DESIGN BRIEF

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1. Introduction

This document is a brief description of the Mega Stage MK IV (Basic Setup) model structural analysis and its results. The aim of the analysis is to verify the stability and the resistance of the structure under combinations of applied loads.

Mega Stage MK IV is an upgrade of Mega Stage MK III that was done in order to increase the maximum applied wind speed from 80 km/Hr (50 mph) to 120 km/Hr (75 mph) three seconds gust.

Mega Stage MK IV-Basic Setup is a steel and aluminium structure that contains the following components:

- A roof that consists of eight secondary aluminium trusses and three secondary steel trusses supported by two main steel trusses. The depth of a secondary truss is variable from 4 ft at the front of the stage to 3 ft at the rear of the stage and is bolted to vertical members of steel trusses; aluminium and steel secondary trusses are 52 ft 9 inches long approximately and they are braced together with aluminium bracings, **additional diagonal steel reinforcing braces are added to both ends of each of the two secondary steel trusses linking the main stage sleeves**.
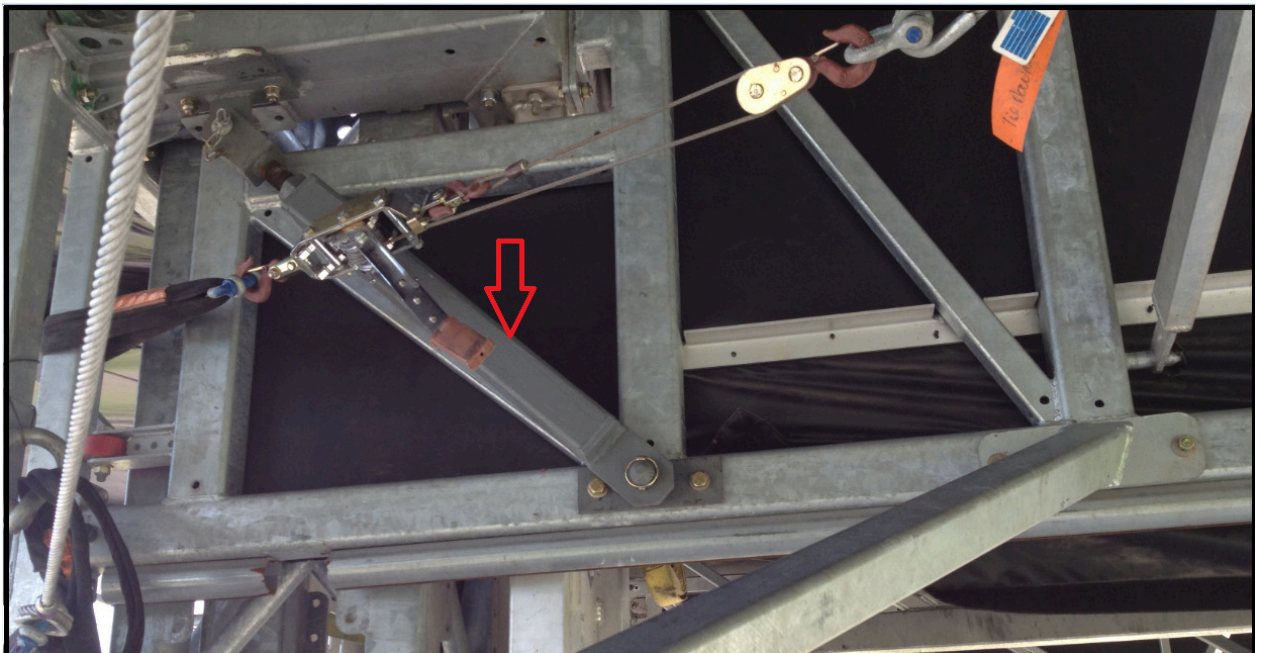
The height of the rear main steel truss is 6 ft 4 inches. The height of the front main steel truss is 7 ft 4 inches. Main steel trusses are 77' ft long approximately (total length). Aluminium I beams that can slides inside the top members of the aluminium and steel secondary trusses are also used as cantilevers to extend the roof 10 ft, these aluminium beams are braced to the bottom of the secondary beam.

- **Four 22x22 steel masts braced with 5/8 inch steel cables above the stage deck level;**

Steel masts are 22 inches x 22 inches 3D steel trusses of 5 ft or 10 ft sections bolted (or straight section) together with four 1-1/8 inches diameter bolts (grade 8), masts are 45 ft high above the deck level. Two stabilizers per each one of the masts are installed under the stage deck to both sides; Masts are also bolted to the deck contour beam directly below the corners of the stage deck. The bottoms of the steel masts are linked together with horizontal steel HSS 10x10x5/16 (or 12x12 Fraco steel masts) in the perpendicular direction of the stage facade.

