Modern Steel Construction

April 2019

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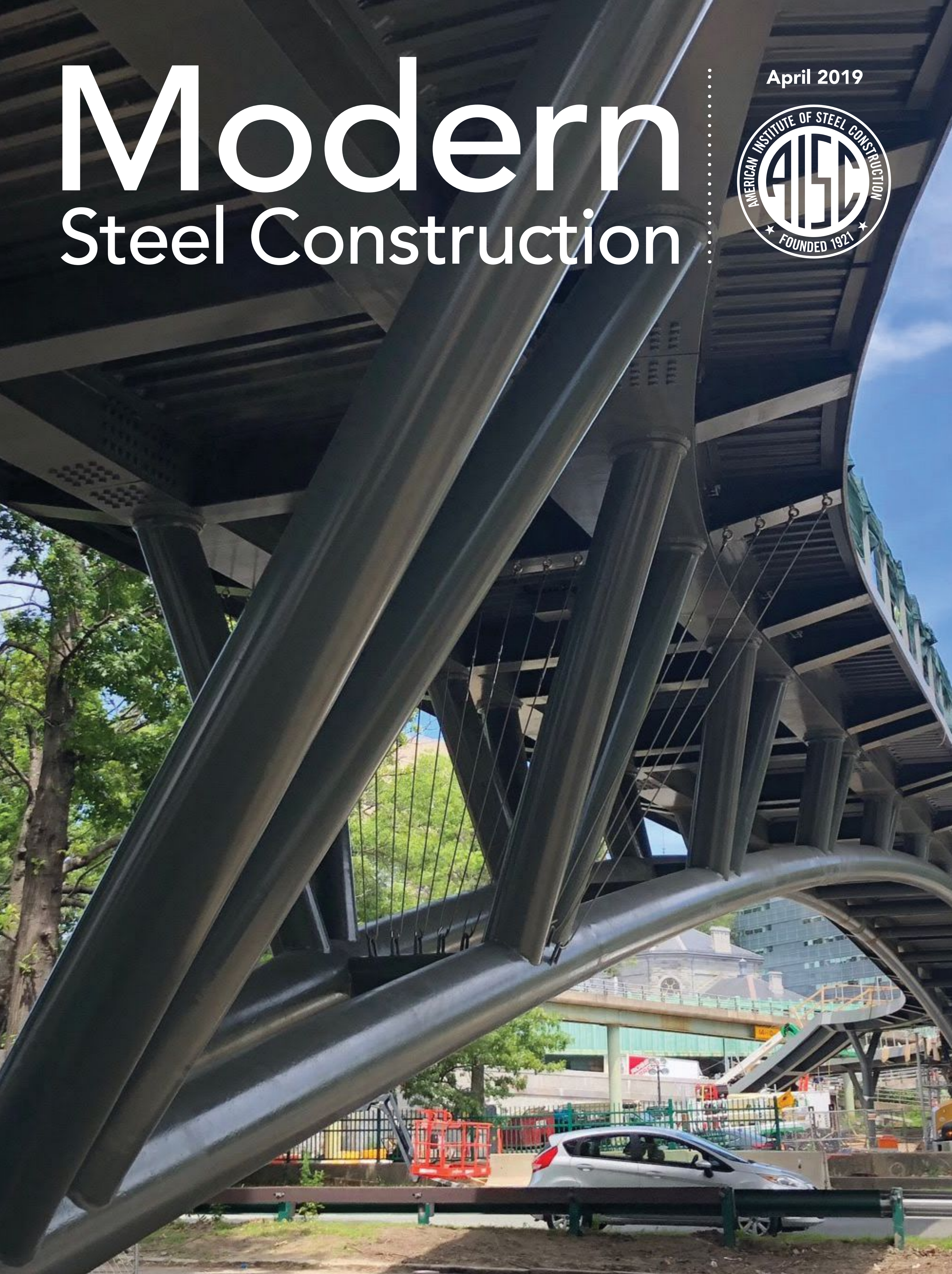

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April 2019

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ON THE COVER:
The Fanny Appleton Bridge reaches toward the Charles River in Boston, p. 24. (Photo: Newport Industrial Fabrication)

MODERN STEEL CONSTRUCTION (Volume 59, Number 5) ISSN (print) 0026-8445: ISSN (online) 1945-0737. Published monthly by the American Institute of Steel Construction (AISC), 130 E Randolph Street, Suite 2000, Chicago, IL 60601. Subscriptions: Within the U.S.—single issues $6.00; 1 year, $44. Outside the U.S. (Canada and Mexico)—single issues $9.00; 1 year $88. Periodicals postage paid at Chicago, IL and at additional mailing offices. Postmaster: Please send address changes to MODERN STEEL CONSTRUCTION, 130 E Randolph Street, Suite 2000, Chicago, IL 60601.

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editor's note

If you go to any conference, it's common to hear a presentation on the care and feeding of millennials and Gen Z.

And if you Google "communicating with millennials" you'll get more than 1.3 million results. But really, there's a much simpler way to understand this topic. Just go to any park on a Saturday or Sunday and watch a youth ball game. Watch the kids, watch the referees, and mostly, watch the coaches.

In less than half-an-hour, you can almost always tell which teams are well coached, and which aren't (hint: it's not always the team that wins). I've played on team sports, I've coached teams, I've refereed, and mostly, I've watched my kids play. The lessons I've learned are the same lessons that can—and should—be applied to any business situation.

Generally, coaching falls into two areas: teaching and motivating.

Have you given your team the tools and knowledge they need to succeed? I routinely hear from principals at design firms that new grads don't know enough and that it takes at least six to 10 months before they are productive employees. If you're a good coach you should expect to have to provide training to your team—and frankly, it shouldn't just be in the first few months. Well-coached teams continue to practice, train, and learn new skills. My youngest has been playing hockey for more than a decade, but they still work on skating skills.

Does each player on your team understand their role? This season, my youngest has played more defense than offense. When he skates up, it's important for a forward to drop back to cover the defense. But that often doesn't happen—and when it doesn't, it means the coach hasn't explained each player's role.

Is the game about the player or the coach? I've seen too many coaches screaming at their players. Statistically, 70% of players quit organized sports by the time they're 13 and when they do, it's the usually the fault of the coaches and parents who made the game "not fun anymore."

If you want to be a better manager, think about getting involved in youth sports, whether you have kids or not. Almost every youth league is crying out for volunteers, and many offer fantastic training programs. For example, more than 850 communities around the country have American Youth Soccer Organization (AYSO) programs. And each of these programs offer coach training. Not into soccer? There are plenty of opportunities in basketball, baseball, hockey, football, and just about every other team sport (and increasingly, there are opportunities with less physical teams, ranging from debate to engineering).

But whatever you choose to do, seek out training and mentoring. We can all become better coaches.

Scott Melnick
Editor

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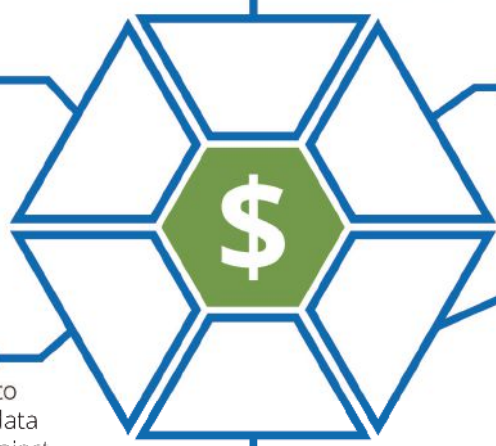

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If you've ever asked yourself "Why?" about something related to structural steel design or construction, *Modern Steel*'s monthly Steel Interchange is for you! Send your questions or comments to **solutions@aisc.org**.

steel interchange

All AISC Design Guides mentioned can be found at ***www.aisc.org/dg****, and all* Engineering Journal *papers can be found at* ***www.aisc.org/ej****. All other AISC publications, unless noted otherwise, refer to the current version and are available at* ***www.aisc.org/specifications****.*

Field Verification and Flange Thickness Tolerance

Structural engineers are commonly asked to confirm that an existing structure can support a new rooftop unit, but we often don't have the original drawings and must make field measurements to determine the member sizes. Sometimes the flange thickness does not precisely correspond to the flange thicknesses provided in the AISC *Steel Construction Manual*. Is there a mill tolerance for flange thickness?

No, there is no mill tolerance for beam flange thickness. These dimensions are indirectly controlled through weight and area tolerances. In ASTM A6 Annex A2, footnote "A" under flange thickness states: "Actual flange and web thicknesses vary due to mill rolling practices; however, permitted variations for such dimensions are not addressed."

It is acceptable to calculate cross-sectional properties based on field measurements. This is stated in Section 5.3.1 in the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360), which states: "All dimensions used in the evaluation, such as spans, column heights, member spacing, bracing locations, cross-section dimensions, thicknesses and connection details, shall be determined from a field survey. Alternatively, when available, it is permitted to determine such dimensions from applicable project design or shop drawings with field verification of critical values."

Also note that AISC Design Guide 15: *Rehabilitation and Retrofit* also provides tables of dimensional and material properties for historic steel shapes that would be helpful. The design guide also contains example problems as well as guidance for handling other design or analysis nuances that arise when dealing with historic steel structures.

Jonathan Tavarez, PE

Local Buckling of Rectangular Bars

I am looking for guidance on designing a connection plate subject to flexure. AISC *Specification* Section F11 addresses the design of rectangular bars. Yielding and lateral-torsional buckling are the only limit states considered. Isn't local buckling also a potential failure mode? Are there any guidelines or current research on how to evaluate local buckling of a plate subjected to non-uniform flexural stresses?

Local buckling is not a consideration for connection elements with a rectangular cross section. This is because the buckled shape is characterized by lateral translation and twisting, which defines the lateral-torsional buckling limit state. This was addressed in the fourth quarter 2016 AISC *Engineering Journal* paper "Stability of Rectangular Connection Elements," which shows that rectangular connection elements subjected to flexure can be designed using AISC *Specification* Section F11. Only the lateral-torsional buckling limit state is required for these elements. An example of this is in Part 9 of the 15th Edition *Manual*, where *Specification* Section F11 (with a modified C_b factor) is used to evaluate the flexural strength of double-coped beams. Extended single-plate connections in *Manual* Part 10 use the same design procedure. You can find further information on this in the first quarter 2014 AISC *Engineering Journal* paper "Local Stability of Double – Coped Beams." As discussed in the *Manual*, the C_b factors in Part 9 are only for cases where the plate is braced at both ends. You will need to use your judgment to determine C_b for other situations.

Bo Dowswell, PE, PhD

Vibration and Low Natural Frequency

I am currently designing a long plate girder supporting an office space. I computed and checked the floor vibrations under walking excitation as per AISC Design Guide 11: *Vibrations of Steel-Framed Structural Systems Due to Human Activity*. I am getting a very low acceleration of less than 0.1% of *g*, but the natural frequency is approximately 1.95 Hz, which is lower than the minimum 3-Hz requirement. Can you advise on the applicability the natural frequency limit?

In my own designs, I try to avoid natural frequencies below 3 Hz. Some of the most dramatic problems I have seen have been when the natural frequency was below that limit. In those cases, rhythmic group loading caused extremely high accelerations. In your case, the 1.95-Hz natural frequency is at the average step frequency of humans, so I would expect resonance on a regular basis.

If your system must have a natural frequency below 3 Hz, then I recommend the following approach using Design Guide 11:

Evaluate the floor for walking using a modified form of Equation 4-1 that accounts for the first harmonic of the walking force and a higher *R* factor.

Evaluate the floor for vandal jumping using the Normal Jumping category in Table 1-2, along with the equations in Chapter 5.

Brad Davis, SE, PhD

Jonathan Tavarez is a staff engineer with AISC's Steel Solutions Center. **Brad Davis**, associate professor at the University of Kentucky and owner of Davis Structural Engineering, **Bo Dowswell**, principal with ARC International, LLC, and **Larry Muir** are all consultants to AISC.

Unzipping Welds

We have been asked by the engineer of record (EOR) to add continuity plates in column webs to prevent zippering of the flange plates of a beam-to-column flange moment connection. I have checked the typical limit states (flange local bending, web local yielding, etc.). Is zippering an issue typically and if so, what exactly is it?

It is not uncommon for different terminology to develop in different regions or relative to different sectors of our business. What some people may refer to a "zippering" may be more commonly referred to as "unzipping." The January 2009 article "Steelwize" (available at **www.modernsteel.com**) explains some of these colloquialisms from different regions. If you are seeking to better understand the intent of the EOR use of the term "zippering," then you will have to seek guidance from the person using the term.

"Unzipping" sometimes refers to concerns that the stress concentration at one end of the weld would be high enough to rupture the weld without first distributing additional load to the remaining weld. While the overall weld may be sized to provide the required strength, there is not enough ductility to distribute the load across the entire weld—and once the weld fractures in one area, it will continue to break along the length (unzip). Section 14.6.3 of AISC Design Guide 21: *Welded Connections – A Primer for Engineers* (Second Edition) provides some further discussion. This may be the engineer's concern.

At any rate, zippering or unzipping is not typically a concern for these types of moment connections. You mention that you check flange local bending. This limit state was originally developed to directly address concerns related to unzipping of the weld. This is discussed in the Commentary, which states: "In the original tests, the strength given by Equation J10-1 was intended to provide a lower bound to the force required for weld fracture, which was aggravated by the uneven stress and strain demand on the weld caused by the flange deformation (Graham et al., 1959)." However, the use of tougher weld metal has lessened this concern, though the check remains unchanged: "Recent tests on welds with minimum Charpy V-notch (CVN) toughness requirements show that weld fracture is no longer the failure mode when the strength given by Equation J10-1 is exceeded. Rather, it was found that the strength given by Equation J10-1 is consistently less than the force required to separate the flanges in typical column sections by ¼ in. (6 mm) (Hajjar et al., 2003; Prochnow et al., 2000). This amount of flange deformation is on the order of the tolerances in ASTM A6/A6M, and it is believed that if the flange deformation exceeded this level it could be detrimental to other aspects of the performance of the member, such as flange local buckling."

If the limit state of flange local bending is satisfied, then unzipping of the weld should not be a concern for conditions considered in the *Specification*.

Regardless, if the EOR is telling you to do something, then you must do it. Section 4.4 of the AISC *Code of Standard Practice for Steel Buildings and Bridges* (ANSI/AISC 303) states: "The owner's designated representative for design is the final authority in the event of a disagreement between parties regarding the design of connections to be incorporated into the overall structural steel frame. The fabricator and licensed engineer in responsible charge of connection design are entitled to rely upon the connection design criteria provided in accordance with Section 3.1.1. Revisions to these criteria shall be addressed in accordance with Sections 9.3 and 9.4."

The final sentence recognizes that while the EOR is the final authority, connection design criteria might be added to the contract when this authority is exercised. In addition to the information in Sections 9.3 and 9.4 of the *Code*, the October 2017 article "Reinforcing the Point" (available at **www.modernsteel.com**) might be helpful.

Larry S. Muir, PE


Unshored Span Calculator
Calculate your maximum unshored span for thick slabs based on your design criteria.
Deck-Slab Diaphragm Strength
Calculate your deck-slab diaphragm strength and stiffness for selected deck profiles based on AISI S310-16.
Composite Deck-Slab Strength

steel quiz

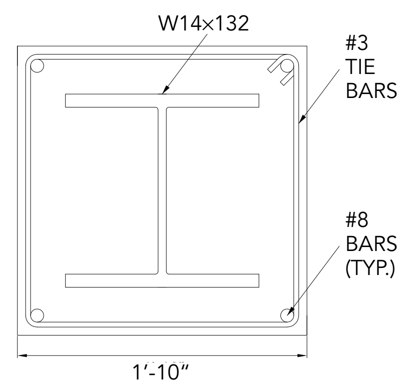
This month's Steel Quiz focuses on seismic design. The answers can all be found in the 2016 AISC *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341, available at **www.aisc.org/specifications**).

1 **True or False:** If a fabricator notifies the engineer of record (EOR) that ASTM A709 is readily available for hot-rolled sections used in the seismic force-resisting system (SFRS) for a project where the requirements in the AISC *Seismic Provisions* need to be met, this is acceptable so long as the EOR fully evaluates the suitability based on strength properties, ductility, formability, soundness, weldability, notch toughness and corrosivity, among other considerations.

2 Which of the following are *not* listed in the *Seismic Provisions* as special moment frame (SMF) demand-critical welds?

a. Column-to-base plate connections
b. Column splice groove welds
c. Welds joining box section elements
d. Beam flange and web CJP welds to columns

3 For the square, moderately ductile encased composite column shown in Figure 1, what is the maximum spacing of transverse reinforcement at the top and bottom?



4 **True or False:** Seismic drift limits, which are commonly used to ensure the serviceability of a structure, are regarded as a matter of judgement rather than absolute design limits.

5 Buckling-restrained braced frames (BRBFs) provide significant inelastic deformation capacity through yielding and shall be designed, tested and detailed to accommodate at least what expected deformation?

6 **True or False.** K-braced frames are allowed to be used as an SFRS so long as the additional brace post-buckling forces are accounted for through inelasticity similar to the link in an eccentrically braced frame (EBF).

TURN TO PAGE 14 FOR THE ANSWERS

steel quiz ANSWERS

Anyone is welcome to submit questions and answers for the Steel Quiz. If you are interested in submitting one question or an entire quiz, contact AISC's Steel Solutions Center at 866.ASK.AISC or **solutions@aisc.org**.

1 **False.** Section A3.1 of the AISC *Seismic Provisions* contains charging language prohibiting the use of materials not included in the list provided. The Commentary for this section explains that the structural steels listed are explicitly permitted for use in seismic applications based on their inelastic properties and weldability.

2 **c.** Section E3.6a in the *Seismic Provisions* provides a list of demand-critical welds that must satisfy the requirements of Sections A3.4b and I2.3. Note that AISC 358 or other test standards may designate welds as demand-critical that are not identified as such by the *Seismic Provisions*.

3 **8 in.** Section D1.4b.1 of the *Seismic Provisions* provides requirements for the maximum spacing of transverse reinforcement at the top and bottom of the column. The least of the following four options shall be used: 12 in.; one-half the least dimension of the concrete encasement section is taken as (22 in./2) = 11 in.; 8 #8 longitudinal bar diameters would be 8(1 in.) = 8 in.; or 24 #3 tie bar diameters would be 24(⅜ in.) = 9 in. Thus, the least of these values is 8 in.

4 **False.** The Commentary for Section C1 of the *Seismic Provisions* explains that drift due to seismic effects differ than that of wind as it impacts the serviceability and stability of the structure. Story drift limits improve frame stability and seismic performance because of the resulting strength and stiffness.

5 Section F4.2 of the *Seismic Provisions* states that the expected deformations correspond to a story drift of at least **2% the story height or two times the design story drift, whichever is larger**. This is in addition to any brace deformations that may result from frame deformation due to gravity loads. The Commentary to this section provides a useful discussion on the basis of these provisions, based on testing.

