DESIGN OF WEIGHT-OPTIMIZED SPACE FRAME FOR THE CANADIAN LARGE ADAPTIVE REFLECTOR

by

YA-YING CHANG

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ABSTRACT

The Square-Kilometer Array (SKA) is an international project for building the next radio telescope. With a collecting area of one square-kilometer, the SKA will be 100 times more sensitive than current radio telescopes. The concepts for the SKA elements include nested phased arrays, large spherical reflectors, and many small parabolic antennas.

The Large Adaptive Reflector (LAR) is the Canadian concept of building the SKA. The LAR is a long focal-length parabolic reflector which uses an airborne platform to support the focal receiver. The feed is held in plane by a tension-structure consisting of three or more tethers tensioned by the lift of a large helium-filled aerostat. The reflector is made up of segmented panels whose height and angle to zenith of segmented panels can be adjusted to focus on any point within zenith and azimuth angle coverage. Unlike conventional radio telescope, LAR is based on reflective optics thus the usable frequency range is limited by the surface accuracy of the reflector.

Main structural components of the LAR are foundations, actuators (primary and secondary), main support structures, and reflector panels. This report includes investigation on the feasibility of using LAR antennas as elements to form the SKA, and the conceptual design of a triangular space frame, which is used as the main support structure.

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1 INTRODUCTION

1.1 HISTORICAL BACKGROUND

Over the past thirty years, steady improvements in receiver sensitivity, digital processing speed, and imaging techniques have resulted in enhancements in sensitivity to all radio telescopes. Astronomers worldwide have a common acknowledgement that the next step in improving sensitivity is to increase the collecting area of the next telescope to one square-kilometer. Large gains in sensitivity are needed to map low-surface brightness emission from phenomena such as HI in the early universe, thermal and non-thermal emission from ionized gas in distant galaxies, and the ionized winds from starts in our own galaxy. This increasing in collecting area would make the telescope one hundred times more sensitive than the Very Large Array (VLA), the benchmark instrument at decimeter and centimeter wavelengths. It is not economical to build 100 VLAs; therefore, innovative techniques should be used to obtain that collecting area.

In June 1996, the National Research Council (NRC) published the report "Canadian Radio Astronomy in the 21st Century - The Challenge" which examines the options for a future radio facility for Canada. In this report, it recommends adopting the Square Kilometer Array as the highest priority for a new national radio astronomy facility.

Square Kilometer Array (SKA) is an international project of building a radio telescope array with a collecting area of one-square-kilometer. The array pattern of the SKA will approximately cover a circular region about 300km to 1000km in diameter, with a concentration of elements in the center (Figure 1.1), therefore, a large sparsely populated region will be needed as a site for this array.

The Square Kilometer Array Science Workshop took place two years later in Calgary, Canada. The concepts for the SKA antenna array elements include nested phased arrays, large spherical reflectors, and use of many small parabolic antennas. A particular achievement from the Canadian perspective is unanimous recognition that the SKA must cover short centimeter wavelengths, which will have considerable impact on the technology chosen for the SKA.

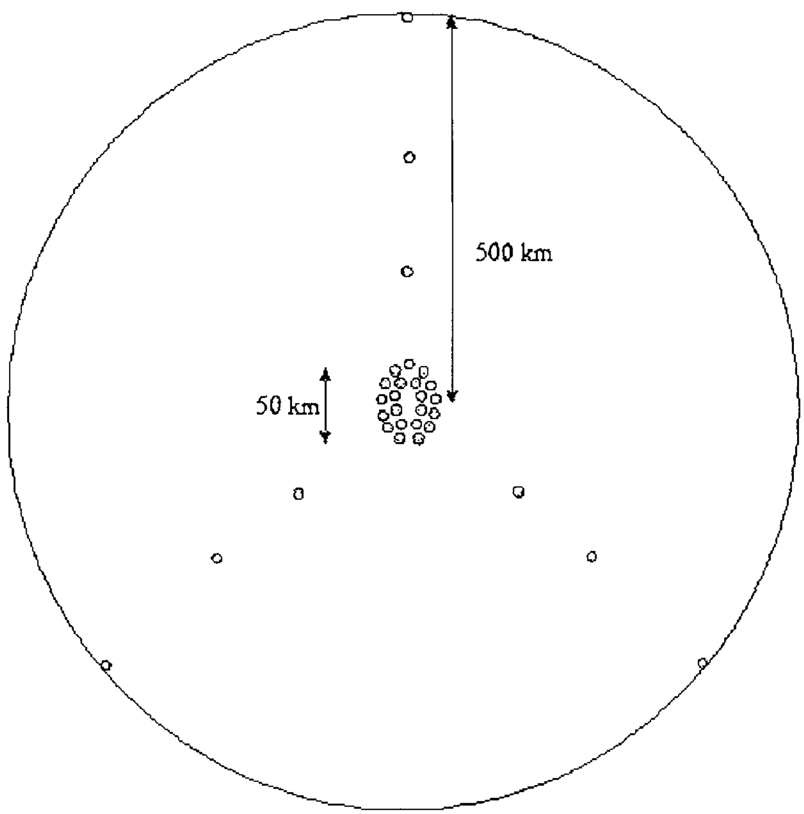

Figure 1.1: Array Pattern of the SKA.

After publishing the report in 1996, P. Dewdney, from the NRC Herzberg Institute for Astrophysics (HIA) in Penticton, BC, contacted researchers all over in Canada. He then organized several research teams from different Canadian universities and industry, which will work together in the next few years with a common objective: study on the realization of the LAR project.

In February 1998, the Technical Group working on the development of the LAR held an organizational meeting in Calgary. Under the coordination of Dominion Radio Astrophysical Observatory (DRAO), sub-projects have been identified and the various groups started to work.

1.2 RESEARCH OBJECTIVES

Fully steerable paraboloidal reflectors (conventional design) have been widely used so the construction has been well optimized to minimize cost. The conventional design is limited to about 100m diameter because of the strength-to-weight ration of steel. The present technologies cannot provide larger increases in performance without very large cost. Therefore, new ides and innovations are required to bring down the cost of building large aperture telescope. There are two general ways to save in the cost: (1) eliminate the expensive rotating mechanical structure of steerable reflectors and (2) keep the structure close to the ground and supported by the ground to reducing the problems of gravitational loading.

The concept LARGE ADAPTIVE REFLECTOR (LAR) was proposed by Legg, 1998. Its central idea is to use very large f/D (focal length to reflector diameter) ratio so the reflecting surface has very little curvature. An airborne platform is used to support the focal receiver. The basic requirements of the LAR include zenith angle coverage of ± 60°, azimuth angle coverage of 360°. It is designed to operate from 250MHz to 22GHz for a required target surface accuracy of 1mm rms.

LAR must be capable of taking on a range of shapes which are sections of an offset paraboloid, so the overall shape of the reflector will consist of a segmented panels that could approximate to the ideal parabolic shape. The telescope is pointed by moving the focus and by simultaneously adjusting the shape of the reflector surface.

The ray angle, θ_{za}, and the focal length, R, define the main geometry of the reflector. The equation below describes the surface of the reflector as a function of position (Legg 1998):

$$z = \frac{x^2 \cos\theta_{za} + y^2 \cos^{-1}\theta_{za}}{4R\left(1 + \frac{x}{2R}\sin\theta_{za}\right)} \tag{1.1}$$

Where z is the height from the center panel, x and y are the coordinates of interest (x is parallel to the ray path and y is orthogonal to the ray path), R is the distance from the center of the reflector to the focus, and θ_{za} is the zenith angle.

The research objective is to investigate the feasibility of using LAR antennas as elements to form the SKA. The following aspects are also considered.

1. Consider innovative alternatives for the overall construction of the reflector, including the innovative use of materials and production techniques, include: an investigation of the feasibility and cost of panels
   a. Consider alternatives which could improve cost by taking advantage of natural structural bending to minimum actuation.
   b. Assess alternatives for actuators and determine the cost as function of actuator throw.
2. Consider the impact of reflector diameter and focal length on the actuator cost, and then the whole cost, including a cost versus diameter curve with varying assumptions of focal ratio and frequency of operation.

3. Consider innovative alternatives for the overall construction of the reflector, including the innovative use of materials and production techniques, include: an investigation of the feasibility and cost of panels
   a. Consider alternatives, which could improve cost by taking advantage of natural structural bending to minimum actuation.
   b. Assess alternatives for actuators and determine the cost as function of actuator throw.
4. Consider the impact of reflector diameter and focal length on the actuator cost, and then the whole cost, including a cost versus diameter curve with varying assumptions of focal ratio and frequency of operation. Final parameters of operation to be determined by client.

The current project consists of three phases; concept development, detail analysis and design optimization, and final design and documentation. The final reflector module size is a function of structural and cost optimization and will be determined by the project.

2 DESIGN DEVELOPMENT

Geometry of the reflector surface depends on the incoming ray angle the focal length of the receiver. The variations in panel elevation are calculated based on Equation 1.1 and Figure 2.1 below shows that the deflected shape of the reflector surface under operational conditions for a 200m diameter antenna with a focal length of 500m.

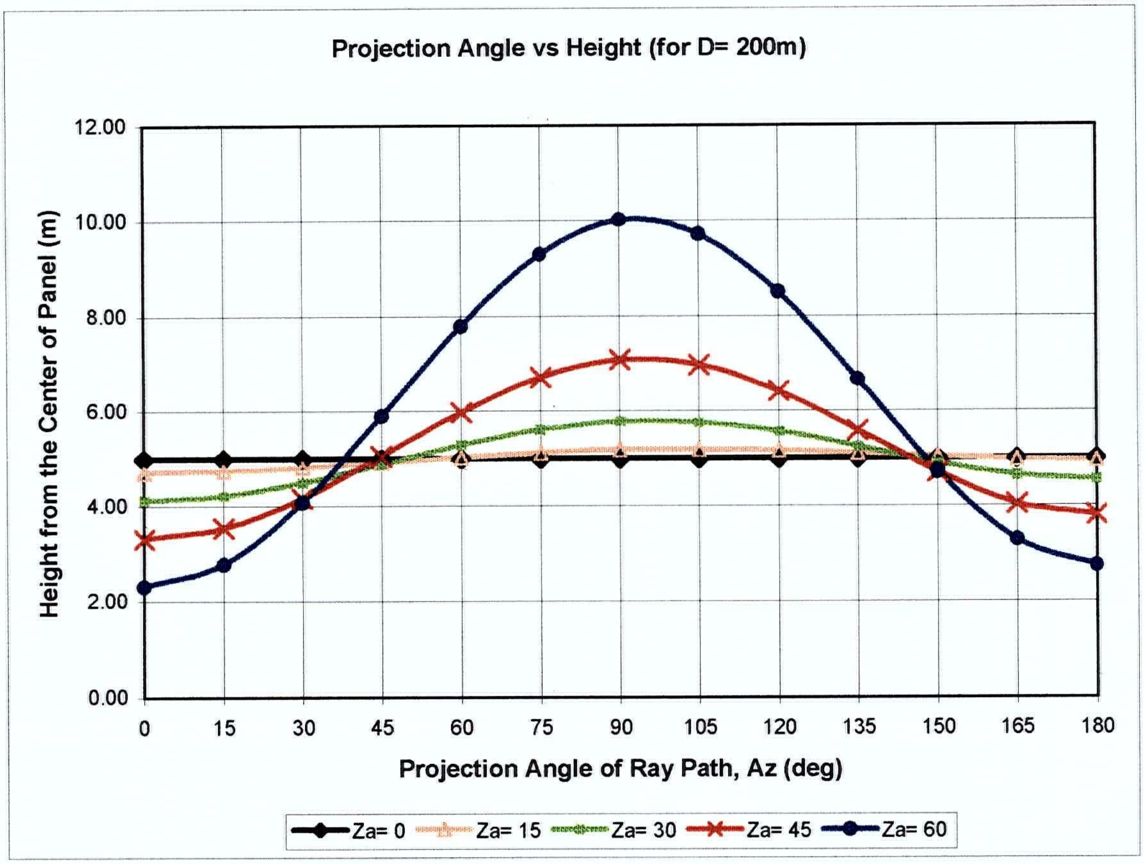

Figure 2.1: Reflector surface variation for different incoming ray angles.

Table 2.1 is a summary of vertical travel required (also called "stroke") for a diameter up to 200m.

Focal length (m)	Max. Elevation (m)	Min. Elevation (m)	Required stroke (m)
500	10.000	2.301	7.699
1000	5.000	1.198	3.802
2000	2.500	0.612	1.888

Table 2.1: Required stroke for different focal lengths.

From the geometric study of the reflector surface, it is observed that the required maximum actuator throw increases exponentially with the reflector diameter.

$$s \propto C_s * r^2 \tag{2.1}$$

Where s is the required actuator throw, and r is the radius of the reflector. The coefficient Cs varies with the focal of the reflector.

To accomplish the change in surface shape and curvature, segmental panels should be used make up the reflector surface. These panels are supported on the ground by actuators, which will provide vertical travel to the panels under operational conditions.

2.1 GRID CONCEPT

Conventionally designed antenna uses a rigid backup structure to support reflector surface and the entire structure is steered by a mechanical rotating device, which sits on the ground. However, the design of LAR requires the implementation of segmental panels, considerations of how to place these segmental panels to form the entire reflector is essential.

Different fundamental shapes for forming the reflector have been considered and the final choice was made based on that three points are required to identify a plane. Also, fewer actuators are required for a triangular grid than a square grid, or any other shapes. The center of the reflector has little variation in elevation when tracking the radio source, so the center portion of the reflector can be any desired shape.

Several shapes for the centerpiece were evaluated. A circular centerpiece is not suitable for it has a curved edge, which would make the segmental panels to be different in size along the radial direction. If a square centerpiece is used, more supports (actuators) are needed than that of a pentagonal or hexagonal centerpiece. Another advantage of a pentagonal or a hexagonal centerpiece is that it can be brake-down into smaller triangular panels if this is required to achieve surface accuracy requirements.

Four geometric layouts shown in the following sections were proposed for forming the entire reflector. The idea here is using triangles to map out the surface area of the reflector.

2.1.1 Geometric Layout 1

The center of Layout #1 is a pentagon panel supported at the center and the corners. This layout is formed with equilateral triangles and two isosceles triangles (66° and 72°). The solid dots indicate the locations of actuators, and each triangle represents a main support structure. Total of five equilateral triangles will be used independently from the choice of grid size. The most often used triangles are in the 72° isosceles triangles. However, equal numbers of isosceles triangles are used for a span of 21m. The longest span will be ~1.2 times greater than the selected grid size.

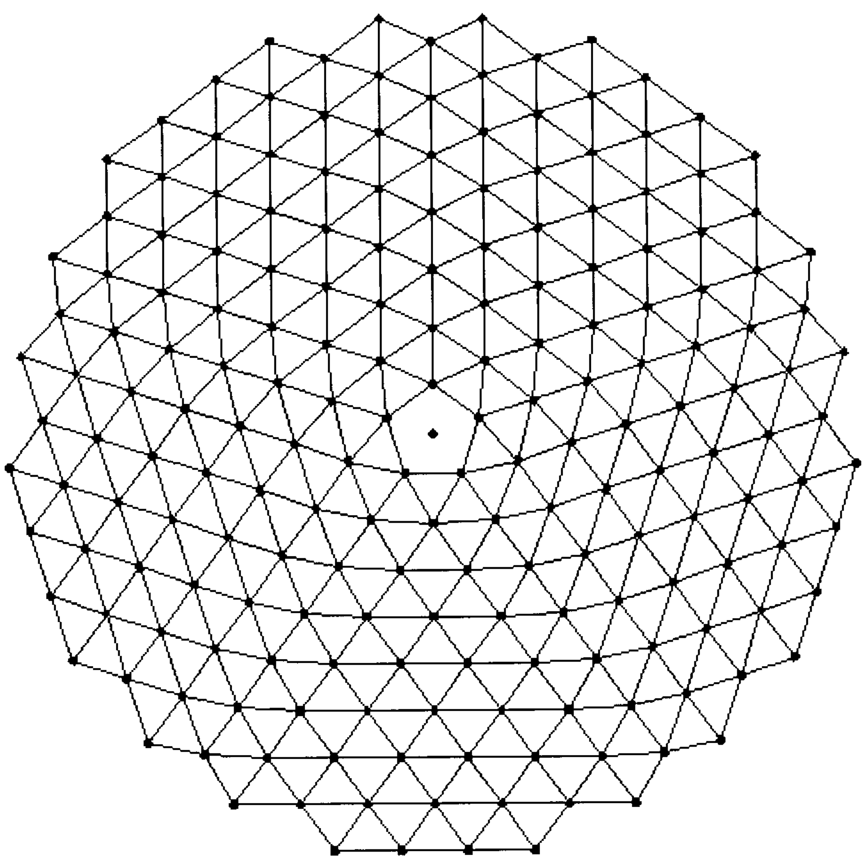

Figure 2.2: Geometric Layout #1.

2.1.2 Geometric Layout 2

This layout is similar to Geometric Layout #1. Again, the centerpiece is a pentagonal panel. One equilateral triangle, one scalene triangle, and two isosceles triangles (46° and 72°) are used to form this layout. For this layout, the 72° isosceles triangle is used the most, followed by equilateral triangles. The longest span of this layout would be ~ 1.2 times greater than the selected grid size, i.e., the largest span is 24.7m for a grid size of 21m.

