BEYOND Limits

BY DAVID RUBY, SE, PE

The fourth installment of the "But It Worked in the Model!" series takes a look at a project that illustrates the limitations of computer-aided design and analysis.

COMMUNICATION IS NOT ONLY CRUCIAL; it's in the code.

The focus of the structural engineer of record should be to communicate, as required by Section 7 of the 2016 AISC *Code of Standard Practice for Steel Buildings and Bridges* (ANSI/AISC 303-16, **www.aisc.org/specifications**), the nature of the structure, the lateral-load-resisting system, its non-structural steel components and any special conditions that are required per the design concept. But at times, this essential information is only partially noted, ignored or even forgotten. It's often considered the contractor's responsibility, referred to as "means and methods" by the design community.

In our previous "But It Worked in the Model!" articles, we have explored structures in which communication errors, omission of important details and/or lack of clarity within design documents has led to fabrication and construction headaches. We've learned that this is what may occur when professionals neglect constructability, ignore the code and blindly rely on computer analysis technology without understanding its limitations.

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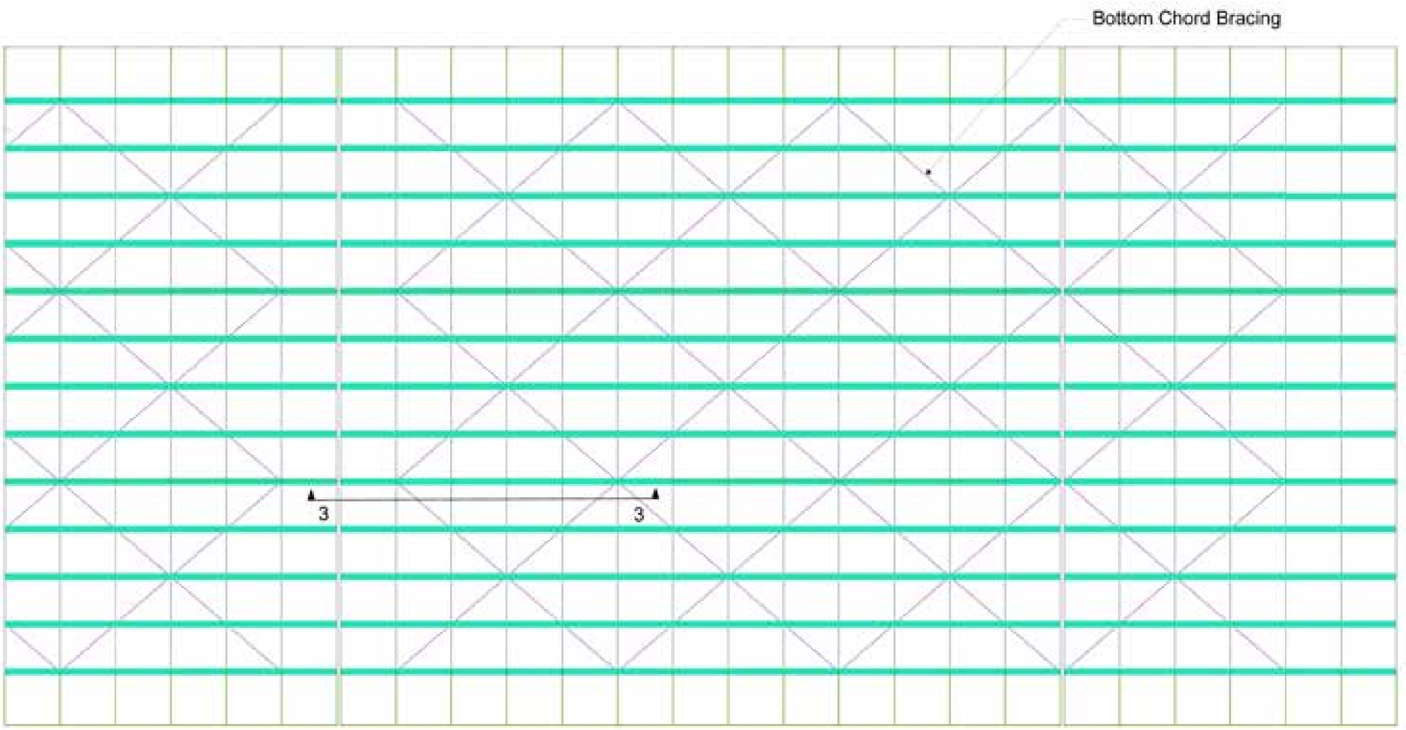
What some perceive as a tool to facilitate a nearly effortless design process can instead challenge the user's fundamental understanding of engineering. The ability to scrutinize information generated by computer analysis requires an advanced understanding and knowledge of structure. The user should be able to clearly identify and subsequently communicate, on the contract documents, the nature of the structure's lateral-load-resisting system and its non-structural steel elements. As we explore the following industrial facility project, we will discover that the least-weight structural design concept that unmistakably "works in the model" requires comprehension far beyond clash detection and interpreting the colors of an analysis report.

