Volume XV, Number 1, 1998

# Welding Innovation

*Advancing Arc Welding Design and Practice Worldwide*

**$25,000**
**Top Award**
See page 9

# Certification for Steel Erectors: New Program Promotes Excellence

Fred Haas

All too often, industry waits complacently for government to establish and enforce standards of quality and safety. Historically, however, the structural steel industry has bucked that trend—and continues to do so today. From shape standardization to auditing fabricators for quality procedures, the structural steel industry has an enviable track record of anticipating and meeting the needs of our members and constituents. The American Institute of Steel Construction, Inc.'s new Erector Certification Program is the latest example.

Developed by AISC in conjunction with the National Erectors Association (NEA) and the Steel Erectors Association of America (SEAA), the Erector Certification Program will serve as a tool to help owners, contractors, engineers and fabricators prequalify erectors. Initiated in October 1997, the program is expected to certify between 30 and 50 erectors by the end of this year.

In concept and practice, the Erector Certification program resembles AISC's respected and successful Quality Certification program for steel fabricators (through which more than 400 fabricators have been certified).

The new program provides two levels of certification: Certified Steel Erector and Certified Advanced Steel Erector. For both levels, the erectors must meet the following standards:

- Erection plan
- Formal safety plan
- Program in place to promote project planning
- Formal program to monitor compliance with welding and bolting procedures
- Written substance abuse plan and policy

To qualify for Advanced certification, companies must also demonstrate:

- Experience in retrofit and maintenance
- Experience with complex projects such as working over water and railroad tracks
- Experience with large-scale erection projects
- Experience with and equipment for rivet removal
- Written procedures for jacking and the use of falsework
- Written erection plan

AISC is the logical entity to administer the program both because of its long track record with similar programs, and because no single erector association represents the entire industry. Encouraging coordination between designers, general contractors, fabricators and erectors is an important emphasis of the program. Ideally, in addition to being a tool for prequalification of erectors, the new program will help to close the gap between practice and the specification.

Fred Haas
*Coordinator*
*AISC Erector Certification Task Force*

Omer W. Blodgett, P.E.
Design Consultant

Volume XV
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The James F. Lincoln
Arc Welding
Foundation


*The serviceability of a product or structure utilizing the type of information presented herein is, and must be, the sole responsibility of the builder/user. Many variables beyond the control of The James F. Lincoln Arc Welding Foundation or The Lincoln Electric Company affect the results obtained in applying this type of information. These variables include, but are not limited to, welding procedure, plate chemistry and temperature, weldment design, fabrication methods, and service requirements.*

# Welding Innovation

*Cover: Hundreds of beautifully ground full-penetration welds were used to create the flowing "pipe waves" of twin all-steel sculptures depicting the Puerto Rican flag. See story on page 23.*

## Award Programs



## Features



## Departments



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# CONTROLLING WELDING FUME
# A Total Systems Approach

By Tom Pumphrey
Product Manager, Environmental Systems
The Lincoln Electric Company
Cleveland, Ohio

## Introduction

Operators are exposed to both fume and gases when welding, and exposures vary depending upon the process and specific working conditions. Fabricators are under continual pressure to reduce worker exposure to potentially harmful substances in the workplace, including welding fume. This article will address the following:

- How welding fume is generated
- The important contributions that design engineers, fabricators, welding supervisors, and management can make to reducing the generation of welding fume
- Highlights of fume extraction technology
- The current U.S. regulatory climate with regard to welding fume
- Current published exposure limits for typical components of fume

## What Is Welding Fume?

Although many people think of gases and vapors from gasoline or other chemicals as "fume," technically, fume is comprised of very small, solid particles. Welding fume is no different. The gases created by arc welding usually are produced in only small concentrations, and are seldom a concern, except in confined areas. Therefore, the issue of secondary gas production will not be specifically discussed here.

During arc welding, iron from molten steel combines with oxygen in the air to form free-floating particles of iron oxide. Alloying elements in the electrode and flux may also form compounds such as zinc oxide, aluminum oxide and magnesium oxide, which can become contributors to the welding fume. These particles are visible because of their quantity, but each particle is only between 0.2 and 1.0 micron in size. In most cases, fume results when components of the electrode are released as the filler metal melts. In certain instances, however, welding fume is a product of both the base metal and the electrode. This is especially true when fabrication involves coated or plated metals (for example, galvanized steels). Welding on cadmium plated steels can result in extremely toxic fume.

## A Shared Responsibility

As with many environmental problems, controlling welding fume should be seen as a shared responsibility. Just as one company, by ceasing to discharge toxic waste into a body of water, has eliminated only one polluting factor while others may remain, a single, one-shot approach to controlling welding fume is unlikely to solve the problem. Rather, effective and economically feasible control of welding fume requires the cooperation of many individuals and departments to achieve a coordinated, well-planned approach.

Although "fume extraction" may be the first solution that comes to mind, other options should be considered from the outset. Approaches to controlling welding fume actually fall into just two broad categories:

- Reducing fume generation
- Limiting operator exposure to fume

Fume extraction is simply a subset of the second category.

## Reducing Fume Generation

***Welding Design Considerations***

Limiting the generation of welding fume begins at the design stage. All other things being equal, a properly sized weld will result in the lowest amount of welding fume for a given process and set of procedures. Overwelding, on the other hand, unnecessarily increases welding fume. As the amount of weld metal increases, the amount of fume also increases. The welding engineer should be aware of the role that weld size plays in the creation of fume.

Many welding design engineers understand, for example, that for a given application, the specification of a 1/4 in (6 mm) fillet weld instead of a 5/16 in (8 mm) fillet weld will reduce welding costs by 50%. However, they tend not to be so aware that the smaller fillet weld can also result in a 50% reduction in the amount of fume generated during welding. Proper sizing of welds truly creates a win/win situation.

**Although "fume extraction" may come to mind first, other options should be considered from the outset**

***Welding Process Selection***

Significant reductions in fume creation can come with a change in the welding process. Therefore, fabricators



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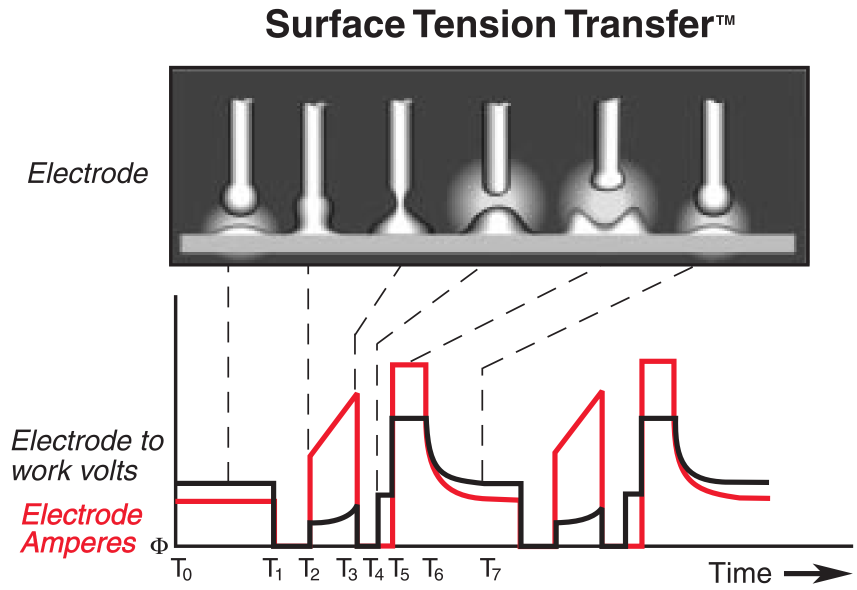


*Figure 1. Graph of STT® waveform output.*

and welding foremen should be aware of the impact process selection will have on fume generation. They must also remember, however, that each process offers specific advantages and disadvantages for a given application and a given situation.

SAW contains the majority of the fume (and the arc) under a bed of flux, making it an excellent choice when reducing fume generation is a primary concern. This process has certain limitations, however. SAW requires flat or horizontal positioning, slag cleaning, and maintenance of the granular flux, and is most commonly used for mechanized welding of relatively thick steel plate.

GTAW also produces very little fume, since the filler metal does not carry the welding current, and the arc is very stable. However, manual GTAW is a low deposition rate process requiring highly skilled operators. As such, it is often the process of choice for precision welding or certain special applications. Using GTAW to weld heavy plate would not be practical.

FCAW processes are usually considered the largest fume producers due to typically high deposition rates. However, many applications are best served by FCAW precisely because of its high deposition rates, especially in out-of-position applications. Fume generation rates vary widely, depending upon the electrode type, grade, and design. The design of the electrode can have a major impact on the amount of fume that will be generated. Several manufacturers offer reduced fume flux cored electrodes. Research indicates that some metal cored electrodes used with a pulsed current power source can yield low fume generation rates.

GMAW is a practical option for many applications, from thin sheet metal to heavy plate. Fume generation in GMAW depends upon procedures, droplet transfer, shielding gas, and the grade of electrode used. ER70S-6, for instance, has higher levels of manganese than ER70S-3. Since manganese levels are often a key factor in determining regulatory compliance, this can be a significant issue.

***Waveform Control Technology***

Another way to reduce fume generation is to use one of the various waveform controlling power sources. With pulsed GMAW, for example, less fume is typically produced than with a conventional constant voltage power source. In this mode, the arc is controlled by pulsing the current from a background level to a peak level at a specified frequency. This reduces the total arc energy and decreases the amount of metal that is vaporized, which leads to reduced fume generation.

Lincoln Electric's new STT® inverter is a waveform controlled power source that has led to the creation of a new transfer mode: Surface Tension Transfer™ (STT) welding. In conventional short-circuit transfer, the current rises to high levels immediately before the droplet detaches from the electrode, causing some of the electrode to vaporize. This causes violent droplet detachment and the creation of spatter and fume. The STT power source tightly controls the current during droplet transfer (see Figure 1).

**The most direct approach to limiting exposure is to limit the amount of time an operator spends welding**

When the droplet is about to detach, the current level decreases, and the droplet is pulled into the puddle by surface tension forces, reducing spatter. After detachment, the current is then controlled to prevent overheating the tip of the electrode. This control significantly reduces droplet temperatures and increases arc stability. Spatter can be decreased by 90% and fume generation by 50%, compared to


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*Figure 2. Invertec STT®, shown here in a pipe welding application, greatly reduces fume generation.*

conventional short-circuit transfer (see Figure 2). STT, however, is limited to applications appropriate for short-circuit transfer.

