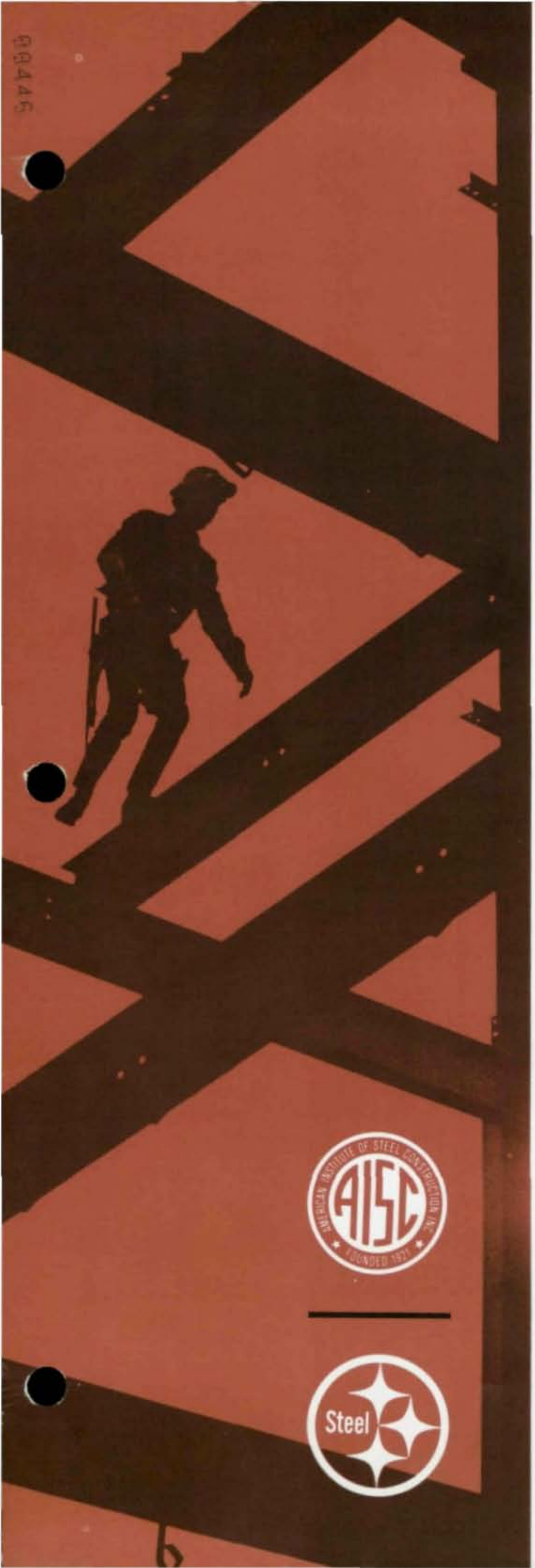


VOLUME XXII NUMBER 2/SECOND QUARTER 1982

MODERN STEEL CONSTRUCTION

Our Tribute to a Giant
An Architectural Expression in Steel
High on a Boston Bridge
Design of Cladding Attachments
Knoxville: A Fair—and a Facelift!

MODERN STEEL CONSTRUCTION

Published by

American Institute of Steel Construction

The Wrigley Building
400 North Michigan Avenue
Chicago, Illinois 60611

EDITORIAL STAFF

Daniel Farb, Director of Publications
George E. Harper, Editor
Amy Kragnes, Editorial Assistant

REGIONAL OFFICES

NORTHEAST REGION	
New York, NY (Hdq.)	212/695-4291
Boston, MA	617/329-7417
Philadelphia, PA	609/858-9354
Pittsburgh, PA	412/443-8840
NORTH CENTRAL REGION	
Chicago, IL (Hdq.)	312/372-8957
Detroit, MI	313/352-5558
Minneapolis, MN	612/888-3791
SOUTHEAST REGION	
Atlanta, GA (Hdq.)	404/458-7679
Charlotte, NC	704/375-6547
Tampa, FL	813/879-0429
SOUTHWEST REGION	
Dallas, TX (Hdq.)	214/630-5236
Houston, TX	713/529-5564
St. Louis, MO	314/721-1332
WESTERN REGION	
Los Angeles, CA (Hdq.)	213/444-4519
Denver, CO	303/831-4622
San Francisco, CA	415/495-3550
Seattle, WA	206/624-5460

VOLUME XXII NUMBER 2/SECOND QUARTER 1982

CONTENTS

1982 FELLOWSHIP AWARD WINNERS ANNOUNCED

The eight winners of the 1982 AISC Fellowship Awards competition were announced by Albert O. Wilson, Jr., president of A.O. Wilson Structural Co. and chairman of the AISC Special Committee on Education, at the March National Engineering Conference in Chicago.

Each winner received a study fellowship of $4,000, with an additional $750 to their academic department heads for administering the program. Students were chosen by a jury of awards from an exceptionally outstanding group of applicants. They were judged on their grade-point average, faculty recommendation and their prospective contribution of a proposed study program to the fund of structural engineering knowledge. The students chosen are:

Ronald E. Berry, *Clarkson College*
George A. Hills, *University of Idaho*
Pollyanna S. Kimrey, *University of South Carolina*
Mark L. Marsh, *University of Tennessee-Knoxville*
Charles S. Nolan, *University of Maryland*
Monrad R. Thue, *University of Florida*
John M. Yadlosky, *Carnegie-Mellon University*
Farrel J. Zwerneman, *University of Texas-Austin*

JUNE "VOLUME II" SUPPLEMENT IN BD&C FEATURES STEEL

For the second year, the "Volume II" Supplement of the June issue of Building Design & Construction *features the advantages of structural steel in buildings. AISC members and staff aided the BD&C staff in searching out exciting examples of the best in steel construction, with highlights on six buildings. A news section covers the latest in industry research, statistics and innovations. Individual copies may be secured from: Membership Services, AISC, 400 N. Michigan, Chicago 60611. $1.50 postpaid.*

HEINS RECEIVES 1982 T.R. HIGGINS LECTURESHIP

Dr. Conrad P. Heins, University of Maryland, has been selected for the 1982 T. R. Higgins Lectureship Award. The award recognizes his paper, "Box Girder Bridge Design—State of the Art," published in the AISC Engineering Journal, *Fourth Quarter 1978.*

An engraved citation and $2,000 was awarded to Dr. Heins by A. O. Wilson, Jr., chairman of A. O. Wilson Structural Company, Inc. and Chairman of the AISC Committee on Education, at the 1982 AISC National Engineering Conference. The NEC was held March 11-13 at the Marriott Hotel, Chicago.

As 1982 award recipient, Dr. Heins will present six lectures, the first he introduced at the NEC on March 13. □

Our Tribute . . .

The structural engineering community has lost a great talent—and a warm-hearted friend.

Dr. Fazlur Khan, a world-renowned engineer, died March 27 of a massive heart attack in Saudi Arabia. He was 52. He had been traveling in Korea and the Middle East when he suffered the attack.

Born in Dacca, Bangladesh, Khan received his bachelor of engineering degree from the University of Dacca. After he came to the U.S., he studied at the University of Illinois, Champaign-Urbana, where he earned degrees of master of structural engineering, master of theoretical and applied mechanics and doctor of structural engineering.

Dr. Khan joined the Chicago office of Skidmore, Owings and Merrill in 1955, and became a general partner in charge of structural engineering in 1970.

His accomplishments and awards read like a Guinness Book of Records. He achieved international distinction for the innovative bundled-tube and long-span structural systems he designed for a wide range of award-winning buildings.

He engineered the giants—the world's tallest building, Sears Tower in Chicago; the John Hancock Center, also in Chicago; Spectrum Arena in Philadelphia; the Haj Terminal in Saudi Arabia and the newly opened Hubert H. Humphrey Metrodome in Minneapolis—to name just a few.

To his design accomplishments, add myriad professional memberships and awards. In recognition of his outstanding contributions, Dr. Khan was elected a Fellow by the American Society of Civil Engineers. He was a member of the National Academy of Engineering, and chairman of the International Council on Tall Buildings and Urban Habitat. He lectured civic and educational groups throughout the world, and was honored by *Engineering News Record* as Construction "Man of the Year," and three more times as "Marksman."

In addition to his many memberships in engineering associations, Khan was also a professional member of AISC. He served on the AISC Beta Factor Task Committee on LFRD, the AISC Committee on Specifications, and he also served as chairman of the Institute's Tall Building Study Committee.

He received the AISC Special Citation Award in 1971, and was the most recent recipient of the coveted J. Lloyd Kimbrough Award in 1973—AISC's highest tribute to professional achievement. This award, established in memory of the first AISC president, honors advances in the "art of design or construction, or both, of structural steel."

Upon receiving his Kimbrough Medal, Khan responded, "I have always felt that every new project, or a system or a building, is not an end in itself, but is a step forward in the continuing process of evolution of ideas and concepts which should respond to human needs, should reflect new technology and economic realities, and should produce exciting fresh forms and architectural expressions. The Kimbrough Medal makes me aware of the past, but even more it will remain as an inspiration in searching for new answers to challenges of the future."

One writer, in his tribute, referred to "Faz," as he is affectionately remembered, as the "gentle giant." He was that—in his relationships with his peers, his friends, and even his students at Illinois Institute of Technology.

He will be missed by his wife, Liselotte; a daughter, Yasmin; a stepson, Martin; a brother, a sister and his mother—and by his thousands of friends in the engineering fraternity around the globe. □

Dr. Fazlur Khan (top), a giant in the engineering fraternity. Below, in 1973 he received AISC's coveted J. Lloyd Kimbrough Medal from then AISC President G.M. Dorland (r.) and David B. Hughes (l.), chairman of public relations committee. Some of his famous structures include world's tallest, Sears Tower (r.), John Hancock Center (far right) in Chicago, and Baxter Travenol headquarters in Deerfield, Ill. Photos courtesy Skidmore, Owings & Merrill

Knoxville: A Fair– and a Facelift!

On our cover: Theme structure of 1982 World's Fair at Knoxville—the Sunsphere (top)—soars 277 ft above 70-acre site (above), redeveloped from center-city railyards.

Photo courtesy Knoxville International Energy Exposition

About this time, the people of Knoxville, Tenn. must be experiencing a trauma of sorts. For the 1982 World's Fair—Energy Exposition 1982—has come to town, with an estimated 11 million people from all over the globe expected at the six-month spectacular. That divides out to over 60,000 visitors per day—a big bite for a city of 184,000. Two weeks into the fair, an average daily attendance of over 80,000 has shattered records for the number of visitors attending any world's fair.

Who would have guessed the Knoxville area could host such masses? Yet, it has been pointed out, almost nine million come each year to the nearby Great Smoky Mountains and the nearby entertainment capital of Nashville.

Energy Exposition '82, an authorized World's Fair, took its theme—"Energy Turns the World"—from its presence in the energy capital of the world, birthplace of TVA and nuclear power at Oak Ridge.

What is more exciting to the people of Knoxville are the benefits to the city itself. Over $224 million has gone into new roads, overpasses and interstates to relieve what the natives refer to as "Malfunction Junction"—the maddening intersection of three interstate highways.

Then, take 70 acres of downtown abandoned railyards, outdated retail operations and falling-down industrial buildings and witness these ruins blossom into a mile-long park, a seven-acre lake, improved commercial land and new residential areas. Add to that a dazzling steel 266-ft high, $3.7-million Sunsphere and dozens of pavilions, most prominent of which is the $21-million U.S. Pavilion.