A Focus on Minimum Weight

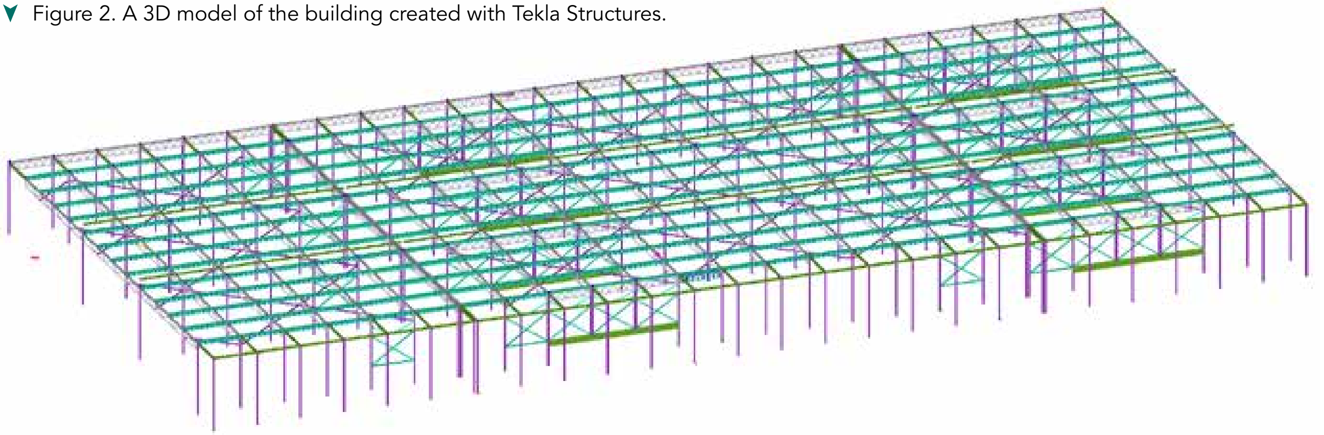
In looking at the sample industrial project's framing plans (Figures 1 and 2) we see a relatively simple braced framing system for a manufacturing facility. The design focuses on minimum weight: a roof system consists of open-web steel joists supported by roof trusses, with bottom chord X-bracing and a longitudinal vertical bracing scheme on the column lines.

Of particular interest here is the structure's lateral load resisting system. As modeled, a lateral load parallel to the roof truss would be resisted by the roof truss/column frame. This in turn is stabilized by the roof framing: an open-web steel joist and roof deck diaphragm. For lateral loads perpendicular to the roof truss, the roof deck diaphragm distributes the lateral load to a single open-web joist framed between columns. The columns transmit the lateral force in bending to the longitudinal vertical X-bracing (Figure 3, page 46). The horizontal bottom chord X-bracing spans the entirety of the bay but only stabilizes the roof truss bottom chord since there are no sway frames. Thus, this structure, which at first glance



▲ Figure1. A partial plan view of an industrial building with horizontal bracing at the bottom chord.

▼ Figure 2. A 3D model of the building created with Tekla Structures.



appears to be conventionally designed, is inherently unstable during construction. The roof trusses can only provide lateral load resistance after the roof joist, roof deck diaphragm and the longitudinal braced frames are in place. The open-web steel joist between the columns has insufficient strength to deliver the lateral loads to the longitudinal vertical bracing without a completed roof deck diaphragm. Without the roof deck diaphragm and longitudinal vertical bracing completely installed, the structural system—its individual pieces and as a whole—is unstable. Or so it seems.

Investigating the Tension Bracing

Stability for lightweight design concepts is often an issue, but something makes this particular facility unique: a tension-only bracing scheme, both vertical and horizontal. The tension-only scheme consists of vertical X-bracing located on the column lines near the ends or expansion joints of the building and horizontal bottom chord X-bracing. Tension-only struts connect the vertical and horizontal braced bays. This bracing scheme becomes functional only when all bracing panels—vertical and horizontal—are in place, the tension-only struts are in place and preloaded and the roof deck is installed. There is no redundancy or alternate load path, and very few members have any compression capacity. Thus, there is little if any stability during installation of the structure. When the building is fully constructed, with the open-web steel joist and roof deck in place, then the lateral and longitudinal load paths exist, stability is ensured and the structure functions as the model predicts.

