

The Design of  
Products to be  
Hot-Dip  
Galvanized  
After Fabrication

# The Design of Products to be Hot-Dip Galvanized After Fabrication

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## DESIGN CONSIDERATIONS

Protection against corrosion begins on the drawing board. No matter what corrosion protection system is used, it must be factored into the design of the product.

Once the decision has been made to hot-dip galvanize steel for corrosion protection, the design engineer should ensure that the pieces can be suitably fabricated for high-quality galvanizing.

Certain rules must be followed in order to design components for galvanizing. These rules are readily applied and in most cases are simply those that good practice would dictate to ensure maximum corrosion protection.

Adopting the following design practices, along with those listed in ASTM A 385, *Practice for Providing High Quality Zinc Coatings (Hot-Dip)*, will produce optimum quality galvanizing, reduce coating costs, assist with the timely processing of the product, and ensure the safety of the galvanizing personnel.

## COMMUNICATION AMONG DESIGN ENGINEER, FABRICATOR, AND GALVANIZER

The most important rule of designing for galvanizing is that the designer, fabricator, and galvanizer should work together before the product is manufactured. Three-way communication can eliminate most issues that could delay or prevent superior galvanizing quality.

The design engineer can better appreciate the design considerations for hot-dip galvanizing if the basic steps of the galvanizing process are understood. Though the process may vary slightly from company to company, the fundamental steps in the galvanizing process are:

**Soil and grease removal** – A hot alkaline solution is used to remove dirt, oil, grease, shop oil, and soluble markings. This process is known as caustic cleaning. However, caustic cleaning will not remove some surface contaminants such as epoxies, vinyls, asphalts, or welding slag. These contaminants must be removed by grit blasting, sandblasting, or other mechanical cleaning methods. The fabricator is best equipped to remove these tough surface contaminants.

**Pickling** – An acid bath is used to remove surface rust and mill scale to provide a chemically-clean metallic surface. Pickling acids are either dilute solutions of hydrochloric acid or sulfuric acid.

**Fluxing** – A steel article may be immersed in liquid flux (usually a zinc ammonium chloride solution) to remove oxides and to prevent oxidation prior to dipping into the molten zinc bath. In the dry galvanizing process, the item is separately dipped in a liquid flux bath, removed, allowed to dry, and then galvanized. In the wet galvanizing process, the flux floats on top of the molten zinc so the item passes through the flux immediately prior to galvanizing.

**Galvanizing** – The article is immersed in a bath of molten zinc at approximately 850 F (455 C). During galvanizing, the zinc metallurgically bonds to the steel, creating a series of zinc-iron alloy layers topped by a layer of pure zinc.

**Finishing** – After the article is withdrawn from the galvanizing bath, excess zinc is removed by draining, vibrating, or, for small items, centrifuging. The galvanized item is then air-cooled or water-quenched.

## Hot-Dip Galvanizing Process



Caustic cleaning



Rust removal (Pickling)



Fluxing



Galvanizing



Inspection

Figure 1

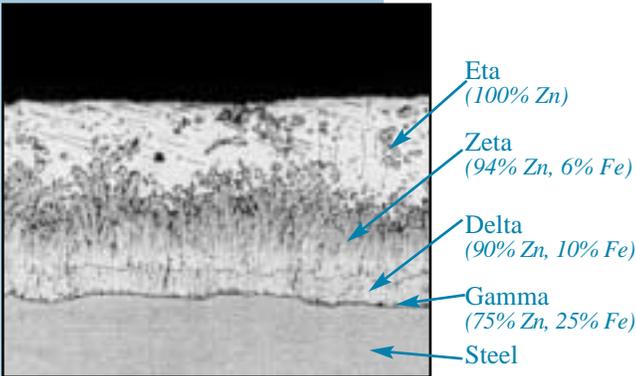
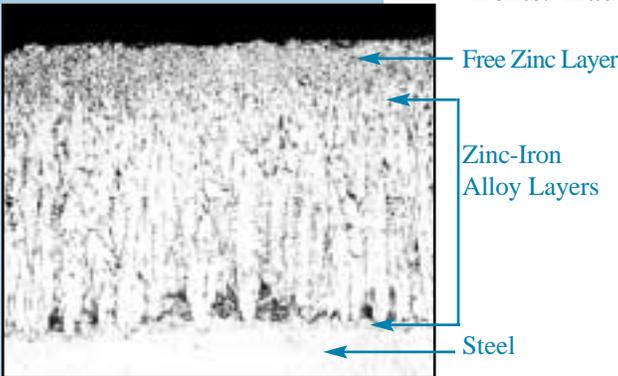


Figure 2



**Inspection** – Coating thickness and surface condition inspections are the final steps in the process. Information on inspection procedures and quality control criteria is available in the American Galvanizers Association (AGA) publication *Inspection of Products Hot-Dip Galvanized After Fabrication* which may be obtained from your galvanizer or the AGA.

Iron and steel articles hot-dip galvanized after fabrication may range in size from small pieces of hardware, such as bolts and washers, to large, welded steel assemblies, weighing several tons. The ability to galvanize these articles can be improved by following the design practices recommended in this manual and by consulting with the galvanizer during the project’s design.

## MATERIALS SUITABLE FOR GALVANIZING

Most ferrous materials are suitable for hot-dip galvanizing. Hot rolled steel, cold rolled steels, cast steels, ductile iron, and cast iron all can be protected from corrosion by hot-dip galvanizing. Structural steel shapes, including those of high-strength (under 150 ksi), and low-alloy materials, are hot-dip galvanized after fabrication to obtain long-lasting protection.

Though most ferrous materials can be hot-dip galvanized, the chemical composition of the material affects the characteristics of the galvanized coating.

During galvanizing, the ferrous material reacts with the zinc to form a series of zinc-iron alloy layers, which normally are covered by a layer of free zinc. For most hot rolled steels, the zinc-iron alloy portion of the coating will represent 50 to 70% of the total coating thickness. *Figure 1* shows a cross-section of a typical hot-dip galvanized coating.

Steel compositions vary, depending on strength and service requirements. Trace elements in the steel, such as silicon and phosphorus, affect the galvanizing process as well as the structure and appearance of the galvanized coating. For example, certain elements present in the steel may result in a coating composed entirely, or almost entirely, of zinc-iron alloy layers. *Figure 2* shows a cross-section of a galvanized coating made up almost entirely of zinc-iron alloy layers. Note the thickness of the free zinc outer layer.

The characteristics of a coating composed primarily of a zinc-iron alloy layer differ from those of a typical galvanized coating:

**Visual** – The zinc-iron alloy coating may have a matte gray appearance due to the absence of the free zinc layer. The free zinc layer imparts the typical bright finish to a galvanized coating.

**Adherence** – The zinc-iron alloy coating tends to be thicker than a typical galvanized coating. As the thickness of this type of coating increases, the coating can experience adhesion problems under external stress such as thermal gradients or sharp impacts.

**Corrosion Resistance** – In general, galvanized coatings are specified for their corrosion resistance. While a gray or matte appearance may occur, this

different appearance does not reduce the long-term corrosion protection of the steel. The corrosion resistance of these coatings, mil for mil, is equal to the more typical bright, shiny galvanized coating.

It is difficult to provide precise guidance in the area of steel selection without qualifying all of the grades of steel commercially available. The guidelines discussed below usually result in the selection of steels that provide good galvanized coatings.

- Levels of carbon less than 0.25%, phosphorus less than 0.04%, or manganese less than 1.35% are beneficial.
- Silicon levels less than 0.03% or between 0.15 and 0.25% are desirable.

Silicon may be present in many steels commonly galvanized even though it is not a part of the controlled composition of the steel. This occurs primarily because silicon is used in the deoxidization process for the steel and is found in continuously cast steel.

The phosphorus content should never be greater than 0.04% for steel that is intended for galvanizing. Phosphorus acts as a catalyst during galvanizing, resulting in rapid growth of the zinc-iron alloy layers. This growth is virtually uncontrollable during the galvanizing process.

**When possible, the galvanizer should be advised of the grade of steel selected in order to determine whether to utilize custom galvanizing techniques.**

## COMBINING DIFFERENT MATERIALS AND SURFACES

Varying surface conditions, different fabrication methods, or ferrous metals with special chemistries, when combined, make it difficult to produce coatings with uniform appearance. This is because different parameters for pickling (such as immersion time, solution concentrations, and temperatures) and galvanizing (such as bath temperatures and immersion time) are required for:

- excessively rusted surfaces
- machined surfaces
- cast steel
- malleable iron
- hot rolled steel
- cold rolled steel
- cast iron, especially with sand inclusions
- pitted surfaces
- steel containing excess carbon, phosphorus, manganese, or silicon

The use of old along with new steel or castings with rolled steel in the same assembly should be avoided (see *Figure 3*). Where assemblies of cast iron, cast steel, malleable iron, or rolled steel are unavoidable, the entire assembly should be thoroughly abrasive blasted with shot or sand prior to pickling to give the best chance for producing a galvanized coating of acceptable quality.

Excessively rusted, pitted, or forged steels should not be used in combination with new or machined surfaces because the difference in required pickling time for sulfuric acid pickling baths can cause over-pickling of the new or machined surfaces. Where this combination is unavoidable, a thorough abrasive blast cleaning of the assembly (normally before any machining is done) provides a more uniform galvanized coating.