## Limiting Operator Exposure to Fume

The second broad category of controlling welding fume covers methods of limiting personnel exposure to the fume. Management will be responsible for initiating the decisions in this category, while employees at various levels of the organization will have to cooperate to ensure their success.

### *Job Sharing*

The most direct approach to limiting personnel exposure is simply to limit the amount of time an operator spends welding. This can often be accomplished via job sharing. For example, an operator could spend half a day welding an SAW application, and the remainder of the day welding an FCAW application. Or, the second half of the day might be spent driving a forklift. It is not a cost-free method; after all, twice as many individuals must be trained and qualified as welding operators for any given application. However, it can yield dividends in terms of higher productivity, greater job satisfaction resulting from mastering a variety of tasks, and a more versatile, cross-trained workforce. This simple approach deserves thoughtful consideration by management.

### *Automated Welding Systems*

Robotics and other automated welding systems provide another route to limiting employee exposure to welding fume. Automation can be a viable alternative if the initial capital expense can be justified by higher productivity and improved quality. However, automated welding cells commonly operate at high duty cycles, and employee exposure to fume must still be evaluated.

## Fume Extraction Technology

The one method of fume control effective for almost any welding process is ventilation. Since the operator's breathing zone is the critical area, localized ventilation, usually called "fume extraction," is the preferred method. Fume extraction technology falls into two categories: low vacuum/high volume, or high vacuum/low volume.

### *Low Vacuum/High Volume*

Regular building ventilation systems are low vacuum/high volume systems, sometimes called "low static, high flow." When industry needed better ventilation solutions, many companies modified low vacuum systems for localized ventilation. Hoses with diameters of 6 to 9 in (150-230 mm) were added for flexibility, and eventually articulated arms were designed to support the hoses and make it easier to position them. Manufacturers began to make these structures with different designs and features, and they are still used in many industries, including the welding industry.

The articulated arms generally move between 600 and 900 cu ft per minute (CFM) of air (900-1500 m³/hr), but use low vacuum levels (3-5 in water gauge [750-1250 Pa]) to minimize power requirements. Water gauge (WG) is a measure of negative pressure: higher numbers mean more negative pressure (more "suction"). With this volume of airflow, the end of the arm can generally be 10-15 in (250-375 mm) away from the arc and still capture the fume. Articulated fume extraction arms are produced by a wide range of manufacturers, using 6 or 8 in (150 or 200 mm) hose, or hose and tubing combinations. Lengths are typically 7, 10, or 13 ft (2, 3 or 4 m), with boom extensions available. The arms may be wall mounted (Figure 3), attached to mobile units (Figure 4), or incorporated into a centralized system.

For greater capture distances, a larger volume of air is required to achieve the necessary "capture velocity" and capture the fume. In practice, however, longer capture distances may mean that breathing zone exposure is compromised. Overhead hoods, for example, capture most of the fume, but only after it has passed through the breathing zone of the operator.



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*Figure 3. Low vacuum/high volume system (wall mount).*

*Figure 4. Low vacuum/high volume system (mobile unit).*

Cross draft ventilation is a variation of overhead hood technology. These systems use a plenum with openings to the side of the work space, rather than above it. Therefore, the fume moves sideways, away from the operator's breathing zone. These systems can be effective for small booths when small parts are being welded. The CFM required for effectiveness varies depending upon the installation design, but frequently can be 1,000 CFM (1,700 m³/hr) or higher.

There are, however, certain disadvantages associated with the low vacuum systems. For example, in systems incorporating articulated fume extraction arms, the operator must stop to reposition the arm over each weld area, which diminishes productivity. These arms also have limited reach, commonly 10-13 ft (3-4 m). The high volume of air flow requires large hoses and ductwork with diameters ranging from 8-36 in (200-900 mm) or more, depending upon the installation. Exhausting air outside often requires make-up air systems and make-up air heaters. Filtration systems are large due to the high air volume being processed.

***High Vacuum/Low Volume***

High vacuum/low volume fume extraction systems are much more specific to point-source applications such as welding. Their chief advantage: they remove the fume directly at the source, within inches of the arc. Because of the close proximity to the source, fume extraction can be achieved with lower airflow rates, typically 80 to 100 CFM (135-170 m³/hr) for suction nozzles, depending upon the design, and 35 to 60 CFM (60-100 m³/hr) for integrated fume extraction guns. The vacuum level is high (40-70 in WG), permitting the use of longer hoses (10-25 ft, or 3-7.6 m) with smaller diameters (1.25-1.75 in, or 30-45 mm). High vacuum equipment ranges from small, portable units (Figure 5) to


*Figure 5. Portable high vacuum/low volume extraction unit.*



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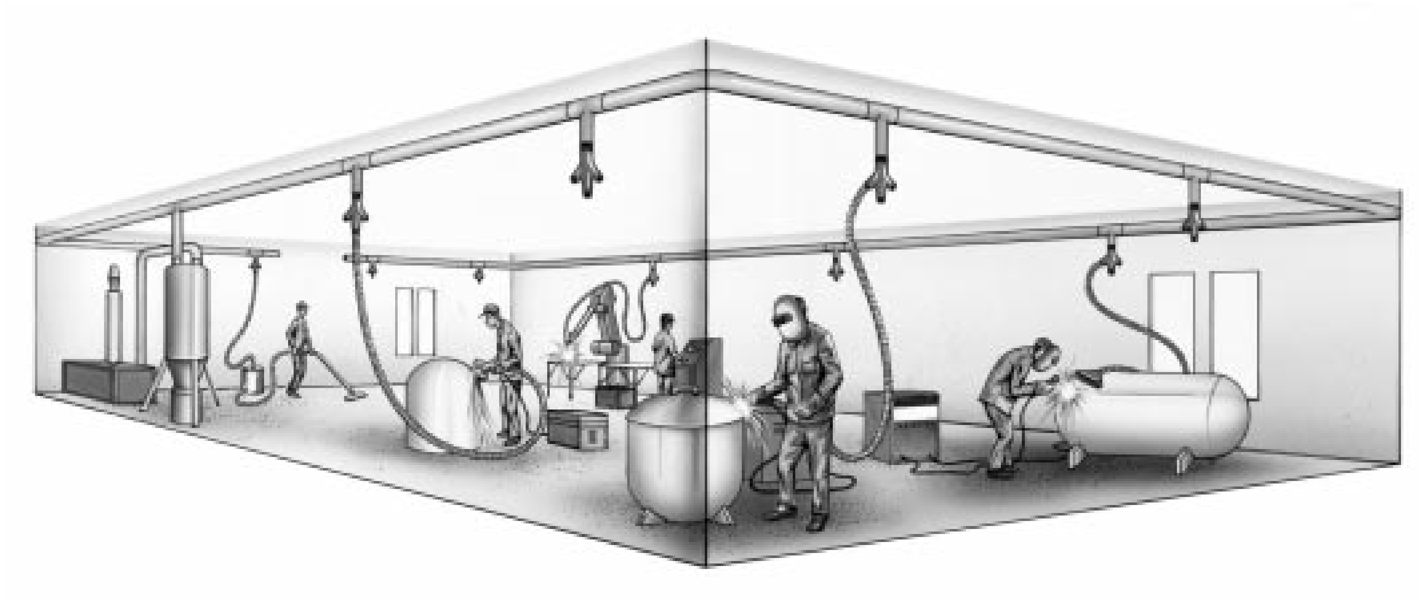

*Figure 6.  A central high vacuum/low volume fume extraction system.*

mobile three-phase systems, to large, centralized systems (Figure 6).

There are two methods of high vacuum extraction: welding guns with built-in extraction, or separate suction nozzles of various designs.  Suction nozzles (Figure 7) are positioned near the weld, typically with magnets, and commonly use capture distances of less than 4 in (100 mm).  Fume extraction guns (Figure 8) use fume capture nozzles built into the gun tube and handle. No repositioning is required, since the suction automatically follows the arc.

High vacuum extraction, like other solutions, has its limitations.  Although manufacturers have greatly improved designs, fume extraction guns are larger than regular welding guns. Furthermore,  fume guns do not control residual fume and smoke, since the gun is moved away immediately after welding is completed.  Finally, unless they are set in weld fixtures, high vacuum suction nozzles also require repositioning.

*Figure 7.  Examples of high vacuum/low volume suction heads.*

Nevertheless, high vacuum/low volume methods of fume extraction offer significant advantages to welding fabricators.  Of chief importance is the removal of fume right at its source, before it can reach the operator's breathing zone, as shown in the "before" and "after" photos (Figures 9 and 10).  Since fume guns eliminate the repositioning required by articulated arms or suction nozzles, productivity is not directly reduced.

Many other advantages come from reducing the total amount of airflow required.  A lower volume of air means smaller ductwork, smaller hoses, much smaller filter systems, and less strain on make-up air systems if the air is exhausted outside.  This translates into lower material, installation and maintenance costs.  A typical low vacuum system for twenty stations, for instance, might require an airflow rate of 12,000 CFM (20,000 m³/hr), whereas a high vacuum system serving the same facility could require an airflow rate as low as 1,200 CFM (2,000 m³/hr).



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Figure 8. Examples of high vacuum/low volume welding guns.

***Filtration***
After fume is removed from the source, it is either exhausted directly to the atmosphere, or it is passed through an electrostatic or cartridge filter. Because electrostatic filters lose efficiency if they are not constantly washed, the welding industry primarily uses cartridge filters, which are more easily maintained.

## Regulatory Bodies

Two major types of organizations study and regulate exposure to welding fume and other particulates in the workplace: privately funded industrial health organizations, and government regulatory agencies. In the U.S., two major industry organizations are the American Conference of Governmental and Industrial Hygienists (ACGIH) and the National Institute of Occupational Safety and Health (NIOSH). They set exposure limits for a variety of materials, including those found in welding fume. The ACGIH calls their limit the Threshold Limit Value (TLV). The TLV is influential in industry and is the standard followed by most insurance companies. As important as the TLV is, however, it is not enforceable by law. The Occupational Safety and Health Administration (OSHA) is the only organization that can establish legally enforceable limits for exposure to chemicals in the workplace. At both state and federal levels, OSHA's mandatory Permissible Exposure Limits (PEL) place tough demands on the welding industry.

Figure 9. "Before"- welding without fume removal gun.

Figure 10. "After" - welding with fume removal gun.

## Exposure Limits

The limits for fume exposure set by OSHA and others are measured in milligrams of particulate per cubic meter of air (mg/m$^3$). The total amount of fume produced is not limited, but rather the *concentration* of fume is limited. During facility testing, a sampling device is placed in the breathing zone of the operator (i.e., inside the head shield, as shown in Figure 11, not on the lapel). At the end of the operator's shift, a number is calculated that reflects an 8-hour Time Weighted Average (TWA) of the fume concentration in the operator's breathing zone, in mg/m$^3$.

