Large Temporary Structure for Special Event

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ABSTRACT

As the entertainment industry continues its efforts to attract audiences and audiences search for ever more dramatic events, engineers are being asked to design and analyze a widening variety of temporary entertainment structures. Whereas concert tours and music festivals typically employ a standard range of modular stages, some events have started using stage structures that are unique and used for one event only. Wrestlemania XXVI in the spring of 2010 at University of Phoenix Stadium is an especially interesting example of this. Standard Stageco rental equipment was combined with several custom-built pieces to create a four-legged pyramid over the main event wrestling ring. In all, 40,000 lbs' worth of truss supported rigging loads equaling 63,000 lb.

Unique, one-off entertainment structures present specific challenges for the engineer, not least because of the normally tight schedules. The loads and structure dimensions can be significant despite the temporary nature of the installations. And it is most often not feasible when problems arise to take the time to determine the cause(s). Usually, issues must simply be worked around if the event is to take place safely and on time. In working on entertainment projects, engineers need to be flexible and creative.

BACKGROUND

The Stageco Group, headquartered in Tildonk, Belgium, has been in operation since 1985. The traditional part of Stageco's business is providing modular truss systems for temporary structures to be installed at a wide variety of entertainment, sporting, and promotional events. However, Stageco also works with production designers to create unique "one-off" structures that will be used only as part of a specific tour or even just a single event.

Beginning in 2003 with Wrestlemania XIX, Stageco has been involved in the staging of World Wrestling Entertainment's (WWE) signature annual event. The WWE wanted a large pyramid structure to support the lighting and audio equipment and video screens above the ring for Wrestlemania XXVI held in the spring of 2010.

THE PYRAMID

The structure envisioned for Wrestlemania XXVI was a straightforward assembly of four trussed legs angled to meet at a point and thereby forming the outline of a pyramid. The pyramid would be 185 feet per side at ground level and 105 feet high. The base perimeter would be formed by cables tying the legs together. Figure 1 shows the pyramid during erection.

A 70'-6" square rigging grid was incorporated into the structure at a height of 58 feet. The rigging grid was constructed of one of Stageco's larger stage roof trusses from their standard equipment inventory. All told the equipment rigged from the pyramid amounted to 63,000 pounds.

The overall structure's size and large payload required that Stageco ship their heaviest-duty truss from Belgium so it could be used for the pyramid's four legs. This steel triangular truss has a depth of 5'-11" with 3.5" diameter chords. The overall strong axis moment capacity is 235,000 ft-lb.

Stage roof truss towers and buttresses in the Stageco system are founded on 6.5' square, steel encased concrete block bases. Each base weighs 4,840 lbs. One of these bases was employed at the bottom of each pyramid leg.

Figure 1. The erected pyramid before installation of rigging loads.

THE VENUE

A state of the art structure with both the roof and natural grass field being retractable, the University of Phoenix Stadium opened in August 2006. The dimensions of the retractable roof opening are 360' x 120'. During Wrestlemania XXVI, the roof was to be open and the grass field was to be in its outdoor location.

Planning to have the stadium roof open during the event engendered much discussion because there was no data available on the wind effects inside the stadium when the roof was retracted. No provisions had been made for wind ballast because the pyramid was being installed indoors. However, the WWE was firm in its decision to keep the roof open. Therefore it was not an option to specify that the roof be closed in the event of the outside wind reaching a certain speed.

For analysis purposes, it was finally agreed that a basic wind speed of 40 mph would be used. Any air turbulence around the roof opening would not have a significant impact on the pyramid because its height was well below the stadium's roof. So in this instance, the Engineer of Record was confident that 40 mph was conservative for a design wind speed. The maximum lateral design force from 40 mph wind on the pyramid was calculated to be 15,200 lb.

THE PYRAMID'S BASE REACTIONS

As with any structure of this type, there was significant outward thrust at the leg bases. When the pyramid was fully loaded, the thrust was 33,000 lbs per leg. Handling forces this large especially from a temporary structure presented quite a challenge. Entertainment projects almost always have a very short lead time and the schedule must be maintained if the event is to occur.