As the fair structures were going up, one did not have to look very far in any direction to see the prominence in the use of steel for all types of applications—both new construction and renovation. Two of the most prominent and talked about are the theme structure—Sunsphere, and the unique U.S. Pavilion.

Sunsphere First Framed for Occupancy

The Sunsphere, theme structure for Expo '82, is the first spherical building ever built for occupancy, according to the structural engineers who designed it. The sphere-topped tower, representing the sun as the source of energy, promotes the fair's theme. It will remain as a permanent landmark after the fair is over. From its flared base, 110-ft in diameter, the hexagonal tower soars 195 ft to a 34-ft diameter, which supports a steel-framed sphere 74 ft in diameter. Nearly 500 tons of steel went into the five-level Sunsphere and its pedestal.

According to Dr. Socrates Ioannides, a member of the structural engineering firm, the problems in erecting the Sunsphere were structural as well as economic. "We were charged with the job of devising an affordable method of construction," he said. "To get the project within budget, we studied various ways to support the sphere. We found that arranging the steel in a geometric repetition gave the structure the needed strength and kept fabrication costs at a minimum."

For the sphere, the structural engineers used highly specialized mathematical techniques and a large computer to set up models in three dimensions. "All together, 3,000 equations needed to be solved for 3,000 unknowns," according to Ioannides. "Ten years ago, this would have been next to impossible. For a run of the computer on the sphere alone, the storage requirement was over a half-million numbers in testing the effects of temperature, wind load and moving load."

The main tower of the Sunsphere is a hexagonal shape with a double column, one inside and one outside, at each point of the hexagon. These are the six main columns to which tension and compression rings transfer loads from the skin of the sphere. Each side of the hexagon is K-braced. At the lower third of the tower, each of the six outer columns flares and forms a vertical truss with the inner column. This vertical truss and the K-bracing provide lateral load resistance. Above the transition level, where tower and sphere meet, the hexagonal shape continues as the main core. Since access is needed to the inner core, which houses elevators and stairs, K-bracing could not be used. Here, inside the sphere, lateral resistance is achieved by end-plated beam-to-column moment connections.

The Sunsphere skin consists of a grid of steel loadbearing tubes inside an aluminum gutter system into which silver reflective glass fits as a part of the skin itself. Usually, one set of structural supports—beams and columns—are used with a separate curtain wall. In this case, the skin is loadbearing.

Each vertical tube member acts like a curved column to support the weight of the skin, plus loads from the framed levels inside. The tube columns terminate at a tension ring at the top and a compression ring at the bottom of the sphere. These rings help transfer loads from the spherical skin back to six main columns at the core.

Horizontal hoops divide the sphere into 13 sections. The hoops, which support the skin structurally, also act as stabilizing members for the vertical curved tube columns. As a result, hoops in the top half are in tension, and those in the bottom half in compression, restraining the vertical tube columns from excessive deflection.

The sphere has five levels, two for restaurants, one for a kitchen and two for observation. Its circumference is divided into 30 sections, and at each of the 30 dividing points there is a vertical curved tube column. Beams radiate from the central core to the outside loadbearing skin at each floor level.

U.S. Pavilion a Structural Challenge

"The design of the U.S. Pavilion provided an exciting experience and challenge for the structural engineer," according to Cecil Chan, project director. "This structure, in essence, is an architectural dream come true."

"In essence, the U.S. Pavilion is a state-of-the-art electronic, computerized cornucopia of energy information. America's role in the world of energy is depicted by talk-back computers, electronic maps and single exhibits, such as a transparent house," says William Morris, U.S. assistant secretary of commerce.

"One of the main concepts in organizing the building as a linear structure was to let the pedestrian flow actually pass under the building in some way that people could interact with the building and see into it as they were passing from one side of the fairground to the other," according to Architect Marvin Housworth. Interconnected towers on either side of the U.S. Pavilion achieve this effect, as do the cantilevered sections of the structure.

"We wanted visitors to walk through the building or under it, so we thought of it as a concourse or sort of a superhighway that runs right through the building. It's a way to have a free pedestrian space without having to force people to go in and out of the building. Visitors can proceed to a point where they look into a giant show window into the main exhibit hall," Housworth says.

A primary challenge was design of the cantilevered sections. The upright "cage" was designed to be erected slightly "out of plumb" by as much as 1⅜ in. toward the south end. The sloping northside steel was then built down from the vertical "cage," and the cantilevered sections at the south end were supported by temporary shoring with 3½-in. camber, while concrete was poured to anchor the hanging steel. Post-tensioned slabs at the top and the base of the "cage" provided stiffening for the entire structure, and minimized deflection and rotation when the shoring was removed. The building settled into place in plumb, or absolutely vertical.

The main building is a triangular-shaped structure, 327 ft long by 133 ft wide by 112 ft high, with its longitudinal axis running east-west. Eight pairs of sloping steel spine trusses support the roof, glass-enclosed balconies and concrete floors. Four of the trusses are located in the middle of the building, supported by a concrete buttress at the north end and an upright steel cage at the south end. The other four are cantilevered trusses located at the east and west end, which range from 76 ft to 106 ft in length and are suspended from the steel cage. The "cage" is the perpendicular, south-side section of the U.S. Pavilion.

The suspension of these cantilevered sections, particularly the three stepped cantilevers over a lakeside terraced plaza, provides a breathtaking vista for visitors at the middle of the World's Fair site. This northwest plaza, which is protected from

One way to beat crowds, ironworkers Bill Cagle and Jimmy Cox dine in golden Sunsphere during construction. Steel-framed globe now hosts visitors for meals and serves as observation tower. Over 600 tons of structural steel went into intricately framed theme structure.

Sunsphere Team

Architect
Community Tectonics, Inc.
Knoxville, Tennessee

Structural Engineer
Stanley D. Lindsey
Nashville, Tennessee

General Contractor
Rentenbach Engineering Co.
Knoxville, Tennessee

Steel Fabricator
Asheville, Steel Company
Asheville, North Carolina

Owner
Sunsphere, Inc.
Knoxville, Tenness

the elements by the cantilevers, will be the staging area for many U.S. Pavilion events during the course of the exposition.

The vertical south wall, from which the northside sloping sections hang, fronts an east-west concourse by which visitors enter the main exhibit hall. Escalators transport visitors to the top exhibit level, from which they will descend through stages to the ground level.

"The sloping shape was conceived out of concerns about residual use of the building. We sloped the north wall to capture daylight and kept the south wall vertical and relatively unfinished to adapt to a future use," according to Architect Marvin Housworth, who headed the architectural team who conceived the Pavilion. "There is a lot of exposed steel structure on the vertical side which will give the eventual owners the capability of putting things in or taking them out."

If the structure had been designed conventionally—using the steel cage to support all the cantilever floor loads—uplift forces at the foundation would have required a resistance of 850,000 lbs., with a downward deflection of up to 18 in. at the tip of the 108-ft cantilever floor. In addition, the longitudinal steel cage would have deflected as much as 12 in. horizontally. The result would have been cracks in the floors and window panes and buckling of metal roof panels.

Space Frame by Computer

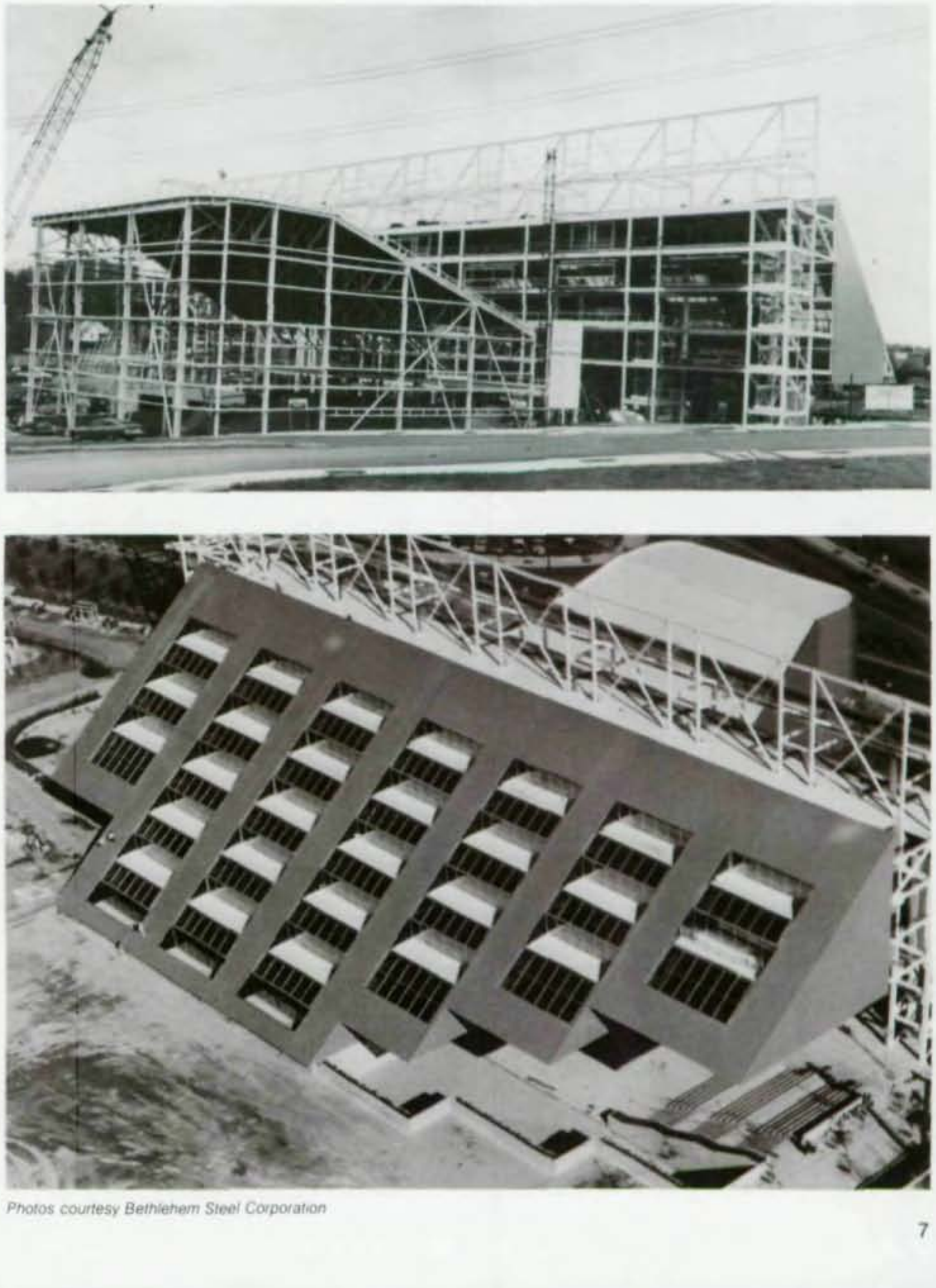
The structure was analyzed by a GTSTRUDL computer program. It solved both the space frame—972 joints and 1,985 members—and finite elements on the concrete diaphragms simultaneously.

All spine trusses (eight pairs) are 12-in. square steel tubes. Major columns of the steel cage are W14 and W12 members with ¼-in. steel side plates at each side of the columns. Major steel beams at the steel cage are W18 members. According to Cecil K. Chan, project director for the structural engineers, a steel frame was "the only possible way to construct it; steel is the only efficient material that can carry such huge forces resulting from 120-ft long cantilevered trusses."

