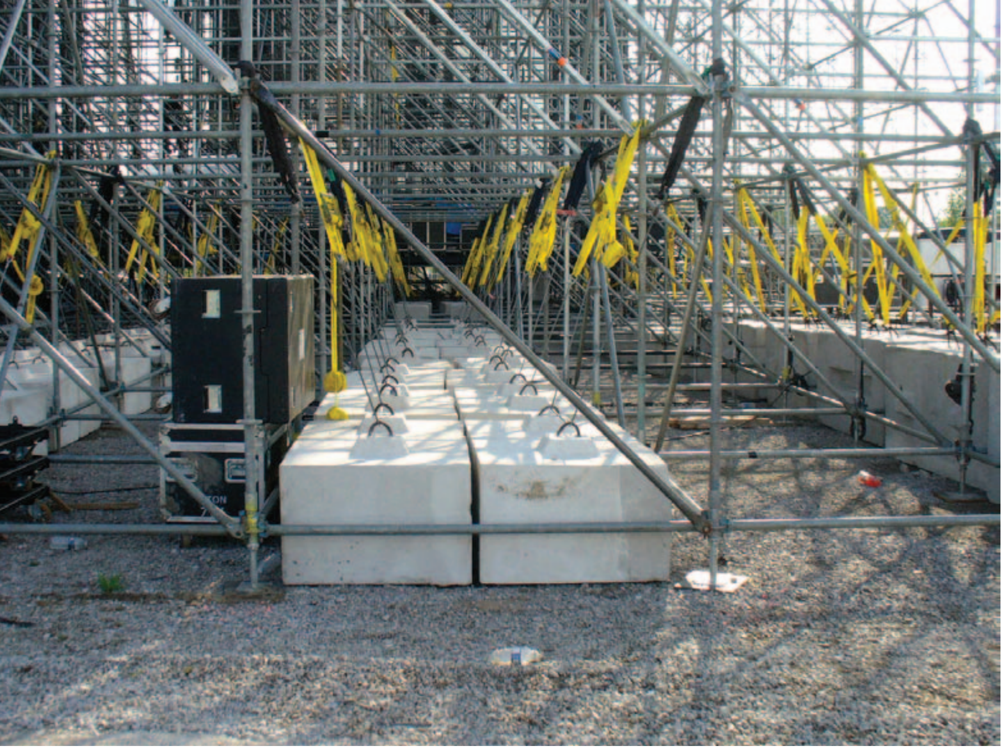

PHOTO COURTESY MOUNTAIN PRODUCTIONS

The ballasts shown are being used to resist uplift, not to anchor guys against a lateral load. The engineering argument for using ballasts to resist uplift is much easier to make than is the argument for using them to resist horizontal loads.

It's summer and a young woman's fancy turns to guys...

BY MIRIAM PASCHETTO

Ballast-anchored guys for temporary outdoor entertainment structures

OR MORE PRECISELY, ballast-anchored guys for temporary outdoor entertainment structures. It's true! Except for the part about being young. 'Tis the season for outdoor concerts, festivals, and the like, and I'm sure I'm not the only one who worries about the safety of all the temporary structures that will be erected this year.

Guys anchored with ballast are one of those things that can keep this structural engineer . . . up at night.

Guys anchored with ballast are one of those things that can keep this structural engineer (and perhaps many other people in entertainment) up at night. I think after reading this article you will understand why, and my hope is that you will also have gained a better understanding of ballast-anchored guy behavior.

I want to start out by briefly discussing the 2011 Indiana State Fair roof collapse for two reasons. One is that it was caused by anchoring the guy cables with an inadequate amount of ballast. Two, everyone is painfully aware of this particular catastrophe. It is an important lesson in how critical it is to get the ballasting right. After the collapse, The Indiana State Fair Commission engaged Thornton Tomasetti (hereafter referred to as TTG), an established and well-respected structural engineering firm, to investigate the cause. They then made the final TTG report available to the public so that we may all learn from it.

