Introduction to Welded Construction

1. WELDING'S IMPORTANCE TO STRUCTURAL FIELD

Welding has been an important factor in our economy. The progress made in welding equipment and electrodes, the advancing art and science of designing for welding, and the growth in trust and acceptance of welding have combined to make welding a powerful implement for an expanding construction industry.

More and more buildings and bridges are being built according to the precepts of good welded design. The economies inherent in welding are helping to offset evolutionary increases in the prices of materials and cost of labor. In addition, the shortened production cycles, made possible by welding, have helped effect a quickening in the pace of new construction.

Welded construction has paid off handsomely for many architects, structural engineers, contractors, and their client-customers. It will become increasingly important as more people acquire a greater depth of knowledge and experience with it.

2. RECOGNITION OF WELDING

The widespread recognition of welding as a safe means of making structural connections has come about only after years of diligent effort, pioneering action by the more progressive engineers and builders, and heavy documentation of research findings and successes attained.

Today, there just aren't many men in industry who speak disparagingly of welding. Most regulatory agencies of local and federal government now accept welded joints which meet the requirements imposed by codewriting bodies such as the American Institute of Steel Construction and the American Welding Society.

With this acceptance, there remains however a considerable task of education and simple dissemination of information to achieve maximum efficiency in the application of welded design. And, there is even a continuing need for more thorough understanding of welding by codewriting bodies who fail to use tbe full strength of welded joints.

3. WHY WELDED CONSTRUCTION?

There are many reasons for using welded design and construction, but probably the two basic ones are 1) welded design offers the opportunity to achieve more efficient use of materials, and 2) the speed of fabrication and erection can help compress production schedules, enabling the entire industry to be more sensitive and react faster to rapidly shifting market needs.

Freedom of Design

Welding permits the architect and structural engineer complete freedom of design—freedom to develop and use modern economical design principles, freedom to

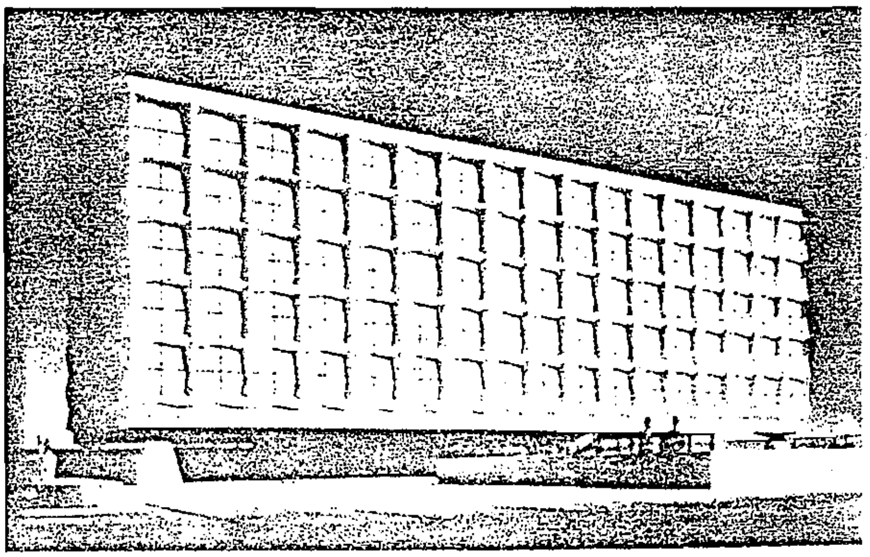


FIG. 1 Indicative of the design freedom offered by unitized welding design, the Yale Rare Book Library's four outside walls are each a 5-story high Vierendeel truss. Each is a network of Greek-type crosses. The structure is all welded—shop and field.

employ the most elementary or most daring concepts of form, proportion and balance to satisfy the need for greater aesthetic value. Just about anything the designer may envision can now be given reality . . . because of welding.

Welded construction imposes no restrictions on the thinking of the designer. Already, this has resulted in wide usage of such outstanding design advancements as open-web expanded beams and girders, tapered beams and girders, Vierendeel trusses, cellular floor construction, orthotropic bridge decks, composite floor construction, and tubular columns and trusses.

Weld Metal Superior to Base Metal

A welded joint basically is one-piece construction. All of the other methods of connecting members are mechanical lap joints. A properly welded joint is stronger than the material joined. The fused joints create a rigid structure in contrast to the nonrigid structure made with mechanical joints. The compactness and calculable degree of greater rigidity permits design assumptions to be realized more accurately. Welded joints are better for fatigue loads, impact loads, and severe vibration.