The pavilion represents a breakthrough in steel design. It is one of the first U.S. structures to be designed with the concepts of "FS3"—fire-safe structural steel—a rational fire protection design method for steel-framed structures. The concept opens a new era in using bare structural steel for buildings. The FS3 concept came out of a study by a British design firm and AISI. They collected a worldwide base of knowledge on exposed steel construction, and from this developed a mathematical theory of combustion engineering and heat transfer applicable to exposed steel structural members.

The Fair is on until October 31. And all sorts of energy expended promise to make it a successful event. The revitalization program means much to Knoxville. Its ancient railway station has been renovated into shops, offices, restaurants and boutiques. An old candy factory and foundry buildings have taken on new life. New offices, hotels and convention facilities have burgeoned as the city bursts into bloom.

The fair generated 37,000 new jobs—17,000 of which are expected to be permanent. A government official recently commented, "Among the modern exposition halls erected are structures preserved because of their architectural and historical significance. In Energy Expo '82, energy and preservation go hand-in-hand." □



U.S. Pavilion/Theater is centerpiece of Expo '82. Photo (top) shows how steel frame slopes to pavilion, which houses numerous exhibits of Dept. of Commerce. Over 1,000 tons of structural steel frames unusual building.

Photos courtesy Bethlehem Steel Corporation

U.S. Pavilion Team

Architect
FABRAP
Atlanta, Georgia

Structural Engineer
O'Kon & Company
[illegible]a, Georgia

General Contractor
Rentenbach Engineering
Knoxville, Tennessee

Steel Fabricator
Tallman Iron Works, Inc.
Maryville, Tennessee

Owner
U.S. Dept. of Commerce
Washington, D.C.

Whither Weathering Steel?

Material Poised for Growth— Some "Do's" and "Don'ts" of Correct Usage

Deere & Co. headquarters, Moline, Ill. New Deere West addition (below) to 1964 structure was also built with weathering steel. Walkway/atrium ties two structures together.

Photo courtesy Kevin Roche John Dinkeloo Associates

With much fanfare and high expectations, weathering steel first arrived on the construction scene in the 1960s. Its initial architectural application, the Deere & Company headquarters in Moline, Ill. completed in 1964, was so successful the same material was chosen for Deere West, a recent 200,000-sq ft addition.

Since then, steel producers, engineers, architects and contractors have amassed extensive experience in specifying, fabricating and handling weathering steel. The material has found its niche in a number of well-suited applications—from bridges and buildings to water tanks and transmission towers, from open-deck parking and high-mast light poles to elevated transit and coal handling systems. Its growth has been steady, although not spectacular.

But weathering steel now seems poised for what may be its true growth phase. A number of current needs and construction industry conditions are stimulating new interest in the potential of this unusual framing material.

1. Substantial rises in maintenance costs, for both labor and paint, have renewed interest in two major advantages of weathering steel. First, in the bare condition, its corrosion resistance eliminates the need for any coating protection of surfaces boldly exposed to the atmosphere, and therefore may greatly decrease subsequent maintenance. Second, when paint systems are required, tests indicate they gain up to twice the service life on a weathering steel surface as on structural carbon steel.
2. Increasingly, the aesthetics of the material are being recognized, accepted and sought. Exposed to the atmosphere, the surface weathers to a rich, dark, earthy color. The oxide formed during the early years of bare exposure—about the same thickness as a heavy coat of paint—becomes dense, adherent and inhibits further atmospheric corrosion. If scratched or marred, the oxide re-forms.
3. Its properties as a high strength/low alloy steel also gain economic importance. Specifiers now capitalize on the fact it is up to 40% stronger than structural carbon steel. This can permit the substitution of thinner plate or smaller shapes to partially offset higher cost.
4. The serious deterioration of older bridges throughout the U.S. and Canada leads many to anticipate an upsurge in new or replacement construction. A large bridge now costs several million dollars just to paint initially, or repaint periodically. Replacement with bare weathering steel, along with painted weathering steel in trouble-spot sections, has a significant cost-cutting potential.
5. With the knowhow derived from more than 15 years of diversified applications, design and installation guides have been developed, to help designers solve problems encountered with weathering steel. This article presents some guidelines for those not fully experienced in working with the material.

Today, weathering steel is available as structural shapes and plates for welded or bolted construction, in ASTM Specifications A242 and A588. The former, usually employed as relatively thin plate, has enhanced atmospheric corrosion resistance several times that of carbon structural steels without copper (0.02% maximum copper content). The latter grade, normally used for structural shapes and thicker plate, embodies about four times the atmospheric corrosion resistance of carbon steel. Both grades have about twice the corrosion resistance as that of copper-bearing

Photos courtesy Steel Products News Bureau

World's longest steel arch. New River Gorge Bridge (l.), Fayette County, W. Va. was built of A588 steel. Above, exposed steel parking decks are up-and-coming application of low-maintenance weathering steel.

steel, which has 0.20% minimum copper.

The materials attain their properties through a combination of alloying elements, not copper alone, but which could also include chromium, nickel and silicon. In fact, A588 will differ by supplier in both alloying ingredients and percentages.

Weathering steel plate is made primarily in widths up to 144 in., and in lengths to about 720 in., with the upper ranges of width and length dependent upon gage: the thinner the plate, the longer and wider it can be. Yield-strength is 50,000 psi, compared to 36,000 psi for structural carbon steel, with the yield diminishing slightly for A588 steel over 4-in. thick.

All structural shapes are available in weathering steel—W, M and S shapes, angles, channels and tees. These are produced mainly to the A588 specification. Exposed structural shapes for bridges and buildings are among the growing applications for weathering steel.

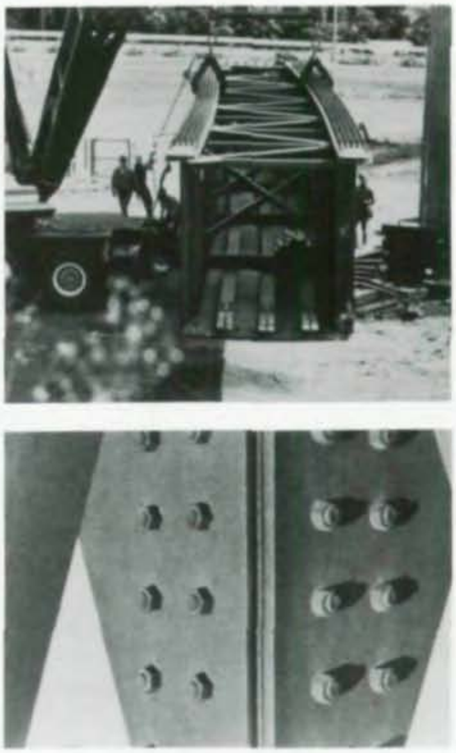
Some Do's and Don'ts

To achieve all the benefits of weathering steels, especially in the bare condition, it is important that proper design, fabrication and handling practices be observed. A few key rules are presented here:

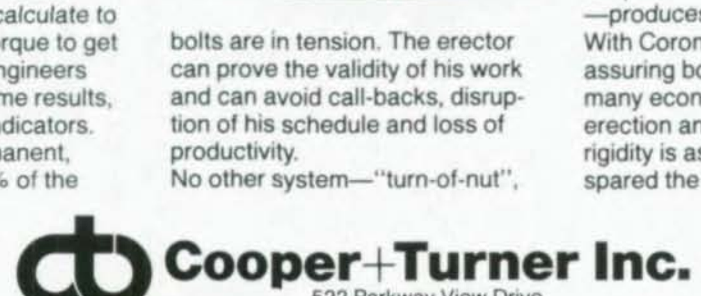
- **Locations:** Use of bare weathering steel is suited to most atmospheric environments—urban, suburban, rural, moderate industrial and moderate marine. There are special areas, however, where usage in an uncoated condition is not recommended because the protective oxide will not form properly. For example: atmospheres containing concentrated, corrosive industrial fumes; marine locations subject to salt-water spray or salt-laden fog; and applications where the steel is continuously submerged in water (salt or fresh), or buried in soil.
- **Drying:** A constantly wet weathering steel surface will corrode at an unacceptably rapid rate. Therefore, detailing of beams, columns, sunscreens, exterior wall systems, etc. should avoid creating sources of water retention—pockets, crevices and faying surfaces. Where such collection spots cannot be avoided, there must be allowance for drainage and ventilation to permit the steel to dry.
- **Stain prevention:** Moisture dripping from the steel, especially during its early years of exposure, will contain particles of insoluble iron oxide, which can stain or streak adjacent materials. Permanent provisions should be made through design, detailing and selection of proper adjoining materials and colors to accommodate this run-off water, or divert it from vulnerable surfaces. Successful solutions include sealants, gutter and downspout systems, overhangs, drip plates and special flashings.
- **Adjacent materials:** Compatible construction materials subject to minimal staining, and which generally can be cleaned include: aluminum, ceramic tile, extruded neoprene, glass, glazed brick, organic coatings (washable, air-drying and thermosetting), porcelain enamel coatings (semigloss and glossy) and stainless steels. Some materials that may undergo severe staining, and are difficult or impossible to clean, are concrete and stucco, galvanized steel (unpainted), matte porcelain enamels, stone, wood and unglazed brick.
- **Glass:** Windows in weathering steel structures require frequent cleaning during the period when the oxide coating is forming. Cleaning frequency will decrease once the oxide has matured, but will be higher than in structures of other architectural materials. Glass is not affected by the corrosive drainage products, but staining will become apparent once the surface has dried. The resulting film—airborne dirt in addition to the iron oxide—is generally difficult to remove by rinsing and may require a mild abrasive cleaner.
- **Interiors:** All interior and other unexposed weathering steel surfaces, including faying surfaces not held tightly together, where weathering and proper oxide formation is prevented, must be protected as if the material were carbon steel. Flat, horizontal surfaces are particularly vulnerable to moisture or condensation, as are those covered by structural or curtain wall gaskets, and the interiors of window frames, door frames and wall panels. A good rust-inhibitive primer, applied on cleaned material, is usually adequate.
- **Bending:** Weathering steels can be cold-formed using conventional equipment and good shop practices. Slightly greater forming pressures, as well as more liberal bending radii are needed than for carbon steel. Hot-forming is recommended for bending of plate over ½-in. thick.
- **Fasteners:** For structural joints where high-strength bolts are required, the ASTM A325, Type 3 bolts must be used. Lower

strength fasteners—standard machine bolts, *self-drilling/self-tapping screws, nuts and* hardened washers are all available in weathering steel. Galvanized steel fasteners are not suitable for use in weathering steel structures; when the zinc coating erodes, it leaves an exposed plain carbon steel unit that is not resistant to atmospheric corrosion.

