Modern Steel Construction

February 2022

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ON THE COVER: The roof of Las Vegas' expanded convention center shows off some steel flair, p. 36. (Photo by Oswald Design, courtesy of W&W/AFCO Steel)

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Duane K. Miller, P.E., Sc.D.

RECOGNITION OF SERVICE

After 44 years of distinguished service to our customers, and to the welding industry at large, Lincoln Electric would like to extend our gratitude to Duane K. Miller, P.E., Sc.D. and wish him all the best in his retirement.

Congratulations, Duane, on a successful career. Please accept my personal thanks for all you have done for Lincoln Electric.

To our customers and to the welding community, let me assure you that the support you have come to expect from Lincoln Electric, delivered in the past by world renowned experts such as Omer Blodgett and Duane Miller, will continue in the future. In doing so, I am equally pleased to announce our consulting partnership with Duane and his firm, Listen to the Steel. Under this consulting partnership, Duane will provide continued technical and educational support to our customers, as well as usher in Curt Decker, P.E., S.E., Ph.D, who will assume the role of delivering exceptional support to the welding industry.

Christopher Mapes
Chairman, President & Chief Executive Officer

LINCOLN ELECTRIC

I waited until after January 1 to write this editorial because, frankly, its message depended on the outcome of a specific football game.

Actually, that's only partially true. Regardless of the outcome, the point was always going to be about crucial moments or potential turning points, with the idea of using a football game as a metaphor for life since a typical game often includes several "big" moments that allow a team to "rise to the occasion" or "fail spectacularly."

In the case of the Citrus Bowl, which pitted the Iowa Hawkeyes (my team) against the Kentucky Wildcats in one of several exciting New Year's Day matchups, I identified at least four crucial moments where Iowa could have taken or lost control of the game. (There may have been more, but I was trying to keep an eye on the game while entertaining and conversing with several houseguests and eating fried chicken and other assorted health foods; see last month's editor's note for more on the role of fried chicken in my house on New Year's Day.) I won't bore you with the details on these moments, but let's just say (in my exceedingly biased opinion) that Iowa failed at every single one. I could point to a few other moments where they performed magnificently, but this is sports and my team lost another heartbreaker, so I'm bitter.

Within one football game, "defining" moments can look really, really good or really, *really* bad. But in the grand scheme of a season that was, by many measures, a success, they don't matter as much—unless you're a hyper-critical fan like me (but I digress). And they matter even less over the course of, say, a long coaching career (Iowa has had the same head coach, Kirk Ferentz, since 1999, and he has already become the program's all-time winningest coach).

Of course, defining moments and opportunities also occur when it comes to, say, steel design and construction. And we are working to create and identify several of them on the way to a long-term goal of increasing the speed at which a steel building or bridge can be designed, fabricated, and erected by 50% by the end of 2025 via our Need for Speed initiative. We're not banking on a Hail Mary pass (though those are certainly fun and dramatic, and very welcome when they work) but rather a balanced drive that leads to a touchdown, perhaps with an electric first-down play that gets the crowd roaring. Or if you're more defensive-minded, a nice Pick Six. Or maybe a season that starts slow but finishes strong. Or perhaps even a years-long build-up to a playoff run. (Hey, I can dream.)

OK, that's a lot of football analogies in a row, but you get the point. Achieving such an ambitious goal takes time and a concerted effort in multiple areas (design, fabrication, erection, detailing, recruiting, in-game coaching, special teams, quarterback play, and… sorry, I'm doing it again). You can learn about AISC's and the steel design and construction industry's ongoing Need for Speed efforts and observations at **aisc.org/needforspeed**.

You can also attend NASCC: The Steel Conference to learn about some of these speed-oriented ideas and perhaps even brainstorm (in person!) about some of your own with your industry peers. This year's edition takes place March 23–25 in Denver. You can learn all about it and register at **aisc.org/nascc**.

I hope 2022 is off to a good start for you, and I hope to see you in Denver!

Geoff Weisenberger
Senior Editor

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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**.

Approved Pretensioning Methods

What are the approved methods for pretensioning bolts in the *RCSC Specification for Structural Joints Using High-Strength Bolts?*

There are five approved methods to pretension bolts:

1. Turn-of-nut
2. Calibrated wrench
3. Twist-off tension control
4. Direct-tension indicator (DTI)
5. Combined methods

The specific requirements of each method are described in *RCSC Specification* Sections 8.2.1 through 8.2.5. There are a few provisions worth noting:

All of the methods require starting in the snug-tight condition. Note that for the combined method, this is achieved through the application of an initial torque, which is defined as the amount of torque necessary to reach the initial tension in a bolting assembly pretensioned with the combined method.

While the snug-tight condition was developed to be less demanding than the pretensioned condition, it does have essential requirements such as some tension (full effort of an ironworker or a few impacts of a wrench) and "firm contact" of the connected elements. The method requires snugging from the most rigid point outward. And it may require a repeat of the process.

Turn-of-nut is a reliable method. Match-marking is encouraged to improve that reliability and facilitate inspection.

Calibrated wrench is very dependent on the condition of the components and connected parts. Because of that, the *RCSC Specification* requires that the required torque be established every day by applying the method to assemblies in a tension-measuring device. The RCSC Committee understands that this is a burden but feels that it is needed to assure the required pretension is achieved. Note that the 2020 *RCSC Specification* added a prohibition against using the calibrated wrench method when the bolt head is the turned element.

Twist-off tension control works but, as with the other methods, depends on snugging prior to pretensioning, and these assemblies are sensitive to lubrication. Incorrect lubrication can lead to insufficient pretension or tension high enough to break the bolt. That is why these bolts are not permitted to be relubricated in the field.

DTIs provide an extra measure of pretension. The method does require a preinstallation verification that includes a demonstration that the device does not indicate required pretension before it should. The orientation and location of the DTI are important; protrusions are to be compressed, not ground off. And as with the other methods, DTIs have to be tightened in a systematic pattern. They deform inelastically, so if the bolt has been tightened and is later relaxed by the tightening of a neighboring bolt, the indicator may not reveal that.

The combined method includes an initial torque and additional rotation. The additional rotation is less than that required for turn-of-nut because the initial torque results in a tension that is greater than that resulting from the effort of an ironworker. That means the initial torque is dependent on the condition of the assembly. Therefore, it has to be confirmed weekly.

Tom Schlafly

Bridge Welding

When welding bridge beams, should I refer to AWS D1.1/D1.1M: *Structural Welding Code—Steel* or AWS D1.5/D1.5M: *Bridge Welding Code*?

Typically, bridges are fabricated per AWS D1.5. However, there are instances where AWS D1.1 should be used instead (both are available at **www.aws.org**). When welding a bridge, you should verify the required AWS standard on the final sealed and signed structural bridge plans (this is typically listed in the general notes). If the required standard isn't noted on the structural bridge plans, it may be specified in the controlling construction standard specifications or additional special provisions. Note that when AWS D1.1 is specified, this is often done for pedestrian bridges using hollow structural sections (HSS).

Devin Altman, PE

All mentioned AISC codes, standards, or manuals, unless noted otherwise, refer to the current version and are available at **aisc.org/specifications**, and AISC Design Guides are available at **aisc.org/dg**.

Repair of Corrosion Damage

Are there any AISC documents or technical guides related to repairing corrosion damage on steel framing?

AISC Design Guide 15: *Rehabilitation and Retrofit* has information on reinforcing steel members. AISC does not publish a document that discusses the strength loss due to corrosion. However, there are some publications that may be useful in your analysis. In the June 2012 ASCE *Journal of Bridge Engineering* article "Development of an Efficient Maintenance Strategy for Corroded Steel Bridge Infrastructures," the authors classify corrosion section loss as minor, moderate, or severe based on the corrosion depth ratio. They also developed equations for the effective thickness of corroded elements. In addition, the Transportation Research Board's *Guidelines for Evaluating Corrosion Effects in Existing Steel Bridges* (NCHRP Report 333) is a comprehensive document to evaluate steel members' corrosion effects.

Note that in order to evaluate the effects of corrosion, the steel must be properly cleaned and inspected. The actual rust coating has negligible structural value and is usually removed so the steel can be painted to prevent further corrosion. For evaluation, the section properties of heavily corroded members can be based on the remaining dimensions of the member, which can be measured with calipers or ultrasonic thickness meters after the corrosion has been removed.

Bo Dowswell, PE, PhD

Flange Local Bending vs. Prying

It is my understanding that when a column flange is checked for prying, the local flange bending limit state per Section J10.1 in the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360) is not applicable.

For example, AISC Design Guide 4: *Extended End-Plate Moment Connections Seismic and Wind Applications* does not require a local flange bending check. I've always assumed that the flange was checked using a yield line analysis. Is my understanding correct, and if so, is this stated explicitly in any AISC reference?

Your understanding is correct. However, I'm not aware of a source where this is explicitly stated. Design examples for end plate moment connections should check the flange strength using the equations in Design Guide 4. Design examples for welded moment connections should check the flange strength using Equation J10-1 in the 2016 *Specification*. Both methods are for the limit state of local flange bending.

The Flange Design Strength equations in Design Guide 4 (Tables 3.4 and 3.5) were developed using yield line analysis for the limit state of local flange bending. The yield line patterns assume the flange bends in double curvature due to the bolt clamping forces.

2016 *Specification* Equation J10-1 also used the yield line method to develop the initial solution based on a single-curvature pattern with a line load representing the loading element (beam flange or plate). For these connections, it is essential to limit the local flange bending deformation to an acceptable level to prevent rupture of the loading element at the center (where the loading element crosses the column web). Therefore, the initial solution was modified based on experimental results, making the final equation semi-empirical.

Bo Dowswell, PE, PhD

Stitch Welds in SCBF Braces

The AISC *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341), in Section F2.5b, specifically prohibits "connectors" from being located in the middle one-fourth of the clear brace length. From the commentary provided for this section, "connectors" appears to mean bolts and not welds. Would the word "connectors" in this sense apply to a welded stitch connector?

Yes. A welded stitch connector is a connector. This can be seen in the reference to "intermediate connectors that are welded" in Section E6.1 of the AISC *Specification*.

Larry Muir, PE

Tom Schlafly (schlafly@aisc.org) is AISC's chief of engineering staff and **Devin Altman** (altman@aisc.org) is a bridge steel specialist at AISC. **Bo Dowswell**, principal with ARC International, LLC, and **Larry Muir** are consultants to AISC.

This month's questions and answers were developed by Michael Desch, an AISC intern and current graduate student at the Illinois Institute of Technology. Thanks, Michael!

This month's Steel Quiz looks at the unique properties of structural stainless steel and how they informed the recently released AISC *Specification for Structural Stainless Steel Buildings*.

This new standard, ANSI/AISC 370-21, is available at **aisc.org/specifications**. (You can also read about it in last month's SteelWise article at **modernsteel.com**.)

1 Austenitic stainless steels have a modulus of elasticity that is ________ the modulus of elasticity used for carbon steel.
a. Higher than
b. Lower than
c. Equal to

2 **True or False:** The limiting width-to-thickness ratios for stainless steel shapes found in Tables B4.1a and B4.1b of the *Stainless Steel Specification* are generally smaller than the width-to-thickness ratios used for carbon steel in the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360-16).

3 The general stiffness reduction factor, τ_g, for all stainless steel shapes is:
a. 0.6 **b.** 0.7 **c.** 0.8 **d.** 0.9

4 **True or False:** When designing structural stainless steel for serviceability, standard structural theory for calculating the deflections of elastic beams may be used without modification.

5 **True or False:** The continuous strength method (CSM) presented in Appendix 2 of the *Stainless Steel Specification* uses an elastic linear-hardening material model for stainless steel, applicable for both static and dynamic design at ambient temperatures.

6 **True or False:** The nonlinear material model for stainless steel given in Appendix 7 of the *Stainless Steel Specification* can be used for both ambient and elevated temperatures.

7 When surfaces are under load and in relative motion, fastener thread galling may occur. Galling is more likely to occur in stainless steel bolting assemblies. Which of the following measures can be taken to avoid galling?
a. Reduce the bolt-tightening speed
b. Use high-silicon stainless steels
c. Use alloys of different hardness for the bolt and nut
d. Keep the bolting interface clean and free of grit and abrasive materials
e. All of the above

TURN TO PAGE 14 FOR THE ANSWERS

Everyone 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 **b.** Austenitic stainless steel has a modulus of elasticity lower than the modulus of elasticity of carbon steel. Per Table User Note A3.1, Austenitic stainless steel has a modulus of elasticity of 28,000 ksi. This is less than the carbon steel value of 29,000 ksi. Table User Note A3.1 also gives the modulus of elasticity, shear modulus, density, and coefficient of thermal expansion for austenitic, duplex, and precipitation hardening stainless steels.

2 **True.** The limiting width-to-thickness ratios found in *Stainless Steel Specification* Tables B4.1a and B4.1b are generally smaller than the ratios used for carbon steel in the AISC *Specification*. Several shape cases that appear in *Specification* Tables B4.1a and B4.1b have been combined in the *Stainless Steel Specification*. Most of the limiting ratios (λ_p, λ_r) in the *Stainless Steel Specification* tables are smaller than their *Specification* counterparts.

3 **b.** For all stainless steel shapes, the general stiffness reduction factor, τ_g, is 0.7. When performing a stability analysis, all stiffnesses that contribute to the stability of the structure should be multiplied by the stiffness reduction factor τ_g. *Stainless Steel Specification* Table C2.1 gives τ_g as 0.7 for all member types. In the *Specification*, there is no τ_g parameter. Rather, there is a 0.8 multiplier for the same purpose found in Section C2.3.

4 **False.** Per Section L2 of the *Stainless Steel Specification*, when designing for serviceability, standard structural theory for calculating the deflections of elastic beams may be used, but the modulus of elasticity E should be replaced with the reduced modulus of elasticity E_r. This substitution is made to account for the nonlinear material behavior of stainless steel. This method is noted to be accurate for cases where the maximum stress in the cross section does not exceed 65% of F_y. At higher levels of stress, it is very conservative.

5 **False.** Per Appendix 2.1 of the *Stainless Steel Specification*, the material model only applies to static design at ambient temperatures. This bilinear model is subject to the limitations of Section A-2.1. For more advanced material modeling, Appendix 7 should be used.

6 **True.** Appendix 7 of the *Stainless Steel Specification* models material behavior using nonlinear models for ambient temperature (Section 7.1) and for elevated temperatures (Section 7.2). The elevated temperature model uses parameters from Tables A-4.2.1, A-4.2.2, A-4.2.3, or A-4.2.4 to determine the strength/stiffness deterioration of the system at elevated temperatures.

7 **e.** All of the above. The user note in section J3.1 of the *Stainless Steel Specification* suggests all of these approaches—and others—to avoid galling.


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Stainless Steel, By the Book

BY MICHAEL MULHERN, PE, AND ERIC BOLIN

AISC's new *Code of Standard Practice for Structural Stainless Steel Buildings* smooths a path for the proper designation and design of structural stainless steel.

Courtesy TriPyramid Structures, Inc.

The custom structural stainless steel support system for these glass panels in Tampa, Fla., incorporated a number of structural stainless steel alloys and fabrication techniques. The materials and processes were chosen to maintain their corrosion resistance in this warm seaside location.

STRUCTURAL STAINLESS STEEL STANDS OUT.

But for a long time, ambiguity clouded its use. As a structural material, stainless steel is sufficiently different from carbon steel, and until recently, there was no U.S. *Code of Standard Practice* support specifically focused on structural stainless steel.

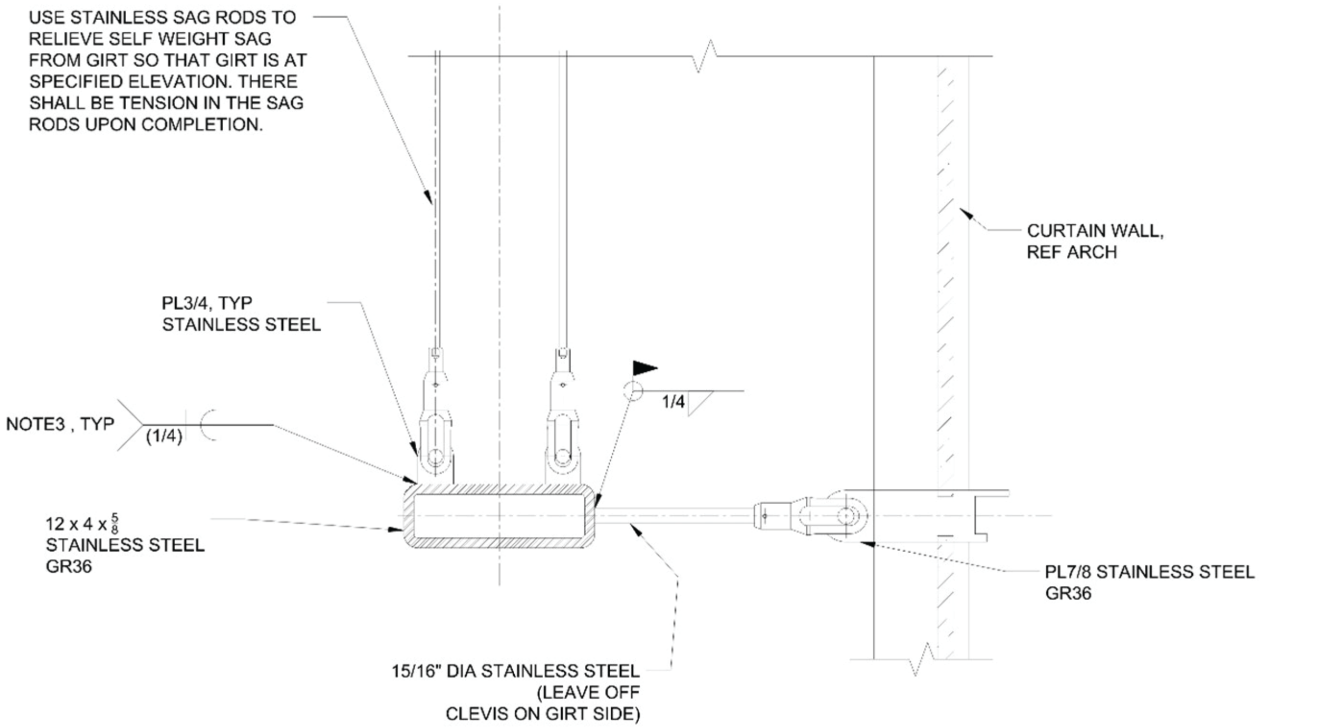
Thankfully, things have cleared up as AISC has released a pair of new standards dedicated to structural stainless steel: the AISC *Specification for Structural Stainless Steel Buildings* (ANSI/AISC 370-21) and the AISC *Code of Standard Practice for Structural Stainless Steel Buildings* (AISC 313-21). The former was covered in last month's SteelWise article "A New Shine on Steel Design" (available in the Archives section at **www.modernsteel.com**). To learn about the latter, keep reading.

The new *Stainless Code* sets forth the trade practices needed to give all stakeholders a high level of confidence and certainty when choosing structural stainless steel for their projects. Structural stainless steel is generally selected based on its corrosion resistance and, often, for aesthetic reasons, so the new code has been crafted with a framework for compliance in these areas.

For the sake of convenience and familiarity, the *Stainless Code* shares the same general organization and most of the same content as the AISC *Code of Standard Practice for Structural Buildings and Bridges* (ANSI/AISC 303). Of course, there are a few significant differences between the two publications, which are highlighted here.

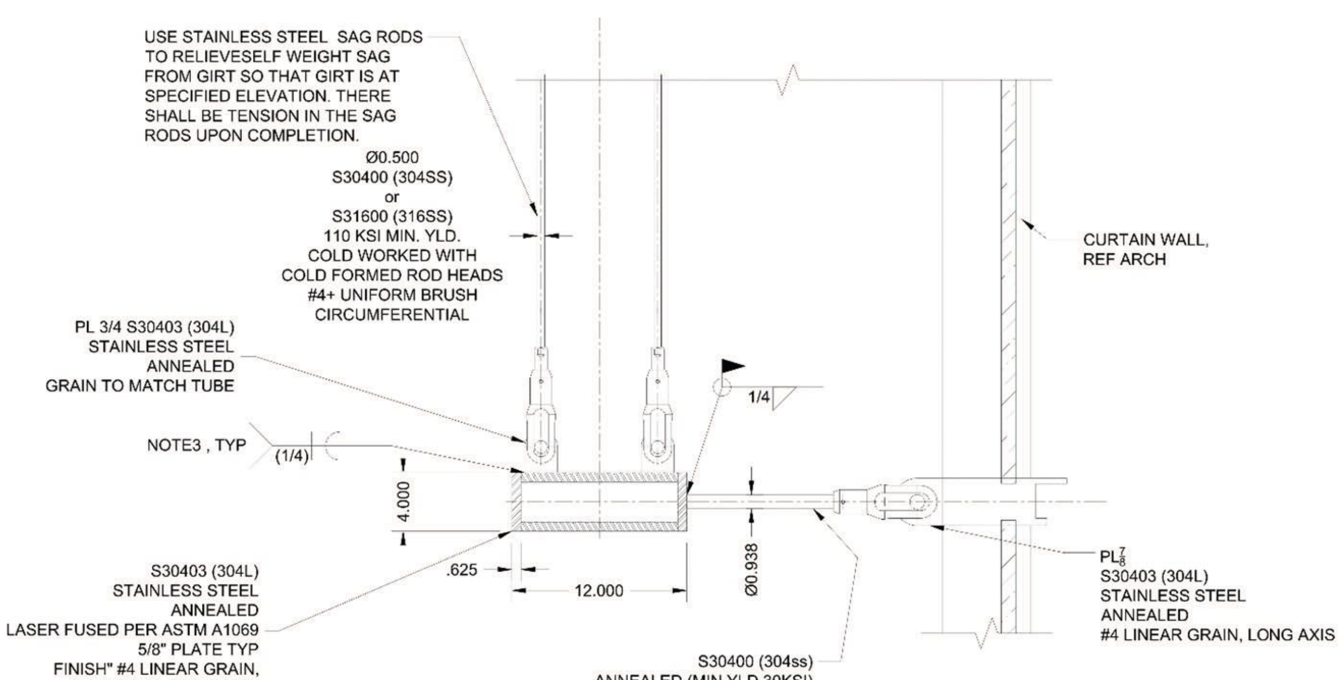
Material Selection

Properly selecting structural stainless steel has often been difficult for practitioners who do not use it on a regular basis. Stainless steel covers a wide range of alloys and grades, each with distinctly different properties—and in fact, improper selection or usage of certain stainless steel grades in the past has led to both property damage



TYPICAL CONSTRUCTION DOCUMENT FOR CURTAIN WALL SUPPORT SYSTEM

This detail illustrates the difficulties the design community has historically had in incorporating structural stainless steel into building applications. In this case, calling out a stainless steel plate as "GR36" will cause ambiguity as to what is required. AISC's new *Stainless Code* requires the alloy, its strength grade, and any finish requirements to be identified in the design documents. The minimum allowable strengths for the chosen alloys can be found in the appropriate ASTM specification or in AISC Design Guide 27.



