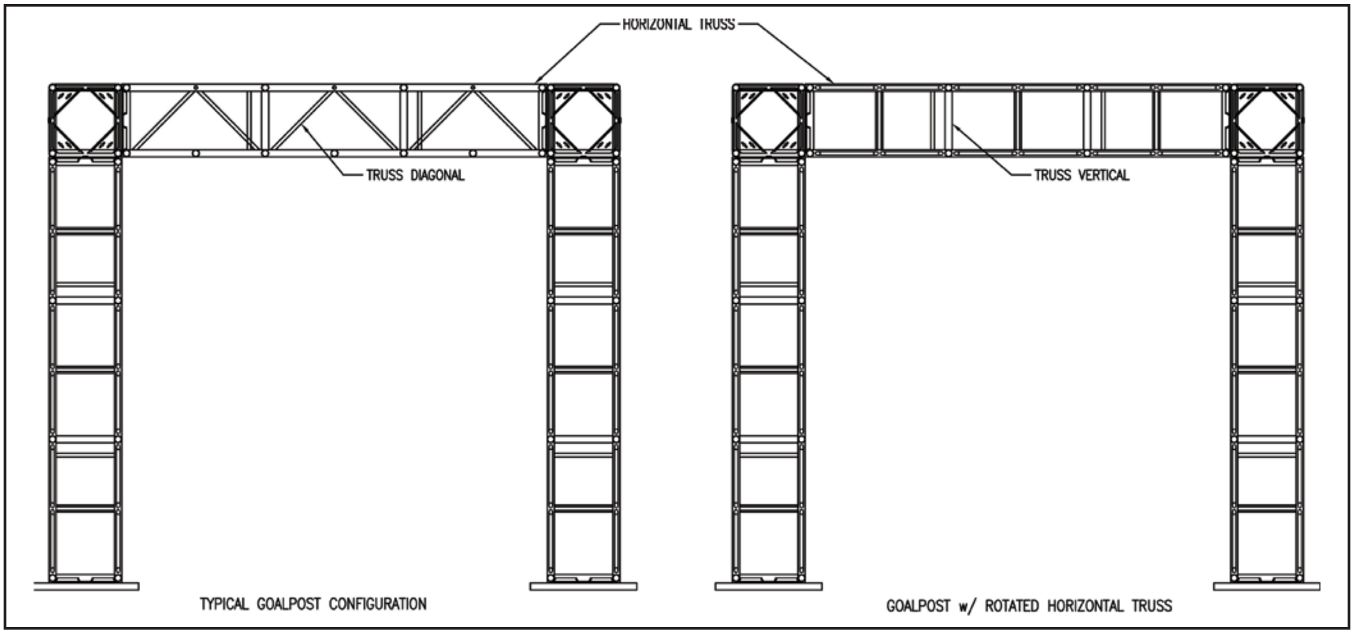


Figure 1

Using entertainment truss outdoors

BY **MIRIAM PASCHETTO**

THIS ARTICLE WAS INSPIRED by one of Geiger's clients who is a rigger. Whenever we review one of his outdoor truss installations, he asks (nay, *begs*) that we try our best to avoid requiring the horizontal truss to be oriented with its diagonal members in the horizontal faces. That is, rotating the horizontal truss 90 degrees from the typical installation orientation. (See **Figure 1**.) From what this client says, whenever we have him rotate his horizontal truss, people will constantly come up and ask him if he knows his truss is installed wrong. And it seems that some fellow riggers see what he has done and then copy the configuration in future installations without understanding why we designed it that way. Evidently, they figure my client knows what he is doing and may know something they do not.

I get why there is push-back. Seeing the horizontal truss rotated just looks so ***wrong***. Indeed, the majority of the time it ***would*** be wrong. On top of which, the vertical loading is tangible and plain to see while the full design wind may never occur while the truss is in use. "That engineer's crazy—the wind would never bring this truss down." However, engineers are in the business of ensuring that structures do not collapse on those occasions when there is extreme loading. Do you know what top wind speed your truss installations can withstand? I would argue that everyone doing outdoor installations should be cognizant of the worst-case wind demands that ***may*** occur during the life of their structure, no matter how temporary in nature.