Welding Saves Weight, Cuts Costs

Connecting steel plates are reduced or eliminated since they often are not required. Welded connections save steel because no deductions need be made for holes in the plate: the gross section is effective in carrying loads. They offer the best method of making rigid connections, resulting in reduced beam depth and weight.

This reduced beam depth can noticeably lower the overall height of a building. The weight of the structure and therefore static loading is greatly reduced. This saves column steel, walls and partitions, facia, and reduced foundation requirements.

Welded connections are well suited to the new field of plastic design, resulting in further appreciable weight savings over conventional rigid frame design.

Savings in transportation, handling time, and erection are proportional to the weight savings.

Available Standards

Arc welding, either in the shop or in the field, has been used long enough to have been proved thoroughly dependable. The AWS and AISC have set up dependable standards for all phases of structural activity. These standards are backed up by years of research and actual testing. They simplify the design of welded connections and facilitate acceptance by purchasers and inspectors.

Other Advantages

Less time is required on detailing, layout and fabrication since fewer pieces are used. Punching or drilling, and reaming or countersinking are eliminated—a substantial saving on large projects.

The typical welded joint produces a smooth, uncluttered connection that can be left exposed, without detracting from the appearance of the structure. Welded

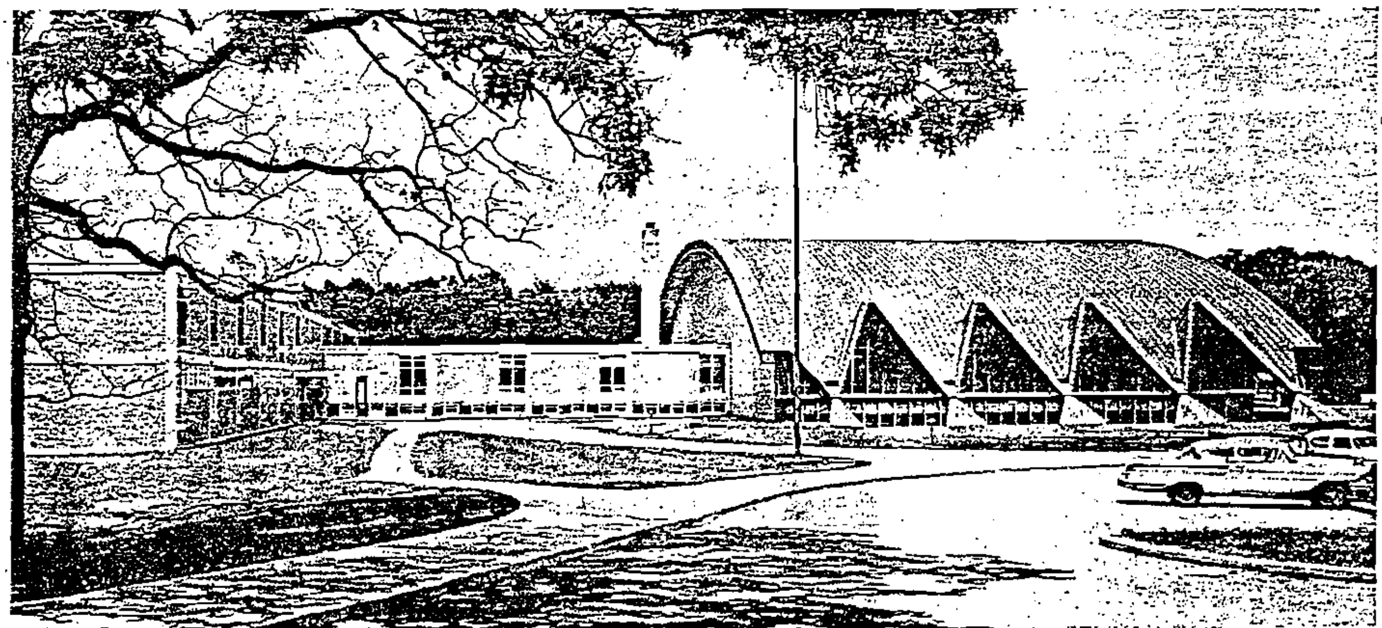


FIG. 2 The athletic unit of Ladue Jr. High School (Missouri) features an all-welded steel lamella roof frame spanning 252', expressing the strength of one-piece welded construction.

joints exhibit less corrosion and require little or no maintenance. The smooth welded joints also make it easier to install masonry, facia and other close fitting members, often reducing the thickness of walls or floors in buildings.

Structures can be erected in relative silence, a definite asset in building in downtown areas, near office buildings or hospitals.

4. HOW GOOD IS A WELD?

Many engineers are unaware of the great reserve of strength that welds have, and in many cases this is not recognized by code bodies.