WALL SUPPORT SYSTEM DRAWING WITH INFORMATION REQUIRED BY AISC 313-21

Here, the detail has been revised to incorporate the information required in the *Stainless Code*. Tube sections of this size are not commonly available in structural stainless steel, thus the assembly would need to be built up from plate. The code requires that built-up sections be fully dimensioned in the construction drawings, not simply called out as 12×4×5⁄8 tube steel, with the materials and finishes identified.

above: Structural stainless steels have been widely used in industrial process applications for many years. In this example, the framing system was fabricated from laser-fused stainless steel plate and will have an extremely long life span, even in a rugged, industrial environment.

right: This band shell in St. Paul, Minn., was built directly in the flood path of the Mississippi River. The 316L (S31603) structural stainless steel was finished with a very fine grain to reduce the chances of crevice corrosion. The tie rod system is made from cold-drawn stainless steel with a minimum yield strength of 110 ksi.

and loss-of-life incidents. As such, a major priority of the *Stainless Code* is helping designers select the appropriate structural stainless steel grade for a specific project. Again, recognizing that structural stainless steel is often specified for its corrosion resistance, the new code directs designers to assess the environmental conditions as the first step in evaluating which structural stainless steel alloy is appropriate.

Covered in the scope statement, the grades of structural stainless steel that are used in construction include austenitic, austenitic-ferritic (aka duplex stainless steel), and austenitic-martensitic (aka precipitation hardening stainless steel). In the case of precipitation-hardening structural stainless steels, the *Stainless Code*'s scope is limited to using the material for tension members, fittings, and fasteners. This does not mean that other alloys can't be used or that precipitation-hardening alloys can't be used in other applications. However, it does mean that when other alloys are used, stakeholders must recognize that this is outside of what is covered by the *Code of Standard Practice*. In some cases, this adds extra layers of research, testing, certification, and perhaps uncertainty as to whom is responsible should difficulties arise.

Surface Finish

Surface finish is another area where structural stainless steel differs from carbon steel. A defining characteristic of stainless structural elements is that they are typically not painted or coated as, in some instances, coatings can be detrimental to the material's ability to resist corrosion. Structural stainless steel has a wide variety of surface treatments available, ranging from a sanded finish to a highly polished full-color buff mirror. Not only does surface treatment satisfy aesthetic goals, but it also impacts the long-term performance of the material, with smoother surfaces providing better corrosion performance.

While the *Stainless Code* doesn't attempt to codify all possible finishes, it does provide guidelines for all parties as to how the finish requirements are to be communicated. It also defines the obligations of the fabricator and erector to provide protection of the finishes so that the erected materials maintain the finish that was applied in the shop.

Built-Up Members

Many of the structural shapes listed in ASTM A6/A6M: *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling* are not readily available as rolled or extruded shapes in structural stainless steel. In the event a shape is not made or available in structural stainless steel, it is common practice to fabricate a built-up shape that is dimensionally similar to a rolled structural shape. The *Stainless Code* provides guidance on information such as tolerances when built-up structural shapes are used for a project.

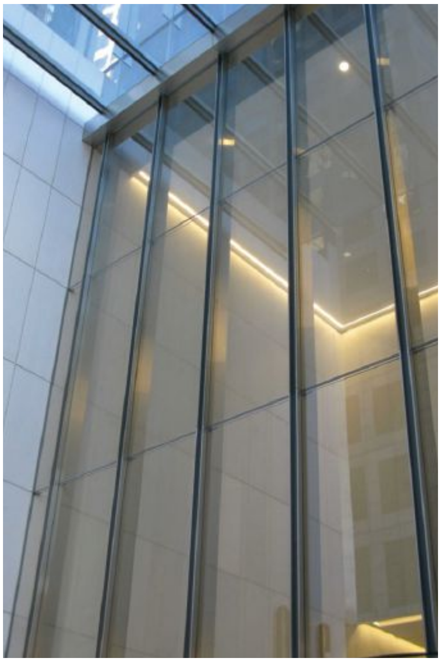
Bimetallic Interface

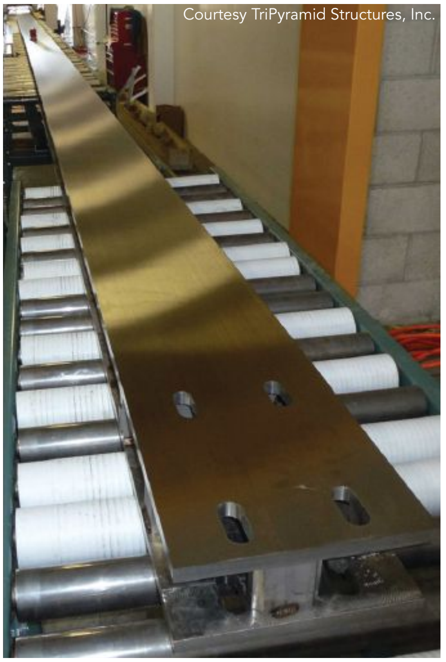
The *Stainless Code* also covers bimetallic interface—when two dissimilar metals are in contact—which is not specifically covered in the carbon steel standards. When structural stainless steel is in direct electrical contact with a dissimilar metal—typically carbon steel or aluminum—and there is an electrolyte present, the possibility of galvanic corrosion arises. As such, bimetallic interface is listed in the *Stainless Code*'s scope statement as an issue that needs to be considered for design. In addition, the Commentary notes that processes or elements needed to mitigate corrosion at a bimetallic interface are outside the scope of the fabricator's or erector's work.

Design Documents

Section 3.1 of the *Stainless Code* lists the information that needs to be communicated in the design documents. Most of the information is the same as what is required for carbon steel projects, with a few additional items:

- Information on the built-up shape, including overall dimensions and plate thicknesses of the constituent shapes
- The method used to mitigate galvanic corrosion at a bimetallic interface, such as coatings, gaskets, bushings, or other means to prevent this issue





Courtesy TriPyramid Structures, Inc.

This glass entry in New York City is framed with vertical structural stainless steel mullions. While the design, fabrication, and erection practices needed to execute this type of work are similar to those used for carbon steel, they are not the same. The *Stainless Code* provides the necessary guidance to properly use these materials.

- Structural stainless steel alloys must be specified by both the Unified Numbering System (UNS) and strength grade where applicable. The UNS is an identification system for metals and alloys that is adopted by ASTM and in compliance with SAE J1086

Surface Contamination

Termed "free iron contamination" in the *Stainless Code*, the surface of structural stainless steel can stain if it comes into contact with deposits containing iron, such as carbon steel or other steel alloys. The use of recycled blast media, recycled abrasives, steel wire brushes, and steel chains for material handling are common sources for free iron contamination. The *Stainless Code* provides guidance on how to avoid free iron contamination when fabricating, transporting, and erecting structural stainless steel.

Exposed Structural Stainless Steel

In some building applications, structural elements are exposed to view and designated to a specific level of architecturally exposed structural steel (AESS), which are listed and detailed in the AISC *Code of Standard Practice*. The *Stainless Code* includes similar provisions for architecturally exposed structural *stainless* steel (AESSS). As with AESS, the AESSS designation lists multiple categories to properly define the finish level required for the exposed elements.

Additional Guidance

Here are a few additional provisions in the *Stainless Code* that may give you a better understanding of structural stainless steel:

- The majority of stainless steel used for structural purposes is in the austenitic group, the most common being the 304/304L (S30400/S30403) and 316/316L (S31600/S31603) grades.
- Using plain or galvanized carbon steel fasteners is prohibited for structural stainless steel connections in the permanent structure. However, they may be used for temporary erection aids with approval by the owner's designated representative for construction. Although not discussed in the *Stainless Code*, it is not permitted to use structural stainless steel fasteners to join carbon steel material that has been galvanized as this can cause galvanic corrosion problems.
- Thermal (oxy-fuel) cutting is not permitted for structural stainless steel.
- Density and the coefficient for thermal expansion differ between carbon and structural stainless steel. Information on these properties can be found in the *Stainless Specification*.

In addition to introducing the new *Stainless Code* and *Stainless Specification*, AISC is in the process of updating its Design Guide 27: *Structural Stainless Steel*, which will be available later in 2022. This updated version will include a wide range of information and design aids to assist with designing projects using structural stainless steel and will be a useful companion to the new AISC structural stainless steel standards.

You can download the new AISC *Stainless Code*, *Stainless Specification*, and *Code of Standard Practice* at **aisc.org/specifications** and Design Guide 27 at **aisc.org/dg**. ■

Michael Mulhern (**mcm@tripyramid.com**) is president of TriPyramid Structures and **Eric Bolin** (**bolin@aisc.org**) is a staff engineer in AISC's engineering and research department.

Warehouse Surge

BY JOE DARDIS

Warehouse work currently offers a lot of opportunity for steel construction.

Fig. 1.
Warehouse Market Percentage by Sq. Ft (Nonresidential)

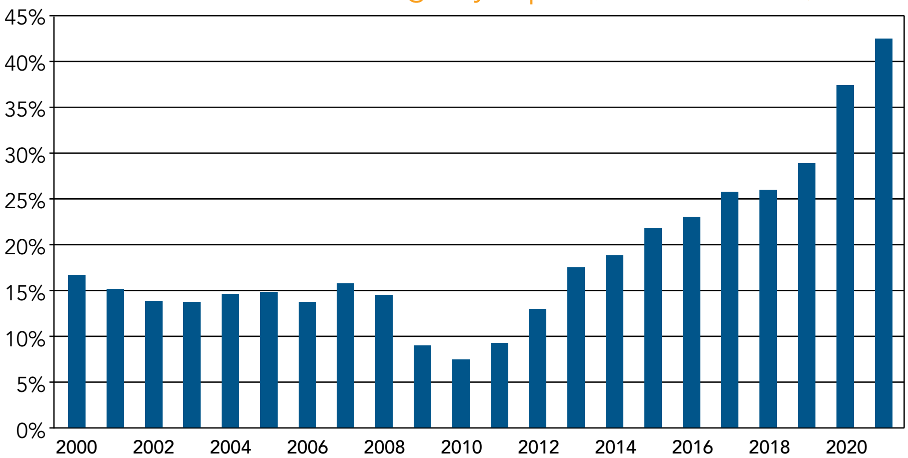


Fig. 2.
Historical and Projected Warehouse Starts (in Millions of Sq. Ft)

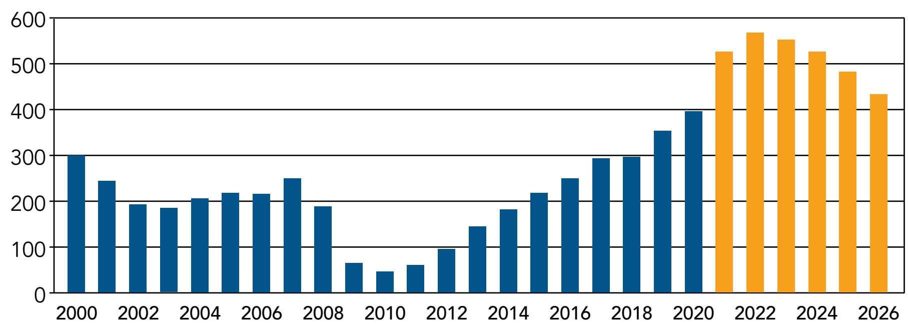
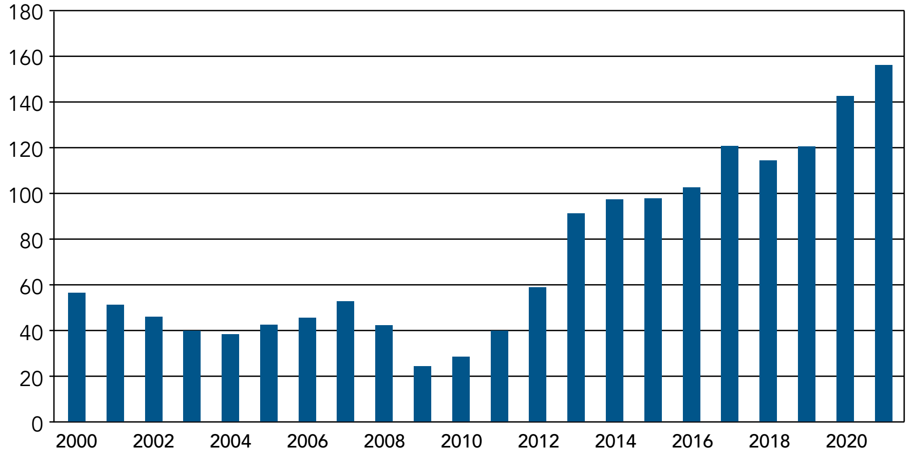


Fig. 3.
Average Warehouse Size (in 1,000s of Sq. Ft)



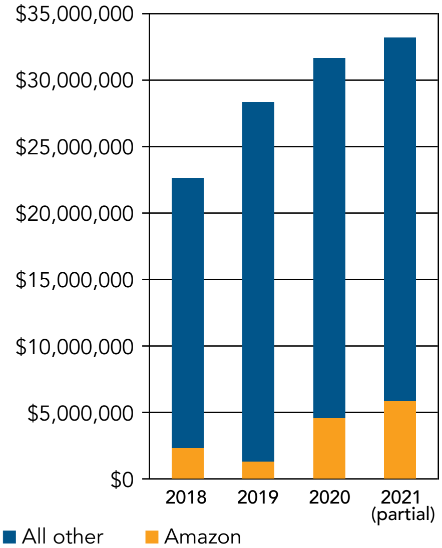
AS THE U.S. NONRESIDENTIAL building market has sputtered in recent years, one component has bolstered it: warehouses. The warehouse market, which has been steadily growing since the Great Recession of 2008, is in the middle of an unprecedented surge and now accounts for about 43% of all nonresidential square footage (see Figure 1). According to Dodge Data and Analytics, the projected 532 million sq. ft of warehouse construction in 2021 will grow to 570 million sq. ft in 2022. While Dodge predicts a steady decline in the warehouse sector beyond 2022, it also predicts that yearly warehouse square footage will still exceed 2020 numbers until at least 2026 (see Figure 2).

Despite the fact that new warehouse square footage is at a record high, the number of warehouses being built today has actually decreased. For example, there were roughly 5,400 warehouse projects built in 2000 and approximately 2,800 built in 2020. While this doesn't appear to add up, the answer is actually simple: Warehouses have gotten bigger. Where the average warehouse size in 2000 was roughly 57,000 sq. ft, today it's roughly 150,000 (see Figure 3).

What's driving the surge in square footage and the desire to build bigger warehouses? In a word, e-commerce. Both warehouse construction and e-commerce had been steadily growing prior to COVID, but when lockdowns were initiated and consumers were restrained or uncomfortable visiting brick-and-mortar retailers, online buying began expanding even more rapidly.

It's probably not shocking that Amazon, which has a 41% market share of all U.S. retail e-commerce, was at the forefront of this expansion. Amazon had been a big warehouse spender prior to COVID, building $2.4 billion and $1.3 billion of warehouse space in 2018 and 2019, respectively. However, this spending increased to $4.6 billion in 2020 and $5.9 billion in 2021 (through November). That's a 354%

Fig. 4.
Value of Warehouse Market
(in 1,000s of Dollars)



increase in just the past two years!). Amazon alone accounted for 18% of warehouse construction spending in the first 11 months of 2021 (see Figure 4). That's more than double the amount of warehouse spending than any other U.S. warehouse owner or property developer.

The current boom and forecasted future demand for warehouse space are definitely beneficial to the structural steel industry in terms of the volume of steel produced and fabricated. While the majority of warehouses are built with precast tilt-up panel exteriors, consider that these facilities will include 500 to 600 million sq. ft of interior space every year for the foreseeable future–all of which can be steel-framed. While the rest of the nonresidential market is still catching up from COVID, warehouses can help fill the gap for steel fabricators that are seeing reduced work in other sectors. ■

Joe Dardis (**dardis@aisc.org**) is AISC's senior structural steel specialist for the Chicago market.

All-around Architectural Enthusiast

INTERVIEW BY GEOFF WEISENBERGER

An AISC steel specialist leverages his diverse background to help design teams make the most of their structural steel projects.

ALEX MORALES IS AISC'S structural steel specialist for the Houston area—whose climate he enjoys because it reminds him of his native Brazil. He grew up with a love of art, drawing, and old buildings—and he has his grandmother to thank for urging him to channel these passions into a career in architecture.

In this month's edition of Field Notes, Alex discusses his grandmother's support and influence, his career working for architectural and general contracting firms, his role and philosophy as a structural steel specialist, how he ended up in Houston, and what he enjoys most about the city (besides the heat and humidity).

Field Notes is *Modern Steel Construction*'s **podcast series**, where we interview people from all corners of the structural steel industry with interesting stories to tell. Listen in at **modernsteel.com/podcasts**.

You're originally from Rio de Janeiro.

Yes, I come from the land of palm trees and sunshine. Rio has a little over 18 and a half million people, and a fun fact is that it's actually the home of the largest urban rainforest in the world.

What brought you to the U.S.?

I didn't quite know where I was going to end up, and the short story is that I ended up in the U.S. for a career. I remember being enthralled with churches and landscapes and drawing. And I was at a time in my life where my grandmother was really pressing me on what I wanted to do when I grew up. She's probably the most phenomenal person I've ever met in my life. She's the one that raised me and instilled the principles of hard work in me.

I enjoyed drawing, sketching, and looking at old buildings, and I told her that I wanted to be an artist. That was my answer to my grandmother, and she quickly interjected and said, "No way. You've got to be able to provide for yourself. I'm not going to be feeding you for the rest of your life." I had a guidance counselor in school that suggested that I might like architecture, and I was always enamored by the old resolute churches that the Portuguese built way back in the 1500s in the 1600s. So I looked at several universities in the U.S., and I ended up in College Station, Texas, at Texas A&M University.

I lived in College Station for a few years when my mom was a PhD student at Texas A&M. What made you decide to go there?

I know this sounds really strange, but it was the heat and humidity since, coming from Rio, they were very familiar to me. But A&M also had a really rigorous and well-rounded architecture program—very credible and recognizable—and I fell in love with the program.

So what did you do when you graduated?

I started in residential architecture. I began with an internship, and I was designing custom homes. It was a small firm, and I worked on a very high-profile project. The only reason I say "high-profile" is because it was the first time we had done a LEED-certified project, back when LEED was first gaining some steam. That internship definitely kicked off my career through residential design, but I wanted to spread my wings and I ended up working for a commercial firm in Houston, and we did anything from K-12 schools to healthcare to fire stations and other municipal, institutional projects. When I had my first chance to go out into the field and interact with the owner and general contractor and sit in meetings with them, it added the dimension of the business aspect. The human interaction, the client engagement, and the project management aspects were a new world. And I started asking questions about the various trades and materials, and I eventually started working for a general contractor. So I ended up going from the design side to the construction side.

That's quite the evolution. I have to ask, as someone whose first love was art drawing, do you still draw or even design buildings?

Yes, I definitely still draw. I work with materials, and I build things. It's like trying to get things out of your head into something that that you can actually see and that others can see and appreciate. I'm still involved locally with lots of architects, and I serve on my local AIA board, and I think I'm always going to be in the world of architecture in some capacity. There are folks that might think that AISC is removed from architecture, but I would actually challenge that and say that we in the steel industry have a peripheral impact on the design process itself. At the end of the day, my goal is to intermarry the worlds of structural steel design and construction and architecture. That's where the big conversations happen and the lightbulb moments come up, and that's when you're able to add value to architects and their designs and provide options they might not have known about before.

On that note, can you talk about your role as a structural steel specialist for AISC?

Sure, we (the specialists) are tasked with delivering subject matter expertise to professionals in architecture, engineering, contracting, and increasingly owners. When I walk into an architect's office, they might say, "You know, we already have a structural engineer that helps us with that aspect of the design, and we defer to them." And as a specialist for AISC, I try to challenge that mindset. We can share our portfolio of knowledge with architects and even structural engineers and say, "Hey, there's actually a better way to do this," or, "There's a more elegant approach to get you where you want to get, and this actually makes more sense for your owner," So what I'm really doing is delivering all of that knowledge in the form of presentations, whether on sustainability or design efficiency or the leanest way that we could realize a project using structural steel. And we have AISC's Steel Solutions Center at our disposal, and we can come up with solutions like saving money by switching from a moment connection to a different type of connection or eliminating some columns and still meet the loading criteria.

And we also try to bring the expertise of our member fabricators into play. They're actually able to say, to an architect, for example, "This is how my shop operates, and if you want a more efficient design, then I suggest that we approach it this way. Maybe we modularize it or use repetitive columns and beams and still meet what you're trying to go for." So these are the conversations that we interject and infuse into the design.

A recent success here in Houston was working with a fabricator—MSD Building Corporation, an AISC member fabricator—for a healthcare client here in Houston, and we ended up flipping a parking garage from concrete to steel. So that's a living, physical example of what we do as specialists out in the field.