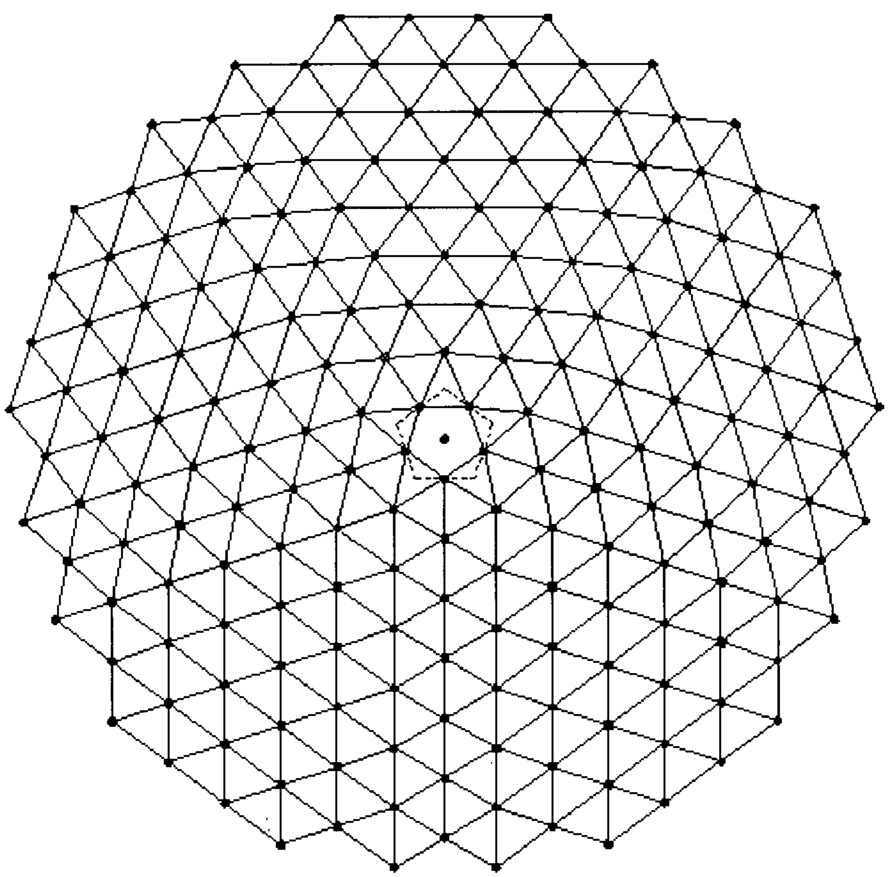

Figure 2.3: Geometric Layout #2.

2.1.3 Geometric Layout 3

Geometric Layout#3 has a hexagonal panel in the center and is mapped with only equilateral triangles. Due to its geometry, the design of main support structures and reflector panels are simplified.

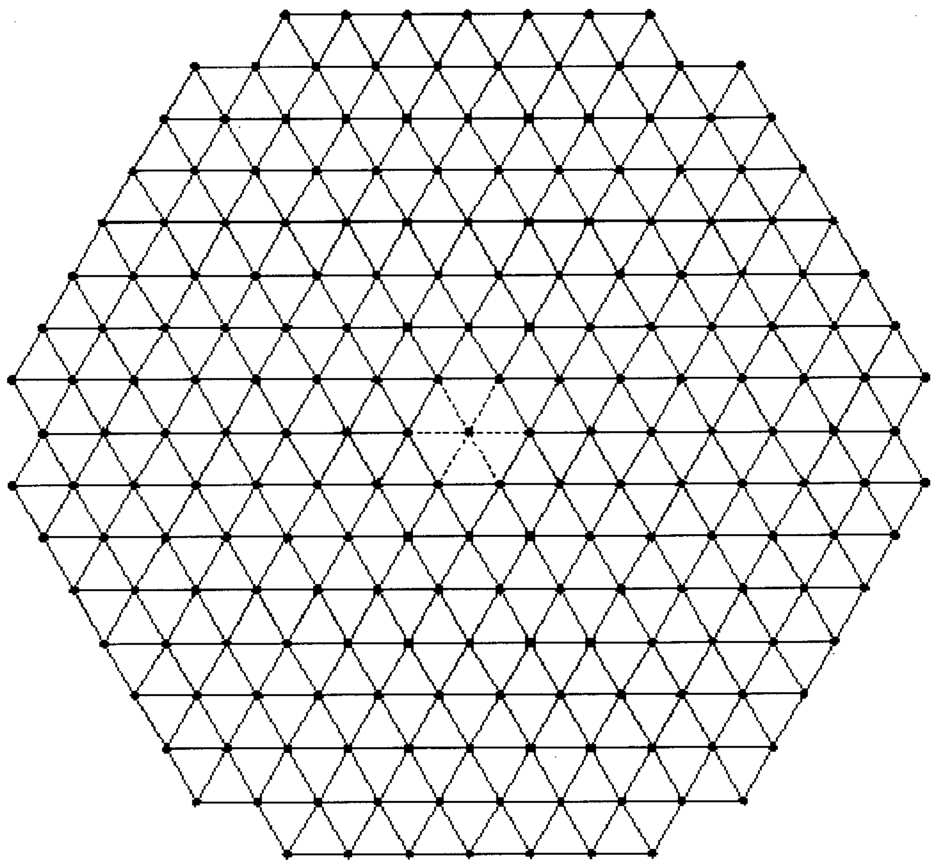

Figure 2.4: Geometric Layout #3.

2.1.4 Geometric Layout 4

Starting with a pentagon in the center, Geometric Layout #4 is a combination of equilateral triangles with 3 different isosceles triangles (48°, 72°, and 84°). Similar to Geometric Layout #2, the 72° isosceles triangles are used the most which is followed by equilateral triangles. The longest span will be ~1.3 times longer than the selected gird size. For example, the maximum span will be 28.1m for a grid size of 21m.

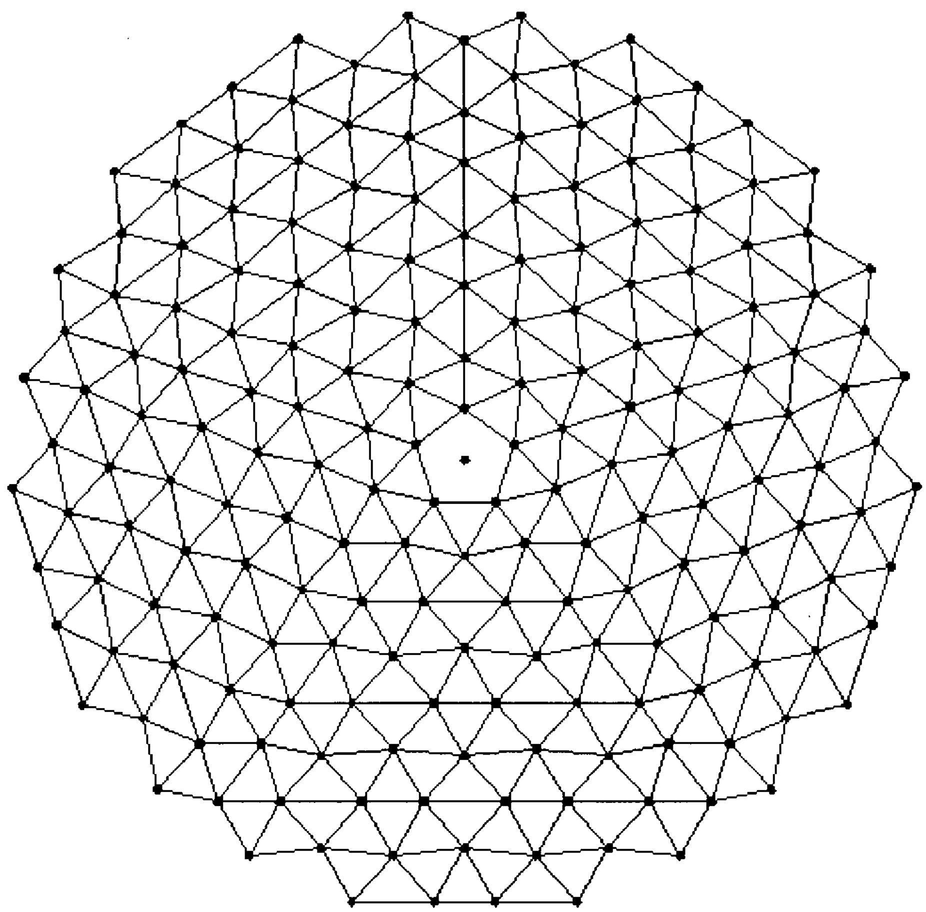

Figure 2.5: Geometric Layout #4.

2.2 SUMMARY OF GEOMETRIC LAYOUTS

Three parameters were investigated in determining the optimal geometric layouts:

1. diameter versus actuator throw,
2. main support structure grid size verses number of actuators, and
3. panel size.

The maximum throw (vertical travel of actuators) is a critical parameter for the reflector. As summarized in Table 2.1, a stroke of 7.7 meters is required if the focal length of the reflector is chosen as 500m and a diameter of 200m which controls the design of actuators. It is recommended that the altitude of airborne platform should not be lower than 500m.

Table 2.2 shows the total number of actuators required verses grid size. Each triangle shown in Figure 2.2 to Figure 2.5 represents a main support structure and is supported by three vertical actuators at the nodes.

Grid Size	Layout #			
	# 1	# 2	# 3	# 4
9 m	476	476	517	476
12 m	291	301	313	291
15 m	196	196	211	196
18 m	136	141	151	141
21 m	101	116	121	111

Table 2.2: Total number of actuators versus different grid sizes.

Since triangular units of size 9- 21meters are the ranges under investigation, these units will have to be filled with smaller sub-structures to provide supports for individual panel, which will have to be individually actuated with short-stroke actuators (refer to as secondary actuators in the following chapters) to compensate the errors in the primary actuation system. Of the four types of grids presented, only the equilateral triangle form (Geometric Layout #3) can be filled with a single panel. Geometric Layout #1 requires the smallest number of actuators and needs 3 types of unit triangles (as opposed to 1 type and 4 types for the other candidates). The final layout for the reflector will depend on the number of actuators, the type of actuators and the surface accuracy requirements. The results show that the most favorable choice is 21m grid of Geometric Layout #1 with sub-structures. Figure 2.6 summaries the number of primary actuators and main support structures for Geometric Layout #1.

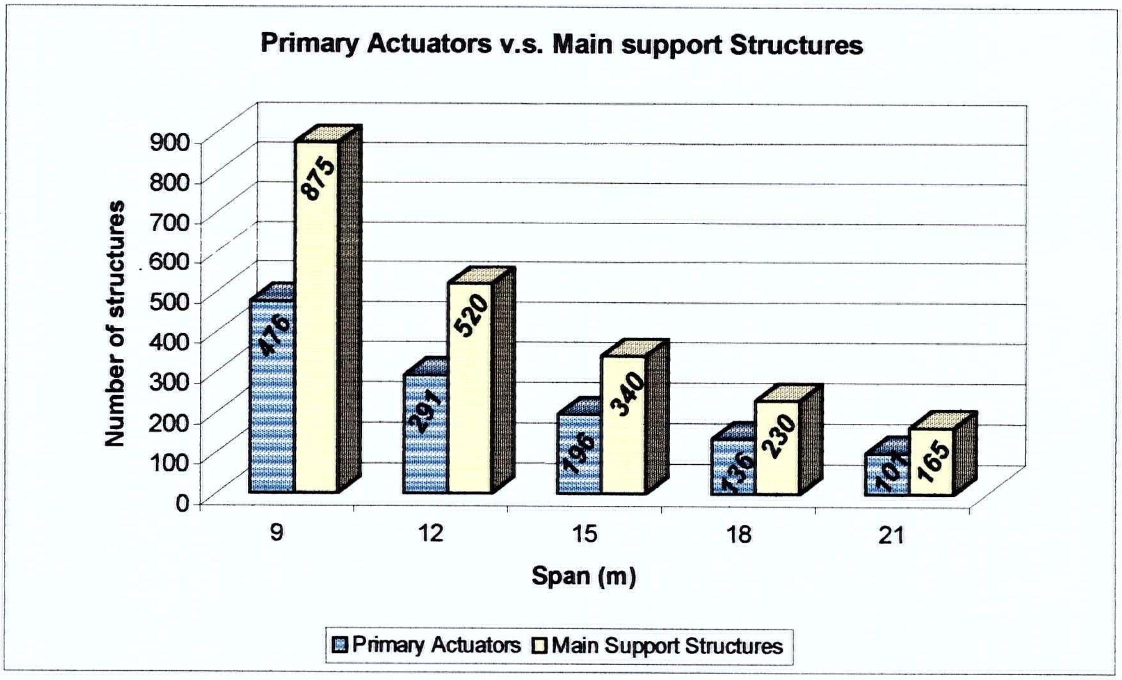

Figure 2.6: Number of primary actuators and main support structures for different spans.

To keep the overall costs of the LAR structure under control, the number of primary actuators has to be minimized (i.e. its spacing has to be maximized). However, the load bearing capacity of a primary actuator is definitely limited; therefore, to achieve a maximum feasible spacing of primary actuators, the weight of both the main support structure and the panel per unit has to be minimized.

The grid size also effects the selection of panel sizes. A desirable size of the reflector panel is 5m, but for numerous grid sizes studied, only the 15m grid can be used with a 5m panel. Therefore, the number of secondary actuators required for each grid size is computed based on different panel sizes for different grid. The possible panel sizes of a 9m span are 3m and 4.5m and since the number of reflector panels should be minimized, panel size of 4.5m is used for computing the number of secondary actuators required. For a 12m span, possible panel sizes are 3m and 4m. A span of 18m can be used with a 4.5m panel or a 6.0m panel. For a 21m span, panel size of 4.5m or 5.25m are both acceptable. The summary of panel sizes verses number of secondary actuators is shown in Table 2.3.

Grid Size (m)	Panel Size (m)	Number of Secondary Actuators
9	4.50	1345
12	4.00	2130
15	5.00	1410
18	4.50	1800
21	5.25	1290

Table 2.3: Number of secondary actuators for different grid sizes.

3 DESIGN OF MAIN SUPPORT STRUCTURES

Main support structures provide supports to secondary actuators and reflector panels. The elevation and angle of a support structure are adjusted continuously by controlling the movement of primary actuators to fit the paraboloid of revolution when tracking the radio source. The ideal main support structure is one that is light, stiff and with a minimum number of members. The final design of the main support structures should be cost-effective, easy to construct and easy to transport.

To reduce the complexity of interactions, each triangular module should be rigid and independent from each other. The dimensions of a triangular module depend on the loads and surface accuracy requirements. From a practicality standpoint, a reasonable maximum depth for the main support structure is 1.8 m. Tilt component is used to correct for error in the position of the focus on the airborne platform but it is not included at this stage of study.

3.1 LOADS

Dead loads and live loads are the two load cases considered for the design. Deflections due to dead loads are the error that could be compensated by measuring systems.

3.1.1 Dead Load

Dead loads considered for the main support structure were self-weight of the main support structures and the weight of reflector panels. The weight of secondary actuators is negligible comparing to the weight of reflector panels.

3.1.2 Live Load

Live loads include wind load and snow/ ice load. Only wind loading is considered when designing the main support structure because this is the component that would introduce error to the measuring system under operational condition.

Wind load

Wind load is applied perpendicular to the reflector panels and the gust wind factor is taken from NBC (assuming the site at Penticton). Wind load of 15m/s was applied, as for operational condition, to the entire reflector. The structural height was assumed to be 12.0m.

Snow and ice load

The reflector cannot be operating when snow is covering the reflector surface; therefore, the loading from snow will only increase the deflection of main support structures and it has no effect on measurement accuracy.

Temperature Load

Temperature load is not considered because the main support structures are covered by the reflector panels. In addition, the gap between these two structure components (main support structures and reflector panels) is large enough that there is no temperature gradient.

3.1.3 Exceptional Loads

Some possible exceptional loads are earthquake load and impact loads (i.e. wind storms, hail, etc.) and it depends on the region where the radio telescope will be erected. Exceptional loads were no considered in this report.

3.2 SELECTION OF STRUCTURAL TYPES

Three structural types are considered for forming the triangular module, and these structural types are discussed separately below.

Plate girder

A plate girder basically consists of flange plates and connected to a relatively thin web plate. It is used for long spans when rolled W sections or WWF shapes do not have the required flexural strength. The typical span lengths for plate girders are 20m to 100m. Since plate girders have very deep slender webs, transverse or longitudinal stiffeners may be used to increase the strength of the web. Usually, heavy concentrated loads and reactions are supported directly on bearing stiffeners.

When designing plate girders with long span, economy may be achieved by reducing the area of flange plates where the bending moment is substantially less than the maximum. However, the cost of making flange splices must be balanced against the weight savings achieved. The compression flange may fail either by buckling or by yielding and will generally govern the flange design of a symmetrical plate girder (Handbook of Steel Construction 1997).

The orientation of a main support structure depends on the radio ray path. The tilting of the main support structure will result in shifting the central of gravity of the structure, and this will introduce a secondary moment to the structure. Plate girders perform well under pure compression loads, but the secondary moment acting on the cross sectional area of plate girders might have warping effects on the structure. Moreover, it is difficult to construct sub-structures within a triangular unit formed with plate girders.

Truss

A truss is a built-up assembly of axially loaded tension ties and compression struts. It consists of a top and a bottom chord, connected to each other by vertical and /or diagonal web members. Angles, channels, double angles, and hollow structural sections are efficient truss members. Trusses generally are long slender structures, so they should be braced laterally to avoid buckling out of the plane of load. Truss depth is determined in relation to the span, loads, maximum deflection, etc., with increased depth reducing the loads in the chords and increasing the lengths of the web members. Efficient truss depths range from 0.08 to 0.12 of the span length.

Open web steel joists

Open web steel joists are standardized prefabricated trusses. There are three categories (Spiegel and Limbrunner 1997):

1. Open web steel joists, K-series: shallow trusses with parallel chords. For a span up to 60 feet with a depth of 8 inches to 30 inches.
2. Long span steel joists, LH-series: usually used for a span of 60-96 ft and a depth of 18-48 in.
3. Deep span steel joists, DLH-series: for span up to 144-ft with a depth of 52-72 in.

