ARC-WELDING OPPORTUNITIES FOR THE CIVIL ENGINEER

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

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THESIS

Arc-Welding Opportunities for the Civil Engineer

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by

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Candidate for the Degree of

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Chapter I

INTRODUCTION

One of the distinct objectives of any engineer is to obtain the most and the best possible for the least cost to his client. The only way that this objective may be approached is for the engineer to be able to apply his knowledge to the particular task with which he is confronted and to choose a method best suited to this type of problem.

To do this, all information which is available must be within reach and any new process cannot be omitted. These methods must be brought to the attention of the persons involved so that they may be used to obtain the best at the lowest possible cost. It seems to the author that since welding is a proven art and has in the past shown many definite advantages over other more standard methods that additional work should be made available in the regular curriculum for those interested. Because of many technical developments during the past few years, arc welding has become an accepted engineering procedure and a standard practice in many industries. It is used in the production of a great many metal products, in construction and in maintenance of equipment and structures throughout the industry. As the adoption and use of welding has increased, ways and means of applying the process to obtain maximum benefits have received increased study.

During the last World War many advances have been made---new designs resulting in better machines built---lighter and stronger structures developed. It is the purpose of this paper to bring out some of the facts concerning the uses of arc welding as might be applied by the Civil Engineer. Special emphasis will be devoted to structures, especially bridges and buildings.

With this information brought to the attention of the reader, another possible solution will become available to the engineer and new ideas may result which will save both time and money and money for the client and be made safer and more pleasant for the workers. Since our present economy is built around the idea of getting the most for our money, it is well worth the effort to be able to discover and apply a possible better solution. Arc welding with its wide applications will answer in several situations proving advantageous.

Chapter II

ADVANTAGES OF STRUCTURAL WELDING

Arc welding possesses many advantages that may be used in structural construction. Several of the situations where it can be used and should be seriously condidered as a possible means to a solution are listed below and will be discussed in detail in following chapters.

1. Arc welding decreased weight and cost of most structural members.
2. Welding saves material in structural connections by making them more compact, and in some cases, by eliminating connection material altogether through the direct welding together of members or structural elements.
3. Saves cost in fabrication, fitting, and assembling by eliminating operations of punching, drilling, countersinking, etc., and by reducing the amount of handling of heavy pieces in the shop and also provides greater flexibility to keep pace with other fabrication and erection operations.
4. Provides greater freedom in architectural and structural design, and better appearance when steel work

is exposed because of smoother surfaces and outlines.

5. Eliminates noise often accompanied by other methods especially riveting, which is objectionable and disturbing to occupants of nearby buildings and is confusing to workmen in the shop and in the field.

6. Facilitates economical and convenient alterations and additions to existing structures with a minimum need for removal of existing walls, partitions, floors, or other members and without field drilling of holes for connections to existing members. It also results in a minimum of noise and other inconvenience to occupants.

7. Reduces corrosion and cost of cleaning, painting and maintenance of exposed steel work because of the smooth surfaces provided by welding construction which prevent the accumulation of corrosive dust and other matter in the framing of power plants and industrial buildings, and which discourages corrosion in coal bunkers and other coal handling equipment. Corrosion is generally greater in rivets than in base metal, but welds are more corrosion resistant than the base metal.

8. Eliminates leakage at joints in storage tanks, boats, piping, etc. This is one of the reasons for welding having supplanted riveting to such a large extent in this class of construction.

Chapter III

SAVING IN WEIGHT

Perhaps the most striking single advantage held by welding is the fact that a tremendious saving can be realized over other types of connecting steel. Any reduction in the weight of the material going into construction has a definite effect on the cost---invariably a saving. Arc welding cannot be overlooked in this respect. Initially the design of a welded structure requires less beam weights because of the continuity possessed of arc welded joints which results in smaller moments in the beam. To carry the equivalant load a smaller beam may therefore be used. Welding is synonymous with continuity---its very process of fusion makes for natural continuity. This continuity is never considered in riveted structures because of the uncertainty of the ability of rivets to transfer moments into the adjoining beam. This is the crux of the difference between a riveted and a welded rigid frame. Since the weld may be designed to be just as strong as the beam itself and can take full moments, this continuity is present and a redesign for a lighter beam is advisable for economy primarily. The continuity is economical as it tends to reduce the moments and forces acting on the component parts of the load-bearing structural system. Lighter weight beams may be used resulting in lower costs.

A lighter weight system, such as an arc welded design, will reduce the cost in one or more of several ways. The initial cost of steel is usually by the pound so any reduction in weight will reduce the cost. The average percentages realized by the saving in this weight range from 15% to 30% or even more depending on the class of structure.

During the last World War, while costs were not of prime consideration, economies followed naturally in the wake of speed through welding. Our Navy Department, generally conservative, reached out boldly, threw aside tradition, changed from riveted to all-welded construction, saved 33% in weight of steel, reduced time of fabrication one-third, and made for added strength and stability. They built some 70,000 ships which were stronger and more durable that the riveted ships could not even compare. Welding made a war record that could not have been made without it.

At the present time and probably as much or even more in the future, transportation will result in a large portion of the construction costs. Since freight rates are dependent upon weight, here again is a chance for a saving in cost of handling with lighter weight members offered by welded systems. When the steel reaches the fabricators, it must then be removed from the rail and taken to the shops where it is fabricated. The shops rehandle each piece and form it into units to be transferred to the site. If the number of pieces in each unit can be reduced or made lighter, the cost will be proportionally reduced. Riveted joints require gusset plates and extra pieces to handle. Welding eliminates these entirely and as before, members of welded design are lighter in themselves.

If weight is a consideration when a structure is designed, the engineer is forced immediately to at least consider welded construction. Welding not only affords the best means of reducing weight, but it does so without affecting its strength or rigidity.

When the fabricator sends the units out to the site any less weight which can be achieved in any of the movement means less handling costs. The contractor in handling this steel during its erection requires equipment of such size to sufficiently care for the weights of the members which he is erecting. Naturally the heavier members used require heavier pieces of equipment for erection which means that overhead charges being dependent on the cost of plant equipment and initial cost will be less for the lighter equipment that is sufficient for the lighter welded members. The contractor charges off the overhead in the cost of the project and are therefore kept at a minimum by using the lighter members.

Foundations are designed according to the weight which it must support. The lighter the structure, the smaller may the footings or foundations or load-bearing members be designed. This statement goes without explaination and need not be discussed further.

The use of arc welding has a definite effect on the choice of section to be used. The shape and method of making the joints usually is the controlling factor in this choice. This is also true of riveted structures, but a wider variety of shapes are possible with a welded connection. A large portion of the economy due to the saving in weight is because of the elimination of certain plates or parts of the connections. This economy is obtained by reducing the amount of material used as well as the elimination of punching, drilling, or machining which reduces the net area and therefore requires larger sizes to start with. Each connection throughout the structure must be designed to take the entire stress to which each of the members is subjected. Therefore, if rivets are used, allowance must be made for holes for the rivets. In welding there are no holes and, therefore, the net section need not be increased for this allowance. In other words, the connection will take 100% of the load to which it is subjected. Towering structures stand testimony to their time-proved strength. Welding unites the entire structure into a homogenious unit. It eliminates the concentration of stresses at rivet holes and permits the full strength of the metal section at the joint. It eliminates the lap and seals all joints against corrosion. It is usual pracitce to add a fraction of an inch to the plate thickness to care for the rapid corrosion around rivet heads. This is unnecessary in welded construction.

