off John Brewer Reef, a large coral formation that is part of the Great Barrier Reef. Four miles long by two miles wide, Brewer Reef sits off the northeast coast of Queensland, 18 degrees south of the equator, in an idyllic climate for a world-class resort.

Consafe Engineering of Sweden and Singapore, a specialist in offshore accommodations, conceived and designed the floating hotel, which was developed by Barrier Reef Holdings Ltd. of Australia. Although the mass and height of the Brewer Reef encircling the shallow lagoon provides a natural barrier to high waves induced by storms, the designers carefully considered the floating structure's need for protection from the vagaries of tropical weather. The solution is a single-point mooring system, similar to that used for anchoring oil supertankers offshore. The hotel engineers can adjust the mooring to conform with changing wind patterns; and the hotel is designed to withstand a 100-year cyclone, thus providing a safety factor significantly greater than that required by codes for land-based buildings in the area.

The resort was built by the Bethlehem Steel Corp. in its Singapore shipyard, where many barge structures have been built that are similar in construction to the Brewer Reef resort. It is supported by a steel barge 292 feet long by 90 feet wide by 19 feet deep, which contains all necessary machinery and equipment to make the floating hotel self-contained and self-supporting. The barge, which includes the main and first levels of the hotel superstructure, is made of 2,300 tons of steel.

The remaining five levels of the seven-story hotel, erected using a modular system, required an additional 1,300 tons of steel. Each module, measuring 46 feet long by 12 feet wide by 10 feet high, contains two guest rooms with a four-foot passageway in the center. Box beams form the frames of the modules, and corrugated steel plate forms the walls and floors. The modules, made of noncombustible and fire-retardant materials, are highly insulated against sound and heat transmission. Each module was completed and outfitted before being hoisted into place.

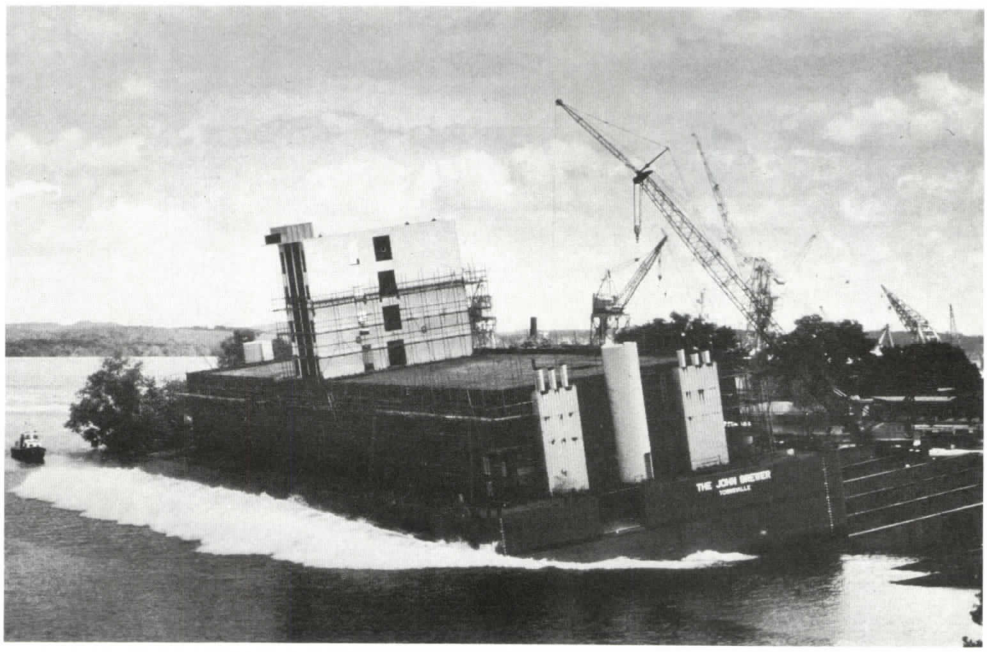
For both strength and protection from the elements, the barge has a double steel skin around the bow, stern, sides, and bottom. An eight-foot space between the side walls and a five-foot space at the bottom of the structure form watertight tanks that can be used to hold water as ballast.

In addition to structural safety, protection of the natural environment was a high priority. Among measures to safeguard the lagoon are self-contained and self-supporting airconditioning and power generation; supply of fresh water through a desalination plant with a storage capacity adequate for seven days of normal resort operations; and strict control of all wastes, even waste water, through the hotel's treatment or incineration plants, with no wastes released into the lagoon.

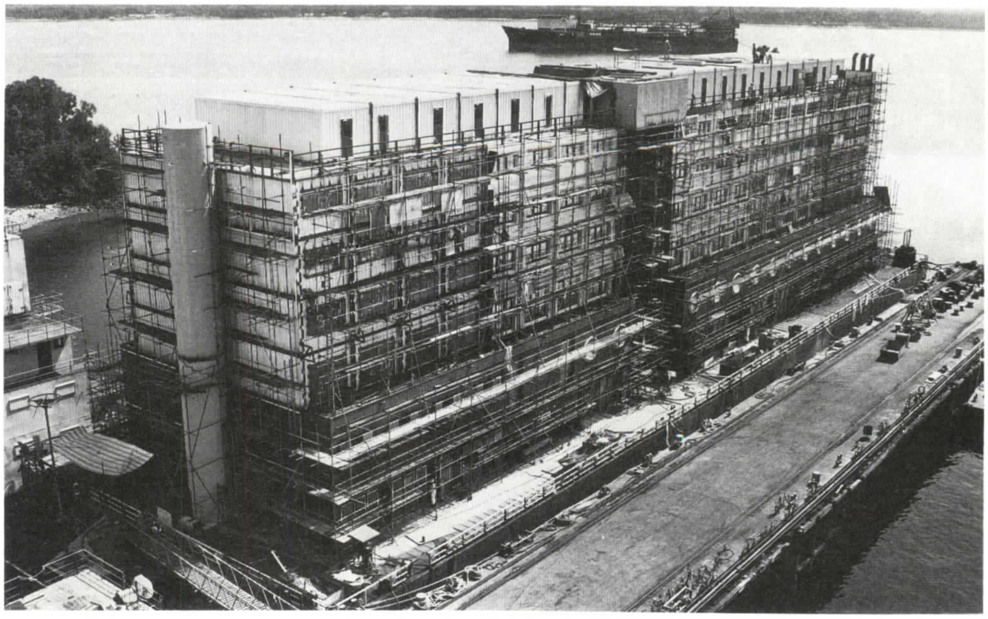
The 9,800-ton structure covers 322,000 square feet of the lagoon. It was transported from Singapore earlier this year by a specially built, heavy-lift, bargelike vessel. The 2,200 mile trip took two weeks.

The world-class resort, which opened in February, can accommodate 400 guests and has meeting facilities for groups of up to 200. Guests are transported to the resort from the Australian mainland by high-speed catamaran or by helicopter. A marina on one side of the hotel permits mooring of small boats. On the other side, pontoons provide open space and walkways, as well as the world's first floating tennis courts. Guests also can enjoy scuba diving, an underwater observatory, coral viewing in a semisubmerged submarine, and an outdoor pool.

In upper photo, floatable barge containing mechanicals and bottom floor is lowered into the water. Lower photo shows steel frame and modular boxes.



Courtesy of Bethlehem Steel



Courtesy of Bethlehem Steel

Two Union Square, Seattle, by NBBJ Group

Seattle's 58-story Two Union Square building, now under construction, has a massive and innovative structural system composed of 10-foot-diameter sections of steel pipe filled with 19,000 psi concrete. Designed by the NBBJ Group of Seattle, the 1.7 million-square-foot office building's main support comes from four huge core columns made up of more than 100 filled pipe sections. Two-foot-wide steel plates projecting from either side of the sections attach the core to a moment-resisting, braced perimeter frame that includes 14 composite columns. The concrete columns have no conventional reinforcing; instead they use permanent ⅝-inch-thick steel shells lined with shear studs on the inside. For additional support, diagonal braces run between the core and the perimeter from the 35th to the 38th floors. Floors are made up of I-beams, metal deck, and infill concrete.

Jon D. Magnusson, senior vice president of the structural engineer, Skilling Ward Magnusson Barkshire, Seattle, says the concrete, which is ready-mix, will be the highest-strength mix used to date in an office tower, topping the current record of 14,000 psi. The extremely high-strength concrete was achieved through a very low water-to-cement ratio, a high content of the strongest available cement, a superplasticizer to provide workability, silica fume additives, and a very strong, small (⅜-inch), round glacial aggregate, which was obtained locally.


© James F. Housel

Architect's model of Two Union Square.

To stiffen the 720-foot building against sway and earthquake accelerations, the engineers at first wanted only to specify a 7.2 million-psi modulus of elasticity (the measure of stiffness), which, at twice the modulus of conventional concrete, they determined would have had more than enough strength. But measuring in modulus of elasticity worried the contractor. Because of liability concerns, the contractor wanted to comply with the more traditional compressive strength specifications for concrete. The engineers therefore translated their design modulus to a compressive strength of 19,000 psi. Bryce Simons of Simons Engineering Services, Seattle, who developed the concrete mixture and test methods for owner Unico Properties Inc., Seattle, believed the American Concrete Institute's formula to translate modulus of elasticity into compressive strength was too simplistic; he used his firm's own lab data to make the translation.

The steel erection and concrete pumping will take place simultaneously, with the steel erection schedule two stories ahead of the concrete pumping. Concrete is pumped up from the base of each two-story (24-foot-high) section, allowing the concrete to permeate thoroughly without air pockets. To meet a nine-month schedule, the contractor is working double shifts and constructing two floors every 3½ days, said Frank H. Anderson, project executive with the Seattle office of the Turner Construction Co., the project's contractor. Shell sections are welded together in place.

According to Magnusson, the savings in steel cut project costs by about 30 percent, even though the concrete price came to about $120 dollars per yard. An all-steel building would have required 25 psf of steel, compared with 11.8 psf of steel used in this system, he said. Skilling Ward Magnusson Barkshire has designed similar but less massive columns for two other buildings now under construction in Seattle.

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George Brown Convention Center, Houston, by Houston Convention Center Architects

The architects for the George Brown Convention Center in Houston chose an unconventional approach for their gigantic convention hall—they relied on a forest of huge, tubular steel, double columns and bracing trusses instead of more typical tension structures, curtain walls, or space frames to create a long-span space. The $105 million center, which opened on time and under budget last September, was designed by Houston Convention Center Architects, a joint-venture firm of Bernard Johnson Inc., 3D/International Inc., and Convention Center Architects. (The last is a joint venture within the joint venture, composed of Goleman & Rolfe Associates Inc., John S. Chase, FAIA, Inc., Molina & Associates Inc., Haywood Jordan McCowan of Houston Inc., and Moseley Associates Inc.)

The 1.7 million-square-foot building, which covers six city blocks, measures 900 feet long and 300 feet deep and is clad in glass and white enameled metal panels. Although the building is as tall as eight stories, it actually contains three levels of public circulation space that open onto two levels of functional space. The ground-floor exhibit area, occupying most of the first and second levels, runs the full length of the center and has doors big enough to admit 18-wheeler trucks simplifying access from the adjacent freeway. The third level contains a smaller exhibition hall, ballroom, theater, meeting rooms, a cafeteria, and a broad "prefunction" gathering area overlooking downtown.

The decision to reserve the first floor for exhibition space and to concentrate the other functions over it resulted in a very heavy structural load on the third level. The 22 double columns, engineered by Robert J. Hansen of Bernard Johnson Inc., are exposed in the cavernous, 100-foot-high exhibition hall. They are erected on pin connections set into massive concrete plinths in the foundation. Each

Opposite page, exterior of Brown Convention Center. Above left, interior boldly exposes its systems. Above right, one of 22 double columns.

142-ton column, made of two 4-foot-diameter pipes connected by diagonal braces, stands 95 feet tall. The primary structural columns are welded to a steel truss system by means of a branching system of secondary columns. Each system of columns spreads out 42 feet wide at the top and converges at the base, where it is braced by asymmetrically placed stiffeners. This structural system is based on the construction materials and techniques devised for offshore oil exploration.

To emphasize the visibility of the structure, the main columns and the trusses are painted bright blue. Services also are presented dramatically—the huge air intake ducts are painted white inside the building, and red where they break through the building's skin, flairing into highly visible red air scoops on the roof line. Ducts and other mechanical systems are painted red throughout the building.

First Interstate Tower North, Denver, by ArchitectureDenver

The corporate law firm of Sherman & Howard wanted a new grand entrance for its Denver offices, which occupy the top eight floors of the First Interstate Tower North building. Designed by Welton Becket in 1972, the building, a 32-story, rigid steel structure with a precast concrete and glass curtain wall, maintains its original appearance. Inside, however, on the 30th floor and extending above, a 26-x40-foot atrium was created inside the law offices. The interiors for the $10 million renovation were designed by ISD of Chicago, with architectural and structural modifications and construction management by ArchitectureDenver. The atrium, which takes up one-sixth of the square footage of the floor plate through three floors, is 44 feet high from floor level to the bottom of the skylight.

Demolition of the existing space and construction of the atrium were done from the inside out, without exterior cranes. Because of the difficulty of bringing materials to the urban site, 90 percent of the existing steel was reused. For new pieces, a shop was set up on the construction floor.

The client wanted the library to be on the top floor, and because law books create a lot of dead load, KKBNA, the Denver-based engineering consulting firm, performed a computerized torsional analysis to determine how redistributing the building load might affect the existing building. The computer modeling and analysis revealed that the existing rigid steel frame would accommodate the planned redistribution of load, even if files and law books were moved within the building and a large chunk of the building was removed for the atrium. Denver's building officials accepted the computer analysis as proof that the planned redistribution was perfectly sound and met all code provisions. Thus, with the narrow building configuration, the floor diaphragms and structural core were able to support the renovation without shoring, scaffolding, or temporary bracing.

In addition to removal of interior beams to create the atrium, the plans called for relocation of an internal elevator to serve the law firm's floors. A three-story elevator was demolished, and an eight-story elevator was moved to the side of the atrium for internal circulation. Construction of the elevator necessitated pouring a new base slab as well as interior beam supports. A cantilevered staircase in the atrium to connect the 30th and 31st floors required two new beams placed in the upper level, which was originally designed as a mechanical floor. The 30th-floor courtyard has also been structurally enhanced beneath the flooring in one corner to support a 30,000-pound sculpture planned for the atrium.

The atrium is topped with a skylight of glass with built-in ceramic dots that reduce light transmittance and heating load.

Opposite page, architect's rendering of atrium space through top three floors.

Nordstrom Medical Tower, Seattle, by Clayton R. Joyce Architects

The technology for magnetic resonance imaging (MRI) has proved so valuable to medical diagnostics that in the last five years hundreds of major facilities have undertaken its construction. In addition to costing more than $1 million, MRI suites mandate structural logistics to install and house an eight-ton magnet, as well as tons of steel sheathing to protect the magnet from outside radio frequency interference. There is little wonder, then, that almost all MRI installations are placed in basements of existing facilities or in their own structures on hospital grounds.

But there is an alternative, as demonstrated by Clayton R. Joyce Architects, Seattle, in the Nordstrom Medical Tower of its home city. Although the firm had done several technically sophisticated health care projects, this was its first MRI suite, and it is located on the ninth floor of a 15-story medical condominium office and parking facility.

The facility, designed by the NBBJ Group of Seattle, originally was not programmed to include an MRI suite. Joyce Architects made significant structural modifications to support 100 additional tons of magnet and steel. The architects also specified major mechanical and electrical changes required for the MRI.

The ninth floor became home to the MRI suite for two reasons. First, study of potential seismic loads revealed that the best place structurally for a heavy load was the midpoint of the building. Second, the building's owner, Swedish Hospital, had placed its laboratories on the fifth and sixth floors. Because the magnet for the MRI has to be separated from the hospital labs' electron microscopes by at least a floor, the ninth level was chosen as the best compromise.


Courtesy of Joyce Architects


Courtesy of Joyce Architects

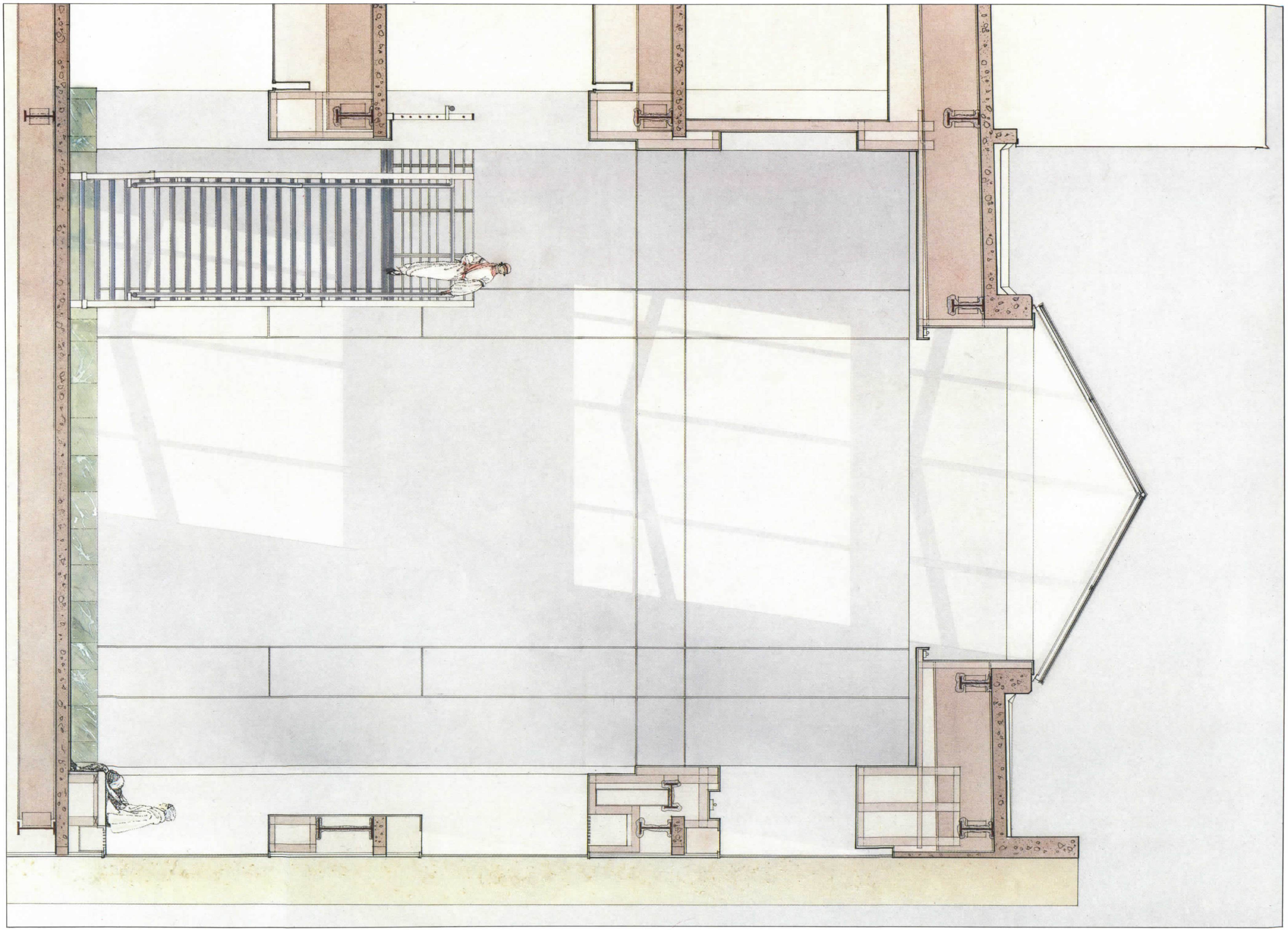
An engineering analysis, showing that the building's original live load of 60 pounds per square foot should be doubled to 120 psf, resulted in doubling the number of 18-inch-deep, 24-foot-long beams in the 14,000-square-foot floor. The beams were placed at 4½ feet on center instead of the originally designed nine feet on center. The floor-to-ceiling height of the MRI suite was increased from 11 feet to 14 feet to accommodate the equipment in the magnet room.

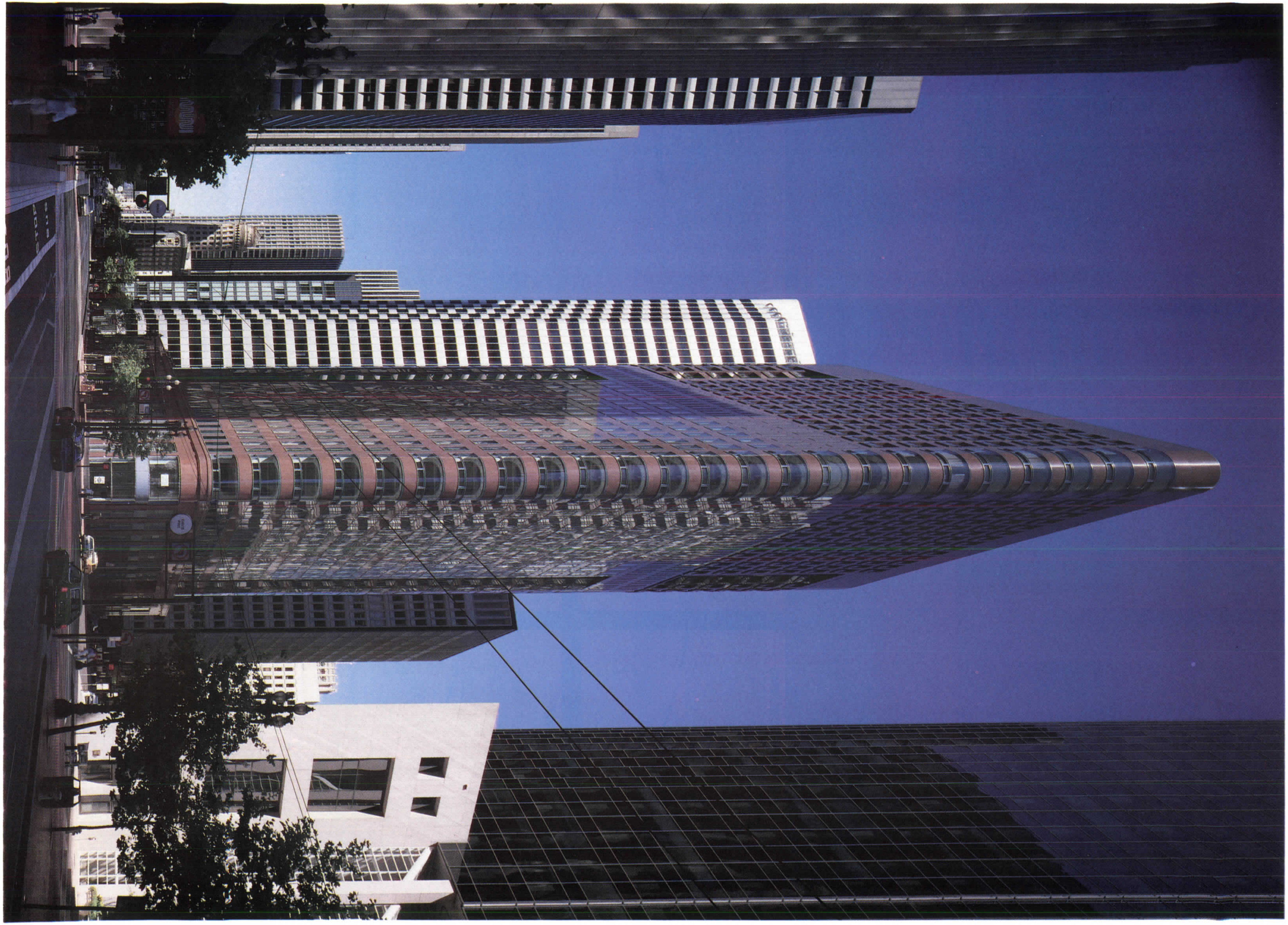
In order to install the 10-ton magnet, the designers unbolted a 20-x10-foot exterior wall panel and bolted two C-beams onto the treatment room floor, cantilevering them out over the side of the building. Workers then hoisted the magnet by crane up to the ninth floor, lowered it onto the track made of the beams, and rolled it into place. The task was accomplished after almost all of the steel sheathing was in place. After workers installed the magnet they bolted the remaining sheathing plates in place.

In the mechanical design, the architects greatly increased the air supply to the room because the magnet uses both helium and nitrogen as cooling agents, and traces of the gases might linger in the treatment rooms. A quench vent was installed, and an emission pipe releases the air directly out the side of the building instead of vertically through six floors of offices. □

Left, the 10-ton magnet for the MRI is hoisted by crane and positioned on C-beam tracks.

Rendering by Paul Filicetti and Gary Morris





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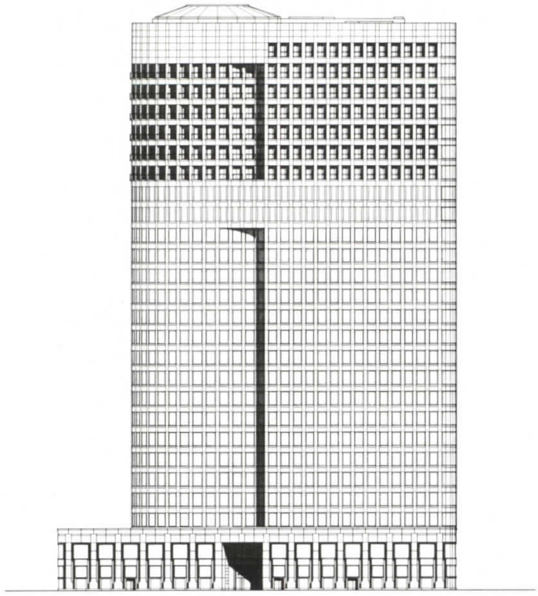
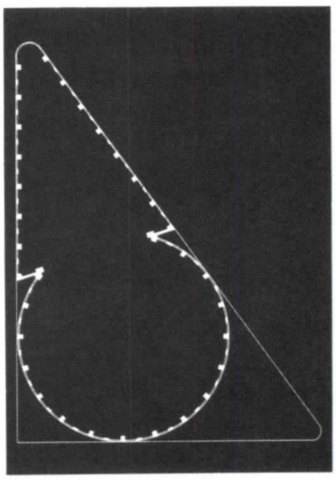


Sinuous Combination of Shapes Creates a Structural Challenge

SOM's 388 Market Street, San Francisco.
By Donald Canty, Hon. AIA



This building's unusual shape is at once one of the sources of its distinction and the structural challenge that it presented. On a triangular site, it resembles New York City's Flatiron Building, but with an intriguing difference. The base is a triangle but the bulk of the building in plan is a circle abutting a kind of arrowhead with a blunted nose.

The resulting form is sleek, undulating, and unusual. The curved surfaces echo the building's taller, circular neighbor, John Burgee and Philip Johnson's 101 California Street tower. The Market Street building differs from the light-skinned tower and others around it by being clad in dark red granite with dark green trim, colors that make it all the more sinuous.

The combination of shapes increased the likelihood of the building twisting and swaying in wind or earthquake. To counteract this the designers studied a number of structural systems, eventually settling on a multiple-tube framing system.

A simple tube framing system is hollow, stiffened by the steel framing of its entire perimeter. The perimeter acts as a beam—in essence, as a bending member. Limited by construction techniques, however, it is never actually a single, integral unit. A very tall, simple tube framing system may be overly flexible. Shear forces (from wind) decrease as they turn corners, and as a result the compression and tension produced are not evenly spread among columns in the walls perpendicular to the wind. The so-called shear lag that is generated can reduce the overall structural effectiveness of a simple tube, particularly when the building's length is much greater than its width.

For 388 Market Street, a long, narrow building, using a simple tube framing system as a monolithic beam strong enough to withstand lateral and torsional forces would not have been cost-effective. Furthermore, the asymmetry of the triangle and circle made it impossible for the center of rigidity and the center of mass to occur at the same point; this increased the tendency for movement.

Therefore, SOM devised a multiple-tube framing system consisting of a moment-resisting perimeter frame connected to a heavy central frame running along the axis where the triangular portion of the building meets the circular portion. In essence, the perimeter frame allows the building to function as a unit, the central framing separates the triangle and circle into two tubes, and the floor system acts as a diaphragm between the two sections. The metal deck slab acts compositely with the steel beams and with the central frame, which includes six columns on each floor. To further strengthen the connection between the two parts of the building, a 31-foot-long beam spans the columns between the triangle and the circle on six of the building's floors.

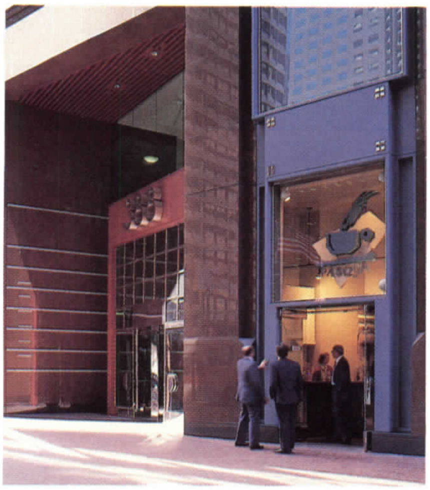
Perimeter and interior framing material is rolled-shape steel columns and 36-inch-deep welded steel beams and deep-rolled girders. Framing members are unusually heavy.

The triangular section of the building is symmetric only about its long axis, indicating that the delicate nose area could be extremely flexible and fluctuate from side to side in torsion from even slight forces. The solution, according to structural engineer Navin R. Amin (Lawrence Doane, AIA, was SOM's partner in charge), was to add three heavy frames across the tip to box columns along the sides.

Stiffness of the multiple-tube framing system greatly depends on connections between columns and beams. Complete-penetration, high-strength welds were necessary because of the depth of steel framing members.

The first two floors of the building are commercial, the third through the 17th floors are offices, the 18th and 19th mechanical, and the 20th through 26th contain 63 condominium units. The mixture of uses is clearly expressed on the exterior, (top).