Notice in Table 1 that the minimum yield strengths of the ordinary E60xx electrodes are about 50% higher than the corresponding values of the A7, A373 and A36 structural steels with which they would be used.

TABLE 1—Comparison of Typical Weld Metals and Steels

Material		Minimum Yield Strength	Minimum Tensile Strength
AWS A5.1 &	E6010	50,000 psi	62,000 psi
ASTM A233	E6012	55,000	67,000
Weld	E6024	50,000	62,000
Metal	E6027	50,000	62,000
(as welded)	E70xx	60,000	72,000
	A7	33,000	60,000 to 75,000
ASTM	A373	32,000	58,000 to 75,000
Steels	A36	36,000	58,000 to 80,000
	A441	42,000	63,000
		46,000	67,000
		50,000	70,000

Many of the commercial E60xx electrodes also meet E70xx specifications. Used on the same A7, A373 and A36 steels, they have about 75% higher yield strength than the steel.

There are numerous reasons why weld metal has higher strength than the corresponding plate. The two most important are:

1. The core wire used in the electrode is of premium steel, held to closer specifications than the plate.

2. There is complete shielding of the molten metal during welding. This, plus the scavenging and deoxidizing agents and other ingredients in the electrode coating, produces a uniformity of crystal structure and physical properties on a par with electric furnace steel.

Because of these, properly deposited welds have a tremendous reserve of strength or factor of safety, far beyond what industry specifications usually recognize. But even without a reduced safety factor, there is a considerable cost advantage.

Inspection and Quality

Much money is spent annually by industry and government in obtaining and inspecting for a specified weld quality. Usually the weld quality specified is obtained, but too often the quality specified has little or no relation to service requirements.

Welds that meet the actual service requirements, at the least possible cost, are the result of—

1) proper design of connections and joints,
2) good welding procedure,
3) good weldor technique and workmanship, and
4) intelligent, responsible inspection.

In the following examples (Figures 3, 4, 5 and 6) test specimens exhibit undercut, undersize, lack of fusion, and porosity. In spite of these adverse conditions,

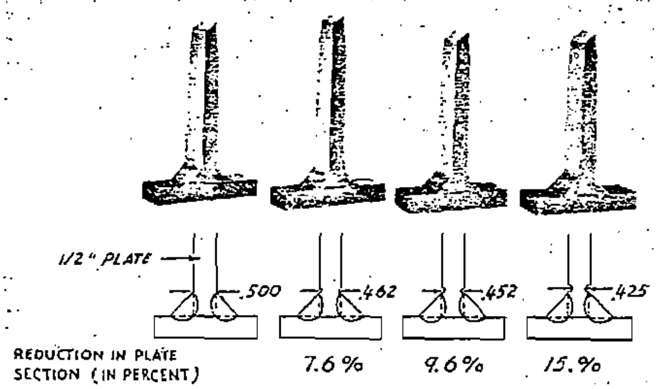


FIG. 3 Test samples prepared to show effect of undercut. Samples were pulled in tension under a static load; in all cases failure occurred in the plate and not in the weld.

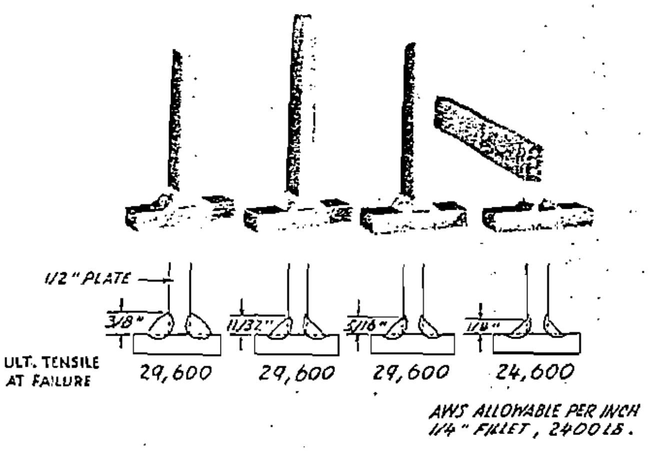


FIG. 4 One rule of thumb says fillet size should equal ¾ plate thickness to develop full plate strength. Using this method, a ⅜" fillet weld on ½" plate should "beat the plate". But so did 11/32" and 5/16" fillets. Not until fillet size was reduced to ¼" did weld failure occur . . . at a stress of 12,300 lbs/linear in., more than 5 times the AWS allowable.