At the bottom of each column, a special steel base is installed; this base is supported by jacks and wood cribbing, and is connected to the column by a special bracket at the bottom of the column from one side and with a ½ inch cable from the other side to the column at 15 ft height from ground level, these bases are destined to support a 43200 lb (each) counterweights in order to stabilize the structure.


- **Four steel sliding frames (sleeves)** surround the steel masts tightly and transfer the loads from the roof to the masts; these sliding frames can slide over the whole length of masts in order to lift the roof to the top after the installation of the roof trusses is done. The sliding frame is bolted to the main steel truss of the roof and could be pinned to the top of the mast to prevent any vertical movement in both directions (up and down).
- A Stage Deck consisting mainly of aluminium tubes supporting a plywood deck, a flat bed trailer truck makes part of the stage deck structure, the trailer is destined to transport the whole stage structure when dismantled to parts, when the stage structure is installed the trailer act as the central beams supporting the deck and as a counterweight

to prevent the sliding of the structure. Aluminum rectangular tubes transfer the loads to main beams (parallel to the trailer long side), shoring jacks supporting the main beams transfer the load to ground below the deck. The deck is at 5 ft to 8 ft from ground level.

- **The sleeves of the front of the stage are attached to two Free standing bases (Fraco or MEGA-BASE) with ½" cables, the bases are installed at a distance of twenty to thirty feet (one to the left and one to the right) form the main façade masts. A counterweight of 28000 lb concrete blocks should be uniformly distributed on each one of these two bases (base and counterweight to remain in place with or without outrigger).**

- **Optional: one 20x20 steel mast with a forty feet height could be installed per each free-standing base, a 20x20 horizontal steel bridge could be installed starting from the top of the 20x20 steel mast to the 22x22 steel masts of the front of the stage. This bridge is allowed to support a 6000 lb of uniformly distributed equipment over its length including a screen (maximum dimensions 20'x15') and a PA (maximum dimensions 20'x4'). The bridge is attached to the 20x20 and 22x22 steel masts with eight 3/8" plates and eight ¾" grade 5 steel rods at each side and it is secured to the top of the masts with a double 3/8" cables.**

Solid fabrics will be covering the entire roof area as a weather protection of the stage and installed equipments. A solid tarp fabric will be covering left and right sides of the stage, wire mesh fabric with 40% porosity cover the rear side of the stage. All the vertical fabric covering the walls of the stage will be secured to the stage structure in order to distribute the wind load evenly at the edges. Even if the structure is able to resist a 120 km/Hr wind speed while the fabric walls are still installed, it is recommended to detach these fabric walls from the structure before having a gusting wind speed of 80 km/Hr (50 mph) since the manipulation of the walls becomes very difficult if wind speed is higher than this limit.

The rear wire mesh fabric wall should be attached to the roof structure at the secondary trusses levels (never below).
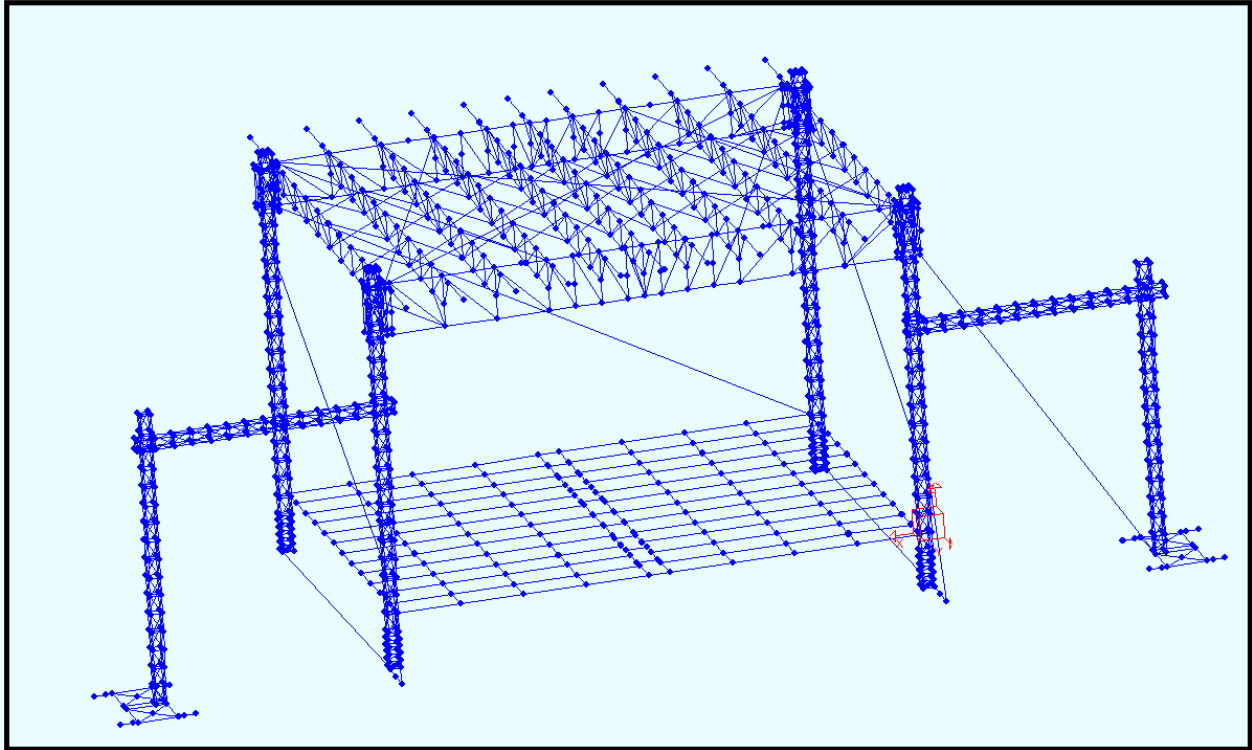
The model of the structure was created and analysed using S-Frame software, the verification was done based on S16-01 for steel and CAN3-S157-M83 for Aluminium.