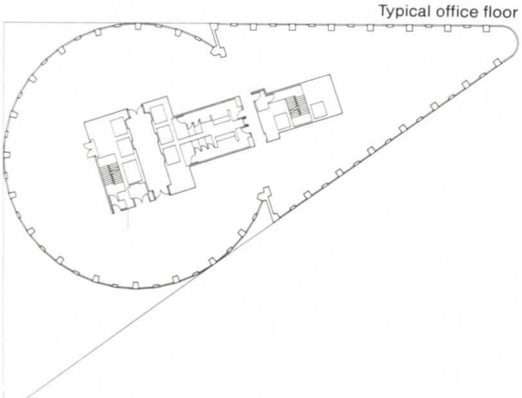
Left, the prow of the building from Market Street. To its immediate left are two earlier SOM towers, to its right 101 California Street. Above, a typical office floor in outline.



Above, the Market Street entrance. Right, two views of the elegant, deco-esque lower lobby, all marble and chrome. Opposite, the building's round end. □

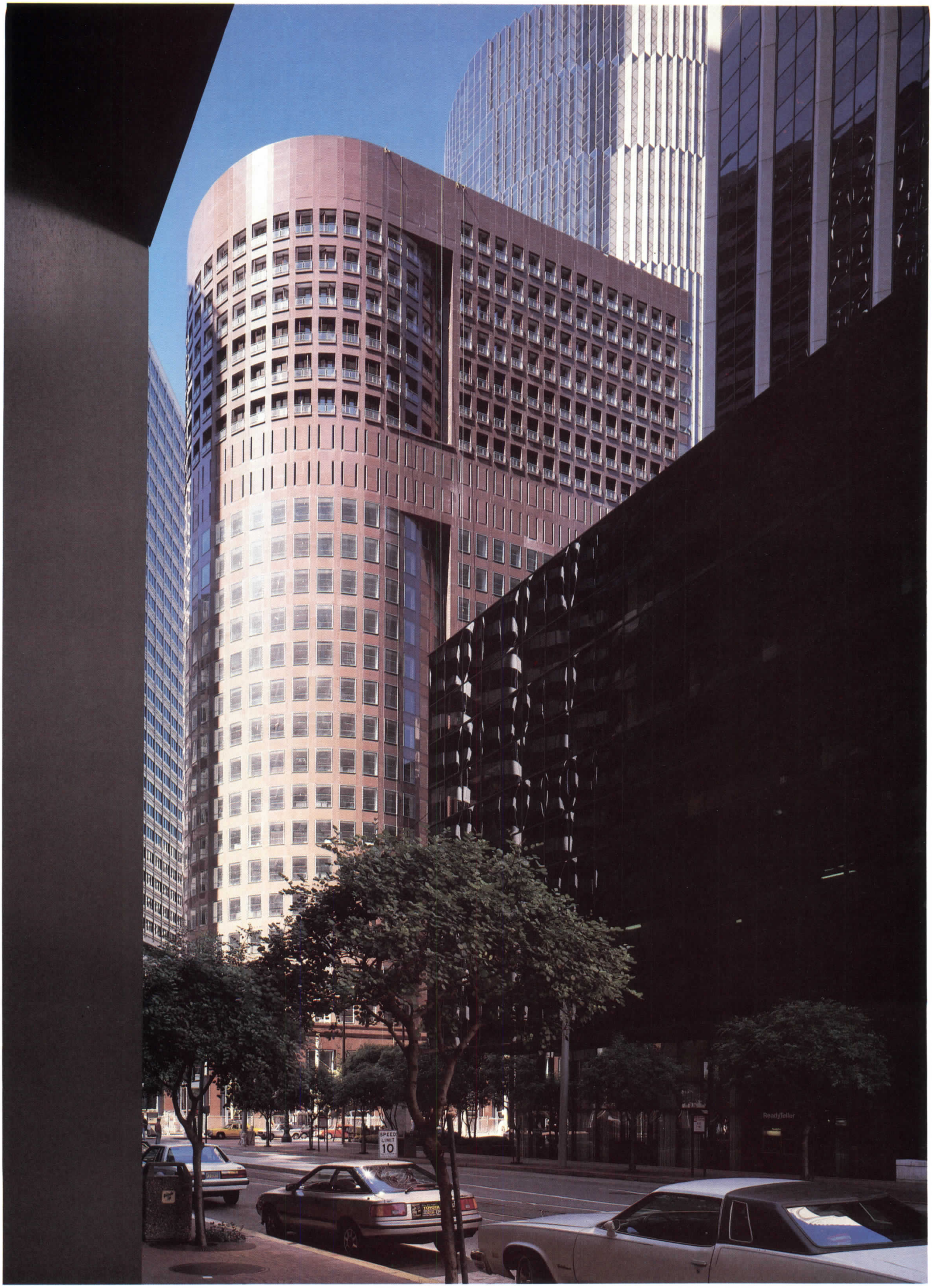
Typical residential floor

Typical office floor



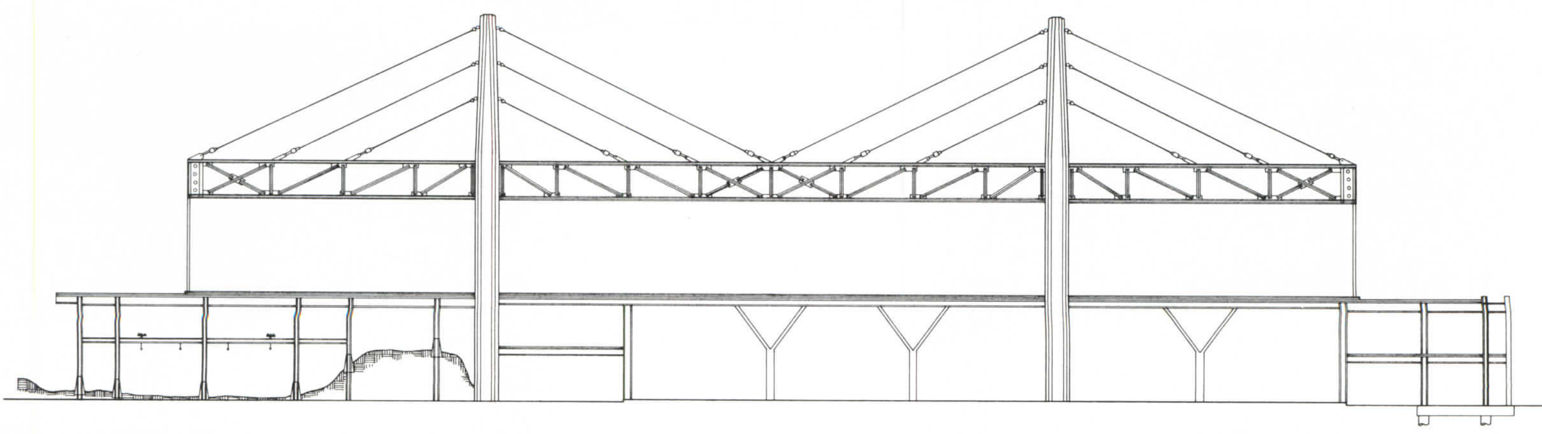
Ground floor

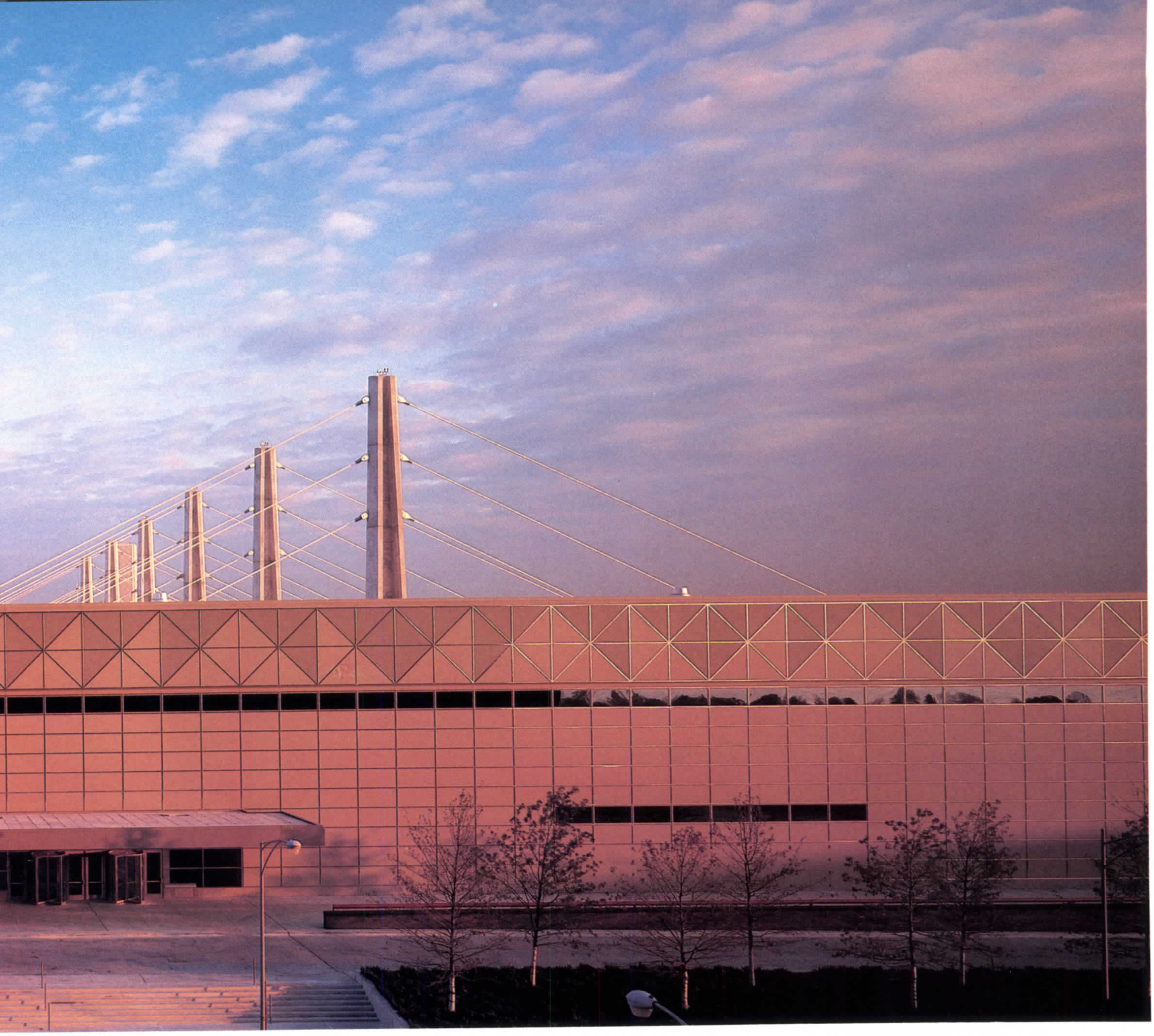
Photographs © Jane Lidz


SPEED LIMIT 10
ReadyTeller

Huge Roof Hung from Pylon-Ducts

SOM's addition to McCormick Place, Chicago. By Nora Richter Greer





© Nick Merrick, Hedrich-Blessing

Long-span structures have been much maligned since the early 1980s, when the roof collapses of the Hartford Coliseum and Kansas City's Crown Center made front-page news. Recently, however, the long span has been making a comeback, spurred by the development of highly sophisticated testing that more adequately analyzes structural integrity. A striking example is Chicago's McCormick Place exhibition facility expansion, designed by Skidmore, Owings & Merrill—a building that both inside and out boldly expresses its framework.

In accepting the commission, SOM partners Gordon Wildermuth, FAIA, Bruce Graham, FAIA, Diane Legge Lohan, AIA, and Srinivasa Iyengar faced no small challenge. Their task was to design 1.5 million square feet, mostly for exhibition space, on a 79-acre site bordered by Chicago's Outerdrive on the east and, on the west, overrun by railroad tracks on one-third of its area. The architects' goal was to provide as much unobstructed interior space as possible for the main exhibition hall. Moreover, a sympathic relationship needed to be developed between the new facility and C. F. Murphy Associates' original McCormick Place, just east of the Outerdrive. (Opened in 1972, McCormick Place was actually the second exhibition hall designed by that firm for the lakefront site; the first burned to the ground in 1967.)

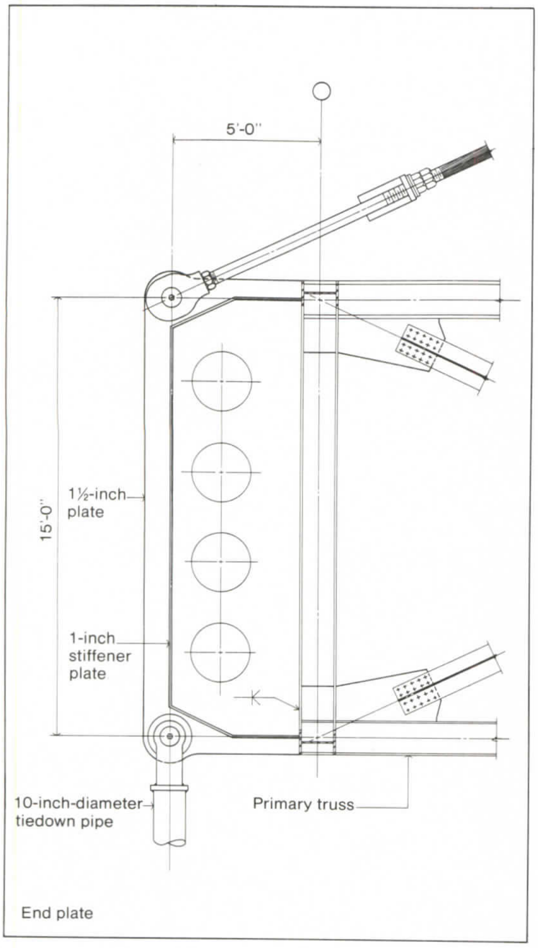
From the beginning it was clear that the railroad tracks would have a major effect on the type of structural system chosen. The railroad property included some unused right-of-way and the air rights over active tracks, along which the Illinois Central Gulf Railroad operates two diesel freight lines and four electric commuter lines. There are several freight sidings. A further complication was an elevated track "jumpover," where freight lines cross over the commuter lines. "The railroad track made it very difficult to put a lot of columns willy-nilly," Graham says. "We had to come up with a structure that would both solve the track problem and create a large enough space free of columns to provide a fine exhibition hall."

More than a half-dozen systems were examined. The more traditional long-span system with side columns supporting trusses was rejected quickly due to interference with the railroad lines. Trussed overhangs, similar to those on the original McCormick Place, would significantly increase the building's height—and its cost. A cable suspension system seemed the best prospect: columns would support a podium, over which the exhibition hall would be suspended.

While some architects and engineers were examining cable suspension systems, others were considering how to rid the exhibition hall's ceiling of mechanical equipment. The exposed trusses then would become "an expression of the structure on the inside," in Iyengar's words.

In the end, the solution was a creative joining of the mechanical and the structural. Twelve concrete pylons rise from the main

Above, the main entrance of the McCormick Place expansion facility as seen from the south. SOM's Sears Tower is in the background. The main exhibition hall's trussed roof is suspended by a series of cables connected to 12 large concrete pylons.



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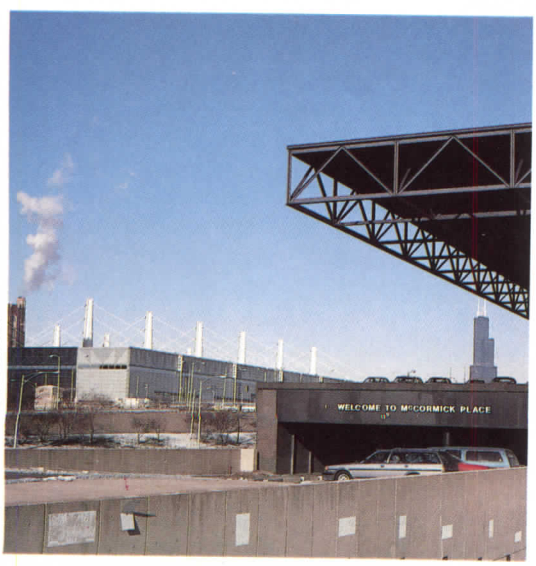

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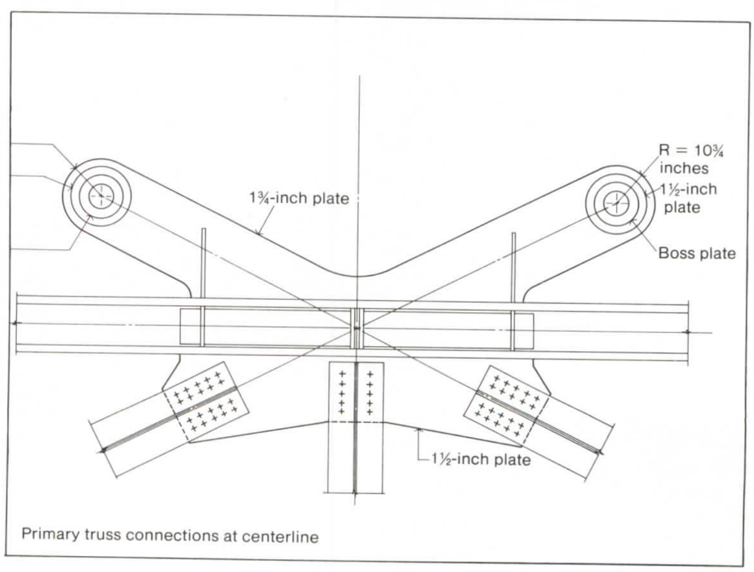


Top, pylons connect to stiffener plates that connect to tie-down pipes that anchor the roof to the podium. Above, primary truss connections at roof's centerline. Lower left, trussed overhang of original McCormick Place (upper right in photo),

© Mark Segal/Panoramic Stock Images

The old and new parts of McCormick Place (right and left, respectively) are separated from each other by Chicago's Outerdrive but connected by a tunnel/walkway system.

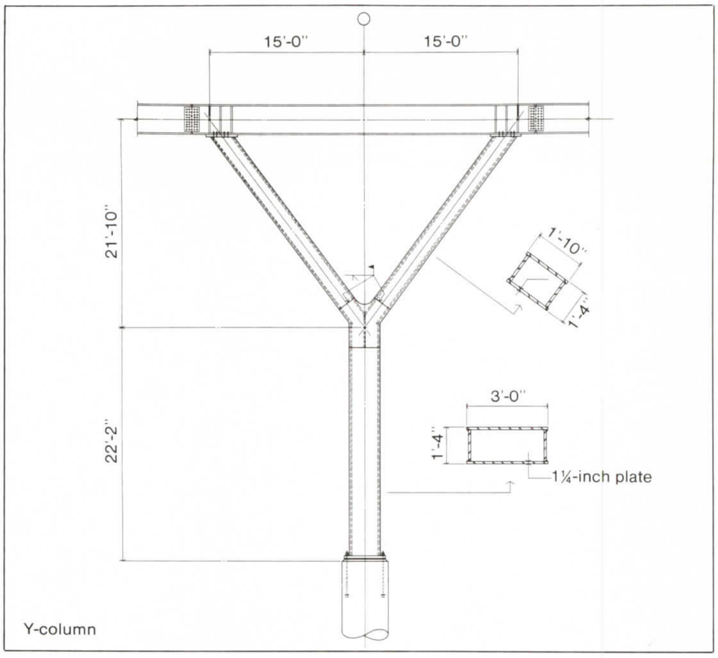
exhibition hall and act as mechanical ducts, the conditioned air from the lower-level mechanical mezzanines being released into the hall through nozzles. Air is then exhausted through the portion of each pylon that projects 60 feet above the roof. And while the pylons with their cables act primarily to suspend the roof, they also offer "enormous lateral stability," according to Iyengar. "The height of the building above the foundation is close to 100 feet, so we needed some wind or lateral stability. Using the massive pylons gave us that kind of stability," he says.

The 12 pylons, supporting deep roof trusses, are spaced on a 120x240-foot grid, with 120-foot overhangs to the east and west. A 600x1,350-foot podium extends out over the tracks and is supported by steel columns. The roof trusses are connected to the podium via tie-down pipes, which act to stabilize the overhangs. Early on, it was determined that no special vibration isolation of the structure was needed for this podium because the trains here travel at slow speeds and cause only minimal vibration.

The cable-pylon system was subjected to extensive wind-tunnel and snow-load tests. More important was the progressive-collapse study that examined what would happen if one or more of the roof's components failed. Those components consist of the concrete pylons, the cables that are attached to the pylons and roof by stainless-steel clamps, and the tie-down pipes that run from the cables at the roof's edge down the facade. The cables are 3¾-inch galvanized steel with a noncorrosive PVC covering; they vary in length from 67 to 134 feet. The final design allows for "some flexibility in being able to lose or remove a cable and not affect the overall integrity of the building," Iyengar says.

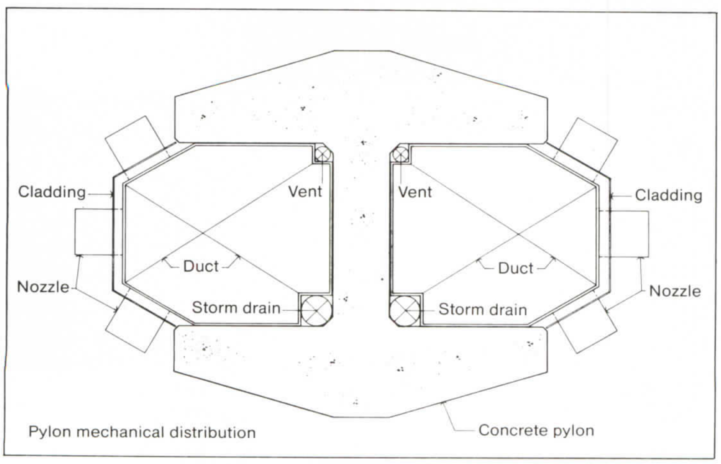
While the design creates a highly articulated, dramatic rooftop, it also allows for a light and airy exhibition hall. Inside, one first notices the clarity of the structural system—the pylons and the ceiling trusses. The primary trusses (running the width of the building) together with the secondary trusses (running the length) constitute a three-dimensional, exposed, light steel frame. Because the pylons contain the mechanical delivery systems, the 15-foot-deep truss system suspended by the roof cables is unobstructed. One hundred twenty-eight skylights above the trusses, in conjunction with a band of windows ringing the exhibition floor, provide enough natural light on sunny days to adequately light the hall.

The 375,000-square-foot main exhibition hall with its 40-foot-tall clear space is the interior's focus. But also important are a storage facility and a 150,000-square-foot secondary exhibition hall. The 22-foot-tall, upper-level storage facility sits on the podium north of the 55-foot-tall main exhibition hall. Designed to handle large exhibition crates, the facility has a 30x60-foot grid of storage bays created by a conventional steel framing system. Below the main exhibition hall are the secondary hall, meeting rooms, and a food service area. The lower exhibition hall is 35 feet high and has a 30x60-foot grid of structural steel with Y-columns, which



Y-column

Photographs © Wayne Cable/Cable Studios



Pylon mechanical distribution

allow for larger bays than would more conventional columns.

A clear expression of the building's structure was also a guiding principle for the exterior design. The curtain-wall cladding is silver-gray aluminum panels attached to polished stainless-steel mullions. A band of vision glass accents the diagonal pattern of the panels above it. That patterned portion in turn is meant to express the trussed roof system inside. Graham calls the facade "an homage to Mies," in that it suggests a scheme by Mies van der Rohe for an unbuilt exhibition hall in Chicago (see page 112). A decision was made to place the tie-down pipes on the exterior as an expression of the structural system.

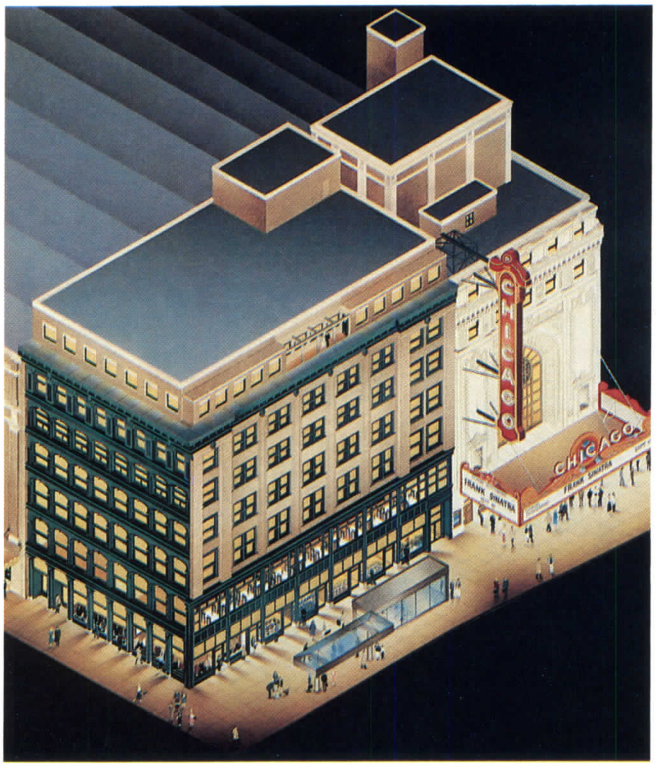
Above, the exposed steel trusses (adorned with banners) and concrete pylons of the main exhibition hall. Left, pylons double as mechanical ducts, releasing tempered air into the hall. Left, middle and above, the smaller exhibition hall has Y columns.

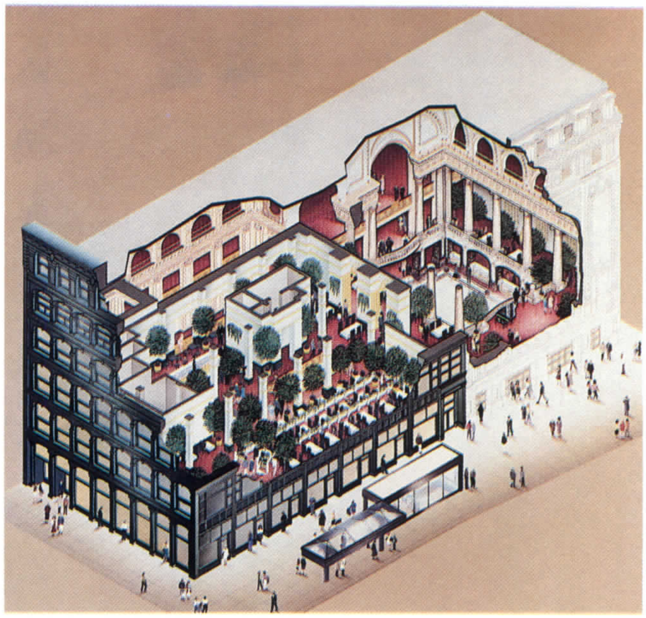
Connected by tunnel and bridge to the original McCormick Place, the expansion gracefully complements the old but at the same time exuberantly expresses a new age. The older facility is actually two buildings—one with 600,000 square feet of exhibition space and the other containing a 4,350-seat theater. Heralded upon completion as a "triumph of proportion and material," its design is evocative of Mies, too, with its glass-and-steel facade. Its structural system is dramatically stated in the giant steel trussed roof that overhangs 75 feet on each side. Its interior, however, suffers from glare—exhibitions are washed out by bright sunlight that streams in through the glass wall.

There is a purity in the new facility that is not found in the old. As Iyengar says, the McCormick Place expansion "is most effective in its simplicity and its economy and its directness. There is nothing in that structure that is contrived." It is bold, strong, delicate, dramatic. □

Existing Structure Used as Formwork For a New One

Chicago Theatre project, Daniel Coffey.
By Michael J. Crosbie





The Chicago Theatre on State Street, a wonderful relic of the days when movie palaces were designed by architects who must have been frustrated French pastry chefs, was completed in 1921. The work of Chicago architects Cornelius and George Rapp, the theater could seat an audience of 3,800, escorted by an army of 125 ushers. Over the years it underwent a number of renovations, including one in the '30s, which changed its blue and green interior scheme to tans and reds, and a disfigurement performed in the '50s by the original architects, oddly enough, that "streamlined" the interior by removing the Perlman crystal chandeliers, covering most of the plaster ornament with drywall, and painting the lobbies pink.