Matte coating



Bright, shiny coating

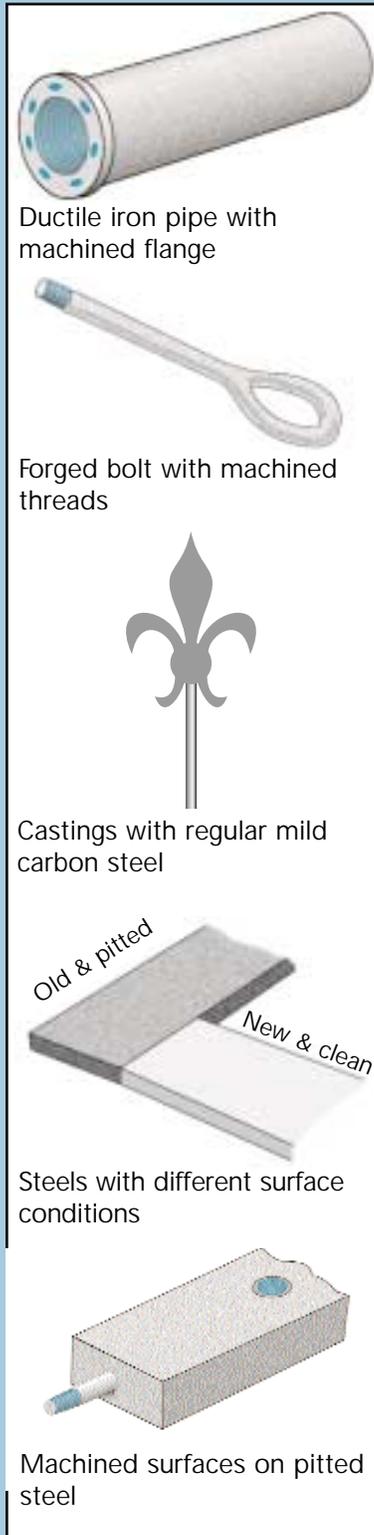
Different steel chemistries will affect the appearance of the galvanized coating, but do not negatively affect the corrosion resistance; the matte coating above will last just as long, or longer than the bright, shiny coating



Varying steel chemistries create visually different coatings, as illustrated by this pipe assembly

## Avoid Combinations of Different Materials and Finishes

Figure 3



Omission of blast cleaning of mixed material assemblies results in a combination of under- and over-pickling of the different surfaces in a sulfuric acid pickling bath, adversely affecting the quality of the finished galvanized coating.

Whenever possible, the materials described should be galvanized separately and assembled after galvanizing. When steels of special chemical composition or varying surface finishes are joined in an assembly, the galvanized finish generally is not uniform in appearance. The corrosion protection provided by the galvanized coating, however, is not affected by variation in the color and texture of the coating. After aging in the environment, the entire coating usually ages to a uniform matte gray appearance.

If abrasive blast cleaning is used to prepare a surface for galvanizing, a coating thicker than normal will be produced for low silicon steel. Abrasive cleaning roughens the steel surface and increases its surface area, resulting in increased reactivity with the molten zinc. Greater zinc-iron alloy layer growth occurs during galvanizing of a blast-cleaned steel, producing thicker coatings at the expense of a moderately rougher surface. These thicker coatings sometimes will have a matte gray appearance because the alloy layers extend to the outer surface.

### WELDING PROCEDURES AND WELDING FLUX REMOVAL

When welded items are galvanized, both the cleanliness of the weld area and the metallic composition of the weld itself affect the galvanized coating's quality and appearance.

The specifics of welding techniques can best be obtained from the American Welding Society (800-443-9353) or your welding equipment supplier. Several welding processes and techniques have been found to be successful for items to be galvanized:

- In welding, an uncoated electrode should be used when possible to prevent flux deposits on the steel or product.
- Welding flux residues are chemically inert in the normal pickling solutions used by galvanizers; therefore, their existence will produce rough surfaces and coating voids. If a coated electrode is used, all welding flux residues must be removed by wire brushing, chipping, grinding, pneumatic needle gun, or abrasive blast cleaning (see *Figure 4*).
- Welding processes such as metal inert gas (MIG), tungsten inert gas (TIG), or carbon dioxide (CO<sub>2</sub>) shielded are recommended since they essentially produce no slag. However, there can still be small flux-like residues that need to be chipped off.
- In the case of heavy weldments, a submerged arc method is recommended.
- If none of these welding methods is available, select a coated rod specifically designed for "self-slagging," as recommended by welding equipment suppliers.
- Choose a welding rod providing a deposited weld composition as close as possible to the parent metal. This will help prevent differential acid attack between the weld area and the parent metal during acid cleaning. The composition and compatibility will yield a more uniform zinc surface appearance.

**Welding rods high in silicon may cause excessively thick and/or darkened galvanized coatings to form over the weld. In smooth products welded together with high silicon weld rods, the coating over the weld material will be thicker than the surrounding coating, causing a bump in an otherwise smooth product. So, a very low or no silicon content rod should be used.**

Galvanized materials may be easily and satisfactorily welded by all common welding techniques. Additional information about welding galvanized steel may be obtained from the AGA.

## MECHANICAL PROPERTIES OF GALVANIZED STEEL

The hot-dip galvanizing process produces no significant changes in the mechanical properties of the structural steels commonly galvanized throughout the world. The mechanical properties of 19 structural steels from major industrial countries around the world were investigated before and after galvanizing in a four-year research project of the BNF Metals Technology Centre, UK, under the sponsorship of the International Lead Zinc Research Organization (ILZRO). Steels conforming to ASTM Standard Specifications A 36 and A 572 Grade 60 and Canadian Standards Association (CSA) Specifications G 40.8 and G 40.12 were included in this study.

The BNF report, *Galvanizing of Structural Steels and Their Weldments* (ILZRO, 1975), concludes that “. . . the galvanizing process has no effect on the tensile, bend or impact properties of any of the structural steels investigated when these are galvanized in the ‘as manufactured’ condition.”

### ***Strain-Age Embrittlement***

Many structures and parts are fabricated using cold rolled steel or cold working techniques. In some instances severe cold working may lead to the steel's becoming strain-age embrittled. While cold working increases the possibility of strain-age embrittlement, it may not happen until after galvanizing. This occurs because aging is relatively slow at ambient temperatures but more rapid at the elevated temperature of the galvanizing bath.

Any form of cold working reduces the ductility of steel. Operations such as punching holes, notching, producing fillets of small radii, shearing, or sharp bending may lead to strain-age embrittlement of susceptible steels.

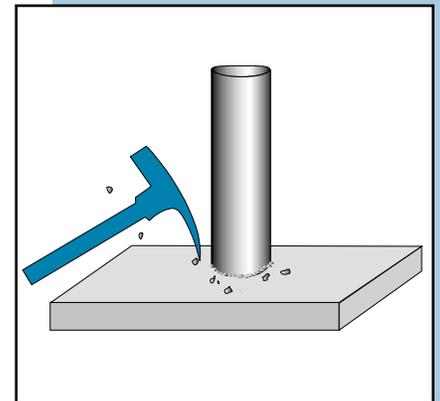
Cold worked steels less than  $\frac{1}{8}$  inch (3 mm) thick that are subsequently galvanized are unlikely to experience strain-age embrittlement. Since cold working is the strongest contributing factor to the embrittlement of galvanized steel, the following precautions are recommended to reduce the incidence of strain-age embrittlement:

- Select *steels with carbon contents below 0.25%*.
- *Choose steels with low transition temperatures* since cold work raises the ductile-brittle transition temperature and galvanizing (heating) may raise it further.
- *Specify aluminum-killed steels because they show less susceptibility to strain-age embrittlement.*
- For steels with a *carbon content between 0.1 and 0.25%*, maintain a bending radius of at least three times the section thickness (3t). If bending is

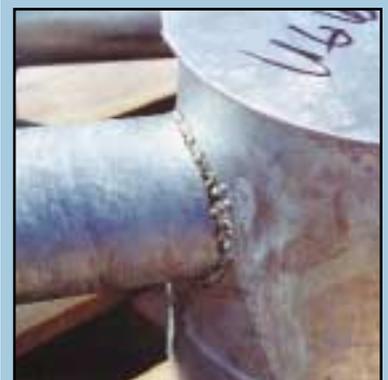


Proper welding techniques should be followed when welded steel will be galvanized

Figure 4

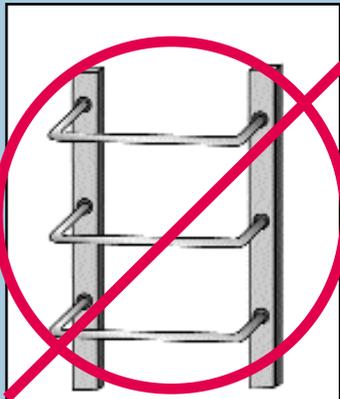


Welding flux residues must be removed by wire brushing, chipping, grinding, pneumatic needle gun or abrasive blast cleaning

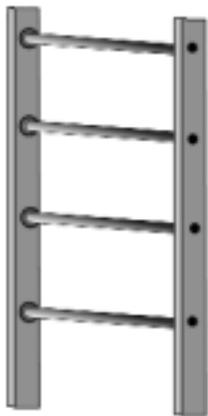


Failure to remove weld residues will result in incomplete galvanized coatings, such as on this joint

## Avoid Severe Cold Working



Preferred Design



required to be less than  $3t$ , the material should be stress relieved at 1100 F (595 C) for one hour per inch (25.4 mm) of section thickness.

- *Avoid notches* because they increase stress. Notches may be caused during shearing or punching operations. Flame cutting or sawing is preferred, particularly for heavy sections.
- *Drill, rather than punch, holes in material thicker than  $\frac{3}{4}$  inch (19 mm)*. If holes are punched, they should be punched undersize and then reamed an additional  $\frac{1}{8}$  inch (3 mm) overall or drilled to size. Material between  $\frac{1}{4}$  and  $\frac{3}{4}$  inch (6.5 - 19 mm) thick is not seriously affected by cold punching if the punching is done under good shop practice. Material up to  $\frac{1}{4}$  inch (6.5 mm) thick that has been cold worked by punching does not need stress relieving operations before galvanizing.
- For *steel sections with edges greater than  $\frac{5}{8}$  inch (16 mm) thick that are subject to tensile loads*, cut using normal shop procedures. Edges of sections up to  $\frac{5}{8}$  inch (16 mm) thick may be cut by shearing.
- *In critical applications*, the steel should be hot worked above 1200 F (650 C) in accordance with the steel manufacturer's recommendations. Where cold working cannot be avoided, stress-relieve the part.

ASTM A 143, *Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement*, and CSA Specification G 164, *Galvanizing of Irregularly Shaped Articles*, provide guidance on cold working and stress relieving procedures. However, it is best to avoid severe cold working of susceptible steels.