TTG gathered data from various sources and determined that the wind speed when the roof collapsed was 59 mph. Note that this is lower than the reduced design wind speed of 67.5 mph applicable for much of the US for a temporary structure in place six weeks or less. For those readers who are not aware: wind pressure changes with the square of the wind speed, a basic property of fluid behavior. Thus, the wind pressure that caused the collapse was only about 76% of the design pressure that the stage roof should have been able to withstand. While it cannot be said absolutely that the roof would have stayed up if adequate ballast had been provided—other problems may have developed—it certainly might have.

Still, I was suffering agita over ballast-anchored guys for years before the Indiana collapse. Why?

First, relying on friction for a structure's stability is problematic, as I hope will be clear later in this article.

Second, having to attach the guy at an angle means that when the wind blows on the outdoor structure the guy is essentially trying to lift **and** slide the ballast at the same time.

Third, according to the relevant standards, ballasted structures require a 1.5 factor of safety to be applied to overturning and sliding resistance. This factor can increase already high amounts of ballast to the point of being totally impractical.

And fourth, when dealing with installations of temporary ballast, such as heavy concrete blocks, it is challenging, at the very least, to ensure that each guy cable can fully engage all the ballast supplied to anchor it. This last I will not address here because it's another full article in itself. (And, you may see that next year.)


PHOTO COURTESY REED RIGGING

The load this concrete block is restraining is also lifting the block, thus reducing friction between the block and the ground.

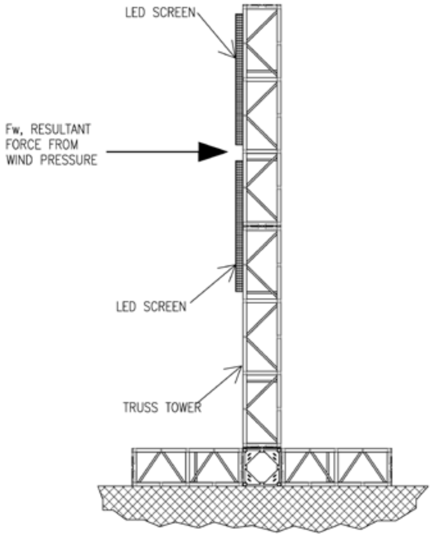

Figure 1 – Side View – Tower with Screens

It's a given that wind is going to blow on temporary outdoor structures. In the case of roofs, the wind creates some combination of uplift and downward pressure over the roof surface in addition to the lateral pressure that acts on any vertical surfaces present. For something like a truss tower, there is only the lateral force from the wind—you're not going to get any uplift, for instance. So to keep things as uncomplicated as I can, I'm going to use a truss tower supporting two large LED screens (see **Figure 1**) to facilitate the discussion here. To simplify things even further, I will only consider the wind pressure on the screens and ignore what acts on the truss itself. As the wind blows on the LED screens, the tower wants to slide across the ground and tip over (if only we would let it) (see **Figure 2**).

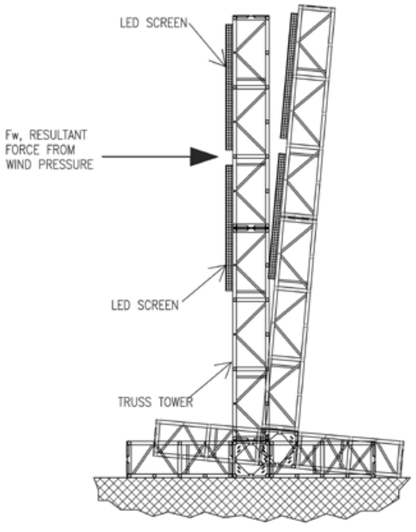

Figure 2 – Moving Truss Tower


PHOTO COURTESY REED RIGGING

Ground anchors don't rely on friction to withstand a lateral load, and they make for neater looking installation.

