Volume XIV, Number 1, 1997

Welding Innovation

Advancing Arc Welding Design and Practice Worldwide

Looking Ahead

It is with great enthusiasm that I announce several changes related to the James F. Lincoln Arc Welding Foundation and this publication. As you have already discovered from the new cover format and title, this publication is now known as ***Welding Innovation***. The redesigned masthead emphasizes our commitment to new technology and new ideas, while the arc-like icon takes us right back to the basic technology that makes welding viable — the electric arc associated with the most popular welding processes used today. As one might deduce from our title change, we will no longer be targeting four issues per year. We are still committed to making this informative journal available at no cost to our readership, but now plan to publish twice a year. In addition, the entire contents of the publication, beginning with this issue, will be available online at http://www.lincolnelectric.com.

Standing: Dick Sabo, Scott Funderburk.
Sitting: Omer Blodgett, Duane Miller.

It is also my pleasure to announce the appointment of our Editor, Duane K. Miller, to the position of Secretary of the Foundation. While I will be continuing in my role as Executive Director, Duane will assume the day-to-day responsibilities of running the Foundation, in addition to his current responsibilities as Editor and as Senior Project Engineer with The Lincoln Electric Company. Duane's international reputation continues to grow, and he is in constant demand as a speaker at seminars and conferences all over the world. His new position as Foundation Secretary will give him the opportunity to interact with our International Assistant Secretaries, coordinating worldwide programs aimed at increasing the quality and reducing the cost of welded components. Even as Lincoln Electric continues to expand into new markets, it is the goal of the James F. Lincoln Arc Welding Foundation to help develop the welding industry in these emerging markets, just as it has done in the past and continues to do currently in the United States and Canada.

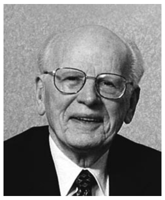
To supply some assistance to Duane Miller, R. Scott Funderburk has been named Assistant Editor of *Welding Innovation*. He will be assuming day-to-day responsibility for the publication, and new ideas and comments may be directly forwarded to Scott. Being part of the newer generation of computer-literate engineers, Scott has requested our readers to contact him at his email address: scott_funderburk@lincolnelectric.com. I am pleased with Scott's contributions to date — in fact, he is largely responsible for most of this edition of the magazine. However, I am even more excited to note that the "mentoring relationship" which is the subject of a continuing series of articles in this publication has moved on to yet another generation. Duane Miller has become Scott Funderburk's mentor, while Omer Blodgett remains our Design Consultant, so that, in effect, a three-generation mentor/protégé relationship is now happily in place.

Amidst all these changes, certain things will continue as before. The James F. Lincoln Arc Welding Foundation is firmly committed to its goal of advancing the use of arc welding through a commitment to ever-improved quality and reducing the cost of welded fabrication. Through our books, seminars, awards programs and such publications as *Welding Innovation*, we look forward to continuing to work with people like you to build a better. . . stronger. . . welded future.

Richard S. Sabo

Welding Innovation

Cover: The Lágymányos bridge on the Danube at Budapest features a unique lighting design. See story on page 20.



Omer W. Blodgett, P.E.
Design Consultant

Volume XIV
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First-Ever Gas-Fired Annealing of a Nuclear Reactor

By Mike Sciascia, Project Engineer
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Piscataway, New Jersey

Introduction

The first-ever indirect, gas-fired, radiantly heated annealing of a nuclear reactor was a major success, thanks partly to computer simulation that validated the process in advance. After years of neutron bombardment, nuclear reactor pressure vessels become brittle. The embrittlement problem forced Yankee Atomic Electric Co. to decommission its Rowe power plant outside Boston in 1992—eight years before its license was due to expire. Annealing restores the ductility and fracture toughness of the weld metal, adding many years of operating life to the reactor vessel. However, the problem is that annealing requires heating the entire vessel to a temperature of approximately 850°F for a week. The annealing approach pioneered by Westinghouse Electric Corp. and Cooperheat, Inc. involves blowing superheated air from gas-fired burners into a heat exchanger that, in turn, heats the reactor vessel. This approach was validated, prior to a successful $6 million demonstration project, by building a functional scale mockup, and by simulating heat transfer and air flow using computational fluid dynamics (CFD) software.

Background

The pressure vessel contains the fuel and control mechanism for the nuclear reactor and is located within the containment building. Metallurgical experiments have shown that annealing the vessel will nearly restore its original metallurgical properties. This requires disassembling the internal components of the reactor (a standard operation during refueling) and providing a means for in-situ heating of the 35 foot tall, 15 foot diameter vessel.

The size of the reactor vessel alone is not a major obstacle. The difficulty of the task relates more to the fact that the inside of the reactor is contaminated with radiological materials that cannot be released to the environment. This eliminates the most common method used to anneal large pressure vessels: circulating superheated air from gas burners inside the vessel and insulating the outside of the vessel to minimize heat loss. The problem is that the hot combustion gases would pick up radioactive dust and other contaminants inside the vessel and spread them into the atmosphere.

Several nuclear reactors in Russia have been annealed using radiant electric heat; however, this approach was not used for various technical and economic reasons. Ironically, despite the fact that the pressure vessel was located within an electric generating facility, obtaining power for the heaters would have been very costly. Another problem with this approach is that a failed electric heater element would have been virtually impossible to repair or replace inside the reactor. The use of redundant electric heaters would have nearly doubled the cost and the weight of the furnace.

Pioneering an Alternate Approach

For these reasons, Cooperheat engineers decided to pioneer an alternate approach for annealing reactors. This method uses gas-fired burners to superheat air and blow it through sealed ducts in existing openings in the containment building, such as the equipment hatch, into the heat exchanger inside the reactor vessel. The superheated air is then discharged outside of containment through another duct to the atmosphere. Since the air never comes into contact with any contaminated surfaces, it does not become contaminated. The gas-fired heaters are located outside the containment building so they can be easily replaced in case of failure.

This approach clearly had the potential to eliminate many of the problems with electric heating. But it also raised several potential difficulties of its own. The main one was insuring that the heat exchanger would be able to maintain temperature uniformity throughout the entire reactor vessel annealing zone. The problem with not achieving adequate temperature uniformity is that it can create excessive thermal stresses. Much analysis was performed to verify that the reactor vessel would not be over-stressed.

The Marble Hill test proved that aging reactor vessels can be rejuvenated and their operating life substantially extended, permitting old reactors to continue operations for many years.

A scale model of the heat exchanger and reactor vessel was built and tested very early in the project to experimentally estimate heat transfer coefficients. A computational fluid dynamics (CFD) method to simulate

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flow distribution and heat transfer within the heat exchanger was utilized to confirm the experimental results. A CFD analysis provides fluid velocity, pressure and temperature values throughout the solution domain for problems with complex geometries and boundary conditions. As part of the analysis, a researcher may change the geometry of the system or the boundary conditions such as inlet velocity, flow rate, etc. and view the effect on fluid flow patterns or concentration distributions. CFD also can provide detailed parametric studies that can significantly reduce the amount of experimentation necessary to develop prototype equipment and thus reduce design cycle times and costs.

FIDAP CFD software from Fluent Inc. (Lebanon, New Hampshire) was selected because FIDAP uses the finite element method, which is ideal for generating the complex and irregular geometries which were involved in the proposed heat exchanger design. The flexibility of the mesh generation tool provided with this software package makes it possible to handle very odd shapes. Another advantage of this program is that a version compatible with the company's existing computer system was available at a very reasonable price.

Designing the Heat Exchanger

The authors first developed an initial design for the heat exchanger. Consultants from Fluent modeled the flow within the heat exchanger using the assumption that it would be uniform. The initial design verified the experimental heat transfer coefficients, based on the assumptions that were made. Next, the consultants modeled the distribution system which provided hot gases to the heat exchanger to make sure that it actually met the uniform assumptions of the first analysis. The initial design had assumed that a single injection point would provide uniform circulation within the heat exchanger. The analysis showed that, with only a single injection point, the hot gases impinged upon the wall of the heat exchanger and created a recirculation zone. This could have caused a cold spot that would have prevented the heat exchanger from uniformly heating the reactor vessel. Consultants changed the model several times and re-ran the analysis to evaluate the results. The engineering team finally settled on the use of four injection points, which provided the uniform flow required to achieve uniform heat transfer.

The heat exchanger prior to its installation inside the reactor vessel.

A Successful Demonstration

With the experimental results confirmed, the design team was able to proceed with confidence that the new process would work as expected. The first opportunity to use it came at a demonstration at Public Service of Indiana's never-completed Marble Hill plant near Paynesville, Indiana. The annealing demonstration at Marble Hill was carried out with the combined resources of the Department of Energy's Sandia Laboratories and an industry consortium including the American Society of Mechanical Engineers, the Electric Power Research Institute, Consumers Power Company, Japan's Central Research Institute of the Electric Power Industry, Westinghouse and Cooperheat.

The reactor vessel was heated for seven days and 10 hours, as the heat exchanger reached a temperature of about 1,100°F. The reactor pressure vessel was brought to its peak temperature at a rate of about 20°F per hour and cooled down at the same rate. Each of the five gas burners produced two to three million BTUs of heat per hour. During the annealing process, the pressure vessel and surrounding components were monitored by over 500 thermocouples, strain gauges and displacement gauges.

An important concern during the testing was showing that the vessel maintains a fairly even temperature distribution during annealing in order to avoid the stresses associated with thermal variations. Another concern was avoiding damage due to the fact that the vessel expands as it is heated, but the piping and other connections surrounding the vessel do not experience the same expansion.
The test was a complete success. All measurements showed that the vessel maintained an even temperature during the annealing process. Preliminary analytical results verify that the metal throughout the vessel walls, welds and attached piping expanded and contracted without damage exactly as predicted. The Marble Hill test proved that aging reactor vessels can be rejuvenated and their operating life substantially extended, permitting old reactors to continue operations for many years.