Important modifications (upgrades) to the structure are written in bold in the above structural components listing.

2. Materials

Steel 44 W for plates and iron angles- Fy=44 ksi

Steel A500-C for structural tubes – Fy = 50 Ksi

Aluminium 6061-T6, Welded – Fy = 16 Ksi

Aluminium 6061-T6, Not welded – Fy = 35 ksi

3. Load Cases

3.1 Dead Load

Dead load is the own weight of the structure including counterweights and is represented by the load case 1- SW (the weight of the structure is approximately 100 000 lb and counterweights are approximately 228 000 lb).

3.2 Wind Load

Wind load is calculated based on a 120 km/Hr (75 mph) and 160 km/Hr (100 mph) three seconds gust measured on site.

For 120 km/Hr (with walls), since the wind speed is measured on site directly and it is not a calculation based on the hourly average wind speed measured at a 10 m height, we can consider that $q \, C_e \, C_g$ = 15 psf.

Based on figures I-8 and I-9 from the NBC2005 structural commentaries-part 4 of division B – Low-rise buildings, $|C_g C_p|$ = 2 maximum for walls and 1.5 maximum for roof (the area is higher than 100 m^2). By taking C_g = 2, C_p = 1 for wind on the walls and C_p = -0.75 for the roof. Pressure resulting from this wind speed is P = 15 psf on the solid walls, perpendicular to the vertical faces of the stage, and an uplift of 11.25 psf perpendicular to the roof of the stage.

Pressure on the rear side is used as 12 psf (20% reduction) since mesh's void is 40 %.

An hourly average wind speed of 80 km/Hr is equivalent to 120 km/Hr three second gust based on Durst Curve (ASCE7-05 Figure C6-4), these values (80 km/Hr hourly average or 120 km/Hr gust) could be used to monitor the wind speed in the weather news to detach the fabric walls if higher winds are expected.

Fabrics transfer the wind loads in all the directions (Figure 1)