- **Welding:** While any of the low-hydrogen welding processes used to join carbon steel plate ordinarily can be used, the alloy content of weathering steels requires that welding procedures be tailored to the thicknesses and types of joints being made. The low-hydrogen, arc-welding processes are commonly used to minimize the need for preheating and to permit use of lower preheating and interpass temperatures. Where the weld metal must exhibit corrosion resistance, weathered color and texture comparable to the base metal, certain alloying elements should be present in the weld metal.
- **Cutting:** Weathering steel plate can be oxygen or plasma-arc cut in accordance with practices suggested in the American Welding Society Handbook. Generally, this steel does not require pre-heating.
- **Bar:** Steel bar is also produced in specifications A242 and A588, and is employed frequently as a reinforcing component to plate in heavy construction. For these purposes, *only shearing and bending to shape* are usually necessary to utilize the bar.
- **Surface preparation:** For most architectural applications, a uniform weathering process is desirable, necessitating a uniform surface for the even formation of the protective oxide. Therefore, all exposed plate and structural shapes to be left unpainted should be blast-cleaned or pickled to remove mill scale. When blast cleaning is required, it should be performed in accordance with the Steel Structures Painting Council surface preparation specification SSPC—SP6-63 *No. 6, Commercial Cleaning*, usually adequate for most exposed applications. Specify that any necessary markings be made in chalk or water-soluble ink, and not in paint or crayon, and that they do not appear on surfaces which will be exposed.
- **Availability:** Although a wider size variety of weathering steels is available from the producing mills, steel service centers do stock weathering steel plate, angles and wide-flange shapes in the most popular sizes. To overcome any problem of small quantity availability, design details should aim at consolidation of sizes and thicknesses, so that mill quantities can be ordered. □



Integral part of many newer bridges is weathering steel box-girder sections (top), rapidly gaining acceptance among designers. Available mechanical fasteners provide both corrosion resistance and weathered appearance.



St. Louise de Marillac Church: An Architectural Expression in Steel

by Lucian Caste

Lucian Caste is owner of the architectural/engineering firm of Lucian Caste, Architects, Pittsburgh, Pennsylvania.

The design for the Church of St. Louise de Marillac was conceived not only as that of a parish church, but also as a pilgrim church, where visitors come from many places to worship, find hope and inspiration.

The tradition of a pilgrim church at its best challenged us to think boldly, to cast our ideals in forms which are valid for time to come, shaping them with the genius of present day materials and techniques. We wanted to provide the best possible space for worship—and to find an appropriate architectural expression.

The architectural character of the church was determined largely by the site, the bold and direct nature of the design, and the use of steel in a strong, basic way.

With the initial decision to use steel, we wanted to express it in both a truly functional manner and a religious manner. We sought to express steel in appropriate ways—strength, economy, boldness of character, precise, rich in detail and dark in color.

The church is an organic expression of structure and materials . . . the rugged Somerset fieldstone is used on both the interior and exterior to continue the unity and tradition of the original parish buildings . . . the exposed steel structure of columns, a tracery beam system and the inter-connecting horizontal truss all ornamented/reinforced with a series of sub-members enhance the heritage of the local culture . . . the steelmaking industry of Pittsburgh.

The liturgical space—the total inner space of the church—is meant to create a sense of personal scale and spiritual uplift. This is the space of community and celebration . . . the space of sacred abundance which warms people and given them a sense of community. The main structure develops from an "open-ring" plan, with the communicants seated in a partial concave vessel—the nave—gathered around the altar. Together, the priest and people become the form and function of the plan.

The main structural form is a basic rectangle of perimeter steel columns that supports the roof structures and creates an open liturgical space. Columns are W8 and W16 sections rising to various heights to accommodate the two sloping roofs and the tracery of sub-framing members (W8 and W12) that support the ends of the basic frame. Two sloping roofs, one projecting above the other, are tied together by a large (67-ft x 13-ft) horizontal fabricated truss of W8, angle, and tie-rod members. The higher roof extends over the low roof to house a continous horizontal skylight which allows natural light to pass through the truss and illuminate the higher ceiling. Long-span joists with laminated wood deck units form the actual roof system.

The main columns are articulated by applying channels and angles reminiscent of the mouldings applied to the Gothic stone columns of medieval churches. Emanating from the main form are the ancillary spaces. These spaces include the vestibule and narthex, the reconciliation rooms, the cry room, the sacristy and the ambulatory, all at the church entrance. These spaces are framed with steel wall-bearing members of various lengths to accommodate the undulating organic forms of the stone walls. To the side of the main nave is a low shed roof area which resembles the traditional transept of medieval churches. It extends to a radial form that continues the theme as

St. Louise de Marillac Church in Upper St. Clair, Pa. finds architectural expression in its worship, and materials shaped to express it.

organic shapes. Here the tracery of sloping W8 members reflect the design of the horizontal truss.

The sanctuary is the focal point of the liturgical design—the altar of sacrifice, the altar of the word, the baptistry and the eucharistic tower. Here the organic forms of the stone walls form the backdrop for the sanctuary. Rising out of these forms are steel columns that establish the focal point of the baptistry and the eucharistic tower which houses the tabernacle.

The daily chapel, located behind the sanctuary, is reminiscent of the radiating chapels in late Gothic churches. The main corner of the rectangular form of the structural frame comes in near contact with the chapel, which is in itself a free circular form. At this point, a large concealed vertical skylight monitor lets in a natural light that illuminates the half round wall of claret red that serves as a backdrop to the altar.

The baptistry is defined by a tall open ornamental steel railing giving a powerful symbolism to this important liturgical element. Springing from one side of the baptismal area is an 8-inch wide flange member with decorative channels and angles.

The eucharistic tower is in the stone encasement of a structural steel column. The stone begins as a free shape accommodating the two levels (sanctuary and the daily chapel) to a place where the tabernacle is expressed in a dual manner. The stone continues to rise in the appearance of a tall stone receptacle, and from this the form of the steel column is seen.

Just as medieval churches were designed to enable pilgrims to circulate with ease through the church spaces, so at St. Louise a way-form or processional path has been designed to let one be part of the totality of the abundant space of the church, and to experience its every part and mood. The way begins at the entry porch, emphasized by a bold steel lintel, through the double portal and into the narthex. Here, the large overhead narthex window lets the color of life, green, flood this space.

Moving eastward, one enters the low stone walls and vaults of the darkened ambulatory and continues to the east side aisle and to the daily chapel. All along the way, the path is punctuated by ornamented steel columns, tracery steel and the presence of steel. The steel columns define the space and lend strength to the plan. In some cases, pews intentionally extend beyond the columns, so those who wish to sit near or behind a column may do so. The way continues through to the daily chapel, the ambulatory behind the sanctuary and to the west transept.

As part of this procession, light enters and fades, darkness sets in, shafts of light/color from stained glass enter the space. The structure and its Christo-centric axis are apparent again.

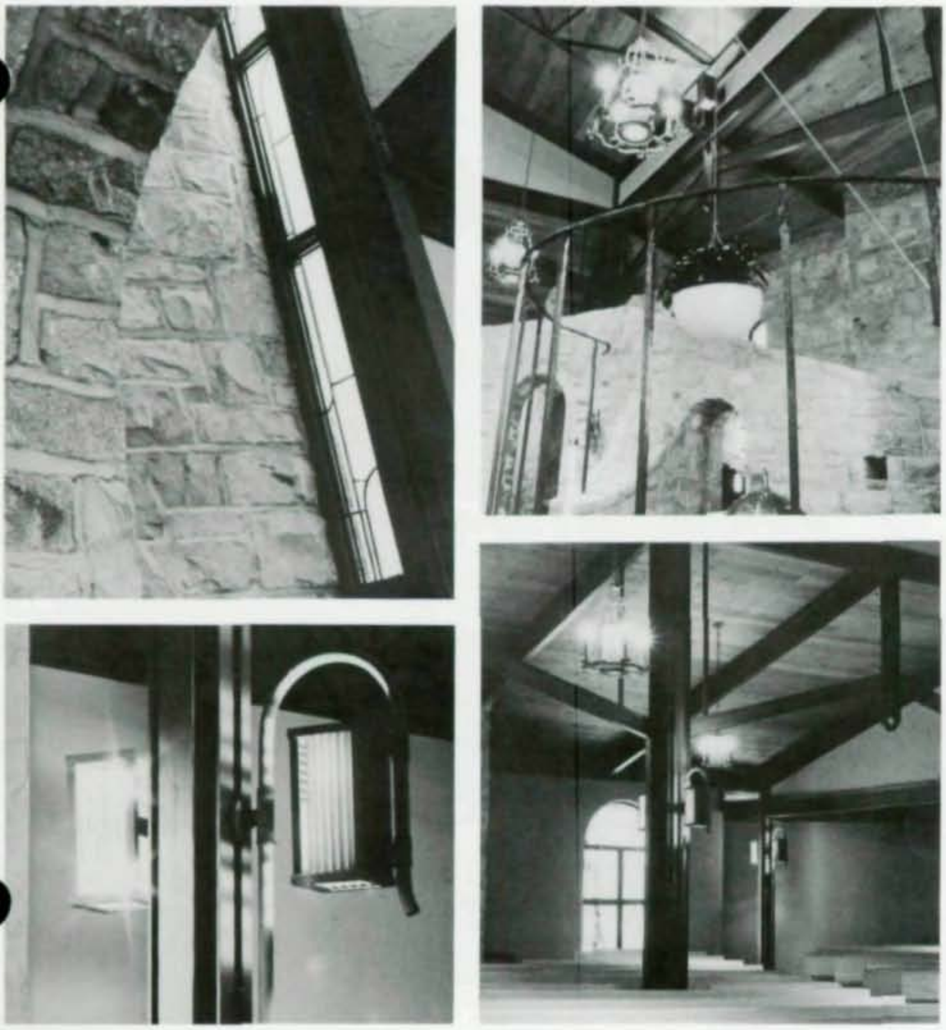
The integral design of the liturgical furnishings are essential to the overall design of the church. The organic expression of steel and stone formed the basis of design for altar, eucharistic tower, tabernacle, light fixtures, doors, railings, candlesticks and baptismal font.

The light fixtures were designed of "rusted" steel as chandeliers for general illumination, shepherd crooks for local lighting at columns to accent the ornamented columns. The steel in the lighting fixtures received a special treatment to produce a rugged-

rusting appearance which blends with the dark cinnamon brown color of the exposed structural steel. The tabernacle doors, candlesticks and railings were designed and fabricated of plain wrought steel, hammered and distressed, then treated to preserve its natural patina. Tabernacle doors were crafted from plain steel bars and plates, decorated with brass, and the open areas (between bars) filled with stained glass set in a clear epoxy. The baptismal font cover was fabricated from a series of sheet steel pie shaped segments welded together to form a dome cover.

The character or expression of any building can only be achieved if it is itself a total expression. Like any work of art, it must be dominated by a strong, simple concept. All of its parts must be active of one dominant attitude. This is true whether the elements are basic, like plan and structural system, or later decisions like liturgical furnishings. The challenge of making a building a total expression is the highest and most difficult one. Besides functioning as the strength and form of the church, steel dramatizes the character of liturgical worship. ☐

Giant 65-ft long x 15-ft high trusses go up to provide main roof support, enlarging central span and eliminating interior columns.



Sanctuary is focal point of liturgical design of St. Louise Church. Steel columns rise out of stone walls to establish design focus. Photos (l.) highlight several uses of steel to add symbolism to worship.