6 **False.** K-braced frames are prohibited, in Chapter F of the *Seismic Provisions*, in ordinary concentric braced frames (OCBFs) (F1.4b), special concentric braced frames (SCBFs) (F2.4c) and BRBF (F4.4b) systems. The Commentary explains that K-bracing can have very poor post-elastic performance. After brace buckling, the action of the brace in tension induces large flexural forces on the column, possibly leading to buckling. No adequate design procedures addressing the high-consequence stability issues are available.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AISC's latest Design Guide focuses on designing areas to safely shelter occupants during high-wind events like tornadoes and hurricanes.

steelwise

DON'T GET BLOWN AWAY

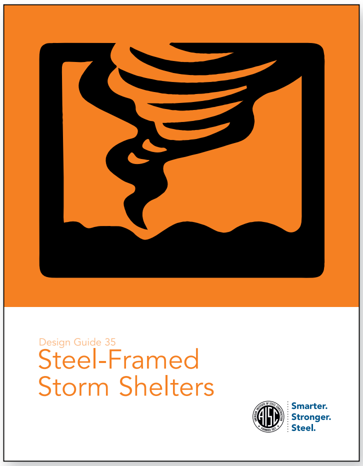
BY JAMES M. FISHER, PE, PhD, AND ROGER A. LaBOUBE, PE, PhD

WHEN A MAJOR TORNADO HAPPENS, it's all over the news.

And every year, the average person may recall hearing about a dozen or so tornado events, if that. So it might be startling to know that on average, the number of tornadoes that touch down each year in the United States, according to **www.ustornadoes.com**, is more than 1,200.

And then there are hurricanes. While fewer in numbers—approximately seven hurricanes strike the U.S. every four years, according to the National Oceanic and Atmospheric Administration (NOAA)—and more limited in terms of areas effected, hurricanes are often devastating in terms of loss of life and property and typically last for days instead of minutes.

This frequency of high-wind events has created a need for storm shelters or safe rooms to be provided in schools and other critical-occupancy buildings—and guidance on designing such shelters. In response, AISC's new Design Guide 35: *Steel-Framed Storm Shelters* summarizes up-to-date design requirements and guidance to incorporate storm shelters or safe rooms using typical industry standard products and materials.



Order of Magnitude

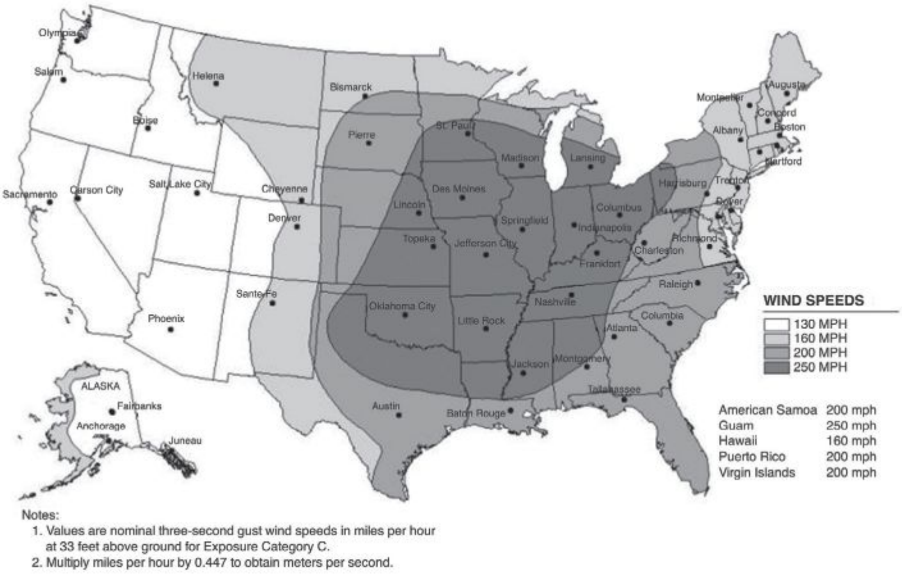
The primary difference in a building's structural system when designed for use as a storm shelter or safe room, as compared to conventional construction, is the magnitude of the design wind forces and the need to resist wind-borne debris. Safe rooms and storm shelters are designed to resist larger wind speeds, which correspond to larger wind pressures than standard designs, as well as windborne "missiles." Note that it is important to understand that these two criteria are not concurrently occurring design events.

A storm shelter will typically be either an interior room within a building or a designated wing of a building, though the concepts presented Design Guide 35 may be also employed for standalone structures or retrofitting existing structures. Also consider that while current design guidelines address both community and residential shelters, this guide focuses mostly on community shelters. Here, we've provided a brief, chapter-by-chapter overview of the new resource.

Chapter 1 provides a discussion of the differences between a safe room and a storm shelter, as well as a brief overview of industry design codes, standards and guidelines. Essentially, the two shelter types are governed by different standards, and safe rooms generally must meet more restrictive criteria than storm shelters.

James M. Fisher (**jfisher.florida@gmail.com**) is emeritus vice president of CSD in Milwaukee, and **Roger A. LaBoube** (**laboube@mst.edu**) is the Curator's Distinguished Teaching Professor Emeritus of Civil Engineering and director of the Wei-Wen Yu Center for Cold-Formed Steel Structures at the Missouri University of Science and Technology in Rolla.

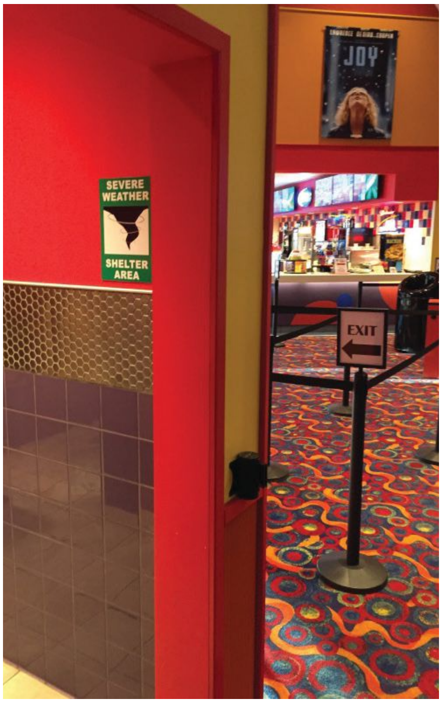
The authors wish to express their appreciation to **Robert J. Neumann** of CSD for his assistance with drawing various figures in Design Guide 35.



A map of shelter design speeds for tornadoes, which is included in Chapter 2 of Design Guide 35.
Excerpted from the ICC 500: ICC/NSSA Standard for the Design and Construction of Storm Shelters; Copyright 2014. Washington, D.C.: International Code Council. Reproduced with permission. All rights reserved. ***www.iccsafe.org***.

Chapter 2 focuses on the structural design load criteria with an emphasis on ICC-500-2014: *Standard for the Design and Construction of Storm Shelters*. The purpose of ICC-500 is stated as establishing "minimum requirements to safeguard the public health, safety and general welfare relative to the design, construction and installation of storm shelters constructed for protection from high winds associated with tornadoes and hurricanes. This standard is intended for adoption by government agencies and organizations for use in conjunction with model codes to achieve uniformity in the technical design and construction of storm shelters."

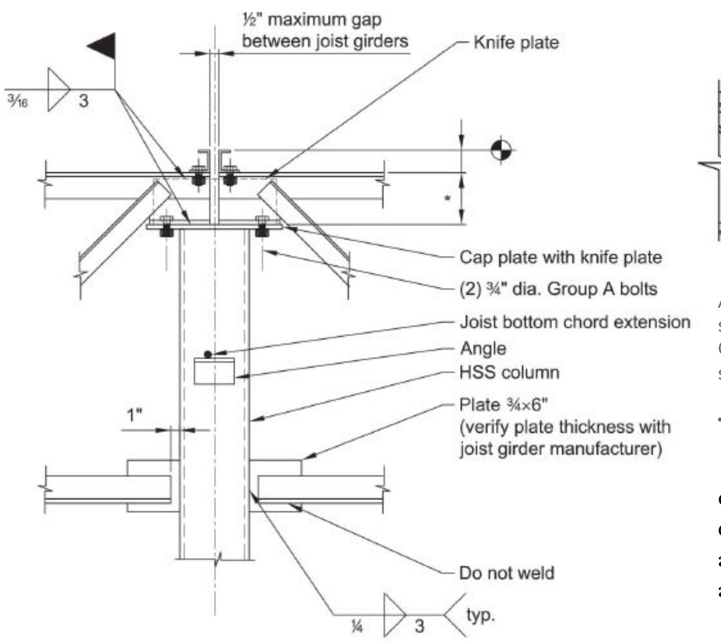
There is also discussion of FEMA P-361: *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms*, as well as ASCE/SEI 7-16: *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*.



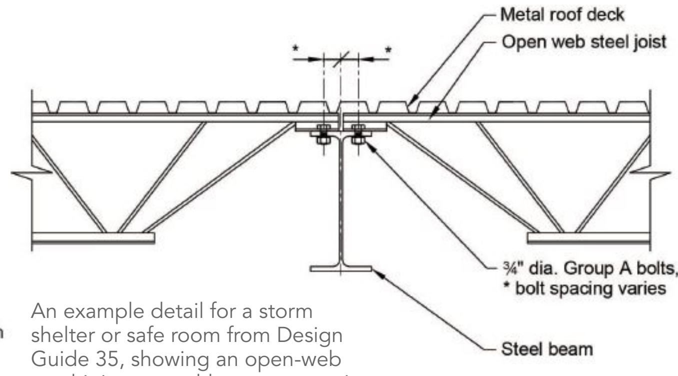
Sample signage directing occupants to a shelter area within a building.

Chapter 3 presents an overview of the various test protocols employed to assess a building envelope's ability to withstand the impact of a wind-borne missile. As a precursor to developing this guide, missile impact tests, using standard steel construction methods and materials, were performed. The findings from this test program are summarized in this chapter, as are previous building envelope system tests.

Chapter 4 addresses the importance of providing an appropriate load path between all building structural elements. The most important load paths indicated by damage observations are the roof-to-wall connections, the wall-to-foundation connections and the connections between the exterior walls at the corners. In addition to the exterior walls, shear walls in the interior of the building may reduce the tendency for the building to rack and or overturn. Adequate shear wall design requires proper anchorage at the ends of the shear walls and sometimes at the ends of shear wall segments. Forces and connection details must be properly specified and shown on the contract documents. In addition, typical connection details are illustrated.



A sample detail from the design guide, showing a joist-girder-to-HSS-column connection.



An example detail for a storm shelter or safe room from Design Guide 35, showing an open-web steel-joist-to-steel-beam connection.

Chapter 5 provides information pertaining to nonstructural design considerations, such as choosing a site for the shelter, occupancy capacity, means of egress and access, signage, fire safety and the need for the following information and qualifiers to be added to contract documents:

- The identified area should be considered by building owners as only a "best available area of refuge" and occupants could still be injured or killed
- Missile-impact tests performed
- Total number of occupants the area can hold
- The approximate maximum safe wind speed for the best available refuge area
- The timeframe before which the area should be reevaluated
- An outline of potential modifications that could be made to the structure to improve its performance in high-wind events
- Changes to the building may make it such that the current refuge area is no longer the best available for that purpose

Chapter 6 presents design examples that are representative of the tornado and hurricane wind load calculations that may be required when designing a storm shelter or safe room.

Design Guide 35 addresses the most current requirements and considerations for storm shelter and safe room design. We hope that it will prove to be an invaluable resource and push your next shelter design project to be as safe as it can be, as efficiently as it can be. The guide will be available by mid-April at **www.aisc.org/dg**, where you can also access AISC's entire library of Design Guides. ■

business issues

FORGING A FRAMEWORK FOR FACILITATING

BY ANNE SCARLETT

Want to become a leader? Becoming a facilitator is one way to start.

Anne Scarlett is president of Scarlett Consulting, a Chicago-based company specializing in AEC-specific strategic marketing plans, marketing audits and coaching. She is also on the adjunct faculty at Columbia College of Chicago and DePaul University. She can be contacted via her website, **www.annescarlett.com**.

EARLY IN YOUR CAREER, it's wise to identify your own opportunities to practice being a leader. (And if you're past the early stage, not to worry! It's never too late to hone leadership skills.)

While leadership is demonstrated in myriad scenarios, one option is to put yourself in a "facilitator" position. What's a facilitator? Simply put, it's an individual that leads a group —of one or many—through a discussion. By no means is the ability to facilitate meetings a prerequisite to becoming an effective leader, but it certainly provides an opportunity to build overall leadership skills.

So where to cut your facilitation teeth? Maybe within a formal presentation at a conference or seminar. Maybe while conducting the weekly internal project team meeting. Maybe during an in-progress project meeting with the client. Or maybe even while running a meeting for a volunteer organization.

Translating Leadership Skills from Volunteering to Work

If you've recently joined the workforce, the latter option might be the perfect one to practice your facilitator skills so that you can enjoy the magic firsthand. After all, young enthusiasts with fresh ideas and energy are warmly welcomed within nonprofit organizations—whether the affiliations are professional such as AISC, philanthropic such as your local animal shelter, cultural such as the junior board of a theater company or all-out recreational such as your local intramural sports league. These organizations all have boards, committees and special project groups; they need you as much as you need them.

Presuming that you've identified an organization that you can genuinely pour your heart into, your next step is become actively involved. Most nonprofit organizations clearly articulate the options, as they know that's the best way to recruit young blood! Fast-forward to the point where you've aligned with a committee or special group. Now is your chance to locate facilitation opportunities.

Rather than having everyone speak to you as the leader in a meeting, help navigate connections between attendees.

Setting the Framework

Like any worthy skill, facilitation cannot be fully explained in a single article. However, here are some initial tips and best practices to apply when facilitating, particularly if you're new to the game.

Focus on the prize: a meaningful overall experience for the group. Believe it or not, attendees are expecting to learn from one another and to be heard. What does this mean for you as the facilitator? Keep your own presenting (lecturing) to a bare minimum, and instead use prompts to encourage discussion. Rather than having everyone speak to you as the leader, help navigate connections between attendees. Some people will do this naturally (e.g., "Building off what Colin said, I had a similar challenge but with a different outcome.") But as the facilitator, you too can help underscore commonalities and connections. Think of the experience as everyone talking to everyone, rather than the group (attendees) talking to an individual (you, the facilitator). The facilitator provides the foundation and the glue. The attendees provide the building blocks.

Collect information from attendees in advance. This effort pays off three-fold:

- **Shape your agenda and ensure involvement.** Who has time to talk with attendees prior to a meeting (or formal presentation) particularly in a volunteer capacity? You do! If you craft an agenda based upon the input of others, they will ultimately have a vested interest in the meeting's success. It's shared ownership. Isn't that worth an extra hour or two? But take note: You're not *asking* attendees to review your full agenda. Rather, you are *surveying* them to gain their insights and/or questions about challenges, ideas, visions, goals, competitors, communication or whatever themes make the most sense for your charge.
- **Feed two birds with one seed. During the meeting or speech, proactively reference relevant attendee information.** "Kaitlyn shared an inspirational story about a recent adopt-a-pet blitz. Sloane spoke of a challenging conversation with a theater patron. Connor mentioned a new idea for the volleyball tournament. Carlos described his eye-opening experience when touring the client's facility." If it's relevant to your meeting and will motivate discussion, weave it in! Attendees will collectively relish the personalization, even if you don't reference each person directly.
- **Create warmth and intimacy, one person at a time.** As an introvert, I welcome connecting one-on-one; it's manageable rather than overwhelming. So when gathering information, dedicate time to learn tidbits about what's going on with that person, at work or otherwise. Then, when the actual presentation or meeting occurs, try to privately reference those side notes, either before the meeting or during a break. In general, other attendees will feed off the energy that exudes from personal connections between the facilitator and individuals. Maybe Michael is expanding his family. Perhaps Cynthia just won an award at work. Heather is dealing with an aging parent. And Marc is training for an Ironman triathlon. Whatever the tidbit, your genuine interest (and it must be genuine—otherwise, don't bother!) will strengthen your connections.

Keep your prepared content (lecture) tight. Sometimes in meetings—and most certainly in formal presentations—you'll need to provide substance for the audience to chew on. It's tempting to data dump a whole lot of information in one fell swoop, with the hope that it will stick. Yet due to today's short attention spans—along with the audience's desire to learn from one another—it's best to "chunk" your content. After delivering a chunk between five and 15 minutes, provide a subsequent prompt for the audience to either discuss or apply. While this approach may feel risky at first, with practice you will discover that it energizes the overall experience.

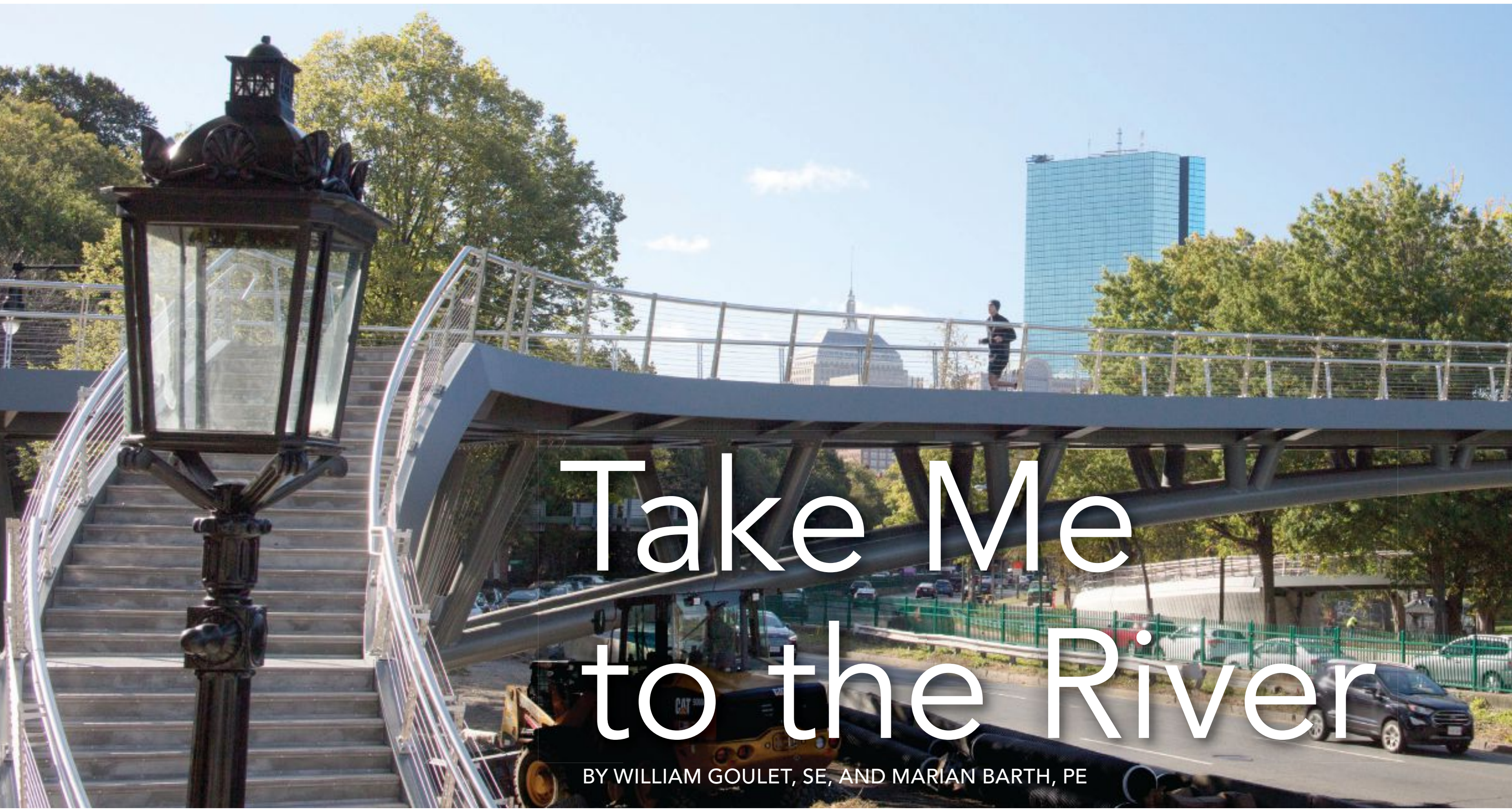
Tap into your inquisitive self while facilitating. Ask thought-provoking questions and listen with open curiosity to responses. Keep your questions tight, and provide initial prompters to encourage quick but thoughtful responses. For example, "In your experience as a project manager, what do you find to be the biggest challenge to motivate your team? Is it identifying interesting projects? Opportunities for career advancement? Continuing education?" These types of questions are more provocative than simply asking, "In your experience as a project manager, what is your biggest challenge to motivate the team?"