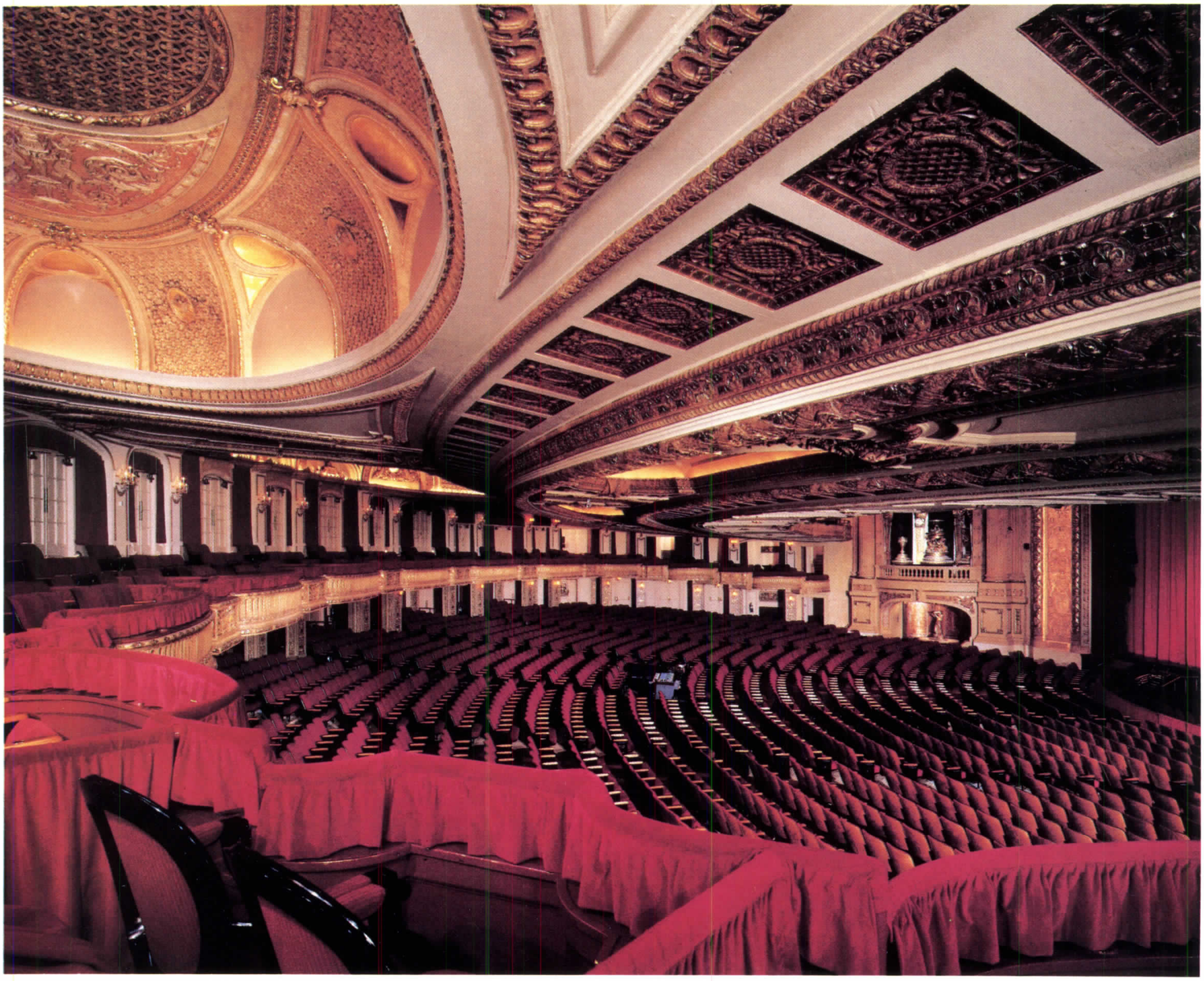
By the 1980s the theater, along with its State Street neighborhood, had fallen on hard times. Now, as part of the city's North Loop Redevelopment plan, the Chicago Theatre has been revived by the local firm of Daniel P. Coffey & Associates, which united the theater with an adjacent office building, a historic structure in its own right.

Joining the two buildings into one mixed-use complex made the theater restoration financially feasible, but the union was not an easy one. The theater's neighbor, the six-story Page Bros. building designed by John Mills Van Osdel, was constructed in 1872 during the post-fire building boom, and its structure originally was wood frame. Its north facade, facing Lake Street, is cast iron, manufactured by Daniel Badger of New York City. Lake Street was once lined with cast-iron-front buildings, but the Page building is now the only one left in downtown Chicago and has earned a spot on the National Register.

The Page building and the theater could not be joined until the former's code-violating structure was replaced with one of steel or, like the theater, concrete. Gutting the building would have been hazardous because the brittle iron front would have to be elaborately braced. A subway passes beneath it, and an elevated train rides over Lake Street, which is also a major bus route. The vibrations could cause the facade to crumble, a loss in itself and potentially of human life, not to mention the tax credits and federal and state funds available through preservation of the iron front.

The architect, working with structural engineer Don Belford, hit upon the idea of using the building's wood structure as formwork for a concrete frame. Thus the iron front would remain undisturbed while workers operated on the building's innards. The concrete frame's columns were positioned at the center of each wood-frame bay, cutting the required vertical members by

Drawings above show Page Bros. building beside Chicago Theatre and (in cutaway) how they were joined at mezzanine level; photos left and above show restored lobby.



a third and opening up the structure to allow flexible office planning. The height of the second floor was adjusted so it would align with the theater's mezzanine. Voids in the concrete left after the removal of the wood columns were filled in.

More space was gained in the old building by excavating the low, dirt-floor basement for more headroom and pouring a slab, and by adding a penthouse floor, boosting the 40,000-square-foot building to 60,000 square feet. The iron front rests on its original footings, independent of the new concrete structure. A minimum of lateral ties between the two will allow the concrete structure to settle without stressing the iron front.

Outside, the iron front had been covered in years past with a fire escape and granite veneer at street level. Both were removed, and beneath the granite were found remnants of the original iron columns, crowned with acanthus leaves. Samples of the ornament were taken and new materials fashioned to match the old. The State Street facade, a later modification to the building, was refurbished and the original wood storefronts restored. The building now contains retail space at street level and office space above.

Compared with the Page building, the theater was in relatively good shape. Its grand lobby, which soars to a height of 55 feet, is now the main entrance to the joined buildings, and a restaurant weaves between the two at the theater's mezzanine level. The interior's gypsum-board shroud was removed and much of the plaster ornament was found intact, requiring only minor patching. New dressing rooms were designed and new restroom fixtures and finishes provided. The lighting was refurbished, some circuits that had been shut off over the years were reactivated, and a three-tiered dimmer in the auditorium (an electrical monstrosity that was the size, Coffey says, "of a small house") was replaced by a laptop, computerized dimmer board that allows a wide latitude of lighting effects. "New" crystal chandeliers were salvaged from demolished theaters of the same period—the chandelier in the main lobby came from a theater in Philadelphia.

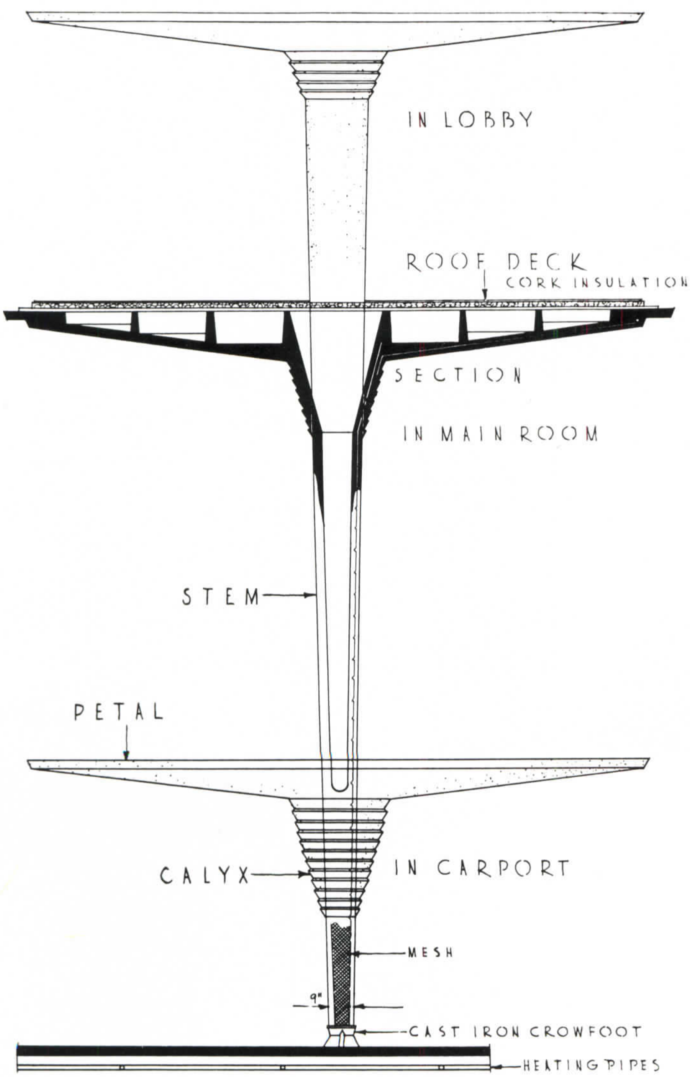
The restored interior's color scheme is close to that of the redecorated theater in the 1930s. The auditorium has a palette of reds, browns, and burgundies. The allegorical murals have been cleaned and restored. All of the draperies, carpeting, and upholstery are replaced in brilliant red. Tan colors are carried out into the lobbies and corridors, with ornament highlighted in gilt or white. □

Above and right, restored auditorium of the 3,800-seat theater. Work included plaster ornament repair and painting; lighting upgrade; murals restoration; new curtains, and upholstery.

Photographs © Barry Rustin

The Structural Architecture of Major Modernists

Illustrated by a selection of their 'divine details.' By Stevens R. Anderson



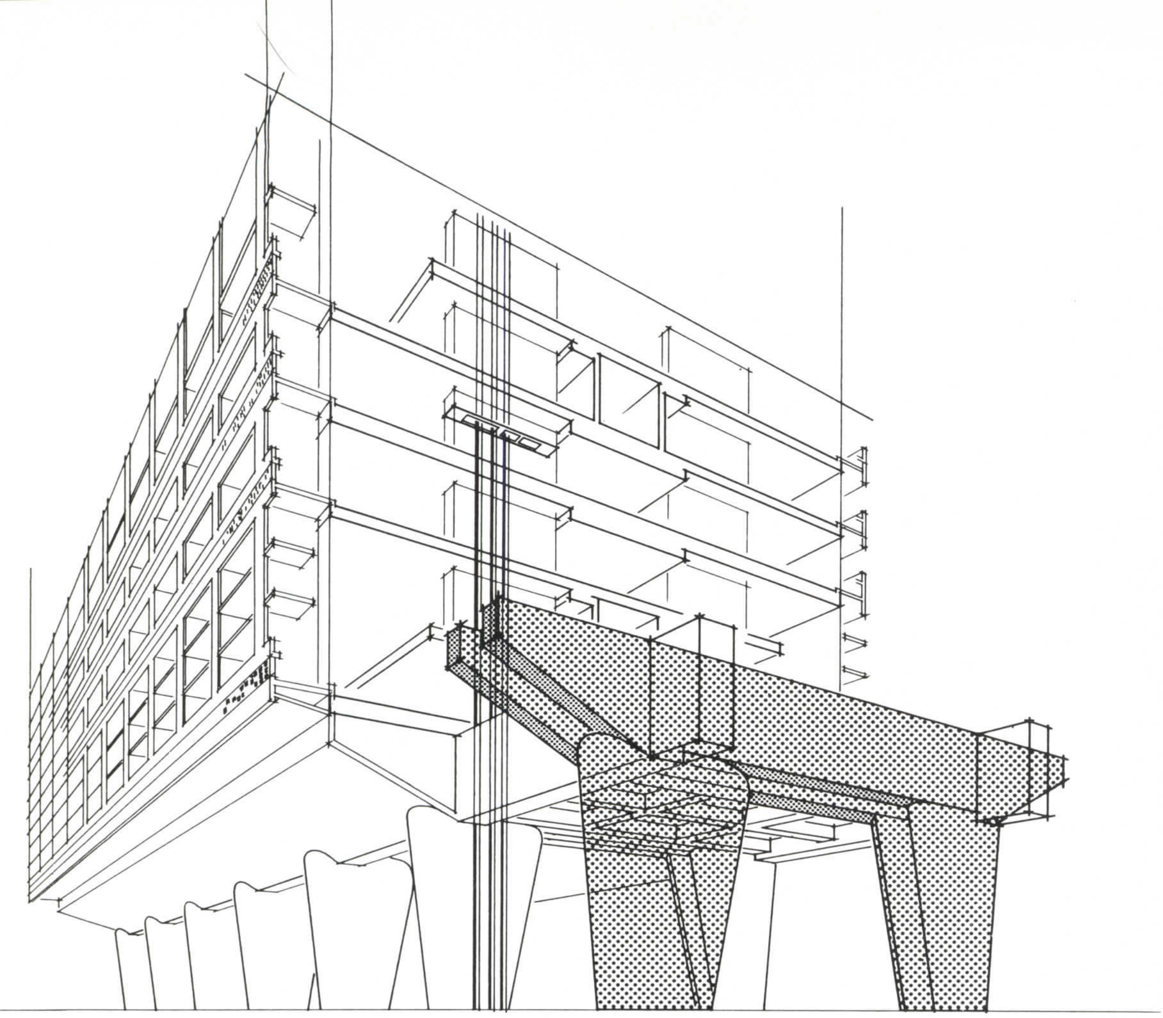
DETAIL OF COLUMNS AT THREE DIFFERENT LEVELS

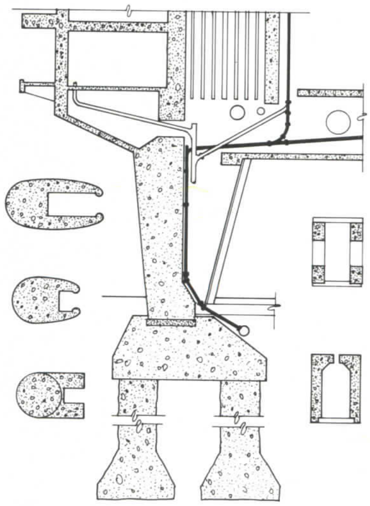
Honesty of structure is one of the three main principles of the modern movement. As Eero Saarinen noted, this principle developed in a curious way during the 20th century from an emphasis on structural honesty to an expression of structure and finally to structural expressionism. (He did not survive to see this principle challenged by the present tendency toward structural deception.) The rapid advance in technology in the early decades of this century, with its emphasis on mass production and prefabrication, offered a serious challenge to the architectural profession. By adapting technology to architecture, Frank Lloyd Wright, Le Corbusier, Walter Gropius, Mies van der Rohe, Philip Johnson, Eero Saarinen, and others achieved in their work a validation of their profession in the modern world.

Their endeavor to synthesize technology into building design produced a structural architecture. "A structural architecture," as stated by Reginald Malcolmson, "implies that the constructive elements of a building can be brought together in a clear and logical manner, freed from ambiguous meaning, into a whole, whose character, both in general and in detail, is governed by a sense of order. In this way order becomes an esthetic discipline, so that construction in its utilitarian and pragmatic sense is transcended, and real architectural values are created." This approach to architecture, with its emphasis on structural detailing, has culminated in the design of several landmark buildings; a selection of six are presented in this article. Wright, Le Corbusier, Gropius, Mies, Johnson, and Saarinen, with their sense of experimentation, have contributed significantly to the development of this structural architecture.

In discussing his design for the Johnson Wax administration building, Frank Lloyd Wright wrote in *Architectural Forum* in 1938, "The main feature of construction is the simple repetition of hollow slender monolithic dendriform shafts or stems—stems standing on metal tips bedded at the floor level." The use of botanical terms in describing the various parts of his mushroom column—stem, petal, and calyx—indicates Wright's interest in the study of nature for structural solutions. It led him to

Mr. Anderson is a graduate student in architectural history at the University of Virginia.





Facing page, Wright believed his dendriform column for the Johnson Wax building marked the end of rod reinforcement. Above, isometric of pilotis in Le Corbusier's Unité d'Habitation; the section shows how concealed utilities reach ground level.

experiment with an expanded steel mesh rather than reinforcing bars in the columns. This was a technical innovation in the use of reinforced concrete, not only allowing for higher stresses and better bonding with concrete, but also withstanding stresses in two dimensions. Wright justified the substitution of this new material by comparing various structural properties of plants, specifically the staghorn cholla found in the Arizona desert, whose cellular structure is similar in principle to that of the steel mesh.

By using a multisupport rigid frame system interconnecting the petals at the roof level, Wright created a partial support system that allowed the 24-foot column base to be a mere nine inches in diameter. When presented to the Wisconsin Building Commission, this detail challenged the state code, which then required that a concrete column of given height with a design load of six tons had to have a minimum base thickness of 30 inches. To gain the approval of the commission, Wright built a trial column to test its loading capacity. The commission required, before agreeing to its construction, that the 18-foot petal hold 12 tons. Wright, in typical fashion, did not stop at the required 12 tons but continued adding weight until it reached 60 tons and the sun had begun to set. There were only slight signs of cracking in the petal when the column was pulled down. After the test Wright said that a new precedent for reinforced concrete construction had been established that marked the end of rod-reinforced columns.

Wright's concrete slab and mushroom column support system achieved a refinement of the system developed in Robert Maillart's 1910 Zurich warehouse. Its structural efficiency was increased through the use of the steel mesh and a higher-strength concrete that was pumped into place from a central hopper, thus preventing settlement of the aggregate. These technical innovations enabled Wright to design the column as an esthetic element rather than a "mere insert for support."

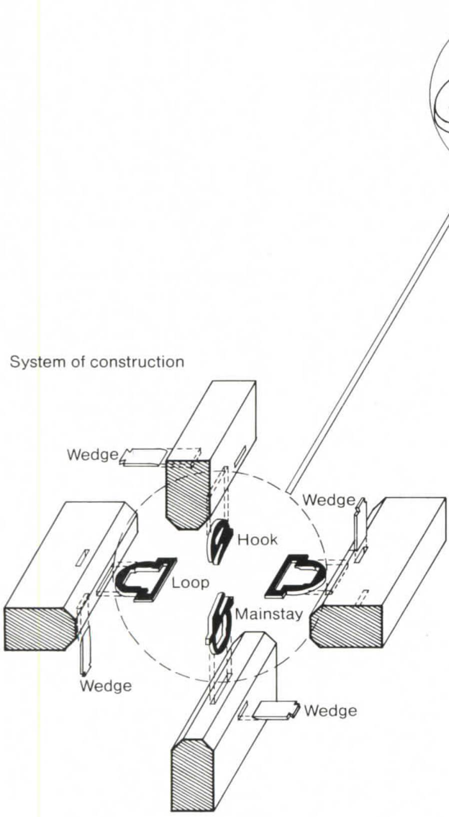
Le Corbusier, in an explanation of the principles governing the design of his 1945 Unité d'Habitation, said, "There is no such thing as primitive man—merely primitive resources." Twentieth-century technology provided him with the modern resources, or tools, to realize his architectural design. He believed that "in architecture all is possible," a statement reminiscent of the earlier influences on him by Peter Behrens. At the same time, Le Corbusier realized the dangers of a machine ethic and developed his proportional system, called Modulor, to govern and maintain a human scale within his work. The Marseilles apartment block represents both Le Corbusier's use of modern technology (his "dear faithful friend concrete" reinforced with steel rods) and the application of the Modulor.

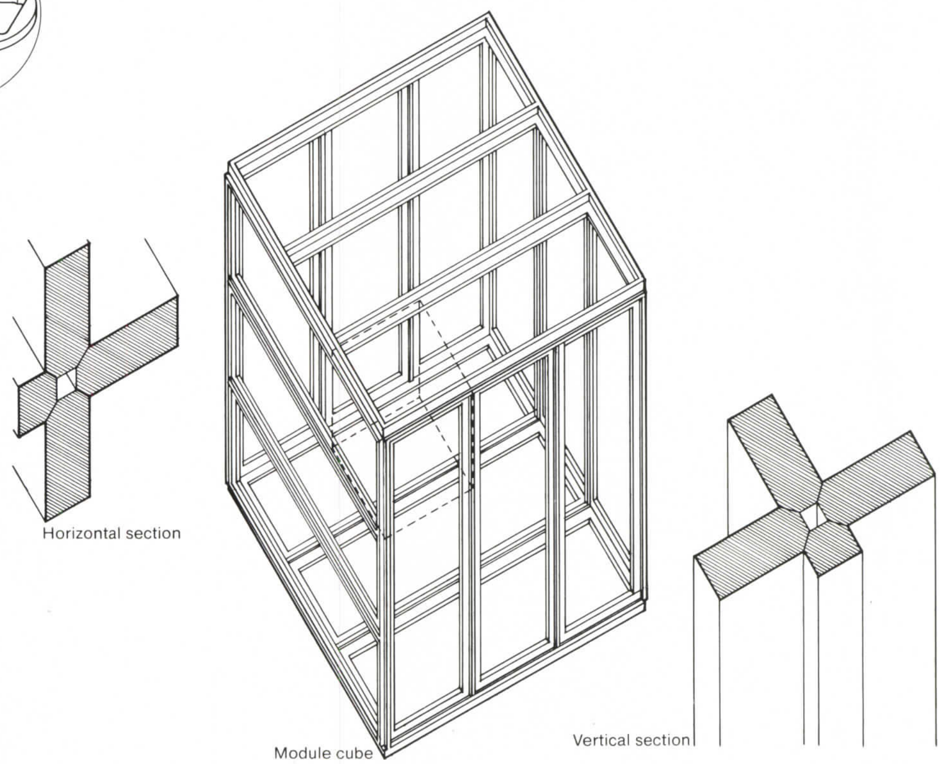
As in his earlier Pavillon Suisse, the main building block at Marseilles is raised off the ground. Two monumental tiers of reinforced concrete pilotis support a concrete slab, or *le sol artificiel,* 23 feet above grade. This rigid-frame construction functions as a platform on which the multistory structural cage of ferroconcrete columns and girders is placed. It measures 450x66 feet and has a height of 185 feet. The vertical loading of the upper stories is carried on two rows of interior supports that center the loading over the pilotis. Part of the load is transferred directly and part indirectly through longitudinal girders.

The pilotis not only support the whole structure but also accommodate utility shafts in which the sewer, water pipes, and electrical wiring are located. These services are threaded through sleeves in a continuous horizontal space running above the open ground floor and are brought down through structural shafts within the pilotis.

Le Corbusier wrote in 1960, "The fundamental principle [in architecture] is from the inside out. Everything in life is in essence biological. The biology of a plan or section is as necessary and obvious as that of a creature of *nature.*" He believed the determining exterior forms were simply an expression of internal construction. It was in the plan and section that his architectural forms were generated and evolved.

Konrad Wachsmann and Walter Gropius teamed up in 1941 to develop "a system of standardized parts which were interchangeable for use in different types of houses." Gropius, like





Left, detail of Konrad Wachsmann's 1944 metal connector enabling flexibility and variation in prefabricated housing. Above, Wachsmann's and Gropius's module system of construction, designed to enable minimum erection time.

Le Corbusier, realized the potential for dehumanization inherent in a technological revolution. But he also believed that there was no other choice but to accept the "challenge of the machine in all fields of production." Wachsmann, on the other hand, saw in science and technology the answer to all problems.

Gropius intended the system of interchangeable parts to transfer construction from the site to the factory and consequently drastically reduce the number of hours required to erect a single-family dwelling. As early as 1924 he had expressed a desire that "not entire houses, but construction elements should be standardized and industrially produced." The invention by Wachsmann of a four-way metal connector promised a prefabricated system that could offer endless variations within the universal system. It was a simple joint that locked together the various panels with effective strength. Every intersection was composed of four complementary structural members, the construction sequence being completed whenever the fourth element was slipped into place. The result was that a house could be fabricated in 20 minutes and erected in 38 hours, greatly reducing costs while still allowing for individual variation in assembly and therefore design.

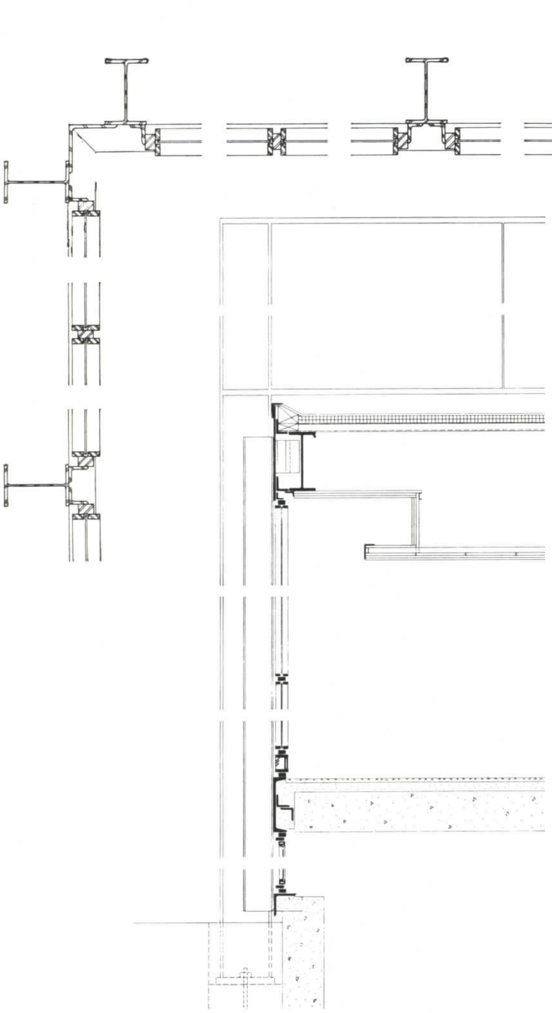
In his 1956 Crown Hall at the Illinois Institute of Technology, Mies van der Rohe achieved his honesty in structure. Earlier steel-frame designs had been hampered by fire-code regulations that required structural I-beams in concrete. Because technology could not provide a solution enabling the steel beam to be left exposed, Mies manipulated his detailing to present a sophisticated illusion of honesty in materials and structure. This was evident in his earlier Lake Shore Drive apartments where he encased the building with what appeared to be a structural steel cage but was actually only applied I-beam mullions that anchored the window frames and fascia plates of the floors. Mies designed the main steel supports beneath fireproofed concrete, which he then faced with steel to express the hidden structure.

Crown Hall, a two-story building less than 20 feet tall with one floor half sunk in the ground, was not required by code to conceal its I-beam supports. This provided Mies an opportunity to expose the actual supports, which led him to say, "I think this is the clearest structure we have done, the best to express our philosophy."

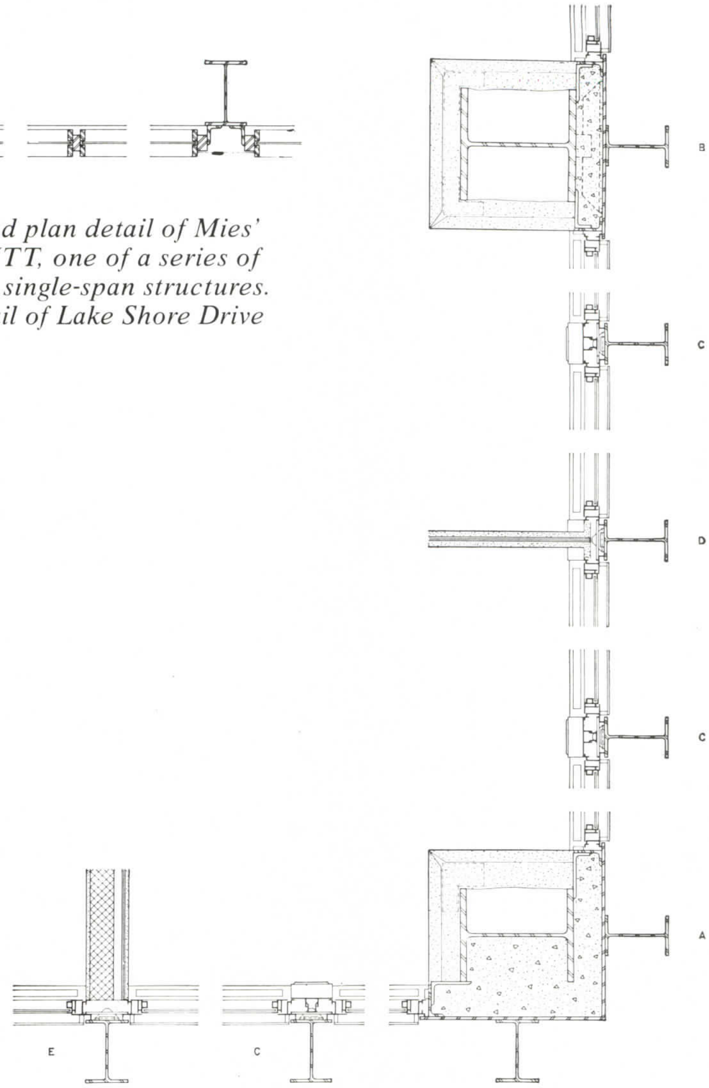
Crown Hall is one in a series of experiments by Mies on the single-span structure with external supports providing an unobstructed interior space. Breaking from the modernist notion that form follows function, Mies sought to create a universal space that would serve any function. The roof is suspended from four plate girders at 60 feet on center, which span the entire width of the building. The steelwork weighs 285 tons and is entirely welded, which prevented the obtrusion of bolted joints. This building type was further evolved in Mies's proposed Chicago convention hall, which was never built. It did eventually find expression in Skidmore, Owings & Merrill's design of McCormick Place (see page 100).

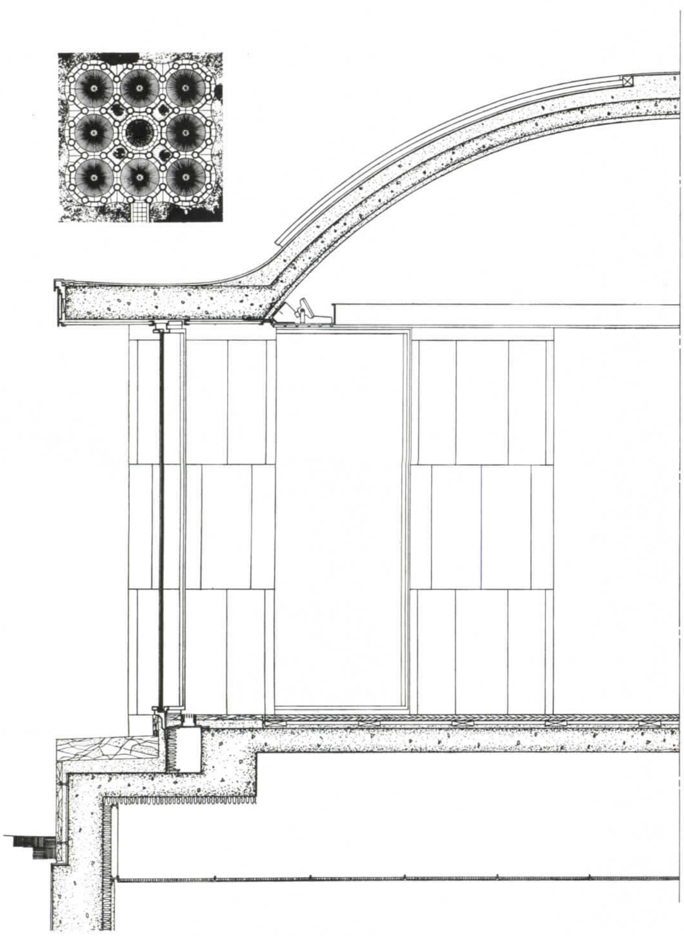
Mies achieved a hierarchy in his composition largely as a result of his careful application of details with subtle differentiations. This is evident at Crown Hall, where the initial impact is that of a glass and steel box with little if any variation among its 22 uniform bays on the front and rear facades. It is only upon closer examination that Mies's efforts become clear in distinguishing the entrance by subtle changes in the handling of detailing. The center six bays contain clear glass below the door head mullions, whereas the remaining bays on either side use a sandblasted glass with a louvered ventilator at the sill. In his attempt to simplify structural details Mies achieved an order and a clarity of purpose in his work where technology reached its "real fulfillment and transcended into architecture."

