

CONSIDERING Corrosion

BY STEVEN A. SEBASTIAN, P.ENG.

Details that take corrosion into account can minimize horizontal surface areas where debris and moisture collect, increase drainage and shorten wetting cycles—thus increasing the overall service life of a structure.

AFTER CHOOSING a steel framing system for a project, how do you choose which steel to use?

In many cases, a structural designer simply selects the steel sections and connections that satisfy the appropriate design code and constructability requirements; the shape and orientation of steel members and connection details are chosen to satisfy strength, stiffness and installation requirements at the lowest cost.

This may not be enough, however, for structures in a highly corrosive environment where safety, reliability and the economic impact of shutdowns, repairs and maintenance may be of greater concern than the lowest initial capital cost. It is important for the designer to recognize steel shapes, arrangements and details that increase corrosion resistance and endeavor to use them. For steel structures in corrosive environments, the designer should select steel shapes, orientations and connections that 1) maximize shop fabrication and coatings, 2) minimize the accumulation and retention of debris and moisture and 3) encourage drainage in service. The worst steel sections and details from a corrosion standpoint have horizontal surfaces, pockets or mating surfaces that accumulate the materials that promote the corrosion process.

Organizations such as AISC and the Canadian Institute of Steel Construction provide guidance on structural steel design and the behavior of bolted and welded connections for structural steel for all types of buildings. These organizations, however, are focused on the strength, serviceability and efficiency of the steel sections and connections. Their consideration of corrosion has been limited to reference standards for surface preparation and coatings. Conversely, organizations like the

National Association of Corrosion Engineers have focused on the material science behind corrosion, cathodic protection and coatings. Information on steel shapes, connections and details that prevent corrosion is limited. This article is intended to open a discussion on the best practices in design to minimize corrosion.

Member Shape and Orientation

With an understanding of the mechanisms of corrosion, the best steel sections and details are those that discourage the accumulation and retention of debris or moisture and reduce wetting times. The best orientation for any structural shape produces the smallest horizontal surface areas and maximizes vertical and sloping surfaces so that they drain quickly. For example, steel angles are commonly used for struts and bracing members; however, the orientation of the member is often not considered in the context of susceptibility to corrosion.

Looking at the single-angle row in Figure 1, a single angle installed in the two orientations shown on the top left will readily collect water and debris and will corrode more quickly. The third orientation, with one leg vertical, is better but orienting the angle as shown on the far right is the best for corrosion resistance—an orientation with the long axis of the member sloped at 45° to the horizontal.

The best orientations for double angles follow the same principles, as shown in the next three rows in Figure 1; the behavior of T-shapes is similar to angles. I-shaped steel sections are best oriented with their strong axis vertical. Channels and S-sections exhibit better corrosion resistance than I-shaped members installed with the same orientation because their

RESISTANCE TO CORROSION

➤ Figure 1. Orientation of structural steel shapes to minimize corrosion.

flanges are narrower and sloped, which produces less accumulation and drains better. An advantage to S-shapes is that they are stockier—i.e., there are thicker sections to corrode and they can often be substituted directly for an I-shape of similar weight.

When it comes to rectangular hollow structural sections (HSS), a typical orientation is simplest for connections, but debris can accumulate on the flat (and sometimes concave) top surface. This best orientation for this type of section is rotated at 45°, which produces the smallest horizontal area and drains readily. A round section as shown in the center is better than one with a flat surface, but debris will usually accumulate on top within an angle of about 30° from vertical.