It is not just my engineering opinion involved. Engineers are required by law to follow local building codes. You may think what you like about the building code, but engineers do not have the choice of ignoring it (except in special circumstances which are beyond the scope of this article). Most, if not all, US building codes reference *ANSI/SEI 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures* published by the American Society of Civil Engineers (ASCE). The wind design provisions in *ANSI/SEI 7* have been developed through extensive wind tunnel testing, including on various truss types, and use of historical weather data. ESTA's *ANSI E1.21 Temporary Structures*

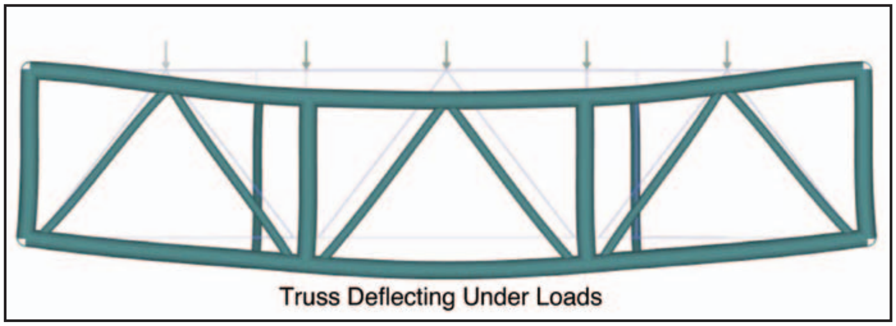


Figure 2

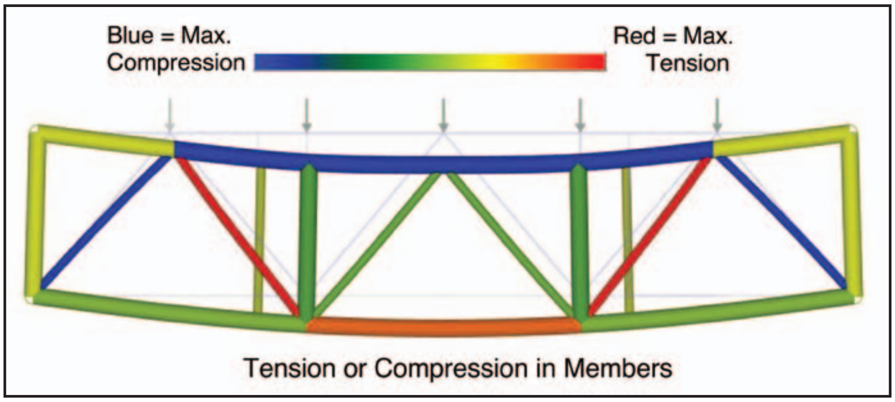


Figure 3

Use for Technical Production of Outdoor Entertainment Events references *ANSI/SEI-7*. Both standards are important for temporary outdoor productions.

First, I want to review trusses. Typical entertainment truss has a strong and a weak axis. (Note that tower truss is equally strong in both axes.) Hence the "right" and "wrong" ways to install a horizontal span of truss. Having the strong axis support the gravity loads (self-weight, equipment, et cetera.) is how these types of trusses were designed. They were not designed to resist lateral loads because they were not envisioned as being used as outdoor equipment. If one just thinks about the allowable load tables published by the manufacturers, it should alert you to the difference in the truss' two axes. Load tables are published for truss' strong axis, only. The weak axis is not meant to take load.

You may be thinking, "Okay. That's all well and good, but everyone installs these trusses outdoors, and I've never had a problem. Plus, how can I address this issue without increasing costs and losing business?" Look at it from a risk perspective: If you do not plan on and design for wind loads, your outdoor truss is going to see some lateral wind, perhaps extreme, that has not been quantified and which will act on the truss' weak axis, for which you have no allowable load data. To my mind, it is cheap insurance to hire an engineer, especially in situations where the truss cannot be taken down in the event that gusting wind or thunderstorms are predicted.

Indeed, it is not just that the wind acts on the truss' weak axis, but that the truss will see biaxial bending—gravity load on the strong axis and wind force on the weak axis acting simultaneously causing bending moment in both axes. As I will illustrate, this means that the truss chords will be loaded twice: from the gravity loads and the wind loads. For two of the chords, these loads will be additive. That is, compression in one of the chords and tension in one of the other chords from the combined gravity plus wind loads.

Let us look at truss behavior and the differences between the typical entertainment truss' strong and weak axes. **Figure 2** shows an eight foot stick of 20" box truss. The end supports are not shown. What is illustrated is the deflected shape that the truss takes under the panel point loading. The amount of deflection is exaggerated to make it easier to see. The grayed-out lines depict the undeflected shape. The deflected truss forms a Mona Lisa smile, if you will. It should be clear that when the truss takes this deflected shape the bottom chords are being stretched and the top chords are being compressed. This is the tension/compression couple that resists the bending moment caused by the application of loads.

