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WHEN ROOF SYSTEMS FAIL: PART 1 Design Forces Acting on the System

“When temporary roof structures fail, they often do it quickly and spectacularly” says Shawn Nolan, division coordinator of Entertainment Structures Group. “Within seconds, an overloaded structure can come crashing down—causing extensive damage and possible injury or death.” Proper design and construction can dramatically reduce the chances of catastrophic failure.

OUTDOOR STRUCTURES SUPPORT A VARIETY OF LOADS

Most users have an intuitive grasp of rigging loads. These loads act downward and like all gravity driven loads; the forces they exhibit on a structure are generally readily apparent. Environmental forces and the stresses they cause often are not. Wind, rain, and seismic forces significantly affect the safety and capacity of temporary outdoor structures. Most users are not aware of the magnitude of these forces or how they can combine with rigging loads & other loads to cause failure. One must consider a variety of load combinations to ensure the safe design of outdoor structures.

Entertainment structures are different than conventional structures. Conventional building structures are almost never loaded to their design capacity whereas outdoor stage structures are almost *always* stressed close to capacity, frequently unintentionally. A roof structure with a heavy rigging load, combined with a moderate wind can easily be overstressed if not designed properly. For most structures, the very same system that supports the rigging loads is the same system that braces the structure against wind, rain, earthquake and any other environmental forces. All systems have a limited capacity and if all of it is used to hold up the rigging loads, there may not be any capacity left to ensure that the wind doesn't blow the structure down. If the worst case load combination is not checked, the only insurance against failure is luck.

It is usually fairly straightforward to add up the rigging load weights and perform some

simple math to see how these loads are acting on a roof system. On the other hand, wind and other environmental forces are much harder to quantify. Since wind force is usually the largest force other than rigging loads acting on a roof system, we'll consider it for our example in this discussion.

WINDLOAD CALCULATION

A general example for wind load is 16 psf acting on the exposed wind area of the structure. This force is fairly close to the typical calculated wind force found in most building codes; based on a 90 mph wind, 3 second gust. The next issue to consider for a wind load calculation is the exposed wind area which can be thought of as the area that would be seen in a straight-on elevation view of the structure (see diagram). If the roof system is covered by solid vinyl sidewalls for example, then the exposed area for that particular wind direction would simply be the area of the width times the height. If the structure is completely open, the only surfaces to attract wind pressure would be the truss system and gear. It can be somewhat complicated to calculate the exposed wind area for irregular surfaces such as truss, lights, speakers, etc. Consider these areas as “solid” for calculation of wind area: For instance, if the truss towers are 12” square box truss the wind area for one leg would be the 1 foot width times the height. This may be a somewhat conservative approach but it is safe.

LOAD CAPACITY / COMBOS

Determination of loads is just the first part of the equation, the second is to check and be sure the system has adequate capacity to support all of the loads and load combinations. Building codes may list up to a dozen possible load combinations, many of which are sufficient for building design but do not completely lend themselves to temporary roof systems. Since roof systems are typically erected with a majority of the rigging loads already in place, it is important to consider the full

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GLOSSARY:

Anchor To lock the stressed tendon in position so it will retain its stressed condition

Ballast Heavy material carried by a moving unit to keep it held down or steady

Bending Loads Loads that cause stresses similar to those found in a typical beam

Control (as in “control” the design) The load combination that causes the largest stress in a structural element

Ground Anchors Plates/Augers embedded in the soil that limit lateral building movement down through tension members tied back to building’s frame

Live Loads Loads imposed on a structure by people or items that are not permanently attached to the structure

PSF Pounds per square foot

PSI Pounds per square inch

Sleeve Block (1) In an aluminum roof grid, the corner component at the system towers that attaches the roof system to the lifting winch and (2) connects the horizontal trusses and guides the roof assembly as it is raised

Tension Stress on a structural member caused by forces tending to draw it apart longitudinally, as in a tie rod

See Part 2 of this article in our September issue:

WHEN ROOF SYSTEMS FAIL

Structural Systems, Ballast and Ground Anchors for Temporary Roof System Stability

rigging load in combination with wind and/or seismic loads. For the typical roof system it is reasonable to consider three different load combinations.