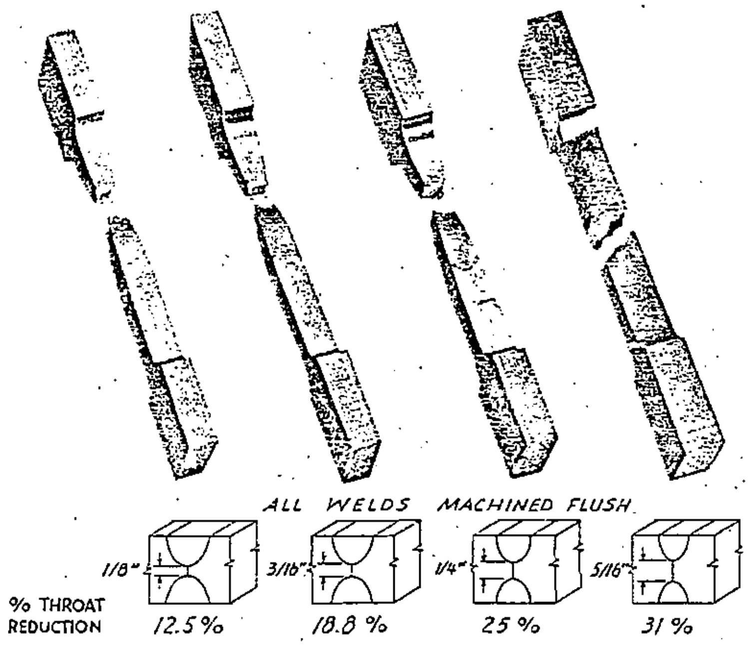


FIG. 5 Weld samples were made, with varying degrees of lack of fusion, as reduced-section tensile specimens. Welds were machined flush before testing, and weld failure did not occur until the unpenetrated throat dimension had reached 31% of the total joint throat.

considered individually, the weld under steady tensile load was found to be stronger than the plate. These examples are not meant to show that the standard of weld quality should be lowered. However, they are striking evidence of how easy it is to make full-strength welds, welds stronger than the plate.

Welding is the only process that produces a unitized, or one-piece, construction. The welded plate is so sound, strong, and ductile as to permit some testing procedures that frequently are impossible or impractical to perform with other connection methods.

The weld is so ductile that it can be readily bent around a small radius, Figure 7. Apparently because it is possible to do so, bend tests are often required. Unfortunately, U-bend test results do not correlate well with actual service performance.

Because it is possible to examine a welded joint by radiographic inspection, some engineers feel this must be done.

Most radiographic inspection is based on responsible standards. These specifications assure the quality required, yet are realistic. Frequently, however, local decisions are made to require more perfect radiographic soundness than the specifications demand.

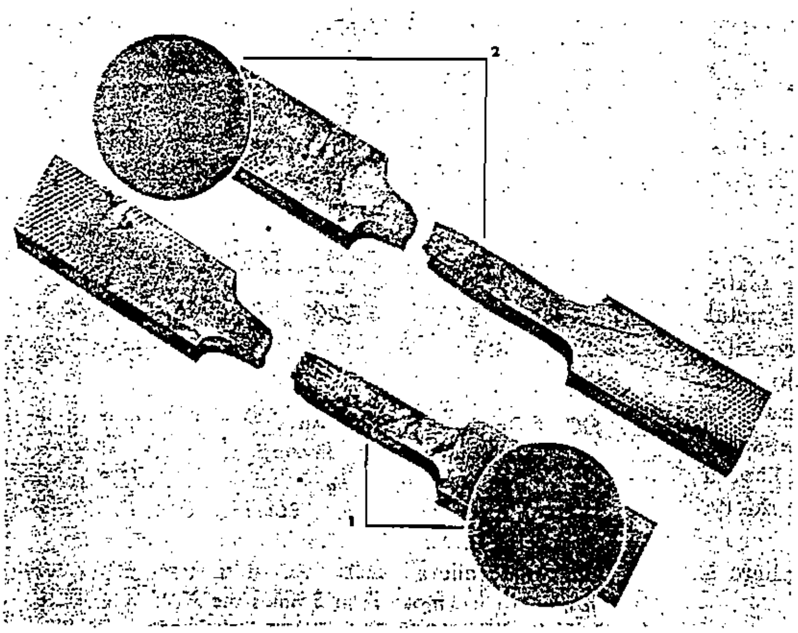


FIG. 6 Excessive porosity (weld 1) as shown by radiograph did not weaken the joint. Weld 2 shows perfect. In both cases the weld was stronger than the plate. Specimens broke in the plate at approximately 60,100 psi.

How Important Is Porosity?