We can make the most of our opportunity to conserve steel by welding at a time when its supply is critically short. The welded frame will result in a stronger body, will possess less weaving and will be longer-lived. It is clear that welding in comparison with riveting shows a remarkable saving in weight and cost, but in comparing welded high tensile steel with riveted mild steel, the weight economy is still more accentuated. The saving in cost however is somewhat smaller due to the higher price of the high tensile steel. The carrying capacity of structures is greater for an equal dead load and may in many cases result in greater financial advantages.

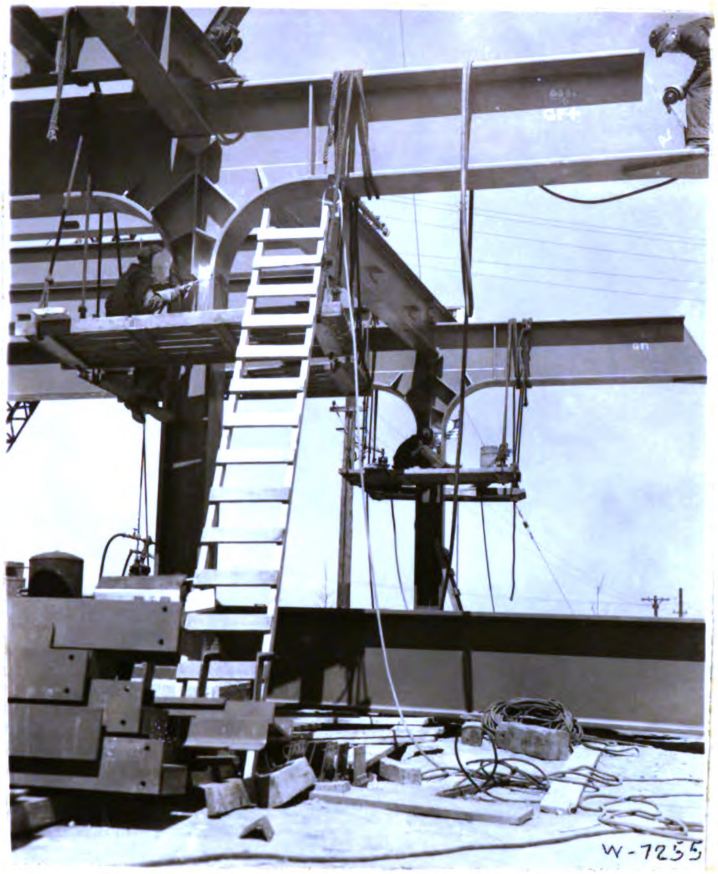
Chapter IV

FABRICATION AND ERECTION

The process of fabrication includes cutting members and processing apart from the erection site, cut to size and shape for a particular place in the assembly. A whole unit may be fabricated such as a tank or container which is completed in a shop and hauled to the erection site. Truly, any saving in fabrication means a lower cost to the completed unit. When the pieces are to be riveted, the holes must be accurately punched or drilled so that they will fit together when they are riveted. Welding does away with the necessity of the accurate template work entirely. Holes do need to be punched for erection purposes, but these holes can be placed with less refinement and with a great saving in fabrication costs. When punched or drilled holes are used in a welded structure, the shop and field connections should be detailed as to require the punching and drilling of as few parts as possible. Such fabrication operations should be avoided for long or heavy members because of the greater cost of handling them in the shop. Holes should be avoided or held to a minimum in main material. Where feasible, riveting and preferably punching and drilling as well, should be avoided on members that must be welded.

Steel which is to be welded requires somewhat less handling and shearing. To fit during erection, the pieces must come together in such a way that all of the holes will line up. With welding, a slight variation in lengths can be taken up by the welded connection, whether it be over-size or under-size within fairly large limits. Steel to be fabricated by welding is held in place while the weld is made by means of jigs or clamps. Jigs should be used whenever possible where any amount of the same type of welded connection is employed. Often, however, they can just be laid together and welded. Other times a tack weld will be sufficient to hold the pieces together while being welded. The entire process is therefore quite simple.

For the sake of economy, joints and connections should be so detailed as to make as much of the welded connection as practicable as possible to be done in the shops where there is a better opportunity for the efficient use of jigs and clamping devices, and where the work can be positioned to the best advantage for welding, even though the work is planned so as to minimize or eliminate the expense of providing and moving heavy platforms or staging. Scaffolding is required at almost all points and this must be of a more substantial nature for a riveting gang than for a welder. Much of the field welding can be done by operators seated or



Courtesy Lincoln Electric Co.
Cleveland, Ohio

Welding on Main Avenue Bridge, Cleveland, Ohio. Joining girder frame to column on one of two 122 ft. over-pass spans. Note the simple scaffolding as used by each of the welders. It can be easily moved by one or two men to a new location.

standing on the steel frame, or on very light staging or seats supported by steel hangers or stirrups of such size that they can be moved by one man. This item represents an appreciable cost due to the large number of points which require riveting and the small number of rivets at each point. Field welding should be arranged to require a minimum of shifting around on the part of the welding operators.

The quality of the weld depends greatly upon the skill of the operators. Consequently, by designing the structure to permit fabrication of large portions in the shop under favorable and controlled conditions, shop welding is more economical than field welding. Most welders are concentenious workers and take a great interest in his ability to make good joints and obviously wants to prove that he is as good a workman as any of the others on the project.

Too, there is the difficulty of inspection except for certain errors which are visible or can be detected by gauges. No suitable, positive, inexpensive method exists for checking the soundness of welds. Inspection and supervision are important, perhaps more than in any other construction, for the reason that flaws are difficult to detect in welded construction. Good inspection during building is of ever increasing importance, having a direct bearing of cost of work, expediency of accomplishment and quality of the final product. Welding involves more sciences than practically any known industrial manufacturing process, and has therefore been made to appear rather complicated. However,when a good welded structure is designed, the sciences are considered and allowances made for the changes which take place and the forces which are brought about during its use.

Arc welded construction presents a simple assemble of steel plates and shapes which many times result in configurations that are extremely rigid and contain concentrations of welding and structural discontinuities that act as severe stress raisers. One of the obstacles that the designer faces is the difficulty of getting test data on large, full scale welded structures which may be used in perfecting his designs. Tests of such structures are very expensive and require facilities which usually are not available. There thus often remains a doubt as to whether data obtained from small-scale laboratory tests can be applied directly to the design of large structures. It has been found by tests conducted at the University of California that the strength of steel when fabricated into large structures may be considerably less than when determined by ordinary 0.505 inch tensile tests or from tests of smaller structures.

It is practically impossible for the average field inspector to have knowledge of all of the sciences involved. Inasmuch as the designer takes these into consideration it should then appear that the field inspector to follow closely the work as it progresses without deviation from the plans and specifications. Strict adherence to the approved plans, or authorized changes by the designer, will minimize difficulties.