Generally, open web steel joist are lighter than truss and thus has a lower unit cost ($/meter). Open web steel joists are commercially available, however, it cannot handle high compressive forces. Both custom-design trusses and open web steel joists can be used to form the triangular space frames. The selection between custom-designed trusses and open web steel joists will depend on the loads from reflector panels.

3.3 TRUSS DESIGN CONSIDERATIONS

The preliminary design of the main support structure consists three linear trusses that form a space truss frame (or a triangular module) and is filled with subs-structures. Hollow structure section (HSS) is selected as the member type for savings in transportation and erection due to less weight than rolled plates. It also represents the most efficient use of a steel cross-section in compression. Two important points are considered when designing hollow structural sections (Packer and Henderson 1997).

1. Chords should generally have thick walls because the stiffer walls of chord members resist loads from the web members more effectively, and the connection resistance increases as width (or diameter) to thickness ratio of the chord decreases.
2. The connection resistance increases as the ratio of chord wall thickness to web wall thickness increases, so webs should have thin walls. In addition, thin web walls will require smaller fillet welds for a full strength joint.

Large thin section for a compression chord is more efficient in providing buckling resistance, so for this member the final HSS wall slenderness will be a compromise between connection strength and buckling strength.

Circular HSS are more expensive to fabricate than rectangular (or square) HSS. Connections of circular HSS require that tube ends be profile cut when the tubes are to be fitted directly together, unless the web tubes are much smaller than the chords.

The most common planer trusses have Warren and Pratt web configurations which are efficient for spans over 20 meters. Longer spans might require two-way trusses which would involve primary trusses in one-direction and secondary trusses spanning between the primary ones. Common truss types are shown in the figure below.

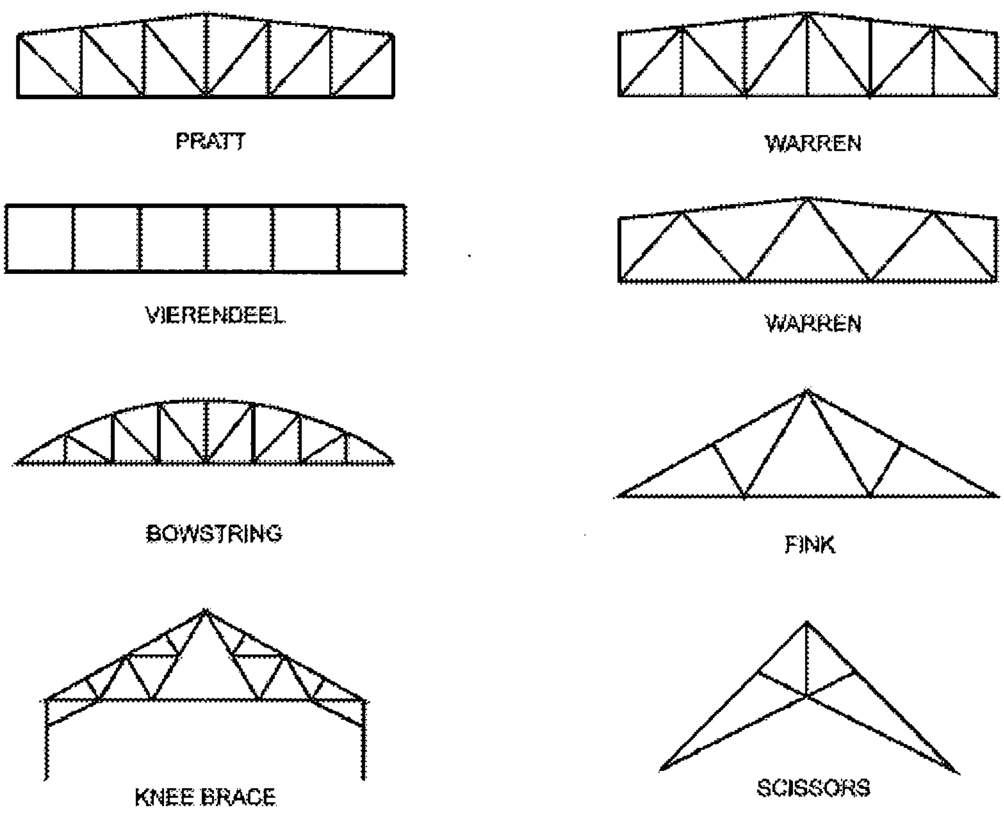

Figure 3.1: Types of trusses.

3.3.1 Truss Design #1

Warren truss provides the most economical solution since long compression web members take the advantage of the fact that HSS are very efficient in compression. Warren trusses also provide greater opportunities to use gap joints. This design is a typical warren truss (Figure 3.2). The distance between panel points is assumed to be 5.25m and the depth of the truss is 1.8m. Since the size of reflector panels has not yet defined, the load is calculated for a lightweight concrete panel with a thickness of 5.0 cm and an uncertainty factor of two is then applied. A concentrated load of 40kN is applied at all panel points except at the mid-span, where a concentrated load of 80kN was applied to taking into account of the load transferred from substructures. Elastic analysis is used assuming that all members are in jointed.

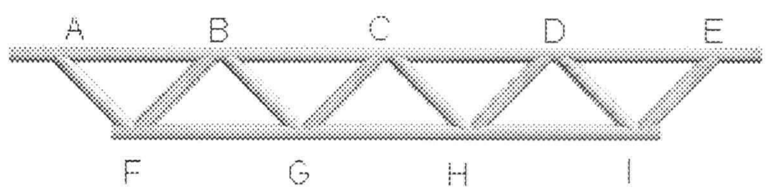

Figure 3.2: Truss Design #1.

The member axial forces were determined by a pin-jointed analysis and are illustrated in Table 3.1. Negative value means the member is in compression and positive value means the member is in tension. Due to its geometry, the table shows the member forces for half of the truss. Top chords were under compressive loads and bottom chords were in tension. Web members were either in compression or in tension.

Top Chord	F_{ab}	-116.7 kN
	F_{bc}	-291.7 kN
Bottom Chord	F_{fg}	233.3 kN
	F_{gh}	350.0 kN
Webs	F_{af}	141.5 kN
	F_{bf}	-141.5 kN
	F_{bg}	70.7 kN
	F_{cg}	-70.7 kN

Table 3.1: Axial forces of Truss Design #1.

The maximum compression force is approximately 300kN for top chords, and the maximum tension force in the bottom chords is 350kN. Sixteen connections are required for this truss design, but due to its symmetry, one weld design can be applied to all connections.

3.3.2 Truss Design #2

Figure 3.3 shows Truss Design #2, which is based on Pratt truss configuration. Fourteen connections are required for this truss design.

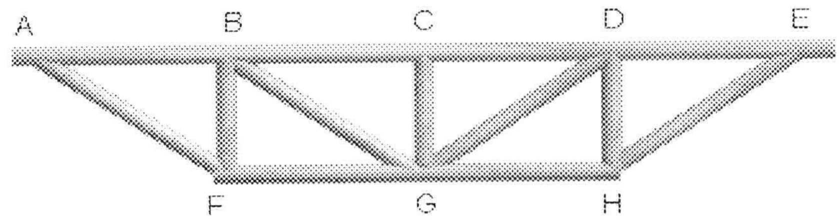

Figure 3.3: Truss Design #2.

Same load conditions are applied to this design and the results show in Table 3.2. It is observed that the maximum tension force of approximately 250kN was found at the web labeled AF (and at EH by the symmetry of the design), which is twice of the forces in other webs. Since the tension forces in the diagonal webs of AF (and EH) and the bottom chords are approximately the same, these diagonal webs should be designed separately from the other webs.

Top Chord	Fab	-233.3 kN
	Fbc	-350.0 kN
Bottom Chord	Ffg	233.3 kN
Webs	Faf	246.7 kN
	Fbf	-80.0 kN
	Fbg	123.3 kN
	Fcg	-80.0 kN

Table 3.2: Member forces for Truss Design #2.

3.3.3 Truss Design #3

Truss Design #3 is a modified Pratt truss. It is assumed that the truss is simply supported. The angle between the top chord (member AB for example) and the bottom chord (member AF) is 9.7 degrees. Between diagonal webs and bottom chords, the angle is 19.5 degrees.

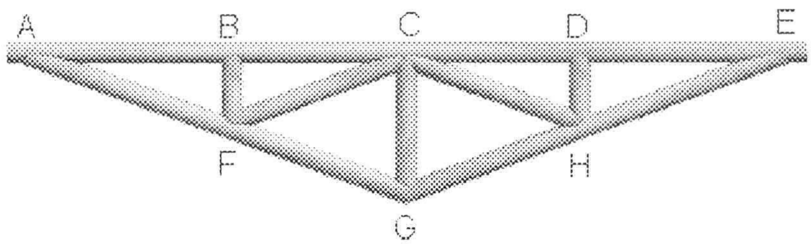

Figure 3.4: Truss Design #3.

Table 3.3 shows the summary of member axial forces. By symmetry, the axial force in member F_{de} is the same as in member $F_{cd,}$ and this also applies to member F_{eh} which equals to F_{af}. The result shows that the vertical web (CG) at the center of the truss is not required it bearings no load.

Top Chords	F_{ab}	-466.7 kN
	F_{bc}	-466.7 kN
Bottom Chords	F_{af}	473.5 kN
	F_{fg}	118.4 kN
Webs	F_{bf}	-40.0 kN
	F_{cf}	118.4 kN
	F_{cg}	-120.0 kN

Table 3.3: Axial force results of Truss Design #3.

There are thirteen connections required for this truss design. Special connection design is required at the bottom of the truss.

3.3.4 Truss Design #4

This is a modified warren truss; it uses the concept of combining the above two designs. Due to the truss geometry, a vertical web member at node C will have zero force. In order to reduce the amount of material required for this design, the redundant web member is removed.

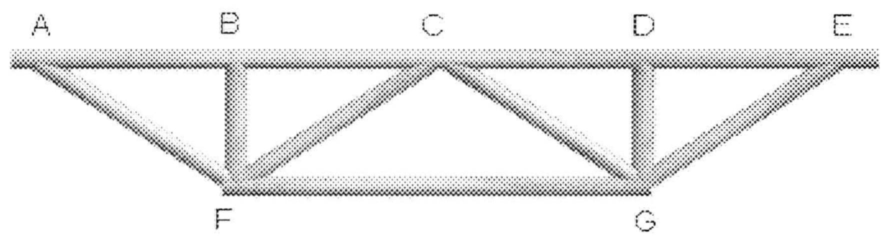

Figure 3.5: Truss Design #4.

The results of member forces are shown in Table 3.4. From this table, it is observed that all the top chords are in compression with a force of 233kN. The maximum tension force in the bottom chords is the same as Truss Design #1. Twelve connections are required for this design.

Top Chords	F_{ab}	-233.3 kN
	F_{bc}	-233.3 kN
Bottom Chords	F_{fg}	350.0 kN
Webs	F_{af}	246.7 kN
	F_{bf}	-40.0 kN
	F_{cf}	-123.3 kN

Table 3.4: Results of member forces for Truss Design #3.

3.3.5 Plane Truss Design Summary

Forces in chords and webs were calculated with a formatted spreadsheet and the detailed calculations are shown in Appendix A. The comparison of member forces between the four designs is shown in the Figure 3.6. Truss Design #3 results in highest tension force in chord members. Truss Design #1 and #4 have the same tension force in the chords, however, the tension force in web is much smaller for Design #1.

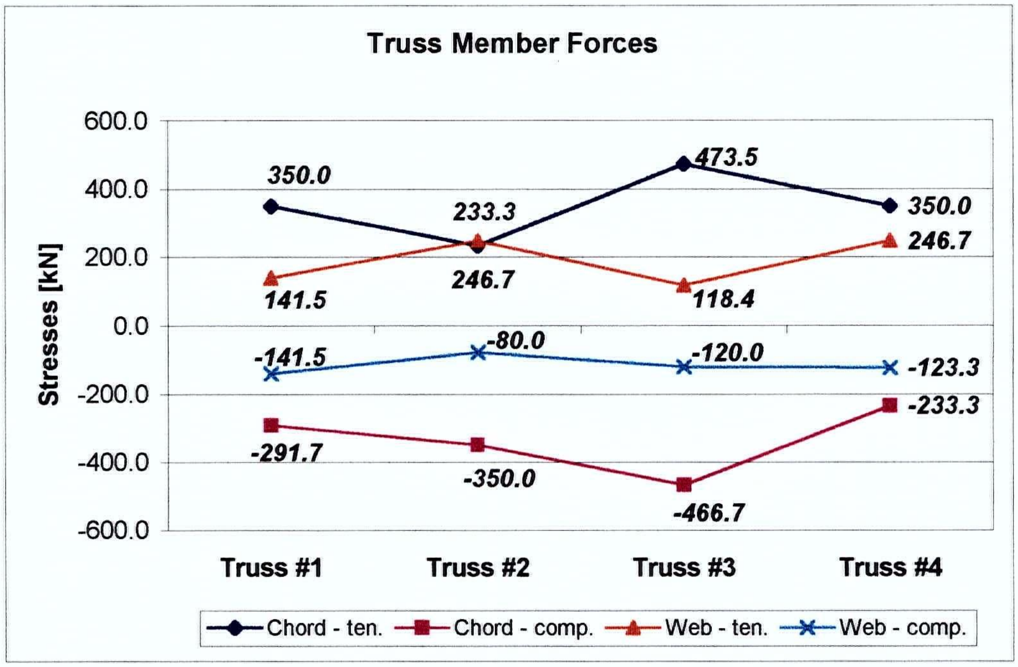

Figure 3.6: Member force summaries.

The dimensions of chords and webs are directly proportional to the maximum forces in the member. According to the design considerations, chords should have thick walls and webs should have thin walls. In another word, the favorable design would have higher forces in chords than in webs. Comparing the tension and compression forces in the members, Truss Design #3 requires a larger cross sectional area for the chords for the highest tension force in all designs, and a larger section is also required for the web to avoid buckling. For Design #2, the maximum tension force is higher in the webs than in the chords, which means the required cross sectional area for the webs might be larger than the chords. Truss Design #1 is selected for the preliminary design of space frame structures because of its simplification in connection design.

3.4 PRELIMINARY DESIGN

The preliminary design of the main support structure consists three linear trusses that form a space truss frame (or a triangular module). Sub-structures are constructed within each triangular module to provide supports for secondary actuators and reflector panels. These sub-structures can also help to reduce the bending at the bottom of main support structures, thus reduce the deflection at the center of the triangular module. Design of sub-structures is similar to the main space truss; sub-structures have the same pipe diameter and depth as the main support space trusses. If necessary, circular pipes connecting to the top chords of the space trusses can be used, in addition to the substructure, to provide supports for the secondary actuators. Figure 3.7 shows the preliminary design of the space frame and Figure 3.8 on the next page shows a typical linear truss. Since each triangular modulus is independent from each other, every primary actuator may support up to a maximum of six triangular modules.

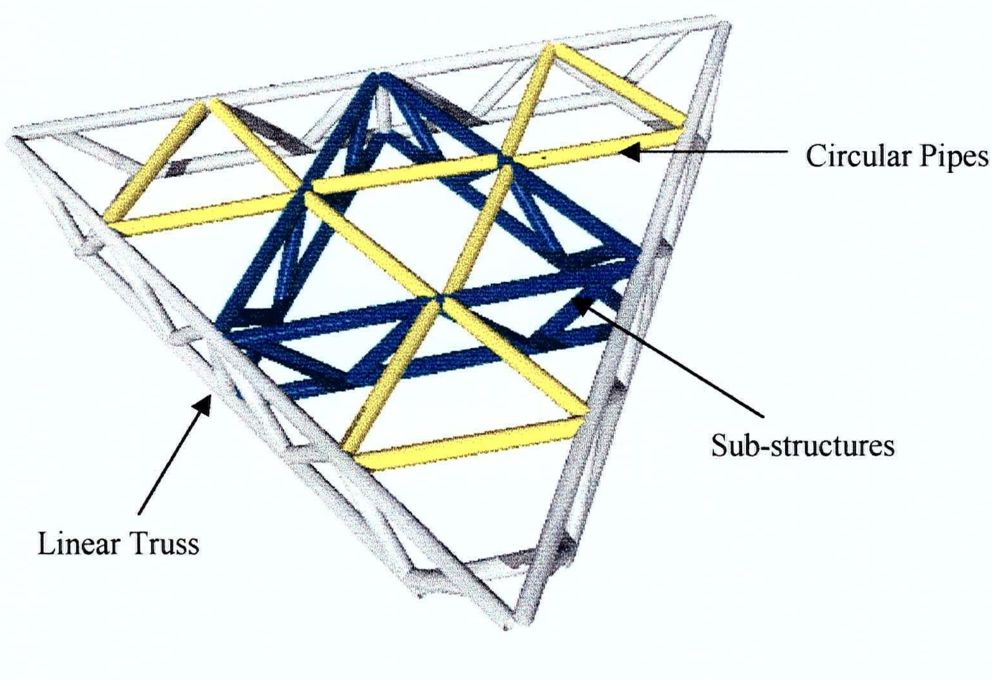

Figure 3.7: A Triangular Space Truss Frame

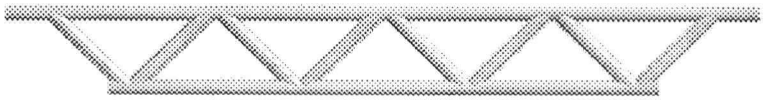

Figure 3.8: Typical Linear Truss

In order to select suitable width (diameter) and thickness for chord and web members, simple static analyses were performed. The self-weight deflection and wind load deflection were considered for the LAR main support structures. Geometric studies were also carried out to investigate the problem of continual radial and tangential extension/ contraction of the reflecting surface resulting from changes in reflector shape during telescope operation.