If there is concern with possible loss of ductility due to strain-age embrittlement, alert the galvanizer. A sample quantity of the cold-formed items should be galvanized and tested before further commitment.

### **Hydrogen Embrittlement**

Hydrogen embrittlement is a ductile-to-brittle change that occurs in certain high strength steels. Hydrogen embrittlement can occur when the hydrogen released during the pickling process is absorbed by the steel. However, at galvanizing temperatures hydrogen is expelled from the steel unless it becomes trapped in the grain boundaries.

Although hydrogen embrittlement is uncommon, precautions should be taken to avoid it, particularly if the steel involved has an ultimate tensile strength exceeding 150,000 psi. If high-strength steels are to be processed, grit blasting instead of acid pickling is recommended in order to minimize the introduction of gaseous hydrogen during the pickling process.

### **Size and Shape**

With the increase in the sizes and capacities of galva-



Galvanizers often rack products in order to effectively galvanize more than one product at a time, such as with these guardrail posts, which are being removed from the zinc bath

nizing kettles, facilities can accommodate fabrications in a significant range of sizes and shapes. Galvanizing kettles up to 42 feet (13 m) in length are available in most industrial areas, and there are several kettles between 50, 60, and 80 feet (15, 19, and 25 m) in length.

Almost any component can be galvanized by designing and fabricating in modules suitable for the available galvanizing facilities. However, it is wise to verify kettle constraints with the galvanizer at an early stage. [Kettle dimensions and phone numbers of member galvanizers are available through the AGA.]

Large structures are galvanized by designing in modules or sub-units that are assembled by field welding or bolting after galvanizing. Modular design techniques often produce economies in manufacturing and assembly because they simplify handling and transportation.

When an item is too large for total immersion in the kettle of molten zinc, but more than half of the item will fit into the kettle, the piece may be double dipped. During double dipping, each end of the article is dipped sequentially in order to coat the entire item (see photos at right). **Always consult the galvanizer before planning to double dip.**

Steel designers should consider the material handling techniques used in galvanizing plants. The use of hoists and cranes is commonplace. Large assemblies are usually supported by chain slings or by lifting fixtures. Special jigs and racks can be used to simultaneously galvanize large numbers of similar items.

Where possible, lifting points should be provided for the galvanizer. All articles are immersed into the galvanizing kettles from overhead, so chains, wires, or other holding devices are used to support the material unless special lifting points can be provided. Chain and wire can leave a touch-mark on the galvanized item. Although this touch-mark is usually fully galvanized, it can be touched up if required for aesthetic reasons.

Large pipe sections, open-top tanks, and similar structures may require the addition of bracing to maintain their shape during handling.

Small items also receive special attention during galvanizing. Pieces less than 30 inches (76 cm) in length are frequently galvanized in perforated baskets. The basket is then centrifuged to throw off excess zinc from the pieces, delivering smoother coatings. Fasteners, small brackets, and clips typify work handled in baskets.



Double dipping: Galvanizing oversized pieces



A perforated basket filled with bolts is placed in a centrifuge to spin off excess zinc

## Good Venting and Cropping

Figure 5

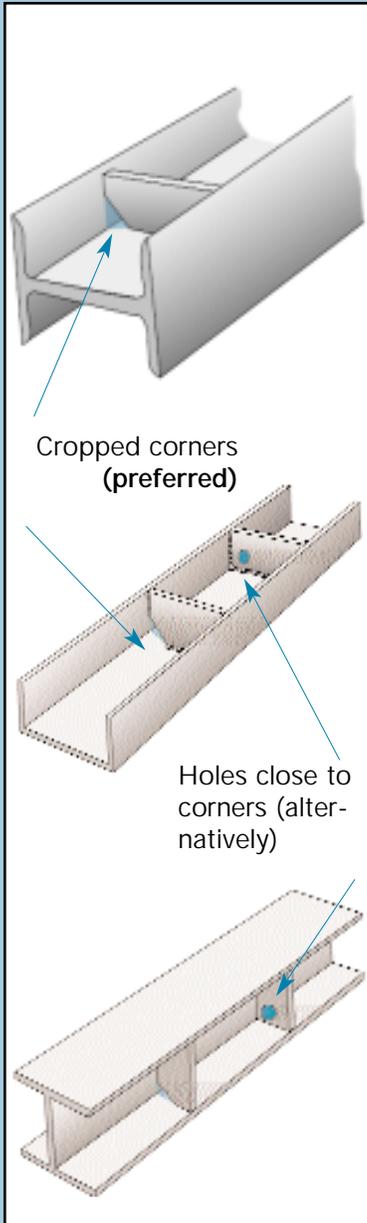
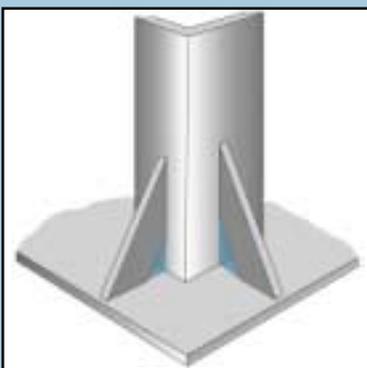


Figure 6



The weight of fabrications also should be considered in the design of products for hot-dip galvanizing because of the handling processes required to move items from step to step in the galvanizing facility. Contact the galvanizer to determine his weight-handling capacity if it appears that weight will be a factor in the design considerations.

### ALLOWING FOR PROPER DRAINAGE

For effective galvanizing, cleaning solutions and molten zinc must flow into, over, through, and out of the fabricated article without undue resistance.

Failure to provide for this free, unimpeded flow is frequently the cause of problems for the galvanizer and the customer. Improper drainage design results in poor appearance, bare spots, and excessive build-up of zinc. All of these are unnecessary and costly.

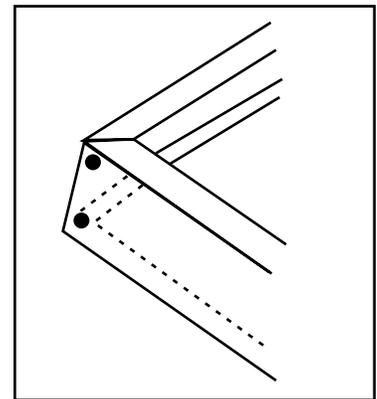
Where gusset plates are used, generously cropped corners provide for free drainage. When cropping gusset plates is not possible, holes at least  $\frac{1}{2}$  inch (13 mm) in diameter must be placed in the plates as close to the corners as possible (see *Figure 5*).

Figure 7

To ensure unimpeded flow of solutions, all stiffeners, gussets, and bracing should be cropped a minimum of  $\frac{3}{4}$  inch (19 mm) (see *Figure 6*).

Provide holes at least  $\frac{1}{2}$  inch (13 mm) in diameter in end plates on rolled steel shapes to allow molten zinc access during immersion in the galvanizing bath and drainage during withdrawal.

Alternatively, holes at least  $\frac{1}{2}$  inch (13 mm) in diameter can be placed in the web within  $\frac{1}{4}$  inch (6 mm) of the end plate. To facilitate drainage, end plates should have holes placed as close to interior corners as possible (see *Figure 7*).



### TUBULAR FABRICATIONS AND HOLLOW STRUCTURALS

Tubular assemblies such as handrails, pipe columns, pipe girders, street light poles, transmission poles, pipe trusses, and sign bridges are commonly galvanized because corrosion protection is afforded to the interior and exterior of the product. To provide an optimal galvanized coating, hollow products require proper cleaning and draining.

#### **Cleaning**

As with all steel, pipe and other hollow materials must be thoroughly cleaned before the molten zinc will metallurgically bond with the steel. Pipe can present two special cleaning difficulties.

First, the mill coating (varnish, lacquer, and similar materials) applied by the pipe manufacturer requires extra time and effort to remove at the galvanizing plant. Some galvanizers do not have the capability to remove this coating. Some organic mill coating formulations, both foreign and domestic, are extremely difficult to remove with common cleaning solutions, so blasting may be required. Ordering uncoated pipe avoids costly removal of these mill

coatings. In some cases, it may be more cost effective to substitute tube for pipe.

Second, welding around mill coatings burns and carbonizes the varnish in the surrounding areas and cannot be removed by the normal cleaning process at a galvanizer. This soot must be removed by blasting or other mechanical cleaning methods.

### **Venting**

The primary reason for vent and drain holes is to allow air to be evacuated allowing the object to be completely immersed in the molten zinc. Proper sizing and location make it safer to galvanize and provide the optimal finish. The secondary reason is to prevent explosions and destruction of the parts. Any pickling acid or rinse waters that might be trapped in a blind or closed joining connection will be converted to superheated steam or gas and can develop a pressure of up to 3800 psi when immersed in molten zinc at 850 F (455 C). **This presents a serious explosion hazard to galvanizing personnel and equipment.**

Proper galvanizing results in the inside and outside of a product that is completely cleaned and coated with zinc. Air and frothy fluxes must be allowed to flow upward and completely out. Cleaning solutions and molten zinc must be allowed to flow in and completely wet the surfaces.

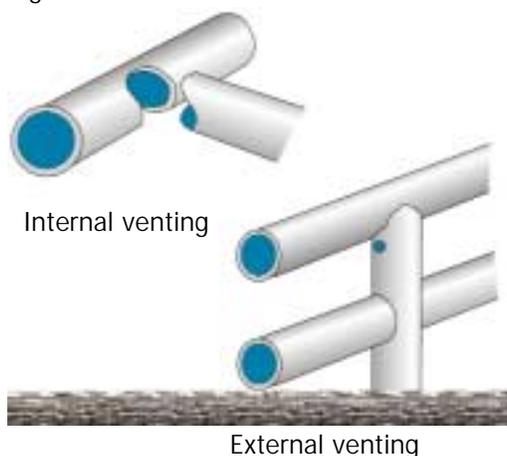
The structure must be lowered into the solution without trapping any air, then raised from the bath without trapping any solution. Consequently, ample passageways allowing unimpeded flow into and out of the part must be designed into the assemblies.

Items to be galvanized are immersed and withdrawn at an angle, so the vent holes should be located at the highest point and drain holes at the lowest point in each member.