Closed Sections

All other factors being equal, the best structural sections to use in a highly corrosive environment are sealed tubes—square/rectangular or round HSS or steel pipe—because:

1. These sections are a good compromise for both compression and bending members. Although they are less efficient as beams than I-shaped sections, they are laterally and torsionally more stable, which allows larger unbraced lengths.
2. The ratio of exposed surface area to cross-sectional area is less than a comparable I-shape, which presents less surface area for corrosion.
3. The outside dimensions on an HSS are fixed. Reserve capacity and reliability can be increased by increasing the wall thickness, without changing the connection detail or interfering with other members.
4. If an HSS is sealed, the potential for internal corrosion is eliminated. All corrosion is on the exterior where it can readily be inspected. The best end connection for an HSS is a flat plate seal-welded to each end as shown in Figure 2. This closes the member and permits the full strength of the section to be mobilized in tension, compression and bending. It must be recognized, however, that a hole would be necessary if this member were to be galvanized.
5. The entire member can be shop welded and coated on all surfaces even if the field connection is bolted.

SECTION	ORIENTATION		
	WORST	→	BEST
SINGLE ANGLE			
ANGLES FACING TOE TO TOE			
ANGLES BACK TO BACK			
STARRED ANGLES			
ANGLES FACE TO FACE			
I SHAPED SECTIONS	I-SECTION		S-SECTION
CHANNEL			
TEE			
HSS			

Steven A. Sebastian

(steve.sebastian@tetratech.com) is a senior structural engineer with Tetra Tech in Winnipeg, Canada.



Some designers are concerned that sealed sections will deteriorate and eventually leak, and so a drainage hole is often provided at the low end of the member. A hole that is large enough will also allow internal coating of the member, such as hot-dip galvanizing. (My opinion is that if the member is not gal-

vanized and will be inspected and maintained on a regular basis, then it should be sealed. If the member will not be inspected and maintained by the owner, then it should be internally coated and have a drain.)

Figure 2 shows two end connection options for HSS. If the field coating

system is of high quality, the welded connection shown in option a, which allows for drainage, is preferable. Otherwise, all components should be shop coated on all surfaces and the connections field bolted, as shown in option b.

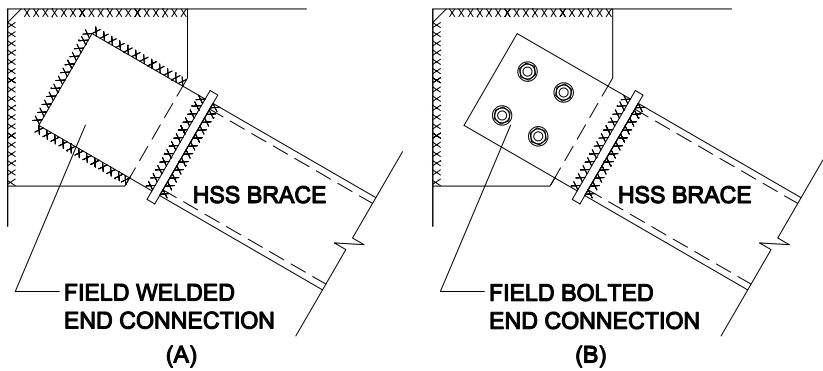
Connections

The best connection details maximize sealed shop-welded surfaces and shop coatings. Connections should shed water and debris and have no concealed spaces that collect and retain water and debris. Options for connecting a flat gusset plate for a bracing member are shown in Figure 3. The relative corrosion behavior of the arrangements would seem intuitive; however, I've seen the arrangements shown in Figures 3c and 3d many times. The result of one of these connections is shown in Figure 4, which provides options for double-angle connections. The option at the top is simple and flexible and has sufficient strength for most applications. However, it is the most susceptible to corrosion because:

1. It has the largest number of concealed spaces that readily collect water and debris.
2. It retains the materials for corrosion in the highest stressed areas: the bearing surfaces of the bolts. Even if the bolts and steel member are shop coated, the coatings are often scraped off during installation. Evidence of corrosion soon appears in the form of rust stain lines originating from the bolt holes.