Steve Trich, General Manager of Westinghouse's Nuclear Services Division, stated: "The technology and overall annealing process demonstrated at Marble Hill went well beyond our expectations. This successful demonstration overturns a major hurdle faced by utilities with aging reactor vessels. Utility executives can confidently plan to extend the life of their reactors knowing that vessel embrittlement need not be an impediment."

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Mentoring in the Engineering Profession

"Big Shoes to Fill"

By Mark V. Holland, P.E.
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This article is the third in a four-part series in which four different engineers recount their unique experiences as protégés of recognized experts in the steel fabrication industry.

Remembering Johnny Griffiths

In October 1995, the engineering community lost a unique individual when John D. Griffiths, P.E., passed away. His contributions to the profession cannot be measured by the papers he wrote, nor by the number of times he spoke, nor even by his role in helping to develop the modern format of the latest A.I.S.C. Specifications and Manuals. John's greatest contribution was his passion for his life's work during a career that spanned more than five decades.

Mark Holland, protégé.

He came from an age when an engineer would sign in at a hotel and proudly write "P.E." after his name. It always saddened him to see engineers use disclaimers and approver notes in an attempt to dilute their responsibility. John was often annoyed by engineers who tried to overcomplicate the behavior of steel. One of his favorite gambits was to ask them to explain, through examples, how adding stiffness to a frame could cause it to collapse. His insight into the behavior of steel would have been invaluable to the engineering community in this post-Northridge environment.

Our Initial Meeting

When I first met Johnny Griffiths, I was a graduate student at the University of Oklahoma working on a research project sponsored by the American Institute of Steel Construction. Certainly, I had no idea that this was the man who, more than any other, would influence the course of my professional life. At the time, John was chairman of the A.I.S.C. research project, which focused on bolted moment end plates, a particular interest of his. He was also vice president of engineering at the Paxton & Vierling Steel Company of Omaha, Nebraska.

The next time I saw John was when my thesis advisor, Tom Murray, and I were traveling through Omaha on a research-related business trip. We stopped in to see John at Paxton & Vierling Steel, and Tom mentioned that I was looking for a job. John casually suggested that I submit a resume, which I subsequently did. It did not really occur to me then that Johnny Griffiths and Paxton & Vierling Steel had very specific plans for me.

Big Shoes

I was hired by Bob Owen (who was John's boss and is still my boss) and charged with working to the point where I would someday fill John Griffiths' shoes. At first, I did not really understand the scope of that expectation. However, as John took me around Omaha and Sioux City, introducing me to his colleagues in the engineering profession as "the young man I am training to fill my shoes," it began to dawn on me. Time and time again, I was told "You've got big shoes to fill!"

John D. Griffiths, mentor.

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John's position at the time was in the engineering-marketing area of Paxton & Vierling. He was expected to be something of a tutor, or engineering guru, for everybody in the area—the guy that everyone could go to with the tough questions. Yet he also had to talk to the general public and educate people about engineering and connection design.

When I read the first article in this series, authored by Duane Miller, I was struck by the parallels between our relationships with our respective mentors, John in my case, and Omer Blodgett in Duane's. Something that Duane and I have always shared is that we stand in the shadows of these great men. When Omer and John searched for their protégés, both of them were looking for the kind of person who could be very theoretical, and at the same time be capable of taking a complicated problem and explaining it to people from any walk of life in a clear way. John was a master at this, and Omer is, as well.

I had no idea that this was the man who, more than any other, would influence the course of my professional life.

Another thing that John and Omer had in common was the fact that both of them worked long past the usual retirement age. In John's case, it was because he could not find the right person to fill his role. At the time of my arrival at Paxton & Vierling in 1983, John was 74, and he had already retired twice, but the people hired to replace him had not worked out, so each time, he had returned to his position.

Priceless Lessons

Once I started working at Paxton & Vierling, Bob Owen made it clear that my time with John was to be my first priority. I am still grateful to Bob for that, because the insights and knowledge I gained were priceless.

Perhaps few us of know what we're getting into when we accept a new job. I had no idea! As the weeks and months went by, I began to get frightened. People expected me to know the kinds of things Johnny Griffiths knew, and of course he had more than forty years of experience in the industry. Furthermore, John's thirst for knowledge never ended. So I realized I would have to develop that same thirst just to keep up with his constant acquisition of new knowledge.

John's and my routine echoed the meetings over morning coffee that Duane described in his article about Omer Blodgett. As in their situation, what looked like a coffee break was really more of a classroom...an advanced course in not only the technical fine points of connection design (though plenty of those were dispensed), but also in how procedures and specifications had been developed: the process, the politics and the

The John D. Griffiths Memorial Scholarship Fund

The family, friends and colleagues of John Griffiths have established the John D. Griffiths Memorial Scholarship Fund at the University of Nebraska. The scholarship fund is intended to preserve and honor the memory of a great engineer by helping to support the education of qualified students with an interest in structural engineering.

Born July 8, 1909, in Takoma Park, Maryland, Mr. Griffiths graduated from the University of Cincinnati with a degree in civil engineering in 1934. After college, he worked in a variety of engineering capacities before serving in the Navy during World War II from 1942 to 1946, ending his naval service as commander of the Civil Engineering Corps.

In a career that spanned five decades, Mr. Griffiths progressed from being one of the original American Institute of Steel Construction regional engineers to eventually become vice president of engineering at Paxton & Vierling Steel Company. He published many papers and two books: *Single Span Rigid Frames in Steel* (A.I.S.C.) and *Multiple Span Gable Frames* (A.S.C.E. Transactions). Throughout his working life, he endeavored to raise the standard of professionalism within his industry, while constantly encouraging young engineers to maximize their potential.

Graduate student Lamont Epp of Lincoln, Nebraska, was named the first recipient of the John D. Griffiths Memorial Scholarship for the academic year 1996-97, and Mr. Epp's scholarship award has been renewed for 1997-98.

Those wishing to contribute to the John D. Griffiths Memorial Scholarship Fund at the University of Nebraska are asked to contact John Erickson, University of Nebraska Foundation, 8712 West Dodge, Suite 402, Omaha, Nebraska 68114-3434.

philosophy behind their development... the actual business of how work gets done. John was personal friends with people I had only read about in text-books.

He was a very, very proper man. If I spoke in an unprofessional way, he would correct me, and correct me, and correct me again. I wasn't just getting technical tutoring, I was being trained in how to sit across a table from some-one and communicate clearly and professionally. It turned out John's mother had been an English professor, and his wife was an English major. I remember the first time I worked for him on putting together a presentation. He gave me a list of materials to gather, including everything from extra light bulbs for the slide projector, to tape to cover the electrical cords. John left nothing to chance when it came to professionalism.

John always made sure that I could arrive at the answer by doing the problem correctly, and then he would show me the easy way.

As the best teachers do, John taught by example. I noticed that he never dominated at the beginning of a conversation. Like a chess player, he would quietly listen to the conversation, letting others talk and define their positions. Then, at the appropriate time, he would use the information he had gained during the conversation to explain his position and persuade the others to his way of thinking.

"Always define the problem before you try to solve it," John would challenge me before I tackled any issue. He stressed that as engineers, we should answer only the questions we *know* the answers to, and research the rest. He emphasized that engineers have an obligation to be honest about what we know, and to find out about what we don't know. Even in the twilight of his career, John was always eager to learn, and he inspired in me that same hunger for learning.

Even with all of his knowledge, John had great respect for those working in other aspects of steel construction. He told me that I could learn more in one week working with a detailer than in a whole semester of an engineering course. When I first started with Paxton & Vierling Steel, he put me into the shop and made sure that I worked with the saltiest old fellow there, who also happened to be the most experienced fitter. This exposed me to a great knowledge base of just how things go together.

John was really good at giving me problems to solve. I would spend *days* working on one of these problems, come up with an answer that I thought was correct, and finally present it to him. He would look at it, perform some really quick, dirty calculations, and arrive at almost the same answer. And then he would say "Here are the rules of thumb that will get you to the quick answer." As a fabricator's engineer, one has to be able to get to the answers quickly.

As the best teachers do, John taught by example.

But John always made sure that I could arrive at the answer by doing the problem correctly, and then he would show me the easy way.

I remember once having to compute the shear center of an odd shape. After several hours and many pages of triple integrals, I proudly showed John my work. True to form, with only a few lines of simple calculations, he approximated my answer more closely than any shop tolerance would require. What the steel industry will miss, with the passing of John and of engineers like him, is this practical, accurate and simple understanding of the behavior of steel.

1997 Design & Welding Seminars

Production Welding — September 29-October 2
Blodgett's Design of Steel Structures — October 6-10
Blodgett's Design of Steel Weldments — November 3-7

Lincoln Electric's seminar series continues to attract top design engineers and production welding personnel from across the country and around the world. All of the seminars are conducted in the state-of-the-art Weldtech Center at Lincoln's world headquarters in Cleveland, Ohio.

Omer W. Blodgett, P.E., and Duane K. Miller, P.E., conduct the Design Seminars. **Blodgett's Design of Steel Weldments** for machine tools, construction, transportation, material handling, agricultural equipment, and manufactured metal products of all types is aimed at reducing manufacturing costs and improving performance through the efficient use of welded steel. **Blodgett's Design of Steel Structures** addresses methods of reducing costs, improving appearance and function, and conserving material through the efficient use of welded steel in a broad range of structural applications. Each 5-day Design Seminar earns 3.3 CEU credits and costs $395.00.

Production Welding is a 4-day seminar conducted by Lincoln's staff of expert welding engineers. It covers welding process selection, welding variables and procedures, weld design, welding metallurgy, and nondestructive testing. The program is designed for welding foremen, superintendents, industrial engineers, and time study, quality control and inspection personnel. The seminar fee is $295.00.

Group size for each seminar is limited. Therefore, it is wise to register early. Rooms will be reserved so that the seminar group can stay together in the same hotel. Other living arrangements can be made if desired.