3.4.1 Loads and Deflections

In the preliminary design stage, the assumption is that the structure is very stiff. The structural performance of the different proposed configurations were evaluated on the basis of dead load and wind load deflections. Deflections due to the self-weight of the structure components are the parameters that can be compensated, so the effects due to dead load and wind load are considered separately. Microsoft Excel was used for the preliminary studies of loads and deflections of main support structures. The results are shown in Appendix B. No load factor is applied at the preliminary design stage. In order to optimize the design, numerous span lengths have been investigated. The span varies from 9 meters up to 21 meters in an increment of 3 meters ($\approx$ 10 feet).

Two load cases covered were:

- The dead load includes the weight of reflector panels and space frames. Deflection of the truss is calculated based on the following equation.

$$\Delta = \frac{5wL^4}{384EI} \tag{3.1}$$

- The wind load case only considers the operational load by assuming wind speed of 15m/s is acting on the entire reflector surface. Assuming structure elevation of 12.0m. The wind pressure is calculated based on the equation below (NBC 1995).

$$P_0 = q_0 * c_e * c_g * c_p \tag{3.2}$$

Where q_o = wind pressure at operational condition

C_e = exposure factor

C_g = gust effect factor

C_p = pressure coefficient

Table 3.5 shows the summary of loads that applied to a linear truss for different gird sizes. These values represent loads from the largest triangular unit of each Geometric Layout. For example, the largest triangular unit for Geometric Layout #1 is a 72° isosceles triangle.

Grid Size		9 m	12 m	15 m	18 m	21 m
Panel Self-weight Load (kN/m)	Layout #1 & #2	1.09	1.46	1.82	2.19	2.55
	Layout #3	1.00	1.33	1.66	1.98	2.32
	Layout #4	1.14	1.52	1.91	2.29	2.67
Wind Load (kN/m)	Layout #1 & #2	0.44	0.59	0.74	0.88	1.03
	Layout #3	0.40	0.54	0.67	0.81	0.94
	Layout #4	0.46	0.62	0.77	0.93	1.08

Table 3.5: Summary of loads for each Geometric Layout and grid size

From the deflection calculation results (Appendix B), a Hollow Structural Section (HSS) with a diameter of 168mm and a thickness of 7.2mm was selected for further static analysis which is presented in the next section. This hollow structural section weights 28.3 kg/m. Figure 3.8 shows the maximum loads from reflector panels for different grid sizes.

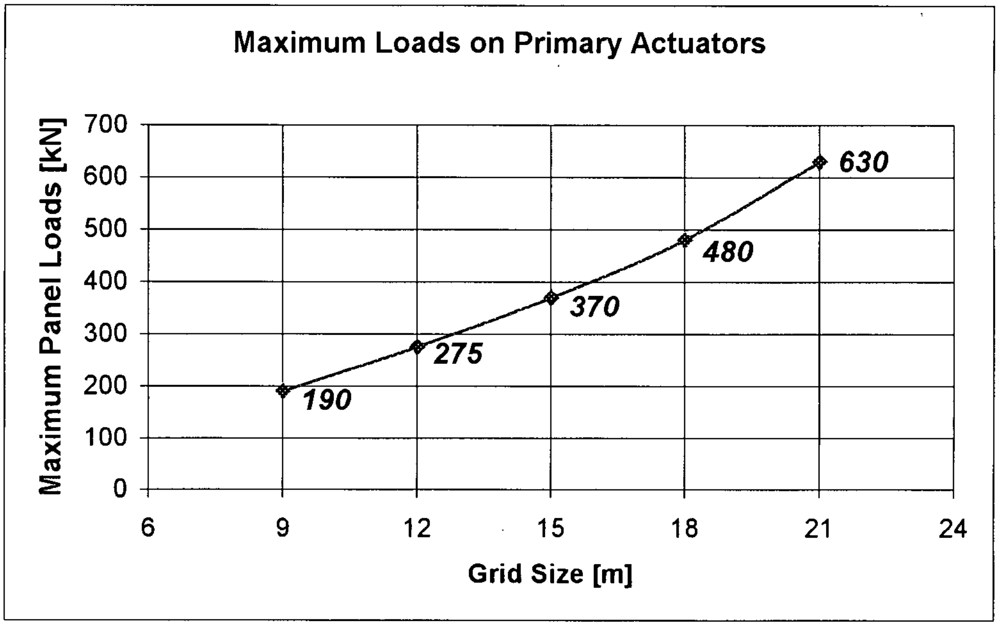

Figure 3.9: Maximum loads on primary actuators

3.4.2 Static Analysis Results

ANSIS-PC/LINEAR ver.5.4 was selected to carry out the static analysis of the preliminary design of the main support structure. The inputs and outputs of this analysis are shown in Appendix C.

Assumptions for the static analysis are:

- The span of 21m is used for minimizing the number of primary actuators and main support structures.
- The distance between two panel points is assumed to be 5.25 meters.
- HSS 168x8 is used for both chords and webs.
- Panel weight is applied as a concentrated load of 20kN (assuming the reflector panel is made with light weight concrete and has a thickness of 5.0cm).

Maximum displacement of the structure of 16.5mm is found at the center of the space truss with an applied load of 20kN per panel. It is estimated that 165 triangular modules were required to form the reflector and an estimated cost of $6.6M in Canadian Dollars. An increase in the panel distance of a truss could result in a decrease in the number of web members required and hence, the fabrication costs. The longer truss members, however, will be subjected to higher forces because of the greater panel distance. Optimization design of the main support structure is required to reduce the overall cost of the LAR per unit area.

3.5 ALTERNATIVES

The preliminary design of the main support structure is rigid but is heavy. The cost of the main support structures comes from two parts: material and labor. By reducing the weight of space frames, the material cost can be reduced. However, the bigger portion of the cost is the labor cost for field welding, which is approximately constant for all similar designs. To reduce the labor cost, the number of members should be reduced. Looking closely at the arrangement of the main support structures, it is noted that the two adjacent space trusses are placed side by side (Figure 3.9) and they have to share secondary actuators. The sharing of secondary actuators will increase the difficulty of designing the main support structure and it will also increase of the cost of designing and fabrication. Other configurations for space truss frames are considered to reduce the cost of this structural component.

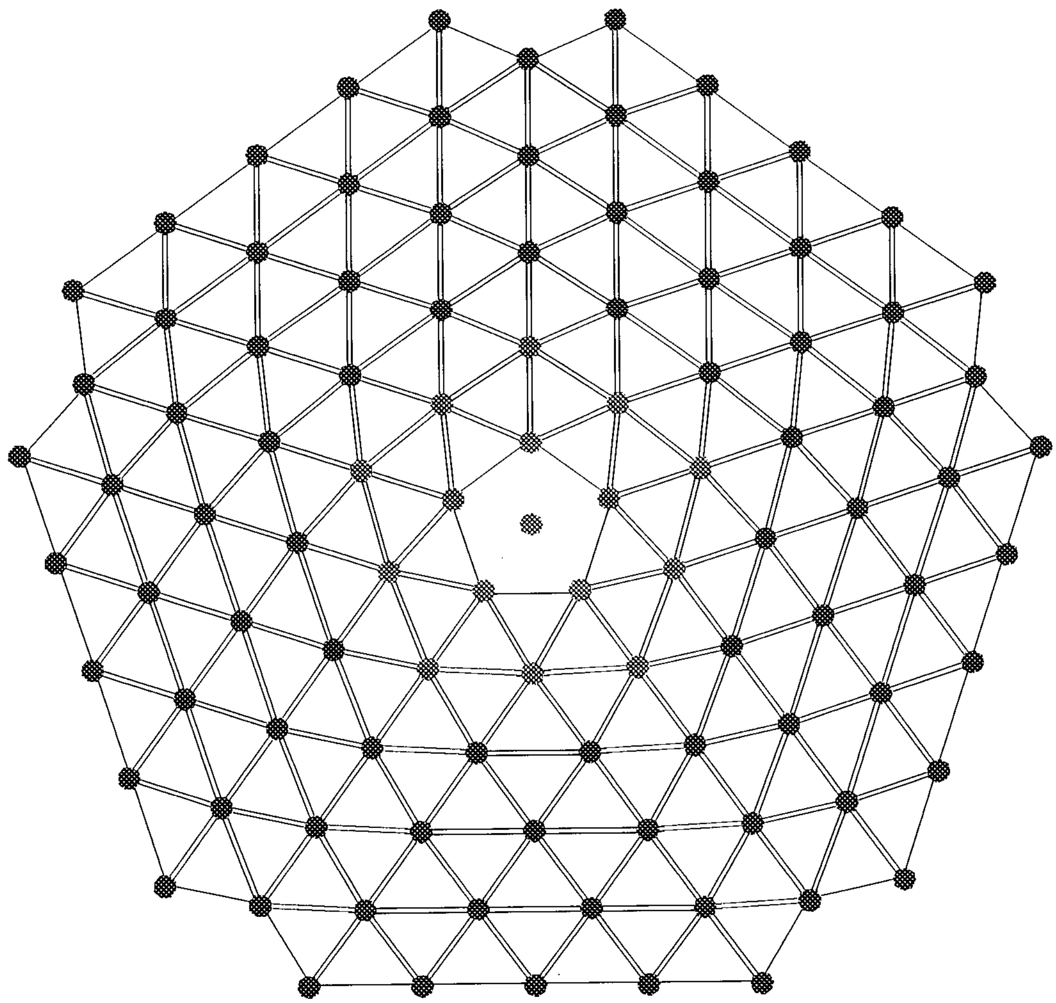

Figure 3.10: Arrangement of preliminary design of space frames.

3.5.1 Possible Configurations

Because each space frame is independent, the trusses composing the sides of space frames would run side-by-side for adjacent space frames (Figure 3.10). To remove the redundant structure, a new concept is considered. By replacing space frames at alternate triangles and extending truss members to provide supports for secondary actuators at adjacent triangles can reduce the total number of space frame. However, the weight of each space frame might increase.

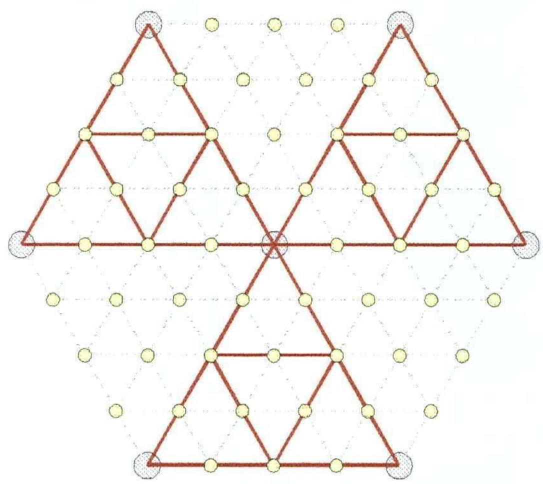

Figure 3.11: Configuration of triangular modules.

The big circles indicate the positions of primary actuators and the small circles represent the positions of the secondary actuators. The solid lines represent typical linear trusses. Thirty-one different configurations for the space frame were introduced and are illustrated in Figure 3.12.

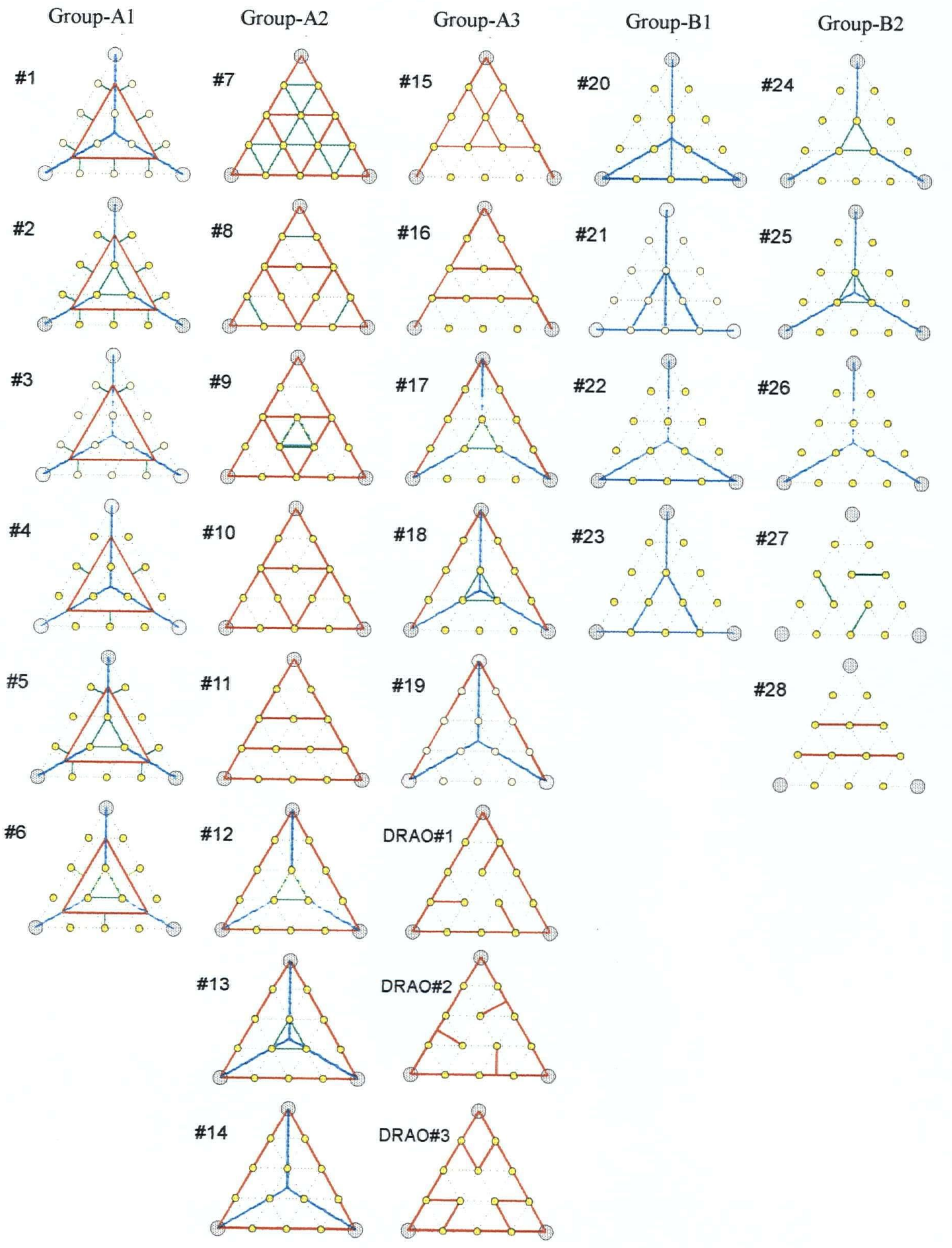

Figure 3.12: Various geometric configurations.

Those alternative configurations for space frame structures are separated into two main groups: Group-A and Group-B. The main difference between the two groups is the number of structure members. Generally, a configuration from group A supports all the secondary actuators on that space frame (illustrated as solid lines in Figure 3.11). There will be three secondary actuators at the center of the adjacent triangle that still require supports, and this is where the Group B configurations fit in.

Group A

Group A configurations are further divided into 3 sub-groups.

1. Group-A1 configurations have main space trusses placed closer to the center of the triangle than the original design. As mentioned in Section 3.4.2, the maximum displacement occurs at the center of a space frame. The idea here is to have the structure members closer to the place where the largest deflection will occur in order to reduce the amount of deflection. In this category, configuration #3 and #5 can only be used with configuration #4 and #6.
2. Starting with the original space frame on the top of the list, the configurations in Group-A2 all maintain the use of three linear trusses forming the space truss frame. The arrangements of sub-structure are somewhat different from the original design in all other possible forms. Three additional configurations were received from Brent Carlson, Ph.D, Research Council Officer, of DRAO on December 6, 1998; these configurations, labeled as "DRAO," fall into this category and are also included in Figure 3.12 to complete the list.
3. The third group (Group-A3) includes configuration #15 to #19. Instead of fully loading one space frame and removing the adjacent space frame as in Group-A1

and A2, the load sharing systems between two adjacent triangular units are introduced. All of the configurations in this group have two typical trusses supporting the secondary actuators along two sides of a triangular unit, and sub-structures are constructed to stiffen the structure and to support secondary actuators.

Group B

Group B layouts include configuration #20 to #28. These configurations are separated into Group-B1 and B2. Since the configurations in Group-A3 provide supports to the sharing actuators at only two sides of a triangular unit, a Group-B1 configuration is required to support the remaining actuators. Group-B2 configurations are designed to pick up the three actuators at the center of the neighboring triangular unit of a Group-A1 (#1 and #2 only) or A2 configuration.

Those configurations were investigated individually in order to select a feasible design for the main support structure. The main considerations are the rigidity of the structure and the field of view for the position accuracy measuring cameras.

The weight of each configuration is calculated assuming the chord and web members have the same width and thickness (Table 3.6). Appendix D presents all the combinations of the layouts that demonstrated in Figure 3.11. The combination of configurations #11 and #27 (Combo #37) is the lightest among all other combination, thus requires the least amount of material.

Group	Configuration #	Weight per unit (kg)
A1	1	10500
	2	12000
	3	9900
	4	9300
	5	10700
	6	10100
A2	7	13500
	8	11500
	9	11500
	10	10900
	11	10300
	12	11000
	13	12500
	14	11800
A3	15	9100
	16	7900
	17	8600
	18	9600
	19	9000
B1	20	7300
	21	6900
	22	6600
	23	5900
B2	24	3800
	25	4800
	26	4200
	27	1900
	28	3100

Table 3.6: Masses of the alternative configurations.