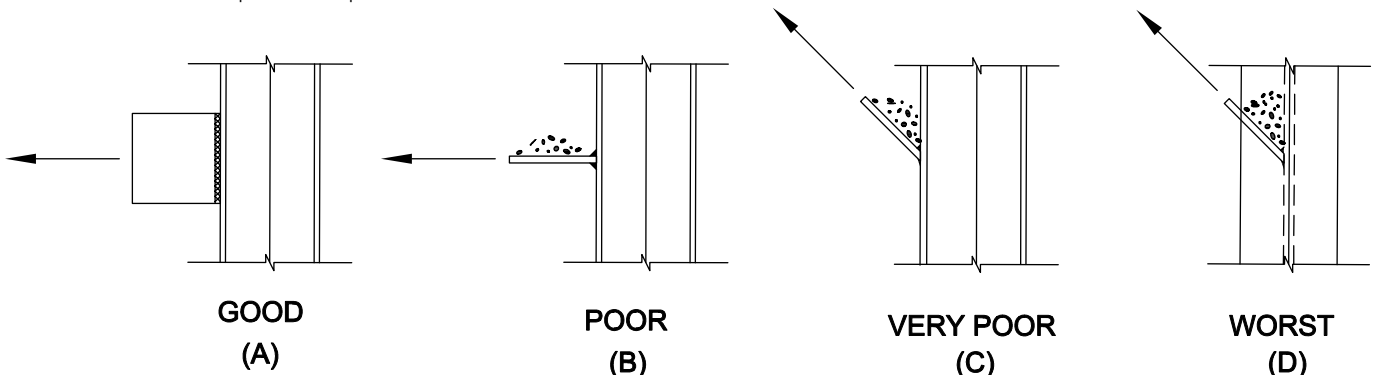
To minimize corrosion with beam connections, the objective is to minimize the number of uncoated or concealed wetting surfaces. If field coatings are installed to the same standard as shop coatings, the best connection for corrosion resistance is a sealed welded connection. The second choice would be a connection sealed on the top and sides and allowed to drain on the bottom. Note that caution should be taken to weld continuously in one direc-

▼ Figure 2. End connection options for an HSS member.