For further information or a registration form, write or call:

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199
Attention: Marion Zagorc
Phone: (216)383-2240

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Ensuring Weld Quality in Structural Applications, Part III of III

Alternate Acceptance Criteria

By Duane K. Miller, P.E.
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The Lincoln Electric Company
Cleveland, Ohio

This three-part series on ensuring weld quality in structural applications covers the following:

Part I reexamined the roles of the Engineer, the Fabricator, and the Inspector, as they relate to welded construction. The proper roles were defined, and misunderstandings corrected.

Part II emphasized the importance of effective visual inspection and its vital role in achieving weld quality.

Part III discusses alternate acceptance criteria and explains the Engineer's responsibility for invoking such criteria.

Throughout the series, reference is made to specific sections of the AWS D1.1-96 Structural Welding Code - Steel.

Introduction

Quality is tied to a given specification. The specification must be suitable to meet the ultimate owner's needs. For most welded construction, the *AWS D1.1-96 Structural Welding Code - Steel* provides adequate acceptance criteria for welded construction. Unusual structures, however, may demand additional requirements. D1.1 criteria may be overly restrictive for some lesser structures. For nonconformances to a standard specification, alternate acceptance criteria may be utilized in order to avoid unnecessary weld repairs. It is the Engineer's responsibility to evaluate the appropriateness of an alternate acceptance criterion before invoking it for a specific project.

Defining "Quality"

One of the currently popular definitions of a quality product is as follows: "A quality product is one that meets specification requirements." By this definition, quality is integrally linked to the applicable specification. As long as the product meets those requirements, it is deemed "quality." Unfortunately, if the specification is incorrect or inappropriate, conformance to those requirements may satisfy this definition but would not satisfy the wants and desires of the ultimate customer. Only when a proper specification is utilized, and when the product integrity meets or exceeds those specification requirements, will a true quality product have been produced that meets customer requirements have been produced. Therefore, a more appropriate definition of "quality" would include the concept of meeting customer expectations in addition to the standard specification requirements. This philosophy is summarized by A.M. Gresnight of Delft University, the Netherlands, as follows:

> "A good weld is any weld which does the job it is intended for during the service life of the structure."

In the structural field, the customer (Owner) has a representative (the Engineer) who develops the necessary specifications (contract documents and cited codes and standards) that enable the manufacturer (Fabricator) to deliver a quality product. In the case of fabricated steel, the commonly cited standard for quality is the *AWS D1.1-96 Structural Welding Code - Steel*.

D1.1 Quality Provisions

An understanding of the philosophy behind the D1.1 code will help the Engineer to determine whether it will adequately address the needs of the Owner. Section 6.8, "Engineer's Approval for Alternate Acceptance Criteria," states: "The fundamental premise of the code is to provide general stipulations applicable to most situations." The emphasis is significant. It is important to consider the scope of the D1.1 code, which covers structures that are static and dynamic: on- and off-shore applications that utilize

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plate, rolled shapes, and tubular members. The products covered range from simple single story metal-framed buildings to 100-story-plus skyscrapers and offshore drilling platforms. In some circumstances, these general stipulations may be overly restrictive, and in other situations, they may not adequately address the demands of the structure. Evaluating the suitability of the specification for the application is certainly the responsibility of the Engineer.

In the commentary to Section 6.8 of the code, the following can be found: "The criteria provided in section 5, Fabrication, are based upon knowledgeable judgment of what is achievable by a qualified welder. The criteria in section 5 should not be considered as a boundary of suitability for service. Suitability for service analysis would lead to widely varying workmanship criteria unsuitable for a standard code. Furthermore, in some cases, the criteria would be more liberal than what is desirable and producible by a qualified welder. In general, the appropriate quality acceptance criteria and whether a deviation produces a harmful product should be the Engineer's decision. When modifications are approved, evaluation of suitability for service using modern fracture mechanics techniques, a history of satisfactory service in similar structures, or experimental evidence is recognized as a suitable basis for alternate acceptance criteria for welds." This commentary makes it clear that the code has utilized what is achievable as the acceptance criterion, not what is necessary for the particular application. This is a reasonable approach for a standard specification, and as is indicated in the commentary, precludes the need for widely varying fabrication standards which would be difficult to monitor in a typical fabrication facility. When the weld quality does not meet these standards, however, it is inappropriate to automatically assume that the weld will be unacceptable for service. This should, however, drive the Engineer to look to fitness-for-service type criteria for further evaluation.

"A good weld is any weld which does the job it is intended for during the service life of the structure."

Few Engineers recognize that the D1.1 code permits the use of alternate acceptance criteria for welds. According to Section 6.8: "Acceptance criteria for production welds different from those specified in the code may be used for a particular application, provided they are suitably documented by the proposer and approved by the Engineer. These alternate acceptance criteria can be based upon evaluation of suitability for service using past experience, experimental evidence, or engineering analysis concerning material type, service load effects, and environmental factors."

These provisions permit the Engineer to utilize alternate acceptance criteria. Since quality is integrally linked to the applicable specification, the acceptance criteria will have a major impact on the final product. The Engineer's responsibility is to assess the suitability of a standard specification to a particular project, as well as to approve an alternate should the need arise.

Considering Alternate Acceptance Criteria

There are three areas in which alternate acceptance criteria should be considered: First, there are the situations where standard acceptance criteria are inadequate to the demands of the structure. Secondly, standard acceptance criteria may be overly restrictive for a particular application. Finally, there are cases in which fabrication is routinely performed to a standard specification, with minor noncompliances that can be accepted through the use of an alternate acceptance criterion. All three are significant issues and will be addressed here.

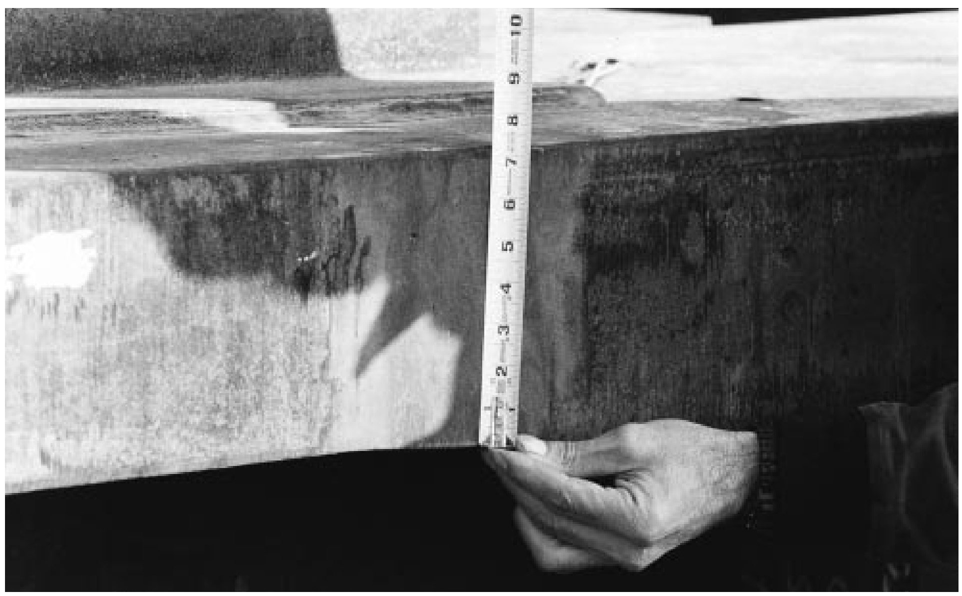

Figure 1. Heavy sections may require especially rigorous alternate acceptance criteria.

Certain structures make unusual demands upon welds and weld quality. When new materials are employed, significant deviations from standard material thicknesses are utilized, new welding processes are employed, and/or when the design of the structure involves a significant departure from established practices, it is prudent for the Engineer to critically evaluate the suitability of standard specifications. For example, the steel

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fabrication industry learned many lessons when "jumbo sections" were initially applied to tension applications in trusses. Standard materials (hot rolled, carbon and/or low alloy steel shapes) in unusual thicknesses (flanges exceeding 5" in thickness) were being used in new applications (direct tension connections). The common workmanship criteria set forth in the various codes and specifications, as well as normally acceptable workmanship criteria, proved to be inadequate in a number of structures. In hindsight, it would have been prudent to employ more rigorous alternate acceptance criteria for these types of structures. Since that time, provisions have been written to address these situations and have been presented in a variety of technical journals. Indeed, the standard specifications now include more rigorous requirements.

The second situation occurs when the standard acceptance criteria are more demanding than is justified for the particular application. An example in the structural field would be in the fabrication of steel joists. These components in steel buildings are usually covered by another specification that is more applicable to the particular product involved. Application of the same acceptance criteria as are applied to other fabricated steel structures and mandated by D1.1 would be overly restrictive, justifying alternate acceptance criteria. The Engineer should be careful when routinely suggesting that alternate acceptance criteria be employed which deviate from, or are less rigorous than, a national consensus standard such as D1.1. This practice would be recommended only for specific applications for components where well established, time-proven practices that have a history of adequacy have been used, and where deviation from these practices would constitute a major hardship. The D1.1 code, however, clearly gives the Engineer the authority to accept an alternate standard in these situations.

Figure 2. The 7" flanges of these transfer girders require careful consideration of the NDT acceptance criteria.

The most important use of alternate acceptance criteria, however, applies to the third situation, where standard acceptance criteria have been utilized for the fabrication practice and minor nonconformances have been uncovered. Alternate acceptance criteria can be utilized to accept these nonconformances and eliminate the need for unnecessary repairs. Obviously, the alternate acceptance criteria chosen must, as is true in the case of all engineering decisions, be applicable and appropriate for the application. Neither poor workmanship nor poor quality can be accepted. However, when the weld that does not conform to the standard specification is suitable for the specific situation, alternate acceptance criteria may be employed to eliminate the need for a repair. There are many reasons why this may be desirable for all (that is, the Owner, the Engineer, and the Fabricator). Unnecessary delays may be avoided. Costly repairs are avoided. Finally, and perhaps most importantly, an "acceptable" repaired weld may actually be inferior to the weld initially rejected as "unacceptable." Again, according to A.M. Gresnight:

> "Standards for weld discontinuities traditionally are based on good workmanship criteria. By extending the traditional standards with the second quality level, based on fitness for purpose, unnecessary and potentially harmful repairs can be avoided."