Since this method focuses on breathing zone exposure, the results are highly unpredictable, even when the process, procedure and other influences are consistent. Therefore, to ensure compliance with exposure limits, companies should test their own operators while they are welding in everyday applications to obtain an accurate concentration value. The results can then be compared to benchmarks such as the TLV or PEL. If the number is higher than the standard, then that company is out of compliance.



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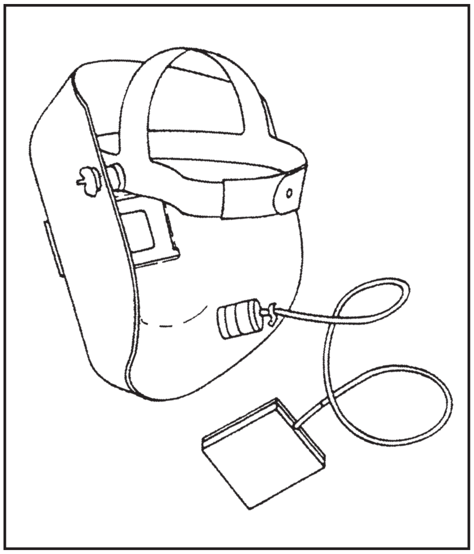

*Figure 11. Drawing of welding head-shield with sampling device installed.*

Listed in Table 1 are the current welding fume exposure limits as specified by OSHA and ACGIH. Note that the table does not contain a PEL for total welding fume. The PEL of 5 mg/m³ established in 1989 was challenged in a lawsuit, and is no longer enforced.

Manganese and chromium are two examples of materials which have strict time exposure limits as well.

**OSHA is the only organization that can establish legally enforceable limits for exposure to chemicals in the workplace**

When limits are measured on an 8-hour TWA, an operator may be exposed to high concentrations in the morning, but the facility may still be in compliance if concentrations are lower in the afternoon. The limits for certain forms of chromium are "ceilings," meaning that any overexposure during the day will cause the facility to fail compliance.

**Exposure Guidelines for Materials Sometimes Found in Welding Fume**

| | ACGIH(1) TLV (mg/m³) | OSHA(2) PEL (mg/m³) |
|---|---|---|
| Welding fume | 5.0 | |
| Iron oxide, as Fe | 5.0 | 10.0 |
| Manganese (all forms | 0.2 | 5.0 (c) |
| Chromium III compounds | 0.5 | 0.5 |
| Chromium VI compounds, sol | 0.05 | 0.05 (c) |
| Chromium VI compounds, insol | 0.01 | .05 (c) NIC.0005 - .005 (both forms) |
| Nickel,insol compounds, as N | (1.0) 0.5 NIC | 1.0 |
| Aluminum, Welding fumes, as Al | 5.0 | |
| Zinc Oxide, fume | 5.0 10.0 (c) | 5.0 |
| Barium compounds, sol, as Ba | 0.5 | 0.5 |
| Beryllium & compounds, as Be | 0.002 .01 (c) | 0.002 .005 (c) |
| Cadmium oxide, as Cd | 0.002 | 0.005 |
| Cobalt oxide, as Co | 0.02 | 0.1 |
| Copper fume, as Cu | (0.2) 0.05 NIC | 0.1 |
| Fluorides, as F | 2.5 | 2.5 |
| Magnesium oxide fume | 10.0 | 15.0 total particulate |
| Molybdenum, insol compounds, as Mo | 10.0 | 15.0 total particulate |
| Tin oxide | 2.0 | 2.0 |
| Vanadium pentoxide oxide, as $V_2O_5$ | 0.05 | 0.1 (c) |

(1) Threshold Limit Value set by ACGIH (American Conference of Governmental Industrial Hygienists) based upon 8 hour TWA (Time Weighted Average), as of 2/98.
(2) OSHA Permissible Exposure Limit based upon 8 hour TWA, as of 2/98.
(c) Maximum Exposure Concentration: not to be exceeded at any time (not a TWA).
NIC - Notice of intended changes

*Table 1. Exposure Guidelines.*

Since the U.S. regulatory climate regarding welding fume depends greatly upon the specific state, local regulators should always be contacted for relevant information. Companies should check the Material Safety Data Sheet (MSDS) for the welding electrode they use. The MSDS report will show not only the composition of the electrode, but also the components of welding fume that can be created by the welding process. The report also shows the TLV and PEL for each item, and gives valuable information concerning health risks and other reference data.

## Conclusion

While there are many approaches to controlling welding fume exposure, the bottom line is this: testing operators while they are welding in the company's actual facilities is the only way to get a clear picture of where a company stands. Once the true exposure risk is known, an appropriate strategy can be developed to address that risk. No matter what strategy is ultimately adopted, it will be most effectively implemented when engineers, fabricators and welding supervisors work together to ensure its success.



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# $25,000 TOP AWARD!

For 1999, the total amount of cash distributed in the James F. Lincoln Arc Welding Foundation's Awards for Achievement program will be increased to $50,000, with $25,000 going to the project judged Best of Program. The Gold Award has been increased to $10,000, and there will be two Silver Awards, at $5,000 each, and two Bronze Awards, at $2,500 each.

For a copy of the rules and an official entry form, visit us online at http://www.lincolnelectric.com, or watch for your next issue of *Welding Innovation*, which will contain complete details. Don't miss out on this exceptional opportunity to gain professional recognition and receive a substantial cash award. Entries are being accepted now!


**1998 Professional Programs**

# DESIGN & WELDING

**Production Welding—Sept. 28-Oct. 1 $295.00**

For: Welding Foremen, Superintendents, Industrial Engineers and Time Study, Quality Control, and Inspection Personnel

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For: Designers, Engineers, Consultants, Architects, Highway Officials, Structural Fabricators, and Inspectors

**Blodgett's Design of Steel Weldments—Sept. 14-18 $395.00**

For: Mechanical Engineers, Welding Engineers, Design Engineers, and Consultants

Lincoln Electric's professional programs continue to attract top design engineers and production welding personnel from across the country and around the world. All of the continuing education programs are conducted in the state-of-the-art Weldtech Center at Lincoln's world headquarters in Cleveland, Ohio. Space is limited, so register early. For full details, visit our website at http://www.lincolnelectric.com, or you may write or call:

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199
Attn: Registrar, Professional Programs
(216)383-2240



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# 1997 Awards for College Engineering and Technology Students

### Jury of Awards:

Burford Furman
Professor of Engineering
San Jose State University

Larry Leifer
Professor of Mechanical Engineering
Stanford University

Vincent Wilczynski
Professor of Engineering
U.S. Coast Guard Academy

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

*(Left to right) Larry Leifer, Vincent Wilczynski, Burford Furman*

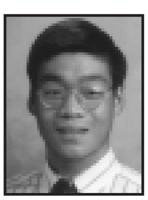
In addition to the following awards to undergraduate and graduate students, The James F. Lincoln Arc Welding Foundation also made grants of $250 to the following universities in recognition of each Best of Program, Gold, Silver, or Bronze Award received by students of that university:

Lehigh University
Loyola Marymount University
Santa Clara University
Stanford University
University of Illinois
University of Minnesota: Twin Cities

## BEST OF PROGRAM—$2,000 EACH

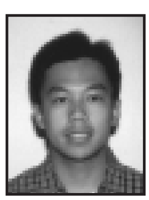
### UNDERGRADUATE

***Design of a Sensing Arm Support for PUMA-Assisted Stroke Patient Rehabilitation***



**Frank Tsai**
Stanford, CA

**Justin Tan**
Singapore



**Steven Tzu-Yen Peng**
Fresno, CA

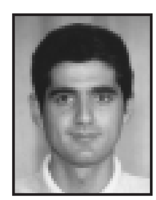
Stanford University, Mechanical Engineering, Faculty: Drew Nelson

### GRADUATE

***Hard Disk Drive Latching Mechanism***

**Brian Eric Lee**
Madison, CT

**Amir Alegheband**
Mountain View, CA



**Aris Cleanthous**
Towson, MD

**Omar Hafez**
Mountain View, CA

**David Payne**
Meridian, ID

Stanford University, Mechanical Engineering, Faculty: Larry Leifer



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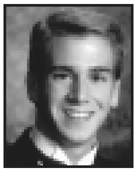
# GOLD AWARDS—$1,000 EACH

## UNDERGRADUATE

***Develop Nondestructive Headspace Measurement Instrument***



**Donald E. Morr**
Oakley, IL

**Christopher A. Senalik***
Champagne, IL

University of Illinois, General Engineering, Faculty: Henrique Reis

**Not pictured*

## GRADUATE

***Full-Scale Real-Time Testing and Analysis of a Viscoelastically Damped Steel Frame***

**Christopher C. Higgins**
Bethlehem, PA

Lehigh University, Civil Engineering, Faculty: Kazuhiko Kasai

# SILVER AWARDS—$750 EACH

## UNDERGRADUATE

***Partition Assembly Process Improvement***

**James G. Haran**
Chicago, IL

**Jonathan A. Jewell**
Belleville, IL

**Dennis A. Frantsve***
Park Ridge, IL

University of Illinois, General Engineering, Faculty: Yong Se Kim

**Not pictured*

***Top Actuated Optical Mount***

**Kimberly Lee Chung**
Richmond, CA

**Ariel Po Wan Tang**
San Jose, CA

**Keri Lin Chang**
Honolulu, HI

Santa Clara University, Mechanical Engineering,
Faculty: Lee Hornberger

## GRADUATE

***Full-Scale Cyclic Experiments of Composite Moment-Resistant Frame Connections***

**Michael A. Gustafson**
Granite Falls, MN

University of Minnesota: Twin Cities, Civil Engineering,
Faculty: Jerome F. Hajjar

***Automotive Lock/Latch***

**Kenneth S. Carrizosa**
Los Angeles, CA

**Jonathan M. Stewart**
Mercer Island, WA

**Winnie Sin-Ming Tam***
Rowland Heights, CA

Stanford University, Mechanical Engineering, Faculty: Larry Leifer

**Not pictured*



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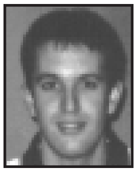
# BRONZE AWARDS—$500 EACH