That is indeed a great success story. Speaking of Houston, what do you like most about it?

It sometimes feels like the world's best-kept secret, but the food scene here is amazing. We've got some world-class chefs. But it's not just about that. It's because the food comes from the diversity of the area. It's the most diverse city in the country, according to sources like the Kinder Institute at Rice University in Houston. I can go to a restaurant here and hear, like, seven different languages being spoken simultaneously. The other thing I love about Houston is, as I mentioned with College Station, the heat and humidity. It's a closer climate to home than in most other places in the U.S.

Speaking of food, what Brazilian dish do you miss most?

There's a traditional dish called feijoada, which is like a black bean stew that can involve any sort of meat. It's interesting that it comes from a really warm climate because it's so hearty, which actually makes it really good for cold climates too. I'd suggest that if you go to a Brazilian restaurant in America, try to get past all the big meats and ask for feijoada, and it will transport you to Brazil. ■

*This column was excerpted from my conversation with Alex. To hear more from him, including his love of soccer (futebol in Portuguese), his role as a polyglot (and also a "polyglutton"), and his thoughts on caipirinhas, check out the February Field Notes podcast at **modernsteel.com/podcasts**.*

Geoff Weisenberger (**weisenberger@aisc.org**) is senior editor of *Modern Steel Construction*.

Early Integration

BY JEF SHARP

Fabricators can benefit in myriad ways from an integrated steel delivery model.

Fenway Center Phase II in Boston (center of image) is a a mixed-use air-rights project over the Massachusetts Turnpike (I-90) and active rail lines and is adjacent to Fenway Park.

Courtesy of Gensler

NEED FOR SPEED

AISC's Need for Speed initiative recognizes technologies and practices that make steel projects come together faster. Check out **aisc.org/needforspeed** for more.

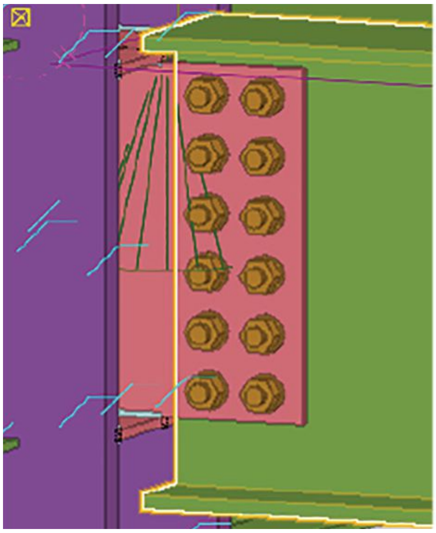
I BELIEVE IN surrounding myself with people who are wiser than I am.

That is what has enabled the Qnect team to build a smart and effective software company. In order for *us* to succeed, we recognized early on that the *fabricator* has to succeed, and that meant we needed to find ways to make the fabricator's job easier.

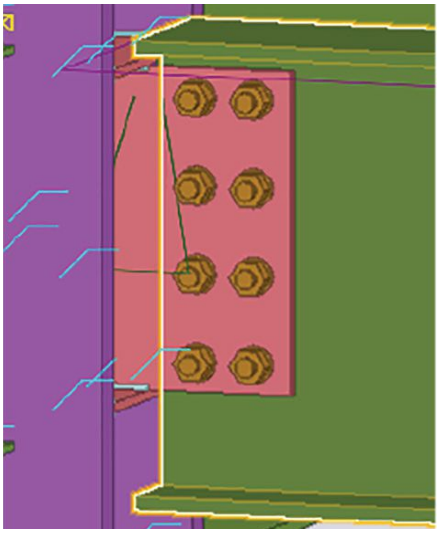
We invited a smart fabricator and a talented structural engineer to the team of Qnect partners/investors to give us feedback and ideas. One of the brightest ideas that came from our initial brainstorming enlightened us on how to best partner with fabricators' goals—one of the most important of which is making design documents more complete. We ran with this concept and coined it "ISD."

What exactly is ISD? You've probably heard of IPD or integrated project delivery. ISD is integrated steel delivery. In the ISD

W24 with R = 90k 12-1″ F3125 Grade A325 bolts with ½″ pl and 5⁄16″ weld



W24 with R = 90k 8-1″ F3125 Grade A325 bolts with ½″ pl and 5⁄16″ weld



A bolted joint before and after optimization.

process, the 3D model of the steel structure is fully connected early, with the connections engineered, detailed, and optimized often before the fabricator is even awarded the job.

So how is it beneficial to fabricators? Here are five ways:

1. It reduces uncertainty in bidding and makes it faster and easier to bid the job. According to Bill Lo, president of Crystal Steel, "It helped us meet a demanding schedule. The whole job went very smoothly."
2. It allows the fabricator to understand the full and exact extent of all the fitting material instead of the usual 10% to 20% guess
3. Many of the issues that tend to surface downstream are resolved early, thus reducing RFIs and giving the fabricator a better chance at stable planning for shop production
4. It reduces labor and material. As Charles Hongell, vice president with WSP, states, "The exact steel length is known at the time of award, which reduces waste material from end cuttings."
5. With the optimization and value engineering that happens in this process, it makes steel be more competitive. It lowers fabrication and erection costs and reduces time so jobs can get built according to the planned schedule

Last year, Qnect was hired to provide an ISD project for the Boston engineering firm LeMessurier. The project, called Fenway Center Phase II, is a mixed-use air-rights project over the Massachusetts Turnpike (I-90) and active rail lines and is adjacent to Fenway Park (home of the Boston Red Sox). The framing system uses 15,000 tons of structural steel.

During the early stages of engineering, which involved connection engineering and modeling, collaboration between LeMessurier, the owner, general contractor, connection engineer, and steel detailer led to several complex joints and framing conditions being optimized. For example, a brace that was initially designed to pass through a beam would have resulted in a very large beam web reinforcement. By determining which upsized beam would eliminate the doubler, the team was able to reduce the overall cost and fabrication complexity.

And by the time the job was ready to bid, the team had reduced material for the fabricator, labor cost in the shop and field, eliminated multiple reinforcement doublers, minimized shop and field welding by identifying efficient shop assemblies, and eliminated more than 20,000 unnecessary bolts. The process created a well-thought-out and fully engineered project model that the fabricator could rely on for fast, accurate estimating and efficient fabrication and erection. The formula delivered repeatable value and will just get better as we continue to evolve and refine the software.

In the process of designing this delivery method, I've picked up a lot of valuable information about construction, steel, engineering, and detailing—and also people. The steel industry is filled with remarkable people, and what everyone does on a daily and weekly basis is nothing short of miraculous. We turn iron ore and scrap metal into fully recyclable structures that will serve human needs for hundreds of years. The producers make it possible with chemistry and electric-arc furnaces, and the fabricators, detailers, erectors, and others carry the ball over the finish line. They deserve a lot of respect and admiration.

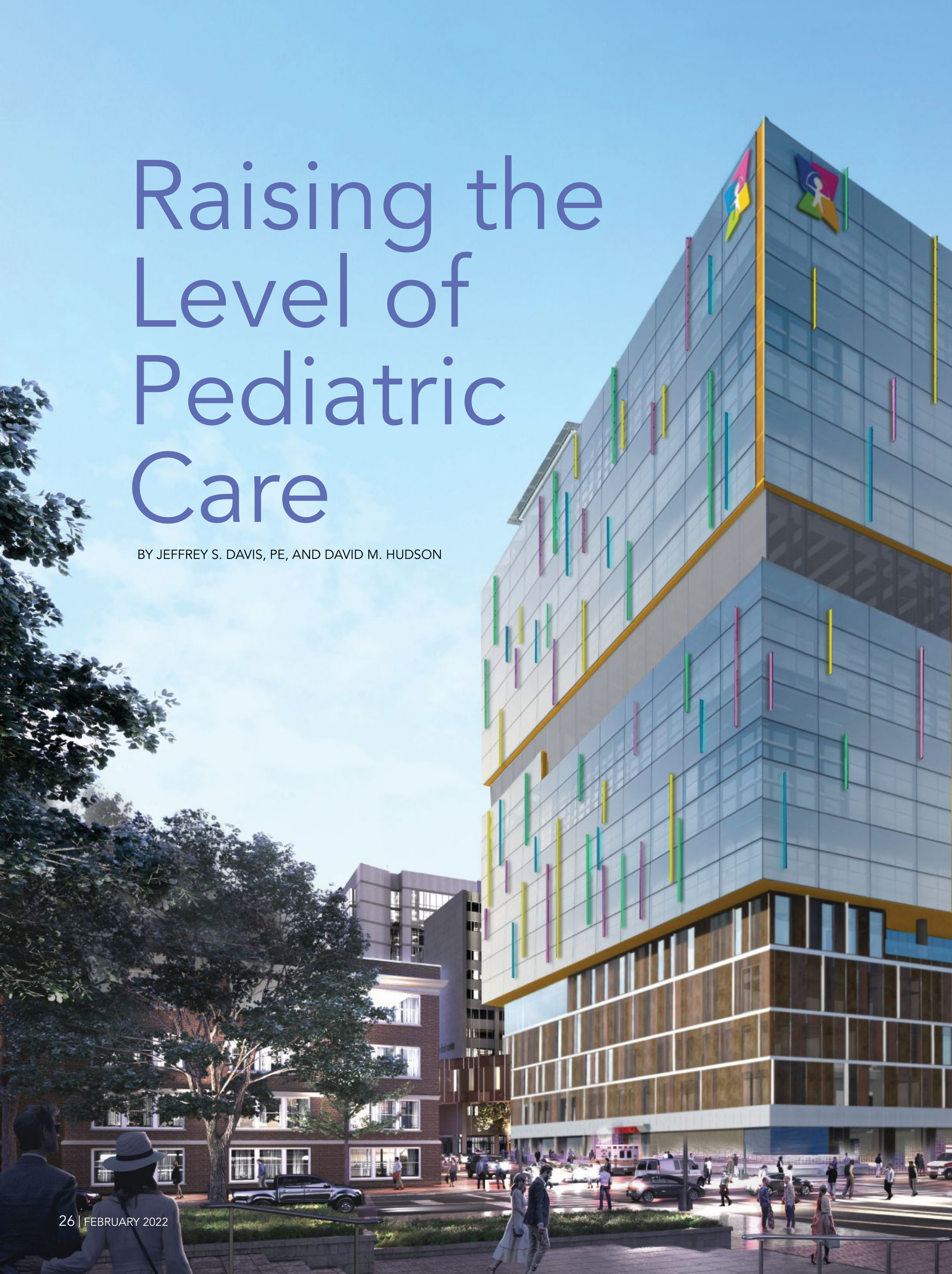
And they also deserve data—early in a project. Early, deep-dive data will continue to assist fabricators and improve the steel industry. With the value created by the intensely collaborative ISD process, we can all produce data that not only identifies and solves issues upstream but also creates the opportunity for leadership decisions that can have positive schedule and cost ramifications. By generating early data that is used to direct an early connected model, we can give fabricators and erectors a complete design and a clearly developed blueprint that will ease and speed up their work. ■

*You can learn more about the connected model by attending the panel discussion "T5: The Myriad Ways that Connected Models Drive Efficiency" at the upcoming NASCC: The Steel Conference in Denver, taking place March 23-25. To register, visit **aisc.org/nascc**.*

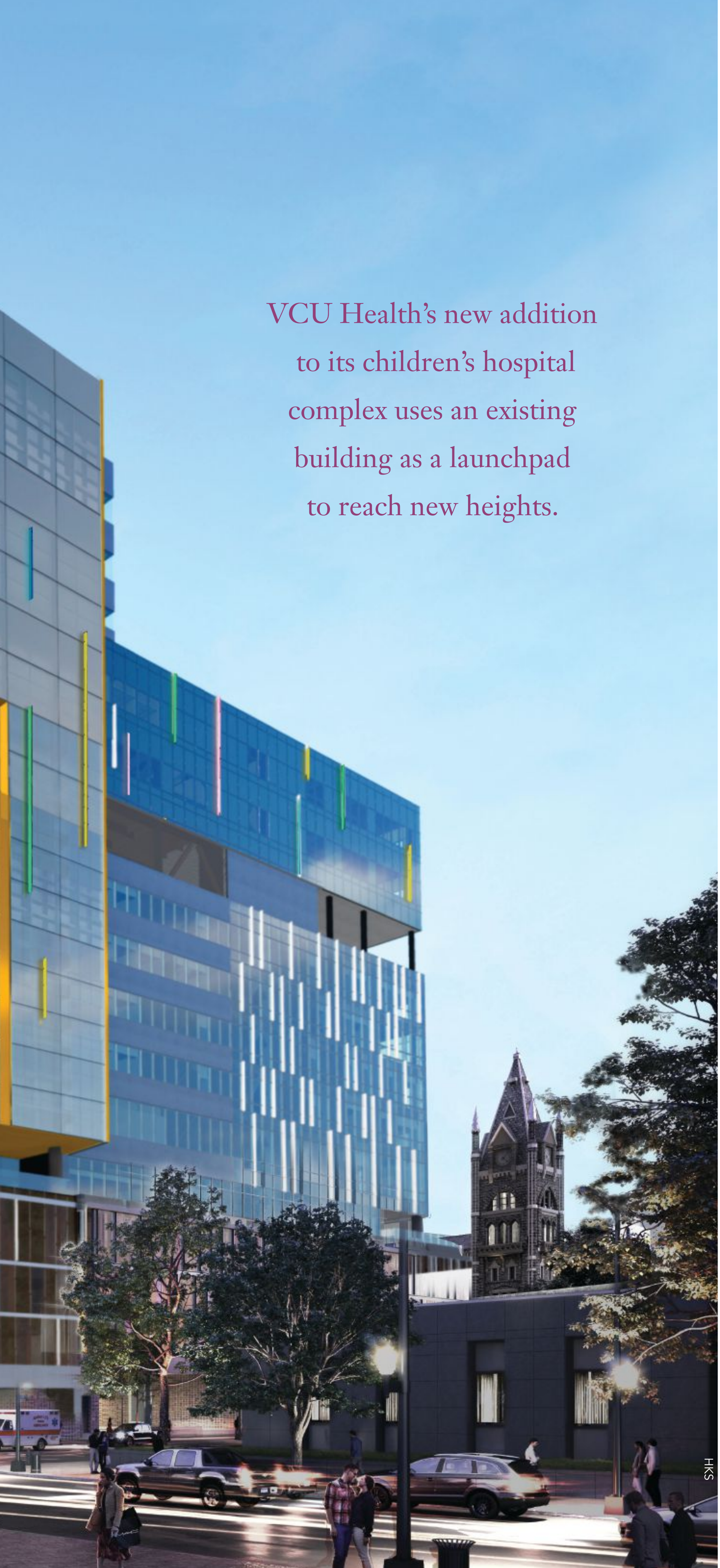
Jef Sharp (**jsharp@qnect.com**) is the CEO of Qnect.

Raising the Level of Pediatric Care

BY JEFFREY S. DAVIS, PE, AND DAVID M. HUDSON



VCU Health's new addition to its children's hospital complex uses an existing building as a launchpad to reach new heights.



HKS

THE CHILDREN'S HOSPITAL of Richmond Pavilion at Virginia Commonwealth University (VCU) is still growing up.

The 640,000-sq.-ft pediatric outpatient care facility on the VCU Health campus in Richmond, Va., opened in 2016 and situated seven steel-framed floors atop an eight-level parking garage (four levels above grade and four levels below). But it was designed to accommodate six additional future clinical floors plus a mechanical penthouse level.

Structural engineer Dunbar, which designed the framing system for the original building, was tasked with an even greater challenge: building alongside, up, and over the top of the existing outpatient facility in order to provide inpatient pediatric medical services, which are currently spread among several other existing buildings around the campus. This consolidation of pediatric services, nicknamed Wonder Tower, culminates in a new 20-story tower, plus three additional penthouse levels for elevator equipment and helipad access, in addition to two new levels atop the original, adjacent outpatient building—600,000 sq. ft of new construction in all.

Constraints and Constructability

The design team didn't have much wiggle room when it came to the new building's dimensions. The available footprint north of the existing outpatient pavilion was 237 ft wide by a mere 90 ft deep. The bottom eight levels of the new building were designated for parking and support space (four above grade and four below) and were constructed using cast-in-place concrete to match the parking scheme of the existing outpatient building, but all framing above the parking levels was steel-framed. In order to provide a floor plate capable of supporting an efficient 24-bed unit per floor, each of the steel-framed levels actually cantilevers beyond the property line above the sidewalk.

DPR Construction, the project's construction manager, prepared for the following trifecta of challenges before the first shovel hit the dirt:

- An aggressive owner goal of admitting the first patient by the spring of 2023 (the project began planning in late 2018)
- A super-tight site since the building went all the way to the property line
- Constructing right up against and tying into a fully operational outpatient children's facility whose drive aisles under the building, loading dock, and ambulance bays couldn't be obstructed

A new 20-story tower on the VCU Health campus is scheduled to admit its first patient next year.

Dunbar

The available footprint north of the existing outpatient pavilion was 237 ft wide by a mere 90 ft deep. In order to provide a floor plate capable of supporting an efficient 24-bed unit per floor, each of the steel-framed levels actually cantilever beyond the property line above the sidewalk.

Dunbar

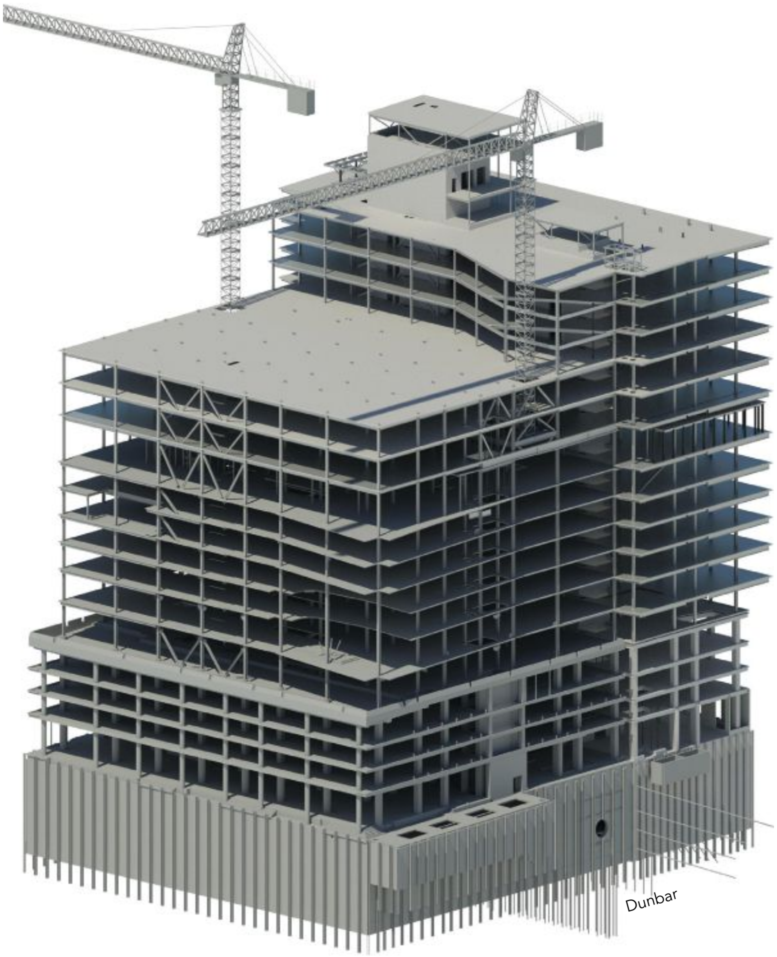
Dunbar

With these and other challenges in place, it was imperative that the design team, owner, and construction manager cooperate in an integrated project delivery (IPD) manner. All stakeholders met onsite every other week in the Children's Hospital "Big Room" during the pre-pandemic design phases of the project. These meetings included the fabricator, Prospect Steel, which scheduled steel shipments to address the extremely limited lay-down area (the framing system uses 3,200 tons of steel in all). Together, the team devised multiple solutions to enhance constructability and adhere to quality and schedule requirements.

Thoughtful Deck Selection

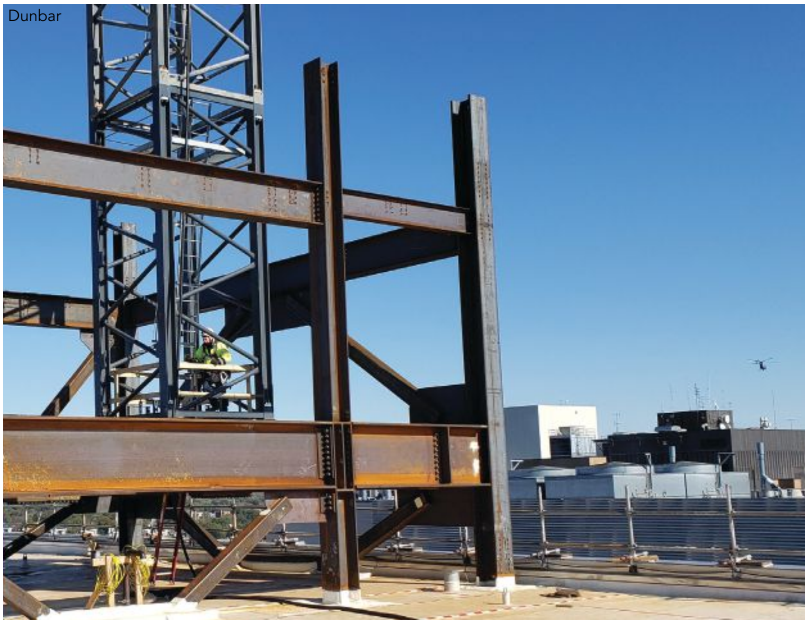
One of these solutions, while seemingly mundane, proved immensely beneficial. The issue was how to address patient bathroom floor recesses, which are typically challenging when it comes to maintaining floor fire ratings. Dunbar suggested that the floor recess be limited to 1½ in. in order to simplify the steel framing, and both architect HKS and DPR agreed that this was feasible. Typical floor framing was specified as 3½ in. of lightweight concrete over 3-in. 20-gage steel deck, for a total slab thickness of 6½ in., in order to provide the designated two-hour fire rating. Typical beam spacing was 10 ft, 4 in., but by tightening up beam spacing to around 7 ft and switching to 1½-in. 18-gage deck under the patient bathrooms, thus reducing the slab thickness to only 5 in., the same 3½ in. of concrete could provide the needed fire-rating without having to vary the top of steel elevation of any of the beams.