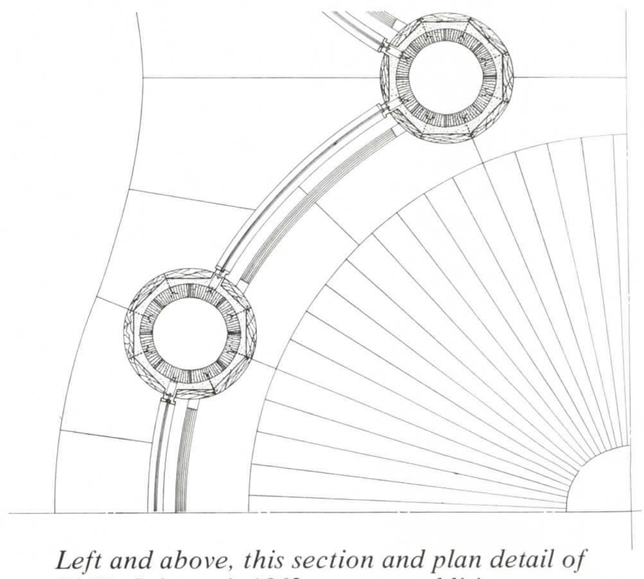
Philip Johnson wrote in 1932, "While the modern architect accepts the machine age, he also transcends it. The building can serve every function of structure and utility and at the same time have elegance and refinement of proportion." Thirty years after making this statement, Johnson presented such a building in his Museum for Pre-Columbian Art at Dumbarton Oaks in Washington, D.C. According to Johnson, this addition is an example in which the "section of a building becomes a detail" in a world where details are hardly more than enlarged structural



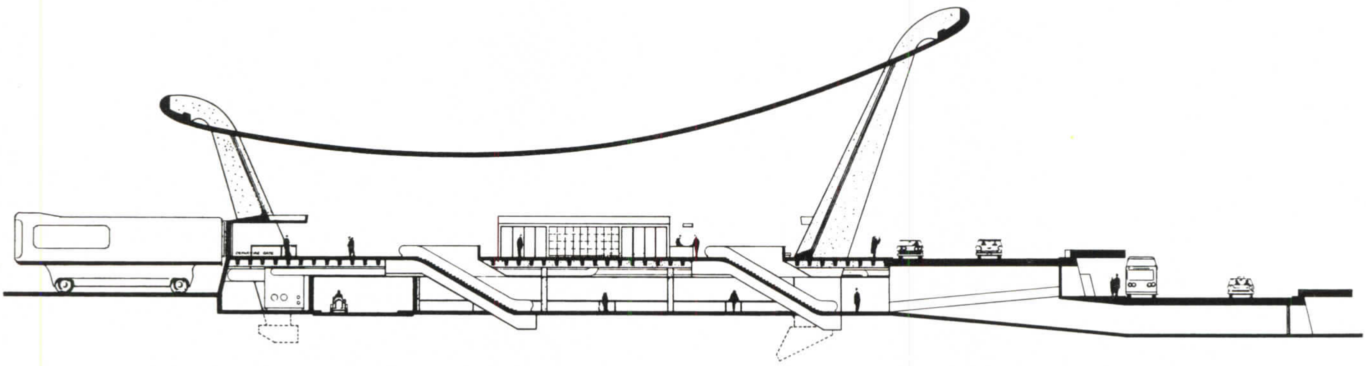
Left, section and plan detail of Mies' Crown Hall at ITT, one of a series of experiments on single-span structures. Right, plan detail of Lake Shore Drive Apartments.

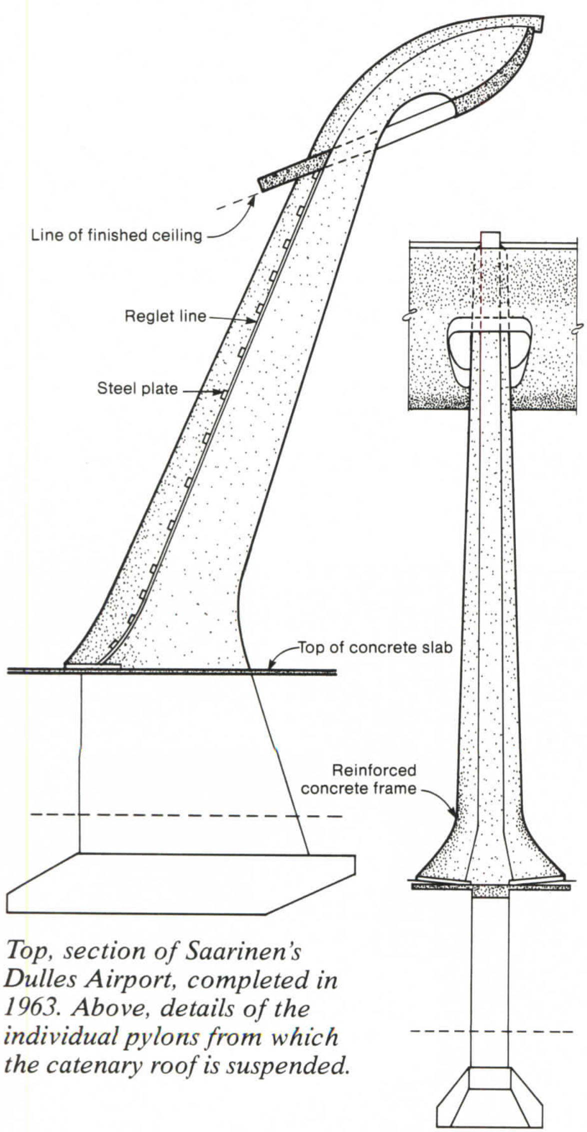






Left and above, this section and plan detail of Philip Johnson's 1963 museum addition to Dumbarton Oaks present the application of technology on a small-scale building.





Top, section of Saarinen's Dulles Airport, completed in 1963. Above, details of the individual pylons from which the catenary roof is suspended.

connections and corners. It is a building whose detailing comes dangerously close to perfection, a jewel balanced between the Miesian concept of visual purity and sensual delight.

The eight glass pavilions, with domed roofs measuring only 25 feet in diameter, are an example of technology applied in a small-scale building on an established site. The various materials Johnson used in harmonious juxtaposition—glass, marble, teak, and statuary bronze—reflect the architect's capability in detailing. Radiant teakwood flooring bordered with verde antique marble, agatan-veined marble columns, and window frames, floor grills, and roof fascia of statuary bronze, are all skillfully combined to create what some consider one of the most beautiful museums of the 20th century.

Eero Saarinen's Dulles Airport near Washington, D.C., is "a strong form between earth and sky that seems both to rise from the plain and hover over it," as Saarinen himself put it, and represents the second generation of modernist thought with functional integrity and honest structural expression embodying an expressive statement. The dynamic and monumental composition with its emphasis on maximum flexibility was for Saarinen a personal explanation of what he believed architecture to be about. It was for him "the best thing [he had] done."

The airport's structural system is based on a 40x150-foot bay, 40 feet being the required distance for two loading docks of the mobile lounge developed by Saarinen. The catenary roof sheathed in poured-in-place concrete panels suspended on tension wires is hung between two rows of 16 reinforced concrete pylons. These slope outward to counteract the pull of the roof cables while providing a dynamic enclosure. With over 20 tons of steel reinforcing rods in each of the larger 65-foot concrete pylons, and with a tension roof spanning 170 feet, Saarinen's airport terminal is structurally expressive of the jet airplane's conquest of gravity.

Saarinen believed architecture to be in a state of continual development. The architect, in his view, was responsible for making sure that new materials and concepts were introduced and tested in the building industry. This would provide unlimited possibilities in the realm of future design. □

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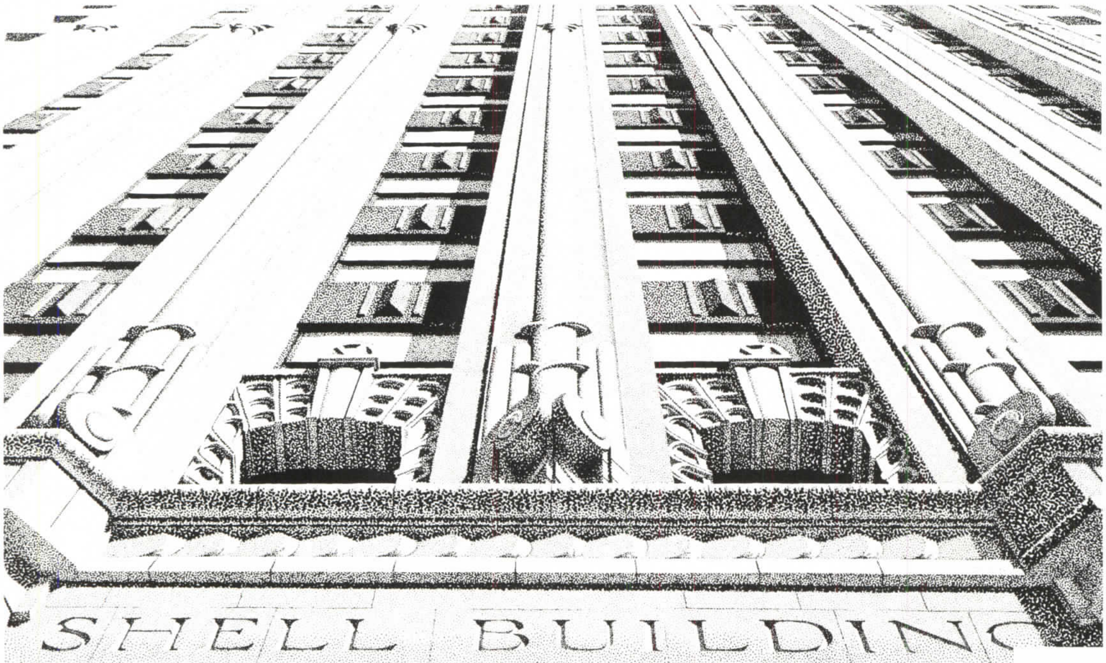

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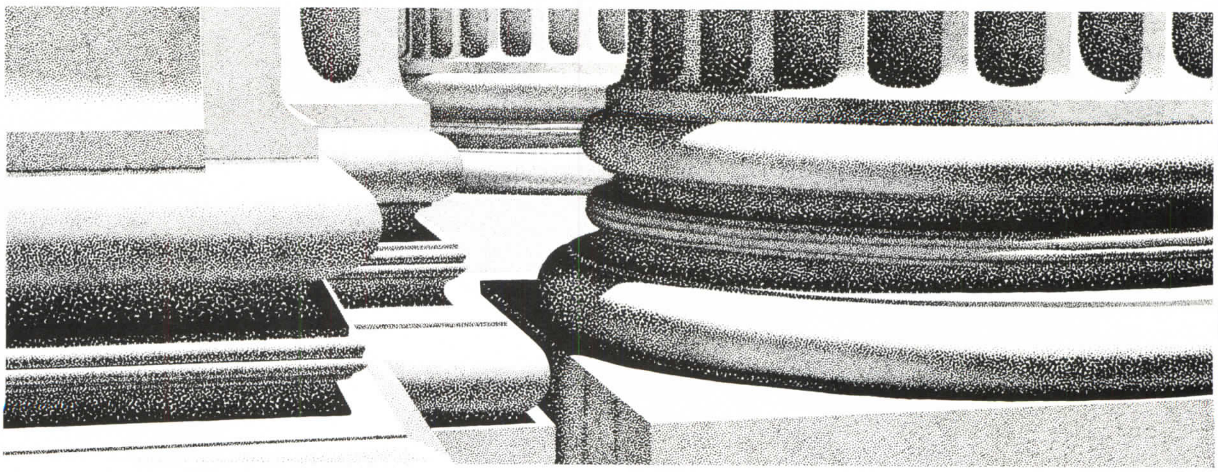

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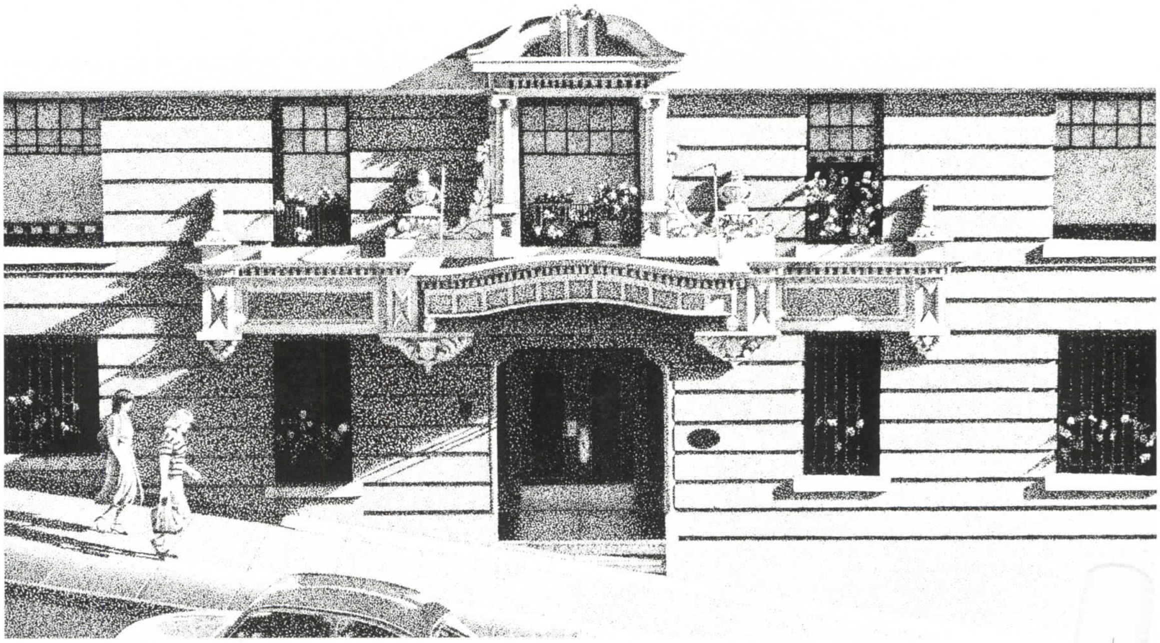

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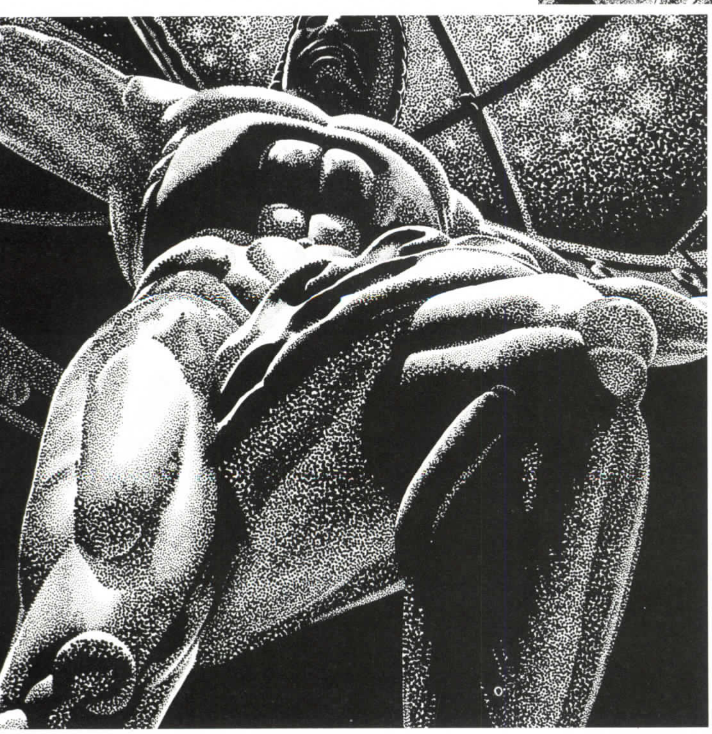

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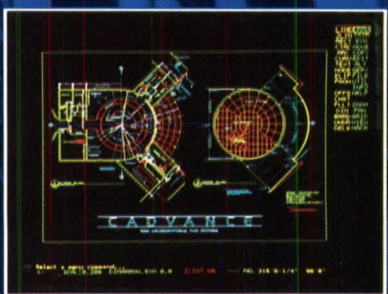

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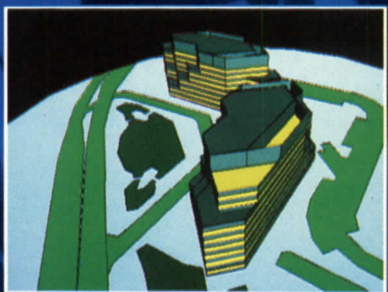

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Dynamic Testing of Wood Shear Panels

Spurred by seismic concern in California.
By Ralph Gareth Gray, AIA, and Edwin G. Zacher

The 1988 Uniform Building Code will include important revisions based on results of dynamic tests of large, wood-frame shear panels. The new test methods may prove useful for developing national standard protocols for dynamic testing of structural assemblies. We performed these tests to show that various aspects of shear panel resistance to lateral loads are inadequately measured by traditional static tests.

While investigating leaks at the request of the owners of a large number of distressed apartment and condominium complexes, we found plywood-sheathed shear panels rendered virtually useless because most of the nails had been overdriven. We also found overdriven staples in other plywood shear panels, as well as gypsum wallboard-covered shear walls with all of the nails undersized and/or almost half of them missing along sole and top plates. These complexes are located very close to the San Andreas Fault.

In one memorable instance, all of the project's ⅜-inch plywood wall sheathing had *80 percent* of the nails driven to ⅛ inch or more below the surface. We were obliged by California law to report this dangerous condition, and a complaint was included in the homeowners' lawsuit. The expert witness produced by the developers and builders proclaimed that overdriving made no difference because "the nails act in pure shear." This claim is contrary to the results of tests dating back to the 1950s, in which failure typically was due to nails pulling out of the framing or the plywood; it is also contrary to experience in earthquakes, including the San Fernando earthquake of 1971, in which buildings collapsed because nails pulled through plywood.

The expert witness presented unpublished results of tests by a well known plywood industry association that seemed to demonstrate that ⅛ inch of overdriving of up to 10 percent of the nails in ⅜-inch plywood would do little harm. Accompanying correspondence showed that code authorities might even accept these tests as permitting without penalty up to 10 percent of nails to be overdriven.

One overdriven nail out of 10 can't compare with the four out of five that we had found in the offending walls, but we feared that, in front of a jury, legal legerdemain would somehow magically equate the "permissible 10 percent" to 80 percent. We were concerned that even sloppier field practices then might be encouraged.

Consequently, we developed a testing program for wood shear panels, with the firm Rosenberg, Gray & McGinnis, AIA, Inc. (now Rosenberg & McGinnis, AIA, Inc.) contributing financial support and personnel time; H. J. Brunnier Associates, Structural Engineers contributing personnel time; Balliet Bros. Construction Co. contributing materials and labor; and grants from the Serramonte Homeowners Association and Eagle Point Homeowners Association.

There were other motives for the tests. Many architects and engineers have believed for some time that the comparative importance of fastener properties versus sheathing properties in predicting deflection in an earthquake is not well understood, that the actual behavior in an earthquake of gypsum wallboard shear panels is inaccurately described by present tests and theory, and that a national standard for dynamic (as opposed to static) testing of earthquake-resisting assemblies is long overdue, particularly for shear panels in wood-frame construction.

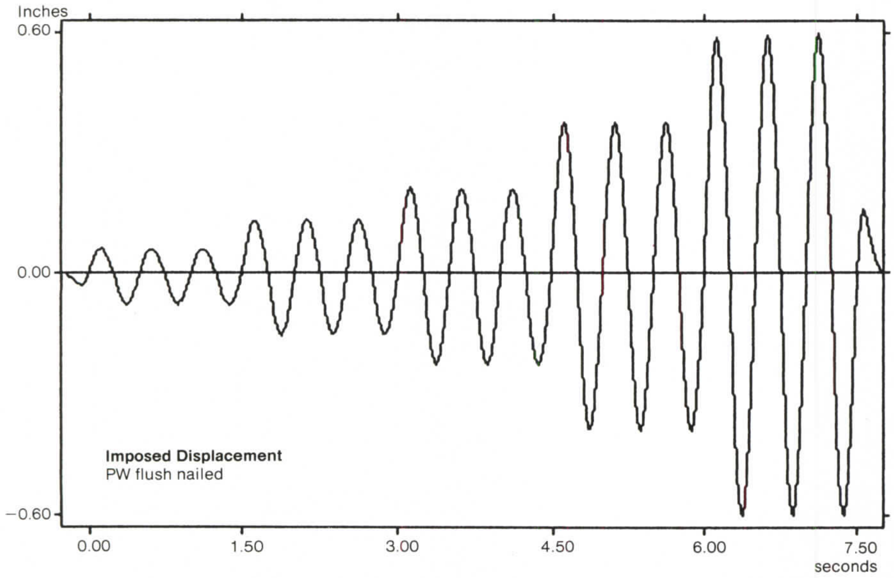
All buildings are subject to vertical live and dead load forces due to gravity, but in regions of high winds or earthquakes buildings also must oppose lateral (horizontal) forces from wind acting on the building as if it were a sail, or from inertial and resonance effects due to an earthquake.

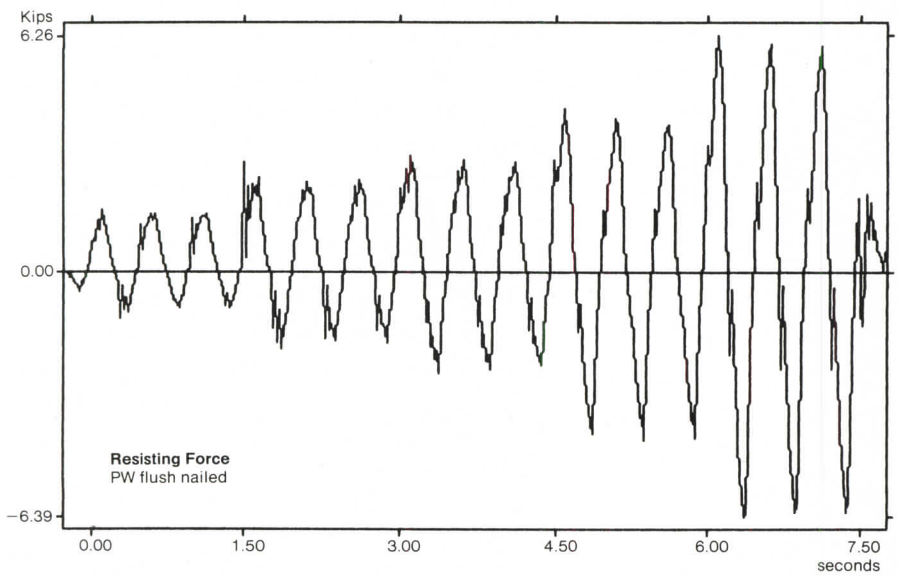
The structural designer probably is impressed most by the violent and unpredictable back-and-forth, up-and-down ground motion of an earthquake, by the enormous and unpredictable energy that motion imparts to a building, and by the relative lack of information available concerning how structures actually behave under such conditions.

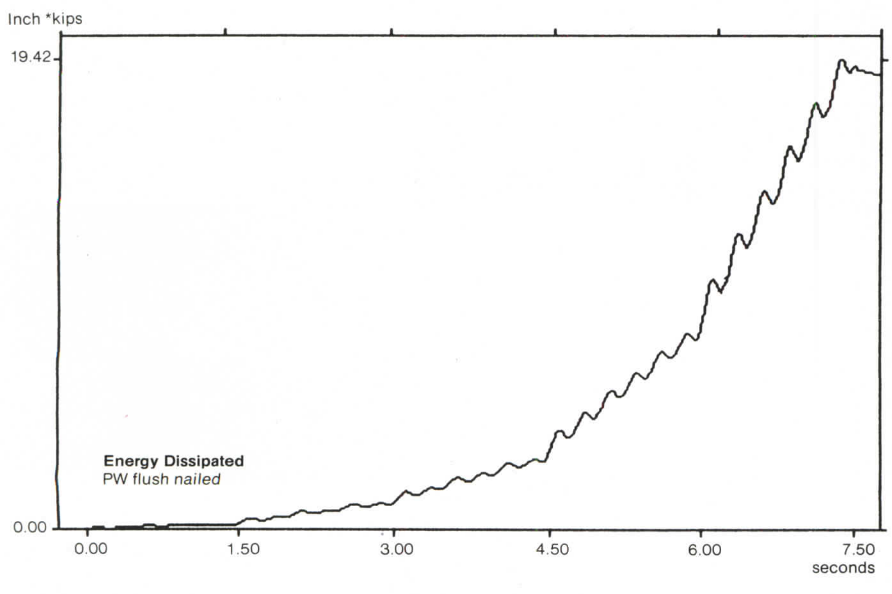
Earthquake effects are dynamic, not static, because the base motion and its consequences vary significantly as a function of time, including by repeated reversal of direction. Anchored to the ground by its foundation, a building is constrained to follow the ground's chaotic motion, accelerating (and decelerating) this way and that, causing not only internal inertial forces that the structural system must resist, but deformation as well. Dangerous amounts of kinetic energy (velocity) and strain energy (as in a stretched spring) are picked up in the process. Furthermore, destructive resonance may occur in buildings with natural periods greater than about 0.8 seconds per cycle.

The term "shear panel" includes wall, floor, and roof assemblies that resist lateral forces, primarily in shear. For wood-frame construction, this usually means use of plywood on joists and rafters and plywood or gypsum wallboard on studs. Structural vocabulary distinguishes "shear walls" from "horizontal diaphragms," but their actions are fundamentally similar; they are thin-web beams. Floor and roof diaphragms resist lateral forces by spanning (in a horizontal plane) between shear walls, which cantilever vertically from the foundation.

Mr. Gray, an architect and structural engineer, and Mr. Zacher, a structural engineer, specialize in seismic design and have practiced in California for 30 years.







How to fail successfully

The forces and deformations induced by earthquakes are not as finely quantifiable as those due to dead, live, or even wind loads, so in seismic design and construction additional structural concepts must be applied.

In a very great earthquake, any building might "fail" in the sense of economically irreparable damage, but collapse and great loss of life may be avoided without vast expenditure if the bracing systems can yield to very high forces without coming apart and can dissipate energy in ways other than collapse. In other words, the structure must stay tied together long enough to dissipate energy in a reasonably safe and economical way; it must give but not break. The combination of force and inelastic (permanent) but controlled deformation dissipates energy. In steel and reinforced concrete buildings, this is called "ductility."

Historically, most shear panel tests have been static and monotonic; the investigators place the sample wall in a testing machine, slowly increase the deformation stepwise, and measure, without undue haste, the resistance developed by the wall at each step. This is called a "static load" test because the distortion is applied so slowly that dynamic (i.e., time-varying) phenomena are insignificant. The tests are also called "monotonic" because there is no full reversal of distortion. However, actual earthquakes aren't that gentle; they cause extremely rapid deformation and violent reversals. Some architects and engineers hesitate to extrapolate the results of such tests into the real world of earthquake motions, but until recently there seemed to be no practical alternative. Virtually all structural testing of full- or large-scale assemblies has been static, not dynamic, mainly because dynamic tests up to now have been impractical. Unfortunately, static testing may conceal hazards that might be revealed by dynamic tests.

Although the methods we used need refinement, we believe they go a long way beyond the current static, monotonic standards. Furthermore, few of the previous dynamic testing methods were aimed directly at actual construction practices or development of an industrywide protocol.

Charts at left graph displacement, force, and energy dissipated for one type of wall. Charts at right compare force development and energy for different walls.