Weld Discontinuities

Weld discontinuities fit into two broad categories: planar and volumetric. Planar discontinuities include cracks and lack of fusion. These are serious discontinuities that are unacceptable, and particularly critical in structures subject to fatigue. Volumetric discontinuities include items such as porosity, slag inclusion, and undercut. These are less significant, and when held within certain limits, are acceptable by most codes even under dynamic loading situations.

Volumetric discontinuities are readily discernible by nondestructive testing methods and, in many cases, by visual inspection. Planar discontinuities are harder to detect, and may even be overlooked by radiographic nondestructive testing. It has been shown that, during initial fabrication, most discontinuities are volumetric in nature. Under repair welding conditions, which are more demanding than original fabrication circumstances, planar discontinuities are more likely to develop. Notice the progression: readily detectable, less significant volumetric discontinuities observed in the original fabrication may be removed and replaced with welds that contain less detectable, but more significant, planar

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discontinuities. This is not to say or imply that welds cannot be effectively repaired. It does mean, however, that haphazard demands for weld repair may actually result in a product of decreased value to the Owner. It should also be noted that the deposition of additional weld metal is likely to increase distortion and residual stresses in the structure. When the nonconforming weld is adequate for the particular application, the responsible approach is to utilize an alternate acceptance criterion to eliminate the unnecessary repair.

Most Engineers are unsure of the suitability of alternate acceptance criteria. The search for appropriate documents that employ the "fitness for purpose" approach is generally a frustrating experience. Apart from finding information regarding the methods that may be employed for analysis, practical ideas as they relate to welds are all too scarce. Mr. Robert E. Shaw, Jr., P.E., of Steel Structures Technology Center, Inc., (40612 Village Oaks Drive, Novi, Michigan 48375-4462) has provided Engineers with a useful source of information regarding alternate acceptance criteria. Shaw has systematically evaluated specific discontinuities, the D1.1 code requirements, and other standards that could be used as alternates. His summary is excellent and provides practical options to Engineers.

Undersized welds are a common problem. The situation is simple: the drawings call for a 5/16" fillet weld and the welder deposits a 1/4" fillet. At least two options are available: first, additional weld metal can be deposited over the surface to build it up to the required size; secondly, an alternate acceptance criterion could be employed that would allow these welds to be acceptable as deposited. It should be noted that the D1.1 code would allow the welds to underrun the nominal fillet weld size by 1/16" without correction provided that the undersized portion of the weld does not exceed 10% of the weld (D1.1-96, Table 6.1, see Part II of this series). If the entire weld, however, is undersized, this provision would not be applicable. In many cases, the deposition of additional weld metal would be routine and would not constitute a major problem. However, the initial weld may have been produced with an automatic, submerged arc welding machine when the travel speed happened to be slightly too high, resulting in a slightly undersized weld. The weld may be beautiful and meet all criteria except for the size. To make the weld repair, a gang of manual or semi-automatic welders may be assigned to deposit the additional weld metal. The finished product may be visually inferior, and subject to all of the potential discontinuities of the starts and stops associated with manual and semiautomatic welding.

Readily detectable, less significant volumetric discontinuities observed in the original fabrication may be removed and replaced with welds that contain less detectable, but more significant, planar discontinuities.

Has the product quality been enhanced by the repair? First, it must be determined if the undersized weld would have been acceptable. As is the case in many situations involving fabricated plate girders, the weld size may have been based upon the minimum prequalified fillet weld size prescribed in the D1.1 code. The design basis was not strength, but this minimum size. A quality, 1/4" fillet weld would have provided all the necessary strength in this particular situation. The reasoning behind the minimum fillet weld size in the code is based upon good workmanship practices and controlling the heat input to preclude weld cracking. However, in this example, it has been assumed that the initial weld is a quality weld, free of cracks, with acceptable weld contours, etc. If this is the situation, leaving the undersized weld in place, unrepaired, is a more responsible approach than demanding the weld repair. The initial weld is probably of higher quality than the repaired weld would be, will have less distortion, is less costly, and will eliminate unnecessary delays.

The decision to invoke alternate acceptance criteria must be made by the Engineer. In a separate article in this series, the roles of the Engineer, the Inspector, and the Fabricator are defined. The Inspector cannot make this decision and neither can the Fabricator. Only the Engineer with an understanding of the loading, design assumptions, and overall structural significance can make these types of decisions.

Conclusion

For most applications, the *AWS D1.1-96 Structural Welding Code - Steel* provides adequate acceptance criteria for welded construction. For welds that deviate from standard acceptance criteria, engineering judgment should be applied before repairs are mandated. If the weld will meet the structural requirements for the project without modification, the responsible approach of the Engineer is to utilize alternate acceptance criteria and accept these welds. Ultimately, a product of improved quality at reasonable cost will be the result of this approach.

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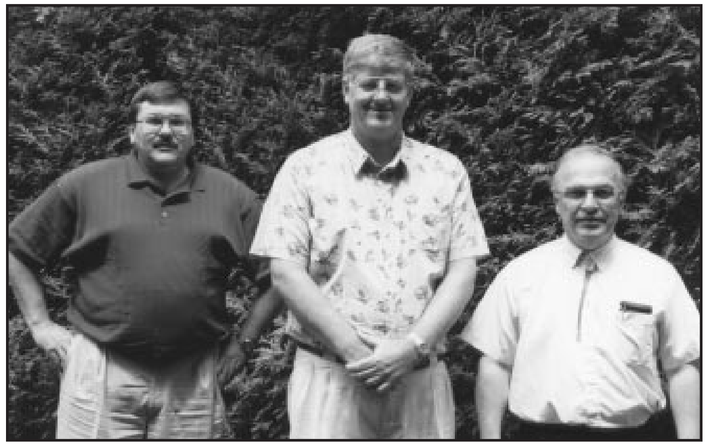
1996 Awards for College Engineering and Technology Students

Jury of Awards:


(Left to right) Brent Hall, Gary Krutz, Walter Massie

Brent Hall
Professor, University of Illinois, Urbana

Gary Krutz
Professor, Purdue University

Walter Massie
Professor, Technical University at Delft
Holland, the Netherlands

Donald N. Zwiep
Chairman of the Jury,
Chairman, the James F. Lincoln Arc Welding Foundation

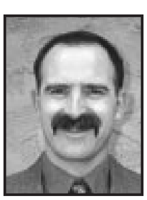
The James F. Lincoln Arc Welding Foundation granted the following awards totaling $15,750 to undergraduate and graduate students in the 1996 Pre-Professional Awards Program. Grants also were made to the following schools:

Cornell University
San Jose State University
Santa Clara University
Stanford University
University of California, Berkeley
University of Illinois, Urbana
University of Maryland at College Park
University of Minnesota
University of Wyoming
Virginia Polytechnic & State University
Worcester Polytechnic Institute

BEST OF PROGRAM—$2,000 EACH

UNDERGRADUATE

Design of a Remotely Operated Safety Release for a Bareback Bronc Rigging



Bradley O. Carlson
Laramie, WY

University of Wyoming
Mechanical Engineering

Faculty: Donald A. Smith

GRADUATE

Experimental and Analytical Studies of Steel Connections and Energy Dissipators

Tzong-Shuoh Yang
Albany, CA

University of California, Berkeley
Civil Engineering

Faculty: Egor P. Popov

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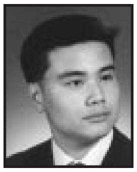
GOLD AWARDS—$1,000 EACH

UNDERGRADUATE

Anheuser: Glue Optimization for Package Strength



Wayne Lee
Marlboro, NJ

Diane Steinkamp
Centralia, IL

Michael Fasolo*
Palatine, IL

*Not pictured

University of Illinois, Urbana
General Engineering

Faculty: Manssour Moeinzadeh

GRADUATE

Intelligent Computer Vision Control & Target Tracking System Design for an Agricultural Grapevine Pruning Robot

Min-Fan Lee
Burnaby, BC, Canada

Cornell University
Agricultural & Biological Engineering

Faculty: Wesley W. Gunkel

SILVER AWARDS—$750 EACH

UNDERGRADUATE

Final Report for a Pneumatic Post Driver

Clay Douglas Price*
Laramie, WY

*Not pictured

University of Wyoming
Mechanical Engineering

Faculty: Donald A. Smith

Silicon Wafter Sensing on Robot "End Effector"

John L. Sullivan
Fremont, CA

Mutsuko Yamada
Menlo Park, CA

Mark Alan Prior
Stanford, CA

Stanford University
Mechanical Engineering

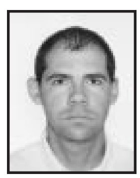
Faculty: Drew V. Nelson

GRADUATE

Integrated CD Charger & Battery Pack

Christian F. Johnson
Santa Clara, CA

Lisa Abruzzini
Mountain View, CA



Alberto Salazar
Mountain View, CA

Santa Clara University
Mechanical Engineering

Faculty: Tim Hight

Retrofitting Fatigue-Cracked Composite Beams with External Prestressing, Case Study: I-79 Bridge

Rostam Pouroushasb
College Park, MD

University of Maryland at College Park
Civil Engineering

Faculty: Pedro Albrecht

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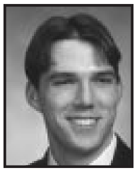
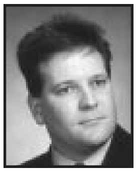
BRONZE AWARDS—$500 EACH