Normally, porosity if it should exist is not a problem, because each void is spherical. It does not represent a notch. Even with a slight loss in section because of the void, its spherical shape allows a smooth flow of stress around the void without any measurable loss in strength.

Tests have shown that a weld can contain a large amount of porosity without materially changing the tensile or impact strength and ductility of the weld. This porosity could amount in total volume to a void equal to 7% of the weld's cross-section without impairing the joint's performance.

The ASME Boiler and Pressure Vessel Code, Section VIII and X, will allow porosity in a weld to the extent shown on charts incorporated into the Code. These charts consider size, distribution, and alignment of voids, versus plate thickness.

The AWS Building Code will allow a slight porosity if well dispersed in the weld. This is defined as "gas pockets and any similar generally globular type voids."

The AWS Bridge Specification allows some porosity. For porosity above $\frac{1}{16}''$ in void size, a table shows minimum clearance between voids and maximum size of void for any given plate thickness.

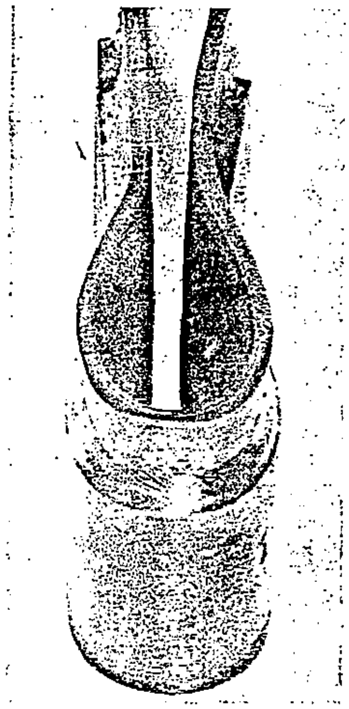


FIG. 7 Weld metal in well-designed joints demonstrate much greater ductility than would be required in any type of structures.

5. DESIGN FOR WELDING

A designer must know the fundamental differences between welding and other assembly methods if he is to detail economical welded members. If a welded girder, for example, were constructed with multiple cover plates, the cost would be excessive. The use of only one flange plate with a reasonable number of butt welded splices, at points where the plate thickness can be reduced, is usually adequate and also gives improved fatigue resistance.

The selection of a connecting system should be made at the design level; for some types of structures, may even influence the architectural concept itself.

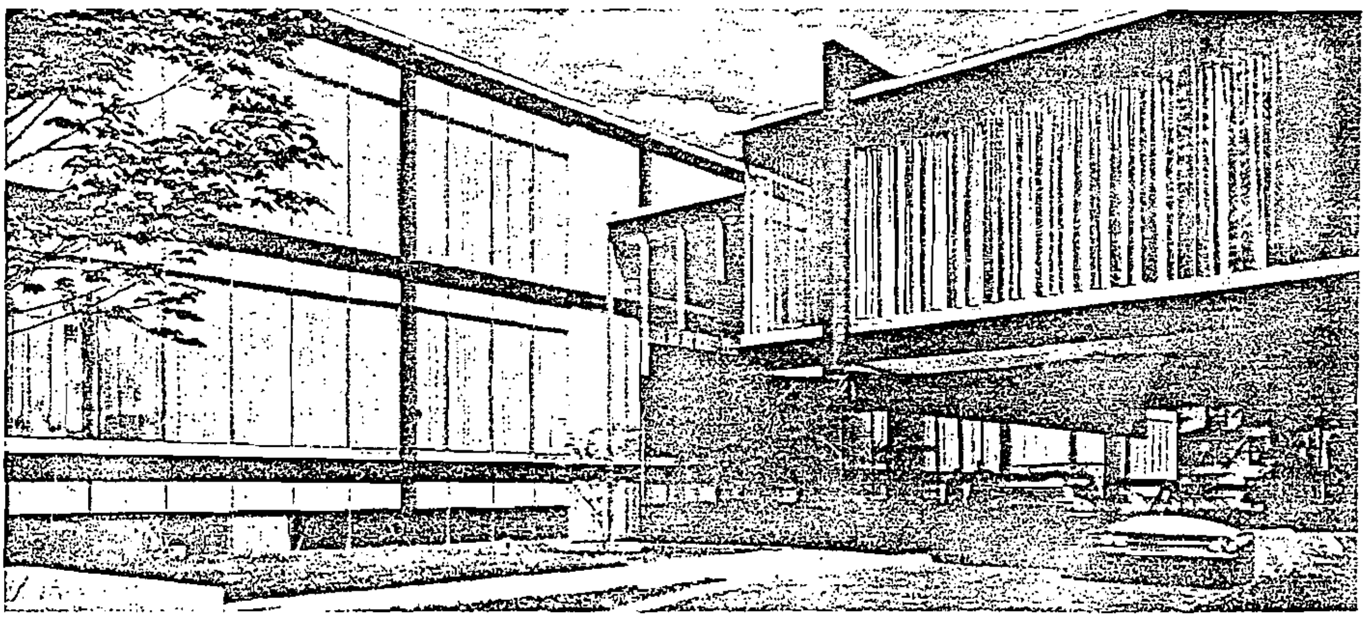


FIG. 8 Many contemporary structures are using exposed steel framing as part of the artistic scheme. Welding provides the unencumbered simplicity of form essential to the modern look in architecture, typified in this showcase building.

