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MODERN STEEL CONSTRUCTION

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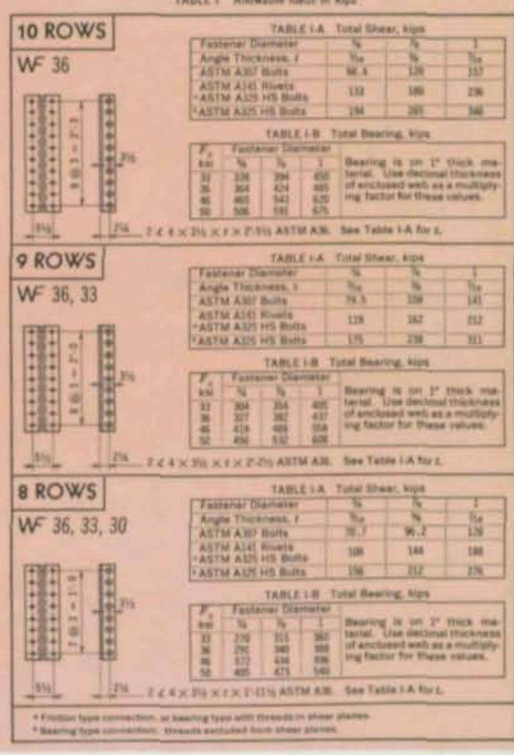

FRAMED BEAM CONNECTIONS

Bolted or riveted

TABLE I Allowable loads in kips

10 ROWS

WF 36

TABLE I-A Total Shear, kips

TABLE I-B Total Bearing, kips

9 ROWS

WF 36, 33

TABLE I-A Total Shear, kips

TABLE I-B Total Bearing, kips

8 ROWS

WF 36, 33, 30

TABLE I-A Total Shear, kips

TABLE I-B Total Bearing, kips

3

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INTRODUCING THE NEW MANUAL

On August 1, the American Institute of Steel Construction announced publication of the sixth edition of the MANUAL OF STEEL CONSTRUCTION, *standard reference and working tool for steel design and construction. This edition of the Manual has been completely re-written and expanded to enable users to design and build steel framed structures under the provisions of the April 1963 adoption of the new AISC Specification. All tables, text and design examples contained in the Manual are based on this Specification.*

Many of the changes are the result of suggestions and recommendations received from over 1200 professionals in construction – engineers, architects, educators and steel fabricators. Their comments, solicited before work started on the Manual over a year ago, covered everything from content and presentation to opinions concerning the best practices. Many of these suggestions have been incorporated in the book.

The Manual is probably the most comprehensive and frequently used handbook ever produced by a single industry. The Sixth Edition is presented with pride by the AISC with the knowledge that its use will enable engineers and architects to translate the economies of the new stronger steels into efficient, aesthetic and enduring structures.

AWARDS OF EXCELLENCE - 1963

by Harlan E. McClure, FAIA

By the first quarter of the nineteenth century steel production had become so sophisticated that high tensile steel cable could be fabricated. In a structural sense Thomas Telford's Conway Castle Suspension Bridge, built in Wales in 1826, was an indicator of things to come. Unfortunately it does not always follow that architectural form goes hand in hand with structural logic. It often takes a period of groping and experimentation before new materials and systems can be fully understood. The towers in Telford's great bridge were regrettably encased in massive medieval stonework to match the ancient castle. And in this country a hundred years later our expanding vertical cities, made possible by steel and mechanical developments, found appropriate form only in rare instances. Happily in recent years there has been a growing concern for expressive use of materials. AISC is dedicated to increasing this awareness.

Steel is a very versatile material which has greatly broadened the architect's palette, and the Architectural Awards of Excellence Program has been offered annually for the past four years to encourage good architectural design and good steel usage. The submissions for 1962 have been judged by a jury consisting of Daniel A. Hopper, AIA of Irvington, N. J.; John B. Skilling, partner of Worthington, Skilling, Helle and Jackson, consulting engineers of Seattle, Wash.; Richard Snibbe, AIA, architect of New York City; Harold Spitznagel, FAIA, architect of Sioux Falls, S. D.; and the author.

Mr. McClure is dean of the School of Architecture, Clemson College, Clemson, S. C. He is currently chairman of the South Carolina Board of Architectural Examiners and a director of the National Council of Arts in Education. He is author of **Architectural Design.**

ROBERT T. BRANDIS

Gibbon Cage, Oakland Zoo, California Architect: Norris M. Gaddis; Associate Architect: John C. Lovejoy

EZRA STOLLER ASSOCIATES

Solar Telescope, Kitt Peak, Arizona Architect: Skidmore, Owings & Merrill

The usual task of an architectural jury is to decide first upon a reasonable and consistent basis for criticism and assessment. It was quickly agreed that no building would be considered for an Award unless it was truly exceptional – generally as well as specifically. Which is to say, the building was first judged as a total performance, in terms of functional solution and beauty, and then for imagination and appropriate use of steel.

Interestingly, there were several excellent buildings which solved unusual functional problems with considerable success. The jury was intrigued with the gibbon cage for the Oakland California Zoo, designed by Norris M. Gaddis, architect of Oakland. The gibbons are playful and arborial primates, and the focal element of this design is a great steel tree. The animal sleeping cages are clustered under an umbrella of steel and fiberglas, from the perimeter of which is draped an enclosing screen of diagonal steel tension cables. This screen combines custodial security with maximum visitor viewing. A spiral steel ramp around the cage permits the visitor to observe the animals from all sides and at several heights. Only greater delicacy in detailing could have improved this distinctive structure.

Immediately compelling was another unusual building designed by Skidmore, Owings and Merrill to house a solar telescope at Kitt Peak, Arizona. The client was the Association of Universities for

Research in Astronomy. One of the jurors remarked how distinctive and dramatic this building was on its lonely site. The solar telescope is a very different instrument from a stellar telescope and requires a very special building, including an inclined shaft 500 ft in length and parallel to the earth's polar axis. The instrument is capable of steady concentration on a 500-mile portion of the sun — 93,000,000 miles away. At its upward terminus the inclined shaft intersects, and is supported by, a vertical heliostat tower, a tubular concrete element with a steel superstructure. The jury was impressed not only with the exacting functional solution and sculptural qualities of the design, but with the logical and unaffected use of materials.

The exceptional elegance and fine relationship of building to site brought Vincent G. Kling's Headquarters for the American Cyanamid Company, Wayne Township, N. J., immediate jury acclaim. The terrain restrictions of a handsome but narrow wooded ridge caused the main building to assume an "S" form. This shape also keeps the very long building from becoming monotonous — internally as well as externally. The structure is framed in steel and detailed throughout with great skill and care. Tinted transparent windows above panels of ceramic enameled glass are framed with extruded aluminum, and spandrels have been developed with a fine sculptural feeling.

"It is difficult to do a good steel residence," said John Skilling of the jury, an opinion quickly echoed by Harold Spitznagel. The jury agreed that the Benjamin E. Weeks residence designed by Nelson, Sabin and Varey, architects of Seattle, was a very good house. The clients wished family unity and individual privacy at the same time, and the central court plan with surrounding rooms accomplished just that. Notable in the design was the logical use of steel structure in combination with wood. The building was arranged to take unusual advantage of its site and is in visual harmony with its setting.

The client represented by one of the entries had a building problem that could not tactfully have been solved other than with steel. The Philadelphia Office and Meeting Hall of the International Association of Bridge, Structural and Ornamental Ironworker's Local No. 401 was considered by the jury to be a visual embodiment of the work of its members. Architects Hassinger and Schwam of Philadelphia developed a two-story steel frame building between existing party walls. The jury felt the bright orange steel portal frame, which forms the facade, and the use of a stair hung with bridge cable in the entry lobby were happy choices.