Do you know what top wind speed your truss installations can withstand?

While the chords handle the bending moment, what are the truss' vertical "face" members doing? The diagonals and verticals transfer the loads to the end supports; in other words, they resist the shear. Like the chords, they accomplish it by going into axial tension or compression. Trusses are efficient for just this reason: under load, the various truss members are in either compression or tension without bending (ignoring local bending when chords are loaded between panel points). (See **Figure 3**.) For gravity loads, the bottom and top chords are in tension and compression, respectively. The verticals as well as the central and end diagonals are also in compression. The remaining diagonals are in tension. As can be seen in **Figure 4**, the individual members themselves have almost no local bending moment.

We have established that a typical truss carries load by its members going into either compression or tension. Now we will throw a wrench into things. In typical entertainment truss, the weak axis is characterized by having no diagonals (as defined by **Figure 1**). This configuration is called a Vierendeel or rigid frame truss. It is not a true truss in the classical sense because the vertical members develop little axial tension/compression when the truss sees weak axis loads, although the chords still do. **Figure 5** shows this and also illustrates the relative weakness of Vierendeel trusses. The loads here are the same as were applied to the strong axis in **Figure 3** and **Figure 4**, but the deflection is much, much larger. In **Figure 6** you will see that, unlike true trusses (see **Figure 4**), the Vierendeel truss members have bending moment. This is how Vierendeel truss supports loads: the verticals go into bending and the chords have bending as well as axial tension/compression.