For realism, all but one of the 8x8-foot wall panels we tested were fabricated by Balliet Bros. Construction Co.'s field crews in their yard, using materials and fasteners obtained from their usual suppliers. All had 2x4 studs at 16 inches on center, doubled at edges, and tie-downs. Nine specimen walls were built of ⅜-inch CD plywood, fastened as follows:

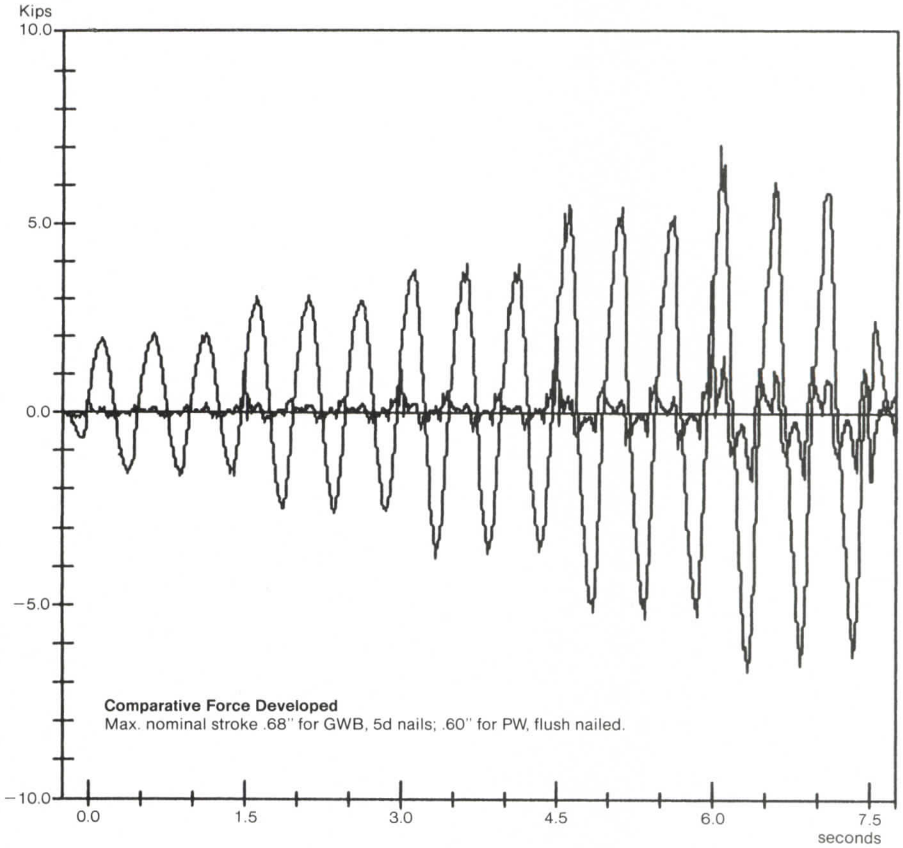
- Two walls with 8d nails at four inches on center driven flush. These represented good field practice and provided experimental control for nails in plywood.
- Two walls with 8d nails at four inches on center with heads set ⅛ inch below the surface.
- One wall with 8d nails at four inches on center, driven by Edwin Zacher of H. J. Brunnier Associates, very carefully located with heads set meticulously ⅛ inch below the surface. This gave the best possible chance for good performance with overdriven nails.
- Two walls with 16-gauge, 1⅜x7⁄16-inch staples at 2½ inches on center driven flush. These represented good field practice and provided experimental control for staples in plywood.
- Two walls with 16-gauge, 1⅜x7⁄16-inch staples at 2½ inches on center set ⅛ inch below the surface.

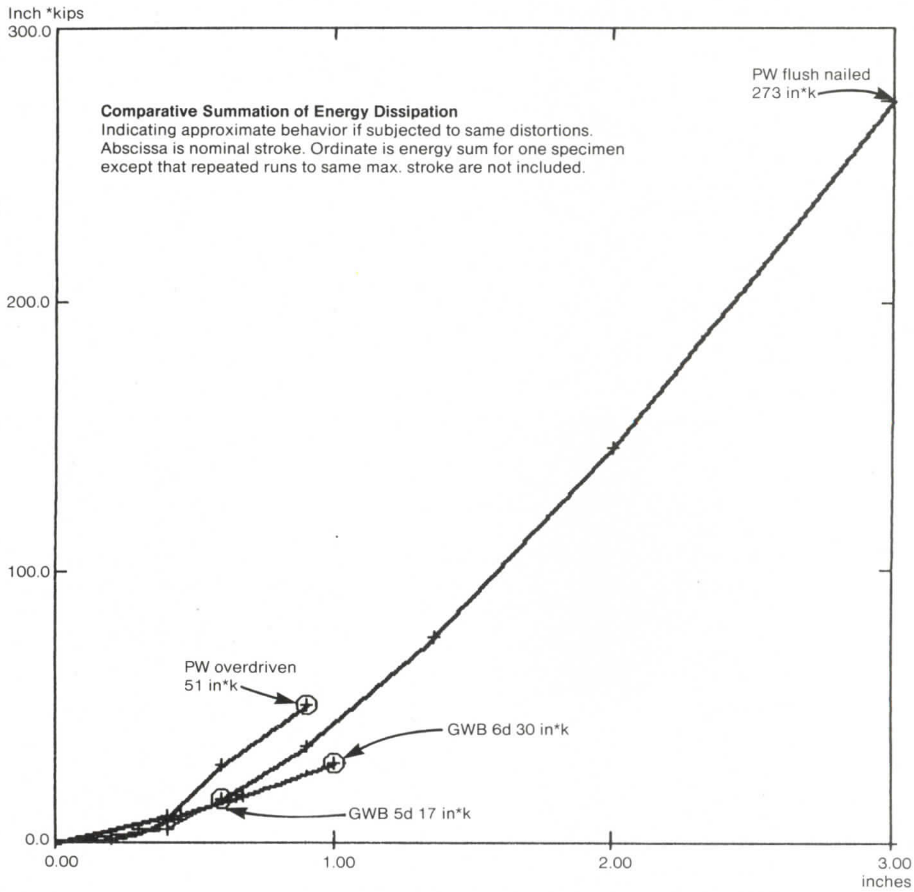
Four specimen walls were constructed of ⅝-inch gypsum board, fastened as follows:

- Two walls with 7d cooler nails at seven inches on center driven flush. These represented good field practice and code-mandated nail size and provided experimental control for gypsum wallboard nailing.
- Two walls with 6d cooler nails at seven inches on center driven flush.

For the wall tests, a welded steel reaction frame provided anchorage for an 8x8-foot wall and support for a hydraulic ram driving a rigid steel headpiece bolted to the top plates of the wall. The wall's sole plate was bolted to the base of the reaction frame, and a common proprietary tie-down was bolted to the double studs at each vertical edge and the base. Signals measuring force and displacement from up to 14 data sensors were sampled in synchrony at up to 500 times per second and recorded for later analysis.

A hydraulic ram following a pattern prerecorded on magnetic tape imposed a deflection to the wall top. At the beginning of each run, the maximum excursion of the ram was selected, from ±0.2 inch to ±3 inches as required by the investigators. The pattern built up step by step





to the maximum excursion. In each run there were five steps of three sinusoidal cycles each, at a set number of cycles per second.

To test the joints, a smaller test frame and ram were used, with less elaborate attachments and only five data sensors, but otherwise, with respect to deflection pattern, the testing was similar to permit direct comparison with the walls.

The testing was done at the University of California Richmond Field Station Structural Laboratories, using the deflection pattern created by their very helpful personnel, particularly director Patrick Quinn and Donald Clyde.

Analysis

For each run, the records of the sensor signals were processed by computer for detailed understanding of what happened and comparison with other runs. This was done after the run rather than during it because, as insight increases, various aspects that were unpredictable before the test may invite study, perhaps months later.

The first step was to read the data for one run into the computer. Each record began before the initial ram movement (time zero) and ceased a few seconds after the ram stopped. Because a sensor sometimes gives a constant baseline signal before time zero when nothing is happening, records must be zeroed with respect to both time and signal. First we offset the ram displacement record (stroke) so data points from well before approximate time zero lay on the horizontal axis of the plot (data zero). Then we established actual time zero by finding the first departure stroke from the horizontal axis. Each remaining record was offset to data zero, and the sign of plot (plus up or plus down) was noted.

With everything zeroed, we can calculate linear combinations of force and displacement records, depending on information desired. We can plot force combinations and displacement combinations as functions of time, plot force combinations as functions of displacement combinations, and integrate force combinations with respect to displacement combinations (yielding energy dissipated). These plots may be combined in many ways for analysis and presentation, as shown in Figures 4 and 5. Many plots of the data have been made (and many more will follow) using the following procedure.

We analyzed the data on a Macintosh microcomputer because we wanted to keep the work in house and because the work is best understood graphically, using a very elegant Pascal program written by Gregory Couch, doctoral candidate in computer science at the University of California.

Observations

Impressions formed by watching the tests and videotapes of them generally are confirmed by numerical analysis (still under way) of the literally hundreds of thousands of data points collected.

We have observed that each plywood sheet translates and rotates almost independently of its partner, practically undeformed; most of the wall deflection is due to nail or staple bending between the plywood and the framing. On the other hand, there is little if any sheet rotation of the gypsum board, but these walls fail at much smaller imposed distortions and loads than the plywood. The nails don't deform so much as excavate holes in the gypsum, and piles of gypsum dust accumulate under each nail along the bottom of the wall.

Failure of the properly nailed or stapled plywood walls is long delayed and difficult to detect, and significant albeit reduced load is maintained at extreme distortions, including repeated runs to ± 3 inches ram excursion. However, failure of the walls with overdriven nails is sudden and occurs at low loads. The sheets come unzipped from the framing because the nails pull through the plywood. This reaction is less pronounced in the case of the staples.

The bolts from the tie-down to the edge studs are in single shear and cause enlargement of the stud bolt holes; they also let the tie-down sag and the nut on the anchor bolt loosen. Typically, the nut could be turned from a quarter to a full turn after each run.

Conclusions

Although we plan to perform further testing and analysis, our research to date permits the following assertions:

1. Dynamic testing discloses important earthquake-resisting properties not apparent from static, monotonic tests. It should be adopted as a national standard.

2. Fastener-panel-framing interaction is the central phenomenon in shear panel behavior.

3. Properly nailed plywood shear panels survive extreme distortion and dissipate very large amounts of energy while still retaining high, if reduced, strength (important in aftershocks); such panels exhibit ductility akin to that found in moment-resisting steel frames.

4. There is little distortion of the plywood sheet itself; distortion and energy dissipation is almost entirely due to nail flexure beyond the yield point. Rubbing of sheet edges also may account for some energy.

5. Properly stapled shear panels are just as effective as nailed ones. However, thin wire staples will corrode rapidly if water gets to them.

6. Overdriven nails in plywood permit sudden failure with severely reduced energy dissipation. While overdriven staples do the same, the reduction isn't as great.

7. Nails in gypsum shear walls move back and forth in the holes that they excavate, dissipating little energy and destroying any strength the wall had.

8. The capacity of gypsum-sheathed shear walls is so low that using 6d nails doesn't significantly reduce capacity compared with 7d nails.

9. Gypsum-sheathed shear panels behave so differently from plywood-sheathed shear walls that they should not be depended on to add to the resistance of plywood shear walls in the same story, certainly not on the same plane, and perhaps not in the same building.

10. Many of the newer wood-frame buildings will fare poorly in the next "big one." The long-held reputation of wood frame for good performance in severe earthquakes is based in part on construction materials, methods, and field control no longer widely used.

11. The allowable earthquake loads in the current codes for gypsum-sheathed shear panels are much too high. Indeed, as a direct result of these tests, while this article was being written, the International Conference of Building Officials cut those loads in half for Seismic Zones 3 and 4. This reduction will appear in the 1988 edition of the Uniform Building Code.

12. Other code changes are likely, involving plywood, nails, nailing techniques, and lateral force design.

13. The current design method for shear panels is incorrect. It assumes that the plywood or gypsum wallboard carries only shear force and the studs and joists carry only direct force. There is no reference to energy dissipation. We intend to pursue developing a better method based on these and further tests. □

Protecting Concrete Shear Walls

A recommendation of triangular reinforcement. By Hrista Stamenkovic

"Why not run reinforcement in the direction of the shear in shear walls?" wondered building engineer Hrista Stamenkovic. His proposal is presented here for readers' comments.—Ed.

During the Alaskan earthquake of 1964, spectacular diagonal tension failures were reported in structures that complied with the Uniform Building Code. No reasonable explanation for these failures was given. It was stated that the relative contribution to shear strength provided by the vertical and horizontal web reinforcement specified in the building codes is not fully understood. Radical changes in design thinking to resist diagonal tension were predicted.

The accepted method of introducing stirrups to counter shear forces has been shown to reach a point where additional stirrups will not increase shear strength. This is not surprising, because the use of vertical stirrups to resist diagonal shear in beams is done more for construction convenience and economy than for structural efficiency. The most rational design, affording the highest degree of safety, would be triangular reinforcement, directing forces as they are channeled in a truss. This is the safest method for reinforcement, because it is based on the rigid geometrical configuration of triangles.

The codes usually describe static forces less than those induced by a major earthquake. Earthquake design is considered to be more an art than a science; therefore, seasoned engineering judgment is a critical ingredient of design solutions. In addition, scientific knowledge concerning building failure induced by earthquakes is limited.

The classical theory of shear wall design is based on a design theory for a cantilever beam on two supports instead of a theory of deformation induced by pure shear action, which is the actual condition of a shear wall under earthquake

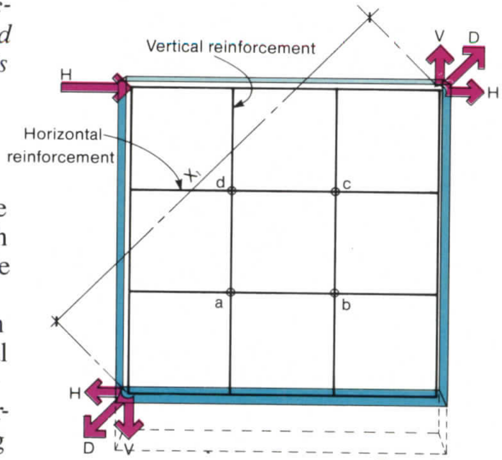


Figure 1a

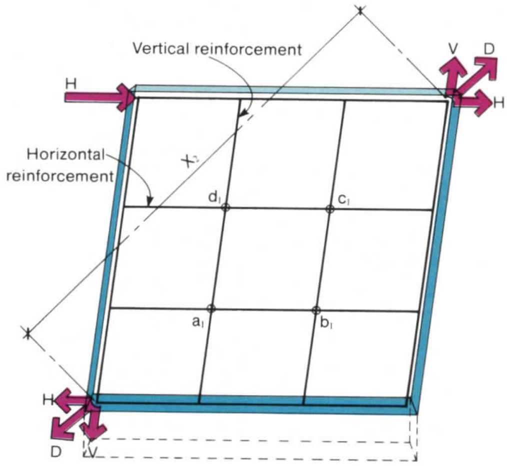


Figure 1b

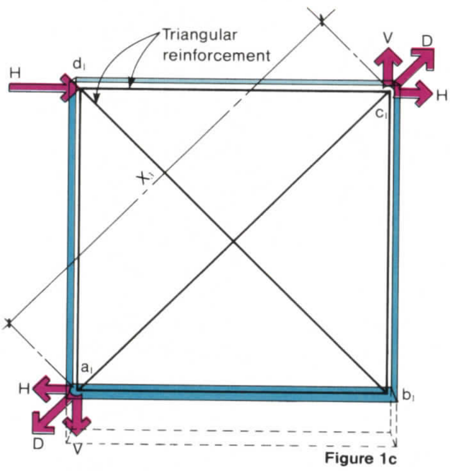


Figure 1c

stress. The primary difference is the tendency of a shear wall to be stretched, that is, elongated on one or the other of its diagonals. This distortion differs from that of a beam on two supports. The theory of a simply supported beam is therefore not applicable to shear walls.

A shear wall is a wall designed to resist lateral forces parallel to the wall, so, for the safety of a building, such walls must exist in both directions. The essential concept of a shear wall is rigidity, or prevention of diagonal elongation within the shear wall. Under current shear wall design practices, horizontal stirrups are present to prevent abrupt failure, even though it is freely admitted that there are limitations to this procedure. These techniques do not satisfy the main objectives of a shear wall, which are to control rigidity and to prevent diagonal failure.

By contrast, triangular reinforcement in a shear wall will provide rigidity and prevent diagonal failure. Existing concepts of shear wall design do not permit full exploitation of the strength of the reinforcement. Diagonal reinforcement encourages its full exploitation.

For further explanation, see "A Triangularly Reinforced Shearwall Can Resist Much Higher Lateral Forces Than an Ordinary Shearwall," in the *Proceedings of the 10th Triennial Conference for Building Research, Studies, and Documentation,* 1986, Vol. 9, page 4263, published by the Center for Building Technology, National Bureau of Standards, Gaithersburg, Md.

Figure 1a
Shear wall reinforcement, according to the classical theory as required for a cantilever, does not possess any rigidity against deformation or elongation of its diagonal members.

Figure 1b
The diagonal of a shear wall (X_2) could be elongated without any resistance from its reinforcement.

Figure 1c
The new concept of reinforcement is truly a rigid configuration.

Mr. Stamenkovic, a building engineer with the Building Department of Riverside, Calif., invented a method for preventing vibrating fatigue failure, patented in the United States and Canada.

Shear wall behavior

Figure 2a shows typical cracking and failure of a deep beam caused by pure punching shear; Figure 2b shows typical cracking and failure of a shear wall caused by diagonal tension.

A = Shearing (sliding) force caused by force R_1.
B = Shearing (sliding) force caused by force F.
α = Cracking slope; varies from 35 degrees to 90 degrees.
V_1 = Vertical shear force caused by the support.
V_2 = Vertical shear force caused by the external load.
T = Flexural tensile force.

The cracks are caused not by diagonal tension but by pure punching shear. All cracks are oriented from the external forces directly toward the supports. The law of punching, where a cracking line starts at one force and finishes at another, can be seen.

The diagonal cracking is a result of the natural tendency of the support to move one portion of the flexurally bent member upward and the natural tendency of the external load to move another portion of the beam in the direction of its action—here, downward.

Such action of a support and external load will cause some diagonal cracking as the only possible failure of the member, if it previously did not fail in flexural bending, in which ultimate tensile resisting stresses are very low compared with ultimate compressive resisting stresses. This is typical of the nature of concrete or any form of masonry.

The pure and clear diagonal punch-shear "wrinkles" developed in a flexurally bent, thin, welded beam are caused by the tendency of a support to move its portion of the beam upward and the tendency of the external load to move its portion of the beam downward. If the same beam were made of concrete, the punch-shear forces would cause diagonal cracking instead of wrinkles.

This diagram illustrates that diagonal cracking in a bent member is caused not by diagonal tension but by resultant punch-shear force Vn, acting perpendicular to diagonal cracks. Punch shear will be created by loads as long as pure bending does not exist. The resultant punch-shear force will be present in a combination of vertical shear with flexural tensile forces leading to diagonal cracking of a bent member.

Simultaneous with the action of punch shear, there exist sliding punch forces acting parallel to diagonal cracking—one upwardly and another downwardly. These forces are caused by a combination of vertical shear forces with compressive forces. Such cracking is not caused by diagonal tension.

The angle of cracking is variable: for a concentrated load at some distance from a support, it will be approximately 45 degrees from the load at the left or right side; for a concentrated load nearer to the support, it will be a straight line between the support and the concentrated load; and for a uniform load it will be approximately 45 degrees from a support, upwardly. For a deep beam with a concentrated load, it will be a straight line between the load and the support; for a uniform load, it will be a straight line between a support and approximately one-third of the length at the top of the beam. As a result of arch creation, cracking is prevented from reaching the middle top of the span, as can be seen in the drawing above.

Figure 2a
Beam on two supports

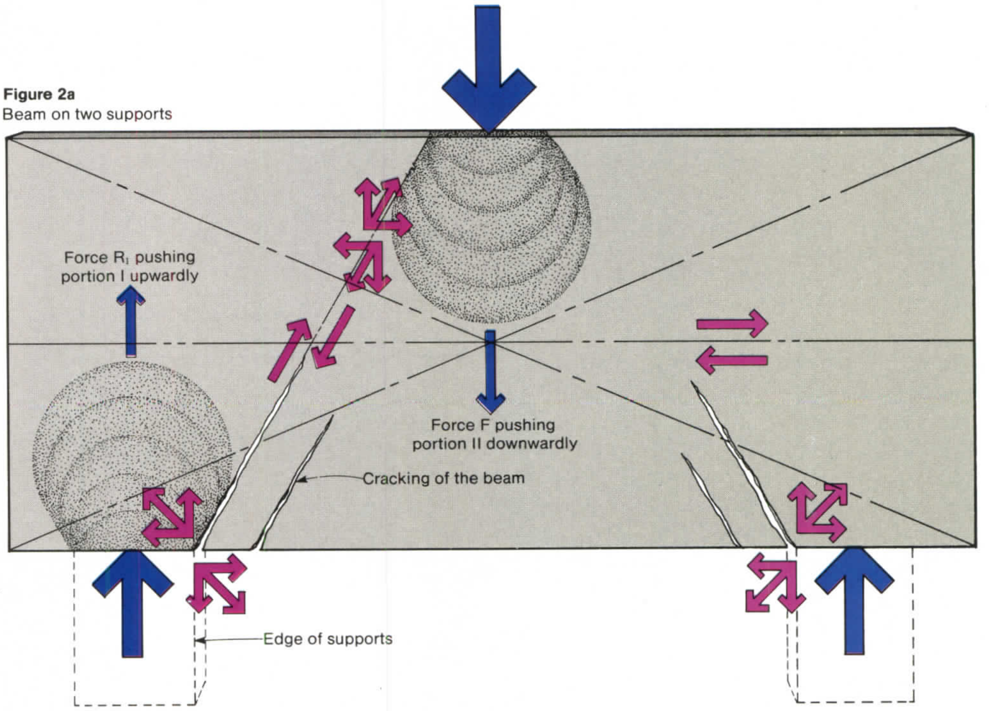


Figure 2b
Same beam as shear wall

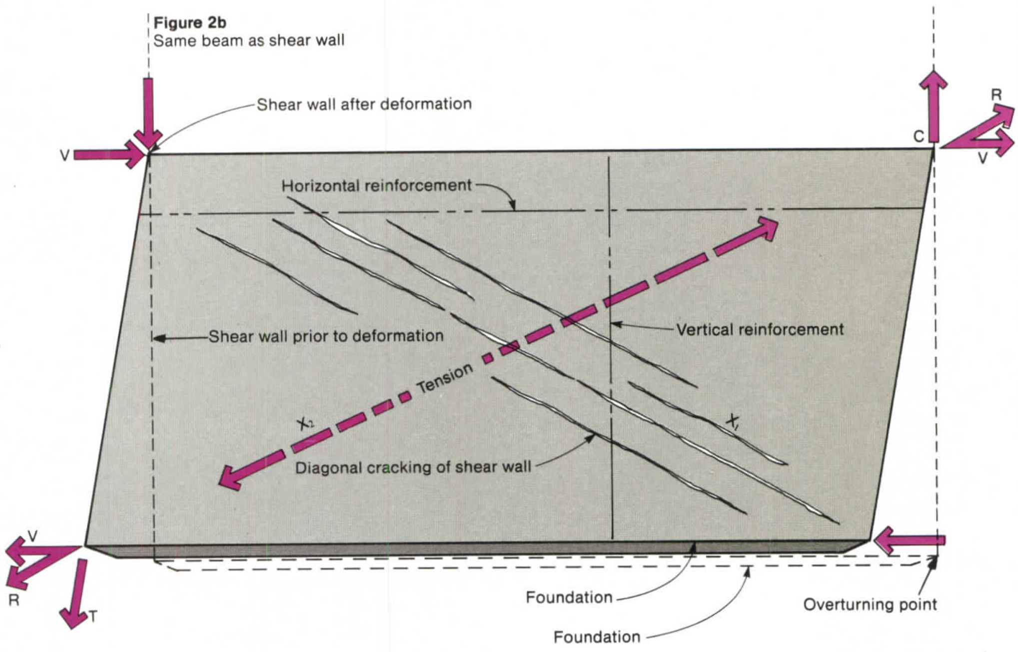


Figure 2a

1. Cracks as shown are caused by pure punching shear of two oppositely oriented forces and not by any diagonal tension.
2. Generally, cracks are oriented from the support toward an external load as a result of the punch-out tendency of two oppositely oriented forces.
3. Diagonal cracking is caused by a combination of flexural tension (T) with vertical shear forces (V_1 and V_2), and not by any diagonal tension.
4. These cracks are totally different from the cracks in a shear wall, because in a beam on two supports there exists no tendency for diagonal elongation of the beam.
5. In general, cracking is oriented toward the concentrated load—for uniform load from the support, while for concentrated load toward the load.

Figure 2b

1. The concept of the truss analogy theory for a shear wall is not applicable here because ties cannot control the deformation.
2. Neither horizontal reinforcement (ties) nor vertical reinforcement can prevent deformation of a shear wall.
3. Diagonal deformation of a shear wall can be controlled only by diagonal reinforcement and not by horizontal ties, as has been suggested, nor by vertical reinforcement.
4. Diagonal reinforcement to prevent elongation of each diagonal must be anchored at the "boundary elements" (edge of wall).
5. To prevent overturning of a shear wall, diagonal reinforcement should be anchored into the foundation.
6. By adding more diagonal reinforcement for any additional external load, rigidity of a shear wall could be unlimited, while the effect of additional ties is very limited.

Figure 3

Graphic guide to reinforcing a shear wall by a single wire (bar): Start with Corner 1 and follow pattern (arrows) from Bar 1 to Bar 12. Bar 7 and the last bar, 12 or 24 (depending on the number of layers), should be welded to each other, or to Bolt 1.

Figure 4

The concept of shear wall rigidity achieved through triangular reinforcement of a flat concrete member where diagonal forces are controlled by diagonal reinforcement. The section shows placement of boundary reinforcement at the top and bottom, diagonal reinforcement, and foundation reinforcement. □

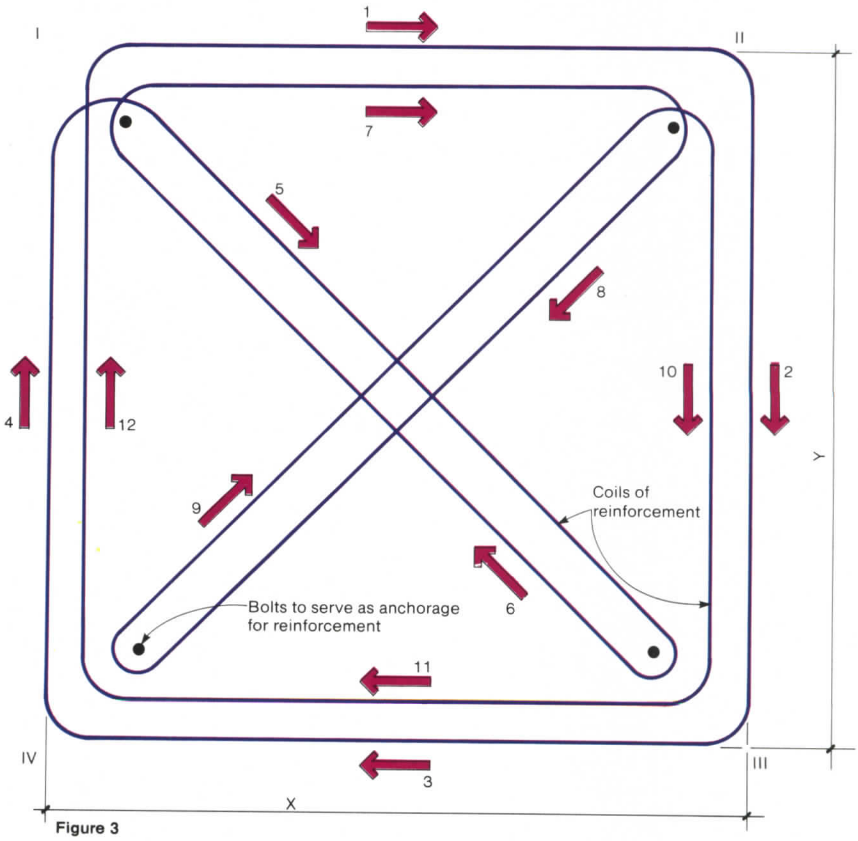
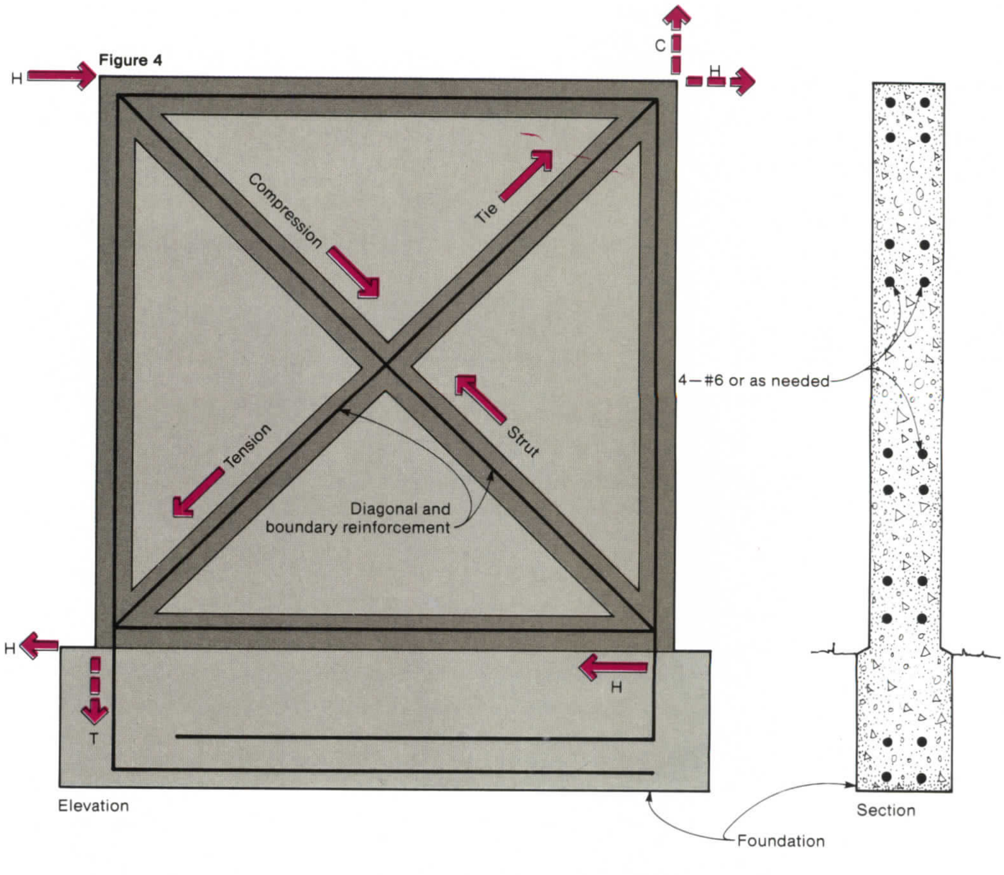
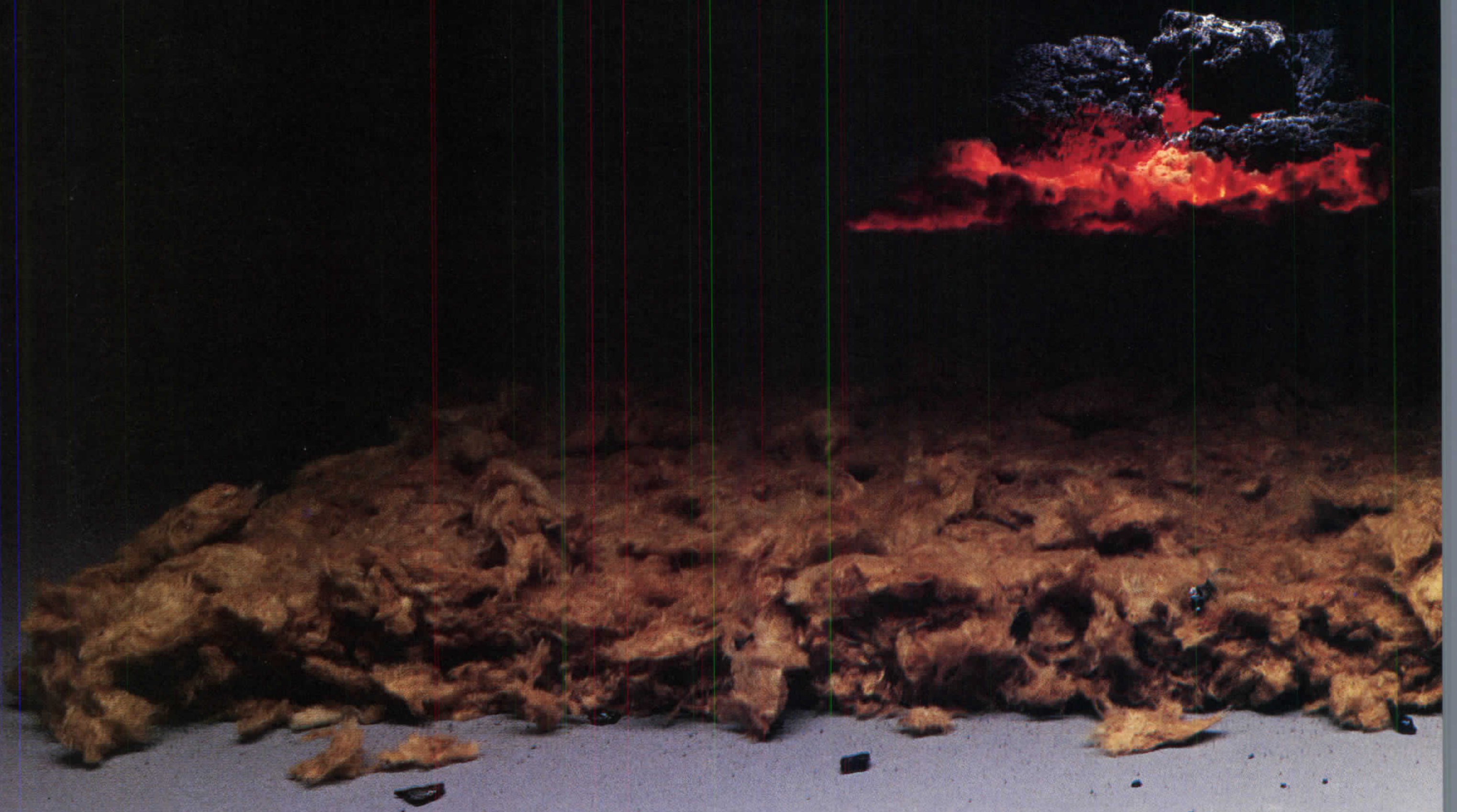