Some building types have long suffered architectural neglect. Such a category is heating plants and power houses. The jury was especially pleased to give an Award of Excellence to the heating plant for the Hill Farm State Office

Headquarters Office Building, American Cyanamid Company, Wayne Township, New Jersey
Architect: Vincent G. Kling, FAIA

CHAS. R. PEARSON

Benjamin E. Weeks Residence, Seattle, Washington
Architect: Nelson, Sabin and Varey

LAWRENCE S. WILLIAMS

Headquarters International Association of the Bridge Structural Ornamental Ironworkers Local No. 401
Architect: Hassinger & Schwam

WILLIAM WOLLIN STUDIO

Heating Plant, State Office Building Complex, Madison, Wisconsin
Architect: Stanley Engineering Company; Marvin E. Werner, AIA

Building Complex in Madison, Wisconsin. Architect Marvin E. Werner, AIA of the Stanley Engineering Co. of Muscatine, Iowa, has gracefully combined a 250-ft brick chimney with two other masses, contrasting brick with blue-green enamel metal siding in this solution. The structural frame, as well as other components, are of steel. Daniel Hopper of the Jury of Awards expressed the pious hope that this building would influence future plant design.

BOB JACOBSON

Aldrich Recreation Arena, Ramsey County, Minnesota
Architect: Haarstick Lundgren and Associates, Inc.

MODERNAGE PHOTO SERVICE, INC.

Consolidated Marine, Inc., San Pedro, California
Joint Venture: Kistner, Wright & Wright, Edward H. Ficket, AIA, S. B. Barnes and Associates

AMIR FARR

Press Box, Pasadena Rose Bowl
Architect: Breo Freeman, AIA

Haarstick Lundgren and Associates of St. Paul, Minnesota, were the architect-engineers for the Aldrich Recreation Arena in Ramsey County, Minnesota. This multi-purpose, low-budget building was designed with simplicity and strength. The jury appreciated these qualities and the pains taken to keep the building mass low, which reduced construction costs and kept the building from becoming too assertive. The steel truss roof structure is expressed by using the roof depth as a bold cantilever above a narrow continuous strip of ribbon windows. Sun control is thus provided and the roof appears to hover. The unobstructed view of the arena for boxing, hockey, basketball, exhibits and conventions was thought most commendable by the jury.

Too often port and dock buildings are an unplanned hodgepodge of corrugated iron. The jury was greatly pleased to find in Consolidated Marine, Inc., port facilities for San Pedro, California, unusual qualities of architectural excellence. The building complex was a joint venture of Kistner, Wright & Wright, architects and engineers, Edward H. Fickett, AIA, and S. B. Barnes and Associates, structural engineers. All of the firms are from Los Angeles. Distinctly nautical in flavor, the building access to the upper level is via forked flying ramp bridges. The pleasant and convenient accommodation of all functions and the dramatic horizontal sweep of the building group was particularly impressive to jury member Richard Snibbe, AIA. After a careful consideration of prestressed concrete, steel was selected for the building not only for the basic structure but also the architectural detailing.

The Pasadena Rose Bowl is well known to most Americans. In view of the national interest in the annual festival in which the famous football game plays a major role, the existing wooden press box has long been inadequate and was removed to make way for a new facility. Breo Freeman, AIA of Pasadena, was given an Award of Excellence for his addition of a new press box to the existing stadium. The jury thought his problem a difficult one, and that he solved it logically and simply with the use of steel. The new press box is approximately 285 ft in length and is located on the west rim of the Rose Bowl. Access is provided by a free-standing elevator tower, a dramatic 100 ft in height, connecting to the box which projects above existing Rose Bowl seats with three levels of bridges. The view from no existing seats was impeded by this new structure.

The jury felt the American Institute of Steel Construction was to be commended for its annual program of Awards for Architectural Excellence. This year's submissions brought home forcefully the broad range of building problems that can be best solved functionally, economically and aesthetically with steel.

INNOVATIONS RESULT IN LOW-COST APARTMENT HOUSE

by Harold C. Smith
Regional Engineer, AISC

Can a steel frame compete with wood construction in the field of one- to four-story apartment buildings? Consulting Engineer Cecil H. Wells, Jr., San Mateo, Calif., together with Architect R. R. Zahm, AIA, Burlingame, Calif., thought so as they started preliminary designs and estimates for a new senior citizens' apartment project to be known as Pilgrim Plaza in San Mateo. Careful attention to detail and an open mind to new ideas and applications of tested methods and materials proved it could: the low bid was $11.30 per sq ft for the steel-framed structure.

To prove their thinking valid, Messrs. Wells and Zahm began with a careful comparison, not only of two structural materials, but of two different structures. Each was laid out to meet the basic project requirements and to utilize best the framing material under consideration. The two criteria established by the architect were low cost and neat, clean-cut architectural lines differing somewhat from the conventional appearance prevalent in low-rise apartment construction. These are not always easily reconciled.

Timber framing generally satisfies the first of these requirements, and the flexibility of steel framing can produce any degree of architectural freedom desired. Both the architect and the engineer felt strongly enough about the importance of the latter requirement to launch their detailed investigation.

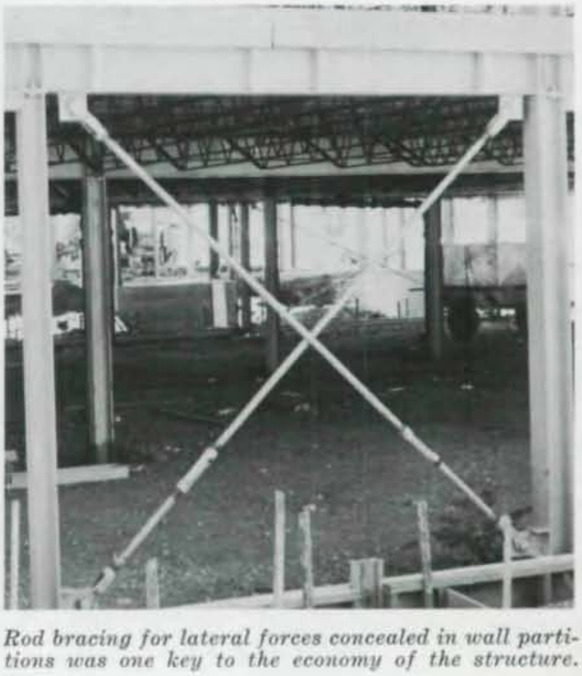
Mr. Wells felt the usual preliminary estimate would not be adequate in this case and set out to make the most economical design and accurate estimate possible. Having experienced success with several new ideas in his own two-story, partial-steel-frame office building, Mr. Wells saw no reason they should not be equally applicable to apartment construction. These ideas were incorporated into various steel and wood designs which were then priced out by the general contractor, H. Christensen & Sons, San Mateo. Mr. Wells was pleasantly surprised to find that his efforts had produced a negligible difference between the steel structure and a similar wood structure. He felt this was a major breakthrough in the type of building thought heretofore to be almost exclusively reserved for wood construction.

As the design reached its final stages, it was found that further savings could be accomplished, leaving enough money in the budget to provide several luxury architectural items. Included among these are private patios for all first-level units, a planted inner court, a large second-story sundeck and social hall for the residents, as well as carpets and draperies throughout the building.

One of the biggest factors in the low cost of this steel frame is the use of rod and turnbuckle bracing for lateral forces. Widely used in industrial construction to obtain simplified connections and maximum utilization of material, this system has seldom been seen in residential buildings. It is frequently ruled out by stud wall construction which leaves no space between the faces of the wall. However, with the employment of all hollow-wall construction, a braced frame became possible. Exterior walls are of steel stud construction and all interior wall surfaces utilize Pabcowall Quiet Zone wallboard. This material is capable of spanning as much as 12 ft vertically. Two thicknesses, one on each face of the wall, give a 47 to 50 decibel sound transmission loss rating according to manufacturer's tests. The wallboard provides space for lateral bracing as well as flexibility and ease of placement for utility lines.

Use of A36 steel also contributed to the low-cost steel frame and the resulting over-all weight of 3.38 pounds of structural steel per square foot. Open-

The planted interior court of Pilgrim Plaza permits direct access to the garage (left) and to the various sections of the apartment house.