## UNDERGRADUATE

### *Ergonomic Improvements for Handling/Packing Lineal Aluminum Extrusions*



**Mark A. Landers**
New Lenox, IL

**Sandra Griner***
Matteson, IL

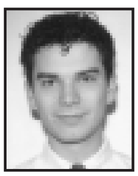
**Edward Tong***
Skokie, IL

University of Illinois, General Engineering, Faculty: Harry S. Wildblood

**Not pictured*

### *Develop Measuring of Rice Polishing*

**Christopher Duffie**
Barrington, IL



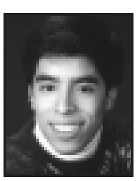
**Christopher Stremlau**
Tinley Park, IL

**Steven Pearce***
Lostant, IL

University of Illinois, General Engineering, Faculty: Harry S. Wildblood

**Not pictured*

### *Vibration Isolation for Dishwasher*



**Peter Barajas**
Sterling, IL

**Kathy M. Holian**
Elmwood Park, IL

**Fred Retter***
Camargo, IL

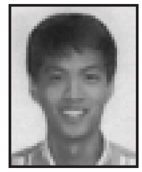
University of Illinois, General Engineering, Faculty: Juraj Medanic

**Not pictured*

## GRADUATE

### *Micro Friction Measuring Device*

**Adrian Percer**
Westminster, CA



**Stacey Chang**
Redwood City, CA

**Bradley Levin***
Palo Alto, CA

Stanford University, Mechanical Engineering, Faculty: Larry Leifer

**Not pictured*

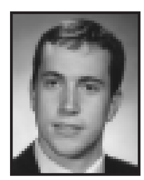
### *Design Refinement of a Large Sleeve Valve*

**Martin L. Smith**
San Gabriel, CA

Loyola Marymount University, Mechanical Engineering,
Faculty: Franklin Fisher

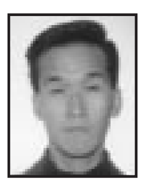
### *Virtual Technologies*

**Lawrence Kuo**
Ottawa, Ont., Canada



**Brandan M. Donohoe**
Upper Saddle River, NJ

**Ruth Kim**
Palo Alto, CA



**Vincent Chiu**
San Jose, CA

Stanford University, Mechanical Engineering, Faculty: Larry Leifer



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# MERIT AWARDS — $250 EACH

## UNDERGRADUATE

***Energy Reclamation from a Kiln***
University of Illinois
*Faculty:* Deborah L. Thurston
**Aimee R. Frake**, Glenview, IL
**Jeffrey T. Mikulina**, Lacrosse, WI
**David J. Rosenberg**, Morton Grove, IL

***Enhanced N-Scale Locomotive Performance***
University of Wyoming
*Faculty:* J. Nydahl & P. Dellenbach
**Cameron J. Turner**, Golden, CO

***Single-Axis Focusing Stage***
Stanford University
*Faculty:* Drew Nelson
**Jeffrey J. Shimon**, Cedar Rapids, IA
**Jeffrey W. Gossett**, Boise, ID
**Naluahi B. Kaahaaina**, Tustin, CA

***Optimize Cam Design on Filling Machine***
University of Illinois
*Faculty:* W. Brent Hall
**Nayanna Abraham**, Chicago, IL
**David M. Kosanke**, Chesterfield, MO
**Robert A. Szewczyk**, Mt. Prospect, IL

***Hyperbaric Aquaculture Test Tank***
University of New Hampshire
*Faculty:* Barbaros Celikkol
**Jim Durham**, Durham, NH
**Sandra R. Pinelle**, Nashua, NH
**David Lange**, Dover, NH
**Bretta Erskine**, Newmarket, NH

***Design of a Shipping Pallet***
Stanford University
*Faculty:* Drew Nelson
**Lisa B. Arrington**, Wilmington, DE
**Wallace C. White**, Nashville, TN
**Tenbite Ermias**, Atherton, CA

***Redesign of Sprinkler in Marine Sanitation System***
University of Illinois
*Faculty:* James V. Carnahan
**Neil A. Krueger**, Elgin, IL
**Ernest C. Manak**, Broadview, IL

***An Investigation of Rink Wall Padding for Ice Skating***
University of Illinois
*Faculty:* Strauss/Ruhl
**Jonathan A. Balasa**, Chicago, IL
**Keren Hasbani**, Wilmette, IL
**Eric A. Rice**, Acton, MA

***Design and Fabrication of a Handgun Dynamometer***
Western New England College
*Faculty:* Mohammad Khosrowjerdi
**James M. Quill**, Ludlow, MA

***Quadro-Cycle: Design and Development***
Brigham Young University
*Faculty:* Larry Howell
**Kirk Johnson**, Provo, UT
**Chris Johnson**, Springville, VT
**Kyle L. Hansen**, Meridian, ID
**Jim Arnold**, Provo, UT

***Tracking Antenna for the CATSAT Small Satellite***
University of New Hampshire
*Faculty:* John A. Wilson
**Kevin R. Scalera**, Hampton, NH
**Willard L. Simmons**, Durham, NH
**Thomas E. Wiley**, Derry, NH

***Pourables Process Optimization***
University of Illinois
*Faculty:* Harry S. Wildblood
**Kevin R. Hyland**, Oak Forest, IL
**Jeffrey J. Paris**, Urbana, IL
**Nicolas J. Psyhogios**, Wilmette, IL

***Design of a Device for Measuring Upper Limb Voluntary Muscle Control***
University of Illinois
*Faculty:* J.W. Nowak
**Adolph G. Galinski**, River Forest, IL
**Greg D. McGlaun**, Troy, MI
**Sen-Yeung Woo**, Bloomfield Hills, MI

***Pottery Kiln Frame, Burner Manifold, Venting Hood and Supply Shelf***
El Camino Community College
*Faculty:* George Rodriguez
**Richard Gralnik**, Lomita, CA

***Enantiomorphic Friction-Stir Welding Head-Pin***
Dartmouth College
*Faculty:* Francis E. Kennedy
**Elijah E. Cocks**, Durham, NC

***Design of an Extra Heavy-Duty Twist Tensioner***
University of Illinois
*Faculty:* J.W. Nowak
**Jocelyn R. Berroya**, Darien, IL
**Erick M. Davidson**, Beaverton, OR
**Betty Lea King**, Holmdel, NJ

***Citrus Tree Branch Lifting Device***
University of Illinois
*Faculty:* J.W. Nowak
**Stephen Kao**, Framingham, MA
**Brad D. Krueger**, Warrenville, IL
**Prajesh V. Patel**, Glendale Heights, IL

***Design of a Parallel Shaft Gear Box***
University of Illinois
*Faculty:* J.W. Nowak
**Michael Barrett**, Eldorado, IL
**Zach S. Peter**, Westchester, IL

***Punch Handle Design***
University of Illinois
*Faculty:* Yong Se Kim
**Michael B. Grimm**, Skokie, IL
**Humera Y. Khan**, Urbana, IL
**John Tae Kim**, Chicago, IL

***Piston Pin Weight Reduction***
University of Illinois
*Faculty:* Edward N. Kuznetsov
**Romano F. Floreani**, Park Ridge, IL
**James M. Fron**, Fort Wayne, IN
**Paul A. Wieshuber**, Park Ridge, IL

***1997 USMA Mini-Baja Project***
United States Military Academy
*Faculty:* MAJ Bradley C. Dick
**Michael Kovacevic**, Beaver Falls, PA
**Jose D. Salinas**, Kittanning, PA

## GRADUATE

***Spring '97 Galileo Design Requirement***
Stanford University
*Faculty:* Larry Leifer
**Brenton A. Baugh**, Stanford, CA
**Theodore M. Bender**, Palo Alto, CA
**Robert H. Yi**, Stanford, CA

***Design of Bolted Semi-Rigid Connections for Moment Resisting Frame***
Lehigh University
*Faculty:* Kazuhiko Kasai
**Arum Mayangarum**, Allentown, PA

***Virtual Reality Motion Platform***
Stanford University
*Faculty:* Larry Leifer
**Gregory J. Clark**, Endicott, WA
**Michelle J. Johnson**, Palo Alto, CA
**Vinod Pabba**, Stanford, CA
**Timothy Wang**, San Jose, CA

***Repair of Welded Steel Moment Connections Using Bolted Haunch Brackets***
Lehigh University
*Faculty:* Kazuhiko Kasai
**Ian C. Hodgson**, San Francisco, CA

***ATM Card Flipping Mechanism***
Stanford University
*Faculty:* Larry Leifer
**Olivier Vogel**, Zurich, Switzerland
**Austair Doig**, Stanford, CA
**Kyle Ginoza**, Kahului, HI

# 1998 AWARDS

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Entries may not be submitted by more than five students.





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## *Key Concepts in Welding Engineering*

*by R. Scott Funderburk*

# The Importance of Interpass Temperature

"Interpass temperature" refers to the temperature of the material in the weld area immediately before the second and each subsequent pass of a multiple pass weld. In practice, the minimum specified interpass temperature is often equal to the minimum specified preheat temperature, but this is not required according to the definition.

## Why Is Interpass Temperature Important?

Interpass temperature is just as important as, if not more important than, preheat temperature, with regard to the mechanical and microstructural properties of weldments. For instance, the yield and ultimate tensile strengths of the weld metal are both a function of the interpass temperature. High values of interpass temperature tend to reduce the weld metal strength. Additionally, higher interpass temperatures will generally provide a finer grain structure and improved Charpy V notch toughness transition temperatures. However, when interpass temperatures exceed approximately 500°F (260°C), this trend is reversed. For example, the American Welding Society (AWS) Position Statement on the Northridge Earthquake recommends that the interpass temperature should not exceed 550°F (290°C) when notch toughness is a requirement.

## Why a Maximum?

It may be important to impose control over the maximum interpass temperature when certain mechanical weld metal properties are required. The AWS Position Statement is one example with regard to notch toughness, and there could be many others. For example, if a designer expects a minimum strength level for a particular component that could experience extremely high interpass temperatures (i.e., due to its size or welding procedures), a maximum interpass temperature should be specified. Otherwise, the weld metal strength could be unacceptably low.

A maximum interpass temperature is also necessary for quenched and tempered (Q&T) steels, such as ASTM A514. Due to the heat treating characteristics of the base metal, it is critical that the interpass temperature be controlled within limits which will help provide adequate mechanical properties in the weld metal and the heat affected zone.

**It may be important to control the maximum interpass temperature when certain mechanical properties are required**

Keep in mind, however, that maximum interpass temperature control is not *always* required. In fact, the *AWS D1.1-98 Structural Welding Code – Steel* does not impose such control.