UNDERGRADUATE

Design & Fabrication of a Backpack Access Device



Christopher Michalak
Penfield, NY



James O'Sullivan
Greenfield, MA

Michael Oliva*
Quincy, MA

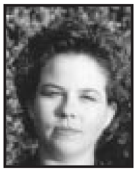
Susan MacPherson*
Hudson, MA

*Not pictured

Worcester Polytechnic Institute
Mechanical Engineering

Faculty: Allen H. Hoffman

Mechanical Hand for Below-Elbow Body-Powered Prosthetic Arm



Kristi Williams
San Jose, CA

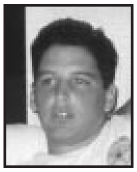
James Ritson
San Jose, CA

John Garcia
San Jose, CA

San Jose State University
Mechanical Engineering

Faculty: Buff Furman

ADM: Corn Steep Water Evaporator Fouling



Joseph B. Kirkey
Chicago, IL

Rodney B. Phillips
Raleigh, NC

James T. Fisher*
Orland Park, IL

*Not pictured

University of Illinois, Urbana
General Engineering

Faculty: Harry S. Wildblood

GRADUATE

The Carpal Wrist, a Parallel-Architecture Robotic Wrist

Stephen L. Canfield
Newport, VA

Virginia Polytechnic & State University
Mechanical Engineering

Faculty: Charles Reinholtz

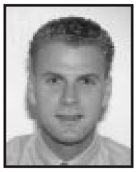
Seismic Analysis and Design of Multi-Bay Rigid Trussed Frames

Matthew W. Beckman
Warrens, WI

University of Minnesota
Civil Engineering

Faculty: Theodore V. Galambos

Studies in Steel Moment Resisting Beam-to-Column Connections for Seismic-Resistant Design



Brent Blackman
Hermosa Beach, CA

University of California, Berkeley
Civil & Environmental Engineering

Faculty: Egor P. Popov

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MERIT AWARDS — $250 EACH

UNDERGRADUATE

GE: Lean Engineering Approach to Packaging of Major Appliances
University of Illinois, Urbana
Faculty: Manssour Moeinzadeh
James G. Beier, Mattoon, IL
Waymond W. Eng, Chicago, IL
Michael S. Pape, Frankfort, IL

Minuteman: Fan Redesign for a Gasoline Powered Vacuum
University of Illinois, Urbana
Faculty: Daniel L. Metz
Joshua Fredrickson, Glenview, IL
Chad Peterson, Marseilles, IL
Matthew Woessner, Sterling, IL

Gearbox Coupling Design for a Vertical Tank Agitator
Purdue University
Faculty: Mark T. Morgan
Todd L. Redlin, West Lafayette, IN

Wellhead Bolt Cleaning Machine
University of Wyoming
Faculty: Paul A. Dellenback
Erik Lundberg, Laramie, WY

A More Functional and Cosmetic Hand Prosthesis for Amputees
Stanford University
Faculty: Drew V. Nelson
Rajiv Doshi, Stanford, CA
Ajit Chaudhari, Cupertino, CA
Clement Yeh, Honolulu, HI

Elco: Monitoring Tool Wear
University of Illinois, Urbana
Faculty: Henrique Reis
Bill Huffman, Charlotte, NC
Matthew J. Jackowski, Naperville, IL
Aaron C. Voegele, Sheldon, IL

Design of a Hand Extension Exerciser
Santa Clara University
Faculty: Mark D. Ardema
David T. Eveland, Woodland, CA
Delia Sauceda-Lopez, San Jose, CA
William M. Richter, Oroville, CA

Eaton: Spurious Response in Engine Knock Sensors
University of Illinois, Urbana
Faculty: Henrique Reis
Ian Bruce, Springfield, IL
Marc Koeppel, Carol Stream, IL
Adam Lack, Orland Park, IL

Fire Safe Project
University of Illinois, Chicago
Faculty: Mun Young Choi
Besher Rayyahin, Chicago, IL
Joseph Coldwate, Chicago, IL
Remus Hotca, Prospect Heights, IL

Testor: Needle Assembly Redesign
University of Illinois, Urbana
Faculty: Wayne J. Davis
Jennifer Bounds, Frankfort, IL
Paul Klaus, Freeport, IL
Anselmo Rosa, Chicago, IL
Peter Wong, Chicago, IL

Design of an Ocean Wave Energy Extraction Device
Worcester Polytechnic Institute
Faculty: Leonard D. Albano
Eric P. Truebe, Mirror Lake, NH

Forensic Investigation of a Fishing Vessel Sinking
U.S. Coast Guard Academy
Faculty: Vincent Wilczynski
Derek Schade, Chesapeake, Virginia

Watlow Gordon: Fluid Bath for Testing Thermal Response Time of Thermometers
University of Illinois, Urbana
Faculty: Roland L. Ruhl
Peter J. Ditmars, Naperville, IL
Janice M. Holba, Frankfort, IL
Melisa K. Olson, West Chester, PA
Dan Pawlak, Champaign, IL

Design of a Retail Store Paint Shaker
Worcester Polytechnic Institute
Faculty: Robert L. Norton
Michael I. Walker, Auburn, MA
Joshua R. Binder, Medway, MA

Sycamore: Design of Modular Drawer Suspension System
University of Illinois, Urbana
Faculty: Roland L. Ruhl
Jennifer Antanaitis, Orland Park, IL
Michael Brennan, Orland Park, IL
Darren Kennell, Shelbyville, IL

North American Glass: Glass Quality
University of Illinois, Urbana
Faculty: Harry S. Wildblood
Gregory Faber, Princeton, IL
Ericka Olson, Litchfield, IL
Erik Parks, Decatur, IL

GRADUATE

Effects of Dent-Damage on the Residual Strength & Repair of Welded Steel Tubular Bracing
Lehigh University
Faculty: James M. Ricles
William M. Bruin, San Francisco, CA

Temperature Sensitive Milling Burrs for Neurosurgical Applications
Stanford University
Faculty: Larry Leifer
Dale B. Perrigo, Anchorage, AK
S. Matthew Desmond, Walla Walla, WA

Measured Stresses in Steel Curved Girder Bridges
University of Minnesota
Faculty: Theodore V. Galambos
Brian E. Pulver, Chicago, IL

Refrigeration Application
Stanford University
Faculty: Larry Leifer
Hacene Bouadi, Palo Alto, CA
Robert Ware, Fairfield, CT
Alfred Hernandez, El Paso, TX

Epidural Anesthesia Simulator
Stanford University
Faculty: Larry Leifer
Joeben Bevirt, Santa Cruz, CA
David Moore, Redwood City, CA
John Q. Norwood, San Francisco, CA

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1998 AWARDS

COLLEGE ENGINEERING AND TECHNOLOGY ENTRY FORM

MAIL ENTRY ON OR BEFORE MIDNIGHT, JUNE 15, 1998 TO SECRETARY:

The James F. Lincoln Arc Welding Foundation, P.O. Box 17035, Cleveland, Ohio 44117-0035

Please submit a current photograph of each author, with the name written on the back, with the Entry.

Fill in information requested and attach to title page of paper being entered in the Program. **ENTRY MUST BE TYPED.**

DO NOT PUT YOUR NAME OR NAME OF SCHOOL ANYWHERE IN YOUR ENTRY OTHER THAN ON THE ENTRY FORM.

Subject or title of paper(put this title on Page 1 of paper also). ___________________

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To be entered in the following division (check only one):

❑ Undergraduate Division ❑ Graduate Division

Department ____

____

Professor or Faculty Advisor ____

School Name ____

School Address ____

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This paper completed by the undersigned author(s) within the period of June 15, 1997 to June 15, 1998.

Entrant(s) signature(s) ____

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NOTE: In case of joint authorship of an award winning Entry, each author will receive a check dividing the total award amount equally unless otherwise indicated. Please check one of the boxes below.

❑ Divide Equally ❑ Divide as follows:

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STATEMENT OF CERTIFICATION

(Must be signed by faculty member)

Following statement must be signed by a professor, instructor or the faculty advisor.

The author(s) of this paper ____

Name(s)

(is/are) (was/were) registered at (school) _________________________________

and to the best of my knowledge this paper was originated and prepared by the student(s) named on this Entry Form.

Signed ____

Professor or Faculty Advisor (Print Name Below)

____

Phone ____

AUTHOR(S)

Please Type — No Abbreviations

CHECK WILL BE SENT TO HOME ADDRESS. NOTIFICATION 10/98.
Home address must be address at which you will receive mail October 1998.

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Entries may not be submitted by more than five students.

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Design File

Use Undermatching Weld Metal Where Advantageous

Practical Ideas for the Design Professional by Duane K. Miller, P.E.

How Strong Does a Weld Have To Be?

The answer is fairly simple: strong enough to transfer the loads that are passed between the two interconnected materials. How strong does the weld metal have to be? The answer to that question is far more complex.

In order to make a weld of sufficient size, the designer has three variables that can be changed to affect the weld strength:

- weld length,
- weld throat, and
- weld metal strength.

Since three variables are involved, there are many combinations that are suitable for obtaining the correct weld strength. It may be necessary to also consider the loads imposed on the base metal to ensure that the complete welded joint has sufficient strength. This edition of "Design File" will focus on the variable of weld metal strength.

For purposes of this discussion, "weld metal strength" is defined as the yield and tensile strength of the deposited weld metal, as measured by an all-weld metal tensile coupon extracted from a welded joint made in conformance with the applicable AWS filler metal specification. "Matching" weld metal has minimum specified yield and tensile strengths equal to or higher than the minimum specified strength properties of the base metal. Notice that the emphasis is placed on minimum specified properties because, in the case of both the filler metal and the base metal, the actual properties are routinely higher. An example of matching weld metal would be the use of E70XX filler metal on A572 grade 50 steel. The weld metal/base metal properties for this combination would be 60/50 ksi (414/345 MPa) yield strength and 70/65 ksi (483/448 MPa) tensile strength. Even though the weld metal has slightly higher properties than the base metal, this is considered to be a matching combination.

All too often, engineers see filler metal recommendations provided in codes that reference "matching" combinations for various grades of steel and assume that this is the only option available. While this will never generate a nonconservative answer, it may eliminate better choices. Matching filler metal tables were designed to give the recommendations for one unique situation where matching weld metal is required, that is, Complete Joint Penetration (CJP) groove welds in tension applications. All other applications permit some degree of undermatching, and undermatching may be a very desirable, cost-effective alternative for applications such as Partial Joint Penetration (PJP) groove welds and fillet welds.