All sections of fabricated pipe-work should be interconnected with full open tee or miter joints. Each enclosed section must be provided with a vent hole at each end.

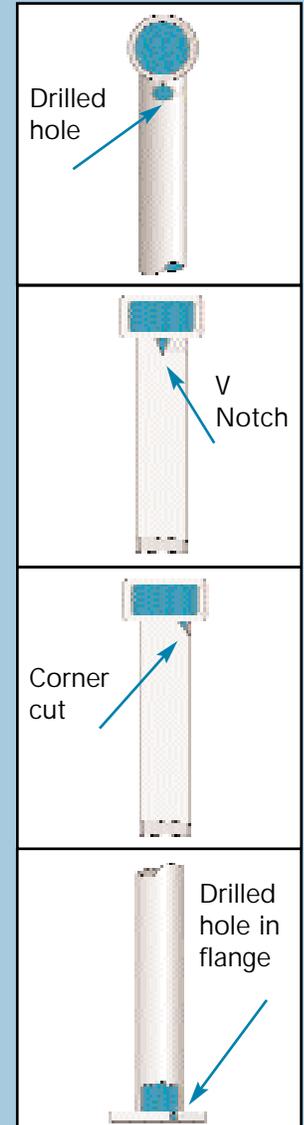
Most galvanizers prefer to visually identify the venting from the outside when the assembly is received. This is necessary to verify the adequacy of the venting as well as to determine that it has not been omitted by mistake. Some galvanizers may hesitate to process com-

Figure 8



## Various Methods of Venting Tubular Fabrications

Figure 9



Vent holes on the outside of pipe assembly

plicated pipe assemblies (such as handrail) unless all venting is visible on the outside and readily accessible for inspection (see *Figure 8* – previous page).

Base plates and end plates must be designed to facilitate venting and draining. Fully cutting the plate provides minimum obstruction to a full, free flow into and out of the pipe. Since this is not always possible, the use of vent holes in the plate often provides the solution.

Vent holes are frequently left open but can be closed with drive caps or plugs after galvanizing.

Various methods of venting are acceptable (see *Figure 9* – previous page), but the subsequent plugging of these holes should be kept in mind where necessary.

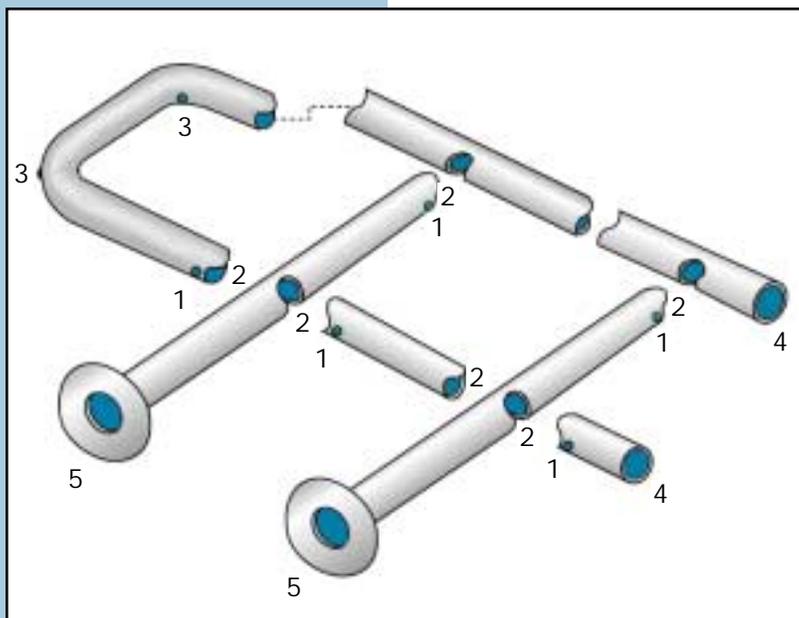
It is recommended that tubular structures be completely submerged in one dip in the galvanizing kettle. This minimizes potential internal coating problems which, because of the size and shape of the item, may be difficult to discover during inspection.

Internal gusset plates and end flanges should also be provided with vent and drainage holes. In circular hollow shapes, the holes should be located diametrically opposite each other at opposite ends of the member.

In rectangular hollow shapes, the four corners of the internal gusset plates should be cropped. Internal gusset plates in all large hollow sections should be provided with an additional opening at the center. Where there are flanges or end plates, it is more economical to locate holes in the flanges or plates rather than in the section.

The following drawings illustrate recommended designs for tubular fabrications and hollow structurals. The vent dimensions are the **minimum** required.

Figure 10



Vent holes should be visible on the outside of any pipe assembly to provide internal vent verification

#### Handrail:

*Figure 10* illustrates the most desirable design for fabrications of handrail for galvanizing. It shows internal venting as well as the minimum amount of external vent holes.

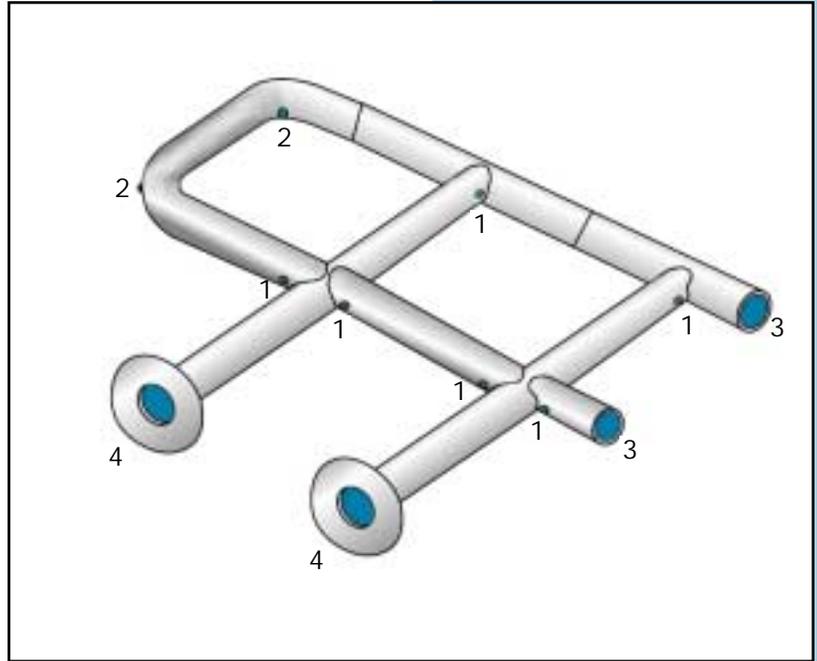
1. External vent holes must be as close to the weld as possible and not less than  $\frac{3}{8}$  inch (9.5 mm) in diameter.
2. Internal holes should be the full I.D. of the pipe for the best galvanizing quality and lowest galvanizing cost.
3. Vent holes in end sections or in similar sections must be  $\frac{1}{2}$  inch (13 mm) in diameter.
4. & 5. Ends should be left completely open. Any device used for erection in the field that prevents full openings on ends of horizontal rails and vertical legs should be galvanized separately and attached after galvanizing.

Figure 11

**Handrail:**

Figure 11 illustrates an acceptable alternative if full internal holes (the full I.D. of the pipe) are not incorporated into the design of the handrail.

1. Each external vent hole must be as close to the welds as possible and must be 25% of the I.D. of the pipe, but not less than 3/8 inch (10 mm) in diameter. The two holes at each end and at each intersection must be 180 degrees apart and in the proper location as shown.
2. Vent holes in end sections or in similar sections must be 1/2 inch (13 mm) in diameter.
3. & 4. Ends should be left completely open. Any device used for erection in the field that prevents full openings on ends of horizontal rails and vertical legs should be galvanized separately and attached after galvanizing.



External vent holes should be visible on the outside of any pipe assembly

**Rectangular Tube Truss:**

*Vertical Sections*

Hole locations for the vertical members should be as shown on Figure 12.

Each vertical member should have two holes at each end, 180 degrees apart in line with the horizontal members. The size of the holes preferably should be equal, and the combined area of the two holes at either end of the verticals should be at least 30% of the cross-sectional area.

*End Plates - Horizontal*

1. The most desirable fabrication is completely open.
2. From Figure 17, if  $H + W = 24$  inches or larger, the area of the hole, plus clips, should equal 25% of the area of the tube ( $H \times W$ ).

If  $H + W =$  less than 24 inches but more than 16 inches, the area of the hole, plus clips, should equal 30% of the area of the tube.

If  $H + W =$  less than 16 inches but more than 8 inches, the area of the hole, plus clips, should equal 40% of the area of the tube.

If  $H + W =$  less than 8 inches, leave it open.