Architect/Engineer
Lucian Caste
Pittsburgh, Pennsylvania

Architect
Caste & Filoni
Pittsburgh, Pennsylvania

Structural Engineer
Brace Engineering
Pittsburgh, Pennsylvania

General Contractor
Mellon-Stuart Co.
Pittsburgh, Pennsylvania

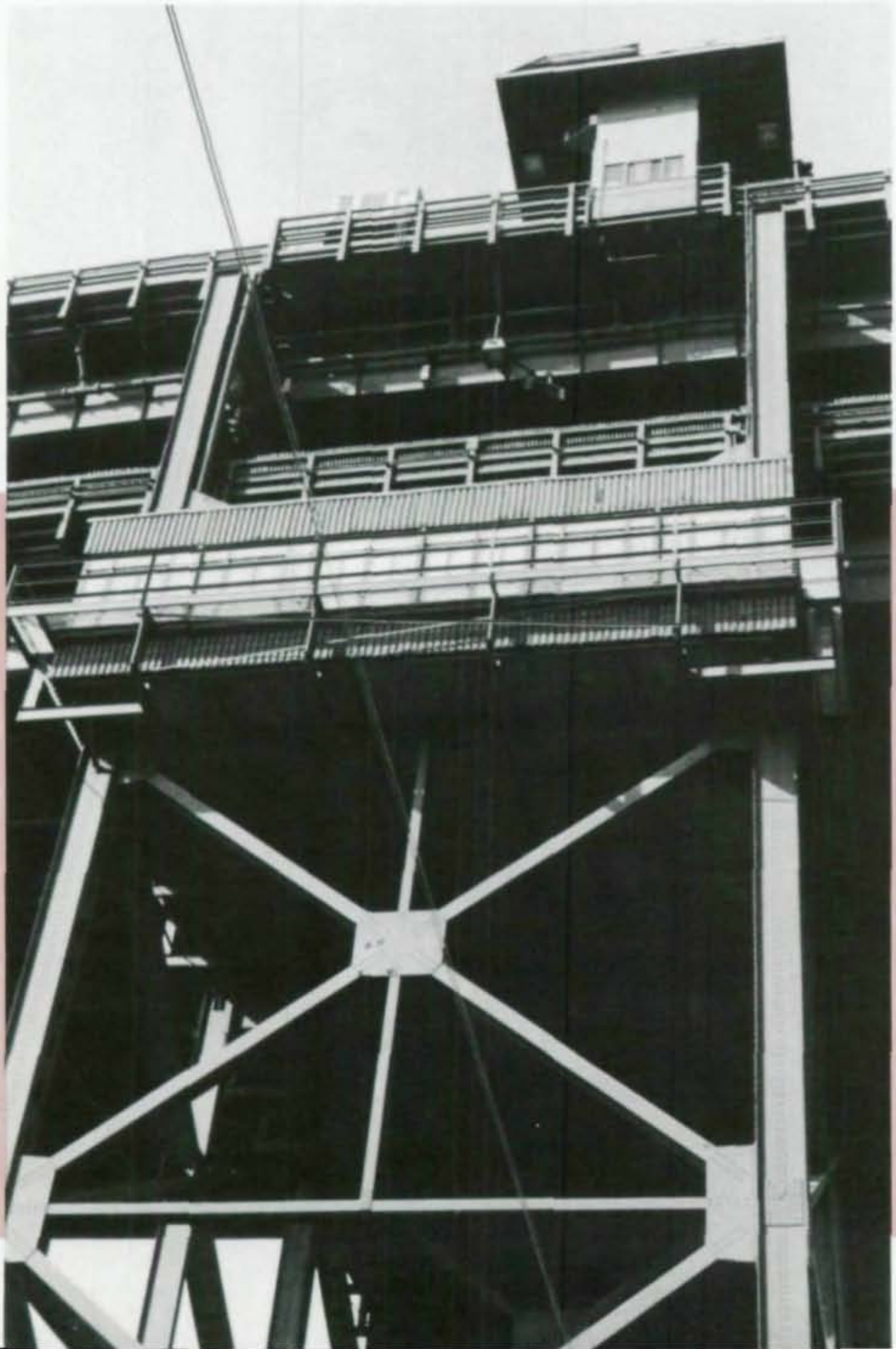
Fabricator
Levinson Steel Co.
Pittsburgh, Pennsylvania

High on a Boston Bridge: Reconstructed Toll Headquarters

Unless you are a toll collector, or get stuck in traffic jams, you may not spend much time on bridges. But supervisors, maintenance personnel and support staff for Boston's Tobin Bridge spend their work days suspended 120 ft above the ground in the administration building attached to the bridge structure. The facility was recently reconstructed with a new enclosure system and complete interior renovation by Architect Andrea Leers. According to MASSPORT Executive Director David W. Davis, the rehabilitation of the uniquely situated facility "has been an extraordinary engineering and construction job."

The Tobin Bridge, a major Boston Gateway linking Charlestown and Chelsea, spans a channel of Boston Harbor. Owned by the Massachusetts Port Authority (MASSPORT), which also owns and operates Boston's Logan Airport, tunnels and other transportation facilities, the bridge is open to administer toll collection 24 hours a day. A major containerport is located below the bridge on filled land between the Mystic River and Channel.

When the bridge was built in 1949, no additional land for an administration building was available where bridge meets the ground. Therefore, the facility was attached to the bridge structure just under the Toll Plaza at midspan. Linked to the bridge above, and the ground 100 ft below by stair and elevator tower, the building is headquarters for toll collectors, supervisors and



Uniquely located, rehabilitated toll collection headquarters (l.) sits high on Boston's famous Tobin Bridge. One hundred feet below, major containerport (r.) operates on landfill. Plan (far right) details unusual structure.

Architect
Andrea Leers Browning Associates
Arlington, Massachusetts

Structural Engineer
Melvyn F.H. Jay & Associates
Cambridge, Massachusetts

General Contractor
Solimando Construction Company
Milton, Massachusetts

Owner
Massachusetts Port Authority
Boston, Massachusetts

maintenance personnel. It also serves as a facility for the sale of passes and tickets to the public.

Building Badly Deteriorated

The need which first prompted the administration building reconstruction project was to replace the deteriorated building skin. The original corrugated steel siding and windows were severely corroded from salts that washed down from the bridge roadway. Roofing was damaged by years of accumulated debris. Inside, the building needed repairs because of a leaking roof and windows, as well as reorganization of its space. But the structural steel framing, erected when the bridge went up in 1949, needed very little re-work. An estimated 10-15% of the framing had to be replaced due to salt damage. Also, some steel was added to strengthen the wall and to hang new window frames. And, some steel framing increased the structural strength at corners that were cantilevered.

Entries to public reception, lounge, locker rooms and maintenance areas were indiscernible from each other. The building had to remain in operation throughout construction. The work process and delivery of materials needed to be planned to avoid interference with bridge traffic.

Two alternate wall assemblies were considered to replace the existing enclosure. The first system totally replaced the existing wall with self-framing insulated steel sandwich panels. The second, and the system ultimately selected, retained existing steel subframing and interior metal liners which proved in good condition. New facing panel and insulation were added. The new exterior system provides a very smooth, taut metal skin and window detail. The painted, factory-finished flush steel panel and window system which replaces the existing corrugated metal panels virtually eliminates cavities and projections where corrosives might collect.

A considerable challenge lay in coordinating the module of the new panel with the existing subframe spacing. Steel windows with a polyvinyl chloride coating were chosen for resistance to road salt and marine air. Opaque spandrel glass continues to the roof, eliminating windowhead conditions where debris might accumulate. Alternating panel colors mark the rhythm of the structural bays of the building. The neutral color of the panels is then accented with red tracery steel windows and catwalk. The roof was replaced with a smooth surfaced built-up system which could be more easily cleaned than tar and gravel. Although the floor slab could not be economically insulated, window area was reduced, insulated glass, wall and roof insulation were installed and exposed piping was covered.

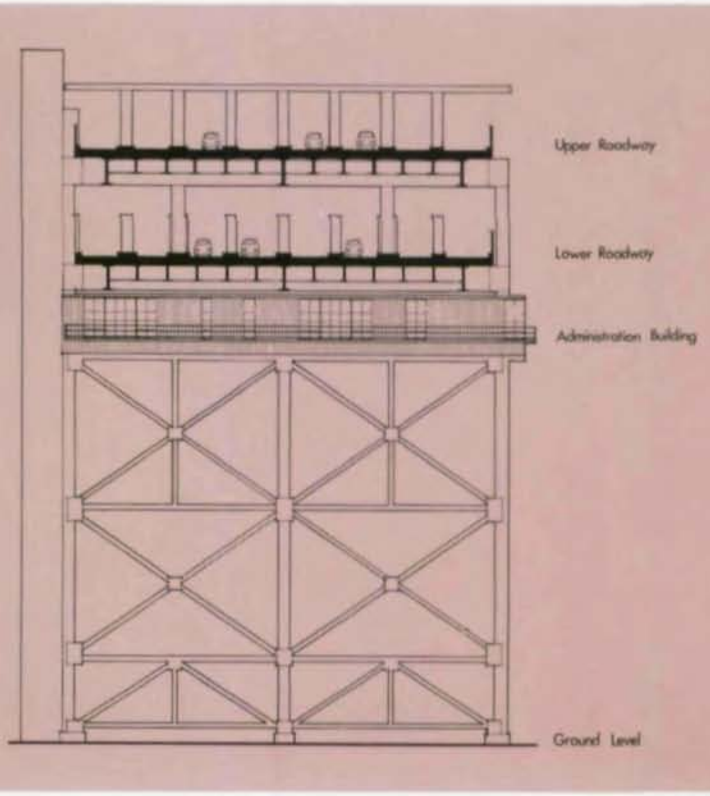
Planned for Staff

Interior renovations were planned in close cooperation with the occupants who, over their years of using the building, had developed certain preferences about its function and materials. Out of a dialogue with administrative staff and union workers grew the mutual desire for the zoning of noisy, active and public spaces from quiet, administrative and essentially private areas.

Clearly defined zones for the public, the staff and the bridge workers are organized along the main passage from entry to board room. This corridor of modulated space changes height, width, shape and color. Special uses such as entry, lounge, reception and board room are marked by specially shaped ceilings highlighted by curving walls and bright red accent colors.

Clear glass block is used where limited visibility between spaces is desired, and patterned glass block is found where borrowed light only is needed. New indirect lighting provides a high level of brightness to offset the glare of brilliant window light. Uplighting at entry, reception areas and board room accent the curved ceilings in those spaces.

Despite problems of access and the fact that some workers were reluctant to work at such a height, construction was completed without any interruption in round-the-clock bridge operations. Work on the exterior was done from scaffolding supported by the bridge. Materials were hoisted from the ground or lowered from the roadway. The resulting colorful, container-like building, re-designed in the spirit of its unique mechanistic setting, is an asset to the bustling and well-maintained environment of bridge and containerport. □



Indian Lakes Resort Hotel:

Space-Frames for a Pyramid

The ball was in the architect's court: design a 330-room resort hotel for a 40-acre site in Chicago's west suburban countryside. Connect it with banquet rooms, restaurants and pool/tennis facilities and an existing clubhouse and golf course. And design a building that caters to convention and weekend family vacationers.

The result is a dazzling pyramid-shaped hotel, with an equally spectacular diamond-shaped atrium that opens a tropical environment to interior guest rooms.

One of the most unusual structural details in the building is the skylight construction. The pyramidal-shaped atrium permits small plexiglas skylights to provide intense natural light to a large base area. The effect is simulated in each guest room where a skylight created of bronze mirror adds a special intimacy to the wood-beamed ceilings. Zig-zag corridors eliminate the monotony of the usual long ones.

Unusual Skylight Construction

Two structural frames were required for the unusual roof project — one over the atrium. The atrium roof is approximately 77 ft x 120 ft, supported on 16 columns. The framing consists of 16 hexagonal grids fabricated of rolled steel W16 wide-flange grids. The side dimension of each hexagon measures 11'-0". The framing supports 5 -ft deep precast concrete liners and is covered with hexagon plexiglas skylights. The second frame, for the carport, consists of a similar pattern of hexagon units. This frame, supported on eight main columns and two secondary bearing points, measures 57'-0"x 87'-9" out to out.