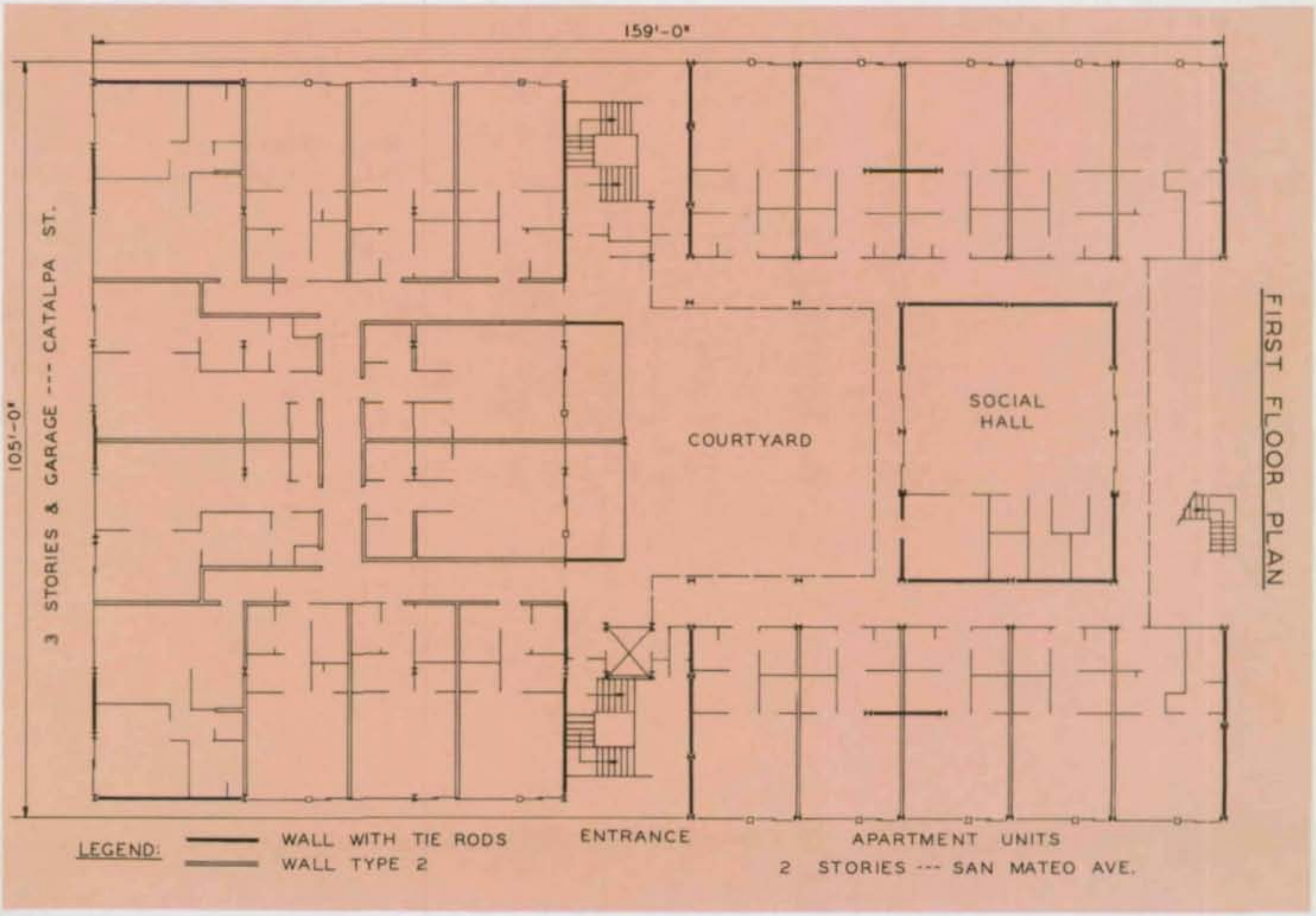
Rod bracing for lateral forces concealed in wall partitions was one key to the economy of the structure.

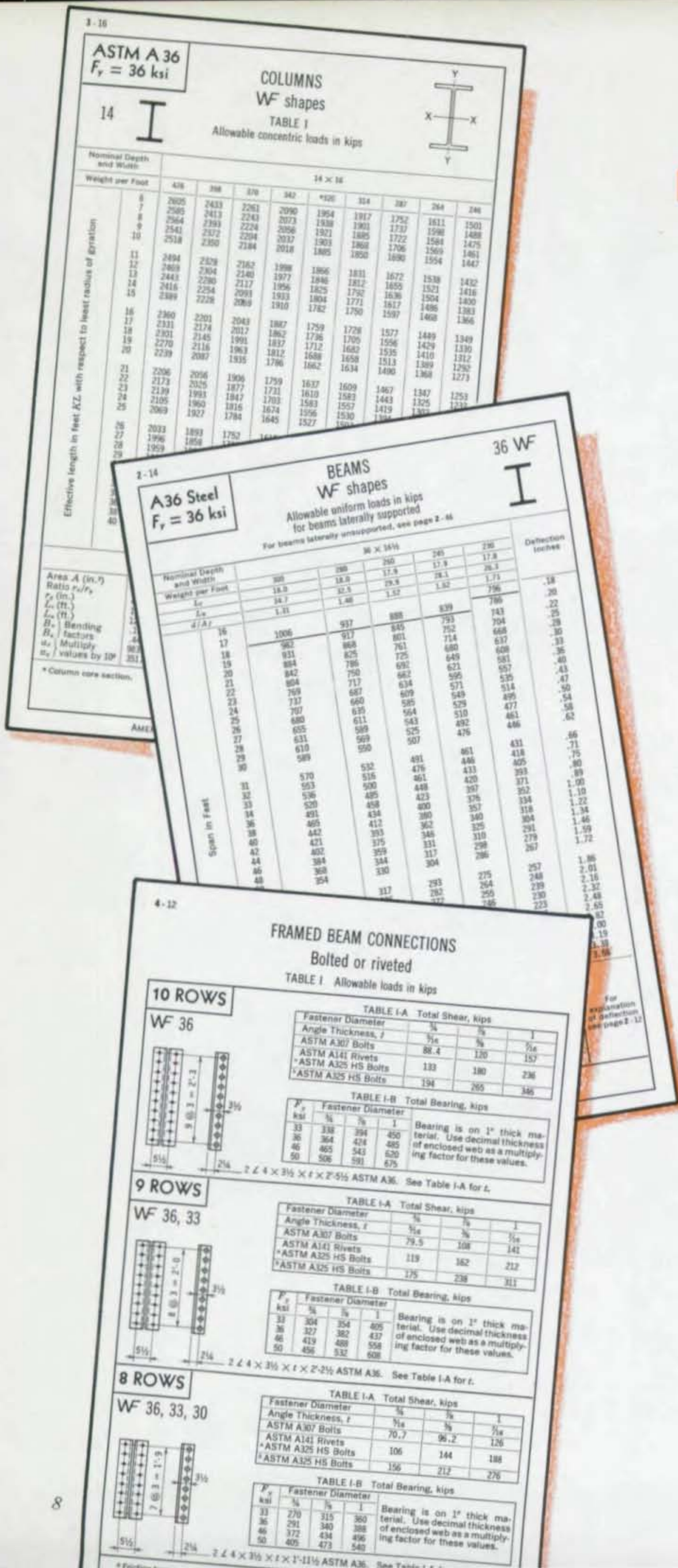
Careful design of the Pilgrim Plaza senior citizens' apartments provided luxury features on an economy budget.

web floor and roof joists and a small amount of Z joists in the exterior corridors amounted to another 2.50 pounds per square foot, for a total steel weight of 5.88 pounds per square foot.

Conventional concrete fill on metal deck was used on the floor over the parking area. Other floors utilized lightweight, sound-absorptive concrete known as "Aerofill" on metal deck. This material, with a maximum density of 100 pounds per cubic foot and a minimum compressive strength of 1700 psi, provides a 50 to 55 decibel floor. Metal deck was 26 gauge high tensile material with a minimum yield point of 90,000 psi. In areas of less than 500 pounds per foot of horizontal shear, the deck was used as a diaphragm as well as furnishing a form for the concrete fill. Structural steel was fabricated by San Jose Steel Company, Inc., San Jose.

Total contract cost of the basic structural frame, including structural steel and joists, metal decking and concrete floor fill was $69,700, for a square foot price of $1.64. This represents less than 15 per cent of the total contract price of $484,000 for the 42,600-square-foot (over-all) structure. The finished project, containing 56 studio and one-bedroom apartments, will be entirely of incombustible construction. It consists of four inter-connected buildings, one having one story, two of two stories and one with four floors.