Figure 12

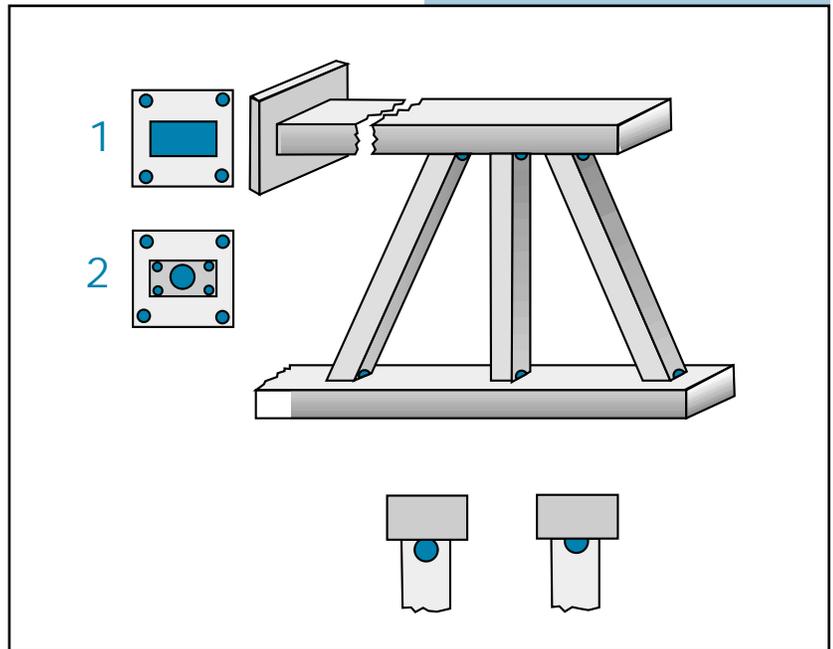
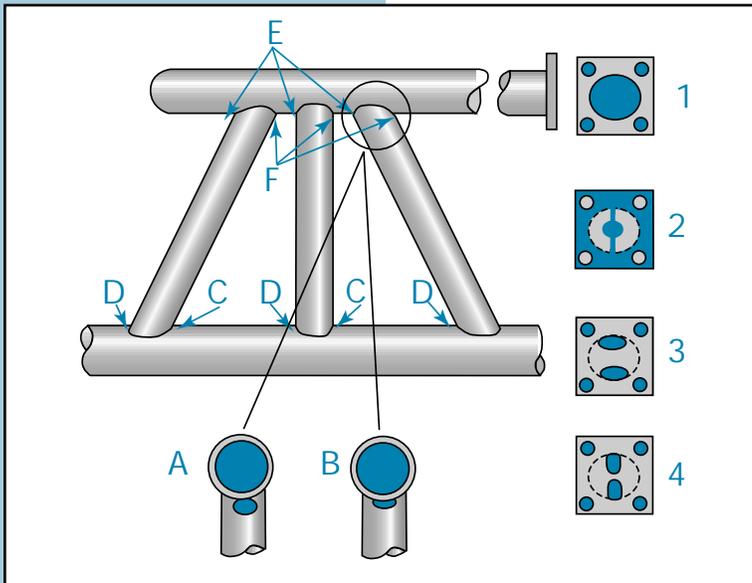


Figure 13



**Pipe Truss 3" & Larger:**

*Vertical Sections*

Hole locations for the vertical members should be as shown in Examples A and B and by the arrows on *Figure 13*.

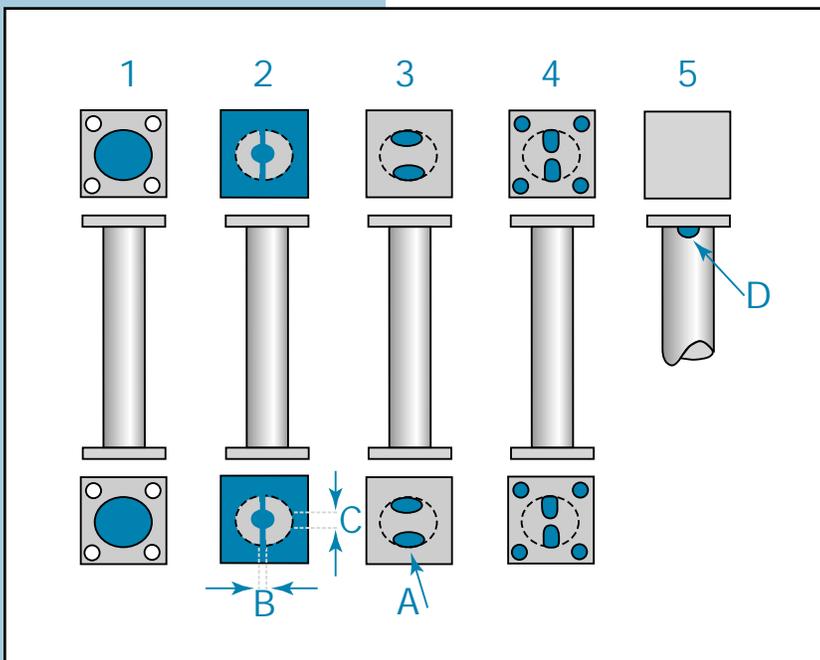
Each vertical member should have two holes at each end and 180 degrees apart in line with the horizontal members as indicated by the arrows. The size of the holes preferably should be equal and the combined area of the two holes at either end of the verticals (Areas C and D or Areas E and F) should be at least 30% of the cross-sectional area.

*End Plates - Horizontal*

1. The most desirable fabrication is completely open with the same hole diameter as the tube inner diameter.

2. & 3. & 4. Equal substitutes would have openings as shown above and would be at least 30% of the area of the inside diameter.

Figure 14



**Pipe Columns, Pipe Girders, Street Light Poles, and Transmission Poles:**

*(With base plates and with or without cap plates, Figure 14.)*

*Location of Openings*

1. The most desirable fabrication is to have the end completely open, with the same diameter as the section top and bottom.

2. & 3. & 4. This is an equal substitute if the full opening is not allowed.

5. This must be used when no holes are allowed in the cap or baseplate: two half circles 180 degrees apart and at opposite ends of the pole.

*Dimensions*

Openings at each end must be at least 30% of the I.D. area of the pipe for pipe three inches and greater and 45% of the I.D. area for pipe smaller than three inches.

Allow 30% of the area of the I.D. for hole sizes at each end.

Illustration 1, end completely open.

Illustration 2, Slot B = 3/4 inch (19 mm), Center hole C = 3 inches (76 mm) in diameter

The following is an example of sizes for a 6 inch diameter section. Illustration 3, Half circle A = 1 3/4 inch (45 mm) radius

Illustration 4, oval opening = 1 3/4 inch (45 mm) radius

Illustration 5, Half circle D = 1 5/8 inch (19 mm) radius

Figure 15

**Box Sections:**

Figure 15 shows the location of holes and clipped corners, which must be flush. Using the following formulas, Table 1 shows typical sizes of holes.

*Internal Gussets* – space at a minimum of 36 inches.

*Box Sections* –  $H + W = 24$  inches or larger, the area of the hole, plus clips, should equal 25% of the cross-sectional area of the box ( $H \times W$ ).

*Box Sections* –  $H + W =$  less than 24 inches but greater than 16 inches, the area of the hole, plus clips, should equal 30% of the cross-sectional area of the box.

*Box Sections* –  $H + W =$  less than 16 inches but greater than or equal to 8 inches, the area of the hole, plus clips, should equal 40% of the cross-sectional area of the box.

*Box Sections* –  $H + W =$  under 8 inches, leave completely open, no end plate or internal gusset.

Table 1 is for square box sections only. For rectangular sections, calculate the required area and check with the galvanizer for positioning of openings.

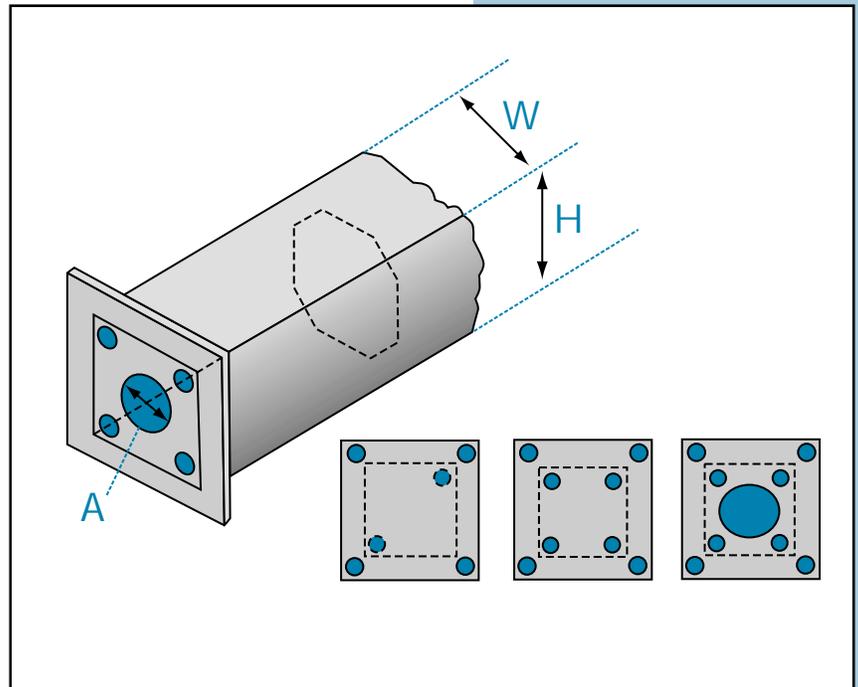


Table 1

Box Size (H + W)	Holes A-Dim
48"	8"
36"	6"
32"	6"
28"	6"
24"	5"
20"	4"
16"	4"
12"	3"

Figure 16

**Tapered – Signal Arm:**

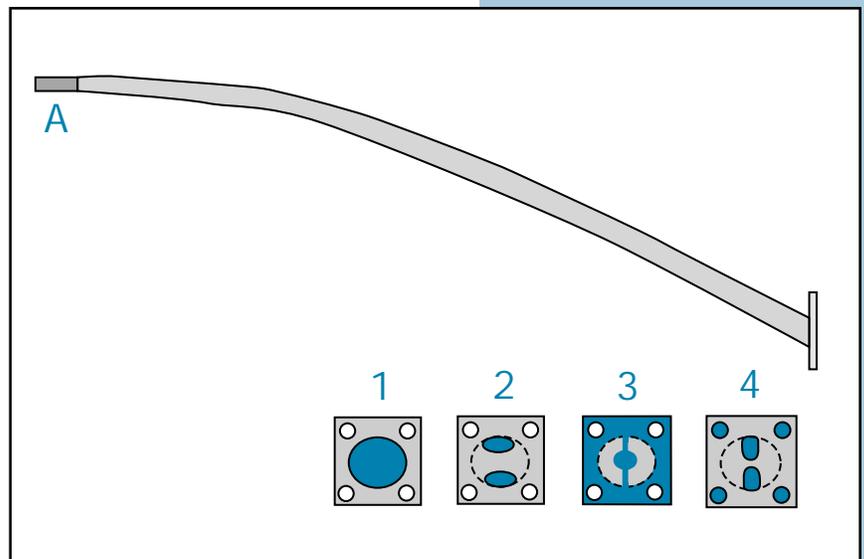
(Figure 16)

**A.** The small end should be completely open.

*Pole Plate End*

**1.** The most desirable fabrication is to have the end completely open.

**2. & 3. & 4.** For acceptable alternatives, the half circles, slots, and round holes must equal 30% of the area of the I.D. of the pole end of the tapered arm for 3 inches and larger I.D.s. The opening must equal 45% of the area of the pole end of the tapered arm if the I.D. is less than 3 inches.