The structural grids for both frames are space-frames insofar as their girders cannot be reduced to planar supporting elements. Unlike most space-frames, however, which are generally highly statically indeterminate, this structure is statically determinate throughout. Moreover, in some areas, it was found that the original layout, as originally conceived, was unstable. Only by introducing torsionally stiff members was it possible to maintain the structural integrity of the framing system.

The two frames were analyzed as space-frames using a STRUDL computer program. In making the initial layout, the following rules were followed:

1) In the construction of hexagon space-frames, each interior joint will be formed by the intersection of three members. These must be fastened to each other with moment-resistant connections.

2) If the grid is composed of regular hexagons, the three end-moments are exactly equal at any one joint.

3) Exterior joints may consist of two or three intersecting members.

4) A three-member exterior joint may be unsupported. It is then treated as a regular interior joint.

5) If a three-member exterior joint is supported by a column, two of the intersecting members may be cantilevers. The moments at the joint, however, are equal for all three members. In this case they are all negative.

6) Exterior, two-member joints may be supported by a column. In this case the member end-moments at this joint must both be zero (simple support).

7) Exterior, two-member joints unsupported must be formed by the intersection of two cantilevers extending from three-member joints.

Where these rules could not be complied with, torsion members were introduced to maintain the structural integrity of the hexagon grid.

The roof span developed moments that exceeded the bending capacity of the W16 framing members, so it was necessary to increase support near the center. Two massive chains were dropped from the adjacent elevator towers down to two centrally located points on the grid in two V-shaped suspension lines. The chains, salvaged from a World War II Victory ship, with a working strength of better than 120,000 lbs., perform similar to cables in a cable-stayed bridge. □

Dazzling skylight (far left) at luxurious Indian Lakes Resort (top left), Bloomingdale, Ill. features unusual structural steel framing details. Pyramid-shaped atrium (r.) provides intense natural lighting for guest rooms and dining areas below. Roof photos (l. and above) show hexagon grid details and massive ship chain supports.

Architect
Erickson and Stevens, Inc.
Des Plaines, Illinois

Structural Engineer
Kolbjorn Saether Associates
Chicago, Illinois

General Contractor
George A. Fuller Company
Chicago, Illinois

Steel Erector
General Erectors
Mokena, Illinois

Owner
Carson International
Bloomingdale, Illinois

Design of Cladding Attachments for High-Rise Steel Buildings

by Thomas Limperis

Figure 1—*Telephone company building faced with granite*

We approach the design of cladding attachments from the structural consulting design engineer's viewpoint.

The outer skin, or exterior wall of a building, to owner and architect, is one of the most important features of a building. It provides the structure with its visual identity; it protects, encloses and shelters contents and inhabitants from the elements. Facades constitute a great portion of the total construction cost and effort of a building program.

Just as the strength of a chain relies on its weakest link, the design of exterior walls relies heavily on the correct design of its attachments.

Design of cladding attachments follows established engineering principles. In itself, the design of the attachments requires a simple structural solution, provided attention is given to the design parameters involved. *To arrive at the design solution, one must* understand the facades being developed and in use today.

Development of a facade is accomplished by the combined efforts of a number of parties. Each has a very special role to play, and a unique responsibility for the success of the final product.

The Design/Build Team

The architect, as the forerunner, carries the responsibility to establish, on contract documents, characteristics required for the exterior wall to perform functionally, as well as to be attractive and give the building a visual identity. He applies his artistic skills and knowledge towards this end. But he must also enlist the aid of other disciplines in this endeavor, such as structural and mechanical consultants.

With this outlook, the structural design parameters take on very special and significant meaning. Performance criteria are established in project specifications by the architect, based on the combined effort of the design team.

The structural engineer must participate with the architect in the facade design from the beginning. He must make certain that the facade components can perform structurally within prescribed limits. He must also consider the influence imposed by the facade support requirements on the structural framing, usually the spandrel beams and exterior columns. He must recognize, delegate, and clearly show on contract drawings the acceptable points of support on the structure. He must design spandrel sections with deflection limits to prevent undue movement onto sash or glass. He must provide for torsional movement restraints of the spandrel.

The final facade design is almost always a custom design, either of a proprietary system, or a system design developed by the contractor, suitable for the project and executed by a licensed professional engineer employed by and responsible to the facade contractor. Thus the architect and

Thomas Limperis, P.E., F.ASCE, is associate partner in the firm of Weiskopf & Pickworth, consulting engineers, New York, New York. His paper was presented at the 1982 National Engineering Conference, Chicago, Illinois.

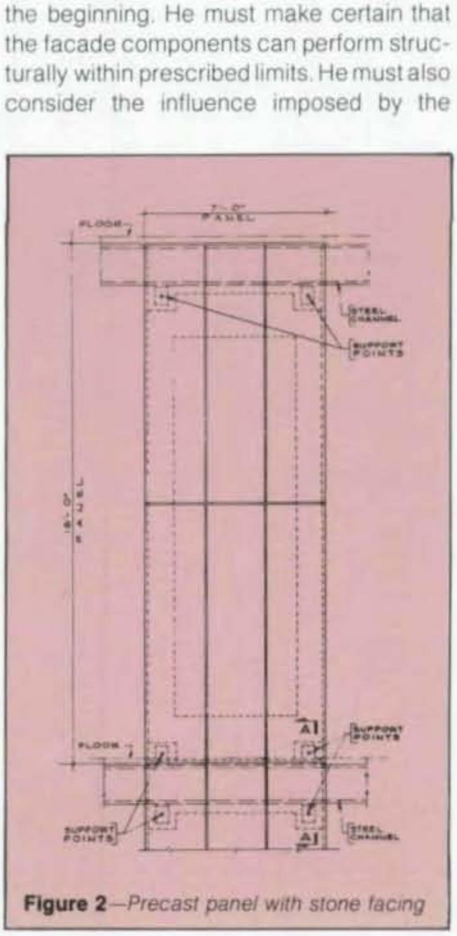


Figure 2—*Precast panel with stone facing*

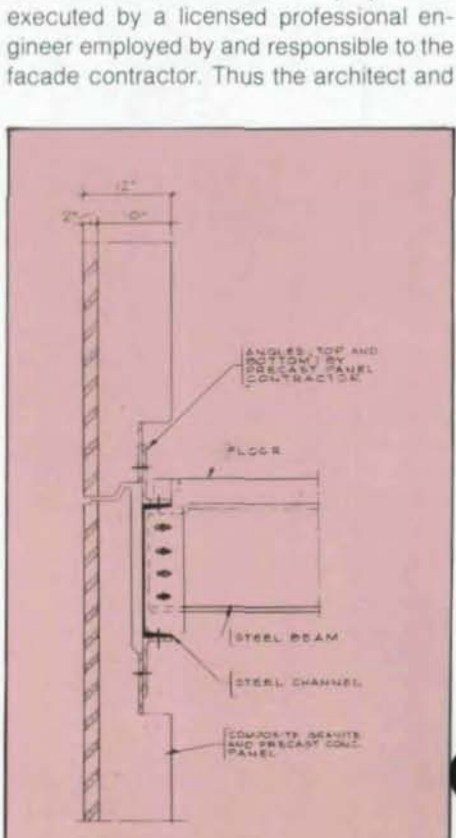


Figure 3—*Final attachments*

the engineer develop the character of the facade, but the design and details of the actual product are usually developed by the facade contractor based on the performance criteria specified by the architect/engineer.

Details for supports on the structure, developed by the facade contractor, are provided to the structural steel contractor, who then must develop and provide connections on the steel frame that receive the facade support, at the points established by the structural engineer.

The general contractor must coordinate the subcontractors' work and plan the construction schedule for the proper sequencing of the erection of the facade. The structure must be ready for this phase of installation, so that the material will not be affected or damaged by construction activities.

Many Facade Variations

To understand the connection of the facade to the structure, one must consider the type of facade structure, and its material.

There are many variations of facade types—solid walls, or walls with partial or full windows. There may be vertical continuous fenestration, or horizontal continuous fenestration, or punched openings. Each wall requires a different possible structural solution.

A type of curtain wall used at exterior walls such as mechanical room penthouses is a windowless wall. Solid architectural panels, metal or masonry, spanning vertically, perhaps between girts, is the usual system for this type. The girts, of course, are the structural elements, and as such are usually part of the steel contract. They support vertical and horizontal load and may be channels with webs horizontal and with sag rods at intermediate points, or the wide-flange beam-channel combination section. For this system, columns or intermediate vertical elements are used as part of the support frame, which must be checked for flexure. The girts are located off the column face and bracket connections to the column must be used.

For solid-faced windowless walls, masonry and precast panels can also be used, spanning from floor to floor.

Figure 1 is an exterior view of a 30-story New York telephone company building faced with granite stone on precast concrete panels. This building, located in downtown Manhattan, was designed by John Carl Warnecke, N. Y. office.

Figure 2, an elevation of a typical panel 7-ft wide by 18-ft high, shows the relation of panel to floor support beams and support points.

Figure 3 shows final attachments. Note:

- Spandrel is adjusted into final position, using adjustable slots, by facade erector.
- Attachment hardware for precast piece is provided by facade contractor.
- Attachment at bottom of panel (top of beam) is rigid.
- Slotted holes for attachment at top of panel allow for thermal movement.

Bolts in slotted holes allotted for movement must be placed at center of slot or movement will not be possible. Slot may have to be enlarged, if necessary.

To avoid placing load on steel spandrels, precast panels spanning horizontally can be used effectively as girders supporting vertically spanning panels above.

For example, the mechanical room for the new childrens' medical/surgical building of the Long Island Jewish Hospital in New York City, needed a much greater story height than the other floors, in addition to requiring a solid wall. The building was designed by The Architects Collaborative, Cambridge, Mass.

One other building features a solid wall of precast architectural concrete. The wall consists of a precast panel, acting as a girder, spanning 30 ft between gravity supports. Panel is 6 ft-8 in. deep, 2 ft-6in. above the floor, and 4 ft-2 in. below. Gravity supports are actually at the end of 10-ft cantilevered structural steel girders, which were designed with deflection limitations. The horizontal panel girder supports vertically spanning panels which are attached to the roof framing at the top and the girder panel.

On the flip side of the wall, the horizontal girder panel at the floor spanning between vertical struts is used only for lateral support. Steel-tube stubs were also placed at intermediate span points for lateral bracing of the girder panel. The stubs extended below the floor and were secured to the steel spandrel top and bottom flange. Steel spandrel in turn was braced against torsional movement by framing beams.

An all-glazed type curtain wall will require

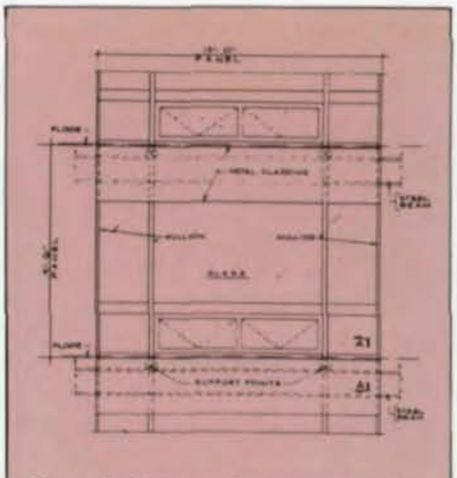


Figure 4—*Curtain-wall panel with mullions*

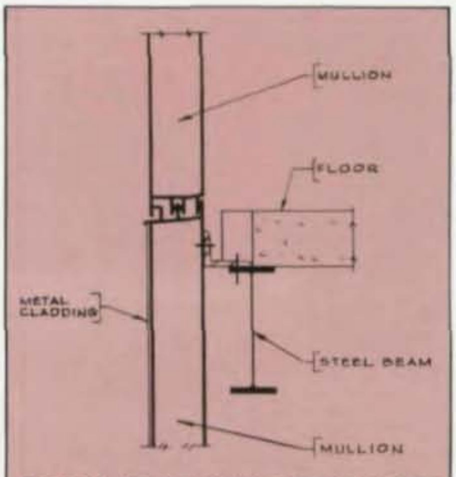


Figure 5—*Section showing support of lower panel at upper point by connection angle*

mullions, or vertical dividing elements between the glazed panels.