3.5.2 Additional Requirements for the Main Support Structure Design

For measuring the surface of the LAR, the measuring scheme of using a CCD camera mounted on the ground to image the targets on the back of the panel is introduced. There will be three LEDs attached to the bottom surface of the panel. By measuring the global coordinates of the LEDs with the CCD camera each point on the panel surface and its global coordinates can be calculated. This concept is illustrated in Figure 3.13. In order for CCD cameras to scan the position of the targets, a clear view (also called as "field of view") is required.

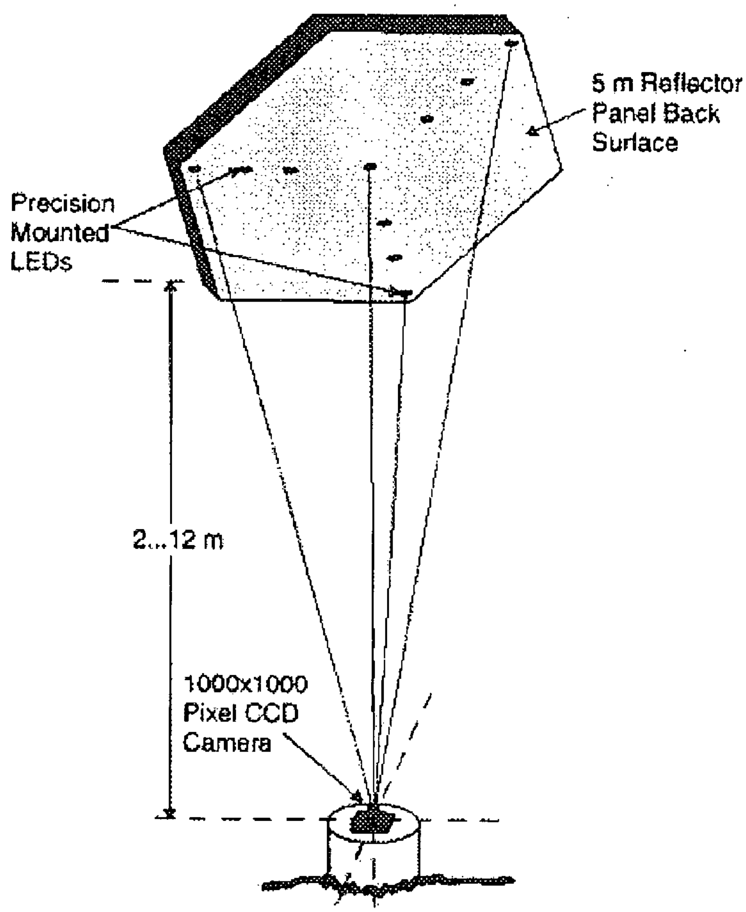

Figure 3.13: Target position triangulation concept for the reflector panel measurement.

3.5.3 Structural Analysis

Due to the additional requirement, the main support structures should not block the filed of view for position accuracy measurements. All the configurations in Group-A1 would not provide a clear view for CCD cameras, so these configurations are eliminated from further studies. Besides, configurations in Group-B1 are not rigid structures so they are also eliminated. Since Group-A3 configurations can only be used with a configuration from Group-B1, these configurations are not applicable for further studies.

From Figure 3.12, configuration #10 and #11 are the most suitable layouts for the LAR project. Configuration #10 is similar to the original space frame but without the use of circular pipes connecting top chords. This configuration has approximately the same stiffness as the original space frame but with a lighter weight. Configuration #11 is the lightest among the configurations in Group-A2, so it might worthwhile to study some combinations using these two configurations.

ANSYS-PC/LINEAR version 5.4 was selected to carry out the static analyses of the space frames. FEM models for Combination #31, #32, #37 and DRAO #1 were built and analyzed separately to show the typical structural behaviors and properties.

The boundary conditions used for the analysis at the three supports were: one fixed in all directions, one is only allowed to move in the radial direction, and one is allowed to move both in radial and tangential directions.

3.5.3.1 Combo #31

This combination is formed with the initial design with extended truss elements that act as cantilever beams. It is noted that greater displacements occur at the ends of these cantilever trusses. As a result, greater stroke is required for the secondary actuators. Besides, nine members were connected to the top chord at the mid-pan of the main linear trusses. This complex connection design will result in a higher probability of connection failure. The vertical webs can be removed to reduce the complexities of the connection.

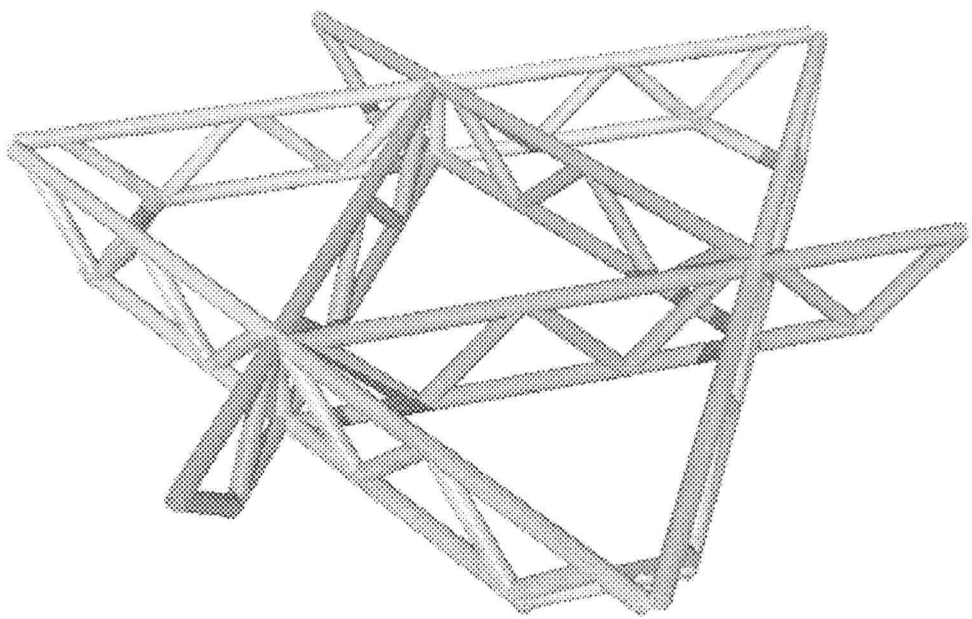

Figure 3.14: Combination #31

3.5.3.2 Combo #37

This combination is formed with a triangular space truss and is connected by two plane trusses through the center of the space truss. Connection between main planer trusses and substructures are simpler than Combo #31. For this configuration, the maximum number of members that have to connect together is five. However, since plane trusses are not braced, these trusses buckled out of the plane of the load; therefore, high deflections occur at the mid-span of trusses.

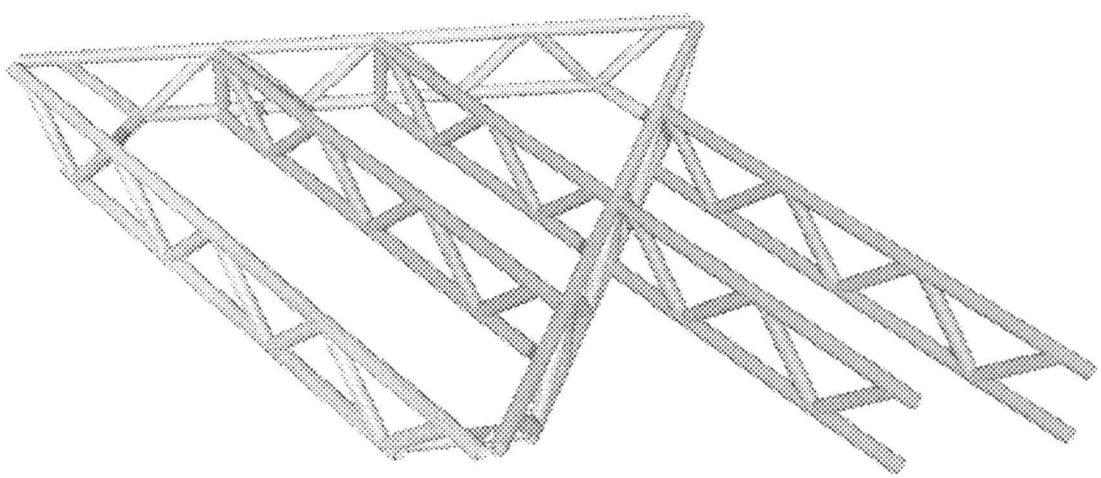

Figure 3.15: Combination #37

3.5.3.3 DRAO #1

This is an idea of combining the two combinations above. The three linear plane trusses are independent from each other and are not linked rigidly. The mid-spans of the linear trusses is experiencing large deflection. The cantilever truss elements are the places where the displacement is at the maximum. Since the trusses are not braced laterally, they tend to buckle out of the plane of loads. Six members are connected at the top chord of the main linear truss.

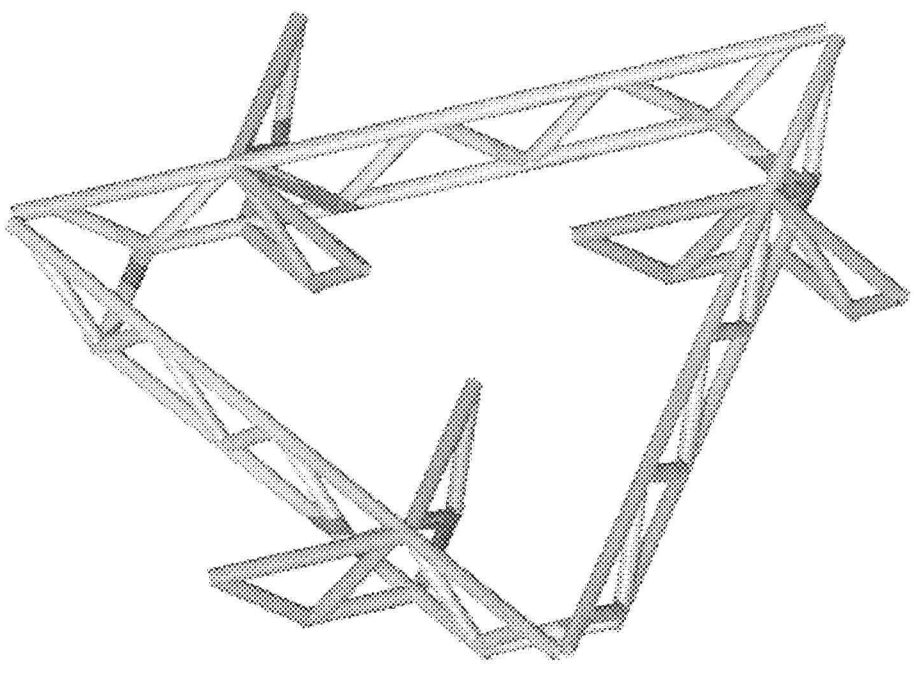

Figure 3.16: DRAO #1

3.5.3.4 Bridging System

The bridging system is similar to Combination #31 but instead of using cantilever trusses, a pair of parallel trusses is used as a bridge connecting two triangular modules. From the analysis on Combo #37, it is clear that a plane truss is not a rigid structure alone; therefore, a modified bridging space truss is introduced. The most complex connection for this configuration is at the place where the space truss is connected to the bridging trusses. The maximum member need to be connected can be reduced to eight if vertical webs are removed.

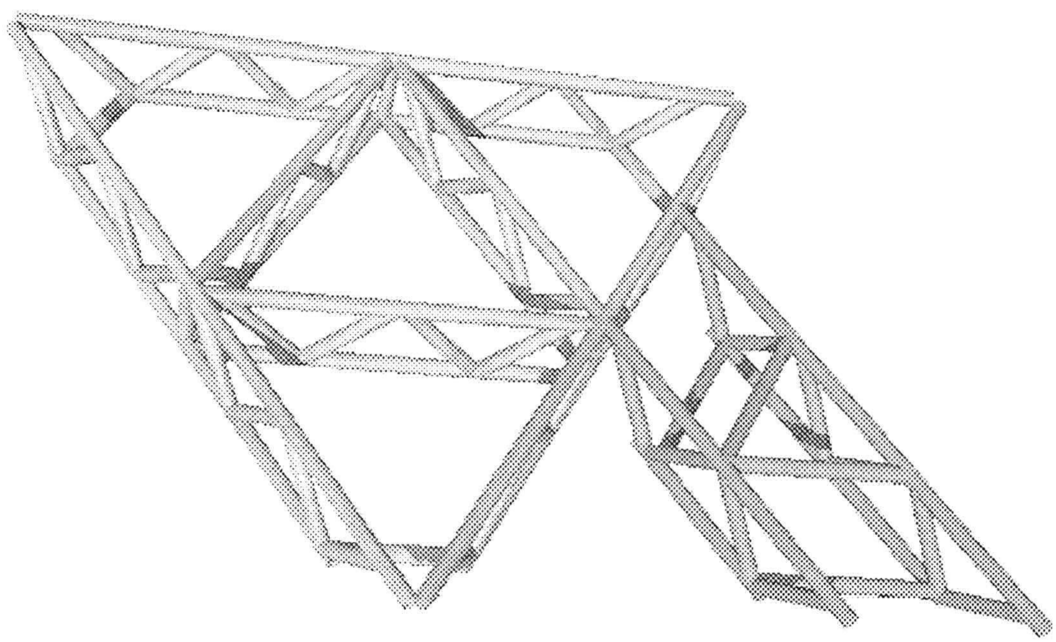

Figure 3.17: Bridging System

3.6 SUMMARY OF MAIN SUPPORT STRUCTURE DESIGNS

Various geometric configurations were laid out for the main backing structure. All of the alternate designs are lighter than the preliminary design. Four configurations were analyses separately by using FEM models. The static analysis results of combination #31, #37, DRAO#1, and Bridging system are presented in Appendix E.

When the four combinations were not tilted and only the self-weight (space truss + panel weight) was encountered, the maximum dead load deflections were less than 30mm. Since the backing structures will be adjusted continuously when tracking the radio source, static analysis was also performed on these combinations with arbitrary angles up to 11 degrees. The tilt angles used were -11° about the x-axis (positive towards z-axis) and +6° about the y-axis (positive toward x-axis). The results are presented in the following table.

	Preliminary Design	Combo #31	Combo #37	DRAO #1	Bridging System
Plane (mm)	16.5	21.9	22.7	25.6	20.7
Tilt (mm)	16.0	48.0	70.0	381.7	30.6
Weight per unit (kN)	368.0	417.6	463.5	401.4	430.5
Units required	165	95	95	95	95

Table 3.7: Comparison of static analysis results

Generally speaking, the centers of gravity of the main support structure and the reflector panels shift when the space frame is tilted. The shifting of the center of gravity will introduce a secondary moment to some of the structure members depending on the configuration geometry, so the displacements for the tilt situation is generally greater.

By comparing the four combinations, DRAO #1 was the lightest and combo #31 was the heaviest with a difference of ~20kN. The results also show that the performance the Bridging system is much stiffer than Combo #37 and DRAO #1. To select between Combo #31 and the Bridging System, one should not only compare the weight and performance of the structure. Even though the Bridging System is slightly stiffer than Combo #31, one the ideal design considerations is that the space frame structure should be light to save the material cost especially when a large quantity of space frame structure is required for the LAR. However, field labor cost for welding on site is another factor to consider when selecting a feasible space frame configuration. For Combo #31, up to nine member are connected together at one connection point. Comparing to Combo #31, the Bridging system will have seven members connected at the mid-span of the main space trusses. In summary, the Bridging System is more feasible than the other combinations for forming the LAR main support structure.

3.7 WELD DESIGN

Welding costs are sensitive to joint geometry, weld type, and weld size. Joint configurations are increasingly expensive progressing from gap to complete overlap to partial overlap. Gap joints have the advantage of a single bevel cut and complete ease of fitting. Partial overlap joints have double cuts with minimum flexibility in fitting especially if both ends are partial overlaps. Circular HSS do not have large minimum gaps as a function of relative member widths; this makes it possible to employ small gaps as a function of web member wall thickness (Packer and Henderson 1997).

Usually, gap connections (for K or N situations) are preferred to overlap connections because the members are easier to prepare, fit and weld. When overlap connections are used, at least a quarter of the height (dimension hi in the plane of the truss) of the overlapping member needs to be engaged in the overlap. An angle of less than 30 between a web member and a chord creates significant welding difficulties, and is not covered by the scope of these recommendations.

Connection Resistance Calculation

The factored resistance of axially loaded welded connections between circular hollow structure sections are calculated based on two failure criterions: chord plastification and punching shear. The connection resistance is calculated for Truss Design #1, as an example, and presented in Appendix F. Because of its geometry, the connection used for Truss Design #1 is K-gap connection. The equations for calculating the factored resistance based on chord plastification are shown below (Packer and Henderson 1997).

$$N_1^* = \frac{F_{y0} * t_0^2}{\sin\theta_1}\left(1.8 + 10.2\frac{d_1}{d_0}\right) f(\gamma, g') f(n') \tag{3.3}$$

$$N_2^* = N_1 \frac{\sin\theta_1}{\sin\theta_2} \tag{3.4}$$

$$\gamma = \frac{d_0}{2t_0} \tag{3.5}$$

$$g' = \frac{g}{t_0} \tag{3.6}$$

$$f(\gamma, g') = \gamma^{0.2}\left(1 + \frac{0.024\gamma^{1.2}}{\exp(0.5g' - 1.33) + 1}\right) \tag{3.7}$$

Where F_{y0} is the yield strength of the chord member

d_0 and t_0 are the diameter and thickness of the chord respectively.