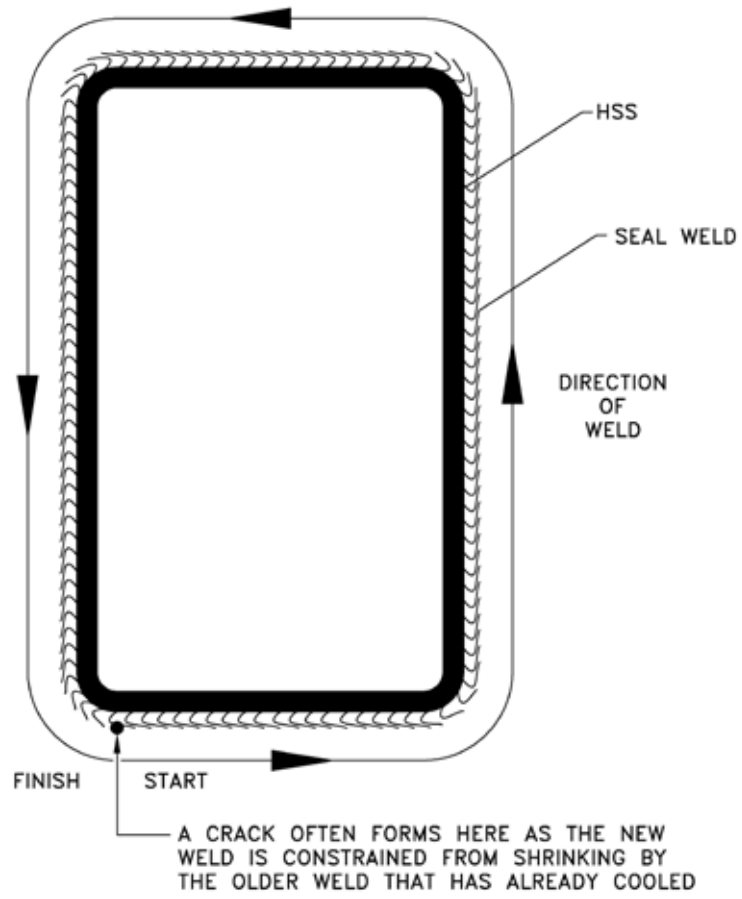
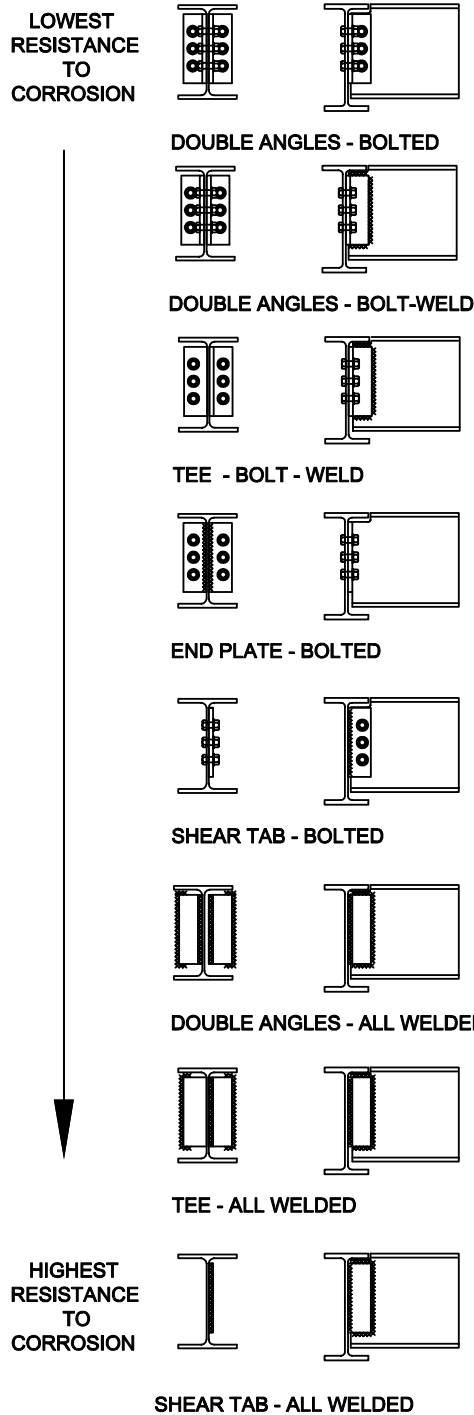
▲ A brace connected with a sloped gusset plate. Note that section loss is apparent while the upper portion of the angle is in good condition.

▼ Figure 3. Options for gusset plate connections, from best to worst: a) a vertical plate with sealed welds; b) a horizontal plate; c) the sloped gusset exacerbates collection of debris and impedes cleaning; and d) connection of a sloping plate to the column web creates a permanent pocket for corrosion.



▼ Figure 4. Beam connections and corrosion resistance.

➤ Figure 5. Continuous seal-welded HSS. Caution should be exercised when welding up to an existing weld as the new weld may be constrained from shrinking and a crack may form. Points like this are better located where the weld is in compression rather than in tension.



tion because a crack will often form where a new weld meets an older (cooler) weld (see Figure 5).

Structures

Simple structures and those with the fewest number of components have the greatest resistance to corrosion. For example, a braced frame similar to one supporting the elevated tank in Figure 6 (a) (on the following page) can likely be found in most process plants. If the tank contents are innocuous, corrosion may not be a concern. However, if the tank contents are corrosive or toxic (sewage, acid, etc.) deterioration of the support may be a more serious matter. (Either way, any collapse analysis should also account for risks to life safety and business interruption.) In the latter scenarios, the frame in Figure 6 (b) (on the following page) would have significant advantages:

1. There are fewer members and connections to collect liquid and deteriorate.
2. All of the connections are sealed and there are no concealed surfaces.

