Unofficial Analysis and Conjecture of Truss Failure Incident

The incident:

On October 24, 2004 at the Spokane Arena, an experienced IA crew assembled a truss and curtain system during a call with the intention to create a more intimate space inside the Arena, which is then referred to as the Star Theater.

This procedure has been done an estimated 30-40 times since approximately 2001.

While the stage left truss and curtain system were being raised, with both motors in motion and a few feet short of trim, the truss failed near the center of the span.

The motors were immediately stopped and the lead on the crew requested that the motor control operator lower the broken assembly while attempting to maintain the angular relationship between the two halves.

Shortly after starting to fly the truss in, the curtain failed and ripped from top to bottom, with the two halves of the truss and each half of the torn curtain swinging to a resting position under each of the supporting motors.

Each piece was then flown in and disassembled.

The crew moved to the stage right side and rigged the truss and curtain in a similar manner and the system was flown to approximately trim height. The lead on the crew, who had taken over the motor control operation, was moving to a place where he could establish a reference for level, when the stage right side truss, which was stationary at the time, also failed, and the stage right curtain also ripped from top to bottom. The stage right truss failed in a similar place to the stage left truss.

The stage right side was then flown in and disassembled.

The truss pieces were labeled with gray gaffer's tape, with the date and stage left / stage right designation noted on the tape, with a note to inspect all of the pieces involved in the incident. The position of each truss section within the total span was not noted.

No one was hurt in this incident and there was no damage to the building infrastructure, building equipment (such as the HVAC system), seats, or any other area. The only damage was to the truss itself and the curtain it supported. The curtain was repaired immediately, onsite.

The Facts:

The span of the truss is 65', and consists of three 10' sections, one 5' section, and three more 10' sections. This pattern is repeated on the other side of the stage.
The truss is suspended from permanently mounted 1-ton motors, which pick the truss approximately 18" from each end (at the first inverted "V"), resulting in an unsupported span of about 62'.

The truss is placed directly under the motor points, the chains are let in, and the spansets are rigged directly under the hanging motor hooks. The truss is flown out straight up from its position of resting on the seats.

There are no special issues with the house that would require multiple adjustments of each side. Both side curtain trusses are flown straight up to approximately trim height and then "bumped" to level.

The truss is triangular, 20" on a side, and made from 6061 T6 aluminum. It consists of two top chords, braced against a compression load by a normal "ladder" configuration, with the bottom chord supported by a normal W, or "web", pattern between the top chords and the bottom chord.

The manufacturer states that they use a design factor of 2:1.

The manufacturers' web site expressly allows the truss to be hung in a "point up" configuration, but does not indicate how a load is to be attached while in this configuration.

The truss was hung in a point up configuration, and the curtain, which is tapered to fit the permanent seats, was hung from the top chord of the truss.

The spansets connecting the truss to the motor were rigged in the following fashion:
The spanset choked a bottom chord, proceeded laterally under the truss, went around the other bottom chord (but did not wrap it), and then proceed upwards to the top chord.
The top chord was wrapped and the spanset proceeded to a shackle, which was connected to the motor hook. Two spansets were used at each end of the truss, one in opposition to the other in the normal manner.

The curtains are 16 oz. Velour, with 50% fullness sew in. There are 3 panels per side.
The onstage panel is 10' wide by 62' tall and weighs approximately 111#. The middle panel is 30' wide by 61' feet tall on the long side and weighs approximately 240#. The offstage panel is 30' wide by 54' feet tall on the long side and weighs approximately 222#.

The top of each curtain is reinforced by jute webbing. The bottom of each curtain has a chain pocket, which is filled with chain, the weight of which is excluded in the overall weight figure.

The curtains are stored in normal canvas hampers. The weather recently has been humid. It is unknown how much the humidity affected the weight of the curtains.

Several eye witnesses confirm that neither the truss nor the curtains were hindered in any way while being flown out.

The truss / curtain system is angled from the onstage end towards the audience to the offstage end at about a 45-degree angle, creating an effect that tends to focus the audience's attention to the stage area.

There is a mixture of two production runs of the truss. One run is from August 1995, and is labeled as "Light Duty" by the manufacturer. The label further states that the load ratings are as follows:

Span	UDL*	CPL*
40	809	404

*CPL: Center Point Load in pounds
*UDL: Uniformly Distributed Load in pounds

There are eighteen 10' sections of this truss, and one 5' section.

The other production run is from June 1999, and is labeled as "Medium Duty" by the manufacturer. This label further states that the load ratings are as follows:

Span	UDL	CPL
10	5254	3180
20	3103	1552
30	1984	992
40	1399	699
50	1027	514

There are two 10' sections of this truss, and two 5' sections.