HIGHLIGHTS O

The 1963 Sixth Edition Manual of Steel Construction is a completely new reference book created to save architects and engineers design time. It contains more precalculated design information, notes and graphs than the previous (fifth) edition to permit quick and accurate solutions of steel structures as well as many changes and additions.

First and foremost is the switch from ASTM A7 to A36 steel as the basic construction material. The entire book has been reoriented toward the use of A36 and higher strength steels. By using accompanying conversion factors, the tables on A36 beams can be applied to high strength steels with yield points up to 50,000 psi (A242, A440 and A441). Separate tables have been added for column loads for high strength steels, and use of a conversion factor is not necessary.

Many innovations are included such as design examples for quick familiarity with the new material as well as references to the specific sections of the Specifications. Even the tables on dimensions, weights and properties of rolled shapes have been thoroughly revised, for, even though the geometry of the shapes has not changed, the applicability of the information has – depending on the particular grade of steel being considered for a design.

Another major improvement is a completely revised chart on "Allowable Moments on Laterally Unsupported Beams." The chart has been simplified so that an engineer can now design directly from the Manual. The chart gives bending moments for compact shapes with maximum bending stress, and for non-compact shapes with reduced stress. It also allows for necessary reductions of moment in spans where bracing is spaced at intervals such that stress reduction becomes necessary.

Use of explanatory notes and symbols for high strength steels throughout the volume will virtually remove the chance

THE NEW AISC MANUAL

for design errors. They will also permit the designer a much more accurate selection of steel grade and section.

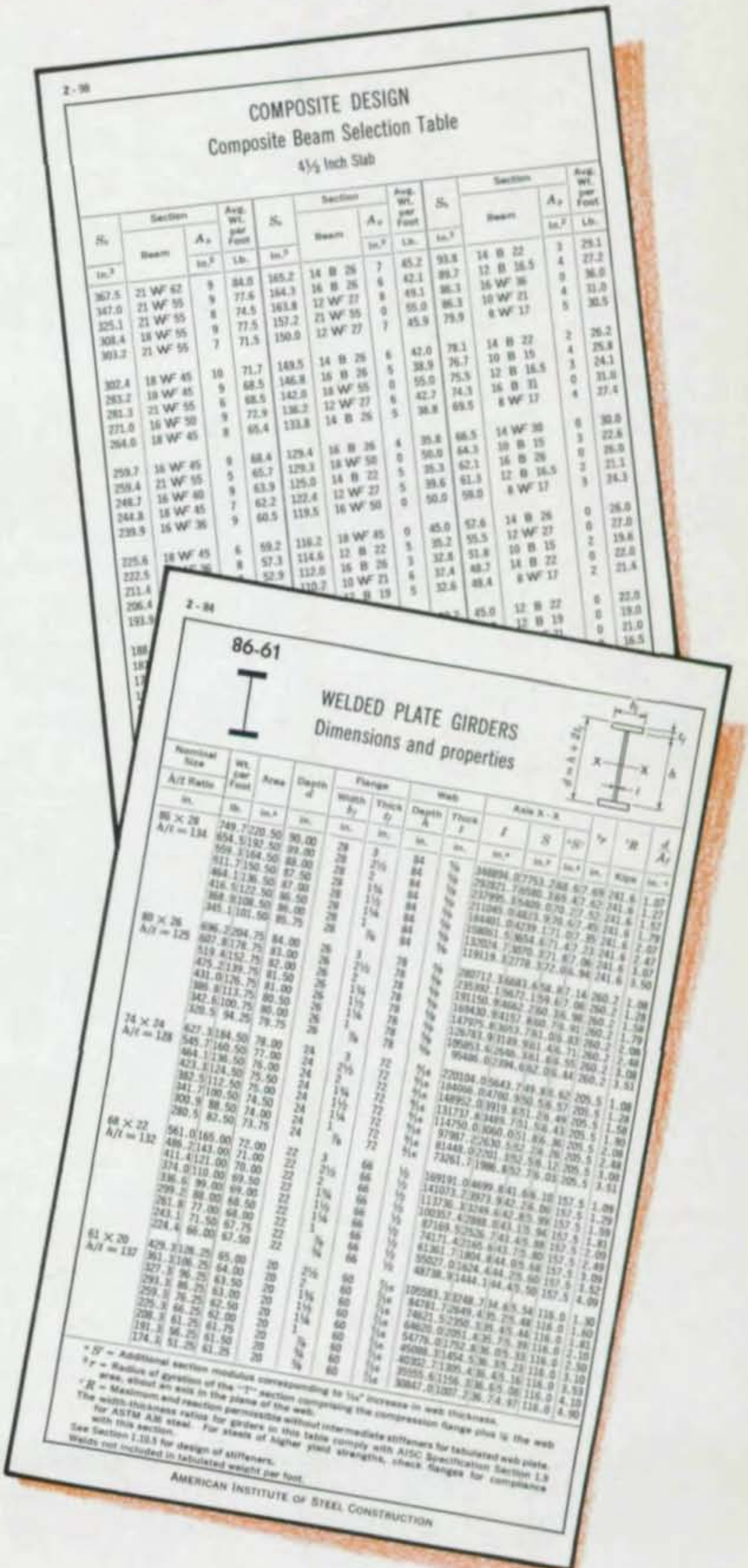
The discussion and tables on column loads have been revised to include factors for interaction formulas, and cover both axially loaded columns and columns with combination axial and bending stresses. With these factors, the new column load tables cover a wide range of conditions that may be encountered, yet they provide a simplified approach to column design. The factors permit the designer to come up with a direct solution to the column design problem for either axial loads or combined axial and bending stresses. With the smaller columns allowed there is the saving in space as well as saving up to 15 per cent of costs and materials.

Another completely new section of the Manual is devoted to connections. Ten principal tables cover bolted, welded and riveted – framed, seated and special connections and combinations of these. The Manual provides simple tables of coefficients for strength of bolt, rivet and weld groups, and combination groupings as they might appear in actual connections. All of these convenient design aids are expected to be important time-savers in designing efficient and economical connections.

In addition to the tables and suggested details, the section on connections outlines steps for designing for continuous welded construction. It also gives detailing practice information on spacing, clearances, weights and dimensions of bolts and rivets. This section permits a wide choice of connections to suit specific loads, design conditions and construction methods.

Two all-new sections cover design of plate girders and composite design for building construction. Economy tables, useful in plastic design, have also been added.

The plate-girder design section contains an all-new presentation based on the "tension field action" design con-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COMPOSITE DESIGN

Composite Beam Selection Table

4½ Inch Slab

2-84

86-61

WELDED PLATE GIRDERS

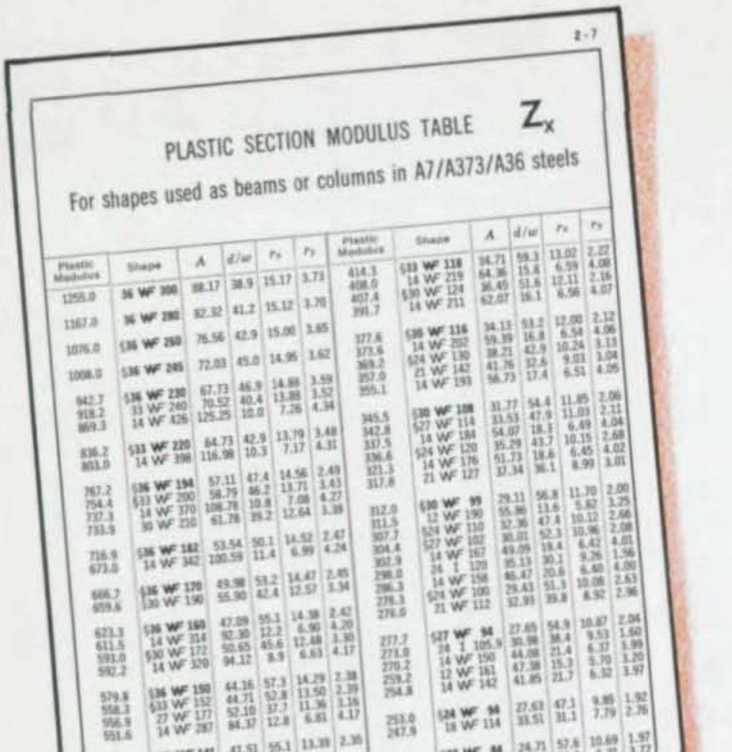
Dimensions and properties

AMERICAN INSTITUTE OF STEEL CONSTRUCTION cept. This design consideration, based on results of research findings, makes obsolete the text on this subject in the fifth edition of the Manual. This new concept, keyed to the new Specification released last year, permits fewer intermediate transverse stiffeners and may permit thinner web plates.