This type of wall was selected for the new Vista International Hotel, designed by Skidmore, Owings and Merrill's New York office. The structure is on the World Trade Center site in downtown Manhattan. The panel selection was deliberate for limiting reasons of restricting the total weight of the structure on its base supports. The base supports, huge transfer girders over occupied space below, were provided for in the original plans, without a preconception of what would be actually built. Restricting the wall weight increased the floor area possible—and the revenue of the hotel.

The mullions were selected for architectural appearance, among other reasons.

☛

They may be extruded aluminum, or formed of gauge steel, or bronze or other metal. Mullions have structural properties, of course, but these may be limited, and additional reinforcing may be required. They are special, in that they have glazing slots and can be supplied in different finishes.

Mullions span from floor to floor with either end connected to the top or bottom flange of steel spandrel beams, or to the slab with concrete inserts. Mullions must be connected with vertical slotted holes at one end with a small space between sections to allow for thermal expansion, and to prevent floor live load from being imposed thereon. Other means of connecting the movable end are also possible.

Figure 4 is an elevation of a typical panel. The panel hangs from the structure at upper points. The bottom of the panel nests into the top of the lower panel.

Figure 5, a section, shows support of lower panel at upper point by a connection angle, provided by facade contractor, on top flange of spandrel beam. Angle sits in a pocket in concrete, and after panel is in final position, the angle is secured and pocket filled with concrete. Panel above nests at top of lower panel. This part of detail was simplified for clarity, to show lateral restraint while providing for vertical movement.

Longitudinal, transverse and vertical slotted holes in beam flange, angle and mullion are provided for complete adjustment. The angle is serrated faced and bolts with serrated washers are used for final connection after adjustment is completed. Angle is aluminum and is painted with bitumastic where it is in contact with steel.

Figure 6 is a section of a wall for a corporate headquarters building now under construction in Rye, N.Y.

Horizontal fenestration, continuous or otherwise, can be accomplished by providing a stiffened metal plate cladding extending between the head of the lower window and the sill of the upper window.

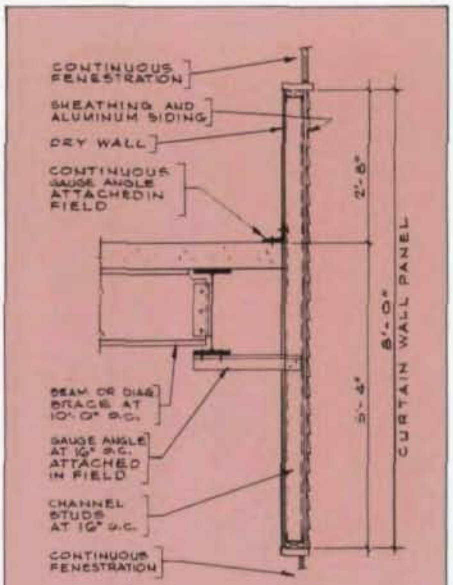


Figure 6—*Curtain-wall panel horizontal fenestration*

The stiffeners are attached to the top and bottom flanges of the spandrel, and thus are cantilevered members. The size of the stiffener must be selected for moment resistance due to this cantilever effect and the wind load on the window supported by the panel must be included in the design. The spandrel beam must be restrained from rotation, or the bottom flange must be capable of spanning horizontally between supports restrictively.

A structurally reinforced metal panel, with truss or girder characteristics, is another type of curtain wall panel used in horizontal fenestration. The solid, full panel is a gauge steel plate with reinforced backing that forms a truss or a girder member, and supported at two locations. The exposed facing is finished to visually acceptable requirements. The gauge thickness selection is important not only for economy, but also, it must not be so thin as to "oil can" or bulge between intermediate backing elements, nor to "ghost" where the plate is attached to the backing.

A unique example of this is the Canadian Imperial Bank of Commerce Tower in Toronto, Canada, designed by Architects I. M. Pei and Partners, New York, and Page and Steel, Executive Architect, Toronto (Figure 7). This 57-story building has a wall with an architectural design calling for an uninterrupted spandrel cladding to express the significance of a 56-ft span. The facade was executed by Kawneer of Canada.

A 1/8-in. thick stainless steel spandrel fascia and half-column cover forming the exterior skin was fabricated and mounted on a back-up frame in one U-shaped piece to cover a 56-ft x 13-ft area.

The fascia assembly is supported by two suspenders of leaf spring steel located near the quarter points (Figure 8).

With a horizontal anchor at midspan, temperature movement is unrestrained horizontally. Clips to beam at top and bottom of panel resist lateral loads from panel (Figure 9).

The exterior skin has to accommodate movements resulting from:

- Temperature differential between itself and the structural frame
- Deflection of the spandrel beams due to gravity and wind loading, the latter also producing column shortening.
- Horizontal displacement of one floor relative to the other, due to lateral loads

Stone and precast architectural concrete are also used to clad buildings. The stone can be backed by precast concrete to create structural panels economically. They can be quite large in size, extending between column lines and deep enough to become the head of the window below the floor and the sill of the window above.

Figure 10 shows the new corporate headquarters for Philip Morris, designed by Ulrich Franzen of New York, located in midtown Manhattan at Park Avenue and 42nd Street.

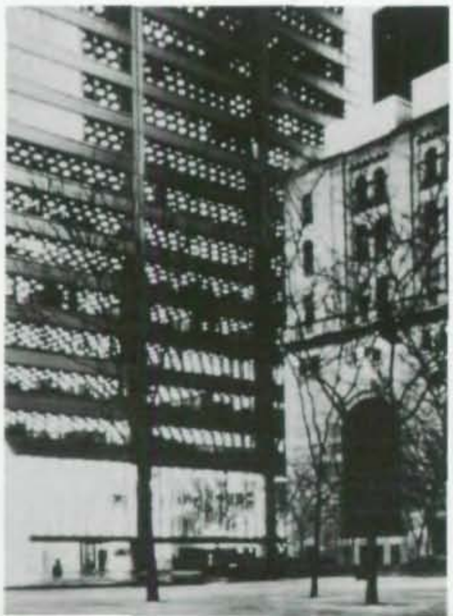


Figure 8

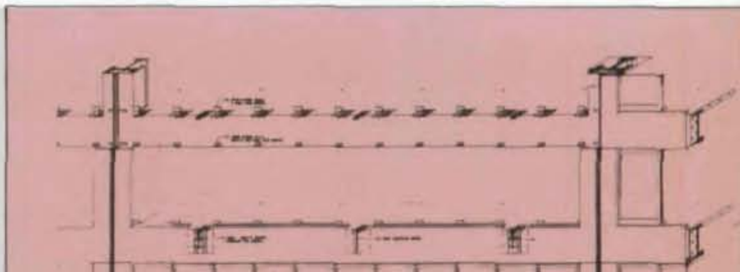


Figure 9—*Clips to beam resist lateral loads*

Figure 7—*Canadian Imperial Bank, Toronto*

Figure 10—*Philip Morris Building, New York*

The Park Avenue side wall is accentuated by vertical column covers, real and false. Horizontal panels between are one-piece, individual panels.

The 42nd Street side is a flush wall. The precast pieces were too large to handle spanning from column-to-column and were designed with a joint at midspan of a bay.

Support for these elements may be on the columns directly, or as close to the column as possible, so as not to affect the spandrel beam size. Panels also are connected at each end to the structure for lateral loads and stability or, a supplementary moment-resisting connection may be devised by the cladding contractor's engineer. Since the panel length is such that the joint is on the spandrel beam, the beam was designed for the imposed loads.

The new corporate headquarters for Arco in Dallas, Tex., designed by I. M. Pei of New York, is shown in Figure 11.

Stone, precast concrete panels as well as masonry are sometimes unitized by preassembling the stone elements on a truss, or other steel framework (Figure 12).

This framework must be designed with respect to support points acceptable on the structural frame. The unitized assemblies span to support columns. The lateral restraint connections at the intermediate points must be flexible, so that vertical loads and movements are not transferred from panel to spandrel, or vice versa (Figure 13).

The beam must be braced to prevent rotation, and if the connection of the panel to the bottom flange of the beam is between braced points, the beam must be checked for bending and torsion between the support points. Compression diagonal braces at the bottom of the beams, or to the bottom of the facade assembly, may be needed where the cost of providing torsional resistance becomes uneconomical, or even prohibitive.

Individual masonry units or panelized units are also used to clad exteriors (Figure 14). Supports for this type are usually lintels hung from spandrel beams. The bottom of the panel may extend below the bottom of the beam, and hangers are provided at 2 ft-6 in. to 4 ft-0 in. spacing, depending on realistic capacities and calculated deflections. Diagonal braces must be provided to prevent the panel from displacing horizontally more than allowed, or the vertical hanger must be sufficiently rigid and connected at the top for moment resistance.

In many cases, however, diagonal braces are not provided at each hanger, and the lintel must span from brace-to-brace when lateral loads are applied. Moreover, hangers transmitting the gravity load to the beam are also eccentric to the beam center line, inducing torsion on the beam between supports. The beams must be checked for this, or additional floor beams framing into the spandrel must be added as needed to prevent rotation.

Design Load Considerations

The design of the attachment must consider all the loading parameters possible.

There is the gravity load, which must include the weight of the panel, window sash and glass, insulation, attached interior finishes, window washing equipment loads at parapets, etc. If the facade is sloping, add snow load or other type of live load. The attachment must be rigid.