Figure 1
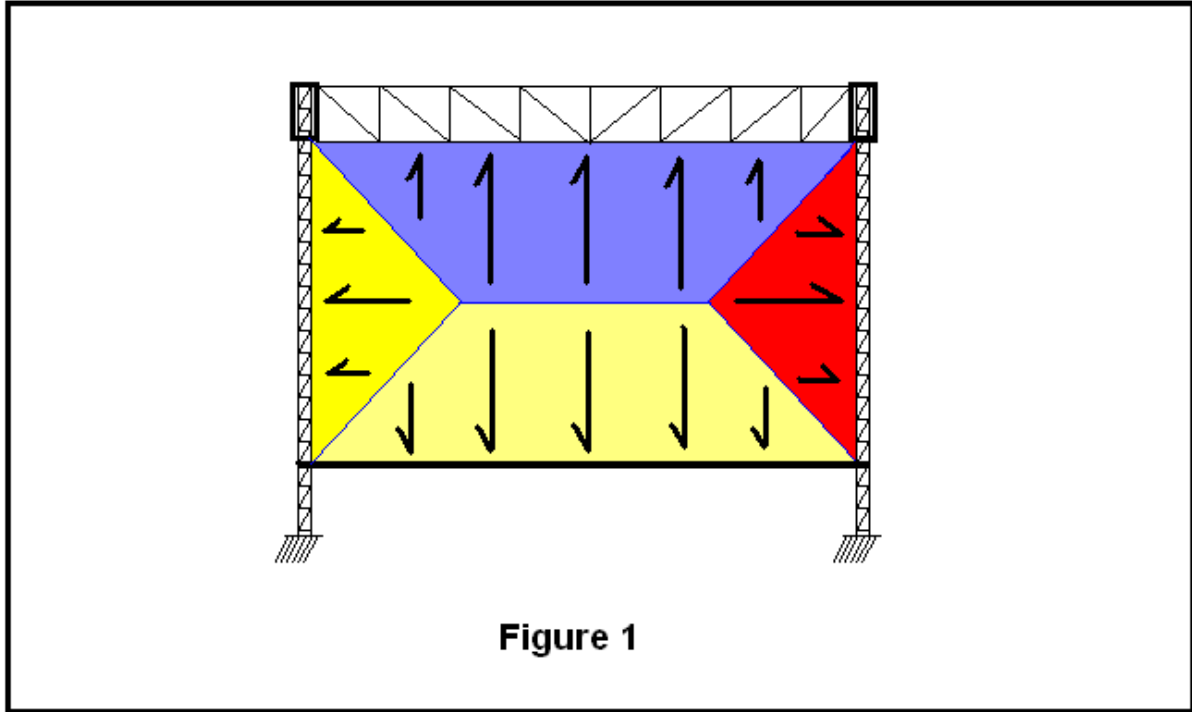
By applying the same calculations for 160 km/Hr (without walls), P = 26.7 psf for horizontal surfaces and 20 psf uplift for the roof.

Wind loads were represented in two load cases:

- Load case 2 – Wind Y: wind load perpendicular to the rear side of the stage (15 psf pushing the stage toward its front side).

- Load case 3 – Wind Uplift: 11.25 psf uplift wind perpendicular to the roof distributed over the complete area of the roof.

- Load case 4 – Wind X: wind load perpendicular to the left side of the stage (15 psf pushing the stage toward its right side).

3.3 Live Load

Equipment and loads are attached to the lower nodes of trusses. Two Live load cases were created, the total live load for both of them is 152 000 lb distributed over the roof structure by two different ways:

- Load case 6 - Main trusses: concentrated loads are distributed uniformly under the main steel trusses. The maximum distributed load is 50 000 lb (for the roof), and 6 000 lb uniformly distributed for each one of the 20x20 steel bridges.

- Load case 7 – Secondary steel trusses: concentrated loads are distributed uniformly under the secondary aluminium and steel trusses. 10 000 lb uniformly distributed under each aluminium secondary truss and 20 000 lb uniformly distributed under each steel secondary truss and 6 000 lb uniformly distributed for each one of the 20x20 steel bridges.

4. Load Combinations

The structural model was verified for the following load combinations:

- Combination 1 – Stability Y: 1.0 x (LC 1) + 1.4 x (LC2) + 1.4 x (LC3)

- Combination 2 – Stability X: 1.0 x (LC 1) + 1.4 x (LC4) + 1.4 x (LC3)

- Combination 3 – Resistance Y 1: 2.0 x (LC 1) + 1.5 x (LC6) + 1.4 x (LC2)

- Combination 4 – Resistance Y 2: 2.0 x (LC1) + 1.5 x (LC7) + 1.4 x (LC2)

- Combination 5 – Resistance X 1: 2.0 x (LC 1) + 1.5 x (LC6) + 1.4 x (LC4)

- Combination 6 – Resistance X 2: 2.0 x (LC 1) + 1.5 x (LC7) + 1.4 x (LC4)

- Combination 7 – Deflection Y: 1.0 x (LC 1) + 1.0 x (LC2) + 1.0 x (LC3)

- Combination 8 – Deflection X: 1.0 x (LC1) + 1.0 x (LC4) + 1.0 x (LC3)

- Combination 9 – Stability Y - without walls: 1.0 x (LC 1) + 1.25 x 0.3 x 1.78 x (LC2) + 1.25 x 1.78 x (LC3) where 0.3 represents the reduction factor of vertical solid surfaces when walls are removed, and 1.78 represents the increase of pressure if wind is 160 km/Hr instead of 120 km/Hr with 1.25 safety factor, these same factors are used also for combination 10.