Exacting requirements for inspection and testing also affect psychological factors. Since the operator knows that his work has to be inspected, supervised, and possibly, tested (especially the important welds) he will realize that the welds will be sound before they are accepted. Only in the shops can these checks on the welds be made with great satisfaction. Therefore, again we see that the greater number of welds possible which are completed in the shops leaves less for the field operator working under unsatisfactory conditions.

Time and labor saving seems to the author to be the untangible factors for which we strive to cut down on for any type of work in progress. The most expensive portion is usually that which requires a greater number of man-hours, therefore, any shortening of this time is definetly saving costs on the whole project. Many methods have been devised to save labor in the past and many are to be discovered for our use in the future. For instance a gang of riveters consist of four men---a heater, one to toss the heated rivet to a third who inserts it in the rivet hole, and a fourth to back the rivet up. Arc welding requires a single

laborer, therefore arc welding will perform well and will continue to perform to acheive a saving in labor costs. There is no limit to the possibilities of welding in the design field for cutting down on the high cost of labor. Because of the flexibility of arc welding, there are infinite number of ways that may be developed to reduce this expense.

Indirectly, time which is reduced on a project reduces labor costs. A recent example is shown by the Naval Forces during World Wars I and II. During World War I a ship of riveted construction required 243 days on the average to build. During World War II a ship of compartive size, the Liberty Ship, of welded construction could be built in 51 days. One of the reasons for the fast completion was that parts of the ships were fabricated at different points and were transported to the launching docks for final assembly. In this way the work was not concentrated and huge sources of power were not required at one point and labor is at the same time distributed over a wider area.

Another example of the speed at which an arc welded unit can be completed is when the Unites States Army was faced with transporting heavy loads of military supplies over a sandy western desert. The Army ordered a 300-ton, 64 wheel trailer for this purpose. Made of welded construction it was completed in 30 days. When time is an important factor it is plain that arc welding has great potentialities.

Welded structures in general can in most cases be completed and put into operation in a shorter period of time than if it were riveted. If in case the costs were greater at the sacrifice of saving time the finincial betterment many times is ofset by an earlier completion date. A further advantage of fabricated structural is that construction can proceed regardless of adverse weather conditions. Ice and snow, for instance, do little to delay the raising of a steel frame building or bridge. A small canvas shelter can often be used to shield the wind, rain, or snow from a welder whereas quite an elaborate shelter would be necessary for the proper protection for a rivet gang of four men plus a large heater which must also be protected from spread- or starting fires.

One of the leading advantages of arc welding is that it is economically adaptable to the alteration of existing steel structures for new purposes. Many construction projects are additions to existing frame-work or are connected to same. If this existing steel is out of plumb or alignment, it would be almost impossible to prefabricate members to be erected with any great amount of satisfaction for connecting the old with the new. Prefabrication in this case would be met with serious difficulty. Also, some contractors use old steel which is not to dimension specified on the plans. Here, too, prefabrication is practically impossible. The flexibility which welding possesses would meet these situations with great success in that the members could be cut and welded to the existing steel work to any dimension. A more complete discussion on this will be taken up in a later chapter on the maintenance of structures.

Another first cost saving has been effected by the use of many welded structures or units instead of steel or iron castings. Machine and die set up charges are entirely eliminated along with the extra handling due to the punching and shearing operations.

Several years ago it was decided that the truss in the arm and head of the Statue of Liberty be strengthened. The plans having been lost, it would have been a huge task to draw up a new set so that the strengthening plates could be cut to size. Prefabrication was practically impossible due to the crampled quarters inside the structure. With the use of welding, the parts were brought in and put together in place simply in the small space provided. Some of the reinforcement was too long to be brought intact so it was cut and then welded when put into place. This could not have been accomplished if it were riveted. Also, it was desirable to have the structure open to the public during the repair. Had it been riveted, the noise inside of the hollow shell would have been so intense that this would have been made impossible. And to the workers themselves, the noise would have been so teriffic as to be unbearable for them. With welding, the sight-seers enjoyed the sights offered by the structure and the workers were able to work comfortably.

Chapter V

STRUCTURAL AND ARCHITECTURAL DESIGN

If welding is to be economically applied to modern fabrication processes and to be competitive with other available methods, it is necessary that the techniques and procedures developed shall be capable of evaluation as to the actual performance and serviceability capable of being produced. There is increasing need for better engineering data which will permit the simple calculation of required dimensions and of the loads that can safely be carried by a large number of different types of designs. Many conditions enter into the selection of design, materials, and method of fabrication, hense many tests are generally essential before intelligent decisions may be made by the designing engineers. The causes of defects in welding are usually preventable faults in welding technique and procedure.

Economical production of a weld depends on economical design plus economical shop practice or field practice. Poor shop practice may offset the merits of good design, or poor design may offset the merits of good shop practice. As an example, the use of a butt weld is most economical for developing strength and presents direct stress flow between the parts connected and is one of the easiest types of welds to perform. Engineering is the process by which a suitable structure for a particular use is obtained and is the most economical in both first cost and in maintenance. In the past, an all-welded design has saved approximately 10% to 40% in the amount of steel used over riveted construction. The closest approach to ideal planning for economy is a reasonable compromise between minimum weight and greatest simplicity.

Arc welded design shows considerable advantages when applied to steel structures. Specialized design of the joints is almost always necessary because a welded joint is rigid and stress distrubution through it is different from that occurring in joints resulting from other methods of construction. In the engineering field, improvements in design of welded joints to increase joint efficiency and economy of fabrication have marked an important step in the phase of endavor.

Before the war there were a number of welded steel framed buildings and bridges, but the war years saw many developments in design, fabrication and erection of welded structures. In the design of rigid frame welded steel structures, it is preferable where possible to employ standard rolled steel sections, but when necessary, sections can be fabricated by welding steel plates together, or rolled steel sections can be strengthened or altered in dimensions by the addition of welded plates or gussets. The designer who is designing a product for welded fabrication may be extremely flexible in his choice of materials and shapes. The use of welding for structural steel work has without doubt progressed rapidly.

The typical welded structure is a rigid frame, a homogenious unit in which columns, beams and girders are rigidly connected. In this sense it is similar to reinforced concrete design. The work involved in rigid frame analysis is to determine the maximum stresses occurring at the joints under all reasonable conditions of loading. The extra work required has discouraged the general use of this type of construction except where the framing system is comparatively simple even though a considerable saving in material can be achieved through the continuity of the joints. There strongly remains the tendency for designers to think in terms of riveted construction, hence full economies and full structural advantages are not always obtained.