A new table serves as a design aid for welded plate girders. The table contains section properties just like the tables for rolled shapes. From the table, a designer can pick a section that suits his conditions, then check it against his problem. This procedure will substantially reduce calculations needed in designing by "trial and error" methods, required where such data is not available.

Composite design for building construction is covered in a new 30-page section and is included in the Manual for the first time. It contains a general discussion of the application of composite design and includes tables and design aids that assist in design.

Because of the infinite number of possible combinations of beam dimensions, beam spacing, concrete strengths and slab thicknesses, all conditions cannot be included in the tables. But they are expected to cover about 80 per cent of ordinary design conditions, based on 3000 psi concrete and a choice of three slab thicknesses, 4, 4½ and 5 inches.


PLASTIC SECTION MODULUS TABLE Z_x

For shapes used as beams or columns in A7/A373/A36 steels

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

One of the tables is similar to the section modulus economy tables for rolled steel sections. There are three versions of the table – one for each of three different slab thicknesses. Another table, also in three versions, covers section properties of the combined steel and concrete beams.

The theory and applications of plastic design, first announced in 1957, are treated separately in the AISC book, **Plastic Design in Steel.** Provisions covering use of plastic design are incorporated in the new AISC Specification, and a plastic section modulus table covering all rolled shapes that may be used is included in the new Manual. The revised Manual makes the plastic design concept simpler and easier to use.

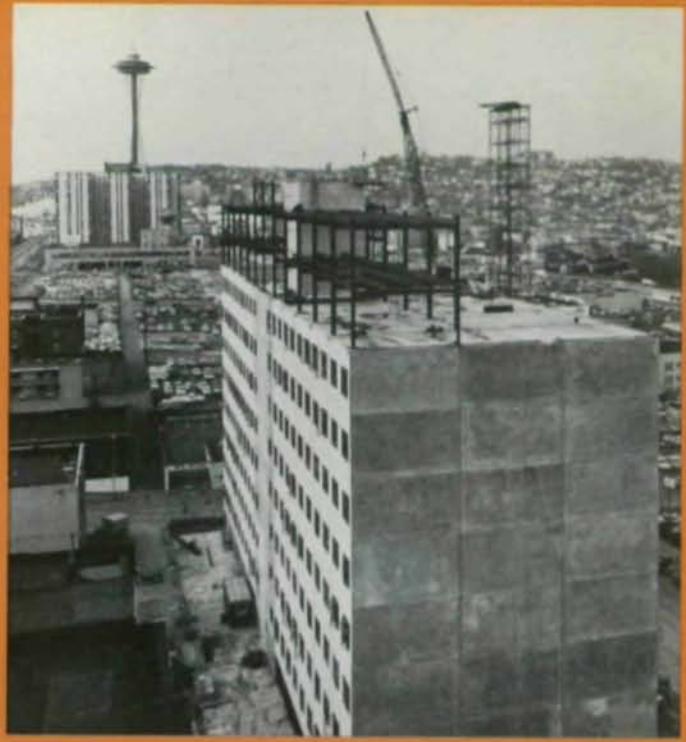
Structural materials and other steel industry information not included in previous editions of the Manual are covered by new tables in the Sixth Edition. For example, it contains all-new tables giving *properties and column loads for* square and rectangular structural tubes and pipe columns in sizes three inches and up and in several wall thicknesses.

The new book also gives dimensions and properties of new lightweight shapes. Properties of tees cut from rolled shapes, adjusted to meet width-thickness requirements of the Specification, now are given in convenient tables. The Manual also contains specifications and load tables for LA, LH, J and H series open-web steel joists. This new material offers the designer a broader selection of structural components that best suit the design conditions.

Physically the contents of the red-covered book have been expanded by about one-third, or to 768 pages, although the Manual is not much thicker than the familiar blue fifth edition because of the use of thinner, very opaque paper. There are six major sections, with thumb-indexing and a table of contents preceding each section: Dimensions and Properties; Beam and Girder Design; Column Design; Connections; Specifications and Codes; and Miscellaneous Data and Mathematical Tables.

The Manual may be obtained through the New York office of the AISC at $7.00 per copy, postage prepaid. A check should accompany the order.

Steel framing for the first six floors of Seattle's 6th & Lenora Building was erected in less than a month. Note web holes located at midspan where shears are low.



The finished structure has 170,000 sq ft of gross area and 135,000 sq ft of rentable area. The famous Space Needle for last year's World's Fair is in the left background.

STEEL DESIGN ALLOWS EXTRA FLOORS

Preliminary planning for tenant accommodation of the 6th and Lenora Building in Seattle, Washington, indicated a six-story structure. But what began as six suddenly shot up to nine, and with a closing flourish jumped two more floors—without adding to the foundation or reinforcing the lower floors.

Stopping and starting construction while the two subsequent and separate design additions were detailed necessarily added to the cost of the building, but because of the simplicity of the framing there were no special problems for the fabricator.

The result was a low-cost steel-framed office building utilizing steel for vertical support and exterior walls for lateral support and with a host of built-in economies. They included duplication of structural parts, a composite floor system, rectangular connections with no diagonal bracing, the exterior wall system, no painted steel, and the use of high tensile bolts for shop and field connections; all combined to keep construction and steel fabrication at a minimum. In addition, the new AISC Specification aided considerably. And, by spreading the end connections to the maximum, the building was sufficiently rigid with a nominal amount of temporary bracing during erection.

Included in the structural steel's total weight of 560 tons were 200 tons of columns, 120 tons of floor beams, 170 tons of joists and 70 tons of struts and miscellaneous steel. A440 was used for the lower columns, A36 for the upper columns, A441 for the floor beams, and A36 for the balance.

The new AISC value for friction-type high tensile bolts was especially valuable for the floor beam connections. These were 16LB 26 with cover plates at the bottom flange and studs at the top for special composite construction. The maximum end shear was 60 kips. Under the new Specification a value of 18 kips each is allowed for seven-eighth-inch high tensile bolts. Previously only 8.75 kips were allowed for a quarter-inch web.

The holes through the webs of the floor beams were located at midspan, where shears were low. The upper (concrete) parts of these composite members have more than ample shear capacity to handle the loads imposed. To strengthen the shear capacity of the concrete and to assist in tying the whole concrete section to the steel, stirrups were provided extending up from the vicinity of the stud shear connectors.

Field erection of the structural components progressed smoothly and rapidly. A rising gang of five men set as many as 80 pieces in an eight-hour day. All connections were "free" – with no threading of beams down columns and no common connections of beams. Erection of the structural steel and the decking for the first two phases was completed in slightly less than one month each. The last three floors, begun nearly two and one half months later, were erected in two weeks. Time and expenses were also saved by setting in the steel decking as the building was erected. This eliminated the need to use temporary wood planking. Total construction time for the entire structure was about nine and one half months.

Architect Chester Lindsey and structural engineer Richard Hadley collaborated on the design. Pacific Car and Foundry Company's Structural Division fabricated the structural steel. All are Seattle firms.