- Combination 10 – Stability X – without walls: 1.0 x (LC1) + 1.25 x 0.3 x 1.78 x (LC4) + 1.25 x 1.78 x (LC3)
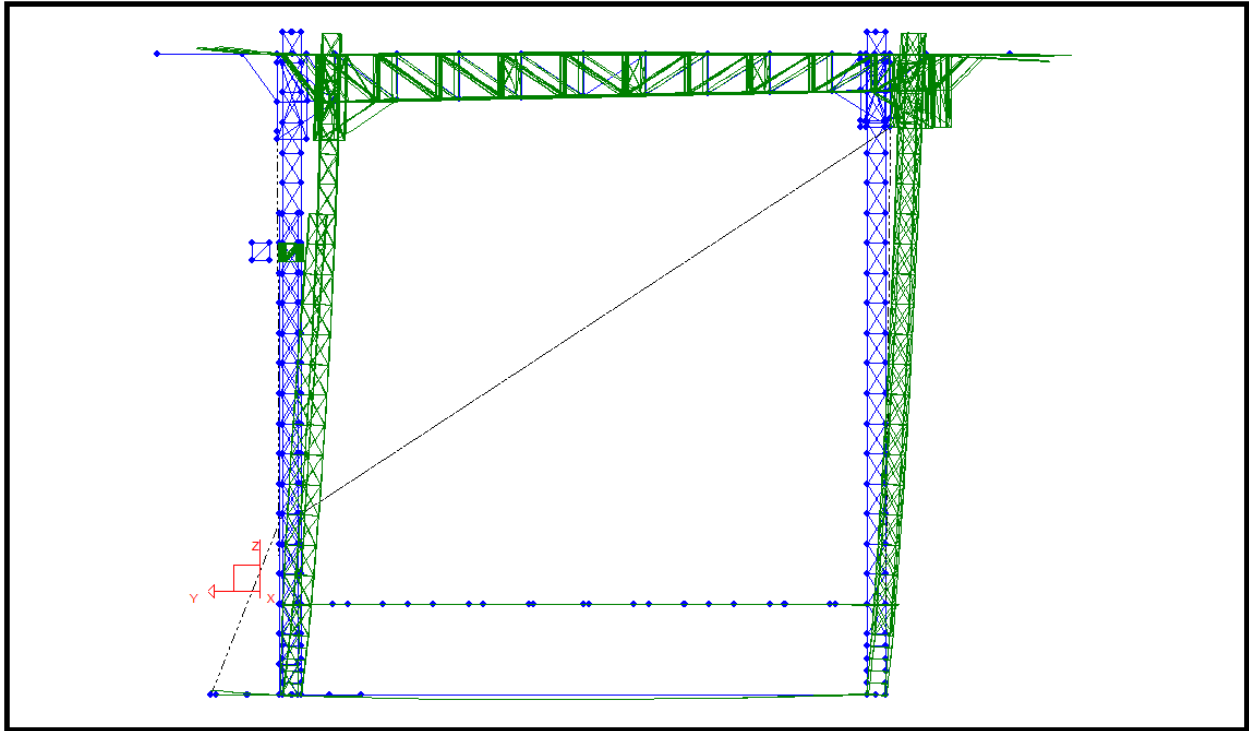
5. Deformation

5.1 Columns

Figure 2

For combination 7 the maximum horizontal displacement of columns is 9'' in Y direction – see figure 2.

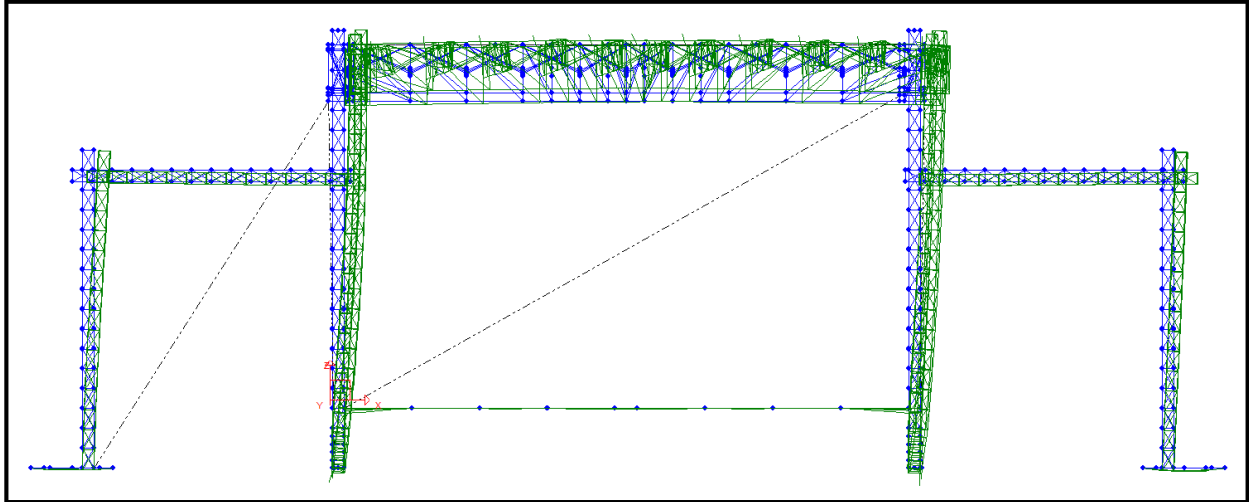For combination 8 the maximum horizontal displacement of columns is 3.5'' in X direction – see figure 3 (below).