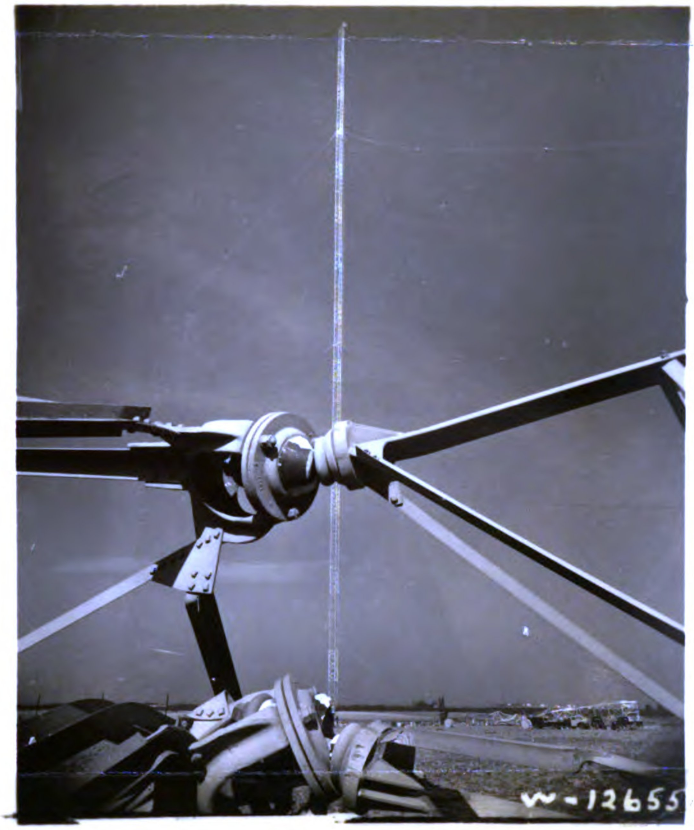
A load placed anywhere on any one member of the frame will influence other girders and columns. Columns are thus subjected to bending as well as compression and girders cannot be considered as simple supported. More accurate strength evaluation and better balanced design results. The advantages gained by welding will offset the additional cost of the design work required to solve for the stresses involved in the more complex analysis of the rigid frame. The completely welded structure is not an assembly of independent structural elements joined together with intermediate connecting pieces, but is a homogenious unit.

Today, through the American Welding Society and the American Institute of Steel Construction, ample information is easily available to every architect and engineer. In addition, many fabricators acquired valuable experience and technical data during the last war. Furthermore, research has yielded welding equipment, such as automatic welders, stud welders and squirt welders, that has decreased the importance of the operator element in obtaining sound welds and increases the efficiency and reliability of structural welding.

Savings are due not only to the characteristics of the rigid frame and reduction of midspan moments of girders, but also, in both rigid column-beam framing, to the simplicity of welded connections which contributes to the reduction of handling and fabricating costs. The reduction in the quantity of steel has indirect implications in additional savings in other materials---the lesser weight of the structure can be reflected in lighter foundations and other load-bearing members. The lightness of the structure results in reduced height of framing members---girders, beams, floor construction. This may mean a considerable saving in outside walls of tall buildings as well as in total space in cubic volume for a given area. The reduction is due mainly to the lower moments to which continuous beams are subjected, as compared to simply supported beams. With construction of continuous beams made more economical by welding, thickness of the over-all floor construction can be reduced by approximately 10% in comparison with simply supported beam construction.

In nearly every design, cost is the most important factor. In most instances, welded construction is the less costly. There are examples, however, where welding is a more costly means of fabrication than some of the other methods of production, however welding may prove to be the most satisfactory means of fabrication. If the product in question is of a complicated nature but only a few are to be made, welding is generally the more economical. The same is true of units where minor changes frequently occur.

Several examples may be cited where welding is the only possible means of connecting parts together. Other methods such as riveting and bolting would be impossible or impracticle. Note the plate on the following page which shows a 750-foot arc welded radio tower. Arc welding makes this type of vertical solid rod antenna possible since bolted or riveted connections cannot be made with rod or tubing.



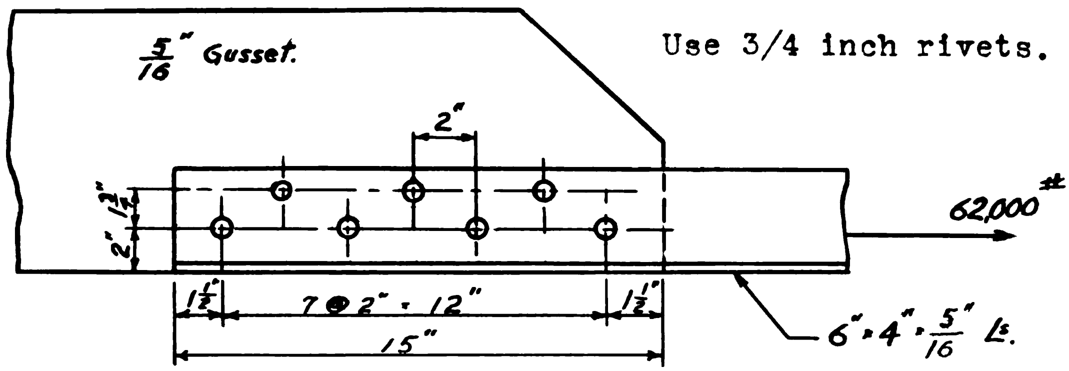
W-12654 - The 104,740 pound weight of the tower rests on this ceramic insulator which is designed to allow movement in the guyed antenna.

W-12655 - A completed 750-foot welded radio tower at Buena Park, Calif. seen through the wreckage of the old bolted, T type tower. Arc welding makes this type of vertical solid rod antenna possible since bolted or riveted connections cannot be made with rod or tubing.

For arc welding, the work of joining must be done following blueprint as there is no mark on the steel indicating the length, location, and the size of welds. On the other hand, the rivet heater has to measure the depth of holes at each point to determine the number and length of rivets to be heated. Weldings shows a considerable economy in this respect when many points require joining with a small amount of work required at each point. The welder can get to the point and complete his work quickly.

Further savings result all along the line. In the drawing room, drawings are made cheaper, the drawing room burden or overhead is proportionally lower for welded work. Note the included blueprint on the next page which shows how extreme detail is necessary for a simple welded connection of a girder plate. The time required to compute the stresses and design the detail is several time over the alternate method of a welded design. Detail drawings such as this are entirely eliminated and unnecessary. Also, the time to compute the size of weld to use is much shorter. Drawings can be made more rapidly which gets the details to the shop more quickly. An example to illustrate this point is brought out by the problem taken from a textbook "Design of Modern Steel Structures" by Linton E. Grinter, which states: "Design the lower chord of a Fink roof truss for a stress of 62,000 lb. using AICS specifications. Design the connection of the member to the end gusset plate. Use two angles placed on opposite sides of a 5/16 inch gusset plate." The computations for the above problem follow and will show without a doubt that the welded design is much the simpler method of design. Besides this factor a definite and measurable saving in weight is outstanding.

RIVETED DESIGN



Use 3/4 inch rivets.

Net Area Required: $\frac{62,000}{20,000}$ = 3.1 sq. in.

Try a 5" x 3" x 5/16" Angle.

Net Area = 4.80 - 2(½ x 3 x 5/16) -2(5/16 x 7/8) = 3.4 sq.in. (OK)

Check Bearing: Bearing value is 40,000 psi.

5/16" x 3/4" x 40,000psi = 9,380 #/rivet.

$\frac{62,000}{9,380}$ = 6.6 or say 7 rivets.

Check Shear:
Single shear = 15,000 psi.

2(.442) x 15,000 = 13,250 #/rivet.

$\frac{62,000}{13,250}$ = 4.7 or say 5 rivets.

Bearing controls therefore use 7 rivets.
Weight of Angle is 8.2 #/ft.