Group 'em, then group 'em again. Personally, I vastly prefer to converse one-on-one or in smaller, intimate groups. Even if your meeting is comprised of just eight people, there's still value in providing opportunities for intimate conversations. Then, to further add to the dynamic overall experience, regroup them. Shake it up. Whether it's rotating or putting pairs with pairs (to create a new group of four, for example) information and ideas will flow. The variety will do them good, and it will provide an opportunity for them to more closely connect with multiple people.

Already mastered some of these tips as a facilitator? Great! Stay tuned for my next column, which will focus on "what-ifs?" and how to troubleshoot on-the-spot during facilitations. ■

Have tips/anecdotes on becoming a leader, particularly a facilitator? Send them to ***melnick@aisc.org****.*

A new steel span provides safe pedestrian passage over a busy street to a prominent gathering spot along the Charles River in Boston.



Take Me to the River

BY WILLIAM GOULET, SE, AND MARIAN BARTH, PE

William Goulet (william.goulet@stvinc.com) is a senior structural engineer and **Marian Barth** (marian.barth@stvinc.com) is a project manager, both with STV, Incorporated.

THE NEW FRANCES "FANNY" APPLETON BRIDGE, named for the second wife of Henry Wadsworth Longfellow, is appropriately adjacent to Boston's historic Longfellow Bridge.

The bridge, which opened this past summer, replaces an existing decaying pedestrian bridge that, due to narrow switchbacks, did not meet current accessibility standards and could not accommodate the mixed use of people on foot and bicycles. The bridge crosses Storrow Drive in Boston and provides an important connection for pedestrians and cyclists from the adjacent Longfellow Bridge and Charles Circle to the Esplanade parkland that extends along the Charles River. The Esplanade is the location of the 4th of July fireworks and Boston Pops concert, attracting hundreds of thousands of people each year.

Undertaken as part of the Longfellow Bridge Rehabilitation Design-Build Project by the Massachusetts Department of Transportation–Highway Division, the new steel bridge—consisting of 280 tons of steel, all metalized and painted with a mid-coat and a topcoat—provides a modern Vierendeel arch structure that contrasts with the traditional arches of the historic Longfellow Bridge. The coating requirements were changed from galvanizing to thermal sprayed metalizing, which eased shop assembly of the larger parts.

Sporting a ribbon-like appearance, the 550-ft-long bridge superstructure, with 100-ft ramp abutment structures at either end, runs through the existing park, weaving in between the trees. The main span is a slender arch whose geometry was primarily determined by site constraints, roadway clearances and the need to maintain accessibility standards. The arch, spandrel columns and approach piers all use hollow structural sections (HSS) while a pair of continuous tub girders run from abutment to abutment. The bridge also incorporates Y-shaped piers that branch out to support the two longitudinal tub girders. Steel castings designed and supplied by Cast Connex Corporation (an AISC associate member) were used to connect the vertical columns of the piers to the angled supports.

right: The point where the tub girders split at the east stair.

below: An elevation view of the Fanny Appleton Bridge's main span and east stair.


Courtesy of STV

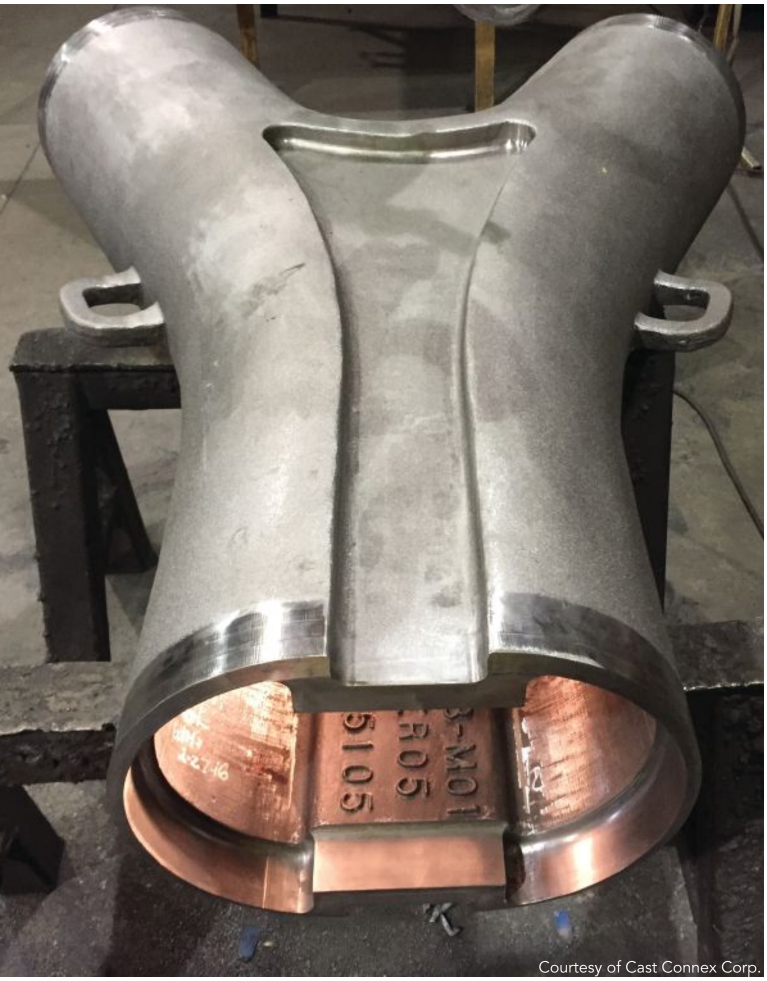

Courtesy of STV

Slender yet Complex

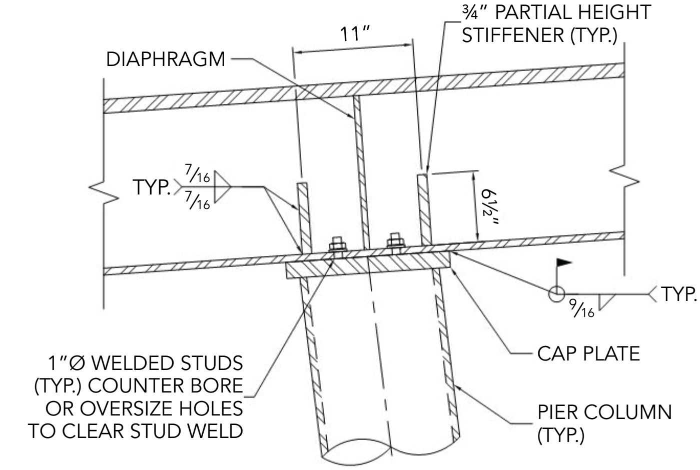
The slender design, complex geometry and site constraints required a design that could be fabricated and erected with minimal disruption to the area while providing the desired aesthetic and expected performance of a modern pedestrian bridge. The continuous fascia plate of the girder that produces the ribbon appearance was held to dimensional tolerances one-half of those typically used for fabrication, with the intent of minimizing horizontal or vertical waves in the fascia plate that would be noticeable to the public. The revised tolerance criteria were also applied to the tub girders that support the fascia plate, as variations in the tub girder would be reflected in the plate. All connections were detailed to be unobtrusive and were welded wherever possible. Connections that needed to be bolted for constructability purposes used splice plates on the interior of the tub girders and had bolts orientated so only the heads of the bolts are visible. Weld access holes at the girder shop splices were also filled with custom 3D printed plastic plugs to maintain an uninterrupted visual appearance. This provided an economical solution that maintained

below: A conceptual model of the bridge.


Courtesy of Newport Industrial Fabrication



Courtesy of Cast Connex Corp.



left: A casting for the Y support connections, made by Cast Connex.

above: Welded studs for alignment at the piers.

The most extreme forming condition involved a reversing *R*=2-ft curve with a 15° off-plumb profile at a grade change.

Courtesy of Newport Industrial Fabrication

the desired appearance while not incurring the cost of plug welds and the associated grinding.

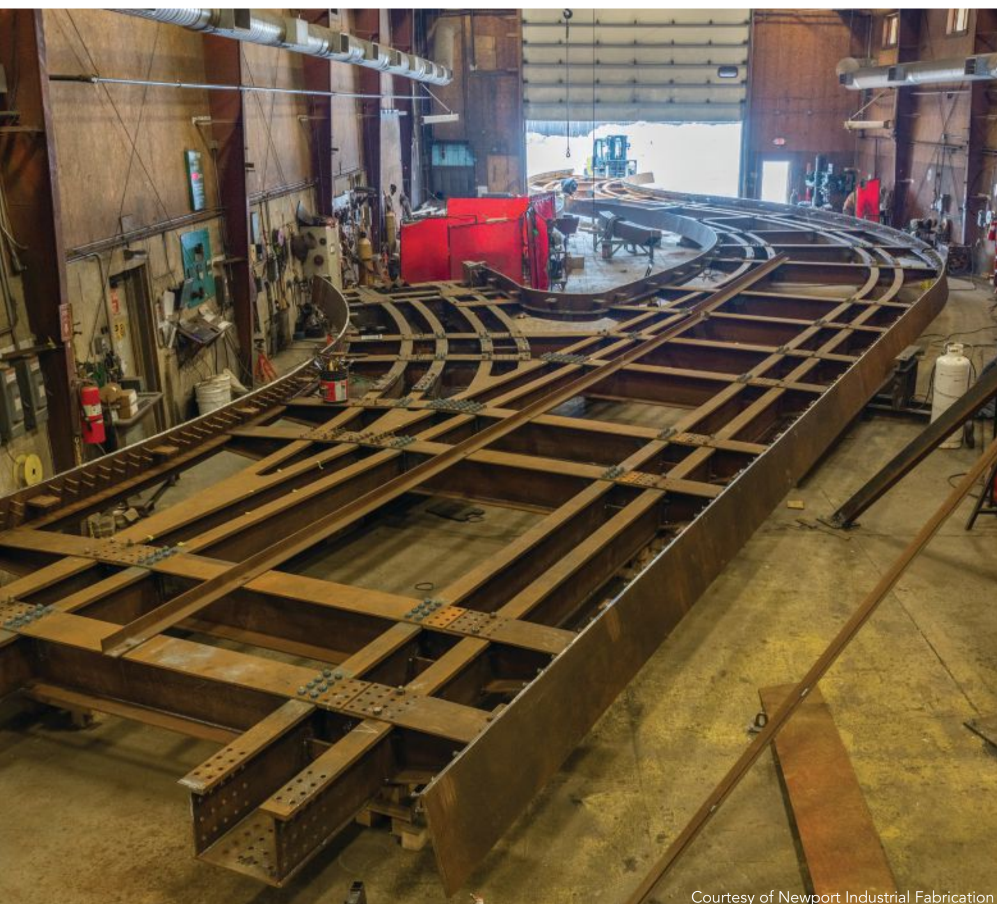
Engineer of record STV's designers recognized early on that a slender main span and flexible pier system could provide the potential for pedestrian-induced vibrations. Multiple publications that address vibration, including AISC's Design Guide 11: *Floor Vibrations Due to Human Activity* (Second Edition, available at **www.aisc.org/dg**), the AASHTO *LRFD Guide Specifications for the Design of Pedestrian Bridges* and the SETRA guide *Assessment of Vibrational Behavior of Footbridges under Pedestrian Loading* were used to evaluate the bridge at different stages in the design process and to evaluate the as-built structure. The various guides provide different analysis methods and varying loading assumptions, and it was determined that the group loading assumptions in SETRA were most appropriate given the size and anticipated use of the bridge. The allowable accelerations from the other guides were also compared to the allowable limits provided by SETRA to confirm that the appropriate limits were being used.

Modifications to the structure were made to improve the dynamic performance of the bridge. However, providing strength and stiffness needed to be balanced with the fact that a continuous curvilinear structure would require a certain amount of flexibility to accommodate thermal movements. Some elements, such as the spandrel columns, were used to improve dynamic performance with only minor impact on the influence of thermal forces. The span-

Courtesy of Newport Industrial Fabrication

above: Transporting massive curved sections to the site.

below: Assembling a portion of the superstructure in the shop.



Courtesy of Newport Industrial Fabrication

drel columns were varied to provide added stiffness in areas of the Vierendeel arch that were determined to be most critical, while at the same time maintaining a lighter structure where the spandrel columns had little influence. The spandrel column connections to the tub girders were welded moment connections and were provided with internal stiffeners at all locations. Although some spandrel columns did not require stiffeners to provide adequate strength at the connections, this lack of stiffeners would provide a significantly more flexible connection due to the width of the tub girder bottom flange—and this added flexibility would have been detrimental to the dynamic performance of the bridge.

Piers and Tub Girders

The approach pier structures required a more balanced approach for dealing with vibration and thermal forces. The piers were connected to the continuous tub girders using welded connections similar to the spandrel columns, so an increase in pier stiffness would also result in increased moments due to thermal expansion of the approaches. The foundation-soil interaction became a critical part of the structural design for two main reasons. First, if foundation stiffnesses were overestimated, the steel structure would still be able to accommodate all of the design forces—but the vibration analysis of the structure would prove unconservative. Second, if the foundation stiffness were underestimated, the vibration analysis would be conservative, but pier forces might exceed those used in design. To deal with these competing issues, both the upper and lower bounds of the foundation stiffnesses were determined. In addition to the multiple stiffnesses used in the design, the team also investigated the possibility of the ground freezing and imparting additional forces into the piers due to the added restraint. Analyses included running a portion of thermal loads with the typical foundation springs and a portion with fixed supports, and applying a service live load since the design load of 120 psf would be unlikely at a temperature of -30 °F.

The continuous tub girders at the deck level presented multiple challenges for laying out the framework of the bridge. Curved staircases frame into the main span from either side and provide a horizontal restraint to the main span. As the framing for the stairs diverges from the main span steel, the tub girders needed to be split so that the exterior appearance would remain consistent with the fascia plate while maintaining the same relative location to the tub girder. The tub sections start with two webs then split, ending with four webs. In working with fabricator Newport Industrial Fabrication, the design team decided that the flanges would be cut to a shape that would provide a radiused transition at the splits. The webs of the girders would have to blend into the main girder web if they were to follow the shape of the bottom flange and would require welding the plates at a sharp angle. To avoid this sharp-angled weld and an abrupt end of the plate at the weld location, it was decided to curve the web plate so that it would return perpendicular to the main tub web. Internal diaphragms and cross frames were located to aid in transferring shear from the incoming webs.

Challenging Curves

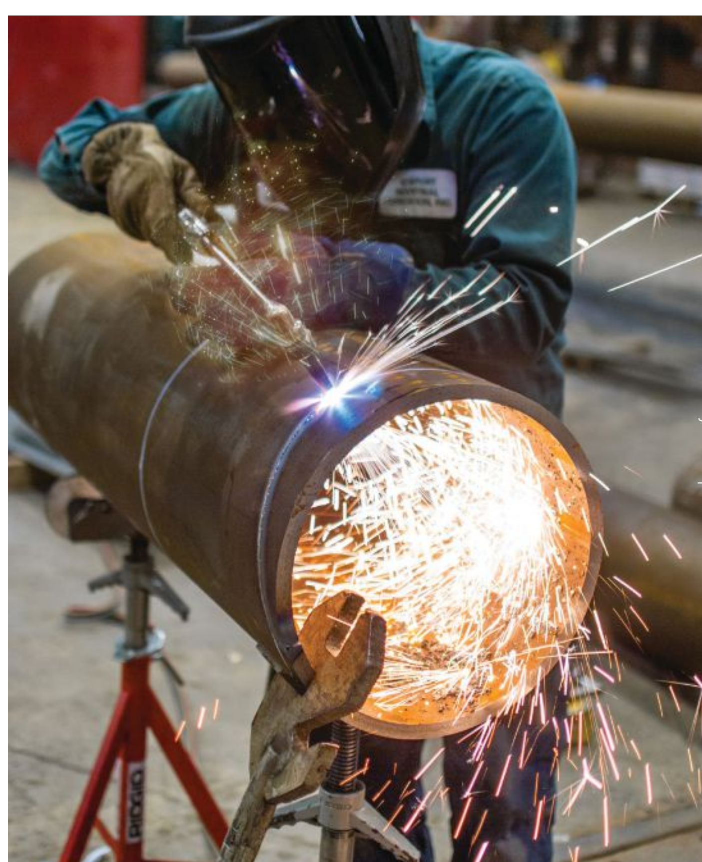
The curved tub-girder and stair members were fabricated as built-up sections with each plate cut to shape and were formed in-house by Newport as needed prior to assembly of the section. The 1-in. fascia plate was challenging to form, as the slope in the fascia plates and fascia girders mathematically cre-

Courtesy of STV

above and below: Erecting the brige over Storrow Drive.

Courtesy of Newport Industrial Fabrication

below: Cutting 18-in. HSS used for the support columns.



Courtesy of Newport Industrial Fabrication

Courtesy of STV

Courtesy of Newport Industrial Fabrication

above: The superstructure, taking shape at Newport's facility.

below: The completed bridge at the west end, near the Charles River's edge.

Courtesy of Newport Industrial Fabrication

Lifting a long bridge assembly at Newport's facility.

ated a "warped surface." While software exists that can perform the necessary flattening function to create blanks, it did not provide adequate forming data. As such, Newport developed custom numeric modeling software to flatten the surface, which allowed shop engineers to program bump scribes on the CNC plasma table and provide the press brake operator with the specific location and direction of each press strike. Knowing the bump frequency, the angular deflection required to approximate the curve was calculated, and the press brake operator used these two pieces of information to build a highly accurate part on the very first try. The most extreme forming condition involved a reversing 2-ft-radius curve with a 15° off-plumb profile at a grade change. Newport began by burning two blanks, assuming it would take at least two attempts to achieve the proper shape. The forming methodology was so reliable that the first attempt was successful and the second blank unnecessary. When it came to the steel arches, the 18-in. × 1.375-in. pipe used for these elements was too large for Newport's equipment, and bender-roller Kottler Metal Products was employed to take on this bending work.

The three main steel sections of the bridge required careful coordination for delivery, due to their length and width, as they were transported through Charles Circle. While delivering such large components was tricky, it allowed Newport to maintain control of the geometry in the shop and greatly reduced field work. The laydown site consisted of a small area between the Charles Circle off ramp, Storrow Drive and the Longfellow Bridge since

A view of the bridge and its position related to the Longfellow Bridge at left.

all of the pathways on the Esplanade side were required to remain open to the public during construction.