The most efficient use of steel is achieved with welded design, the advantages of which grow with the size of the structure. In fact, the full advantages of using steel in competition with other materials will only be realized when the structure is erected as a welded design, and when fabricators and erectors use modern techniques of welding, production scheduling, and materials handling.

A welded office building in Dallas, Texas, is an example of the economies possible in structural welding. The building is 413 feet high, has 34 floors, and contains 600,000 square feet of usable floor space. The savings are impressive. The contractor states that by designing for welding he saved 650 tons of steel. Comparison estimates show an additional saving of approximately $16.00 per ton in fabrication and erection. Futhermore, approximately six months in construction time will be saved as a result of using a welded steel frame.

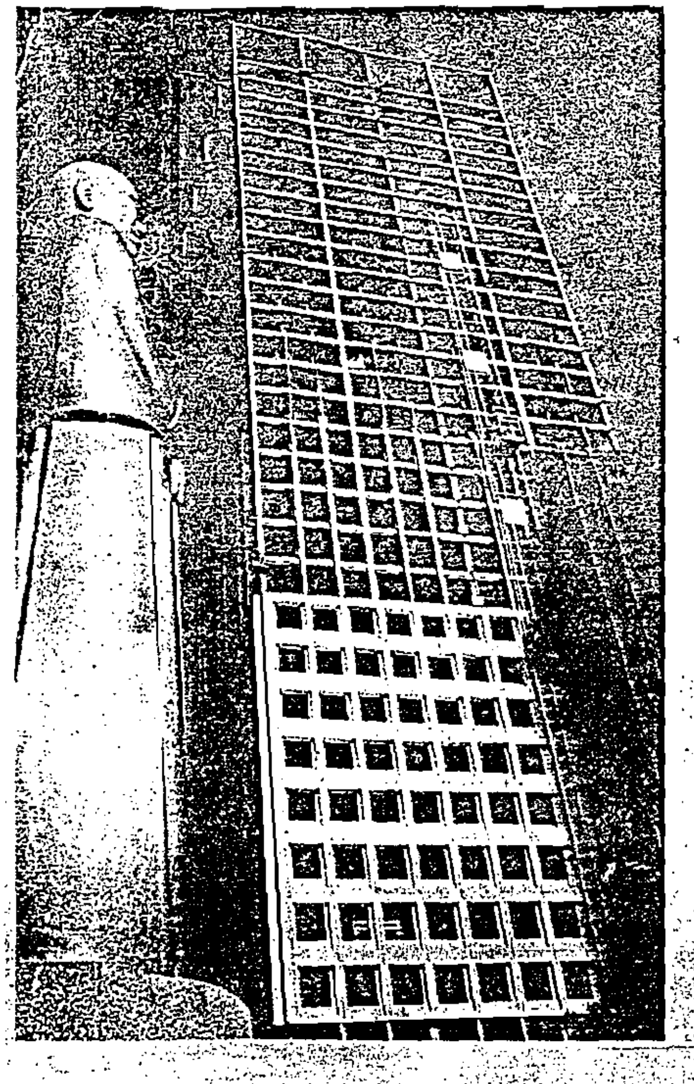


FIG. 9 Welded connections contributed to safer and more economical erection of the stately 33-story Hartford Building in San Francisco, California's tallest skyscraper. Semi-automatic welding, using self-shielding cored electrode, speeded completion of 80 beam-to-column connections per floor.

Comparative experience has proved that had this type structure involved welded connections that were simply converted from another type of connection, there still would have been savings but substantially less than when designing specifically for welding.

6. WELDED DESIGN OF BUILDINGS

The taller that buildings grow, the greater the role of welding. This applies to the shop fabrication of columns and other structurals, and also to the field welding associated with erection.

A majority of the more recently built skyscrapers are of welded design. These are found in all sections of the country, including earthquake-prone San Francisco.

