conference preview

ERECTION ENGINEERING: THE SCIENCE BEHIND THE ART

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The need for an engineered plan for construction has grown more important as steel structures have grown more complex.

HAVE YOU EVER seen a note on a set of structural drawings that reads something like this:

"The structure is stable only in its completed form. Temporary supports required for stability during all intermediate stages of construction shall be designed, furnished and installed by the contractor. Contractor is responsible for construction analysis and erection procedures, including design and erection of falsework, temporary bracing, etc."

That's a great note for a structural engineer. But what exactly does it mean for the contractor, or more specifically, for the steel erector? It means that the erector is responsible for the stability of the steel frame through all stages of construction until the final structure is complete.

But how exactly is the erector supposed to accomplish this? Erecting steel structures is very much an art. In many cases, it is simply a matter of experience and intuition, both of which help guide erectors in determining proper sequencing and special measures to ensure the steel remains stable throughout the erection process. And this approach works well with typical steel structures. However, structures are becoming more and more complicated, and so are the means of erecting them. As such, experience can no longer be the only guide, and this is where the field of erection engineering comes into play.

The Rules

The obvious places to start looking for erection engineering requirements are the AISC *Specification* and the AISC *Code of Standard Practice*. Section M4.2 of the 2010 AISC *Specification* spells out the basic requirement that "the structure shall be secured to support dead, erection and other loads anticipated to occur during the period of erection." It further states that "temporary bracing shall be provided… wherever necessary to support the loads to which the structure may be subjected." Section 7.10.3 of the 2010 *Code of Standard Practice* states "the erector shall determine, furnish and install all temporary supports, such as temporary guys, beams, falsework, cribbing or other elements required." What you will not find within either of these documents, however, is guidance on how to achieve the above requirements, including exactly what "other loads" can be anticipated to occur and how to determine temporary bracing requirements.

On top of that, erection engineering rules and regulations are simply very different from those of structural design. Aside from OSHA rules (which do not come close to covering all the bases) the prescriptive confines representative of current building codes are largely missing in regulating erection practices. While this approach might be refreshing in that it seems to bring back the basic elements of engineering judgment and creativity, it also can leave a disconcerting lack of guidance.

That said, we have found several documents that provide helpful guidance. One is AISC's *Steel Design Guide No. 10, Erection Bracing of Low-Rise Structural Steel Buildings*. This design guide outlines the basic concepts one needs to consider when trying to keep a steel structure stable through the various stages of erection. For the design and selection of hardware that is used for making lifts, other useful documents include ASME BTH-1-2008, *Design of Below-the-Hook Lifting Devices; the Wire Rope Users Manual*, 4th Edition, published by the Wire Rope Technical Board; and catalogs from various rigging manufacturers such as Certex and Crosby.

Loading

What about loads? The primary document that addresses construction loading is ASCE 37-02, *Design Loads on Structures During Construction*. This document is essentially the "ASCE 7" (*Minimum Design Loads for Buildings and Other Structures*) for construction engineering and provides temporary loading information, including load combinations, live load values and wind velocity reduction factors for temporary construction loading. It is important to note that ASCE 37 is not referenced by the *International Building Code*—in fact, the *IBC* does not mention the word "erection" a single time within its 676 pages—so while it is helpful, its use is not mandatory.

When it comes to erection engineering, temporary wind loading often controls the design; based on our experience, there is a significant disconnect between what erectors are accustomed to using and the bracing necessary to meet ASCE 37 requirements. The temporary wind loads calculated in accordance with ASCE 37 often far exceed those determined per ASCE 7 for the permanent structure, thanks to the drag factors and multiple wind surfaces associated with open-structure wind loading. Though the effects of shielding do help, ASCE 37 recommends a maximum force reduction of only 15% due to shielding for members in the fourth and subsequent rows of framing.

To put these loads into perspective, temporary wind loads were calculated for the five-story office building designed in

Part III of the AISC Design Examples accompanying the 14th Edition *Steel Construction Manual*. As seen in Section 6.2.1 of ASCE 37-02, a maximum wind velocity reduction of 0.8 is applicable for structures constructed within a timeframe of six weeks to one year. Even when considering velocity reduction and assuming the maximum shielding reduction, the base shear for temporary wind loading in the east-west direction for the complete building frame is roughly three times that of the permanent base shear. Obviously some engineering judgment is required when applying these provisions. However, the point is clear: temporary wind loading is a large factor in engineered erection design, and erectors should be made aware that the bracing involved can be significant.