Figure 3





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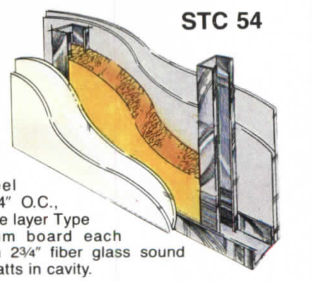

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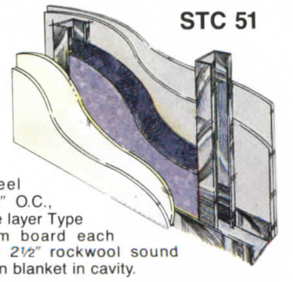

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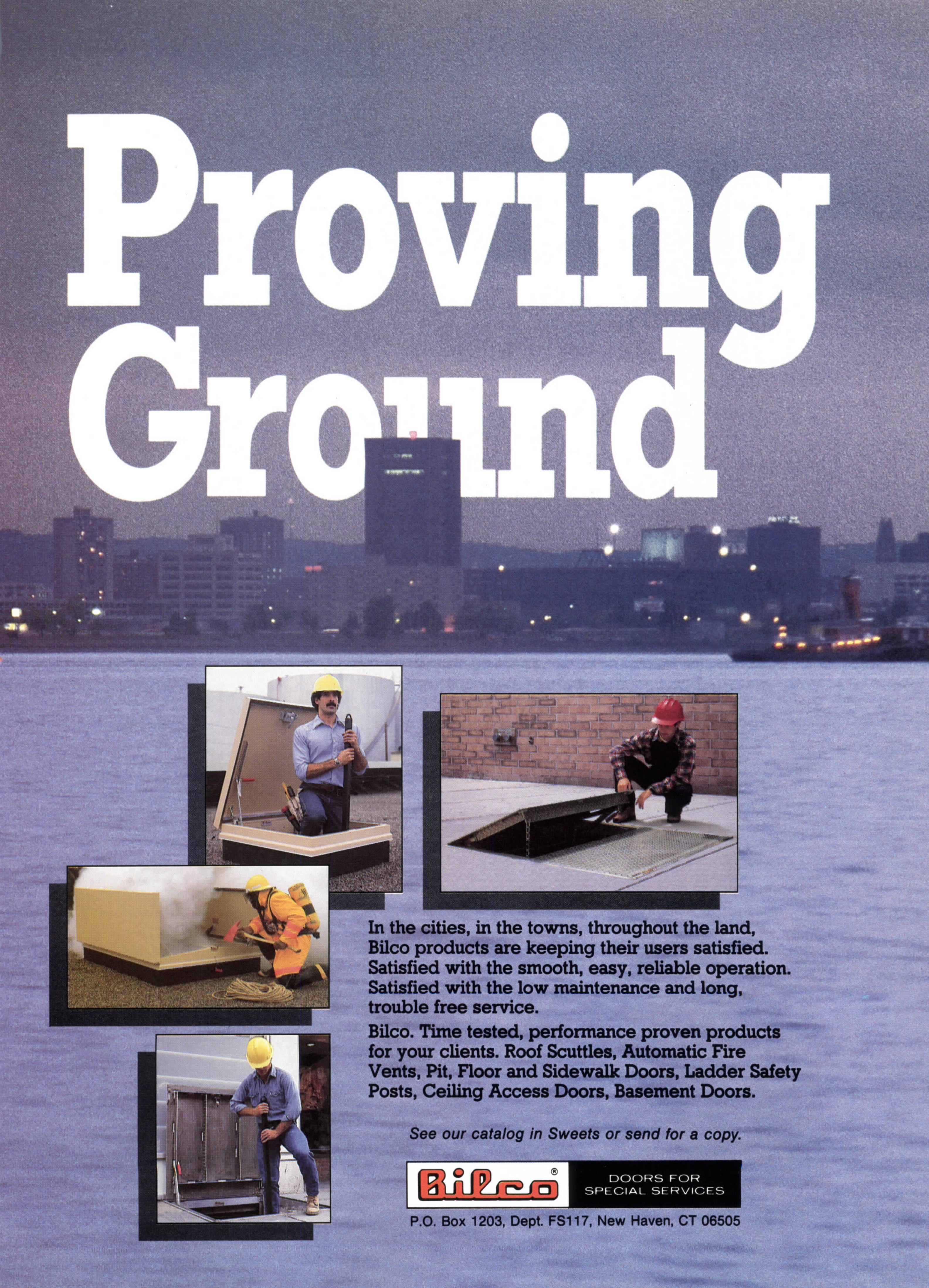
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Causes of Deterioration In Reinforced Concrete

Many are intrinsic. By Elena Marcheso Moreno

In the 1960s and early 1970s, exposed reinforced concrete was the material of choice for top designers, who believed it to be durable and adaptable to a wide range of plastic and sculptural configurations. Yet a look at many concrete buildings from that era—and even some more recently constructed—reveals deterioration that mars both appearance and structural integrity.

Concrete damage usually occurs as spalling, cracking, and rust staining; in many cases the inherent nature of the reinforced concrete system and the properties of its materials are the underlying factors. In the setting process, concrete shrinks as water evaporates from the mix. Contraction would not be so troublesome if the material, which has little tensile strength, were not restrained. Reinforcements and contact with other members hold the concrete back and encourage cracking. Properly designed concrete has acceptable crack widths—so small that water cannot penetrate. Too high a ratio of water to cement makes matters worse; it will cause fairly rapid crack formations as water evaporates.

Factory-precast reinforced concrete can crack and corrode as badly as site-cast, although typically the precast components are manufactured with greater quality control. Connections and anchors, rather than reinforcements, tend to be precast trouble points. Collapses in precast systems occur during construction because members frequently are not well braced.

Distress in concrete construction can result from structural movements such as foundations shifting in the earth, overloading of the structure, chemical attack from external environments or from reactive aggregate, and, most common of all, corrosion of reinforcing steel.

Rusting of steel reinforcement tends to be a slow but progressive deterioration. Some cracking can always be expected in concrete, usually with no structural effect, although the appearance might be diminished. Some cracks are deep enough and wide enough to allow moisture penetration. Add to that an inferior, or at least not top-quality, concrete that is highly permeable with rebar placed close to the surface, and a number of elements corrosive to steel—such as oxygen, hydrogen, and chlorine—can penetrate to the reinforcement. In general, however, poor-quality construction causes more rebar corrosion than does cracking.

Properly mixed, high-quality concrete is highly alkaline and protects steel from rusting by contributing to the formation of a thin protective film at the metal surface in what would otherwise be an ideal circumstance for rust—a damp environment with readily available oxygen. The film will remain stable, or passive, indefinitely, but the loss of alkalinity or introduction of a contaminant such as chloride can destroy the film. Almost any crack can interrupt the passive film, leaving areas of steel vulnerable to attack. As corrosion begins, concrete cracking will accelerate because rust has as much as four times the volume of the metal it replaces.

Hairline cracks running parallel to the reinforcement are the first indication that serious rusting has begun. Because of the concrete's low tensile strength, even a little rusting, hardly noticeable to the unaided eye, can increase the metal volume enough to crack the concrete.

Lengthwise cracks directly above reinforcement indicate rusting that will lead to spalling and possibly total loss of the concrete cover if left untreated. The normal procedure is to remove the concrete at least to the level of the steel, clean the rust off, and replace the concrete. This is inadequate, however, if chloride is present. All of the concrete must be removed if it has been contaminated with chloride. Settlement cracks form before hardening and are due to improper construction as well as to inadequate mixes that can cause water to bleed to the top.

Transverse cracks that form after concrete has hardened are caused mainly by shrinking and contracting. Only when reinforcement is placed in two different directions does the potential for transverse cracking to damage reinforcement arise. A crack that runs transverse to one axis of reinforcement will run along its other axis, increasing the chance for corrosion of that reinforcement. Map cracks are fairly consistent short cracks dispersed in all directions on the concrete surface and are not derived from corrosion but from shrinkage and movement during hardening.

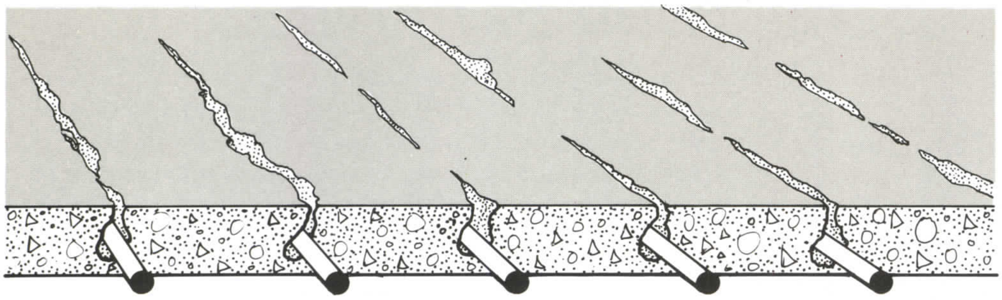
Despite the occurrence of deteriorated reinforced concrete buildings, most concrete corrosion research has been conducted on bridge and highway components and cannot be directly correlated to most building types, says Robert Heidersbach, a professor of corrosion engineering at California Polytechnic. Parking facilities are the major exception, and there have been numerous performance failures of these structures.

Chloride damage to reinforcement is a particularly onerous problem in parking structures. The salts brought in on car tires or used to de-ice bridge decks leave chloride residues that penetrate to the steel. And in many cases external chloride contamination is only part of the problem. Until recently, calcium chloride was added to the concrete mix to speed up curing and prevent freezing in winter. In the United Kingdom, hundreds of thousands of residences are now showing damage from chlorides. A parking garage collapsed in Minneapolis for much the same reason.

Heidersbach says that chemical attack is certainly an issue, but it is only one source of trouble for reinforced concrete. He points to the Watergate apartment complex in Washington, D.C., as an example of a panelized facade failure caused by an attachment system that rigidly attaches too many corners and does not provide for sufficient movement. As a result, many of the precast panels are cracked in the same places—in the lower and upper thirds of the panels and radiating from the corners. If moisture enters the cracks, the steel will be attacked, and deterioration will increase.

Corrosion in concrete reinforcement also occurs by a process called galvanic action, which generates a low-level electric current needing either direct or electrolytic contact (such as moisture) and oxygen. Galvanized steel will interfere with formation of the electric cell, and typically the zinc coating delays corrosion. Epoxy-coated rebar is a far more popular solution.

Potential corrosion of pretensioned and



posttensioned concrete reinforcements should be of major concern to designers and building owners, says Heidersbach. In conventionally reinforced concrete, the substrate shows cosmetic damage far in advance of serious structural degradation. This is rarely the case with tensioned reinforcements. Cracks that appear to be insignificant can allow enough moisture into tensioned steel cables to negatively affect their structural properties. If a posttensioned cable breaks, substantial failure, or even collapse, can be imminent. "So far this has been a problem with bridges and parking garages," says Heidersbach, "but it is my guess that it will start happening in other building types soon."

Research on stressed tendon corrosion is not conclusive. One study found that posttensioned concrete corroded less with greater amounts of steel tensioning. If this is so, Heidersbach worries that designers will find the tensioned concrete elements able to carry greater loads, indicating that some number of steel tendons could be eliminated. He finds fault with that because redundancy would be lost and safety factors diminished.

Freeze-thaw cycles are yet another cause of deterioration. Corrosion cracks from rusting steel reinforcements are likely to expand and can cause scaling of the concrete and increase the overall rate of deterioration. Adrian Ciolko of Construction Technology Laboratories Inc. says the best way to prevent excessive freeze-thaw damage is to use a high-quality concrete with a low water-cement ratio—preferably less than 50 percent. Concrete strength is greatest for mixes with the least water possible. Circumventing the freezing problems, in addition, depends on proper air-entrainment. It is also best to avoid flat surfaces where water is sure to pond and remain long enough to penetrate the concrete.

Destruction of reinforced concrete often results from impractical detailing, Ciolko says. For example, an architectural reveal will be specified to provide rustication strips on the facade of a building. However, the reveal cuts down the amount of concrete cover over the steel. If the design calls for 1½ inches of concrete cover, with ½-inch rustication strips formed into sections of the concrete, the steel has only 1 inch of protection left. That is "an invitation to corrosion if I ever saw one," Ciolko says.

Carbonation of concrete is a natural process by which the material's alkalinity is destroyed by the combination of water with carbon dioxide to form carbonic acid. It is not the presence of carbonation, however, that is important, but rather its degree. In high-quality, high-strength concrete, carbonation might penetrate ¼ inch into the surface over a period of 40 years, while in poor-quality concrete it could reach the level of steel reinforcement in fewer than 10 years. Carbonation, like chloride, destroys the passive film.

Aside from cracking the concrete, which leads to progressive deterioration, rusting weakens the rebar. A loss of more than 15 percent of cross-sectional area may indicate the need to replace steel reinforcement, says Ciolko. Repairing corroded metal is accomplished most easily in mild-steel reinforced concrete. The steel can be cleaned and new pieces of steel rebar tied to it before a new layer of concrete is applied. It is impossible, on the other hand, to splice into tensioned tendons. Instead, the whole tendon has to be replaced, requiring a great deal of specialized engineering analysis.

Untensioned steel reinforcement is not without its own problems. The reinforcing mesh that is often used in horizontal components, for example, should be placed at the top of the lower third of the concrete layer. However, experts say that more often than not it is quite a bit lower—too low to be of much use. In most cases workers have tramped on the fragile mesh, pushing it far down in the forming. Norman Scott, president of Consulting Engineers Group in Chicago, finds that this kind of concrete reinforcing system usually does not produce strengths any greater than unreinforced concrete. A better solution is to skip the mesh altogether and specify more control joints in plain concrete, he says.

The perfect repair for damaged reinforced concrete does not yet exist, but several fairly sucessful methods are available. Restoration materials are either cementitious or chemically modified with epoxy or latex. Ciolko has found high-quality cement the least expensive and most nearly foolproof, but it requires formwork; shotcrete can be easily spray-applied and it bonds well with the base concrete, but it must be put in place by skilled workers; hand-applied latex and polymer mortars provide good bonding and durability, but they can be very expensive and require special handling.

Deteriorated concrete that has not yet spalled can be sealed with an epoxy injection. Active cracks, which indicate unresolved changes in concrete, can successfully be filled with flexible, elastomeric materials.

Typical concrete facade repairs are costly. On a building of 10 stories or more, Ciolko says, concrete removal and restoration can cost \$40 to \$60 per square foot, or even more. Routing and sealing cracks will cost \$5 to \$10 per lineal foot, while sealing with epoxy injection can cost \$15 to \$25 for each lineal foot. Adding a coating is the cheapest repair, at about \$3 per square foot. Total cost of facade repairs could easily reach \$1 million for a moderate-size building.

Cathodic protection sometimes is specified for repair and also as an original construction procedure. In this process a sacrificial piece of metal is added to the steel reinforcement system, an electric current is induced, and corrosion occurs at the added metal (which acts like a cathode in a battery) and not at the reinforcement. One drawback is that all of the reinforcing steel must be in contact with itself, creating a single circuit, or isolated areas of deterioration can be initiated. This is a relatively expensive design, which to date the building industry has used only for parking facilities.

Repairing deteriorated concrete requires care on the part of the designer. Patching materials must be physically and chemically compatible with the base concrete, and they must not be subject to rapid deterioration under conditions that caused the original decay. Cracks may be an inherent part of concrete construction, but it is not necessary for steel corrosion immediately to follow. □

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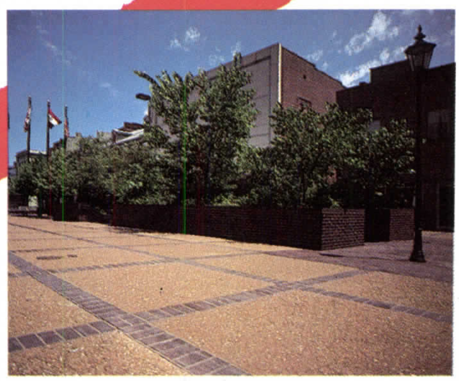

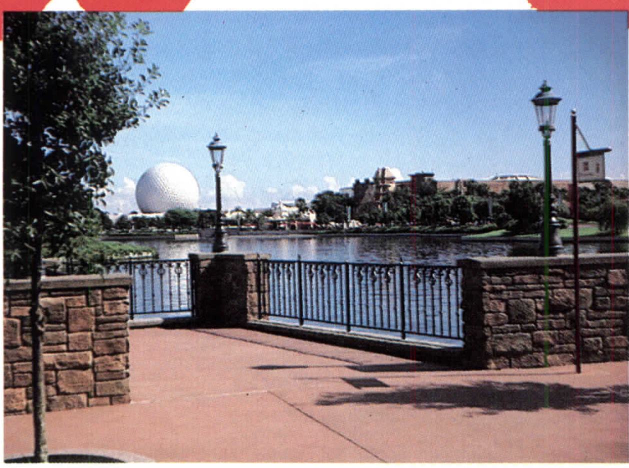

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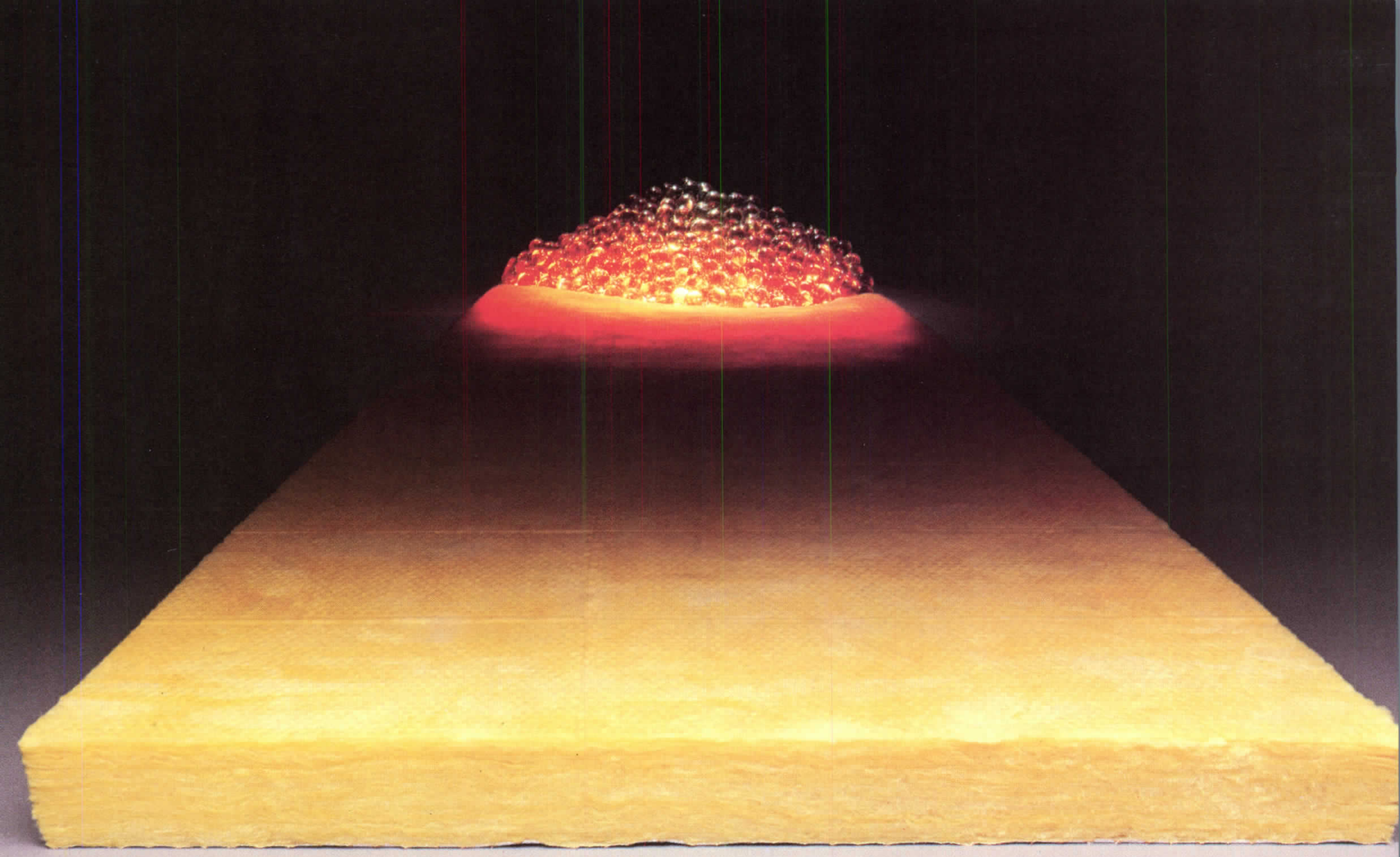

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The Nuts and Bolts of Nuts and Bolts

A crisis in quality of fasteners and some tips for dealing with it.
By Timothy B. McDonald

Recent testimony before a subcommittee of the U.S. House of Representatives identified poor-quality, substandard fasteners as a pervasive problem of the American construction industry. Manufacturers, engineers from testing laboratories, suppliers, salespersons, law enforcement officials, and contractors presented the problem to the subcommittee on oversight and investigation of the House energy and commerce committee last year. Much of the testimony focused on Grade 8 bolts—their procurement and use in the military and its related industries. Despite this narrow focus, the witnesses' testimony left no doubt that the problem extends far beyond the military/industrial complex and into the private sector. "No one knows the true extent of the problem . . . We do know the problem is massive," said subcommittee Chairman John Dingell (D-Mich.) in his opening statement.

Each witness brought to the hearings his or her particular insight into the primarily foreign fastener market that today supplies most of the 200 billion fasteners used in this country each year. Until 10 years ago, the U.S. fastener industry was dominated by domestic manufacturers and was largely self-regulating.

An important component of regulation has been the "certificate of compliance," issued by fastener manufacturers, which attests that the fasteners meet industry specifications and standards. The certificate is the customer's primary means of tracing the product back to its manufacturer. When the market was predominantly domestic, a customer was assured a short paperwork trail to the manufacturer. If, for instance, a contractor received a shipment of bolts marked A-490 but found them substandard or mismarked, the contractor simply contacted the manufacturer directly or a supplier who then contacted the manufacturer. If that manufacturer's bolts continued to be found substandard, or if the supplier persisted in substituting poor-quality bolts, the word quickly got around and contractors stopped buying from those unreliable sources.

But the paper trail no longer is clear, and it is difficult now to find someone to take responsibility for the quality of bolts. Today the trail often starts with a foreign manufacturer, usually in Japan, Korea, or Taiwan. That manufacturer will sell, for example, a large order of A-325 bolts to an importer. The importer in turn sells the bolts to a distributor, who often sells to a succession of vendors and suppliers, who may never see the bolts they are buying and selling. When the customer receives the bolts, he or she still gets a certificate of compliance, but it is no longer as reliable and helpful as it once was.

Along the trail, the original bolt lot can be broken into smaller and smaller lots, and these can be combined with lots from other manufacturers. The original bolts might have met all the required standards for bolts sold in the United States, but, once mixed with substandard, mismarked, or counterfeit bolts, the sound bolts cannot be identified. There are also distributors who knowingly falsify or forge paperwork.

Unfortunately, the addition of middlemen between the manufacturer and customer has increased the industry's reliance on certificates of compliance, according to Raymond and Ilene Plummer of Plummer Design and Testing, a metals testing and analysis firm in Toledo. They testified before the subcommittee last July: "More and more, no one wants to take the time, effort, expense, or the responsibility of checking for product integrity. It is commonly assumed that the manufacturer has produced a quality product, or the importer or distributor has checked the quality of their inventory before it is distributed to the end user." But, the Plummers added, the distributors often see themselves only as "the middlemen for the product and [hold that] the end user should be testing."

Among the horror stories related to the subcommittee was one concerning a nuclear power plant at Midland, Mich. Failure of a bolt holding the reactor vessel in place led to an investigation of the approximately 67,000 bolts already installed. Six thousand of these bolts were actually examined and tested, and from that sample it was estimated that 32,000 of the 67,000 bolts did not meet specifications.

Research on imported fasteners indicates that the problem encompasses substandard and/or counterfeited A-325 and A-490 bolts, as well as Grade 8 bolts. Several engineering consultants, building officials, and architects in the process of investigating failures of these bolts were unable to comment because of pending litigation. However, the severity of the problem makes itself clear, sometimes in devastating ways.

For example, when an earthquake struck Los Angeles last October, the U.S. Postal Service bulk mailing facility, still under construction, had several A-325 bolts shear and several steel members come crashing down. Subsequently, Paul L. Kelly, the Postal Service's senior project manager responsible for overall construction management on the 1,133,000-square-foot facility, appeared before the House subcommittee on oversight and investigations. Kelly, unlike some professionals in the private sector, was able to speak about substandard A-325 nuts and bolts. He brought to the hearings one of the bolts that had sheared during the earthquake.

"Major structural steel connections for the general mail facility and the vehicle maintenance facility require in excess of 80,000 fasteners with perhaps another 50,000 fasteners being required for other steel flange connections throughout the building," Kelly testified. "During the replacement of the nuts [which at first were thought to be the only substandard elements], several bolts were found to be substandard. . . . In our project, the problem with fasteners appears to center on a supplier who either knowingly or unknowingly provided false certifications. The problem was compounded by the failure of the contractor and subcontractor to insist on compliance through the submittal of certified and traceable original documentation prior to proceeding with installation of construction materials."

Types of fasteners

Architects should be aware of the criteria for classifying fasteners. The three- to five-year review process for setting these criteria involves tooling manufacturers, the Industrial Fasteners Institute, end users, government agencies, and major technical societies including the American Society of Mechanical Engineers, Society of Automotive Engineers, Standards Engineering Society, American Society for Testing and Materials, and American National Standards Institute. In buildings, the bolts most commonly used to connect structural components are classified by ASTM as A-307, Grade A; A-325; A-490; A-449; and A-354, Grade BD. Each has its own special properties and appropriate uses.

The ASTM A-307, Grade A bolt is a low-carbon steel fastener used primarily in light structures subject to static loads. Bolts manufactured as A-307s have a specified minimum tensile strength of 60 ksi. Their standard sizes start at ¼ inch in diameter and increase incrementally to four inches in diameter. The A-307, Grade A bolt is manufactured with a regular or a heavy hexagonal head, depending on its diameter. Although the bolt is marked, its corresponding nut often is not.

Unlike other structural bolts, the axial force exerted by the A-307 bolt assembly to prevent movement of the connecting members can vary substantially from bolt to bolt. Because the actual force in the bolt is not closely controlled, little friction resistance is developed, allowing the bolt to slip in bearing. This slippage causes shear stresses in the bolt as well as contact stresses at the points of bearing.