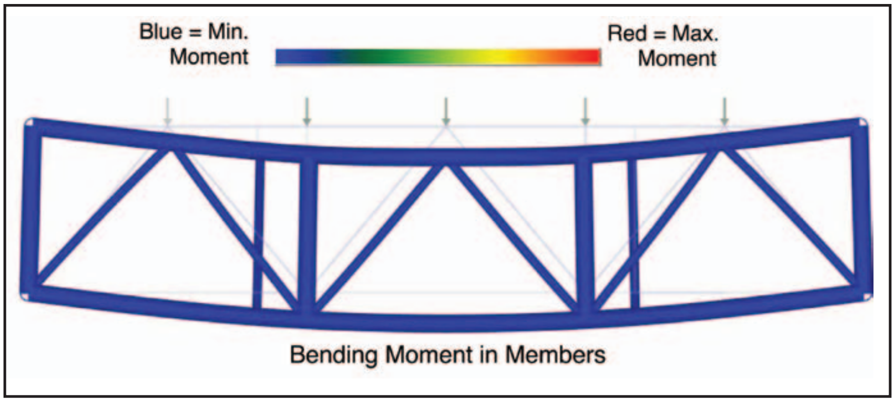


Figure 4

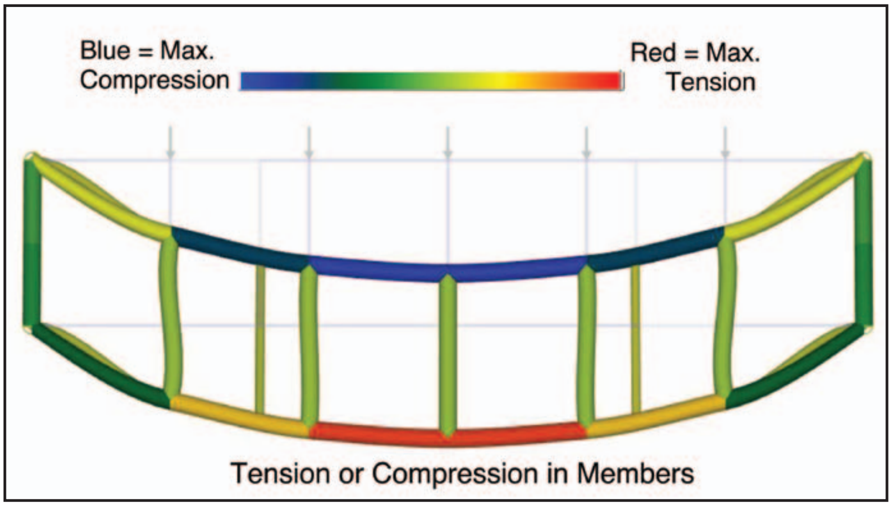


Figure 5

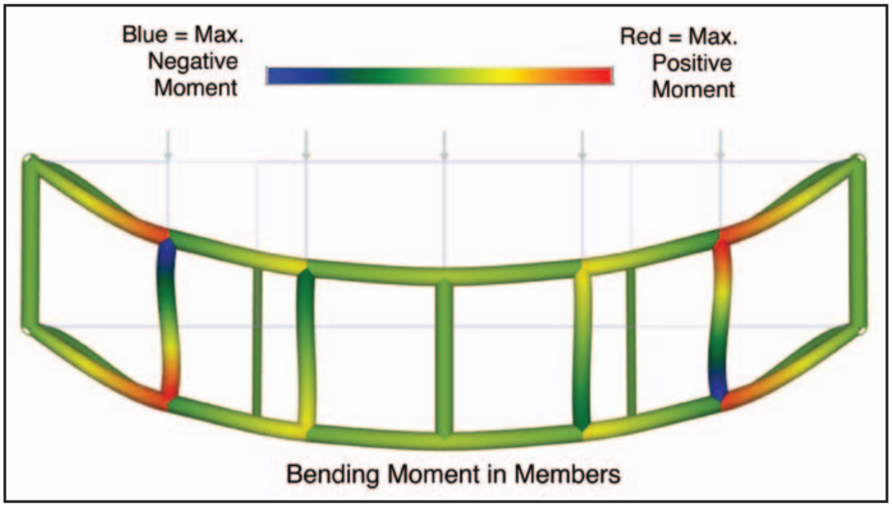


Figure 6

. . . you do not want your weak axis to be set up to resist the larger of your biaxial loads.

Let us dig into an actual project at this point. A large outdoor goalpost truss structure was designed to serve as the temporary entrance for a national camping event. The gateway's horizontal truss spanned 20' and cleared 16' over the ground. The gateway was clad with soft goods and supported lighting on its vertical legs only. Thus, the horizontal truss supported its own weight and resisted wind load only. In **Figure 7** and **Figure 8**, we show only the horizontal truss span of the gateway, with the standard installation (diagonals in the vertical faces) on top and rotated orientation below. The self-weight and wind loads are the same for both the top and bottom trusses.

You can see in **Figure 7** that the two trusses show the same general pattern of compression and tension in their various members as was seen above in **Figure 3**. However, there are two differences that may not be immediately evident. The first is that the two chords in tension are on the

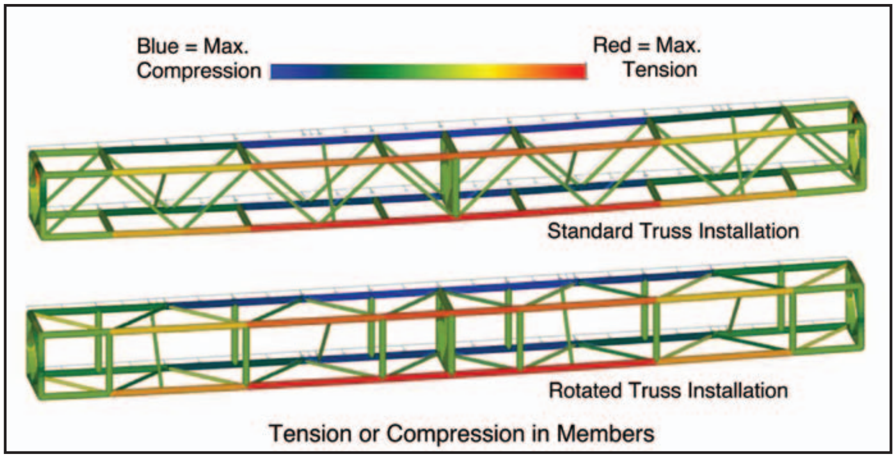


Figure 7

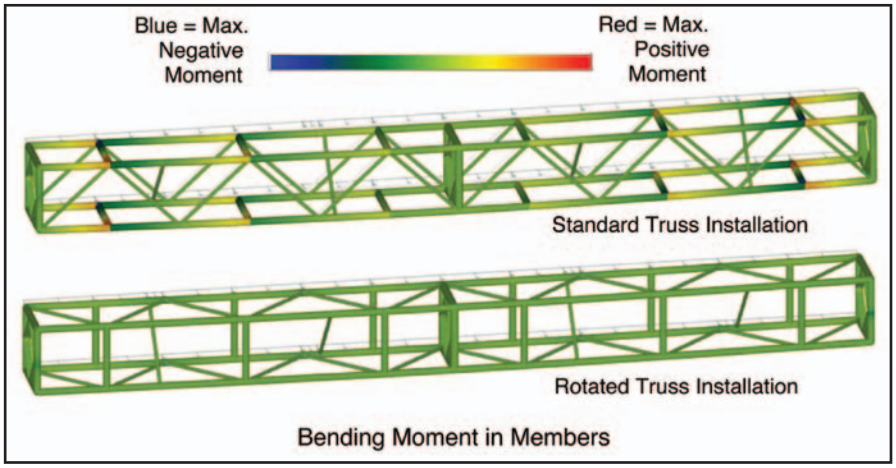


Figure 8

front face instead of the bottom and the two compression chords are in the back rather than the top. This is because the design wind load is roughly ***seven*** times that of the self-weight. The wind load dominates the truss' response to the biaxial loading.