Spacing of Rivets:

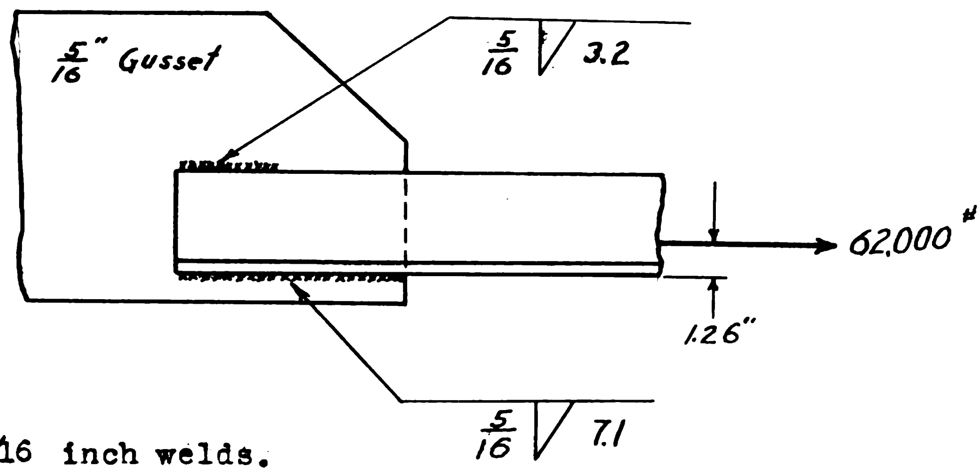
First rivet placed at 1½" from end of angle.
In order to maintain minimum spacing of 3d the rivet spacing must be at least 2".

Net Section:

Area to deduct = $A_{hole} \left(1-\frac{s^2}{4gh}\right)$ = .274(1-.347)
= .369

Net section = 4.80 - 2(.369) -2(½x3x5/16)
= 3.17 greater than 3.1 (OK)

WELDED DESIGN



Use 5/16 inch welds.

Length of Weld: $\frac{31,000 \times 1.414}{13,600 \times 5/16} = 10.3"$

Net Section Req'd same as for riveted angle = 3.1 sq.in.

Try a 4" x 3" x 5/16" angle.

Net Area = 4.18 - 3 x 5/16 = 3.2 sq.in. (OK)

Balance weld about centroidal axis:

$a + b = 10.3"$

$1.26b = 2.74\,a$

$\left(\frac{1.26}{2.74} + 1\right)b = 10.3$

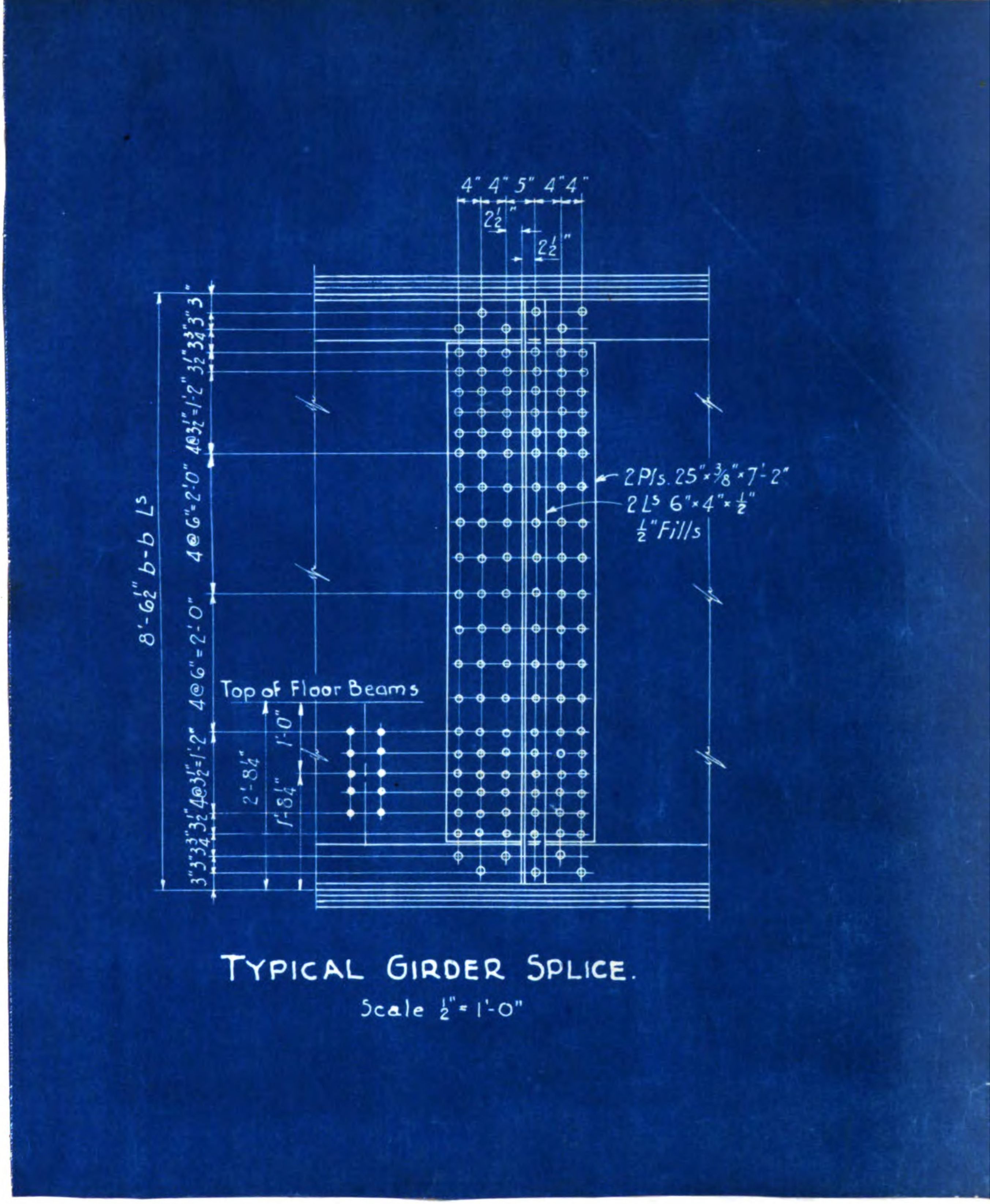
$b = 7.1"$

$a = 3.2"$

Weight of Angle = 7.2 #/ft.

* * * * * * * *

A saving in weight of 1#/ft can be realized in the welded design over the riveted design of the same connection.



Drawing No. 1

This plate shown the extreme detail required of a joint of riveted design. This entire sketch is eliminated in welded design.

Welding can play a vital part in erecting the tall towers needed for telecasting, these structures demand heavy footings and anchors. Since, by the use of welding, large anchoring forces can be applied to a small area, much material may be saved and design detail simplified by this method of attachment. In many other cases also, detail working drawings can be prepared in less time on welded work than on riveted provided that the structure has been designed for welding from its inception. Costs are greatly increased when the design requires both welding and riveting on the same member. When the job is welded, it goes through the welding shops. If rivets are to be driven, the work must be brought into another part of the plant, and the extra handling runs up the cost proportionally.