VCU Health and HKS determined that the outboard patient bathroom was the preferred arrangement, further simplifying



above:
A 3D model of the project's structural framing system.

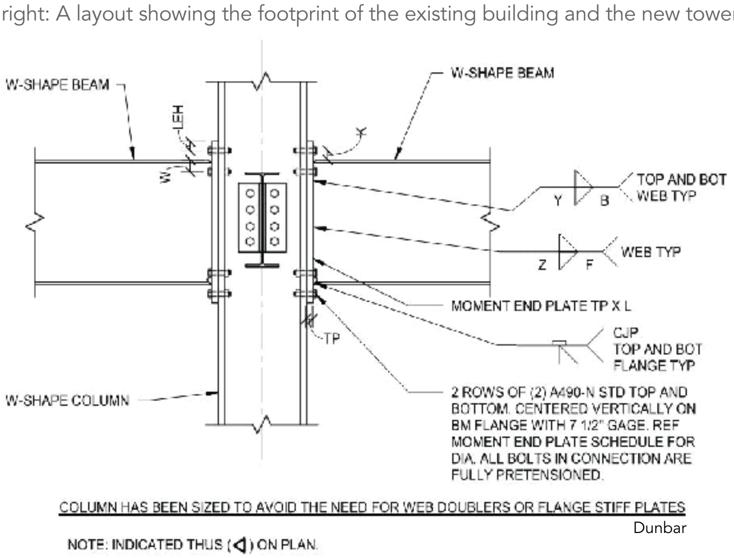
left and below: The steel frames supporting the tower cranes each used five building columns, floor and roof beams for the planned building expansion, and some permanent vertical building bracing.



above: One of the two tower cranes supported above the existing roof.

below: A detail drawing of a typical moment connection to a column flange.

right: A layout showing the footprint of the existing building and the new tower.



framing accommodations. The entire cantilevered perimeter of each patient floor was transitioned to the 1½-in.-thick composite deck, which sped up steel erection, simplified steel detailing, and minimized needed spray-applied fireproofing.

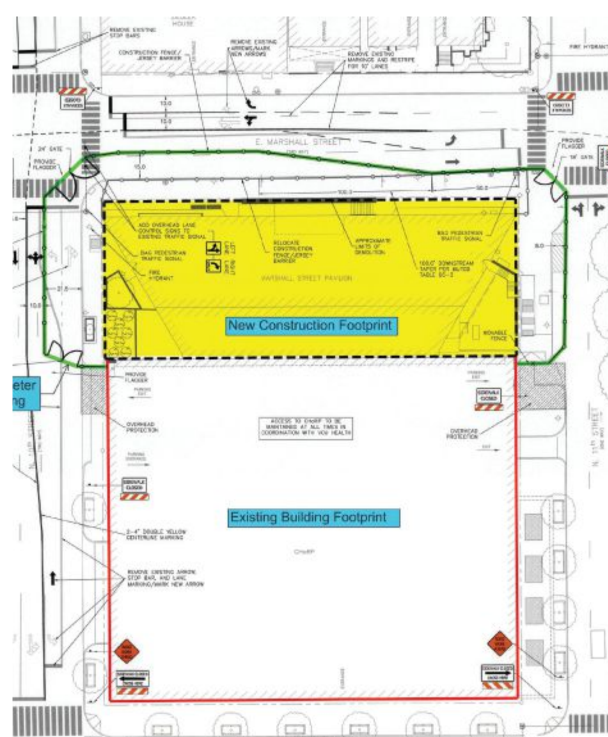
Quick and Easy Moment Connections

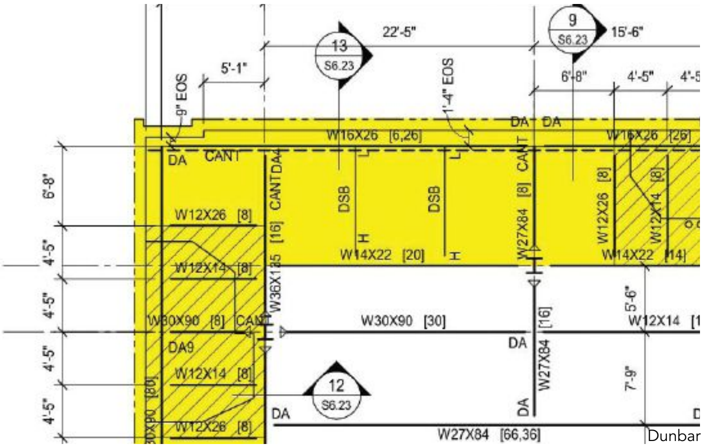
The cantilevered floor edges at the north, east, and west faces of the patient floors were achieved with gravity moment connections at each column location (a total of 340 moment connections to column flanges). On the design side, the simplest approach would have been to pull out tried-and-true details of complete-joint-penetration (CJP) field-welded connections to connect the beams to the column flanges, complete with continuity stiffener plates. Instead, Dunbar invested about a week of engineering time to perform a deeper examination of the challenge and identify a more optimal solution.

For the most part, these cantilevered beam sizes were selected for deflection control, and their design moments were not close to member capacity. During this week of moment connection design, Dunbar's engineers:

- Checked each column with gravity moment connections to determine if continuity stiffener plates were required, increasing a handful of upper-level column sizes to eliminate the need for these plates and allow for clean columns
- Determined the maximum moment and shear for each cantilevered beam or backup beam size
- Designed an 8-bolt end-plate moment connection tabulated for each beam size.

The simple switch to this connection type proved beneficial. It allowed steel erection to become quicker and safer since the time-consuming CJP welding was shifted from the field to the shop, reducing the total time of steel erection by 8%. (On a project of this size, this equates to approximately three weeks' time savings and a theoretical



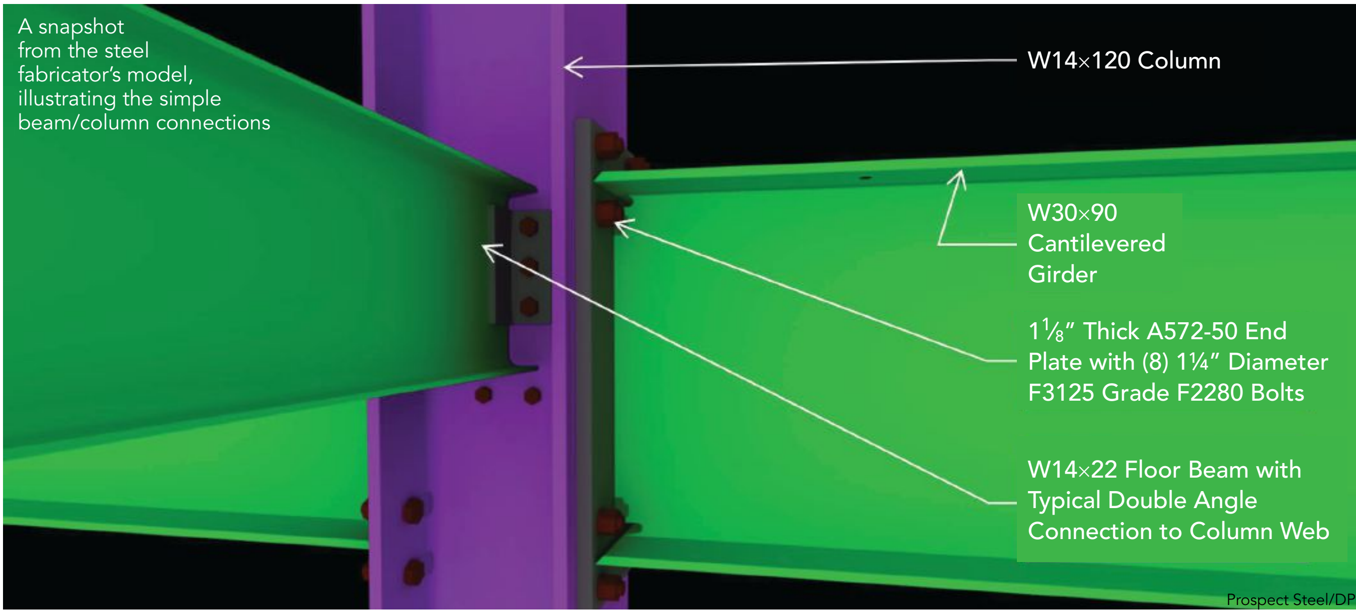


The cantilevered floor edges (indicated above in yellow) at the north, east, and west faces of the patient floors were achieved with gravity moment connections at each column location.

General Conditions savings of $350,000.) Another advantage came in the form of reducing special inspections. As a Risk Category IV building, 100% of the CJP welded connections were ultrasonically tested in the shop, eliminating the need for this specialty equipment and personnel from the field for all 340 of these connections—and resulting in an estimated cost savings of $20,000.

Towers on Tower

The patient floor cantilevers came into play in a big way with respect to project constructability, specifically when it came to the



A snapshot from the steel fabricator's model, illustrating the simple beam/column connections

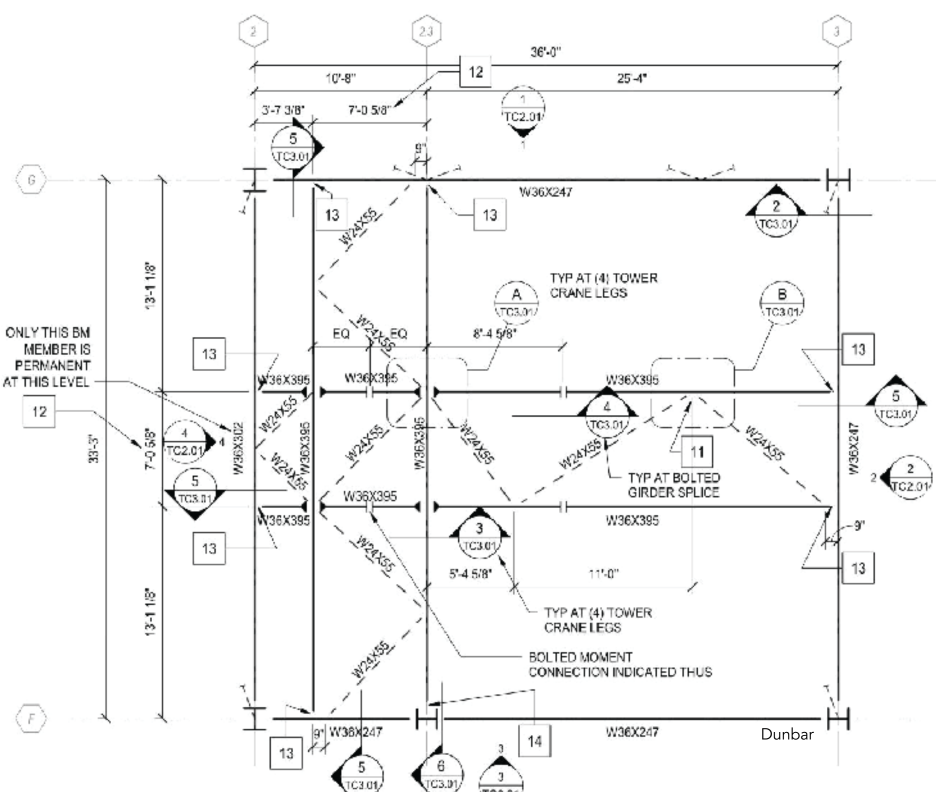
Prospect Steel/DPR

tower cranes. In order to keep the project on schedule, DPR's plan involved two cranes. However, due to the floor overhangs from Levels 2 to 13, they couldn't be situated on the sidewalk, and placing them within a stair or elevator shaft would have proven detrimental to the schedule. There was only one other feasible place to put them: on top of the existing building.

DPR approached Dunbar with this plan while the latter was focused on the aggressive construction documents schedule, and a separate team of two Dunbar engineers branched off to tackle this rather tall order. Walter P Moore provided assistance in the form of creating a fabrication model and providing constructability review and a peer review of the structural design. The west tower crane had a hook height of 174 ft, 6 in. and a reach of 180 ft, 5 in. while the east tower crane had a hook height of 213 ft, 3 in. and a reach of 229 ft, 9 in. Both of these hook heights were in addition to the cranes' "starting point" at an elevation 182 ft above street level.

A major question, of course, became: Could the existing structure handle the loads of the tower cranes? The answer, generally speaking, was: Yes—with a few modifications. Additional reinforcement came in the form of cover plates for two columns in the tall mechanical room floor below as well as bottom flange bracing to two existing roof beams at the quarter points of their spans. Regardless of these additions, the entire plan wouldn't have been possible had the

A framing plan for the tower crane support platform.



Dunbar

Two tower crane stool plates atop the support structure in the fabrication shop.


Dunbar

The project includes a new 20-story tower, plus three additional penthouse levels for elevator equipment and helipad access, in addition to two new levels atop the original, adjacent outpatient building—as well as a pedestrian bridge connecting the new tower to another existing VCU Health building—for a total of 600,000 sq. ft of new construction.

HKS

existing structure not been designed for an additional seven floors.

The steel frames supporting the tower cranes each used five building columns, floor and roof beams for the planned building expansion, and some permanent vertical building bracing. The large W36×395 and W36×247 girders that create the tower crane platform were temporary and have since been removed to create occupiable space within the building.

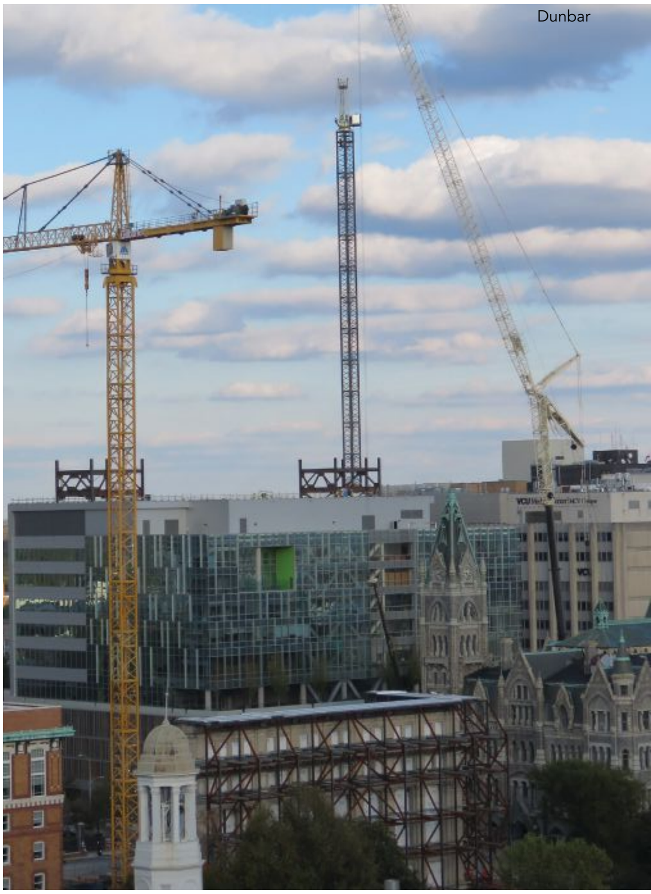
From an engineering standpoint, there were two main challenges to address in order to ensure the success of the tower crane scheme:

1. Provide a steel platform that kept differential vertical deflection between any two tower crane posts to ½ in. maximum. This criterion was provided by the cranes' supplier P&J Arcomet.
2. Provide a connection at the base of each tower crane leg that would adequately transfer uplift forces of about 475 kips to the frame below.

HKS

The design team didn't have much wiggle room when it came to the new building's dimensions, given the relatively small available footprint north of the existing outpatient pavilion. Material lay-down space was also tight, requiring fabricator Prospect Steel to schedule steel deliveries accordingly.

Dunbar



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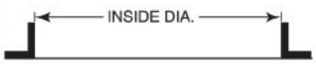
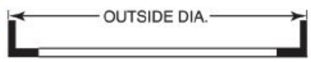
1 Angle Leg Out



10" x 10" x 1" Angle

2 Angle Leg In

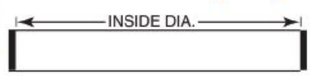


10" x 10" x 1" Angle

3 Flat Bar The Hard Way

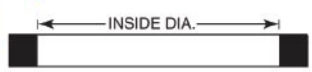
24" x 12" Flat

4 Flat Bar The Easy Way



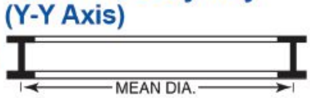
36" x 12" Flat

5 Square Bar



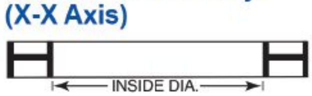
18" Square

6 Beam The Easy Way (Y-Y Axis)



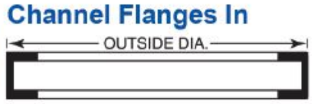
44" x 335#, 36" x 925#

7 Beam The Hard Way (X-X Axis)



44" x 285#

8 Channel Flanges In

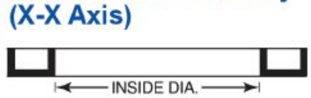


All Sizes

9 Channel Flanges Out

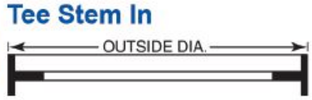
All Sizes

10 Channel The Hard Way (X-X Axis)



All Sizes

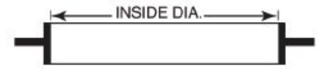
11 Tee Stem In



22" x 142$^{1}/_{2}$# Tee

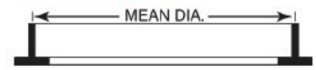
We bend ALL sizes up to:

12 Tee Stem Out



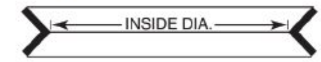
22" x 142$^{1}/_{2}$# Tee

13 Tee Stem Up



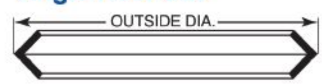
22" x 142$^{1}/_{2}$# Tee

14 Angle Heel In



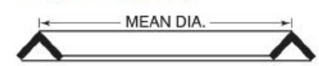
8" x 8" x 1" Angle

15 Angle Heel Out



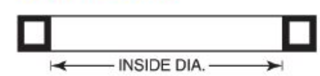
8" x 8" x 1" Angle

16 Angle Heel Up



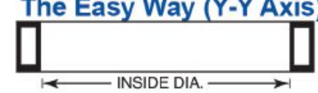
8" x 8"x1" Angle

17 Square Tube



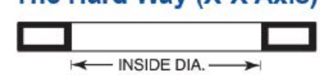
24" x $^{1}/_{2}$" Tube

18 Rectangular Tube The Easy Way (Y-Y Axis)



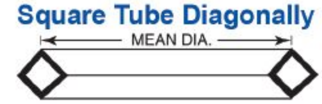
20" x 12" x $^{5}/_{8}$" Tube

19 Rectangular Tube The Hard Way (X-X Axis)



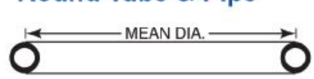
20" x 12" x $^{5}/_{8}$" Tube

20 Square Tube Diagonally



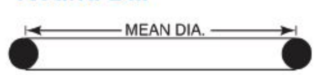
12" x $^{5}/_{8}$" Square Tube

21 Round Tube & Pipe



24" Sched. 80 Pipe

22 Round Bar



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The design team addressed the first challenge by creating a 3D analytical model with more than 200 load combinations for the crane loads in eight compass point positions. From there, the team refined the framing arrangement, but for the most part the brute force of the platform's W36 members did the lion's share of the job. Almost all field connections for the platform, including massive beam splices, were designed using bolts in lieu of welds.

The solution for the tower crane base connection was originally floated by the Walter P Moore fabrication model team. Dunbar took P&J Arcomet's preferred stool plate detail and asked them to thicken up the base plate to be compatible with the W36×395 support girders and then dropped it into the coped flanges of the support girders. P&J Arcomet's fabricator shipped these stool plate pieces to the structural steel fabricator for welding to the main members. A section of the tower crane mast was also provided so that shop fit-up of the entire assembly could be tested before sending members out to the field.

Following topping out of the new tower, both tower cranes were removed after two years of service to the project, and construction is still on schedule to greet the first patient in the spring of 2023. Moving forward, the new facility will provide all patients with forward-thinking medical care and solutions mirroring the forward-thinking constructability solutions that brought the building to fruition. ■

Jeff Davis (jdavis@dunbarstructural.com) is a principal with Dunbar, and **David Hudson** is a project manager with DPR Construction.

Owner
VCU Health

Owner's Program Manager
JLL

Construction Manager
DPR Construction

Architect
HKS

Structural Engineers
Dunbar
Walter P Moore (pedestrian bridge and peer review)

Steel Fabricators
Prospect Steel, a Division of Lexicon, Inc.
SteelFab of Virginia (tower crane support and the original tower)

Tied with a Ribbon

BY DEREK M. BEAMAN, SE, PE, AND C. STEPHEN POOL, SE, PE

IN A CITY FAMOUS for outsized, neon-lit resorts, the newly expanded Las Vegas Convention Center's (LVCC's) "ribbon" roof is a rippling architectural element that claims a unique and tasteful place of its own.

Designed to dazzle and inspire visitors, this roof, which includes a signature "snow cone" shape over the grand entry lobby, delivers an iconic postcard image that some might argue LVCC has lacked throughout its 60-year history.