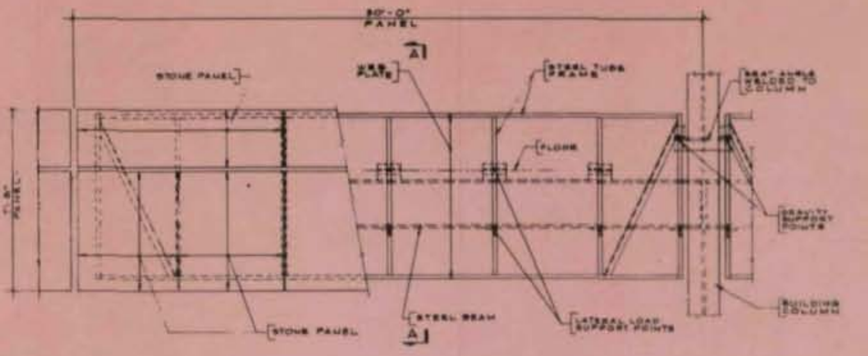


Figure 12—*Unitized stone panels on steel frame*

Figure 11—*New Arco headquarters, Dallas*

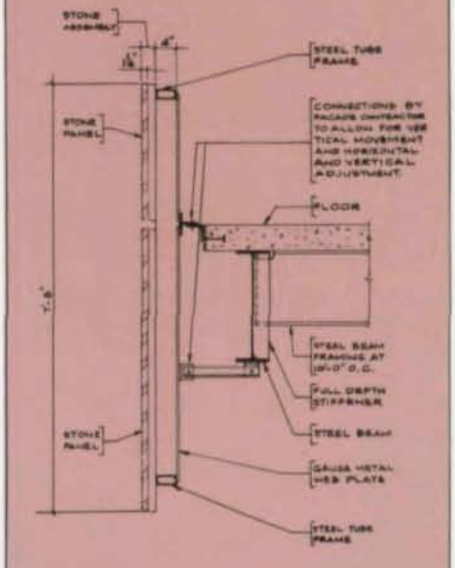


Figure 13—*Lateral load support at each vertical frame member*

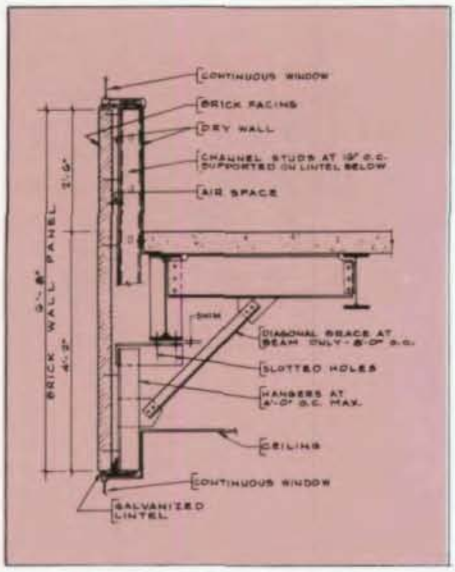


Figure 14—*Individual brick panel unit*

The gravity load discussed may be in a different plane from the point of support of the attachment at the structure. Thus, consider the effect of eccentricity when designing the attachment. This can be resolved by having the connection rigidly connected to the panel and supported on the structural frame as a direct load. The panel, then, must be capable of resisting the moment induced in it from this condition. If the structure has the capability of resisting the eccentric load, the attachment could be a bracket from the building member.

Wind loads to be resisted are established by the architect and engineer. They usually are not the same as the wind load used in the design of the structural frame. The wind loads may be as established by local governing codes, by wind-tunnel study recommendations, if any have been made, and by experience or judgment on the part of the engineer. They must be included in the specification or on the design drawings.

In addition to wind loads thus established, special considerations should be made for suction, wind effect at corners, reentrant reveals, height and any other peculiar building geometry that can be affected adversely by resulting wind forces.

In seismic zones, acceleration effect in any direction is possible during an earthquake. In designing the attachment, consider the zone, building use and public safety.

Another important loading parameter that must be considered is thermal effect. Panels should be designed with expansion joints to enable them to prevent thermally induced stresses with changes in temperature. This relief is defeated if all the supports are fixed. For larger panels especially, it would be very difficult to provide for the load that results from fixity. However, the attachment at the expansion joint must be detailed to permit movement in the line of expansion only, while providing support for other modes of loading.

Erection and Tolerances

The most critical and difficult aspect of cladding attachments is the erection phase—the actual marriage of the exterior facade to the structural frame. The architect and the engineer have designed the basic structure and the cladding to their satisfaction. The contractor's shop drawings have been prepared and all technical requirements have been met. The steel structure is in place, waiting for application of the facade. The facade contractor has fabricated the elements needed to build the wall, and has delivered them to the job site. The facade erector proceeds to build the wall, and although the drawings establish the distance from the center line of column to the face of building wall, the erector soon discovers he cannot hold that figure without adjustments.

We now enter the world of tolerances.

What happens next depends on the architect's specifications as to what is acceptable for facade position; true laser straight vertical plane, or otherwise; and was the structural frame erected within the prescribed limits of the AISC *Code of Standard Practice*, or other specification provisions?

The criteria for column erection plumbness are stated in the *Code of Standard Practice*, paragraph 7.11.3.1. The commentary explains, "The limitations described in section 7.11.3.1, and illustrated in Figures 2 and 3, make it possible to maintain built-in-place or prefabricated facades in a true vertical plane up to the 20th story if the connections which provide for 3-in. adjustment are used. Above the 20th story, the facade may be maintained within 1/16 in. per story, with a maximum total deviation of 1-in. from a true vertical plane, if the 3-in. adjustment is provided."

Furthermore, "Connections permitting adjustment of plus 2 in. to minus 3 in. (5 in. total) will be necessary where the architect or owner insists upon attempting to construct the facade to a true vertical plane above the 20th story."

These criteria are only for plumbness away from and toward the building. Tolerance displacements in other directions are also provided for in the code.

Some designers feel these values for the structural frame are too liberal. Project specifications are sometimes written in a manner that additionally restricts AISC allowances. This tends to increase the steel tonnage price.

Sometimes, designers specify connections with adjustment limits less than permitted by AISC, feeling (or hoping) the frame will be erected more plumb than AISC requires. This is speculative, and if the frame does move out of position more than can be accommodated by connection details, redesign of the connections, at the minimum, and redesign of frame members possibly, will have to be done. Ensuing delays and extra costs will result, not to speak of controversies, and even entanglements with insurance companies and lawyers.

At present, tolerances set forth in the *Code of Standard Practice*, when dealing with buildings below 20 stories, present little attachment design difficulty and no serious cost penalties. However, above 20 stories, tolerances set forth must be dealt with on a special and individual basis.

In high-rise buildings, the practice in our office is to call attention to the facade attachment system at the earliest possible time. Depending on the architectural treatment under consideration, several evaluations are made:

- Facade position—true laser straight or otherwise
- Connection—number and types; material; welding or bolting; shims; slotted holes; installation and adjustment limitation
- Erection tolerances—column plumbness; spandrel straightness
- Cost penalties—cost of steel fabrication and erection to meet tighter than AISC tolerances versus cost of special facade attachments and spandrel beam provisions.

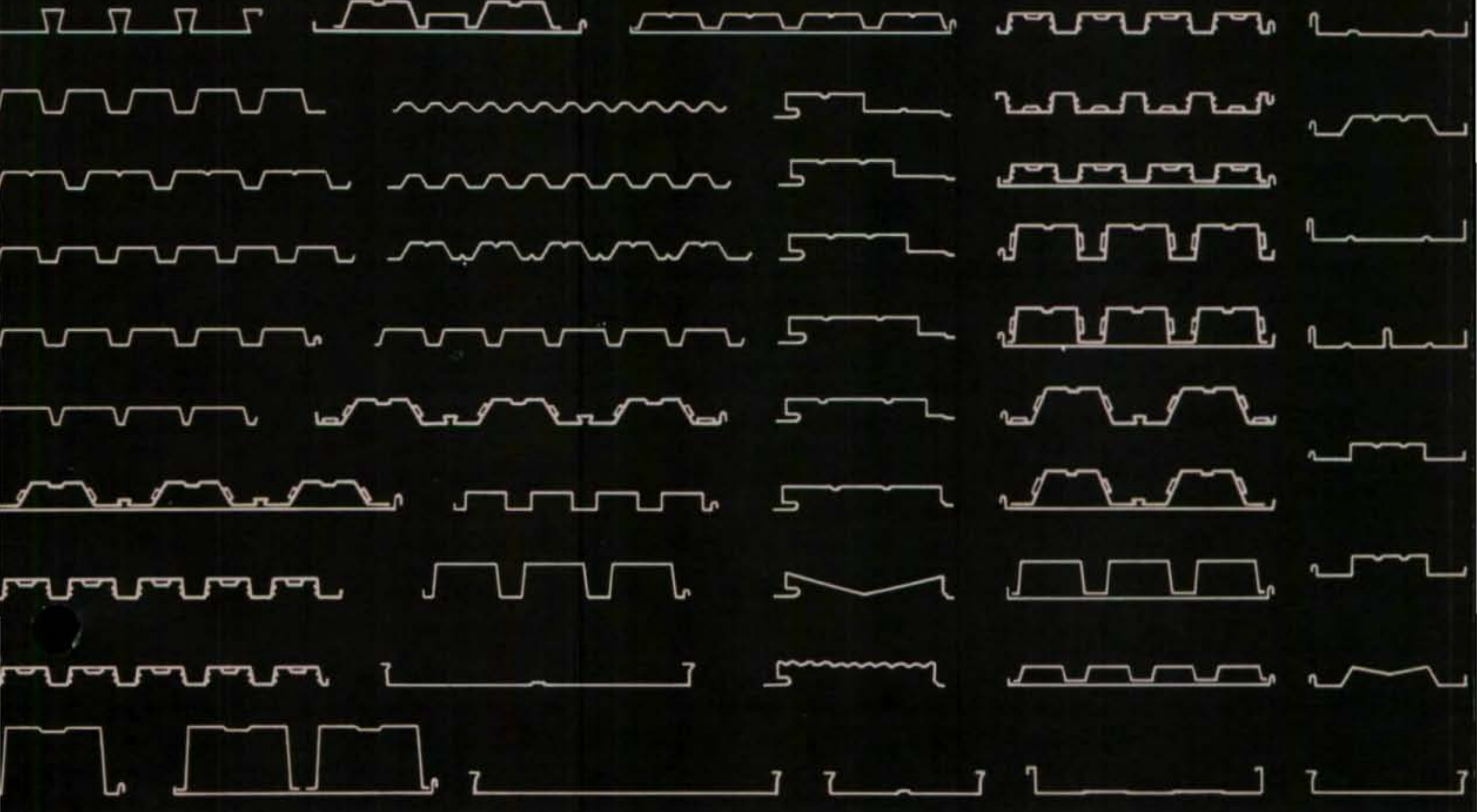
We do not recommend indiscriminate modification of standard AISC tolerances, but intelligent planning and design to determine the least costly method of achieving facade position in the completed structure.

Inspection & Conclusion

It is prudent, and definitely good practice, for the architect/engineer to insist that the owner provide for inspection of connections during the erection phase by an inspection agency hired by the owner, in addition to the architect and structural engineer's full-time field inspection.

The owner, the design team and the builders must understand each other's problems. Their goals are the same, and they must work together, rather than at cross purposes. Experience is a great teacher, but also it may lull the practitioner into rote. There is no substitute for intelligent planning, and exercising the credo that continuous vigilance in what we do must be the watchword. □

STEEL FLOOR DECKS, ROOF DECKS, CELLULAR RACEWAY SYSTEM, SIDING AND WALL PANELS.



Pick the Profile that's right for you!

Need Some Help?

Epic Metals Corporation is involved daily in engineering and manufacturing Composite Decks, EPC Cellular Raceway System, Cellular Decks, Roof Decks, Form Decks, Roofing and Siding.

Our staff is ready to serve your needs. Architects, Engineers, Contractors . . . give us a call . . . write . . . telex . . . or come and visit.

We also manufacture some of the above profiles in aluminum.

Manufacturing Plants:

- Pittsburgh, Pa.
- Chicago, Ill.
- Toledo, Ohio
- Lakeland, Fla.

Contact us today for Prompt Domestic and International Shipments.

EPIC©
METALS CORPORATION

Eleven Talbot Avenue, Rankin PA 15104
PHONE: 412/351-3913
TWX: 710-664-4424
EPICMETAL BRDK

AMERICAN INSTITUTE OF STEEL CONSTRUCTION
The Wrigley Building, 400 North Michigan Avenue
Chicago, IL 60611

Address Correction Requested

BULK RATE
U.S. POSTAGE
PAID
WHEATON, ILL.
Permit No. 1786