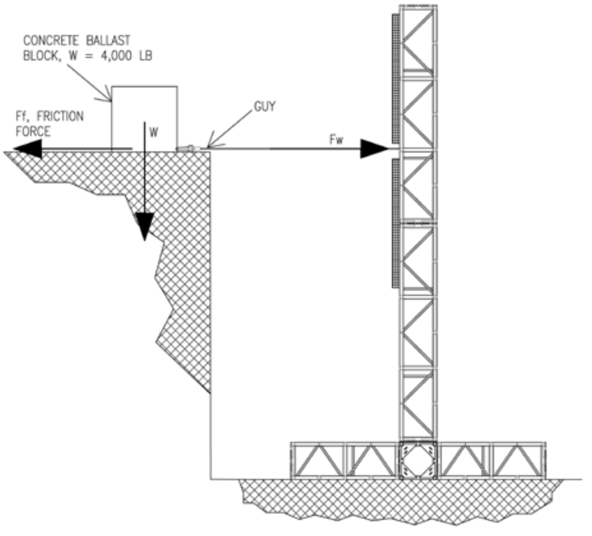

Figure 3 – Flat Guy

To prevent this, a guy cable is attached to the tower and its free end is anchored at the ground with ballast. I'm going to progress through slightly different (and idealized) guy cable configurations for this tower to isolate the issues I want to cover.

Imagine you had the extremely odd but really quite fortunate ground condition shown in **Figure 3**. Your ballasted guy would be perfectly in line with where the wind's resultant force, Fw, will act. If you rotate the figure clockwise, this set up should be quite familiar—the guy becomes the equivalent of a dead hang in rigging. It's just that the rigging load is from wind instead of theatrical equipment and the supporting structure is a ballast block. But what could be better, right? A nice straight shot.

The first complication arises from the fact that the ballast is just sitting on the ground and is not attached to it. The only thing resisting the wind force is static friction between the ballast and the ground. It may be obvious to you that we do not even want to think about kinetic friction: what develops when two surfaces are sliding against each other. (Say you are trying to push a heavy box across the floor. It gets a lot easier once you've got the box moving; the initial resistance is from static friction and the lower moving resistance is from kinetic friction.) Kinetic coefficients of friction are generally much lower than static coefficients, so if your ballast starts to slide even a little it could be disastrous. One reason among many that we apply the 1.5 factor of safety mentioned earlier. Note that hereafter I will be discussing static friction **only**.

The friction force you can develop to resist the wind force Fw depends on just two things: the weight (W) of your ballast and the coefficient of friction (COF) associated with the surfaces you've got. What the surfaces are made of and whether they are clean, dry, greasy, or wet will all affect the COF value. The friction resistance provided by the ballast block, call it Ff, equals the force acting perpendicular to the ground, W, times the friction coefficient COF.

I like to think about extremes when getting a feel for a physical behavior, because often the extreme cases are really obvious and thus an easy place to start. So okay, what if there were a coating of fully frozen ice (no surface melt) under the concrete block? The weight, W, of the block hasn't changed, but your Ff will be quite low because, of course, ice is slippery. We'll say the COF of concrete against solid ice is 0.1. Then for a typical concrete ballast block weighing 4,000 pounds the Ff is only 400 pounds (= 0.1 x W). At the other extreme, if instead of ice there is a dry rubber mat with a COF on concrete of 1.0, your Ff = 4,000 pounds. A 10-fold difference!

It's just not a good idea to live right at the limit.

Now, let's move on to a more common surface under the ballast. In many outdoor entertainment installations, the concrete ballast blocks sit on hard-packed soil. Above, the conditions were assumed to be dry, but we can't guarantee that will be true when the ballast is required to act because wind often comes with rain. For determining outdoor ballast amounts, one should assume that the ground/pavement will be wet and therefore more slippery when the structure is experiencing wind. (Note that the 1.0 COF for dry rubber on concrete, above, drops to 0.45 when the surfaces are wet and then Ff suddenly becomes 1,575 pounds instead of 4,000 pounds.) The COF for wet concrete on soil is about 0.2 according to *ANSI/PLASA E1.21*—the quite hefty 4,000-pound concrete ballast block will provide 800 pounds (= 0.2 x 4000 pound) of sliding resistance, **at most**.