# Venting of Tanks and Vessels

Figure 18

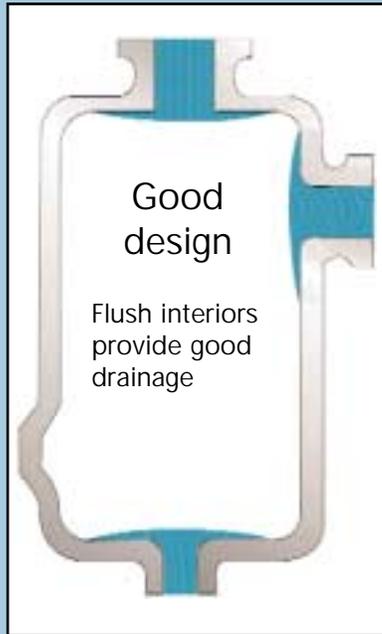


Figure 19

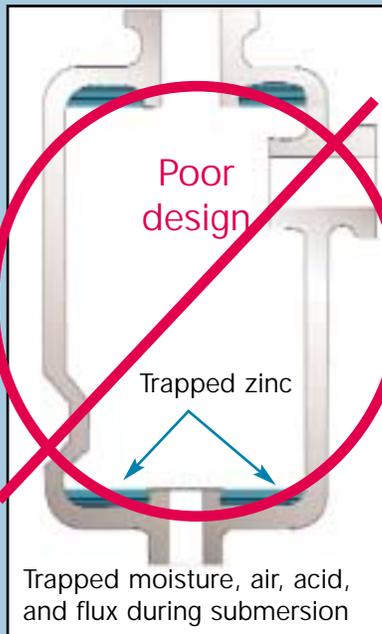
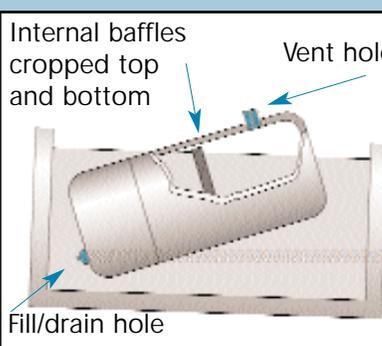


Figure 20



## Designing for Proper Venting and Draining of Enclosed and Semi-Enclosed Products

Tanks and enclosed vessels should be designed to allow acid cleaning solutions, fluxes, and molten zinc to enter at the bottom and trapped air to flow upward through the enclosed space and out through an opening at the highest point. This prevents air from being trapped as the article is immersed (see *Figure 17*). The design must also provide for complete drainage of both interior and exterior details during withdrawal. The location and size of fill and drain holes are important. As a general rule, the bigger the hole the better the air and zinc flow.

When both internal and external surfaces are to be galvanized, at least one fill/drain hole and one vent hole must be provided. The fill/drain hole should be as large as the design will allow, **but at least 3 inches in diameter for each cubic yard (10 cm in diameter for each 1.0 cubic meter) of volume. The minimum diameter is 2 inches (50 mm).** Provide vent holes of the same size diagonally opposite the fill/drain hole. This allows the air to escape.

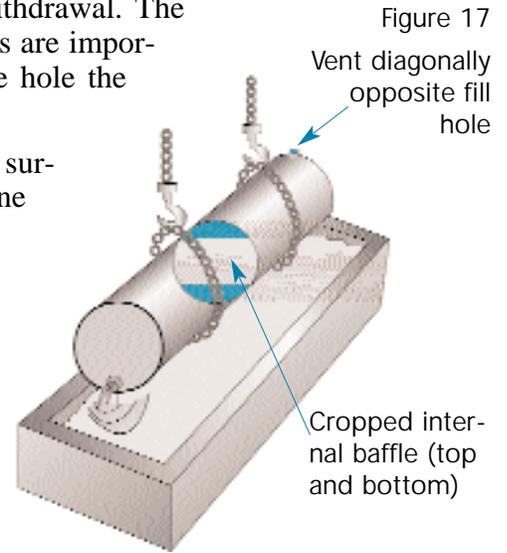
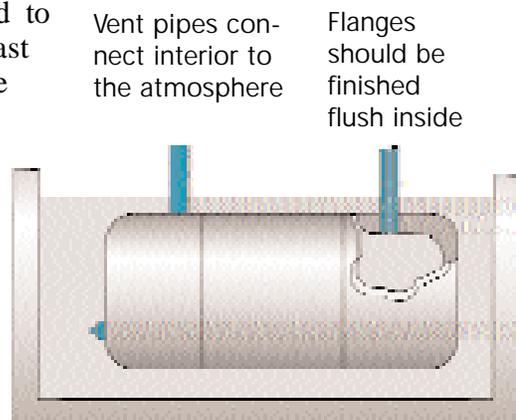
In tanks, internal baffles should be cropped on the top and bottoms or provided with suitable drainage holes to permit the free flow of molten zinc. Manholes, handholes, and openings should be finished flush inside to prevent trapping excess zinc (see *Figures 18-20*).

Openings must be placed so that the flux on the vessel can float to the surface of the bath. These openings also prevent air pocket formations that may keep the acid bath from completely cleaning the inside of the vessel.

Items such as vessels or heat exchangers that are galvanized on the outside only must have snorkel tubes, or extended vent pipes. These openings provide an air exit from the vessel above the level of molten zinc in the galvanizing kettle (see *Figure 21*). **The galvanizer should be consulted before using these temporary fittings because special equipment is needed.**

The galvanizer should always review the drawings of enclosed or partially-enclosed vessels before fabrication. Galvanizers may recommend changes that would provide a better galvanized product. If a change is needed to facilitate galvanizing, the least expensive time to make the change is before fabrication.

Figure 21



## MINIMIZING DISTORTION

Some fabricated assemblies may distort at the galvanizing temperature as a result of relieving stresses induced during manufacturing of the steel and in subsequent fabricating operations. A channel frame with a plate should be galvanized separately and bolted later rather than welded together before galvanizing, or it can be welded after galvanizing. Guidelines for minimizing distortion and warpage are provided in ASTM A 384, *Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies*, and CSA Specification G 164, *Hot Dip Galvanizing of Irregularly Shaped Articles*.

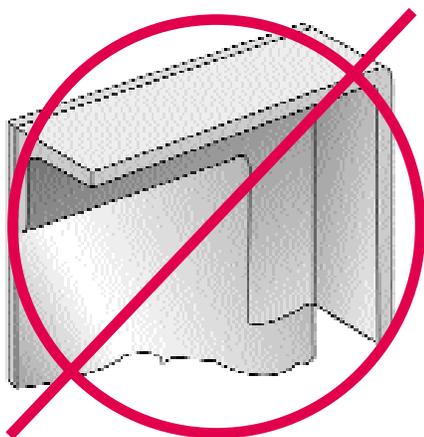
To minimize distortion, design engineers should observe the following recommendations:

Where possible, *use symmetrically rolled sections* in preference to angle or channel frames. I-beams are preferred to angles or channels.

*Use parts in an assembly that are of equal or near equal thickness*, especially at joints (see Figure 22).

*Bend members to the largest acceptable radii* to minimize local stress concentration.

Figure 22



*Accurately pre-form members of an assembly* so that it is not necessary to force, spring, or bend them into position during joining.

*Continuously weld joints using balanced welding techniques* to reduce uneven thermal stresses. **Pinholes from welding are very dangerous in items to be galvanized and must be avoided.** Staggered welding techniques to produce a continuous weld are acceptable. For staggered welding of  $\frac{1}{8}$  inch (4 mm) or lighter material, weld centers should be closer than 4 inches (10 cm).

*Avoid designs that require double dip galvanizing or progressive galvanizing.*

It is preferable to build assemblies and subassemblies in suitable modules so that they can be immersed quickly and galvanized in a single dip. In this way, the entire fabrication can expand and contract uniformly. Where double dip or progressive galvanizing is required, consult the galvanizer.

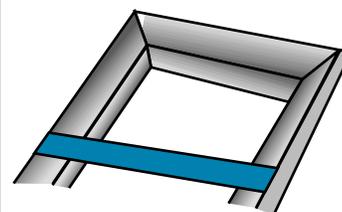
Consult with the galvanizer regarding the use of *temporary bracing or reinforcing to minimize warpage and distortion during galvanizing* (see Figure 23).



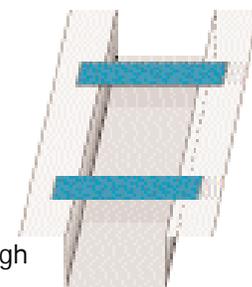
Some fabricated assemblies may distort at the galvanizing temperature as a result of relieving stresses induced during manufacturing of the steel and in subsequent fabricating operations

Figure 23

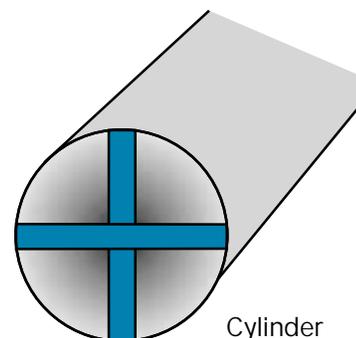
### Temporary Bracing



Channel frame typically fabricated toe-out



Trough



Cylinder

## PRECAUTIONS FOR OVERLAPPING AND CONTACTING SURFACES

When designing articles to be galvanized after fabrication, it is best to avoid narrow gaps between plates, overlapping surfaces, back-to-back angles, and channels (see *Figure 24*), whenever possible.

When overlapping or contacting surfaces cannot be avoided and is  $\frac{3}{32}$  inch (2.5 mm) or less, all edges should be completely sealed by welding. The viscosity of the zinc keeps it from entering any space tighter than  $\frac{3}{32}$  inch (2.5 mm). If there is an opening, less viscous pickling acids will enter, but zinc will not. The pickling acid may cause iron oxide weeping out of the joint later on.