Expanded open-web beams and girders—fabricated from standard rolled beams—are providing great savings in both bridge and building design. An open-web girder designed to have the required moment of inertia will result in a weight saving as high as 50%. In multi-story buildings, where utility supply lines can be run through these beams and girders rather than suspended below, the overall building height is substantially shortened. This results in significant savings in material costs—for columns, facia, stairs, etc.

The ease with which tapered beams and girders can be fabricated from standard rolled beams permits an endless variety of savings in building design. Tapered spandrel beams are often made deep enough at the column end to reduce the bending force and eliminate need for column stiffeners. The spandrel beam is shop welded to the column for lowest cost and shipped to the site.

Special built-up columns can be used to obtain open, column-free interiors, to mount facia economically, to provide the steel-and-glass look which dominates today's downtown and industrial park architecture.

The new look in building design—especially research centers, office buildings, libraries and museums—calls for a heavy use of exposed steels, including the corrosion-resistant steels such as ASTM A242. The clean trim lines which are demanded with this use of exposed steel can be achieved only by welding.

Light, airy roof supporting space frames—three-dimensional truss systems—are being shop-fabricated in sections, final assembled on the ground at the site and lifted into place. Welding facilitates the use of such designs, since there is a lack of extraneous material in the multiplicity of connections as would be the case with any other means of assembly.

Plastic design does not use the conventional allowable stresses, but rather the calculated ultimate load-carrying capacity of the structure. In the case of rigid framing, plastic design requires less engineering time than does conventional elastic design and, in most cases, results in significant savings in steel over the use of elastic design. Welding is the most practical method of making connections for plastic design. This is because the connection must allow the members to reach their full plastic moments with sufficient strength, adequate rotational ability, and proper stiffness.

7. WELDED CONSTRUCTION OF BRIDGES

Today bridges of every type—suspension, arch, truss, plate and box girder, etc.—are constructed of steel because of strength, dependability, and permanence. Because there are no limitations placed on welding, the bridge engineer is not limited or restricted in his thinking. Due to this new freedom of design effected by welding, some rather unusual and unique bridges have appeared in recent years.

The State of Connecticut has favored welding design for its highway bridges for over 20 years. The Turnpike has 28 all-welded bridges, the largest of which is the 24-span, 2661-foot Mianus River Bridge at Greenwich. The experience of the States of Connecticut, New York, Texas, California and Kansas has clearly shown that substantial savings are possible in properly designed welded bridges.

Bridge girders of variable depth enhance the appearance of the structure, while placing the metal where needed and taking it away where shallower section depth is permissible—thereby saving tons of steel.

A 900' long welded bridge spanning the tracks of the Erie Railroad on the New York Thruway had to be shaped to meet site requirements. The Thruway at this point is on both a vertical grade and a horizontal curve, requiring superelevation. It is estimated that more-flexible welded design also developed a 50% savings in the weight of steel.

In both building and bridge construction, the development of welded shear connectors and specialized welding equipment for attaching such connectors has accelerated the use of composite floor construction —where the concrete and steel act together with a strength greater than either component, resulting in large savings.

Orthotropic bridge design, long accepted in Europe, is coming into prominence in America as a major approach to reduction of bridge costs. This concept calls for the complete deck to act as a unit. Orthotropic design could not be executed without welding.

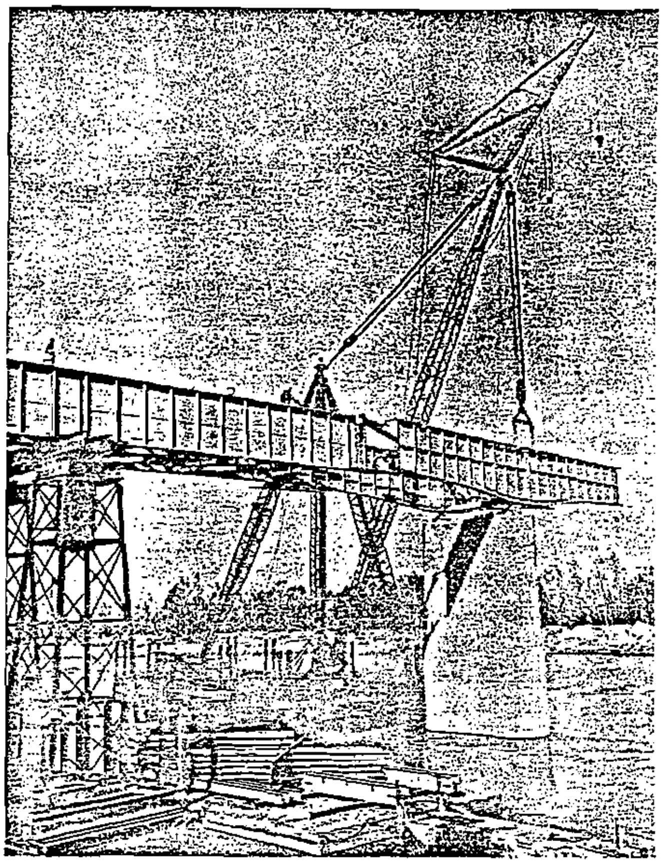


FIG. 10 Large bridge sections are shop-fabricated, shipped to the site, and lifted into position. This lowers erection costs and compresses the project timetable.