As post-pandemic business travel increases and large meetings and conventions resume, visitors returning to LVCC after being away for a few years will surely notice significant changes in addition to the venue's billowing roof. The facility's $980 million, 1.4-million-sq.-ft expansion includes a 600,000-sq.-ft exhibit hall, 210,000 sq. ft of concourse space, 150,000 sq. ft of space for meetings and multipurpose activities, a 14,000-sq.-ft outdoor terrace roomy enough for 2,000

The newly expanded Las Vegas Convention Center's architecturally expressive "ribbon" roof is designed to dazzle and inspire.

Courtesy MKA

visitors, and more than 500,000 sq. ft of back-of-house service and support space.

Beyond these programmatic elements, LVCC's owner established a series of aspirational goals early to guide the building's design, one of which was to create a signature element the likes of which LVCC had never seen. As the design evolved, the overall building emerged as a combination of three major subcomponents: the Exhibit Hall Block on the east side, Meeting Room Block on the west side, and Atrium Triangle Block in between, with a grand entry lobby space and architecturally expressive roof delivering that "wow factor" the owner desired.

Creative Engineering Solutions

While Level 3 and below of the Meeting Room Block are concrete framed, the roof of the Meeting Room Block and all of the Atrium Triangle Block and Exhibit Hall Block are steel-framed (the entire project incorporated approximately 22,000 tons of structural steel). The glass wall at the lobby's southern edge is 350 ft wide and 125 ft tall at its highest point. The snow cone roof spans 120 ft to the north of the entry wall and above the 35,000-sq.-ft, column-free grand lobby space, the majority of which is open to the roof above. In addition to enclosing the lobby, the roof cantilevers 125 ft to the south of the entry wall, providing an awe-inspiring sunshade over the outdoor space below.

The roof is asymmetric, geometrically complex, and covers an area of more than 117,000 sq. ft. At the south end, above the lobby and outdoor space, built-up steel rib girders are radially arrayed over each of the seven 48-in.-diameter hollow structural section (HSS) columns located just inside the lobby wall. Horizontally oriented wide-flange top and bottom chords and steel plate webs comprise the girders, and each measures 16 ft deep at the point of maximum moment above the columns. At the cantilever's southern tip, the girders taper down to 12 in. Meanwhile, 82 triangular openings are located between the girders and glazed as skylights over the lobby below to afford more natural light into an area frequently populated by LVCC's visitors.

All of the secondary roof trusses (with 90-ft spans) were designed using a depth that could be prefabricated. With only one splice in the middle of each truss, the two halves of each secondary truss could be quickly spliced together and erected into place.

Although the primary trusses (270-ft center spans) could not be prefabricated, the splices were located to allow the end spans to be erected first and cantilever over the permanent building columns, with the center span subsequently erected into place. This strategy precluded the need for any shoring towers; only the permanent structure was required to erect the exhibit hall roof.

While the geometry and spans of the gravity framing system were challenging to begin with thanks to the roof's size and shape, developing the lateral force-resisting system added yet another layer of difficulty, mainly because the Atrium Triangle Block is wedged between three separate building structures separated by seismic joints: two in the Meeting Room Block and one in the Exhibit Hall Block. The project team arrived at a solution that allowed the roof to receive lateral support from only the southern Exhibit Hall Block. Because the roof's west edge required vertical support, slide bearings were fitted atop the Meeting Room Block's columns from the south and north meeting room buildings. These slide bearings allowed for lateral movements of the roof up to 14 in. in all horizontal directions without transferring lateral loads between the roof and the base buildings.

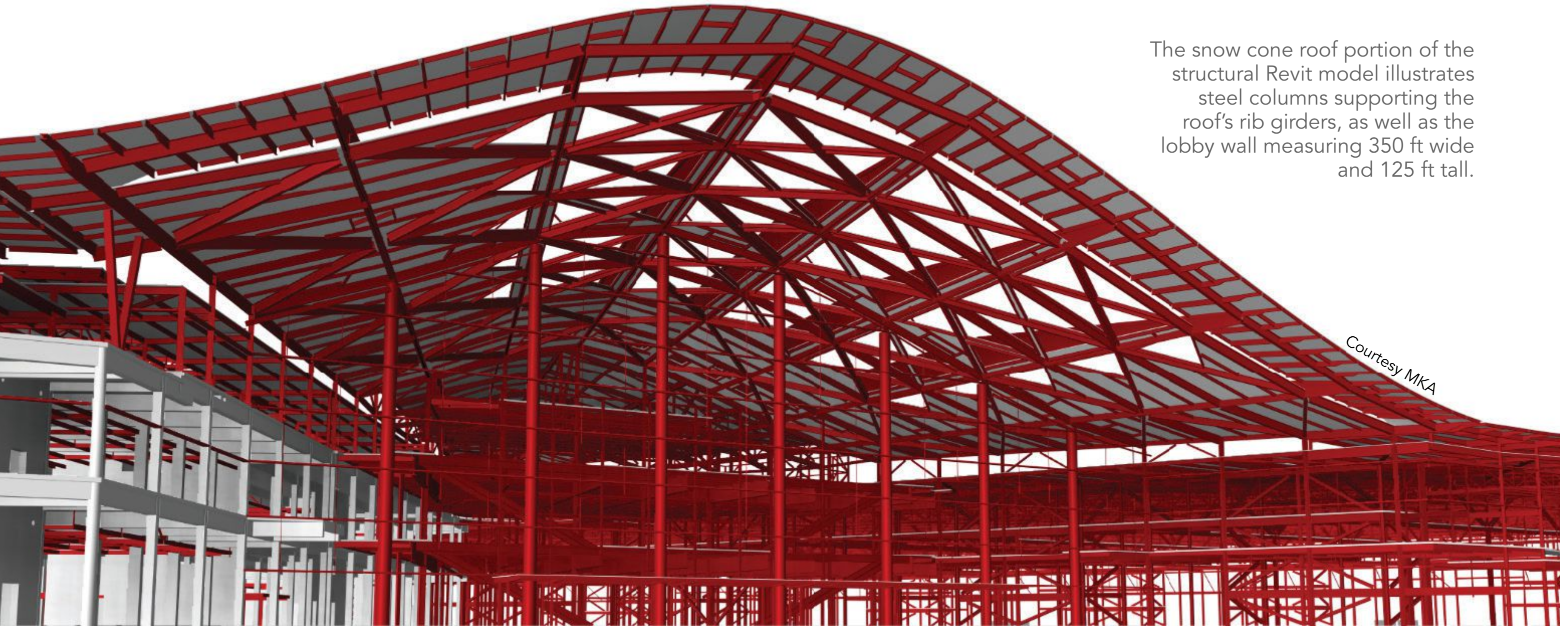
Outside of the visually stunning snow cone is the lacy ribbon roof—located along and architecturally interconnecting the west and south sides of the Meeting Room, Exhibit Hall, and Atrium Triangle Blocks—which required its own set of engineering design solutions. At the west and south sides of the Meeting Room Block, where the structural roof was typically well below the ribbon, a "flying ribbon" condition was created. At these locations, steel V-columns made up of 18-in. square built-up box columns supported the ribbon. These columns support steel girders that cantilever up to 65 ft and also support the steel roof deck and in-fill beam framing necessary to create the architectural expression that beautifully puts a "bow" on the facility's overall design.

Courtesy MKA

above: The lobby's "snow cone" roof cantilevers 125 ft to the south of the entry wall.

below: The ribbon roof provides an awe-inspiring sunshade over the outdoor space below.

Courtesy MKA



The snow cone roof portion of the structural Revit model illustrates steel columns supporting the roof's rib girders, as well as the lobby wall measuring 350 ft wide and 125 ft tall.

below: The 350-ft-wide glass entry wall allows natural light to pour into the atrium lobby.

Construction of the convention center's 14,000-sq.-ft outdoor terrace included steel V-shaped columns to support tapered steel girders that cantilevered up to 65 ft in each direction.

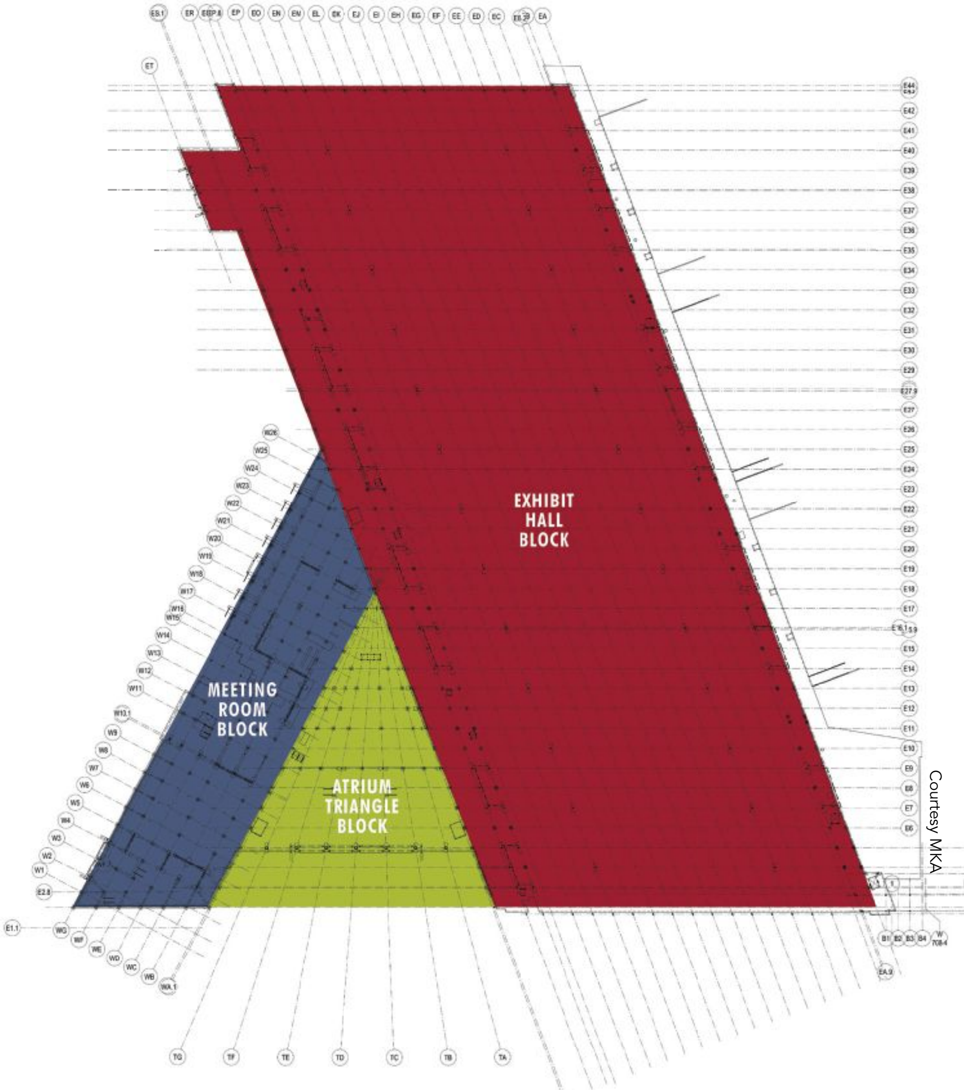
Courtesy MKA

Courtesy MKA

The long cantilevers allow the ribbon roof to "float" above the outdoor terrace space and provide shade and comfort for visitors.

Courtesy MKA

Visitors celebrate the expanded facility's grand opening on the outdoor terrace.



Courtesy MKA

Three subcomponent "blocks"—Exhibit Hall, Meeting Room, and Atrium Triangle—comprise the Las Vegas Convention Center Expansion's overall building design.

Derek Beaman (**dbeaman@mka.com**), senior principal and Convention Center Design Leader with Magnusson Klemencic Associates, functioned as Principal-in-Charge for the project. **C. Stephen Pool** (**cpool@mka.com**), associate with Magnusson Klemencic Associates, was the project manager.

LVCC's expansion was designed, constructed, and completed in a record 36 months, a feat never achieved for a convention center of this size and complexity, thanks to creative engineering solutions and seamless collaboration. The expansion bolsters Las Vegas's economic future and furthers the city's position as the top trade show destination in North America, and visitors attending meetings, trade shows, and other large events at LVCC will appreciate the additional space and new features. Equally significant is the venue's ribbon roof, which delivers on the owner's aspirational goal of creating a jaw-dropping, architecturally expressive element that stands out, even in a city that exists to grab your attention at every opportunity. ■

Owner
Las Vegas Convention and Visitors Authority

Project Manager
Miller Project Management

Construction Manager-at-Risk
Turner-Martin Harris, A Joint Venture

Architects
TVS Design (prime architect)
TSK Architects
Simpson Coulter Studio
KME Architects
Carpenter Sellers Del Gatto Architects

Structural Engineers
Magnusson Klemencic Associates (prime structural engineer)
Poggemeyer Design Group
Sigma Engineering

Steel Team

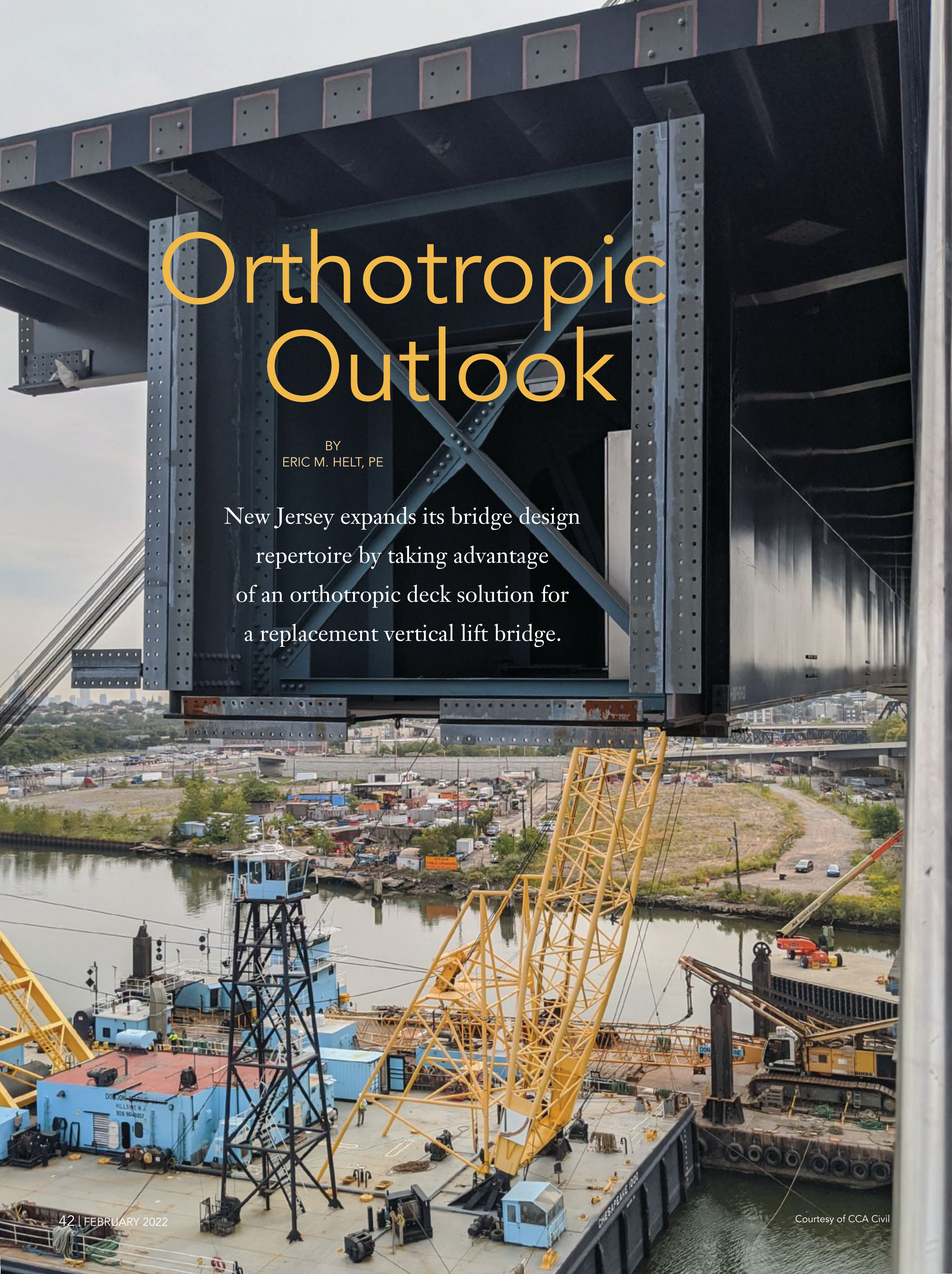
Fabricator and Detailer
W&W | AFCO Steel (AISC Certified Fabricator)

Erector
W&W Steel Erectors (AISC Certified Erector)

Orthotropic Outlook

BY
ERIC M. HELT, PE

New Jersey expands its bridge design repertoire by taking advantage of an orthotropic deck solution for a replacement vertical lift bridge.



Courtesy of CCA Civil

The new Wittpenn Bridge is New Jersey's first orthotropic bridge and an integral component of the state's Portway Corridor project.


Courtesy of CCA Civil

THE WITTPENN BRIDGE is a first for the Garden State.

The new 3,277-ft-long crossing, which carries Route 7 over the Hackensack River between Kearny and Jersey City, is New Jersey's first orthotropic bridge and an integral component of its Portway Corridor project. It also serves as a symbol of the state's renewed emphasis on infrastructure redevelopment, especially with the recent passage of the $1 trillion infrastructure bill.

Replacing a deteriorating vertical lift truss bridge built in 1930—which will be demolished and whose four 10-ft travel lanes included no shoulders or any physical separation between opposing traffic—the new vertical lift structure, designed by Jacobs, is wider and safer than the original crossing. In addition to shoulder and median placement, the vertical clearance was doubled from 35 ft to 70 ft in the closed position, reducing the frequency of bridge openings that affect marine and vehicle traffic.

The New Jersey Department of Transportation (NJDOT) divided the project into five separate contracts, allowing work on different portions to take place simultaneously (other phases include connecting exits and demolition of the old bridge and its approach roads). The third contract, awarded to CCA Civil, included the main span vertical lift towers and the main lift span, which is comprised of three steel box girders and a steel orthotropic deck system. The orthotropic approach employs a steel plate deck stiffened either longitudinally with ribs or transversely or in both directions.

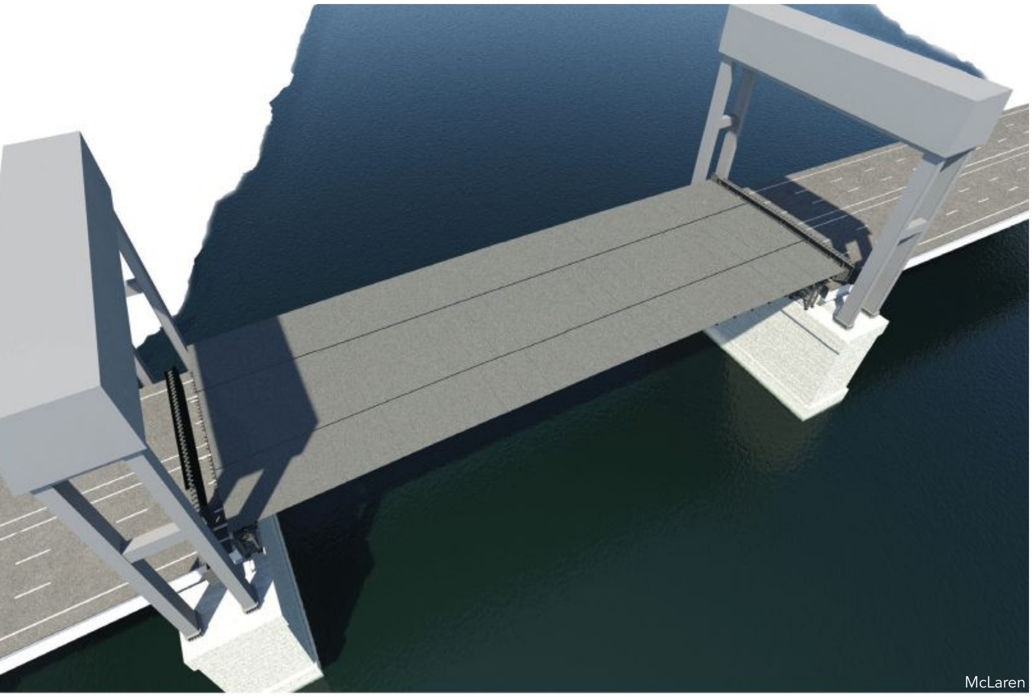
Nearly impossible to achieve without the strength of steel, the new bridge's main lift span measures 324 ft long and 110 ft wide and weighs in at nearly 2,500 tons. Fabricated by Vigor, the steel framing scheme features an orthotropic deck system with integrated floor beams and box girders, where the ¾-in.-thick deck serves as the top flange to the U-ribs, transverse floor beams, and primary box girders. This integrated system not only makes the bridge more efficient for such a long span but also allows the deck to directly bear vehicular traffic loads, with only a thin wearing surface for texture. This type of system reduces overall bridge weight, improves construction schedule, and minimizes long-term maintenance.

McLaren Engineering Group's construction team was contracted by CCA Civil to serve as the project's erection engineers and was tasked with helping meet the strict contract tolerances, which included erecting the bridge within a 1⁄16-in. tolerance over 324 ft in the longitudinal deck joints. The challenge required innovative engineering solutions in the development of erection sequences and means and methods, temporary works, crane plans, and custom rigging solutions. All of this was closely coordinated with Vigor, which mimicked the proposed erection sequence in its shop yard—not only to ensure that contract tolerances were met but also to vet the proposed sequence and procedures, work out any kinks, and ensure seamless erection in the field.