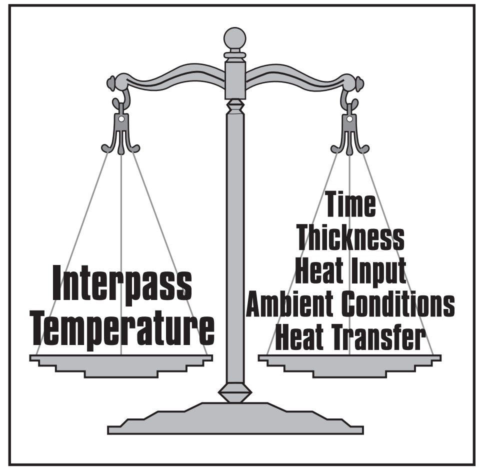


*Figure 1. Balancing the variables of interpass temperature.*

## A Delicate Balance

Particularly on sensitive base metals, the minimum interpass temperature must be sufficient to prevent cracking, while the maximum interpass temperature must be controlled to provide adequate mechanical properties. To maintain this balance, the following variables must also be considered: time between passes, base metal thickness, preheat temperature, ambient conditions, heat transfer characteristics, and heat input from welding.

For example, weldments with smaller cross-sectional areas naturally tend to "accumulate" interpass temperature: as the welding operation continues, the temperature of the part increases. As a general rule, if the cross-sectional area is less than 20 $in^2$ (130 $cm^2$), then the interpass temperature will tend to increase with each sequential weld pass if normal production rates are maintained. However, if the cross-



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sectional area is greater than 40 in$^2$ (260 cm$^2$), then the interpass temperature generally decreases throughout the welding sequence unless an external heat source is applied.

## How Is Interpass Temperature Measured and Controlled?

One accepted method of controlling the interpass temperature is to use two temperature indicating crayons. A surface applied temperature indicating crayon (often referred to by the trade name Tempilstik) melts when the material to which it is applied reaches the crayon's melting temperature. The crayons are available in a variety of melting temperatures, and each individual crayon is labeled with its approximate melting point.

*Figure 2. Tempilstiks™ help control interpass temperature.*

One temperature indicating crayon is typically used to measure both the minimum specified preheat temperature and the minimum specified interpass temperature, while the second is a higher temperature crayon used to measure the maximum specified interpass temperature (if required).

The welder first heats the joint to be welded and checks the base metal temperature at the code-designated location by marking the base metal with the first temperature indicating crayon. When the minimum specified preheat temperature is reached (when the first crayon mark melts), the first welding pass can commence. Immediately before the second and subsequent passes, the minimum and maximum (if specified) interpass temperature should be checked in the proper location. The lower temperature crayon should melt, indicating that the temperature of the base metal is greater than the melting temperature of the crayon, while the higher temperature crayon should not melt, indicating that the base metal temperature is not above the maximum interpass temperature.

If the lower temperature crayon does not melt, additional heat should be applied to the joint until the crayon mark on the base metal melts. And if the upper temperature crayon melts, the joint should be allowed to slowly cool in the ambient air until the upper temperature crayon no longer melts, while the lower temperature crayon does melt. Then the next welding pass can begin.

## Where Should Interpass Temperature Be Measured?

There are both codes and industry standards that specify where the interpass temperature is to be checked. Both the *AWS D1.1-98 Structural Welding Code – Steel* and the *AWS D1.5 Bridge Welding Code* require that the interpass temperature be maintained "for a distance at least equal to the thickness of the thickest welded part (but not less than 3 in [75 mm]) in all directions from the point of welding." This makes sense, and is conservative when controlling the minimum interpass temperature. However, if maximum interpass temperature is also to be controlled, then the actual interpass temperature in the adjacent base metal may significantly exceed the maximum specified interpass temperature. If this is the situation, it is more appropriate to measure the temperature 1 in (25 mm) away from the weld toe.

In other cases, specific industries have adopted self-imposed regulations. For example, in one shipyard the interpass temperature must be maintained 1 in (25 mm) away from the weld toe and within the first foot (300 mm) of its start. In this particular case, the preheat is applied from the back side of the joint so as to completely "soak" the base metal.

Although there is some debate as to where the interpass temperature should be measured, most experts agree that it must be maintained for some reasonable distance away from the welded joint. Since this decision may greatly influence the fabrication cost, a reasonable and practical location must be determined. One foot away from the joint is probably excessive, while a tenth of an inch, or on the weld itself, is not right either. However, one inch from the weld toe seems appropriate.

**Weldments with smaller cross-sectional areas tend to "accumulate" interpass temperature**

## Summary

- The effects of the welding process, procedures, and sequence of welding must always be taken into account to maintain interpass temperatures within the proper range.
- The effects of both minimum and maximum interpass temperature should be considered with regard to the mechanical and microstructural properties of the weld metal and the HAZ.
- The interpass temperature should be maintained throughout the full thickness of the base metal and some reasonable distance away from the weld, approximately equal to one inch, unless codes specify otherwise.

## For Further Reading...


*AWS Structural Welding Committee Position Statement on Northridge Earthquake Welding Issues.* The American Welding Society, 1995.

*ANSI/AWS D1.1-98 Structural Welding Code – Steel.* The American Welding Society, 1998.

*ANSI/AASHTO/AWS D1.5-96 Bridge Welding Code.* The American Welding Society, 1996.

Evans, G.M. and Bailey, N. *Metallurgy of Basic Weld Metal.* Abington Publishing: Cambridge England, 1997.




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# Mooring Buoy Seabed Anchor Pile

By Alan B. Christopherson
Senior Vice President
Kenton W. Braun
Staff Engineer
Peratrovich, Nottingham & Drage
Anchorage, Alaska

*Figure 1. The two sections of the anchor pile were brought together for the welded field splice.*

## Introduction

Following the Exxon *Valdez* oil spill, five marine mooring buoys were constructed near Valdez, Alaska, to provide safe moorage for a tanker-escort tug fleet and a multitude of barges and oil spill response vessels. These buoys consisted of welded steel anchor piles connected by chain to floating moorage buoys. The piles were installed into the seabed so that the tops of the piles were located approximately at the seabed floor. A welded steel follower pipe extending above the water surface was used to drive the piles in water up to 90 ft (27 m) deep. Because of the deep water and the steeply sloping seabed, the use of the anchor pile systems saved $480,000 versus conventional chain and anchor type systems.

In 1993, an incorrectly installed wire cable connection between the mooring chain and one anchor pile failed. The connection could not be reestablished because it was located below the seabed, approximately 15 ft (5 m) inside the pile. Therefore, the owner requested an improved anchor pile design which would place the chain connection above the seabed at the top of the pile. In addition, the new buoy was relocated to provide a swing radius that would accommodate larger vessels.

## Site Conditions

The new anchor pile location was established about 450 ft (140 m) northwest of the original, and in deeper water. The seabed at this site was approximately minus 100 ft (30 m) MLLW (Mean Lower Low Water) and located on a steep slope of about 20 degrees. An exploratory program was developed to drive a steel pipe test pile at the new location in order to determine the soil characteristics and depth to bedrock. However, analysis of the costs to mobilize the necessary equipment to the site for the testing program showed that the estimated program cost would far exceed the value of the information to be obtained. It was then decided to combine the test pile program and the anchor pile installation in a single operation, incorporating the mobilization cost of the anchor pile installation into that of the test pile. The test pile would be driven by the contractor immediately prior to the actual anchor pile installation. This method forced the designers to rely upon information from the original anchor pile installations, and to incorporate field adaptability into the design. The most economical method of including the required field adjustments was welding two steel pipe anchor pile sections together on the project site to match the required final length.

Information obtained during the installation and the test pile program of the original anchor pile installations had shown that the soil overlying bedrock near the anchor pile location consisted of very soft material. The soils had been unable to support the 24 in (600 mm) diameter test pile, which sank 29 ft (9 m) into the seabed under its own weight. In addition to the soft soil conditions, the original anchor pile and test pile installations suggested that the depth from the mudline to bedrock in the area was shallow, approximately 30 to 40 ft (9 - 12 m). The limited information, soft soils, shallow embedment depths and short construction period provided a challenging set of conditions.



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*Figure 2. Field splicing the anchor pile. The API 5LX-60 steel required preheating and interpass temperature control throughout the welding operation.*

## Design

To provide safe moorage for the design marine vessels, the new anchor pile was required to resist a 100,000 lb (450 kN) horizontal load at the mooring buoy. This load translated into a required pullout capacity of 77,000 lbs (340 kN) and a required lateral pile capacity of 100,000 lbs. To resist these tremendous loads in such adverse seabed conditions, the anchor pile design had to provide greater pullout capacity and lateral resistance than a conventional pile. The increase of pile pullout and lateral capacities was accomplished through the use of spin fin plates at the pile tip, and vertical plates near the top of the pile, respectively. In addition, the pullout

**Limited information, soft soils and shallow embedment depths provided challenging conditions**

resistance of the pile could be significantly increased with a corresponding increase of pile embedment. To obtain the maximum embedment possible at the final site, the pile was fabricated in two sections that were cut and spliced in the field based on the test pile driving results.

The design of the new, higher capacity anchor pile focused on maximizing the amount of work done in the shop, thereby minimizing the required field effort. The pile was completely fabricated in two sections of 30 in (760 mm) diameter x 3/4 in (19 mm) thick API 5LX-60 steel pipe, so that the top section could be trimmed to the required length and then attached to the bottom section in the field with a single, full penetration butt weld. The bottom half of the pile was field supplied in a 20 ft (6 m) length, with spin fin plates and an inside flange cutting shoe attached, and with the top end of the pile beveled in the shop for the field splice. The top half of the pile was supplied to the field in a 40 ft (12 m) initial length with the vertical plates and the pad eye weldment attached.

Eight 1 in (25 mm) thick x 8 ft (2.4 m) long ASTM A572, Grade 50 spin fin plates were welded on the pile tip to ensure adequate tensile capacity of the pile. Spin fins are curved plates welded to the pile tip at a batter that effectively increases the pile diameter and causes the pile to act as a screw during driving operations. The plates are welded to the pile such that the center portion of the plate is oriented perpendicular to the pipe wall. In addition, eight 12 ft (3.6 m) long x 2 ft (600 mm) wide ASTM A572 Grade 50 vertical fins were welded to the top of the pile both to aid in lateral pile resistance in the soft soils, and to resist the tendency of the spin fin pile to turn as it is driven or extracted, thereby increasing the tensile capacity of the pile.

The principal difference between the new anchor pile and the original was the mooring chain attachment and the corresponding required method of installation. The original design used a shackle connection located approximately 15 ft (4.6 m) inside of the pile. The placement of the connection inside the pile allowed the follower pipe, required to drive the pile in deep water, to fit inside the anchor pile during driving operations. However, after the original mooring chain connection failed, the owner requested the new mooring chain connection be located on top of the pile, so it could be inspected easily, and/or repaired by underwater divers or remote operated vehicles. The key to designing the exposed mooring chain connection was

*Figure 3. Driving the anchor pile with a diesel impact hammer.*



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developing a cost-effective means of driving the anchor pile without damaging the connection.