Figure 3

5.2 Secondary trusses

The maximum vertical deflection of the steel secondary truss is 0.89''.

The maximum vertical deflection of the aluminium secondary truss is 1.05'' (figure 4), the length of the truss is 53 ft, L/360= 1.76'' > 1.05'' O.K.
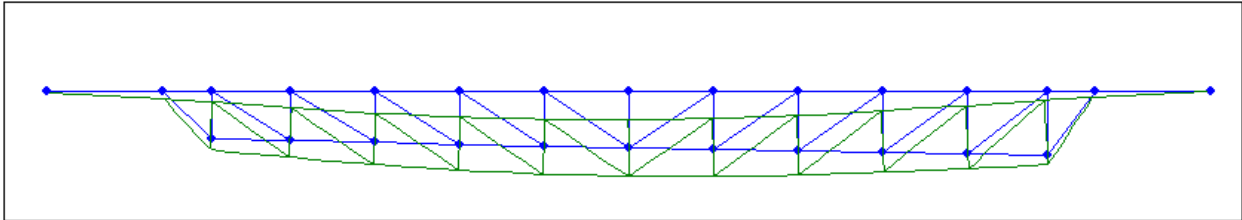

Figure 4

5.3 Main Steel Trusses

The maximum vertical deflection of the steel truss is 2.13'' (figure 5), the length of the steel trusses between the columns is 77 ft, L/360= 2.57'' > 2.13'' O.K.
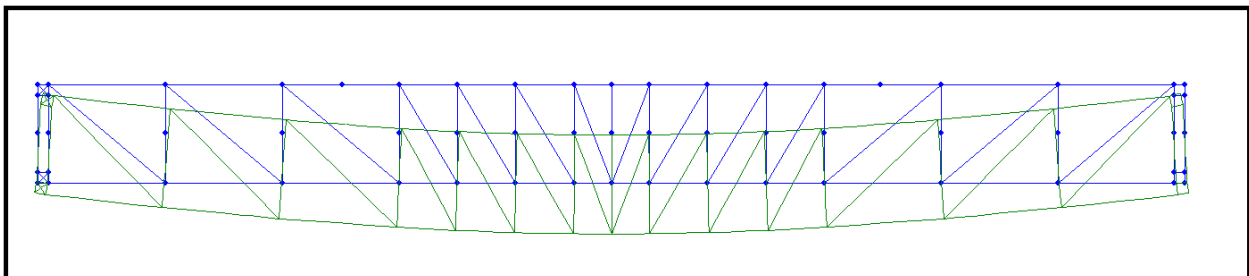

Figure 5

6. Stability

For load combinations 1, 2, 9 and 10 (dead loads with counterweights and factored wind load), all the supports reactions were positive, which means that there was no uplift for any support and the lowest reaction was 4.95 kips for a 120 km/Hr wind. With low reactions values like this case, friction is not enough to resist the sliding of this support, but in our case the bottoms of the columns are linked together in order to transmit the horizontal force to supports having very high compression values which will insure enough friction to resist sliding of the structure.

The total horizontal factored load in Y direction is approximately 90'x53'x12psfx1.4/1000 = 80.1 kips, if we assume a 0.5 friction factor, this means that we will need a minimum of 80.1 kips/0.5 = 160.2 kips to be able to resist the sliding, the sum of reactions for these load combination is: 200 kips.

Maximum factored tension in cables is 36 kips (safety factor for wind is 1.4), if we increase the safety factor to 2.0 the limit becomes 52 kips. **Cable and turnbuckle resistance should be 52 kips minimum**.

7. Members resistance

The analysis of the steel components was done with S-steel, which is a module of S-Frame that verifies the resistance of steel members.

To verify the resistance of aluminium components, we will use the maximum values of axial forces calculated in S-Frame and compare them to resistance of members.

7.1 Steel masts

The highest stresses occur in columns of the back face of the stage (figure 7).

Figure 8 shows the values of the ratio described in clause 13.8.3-S16-01 (should be less than one) where members with high stresses exist, based on load combinations described above.