System selfweight + rigging + wind load

Wind load will typically produce vertical and/or bending loads in columns which need to be added to the column gravity load. This combination will likely control the design of the columns. Typically wind load will control the design over seismic loads for these types of structures. However, seismic forces must always be considered.

System selfweight + rigging

This load combination typically controls the gravity design of the roof trusses and possibly the columns. This combination should always be checked.

System selfweight + wind load

Although this combination may not occur in all cases, it is plausible to assume that the rigging loads will be removed while the structure is still standing. This combination is used for the design of the ballast if there is any net uplift on the structure.

WIND LOAD DETERMINATION

A simplified wind pressure calculation for wind blowing from upstage (assumes 50% open back wall):

$$\text{Tributary Area} = 25' \text{ h} \times 40' \text{ w} = 1,000 \text{ sq ft}$$

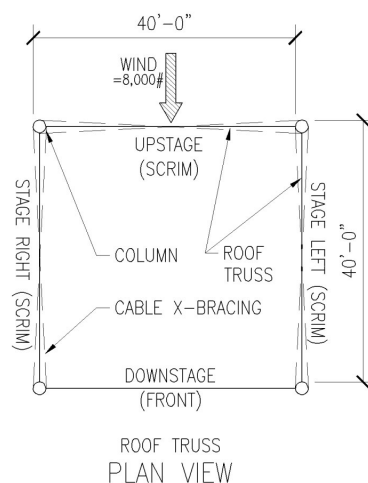
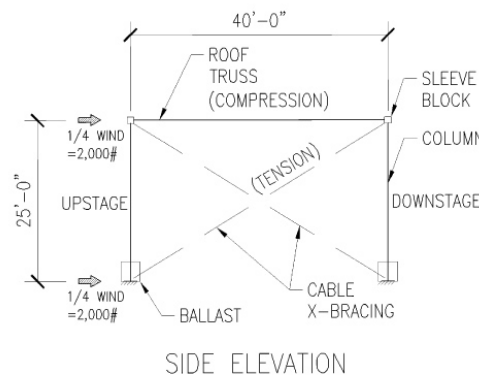
$$\text{Pressure} = (\text{Area}) \times 16 \text{ psf} \times 50\% \text{ open} = 8,000 \text{ lbs}$$

The roof is braced in the upstage/downstage direction to resist wind loads with “interior” diagonal wire ropes (wire rope X-braces on the two side walls). The ropes are connected to the corner sleeve blocks at the top and to ballast at the base.

When the wind blows from upstage a simple assumption is that half of the wind force pushes on the roof and half pushes on the ballast at the base of the scrim. The wind force pushing on the roof is further divided in two with 25% of the total “push” acting at the sleeve block at each upstage tower.

$$(8,000 \text{ pounds} / 4) = 2,000 \text{ pounds}$$

This 2,000 pound (1 ton) force must be transferred down to the ground anchor system. In our example, the force acting at the upstage sleeve blocks pushes on the stage-right and stage-left eave trusses until it reaches the downstage sleeve blocks; putting the two side eave trusses in compression. The horizontal force applied to the downstage eave blocks in turn is resisted by the diagonal wire cable bracing that tie the downstage eave block to the ballast anchor at the base of the upstage column. The ballast must be sufficient to resist both the sliding and uplift from the tension in the cable bracing.



SUMMARY

Once the loads have been determined, the structural capacity of the system needs to be checked to be sure it can support the loads for your set up. These loads have to be safely and adequately transferred into the earth. Foundation systems must spread the load through the structure over an adequate area to make sure the system doesn’t settle or become unstable.

Careful consideration of loads, load combinations and the stress they place on a structural system will ensure that your system is safe and adequate for your set-up.

Disclaimer

This article is not intended to be a thorough treatment of the topic of structural evaluation. Local, state and national building codes should be consulted. The author cannot be responsible for any evaluation based solely upon this article.