The mooring chain connection consisted of a heavy pad eye weldment composed of a 3 in (760 mm) pad eye plate, two 3 in pad eye stiffener plates and a 2 in (500 mm) pile cap plate, all of which were constructed of ASTM A572 Grade 50 steel. In addition to providing the connection between the anchor pile and the mooring chain, the pad eye weldment also acted as a centering mechanism for the follower pipe guide sleeve. Although the weldment was designed so that welds were not placed in critical areas, the thickness of the plates required that each plate be ultrasonically tested for any laminations that could result in lamellar tearing around the welds. The weldment was designed to be fabricated as one piece, and then slipped onto the pile through slotted holes; the vertical plates and the pile cap plate were then welded to the pile.

Since the mooring chain connection was located on top of the pile, the steel follower pipe used for driving the pile into the seabed had to be designed to transmit the pile driving forces, remain joined to the anchor pile during driving operations, and ensure the mooring chain connection would not be damaged. The follower design consisted of a 30 in (760 mm) diameter x 3/4 in (19 mm) thick x 140 ft (42.7 m) long API 5LX-60 pipe with a 38 in (1 m) O.C. x 24 in (600 mm) I.D. x 1-1/4 in (32 mm) baseplate that would rest against the pile cap plate to transfer the driving forces to the anchor pile. Attached to the follower pipe base plate was a 36 in (900 mm) diameter x 3/4 in thick x 7 ft (2.1 m) long API 5LX-60 guide sleeve, which slipped over the anchor pile and pad eye weldment. The guide sleeve was used to keep the follower pipe and anchor pile together during the pile driving.

## Construction

After mobilizing the required equipment to the site, the contractor assembled a welded steel pile driving template on the side of the working barge and began to drive the 24 in (61 cm) diameter x 3/4 in (19 mm) thick test pile. Since the crane used on the project had a limited boom length, the contractor was forced to place 45 ft (14 m) sections of pipe into the driving template and field weld the sections together. After completion of the welds, the pipe was sequentially lowered down until the final length was driven into the seabed. The test pile was driven to bedrock with an embedment of 36 ft (11 m) using a vibratory hammer with an eccentric moment of 2,200 in-lbs. The test pile was then pulled vertically out of the soil using a crane with a load indicating device. From the load indicating device, the ultimate soil resistance on the 24 in (600 mm) diameter test pile was determined to be 20,000 lbs (88,964 N). Although the 20,000 lb resistance of the test pile was significantly lower than the 77,000 lb (342,282 N) design pullout resistance, the pullout resistance of the fabricated spin fin anchor pile was determined to be sufficient. The final length of the anchor pile was set at 40 ft (12 m) in the hope that three to four feet of the pile could be socketed into the bedrock, thereby increasing its capacity.

*Figure 4. Final connection of the mooring buoy to the mooring chain.*

To splice the anchor pile, the contractor performed the weld in the horizontal position so that the two halves of the pile were placed in the vertical position in the pile driving template for welding. Before placing the top half of the pile onto the bottom half, the contractor cut the top half to the required 20 ft (6 m) length and beveled the end in preparation for welding. The first section of the follower pipe was then connected to the top half of the anchor pile with a chain and shackle assembly, and both the first section of follower pipe and the top half of the anchor pile were lifted on top of the bottom half of the anchor pile for field welding of the splice. After the anchor pile was spliced, the file and follower pipe were lowered down to the seabed in stages as the contractor welded 40 ft (122 m) sections of follower pipe sequentially together, as was done with the test pile.

The anchor pile/follower pipe assembly was then driven with a diesel impact hammer, with a maximum energy rating of 107,000 ft-lbs (145 kJ). The large impact hammer was used because energy losses could be expected between the follower pipe and anchor pile. The anchor pile was driven to refusal with a total embedment of approximately 38 ft (12 m), leaving the top of the pile 3 ft (1 m) above the seabed.

## Conclusion

The successful design and construction of the fabricated anchor pile produced a 23,000 lb pile capable of resisting a 77,000 lb upward and 100,000 lb horizontal load. The anchor pile pullout capacity is approximately 3.0 times the capacity of a conventional pile. The vertical fans welded to the top of the anchor pile effectively increased the pile diameter and the lateral pile resistance by 2.6 times the capacity of the pile.

Despite poor soil conditions, deep water, and the large loads applied to the anchor pile, a cost-effective and successful project was accomplished using an innovative design and welding technology that minimized the required amount of steel, but maximized the load carrying capacity of the system.

## Design File

# Consider Penetration When Determining Fillet Weld Size

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

## Introduction

A flat-faced, equal-legged fillet weld in a 90° T-joint has a theoretical throat dimension of 0.707 $\omega$, where $\omega$ is the leg size (Figure 1). This assumes fusion is achieved to the root of the joint, but not necessarily beyond that point.

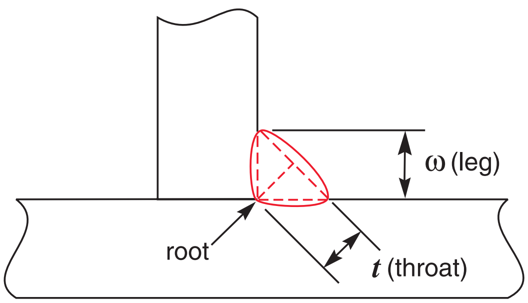


*Figure 1. Fillet weld dimensions*

When the welding process and procedure achieve a depth of penetration beyond the root, then the effective throat dimension is increased for fillet welds with equal leg sizes. The effective throat dimension, $t_{eff}$, is then equal to the theoretical throat, $t_{th}$, plus some additional value due to penetration (Figure 2). Therefore, if penetration beyond the root is achieved, the leg size can be reduced and the same weld strength can be achieved. This reduces the required quantity of filler metal and, if the penetration fillet weld can be made at the same or higher travel speeds, welding costs can be reduced.

It is possible for the designer to use this increase in throat size due to penetration when sizing welds, but the effort must be coordinated with manufacturing. If a consistent depth of penetration can be obtained, then leg size can be reduced without sacrificing weld strength. There are several practical issues that must be addressed, however, such as applicable welding code provisions, penetration capability and consistency through process and procedure control, geometric effects, and metallurgical characteristics. It is not always practicable to utilize this concept; however, engineers should consider penetration when determining fillet weld size.

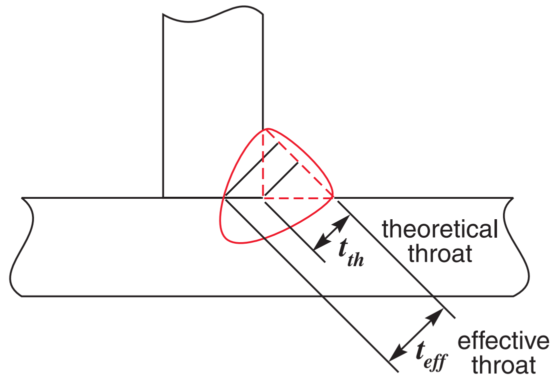


*Figure 2. Effective throat dimension with significant penetration.*

## What Do the Codes Say?

Currently, the *AWS D1.1-98 Structural Welding Code – Steel and the AASHTO/AWS D1.5-96 Bridge Welding Code* do not account for penetration when determining fillet weld sizes. However, several codes do have provisions permitting reduced fillet weld sizes.

In general terms, the AISC LRFD specification permits consideration of penetration when sizing fillet welds made by submerged arc welding (SAW), while the other codes listed below all permit consideration of penetration when the welding procedure is qualified by test, regardless of which process is used.

| Code | Application |
|---|---|
| AISC LRFD | Buildings and other structures |
| AWS D14.1-85 | Industrial mill cranes and other material handling equipment |
| AWS D14.2-86 | Metal cutting machine tool weldments |
| AWS D14.3-94 | Earth moving and construction equipment |

*Table 1. Codes permitting reduced fillet weld sizes due to penetration.*




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Specifically, section 8 of AISC LRFD reads as follows:

> "The effective area of a fillet weld Aω is the product of the effective length of the fillet weld times the effective throat thickness of the fillet weld. Except for fillet welds made with the SAW process, the effective throat thickness of the fillet weld is 0.707ω, where ω is the weld size. The deep penetration of fillet welds made by the SAW process is recognized in the LRFD Specification Section J2.2a wherein the effective throat thickness is considered to be equal to the weld size for 3/8-in. and smaller welds, and equal to the effective throat thickness plus 0.11 in. for fillet weld sizes over 3/8 in."

For example, assume a weld throat of 0.45 in (11 mm) is required. A standard 5/8 in (16 mm) fillet weld will achieve this result. According to AISC LRFD, if SAW is used, a fillet weld with a leg of 1/2 in (13 mm) could be used, resulting in a throat of 1/2 in (0.707) + 0.11 = 0.46 in (12 mm). The volume of weld metal required would decrease from 0.195 $in^3$/linear in (125 $mm^3$/linear mm) to 0.125 $in^3$/linear in (80 $mm^3$/linear mm), resulting in a 56% savings. However, the savings will often be even more significant with fillet welds under 3/8 in (10 mm) where the effective throat is considered to equal the leg size.

Other codes do not restrict this concept to SAW, or to particular weld sizes. For example, *AWS D14.1-85*, Table 5, footnote (b) states that

> "The intent of this table is not to establish the arc welding processes that provide deep penetration, but rather, to establish the typical allowable decrease of fillet weld size, provided the manufacturer can demonstrate that the required effective throat can be obtained by the qualified welding procedure in accordance with Section 7."

*AWS D14.2-86*, section 4.4.2, stipulates:

> "No allowance for penetration into the plate surfaces at the root of a fillet weld shall be made when computing the effective throat, except when sectioned test pieces show that the welding procedure gives penetration ≥ 3/32 in. (2.4 mm) beyond the root of the joint. Then the effective throat may be considered to extend from the root of the weld to the face of the weld ..."

*AWS D14.3-94*, paragraph 2.3.1.1, reads as follows:

> "Design values based on depth of penetration or effective throat, or both, which are beyond the root of the joint shall only be used when the values have been determined from a significant number of cross-sectioned samples which reflect the range of materials, material thickness, and welding conditions."

All four specifications imply that some restrictions on the use of this concept are warranted to ensure repeatable results. Regardless of code treatment, the principle is sound, but control of welding conditions is essential.