Working closely with the contractor and fabricator from the beginning of the project, the team was able to achieve the design goals, fabricate to the stringent and complex geometries and achieve the required erection tolerances. As a result, Boston now has an attractive new pedestrian route to the Charles River waterfront. ■

The Fanny Appleton Bridge is featured in the presentation "Pedestrian Bridges: Unique Design and Analysis" at the 2019 NASCC: The Steel Conference, taking place April 3-5 in St. Louis. For more information, visit ***www.aisc.org/nascc****, where you can also view a recording of the presentation approximately 45 days after the conference.*

Owner
Massachusetts Department of Conservation and Recreation

General Contractor
WSC-Joint Venture of J.F. White Contracting Co., Skanska and Consigli Construction Co., Boston

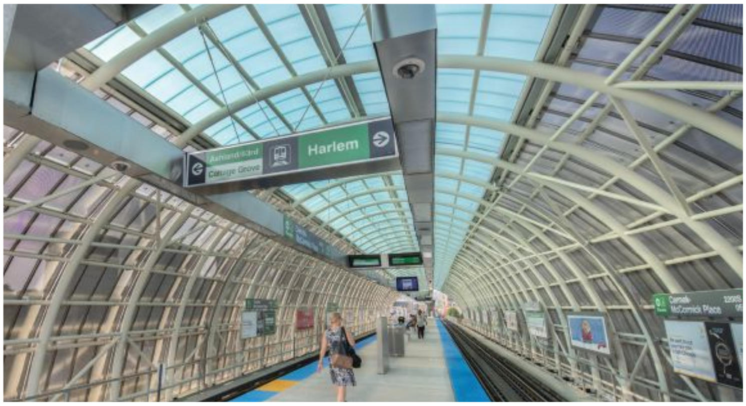
Structural Engineer
STV, Incorporated, Boston

Steel Team

Fabricator and Detailer
Newport Industrial Fabrication, Newport, Maine (AISC Certified Fabricator)

Erector
Saugus Construction Corp., Georgetown, Mass. (AISC Associate, Certified Erector)

Bender-Roller
Kottler Metal Products, Willoughby, Ohio (AISC Associate)



2015 AIA Distinguished Building Award - HSS 8” pipe featuring an ellipse curvature with multi-radius bends for the structural ribs for CTA Cermak-McCormick Place Station. Chicago, IL

2012 IDEAS² Merit Award - 133 tons of 16” pipe curved for the Rooftop Tiara of the Great American Tower at Queen City Square. Cincinnati, OH

2011 IDEAS² National Winner - 420 tons of rectangular tubing, pipe and beams for the roof at the Norman Y. Mineta San Jose International Airport. San Jose, CA

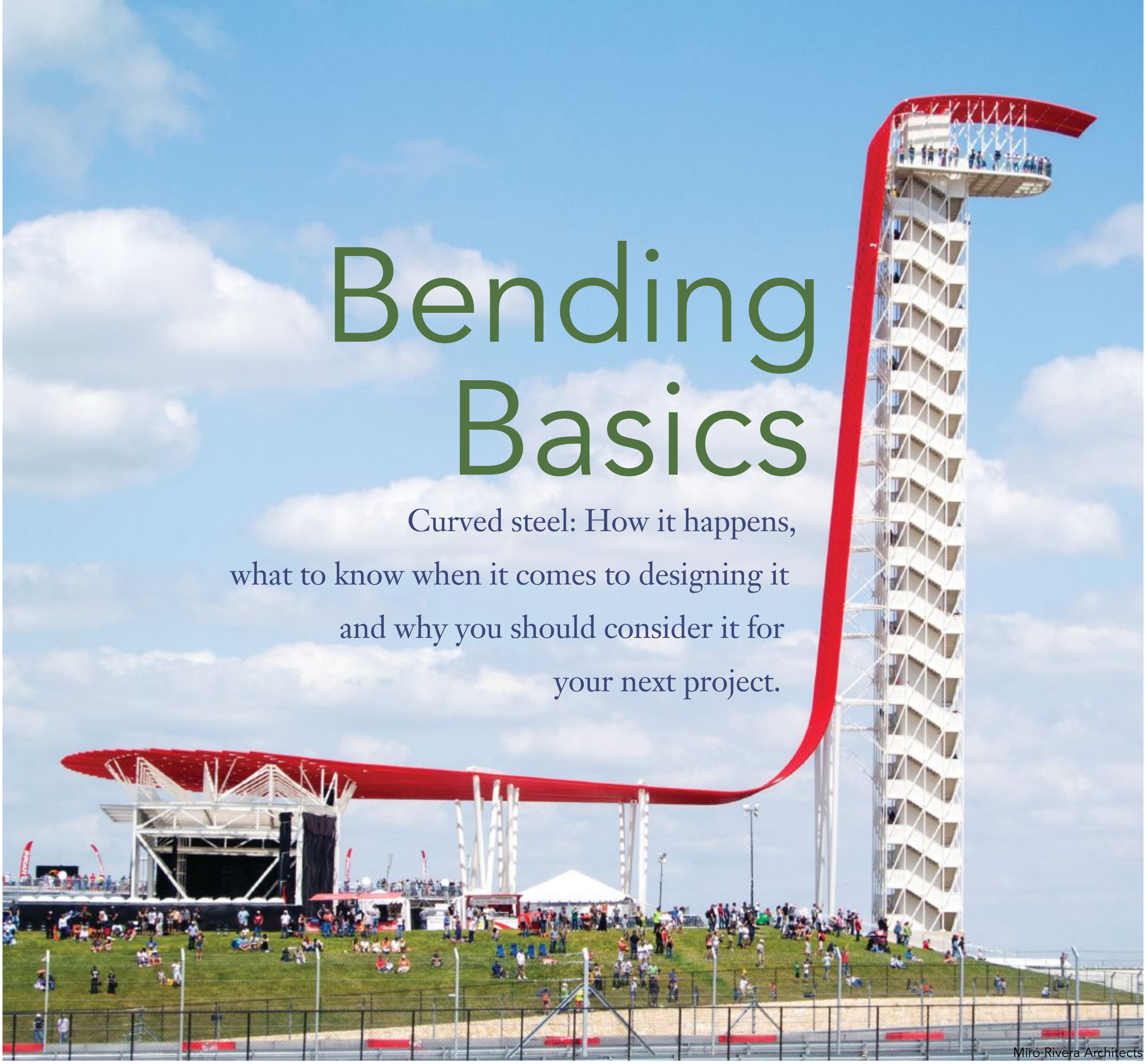
2013 IDEAS² Merit Award - 3600 pounds of pipe each curved with multiple radii for a solar canopy to recharge batteries on electrical vehicles. Chicago, IL

2007 NSBA Special Purpose Prize Bridge Award - 152 tons of 18” pipe curved in our Kansas City plant for the Highland Bridge. Denver, CO

2010 NCSEA Award Winner - 200 tons of beams, channels and angle for the roof of the University of Illinois at Chicago Forum. Chicago, IL

Bending Basics

Curved steel: How it happens, what to know when it comes to designing it and why you should consider it for your next project.



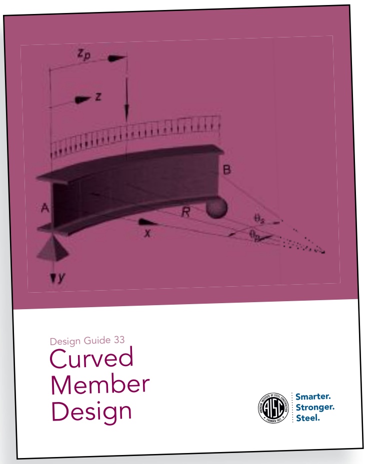
Miró Rivera Architects

The observation tower at Austin's Circuit of the Americas racetrack uses curved steel—painted bright red, no less—on a grand scale, creating an icon that can be seen from great distances.

LET'S FACE IT: Curved structures command attention.

The most successful structures often feature a memorable design feature that allows you to reference the building, even if you don't remember the address.

"I got a latte this morning at a new coffee shop a few blocks from the office on State Street, kitty-corner to that building, the one with the round windows." Or the one with the gray brick and the terracotta window frames. Or the one with the curved steel arch over the entrance.



Curved steel gets noticed. It is an elegant yet strong method for bringing flair to a building, that extra "oomph" that not only draws the eye but also stimulates the imagination. It allows for flexibility in construction and the ability to create signature, flowing shapes that can range from merely adding an attention-grabbing element to elevating an edifice to the level of award-winning masterpiece. Given the infinite number of geometric possibilities possible, curved elements can adapt to or enhance their surrounding structures and elements, from a simple arc to a complex form that prompts viewers to wonder, "How did they do that?"

In addition to the dramatic aesthetic effect of curved elements, their structural efficiency also makes them an attractive choice, and many commercial and industrial structures rely on horizontally curved members where straight members would be impractical.

Despite the widespread use of curved structural steel members, detailed design guidance in the U.S. was, up until recently, relatively scarce. This is why AISC released Design Guide 33: *Curved Member Design* last year. The purpose of this publication, which you can access at **www.aisc.org/dg**, is to provide design guidance and practical information on the fabrication and detailing of curved members.

Images this spread courtesy of Thornton Tomasetti

In addition to Design Guide 33, this special curved steel section provides a look at the basics of bending and rolling steel and how to make the most out of a curved steel project from a design, cost and schedule standpoint.

AISC has more than a dozen bender-roller members, all of whom offer specialized processes and skills that can provide insightful information on designing and fabricating curved steel. A list of AISC benders-rollers can be found at **www.aisc.org/benders** as well as on the last page of this article.

So... What's It Going to Cost Me?

One of the first questions that comes to mind in relation to curved steel is "Will curved steel add significant cost to my project?" The short answer is no, but here are some considerations and tips to ensure that answer remains true and that there are no surprises late in a project.

Get involved early with a bender-roller. As with a steel fabricator, it is important to engage a bender-roller as early in the design process as possible to discuss materials that can be bent to specific configurations. An AISC member bender-roller will be able to provide you with quality information during the design stage and before a project is budgeted.

Curving steel is more economical than "faking" a curve. It is less expensive to curve a length of steel than to separate a span into small sections and miter cut and weld each section to create the appearance of a curved section.

Time is money, but curved steel doesn't add time. Curved steel is like any other component. If it is planned for early in the design phase and obtained it in a timely manner, it will not add extra time to a project's schedule.

Different bending methods will result in different cost structures. The various bending methods (discussed later in this article) are dictated by the material size, material thickness, bend radius and architecturally exposed structural steel (AESS) level. A bender-roller can offer the best process for your specific project.

Tolerances will be a cost factor. Bender-rollers perform their work to the AISC *Code of Standard Practice* tolerances for bending, unless alternative tolerances are agreed upon. If tighter tolerances are required, then costs will increase.

Increasing wall thickness can lower costs in the long term. Although increasing wall thickness of material to be curved may increase the up-front cost, it may reduce the labor costs of the bender-roller and also may reduce costs by simplifying fabrication/erection due to less cross-sectional distortion.

Designing curves with uncommon material sizes and thicknesses can increase bending-rolling costs. Odd-sized materials and wall thicknesses can be difficult to curve, due to the tooling that each bender-roller has in their shop. Bender-rollers will not make a large investment into tooling they may only use one or two times to accommodate such materials. This is why it is ideal to design with common, readily available materials.

AESS level is a major determining factor for curved steel costs. There are significant cost differences when comparing standard structural steel (i.e., not exposed) versus AESS 4 (close-to-view) showcase elements. Identifying the proper level of AESS early in the design process will help define the bending costs. If the product will not be highly visible, then do not request a high level of AESS. Also, when working with HSS members, specifying the location of the weld seam in relation to the bend is critical when the bent material needs to adhere to AESS standards. The weld seam can cause greater distortion during the bending process and if the material needs to meet AESS standards, the preference would be to have the weld seam on the least visible side. For more on AESS and the various categories/levels, see "Maximum Exposure" in the November 2017 issue, available at **www.modernsteel.com**.

The roof of the Anaheim Regional Transportation Intermodal Center employs 14-in.-diameter curved, interlocking HSS to form a diagrid shell.

Common Questions

Now that cost has been addressed, there are several other questions that will no doubt arise when it comes to considering curved steel on a project, and AISC's Bender-Roller Committee members have provided answers.

When designing with curved steel, when should an architect involve a bender-roller?

As early as possible and preferably during the preliminary design phase. Again, the earlier a bender-roller is involved in project design, the better. Providing as much information up front as you can will help clarify the design possibilities, decrease the number of requests for more information and control the costs. Sometimes, small changes in the size or member can significantly impact the project's outcome.

Does curving steel affect its strength and integrity?

The curving process does not reduce the strength or structural integrity of the

Curved steel components are a structural highlight of The Spheres in downtown Seattle.

steel. When a shape has been curved successfully, the strains the member will experience under actual service conditions will be much smaller than those associated with the curving operation. Once the curving is done, the member can be expected to perform as needed.

Is curving steel a better option than creating the appearance of a curve with multiple segments?

As noted previously, it's less costly to curve a length of material versus miter cutting and welding multiple segments to achieve the appearance of a curved assembly. In addition, a continuous curve facilitated by the bending process appears much smoother than a segmented assembly made from multiple sections. Bottom line, curved steel looks better than a "faked" curve.

What items will a bender-roller ask you for when you approach them with a curved steel project?

For starters:

- Your overall vision for what you want to bend
- Member shapes and sizes and material type to be bent
- How the members will be oriented
- Correct nomenclature to match what is drawn (i.e., "inside radius")
- AESS requirements, if any, for the curved members

Diving deeper, what details should designers include on curved steel documentation for bender-rollers?

Since a curved member's size and specified radius will determine how a bender-roller will approach the forming operation, and ultimately determine the process and machine used to form said member, it is extremely important to accurately convey as much detailed information as possible on curved members in the architectural and structural documents in order to get the most accurate cost for what is typically referred to as the "curved/formed metals package."

Many construction projects if not all, release structural and architectural prints for the general contractors and subs to bid on. A vast majority of these prints containing rolled members do not contain the necessary details needed to accurately calculate the costs of producing formed members. A properly detailed print containing rolled members should always detail radius and arc length, along with the proper section views to determine the orientation that the member is rolled or formed. Many times, this lack of information has forced subcontractors to speculate on the curved member's radius and/or to scale the rolled member from other members on the print and use that information to make a best guess at the radius. The result is that what was bid/quoted is not what was needed or intended to be conveyed by the design documents provided. This can cause major delays and cost increases for a project, especially when it happens mid-fabrication/erection.

What's the best way to bend steel?

Several factors determine the best technique, including the overall member size, web and flange thickness or HSS wall thickness, radius requirement and end application of the material. Also, keep in mind that varying amounts of extra material are required at one or both ends of the member, depending on the process used; you don't want to have to splice additional material to one or both ends. Talk to a bender-roller about the best options for your particular application as well as their capabilities. The various bending types and methods are discussed later in this article.

Does AISC impose any tolerances on curved beams?

There are limited tolerances for curved members in the AISC *Code of Standard Practice for Steel Buildings and Bridges* (ANSI/AISC 303, a free download at **www.aisc.org/specifications**.) According to Section 6.4.2, "For curved structural members, the variation from the theoretical curvature shall be equal to or less than the variation in sweep that is specified for an equivalent straight member of the same length in ASTM A6/A6M." Other acceptable tolerances, such as any cross-sectional distortion, are not generally available because they are dependent on whether the member is AESS as well as any effect they may have on the member strength. AESS tolerances are discussed in Section 10 of the *Code*. The actual geometric imperfections for rolled members are dependent on several factors, including:

- Cross-sectional shape of the beam
- Bending radius
- Bending axis
- Bending method used by the bender-roller
- Equipment limitations of the bender-roller

It is best to discuss the required tolerances with the bender-roller who will provide the service—and be sure to add the required tolerances to the contract documents to ensure that you get what you are asking for.

What are some considerations for members with multiple curves?

Designing compound/multi-radial members allows architects to bring a "wow" factor into their design, but it also helps in eliminating connections (especially if the shrinkage/growth of curved members and the specified connections of those members is a consideration). It is important to understand and grasp the idea and principle of tangential arcs. When a design calls for a single member with adjacent arcs of differing radii—commonly referred to as a compound or multi-radial member—it is extremely important to design the arcs tangent to one another. If the arcs are not designed tangential to one another, then it is like having a miter cut at that point, or having to bend the member at that point with a press brake or a three-point gag press/ram bending machine.

The question arises: How do you know when arcs are tangential to one another? The answer can be found in the detailing or dimensioning of the arcs. When arc dimensions are pulled on each of the radiused portions of the curved member, one can tell if the arcs are tangential by looking at the leader lines of the arc dimensions. If adjacent dimensions' leader lines fall exactly over one another and cannot be distinguished from one arc to the next, then the adjacent arcs/lines are tangent. If the two leader lines


Freyja Bardell


Freyja Bardell

above: The "Lupe" sculpture, which lives at the Lower Guadalupe Trail in San Jose, Calif., is comprised of 78 layers of bent steel pipe, stacked and welded to form a full-scale mammoth.

below: The new curved canopy at Hartsfield-Jackson Atlanta International Airport.

Blueprint22 Photography


Blueprint22 Photography

Two Chicago Transit Authority projects, both on the elevated train system's Green Line, use curved steel to create two very different structures—one a steel and glass shelter over a station platform and the other a "muffler" over a university building.


Naotake Murayama


Jeremy Atherton

of adjacent arcs form an angle and are completely distinguishable from one another, then the two arcs or radii in question are not tangent and, as described above, would either need to be pressed/kinked at that point in order to achieve the desired geometry or be miter cut and have a connection placed between the adjacent arcs. Designing with tangential arcs or radii simplifies the curving process and is necessary to achieve the desired geometry when using bending-rolling methods without pressing or kinking.

Is it possible to put a 90° bend in a pipe?
Yes. The key factors are the radius and the bending method used. You will need to contact a bender-roller or a fabricator to discuss the limits, options and costs.

When are reverse curves necessary?

It is sometimes necessary to design reverse curves with a small amount of straight or tangent in between opposing radii. This is due to the necessary bending moment needed to induce the second curve, which is required due to machine limitations. Most members can be redesigned to achieve this mid-tangent. In some cases, and with special machinery, it is possible to eliminate or drastically reduce the straight needed in between opposing curves.

What is the maximum geometric camber that I can specify for, say, a W27 rolled beam?
The capabilities of bender-rollers and fabricators vary, as do the equipment used and the cost. A tighter radius can often be obtained using a more sophisticated and costly process. It is best to speak with a bender-roller and a fabricator to get their opinions.

Is there a minimum radius for bending?

Minimum radius is merely a concept. Each bender-roller has their own practices, machinery and developed technologies that, when applied to specific rolling jobs, can produce very different results.

Curved steel members of various lengths and radii form a sculptural canopy at the Tecumseh Monument.

How do you address cross-sectional distortion with curved members?

Regardless of whether you can eliminate wrinkles and/or concavity (which is the most common type of undesirable distortion) shrinkage and growth can severely limit the ability to make connections and can cause major delays and have cost implications to a project. Welded connections, especially full-penetration, require a very good fit-up in order to achieve the desired results. Cross-sectional distortion in the form of shrinkage and or growth can drastically limit the ability of the fabricator to make welded connections.