Calculation details of member having the highest ratios in this column are also shown in the annex in the end of this report.
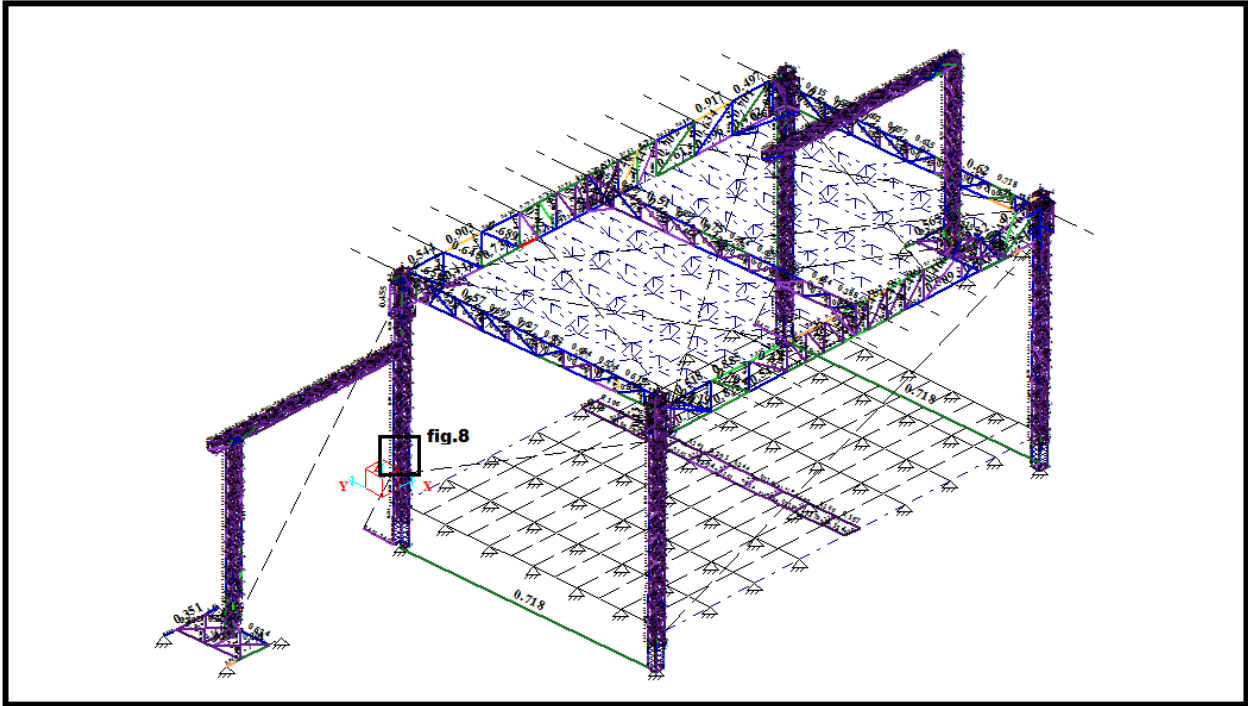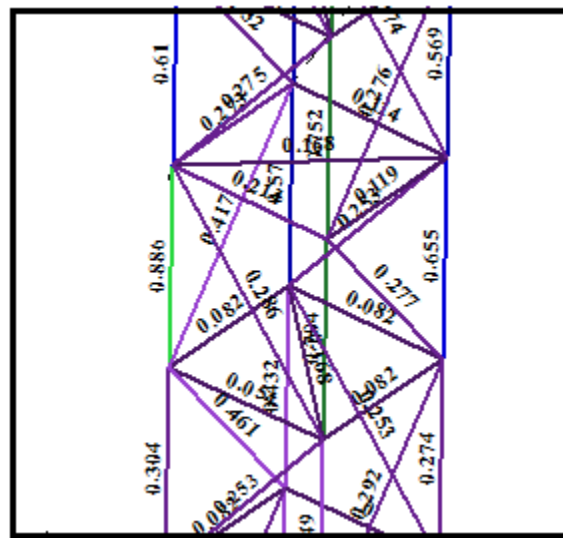
Figure 7

Figure 8

7.2 Main steel Trusses

Figure 9 shows the values of the ratio described in clause 13.8.3-S16-01 (should be less than one) based on load combinations described above, the highest value is 1.017 (accepted).

Calculation details of member having the highest ratios in this steel truss are also shown in the annex in the end of this report.
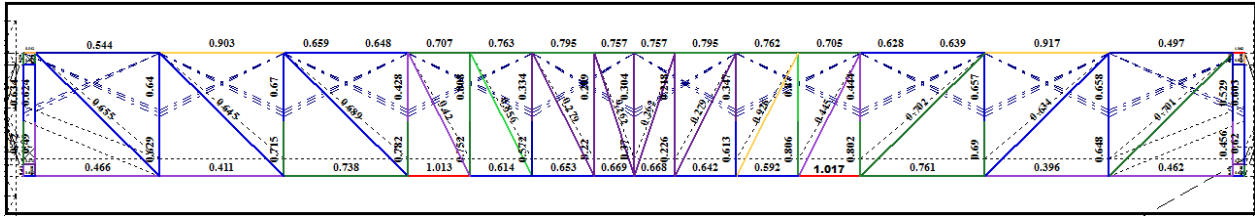

Figure 9

7.3 Secondary steel trusses

Figure 10 shows the values of the ratio described in clause 13.8.3-S16-01 (should be less than one) based on load combinations described above, the highest value is 0.750.