θ_1 is the angle between the chord and the compression web.

θ_2 is the angle between the chord and the tension web.

g is the gap between two webs.

To check for punching shear, the following equation is applicable for all types of connections.

$$N_i^* = \frac{F_{y0}}{\sqrt{3}} t_0 \pi d_i \left(\frac{1+\sin\theta_i}{2\sin^2\theta_i} \right) \tag{3.8}$$

The index i =1 for compression web member, and i =2 for tension web members. HSS 164x4.8 is selected for chords and HSS 89x3.8 is used for webs.

The sample hand calculations and a formatted spreadsheet printout are included in Appendix F. If the angle between chords and webs is smaller than 30 degrees, the equations above are no longer valid.

4 FINAL CONFIGURATION OF THE REFLECTOR

4.1 STRUCTURAL COMPONENTS

Major structural components of the reflector are foundations, actuators (primary and secondary), main support structures, and reflector panels. A briefly description of each structural component is included in the following sections.

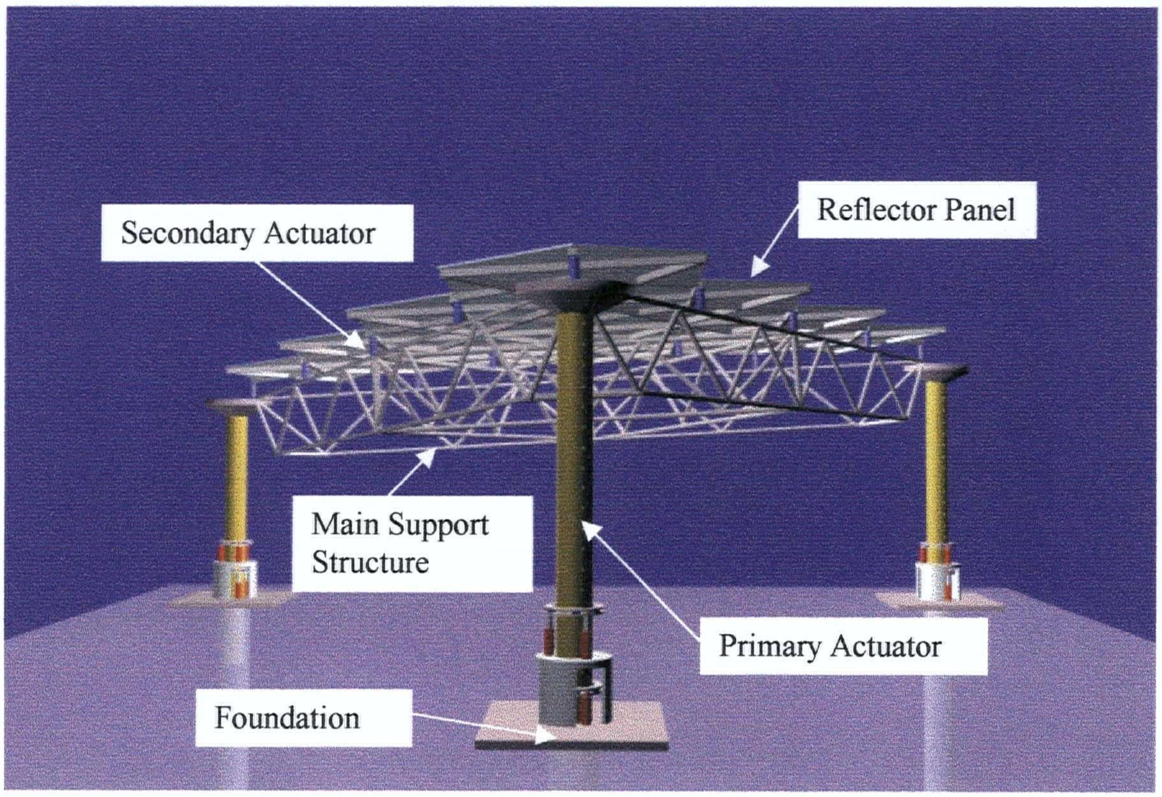

Figure 4.1: Structural components.

4.1.1 Foundation

The primary actuators exert mainly high compressive forces combined with small bending moments due to the tilt of the main support structures; therefore, these foundations can be dealt easily and cost-effectively by applying concrete standard techniques.

4.1.2 Primary Actuator

Primary actuators are the linking between the foundations and the main support structures. Their main functions are configuring the shape of the reflector and supporting the main support structures. The primary actuators only move vertically; hence, any reflector surface stretch is achieved with shear and universal joints on the primary actuator crown. The shear forces will cause bending within the primary actuator and these moments need to be transferred to the foundations.

Larger throws are usually more complex to construct, associate with higher cost, and may take longer to activate. The type of actuators will depend on accuracy, feasibility, accessibility for maintenance, and the cost. Several possible types of actuators are considered for the LAR project which include water pontoon, Airstroke, and hydraulic actuation and are discussed separately below.

a) The water pontoon actuation is having several water ponds at desired radial distances from the center of the reflector. Stroke is provided by releasing water in and out of the water ponds. The advantages of this method are that water is inexpensive and the water pontoon is easy to construct. The disadvantage of this method is that water surface is exposed, so evaporation rate might influence the accuracy of movements. This method is not suitable for the LAR project because for the required stroke of 8 m, it requires a great amount of water for the system.

a) The Airstroke idea is using air springs for actuation. These air springs are rubber/fabric flexible bellows which contains a column of compressed air. A single air spring can provide up to 22.5kN of linear force and a stroke up to 35cm. Also, it is permissible to stack Airstrokes to increase stroke. The actuation fluid may be filled with liquid or gas. The advantage of Airstroke is that air is readily available. The disadvantage of Airstroke is that air is fairly sensitive to temperature changes so the accuracy might be affected. In addition, there might be a damping/ resonance problem. Besides, this is a new technology introducing to the telescope design.

b) Hydraulic actuation is similar to air actuation but it uses water as the actuation media but water is used instead of air. Hydraulic actuation is a proven technology and it is commercial available. These hydraulic actuators will be contained in telescoping cylinders. The cost is about $70,000 per cylinder. If use hydraulic actuators at every supporting location, 240 cylinders will be required for the proposed geometric layout.

One problem occurs when analyzing the structure: the total radial stretch is about 60 cm. For 21 m grid, the radial stretch (max. stretch $\approx$ 26 cm) and tangential stretch (max.

stretch $\approx$ 16 cm) are too large to be compensated if using vertical actuators. Possible solutions for this problem are 1) using smaller grid sizes to average out the stretch per triangular unit; however, the number of primary actuators required increases, and 2) using sloping actuators.

By using smaller grid size (to about 9 m), the amount of stretch per triangular unit is negligible. However, the number of primary actuators increases dramatically. On the other hand, if use sloping actuators moving in the desirable direction (from 1 degree up to 5 degrees depending on the location), the amount of radial stretch per triangular unit is reduced from 260 mm to about 70mm. However, one challenge arises with sloping actuators: telescoping cylinders cannot take lateral loads. To solve this problem, we proposed three solutions:

1. Build a support structure and let the cylinder resting on the top of the structure. The actuators in sliding along the structure in the pre-determined direction.
2. Use pistons inside the cylinders to take the moments.
3. Pinned both the top and bottom of the cylinder so that the cylinders take only axial loads.

The innovative design of the primary actuators is using a jacking system as shown in Figure 4.1. The arrangement of the jacking system allows the use of sturdy pipe columns with minimum manufacturing cost. The sequence of jack movement is as follows: when the lower pins are engaged, the lower jacks start to extend. Meanwhile, the upper pins immediately extract and upper jacks retract bringing upper ring down. Then upper pins are engaged in next set of slotted holes. Upper jacks then extend at double the average raising velocity and start carrying load. At the same time, the lower jacks contract at the raising velocity. At the end of the stroke the lower pins are again set and the cycle is repeated continuously to raise the actuator.

4.1.3 Main Support Structure

The main support structure supports the secondary actuators and the reflector panels. The elevations and angles of the main support structures are adjusted continuously by controlling the movement of primary actuators to fit the paraboloid of revolution. Each main support structure is a space frame, which is formed with linear trusses and sub-structures. The linear trusses and the sub-structures are connected rigidly through welding. The design optimization was discussed in Chapter 3.

4.1.4 Secondary Actuator

Secondary actuators are required for compensating inaccuracy of the primary actuation system. These actuators also provide supports for reflector panels and are shared by adjacent panels. The number of secondary actuators depends mainly on the number of reflector panels. Since the required strokes for secondary actuators are much less than that for the primary actuators, commercial products of electrical/ mechanical actuators can be used. Two types of actuators are considered: ball screw actuators and ACME screw actuators. Rubber bearings can be used to connection this structural component to reflector panels.

4.1.5 Reflector Panel

Reflector panels make up the reflecting surface of the telescope. The requirements for the reflector panels are that they are inexpensive, easy to construct, and stiff enough to meet the surface accuracy requirements. Different types of constructions and materials are investigated in order to minimize the overall manufacturing cost and to attain the required high precision collecting surface. Hexagonal panel is chosen for it has larger area than a triangular panel and it requires one less support than a rectangular panel. Each panel is support by three secondary actuators at alternate corners. The preliminary design of the reflector panel has a flat-to-flat distance of 5.25m. A possible construction technique is to use steel-fiber reinforced concrete with an embedded steel frame (Kürschner 1999).

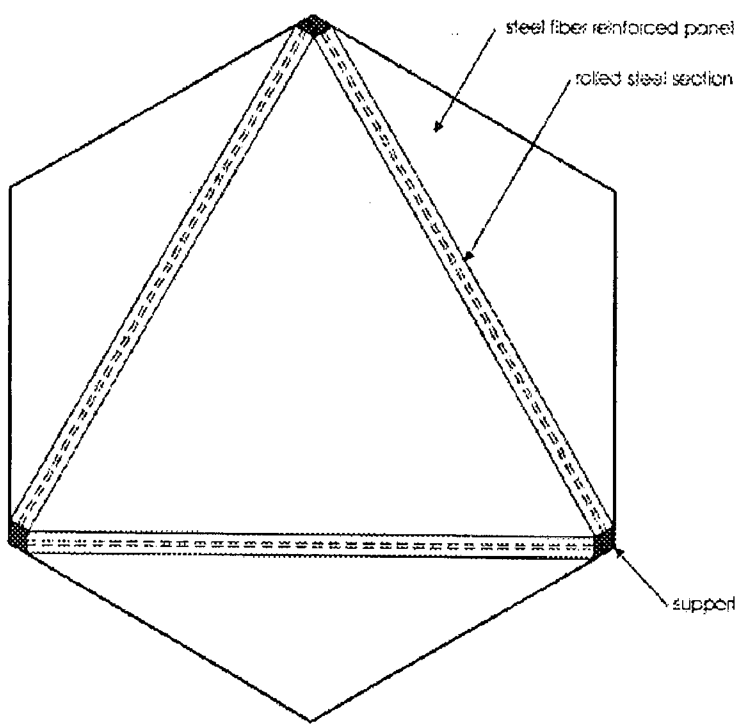

Figure 4.2: A hexagonal panel.

A possible arrangement of a LAR is shown in Figure 2.8. This picture shows the radio signals come in to the reflector at different angles. These signals are reflected by the reflector panels to the focal receiver, which is lifted by a helium-filled aerostat.

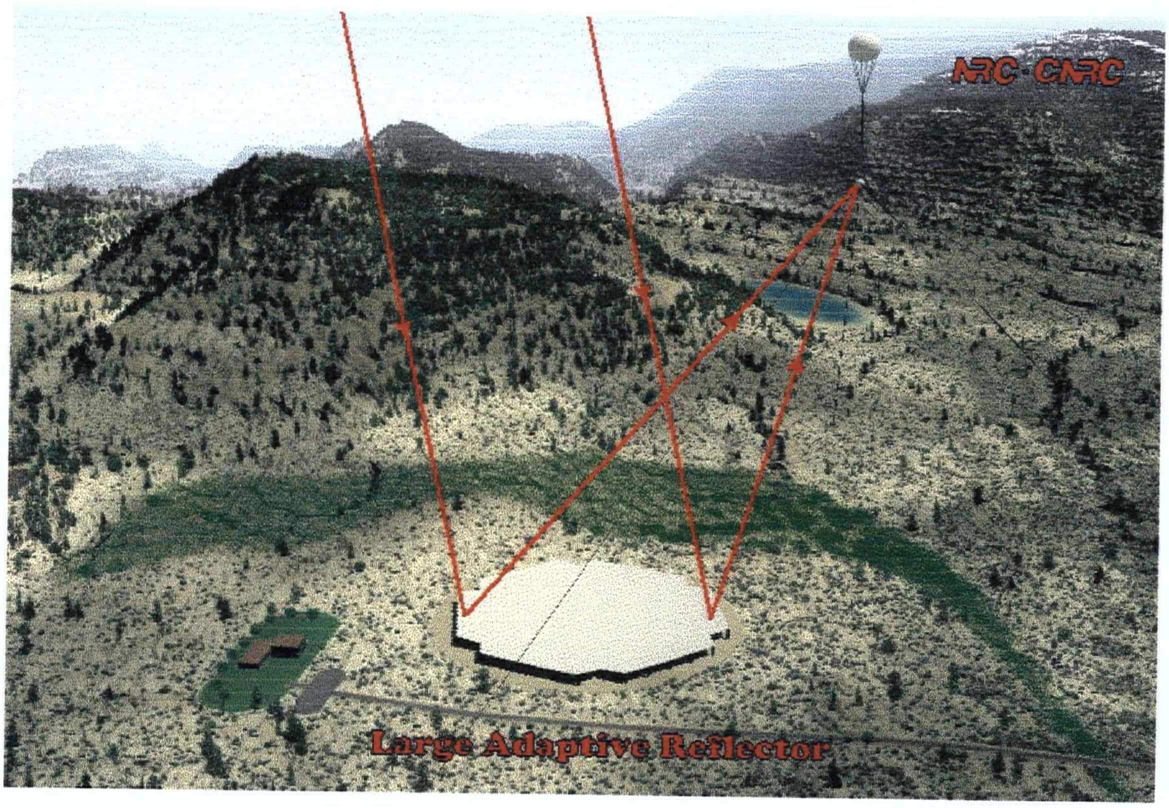

Figure 4.3: Large Adaptive Reflector

4.2 CLOSURE OF THE REFLECTOR

After selecting the most cost-effective configuration for the main support structure, it is important to layout the combination on the proposed main support structure grid to form the entire reflector. It is noted that the number of triangular units around a circumference is an odd number. If the main support structures are used in a pair, it requires an even number of triangular modulus around a circumference. If one of the combinations is used for the main support structure, the pair of choice will not be able to close up and form the entire reflector. Special designs are required for Geometric Layout #1, #2 and #4 (see Chapter 3). An example of using four different space frame structures to form the entire reflector is shown in Figure 4.4. This form is based on using the Bridging System discussed in Section 3.5.3.4. To fill all of the triangular units, two other space frame configurations other than the proposed Bridging System are needed.

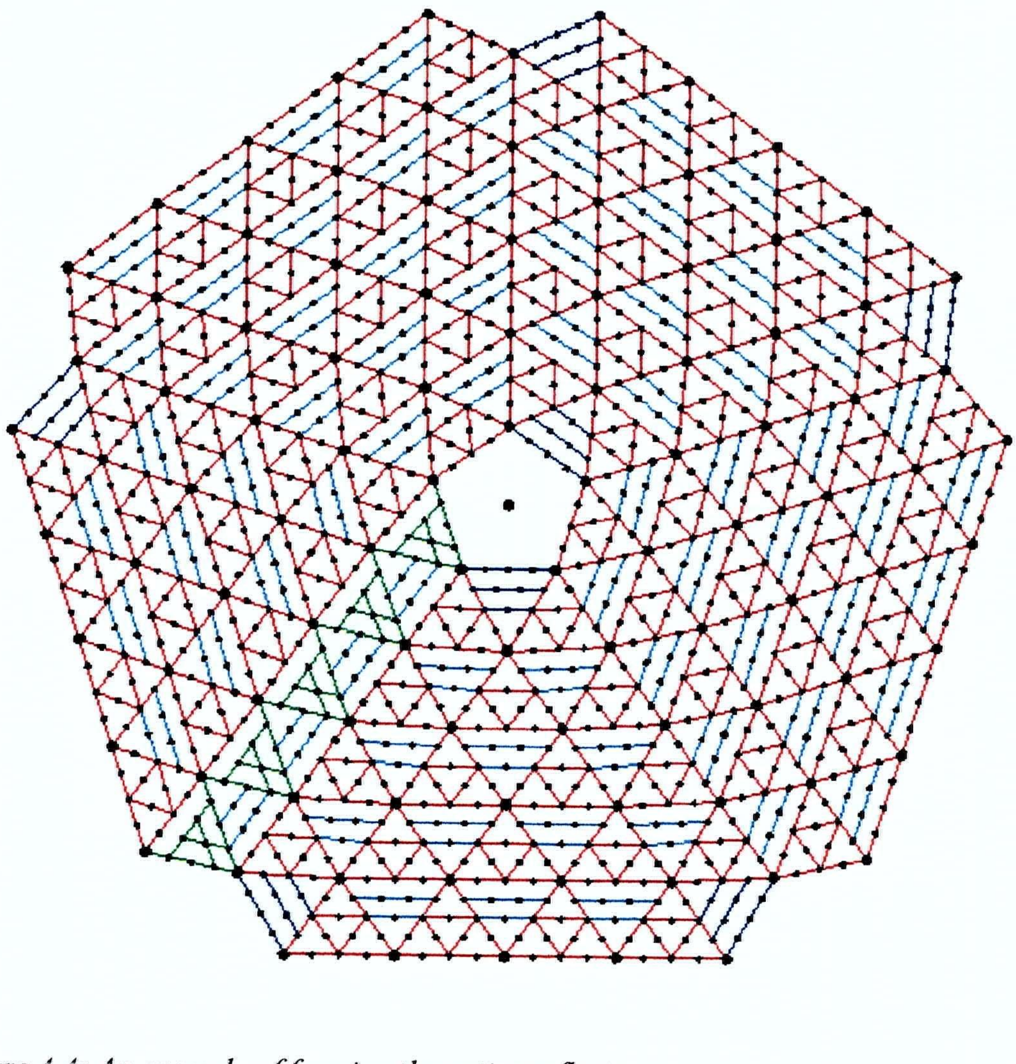

Figure 4.4: An example of forming the entire reflector.