The second difference is that the two front chords have an unequal amount of tension, just as the rear chords have unequal compression. This results from biaxial loading. The two front chords are in tension from resisting the wind. The two bottom chords have some tension from supporting the truss self-weight. When the wind and self-weight act simultaneously, the tension from each is additive in the front bottom chord. By the same token, the top rear chord has additive compression. The other two chords see a mix of tension and compression. That is, the top front chord is in tension from wind, but it also experiences some compression from the self-weight. The tension is the larger force so the compression just reduces it a bit. That is why the two front chords do not see the same tension force. The same reasoning applies to the bottom rear chord that sees some tension but has net compression.

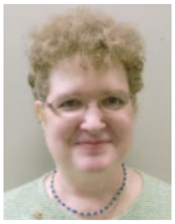
Moving on to the bending moments shown in **Figure 8**. The horizontal truss members in the typical installation show significant bending moment because the wind acts on the truss' weak axis that resists the load through Vierendeel action—members in bending in addition to the axial tension/compression forces. Conversely, in the rotated truss where the strong axis resists the wind and the weak axis supports the self-weight, there is no bending moment for all intents and purposes. The truss is configured such that the heavier load, in this case wind, acts on the strong axis. The weak axis handles the lighter self-weight load. Note that although the bending moments in the top truss' outer end members may not look all that bad—just a little bit of red and blue areas, right?—in this case the moments are 50% above what the members can safely withstand.

To sum up, there are several important things to keep in mind when looking to install entertainment truss outdoors. First of all, you do not want your weak axis to be set up to resist the larger of your biaxial loads. When using truss outside, you should be prepared for the code-prescribed wind load. In the example above, the higher force was the wind acting on the surface of a wrapped truss. The only thing that makes sense is to have the strong axis taking the larger of the load directions.

You may be thinking that well, no one would be around if the wind were gusting up to 85 mph so the only risk is to the truss. First, even with active supervision of the site, this is difficult to guarantee. Second, for our example above, imagine a line of thunderstorms rolls in. It is not a stretch to expect that the wind could approach 85 mph gusts while everyone is breaking camp and packing up. The campers would be stuck in the long line of cars leaving the site as the gateway experiences its design wind load—right when there is the highest risk to the carloads of families driving beneath it.

The second important thing to remember is the additive axial chord forces caused by applying biaxial loading to a truss. If your truss is loaded to its published allowable capacity, then any amount of wind acting on it will overstress the chords. A 40 mph wind in the example above would be approximately 13 lb/ft lateral load on a wrapped truss. If the truss were longer and heavily loaded with equipment, then a 40 mph wind could quite conceivably bring it down by overstressing the chords, if the Vierendeel type bending moments did not initiate a collapse first.

Outdoor installations will not always experience moderate to high wind forces, but I hope I have demonstrated that considering wind loads in designing outdoor installations of entertainment truss is important and worth the trouble—even if you have to install your horizontal truss oriented the “wrong” way. ■



Miriam Paschetto is a licensed PE in New York State and works as an Associate at Geiger Engineers. For more than 19 years she has provided structural engineering services for entertainment projects around the world, among them the Metropolitan Museum of Art’s recent exhibit *About Time: Fashion and Duration*; the sound system supports for Globe Life Field in Arlington, TX; rigging capacity analysis for the Albany Civic Center in Albany, GA; the outdoor stage for the 150th Cinco de Mayo Celebration in Puebla, Mexico; rigging plot reviews for venues across the US; and numerous Super Bowl Halftime shows. Miriam is an active member of ESTA’s TSP Rigging Working Group. She is also a member of the American Society of Civil Engineers and the Structural Engineers Association of New York. Miriam has published several articles in ESTA’s *Protocol* journal and given presentations at the 2021 New World Rigging Symposium, 2016 NATEAC, and the 2015 Event Safety Summit.