In the case of this building, the contract documents were missing a narrative explaining the nature of the structure. This important narrative would have indicated the tension-only lateral load resisting system and its interdependence on the structural steel, open-web steel joist and metal roof deck. While the computer analysis successfully accounted for strength and stability and accurately identified a clash-free system—i.e., "it worked in the model"—the model fell short in its ability to account for constructability.

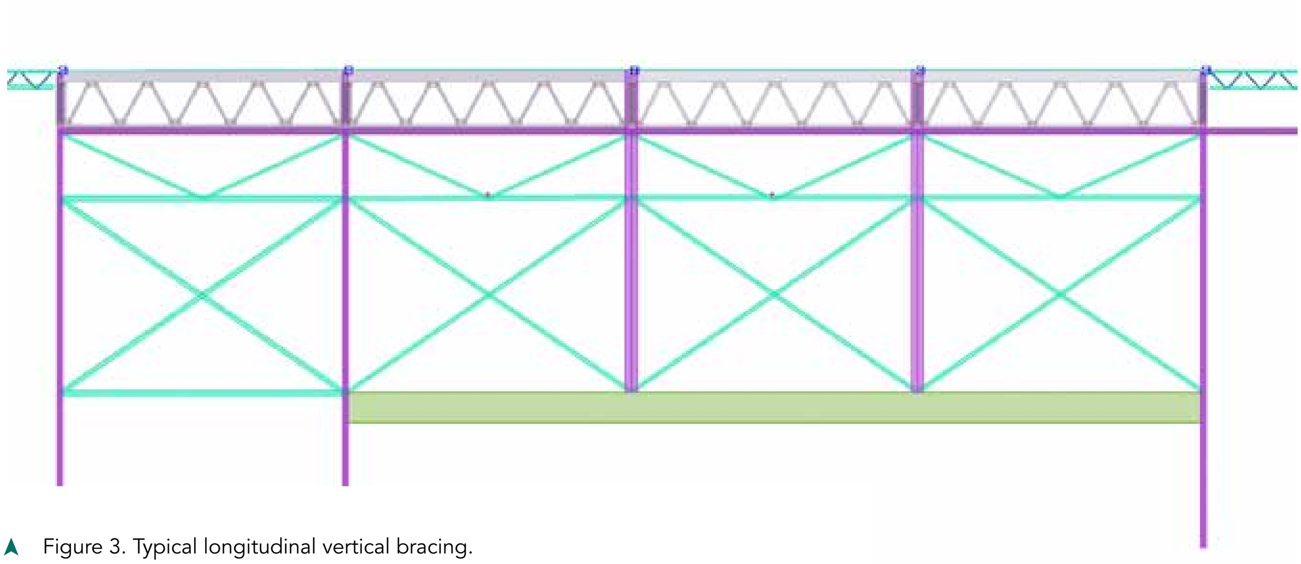


Figure 3. Typical longitudinal vertical bracing.

In this case, the erector was totally unaware of the structure's stability requirements until the roof structure shifted, as shown in Figure 4 (following page). The first four bays were in distress but did not collapse. To the erector's surprise, this industrial structure, which would not normally require any significant temporary bracing, required an extensive temporary bracing system to maintain stability until tension-only elements were properly installed and the roof deck was complete.

What Went Wrong?

For this project, the structural engineer neglected to provide the information required by Section 3.1.4 and Section 7.10.1 of the AISC *Code*. The engineer did not define the lateral load resisting system, its dependence on the non-structural steel elements (open-web joists, joist girders and metal deck are not considered to be structural steel per Section 2.2 of the *Code*) and the connecting diaphragm elements. In addition, the structural engineer did not indicate the unique design concept: a tension-only lateral bracing scheme. The erector proceeded to erect the initial four bays conventionally such that the framing was in place prior to the installation of the metal decking. The partially erected system became unstable, devoid of a diaphragm and vulnerable to wind and construction loads. Lacking sway frames and left temporarily unbraced, the top chord of the joist girders bowed due the loads induced by gravity. The intended load path, reliant on the presence of the roof deck, was critically disrupted. As evident by the visible lateral movement of the system, the structure was unstable and in danger of collapse if not immediately braced. In hindsight, it's clear that this system "worked in the model" but wasn't conventionally constructable—a fact not noted in the design documents.

This is an example of the designer relying too heavily on computer-aided design and failing to recognize its limitations. In addition, the designer ignored a responsibility to communicate the nature of the design concept, its lateral load resisting system, non-structural steel elements and design concept-related special erection conditions. The critical concepts of constructability and lateral stability were not communicated.