The significance of weld metal strength, as compared to base metal strength, has increased in recent years, as the number of higher strength steels continues to grow. When A36 was the predominant steel, commercially available filler metals would routinely overmatch the weld deposit. As steels with a 50 ksi (345 MPa) minimum specified yield strength became more popular (e.g., A572 grade 50 and A588), the use of the E70XX grades of filler metals provided for a matching relationship. Steels with minimum specified yield strengths of 70 ksi (483 MPa) through 100 ksi (690 MPa) have become more and more popular. Although matching strength filler metals are available, the option of using undermatched weld metal, where applicable, is increasingly attractive.

When undermatching weld metal is utilized, the designer must ensure that weld strength is achieved, but this is easily done with the standard equations used to determine the allowable stress on the weld.

For fillet welds in 90° T-joints, the maximum allowable load on the weld can be determined from the following equation:

$$F = (0.3)\ (0.707)\ \omega\ (EXX)\ L$$

where,

ω = weld leg size
EXX = minimum specified tensile strength of the filler metal
L = length of the weld

By substituting in the strength level of the undermatched filler metal, the weld strength can be determined. Undermatching may be used to reduce the concentration of stresses in the base metal. Lower strength weld metal will generally be more ductile than higher strength weld metal. In Figure 1, the first weld was made with matching filler metal. The second weld utilizes undermatching weld metal. To obtain the same capacity for the second joint, a large fillet weld has been specified. Since the residual stresses are assumed to be of the order of the yield point of the weaker material in the joint, the first example would have residual stresses in the weld metal and in the base metal of approximately 100 ksi (690 MPa) level. In the second example, the residual stresses in the base metal would be approximately 60 ksi (20 MPa), since the filler metal has a lower yield point. These lower residual stresses will reduce cracking tendencies, whether they might occur in the weld metal, in the heat affected zone, or as lamellar tearing in the base metal.

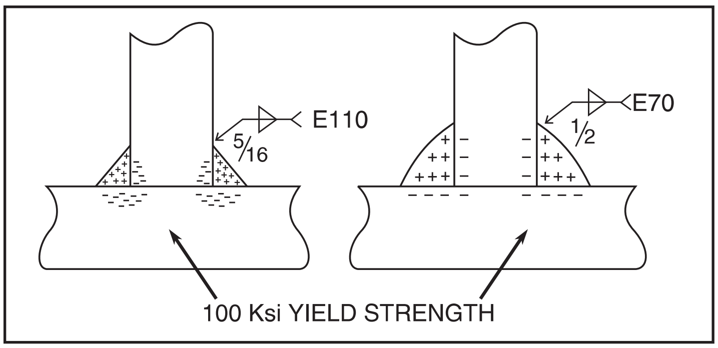

Figure 1. Matching and undermatching filler metal.

Overmatching is undesirable and should be discouraged. Caution must be exercised when overmatching weld metal is deliberately used. The strength of a fillet weld or PJP groove weld is controlled by the throat dimension, weld length, and strength of the weld metal. In theory, overmatching filler metal would enable smaller weld sizes to be employed and yet create a weld of equal strength. However, the strength of a connection is dependent not only on the weld strength, but also on the strength of the fusion zone. As the weld size decreases, the fusion zone is similarly reduced in size. The capacity of the base metal is not affected by the selection of the filler metal, so it remains unchanged. The reduction in weld size may result in overstressing the base metal.

Consider the three PJP groove welds shown in Figure 2. A load is applied parallel to the weld, that is, the weld is subject to shear. The allowable stress on the groove weld is 0.30 times the minimum specified tensile strength of the electrode (i.e., the “E” number). The allowable stress on the base metal is required not to exceed 0.40 times the yield strength of the base metal. The first weld employs a matching combination, namely A572 grade 50 welded with E70 electrode. The second example examines the same steel welded with undermatching E60 electrodes, and the final example illustrates overmatching with an E80 electrode.

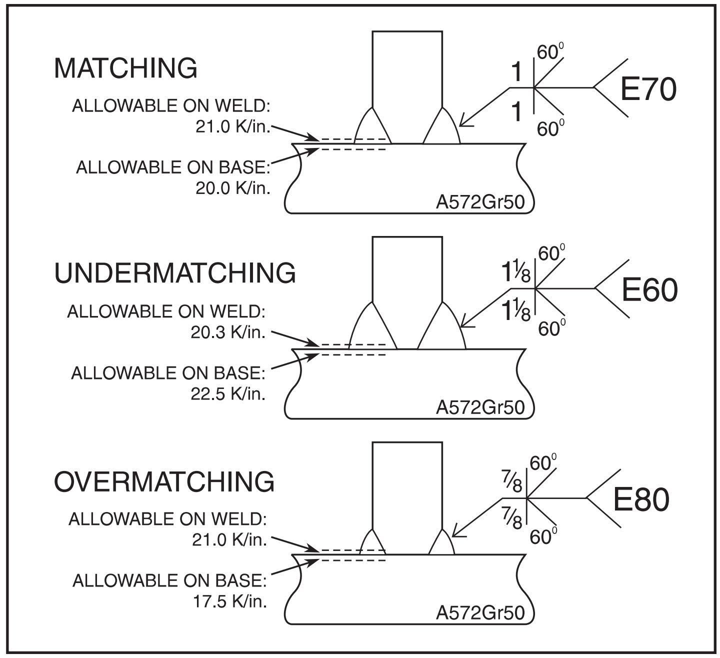

Figure 2. Effect of filler metal strength level.

As shown in Figure 2, the allowable stress on the weld and the allowable stress on the base metal have both been calculated. In the case of undermatching weld metal, the weld metal controls the strength of the joint. For matching weld metal, the allowable load on both the weld and the base metal is approximately the same. In the case of the overmatching weld metal, however, the base metal is the controlling variable. For this situation, it is important to check the capacity of the base metal to ensure that the connection has the required strength.

Practical Applications

Although it is relatively easy to determine which situations are suitable for the use of undermatching weld metal, some designers may simply choose to use the “conservative” approach and specify matching weld metal for all situations. However, matching weld metal may actually reduce overall weld quality, increasing distortion, residual stresses,

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and cracking tendencies, including lamellar tearing. The use of undermatched weld metal is an important option for successfully joining higher strength steels.

When welding on higher strength steels with undermatching weld metal, it is important that the level of diffusible hydrogen in the deposited weld metal be appropriate for the higher strength steel that is being welded. For example, whereas an E6010 electrode is suitable for welding on lower strength steels that are not subject to hydrogen assisted cracking, it would be inappropriate to utilize this as an undermatching weld metal on 100 ksi (690 MPa) yield strength A514 or A517 since these are highly sensitive to hydrogen cracking. When undermatched weld metal is used, it must not exceed the maximum levels of diffusible hydrogen appropriate for matching strength weld deposits. Also, any preheat requirements for matching strength relationships must be maintained even when undermatching weld metal is utilized.

There are economic considerations as well. While many filler metals from various welding processes are capable of delivering 70 ksi (490 MPa) weld deposits, the number of options available to the fabricator is greatly reduced when 100 ksi (690 MPa) yield strength weld metal is required (i.e., E110 class filler metals). The metallurgical characteristics necessary for the deposition of weld metal at this strength level may impose restrictions on the electrode designer which limit the attainable welding speeds and/or operational characteristics. In contrast, the requirements for lower strength filler metals give the electrode designers more latitude and may result in improved operational characteristics.

For many beam-like sections that are subject to bending, the resultant longitudinal shear that must be transmitted between the web and the flange of a built-up section is relatively small. Weld sizes that are based upon the transfer of the stress alone may result in surprisingly small welds, welds so small that they may be difficult to make on a production basis. The heat input associated with these small welds may be so small that weld cracking results. For these reasons, the D1.1 code has established minimum fillet weld sizes that, regardless of the level of stress imposed on the weld, should be maintained in order to obtain sound welds. For example, the minimum fillet weld size for 3/4 in. (18mm) steel is 1/4 in. (6mm). For materials greater than 3/4 in. (18mm), a 5/16 in. (8mm) fillet weld is the minimum acceptable size. The implications of this are that, for most structural fabrications involving built-up sections, the minimum fillet weld size is 5/16 in. (8mm). This is often greater than the required fillet weld size necessary to transfer the longitudinal shear. Particularly in these applications, undermatched weld metal offers a significant advantage because the minimum required weld size can be achieved utilizing the undermatched weld metal, and this may also satisfy design requirements.

The following welding procedures have assumed that the governing factor for the design of the members subject to bending is the minimum weld size, not the allowable stress on the connection. This will not always be the case. However, comparing the welding procedures associated with the two connections shows the benefit of utilizing the undermatched filler metal.

Example – Matching Versus Undermatching Filler Metal

Given: T-joint formed by 3/8” and 1” plates, 5/16” fillet weld, horizontal position, automatic SAW

Find: Cost savings for using undermatching versus matching filler metal

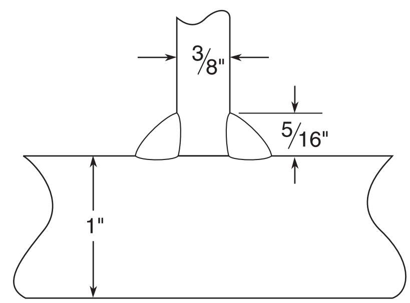
Assumptions: SAW Flux/electrode combinations – 960/L-61 (undermatching) and 880M/LAC-M2 (matching)

Labor & Overhead = $40.00/hr.