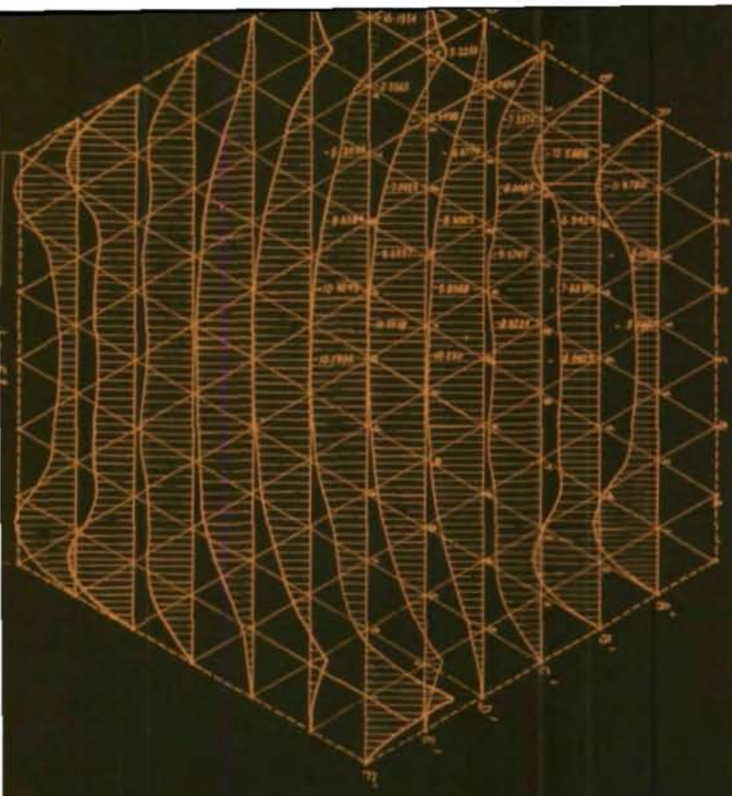


DIAGRAM 1. *Bending moment diagram under u.d. loading covering the whole area.*

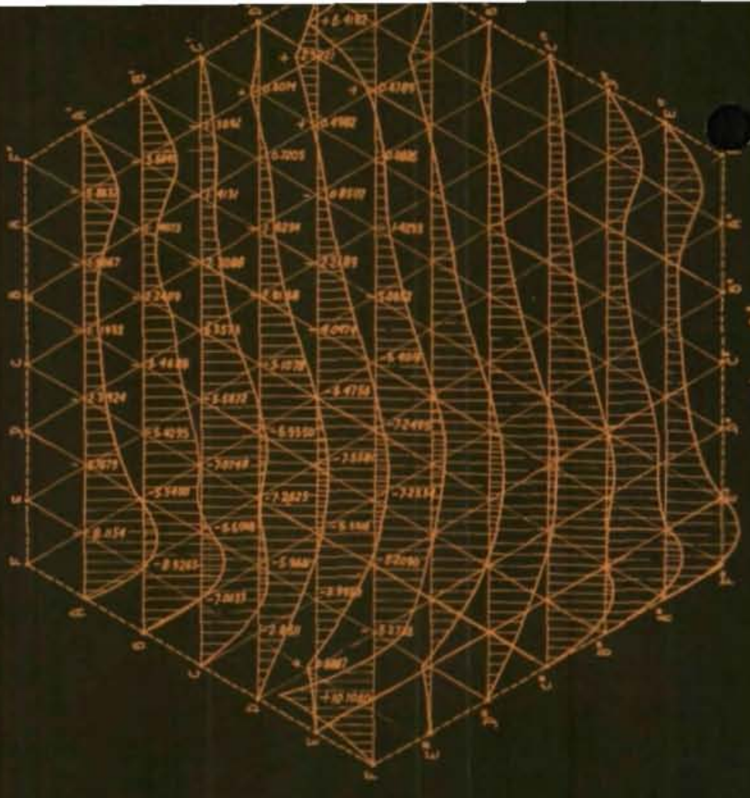


DIAGRAM 2. *Bending moment diagram produced by snow covering half of the structure.*

SPACE STRUCTURES I

by Z. S. Makowski, Ph.D., DIC, AMICE
Department of Civil Engineering
Battersea College of Technology
Battersea, England

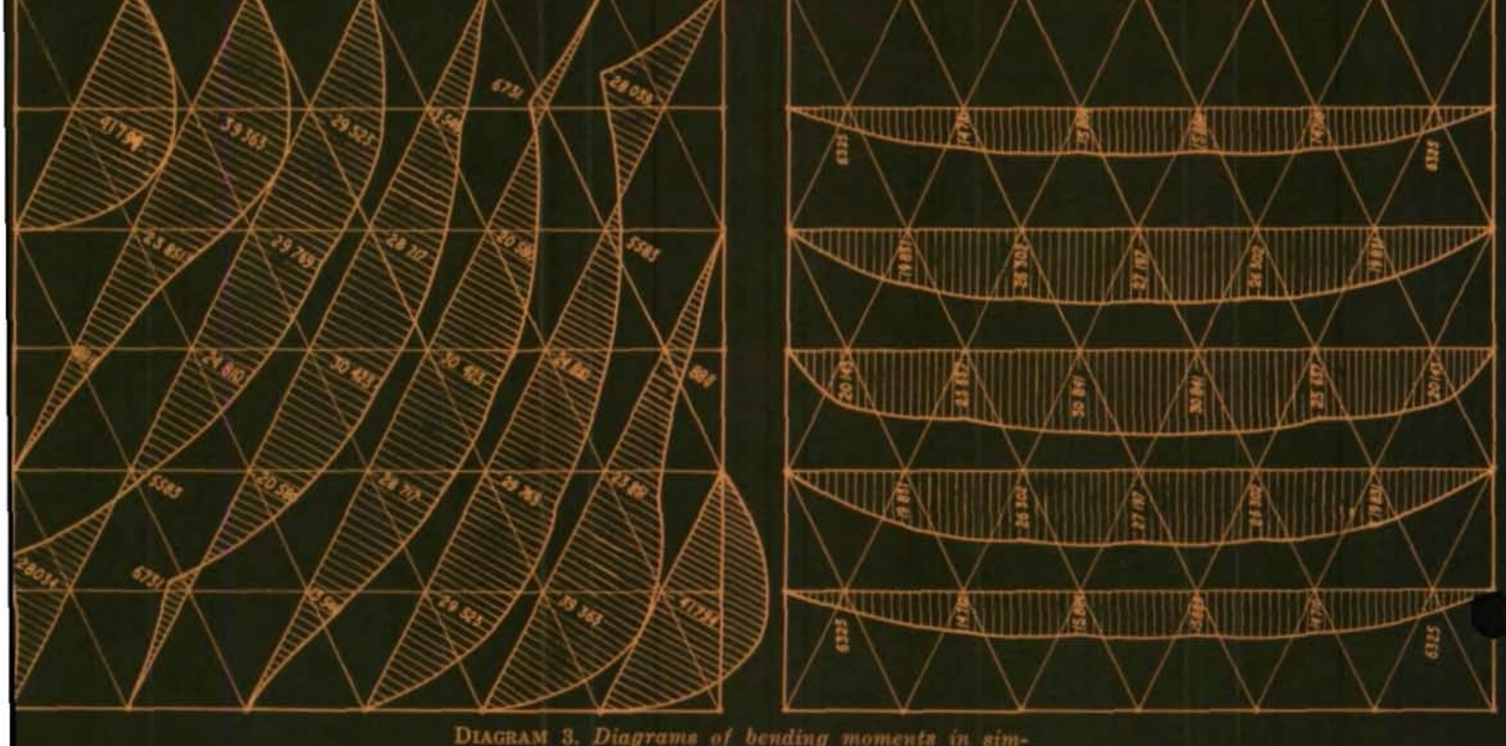


DIAGRAM 3. *Diagrams of bending moments in simplified layout of three-way grid covering swimming pool at Bilancourt, Paris, produced by uniformly dis-*

STEEL

Contemporary architecture differs basically from the traditional in its fundamental concept and its sincerity of expression. New structural shapes are being introduced and new techniques developed. A hyperbolic paraboloid – a structural form virtually unknown 25 years ago – has now become one of the best known and accepted architectural shapes. Suspended cable roof structures are another convincing example of the great changes now taking place in the basic design concepts of structural engineers.