Computer analysis of the pyramid showed that creating a pinned condition at the leg bases would cause some truss members to become overstressed when all loads were applied. At the other extreme, allowing the leg bases to slide freely under load caused the trusses to become even more overstressed than in the pinned configuration. Further computer analysis of the pyramid with intermediate amounts of restraint at the bases found that allowing some spreading reduced all trusses' internal forces to allowable levels.

There was no ability to follow any design path except this last one, allowing the bases to spread a specified distance. Stageco's most heavy duty truss was already being used so the legs could not be made stronger. The rigging loads could not be significantly reduced because the client would be left with a lackluster show. The issues associated with partially restraining the bases would have to be dealt with, namely how to stabilize the bases once the desired displacements have occurred and how to ensure the bases' sliding will take place in a controlled manner.

Leg Base Restraint Methods. Two ways the bases could have been secured once they had moved the correct distance were quickly dismissed - anchoring the bases to the stadium floor or adding more ballast to them to maintain their positions. There was no doubt that neither the University of Phoenix nor Stageco would be interested in drilling into the stadium's concrete floor for anchorage. Similarly, from an engineering perspective it was considered inadvisable to rely on ballast alone to keep the bases in their proper locations because if the they spread too much the entire structure would fail.

Clearly, the base cables that were part of the original designer's concept would be a suitable alternative. These base perimeter cables that tied the legs together would be sized not just for strength but also for the right amount of stretch.

The elongation of the cables would partially release the legs and allow them to spread the desired distances. Beyond that, the cables would restrain the bases from any further spread. The final cable force was 22,000 lbs with the bases each displaced a total of 7 inches outwards.

Once the pyramid reached the desired deflected shape, gravity loads would provide enough friction at the bases to resist sliding forces that might arise from wind forces. The maximum lateral force for 40 mph wind was calculated to be 15,200 lbs. A 3,000 lb water tank was attached to each base to bring the total normal force up to a safe level for sliding resistance assuming a friction coefficient of 0.3 and including a factor of safety of 1.5.

Base Sliding. It was crucial that the bases spread a specified amount in order to keep the structure from being overstressed when fully loaded. Implied in this is that the bases needed to displace equally and in a straight outward line. See Figure 2 for the idealized displaced pyramid shape.

One fear was that a base which had not moved far enough under dead load might suddenly and violently release when rigging loads were being applied. Also, unequal movement of the bases would put additional, undesirable stress on the structure. The truss legs were strong in major axis bending and axial loading but they were not intended to resist any significant amount of weak axis bending. Although in theory the normal loads on the bases would not be high enough to create adequate frictional force to resist the thrust, in practice each base would see different floor conditions and one could easily get stuck. See Figure 3 for the expected displaced shape for this particular problem.

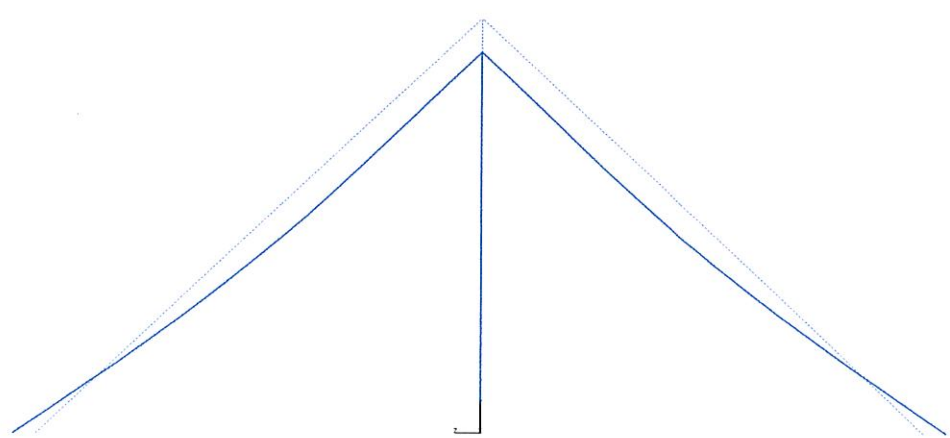

Figure 2. The desired deflected shape for the pyramid.