Equations: Cost = Labor + Materials

$$\text{Cost (\$/ft)} = \left[\frac{\text{Labor \& Overhead (\$/hr)}}{\text{Travel Speed (in/min)}} \; \frac{\text{12 in/ft}}{\text{60 min/hr}}\right]$$

+ [electrode used (lb/ft) x electrode cost ($/lb)]
+ [flux used (lb/ft) x flux cost ($/lb)]



	Undermatching 960/L-61	Matching 880M/LAC-M2
Labor & Overhead ($/hr.)	$ 40.00	$ 40.00
Travel Speed (in./min.)	20.0	16.0
Electrode Used (lb./ft. of joint)	0.19	0.28
Electrode Cost* ($/lb.)	$ 0.87	$ 1.84
Flux Used (lb./ft. of joint)	0.24	0.15
Flux Cost* ($/lb.)	$ 0.53	$ 0.93
COST ($/ft.)	**$ 0.69**	**$ 1.16**

*Prices based on current Industrial Prices in Lincoln Electric price book (April, 1997)

Solution:
In this particular situation, savings of 40% were achieved by utilizing the undermatching option. Design requirements were satisfied, and the likelihood of welding-related problems such as weld cracking or lamellar tearing has been reduced.

Sixty Years of Welded Bridges in Hungary

By Dr. Sandor Domanovszky
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The material in this article has been extracted, with permission, from the author's paper entitled "60 Years of Welded Structures, in Particular Welded Bridges, in Hungary," which was presented at the 49th Annual Assembly of the International Institute of Welding in Budapest, Hungary, September 2-3, 1996, and is contained in the "Proceedings of the International Conference on Welded Structures, in Particular Welded Bridges."

The Welding Industry in Hungary: A Brief History

Procedures

The industrial use of arc welding in Hungary began in 1930 with shielded metal arc welding using a covered electrode (SMAW). Starting in the 1950s, Hungarian industry began to use submerged arc welding (SAW) and gas metal arc welding (GMAW), the latter at first with CO_2 and later with mixed gas (mostly 82/18 Ar/CO_2). In the 1970s, gas-shielded flux cored metal arc welding (FCAW-g) became commonplace, and by the 1990s, self-shielded flux cored welding (FCAW-s) was added to the repertoire. Most recently, gas tungsten arc welding (GTAW) has been preferred in Hungary for welding the root pass.

Equipment

In the early years, Hungarians used generators and transformers, at first imported from Germany and later domestically produced. In the 1950s, SAW equipment was imported from the Soviet Union and Western Europe; in time, Hungarian manufacturers also entered this market. Today, both European and U.S. equipment manufacturers have distributors in Hungary.

Consumables

Even in the infancy of the Hungarian welding industry, covered electrodes were manufactured domestically. In 1980, a modern factory with a capacity of 30,000 tonnes per year of covered electrodes and fluxes was built. Solid wires for semi-automatic (GMAW) and automatic (SAW) welding also are produced in Hungary, but imported consumables are used in great quantity, as well.

Base Materials

The Hungarian steel industry was established in the nineteenth century. However, the manufacture of good weldable steel (mostly grades 37 and 52, nominal tensile strength) that would resist brittle fracture was not standardized and introduced until 1965. One catastrophe occurred in 1969, when two 30 m^3, 15 Bar (217.5 psi) service pressure spherical receivers that had been manufactured in 1960 exploded, killing thirteen people. They had been fabricated of a material totally unfit for the purpose: 22 mm thick plates, grade A42.21 (a structural steel used for riveted construction according to the Hungarian standard MSZ 21:1950).

Education, Certification & Professional Organizations

Programs of welding engineering were introduced in 1961/62 in two Hungarian technical universities: Miskolc and Budapest. Since then, about 700 engineers have received certificates. Since 1993, Hungary's standards for education and training have met the Guidelines of the European Welding Federation (EWF) and now, in cooperation with the Austrian Welding Institute, it is possible for Hungarian engineers to qualify for and receive the EWE (European Welding Engineer) certificate.

Education of welding experts at the level of "European Welding Technologist" (EWT) takes place at both of the aforementioned technical universities, and also at two technical colleges, the ME Dunaujvarosi Foiskolai Kar 300, and the Banki Donat Gepipari Muszaki Foiskola.

The Central Welding Section of the Scientific Society of Mechanical Engineers, formed in 1949, represents Hungary and its welding professionals within the International Institute of Welding (IIW). In 1990, the Hungarian Association of Welding Technology was formed by 32 member companies and institutes; today, there are 65 member organizations. About 3,000 welders per year are qualified by 30 certified training schools.

Quality Assurance & Control

The quality and safety of welded structures requires, first of all, welding experts who are highly trained and educated in the fields of design, manufacturing and fabrication. Hungary has taken all the necessary steps to ensure reliable quality assurance and

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control: issuing manufacturing and welding instructions, qualifying welders, destructive and nondestructive testing of the welded joints, and building the necessary jigs to ensure the best position and the correct shape of structures. Many Hungarian companies have instituted Total Quality Management systems.

A Transitional Period

Along with every other sector of the Hungarian economy, the structural steel industry is in an important period of transition. In the post-World War II period, Hungary's production of steel structures totalled about 150,000 tonnes (1 tonne = 1000 kg) per year, with more than 60 percent accounted for by buildings. The collapse of socialism has brought about privatization of Hungarian industry since 1990. However, economic times are very hard, and many of the newly privatized companies have gone bankrupt. The contractors who are operating in this market come mostly from Western Europe. The transition is extremely difficult, yet the Hungarian people still endeavor to work together to solve the problems facing our country.

Welded Bridges

Special Challenges of Orthotropic Deck Design

The majority of Hungarian welded bridges are of orthotropic deck design. The definitive characteristic of orthotropic deck design is its unique ability to perform all of the functions previously derived from several separate girders forming a floor of longitudinal and transversely integrated girders coordinated with the main girders. From a manufacturing point of view, the components of this complex girder system are more difficult to fabricate and fit than simple plane units for conventional structures.

For example, a traditional I-beam girder consists of only three main parts, and in the course of adjustment only six locations have to be fitted to two adjacent girders. A typical orthotropic unit, by comparison, forms a complex of longitudinal and transverse girders connected with the deck plate. This requires about fifty units being fitted to four adjoining units. Also, while the conventional girder expands in only two directions, the orthotropic structure expands in three, so moving and turning of the units requires more skill, making it difficult to secure dimensional accuracy.

With conventional girder construction, assembling components such as web plates, flanges and stiffeners, and straightening the finished girder are simpler than the same operations on an orthotropic structure. Therefore,

The definitive characteristic of orthotropic deck design is its unique ability to perform all of the functions previously derived from several separate girders forming a floor of longitudinal and transversely integrated girders coordinated with the main girders.

careful attention must be paid to the stability of such a large structure, which will be exposed to permanent spatial stress and dynamic loading. The risk of brittle fracture is greater than with the conventional and often smaller girder, which is usually bolted and riveted and has to withstand a smaller proportion of the dynamic load. Joints that are bolted and riveted on traditional girders allow for more tolerance and are easier to fit than welded joints on orthotropic structures. Meeting the challenges of orthotropic deck construction in an economical, cost-effective fashion demands meticulous care and great skill.

Orthotropic Deck Assembly

The most complicated aspect of orthotropic deck assembly is securing the optimum coordinate position for the numerous fitting edges of the units involved. The manufacturing technology should focus on this critical requirement.

There are two aspects to the requirement: ensuring that the dimensions of the components are precise, and ensuring the correct positioning of the components.

The dimensional accuracy of the components can be achieved in several ways. By accounting in advance for the shrinkage that will be caused by welding and straightening (in strict compliance with specifications and instructions), the components can be cut to size before assembly. A more dependable, but also more expensive, solution is to cut one of the edges of the components with an allowance in either one or two directions (for example, the bridge axis). After welding has been completed, the members can be cut to size, and the entire orthotropic unit straightened.

There are two ways to ensure the accurate positioning of units. With the first method, orthotropic components can be assembled in a jig; this method is preferred if the bridge consists of a number of identical assembly components. An alternate method is one in which adjacent and consecutive units are assembled on a suitable bench, in reverse position, carefully joining each piece to be fitted. This requires more room and more labor than the previous approach, but it is secure and simple, and can be applied when only a few structural components are involved. It is also possible to combine the two methods when components are assembled alongside each other. Some simple fixturing will facilitate the correct positioning of the components.

Welding

In an orthotropic bridge, the deck structure contains about 60 percent of the welded joints. Expert welding of

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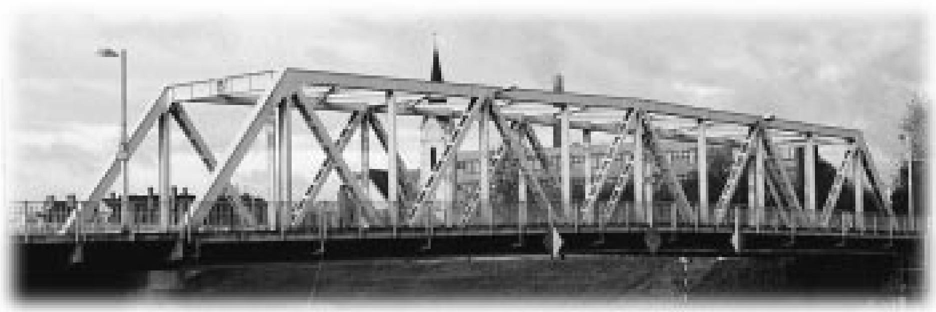

Figure 1. The first welded bridge in Hungary, at Győr, opened in 1935 (span: 53.1 m).

Figure 2. The first bridge in Hungary with a fully welded orthotropic deck spans the Tisza River at Szolnok, and was opened in 1962 (spans: 54.8 + 79.3 + 54.8 m).

the orthotropic unit requires selection of the most suitable welding process, and a decision about the order in which components will be welded. The process selected will usually influence the order of welding. Depending on the specific circumstances, any of the following processes may be used:

- Manual arc welding
- Gas metal arc welding
- Submerged arc welding
- The Elin-Hafergut procedure (a patented procedure developed in the 1930s and primarily used for connecting longitudinal stiffeners)
- A combination of the above methods.