The webbing of the truss and the rectangular end members are welded to the truss chords using a TIG process (as noted by others), as is evidenced by the frosted area around the welds caused by the High Frequency and AC on the TIG machine.

The connector plates of the 1995 series of truss are welded to the rectangular end members, as noted by others, using a classic slow pulsed aluminum MIG weld.

The connector plates of the 1999 series of truss are welded to the rectangular end members using a MIG process, again as noted by others, running in short circuit MIG, pulsing manually or using a pulsed power supply, as is evidenced by the light spatter around the welds. It is not known whether the manufacturer is using 4043 or 5356 filler.

The wall thickness of the end members of the 1999 series is .115 inches, or roughly, a little over 3/32 of an inch.

Comments:

As noted by myself and others, the rigging of the spansets was unusual.

The arrangement applied a compression load between the two bottom chords, but it also applied a compression load between the non-choked bottom chord and the top chord, while at the same time applying a tension load between the choked bottom chord and the top chord.

But because the spansets were rigged in pairs, it created both a compression load and a tension load on each set of webbing of the truss, while creating only a compression load on the ladder of the truss.

The effect is similar, but not identical, to rigging a single spanset in the form of a basket. It is the opinion of myself and others that the rigging of the spansets was not a factor in this incident.

The maximum load rating for the truss sections involved in the incident is 809# uniformly distributed with a maximum rated span of 40'. (The combining of the Light Duty and the Medium Duty sections require de-rating the assembly to the weakest sections.) The truss is not rated for longer spans. The load of the curtains is approximately 573# and more or less continuously variable over a 65' span due to the tapered cut to accommodate the seats.

The truss failed between a 1999 series Medium Duty 5' section and the adjacent 1995 series Light Duty 10' section. It is unknown which side of the 5' section the break occurred on, the onstage or offstage side.

The curtain was hung from the top chord of the truss, creating a torsional component of approximately 477 foot pounds over the entire length of the truss. The torsional load was not constant, however, due to the differing weights of the curtains. The difference would have been concentrated at the boundary between the Medium Duty truss section and the Light Duty truss section, due to the fact that the Medium Duty section would have created an essentially rigid component between the two, more flexible, Light Duty sections.

The truss is not rated for any torsional force.

The truss was overloaded, which created a bending moment of the top chord, which further contributed to the torsional load.

There is evidence of excessive torsional load on all but one of the truss sections currently in use, including those not involved in this incident. Several of the bottom chords (which in a “point up” configuration become the top chord) exhibit a slight bending, or bowing, deformation.

The manufacturer states that the truss will fail in the connector plate area first, and in fact this is what happened. The welds at the connector plate failed, with the connector plates remaining attached via the grade 8 bolts to the 10’ section of Light Duty Truss. The welds that failed were on the 5’ sections of 1999 series Medium Duty Truss.

High resolution photographic analysis by others reveals that several of the welds between the connector plates and the rectangular end members were non-penetrating welds, otherwise known as “cold” welds. There is inadequate fusion at the edges of the bead, and too much height of the bead.

Analysis of existing welds by others indicates a systemic problem of this nature for this manufacturer in the 1999 series of truss.

It was also noted by others that when using the specific welding method employed to attach the connector plates to the rectangular end members on these truss, it is particularly difficult to achieve a properly penetrating weld. In the opinion of others, since the manufacturer was using MIG, they should have been running in Spray mode for better penetration. It was also noted by others that TIG welds are more ductile and tend to deform much more before failure than MIG welds, especially on aluminum.

Most manufacturers of truss today use a TIG process throughout.

It is the opinion of others that a wall thickness of the rectangular end members of .115” will not support the ratings stated by the manufacturer, and further, it is their opinion that destructive testing would not bear these ratings out. The manufacturer confirmed that they do not engage in destructive testing.

Even though there are very, very few people in our IA Local who have knowledge of the engineering principals involved, and who have knowledge of and experience with the equations involved, and a good grasp of the other math involved, combined with experience in theoretical and practical applications, those involved in the assembly of the truss / curtain system **assumed** that **someone** had, in fact, performed **all** of the calculations, including those involving the torsional load component.

Had those of us qualified to do so, performed the most cursory examination, we would have immediately noticed that we were operating outside the stated specifications from the manufacturer.

Recommendations:

It is recommended that the house add a third motor near the center of the 65’ span to reduce the unsupported span.

It is recommended that the entire existing truss be replaced.

It is recommended that the replacement truss be hung in a “point down” configuration, and that the curtain be hung from the bottom chord only.

The truss manufacturer is **strongly** encouraged to review their current construction methods, procedures and practices, as well as the materials used.
It is further suggested that the truss manufacturer engage a qualified lab to do destructive testing on their product.

It is recommended that the house keep on file, and make available to any qualified person who may inquire, the load ratings, calculations, and approved methods of assembly for each of the flown pieces that they may use.