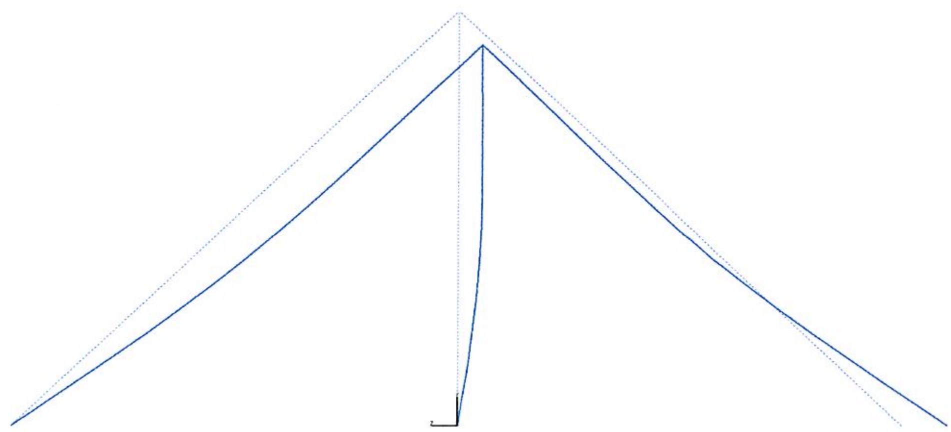

Figure 3. The deflected pyramid if the left hand base does not slide
and the other three bases slide as needed.

Overall Sliding Resistance. The pyramid legs must slide during loading. However, they must also not be allowed to slide under wind forces once the structure has been completed and fully rigged. Whatever was designed to guide the legs during sliding, it would have to include a method for removing, at the appropriate point during installation, the ability to slide.

SLIDE BEARINGS

It was clear that some form of slide bearing would have to be designed for the pyramid bases. This was the only viable choice despite the attendant challenges. The remaining questions then were how to design something that could be quickly fabricated, easily installed on site, and safely used by the rigging crew.

When these decisions were being made, time and budget had become very short. The slide bearing design was therefore focused on using wood products. They were available at local DIY stores, easy to work with, lightweight, and inexpensive. Essentially, large wooden sleds were envisioned to receive and guide the pyramid's concrete bases. A plywood pad would be laid on the concrete floor of the stadium with another plywood pad on top of it and the concrete base on top of that. The plywood to plywood interface material would be selected to have a very low coefficient of friction. Blocks of wood would be nailed to the bottom pad to ensure that the legs did not slide sideways. And when the time came, the two plywood pads would simply be nailed together to secure the bearing pad assembly.

Below is provided for reference the equipment list and set of instructions given to the Stageco crew for the slide bearings. See Figure 4 for a photo of an assembled slide bearing.

Equipment:
8x4' sheet of ¾" plywood, 16 required
8x4' masonite sheet, approx. 3/16-1/4" thick, 16 required
250 ct. ¼" x 1-3/4" lag bolts