Either one of two fundamentally different approaches may be taken with regard to the order of welding. The entire deck structure can be assembled before the joints are welded, or the longitudinal girders can be joined initially to the deck plate, and its corners welded so that cross girders can be placed and welded subsequently.

The first approach is more common. It has a significant advantage over the second method in that during the course of assembly, the joining of individual units (longitudinal stiffeners and cross girders) can be secured without difficulty. Since, in the course of welding, only lengthwise distortion occurs, it can be minimized by prestressing in the jig, thus leaving a negligible amount of straightening work. The major disadvantage of this approach, however, is that due to frequent interruptions in welding the joints, welding cannot be automated.

The second approach was developed to eliminate the disadvantage of the first, making it possible for the many long joints of the longitudinal stiffeners to be welded automatically. This may be advantageous, but it must be noted that automatic welding increases productivity only if jigs are used, and that is expensive. The major disadvantage of this method is that erecting cross girders between the already fixed longitudinal stiffeners complicates accurate assembly. The deck unit may tend to bend when the cross girders are not in place during the welding of the longitudinal stiffeners. Although the tendency to bend in one direction (preferably the transverse) can be eliminated by prestressing, the other bending moment inevitably requires additional straightening work.

Naturally, both approaches require the welding of structural units to be in jigs. This will ensure the welding of joints in correct positions, either flat or horizontally, and by correct straightening, the number of deformations can be reduced.

Straightening and Assembly

The straightening of orthotropic units is a very costly operation, due to their large dimensions and complicated design. To reduce the amount of straightening required, it is important to choose the welding technology, the procedure, the order of welding, and the jigging with great care. Straightening can be done with a gas flame, local hammering, or preferably, with a hydraulic press.

To facilitate the process of on-site assembly, finished orthotropic units (separately or with the main girders in the full cross section of the bridge) are

Figure 3. The welded lattice girder composite bridge over the Tisza at Tiszafüred is composed of spans measuring 30.0 +3x70.0 + 30 m.

Figure 4. This photo shows the last 100 tonne deck unit of the Erzsébet cable bridge being set into place in 1964.

prefabricated to the greatest degree possible. The facilities at the fabrication plant are a decisive factor. Prefabrication provides an opportunity for checking and correction of local root openings, and in the case of riveted or bolted joints, for reaming up joint plate holes to final size. Effects on the designed shape of the bridge can also be checked at this time.

Examples of Welded Bridges in Hungary

The very first bridge structure in Hungary to be created by welding was built sixty years ago and is still in service today (Figure 1). The 53.1 m span is of lattice girder design.

Hungary's first up-to-date welded bridge with a fully welded orthotropic deck structure was built over the Tisza River at Szolnok and opened in 1962 (Figure 2). It was fabricated using manual metal arc welding, with all of the deck units assembled and welded in special jigs. Each cross section (6 m long by 8 m wide), consisting of four manufacturing units, was assembled on site, using a suitable bench. To ensure the flat position, the whole structure was placed in a prestressing rotary jig. The completed welded units were cut to size after being set on the two main girder webs, and the joints of these were then riveted.

Figure 5. The Erzsébet cable bridge at Budapest, shown today (spans: 44.3 + 290.0 + 44.3 m).

On the lattice girder bridge at Tiszafured, dating from 1966 (Figure 3), the joints of the (box structure) upper and bottom flanges were field-welded, but the diagonals were high-tensile bolted. The two 30 m long side structures were fully welded on site using SAW.

In 1964, the 10 m long, 4 m wide orthotropic deck units of the Erzsébet cable bridge, shown during construction in Figure 4, were welded differently from those of the Szolnok bridge. At first, only the longitudinal stiffeners were assembled onto the deck plate and welded in a prestressing-tilting jig using SAW. After that, the cross girders were built and welded using manual metal arc with a covered electrode. The 27.5 m wide by 380 m long bridge, shown as it appears today in Figure 5, contains 100,000 m of welded joints, 70 percent of them made with SAW, and 30 percent with manual metal arc.

In the composite bridge at Algyő, opened in 1974, only the main girders were laid out in the course of preassembly. Because the bridge (Figure 6) was erected with a floating crane by the cantilever method, it was very important to ensure the exact positioning of all of the cross girder and wind bracing joint holes on both main girders.

The orthotropic deck plate of the bridge over the Tisza at Szeged (1979) has the longest spans of any girder type bridge in Hungary, at 52.0, 97.5, 144.0 and 78.0 m (Figure 7).

This was the first instance in which the welding of the site joints was done with SAW, using backing plates.

In 1985, the 120 m main span lattice girder railway bridge at Csongrad opened (Figure 8). With 3,000 tonnes of dead load, it is the heaviest bridge on the river Tisza.

Figure 6. The composite bridge over the Tisza at Algyő has spans of 57.6 + 102.4 + 57.6 m.

The Ganz Company began exporting bridges in the 1930s, and since then has delivered almost 100 bridges to foreign countries. In the 1970s, Ganz designed, manufactured and erected nine bridges for Yugoslavia. The most impressive of them is the bridge over the Danube at Novi Sad, shown in Figures 9 and 10. Professor Nikola Hajdin designed the structure with a main span of 351 m, which at the start of manufacturing was the longest in the world and today remains the longest on the river Danube. The total length of the main structure with the orthotropic deck is 590 m., with composite side bridges of 240 + 180 m. The dead load of the steel structure is nearly 10,000 tonnes. The bridge opened in 1981.

The Årpád bridge at Budapest was opened originally with two tram and two highway lanes. In the early 1980s, the old structure was widened on both sides with the addition of two independent bridges, each 14 m wide. The orthotropic deck structure is the longest bridge in Hungary, and has a dead load of 8,500 tonnes. It is shown in Figure 11 as it appears today.

The highway bridge at Haros, opened in 1990, is a box girder with reinforced concrete deck slab (Figure 12). To connect the deck with the steel girders, stud welding, involving almost 100,000 studs, was used in Hungary for the first time. The bridge is 22 m wide, its total length spans 805 m, and the dead load of the steel structure is 4,500 tonnes.

The Lágymányos Bridge

The Lágymányos bridge on the Danube at Budapest was completed in 1995 (see cover). It is 500 m long, 30 m wide, and the dead load of the steel structure is 8,000 tonnes. The box girder cross section was built up from 15 manufactured units. Lengthwise, there are 41 sections, so the bridge consists of 615 manufactured units of different types. To ensure correct dimensions and shape, 300 tonnes of various jig structures were built for prefabrication and 150 tonnes of various jig structures for pre-erection and site erection work.

Construction was carried out in the following five major stages:

- Prefabrication of the units
- Preassembly of the box girder, without the cantilevers
- Application of corrosion protection
- Assembly of the cross sections
- Site erection (one cross section in two units) by floating crane

The bridge is lit according to a unique design: in the center of each pylon, there is a lamp which lights mirrors at the top of the beam. These mirrors then reflect light onto the bridge without blinding the drivers below (see back cover).

The units of the structure and the site joints on the orthotropic deck were fully welded using SAW and GMAW procedures. The other site joints were high-tensile bolted, but all joints of the five pylons and the slant staying girders were welded.

The Lágymányos bridge designed by Dr. Tibor Sigrai contains approximately 150,000 m of welded joints, more than 95 percent of them produced using automatic or semi-automatic procedures. Site erection was also accomplished using self-shielded flux cored arc welding for the root pass. It was the first time FCAW-s had been used in Hungary, and we had a very good experience with the process. Five pipelines, from 300 to 800 mm in diameter, were incorporated into the bridge. These were welded using the GTAW process. In addition, 22,000 welded studs were used to secure the tram rails.

Conclusion

Hungary is a small country in central Europe, with a population just over one percent of the total population of Europe. Due first of all to the size of the country, Hungary is not destined to be a world leader in building welded bridges. However, the technology of welding has made a significant impact on our infrastructure, particularly as demonstrated by the welded steel bridges that contribute so much to our landscape, and to our way of life.

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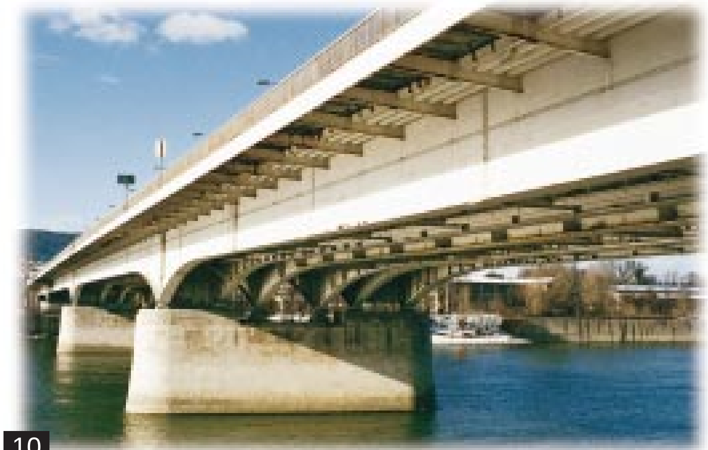

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Figure 7. The orthotropic bridge over the Tisza at Szeged (spans: 52.0 + 97.5 + 144.0 + 78.0 m).

Figure 8. The railway bridge at Csongrád over the Tisza (spans: 107.7 + 120.0 + 107.7 +4x42.0 m).

Figure 9. A section of the bridge destined for Novi Sad, Yugoslavia, being preassembled in Budapest in 1980.

Figure 10. The cable stayed bridge over the Danube at Novi Sad, Yugoslavia, 1981 (spans: 4x60.0 + 2x60.0 + 351.0 + 2x60.0 + 3x60.0 m).

Figure 11. The Årpád bridge over the Danube at Budapest (1981), which boasts a total length of 928 m.

Figure 12. The highway bridge over the Danube close to Budapest is a composite structure. Opened in 1990, it has spans of 3x73.5 + 3x108.5 + 3x73.5 m.

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This striking bridge over the Danube at Budapest features a unique lighting design. See story on page 20.

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