8. WELDED CONSTRUCTION OF OTHER STRUCTURES

Welding has facilitated the design and construction of a great variety of structures with the contemporary look. Even water towers have taken on a beauty that complements adjacent architecture.

Stadiums for big-league sports clubs and for big-name colleges are leaning heavily on welding. Among these are Shea Stadium, Anaheim's new home for the Angels, and others. A very unique feature of the modern stadium resulting from welded steel design is the cantilevered roof which removes columns as obstructions to spectator vision and pleasure.

Towers, space needles, huge radio telescopes, radar antennas, off-shore drilling rigs, ore unloaders, and many other structures are being designed for welded construction.

9. REVOLUTION IN SHOP FABRICATION & ERECTION

Today's structure goes up quickly due to welding. The trend is to build the structure on a sub-assembly basis, doing as much work as possible under ideal shop conditions where mass-production techniques can be fully employed.

The progress made in recent years in automatic and semi-automatic welding equipment and in positioners and manipulators has made shop fabrication of special girders, knees, and built-up columns extremely attractive. In many cases, the ingenious designer can make tremendous savings through the design of special structural members. This includes members having complex cross-sectional configuration and hybrid members that are a mix of steels having different analyses.

Modern structural fabricating shops have fixtures for assembling plates into columns and girders, manipulators for welding automatically, and positioners for supporting members so that attaching plates may be welded in the flat position.

Welding developments in the past few years have greatly increased welding speeds, while assuring high quality welds. In submerged-arc welding the use of multiple arcs, with two and three welding heads has tremendously increased welding speeds. Continuous wire processes for semi-mechanized welding for both shop and field applications have substantially increased productivity.

Much progress has been made in automatic manipulators, enabling the welding head to be put into proper alignment with the joint of the member in a matter of seconds. This alignment is automatically maintained along the length of the joint during welding. These manipulators represent a major cost reduction possibility. As the size of the structure increases, the total arc time on a welded job becomes a decreasingly smaller percentage of the total fabricating time. Thus savings in handling time and increasing manufacturing cycle efficiency are the major potentials for cost reduction.

Semi-automatic field welding is speeding up erection and lowering costs. Submerged-arc has long been used in the field for flat welding. Recently the use of self-shielding cored electrode wire, automatically fed, has greatly extended the speed and uniform quality inherent with semi-automatic welding. This process is rapidly winning general acceptance. It is not affected by rather severe wind and other adverse climatic conditions. Both submerged-arc and certain cored electrode processes are considered low hydrogen.

1/2" FILLETS ON BEAMS AND COLUMNS

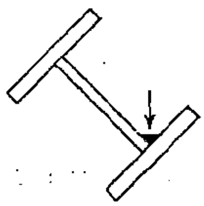
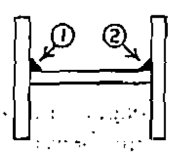
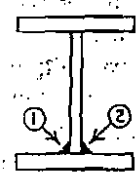
	WELDING METHOD	ARC SPEED IN./MIN.
	STICK ELECTRODE (E7028)	5 1/2
	SINGLE ARC SEMI-AUTOMATIC (SUB-ARC)	12
	SINGLE ARC SEMI-AUTOMATIC (INNERSHIELD)	12
	SINGLE ARC AUTOMATIC (SUB-ARC)	15
	TWIN ARC AUTOMATIC (SUB-ARC)	25
	TANDEM ARC AUTOMATIC (SUB-ARC)	30
	TANDEM AUTOMATICS (SUB-ARC) ① (BOTH WELDS ① AND ② SIMULTANEOUSLY = 36 IN. 1/2 FILLET/MIN.)	18 (2=36)
	TRIPLE TANDEM AUTOMATICS (SUB-ARC) ① (BOTH WELDS ① AND ② SIMULTANEOUSLY = 50 IN. 1/2 FILLET/MIN)	25 (2=50)

FIG. 11 Many fabricating shops have realized substantial savings through step up in selection of welding process and equipment. This chart shows numerous ways to make the 1/2" fillet weld, which is common to many large structural members.