The A-325 bolt is the workhorse of the building industry; it was developed especially for use with high-strength steel members. These high-strength carbon steel bolts are heat-treated by quenching (cooling by immersion) and tempering and are manufactured in three types. Type 1 is made from a medium carbon steel, Type 2 from a low-carbon martensite steel; both can be galvanized. Type 3 is not galvanized because it is manufactured from a steel that is resistant to atmospheric corrosion.

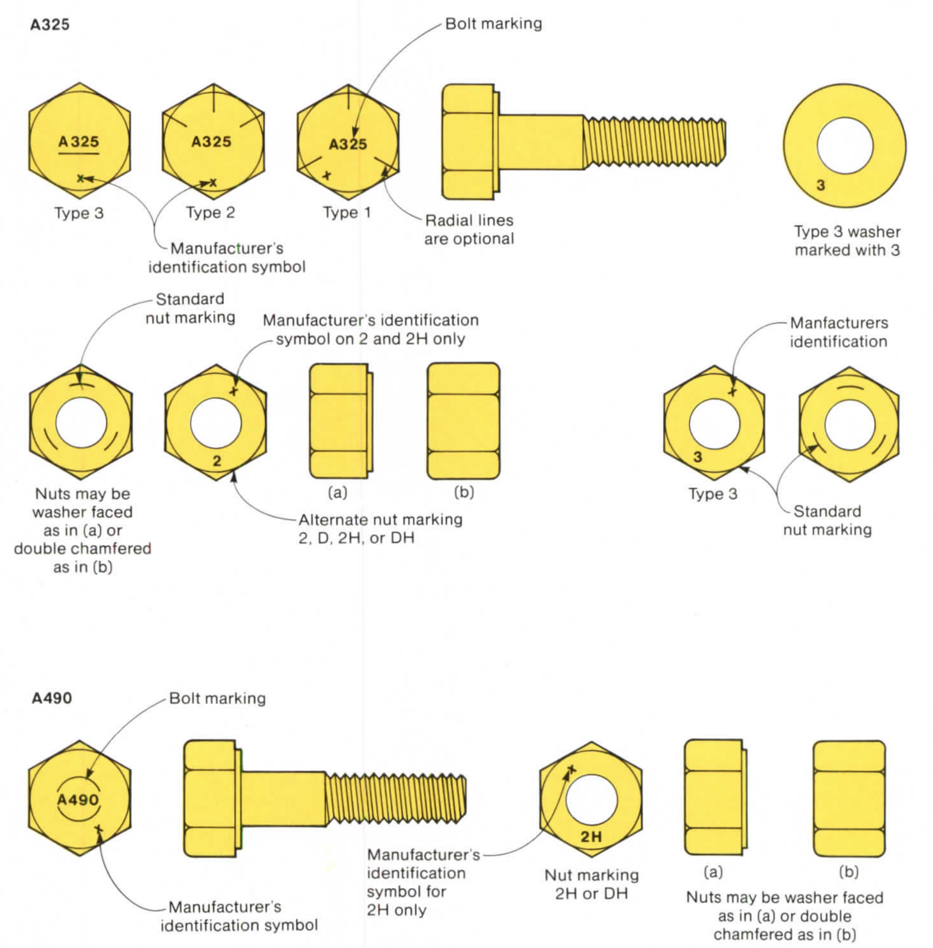
The available diameter range is the same for all three types, and specified minimum tensile strength varies by size, not by type of bolt. Bolts with a diameter of up to one inch must meet a specified minimum strength of 120 ksi; bolts with diameters of 1⅛ inch to 1½ inch must have a minimum strength of 150 ksi.

A-490 bolts also are available in three types, and, like the A-325 bolts, they range in diameter from ½ inch to 1½ inch. But unlike the A-325s, the A-490 bolts' specified minimum tensile strength does not vary according to bolt size—it is a constant 150 ksi. Like the A-325s, Type 1 A-490 bolts are made from alloyed steel, Type 2 from a low-carbon martensite steel, and Type 3 from a steel resistant to atmospheric corrosion. However, because of their susceptibility to stress-corrosion cracking and hydrogen embrittlement, A-490 bolts should not be galvanized. Additionally, while galvanizing has no effect on tensile or shear strength of the bolt, the zinc layer can cause the nut to seize when the bolt is tightened, resulting in premature torsional failure because the bolt can't move freely. Galvanized threads also add frictional resistance that can cause a considerable decrease in ductility and a reduction of maximum bolt tension.

ASTM specifications for A-449 and A-354 cover heavy-head, short-threaded structural bolts more than 1½ inch in diameter, as well as other types of fasteners and fastener components. Specifications for A-449 cover externally threaded fasteners, such as the interference body bolt, which have mechanical properties similar to the A-325 bolt. The interference body bolt meets the A-325 requirements for strength, and its ribbed shank prevents slippage between structural members by developing an interference fit once it is fastened in place.

The mechanical properties of A-354, Grade BD externally threaded fasteners are similar to those of A-490 bolts. One example is the swedge bolt. Also called a "swage" bolt, it has a pin-tail section with pulling grooves that engage a hydraulic driving tool that applies tensile force. During installation, when the swedge bolt's preload tensile capacity is reached and the collar is locked into the locking grooves, the pin-tail section breaks off, leaving the swedge bolt in proper tension.

Bolt markings for high-strength bolts



The swedge bolt and another device, a tension-control bolt, permit installation by one person. However, both are difficult to remove if alteration or dismantling is required.

A-325 and A-490 bolts, nuts, and some washers are marked for easy identification. The markings identify the bolt as either A-325 or A-490, its type (1, 2, or 3), and its manufacturer with a registered letter or symbol (see illustration). Until recently, this simple system was reliable, and what you saw was what you got. Today, however, it is a case of *caveat emptor*—the markings can be counterfeit and the bolts substandard.

Whether washers are a necessary component of bolt installation depends on the application. Traditionally, washers were required under the bolt head and the nut if the load had to be spread, or if a high clamping force had to be maintained, or simply to prevent galling (chafing away by friction) of the softer steel of structural members. With the introduction of the turn-of-the-nut method of tightening high-strength bolts, tests were conducted by the Research Council on Structural Connections to determine whether washers actually were necessary. The results indicated that washers weren't needed to prevent the minor relaxation due to high-stress concentrations under the bolt head or the nut, and that any galling that did take place was minor and did not prove detrimental to the static or fatigue strength of the joint. Therefore, the RCSC specifications no longer require washers under A-325 bolts. However, washers are still required with A-490 bolts when the connecting materials have a yield point of less than 40 ksi, to prevent galling of the connected parts.

Types of connections

A structural connection may be classified by how the fastener takes stress, be it in tension, shear, or a combination of the two. The behavior of a bolt under expected loading conditions is studied to determine the classification of the connection. For example, splices and gussets normally subject fasteners to shear. Beam-to-column connections commonly place fasteners in tension, but occasionally they place fasteners in both tension and shear.

Bolts in direct tension connections, or "slip-critical" connections, require a greater degree of installation control than bolts in shear, and they are installed to a preload stress equal to 70 percent of their specified tensile strength. An early method of producing proper tension during installation was torque control with a calibrated wrench. However, the torque-to-tension relationship achieved with the wrench proved less than accurate. Too many variables, including thread condition and lubrication, became part of the stress calibration, thereby reducing the tension applied to the bolt. But because connections traditionally were overdesigned, with more bolts per connection than necessary, the variation did not cause a noticeable problem. Today, however, structural designs demand closer tolerances and can't allow this erratic variation from bolt to bolt in a single connection.

The turn-of-the-nut method for producing proper preload stress requires that the bolt be brought up snug to the nut and then the nut turned a degree of rotation beyond snug. The degree of rotation varies with the diameter and length of the bolt; the definition of "snug" is constant.

For direct-tension, slip-critical connections where close tolerances are required, a direct-tension-indicator (DTI) washer is increasingly being used. Designed to meet ASTM F959-85 specifications, a DTI has a number of protrusions that compress when the bolt is tightened, leaving a measurable gap between the head and the washer. Inspection to determine whether the bolt is properly tightened then becomes simply a matter of measuring the gap. A properly designed DTI allows for greater accuracy of tension and can help prevent overtightening the bolts.

Imported DTIs often manifest the same problems of substandard quality and counterfeit certification as other fasteners. During the hearings last July of the House subcommittee on oversight and investigation, Jonathan Turner, president of J & M Turner Inc., a manufacturer of DTIs, testified that a company in Houston "lifted artwork from our literature and used it to produce their own literature to promote somebody else's product. We then discovered their product [DTIs] to be nonconforming." He explained the results of independent tests conducted on some of those DTIs: "On the ¾-inch and one-inch bolts, compression to the required gaps would result in bolts being dangerously overstretched. Some of the DTIs were beyond the ultimate tensile strength of the bolts. This not only could endanger the safety of the installer, but also could leave a steel connection in a condition that could promote structural failure due to delayed fracture of the fasteners. The ⅞-inch samples would produce bolts substantially undertensioned, which could cause slip-critical connections to slip into bearing, and, on connections subject to load reversals, the reversals of stress could be greater than the bolts were tensioned to, which could also in extreme cases cause bolt failure and endanger public safety."

Testing indicates that properly manufactured DTIs are quite precise. The architect should ascertain that the manufacturer of these washers is indeed a reliable source.

Until legislation is enacted to end importation and distribution of counterfeit and substandard fasteners, architects and engineers should be extremely careful about specifying fasteners and should follow up with careful field inspections and tests. Because the architect seldom specifies the structural fasteners in buildings, he or she should make sure the specifying engineer is aware of the problem. Immediate steps the architect and engineer can take include these:

- Specify by name or names those manufacturers or distributors from which the contractor should buy fasteners. This is one place where the "or equal" clause can get you into trouble.
- Insist that the contractor buy directly from the manufacturer or from a distributor that buys directly from a reliable manufacturer. The Industrial Fasteners Institute (IFI) is a good source of information about reliable manufacturers and distributors.
- Don't just specify the standards the fasteners must meet and leave it at that. Insist on an independent audit of the supplier's inventory of the particular product you are buying. Before any structural fastener goes into your building, make sure a sample (of several individual items) from each lot has been tested and meets all required specifications. Send the samples to the testing lab yourself. There is no way, short of chemical analysis, to distinguish a correctly marked bolt from one falsely marked, according to IFI.
- Demand proof-load testing on sample bolt and nut combinations. Think of the bolt, nut, and washer as a fastener system and require that it be tested as a system.

It would be reassuring if we knew the bolts already installed in the field meet our standards and specifications. It would also be reassuring if we knew they were all substandard; we could then proceed to replace them. But we don't know the quality of these bolts without testing each one.

For further information, contact the Industrial Fasteners Institute, 1505 East Ohio Building, Cleveland, Ohio 44114. □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The Behavior of Staggered Truss Systems

They achieve strength and stiffness with minimum steel. By Elena Marcheso Moreno

When economy is an issue, an advantage of the staggered truss system is its conservation of framing materials. Best suited to relatively uncomplicated building configurations with repetitive floor plans, the reduced weight of this structural system can provide substantial savings in apartment and multifamily residential buildings.

Developed at the Massachusetts Institute of Technology in the 1960s for United States Steel Corp., the concept of staggered trusses provides full-floor-height trusses in a building, spanning alternate end columns on alternate floors (see diagram). The inherent rigidity of the trusses provides both strength and stiffness to the structure with a minimum amount of steel.

The staggered truss is especially appropriate for tall, narrow structures and is a good consideration for residential and hotel buildings in dense urban areas. Because the staggered steel truss system is made up of story-high trusses that span the building width along each line of columns, staggered on alternate floors, every other floor has an identical plan. For example, the first, third and fifth floors would all have the same layout.

Despite the constraint that all odd (and all even) numbered floors have the same layout in terms of truss locations, adjoining floors can have very different schemes. Nor is the staggered truss system restricted to rectangular configurations. It can be applied as well to other building shapes—curvilinear, circular, and a combination of offset rectangles.

Spans of trusses are supported only at their ends by columns, which is the reason a narrow building is optimum for this system—perimeter columns can provide virtually all of the support necessary and completely eliminate the need for interior columns. The open space that results is two bays wide in the building's long direction.

Foundations are required only at the line of exterior columns, and simple strip footings are sufficient. In addition, the structural system allows for large clear-span areas at ground level where there are only exterior columns and no trusses, allowing for parking or other uses. If design considerations limit the use of trusses at roof level, posts and hangers may be used for support, although the trusses that support them will need heavier members than the other trusses.

Top and bottom chords in each truss are typically ASTM A36 steel in wide flange shapes. Supporting web members—the verticals, which are in compression, and the diagonals, which are in tension, in a Pratt truss—are smaller versions of the wide flange chord sections or angles. By reaching full floor height, the trusses are designed to resist gravity and transverse lateral loads.

Diagonal members are eliminated in isolated areas of the trusses to provide for corridors and openings to adjoining spaces. In theory the openings could be spaced close together or be unusually wide, but such practice would interfere with the economies of the staggered truss system. The larger the opening, the greater the required mass of the structural members, which then eliminates much of the savings of the lightweight structure. In a vierendeel panel, produced when the diagonals of a Pratt truss are eliminated for corridors, shear is carried by the chord members, which indicates that openings should be kept as close as possible to the center of the truss where shear forces are lowest. A minimum of smaller openings, such as doorways, can be accommodated where necessary, but developers of the system caution against placing any openings too close to the ends of the span.

Stabilizing a building about its short axis is generally the most difficult task. Therefore it is difficult to eliminate columns in conventional framing, but in this system the story-high trusses and their connecting floor system solve the problem. Research indicates that a lateral load at a truss-free point on a floor will be transferred by the floor (acting as a diaphragm) to a truss on the adjacent column line. Wind loading in the longitudinal direction can be resisted by bracing bays or by another means appropriate to the architectural treatment of exterior walls.

Gravity loads are best resisted by floors that have simple spans between trusses or else are continuous for two bays. Each floor span should be supported by the top chord of a truss below it and the bottom chord of a second truss above it. In effect, the entire floor performs as a deep beam, so it must resist in-plane loading and deformations.

A number of floor systems can be used with the staggered truss system, but the most common floor is precast concrete planks topped with lightweight, reinforced concrete. Weld plates cast in the planks or connectors on the chords transfer shear from the trusses to the floor. Another good choice for a floor system is lightweight concrete on a long-span composite steel deck. In this case, welding the deck to the trusses transfers shear forces.

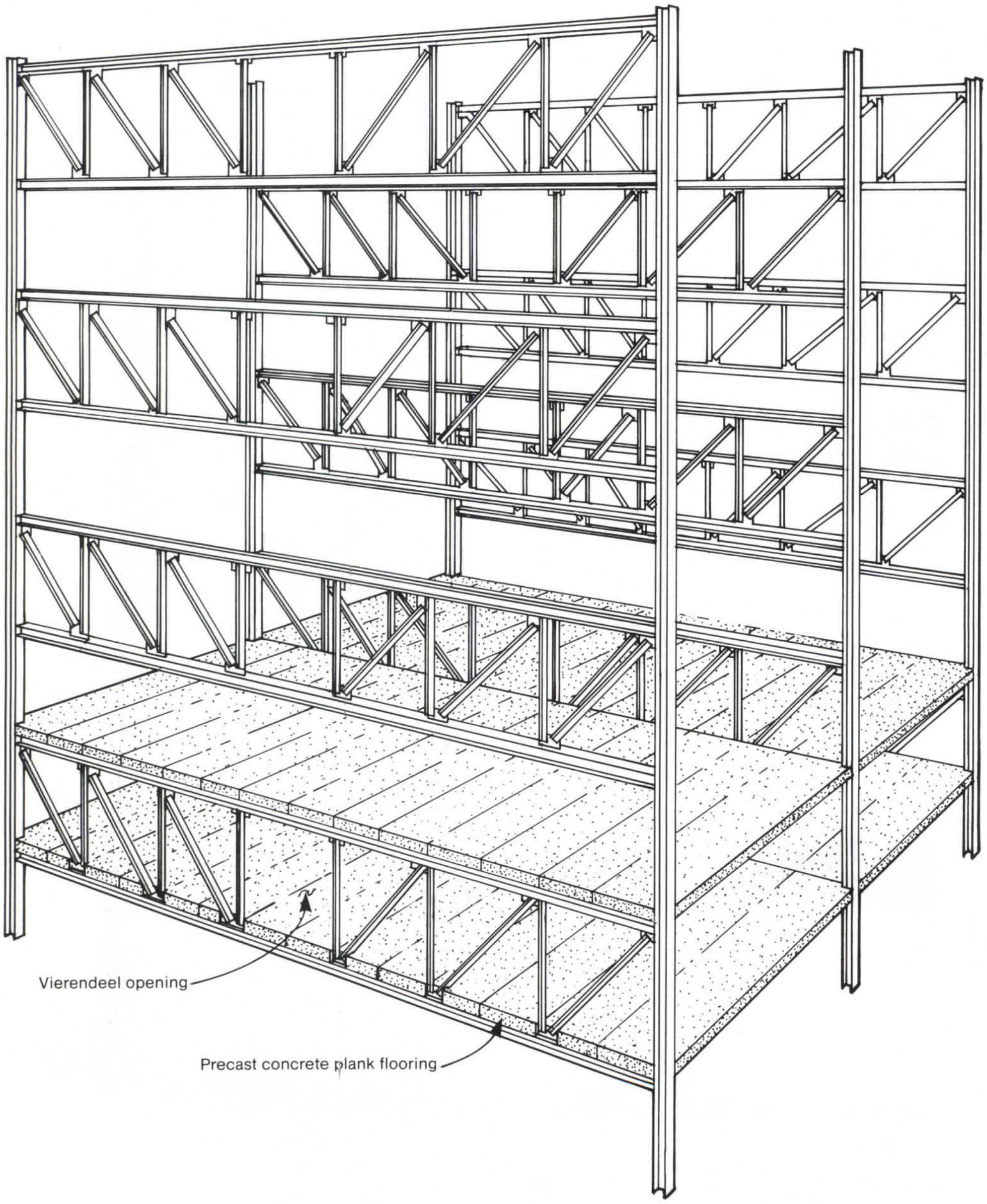
The inherent modularity of the staggered truss system suggests that spacing between trusses (and columns) should allow for a complete dwelling unit. However, it is possible to vary the distance between trusses to arrange units of different sizes on the same floor by varying column spacing.

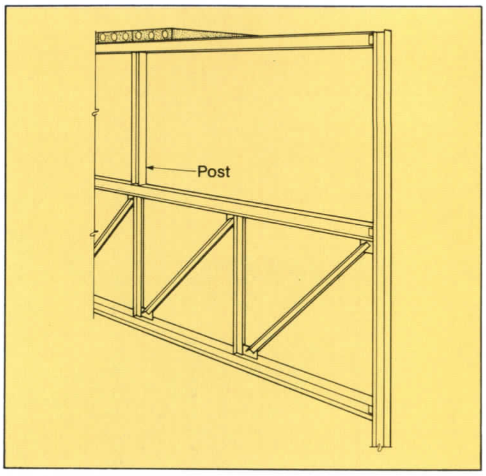
Trusses are generally enclosed in walls or partitions that separate apartments or hotel rooms, so the whole wall assembly must meet building code requirements in addition to the structural fire-resistance requirements for the truss. Fire protection is achieved by enclosing trusses in a fire-resistive envelope, for instance, drywall mounted on cold-formed steel studs and runners.

Integration of HVAC and electrical systems with individual units can be accomplished through corridors where ceilings can be lower and where truss diagonals have already been removed.

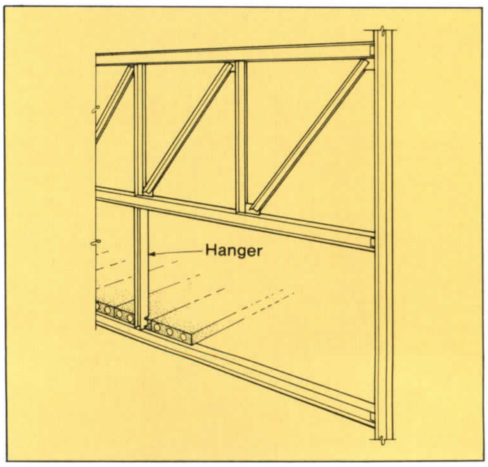
The framing system has been shown to be reliable under seismic conditions, but floor slab cracks perpendicular to the trusses are likely. To avoid this problem, control joints should be detailed at locations where cracking is expected. To further protect against earthquake damage, truss chords should be continuous across three panels wherever there is an opening.

Significant savings in materials are possible because the staggered truss system





Left, Pratt trusses spanning between columns in long, narrow buildings eliminate the need for interior columns. Staggering the trusses to alternate columns on each floor provides two-bay-wide areas. Posts (above) and hangers (below) support the roof and second floor, respectively.



uses 20 percent to 40 percent less steel than conventional column and beam framing. The system is also much lighter than reinforced concrete or wall-bearing construction and is a good choice in circumstances where the extensive reinforcement required by inferior subsoil could drive up foundation costs for other structural systems.

To achieve the most economical use of a staggered truss system, some limitations must be considered. Building height is likely the most important limitation. The staggered truss system is well suited to tall buildings because of its ability to resist lateral loads. But, as height declines, so do the potential lateral loads the building must withstand. Studies indicate that the break-even point is eight to 10 floors. Also, trusses tend to be more expensive to produce than beams, so longer trusses, and thus fewer of them, are cost effective. The system is recommended for buildings 58 feet or wider. A large degree of economy is sacrificed when trusses span buildings that are narrower than 45 feet.

Most high-rise residential and hotel building sites are in urban areas where there are sufficient numbers of ironworkers available to erect the staggered framing at costs competitive with other systems. Particularly when used in combination with precast concrete floor planks and wall spandrels, eliminating the need for most concrete, masonry, or plaster work, a building with a staggered truss framing system can be erected completely by dry trades. □

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Software Programs for Structural Design

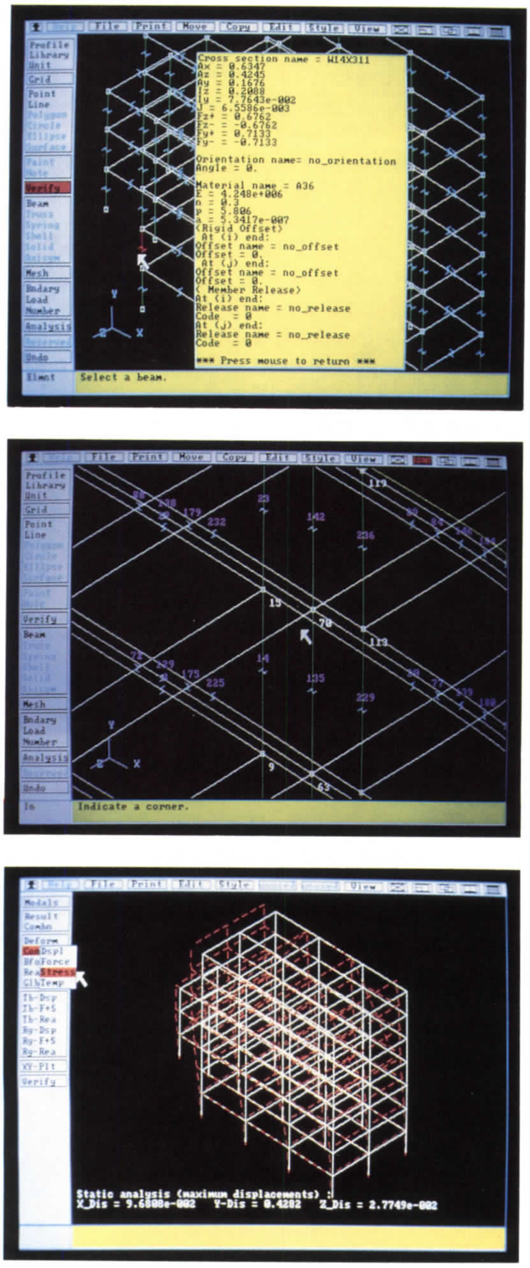
Producing visual aids and calculations concurrently. By Oliver R. Witte

Architectural engineering traditionally has been a number-crunching operation requiring the designer to form a mental picture of the results of the calculations. When computers became available, the number crunching was moved to the screen but the picture remained in the architect's head. The first iterations of microcomputer structural design and analysis programs eased for the architect some of the pain of numerical calculation (including calculus, the "c-word" to many visually oriented designers) but generally required the user to follow a highly structured sequence of steps in order to obtain the desired value. If an input changed, it was back to square one and a repeat of all the calculations to achieve the end result. Spread sheets and iterative procedures are an improvement and serve as an intermediate development, but they still require supplemental sketches of frames and moment and shear diagrams drawn on trace for the user to "see" calculations in an architectural vocabulary. Today, available microcomputer programs enable the architect to produce these structural visual aids concurrently with their calculations, sometimes at the touch of a single key.

Architects may use these new software programs for preliminary structural design, for analysis of selected structural elements or systems, or for design optimization. In all three processes, they can iterate quickly among designs using different sizes of members. Where most medium-sized and large buildings are structurally designed by engineers, the programs provide a quick way for an architect to check the engineer's calculations. They also can be used to ascertain code compliance.

One example of a new program that displays the structural picture on the computer screen and permits the user to make changes graphically has been introduced by Fujitsu America, San Jose, Calif. The program, Engineering Library for Modeling (ELM), performs finite-element analysis on a desktop computer. It shows the designer not only where a structure will fail but how. ELM can simulate earthquake conditions to prove a structure's integrity.

Finite-element analysis (FEA) programs also are available on mainframe computers, but they are much more expensive. ELM costs $495 for the 2D version and



Fujitsu America's ELM software displays input conditions (top), color-coded elements and loads (middle), and, in red, a structure's response to loads (bottom).

$3,990 for the 3D version. The disadvantage of ELM is the time required to perform the calculations on a personal computer. What would take five minutes on a mainframe might require more than an hour on a personal computer, depending on the complexity of the structure.

"Although CADD has been around for a few years, FEA is just coming into widespread use," said George Tripsha Jr., marketing director for Fujitsu America. "Our FEA acts like a graphics package. We can prove visually that the structure will be sound before going into drafting. ELM is like a front end to CADD, making sure you are using the right size beams with the right strength before doing a lot of other work. It saves time and prevents overengineering."

Tripsha emphasizes that ELM is an analysis program, not a CADD program, although it does permit the designer to resize and replace beams that fail during the computerized simulation.

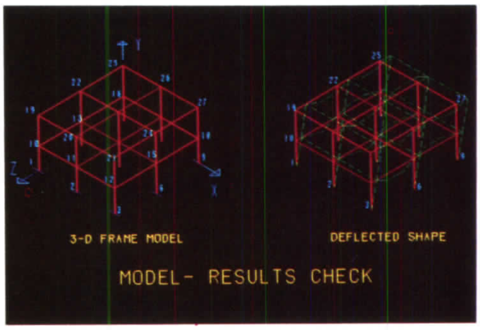
ELM illustrates how communication between architect and structural engineer can be facilitated. The engineer can show the architect the structural effect of a design decision. Or, the architect can use the program for preliminary review of a design before sending it to the structural engineering consultant.

Another visual structure analysis program is SCADA, from American Computers & Engineers, Los Angeles. SCADA is a finite-element analysis and design program that solves linear and nonlinear problems, including 2D and 3D graphic representations. SCADA is actually a family of software packages that allow the purchaser to build a modular system of capabilities to suit individual needs (with total cost approaching $30,000).

Although some of the subsystem software is nonarchitectural, most programs are applicable to selection of structural elements and analysis of structural diagrams.

The base program, SCADA/A, is a complete, stand-alone, 3D frame analysis program that is capable of handling any size of structure. The program calculates trapezoidal or concentrated loading at any angle, forced displacement and differential settlement, weight effects, and linear and angular acceleration in any direction. Among its other features is a library of steel sections. Base cost is $2,800.

Of the 16 other add-on options, those applicable to structural problem solving include features such as graphically displayed deformed and undeformed shapes;



SCADA permits analysis and 3D view of a frame's deflection under a set load.

moment and shear diagram plots; time history plots for displacement, velocity, acceleration, force, and stress; triangular and quadrilateral plate and shell element analysis; 2D elasticity analysis of axisymmetric structures; 3D elasticity analysis of regular and triangular prisms and tetrahedrons; checking and designing of 2D and 3D steel or concrete frame and truss elements for adherence to code; concrete flat slab design, regardless of geometry and placement of columns, openings, or load distributions; concrete shear wall design; and a 3D model generator in which the user defines a geometry and the computer creates a finite-element mesh on that geometry, including nodal coordinates and element connectivity.

SCADA is supported by VAX, Sun, Apollo, Cromemco, IBM-AT and compatibles, Calcomp, and the manufacturer's own workstation.

The instrumental influence of spread sheets on programs for graphic structural design is readily apparent in the products of Enercalc Engineering Software, Newport Beach, Calif. The company offers a library of 40 structural engineering programs, including aids for design and analysis of square footings, composite beams, circular concrete columns, tilt-up walls, glued-laminated beams, and masonry walls. All of the programs work with the user input of Lotus 1-2-3 or Symphony, popular spread sheet programs; some, where it's appropriate, provide moment, shear, force, pressure, and other diagrams as a built-in feature. The spread sheet format allows data to be entered and easily changed with a nonsequential, fill-in-the-blank approach. Analysis for an entire design or redesign can then be accomplished simply by striking the "calculate" key. The library of 40 programs, which are designed for analysis of low- and mid-rise commercial, industrial, and residential structures, is available for $845; individual programs may also be purchased.

Enercalc's spread-sheet-based programs have evolved into a newly released program called FastFrame, which allows two-dimensional finite-element analysis employing Lotus 1-2-3 as a user interface. Its program could have special appeal to architects because it offers full-screen static and deflected structure plots at the touch of a button. Beams shown on the screen are color-coded according to stress levels, as defined by the American Institute of Steel Construction's code provisions. A "zoom" window allows exploded views of large structural frames.