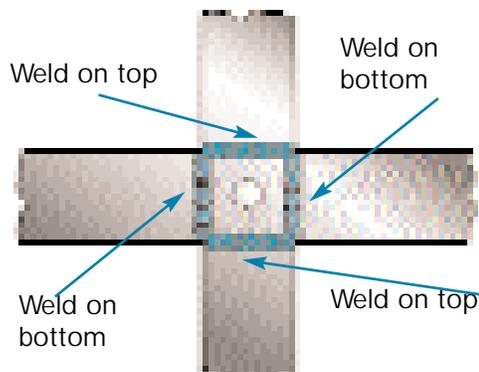
Further difficulties encountered with tightly overlapping surfaces include:

1. Pickling acids that may be trapped will flash to steam when the part is immersed in the galvanizing bath. This steam can wash the flux off of the part near the gap, causing bare areas adjacent to the lap joint.
2. Pickling acid salts can be retained in these tight areas due to the impossibility of adequate rinsing. The galvanized coating may be of good quality in the adjacent area, but humidity encountered weeks or even months later may wet these acid salts. This will cause an unsightly rust staining to seep out onto the galvanized coating.
3. Cleaning solutions will not effectively remove oils and greases trapped between surfaces in close contact. Any residual oil and grease will partially volatilize at the galvanizing temperature. This will result in an unsatisfactory zinc coating in the immediate area of the lap joint.

It is important to contact the galvanizer before constructing any piece that will include overlapping surfaces. The trade-off between a completely sealed weld joint that may undergo expansion and cracking when subjected to galvanizing temperatures and a skip-welded joint that may experience weepage and staining later becomes a very difficult choice. The galvanizer's experience may greatly assist in making this decision.

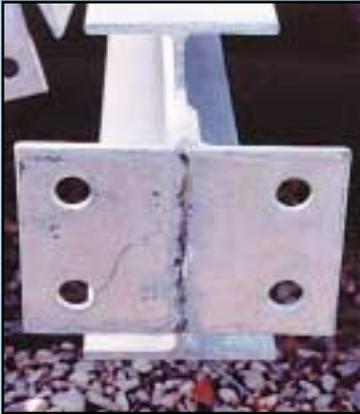
When a weld joint is completely sealed there must be no weld imperfection or pinholes. The penetration of moisture into the sealed cavity could cause significant safety hazards during the hot-dip galvanizing process as the sealed air will greatly expand when the part reaches

Figure 24



the galvanizing temperature. This gas expansion can cause the molten zinc to splash out of the bath and endanger galvanizing workers.

If the area of a seal-weld overlap is large, there should be vent holes through one or both sides into the lapped area. This is to prevent any moisture that gets in through a pinhole in the weld from building up explosive pressure while in the galvanizing bath. This venting becomes more important the greater the area. Consult the galvanizer or the AGA publication *Recommended Details for Galvanized*



Failure to seal weld small spaces may result in iron oxide weeping and staining caused by moisture wicked into the gap

*Structures* for vent size and quantity. Vent holes can be sealed after galvanizing. Seal welding is not mandatory but prevents trapping moisture, which can result in internal rusting and weepage.

Where two bars come together at an angle, a gap of at least  $\frac{3}{32}$  inch (2.5mm) after welding must be provided to ensure the area is wetted by the molten zinc (see *Figure 25*). An intermittent fillet weld may be used. This can be on one side of the bar only or, where necessary, an intermittent staggered fillet weld may be employed on both sides so that a pocket is not formed. This type of welding, however, is not suitable for load-bearing members.

## CASTINGS

High quality castings and forged parts can be galvanized successfully. The quality of the galvanizing is strongly influenced by the quality of the casting. Cleanliness is very important to achieve proper and complete galvanizing of castings. Thorough abrasive cleaning is the most effective method for removing foundry sand and impurities. This is conventionally accomplished by grit, shot, or sand blasting. Grit blasting or a combination of grit and shot generally is preferred. Castings are usually cleaned at the foundry since most galvanizers do not have abrasive blasting facilities.

Conventional acid cleaning processes employed by most galvanizers do not clean castings well because sand and other surface inclusions are not removed by hydrochloric or sulfuric acid. After castings have been abrasively cleaned they may then be pickled in preparation for galvanizing.

Galvanizing sound, stress-free castings with good surface finishes will produce high quality galvanized coatings. The following design and preparation rules should be applied for castings to be galvanized:

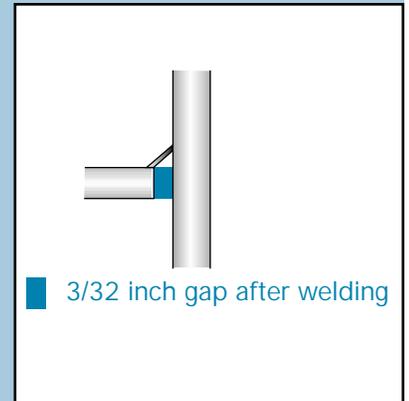
- Avoid sharp corners and deep recesses.
- Use large pattern numerals and generous radii to facilitate abrasive cleaning.
- Specify uniform wall sections. Non-uniform wall thickness in certain casting designs may lead to distortion and/or cracking. Cracking results from stress developed as the temperature of the casting is increased during the galvanizing process. Uniform wall sections and a balanced design will prevent cracking.

## THREADED PARTS

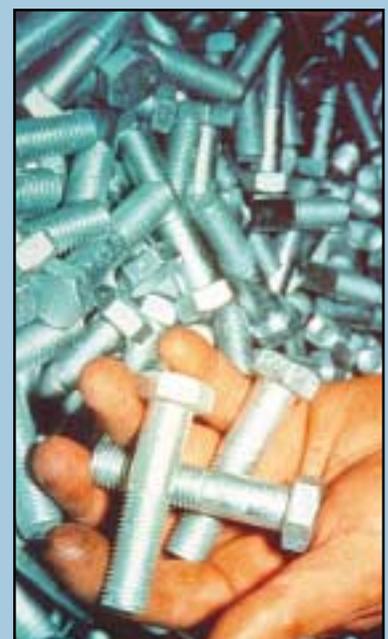
Hot-dip galvanized fasteners are recommended for use with hot-dip galvanized subassemblies and assemblies. Galvanized nuts, bolts, and screws in common sizes are readily available from commercial suppliers.

Bolted assemblies should be sent to the galvanizer in a disassembled condition. Nuts, bolts, or studs to be galvanized also should be supplied disassembled.

Figure 25



Castings must be abrasively cleaned in order to achieve a fully galvanized coating



Galvanized bolts

## Overtapping Guidelines for Nuts and Interior Threads

Table 2\*

Nominal Nut Size (inches) and Pitch	Diametrical Allowance (inches)
0.250-20	0.016
0.312-18	0.017
0.375-16	0.017
0.437-14	0.018
0.500-13	0.018
0.562-12	0.020
0.625-11	0.020
0.750-10	0.020
0.875-9	0.022
1.000-8	0.024
1.125-8	0.024
1.125-7	0.024
1.250-8	0.024
1.250-7	0.024
1.375-8	0.027
1.375-6	0.027
1.500-8	0.027
1.500-6	0.027
1.750-5	0.050
2.000-4.5	0.050
2.250-4.5	0.050
2.500-4.5	0.050
2.750-4	0.050
3.000-4	0.050
3.250-4	0.050
3.500-4	0.050
3.750-4	0.050
3.750-4	0.050
4.000-4	0.050

\* For metric overtapping allowances, see ASTM A 563M, section 7.

When the item to be galvanized incorporates threaded assemblies, the pitch diameter of the female threads must be increased to permit hand assembly after the addition of zinc to the male threads of the mating part.

Bolts are completely galvanized, but internal threads on nuts must be tapped oversize after galvanizing to accommodate the increased diameter of the bolts. While chasing or retapping the nuts after galvanizing results in an uncoated female thread, the zinc coating on the engaged male thread will protect both components from corrosion. For economy, nuts are usually galvanized as blanks and the threads tapped oversize after galvanizing (see *Figure 26*).

To remove excess zinc and produce smoother coatings, small parts, including fasteners, are centrifuged in special equipment when they are removed from the galvanizing bath.

Items too long or too large to centrifuge, such as long threaded rods, may be brushed while hot to remove any excess zinc from the threads.

Studs welded to assemblies may have to be cleaned after the assembly has cooled. This requires reheating with an acetylene torch and brushing to remove excess zinc. Alternatives to welded studs should be considered when possible.

Masking to prevent galvanizing threads on pipe or fittings is very difficult. The recommended practice is to clean and tap after galvanizing.

Anchoring devices (such as threaded rods and anchor bolts) sometimes are specified to be galvanized in the threaded areas only or in the areas to be exposed above-ground. This can be more expensive than galvanizing the complete unit because of the additional handling required. Complete galvanizing can be specified for items to be anchored in concrete. Research has proven the high bond strength and performance of galvanized steel in concrete.

Tapped-through holes must be retapped oversize after galvanizing if they are to contain a galvanized bolt after assembly. Tapping of all holes after galvanizing is recommended to eliminate double tapping costs and the possibility of cross-threading.

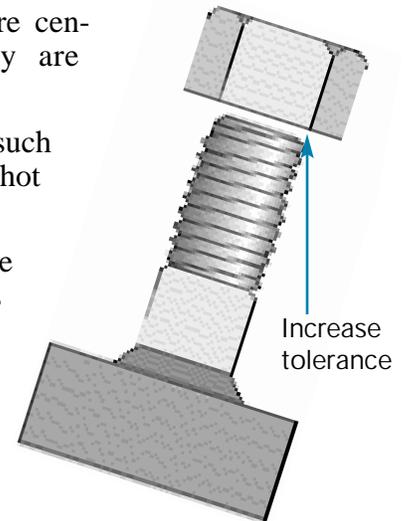
Table 2 shows the recommended overtapping for nuts and interior threads as detailed in ASTM A 563, *Specification for Carbon and Alloy Steel Nuts*.

On threads over 1½ inches (38 mm) it is often more practical, if design strength allows, to have the male thread cut 0.031 inches (0.8 mm) undersize before galvanizing so a standard tap can be used on the nut.