Many eminent architects state that we are now at the beginning of a great architectural revolution marking a transition from the two-dimensional structures of the past to the three-dimensional space systems of the present. The space structure fits into the picture of general scientific and technological progress very well indeed for it is a very modern form of construction. Its popularity is increasing rapidly because of pefabrication, new techniques of mass production of the component parts and improved methods. It is also greatly influenced by the recent development of electronic digital computers.

The advantages of space structures, their inherent lightness combined with great rigidity because of three-dimensional arrangement of members, were well known to engineers many years ago, but the chief barriers to a greater use of three-dimensional structures in the past were the complexity of design calculations and the difficulty of joining the several members at different angles in space.

Welding has greatly influenced the present development of space structures; modern techniques of prefabrication have speeded it up, and standardization of component parts has led to lower costs and simplified erection.

Space structures, as a rule, are highly indeterminate, and their analysis by exact methods leads to a large number of simultaneous equations and makes the computation extremely tedious and time-consuming. For this reason approximate methods had to be employed. The danger of over-estimating the stresses could be avoided only at the risk of under-estimating them. Most space structures built in the past were designed with an unnecessarily high factor of safety and so lost the economic advantage which is one of the main features of good design.

The advent of the electronic computer is changing the whole outlook. It is now possible to tackle and solve very complex structural analyses in a reasonable time. Some commercial firms, specializing in prefabricated space framework, have programmed standard layouts for the computer. By varying certain factors, and keeping others constant, it is now possible to produce a family of curves suitable for interpolation and rapid design. With such tables the designer can compare several alternative arrangements and select the most economical.

In the past, the pressure of time in the design office often prevented a thorough study of several different layouts and made it difficult to determine whether the adopted solution was really efficient or not. The use of an electronic computer changes this approach. It now makes the production of three-dimensional structures both feasible and economical. Some people call this a revolution – perhaps it would be more logical to call it simply just another step in technological progress.

There are various types of space structures already well established in civil engineering practice. Prefabricated grids, braced domes and barrel vaults are probably the most popular ones. Most of these structures have been built in steel because of its strength, reliability, adaptability and economy. By the imaginative use of steel, very interesting space structures can be achieved.

Recent trends in prefabricated steel space structures put special emphasis on three-way grid systems. Structural engineers are interested in this particular arrangement because of the exceptionally uniform stress distribution in grids of this type. Architects like it because it allows great flexibility in design.

A typical example is the three-way spherical grid dome covering a recently built church in Chartres, France. The structure was designed by French architect-engineer S. Du Chateau. He used the SDC system based on a special node connector, into which six steel tubular members may be introduced. The connection allows almost any adjustment in height and inclination of the members prior to final welding. For shallow spherical domes the members forming the grid are not of the same length, though the difference is quite small. This, of course, would be a disadvantage if a conventional method of joining the members were used.

In the SDC system all the tubular elements are cut originally to the same length; they do not require any edge preparation and their length can be adjusted by sliding into the cast connector. Though many engineers are still afraid of site-welding, emphasizing its high cost, the space structures built so far by this system have most convincingly proved their economy.

The structure is monolithic with the members rigidly connected at the nodes. This allows the compression members to have their buckling lengths reduced to 0.7L, leading to substantial savings of material in dome structures, which resist most of the applied loading by compression.

Without a computer the precise analysis of this grid dome would have been virtually impossible. With its help several different loading cases were considered; also the effect of changes in the boundary conditions were readily ascertained. Because of the very small height-to-span ratio of the dome and the rigidity of the welded nodes the members of the structure in addition to axial forces were also subject to bending moments. Diagrams 1 and 2 illustrate the bending moment under uniformly distributed loading covering the whole area and snow lying over half of the roof respectively. It shows the advantage of the grid construction in which the shorter beams, owing to their greater relative stiffness, provide intermediate supports for the longer beams, which then become continuous beams, resting on yielding supports and having overhangs at each end. This considerably reduces the stresses

FIGURE 1. *Internal view of grid dome covering the church at Chartres.*

FIGURE 2. *Three-way double-layer grid built for testing purposes.*

FIGURE 3. *Three-way double-layer grid under test. Steel tubes have been used as the superimposed loading.*

in the central zone of the structure and produces the reversal of stress towards the corners.

Experiments have been carried out on small and large-scale models of three-way grid structures. In 1961 a full-size prototype of a double-layer grid structure was tested under the guidance of the author (Figures 2 and 3). This system, known as the Met-Ram space frame, is another version of the three-way grid and consists of prefabricated latticed units jointed together at the nodes by bolting. All the units are completely interchangeable. The field tests, under a load several times the design load with no sign of structural failure, proved the great stiffness of the grid and its suitability for large spans. After the tests the structure was dismantled and all the units used again as the roof for a school assembly hall in Wales.

Various other designs have been carried out in this system; some have been completed, others will be built in the near future. The test strain readings corresponded very closely with the results of the mathematical analysis carried out by the author using the computer and enabled the flexibility co-efficients of the node connection to be precisely determined.

A more spectaular case of a recent application of such a double-layer three-way grid construction is the roof covering the swimming pool at Bilancourt in Paris (Figure 4) from the design of M. Du Chateau. The SDC system was again used. The structure covers an area 160 ft square. Steel tubes with a constant external diameter of 90 mm. and a wall thickness varying from 3·25 mm. to 8·00 mm. were used for the upper and lower layers of the structure. One of the directions of the three-way grid is parallel to a side of the area.

Because of the versatility of the prefabricated node it was very easy to introduce camber in the structure still using the prefabricated latticed unit of the same overall dimensions. Diagram 3 shows the bending moments for this grid obtained by the author on a computer. This structure is perhaps the best example of the structural changes now taking place from the few massive, solid girders of the past towards systems of gossamer delicacy composed of numerous light-weight members assembled in regular geometrical patterns which are as intriguing to the eye as they are stable in behavior.

One thing only does not change — the material. It is still steel.

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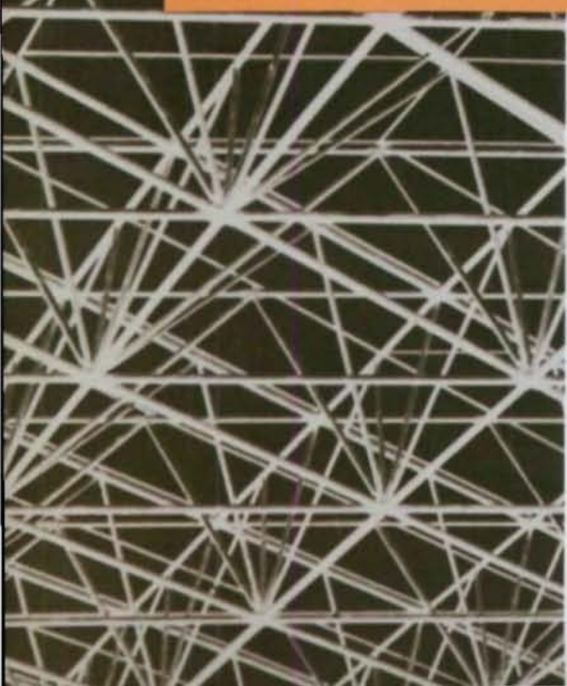


FIGURE 4. *The three-way double-layer grid covering a swimming pool in Paris.*

NEW WELDING SPECIFICATION SETS RADIOGRAPHIC STANDARDS FOR BRIDGES

by Samuel H. Clark
Chief Engineer, AISC

Many structural steel fabricators and highway bridge engineers welcome the new Bridge Specification (D2.0-63) of the American Welding Society released this spring. It is a real accomplishment in keeping pace with modern welding practices. In the seven years since the 1956 Specification was published, a number of new developments have come into common use and are now covered in the Specification. One of the most significant is the standard of acceptability for radiographic inspection.