It is important to note that the industrial structure in this case was salvaged by developing an engineered erection plan after constructability issues became apparent. The engineered erection plan focused on the stabilization of the roof trusses, the open-web steel joist and the supporting columns. A temporary tension bracing scheme (Figure 5, following page) was introduced to brace the main column lines and maintain tension in the steel joist. Temporary sway frames and top chord cable bracing were necessary to reduce the unbraced length of the roof truss top chords. Additional horizontal open-web steel joist cable X-bracing provided a load path for lateral load distribution. The temporary tension bracing on the column lines was preloaded to maintain a tension load in the open-web steel joist framing, column to column. This tension bracing scheme was necessary due to the minimal compression capacity of the joist framing between the columns, which precluded the use of typical cable X-bracing. The temporary tension bracing was leapfrogged every fourth bay, as were the joist girder temporary bracing and sway frames. This approach provided temporary longitudinal and transverse stability. The temporary tension bracing was necessary until the key elements of the structure's lateral load resisting system were installed, including the tension-only bracing and roof deck diaphragm.

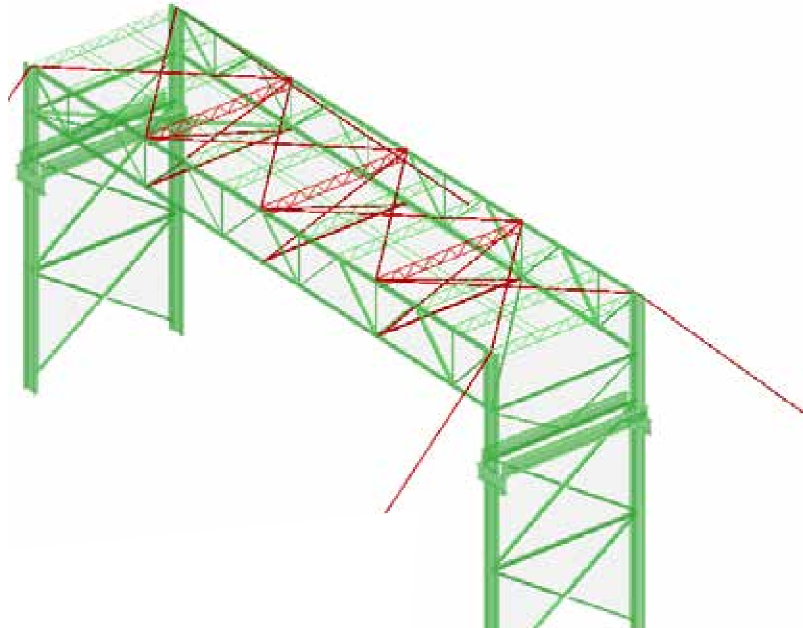
Lessons Learned

Prior to the advent of computer-aided design and analysis and the integration of BIM, the design process was, in a way, more intimate and allowed designers to better identify and address design or construction challenges. Discrepancies that formerly jumped off the page in plan form are now hidden within computer-aided analysis and design programs.

We can conclude that the computer is only a tool and not a decision-maker. As structural engineers, our experience and knowledge must be used to ensure that our design documents contain the information noted in the 2016 AISC *Code* (Sections 3 and 7) as well as reflect their purpose as described in CASE Document 962D: *A Guideline Addressing Coordination and Completeness of Structural Construction Documents*:

> "Documents, including building information models, drawings and specifications, are the tools structural engineers use to communicate the elements of the design of structures to contractors. Contractors use the Documents to develop and submit bids for construction of the structure and then,

▲ Figure 4. The erector was totally unaware of the structure's stability requirements until the roof structure shifted, as shown here.



▲ Figure 5. A temporary tension bracing scheme for the building.

if selected, to implement the design. In order for the bid to be accurate, the Documents must describe in sufficient detail the elements of the structure to be built, the quality with which it is to be built, and any special requirements governing its construction. Regardless of the format, the Documents must be developed to a sufficient level of completeness and coordination so that contractors can, within customary time constraints, develop a price, submit a bid, and after award of the contract, build the structure in a manner consistent with their understanding of the scope of the documents at the time of bidding."

Though technology has served to truly revolutionize the industry, it can only be effective and efficient if its potential and its limitations are fully understood. No professional should rely exclusively on a design that "worked in the model" in providing construction documents. As evident in this example, the computer model did not communicate all aspects of the design concept, nor did it describe the nature of the structure. Despite the fact that the model in this case incorporated all elements of the structure, including its lateral load resisting system, it did not specifically note the structure's dependence on the nonstructural steel elements for overall stability. In the end, technology can never replace knowledge and experience grounded in sound engineering principles. ■

*For past articles in the "But It Worked in the Model!" series, see the April, July and October 2017 issues, available at **www.modernsteel.com**.*