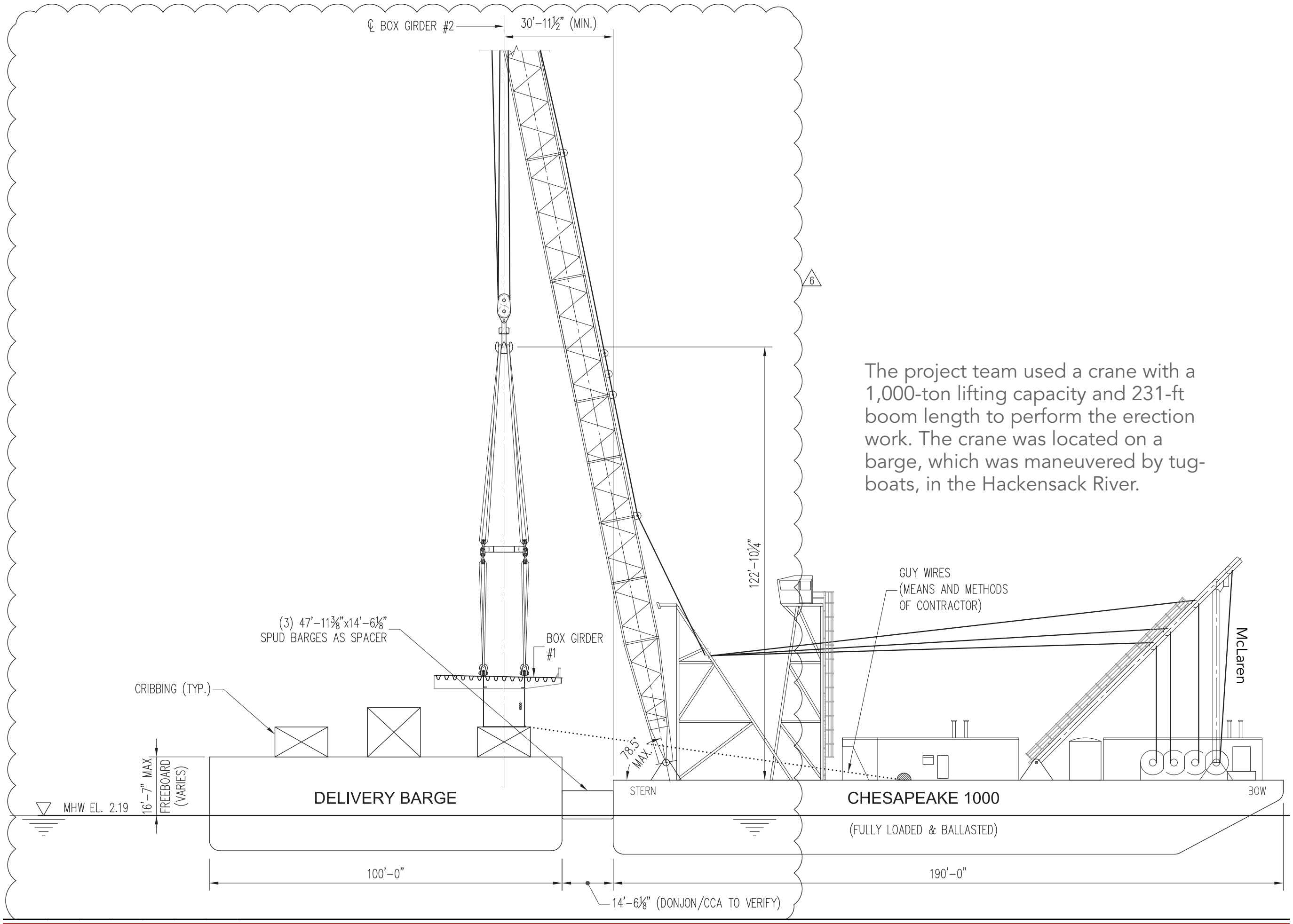
Given the massive weight and scale of the three box girders—which were 12 ft wide and 15 ft deep—with integrated orthotropic steel deck, the project team used a Donjon Chesapeake 1000 crane, one of the largest heavy-lift cranes on the East Coast, and took advantage of its 1,000-ton lifting capacity and 231-ft boom length, to perform the erection work. The crane was located on a barge in the Hackensack River, which was maneuvered by tugboats.

above: Three longitudinally split, approximately 700-ton deck spans were lifted into place, one per day.

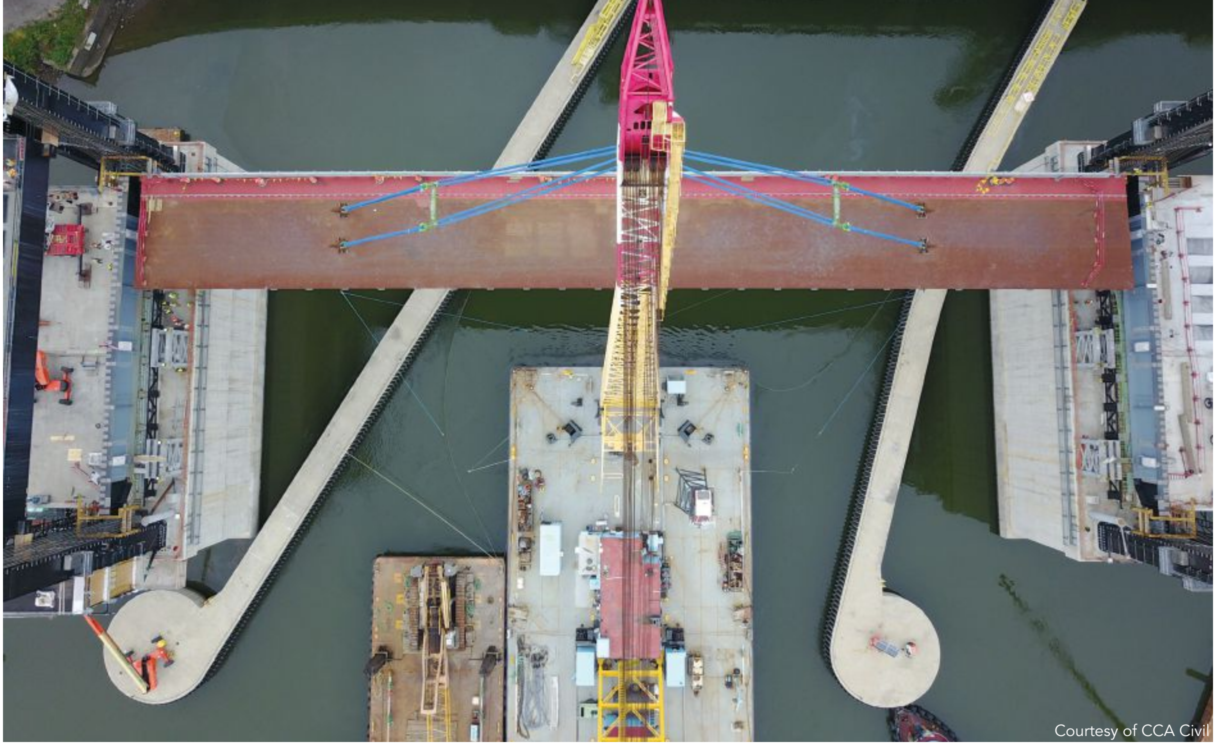
below: A rendering of the lift bridge with all three deck spans in place.



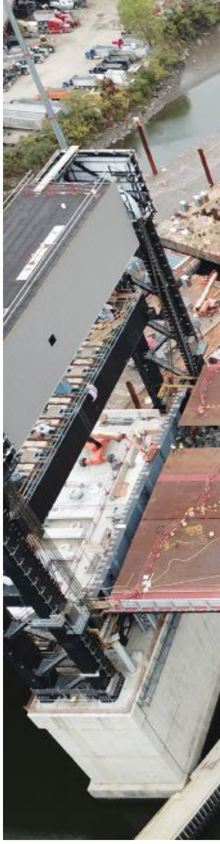
Three longitudinally split, approximately 700-ton deck spans were lifted into place, one per day, and the ¾-in.-thick deck was field-welded together with full-penetration welds (for a total of 644 ft of weld length). Given the overall span geometry, the main span (box girders and end floor beams) would only fit between the approach spans and lift towers once it was fully assembled. With that in mind, McLaren designed temporary shoring towers to raise the bridge's elevation approximately 18 ft during erection and used slide rail systems to support the erection procedures. The bridge was erected on temporary shoring towers, which allowed the end floor beams to be slid back onto the approach span while erecting the three box girder sections. Following the erection of the box girders, the end floor beams were then slid into position, tight to the ends of the box girders, where they were bolted to the end floor beam.



The project team used a crane with a 1,000-ton lifting capacity and 231-ft boom length to perform the erection work. The crane was located on a barge, which was maneuvered by tugboats, in the Hackensack River.

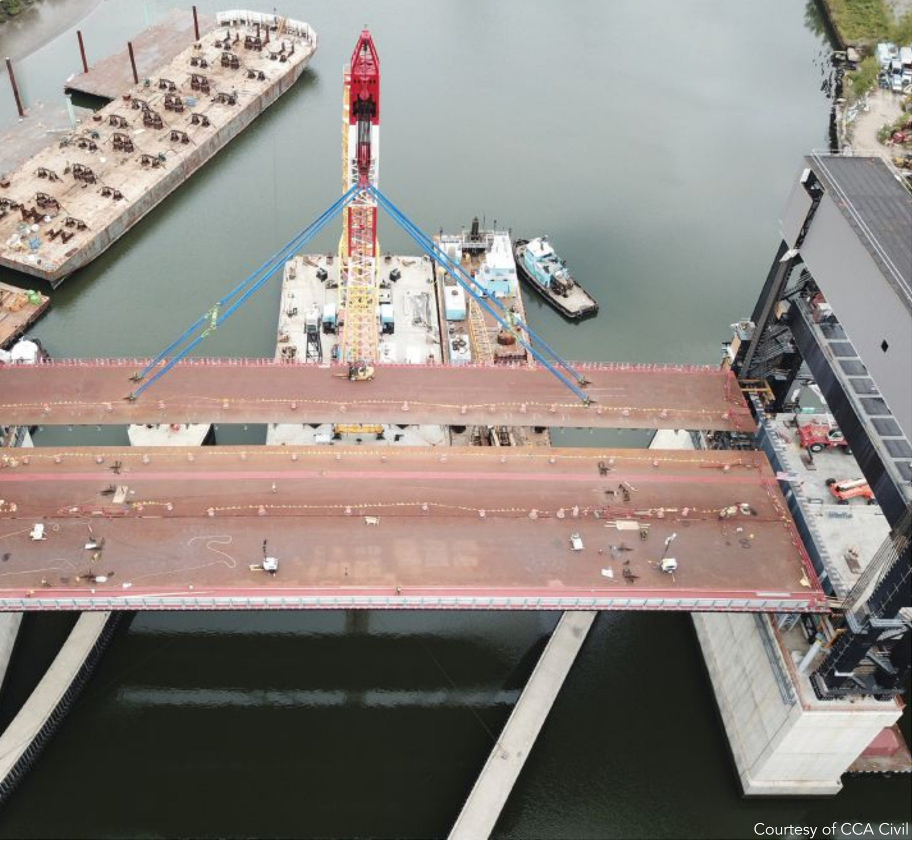


Courtesy of CCA Civil

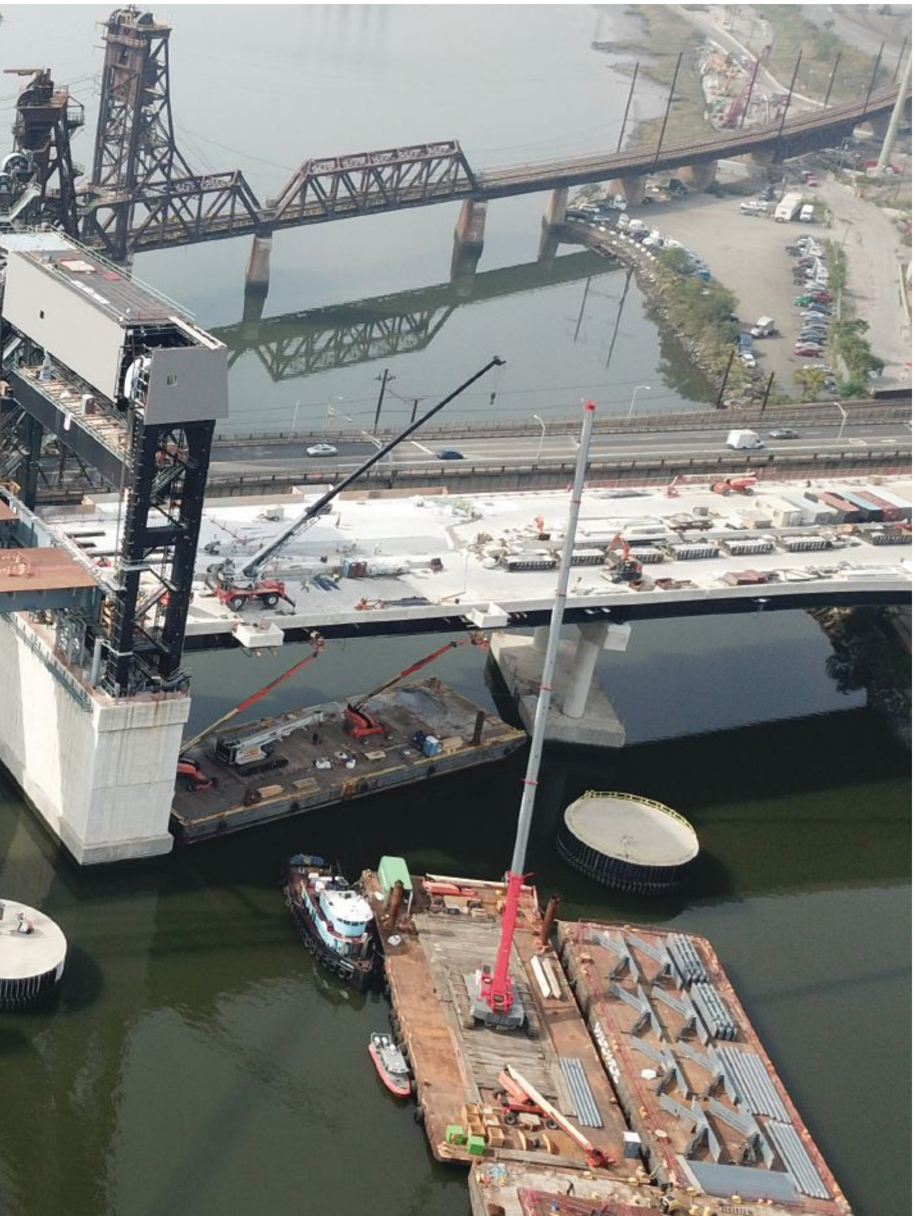


The new bridge's main lift span measures 324 ft long and 110 ft wide and weighs in at nearly 2,500 tons. Fabricated by Vigor, the steel framing scheme features an orthotropic deck system with integrated floor beams and box girders, where the ¾-in.-thick deck serves as the top flange to the U-ribs, transverse floor beams, and primary box girders.

Courtesy of CCA Civil



Courtesy of CCA Civil



Because the bridge was being erected 18 ft above its final location, the counterweight had to be erected 18 ft below its final contract elevation to maintain contract geometry. McLaren designed temporary link bar extensions to suspend the counterweight so that the relative distance from the partially elevated bridge, up around the sheaves at the top of the lift towers and back down to the counterweight, remained unchanged.

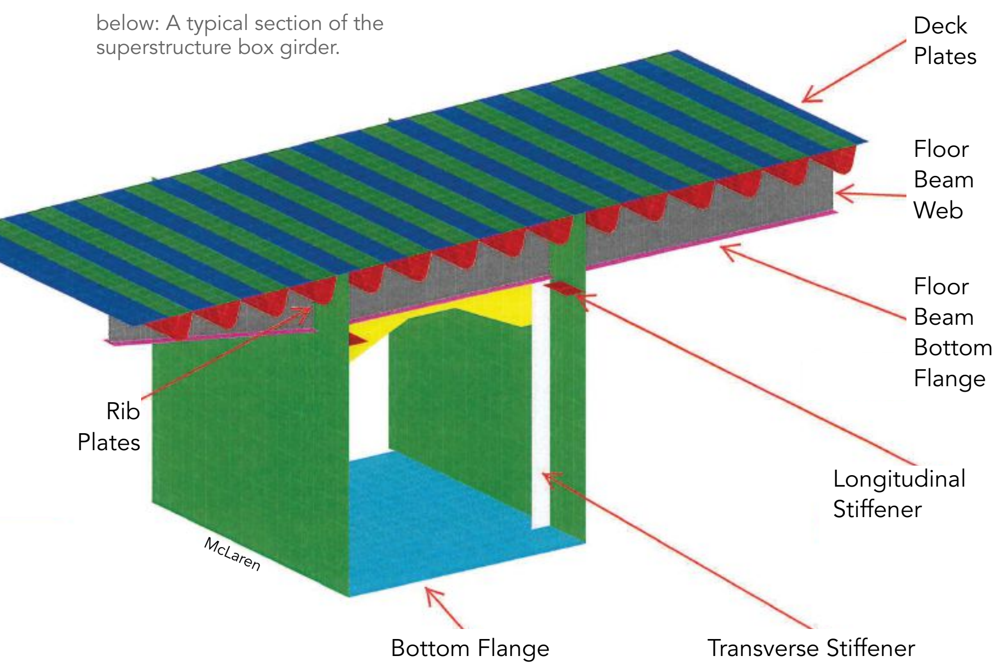
Properly positioning the pick points was critical to the stability of the bridge. During the pick, stresses in the box girders were reversed, putting portions of the bottom flange and web into compression, yet the bridge was not designed for this condition. As such, it didn't have longitudinal web stiffeners at the bottom of the box girder. McLaren coordinated with Donjon Marine and developed crane pick plans for the Chesapeake 1000, which maximized the reach capacity of the crane and ultimately maximized the spread of the pick points on the box girders. This enabled the reduction of negative flexure in the bridge sections during their pick. A finite element analysis (FEA) of the bridge was developed to check the global stability of the box elements for this temporary condition and to perform a local buckling analysis of the box girder webs, specifically near the pick points. Lifting lugs were designed and integrated into the web of the box girder by upsizing the thickness of the web steel plates in this portion of the box, welding this portion to the adjacent web plates, and allowing it to protrude through the top of the deck to create a continuous portion of the web plate up through the bridge deck. Stiffeners and cheek plates were added to the web extension on the top side of the bridge deck to complete the make-up of each lifting lug. This lug design eliminated the risk of lamellar tearing in the deck plate, which could be a failure mode if the lug was just welded directly to the deck plate.

The individual deck span sections were connected to two end floor beams, each in the neighborhood of 200 kips. However, due to the self-weight of the bridge and camber in those floor beams, the bolt patterns to connect the box girders wouldn't line up in a zero-load condition. To solve this, McLaren worked with Vigor to initiate incremental connection and load transfer procedures. First, the middle box girder was connected with only 50% of the bolts and then unloaded slightly to release some of the camber in the end floor beams. This allowed more bolt holes to line up and be connected. After erecting the middle box girder, about 80% of the camber was out of the end floor beam, allowing the team to move on to connecting the two exterior box girder sections in a similar fashion. In the final condition, the box girders are supported at the ends as a simple span bridge.

Each of the moment frame permanent vertical lift towers was comprised of four tower legs, two

above: The orthotropic deck was manufactured by Vigor at its facilities in Clackamas, Ore., and Vancouver, Wash. The deck was then transported by a barge, which traveled through the Panama Canal on its way to New Jersey.

below: A typical section of the superstructure box girder.



Orthotropic Advantage

Why orthotropic? The New Jersey Department of Transportation, which had never implemented an orthotropic bridge before, looked to this system type for the Wittpenn Bridge based on several advantages, according to its website:

- Shop prefabrication, resulting in faster construction and higher quality control
- Lightness, which is critical for movable bridges
- A high level of redundancy
- Longer allowable span lengths, providing a better riding surface than others since it contains fewer connections
- Good cold weather constructability, since there is not a temperature requirement for concrete to cure
- Excellent corrosion resistance, partially due to the closed ribs

transverse cross beams, and two top sheaves, a total of 16 major picks upwards of 200 kips; all of these major tower components were erected using a Weeks Marine 533 Barge Crane with 360° rotation capability. Due to the eccentricities, the tower sections required custom rigging and pick plans to ensure a level lift that dropped smoothly into place. Additionally, a staged analysis of the towers was performed during erection to ensure stability during temporary conditions. It also helped guarantee that interim deflections encountered during erection would not impact the overall shape of the final erected tower and that there wouldn't be any issues with steel fit-up during erection.

The Wittpenn Bridge replacement project required intensive pre-planning and coordination with the New Jersey Department of Transportation, subcontractors, vendors, and work crews to ensure a safe and coordinated operation. In the end, the team delivered a successful project and completed the erection of the main span.

The bridge opened this past October 1, just 200 ft north of the original structure, and now delivers a safer and less congested crossing over the Hackensack River between Jersey City and Kearny. Not only that, but New Jersey now has one steel orthotropic deck bridge project under its belt, thus clearing the way for other bridge projects to take advantage of this system. ■

Owner
New Jersey Department of Transportation

General Contractor
CCA Civil

Structural Engineer
Jacobs Engineering, Morristown, N.J.

Erection Engineer
McLaren Engineering Group, Woodcliff Lake, N.J.