Calculation details of member having the highest ratios in this steel truss are also shown in the annex in the end of this report.
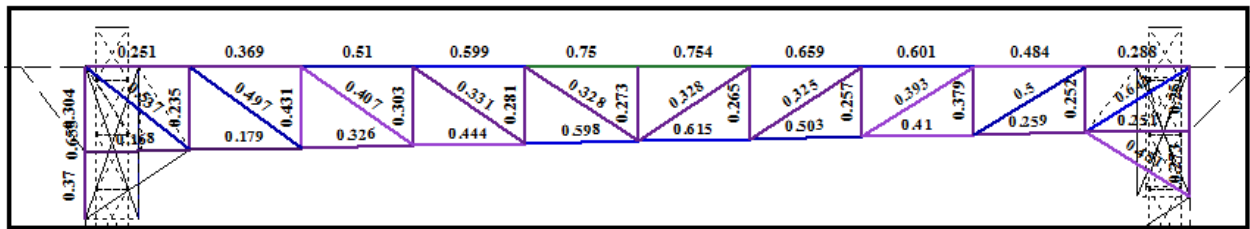

Figure 10

7.4 Secondary aluminium trusses

Horizontal members

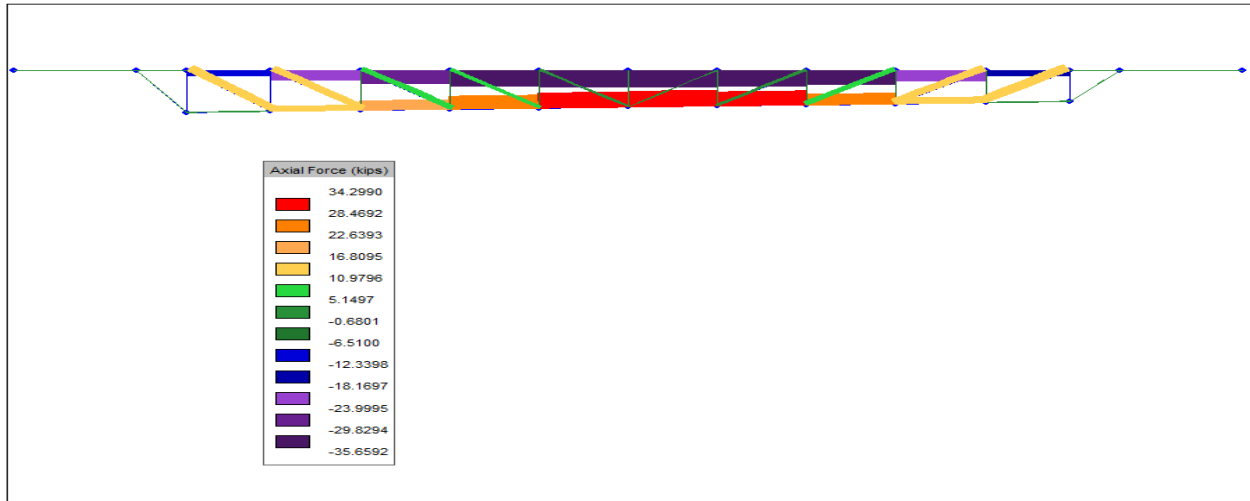Highest axial forces in horizontal members are generated by combination 6 (Figure 11)

Figure 11

Since the weakest point in the horizontal members is joints due to welding at these places, we will take Cr = Tr = Ø Fy A, and we will use Fy = 16 ksi, Fy in the middle of the member is much higher (Fy = 35 ksi) since the aluminium in the middle is not influenced by welding, this will make Cr at the middle of the member higher than Cr at the edges even with the buckling effect.

For a 4''x3''x1/4'' tube A =3.08 in² => Cr = Tr = 0.9 x 16 x 3.08 = 44.35 kips > Cf = 35.66 kips

Vertical and diagonal members

Highest axial forces in vertical and diagonal members are generated by combination 6 (Figure 11)

Verification will be done also at joints with Fy = 16 ksi.

2''x2''x1/8'' tube A =0.9 in² => Tr = 0.9 x 16 x 0.9 = 13 kips ~ Tf = 13.09 kips

ANNEX

Detail calculation example of members with high

Internal forces – Main steel truss and column

(Software output)