5 CONCLUSION AND RECOMMENDATIONS

Numerous Geometric Layouts were proposed for the Large Adaptive Reflector. Geometric Layout #1, which used three different triangle types, requires the least number of primary actuators when comparing to the other three Geometric Layouts. To form the entire reflector structure, if a 21m-grid size of Geometric Layout #1 is used, it requires 101 primary actuators and 165 triangular units. Thirteen different reflector panel types are needed for Geometric Layout #1. The number of secondary actuators is independent from the design of main support structure, but the grid size and reflector panel size control the number of secondary actuators.

Triangular space frames form the main support structure. Three different linear truss designs were evaluated to optimize the design for space frame structure. As discussed in section 3.3.5, Truss Design #1 is superior than the other three designs because of its simplified design of weld connections. Thirteen K-gap connections will be used.

The original design of the space frame was estimated to be $6.6 million. This cost is composed by material cost and field labor cost. The optimization of this structural component was done through minimizing the amount of steel used in the construction and reducing the number of connections. For the various space frame configurations, the Bridging System is the most promising design. The maximum dead load displacement is 20.7mm (compared to 16.5mm for the original design) when the system is placed in elevation, and the maximum displacement is increased to 30.6mm (compared to 16.0mm for the original design) when it is tilted at the maximum tilt angle of 11 degrees in the radial direction and 6 degrees in the tangential direction. The weight of the Bridging System, including self-weight of the space frame and weight of reflector panels, is ~ 431kN. Even though the weigh of the Bridging System is heavier than the preliminary design, the number of space frame structures required is reduced by a factor of 1.7. In summary, the Bridging System is a feasible solution for the space frame structure for the LAR. The design can still be optimized by examining the trade-offs between structural member dimensions and the deflections of the structure. For example, as the diameter and thickness of the chords decreases, the moment of inertia of the space frame decreases and this leads to a significant increase in deflection of the structure. The increase in deflection would result in an increase stroke for the secondary actuators.

Since the bridging trusses are spanning over two space frames, they are actually 'floating' on top of these two space frames. The orientation and position of the bridging trusses are mainly depend on the bridged space frames. Although rubber bearing may be used for connecting the two structural elements (the main space truss and the bridging trusses) of the Bridging System, detail design of the connection is required to check the adequacy of rubber bearing connections if this configuration is selected as the main support structure.

Another aspect should put into consideration is the fact that the reflector surface changes its shape when tracking radio signals. As the zenith angle increases, the reflector is actually "closing up." Further studies on the behavior of the reflector are needed to approach the problem of stretching and contraction of space frame structures.

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APPENDIX A: TRUSS DESIGN CALCULATION

FORMATEED SPREADSHEET PRINTOUT OF TRUSS DESIGNS

	PROJECT	LAR	SECTION	1
	TITLE	Truss Design #1: Member Forces	DATE	3/02/00
	FILE	Truss_1.xls	TIME	10:51 AM

Case 1: Typical Warren Truss

INPUT						
Dead load	DL	=			-40	kN
Total length (=span)	L	=			21	m
Unit length	U_L	=			5.25	m
Unit depth	U_d	=			1.8	m
Modulus of elasticity	E	=			200000	Mpa
Angle btw chord & web	□	=	atan(U_d/(U_L/2))	=	0.6	rad
reactions	RF	=	-DL*(L/UL+2)/2	=	120.0	kN
web length	w_L	=	sqrt(U_d^2+(U_L/2)^2)	=	3.2	m
MEMBER FORCES						
	Faf	=	(DL+RF)/sin(θ)	=	141.5	kN
	Fab	=	Faf*COS(θ)*-1	=	-116.7	kN
	Fbf	=	Faf*-1	=	-141.5	kN
	Ffg	=	Faf*COS(θ)-Fbf*cos(θ)	=	233.3	kN
	Fbg	=	DL/sin(θ)-Fbf	=	70.7	kN
	Fbc	=	Fab+(Fbf-Fbg)*cos(θ)	=	-291.7	kN
	Fcg	=	Fbg*-1	=	-70.7	kN
	Fgh	=	Ffg+(Fbg-Fcg)*cos(θ)	=	350.0	kN
	Fch	=	2*DL/sin(θ)-Fcg	=	-70.7	kN
	Fcd	=	Fbc+(Fcg-Fch)*cos(θ)	=	-291.7	kN
FORCE SUMMARY						
Max. tension force	MaxF	=	max(Faf,Fab,Fbf,Ffg,Fbg,Fbc,Fcg,Fgh,Fch,Fcd)	=	350.0	kN
Max.comp. force	MinF	=	min(Faf,Fab,Fbf,Ffg,Fbg,Fbc,Fcg,Fgh,Fch,Fcd)	=	-291.7	kN
chord length required	lenc	=	7*U_L	=	36.8	m
web length required	lenw	=	8*w_L	=	25.5	m
effective length (chord)	KLc	=	0.9*U_L*1000	=	4725	mm
effective length (web)	KLw	=	0.75*w_L*1000	=	2387	mm
PRELIMINARY SELECTION						
Chord						
Max. tension force	MTFc	=	max(Fab,Ffg,Fbc,Fcg,Fgh,Fcd)	=	350.0	kN
Max.comp. force	MCFc	=	min(Fab,Ffg,Fbc,Fcg,Fgh,Fcd)	=	-291.7	kN
required area	Ac	=	MTFc*1000/(0.9*Fy)	=	1111.1	mm^2
Web						
Max. tension force	MTFw	=	max(Faf,Fbf,Fbg,Fcg,Fch)	=	141.5	kN
Max.comp. force	MCFw	=	min(Faf,Fbf,Fbg,Fcg,Fch)	=	-141.5	kN
required area	Aw	=	MTFw*1000/(0.9*Fy)	=	449.1	mm^2
yield strength	Fy	=			350.0	Mpa

Note: Positive in tension; negative in compression

	PROJECT	Large Adaptive Reflector	SECTION	1
	TITLE	Plane Truss Design #2: Member Forces	DATE	3/13/00
	FILE	Truss_2.xls	TIME	10:18 AM

Case 2: Pratt Truss

INPUT						
Dead load	DL	=			-40	[kN]
Total length (=span)	L	=			21	[m]
Unit length	U_L	=			5.25	[m]
Unit depth	U_d	=			1.8	[m]
Modulus of elasticity	E	=			200000	[Mpa]
Angle btw chord & web	□	=	atan(U_d/U_L)	=	0.33	[rad]
reactions	RF	=	-DL*(L/U_L+2)/2	=	120.0	[kN]
web length	w_L	=	sqrt(U_d^2+(U_L/2)^2)	=	3.2	[m]
MEMBER FORCES						
	F_{af}	=	(DL+RF)/sin(θ)	=	246.7	[kN]
	F_{ab}	=	Faf*cos(θ)*-1	=	-233.3	[kN]
	F_{bf}	=	Faf*sin(θ)*-1	=	-80.0	[kN]
	F_{bc}	=	F_{ab}-F_{bg}*cos(θ)	=	-350.0	[kN]
	F_{bg}	=	(DL-F_{bf})/sin(θ)	=	123.3	[kN]
	F_{fg}	=	Faf*cos(θ)	=	233.3	[kN]
	F_{cg}	=	2*DL	=	-80.0	[kN]
FORCE SUMMARY						
Max. tension force	MaxF	=	max(Faf,Fab,Fbf,Fbc,Fbg,Ffg,Fcg)	=	246.7	[kN]
Max.compression force	MinF	=	min(Faf,Fab,Fbf,Fbc,Fbg,Ffg,Fcg)	=	-350.0	[kN]
Length of the chords	L_c	=	6*U_L	=	31.5	[m]
Length of the webs	L_w	=	4*w_L+3*U_d	=	18.1	[m]
equivalent length required	Mlen	=	L_c+L_w	=	49.6	[m]
Preliminary Selection						
Yield stress	F_y	=			350.0	[Mpa]
(1) Top Compression Chord						
max. compression force	MCF	=	min(Fab,Fbc)	=	-350.0	[kN]
	KL_{tc}	=	0.9*U_L*10^3	=	4725	[mm]
(2) Bottom Tension Chord						
max. tension force	MTF	=	MAX(Ffg)	=	233.3	[kN]
	KL_{bc}	=	0.9*w_L*10^3	=	2865	[mm]
required area	A_{bc}	=	MTF/(0.9*F_y)*10^3	=	741	[mm^2]
(3) Web						
max. tension force	MTF_w	=	Max(Faf,Fbf,Fbg,Fcg)	=	246.7	[kN]
max. compression force	MCF_w	=	Min(Faf,Fbf,Fbg,Fcg)	=	-80.0	[kN]
effective length (diag.)	KL_w	=	0.75*w_L*10^3	=	2387.1	[mm]
required area	A_w	=	MTF_w/(0.9*F_y)*10^3	=	783.1	[mm^2]
effective length (vert.)	KL_{v1}	=	0.75*2*U_d*10^3	=	2700.0	[mm]
effective length (vert..)	KL_{v2}	=	0.75*U_d*10^3	=	1350.0	[mm]

Note: Positive in tension; negative in compression

	PROJECT	Large Adaptive Reflector	SECTION	1
	TITLE	Plane Truss Design #3: Member Forces	DATE	3/21/00
	FILE	Truss_3.xls	TIME	12:05 PM

Case 3: Modified Pratt Truss

INPUT						
Dead load	DL	=			-40	[kN]
Total length (=span)	L	=			21	[m]
Unit length	U_L	=			5.25	[m]
Unit depth	U_d	=			0.9	[m]
Modulus of elasticity	E	=			200000	[Mpa]
Angle btw chord & web	□	=	$atan(U_d/U_L)$	=	0.17	[rad]
reactions	RF	=	$-DL*(L/U_L+2)/2$	=	120.0	[kN]
web length	w_L	=	$sqrt(U_d\verb|^|2+(U_L/2)\verb|^|2)$	=	2.8	[m]
MEMBER FORCES						
	F_{af}	=	(DL+RF)/sin(θ)	=	473.5	[kN]
	F_{ab}	=	Faf*cos(θ)*-1	=	-466.7	[kN]
	F_{bf}	=	DL	=	-40.0	[kN]
	F_{bc}	=	F_{ab}	=	-466.7	[kN]
	F_{fg}	=	F_{bf}/SIN(θ)/2+F_{af}	=	355.1	[kN]
	F_{cf}	=	0.5*F_{bf}/SIN(θ)*-1	=	118.4	[kN]
	F_{gh}	=	F_{fg}	=	355.1	[kN]
	F_{ch}	=	F_{cf}	=	118.4	[kN]
	F_{cg}	=	2*DL-(F_{ch}+F_{cf})*sin(θ)	=	-120.0	[kN]
	F_{cd}	=	F_{bc}+(F_{cf}-F_{ch})*cos(θ)	=	-466.7	[kN]
FORCE SUMMARY						
Max. tension force	MaxF	=	max(Faf,Fab,Fbf,Fbc,Ffh,Fcf,Fgh,Fch,Fcg,Fcd)	=	473.5	[kN]
Max.compression force	MinF	=	min(Faf,Fab,Fbf,Fbc,Ffh,Fcf,Fgh,Fch,Fcg,Fcd)	=	-466.7	[kN]
Length of the chords	L_c	=	$4*U_L+4*w_L$	=	32.1	[m]
Length of the webs	L_w	=	$2*w_L+4*U_d$	=	9.2	[m]
equivalent length required	Mlen	=	L_c+L_w	=	41.3	[m]
Preliminary Selection						
Yield stress	F_y	=			350.0	[Mpa]
(1) Top Compression Chord						
max. compression force	MCF	=	min(Fab,Fbc,Fcd)	=	-466.7	[kN]
	KL_{tc}	=	$0.9*U_L*10\verb|^|3$	=	4725	[mm]
(2) Bottom Tension Chord						
max. tension force	MTF	=	MAX(Faf,Ffh,Fgh)	=	473.5	[kN]
	KL_{bc}	=	$0.9*w_L*10\verb|^|3$	=	2497.5	[mm]
required area	A_{bc}	=	$MTF/(0.9*F_y)*10\verb|^|3$	=	1503.1	[mm²]
(3) Web						
max. tension force	MTF_w	=	Max(Fbf,Fcf,Fcg,Fch)	=	118.4	[kN]
max. compression force	MCF_w	=	Min(Fbf,Fcf,Fcg,Fch)	=	-120.0	[kN]
effective length (diag.)	KL_w	=	$0.75*w_L*10\verb|^|3$	=	2081.3	[mm]
required area	A_w	=	$MTF_w/(0.9*F_y)*10\verb|^|3$	=	375.8	[mm²]
effective length (vert.)	KL_{v1}	=	$0.75*2*U_d*10\verb|^|3$	=	1350.0	[mm]
effective length (vert..)	KL_{v2}	=	$0.75*U_d*10\verb|^|3$	=	675.0	[mm]

Note: Positive in tension; negative in compression

PROJECT	LAR	SECTION	1
TITLE	Truss Design #4: Member Forces	DATE	3/21/00
FILE	Truss_4.xls	TIME	12:07 PM

Case 4: Modified Warren Truss

INPUT						
Dead load	DL	=			-40	kN
Total length (=span)	L	=			21	m
Unit length	U_L	=			5.25	m
Unit depth	U_d	=			1.8	m
Modulus of elasticity	E	=			200000	Mpa
Angle btw chord & web	□	=	$atan(U_d/U_L)$	=	0.330	rad
reactions	RF	=	$-DL*(L/U_L+2)/2$	=	120.0	kN
web length	w_L	=	$sqrt(U_d\char`^2+U_L\char`^2)$	=	5.55	m
MEMBER FORCES						
	F_{af}	=	$(DL+RF)/sin(\theta)$	=	246.7	kN
	F_{ab}	=	$-F_{af}*cos(\theta)$	=	-233.3	kN
	F_{bc}	=	F_{ab}	=	-233.3	kN
	F_{bf}	=	DL	=	-40.0	kN
	F_{cf}	=	$-F_{bf}/sin(\theta)-F_{af}$	=	-123.3	kN
	F_{fg}	=	$(F_{af}-F_{cf})*cos(\theta)$	=	350.0	kN
	F_{cg}	=	$(-F_{cd}+F_{bc})/cos(\theta)+F_{cf}$	=	-123.3	kN
	F_{cd}	=	F_{de}	=	-233.3	kN
	F_{dg}	=	DL	=	-40.0	kN
	F_{de}	=	$-F_{eg}*cos(\theta)$	=	-233.3	kN
	F_{eg}	=	$(DL+RF)/sin(\theta)$	=	246.7	kN
FORCE SUMMARY						
Max. tension force	MaxF	=	max(Faf,Fab,Fbc,Fbf,Fcf,Ffg,Fcg,Fcd)	=	350.0	kN
Max.compression force	MinF	=	min(Faf,Fab,Fbc,Fbf,Fcf,Ffg,Fcg,Fcd)	=	-233.3	kN
equivalent length required	Mlen	=	$6*U_L+4*w_L+2*U_d$	=	57.3	m
equivalent length required	lenc	=	$6*U_L$	=	31.5	m
equivalent length required	lenw	=	$4*w_L+2*U_d$	=	25.8	m
PRELIMINARY SELECTION						
Yield strength	F_y	=			350	Mpa
(1) Top Chord (Compression)						
max. comp. Force	M_{CF}	=	min(Fab,Fbc,Fcd,Fde,Ffg)	=	-233.3	kN
	KL_{ct}	=	$0.9*U_L*1000$	=	4725	mm
(2) Bottom Chord (Tension)						
max. tesion. Force	M_{TF}	=	max(Fab,Fbc,Fcd,Fde,Ffg)	=	350.0	kN
required area	A_{cb}	=	$M_{TF}/(0.9*F_y)*10\char`^3$	=	1111.1	mm^2
slendemess ratio	SR	=			300.0	
effecitve length	KL_{bc}	=	$U_L*2*1000$	=	10500	mm
required radius of gyration	r	=	KL_{bc}/SR	=	35.0	mm
(3) Web						
(i) Compression						
max. comp. Force	M_{WC}	=	Min(Faf,Fcf,Fcg,Feg)	=	-123.3	kN
	KL_{wc}	=	$0.75*w_L*10\char`^3$	=	4163	mm
(ii) Tension						
max. tesion. Force	M_{WT}	=	MAX(Faf,Fcf,Fcg,Feg)	=	246.7	kN
required area	A_w	=	$M_{WT}/(0.9*F_y)*10\char`^3$	=	783.1	mm^2
(iii) Vertical						
max. comp. Force	M_{WV}	=	if(min(Fbf,Fdg)<0,min(Fbf,Fdg),0)	=	-40.0	kN
	KL_{wv}	=	$0.75*U_d*10\char`^3$	=	1350	mm

Note: Positive in tension; negative in compression.