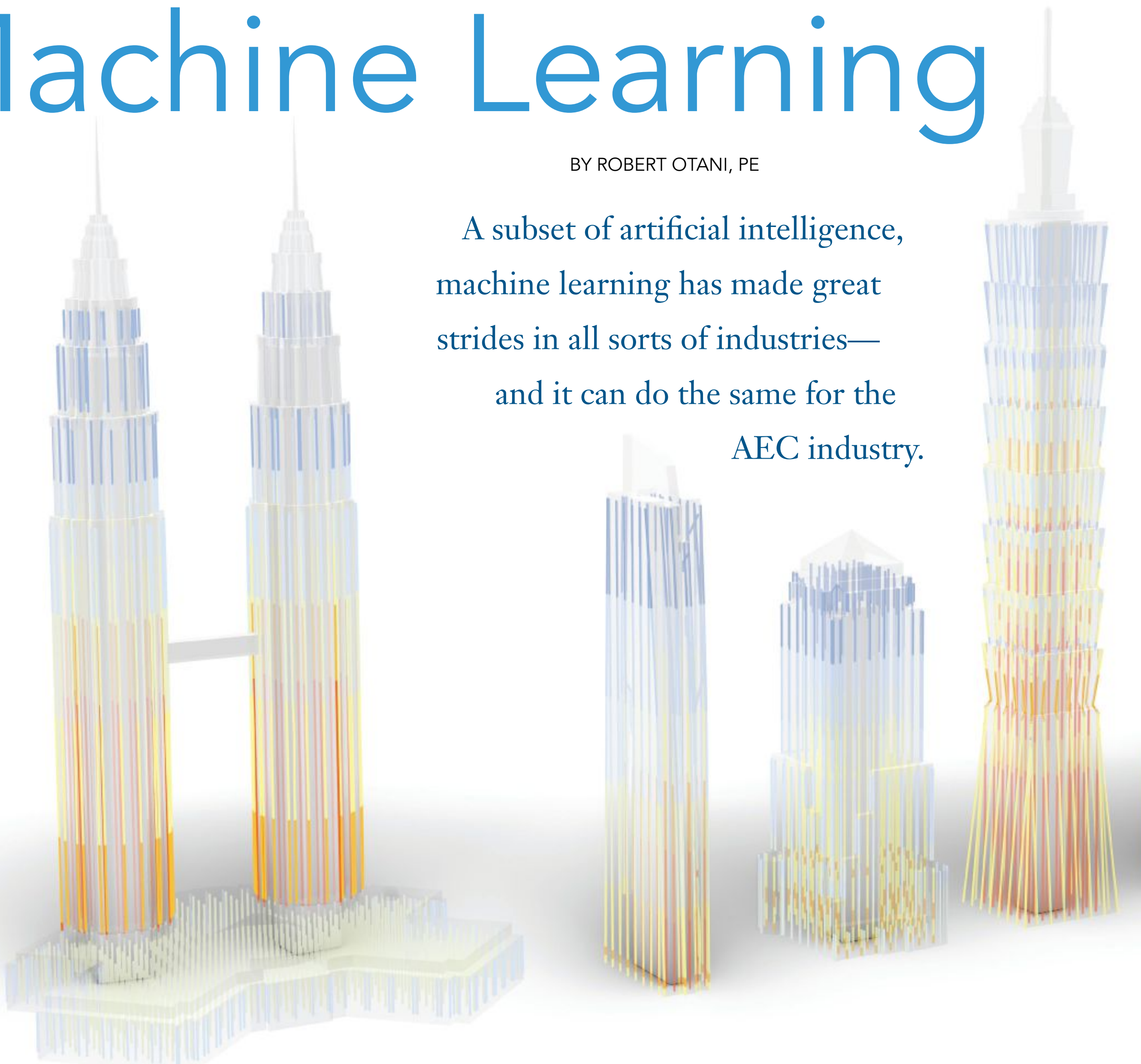
Steel Fabricator
Vigor, Portland, Ore.

Eric M. Helt (**ehelt@mgmclaren.com**) is McLaren Engineering's technical director of construction engineering.

Machine Learning

BY ROBERT OTANI, PE

A subset of artificial intelligence, machine learning has made great strides in all sorts of industries—and it can do the same for the AEC industry.



ARTIFICIAL INTELLIGENCE (AI) and machine learning (ML) have become ubiquitous.

From chatbots and personalized advertisements on social media to self-driving cars, AI and machine learning ML can be found in nearly all aspects of our everyday lives—and they have the potential to significantly outperform humans in a range of tasks.

Take, for instance, the computer program AlphaGo. Created in 2016 by the AI company DeepMind, AlphaGo was trained on datasets of 100,000 games played by humans. It was able to defeat the world's best Go (a strategy board game) player four games to one. In 2017, the next generation, AlphaGo Zero, was trained by playing itself over and over again at superhuman speeds and went on to defeat AlphaGo 100 games to nil.

So what is ML? Analytics software company SAS defines it as "a branch of artificial intelligence based on the idea that systems can learn from data, identify patterns and make decisions with minimal human intervention."

And what does AI/ML technology mean for the AEC industry? Plenty. AI/ML technology promises to solve many of the industry's current problems. These include consulting fee pressures and low profit margins, the shortage of skilled engineers, and the ever-increasing scope creep and compressed design and construction schedules, which necessitate a more automated workflow.

By all indications, AI/ML technology will greatly disrupt the AEC industry in a number of ways. It will vastly accelerate production through the automation of repetitive tasks and will provide

This image shows a group of iconic Thornton Tomasetti projects whose column sizing was "designed" in a matter of minutes using the company's Asterisk machine learning software.

multitudes of "smart" solutions based on years of institutional knowledge capture. We will be able to evaluate outcomes of vast combinations of design variables instantaneously and expedite the learning process for young engineers. This technology also holds the potential for discovering new design methods and/or construction methodologies not previously used before due to its vast computing power and inference capabilities.

In 2018, Thornton Tomasetti's CORE.AI team developed Asterisk, an ML-powered "optioneering" design software package that can produce the structural design of a high-rise building in under a minute. Two years later, we introduced T2D2.AI, a deep learning software platform that detects, classifies, and quantifies visible damage to building facades and infrastructure using AI computer vision models. Both of these technologies get the job done far more efficiently than traditional processes and have been a catalyst for investing and developing new AI/ML tools.

Through the research and development process, we've learned more about the complexities of synthetic data generation for training datasets, data mining current and prior projects, as well as the importance of having very experienced engineers oversee the entire process. This includes the ability to confirm the accuracy of the results, trust the results, and, if needed, overwrite those ML predictions. Engineers have been trained *not* to rely on computer-generated results without having rigorous quality control and quality assurance mechanisms for checking the inputs, processes, and outputs. Therefore, AI/ML models and related applications need to have similar reviews in order for professional engineers to adopt an AI/ML-powered application, which is seemingly a "black box" result.

With all of its promise, building machine learning applications requires a substantial investment and expertise, including application software development, data science, and machine learning operational management (MLOps). Thornton Tomasetti's CORE.AI team uses an agile process model in both its software and ML model development as well as robust verification of its ML model prediction accuracy with comparisons to code-based results to ensure trust and transparency among the engineering staff.

While AI/ML may never be able to fully automate engineering or construction, it does have the potential to automate up to 30% to 40% of a typical engineering and construction process. This will not only improve efficiency but will also give engineers more time to focus on creativity and innovation. ■

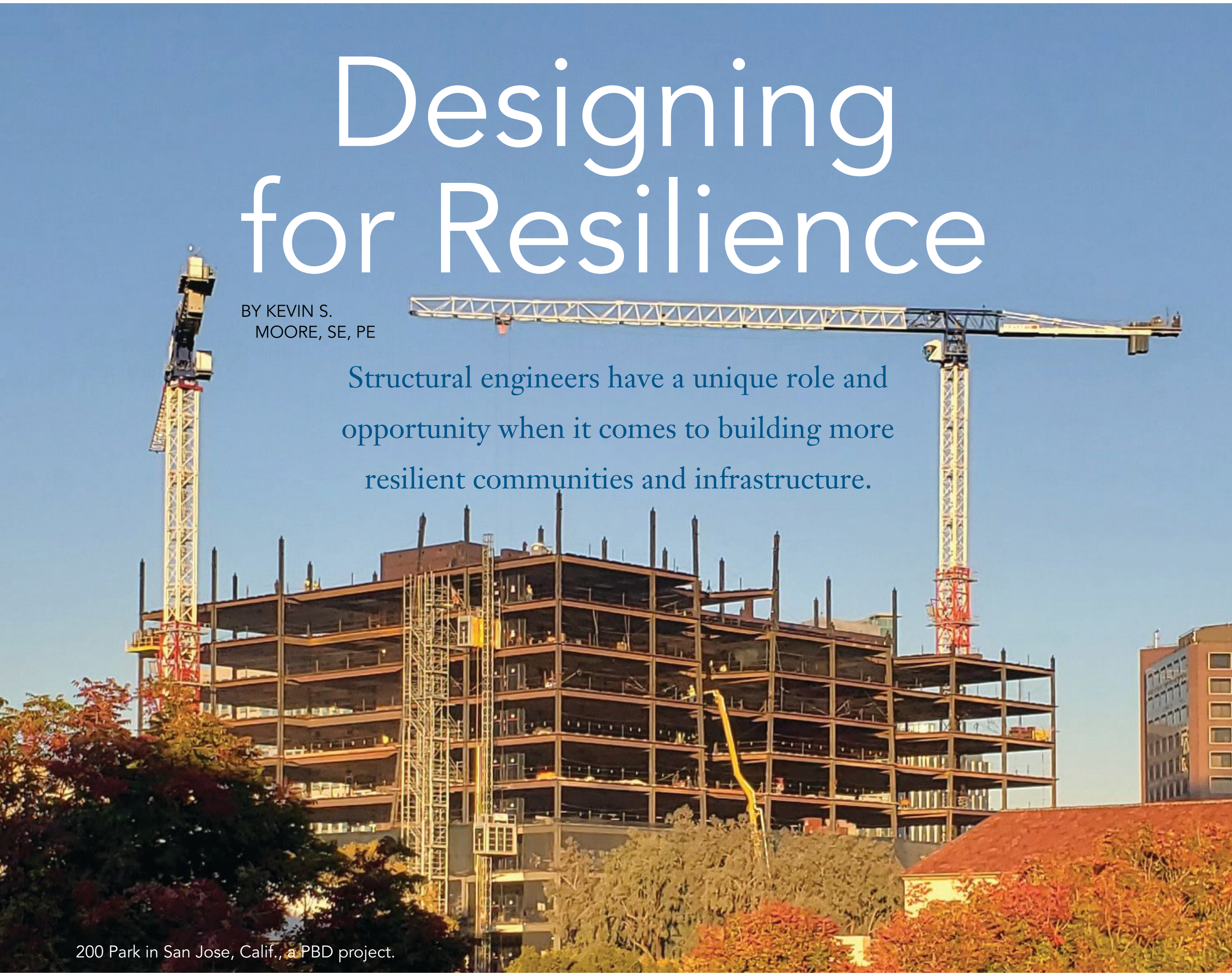
This article is a preview of the 2022 NASCC: The Steel Conference session "Artificial Intelligence: The New Frontier in Structural Design." The conference takes place in Denver, March 23-25. For more information and to register, visit ***aisc.org/nascc****.*

Robert Otani (rotani@thorntontomasetti.com) is chief technology officer and head of CORE Studio at Thornton Tomasetti.

Designing for Resilience

BY KEVIN S. MOORE, SE, PE

Structural engineers have a unique role and opportunity when it comes to building more resilient communities and infrastructure.



200 Park in San Jose, Calif., a PBD project.

OUR WORLD IS CHANGING at an alarming rate.

From pandemics to wildfires and atmospheric rivers (large water vapor streams that move through the sky), we are struggling to keep up with the challenges thrown at our built infrastructure.

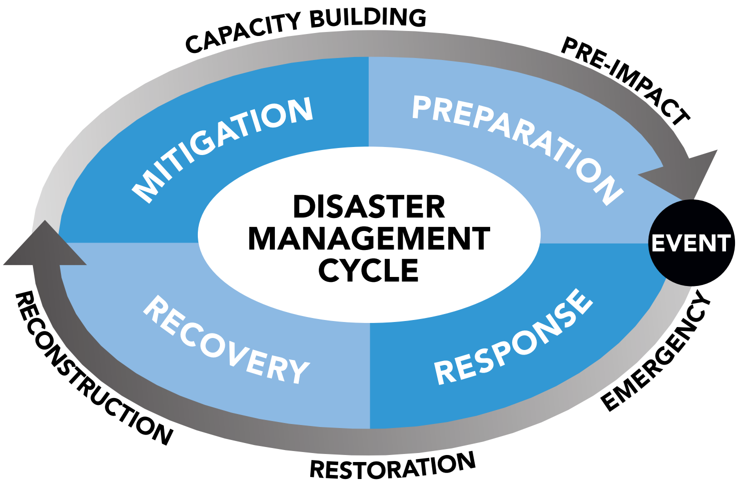
The U.S. government spends billions of dollars every year helping states and local municipalities recover from "acts of god" and "natural disasters" that continue to devastate our communities and test our ability to recover and recapture our lives before the associated disruption. *Resilience* is the word most appropriate to describe our ability as a nation, state, city, or community to recover from devastating events, usually natural hazards like earthquakes, floods, hurricanes, and wildfires. Buildings are not resilient—people and communities are—but our built infrastructure provides shelter, utility, and safety that supports communal and personal recovery, thus contributing to resilience.

Structural engineers have a unique insight and boundless capacity to shape a resilient future for urban infrastructure systems and facilities, and they have an opportunity—and responsibility—to develop future-focused design solutions and advocate within their spheres of influence. But wielding that influence can be difficult. So what do we, as structural engineers, have to help us navigate this ever-changing environment? Unsurprisingly, performance-based design (PBD) is the sharpest tool we can use to solidify our role in the resilience dialogue.

PBD is not a new concept, but it has yet to be ubiquitous in its application. Building codes are compilations of prescriptive regulations that have dominated our design process for decades. The prescriptive-based design process includes a regulation enforcement-based plan review that rigidly defines design acceptability. PBD is focused on a *performance* goal, typically related to probable damage associated with a particular external load, with the "acceptability" of anticipated performance determined by analysis. The process is iterative, dependent upon research-based analytical methods, and correlated against physical testing results and post-event observations. The PBD process lends itself to the resilience discussion because a stable but useless building will not contribute to community resilience.

Although earthquake engineering has developed the most advanced methods and standards in terms of PBD, structural behavior tools are just as useful in a wind, flood, tsunami, and tornado context. Event probability, hazard definition, load development, and acceptability criteria are the most difficult hurdles that delay the widespread application of PBD for all potential hazards. PBD is a more challenging engineering endeavor that takes more effort, requires more skill and training, and results in better-performing structures that do not immediately benefit from the advanced design method.

Fortunately, building codes are also changing to help structural engineers design structures that will perform better in natural and human-made hazards. Earthquakes, high-wind events, floods, tsunamis, and fire are hazards that are all present in the soon to be published *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-22). This evolving standard (in addition to the model building code that incorporates the standard by reference) establishes a minimum performance standard that intends to maintain stability and related safety while striving to minimize damage to the structure when subjected to loads associated with the most likely events. We can use these code changes and our ability to translate event data into external influence factors, thus providing guidance to our clients on their projects. The continuously present specter of devastating natural hazards presses practitioners into students, learning about the intersection of resilient structural design and "community resilience." Structural systems, designed by structural engineers to remain functional after a major event, will help contribute to the resilience of the communities they serve.




Salesforce Tower in San Francisco is another PBD structure.




Understanding a simplified method for improving building performance design can be incredibly powerful in a new construction context. A significant increase in post-event functionality can be accomplished by using provisions associated with a building intended to be functional following a catastrophic event (identified as Risk Category IV on a scale that ranges between Risk Category I and IV). While not as elegant as true PBD, this shorthand method can help the structural engineer provide options to a client recognizing the importance of building functionality in their own recovery and the recovery of the surrounding community.

In certain environments, structural engineers serving on standards-development organizations can, and do, incorporate climate change projections and related uncertainty into design standards. While code-based design is not intended to be the method that improves structural performance, its evolution toward PBD ensures the opportunity for structural engineers to provide input to the resilience discussion, educating our planners and users about the importance of functional infrastructure in successful community recovery.

Nuclear power plants, hospitals, high-rise structures, transportation facilities, and emergency operation centers are all designed to a high-performance target, typically beyond that described in the model building code. For example, 200 Park in San Jose, Calif., Loma Linda Hospital, and Salesforce Tower in San Francisco are all notable PBD structures that were intended to provide functional spaces immediately following a major earthquake—and this functionality is a key contributor to the resilience of their respective communities.

Resilience is a modern concept and emerging field of practice, as it adds a planning level dimension that is typically outside of a normal design commission. Incorporating resilient design outcomes in a larger planning context will challenge the engineering community to think about how buildings and systems serviceability following disasters or chronic stressors like climate change have a real impact on people's quality of life. By using tools like PBD, structural engineers can lead the most important conversations about recovery and a return to "normalcy" following a devastating event. ■

This article is a preview of the 2022 NASCC: The Steel Conference session "Resilience and What it Means to the Structural Engineer." The conference takes place in Denver, March 23-25. For more information and to register, visit ***aisc.org/nascc****.*

Kevin S. Moore (**ksmoore@sgh.com**) is the Chair of the NCSEA Resilience Committee and a senior principal and Western Region Head of Structural Engineering at SGH.

Finding Failure

BY CRAIG QUADRATO, PE, PhD

A formwork collapse incident.

A panel discussion at NASCC: The Steel Conference will let the audience vote on the controlling factor in five stability failure scenarios.

HAVE YOU EVER WONDERED how you would perform as a forensic engineer?

Now is your chance to "make the call." In this instructive and entertaining session, a panel of experts will weigh in on possible root causes for five stability-related failures. After each failure is described, you will be given the opportunity to vote for the expert who you think has correctly identified the controlling factor. Once the votes are in, the results of a detailed investigation for each failure will be briefly presented and the root cause revealed.

Steel and other metallic materials possess high strength and stiffness-to-weight ratios, allowing their use in highly efficient structural systems. Such designs, however, can often result in slender systems, members, and cross sections that require significant attention on structural stability. Failing to appropriately account for stability in design and erection has led to structural failures. While such a failure is often sudden and can be catastrophic, these events are often instructive in preventing future collapses and their potentially tragic consequences.

This session is a sequel to the standing-room-only "Stability Game Show" session presented at previous AISC and ASCE conferences. This year, the case studies are all new and include a bridge and building under construction and an existing structure under unique loads. Each case study provides for the exploration of loading conditions, structural details, and bracing schemes that can impact the local and global stability of a structure. Although hard hats are not required during the session, please bring your thinking caps and be ready to learn and contribute to identifying the conditions for and the prevention of future structural stability failures.

This year's experts are Cliff Bishop, SE, PE, PhD, managing engineer, Exponent, Inc.; Erica Fischer, PE, PhD, assistant professor, Oregon State University; Larry Griffis, PE, senior consultant, Walter P Moore; John Hooper, SE, PE, senior principal and director of earthquake engineering, Magnusson Klemencic Associates; and Craig Quadrato, PE, PhD, associate principal, Wiss, Janney, Elstner Associates, Inc. Ronald D. Ziemian, PE, PhD, professor at Bucknell University, will serve as the moderator. ■

*This article is a preview of the 2022 NASCC: The Steel Conference panel discussion "Structural Stability Failures." The conference takes place in Denver, March 23-25. For more information and to register, visit **aisc.org/nascc**.*

Craig Quadrato (**cquadrato@wje.com**) is an associate principal with Wiss, Janney, Elstner Associates, Inc.

Winning Change Orders

BY MICHAEL SENNEWAY

Change orders happen. Steel fabricators and erectors should have a plan in place for recovering costs when change orders happen to *them*.

A SUCCESSFUL RECORD of change order recoveries stands as a reliable predictor of financial strength for steel fabricators and erectors.

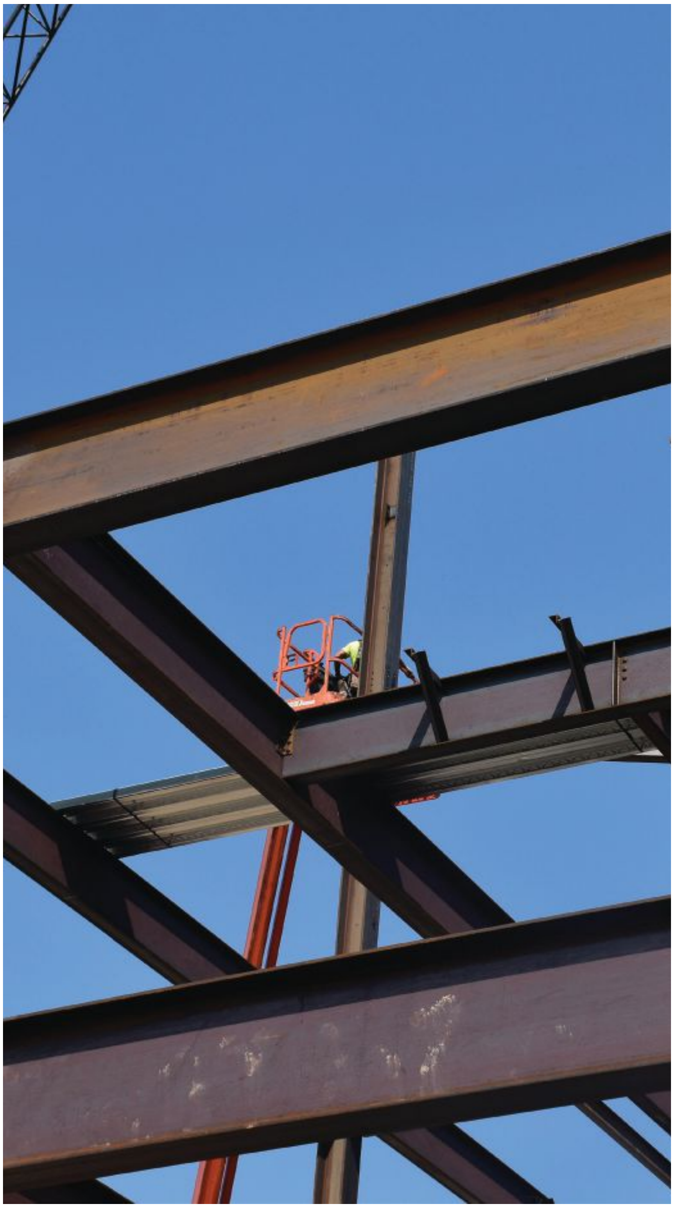
Since construction change events occur as certainly as dandelions in the spring, it is crucial that these companies are positioned to win change order battles. From my operational experience and participating in change management interactions between fabricators, erectors, owners, and general contractors/construction managers through my consulting, too few steel companies adequately prepare for these occurrences. Thus, when change events occur, many fabricators and erectors fall short in fully recovering what the changes cost them.