When a curved member is to be connected to a straight member or if two curved members of differing radii are to be connected with a welded joint, it is always best to keep in mind the possibilities of cross-sectional distortion and how that may negatively affect the fabricator's ability to make a connection. Bender-rollers do their best to limit this type of distortion, which is often referred to as shrinkage and or growth (some companies have established "up to and including 5%” as in-house tolerances) but seeing that there is not an established AISC tolerance on the amount of acceptable cross-sectional distortion of a curved member, it is always best for architects to design with this in mind.

Bending Geometries

There are various geometries available for curved members and the methods used to bend them. Due to the wide variety of bending equipment available, almost any structural shape can be curved, including HSS, hot-rolled open sections, welded built-up members and multi-sided shapes formed by cold bending.

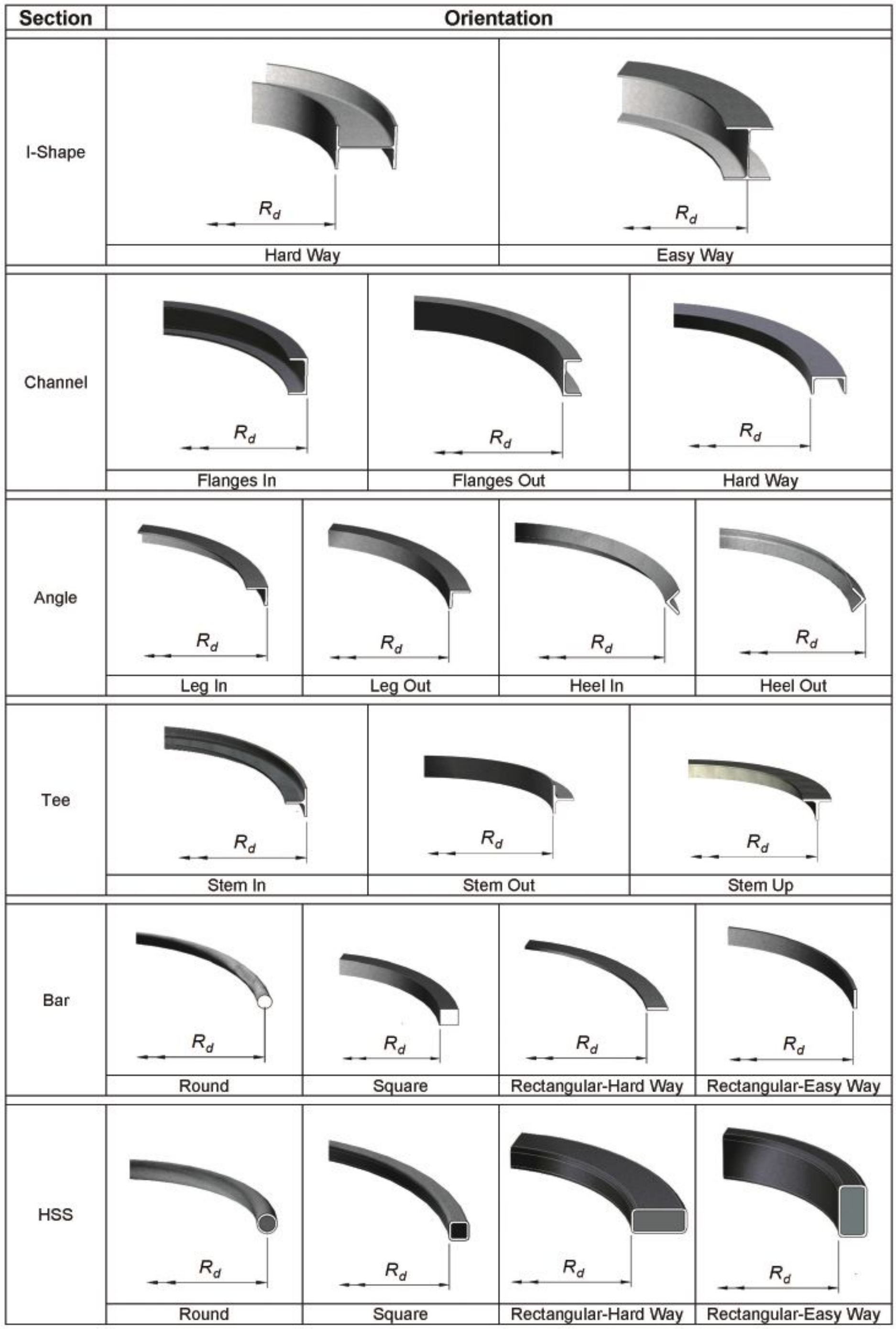
Standard bends are the simplest type, where a member is bent about a principal or geometric axis to form a single-radius curve. Members can also be bent about a non-principal axis or about more than one axis, providing three-dimensional curvature. Bender-roller companies have the capability to provide multiple arcs within a member, as well as parabolic, elliptical and other non-circular bends. Spirals are another common specialty bend.

Because each bender-roller has different capabilities, early communication of bending requirements will allow potential complications to be addressed in the preliminary design stages. The following are different bending types, as detailed in Design Guide 33.

Standard bends. Standard bends are those where a member is bent about a principal or geometric axis to form a single-radius curve.

In this case, the member can be bent about the weak axis, known as bending the easy way, or bent about the strong axis, known as bending the hard way. Hard-way and easy-way bending are sometimes called camber and sweep, respectively. However, be aware that these terms are typically also used to describe mill tolerances or a small curvature induced in a beam to partially offset gravity-load deflections. Standard bending orientations for several common structural shapes are illustrated in the chart at right.

Off-axis bends. For off-axis bends, also called conical rolling, the member is curved about a non-principal or non-geometric axis. Most off-axis bends are fabricated with a constant rotation relative to the plane of curvature; however, they can also be formed with a variable

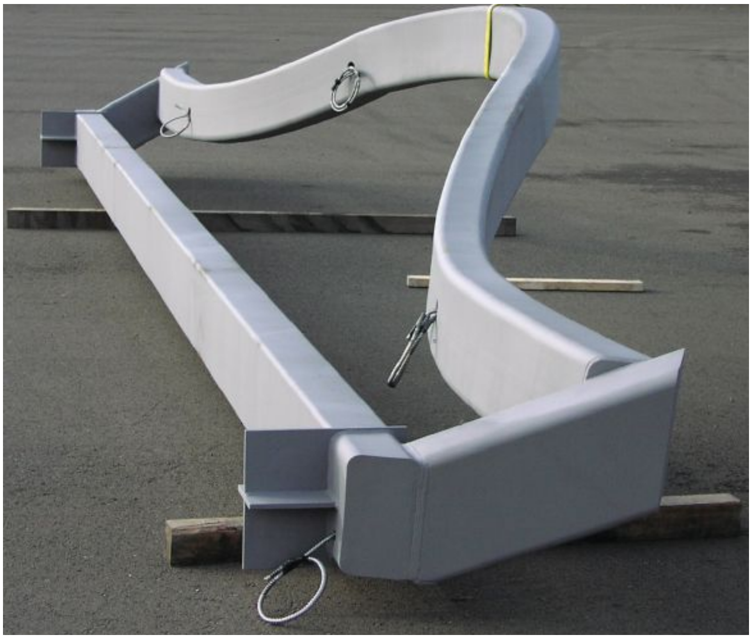


above: Bending orientations for various types of steel members.

below: Curving round HSS.

An off-axis bent wide-flange member.

Rectangular HSS displaying reverse-compound bends.



Rectangular HSS displaying multi-axis bends.

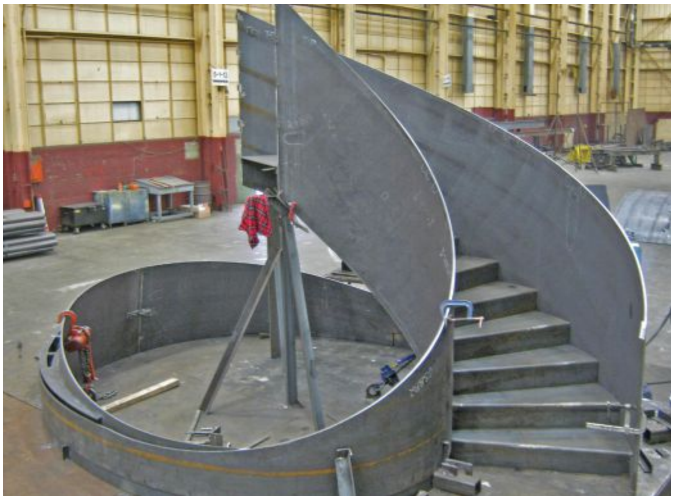
An illustration of parabolic multi-radius bends.

10 Things Everyone Should Know About Curved Steel

1. Curved steel members don't just "come that way" from the mill. Curved steel members are produced from straight lengths of material and are curved per your specifications by a bender-roller company.
2. Studies have shown that the curving process does not reduce the strength or structural integrity of the steel. When a shape has been curved successfully, with no buckling or localized cracking in the steel, the strains the member will experience under actual service conditions will be much smaller than those associated with the curving operation. Once the curving is done, the member can be expected to perform as needed.
3. Steel can be curved with minimal distortion and is very attractive for AESS applications. The most qualified bender-roller companies have an internal quality-control system as well as internal tolerances that they adhere to when curving a steel member.
4. The radius and orientation of a bend are the most critical pieces of information required to curve a steel member. This information dictates the type of bending process to be used.
5. The terms "easy way" and "hard way" have nothing to do with how easy or how hard it is to bend or curve a steel member. Easy way is bending a member around the weak axis, while hard way is bending a member around the strong axis.
6. It is possible to spiral-bend true HSS material. This allows for stringers and other architectural forms to meet design needs.
7. Curved steel sections that create a smooth, consistent arc are more aesthetically appealing and less labor-intensive than fabricated straight sections that need to be welded or spliced together.
8. Straight material and curved material with the same theoretical outside dimensions can be welded together after the bending process. Qualified bending companies can control the amount of deformation or distortion of the bent steel member to ensure proper fit/alignment with the straight member.
9. Steel does not usually have to be heated in order to be bent or curved. In most instances, steel sections can be curved by a hot or cold bending process, but note that tighter radii may be achieved through a hot-curving process.
10. A bender-roller can secure material from a local steel service center, or the project fabricator can contact the service center, who will then arrange for the material to be shipped to the bender-roller for labor-only processing.

twist along the member axis. Special tooling is often required to limit distortion and ensure dimensional accuracy. Off-axis bends are used when members are both curved and sloped, and a member axis must be parallel to the curved surface. In commercial structures, this can occur in canopies, arched roofs and horizontal members in a dome. These members are also used for circumferential stiffeners in industrial cone-shaped plate structures, such as hoppers and stacks.

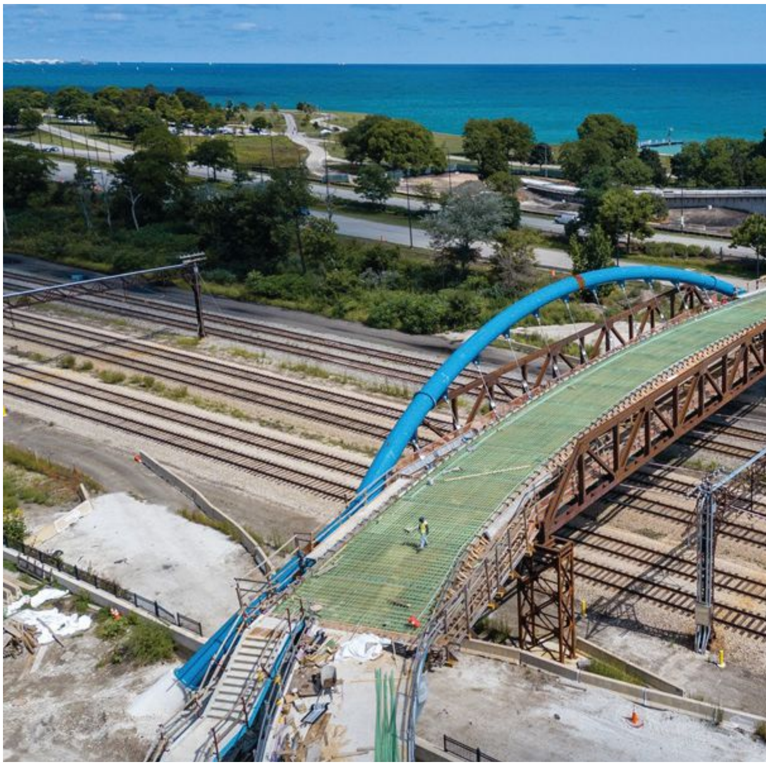
Curved steel offers an endless array of spiral stair possibilities.



Anvil Craft Corp.

Compound bends. A compound curve has two or more arcs in the same plane, joined tangentially without reversal of curvature. The members can be fabricated as a continuous curve or with a straight segment between tangent points. Compound bends can be formed from a single straight member or by bending two or more straight members into simple curves and splicing them together. Members with compound bends are used to support both vertically and horizontally curved architectural features. In industrial structures, they are typically used for monorail beams.

Reverse-compound bends. A reverse-compound curve, also known as an S-curve, has two or more arcs in the same plane joined tangentially with reversal of curvature. Completed I-shaped and HSS members with reverse-compound bends are used in the same applications as compound bends.



A curved stair stringer with markings for the treads and risers.

In this method, the member is removed from the machine after the initial bend is completed, turned over and placed back into the same machine, or a different machine, to complete the second bend. Due to the difficulty in fitting the member into the machine after the first bend is completed, a straight segment between the tangent points of each curve may be required. The minimum straight segment length varies with the member geometry and the bending machine; therefore, the bender-roller company should be consulted for specific requirements. S-curves can also be formed

Curved steel can transform bridges, like the 41st Street pedestrian bridge in Chicago (above) and Calgary's George C. King Bridge (below), from merely functional crossings to iconic, artistic spans.

by bending two straight members and splicing them together at the tangent point.

Curved steel forms the rotunda of the Transportation Museum in Bellefontaine, Ohio.

Bending Processes

So how, exactly, is steel bent? There are multiple ways to curve steel, which are listed in Section 2.3 of Design Guide 33. These include pyramid roll bending, incremental step bending, induction bending, rotary draw bending and other processes. Some methods are more common in the steel construction industry, while others are used more in the forming of parts for automobile, piping and other industries. Members of almost any shape can be curved by bending, including rolled open shapes, welded built-up shapes and closed shapes.

Cold bending, where the member is bent at room temperature, is usually more economical than hot bending or induction bending; however, there are cases where the required geometry cannot be formed by cold bending. The primary advantage of hot bending is that the material yield strength is lower compared to the room temperature value, requiring smaller forces to be exerted by the bending machine.

Each bending method has advantages and disadvantages, and each bender-roller company has developed unique bending methods and often use one-of-a-kind, patented machines. Developing proper bending techniques that ensure accurate and consistent dimensions requires significant judgment and experience. Due to differences in equipment, technique and personnel, the capabilities of each bender-roller vary significantly.

For example, one shop may have the capability to bend heavy members the hard way, another shop may specialize in spiral bends and another may be able to bend hollow shapes to a tight radius with minimal distortion. It is advantageous to involve a bender-roller early in the design process to provide information on the results that can be expected from each bending process.

When a member is bent to form a permanent curvature, it must be strained beyond its yield point, inevitably causing some level of cross-sectional distortion. The tendency for cross-sectional distortion during the bending process can be controlled using various techniques. HSS wall distortion is often limited by using an internal support mechanism such as a mandrel, a smaller HSS member or filling the member with a supporting material like sand. Many bending machines control the distortion of open shapes with specialized rolls and various forms of mechanical restraint. Bender-roller companies may have hundreds of specialized rolls, mandrels, die sets and other tooling to bend various HSS and open shapes with minimal distortion.

Pyramid roll bending. Pyramid roll bending is a cold-bending method where a member is bent progressively by repeatedly passing it through a set of three adjustable rolls in a pyramid arrangement. Force is applied by opposing rolls, and the distance between rolls is manipulated before each pass, bending the member into successively smaller radii. This process is repeated until the proper curvature is formed. Pyramid roll bending can be used to provide curvature up to a 360° angle. When curving I-shaped sections, the tension and compression flanges tend to bend locally

Talking the Talk

Here is a glossary of common bending-rolling terms, taken from Design Guide 33.

Arc. Part of the circumference of a curve. The curved portion of a bend.

Arc length. The curved distance along a circumferential line. The length of the curved portion of a member.

Bend radius. The radius of curvature, measured to a reference point on the cross section.

Center-to-center. The distance between tangent points of two adjoining bends.

Chord. The straight distance between two points on a curve.

Cold bending. Any bending process where curvature is induced by load application at room temperature.

Compound bend. A curve made up of two or more arcs in the same plane, joined tangentially without reversal of curvature.

Degree of bend. The angle to which a bend is formed.

Distortion. A deviation from the original cross-sectional shape.

Ductility. The ability of the material to deform without fracture.

Easy way. The orientation of a member where bending occurs about the weak principal axis.

Gag pressing. A cold-bending method that uses hydraulic rams to simultaneously apply bending forces at discrete, widely-spaced, locations along the member. Also known as point bending.

Grip. An additional straight length at each end of a curved member required in the bending operation. Also known as "hold and tail" or "lead and tail" to emphasize the additional length is required at each end of the member.

Hard way. The orientation of a member where bending occurs about the strong principal axis.

Heat curving. A bending process that relies only on the application of heat in specific patterns to induce curvature.

Horizontally curved member. A member with curvature in the horizontal plane.

Hot bending. Any bending process where curvature is induced by load application at an elevated temperature.

In-plane flexure. Bending of a curved member where moment is applied about the axis of curvature. The primary flexural stresses and deflections are in the plane of curvature.

Incremental step bending. A cold-bending method that uses hydraulic rams to apply bending forces at several discrete, closely spaced locations along the member.

Induction bending. A hot-bending method that utilizes an electric induction coil to heat a short section of the member before it is curved by force.

Local buckling. A type of potential cross-sectional distortion that is caused by compression stresses in the member induced during the bending operation. Local buckling can be in the form of a single half-wave or a series of wrinkles along the entire bend length. Also known as waving or wrinkling.

Mandrel. A tool that can be inserted into a HSS member to support the walls and minimize cross-sectional distortion during the bending process.

Multi-axis bend. A bend with curvature about more than one axis. Also known as a multi-plane bend.

Normalizing. A thermal treatment where the member is heated to a suitable temperature above the upper transformation temperature, followed by cooling in still air at room temperature.

Off-axis bend. A bending orientation where the member is curved about a non-principal or non-geometric axis. Also known as conical rolling.

Oil-canning. A form of local buckling that can cause collapse of the cross section due to the combined effect of ovalization and local buckling in a single half-wave.

Out-of-plane flexure. Bending of a curved member where moment is applied in the plane of curvature. The primary flexural stresses and deflections are in perpendicular to the plane of curvature.

Ovality. The cross-sectional distortion of a round HSS where the deviation from the theoretical shape forms an oval.

Pyramid roll bending. A cold-bending operation where a member is bent progressively by repeatedly passing it through a set of three adjustable rolls in a pyramid arrangement.

Reverse-compound bend. A curve made up of two or more arcs in the same plane, joined tangentially with reversal of curvature. Also known as an S-curve or an offset bend.

Rise. The distance, perpendicular to the chord, between the mid-point of a chord and an arc. Also known as the mid-ordinate.