To make a simple riveted connection, three pieces must be handled, the two members to be connected and the connecting element, usually an angle or a plate. An arc welded connection can be made with only two of these pieces---the two which are to be connected. In riveted connections, holes must be punched in all of these members; three separate operations and two different machines are required. The welded connection can be made with two operations and with only one type of equipment. These are the factors which contribute to the economy of welded construction, but that economy can be fully realized only when the simplicity of welding is completely and ingeniously exploited. Better stress distribution in the welded joints results from the fact that they are inherently more compact than the corresponding riveted connections. Stress distribution around rivet holes set up concentrations around those holes, whereas in a connection which is welded, stress distribution is uniform.

Since welding has been adopted in steel building and bridge construction, a definite advance in building technique has resulted. The practical advantages offered by welded steel structures---simplicity and economy---make it definitely worth consideration. However, to some designers and builders, the complex procedure of analysis of its members is not fully understood. This tends to discourage many bewildered engineers, but it is not necessary for the practicing engineer or architect to comprehend all of the aspects of the welding process. It is only necessary to learn those qualities of welded steel structures which make them different from other types of structures. Familiarity with the characteristics of welded steel structures and intelligent reasoning should be sufficient knowledge of the practices of welding to enable one to make a decision

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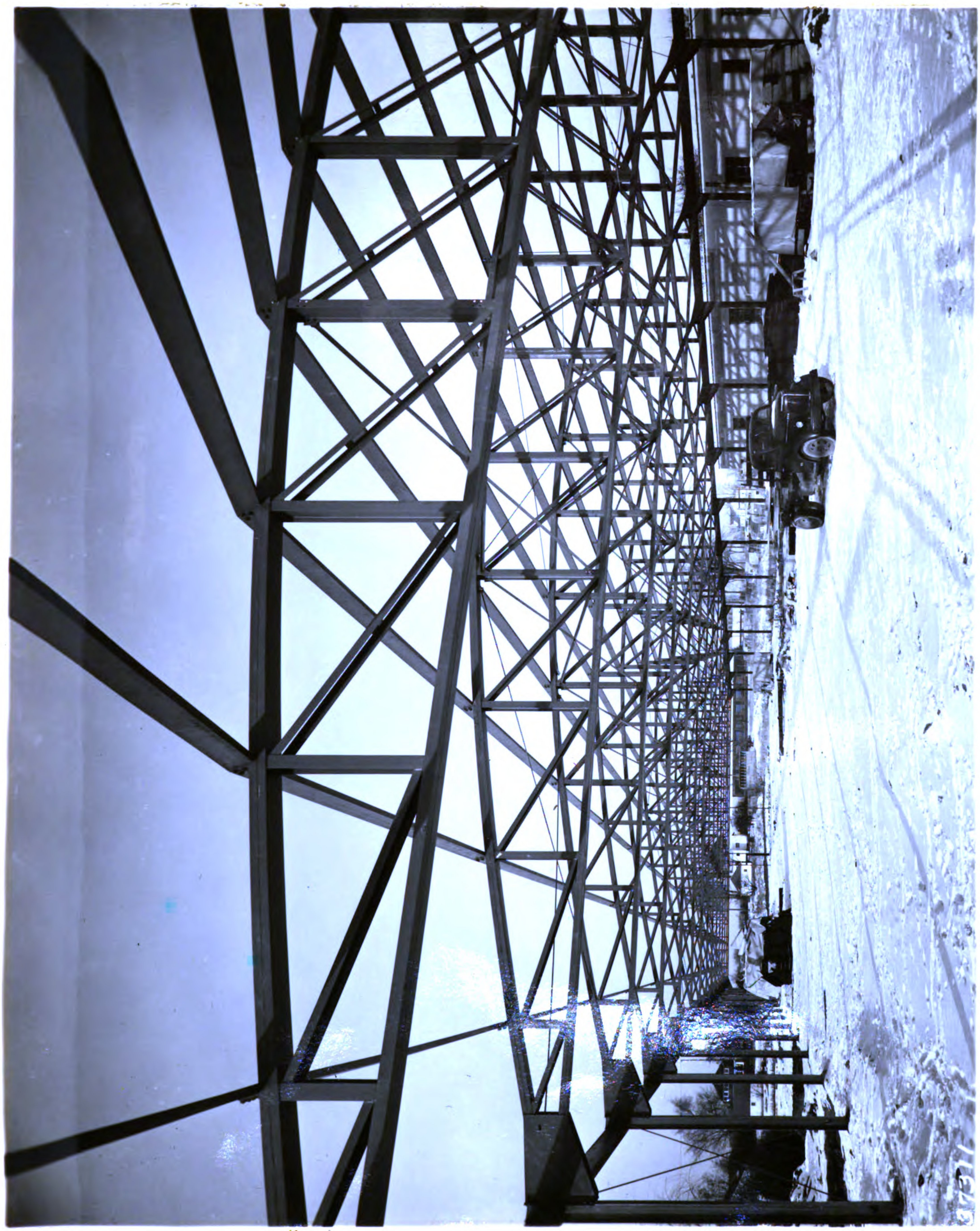
Following Plates: Pictures showing arc welded steel trusses erected for a motor company by Jarvis Engineering Works in Lansing, Michigan. The roof trusses are lighter and simpler to erect and also will require less maintenance.

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as to whether a particular structure can be economically constructed by welding. This statement will, however, hold for any type of structure in that one must be familiar with its special characteristics to intelligently make decisions about the structure itself.

Chapter VI

AESTHETIC QUALITIES - PUBLIC ACCEPTANCE

It is generally conceded that the American standard of living has been built up through the application of technology to all forms of industrial behavior. By enabling men to increase their productiveness, wages have raised and manufacturing costs reduced. The buying power of an hour's labor is greater here than anywhere else. As a result this county leads in the worlds per capita ownership of necessities and luxeries for which people yearn.

Public acceptance governs many phases of any construction project. The principal considerations in determining what contributions a welded structure possesses toward social betterment are by nature economic, progressive, labor saving, aesthetic, and civic.

The first has been discussed in forgoing pages. The second---progressive---will also be substantiated if it will be admitted that the experience gained by the building of welded structures adds to the store of human knowledge. This should be significant to everyone who seeks to improve his use of a comparatively new method of joining metals. Undoubedly it has incouraged the spread of the new psychology of product improvement and development.

In regards to labor saving, anything that contributes to the improvement of labor conditions or to labor efficiency, such as lessening the drudgery by simplifying production, reducing weights, and the elimination of nerve-racking noise, surely has furthered to a degree social improvement. This saving to labor has also been discussed in previous chapters.

The forgoing pages will cover the fourth consideration---aesthetic--which gives due to arc welding a pleasing appearance because of the excellent disposition of surfaces made possible only be welded connections. It has an obvious advantage over riveted structures. Lasting satisfaction and approval of the public are considerations for which arc welding is qualified to give. Interior beams and columns of a shop building employing men and women on routine jobs are usually an eyesore because of their bulky joints which are not in any desireable proportion whatsoever. Welding, because of its continuity at the joints, permits extra reinforcement to be omitted at these points. This reinforcement is usually made up of extra plates riveted to the beams or columns. With these left off, a more pleasing appearance results. The rivets themselves do not add to the beauty of any structure. Inside they will collect dust and dirt which proves to be undesireable. Surfaces which are not smooth are difficult to paint and are thus more difficult to maintain.