## Practical Considerations

Consistency is a must. To make this approach work "off the drawing board" and in the shop, there must be tight controls over all the variables which affect penetration. Some of these include:

- Welding procedures
- Electrode placement, which can be influenced by the helical nature of coiled electrodes
- Fitup and alignment
- Welding position
- Polarity
- Electrode diameter
- Current and current density
- Voltage
- Wire feed speed
- Travel speed
- Preheat and interpass temperature

Traditionally, this principle has been applied to SAW, but other welding processes, such as FCAW-g and GMAW, are capable of achieving this penetration too (see Figure 3). Two GMAW weld samples in Figure 3 reveal the potential for significant penetration. Also, it must be noted that SAW

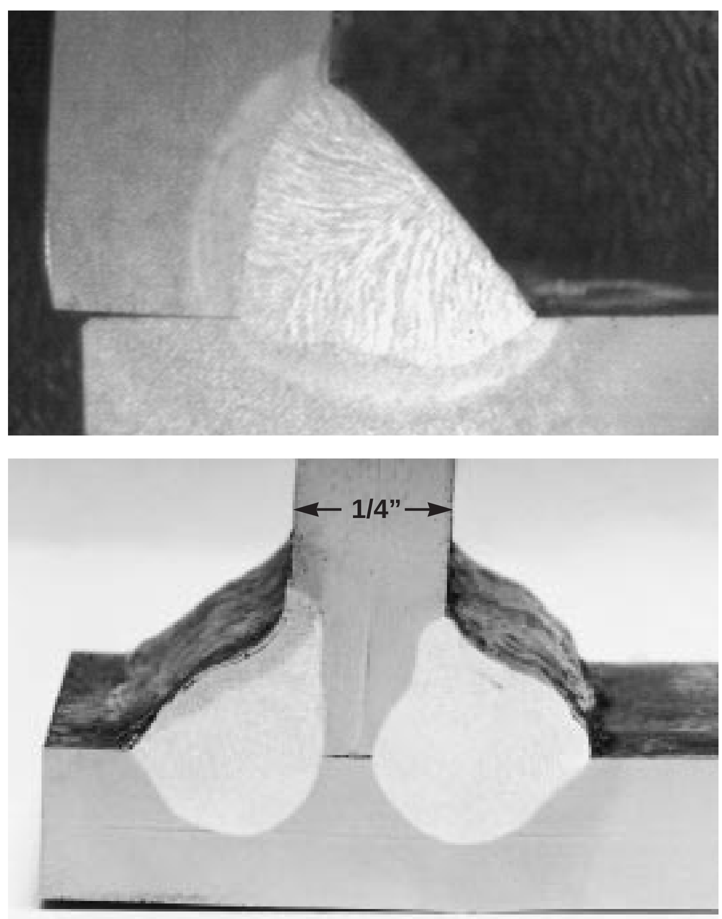


*Figure 3. Penetration beyond the root is not limited to SAW, but can be achieved with other processes such as GMAW shown here.*

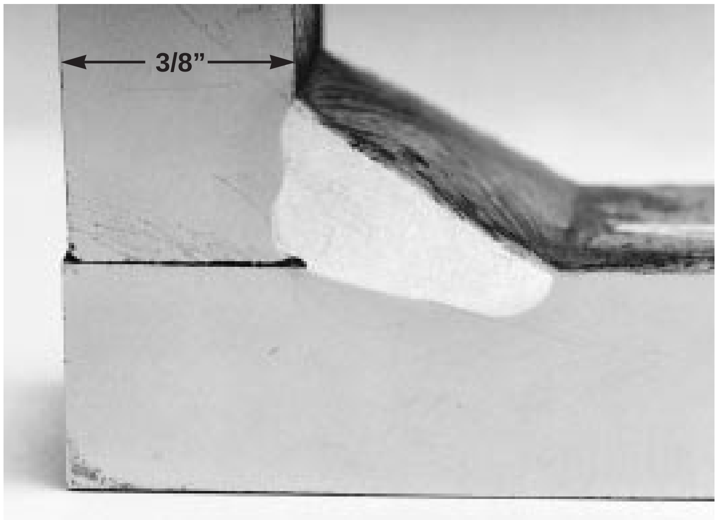


*Figure 4. The use of SAW does not guarantee penetration beyond the root.*

does not always achieve this penetration as revealed in Figure 4. Although this is an unequal-legged fillet, notice that there is no penetration beyond the root.

Some applications lend themselves to this approach more readily than others. For example, penetration can be optimized where high currents are employed, high current densities are used, and fitup is consistent, and where welding operations are easily controlled. However, if a hand-held, semi-automatic SAW fillet weld is made with DC– polarity and a long stickout, penetration beyond the root may not be consistently achieved.

## Caution Regarding Width-to-Depth Ratio

A balance must be maintained between the depth of penetration and the width of the root pass. As penetration increases, the width-to-depth (w/d) ratio becomes more critical. In order to help prevent centerline cracking, the w/d ratio should not exceed 1.2 (see Figure 5).

## Caution Regarding Metallurgical Issues

Admixture can pose problems when penetration is increased. As the base metal is melted and combined with the welding electrode, elements such as carbon, copper, sulfur and phosphorus can enter into the liquid weld pool from the base metal. Since these elements have lower solidification temperatures, they are often pushed to the center of the weld. While the reminder of the weld is solidified, these low melting point materials can remain in the joint and contribute to unacceptable cracking. More rigorous control of the base metal chemistry may be warranted when deep penetration is desired.

## Recommendations

The possibility of lowering welding costs by reducing fillet weld sizes due to penetration beyond the root should be considered in some situations. When the weldment is to be fabricated with high currents, high current densities, consistent fitup and alignment, automated welding operations and controlled procedures, then it may be a candidate for this approach. Under less controlled conditions, however, the designer should not rely on penetration for calculating weld strength or determining weld sizes.

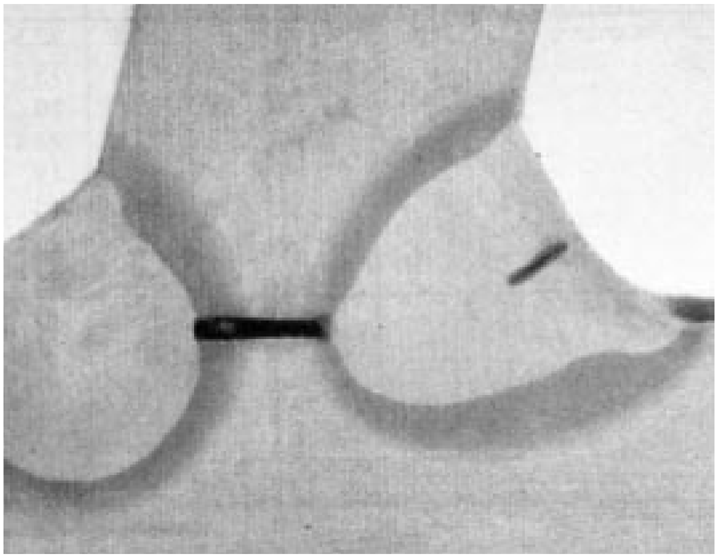

*Figure 5. A weld that cracked due to an excessive width-to-depth ratio.*

# Steel Gateways for a Community Commercial District

By James R. DeStefano, FAIA, RIBA
Principal in Charge
John Adams Dix, AIA
Management Principal
John Edward Windhorst
Project Architect
DeStefano and Partners
Chicago, Illinois

Two all-welded, all-steel sculptures in the form of abstracted Puerto Rican flags were conceived and designed as marker/gateways for an inner city Puerto Rican commercial district in Chicago, Illinois. The project was commissioned by the city's Department of Transportation to provide neighborhood identity and promote community economic development.

## Design Intent

Displayed in various creative forms, the Puerto Rican flag was already an important symbol for this community. DeStefano and Partners chose to adapt and abstract it to generate two monumental gateway sculptures spanning the street. Although only a single gateway was requested in the brief, the city agreed with the architects' recommendation that two structures would most effectively bracket the half-mile long commercial strip. Spanning the 50 ft (15 m) wide public way was the obvious way to maximize the impact of the design.

**The flag structures were designed to be dynamic and seamlessly flowing**

Visually, the flag structures were intended to be uncompromisingly dynamic and seamlessly flowing. It was immediately clear that only steel could offer a sculptural and structural form that was maintainable, economical, and deliverable within the project's six month schedule. Design wind-loading led to a double-latticed structural solution, which was then realized architecturally in flowing "pipe-waves" and eventually, hundreds of beautifully ground full-penetration welds. The complex geometries of the rolled pipe and curving plate assemblies were derived from the architectural firm's three-dimensional CAD model, which was then transferred to the fabricator's computers and used to generate shop drawings. In addition to relying upon the superb drawings, the fast-track fabrication was also supported by frequent shop-floor reference to the model. The two flags were fabricated in less than 90 days for $300,000 each, including caissoned foundations and lighting.

Making the sculptures appear as lightweight, flowing forms required relatively large quantities of steel (about 30 tons for each flag) and hundreds of feet of weld metal. The structure is, of course, largely internalized, so plate and pipe thicknesses and the filling of the mast with concrete (for dynamic control) go unnoticed. To keep the pipe-waves slender, paired 3 in (55 mm) diameter double-extra-strong pipe was chosen. Each pair is connected every two to three feet by a 1-1/2 in (38 mm) diameter solid steel rod. In elevation, as when traveling by car along the street, these double waves appear as a single 3 in thickness. The triangular "pennant" with the star cutout is formed by two 3/4 in (19 mm) rolled plates separated internally by welded 4 in (100 mm) lengths of 3 in pipe. The pennant sandwich was closed at its edges with 3/16 in (5 mm) plate cut and welded to form a "tent" in section, which gave the 5-1/2 in (140 mm) thick edge a mid-point shadow-line and thus, an even more slender appearance. All of these efforts were part of a strategy to make this ten-ton component appear as light as fluttering cloth. The pennant is connected to the 3/4 in (19 mm) plate square section mast by just two seemingly tiny tabs, but these tabs are, in fact, 4 in (100 mm) solid plate extending through the mast and deep into the pennant "sandwich." (These connectors emerge from the mast and take an immediate 30 degree bend. The 4 in to 4 in weld needed to achieve this turn fortunately was not required to be full-penetration.) At the scale of the street, these 4 in connectors almost disappear. All of the individual steel components are connected by major welds ground smooth until the finished effect is visually seamless.