Rotary-draw bending. A bending method where the member is clamped to a form and bent by rotating it around a bend die.

Slope. The angle of an inclined member designated using the vertical (rise) and horizontal (run) distances between two points. Also known as bevel or pitch.

Snap-through buckling. A type of instability where the load-displacement diagram descends after reaching a limit point and the structure abruptly transforms from one equilibrium state to another remote equilibrium state on the ascending, stable portion of the curve.

Spiral. A three-dimensional curve with an arc in one plane and a constant slope in a perpendicular plane. Also known as a helix or helical curve. The curving process is often called sloped rolling or pitched rolling.

Springback. The deformation of a bent member immediately after a bending load is released, where a portion of the curvature is lost.

Strake. A protruding fin that can be connected to a structure to improve aerodynamic stability.

Synchronized incremental cold bending. A cold-bending process where synchronized forces are applied at several locations along the member.

Tangent. A straight line, perpendicular to the radius, that touches a curve at a single point. A straight member adjacent to a curved segment.

Tangent point. The start or end point of a curve.

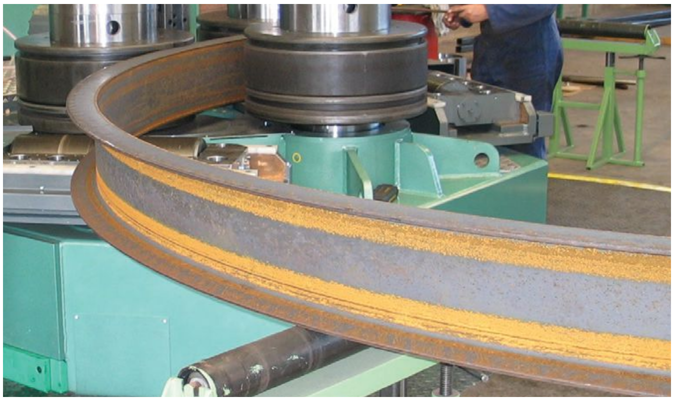
Variable-radius bend. Parabolic, elliptical and other noncircular bends with variable radii. Also known as multiradius and a non-circular bends.

Vertically curved member. A member with curvature in the vertical plane.

Waving. See *Local buckling.*

Wrinkling. See *Local buckling.*

Yield point. The curvature at which a member will deform permanently during bending.



above: Pyramid roll bending a steel channel.

right: Curved steel tops a concourse at Norman Y. Mineta San Jose International Airport.

below: Heat induction bending.

Sherman Takata

toward one another. These flange forces induce web compression stresses, potentially causing web buckling distortion. This can be controlled with supplementary rolls providing a restraining tension force on the inner surface of the tension flange on both sides of the web. In some cases, the web is restrained against buckling by compression rollers on each side of the web. To provide support during the bending operation, the rolls are contoured to match the cross-sectional shape of the workpiece. Contoured rolls can also be used for other cross-sectional profiles, and special rolls can be used to stabilize the cross-sectional elements and reduce distortion in common rolled shapes.

Incremental step bending. Incremental step bending is a cold-bending method that uses hydraulic rams to apply bending forces at several discrete, closely-spaced locations along the member. Cross-sectional elements can be supported mechanically or hydraulically to reduce distortion during the bending operation, resulting in the potential for small-radius bends with minimal distortion.

Induction bending. Induction bending is a hot-bending method that uses an electric induction coil to heat a narrow band—typically between 2 in. and 6 in.—around the member circumference to between 1,500 °F and 1,950 °F before it is curved by force. Equal wall thickness around the perimeter of the cross section is necessary for uniform heating throughout the section. As the member moves through an induction heating coil, it can be bent incrementally (similar to incremental step bending) but is usually rotated around a fixed-radius pivot arm. When a pivot-arm is used, a hydraulic ram pushes the straight section of the member through the coil at a constant rate (typically 1 in. to 2 in./min), with the leading end following the arc set by the pivot arm. After passing through the coil, the material adjacent to the heated section is usually sprayed with a coolant (usually water) or cooled with forced air, or the member is sometimes allowed to cool slowly in still air.

Although induction bending usually costs more than cold bending, there are several advantages that can make it the most appropriate bending method for some structural members. Because the inelastic bending strains are confined to the narrow heat band, small-radius bends are possible with high dimensional accuracy and low cross-sectional distortion. Also, heavy shapes that exceed the capacity of cold bending machines can often be bent with induction bending machines. Hollow shapes with wall thicknesses up to 6 in. have been successfully bent with induction bending equipment; shapes with 12-in.-thick to 2-in.-thick walls are commonly bent.

Induction bending may provide a viable method when the dimensional requirements cannot be met with cold bending. For example, induction bending may be the only method with the capability to bend a multi-sided hollow shape to a small *R/D* ratio with limited cross-sectional distortion. Because bending special shapes requires a significant investment in tooling, duplicate member quantities are required to make this method economically feasible.

Rotary draw bending. Rotary draw bending is a cold bending method where the member is clamped to a rotating bend die and drawn around the bend die. The tailing tangent is held against the bend die by a pressure die, and the bend die rotates until the desired geometry is formed. A mandrel is often placed inside the member to restrain cross-sectional distortion during the bending process. Bends can also be formed with special draw-bending equipment where deformations are controlled by tensioning along the member axis. Rotary draw bending is commonly used to form small-radius bends in smaller-size round, square and rectangular HSS members. Specific tooling is required for each member size, shape and bend radius; therefore, this method is best suited for projects requiring many identical bends. Some bender-roller companies have hundreds of die sets, likely eliminating any initial tooling costs for common geometries.

This bending method is primarily used in the machine and parts industry and for piping. The maximum degree of bend is 180°, but the minimum bend radii of round HSS is approximately 50% smaller than that of other cold-bending methods.

Other methods can be used to bend members, including ram bending gag pressing and hot bending.

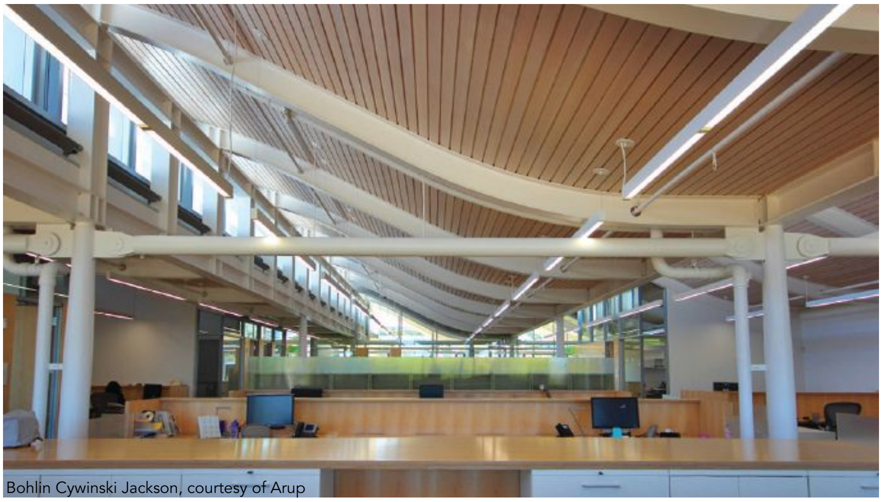
Ram bending. Ram bending is a cold-bending method that uses a hydraulic ram to apply a force near the mid-span of two widely spaced supports. The member is moved through the machine so the force can be applied at discrete locations as required to produce the desired curvature.

Gag pressing. Gag pressing, also known as point bending or cold cambering, is a bending method that uses hydraulic rams to simultaneously apply forces at discrete locations along the member to produce large-radii bends. This is the most common method for cambering beams to offset a portion of the service-load deflections; therefore, the hydraulic rams are located approximately at one-third points to produce a curved shape approximating a typical beam deflection curve. The supports for most cambering machines are between 20 ft and 28 ft apart.

Beams are usually cambered in a custom-built machine at the fabricator's shop; however, members can also be cambered by a bender-roller company. Because beam lines can be used only with straight members, beams are usually cambered after they are cut to the final length and holes are punched or drilled. If the machine capacity is exceeded, heat can be applied to the member to reduce the yield stress. Because many bender-roller companies have specialized, high-capacity equipment, it can be more economical for the fabricator to sublet the cambering of large beams.

LEO A DALY

left: A gentle curved steel frame supports an Omaha hospital entry canopy.



Bohlin Cywinski Jackson, courtesy of Arup

above: The Newport Beach Civic Center features curved steel wave roof assemblies that are prominent both inside and outside the building.

below: Curved steel takes on an industrial aesthetic at Southwest University Park in El Paso (home of the El Paso Chihuahuas!).

Photo: © Brian Wancho, courtesy of Walter P Moore

Hot bending. Hot bending is any process where curvature is induced by load application at an elevated temperature. Also known as heat-assisted bending, the primary advantage of hot bending is that the material yield strength is lowered from the room temperature value, requiring smaller forces to be exerted by the bending machine. Heat is applied directly to the member by flame, by heating in a furnace or by induction coil, followed by the application of a bending force. The member can be bent around preset forms, but more often the bending force is applied using one of the previously discussed bending methods. For HSS members, the heat can be applied either externally or internally. For cambering beams by gag pressing, the application of heat is typically used only where the beam strength exceeds the machine capacity. To ensure any changes to the member mechanical properties are insignificant, temperatures are held below the limits in AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360, a free download at **www.aisc.org/specifications**) Section M2.1: 1,100 °F for ASTM A514/A514M (ASTM, 2016) and ASTM A852/A852M (ASTM, 2007) steel and 1,200 °F for other steels. These temperatures are much lower than those induced during induction bending.

AISC Bender-Roller Committee

Here is a list of current AISC Bender-Roller Committee members:

- A-1 Roll Company
- Albina Company, Inc.
- BendTec, Inc.
- Chicago Metal Rolled Products
- Greiner Industries, Inc.
- Hodgson Custom Rolling, Inc.
- Holloway Company, Inc.
- Hornsby Steel
- Kottler Metal Products
- Kubes Steel, Inc.
- Linders Specialty Company
- Max Weiss Company
- Midwest Metal Products
- Paramount Roll and Forming
- Shaped Steel, Inc.
- SIMS Steel, Inc.
- Trilogy Machinery, Inc.
- Whitefab

Visit **www.aisc.org/benders** for contact information for all of these companies. And for more information related to curved steel, visit **www.aisc.org/curvedsteel**.

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16 Rules for Connection Design

BY CAROL DRUCKER, SE, PE, PENG, BILL THORNTON, PE, PHD,
DOMINICK D'ANTONIO, PE, PATRICK J. FORTNEY, SE, PE, PENG, PHD, AND SNEHAL SUPE

Structural connections connect everyone—engineers, detailers, fabricators and erectors. And the better they are designed, the better it is for all parties involved with steel framing systems.

STRUCTURAL STEEL CONNECTIONS have a direct impact on a project's success.

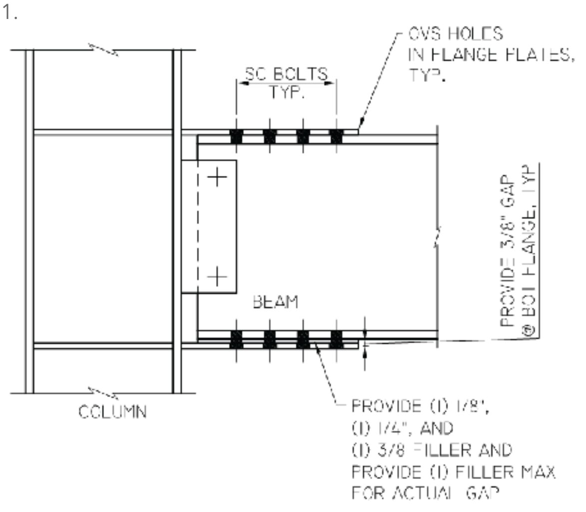
Those of us who design and build with steel are well aware of this, as well as the fact that connections should be strong and stiff enough to resist the required loads, cost-effective to fabricate and safe and easy to erect. Sound advice and insightful tips from industry experts can help you raise your connection game and achieve the most efficient balance between these fundamental criteria. Here are some tips from around the structural steel world—education, design, detailing, fabrication and erection—on how to provide efficient connection design and avoid costly missteps.

1. Read user notes and Commentary in the *Specification*. The user notes in the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360) contain helpful information that is not considered *Specification* language. For example, the user note in *Specification* Section J4.3 indicates that typical cases where the block shear reduction coefficient, U_{BS}, should be taken as 0.5 are illustrated in the Commentary, which contains a wealth of knowledge and design guidance for the *Specification*.

2. Confirm the erector's preferred hole type for single-plate beam-to-column connections. While short slotted holes are typically preferred at double-angle connections and end plate connections, erector preferences at single-plate connections to column flanges and webs may vary. Some erectors prefer short-slotted holes to allow for additional erection tolerance while others prefer standard holes to help plumb the column. The exact, preferred hole type should be confirmed with the erector before finalizing the design.

3. Coordinate the filler plates at slip-critical connections. Oversized holes with slip-critical bolts are commonly preferred at bolted flange-plated beam-to-column moment connections to allow for additional erection tolerance. Due to possible overrun of the beam depth and flange tilt, filler plates are needed at the beam bottom flange. The gap left for the fillers is typically ¼ in. to ⅜ in. If multiple fillers are used, there is a 15% reduction in bolt slip resistance due to the factor for fillers, h_f. The penalty for multiple fillers should be considered and coordinated with the fabricator and erector. To avoid an increase in bolts due to multiple fillers, the fabricator can provide alternate filler thicknesses for the connection (but this may increase cost.) The exact filler used will depend on the actual gap (see Figure 1).

Fig. 1.



4. Keep it symmetric. The single-plate shear connection, if symmetrical, can be installed upside-down or opposite-hand with no effect (see Figures 2 and 3 for examples). The small increase in material will offset possible fabrication errors, and the symmetrical pattern helps to avoid base plate-to-column errors and anchor rod placement errors. Figure 3 shows a base plate with a doubly symmetrical anchor rod pattern.

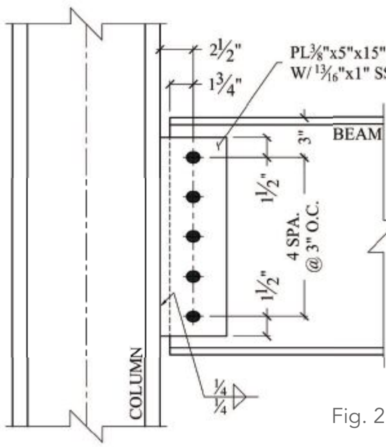


Fig. 2.

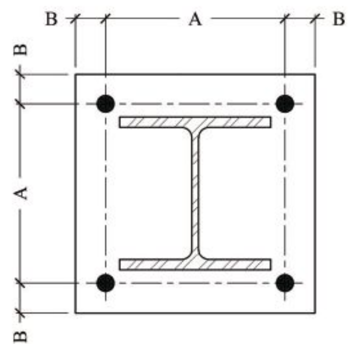
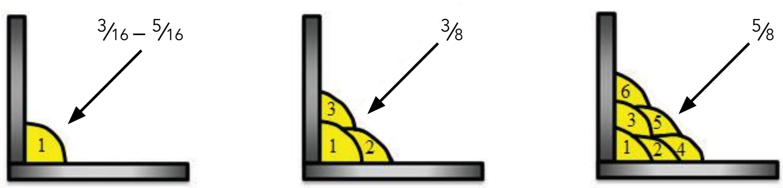


Fig. 3.

5. Use single-pass fillet welds. If possible, try to use single-pass fillet welds. Figure 4 indicates that a ⅜-in. fillet weld requires three passes, which is approximately three times the cost for a strength increase of 20%. Figure 5 indicates that doubling the fillet weld strength will increase the cost to approximately six times that of a single-pass weld. The increase in welding cost for multiple-pass welds is generally much more than the increased material cost required to accommodate single-pass welds.

Fig. 4.



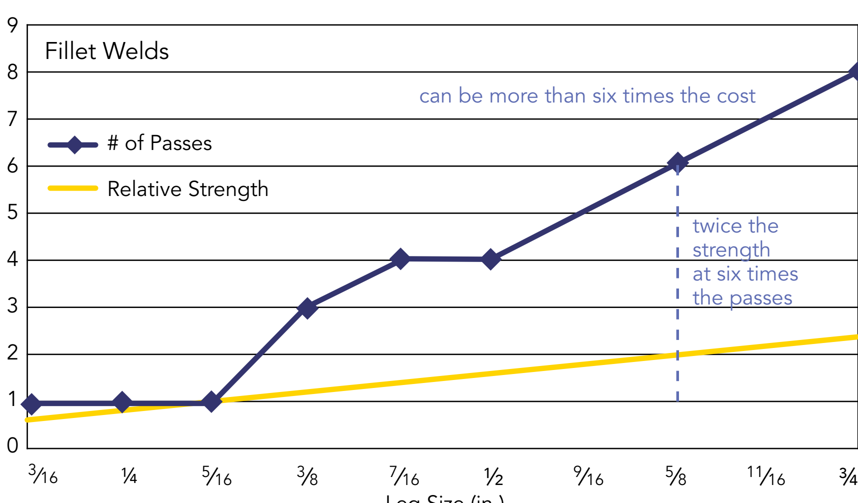


Fig. 5.

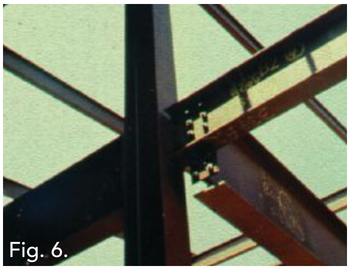
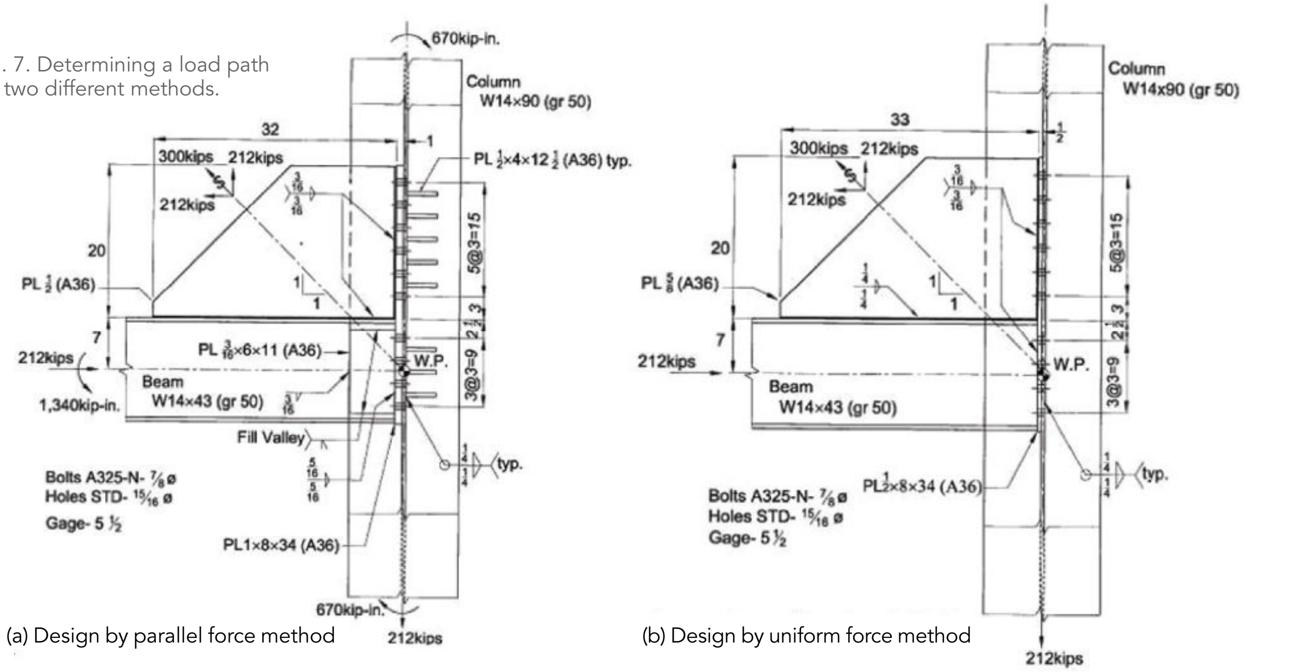


Fig. 6.