Eight hundred pounds is the maximum we can expect to get only if all the actual conditions are what we assumed they would be. The concrete may be dirty or oily on the bottom. Soils are extremely variable. It's just not a good idea to live right at the limit. Therefore the 1.5 factor of safety for ballasted structures gets applied now to the 800 pounds. So it all boils down to being able to safely rely on only about 530 pounds (= 800 pounds/1.5) of lateral resistance from the 4,000-pound ballast block.

But what kind of wind does this relate to? If, as an example, the two LED screens shown in the figures are 10' x 15' each, the 530-pound resisting force would be adequate for wind gusts of no more than 25 mph. Which is to say, this particular screen/tower/guy/ballast-block arrangement would not be acceptable under the *ANSI/PLASA E1.21* standard (or indeed under the majority of local building codes). The minimum design wind speed for anything which can be very quickly dropped and secured is 40 mph. If the screens could not be dropped quickly, the tower would have be designed for 67.5 mph wind. These wind speeds correlate to a 156% and 629% increase in pressure, respectively, over the 25 mph wind.

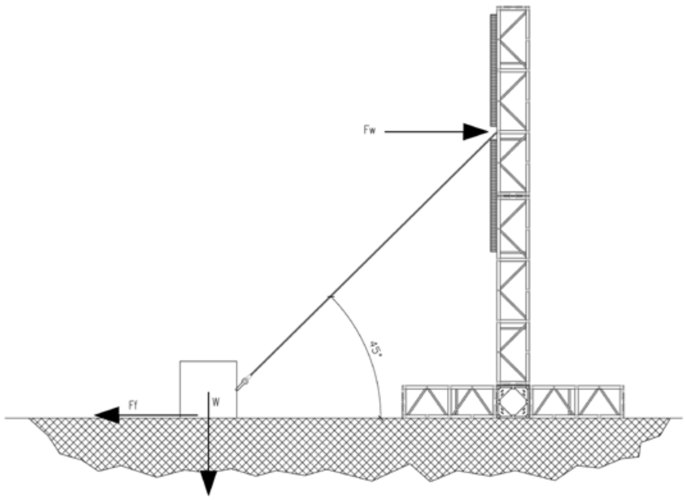

Figure 4 – 45-Degree Guy

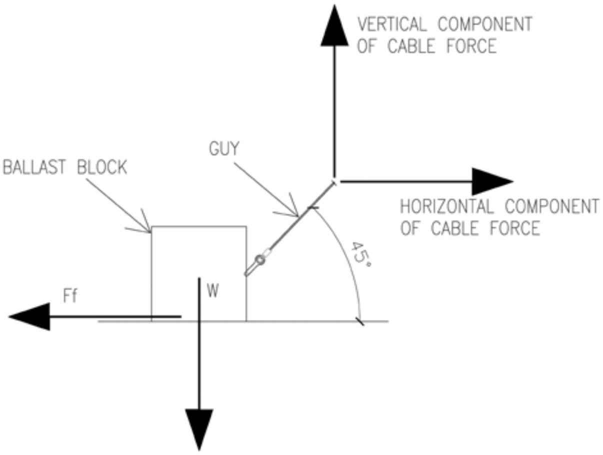

Figure 5 – Ballast Block Detail

Which is to say the ballast would need to weigh 10,240 pounds for the 40 mph wind case and 29,160 pounds (!) for the 67.5 mph wind. And, don't forget that you need a guy with ballast both front **and** back of the screens. Each guy resists wind from only one direction.

All right, so friction doesn't get us much resistance even with a very heavy ballast block, and this is still with the forces acting in line with each other. Our "horizontal dead hang" configuration of **Figure 3**, after all, isn't realistic. We need to move on to what's shown in **Figure 4**: a guy at 45 degrees anchored with a concrete block. Screen sizes and ballast weight W are the same as the example above except the ballast block is now sitting down on the same level as the truss base, making the angled guy necessary.