There are many elements that contribute to a comprehensive program for winning on change orders. I have found that additional planning and preparation for change events to be the area where most firms can readily improve their recovery ratio. From my observations, firms that incorporate the following strategies into their change management protocols experience significantly better change order recoveries.

Plan for Change

Whether lost productivity to production flow interruptions, re-detailing time, reengineering of connections, excess material drops/scrap, shop rework, shop holds, extra handling, extra freight due to light or additional loads, or field rework, changes are expensive. Additionally, changes on one project can cause schedule/productivity cost problems on concurrent contracts, which can also result in significant cost events.

To turn change order deficits into positive impacts to the bottom line, it is critical to plan for the inevitable changes to come by anticipating when and which type of changes are likely to occur and then developing strategies to minimize their collective cost



impact. The firms I see perform the best in change event cost recovery start planning for the inevitable changes as early as when deciding which projects to bid and as they prepare for contract signing. Looking at historical results of change management on various projects over the years, it is apparent that different types of projects, as well as various engineers, architects, GCs/CMs, and owners in the marketplace, often display tendencies regarding the type, frequency, magnitude, and resolution of change events likely to occur on a given project. The fabricator and erector need to consider the nature of the project and the specific players involved when assessing the risk of likely future changes when determining their bid price and, more importantly, qualifying the terms and conditions they will accept/require in the contract.

"Best in class" firms develop a reference resource by cataloging change order histories by project type, owner, and GC/CM, including the names of key personnel involved (so as to track players who might switch firms later). Preparing this pre-contract assessment and deciding to address these tendencies for a particular project can loom large in determining the ultimate margin to be realized on a project.

For example, bridge projects are usually 100 % designed when bid, so the risk in these projects tends to coalesce around site conditions, constructability, schedule, and quality acceptance issues, whereas a speculative high-rise building often is released for construction once the critical mass of tenants is committed, but with only 35% to 80% of the design completed. On top of an aggressive completion schedule impetus, the tenants usually propose/demand changes that fall in the middle of the fabricator's or erector's construction process. Therefore, all manner of design changes and refinements are to be expected throughout the project. Alternatively, industrial building projects often are held hostage to the owner's or user's final selection of equipment and process line choices, which might have a large impact on member loading and layout within the structure leading to member, connection, and geometry changes. Transportation projects, airports, and anything touching railroads are super-prone to schedule disruptions and interruptions as contractors must work around actively operating facilities and respect public safety.

Besides anticipating and planning for technical and schedule change events, successful recovery—i.e., actually getting paid—can also depend upon the fabricator/erector having a clear understanding of the owner's perspective on the project with regard to funding, the representative's authority, and their specific concerns for the project. In other words, how would the owner describe a "successful project?" How might the changes anticipated affect these owner expectations?

When assessing change event recovery, the fabricator/erector must recognize that a public entity, such as a public authority (port, dormitory, hospital, etc.), the Army Corps of Engineers, or a state department of transportation, presents a much different recovery scenario than a well-funded industrial/commercial client building a facility for its own use or a developer (e.g., a job-specific LLC) of a speculative property using borrowed funds overseen by a bank.

While public agencies typically have "no extra money" to pay for changes and must rigorously follow the contract or laws inhibiting fabricator/erector recovery, a private entity, on the other hand, may have the latitude to "spend money to save money," move funds from one construction sub-account to another to cover change issues, or simply pay for what it wants. The latter case opens possibilities for flexibility in settling change event issues. The fabricator/erector change recovery plan for the project should account for these differences.

Execute Methodically

After assessing change order risk, the fabricator/erector must actually implement its plan to effectively recover the costs of changes. The first order of business is to get the contract "right." In my opinion, the project manager's success or lack thereof in collecting on change order requests is over 50% influenced by the strength of the contract language and the negotiated terms they receive.

For example, in the engineering phase, it is critical to specify upfront when final design information will be received by building tranche, the timeliness of RFI responses, flexibility on the acceptance of substitutions, time relating to connection engineering submittals and responses, the volume and pace of approval returns, and how and at what price reengineering and re-detailing charges will be approved—always with a means to address associated schedule adjustments.

In the fabrication phase, quality constraints and expectations such as camber measurement and acceptance, weld procedures and inspections, coating requirements and acceptance, and shipping pace all need to be clear to all parties.

Site condition requirements and access must be clarified, especially if they're key to the erection process and schedule. For example, it is important to specify what "start" means. If an erector brings a crane in early, then is that the "official start" of the contract time allowed? What if only a portion of the site is available and the erector must start work with a limited crew—is that

the official "start of the clock?" What if key access points or areas critical to the erector's plan are not available? These types of issues must be addressed at contract signing. Trying to resolve them at the job site when erection is underway is too late.

Often, contracts contain "unit price schedules" for extra work. Loosely or poorly defined terms and whatever triggers the applicability of these prices often lead to disputes and less than full recovery of extra work costs. For example, does the unit price cover the connections for the added/deleted pieces—in the shop or the field? What if the piece involves less than mill-quantity material or late-added material—is any warehouse premium covered? Who "owns" the deleted material? What happens if the changed pieces are partially complete? Are unit prices for adds and deletes applied similarly?

Once underway, the usual admonitions regarding notice requirements and scrupulous documentation must be followed. The easiest point for an arbitrator or a judge/jury to focus upon in a complicated construction claim case is a failure to follow notice requirements. Notice failures present an understandable objective finding of fact for the laymen deciding these cases amidst a sea of confusing and conflicting technical arguments.

A special note on documentation: In today's world of texts and emails, it is easy to forego formal documentation in the rush to get the job done. Fatal mistake. The fabricator/erector project manager *must* take the time to summarize meeting notes and decisions, especially with the fluid participation in Zoom calls and such. The project manager also needs to document for recalcitrant customers by sending confirming emails or letters, which put into writing directives and agreements reached on calls or in online meetings. (By the way, it is always better for the project manager to strike a collegial tone in these missives and avoid being confrontational or dictatorial.)

Enhancing Opportunities

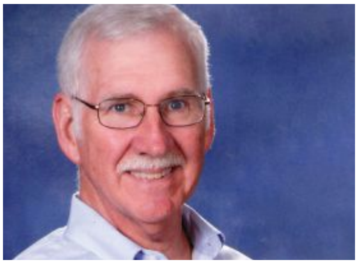
To enhance the opportunity for successful recovery, the project manager should fully document the change, submit supporting drawings and sketches, and tie labor hours by incident or location with the take-off for the change event. Many times, contractors are overwhelmed with the volume and complexity of changes encountered. It behooves the fabricator/erector project manager to "make it easy" for the contractor by defining what changed and quantifying the requested cost recovery. Clear matching of pieces deleted against pieces added is effective, and using contract unit prices when possible avoids disagreements over cost valuation.

A final note on successful recovery strategies: Remember the "big picture." The project manager is often in a position to "sell" the next job for the fabricator/erector. Long after the salesperson has left the scene, the project manager becomes the face of the company to the contractor/owner. How the project manager conducts themself, especially in the touchy area of change order resolution, can carry serious weight when the contractor/owner is considering trusted contractors for the next job.

Also, it is important to remember that the person representing the contractor is human and has a boss too. They must justify any recommendations or agreements to pay for extra charges to their boss and ultimately the owner. The project manager needs to provide the rep a solid case that the latter can justify carrying "upstream." While the project manager may be handling several projects simultaneously for the owner and construction manager's representative, the project at hand is often the only project for them. They are looking for a "partner" who shares their concerns and passion for the success of that project, not an adversary. Thus, the project manager must always consider whether it might be better to "give" on a particular change order so as to build the relationship and establish trust for the resolution of bigger issues to come, rather than pressing for the "win" in every instance.

By integrating these change management strategies into a comprehensive change management program, the fabricator/erector will significantly increase its rate of change order recovery and directly improve the bottom line for the company. ■

This article is a preview of the 2022 NASCC: The Steel Conference session "Winning Change Orders." The conference takes place in Denver, March 23-25. For more information and to register, visit ***aisc.org/nascc****.*



Mike Sennaway (**mikes.mjsmanagement@gmail.com**) is the owner of MJS Management.

This month's New Products section features two new producer offerings focusing on size, speed, and sustainability.

Nucor Econiq

Nucor has launched Econiq, a line of net-zero carbon steel products. A first of its kind at scale for the U.S. steel industry, Econiq was introduced to offer steel consumers emissions-free steel products to help meet their sustainability goals. Net-zero means that any greenhouse gas (GHG) emissions released into the atmosphere during steel production are balanced by an equivalent amount being removed. Econiq certification ensures that the steel has been made in a way that eliminates or offsets any Scope 1 and 2 emissions. The U.S. is the cleanest place in the world to make steel, accounting for less than 2% of the GHG emissions from the global steel industry. Nucor's use of recycled scrap-based electric arc furnace technology at all of its 24 U.S. mills enables the company to operate at 72% below the current GHG intensity for the steel industry and meet even the most aggressive emission intensity benchmarks that are part of the Paris Climate Agreement. Econiq steel will extend that leadership even further, using 100% renewable electricity and high-quality carbon offsets to negate any remaining Scope 1 and 2 emissions. The Econiq brand will be available across the complete line of Nucor steelmaking products, including wide-flange sections, plate, joist, deck, and HSS. For more information, visit **nucor.com/econiq**.

And to read about another producer (**Steel Dynamics, Inc.**) who recently opened a new flat-roll steel mill in Sinton, Texas, see "Texas-Sized Steel" in the January issue (available in the Archives section at **www.modernsteel.com**).

Atlas Tube Jumbo HSS

In 2019, Atlas Tube, a division of Zekelman Industries, announced a significant investment into the domestic structural steel industry when it released plans to build the largest single-seam electric resistance welded (ERW) hollow structural section (HSS) mill in the world, located in Blytheville, Ark. Now completed, the mill produces the largest domestically available HSS, facilitating framing designs that are wider, taller, and larger without compromising on functionality or aesthetics. The facility uses 100% electric arc furnace (EAF) produced coil to produce HSS that meet the most demanding sustainability requirements. In addition to rolling the biggest HSS sizes available in North America, the mill uses advanced "Quick Change" technology to minimize cycle times, meaning delivery lead times of just two to four weeks, the shortest in the industry. Sizes are available in squares up to 22 in., rectangles up to 34 in. by 10 in., and rounds up to 28 in. OD, all with 1-in. walls. For more information, visit **www.atlastube.com**.

IN MEMORIAM

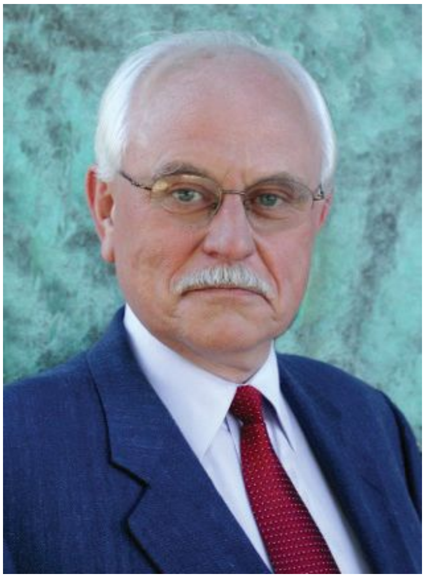
Reidar Bjorhovde, Prominent Steel Educator and Researcher, Dies at 80

Reidar Bjorhovde, PE, PhD, a leading researcher, educator, and steel consultant, died this past November 29 at the age of 80.

Born in Norway, Bjorhovde earned a doctor of engineering from the Norwegian Institute of Technology before enrolling at Lehigh University, where he received a PhD in civil engineering in 1972 and where he first gained renown for his research on the strength of steel columns, which was later used as a basis for advancements in both the AISC *Specification* and international design codes. He ultimately earned both a T.R. Higgins Lectureship Award (1987) and an AISC Lifetime Achievement Award (2011). His long involvement with the structural steel industry included his role as an AISC regional engineer and more than 22 years as an industry consultant.

"Reidar has been a big part of AISC standards development since I came to AISC in the mid-80s and before, and I always admired his dedication to the industry and his enthusiasm," said Cindi Duncan, AISC's director of engineering.

"Reidar was a good friend to all of us in the steel fabrication industry, and he was a special person in my life," added Ted Galambos, emeritus professor of structural engineering at the University of Minnesota. "He was, in my ideal opinion, a real gentleman! I appreciated his sophisticated mind, his liberal views, his musical talent, and our ability to talk with each other in the German language. He gave a lot to the structural engineers of the world. He was well versed in structural mechanics, but in his publications he was always able to communicate to the practicing engineer. Our profession, including especially AISC, lost a very sensible guide! I will miss him very, very much."



Bjorhovde also spent a portion of his career as an educator, teaching at the University of Pittsburgh, the University of Arizona, and the University of Alberta. A distinguished member of ASCE and a Fellow of the Structural Engineering Institute, he also served as research editor of AISC's *Engineering Journal* and editor of Elsevier's *Journal of Constructional Steel Research*. He published more than 250 papers during his long career, which also included work as a member of the AISC Committee on Specifications and the NASCC: The Steel Conference planning committee.

"I've known Reidar for more than three decades as a friend, colleague, and collaborator," said Scott Melnick, senior vice president at AISC. "One of my fondest memories was traveling in China with him in 2001 as delegates to the Pacific Steel Construction Conference. His knowledge of steel and his network of international contacts was unparalleled, but even more impressive was his erudite attitude, willingness to explore new places and ideas, and eagerness to meet new people."

A true Renaissance man, Bjorhovde shared his love of classical music with the world and, for nine years, was a popular weekend announcer for Tucson's classical music station, KUAT-FM.

To learn more about Bjorhovde, listen to AISC Podcast #11, which was first broadcast in 2011, at **aisc.org/podcasts**.

People & Companies

Trimble and **Microsoft** recently announced a strategic partnership to advance technology adoption and accelerate the digital transformation of the construction, agriculture, and transportation industries. By leveraging the Microsoft cloud, the two companies will collaborate to develop, build, and deliver industry cloud platforms and solutions that connect people, technology, tasks, data, processes, and industry lifecycles. This collaboration represents a significant milestone to advance Trimble's Connect and Scale 2025 strategy, which centers on building industry-leading cloud platforms.

Tim Karp, a financial executive with more than 25 years of experience, has been named controller of AISC member bender-roller **Max Weiss Company**, the region's leader in custom metal bending and fabricating.

Magnusson Klemencic Associates' (MKA) Travis Corigliano, SE, PE, has been named an ICSC+CenterBuild 2021 Leader Under 40. An associate at MKA, Travis, 32, is a leader of the firm's Retail Specialist Group and a go-to resource for clients looking to successfully retrofit, reposition, and transform legacy big-box anchor stores at malls and shopping centers into modern and lively entertainment and mixed-use destinations.

KCI Technologies Inc., a multi-disciplined engineering firm with offices throughout the U.S., has acquired Texas-based **Civil Engineering Consultants (CEC)**. CEC's wide-ranging civil engineering, construction management, and surveying expertise will complement KCI's continued expansion throughout the state.

KAI Design announced the hiring of **Charles Keefer, AIA**, as a senior project manager at its St. Louis office. With more than 20 years of experience in both architecture and project management, Keefer has been exposed throughout his career to a wide range of projects, clients, environments, and challenges.

NASCC

2022 NASCC Registration Now Open

Get ready. For the first time in nearly three years, NASCC: The Steel Conference will take place in person—and registration is now open!

Scheduled for March 23-25 in Denver, NASCC is the premier educational and networking event for the structural steel industry, bringing together structural engineers, structural steel fabricators, erectors, detailers, and architects. In addition to more than 200 practical seminars on the latest design concepts, construction techniques, and cutting-edge research, the conference also features 250 exhibitors showcasing products ranging from structural design software to machinery for cutting steel beams, as well as plentiful networking opportunities. One low registration fee gains you access to all of the technical sessions, the keynote addresses, the T.R. Higgins Lecture, and the exhibitor showcase.

NASCC is your once-a-year opportunity to learn from leading experts in the steel community and earn PDHs. Also included are multiple conferences within a conference: the World Steel Bridge Symposium, QualityCon, and the NISD Conference in Steel Detailing. One low registration fee gains you access to all of these conferences/sessions, the keynote sessions, and the exhibition hall.

For more information and to register, visit **aisc.org/nascc**.

STANDARDS

New AISC Standards Available for Public Review

Drafts of the 2022 AISC *Specification for Structural Steel Buildings*, 2022 AISC *Seismic Provisions for Structural Steel Buildings*, and 2022 AISC *Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings* are available for public review until February 21. Please see **aisc.org/publicreview** for more information and the draft specifications, along with the review forms. (You can also request a hard copy—for a $35 charge—by contacting Martin Downs at **downs@aisc.org**.)

Please submit comments to Cynthia J. Duncan, director of engineering, at **duncan@aisc.org** by February 21.

SAFETY

OSHA Accepting Electronic Injury Reports through March 2

A major component of any company's safety program is reporting injury incidents. While Occupational Safety and Health Administration (OSHA) Injury and Illness Logs for qualifying companies must be posted from February through April 30 each year, many organizations must also submit injury data electronically to OSHA by March 2. Companies with 250 or more employees that are currently required to keep OSHA injury and illness records, and establishments with 20 to 249 employees that are classified in industries with historically high rates of occupational injuries and illnesses (including steel erection and fabrication), are required to submit logs. You can visit **osha.gov/injuryreporting/ita** for more information on how to submit injury/illness data and whether your company is required to do so.

AISC is always on the lookout for safety-related article and webinar ideas that are of interest to our member companies. If you have any safety questions or suggestions, please send them to **schlafly@aisc.org**. You can also visit AISC's Safety page at **aisc.org/safety** for various safety resources.

MILEK FELLOWSHIP

AISC Awards First Milek Fellowship for Bridge Research

AISC awarded the 2021 Milek Fellowship to **William N. Collins, PE, PhD**, associate professor at the **University of Kansas School of Engineering**.

The four-year fellowship will provide Collins with a total of $200,000 to research innovative steel deck systems for highway bridge applications—the first Milek Fellowship project to focus on bridges.

"AISC and NSBA are pleased to fund the bridge research that Dr. Collins has proposed," said AISC Director of Research Devin Huber, PE, PhD. "His research on steel deck systems will create a vital path for steel to replace concrete in more short- and medium-span steel bridge projects going forward." The goal of Collins' research is vital: to reduce weight and increase the speed of erection.

Named for former AISC Vice President of Engineering and Research William A. Milek, Jr., the Milek Fellowship recognizes a promising young university faculty member who teaches and conducts U.S.-based research investigations related to structural steel.

At least half of the Fellowship funds will support a doctoral candidate who, in Collins's opinion, demonstrates outstanding potential for future contributions to the U.S. structural steel industry. In addition to research funding, Collins will also receive complimentary registration to NASCC: The Steel Conference for four years.

There are also three additional Milek Fellowship projects currently underway:

2020 Milek Fellow Matt Yarnold of Texas A&M University is investigating the behavior of hot-rolled asymmetric steel beams. Yarnold is working with steel mills as well as engineers and fabricators to explore bringing production of these shapes into the domestic market while ensuring that any geometries developed are useful for designing and building actual structures. Yarnold and his team have started laboratory testing to examine large-scale system behavior of asymmetric beams as part of a floor system, both during construction and in service.

2019 Milek Fellow John Judd of Brigham Young University is researching inelastic design methods for steel buildings subjected to wind loads to determine whether a moderate degree of ductility will allow the main wind force-resisting system to be designed with significantly reduced design forces, which would lead to more economical structures. Judd has thus far conducted extensive analytical studies to determine the wind load characteristics for nonlinear response history analysis, identify the types of structures most suitable for inelastic design, and develop archetypical model structures. He will next work to develop design and implementation guidelines for practicing engineers.

2018 Milek Fellow Gary Prinz of the University of Arkansas is developing comprehensive seismic design guidelines for skewed special moment frame connections using both full-scale experimental testing and detailed parametric finite element analysis. Prinz will complete six pre-qualification tests by the end of the year, with more to follow, and has published some early findings in the journal *Steel Construction* (visit **onlinelibrary.wiley.com/journal/18670539O**).

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A Good First Impression

FOR BBM STRUCTURAL ENGINEERS, moving into a new office space provided an opportunity to show off a bit.

From day one of the design stage, the company committed to including an iconic piece of furniture or wall element in its new digs in the Orlando, Fla., metro area that would showcase its aptitude for structural steel design—and ended up choosing both.

Following a design charette, firm leadership decided to feature a conference room table constructed of structural steel, a feature wall highlighted by a steel chevron brace, and a reception desk constructed of concrete tilt-up panels front and center. While the primary intent of these elements was to showcase what the firm designs as structural engineers, it also provided an opportunity to have the steel elements serve as a learning tool for younger engineers and clients visiting the office. For example, snug-tightened N bolts were used to connect the table and brace members and allow visitors to see the threads included in the shear plane. The two elements also employ tension-control bolts, with some snug-tightened so that the splines remain intact, providing an "inspection" lesson to determine whether the bolts are properly pretensioned.

Both the conference room table and chevron brace pieces and parts were coordinated and designed to be small enough to be transported via elevator to BBM's suite on the second floor of the three-story building, and most connections were bolted to minimize the need for any welding inside of the building. The design team at L2 Studios provided both 2D and 3D documents that were sent to the AISC member fabricator Industrial Steel, with AISC member Hollywood Structural Detailing providing the steel detailing work.

The result is a one-of-a-kind entrance that not only educates and serves as a showcase of sorts but also brings to the forefront elements that, more often than not, are hidden by finishes. ■


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