250 ct. ¼" x ¾" long flathead wood screws
lithium grease

Steps:
1. Assemble the slide bearing pads. One pad is to be made up of 4 panels in two layers – two plywood sheets in one layer and the masonite sheets in the other layer. It is important that the rougher side of the masonite, if there is one, is placed against the plywood. The smoothest face of the masonite should be the sliding surface. The bottom two sheets run in the perpendicular direction of the top sheets. The top and bottom layers are to be glued and screwed together.
2. Half of the slide bearing pads are to be cut down to 7' square overall dim's. These will be the top layers of the slide bearings.
3. Screw a guide block onto each offstage side of the exposed masonite surface of each of the 8' x 8' bottom slide bearing pads.
4. Place the 8' x 8' bottom slide bearing pads in the stadium with the masonite surface up and the masonite seam running parallel to the direction of slide. Proper alignment of the bottom pad along the direction that the base will move is critical.
5. Liberally grease the entire top masonite surface of each bottom slider bearing pad as well as the inner faces of the guide blocks.
6. Place the 7' x 7' top slide bearing pads on top of the bottom pads with the masonite surface down.
7. Place the concrete base on the slide bearing.
8. Put together the base cube assembly with the ground perimeter cables. Do not yet attach the base frames to the base cubes.
9. Tighten the perimeter cables to remove any slack.
10. Mark the current, unloaded location of the slide bearings' top pads relative to the bottom pads. Continue with assembly of the pyramid structure.
11. Once the pyramid is pinned to the base cubes, have the crane operator slowly release the load. The slide bearings should all move outwards approximately the same distance at each base – the concrete base and top pad moving together over the bottom pad – as the pyramid "settles". The guide blocks will prevent unintentional side to side movement. Note should be made of how far each base moves under self weight and also under self weight plus full rigging loads.
12. Check that each slide bearing seems to be moving properly. If there is any binding up, stop and resolve the issue. A strong hammer hit may be sufficient.
13. Once the entire self weight of the pyramid has been released from the crane, check the amount of overall movement in the slide bearing at each base. The distances should be approximately 4" and all about the same.
14. Rig the structure. The slide bearings will continue to move outwards as load is added to the pyramid.
15. Once all of the live load is in place, make one final check that each slide bearing moved a total of approximately 7" outwards.

16. Screw each slide bearing top pad to the bottom pad with 60 screws evenly spaced around the perimeter of the concrete base.
17. Attach the base frames.
18. For strike, reverse the above steps.

Figure 4. Assembled slide bearing shown with concrete base and steel base frame on top awaiting pyramid leg attachment.

IMPLEMENTATION

Challenges continued to crop up when the pyramid with its slide bearings was erected. The pyramid was assembled, still suspended from the crane, and pinned into the bases. As the crane released its load, the turnbuckle in one of the perimeter ground cables unwound, one of the bases did not slide, and the opposing base moved twice the distance it should have.

Work was halted and the structure was inspected. There was clear warping of the pyramid truss legs, as illustrated in Figure 3. It was decided that the crane operator should re-engage the pyramid in the hopes that the bases would return to their original positions. As the crane picked up load, there was some amount of rebound but not enough. Forklifts were used to "encourage" each slide bearing to return to its starting location. After several impacts from the forklifts, the slide bearings were acceptably close to where they should have been.

The turnbuckles were checked and tightened as necessary so that each perimeter cable was, as nearly as possible, under the same amount of tension. The crane operator was again directed to start releasing the pyramid structure. This time a forklift was stationed at the previously stuck base so that it could be pushed if it still did not move.

The bases moved the correct distances after some prodding. However, there was a great deal of concern over whether the bases would slide evenly when the rigging loads were applied to the structure. It was thought that the best way forward was to add pre-stress to the perimeter ground cables. This would put inwards force on the bases which would be counteracted as the live load outward thrust started to act. Accordingly, the turnbuckles were tightened an amount that corresponded to the desired cable length decrease necessary to match the tension that would arise from the live load thrust. The pyramid was rigged without further problems and Wrestlemania went off without a hitch. The above steps were reversed for strike and went smoothly.

In hindsight, it was thought that two things were the most to blame for the stuck bearings. One was that the lithium grease seeped into the masonite and either caused it to swell or somehow become sticky. By the time the event was over and the structure was being taken down, the bearings had completely dried out and loosened up. And indeed the bearings behaved as they should have during strike. The other factor was a pair of guide blocks that had been attached too closely to the sides of the upper bearing pad of the slide bearing assembly that had caused the most problems during installation.

CONCLUSION

Unique, one-off entertainment structures present specific challenges for the engineer, not least because of the tight schedule constraints. The loads and structure dimensions can be significant in light of the temporary nature of the installations. And as with anything that is only designed and built once, there are always unforeseen issues that arise and must be addressed.

The slide bearings for the Wrestlemania pyramid are a case in point. In particular, one of the four slide bearings did not behave as expected and there was no time to disassemble the pieces to find the cause. The problem simply had to be worked around if the WWE event was going to take place safely and on time. In working on entertainment projects, engineers must be willing to deal with this type of situation on a regular basis if their clients are to be well served.