**Design wind-loading led to a double-latticed structural solution**

## Role of Welding

Once the project had been conceived and drawn, its success depended entirely upon the cutting and welding skills of the steel fabricator which, happily in this case, were well established. The fabricator had worked extensively with the architectural firm in the past, making possible the necessary collaborative sharing of both information and risk. The structural engineer for the project was frequently called upon to modify the design as shop experience accumulated.



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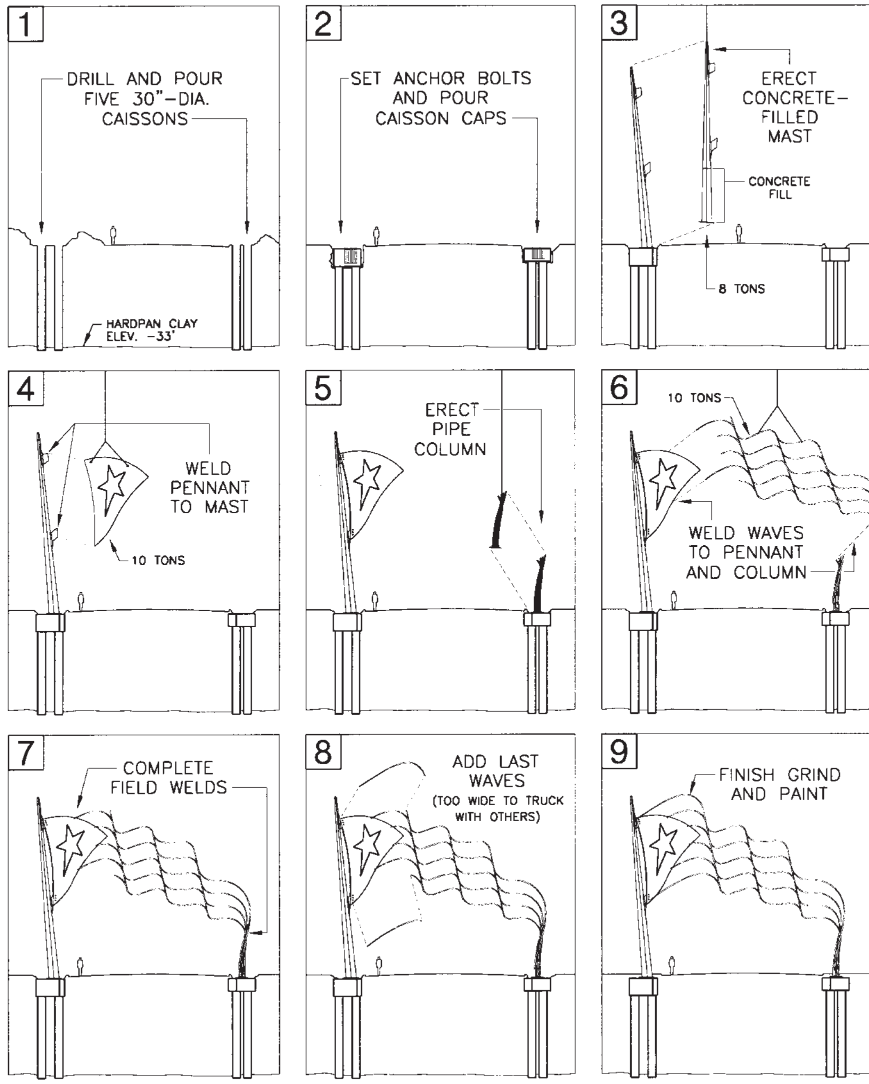
Perhaps the most difficult welding challenge of the project was the joining end-to-end of the many individually radiused pipe segments to form the flowing waves of the flag. In several cases, as many as seven pipes—each a different radius and length—had to be joined in space end-to-end to create a single three-dimensional segment of a wave. Each such joint was a full-penetration weld in 5/8 in (16 mm) walled pipe, which had to be ground to a perfect surface, betraying no “kinks,” segment-to-segment. Each flag had more than 200 of these welds. In addition to shop fabrication, many additional welds were required in the field erection of both the plate and pipe components.




## Results Achieved

The objective of this project was to produce an iconic and progressive architectural design of which the local community could be proud. As sculpture and as a gateway, the project has received wide praise from the community, the city at large, and the design profession. Taking the capabilities of welded structural steel to their aesthetic and structural limits permitted the economical creation of a durable and evocative urban design.

## Protégé Recalls Mentor’s Award

When contacted about the Silver Award he and his colleagues at DeStefano & Partners had received for their Steel Gateways project, John Edward (Ed) Windhorst remarked,

*Myron Goldsmith (left) and Ed Windhorst in 1993, viewing Mr. Windhorst’s Master of Architecture thesis project at the Illinois Institute of Technology.*

“This award is especially meaningful to me because my architecture professor, and mentor, the late Myron Goldsmith, also received an award from the James F. Lincoln Arc Welding Foundation for one of his designs. I remember how proud he was.”

Mr. Goldsmith and James R. DeStefano were co-advisors for Mr. Windhorst’s thesis work in architecture at the Illinois Institute of Technology.

Myron Goldsmith and Fazlur Kahn received a JFLAWF Award in 1970 for a project entitled “Welded Steel Canopies for Rapid Transit Stations.” At the time, Mr. Goldsmith and Mr. Kahn were both partners in the Chicago office of Skidmore, Owings and Merrill. Mr. Kahn died in 1981, and Mr. Goldsmith passed away in 1996.

**Do you have an anecdote about a mentoring relationship that has enhanced your life?** If so, please send it to the attention of Scott Funderburk, via email (innovate@lincolnelectric.com) or the U.S. Postal Service (Scott Funderburk, Assistant Editor, Welding Innovation, P.O. Box 17035, Cleveland, Ohio 44117-0035). If you have a photo of your mentor, or better yet, the two of you together, either mention it in the email, or include it with your letter. We hope to feature your submissions in a future issue.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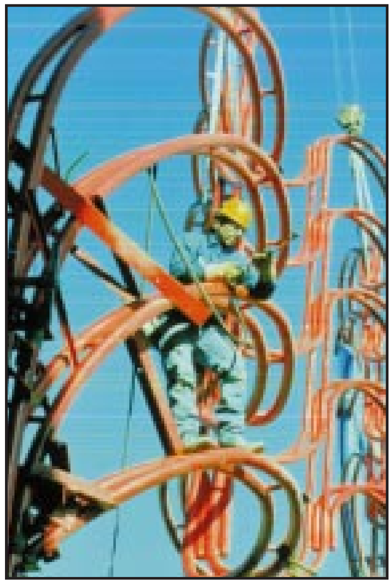

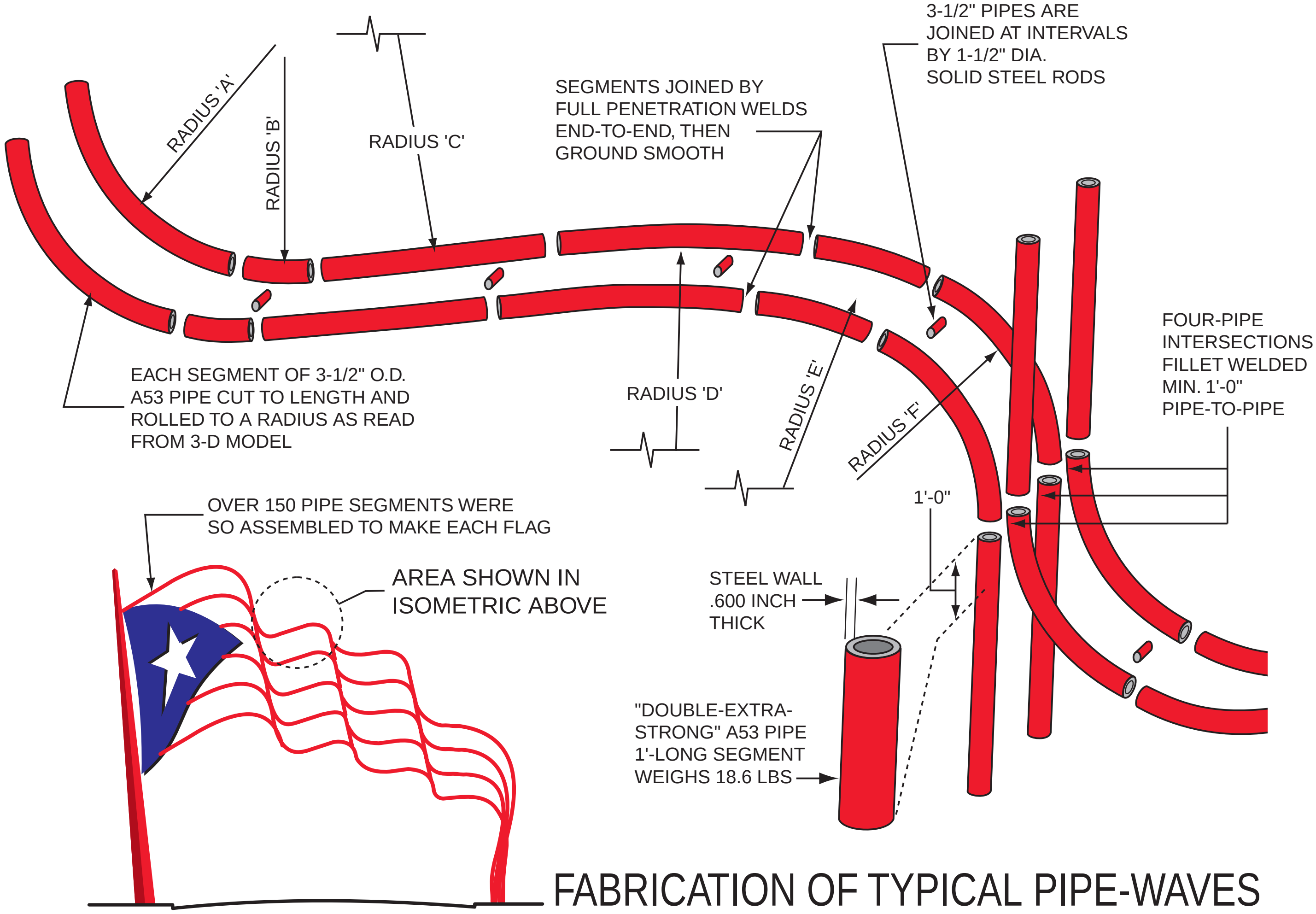


FABRICATION OF TYPICAL PIPE-WAVES

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The
James F. Lincoln
Arc Welding
Foundation



*This all-welded sculpture of the Puerto Rican flag is one of two "gateway" structures designed for a community commercial district.* *See story on page 23.*

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