While the probability of maximum wind loading occurring during construction is low, the dead loads that the structure will see during erection are very real. With erection engineering, there are no 100-psf live loads padding the design. Temporary shoring and rigging must be adequate to safely support the weight of the structure, but keep in mind that the deflection limits associated with permanent construction do not necessarily need to be applied to temporary conditions.

Stability

The driving force behind most erection engineering analysis is stability, and the subject of stability is certainly well studied. However, its application to the types of problems seen by erectors is lacking. Take, for instance, a simply supported beam. With simple shear connections in a typical frame, we know exactly how to check this beam for all limit states that could reasonably apply. But the same rules do not apply when you take the same beam and use it as part of a temporary support system where it simply rests on its supports at the ends. In this case, the lateral torsional buckling equations within Chapter F are not strictly applicable. According to Section F2 of the 2010 AISC *Specification*, the provisions only apply to beams whose ends are "restrained against rotation about their longitudinal axis."

What about something a little more complicated, like a truss? Consider, say, a fairly substantial, single-piece truss. The erector needs to know if it is acceptable to take the truss off the hook once it is in place or if additional bracing and guy wires are needed beforehand. In this case, one might try to simplify the issue by looking at the top chord of the truss as if it were a very long column in compression. In concept, this should work.

But what about the construction wind loads and the associated second-order effects due to the compression on the top chord occurring concurrently with the lateral deflection? This type of simple analysis is fairly accurate and can give you a feel for the problem. However, for final analysis we have found the direct analysis method to be the most useful tool used when investigating truss stability. This more robust analysis is performed by sweeping the geometry of the chord members, reducing member stiffness and running an iterative second-order analysis to ascertain if the model converges (i.e., if the truss is stable) and if the corresponding member internal forces are acceptable. This method has the added benefit of being able to produce splice forces and moments for multi-segmented trusses.

As a real-world example, we recently checked the stability for a two-piece, 398,000-lb truss to be erected over an existing and fully operational hospital, as shown in Figure 1. The bolted splice connection was designed to resist out-of-plane temporary wind and stability moments in combination with the construction dead-load and live-load-induced axial forces until the permanent splice welds could be completed.

At the higher end of the complexity scale is the engineering of "on the hook" stability, in which the capability of a truss to be lifted at certain points by a crane (or cranes) is determined. It turns out that many erectors simply use a trial-and-error method of lifting and setting down until things look and feel right. We recently performed this type of analysis on a 226-ft-long barrel truss,

Fig. 1: A two-piece truss being erected over an existing hospital building.

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shown in Figure 2. However, in our case the erector for the job was looking for something better than this typical approach, so we turned once again to an analytical approach.

One of the first stumbling blocks encountered in this situation was the fact that analysis software generally requires several more boundary conditions than were presented in this real-world case in order to even run. In the end, the solution was to employ a low-stiffness spring element at each node to provide the analytical stability necessary to determine an eigenvalue buckling shape, to which the truss geometry was changed. It was then reanalyzed with a reduced stiffness direct analysis check to determine final stability. (Quite frankly, we don't think the trial-and-error approach is necessarily a bad idea. However, the more comprehensive analysis should at least give the erector for this project a better starting point.)

Putting it All Together

As with more typical structural engineering, all of the analysis in the world is moot unless the results are effectively communicated to the erector and ultimately their field personnel. This communication can be as simple as a bulleted list of erection steps and as complicated as an annotated 3D Revit erection plan for each step. The format of the final product should be discussed at the beginning of the job so that all parties are aware of the intended level of detail to be reached. It is important to keep in mind that the erector already has a pretty good idea of how to best erect the structure. A good erection plan should start with the erector's ideas and then build upon those ideas with sound erection engineering principals. The end plan may not be exactly what the erector originally envisioned, especially when it comes to temporary bracing. However, at the very least the final plan will not be at odds with the original plan, and it will more likely be followed in the field. MSC

Fig. 2: A multi-crane lift of a 226-ft-long barrel truss.

This article provides a preview of what the authors will present in Session N3 at NASCC:The Steel Conference, April 18-20 in Dallas. Learn more about The Steel Conference at ***www.aisc.org/nascc****.*