6. Avoid UDL. UDL (uniform design load)—which is covered in Table 3-6 of the AISC *Steel Construction Manual*—is not an economical design choice and can actually be unsafe. Figure 6 shows two beams framing to a column, with one offset from the column line; each was designed for UDL. This is obviously not safe in this situation, and a point load near a beam end negates the uniform load assumption.

Carol Drucker is founding principal of Drucker Zajdel Structural Engineers; **William Thornton** is a corporate consultant to Cives Corporation; **Dominick D'Antonio** is vice president of W&W Steel Erectors, a division of W&W/AFCO Steel, **Patrick Fortney** is an associate professor at the University of Cincinnati; and **Snehal Supe** is a general manager with Pan Gulf Technologies.

Fig. 7. Determining a load path via two different methods.



(a) Design by parallel force method

(b) Design by uniform force method

7. Load paths have consequences. The essence of connection design (and all design) is the determination of a statically admissible load path. The uniform force method (UFM) and the parallel force method (PFM) both provide statically admissible load paths for bracing connections, as shown in AISC Design Guide 29: *Vertical Bracing Connections—Analysis and Design*. These methods both produce safe and acceptable designs, but not the same design. Figure 7 shows designs for the same location in a building using both methods. Which do *you* think is the more economical of the two?

8. Engage the erector as soon as possible. Engage the erector, preferably before detailing and connection design begins, in order to understand their bolting and welding preferences/procedures, as well as the overall erection plan, sequencing and any special requirements—cranes, logistics, etc. Connection designs, detailing and fabrication need to meet these requirements.

9. Share the design basis for connections with your erector to avoid problems in the field. That is, are connections SC- or N-type or Class-A or B slip-critical, do they use oversized or standard holes, are there any special washer requirements, are multiple fills allowed or not, etc.? If the erector knows what to expect, they can help ensure that detailing and fabrication are in conformance with design during erection.

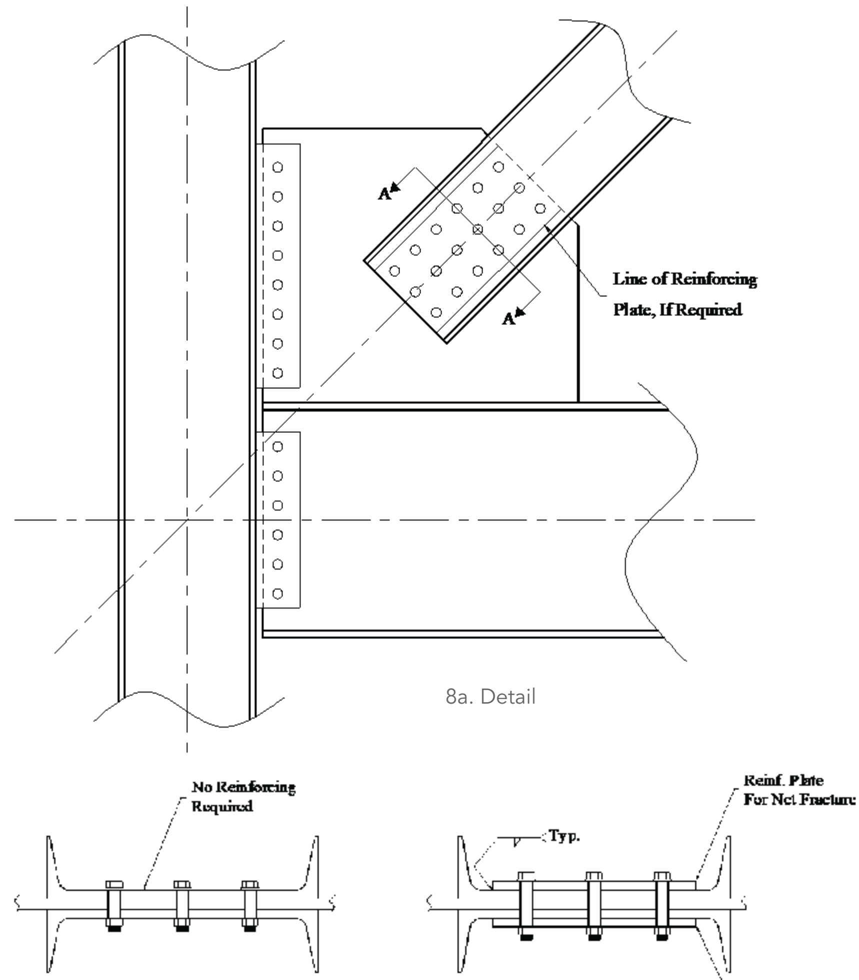
10. Design connections with erection forces in mind. Member forces and resultant end reactions during erection, as well as while a structure is in a temporary condition during construction, may exceed the final design reactions. Connections need to be designed with this in mind and should be coordinated with the erector. Some examples of this are:

- Truss web member sizes/loading may exceed final design during rigging/erection.
- Beams supporting cranes/crane ties may need to be upsized and may have significantly greater end reactions in the temporary conditions versus the permanent condition.
- The axial demand in temporary conditions for members subject to temporary axial loads but not designed for axial loading under permanent conditions.

11. Stress Limits on members with bolted connections. When making preliminary and final member size selections, set your stress ratio limits in a manner that allows for bolted connections. Placing holes for bolted connections can create net section rupture issues if not accounted for in main member design. This is true not only for axial members, but also for moment connections (see Figures 8 and 9 for examples of these connection types). Reinforcement plates increase design and shop time and can quickly drive up the cost of the steel package. As a rule of thumb, reducing stress ratio upper limits from 1.0 to 0.85 can avoid such a costly outcome.

12. Geometry and bolting spatial considerations. Line drawings and details can be tricky. As connection designers, we have to see things in an extruded form from a 3D perspective; see the beam-column moment connection in Figure 9 for an example. Typically, beam flange and web bolts are detailed with the same pull-off. In most cases, this works just fine without really even having to think about it. However, beam/column combinations in heavily loaded joints may require k-riding for

Fig. 8. Potential net section reinforcement plates on an axially loaded member.

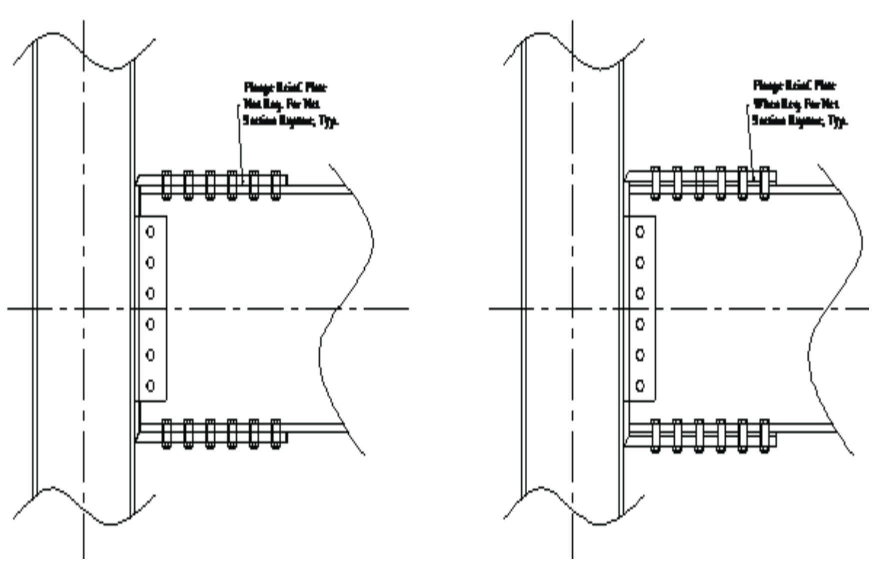


8a. Detail

8b. Section A-A
Without reinforcement

8c. Section A-A
With reinforcement

Fig. 9. Bolted flange connections in axially loaded beams or beam-to-column moment connections.



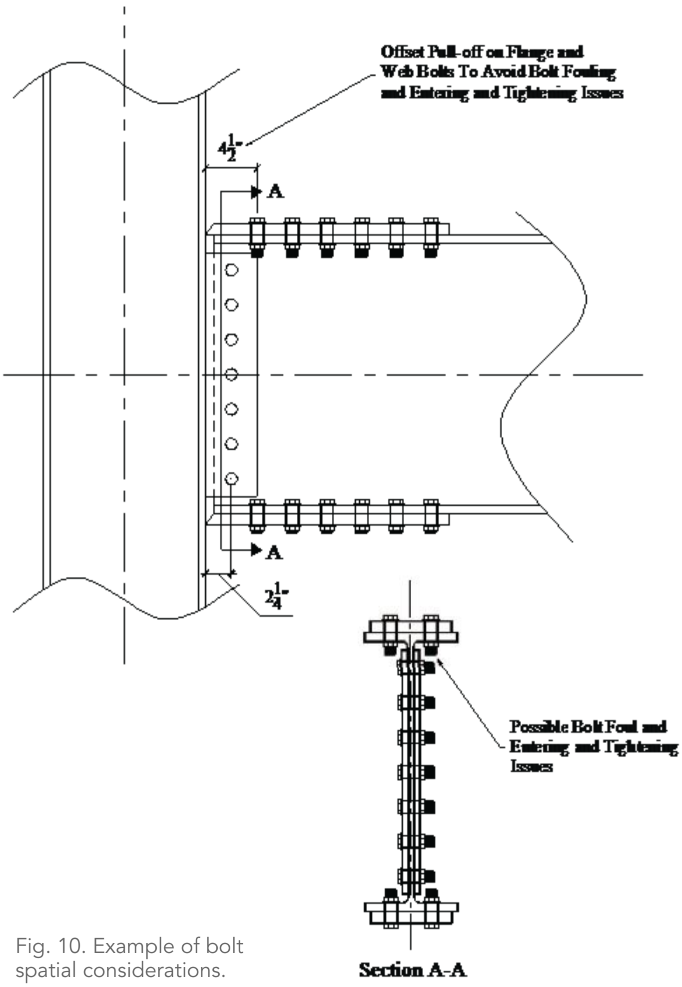


Fig. 10. Example of bolt spatial considerations.

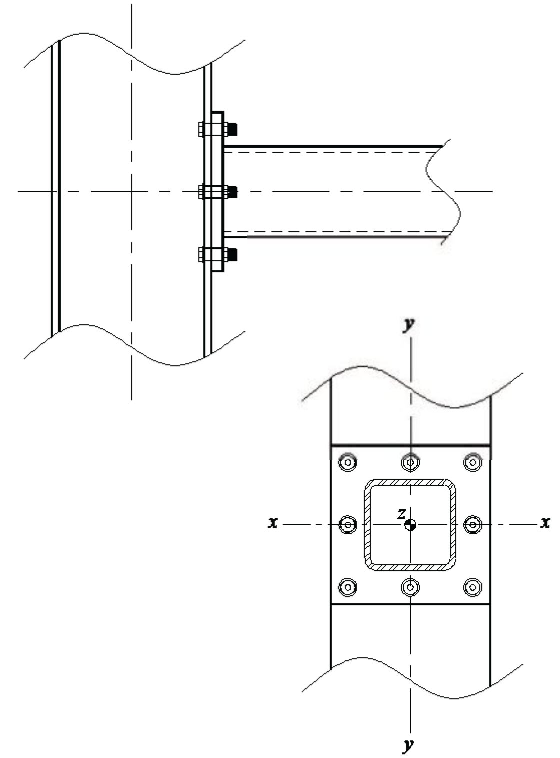


Fig. 11.

fit-up of the web connection plate, as shown in Figure 10. This, in combination with relatively narrow beam flanges, can cause bolt fouling or entering and tightening issues. In this case, one possible solution is to use a longer pull-off for the beam flange bolt group (again, indicated in Figure 10). Just be sure to consider the stability of the flange connection plate for pull-offs on plates in compression. Note there are myriad issues in regard to entering and tightening. Figure 10 shows just one condition.

13. Keep analysis and boundary conditions in mind. You should always carefully consider the degrees of freedom required for the desired structural behavior and performance during analysis. Some commercially available software assumes no releases in the default condition, so be sure to provide releases where appropriate. Figure 11 shows an example of a typical hollow structural section (HSS) beam-to-wide-flange-column connection. The loading chart in Table 1 suggests axial load, shears and bending moments for all three axes. Notice that the connection at joint A-1 requires design moments of M_y and M_z equal to 500 lb-in. and 250 lb-in., respectively, in combination with the other required loads. This can complicate connection design and drive up design and effort time, as well as the cost of the steel package. For the typical structure, releases are appropriate. If all of the degrees of freedom truly are required, so be it.

When communicating connection loading information to the delegated connection designer, it is best to provide the loads required from analysis. Simply requiring a connection to develop the strength of the member being connected is not necessary in most cases. This can be significantly exacerbated when no releases are provided. Not only is the member being connected overstressed (at least mathematically) but the supporting member may be overstressed as well. Loading for joint A-2 in Table 1 represents such a case.

Table 1. HSS-beam-to-wide-flange-column moment connection design loads.

Joint	A_z	V_x	V_y	M_x	M_y	M_z
Coord.	(kips)	(kips)	(kips)	(k-in.)	(k-in.)	(k-in.)
A-1	35	15	42	95	0.50	0.25
A-2	*	*	*	*	*	*

Provide available axial, shear or moment strength of HSS.

14. Use extended shear tabs for connecting braced beams to column webs. When installing a braced beam between two column webs, the beam needs to be slid down. Due to the presence of gussets, swinging a braced beam inside the column is a difficult task for the erector. And the presence of cap plates or stiffeners in column webs can make installation nearly impossible. Extended shear plate connections offer many advantages like avoiding member coping and less detailing erection and detailing required. A major concern for the designer is to design an extended tab for the moment at the group of bolts due to eccentricity and transfer only shear load at the center of the column—which makes the tab thicker and requires more bolts. If precise loads are supplied by the engineer of record (EOR) these connections can be designed lighter as compared to those designed for generalized UDL criteria. If extended tabs are specified at the start of the job, the beams can be procured in lesser lengths (up to the column flange edge) thereby lowering material requirements.

Fig. 12. A paddle plate-bolted moment connection.

15. Chose bolted flange-plate moment connections over field-welded connections for beams. Most of the time, the EOR specifies field-welded complete-joint-penetration (CJP) moment connections in lieu of bolted moment connections. Field-welded connections are typically more costly and time-consuming since they involve special end preparation for the beams, masking paint at beam ends and columns, the actual welding, thorough field inspection of welds and repainting. Hence, it is preferable to provide paddle plate-bolted moment connections, which can reduce fabrication efforts, erection time and cost (see Figure 12). The EOR should design the section sizes such that this type of bolted moment connection can be easily designed for given loads.

16. Size beams so that normal connections can be used. For beams with heavy shear plus axial loads, the EOR should size the beams in such a way that normal connections can be designed. Normal connections are those that avoid costly added elements like stiffeners, web doublers, beam haunches, multiple columns of bolts, flange extension plates, etc. In order to facilitate normal connections, the EOR must precisely select section sizes, design sample connections for actual loads to ensure that these sections really deliver the intended results and provide precise loads to the connection designer for connection design. This may entail a higher beam/column material cost, but it will lower connection material and fabrication costs as well as expedite connection design and detailing.

Effective connection design is often said to be more of an art than an exact science. These tips—and many more found in AISC's myriad design resources at **www.aisc.org/publications** (where you can also access the various publications mentioned in this article)—can help you become a better connection engineer and achieve the proper balance between stiffness, efficiency and constructability. They will also be presented, along with several others, in the presentation "30+ Good Rules of Connection Design" at the 2019 NASCC: The Steel Conference, taking place April 3–5 in St. Louis. For more information, visit **www.aisc.org/nascc**, where you can also view a recording of the presentation approximately 45 days after the show. ■

A new coalition aims to close the skilled trades gap.

Filling the Gap

BY ROLINE PASCAL

Roline Pascal (rpascal@aws.org) is assistant editor of the American Welding Society's *Welding Journal*.

ONE OF THE HARDEST SEGMENTS of the workforce for employers to find skilled talent has been the skilled trades: the welders, electricians, machine tool operators, pipefitters and other tradespeople who are essential in manufacturing and construction.

But if these skilled trade workers are difficult to find now, in a few years, this will likely become a disconcerting situation. It is estimated that two million manufacturing jobs will go unfilled by 2025. So the question is: What can we do to solve this problem?

On December 5, 2018, 17 industry organization leaders gathered at the American Welding Society (AWS) World Headquarters in Miami for the first meeting of the Skilled Trades Coalition (STC), which was founded as a response to the rising shortage in skilled trade workers. The mission of the STC is to bring together a group of thought leaders who are shaping the future of work in their respective trade disciplines to explore awareness, recruitment, training and retention of skilled trade workers to close the skilled trades gap.

"Over the last several years of my career, I have been hearing a common theme from multiple industries, which is the growing deficit in access to qualified skilled workers," said AWS executive director and CEO Matt Miller. "We began reaching out to our counterparts at other technical associations and discovered that the challenge we're having with attracting workers to welding is mirrored in many other trades, so we put together a charter to see if we could engage other groups to elevate the conversation around the skilled trades. Our original goal was to bring together five organizations, but the interest was so large that we quickly found we had 17 willing partners."

At the gathering, Coalition participants had the opportunity to interact, share information and gain consensus on key topics, detail best practices and identify common challenges, brainstorm, collaborate on awareness of the trades employment gap and combine resources to accelerate problem solving. The group developed several insightful panel-based sessions to explore the questions and answers to the skills gap. Central in the discussion was development of strategies to draw more workers to skilled trades, dispel myths and influence public perceptions.

Attracting Workforce Talent

Amongst the executive partners, a panel was brought in to share insights into opportunities and challenges facing the skilled trades in the areas of attracting talent and managing common misconceptions. The panel included Gardner Carrick, vice president, strategic initiatives, with the Manufacturing Institute; Darrell L. Roberts, executive director of Helmets to Hardhats, Center for Military Recruitment, Assessment and Veterans Employment; and Pim Bexkens, software engineer and team leader with WorldSkills Netherlands.

Data from the panel demonstrated that while employment and job openings in the trades are growing, the industry cannot meet the supply and demand of skilled workers. Thus, there is an urgency to attract young people to the skilled trade workforce as they are key to closing the gap. The pending retirement of baby boomers, strength of the economy and gap between the skills that employers need and available workers put other issues to the forefront.