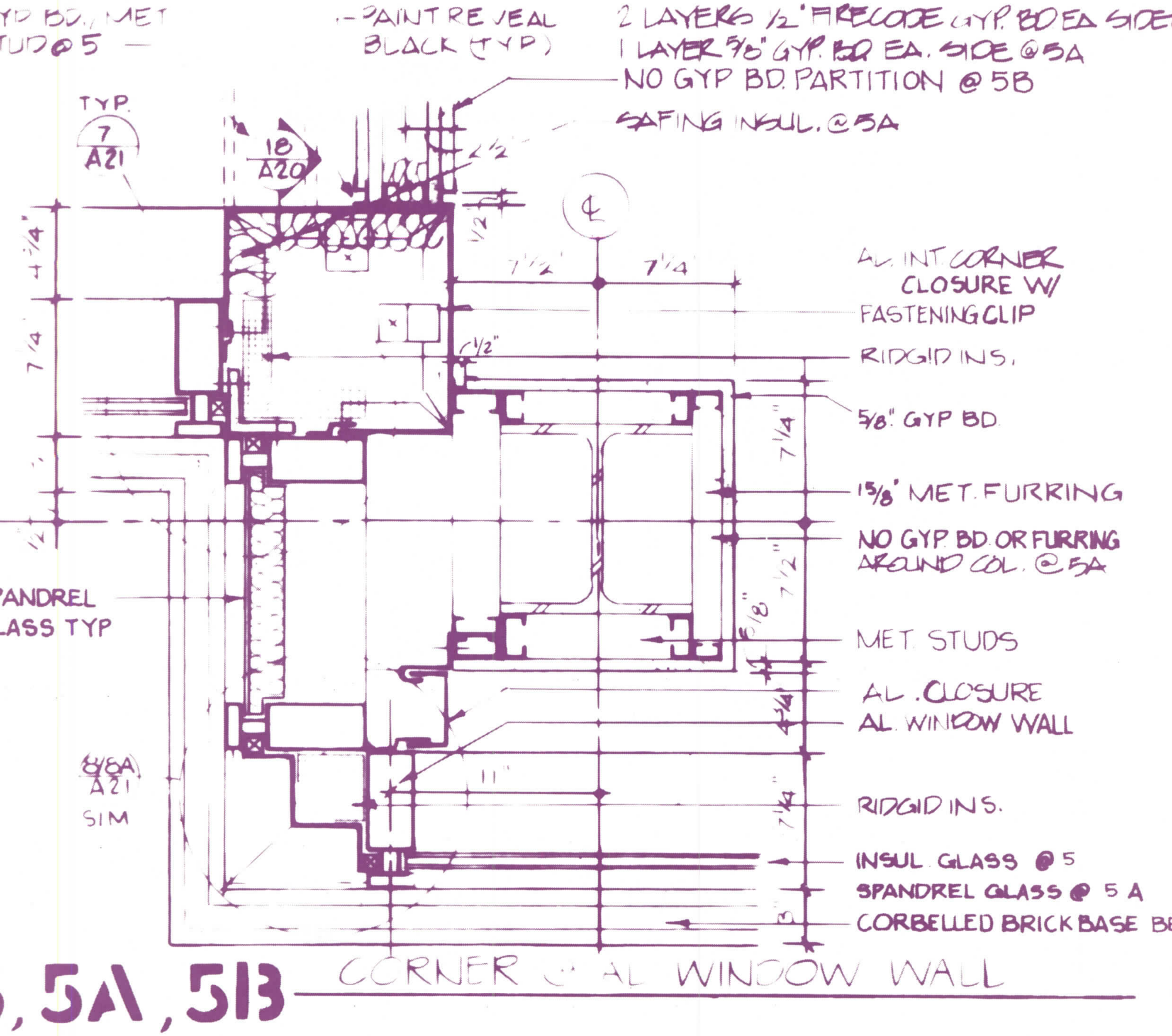
Placing the cursor on any particular beam in the frame and touching another button shows the beam's stress analysis at 1/250th points, by graphically depicting moment, shear, deflection, and AISC unity check diagrams. The user can also view an exploded diagram of each.

If the user so chooses, he or she can perform AISC unity checks for each beam during the frame analysis, performed at 1/5th points. A subsequent plot can be made to show all the beams color-coded according to the stress level on systems.

FastFrame also allows automatic selection of steel sections for individual beams or for the entire frame, according to AISC specifications. The user can define selection criteria for deflection ratio, maximum and minimum depth, maximum unity value, and section type. Approximately 3,000 steel sections from the AISC handbook, and their properties, can be scrolled to aid in selection.

FastFrame includes a special menu system through which a mouse can be employed to move quickly around the work sheet on the screen. The mouse can also be used with the structural plots to create zoom windows. Enercalc plans to expand the graphics portion of FastFrame to enable 3D analysis, which will include added stress elements, dynamic analysis, and second-order analysis.

An annotated source of structural software programs is available from the American Consulting Engineers Council, based in Washington, D.C., as part of its "Database for Engineers and Architects to Locate and Utilize Software" (DAEDALUS) program. The 273-page, $25 structural section reviews more than 200 software packages. However, the majority of the software is written to support engineering calculations without graphic backup and is intended for minicomputers rather than the more affordable but less powerful personal computers. □



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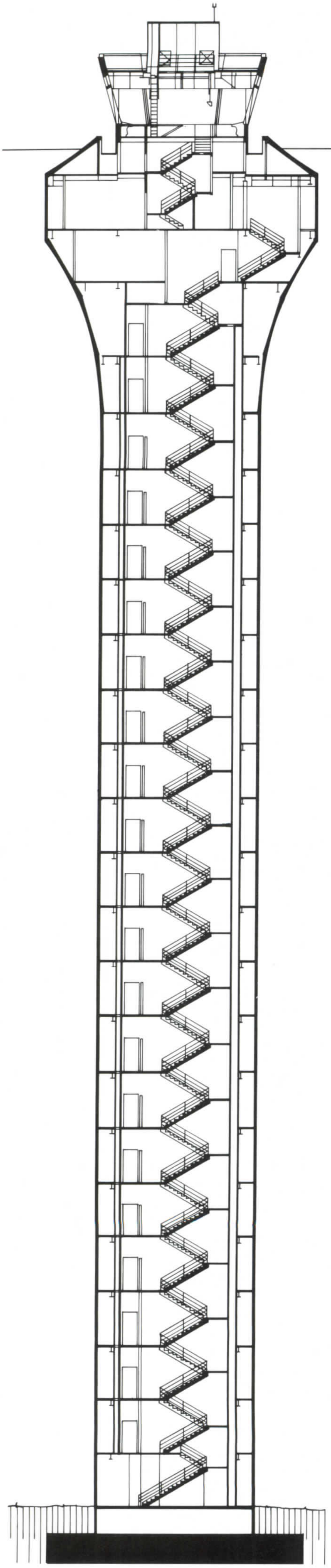


Prototype Control Tower Uses New Connection Device

A 325-foot prototype air traffic control tower for Houston Airport, recently developed for the Federal Aviation Administration by the Leo A. Daly Co. of Omaha, uses a relatively new connection that joins two precast concrete panels as rigidly as if they were a single slab. The device, called a splice sleeve, enables the load-bearing walls of the tower to withstand forces created by wind velocities of 86 miles per hour or higher. The splice sleeves enable the tower to be constructed of precast, prestressed concrete, saving construction time and money over traditional poured-in-place or steel construction.

The lower portion of the prototype tower was constructed of structural precast, prestressed concrete panels to a level of 240 feet. It is topped by a 60-foot, steel-frame structure clad with architectural precast panels. The tower is capped by a 25-foot-square cab with eight-sided windows. There are no openings in the tower shaft, other than louvers for mechanical and electrical requirements. A walkway surrounds the cab so that windows can be cleaned. Elevators and a staircase serve the cab.

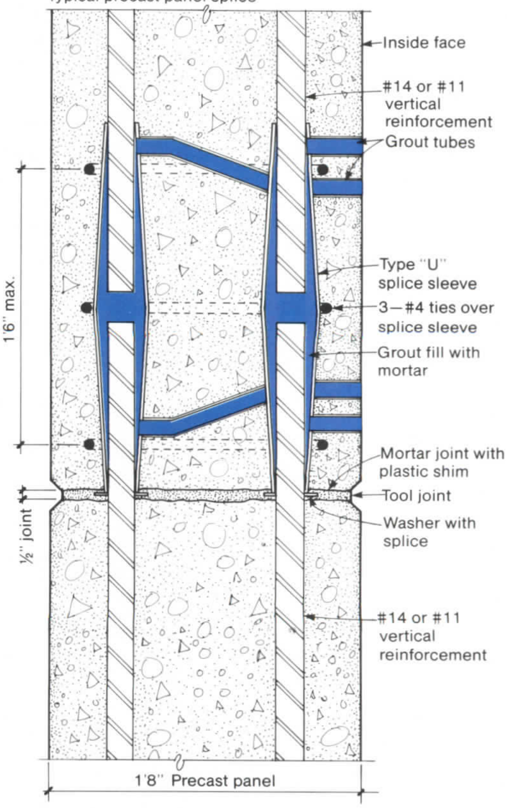
The shaft's corner panels, mitered at 45 degrees, reduce the overall effect of wind loading. The tower is specially designed to resist the dynamic effects of "vortex shedding," which produces strong crosswind forces. These forces create structural stresses on the panels that the sleeve-joined rebars help combat.

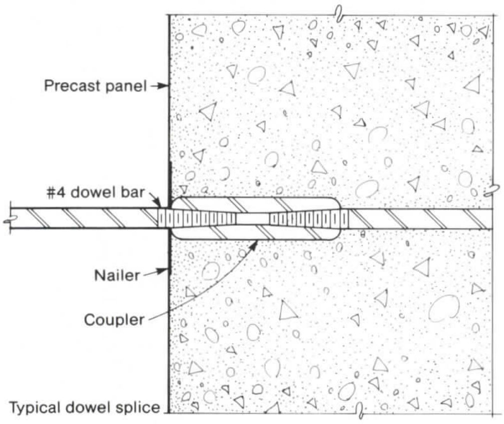
To form the joint, tubelike sleeves are cast at the plant in one end of each of the precast concrete panels. Steel reinforcing bars in each panel project from the sleeveless end of the panel only. The bars projecting from one panel slip into the sleeves cast in the next panel.

On site, two vertical panels are held in position, one on top of the other, and the sleeve is filled with high-strength, expandable grout. Grouting of the sleeve is done either by pouring the grout into the sleeve, when it is located in the top of a precast panel, or by pressure-grouting the sleeve, when it is located in the bottom of a panel. The grout expands and hardens, ultimately reaching 10,000 psi, and locks the reinforcing bars inside the sleeve, simulating the structural strength of one continuous bar.

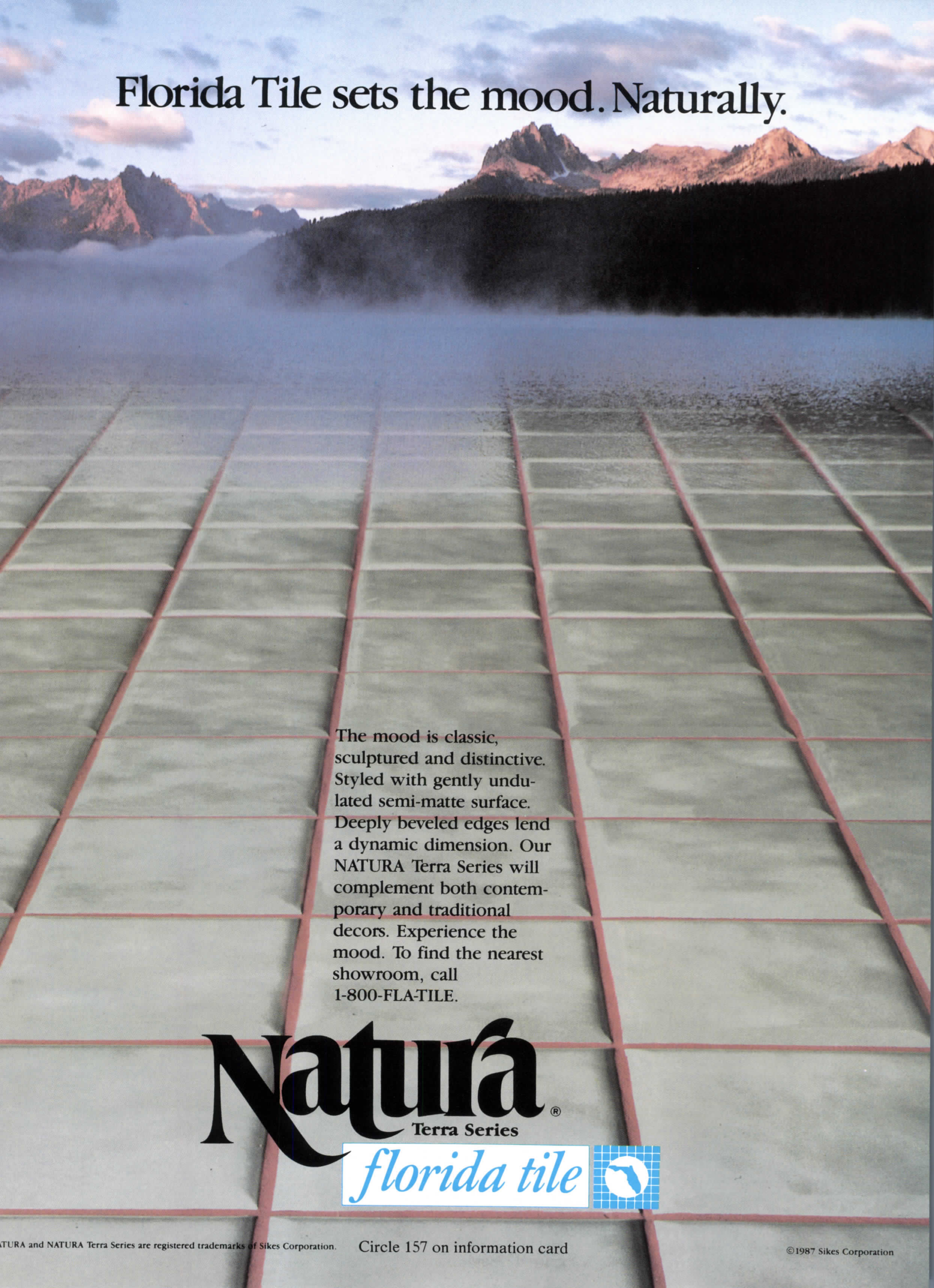
Unlike many other devices used to connect reinforcing bars in cast-in-place concrete, the sleeve can be cast directly in the precast element at the plant. Because it is completely covered by concrete, the connection is weatherproof and fireproof and requires no subsequent patching, pouring in, or covering by fireproof materials. Patch pockets to match the architectural finish on the precast concrete become unnecessary. *continued on page 158*

Typical precast panel splice





Typical dowel splice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Products *from page 155*

In the Houston tower, more than 4,000 of the splice sleeves will join the 300 No. 14 and No. 11 rebars that strengthen the structure. The structural concrete panels measure 11x12 feet and are 20 inches thick. The splice develops at least 125 percent of specified rebar yield strength, fulfilling both American Concrete Institute and Uniform Building Code requirements for connection strength.

The sleeve device was invented by Alfred A. Yee of the Daly Co. and was first used in 1970 for connecting integrally placed beam-column units called "column trees" in a 38-story hotel in Honolulu. The patent rights to the connector were subsequently acquired by a Japanese firm. Japanese code authorities, because of the considerable seismic loads on buildings in their country, required extensive testing of the connector. These tests, modified for North American reinforcing steels, eventually were used successfully to obtain code acceptance in this country by the International Council of Building Officials and the Council of American Building Officials. The U.S. distributor of the device reports that more than 50 American firms have ordered the splice sleeve since its introduction to the U.S. market in 1970.

The Houston tower is the first built of the 325-foot-tall "major-activity-level" prototype tower design by the Daly Co., under contract with the FAA. A similar tower of equal height, also using the new splice sleeve design, was completed in Cleveland earlier this year. Daly also has designed major-activity-level tower prototypes for heights of 90, 120, 150, and 180 feet, all supporting 525-square-foot cabs. A prototype using a structural steel frame with nonstructural precast panels meets Seismic Zone 4 requirements, and a 250-foot-tall version of it is on the boards for Los Angeles International Airport. Five intermediate-activity prototypes are 61, 77, 93, 109, and 125 feet tall, and low-activity towers range from 45 to 95 feet.

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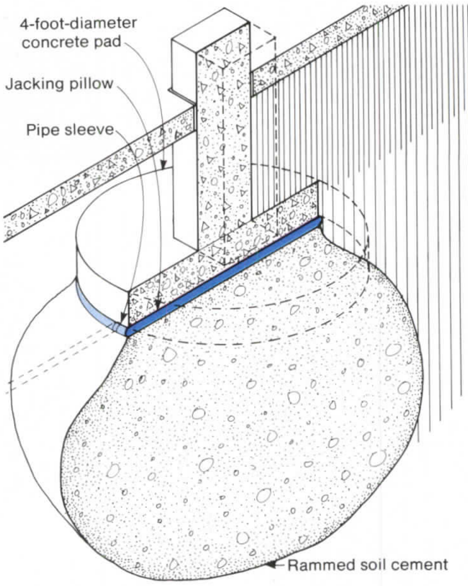
Prototype for a Grouted Pillow Foundation Support

Buildings set on unstable soil have a new foundation type on which to rest easy—pillows. The prototype for a grouted pillow foundation support was built in Livonia, Mich., where plans to construct a $3.5 million, one-story medical mall threatened to be hampered by the condition of the chosen site, an old gravel pit filled 60 feet deep with concrete rubble, sand, and organic soil.

Normally, Soils and Materials Engineers of Livonia, the project's geotechnical consultant, would recommend caissons on steel piles with a structural floor slab as a foundation on this type of site. But for the 44,000-square-foot Livonia Building this method seemed prohibitively difficult and expensive, and large slabs of concrete rubble were likely to force pile relocation or slab removal, significantly increasing project downtime. Therefore, the consultants recommended an innovative, jackable foundation system that includes dynamically compacted soil-cement footing and grout-filled pillows.



The system, developed by Wallace H. Baker, president of Geobase Inc., Crofton, Md., first compacts the soil in selected places by dropping weights on the spots where the columns will be located and on spots halfway between each pair of columns. These depressed areas then are filled with a cement and sand mixture. Next, an inflatable jacking pillow, with woven geotextile fabric outside (for strength) and a rubber bladder inside (for impermeability), is placed on each hard spot, and a 48-inch-diameter concrete pad is cast on top to form footings for the slab.

As a grouting specialist and a foundation engineer, Baker came up with the grout pillow concept simply by combining his areas of expertise, he said. The system employs a series of pillows (in this case, five) fitted with check valves, which are attached to buried pipe sleeves. The pillows, once in place between compacted soil and the building slab, can be inflated as needed with grout pumped through pipes that are slipped into the pipe sleeves. This method keeps the feeder sleeves free of grout, which means a pillow can be grouted more than once, if necessary. Part of the warranty offered with the system to the building owner is a survey program that monitors building plumb. If an area begins to sink, the contractor comes back, sets up a grout pump, and corrects the deviation right there on the spot. The pillows can generate 36 to 40 kips of lifting force, according to Baker.

Though the Livonia project was the first one to use this method (Baker conducted his own testing of the pillow concept before using it in Livonia), he is already planning a similar application with a water tower. The method should be effective for just about any small, simple structure.

Frank Jonna, executive vice president for the project's general contractor, Jonna Construction Co. of Farmington Hills, Mich., estimates that using a customized supported slab system saved about $100,000 on the foundation alone.

GeoBase Inc. Foundation Systems
1654 Crofton Blvd., Suite 17
Crofton, Md. 21114
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Nondestructive System of Reinforcing Existing Walls

David C. Breiholz, a Lomita, Calif., civil engineer, has developed a nondestructive method for bringing unreinforced masonry walls into compliance with seismic code requirements. In conjunction with engineers Edward O'Connor and Joseph Plecnik, Breiholz developed the CenterCore strengthening system, which allows placement of reinforcement in existing masonry walls. The system, first tested in 1984, places reinforced grouted cores down the center of an existing wall. It is different from conventional methods of restoration, such as sawtooth rib or Gunite applications, because it causes minimal site disturbance.

The concept of restoring buildings by adding reinforcement to masonry is particularly pertinent in California, where Breiholz estimates that 30,000 unreinforced structures survive. In 1934, the California Field Act required earthquake reinforcement in new buildings, and, as earthquake codes become increasingly stringent, more and more California municipalities require either demolition or repair of unreinforced buildings constructed before 1934.

The major structural concern with unreinforced masonry walls is that they lack the ductility to resist dynamic seismic loads and consequently may collapse during an earthquake. A reinforced wall exhibits a higher degree of flexibility during ground shaking and usually can restore itself after tremors. Reinforcement strengthens the bearing wall to carry in-plane shear and, in a less predictable way, to resist out-of-plane bending. The concept of placing reinforcing steel in an existing masonry wall is not new; the trick is to do it in a nondestructive manner.

Breiholz offers the CenterCore technology through David C. Breiholz & Co. Inc., his engineering and architectural firm. The cores, or vertical holes, that are the heart of the CenterCore system extend continuously from the top of a previously unreinforced wall to the bottom of the wall's footing. Achieved through oil-well drilling techniques, the cores range from four to six inches in diameter.

After cleaning the drilled cores, workers place a No. 6 or No. 7 steel reinforc-

continued on page 160

Products *from page 158*

ing bar vertically in each hole and pump a polyester/sand grout from the top of the wall to the bottom of the core. The interaction of this composite of grout mixture and surrounding masonry is the key to the CenterCore system's success because the grout migrates into cracks and openings in the surrounding masonry—it "grabs" a lot of the existing brick and mortar, creating in effect a series of columns that can withstand bending and other earthquake forces. At the same time, the cores confine the masonry that doesn't receive grouting.

Along the strengthened wall, roof/wall and floor/wall anchors are attached to the necessary points. Because workers carry out the reinforcement operation from the roof, building occupancy is disrupted minimally if at all.

CenterCore work is now under way on the 74-year-old First Congregational Church in Long Beach, Calif. The 44,000-square-foot church is composed of two- and three-story sections with separate basements and a 105-foot-tall, steel-framed, masonry-infilled bell tower. The separate pieces added up to a difficult configuration for placement of reinforcement. But luckily the church had retained drawings for repair work undertaken just after a 1933 earthquake. The drawings, supplemented with field measurements, helped the architects determine which areas of the building performed without damage in 1933, where previous weaknesses were, and where future distress might occur.

Workers core a masonry wall prior to placing and grouting rebar for seismic compliance.

By means of a coring rig, cores up to 55 feet deep were taken from the top of the sloping parapet wall down to the bottom of the footings or into the reinforced concrete basement wall. Once the rig was in place, the coring rate averaged about an inch per minute. In all, construction workers cored out a total of 4,400 linear feet. The workers used both wet and dry coring on the church walls. Wet coring is faster and produces a cleaner core but can be employed only where water flow can be controlled. The contractors used pilot holes to control the water and removed it as the coring progressed.

The architects specified a relatively inexpensive polyester grout mix of sand and polyester, 2:1 by volume, as the optimum effective grout for the church, and, based on tests for flexure, chose to use No. 6 rebars.

Most of the coring activity, including removal of the extracted masonry cores, took place on the roof. After the CenterCore phase of the work was complete, the clay tile roofing was removed for placement of a new plywood diaphragm over the roof areas where existing sheathing or ceilings were judged to be ineffective diaphragms. The last structural phase of the work was to anchor the diaphragms to the strengthened walls.

The CenterCore technology, developed with the aid of a National Science Foundation grant, was field-tested extensively on a building in Long Beach that was scheduled for demolition prior to the 1984 Summer Olympics. The testing measured in-plane shear and out-of-plane bending using a variety of grouts while varying the reinforcing steel and the core diameter.

continued on page 163

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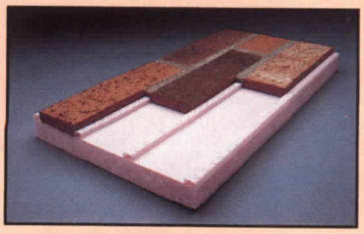

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Products *from page 160*

The test results were significantly good for polyester and epoxy grouts, including the mix that was subsequently used in the First Congregational Church. Demolition of the tested wall sections revealed a migration of grout far beyond the vicinity of the core, and far beyond the expectations of the architects. They concluded that the high test values for both in-plane shear and out-of-plane bending resulted from the grout migration together with its excellent bond capacity that developed a fairly large and somewhat uniform composite section for the full height of the grouted core. The test results prompted Long Beach city officials to approve Center-Core's use on a building-by-building basis. The technology also has been presented to other municipalities for their approval.

Further unanticipated testing came on Oct. 1, 1987, as a small earthquake struck before the First Congregational Church job was completed. "Even in its relatively weakened condition, the structure performed better than we anticipated," said Breiholz & Co.'s Cameron Duncan.

David C. Breiholz & Co. Inc.
1852 Lomita Blvd.
Lomita, Calif. 90717
(213) 530-3050

NEW AND NOTEWORTHY

Hinged Joining Purlin System

A hinged joining purlin system offers proper glass support and alignment with the purlins located at segmented joints in rafters, such as in segmented barrel-vault skylights. With hinged joining purlins, the glazing platforms are always parallel to the glass. The purlin system will accommodate inside joint angles from 90 to 225 degrees (both inside and outside corners), and can be used with dry, wet, and structural silicone glazing methods. Gutters on the upper and lower sides of the purlins capture any condensation and transfer it to the rafter condensation gutters at each end of the purlin.

Regal Manufacturing Co., division of Arcorp Inc.
Circle 241 on information card

Glass Block Connectors

Accu-Speed glass block connectors facilitate the erection of curved or straight glass block panels and ensure uniform alignment and spacing. Structural rigidity and reinforcement are provided through their shape, which is like a plus sign.

The connectors transfer the weight of the top course directly to the course below so the blocks don't bear down on the mortar. The high-density polyethylene connectors are available in two configurations for straight or curved panels. The connectors facilitate joint sizes of approximately ¼ inch on thin-line block and ⅝ inch on regular-size block.

Mayer Equity Inc.
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(202) 626-7300

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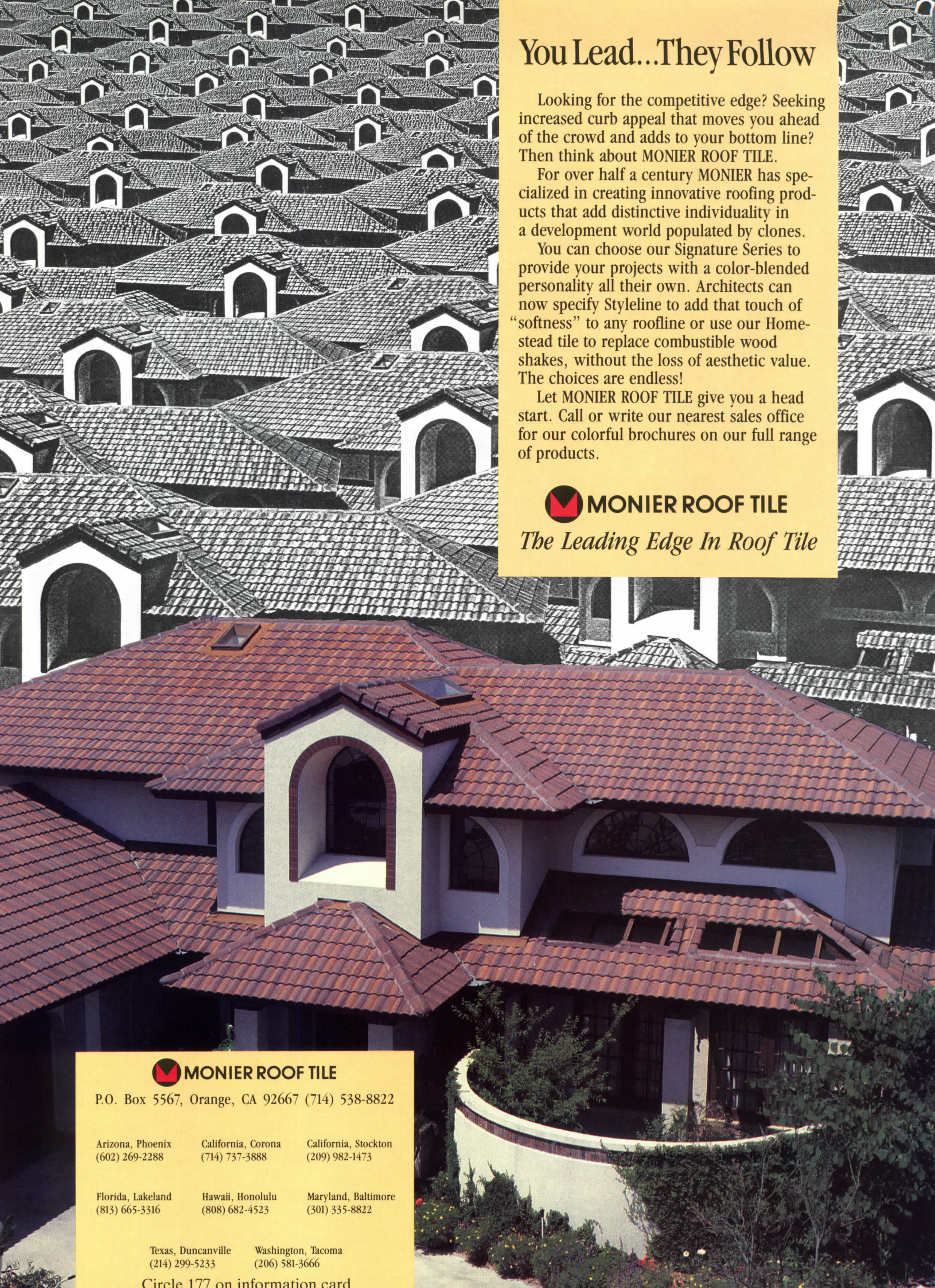
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