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WHEN ROOF SYSTEMS FAIL: PART 2

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

In August 2003 national dignitaries gathered on an outdoor stage in celebration of South Africa's Women's Day. During the event a sudden gust of wind caused the temporary stage roof to collapse, paralyzing one woman, injuring another, and narrowly missing the President of South Africa.

An investigation into the collapse determined that the roof structure lacked sufficient diagonal bracing and ground anchorage. Furthermore, the contractors did not use an engineer to verify that the structure was safely designed and assembled.

Wind-related failures like the Women's Day stage roof collapse can be expensive, dangerous, and even fatal. More importantly, they can be avoided. Proper bracing and anchorage ensures a temporary roof system's stability in high winds.

A common temporary stage roof uses steel or aluminum roof trusses which form a grid to support rigging equipment. That grid is elevated by four steel columns, one in each corner. The steel columns are generally strong enough to support the gravity load caused by the weight of the roof and the rigging equipment, but alone, they cannot provide the stability needed to resist lateral loads caused by wind or seismic forces. (See the July 2005 ESG Report for a discussion regarding how to calculate the gravity and wind loads that act on a structure.)

When designing a stable roof system, a critical issue to consider is load path. For a roof to remain standing during a strong wind, the system must effectively transfer the wind load from the roof down to the foundation. Wire-rope X-bracing is the simplest and most effective way to achieve this load transfer. X-bracing is typically located on the upstage, stage-right, and stage-left sides of the structure. This arrangement provides lateral support for the roof structure while leaving the audience with an unobstructed view of the stage.

Although X-bracing holds a structure together during wind gusts and other lateral loads, the force that lateral loads create against the top of the X-bracing results in an upward pull at the base of the bracing. Additionally, as wind blows around and over a roof structure, it tends to result in an upward pull on the whole structure. These uplift forces can cause a roof structure to blow over, slide sideways, or become airborne in a strong wind. To prevent such movement, a roof system must employ ground anchorage.

One way to anchor a roof system is through the use of ballast, any heavy material used to resist uplift forces. For a standard temporary stage roof installation, the easiest and cheapest form of ballast is concrete block. When heavier material is needed, concrete road barriers can be used as ballast. Another convenient form of ballast is water. Most steel roof systems have base trusses which can be fitted with a bladder and filled with water. When full, these ballast are heavy enough to resist uplift forces that may act on a structure. When empty, they are light enough for convenient transport.

A third option for anchoring roof systems is to use earth anchors, massive screws which twist firmly into the ground and are used like tent stakes to tie a structure down. They are also available in the form of metal plates which, when buried in the ground, can stabilize a structure. Earth anchors are less obtrusive than ballast and much easier to transport. However, during installation earth anchors can damage asphalt or concrete, so their use may be limited to unpaved surfaces.

For the typical temporary stage roof, the correct combination of earth anchors, ballast, and diagonal bracing will guarantee the structure's lateral stability. For more complex projects, structural engineers can use variations of those same techniques to ensure a roof system's stability.

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GLOSSARY:

Ballast: Heavy material, such as concrete or containers of water, used to resist uplift forces by weighing down a structure.

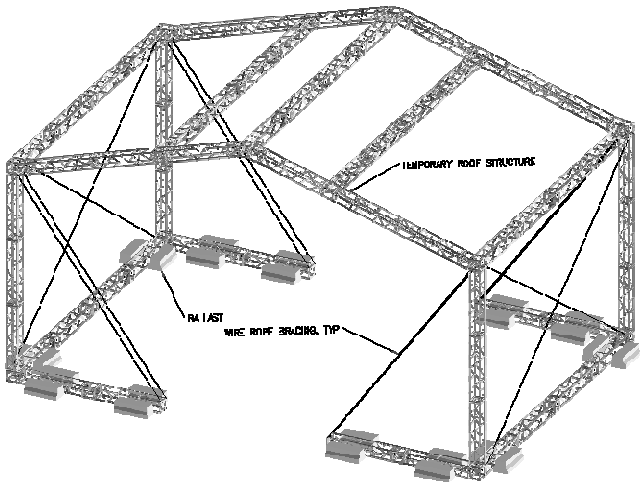
Ground/Earth Anchors: Plates or augers embedded in the soil that limit a structure's lateral movement and resist uplift forces through tension cables tied back to the structure's frame.

Load Path: The route a load takes as it is applied to a structure and transferred through structural components until being absorbed into the earth.

X-Bracing: Wire ropes diagonally connecting the top of one column to ballast at the base of a second column and the top of the second column to ballast at the base of the first column. When a wind load acts to push one column over, X-bracing holds the column upright and simultaneously transfers the load down to the base of the opposite column.

For example, ESG was hired to design a temporary roof system that would cover an entire movie shoot. The project was unique in that the roof trusses had to clear a 124-foot span, which is at least twice the size of a typical temporary roof system (see drawing below). Secondly, the front and back ends of the structure needed to remain open, so while X-bracing was used on either side, it was not an option on the ends. Instead, on each side a base truss was extended 40 feet toward the center from both side columns, leaving the middle third of the structure completely open. A single line of wire cable was stretched from the tip of each base truss back to the top of the side columns, achieving the same function as X-bracing. A combination of water and concrete ballast was used to resist uplift forces. When a storm blew through while the roof was standing, the system held securely.

Because temporary roof systems may only remain assembled for a few days, they are typically built to withstand only moderate gusts of wind. However, in severe windstorms high gusts can cause damage to even the most carefully designed structure. Severe weather is always a possibility; therefore, event operators must always be prepared. For the safety of the audience and crew members, an emergency action plan should be established, clarifying the steps crew members should take to safely reduce wind pressure on a system during high wind gusts. ESG routinely provides high-wind action plans on all temporary roof systems located at outdoor venues.



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