American Welding Society (AWS) hosted 17 industry organizations for the first Skilled Trades Coalition meeting on December 5, 2018. Pictured at AWS Headquarters in Miami, Fla., are (from left) Scott Lynch, ABMA; Ken Rigmaiden, IUPAT; Matt Miller, AWS; Scott Cargill, ASNT; Darrell L. Roberts, Helmets to Hardhats; Charles J. Carter, AISC; Edward A. Abbott, Ironworkers International; John Ospina, GAWDA; Arnold Bereson, ASNT; Michael Harris, ITI; Raquel Tamez, SHPE; Matthew E. Croson, AGMA; Jeannine Kunz, Tooling U-SME; David W. Viola, IAPMO Group; Sheila LaMothe, CCAI; Edward S. Youdell, FMA International; Tom Underhill, SEAA; and Robert H. Chalker, NACE International.

Negative connotations and stereotypes of trade workers have penetrated society and contributed to the problem by discouraging young people from pursuing careers in the trades. Most people have no idea of the importance of manufacturing and its contribution to the American economy, including manufacturing employees and executives.

"The changes that have been occurring in our pre-professional education system have contributed greatly to the skilled workforce shortage problem. Over the years, we have put a focus on the value of a college education, while at the same time devalued the career opportunities of the skilled trades, discouraging people from entering these fields," said Robert H. Chalker, CEO, NACE International.

Influencing Public Perceptions

Research has explored what today's young people are looking for in their careers, how they make career choices and how well today's educational programs support careers in manufacturing. It touches on the fact that high schools in the United States have shifted their focus to preparing students for four-year colleges rather than vocational schools. Most of the agricultural arts programs that were so popular 50 years ago have been removed from high schools, and the educational system exacerbates the negative perception of manufacturing.

"The shift in the national education system 30-40 years ago away from supporting vocational programming as part of the curriculum and a big push to have students follow a 'college prep' curriculum was a defining moment in creating the skilled trades workforce shortage," said Edward S. Youdell, president and CEO of FMA International. "This sea change in approach funneled many people away from careers in either manufacturing or skilled trades, where great value is placed on the ability to work with both one's hands and mind."

Half of high school graduates who attend college drop out. However, the educational system has failed to engage these students and help them enter alternative postsecondary programs. Those who do graduate may not find employment requiring a four-year degree. Meanwhile, many well-paid and rapidly increasing manufacturing jobs remain unfilled.

"This push towards college or bust shifted the culture's perception of our great career alternatives into meaning something less than the white collar variety," said Youdell. "We should also stop referring to our employees as workers or laborers. Who ever wanted to grow up to be a worker? Change the paradigm. We can do better."

The Coalition strives to eradicate public perception and restore the image of essential skilled personnel. A few key takeaways from the meeting as they relate to improving the skilled trades perception on the national and local levels and attracting skilled trade workers include: 1. targeting women, minorities and young people (researching key influencers); 2. investing in resources to craft a message and get it out to the public (e.g., TV commercials and social media); 3. investing in a central location for resources; 4. building on and leveraging existing programs; and 5. engaging other organizations/groups who are also working in the same space.

Next Steps/Action Planning

Over the next decade, nearly 3.5 million manufacturing jobs will likely be needed. This skilled workforce shortage is not new. The urgency of the problem was described as far back as the 1990s and has been well documented over the past 15 years.

"Certainly the skilled trades and manufacturers themselves bear some responsibility for this situation because, collectively, we lost control of the narrative and did not respond strongly enough about the value of our industries and career opportunities," said Youdell.

As for the question posed in the beginning, what can be done to solve this problem, the answer is to establish partnerships with industry organizations, schools and the public, and the STC has taken the first step. As part of this nationwide effort, the partners have shared stories, data and ideas to inspire action. Collaboration is at the heart of the Coalition, and the participating partners demonstrate their enthusiasm to work together with all of their knowledge to bring the tools and information necessary to help the industry when skilled trades issues arise, being a strong voice for trades within industry to provide assistance and solve problems.

"While the Coalition is made up of a diverse set of industry leaders and associations, our ability to find common ground for a shared issue will hopefully lead to a set of solutions that can be deployed to raise the visibility of the issue on a national scale," said Youdell. "From there, communicating the solutions to our individual industry's members, stakeholders, suppliers and original equipment manufacturers, and then having them adopt them into their operations, can hopefully alleviate the shortage of skilled professionals."

Consensus has been sought for action moving forward. The 17 partners have started their focus in the areas of initiative, coalition governance, data mining, marketing campaigns, stakeholders and funding. Executive sponsors have volunteered to helm the projects, with assistance from one or two groups.

"Each of the organizations in the Coalition is doing something to promote the value of a profession in the skilled trades, but as individual groups, with limited resources, we can only accomplish so much," said Chalker. "Together, combining our efforts and resources, we can amplify our impact. I see the most important role we can play is to reestablish the skilled trades as a long-term, secure career for young men and women in the formative years while they are making career decisions."

The partners will be exploring initiatives at the upcoming teleconference this month. Subsequently, AISC will host the second in-person Skilled Trades Coalition meeting September 5 and 6 at its headquarters in Chicago.

It is time to act. ■

This article originally appeared in the March 2019 issue of Welding Journal *and is being reprinted here with the permission of the American Welding Society.*

The 17 partners in the Skilled Trades Coalition include:

American Boiler Manufacturers Association
American Gear Manufacturers Association
American Institute of Steel Construction
American Society for Nondestructive Testing
American Welding Society
Chemical Coaters Association International
Helmets to Hardhats
Fabricators and Manufacturers Association, International
Gases and Welding Distributors Association
International Association of Plumbing and Mechanical Officials
Iron Workers (International Association of Bridge, Structural, Ornamental and Reinforcing Iron Workers)
International Training Institute
International Union of Painters and Allied Trades
NACE International
Steel Erectors Association of America
Society of Hispanic Professional Engineers
Society of Manufacturing Engineers

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AISC to Honor Eight Structural Steel Leaders at NASCC: The Steel Conference

Eight leaders from across the structural steel design, construction and academic communities will be presented with awards by AISC at the 2019 NASCC: The Steel Conference, taking place April 3–5 in St. Louis. The awards presentation and opening keynote will take place on Wednesday, April 3, from 10:30 a.m. to 12:15 p.m. at the America's Center Convention Complex. The awards honor significant individuals who have made a difference in the success of the fabricated structural steel industry. Whether it's for an innovative design, an insightful technical paper or a lifetime of outstanding service, an AISC award bestows prestige and well-deserved recognition upon its recipient.

The **Lifetime Achievement Award** honors individuals who have made a difference in AISC's and the structural steel industry's success and provides special recognition to those who have provided outstanding service over a sustained period of years to AISC and the structural steel design/construction/academic community. This year's Lifetime Achievement Award winners are:

- **Michel Bruneau, PhD, PEng**, Professor, University at Buffalo
- **John P. Cross, PE, LEED AP**, Consultant, Former Vice President (Retired), AISC
- **David B. Ratterman**, Senior Member of Stites & Harbison, PLLC, and Former AISC General Counsel
- **Doug Rutledge**, Chief Integration Officer, KL&A, Inc.

The **Early Career Faculty Award** provides recognition to faculty who demonstrate promise in the areas of structural steel research, teaching and/or other contributions to the structural steel industry. This year's recipients are:

- **Matthew Yarnold, PE, PhD**, Assistant Professor, Texas A&M University
- **Matthew Hebdon, PE, PhD**, Assistant Professor, Virginia Tech University

The **Special Achievement Award** recognizes individuals who have demonstrated notable achievements in structural steel design, construction, research or education. It honors those who have made a positive and substantial impact on the structural steel design and construction industry. This year's award recipients are:

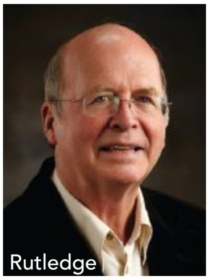
- **Heather Gilmer, PE**, Steel Operations Manager, HRV Conformance Verification Associates, Inc.
- **Francesco M. Russo, PE, PhD**, Vice President and Technical Director, Bridge Engineering, Michael Baker International

For more information on The Steel Conference, visit **www.aisc.org/nascc**. And to learn more about AISC's award programs, visit **www.aisc.org/awards**.


Bruneau


Cross


Ratterman


Rutledge


Yarnold


Hebdon


Gilmer


Russo

People and Companies

- **DeSimone Consulting Engineers** has recently promoted **Robert Stimson** and **Tarek Bannoura** to associates of the firm's Structural Engineering Practice in Las Vegas. Together, the new associates will facilitate the company's expanding presence in the Western United States. Stimson brings over 40 years of experience in structural engineering and management experience, and Bannoura has over 25 years of experience, both with an extensive range of project types.

- **AZZ, Inc.**, a provider of metal coating services, welding solutions, specialty electrical equipment and highly engineered services, announced it has reached a preliminary agreement to acquire **Tennessee Galvanizing, Inc.**, a metal coatings company with four operating galvanizing lines; both companies are AISC associate members. The transaction is expected to close in the spring of 2019, pending completion of final due diligence activities. The facility will operate as AZZ Galvanizing – Chattanooga.

- **Dewberry** has announced the promotion of two structural engineers in its Boston office. **Jeff Finitz, PE**, transportation department manager, has been promoted to senior associate, and **Daniel Johnson, PE**, a project manager in the structural engineering department, has been promoted to associate.

ENGINEERING JOURNAL

Second Quarter 2019 *EJ* Now Available

The second quarter 2019 issue of AISC's *Engineering Journal* is now available. You can access the current issue as well as past issues at **www.aisc.org/ej**. Below is a summary of this issue, which includes articles on torsional design, welded connection considerations, Chevron-configured special concentrically braced frames and steel diaphragm research. The various AISC publications mentioned are all accessible at **www.aisc.org/specifications**.

Torsion of Rectangular Connection Elements
Bo Dowswell

Traditionally, the torsional design of rectangular members has been based on elastic calculations. For member design, this approach is justified because beams subjected to torsion are usually controlled by torsional rotation serviceability limits. However, designs that are based on a first yield criterion underestimate the strength of connection elements. To evaluate the true torsional behavior of connection elements, various factors affecting the torsional strength of short rectangular members are investigated, showing that the torsional strength of connection elements can be predicted with rational analysis models using an ultimate strength approach.

Guidance on Shear Rupture, Ductility and Element Capacity in Welded Connections
Patrick J. Fortney, Larry S. Muir and William A. Thornton

Several considerations need to be made while in the process of designing welds and welded connections. For the most part, the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360), in combination with corresponding parts of the AISC *Steel Construction Manual*, provides fairly good guidance on what is required to design *Specification*-compliant welds. However, there seems to be some confusion and controversy in regard to a few of these considerations, specifically: (1) When is the load path from the weld to the connecting element(s) unclear? (2) When should the ductility factor be applied to a weld? (3) When should a weld be sized to develop the strength of a connecting plate?

Probabilistic Assessment of Seismic Force Demands in Biaxially Loaded Columns in Chevron-Configured Special Concentrically Braced Frames
Henry V. Burton, Nilofar Doorandish and Thomas Sabol

Special concentrically braced frame (SCBF) columns are designed as force-controlled elements and are intended to respond elastically during moderate-to-high return-period events. When placed at the intersection of orthogonal chevron-configured braced frames with fixed beam-column connections, SCBF columns are subjected to biaxial loading, including flexural demands developed in the beams due to unbalanced tension-compression brace forces. A probabilistic assessment of the force demands in biaxially and uniaxially loaded columns in chevron-configured SCBF is presented herein. Nonlinear response history analyses are performed on 3D models of 3-, 9- and 20-story SCBFs, and statistical descriptions of the results are used to investigate (1) the force demands relative to the capacity-design-based and elastic designs suggested by the AISC *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341), (2) the implications of the flexural demands transmitted to columns (via braced frame beams) and (3) the combinatorial effects of demands in biaxially loaded columns generated by orthogonal ground-motion components.

Steel Structures Research Update: Steel Diaphragm Innovation Initiative
Judy Liu

The Steel Diaphragm Innovation Initiative (SDII) is a multiyear academic-industry partnership to advance the seismic performance of steel floor and roof diaphragms in steel buildings. The team includes AISC T.R. Higgins and Milek Fellowship Award winners for topics ranging from developments in long-span composite slabs to buckling-restrained braced frames (BRBFs) to continuity plate detailing for steel moment-resisting connections. The motivations for creating SDII stemmed from issues with respect to the knowledge base for steel diaphragm performance, codes and standards and missed opportunities for advancements in seismic performance-based design. Available research on steel diaphragms primarily focused on the strength of isolated systems; little was known about ductility or whole-building performance. The team developed a five-year plan to "advance the seismic performance of steel floor and roof diaphragms utilized in steel buildings through better understanding of diaphragm-structure interaction, new design approaches and new 3D modeling tools that provide enhanced capabilities to designers utilizing steel diaphragms in their building systems."

For more on this research update, see "Dedicated to Diaphragms" in the special NASCC: The Steel Conference issue of *Modern Steel Construction*, available at **www.modernsteel.com**.

STANDARDS

New AISC Seismic Standard now Available for Public Review

The current draft of a new AISC standard, *Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings* (AISC 342), is available for public review until May 1, 2019. The standard will provide provisions to be used with ASCE/SEI 41, which focuses on seismic evaluation and retrofit of existing structural steel buildings.

The standard and review form are both available for download at **www.aisc.org/publicreview**. Copies are also available (for a $35 charge) by calling 312.670.5411. Please submit comments, using the review form, to Cynthia J. Duncan, AISC's director of engineering (**duncan@aisc.org**), by May 1, 2019 for consideration.

news & events

AWARDS

Ed Wasserman Named Recipient of 2019 Richard S. Fountain Award

The Steel Market Development Institute's (SMDI) Steel Bridge Task Force has named Ed Wasserman, senior engineer of bridge design and engineering at Modjeski and Masters, as the recipient of the 2019 Richard S. Fountain Award.

Established in 2001 and named for the founder of the Steel Bridge Task Force, the Fountain Award recognizes leadership in steel bridge research and outstanding efforts to advance AASHTO specifications. Wasserman received the award at a Steel Bridge Task Force meeting in January in Orlando. The task force was formed more than 40 years ago to coordinate research that establishes safe, cost-effective steel bridges and to implement these developments into steel bridge design codes, specifically the AASHTO design codes.

"Throughout his career, Ed has made lasting contributions to the improvement of steel bridge design," said Robert Wills, vice president of construction market development for SMDI, a business unit of the American Iron and Steel Institute (AISI). "When he chaired the AASHTO T-14 Committee, Ed championed a multi-year research project that completely overhauled the AASHTO specifications to unify the design of straight and curved steel girders, resulting in more cost-effective steel bridge designs. He was always quick to engage the Tennessee Department of Transportation in the development and testing of new design strategies for construction innovations such as high-performance steels [HPS]."

Before joining Modjeski and Masters, Wasserman was director of the Structures Division at the Tennessee Department of Transportation, which won 34 design excellence awards over the course of his leadership. He served as chairman of the AASHTO T-14 Committee for 25 years as well as chairman of the AASHTO T-10 Technical Committee for Prestressed Concrete Design (later subsumed into the Technical Committee for Concrete Design). He has also won an AISC Lifetime Achievement Award.


SMDI

From left to right: Chris Garrell, National Steel Bridge Alliance, AISC's bridge division; Wasserman; Ronnie Medlock, High Steel Structures and chairman of the Steel Bridge Task Force Oversight Council; and Tom Macioce, Pennsylvania Department of Transportation and chairman of the AASHTO T-14 Committee.

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As a 100% American and employee-owned firm, Barton Malow provides construction services through a variety of delivery methods. Focused on safety, quality and productivity, we bring self-perform capabilities and custom technology applications to market in support of industrial and institutional clients across North America. Established in 1924 and now recognized as a Top 30 ENR Contractor, our team includes over 2,200 employees across 15 offices.

Barton Malow's Self-Perform Structural Steel team is currently seeking professionals in the following roles based at our Headquarters in Southfield, Michigan:

Senior Estimator • Project Manager • Superintendent

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QMC Contract Auditor

Quality Management Company, LLC (QMC) is seeking qualified independent contract auditors to conduct site audits for the American Institute of Steel Construction (AISC) Certified Fabricators and Certified Erector Programs.

This contract requires travel throughout North America and limited International travel. This is not a regionally based contract and a minimum travel of 75% should be expected.

Contract auditors must have knowledge of quality management systems, audit principles and techniques. Knowledge of the structural steel construction industry quality management systems is preferred but not required as is certifications for CWI, CQA or NDT. Prior or current auditing experience or auditing certifications are preferred but not required. Interested contractors should submit a statement of interest and resume to **contractor@qmconline.org**.

LATE MODEL STRUCTURAL STEEL FABRICATING EQUIPMENT

Peddinghaus FPDB-2500 CNC Heavy Plate Processor, 96" W, (3) Spindles, HPR260 Plasma, (1) Oxy, Siemens 840D, 2008 **#27974**

Peddinghaus FDB-2500A CNC Plate Drill with Oxy/Plasma Torches, (3) Head Drill, 96" Max. Plate Width, 2003 **#29542**

Controlled Automation DRL-336 CNC Beam Drill, 36" x 18", (3) 15 HP Spindles, Hem WF140 Tandem Saw, 2005 **#29344**

Peddinghaus PCD-1100 CNC Beam Drill, 44" x 18", (3) Spindles, 13.5 HP, 900 RPM, 3" Max. Diameter, 13" Stroke, 2008 **#29286**

Controlled Automation DRL344 CNC Beam Drill Line, Hem WF140 Saw, Tandem Line, 2008 **#24937**

Ficep Gemini 324PG Plate Processor, 10' x 40', 15 HP Drill, HPR260XD Plasma Bevel Head, (1) Oxy, 2014 **#28489**

Peddinghaus 623-0 CNC Angle Line, 6" x 6" x 5/8" Capacity, 75 Ton Punch, 230 Ton Shear, Siemens CNC Ctrl, 2006 **#29317**

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Anton Grassl

MAKING AN ENTRANCE

USING GRAPH PAPER to draw a building is typical. Using graph paper to *inspire* a building is not.

For the angular entry pavilion of the Exchange at 100 Federal Street in Boston, the design team of Perkins+Will (architect) and McNamara/Salvia, Inc. (engineer) did both.

The sharply faceted glass and steel structure, inspired by a piece of folded graph paper, incorporates a grid of steel plate fabricated by AISC member and certified fabricator Cives Steel Company–New England Division to achieve 75-ft main spans while also meeting the architectural vision of narrow members (less than 6 in. wide) with sharp edges. While the plate shapes required frequent lateral bracing, this issue was addressed via additional steel bracing plates that matched the panel spacing of the curtain wall system, thereby eliminating additional aluminum mullions in the process. In addition, Cives located and oriented all plate members to accurately maintain the 5$\frac{3}{8}$-in. offset required by the curtain wall. Where the vertical rib members were not oriented perpendicular to the plane of the glass, the outside plate edge was chamfered parallel to the glass plane.

The Exchange at 100 Federal Street is one of this year's AISC IDEAS^2 Award winners. You can read about all of the winners—and see plenty of amazing photos—in the May issue. And for more on the Exchange's entry pavilion, see "Functional Folds" in the January 2018 issue, available at **www.modernsteel.com**.