It's at this point that I wish I could re-write the laws of physics. The 45-degree angle means that the guy cable will be partly lifting up on the ballast at the same time that it is pulling horizontally on it. The wonderful W = 4,000 pounds that turned out to be so wimpy in the configuration above? Well, we can't use all of it towards our friction resistance force anymore because as the wind force engages the guy, it starts to support part of the ballast weight.

Let's look at the 25 mph wind on the two 10' x 15' screens mentioned above. For this case, the guy cable and ballast need to resist a 530-pound force from the wind, but the cable is no longer in line with the resultant wind force Fw. To develop the resisting horizontal force in the cable means there will also be a vertical force (see **Figure 5**). This is basic physics and there's no getting away from it no matter what I might wish. It's similar to rigging bridles where at the supports you get horizontal forces even though you are only supporting a vertical load.

For a cable at 45 degrees, the vertical and horizontal forces exerted will be equal. If the guy puts 530 pounds of horizontal force on the block it will also pull up on it with a force of 530 pounds. The 530

In my ideal world . . . temporary outdoor structures would be tied off to nearby permanent structures or earth anchors.

PHOTO COURTESY STAGE RIGGING

This trial setup in a field is using multiple jersey barriers as ballasts. Getting multiple blocks of concrete to act as one unified ballast can be difficult.

pounds of W that is being lifted by the cable has to be subtracted from the 4,000 pounds before calculating what sliding resistance is available. Take 530 pounds from the original W of 4,000 pounds and there is 3,470 pounds left to create the frictional resistance needed to prevent sliding, but this reduced weight won't be enough to handle the 530 pounds of sliding force. We already showed that you need the full 4,000 pounds for that.

It's necessary to provide more ballast to handle just the 530-pound vertical force. That way there will still be 4,000 pounds to resist the sliding force. So multiply 530 pounds by 1.5, the safety factor remember, to get 795 pounds. Add this to the 4,000 pounds for a total ballast amount of 4,795 pounds required to meet the combination of horizontal and vertical forces from the guy cable. Again, this is only for the fairly low wind speed of 25 mph. To meet 40 mph, the ballast would have to weigh 12,275 pounds. For 67.5 mph wind, it would have to be 47,950 pounds.

See why using ballast worries me so much? The ballast amounts required are almost impossible to believe, yet getting the weight right is critical for the structure's stability and safety. And we've been looking here at something relatively small: a total windage area of 300-sq.-ft. for the two screens. The side wall of a stage can easily be eight times as much. We're talking about ballast amounts in the range of 98,000 pounds to anchor the 45-degree guy cables on both stage left and stage right, and this is assuming the sidewalls can be brought down at 40 mph wind speeds.

My suggestions? In my ideal world, guys would never be anchored by ballast. Temporary outdoor structures would be tied off to nearby permanent structures or earth anchors. But, of course, I understand that ballast is often the only practical solution even when it involves quite large amounts of weight. Have a qualified person review the ballast layout; ensure surfaces have been cleaned before placing the ballast; and inquire about driving stakes on site. If the site owners allow staking into the ground, you can avoid relying on friction by having the ballast bear laterally on stakes, which should also be reviewed by a qualified person. ■

Miriam Paschetto is an Associate with Geiger Engineers and a licensed P.E. in New York State. For the past 12 years she has provided structural engineering services for entertainment projects around the world, among them the outdoor stage for the 150th Cinco de Mayo celebration in Puebla, Mexico; LEGO's X-Wing Fighter reveal in Times Square; *Spider-Man: Turn Off the Dark* on Broadway; the *King Kong* production in Melbourne, Australia; the roof-top stage set for NBC's *Million Second Quiz*; several Wrestlemanias; and a number of Super Bowl half-time shows. Miriam has been active in PLASA's Rigging Working Group for five years, serving on the task groups for two ANSI approved standards. Technical questions may be sent to: mgp@geigerengineers.com.