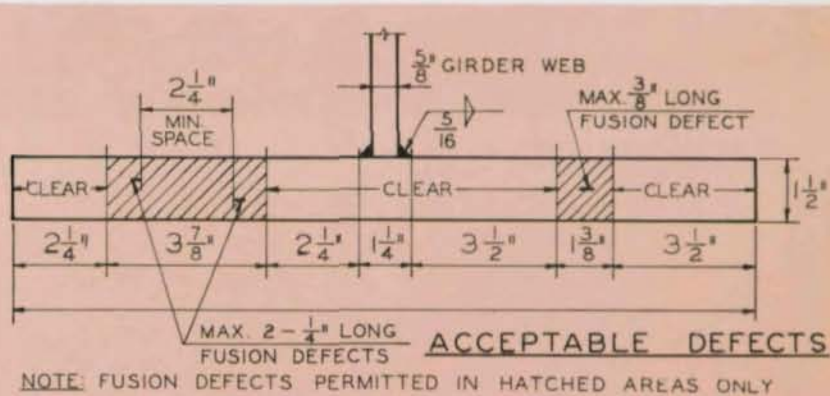
This standard of acceptability is consistent with standards in other types of welding, and it is similar in its requirements to the "Boiler Code" – or the ASME Code for Unfired Pressure Vessels. Now for the first time, structural steel welding has its own "yardstick" for measuring weld quality.

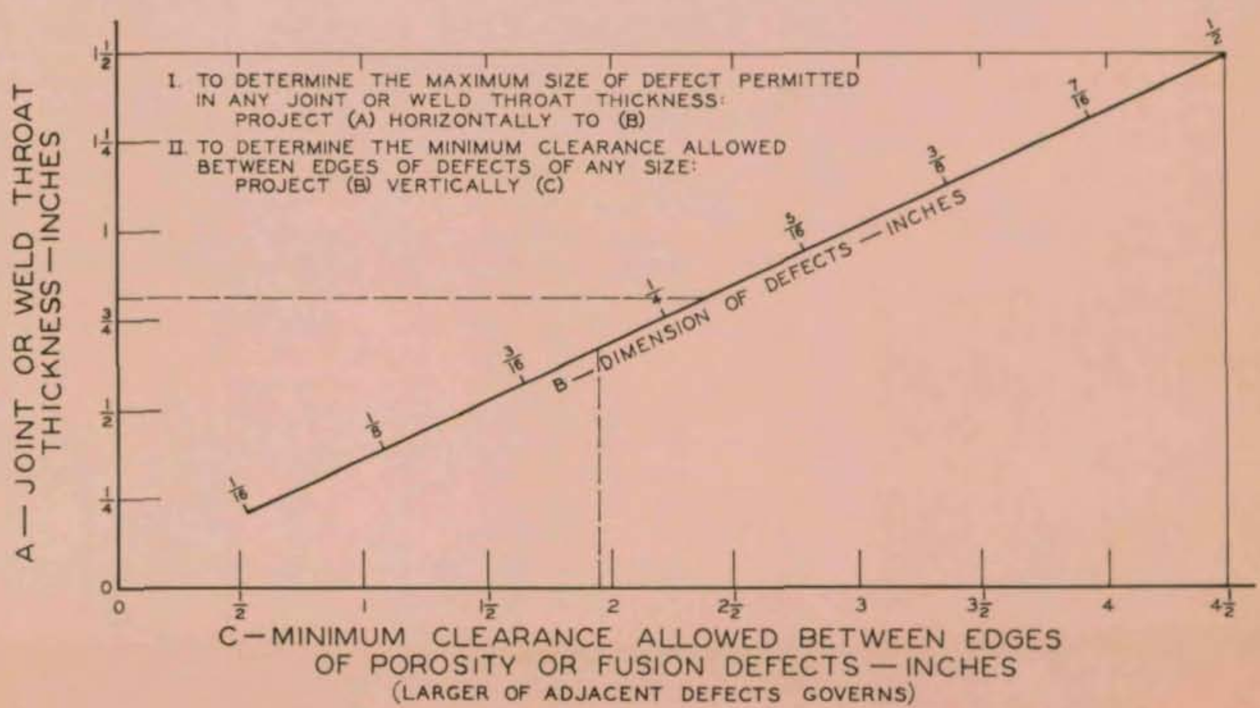
The need for a radiographic specification applicable to bridges has been evident in recent years, but this standard is not necessarily a proper one for buildings where such inspection is not considered necessary. The type of dynamic impact loading found in bridges seldom occurs in a building where static loads only are involved. The level of workmanship in welding should be related to the type of service loads and does vary for different types of work.

The principal requirement which varies from one industry to another is the allowance for porosity and fusion defects. The definition of fusion defects includes three principal types: "Fusion defect signifies (1) slag inclusions, (2) incomplete fusion, (3) inadequate penetration and similar generally elongated defects in weld fusion."

All AWS Standards, whether for boilers, tanks, pipelines or ship hulls, prohibit cracks and require thorough fusion in full penetration butt-welds. The allowance for fusion defects within the joint is given in the chart below (Figure 409 in the AWS Bridge Spec.):

What does all this mean to the inspector and the engineer? Since the typical groove-welded joint in the highway bridge is a splice in a girder flange, special limits are prescribed which prohibit these fusion defects at the edge of a joint and at the junction of flange and web. As an example, the sketch below shows a typical girder flange cross section, as an aid in interpreting the above chart pictorially. This is approximately what the radiograph or the X-ray picture would show as typical of defects allowed in a good weld.



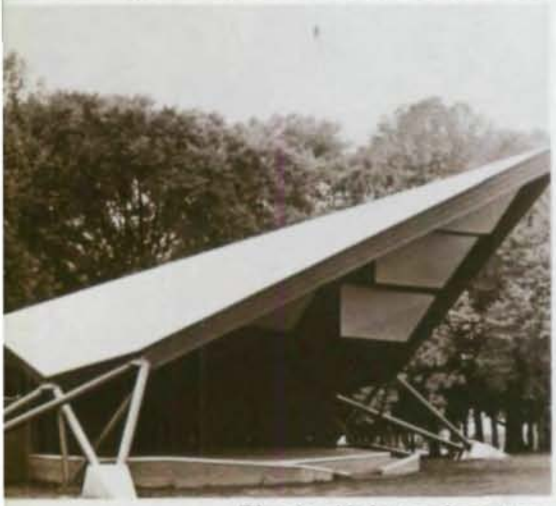


ON WINGS OF SONG

The free-standing roof of the Sertoma Band Shell is like a square that has been folded on a diagonal, with one peak tipped up, and its "wings" clipped.

"Every time I see our Sertoma Band Shell," says one citizen of Lancaster, Pa., "I think of the line, 'On Wings of Song'." However poetic the public response to the structure may be, what got it off the ground was a successful stint of trigonometry.

The double tilt of the roof called for determining the complicated relationship of each roof member to others. The appearance of the structure is deceptive. Its structural system is simpler than a first glance reveals. Actually, the principal roof framework is statically determinate, consisting of a wood deck supported by steel purlins which, in turn, frame into rafters that span from the ridge line down to the foundation. Both purlins and rafters are simply supported.



The six-sided stage has space for a 200-member choral group or a 100-piece orchestra.

Two space frames support the roof. Each is composed of seven pipe sections. Stresses in these members were calculated by the simultaneous solution of the joint equations. Here again, a statically determinate analysis was possible by equating certain reactions to zero.

Design of roof rafters considered the varying axial load due to the difference in the elevation of the supports. Incidentally, critical design loads for the structure were determined by investigation of five combinations of dead, snow, and wind loads. Deflection calculations indicated that certain rafters were not deep enough. To go to a larger wide-flange section in only a few places would have been architecturally objectionable, and from the structural point of view more steel would have been provided than was necessary.

The split or castellated beam was then tried. Not only did this satisfy the deflection requirements, but actually reduced the size of the members. The new radius of gyration about the main axis was substantially higher than before, which, in turn, increased the allowable unit axial stress in each member. For example, the heaviest member in the first design was an 18WF77. The member used in the final design was an 18WF60 expanded to a 24-in. depth.

The band shell was originally designed in 1959 using laminated cypress beams to support the free-standing roof. As with many public subscribed endeavors, fund raising ran into difficulties, and by the time funds were available, construction costs had increased so significantly that the structure had to be redesigned in steel to maintain the original estimate.

A. W. Lookup, structural engineer of Philadelphia, in conjunction with Coleman & Coleman, architects of Landesville, designed the Band Shell. John W. Wickersham of Lancaster, Pa., was the general contractor. The steel was fabricated by A. B. Rote and Company, also of Lancaster.