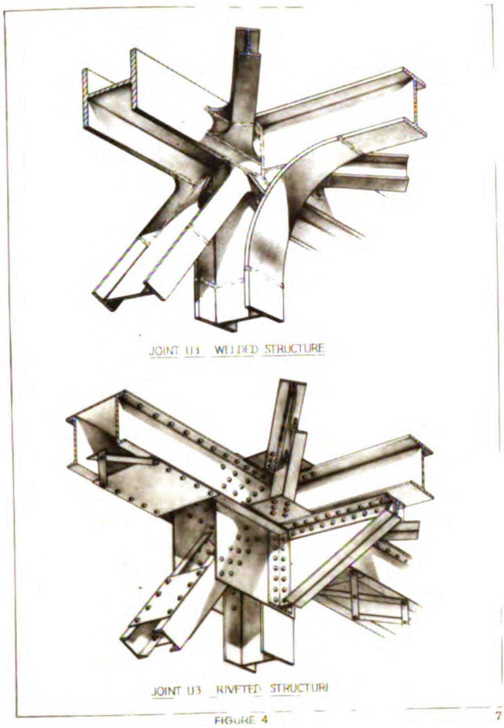

FIGURE 4

Courtesy Lincoln Electric Co.
Cleveland, Ohio.

Besides serving many utilarian purposes in the design, welding affords excellent opportunities to the improvement of its appearance. When two intersecting road grades are separated, the motoring public reaps the benefit of having a major traffic hazard removed. The benefits derived after the mental and physical hazards have been eliminated are then dependent upon the economy of the type of structure which is to be selected over any other, and to no less extent upon the grace and aesthetic applications for appeal. When a material, highly lauded for its permanence, durability, beauty, and all of the rest in the long line of sales promotion adjectives, begins to show serious signs of deterioration in a few years after its debut, the public begins to wonder whether the choice of material was a wise one.

The tendency of the design of structures is influenced greatly by their aesthetic features as well as by their construction principles. Accordingly, the engineer must be familiar with these qualities if he is to accomplish what is expected in a finished structure. To this point, welding means much to this accomplishment. The beauty of a structure means that to the theoretical design for construction alone, many changes must be made to meet with eye appeal. The many various properties which arc welded joints offer make welding ideal in achieving this goal.

First of all, a bridge which is short and stubby and with heavy appearing beams is far from being of scenic beauty. On the other hand, one with slim characteristics stand out on the horizon as an asset to the landscape. With the rigid framing possessed of welded joints, it is possible to build our structures of slim design because of the lightness of the members which can be utilized and still keep up with construction requirements. Note the picture on the previous page which shows one joint of column and beam framing.

A basic rule to follow is again that the simplest and most straightforward treatment of the problem will usually produce the most satisfactory rusults and at a least expense. However, where curved work is employed on the basis of aesthetic grounds, fabricating costs are increased in most cases. It is better to keep the number of component parts to a minimum, using comparatively heavy material if necessary, to avoid the introduction of reinforcing plates and elaborate stiffener systems. In the past every effort has been made to conceal the steel skeleton whenever possible, whereas with arc welding it is undesireable to cover its natural beauty. It is also left open for visual inspection periodically.

The public as a rule estimate the progress of work accomplished by basing their opinion upon the amount of steel erected. With riveted structures this method may hold fairly true to actual progress, but with welding it is definetly not the case. Members cannot be erected to far in advance of the welding operators as the weight of material does not allow freedom of movement of the members being welded and also excessive weight causes slight deformities in the unwelded members and upon completion of welding stresses are locked up in the structure. In welding construction completion is dependent upon the speed of the welding operation rather than on the erection of steel. The number of welders available that can be utilized economically is therefore the factor which is dependant upon the completion date.

The erection of welded steel structures is noiseless, which is an advantage not only to occupants of nearby buildings, but also the workman. Some field cutting may be required; use of the cutting torch will eliminate the noise of shearing and clipping in both the shop and in the field. Noise elimination is especially important in remodeling work(for which welding is best suited) since persons usually occupy parts of the building not being remodeled. Construction sites which are near hospitals, office buildings, schools, hotels or other places where the noise of riveting would be undesirable or even impossible, would be just cause for welding consideration. The last consideration---civic---cannot be overlooked because it deals with the public. The elimination of noise during construction is very apparent, and infringes less on the rights of the community by eliminating a source of distressing, fatigue-causing nuisance. There can be little argument as to the advantages this method carry when the welfare of patients in hospitals is concerned. These features are worthy of consideration aside from the cost of the operation.

Chapter VIII

MAINTENANCE AND REPAIR

The long life, low up-keep cost, as well as the reliability and economy of arc welded structures is proven by its wide use in the field of the Civil Engineer. Its flexibility and dependability are well established. Anything made by man, regardless of its efficiency, is subject to breakdowns, unforseen accidents and failures at some time. The development of repair and maintenance services is therefore desireable.

The most important factor of welded construction regarding corrosion is that it eliminates lap joints by sealing all exposed corners and crevices. Welded seams are permanently water tight and require little or no upkeep. They corrode no more than the steel plates which it connects. All welded joints are rigid; they prevent corrosion because the paint does not crack at the joints as would be the case in a non-rigid connection.

Major repairs can be accomplished by cutting out the damaged parts, fitting and welding in new parts with the least amount of delay. Railroad cars of riveted construction are made up of numerous overlapped joints. These joints form ledges or pockets where coal and moisture can collect causing rapid corrosion at these points and making it necessary to replace these points. New cars of arc welded design have these lap joints eliminated and leave no place for moisture to collect and cause any damage. Old cars initially riveted, which are rusted through at these points, are easily repaired with arc welding. The joint is cut out in a norrow strip. A new plate is then cut to the size of the hole and is welded in place. The seam can be ground smooth and painted and the patch made invisible. This can be done at a considerable less cost than can riveting and a minimum amount of material is used. The railroad car is out of service for a much less time than would be required for a riveted repair. Many worn or broken parts on railroad cars can be reclaimed by welding which would be impractical by any other means.

In shipbuilding there are many advantages to be offered by the use of welding. A few of these should be mentioned here. Welded steel boats will not leak. The inside will be dry and can even be painted while afloat. Because of the lightness, the boats will almost always be faster, cleaner, safer, cleaner on the outside, and more seaworthly, and have a greater carrying capacity. They can also be kept afloat long periods of time without having to watch or pump out the water.

The salt spray of sea water is a severe cause of corrosion. With welded design the steel plates can be kept painted without cracking and allowing a crack for corrosion to start at the joints as would happen in the case of riveted joints. Because of the fact that the inside is perfectly dry, paint will do a thorough job of protection.

Usually the details of the older existing structures are such that much of the brickwork or walls and partitions would have to be removed before the riveters could get their hammers up to the rivet head to tighten it if the addition or remodeling were designed for riveted joints. Arc-welded joints are, however, easily accessible to the welder and the much more remote points can be reached without destruction to existing walls or partitions. This may amount to a considerable saving on many constructions.

A recent deviation from standard procedures was made with the use of H-sections entirely in truss members. The members all butt against the ends of the members and are fillet welded entirely. Since weld material is run around all of the members at their end connections, all edges are covered and only the original rolled surfaces are exposed. This greatly increases the resistance to corrosion and simplifies painting and maintenance.