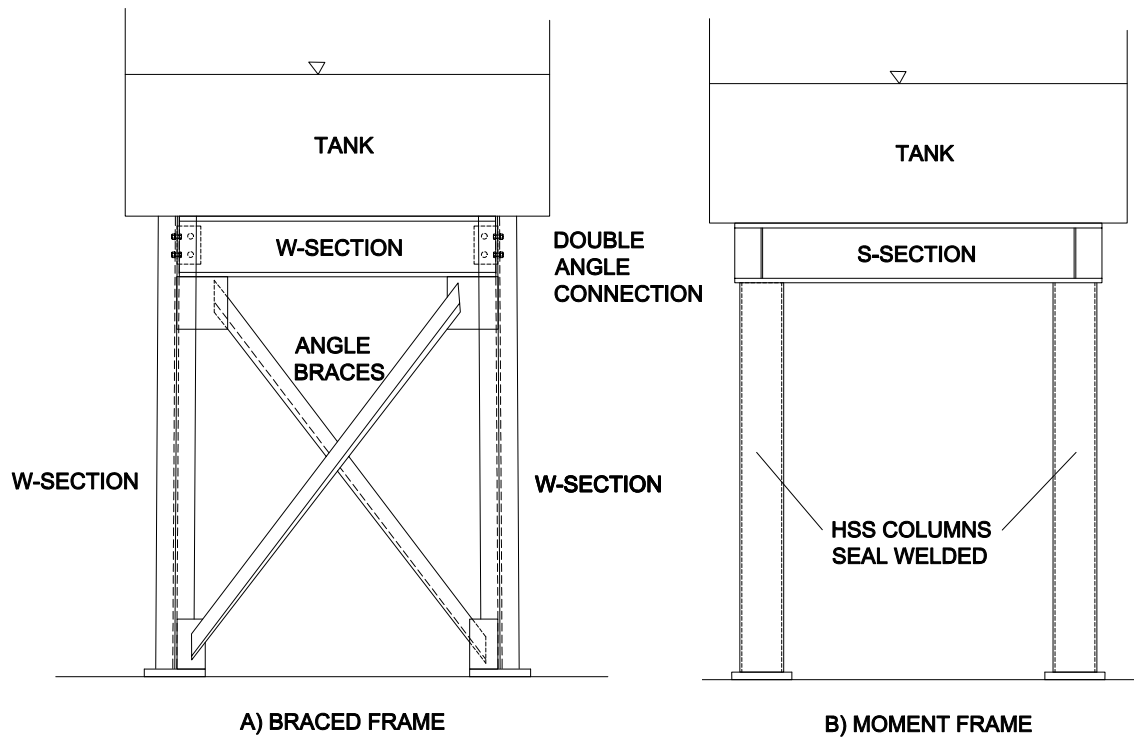
3. By its nature, the moment frame will have stockier members that would take longer to corrode.

The frame on the right may be more expensive, but the higher initial cost may be offset by the increase in safety and reliability and lower maintenance costs.

Bolting

Bolts are often galvanized, coated with cadmium or painted the same as the structural steel. Zinc galvanizing is economical and has good resistance to corrosion in wet environments; however, the zinc may deteriorate quickly in an acidic environment. Cadmium coatings provide more corrosion resistance, but there are increasing concerns about toxicity to workers. Ordinary shop or field applied paint systems for bolts are susceptible to damage from poor application or installation. The petroleum takes advantage of bolts that are factory-coated with special polymers (Teflon, epoxies, etc.) that are robust enough to survive harsh service conditions.

To recap, if corrosion is a concern, consider the following:



▲ Figure 6. Frame options for supporting a tank.

1. Select structural systems that are simple, with the least number of members and connections (this is good advice for any designs regardless of corrosion concerns).
2. Choose steel sections, member orientations and details that discourage accumulation and retention of water and debris. Closed sections and seal-welded connections are superior to open sections.
3. Joints sealed by welding are better for corrosion resistance, but only if the field coatings that are subsequently required offer the required corrosion performance. If that is not the case, then shop coatings and bolted joints should be used. ■