Manufacturers of threaded parts recognize that special procedures must be followed in their plants when certain items are to be galvanized. Following are some examples:

- Low carbon bars are recommended since high carbon or high silicon cause a heavier, rougher galvanized coating on the threads.

Figure 26



- Hot formed heading or bending requires cleaning at the manufacturing plant to remove scale before threading. Otherwise, over-pickling of threads will result during scale removal.
- Sharp manufacturing tools are mandatory. Ragged and torn threads open up in the pickling and galvanizing processes. Worn tools also increase bolt diameters. Frequent checking is necessary on long runs.
- Standard sized threads are cut on the bolt, while standard sized nuts are retapped oversize after galvanizing.

## MOVING PARTS

When a galvanized assembly incorporates moving parts (such as drop-handles, shackles, and shafts), a radial clearance of not less than  $\frac{1}{16}$  inch (1.5 mm) must be allowed to ensure full freedom of movement after the addition of zinc during galvanizing (see *Figure 27*).

Whenever possible, work should be designed so that hinges can be bolted to frames, covers, bodies, and other items after galvanizing.

Hinges should be galvanized separately and assembled after galvanizing. All hinges to be galvanized should be of the loose pin type. Before galvanizing, any adjacent edges should be ground to give at least  $\frac{1}{32}$  inch (0.8 mm) clearance (see *Figure 28*). The pin holes can be cleared of excess zinc during assembly. After hinges are galvanized, it is recommended that an undersized pin be used to compensate for the zinc picked up during galvanizing. If desired, the pin holes in the hinges may be reamed  $\frac{1}{32}$  inch (0.8 mm) after galvanizing to permit the use of regular size pins.

On hinges, all adjacent surfaces must be ground  $\frac{1}{32}$  inch on both pieces to allow for thickness increases. Grinding both pieces is necessary.

At times, moving parts must be reheated in order for them to work freely. Heating may cause discoloration of the galvanized coating near the reheated area. This discoloration does not affect the corrosion protection of the galvanized surface.

Figure 27

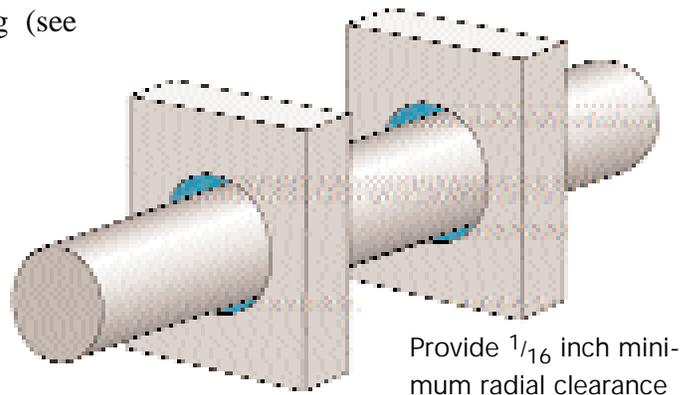


Figure 28

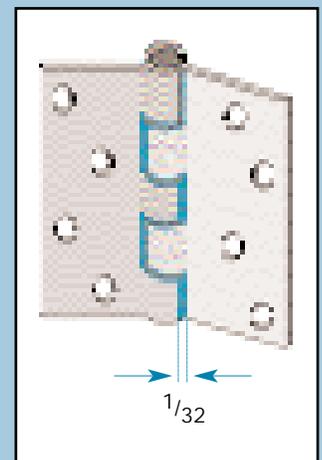
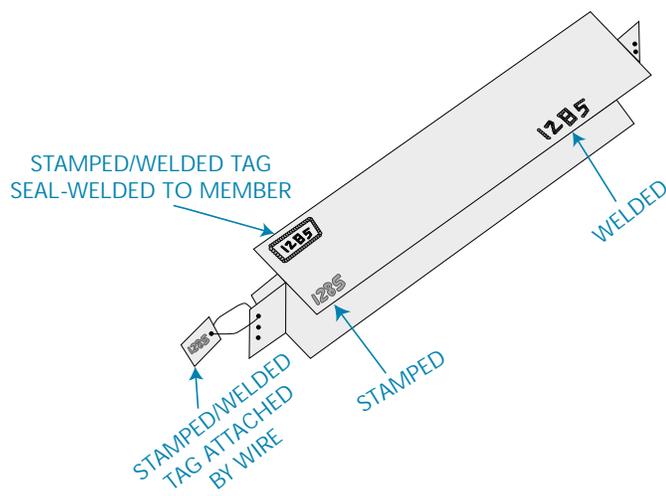


Figure 29



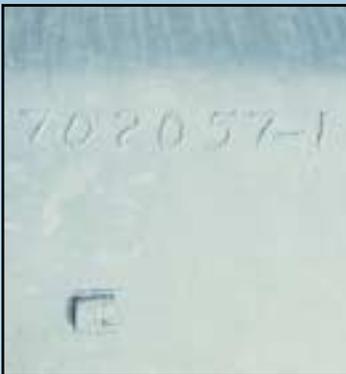
## MARKING FOR IDENTIFICATION

Identification markings on fabricated items should be carefully prepared before galvanizing so they will be legible after galvanizing and not jeopardize the integrity of the zinc coating.

Do not use paint, grease, or oil-based markers to apply addresses, shipping instructions, or job numbers on items to be galvanized. Pickling acids do not remove oil-based paints and crayon marks, resulting in extra work for the galvanizer to properly prepare the steel for galvanizing.

Detachable metal tags or water-soluble markers should be specified for temporary identification.

Figure 30



Identify by stamping the surface of the item using die-cut deep stencils or a series of punch marks

Where permanent identification is needed, there are three suitable alternatives for marking steel fabrications to be hot-dip galvanized. Each enables items to be rapidly identified after galvanizing and at the job site (see *Figures 29 through 31*).

*Stamping the surface of the item* using die-cut deep stencils or a series of center punch marks. These marks should be placed in a standard position on each of the members. They should be a minimum of  $\frac{1}{2}$  inch (13 mm) high and  $\frac{1}{32}$  inch (0.8 mm) deep to ensure readability after galvanizing. This method should not be used to mark fracture critical members (see *Figure 30*).

*A series of weld beads* may also be used to mark letters or numbers directly on the fabrication. It is essential that all welding flux be removed in order to achieve a quality galvanized coating (see *Figure 29*).

*Deep stenciling a steel tag* (minimum #12 gauge) and firmly affixing it to the fabrication with a minimum #9 gauge steel wire. The tag should be wired loosely to the work so that the area beneath the wire can be galvanized and the wire will not freeze to the work when the molten zinc solidifies. If desired, tags may be seal-welded directly to the materials (see *Figure 31*).

Figure 31



A deep stenciled steel tag firmly affixed to the fabrication with a minimum #9 gauge steel wire

## REPAIR OF DAMAGED GALVANIZED SURFACES

Sometimes hot-dip galvanized coatings are damaged by excessively rough handling during shipping or erection. Welding or flame cutting also may result in coating damage. When limited areas are damaged, the use of low melting-point zinc alloys, inorganic zinc-rich paints, or zinc metallizing is recommended to protect the area. ASTM A 780, *Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings*, details acceptable methods of reconditioning damaged areas.

## AFTER-GALVANIZING CONSIDERATIONS

### ***Wet Storage Stain Prevention***

When galvanizers know that galvanized items will be stacked or stored in humid environments, application of a post-galvanizing treatment designed to inhibit wet storage stain, or white rust, often is suggested.

Wet storage stain is an attack on the galvanized coating that produces white compounds of zinc oxide and zinc hydroxide. It is caused by retention of condensation or runoff water between contacting surfaces when air circulation is poor. While the attack is frequently superficial, its appearance may be objectionable. The galvanizer can discuss simple treatments that can be applied at the galvanizer's facility. AGA's publication, *Wet Storage Stain*, provides more details about the prevention and treatment of wet storage stain.

### ***Painting***

If the steel is scheduled to be painted after galvanizing, it is important to alert the galvanizer in order to eliminate any post-galvanizing treatments such as water quenching that interfere with paint adhesion.

Painting over galvanized steel, also known as a duplex system, is frequently used for aesthetics, identification or warning, camouflage, or added corrosion resistance under severely corrosive conditions.

The success of a duplex system largely depends on the surface preparation of the galvanized steel immediately prior to painting. Notifying the galvanizer of plans to paint aids in the success of a duplex system.

For more information about painting over galvanized steel, refer to the AGA publication *Duplex Systems: Painting Over Hot Dip Galvanized Steel*.



Poor storage, shown here, can lead to wet storage stain



Painting over galvanized steel provides a highly corrosion-resistant coating and aesthetic flexibility

## RELATED SPECIFICATIONS

ASTM A 36	Specification for Structural Steel
ASTM A 123	Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
ASTM A 143	Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
ASTM A 153	Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
ASTM A 384	Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies
ASTM A 385	Practice for Providing High Quality Zinc Coatings (Hot-Dip)
ASTM A 563	Specification for Carbon and Alloy Steel Nuts
ASTM A 572	Specification for High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality
ASTM A 767	Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
ASTM A 780	Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
ASTM B 6	Specification for Zinc
ASTM D 6386	Practice for Preparation of Zinc (Hot-Dip galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting
ASTM E 376	Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Test Methods
G 40.8*	Structural Steel with Improved Resistance to Brittle Fracture
G 40.12*	General Purpose Structural Steel *Superseded by G 40.20/G 40.21 General Requirements for Rolled or Welded Structural Quality Steel
G 164	Galvanizing of Irregularly Shaped Articles

### ***Duplex Systems: Painting Over Hot Dip Galvanized Steel***

American Galvanizers Association, Aurora, Colo., 1998.

### ***Inspection of Products Hot Dip Galvanized After Fabrication***

American Galvanizers Association, Aurora, Colo., 1999.

### ***Recommended Details for Galvanized Structures***

American Galvanizers Association, Aurora, Colo., 1990.

### ***Welding Galvanized Steel***

American Galvanizers Association, Aurora, Colo., 1992.

### ***Wet Storage Stain***

American Galvanizers Association, Aurora, Colo., 1997.



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