Welded structures are more resistant to corrosion than are riveted ones due to the smooth surfaces which can be obtained at joints through welding. In riveted steelwork, corrosion usually starts at the rivets where corrosive matter can accumulate, while welds done with coated electrodes are more resistant to corrosion than the base metal. This advantage is especially important in exposed welded steel structures, which make capital of the attractively smooth surface and lack of small detail.

Welded connections, especially for industrial buildings, can be fitted and the structure plumbed and aligned economically by the use of temporary tack welds. The parts are held firmly in correct position until the connections are tacked and welded, thus avoiding the measurement of each individual member to be erected. By the use of arc-welding, the members can be cut off at the side of the project and welded in place.

Welded fabrication cuts down dependance on outside sources of supply and permits closer control of production. A particular piece which needs to be replaced can be built up by arc welding and fitting to the particular situation. Waiting for delivery holds up production and cuts down profits. Pattern costs and storage is eliminated.

Chapter IX

LEAKPROOF AND AIR TIGHT JOINTS ARC-WELDED

It is obviously necessary to have leakproof joints in many phases of engineering, such as would be required in a gas refrigerator in a home where peoples' lives would be endangered should a leak be present. Permanent tightness is an essential factor as well as for efficiency and for safety.

Containers which are constructed to hold liquids or gasses have proved so successful when welding was employed that other methods have been entirely eliminated. The biggest reason for such success is that tight joints are made possible only by welding. Liquids do not leak out and gasses do not escape, either of which is wasteful and sometimes dangerous. Leaking liquids are known to cause rapid corrosion where the liquid is in contact with the metal. The danger of corrosion is here eliminated. In the opposite direction, vaccum tight joints are likewise made possible only by welding.

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Following page: Three 12,500 bbl. Hortonspheres of all welded steel construction for operation under 50 lb. pressure in a large refinery in southeast Texas. Courtesy of Lincoln Electric Company.


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The widespread advance of welding in the steel fabrication industry is perhaps most notably illustrated in the current trend toward the substitution of welding for riveting in practically all types of steel plate construction as in ship building and in the construction of pressure vessels.

Arc welding pipe fittings simplify installation and provide more permanent systems. Seamless steel tubing and fabricated steel tubing with simple circumferential welded joints in place of the expensive flanges and couplings are advantageously used for water, gas, oil and steam pipe lines. These arc welded joints give a high mechanical efficiency, ease of layout and construction, low maintenance costs, smooth exterior surface making wrappings of any type easily applied.

An important consideration is the strength and the material saving as applied to a tank or container of arc welded construction. A riveted tank is only from 45 to 75 per cent as strong as the plates because of the reduction in allowable stresses caused by the rivet holes and the riveted connection at the joints. In sharp contrast a welded joint may be designed to be equally strong as the steel plates themselves as there is no deduction for rivet holes and sufficient weld metal may be used to take the stresses existing in the plates. A thinner plate can therefore be used to obtain the same strength. This saving in material results in lower costs.

In tank constructionthe joints must be tight to be free from leaks. In order to make a riveted joint tight and free from leaks, the rivets must be caulked. Caulking is costly and is not always entirely satisfactory, while the arc welded joints are tight to begin with as they are fused together into a homogeneous structure and require no caulking whatsoever.

Every few years any standing tank or container which is exposed to the weather requires painting to preserve it. Here again it seems quite obvious that a smooth surface would be much easier to paint than one which is uneven as in a riveted plate structure. The absence of rivet heads therefore tends to reduce the cost of periodic painting.

In other fields, too, there are numerious ways that welding can be used to save material and labor. One refrigerator manufacturing company uses welding entirely for the coils. This requires extreme care in order to obtain a tight joint. It has been used successfully here and has saved the company many expenses by eliminating and reducing material costs.

Chapter X

CONCLUSION

It has been attempted in this treatise to prove to the reader that arc welding is practical from both an engineering and a financial standpoint. Millions of dollars worth of our natural iron and steel resources can be conserved annually by merely adopting the natural advantages possesed of arc welding. Thousands of bridges and buildings are constructed each year along with the other items too numerous to list in the United States and in other parts of the world and the saving of each structure multiplied by the total number of structures would add up to a goodly sum in our economy.

It has been explained in the first part how arc welding may well be used to conserve material and to reduce weight by the elimination of certain members, especially connection plates, or by the reduction of total weight in the members themselves by one or several ways. The design for welded connections takes into consideration the rigid framing of the structures in that the moments are distributed throughout the total numbers of members connected. In the design of direct stresses, the net section in welded design does not have to be reduced in order to allow for rivet holes. Design for welding can only be effective to the utmost or to the greatest degree when it is designed from its inception and under no consideration should the two be combined for the welds and rivets to act simutaniously to take the stresses.

An indirect first cost saving can be realized during the operations of fabrication and erection by cutting down on the individual unit operations within the scope of the structure. It has been discusses as to how many operations can be reduced or eliminated entirely by the use of welded design. First cost is usually a prime factor and funds available may decide whether or not the structure can be erected. Arc welded design often results in a lower first cost and may therefore come within the limits of the funds available. It could be in many cases a method to get what is wanted at the time needed and also benefit by the welded design. Aside from first cost the maintenance of welded structures is decidedly lower than a comparative riveted unit. Maintenance often is a more expensive factor than the original cost. In this event the lower maintenance rates would by the one to choose. Arc welding is able to outreach other types of connections in this respect. One large factor which contributes to the low upkeep of structures of arc welded design is that it is more corrosion resistant to begin with than the riveted construction. On exposes steel work the ease of painting is an obvious advantage when maintence work is contemplated.

The aspect of welding in maintenance is limited only by the ingenuity of those supervising the work. Welding has long been used to repair metallic metals. The process of reclaiming worn steel parts by building up the worn surfaces with weld metal is widely used in industry today. Stripped holes, broken gear teeth are not scrap, but can be reclaimed and put back into operation. Its useful life is prolonged and service expense reduced.

In the field as well as in the fabrication shops welding plays an important role. If it were not for the versality of welding many field projects would be so expensive to be almost prohibitive. The ease with which the welder can connect two or more members in the most remote points has made the progress of arc welding rapid and satisfying.

The largest factor of saving other than the large quantity of metal saved in the shops is probably due to the elimination of some of the operations which would be required of riveting such as shearing, punching or drilling and reaming. Also extreme care is unnecessary for the fitting of two or more pieces together and a simple jig or clamp may be used for the welding operations. Handling operations are likewise reduced in that fewer changes in position are required to weld the members together. Besides this the metal parts are of lighter weight and are easier to move around.

The engineer's job is to provide for the people that he serves a structure that is suitable for its purpose and also a structure that is safe, but at the same time as economical as possible. The people evaluate such structures upon their preformance and the asset to the community. The pleasing appearance of welded joints and seams along with its structural capabilities provide for the engineer a method which satisfys these conditions better than other methods in the majority of instances.

It has not been the purpose of this paper to degrade riveting or other forms of connecting metals, but to give the advantages of welding as to how it may be used in preference to other forms or methods. To do this a comparison had to be made in a great many cases with riveting to clearly show the desireability of arc welding. Much is to be gained by the use of arc welding in the structural field. It is hoped that the reader will benefit by the treatment herein.

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