APPENDIX B: PRELIMINARY LOAD DEFLECTION CALCULATIONS

SPREADSHEET PRINTOUTS OF DEAD LOAD AND WIND LOAD DEFLECTIONS

LAR - DEAD LOAD AND DEFLECTIONS

Assumptions:

1. Material for the panel is lightweight concrete.
2. Assume that the panel thickness = 2 inches.

Lightweight Concrete= 16 psf

Max Unit Angle	Max Unit Angle	Triangular	Area per Triangular Unit (ft^2)					
			9	12	15	18	21	(m)
(rad)	(deg)	Unit Size	30	40	50	60	70	(ft)
1.26	72	Layout #1	414.6	737.1	1151.8	1658.6	2257.5	
1.26	72	Layout #2	414.6	737.1	1151.8	1658.6	2257.5	
1.05	60	Layout #3	377.6	671.2	1048.8	1510.3	2055.7	
1.47	84	Layout #4	433.6	770.8	1204.4	1734.4	2360.7	

Angle	Angle		Total Weight per Triangular Unit (lbs)					
(rad)	(deg)		30	40	50	60	70	(ft)
1.26	72	Layout #1	6634	11794	18429	26537	36120	
1.26	72	Layout #2	6634	11794	18429	26537	36120	
1.05	60	Layout #3	6041	10740	16781	24165	32891	
1.47	84	Layout #4	6937	12333	19271	27750	37771	

Angle	Angle		Weight Supported by Each Truss (lbs)*					
(rad)	(deg)		30	40	50	60	70	(ft)
1.26	72	Layout #1	2211	3931	6143	8846	12040	
1.26	72	Layout #2	2211	3931	6143	8846	12040	
1.05	60	Layout #3	2014	3580	5594	8055	10964	
1.47	84	Layout #4	2312	4111	6424	9250	12590	

Angle	Angle		Equivalent Uniformly Distributed Load (lbs/ft)					
(rad)	(deg)		30	40	50	60	70	(ft)
1.26	72	Layout #1	74.9	99.9	125	150	175	
1.26	72	Layout #2	74.9	99.9	125	150	175	
1.05	60	Layout #3	68.2	90.9	114	136	159	
1.47	84	Layout #4	78.3	104	131	157	183	

Angle	Angle	Triangular	Moment (lbs-ft)					
(rad)	(deg)	Unit Size	30	40	50	60	70	(ft)
1.26	72	Layout #1	8425	19971	39005	67401	107030	
1.26	72	Layout #2	8425	19971	39005	67401	107030	
1.05	60	Layout #3	7672	18185	35518	61375	97461	
1.47	84	Layout #4	8810	20883	40788	70481	111922	

Note:

- *Three trusses per triangular unit.
- Area per Triangular Unit Size:

$$Area = \frac{L^2}{2} * \sin(\max\ UnitAngle) * (3.281)^2$$

- Total Weight per Triangular Unit:

$$Weight = Area * 16 psf$$

- Equivalent Uniformly Distributed Load:

$$w_n = \frac{Weight}{3 * L}$$

- Moment:

$$Moment = \frac{w_n * L^2}{8}$$

where L is the triangular unit size.

THE LARGE ADAPTIVE REFLECTOR
PANEL WEIGHT AND THE WEIGHT OF THE BACKUP STRUCTURE

Elastic Modulus, E = 29000 ksi
Depth, h = 6 ft

Geometric Layout	Equivalent Uniformly Distributed Load (lbs/ft)				
	30	40	50	60	70
1 & 2	74.9	99.9	125	150	175
3	68.2	90.9	114	136	159
4	78.3	104	131	157	183

Top/ Bottom Chord:

Pipe Diameter	Wt per Pipe	Total Wt of Pipes	A	I	d = h/2	I+Ad^2
(in)	(lbs/ft)	(lbs/ft)	(in^2)	(in^4)	(in)	(in^4)
3	7.58	15.16	2.23	3.02	36	2893.1
3-1/2	9.11	18.22	2.68	4.79	36	3478.1
4	10.79	21.58	3.17	7.23	36	4115.6
5	14.62	29.24	4.30	15.2	36	5588.0
6	18.97	37.94	5.58	28.1	36	7259.8
8	28.55	57.1	8.40	72.5	36	10959
10	40.48	80.96	11.9	161	36	15583
12	49.56	99.12	14.6	279	36	19201

Web Pipe:
Pipe Spacing = 11.5 ft

Pipe Diameter	Wt of Pipe	Wall Thickness	I	Total Weight of Web Pipes (lbs/ft)				
				30	40	50	60	70
(in)	(lbs/ft)	(in)	(in^4)	(ft)	(ft)	(ft)	(ft)	(ft)
1-1/4	1.68	0.140	6708	3.10	2.93	2.83	2.76	2.72
1-1/2	2.27	0.145	6948	4.19	3.96	3.83	3.73	3.67
2	3.65	0.154	7379	6.74	6.37	6.15	6.01	5.90
2-1/2	5.79	0.203	9727	10.7	10.1	9.8	9.5	9.4
3	7.58	0.216	10350	14.0	13.2	12.8	12.5	12.3
3-1/2	9.11	0.226	10829	16.8	15.9	15.4	15.0	14.7
4	10.79	0.237	11356	19.9	18.8	18.2	17.8	17.4
5	14.62	0.258	12362	27.0	25.5	24.6	24.1	23.6
6	18.97	0.280	13416	35.0	33.1	32.0	31.2	30.7
8	28.55	0.322	15429	52.7	49.8	48.1	47.0	46.2

THE LARGE ADAPTIVE REFLECTOR
PANEL WEIGHT AND THE WEIGHT OF THE BACKUP STRUCTURE.
DEFLECTION DUE TO DEAD LOAD ONLY.
Elastic Modulus, E = 29000 ksi
Triangular Unit Size = 30 ft
Depth, h = 6 ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	1-1/4							1-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	9601	93.2	0.155	86.5	0.144	96.6	0.161	9841	94.2	0.153	87.5	0.146	97.7	0.162
3-1/2	10186	96.2	0.151	89.5	0.140	99.6	0.156	10426	97.3	0.149	90.6	0.142	100.7	0.158
4	10824	99.6	0.147	92.9	0.137	103.0	0.152	11063	100.7	0.145	94.0	0.139	104.1	0.153
5	12296	107.2	0.139	100.5	0.131	110.7	0.144	12536	108.3	0.138	101.6	0.132	111.7	0.145
6	13968	115.9	0.132	109.2	0.125	119.4	0.136	14208	117.0	0.131	110.3	0.126	120.4	0.138
8	17667	135.1	0.122	128.4	0.116	138.5	0.125	17907	136.2	0.121	129.5	0.117	139.6	0.126
10	22292	159.0	0.114	152.3	0.109	162.4	0.116	22531	160.0	0.113	153.3	0.110	163.5	0.117
12	25909	177.1	0.109	170.4	0.105	180.5	0.111	26148	178.2	0.109	171.5	0.106	181.6	0.112

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	10272	96.8	0.150	90.1	0.140	100.2	0.156	12620	100.7	0.127	94.0	0.119	104.2	0.132
3-1/2	10857	99.8	0.147	93.1	0.137	103.3	0.152	13205	103.8	0.125	97.1	0.117	107.2	0.130
4	11495	103.2	0.143	96.5	0.134	106.6	0.148	13842	107.2	0.124	100.5	0.116	110.6	0.128
5	12967	110.9	0.136	104.2	0.128	114.3	0.141	15315	114.8	0.120	108.1	0.113	118.2	0.123
6	14639	119.6	0.130	112.9	0.123	123.0	0.134	16987	123.5	0.116	116.8	0.110	126.9	0.119
8	18338	138.7	0.121	132.0	0.115	142.1	0.124	20686	142.7	0.110	136.0	0.105	146.1	0.113
10	22962	162.6	0.113	155.9	0.108	166.0	0.115	25310	166.5	0.105	159.8	0.101	170.0	0.107
12	26580	180.7	0.109	174.0	0.105	184.2	0.111	28928	184.7	0.102	178.0	0.098	188.1	0.104

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	13243	104.0	0.125	97.3	0.117	107.5	0.130	13243	106.9	0.129	100.2	0.121	110.3	0.133
3-1/2	13828	107.1	0.124	100.4	0.116	110.5	0.128	13828	109.9	0.127	103.2	0.119	113.3	0.131
4	14465	110.5	0.122	103.8	0.115	113.9	0.126	14465	113.3	0.125	106.6	0.118	116.7	0.129
5	15938	118.1	0.118	111.4	0.112	121.5	0.122	15938	120.9	0.121	114.2	0.114	124.4	0.125
6	17610	126.8	0.115	120.1	0.109	130.2	0.118	17610	129.6	0.118	122.9	0.111	133.1	0.121
8	21309	146.0	0.109	139.3	0.104	149.4	0.112	21309	148.8	0.111	142.1	0.106	152.2	0.114
10	25933	169.8	0.105	163.1	0.100	173.3	0.107	25933	172.7	0.106	166.0	0.102	176.1	0.108
12	29550	188.0	0.102	181.3	0.098	191.4	0.103	29550	190.8	0.103	184.1	0.099	194.2	0.105

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	15472	116.4	0.120	109.7	0.113	119.8	0.124	16478	123.4	0.120	116.8	0.113	126.9	0.123
5	16944	124.0	0.117	117.3	0.111	127.5	0.120	17950	131.1	0.117	124.4	0.111	134.5	0.120
6	18616	132.7	0.114	126.0	0.108	136.2	0.117	19622	139.8	0.114	133.1	0.108	143.2	0.117
8	22315	151.9	0.109	145.2	0.104	155.3	0.111	23321	159.0	0.109	152.3	0.104	162.4	0.111
10	26939	175.8	0.104	169.1	0.100	179.2	0.106	27946	182.8	0.104	176.1	0.101	186.3	0.106
12	30557	193.9	0.101	187.2	0.098	197.3	0.103	31563	201.0	0.102	194.3	0.098	204.4	0.103

Note:

- w1 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #1 & #2.
- w3 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #3.
- w4 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #4.
- Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
PANEL WEIGHT AND THE WEIGHT OF THE BACKUP STRUCTURE.
DEFLECTION DUE TO DEAD LOAD ONLY.

Elastic Modulus, E = 29000 ksi
Triangular Unit Size = 40 ft
Depth, h = 6 ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	1-1/4							1-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	9601	117.9	0.620	109.0	0.573	122.5	0.644	9841	119.0	0.610	110.0	0.578	123.5	0.649
3-1/2	10186	121.0	0.599	112.1	0.555	125.6	0.622	10426	122.0	0.591	113.1	0.560	126.6	0.627
4	10824	124.4	0.580	115.4	0.538	128.9	0.601	11063	125.4	0.572	116.5	0.543	130.0	0.606
5	12296	132.0	0.542	123.1	0.505	136.6	0.560	12536	133.1	0.535	124.1	0.509	137.6	0.565
6	13968	140.7	0.508	131.8	0.476	145.3	0.525	14208	141.8	0.503	132.8	0.480	146.3	0.528
8	17667	159.9	0.457	151.0	0.431	164.4	0.470	17907	160.9	0.453	152.0	0.434	165.5	0.473
10	22292	183.7	0.416	174.8	0.396	188.3	0.426	22531	184.8	0.414	175.8	0.398	189.3	0.429
12	25909	201.9	0.393	193.0	0.376	206.5	0.402	26148	202.9	0.392	194.0	0.378	207.5	0.404

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	10272	121.4	0.596	112.5	0.552	125.9	0.619	12620	125.1	0.500	116.2	0.464	129.7	0.518
3-1/2	10857	124.4	0.578	115.5	0.537	129.0	0.599	13205	128.2	0.490	119.3	0.456	132.7	0.507
4	11495	127.8	0.561	118.9	0.522	132.4	0.581	13842	131.5	0.479	122.6	0.447	136.1	0.496
5	12967	135.5	0.527	126.5	0.492	140.0	0.545	15315	139.2	0.459	130.3	0.429	143.8	0.474
6	14639	144.2	0.497	135.2	0.466	148.7	0.513	16987	147.9	0.439	139.0	0.413	152.5	0.453
8	18338	163.3	0.449	154.4	0.425	167.9	0.462	20686	167.1	0.407	158.1	0.386	171.6	0.419
10	22962	187.2	0.411	178.3	0.392	191.7	0.421	25310	190.9	0.381	182.0	0.363	195.5	0.390
12	26580	205.3	0.390	196.4	0.373	209.9	0.398	28928	209.1	0.365	200.2	0.349	213.6	0.373

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	13243	128.2	0.489	119.3	0.455	132.8	0.506	13243	130.9	0.499	122.0	0.465	135.5	0.516
3-1/2	13828	131.3	0.479	122.4	0.446	135.9	0.496	13828	134.0	0.489	125.0	0.456	138.5	0.505
4	14465	134.7	0.470	125.7	0.439	139.2	0.486	14465	137.3	0.479	128.4	0.448	141.9	0.495
5	15938	142.3	0.451	133.4	0.422	146.9	0.465	15938	145.0	0.459	136.1	0.431	149.6	0.473
6	17610	151.0	0.433	142.1	0.407	155.6	0.446	17610	153.7	0.440	144.8	0.415	158.3	0.453
8	21309	170.2	0.403	161.3	0.382	174.7	0.414	21309	172.9	0.409	163.9	0.388	177.4	0.420
10	25933	194.0	0.377	185.1	0.360	198.6	0.386	25933	196.7	0.383	187.8	0.365	201.3	0.392
12	29550	212.2	0.362	203.3	0.347	216.8	0.370	29550	214.9	0.367	205.9	0.352	219.4	0.375

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	15472	140.3	0.457	131.3	0.428	144.8	0.472	16478	146.9	0.450	138.0	0.423	151.5	0.464
5	16944	147.9	0.440	139.0	0.414	152.5	0.454	17950	154.6	0.435	145.7	0.409	159.2	0.447
6	18616	156.6	0.424	147.7	0.400	161.2	0.437	19622	163.3	0.420	154.4	0.397	167.9	0.432
8	22315	175.8	0.397	166.9	0.377	180.3	0.408	23321	182.5	0.395	173.5	0.375	187.0	0.405
10	26939	199.6	0.374	190.7	0.357	204.2	0.382	27946	206.3	0.372	197.4	0.356	210.9	0.381
12	30557	217.8	0.360	208.9	0.345	222.4	0.367	31563	224.5	0.359	215.6	0.345	229.1	0.366

Note:

- w1 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #1 & #2.
- w3 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #3.
- w4 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #4.
- Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
PANEL WEIGHT AND THE WEIGHT OF THE BACKUP STRUCTURE.
DEFLECTION DUE TO DEAD LOAD ONLY.

Elastic Modulus, E = 29000 ksi
Triangular Unit Size = 50 ft
Depth, h = 6 ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	10272	146.1	1.75	135.0	1.62	151.8	1.82	12620	149.7	1.46	138.6	1.35	155.4	1.52
3-1/2	10857	149.2	1.69	138.0	1.57	154.9	1.76	13205	152.8	1.43	141.6	1.32	158.5	1.48
4	11495	152.5	1.63	141.4	1.52	158.3	1.70	13842	156.2	1.39	145.0	1.29	161.9	1.44
5	12967	160.2	1.52	149.0	1.42	165.9	1.58	15315	163.8	1.32	152.7	1.23	169.5	1.36
6	14639	168.9	1.42	157.7	1.33	174.6	1.47	16987	172.5	1.25	161.4	1.17	178.2	1.29
8	18338	188.1	1.26	176.9	1.19	193.8	1.30	20686	191.7	1.14	180.5	1.075	197.4	1.18
10	22962	211.9	1.14	200.8	1.077	217.6	1.17	25310	215.5	1.049	204.4	0.995	221.2	1.077
12	26580	230.1	1.066	218.9	1.014	235.8	1.09	28928	233.7	0.995	222.5	0.948	239.4	1.019

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	13243	152.8	1.42	141.6	1.32	158.5	1.47	13243	155.3	1.44	144.2	1.34	161.0	1.50
3-1/2	13828	155.8	1.39	144.7	1.29	161.5	1.44	13828	158.4	1.41	147.2	1.31	164.1	1.46
4	14465	159.2	1.36	148.0	1.26	164.9	1.40	14465	161.7	1.38	150.6	1.28	167.5	1.43
5	15938	166.8	1.29	155.7	1.20	172.5	1.33	15938	169.4	1.31	158.3	1.22	175.1	1.35
6	17610	175.5	1.23	164.4	1.150	181.2	1.27	17610	178.1	1.25	167.0	1.17	183.8	1.29
8	21309	194.7	1.125	183.5	1.061	200.4	1.16	21309	197.3	1.14	186.1	1.076	203.0	1.17
10	25933	218.6	1.038	207.4	0.985	224.3	1.065	25933	221.1	1.050	210.0	0.997	226.8	1.077
12	29550	236.7	0.987	225.6	0.940	242.4	1.010	29550	239.3	0.997	228.1	0.951	245.0	1.021

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	15472	164.6	1.31	153.4	1.22	170.3	1.36	16478	171.0	1.28	159.9	1.195	176.7	1.32
5	16944	172.2	1.25	161.1	1.171	177.9	1.29	17950	178.7	1.23	167.5	1.150	184.4	1.27
6	18616	180.9	1.20	169.8	1.123	186.6	1.23	19622	187.4	1.176	176.2	1.106	193.1	1.21
8	22315	200.1	1.104	188.9	1.043	205.8	1.136	23321	206.6	1.091	195.4	1.032	212.3	1.121
10	26939	224.0	1.024	212.8	0.973	229.7	1.050	27946	230.4	1.016	219.3	0.966	236.1	1.041
12	30557	242.1	0.976	231.0	0.931	247.8	0.999	31563	248.6	0.970	237.4	0.926	254.3	0.992

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	6							8						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
6	20676	194.7	1.160	183.6	1.094	200.4	1.194	22689	210.9	1.145	199.7	1.084	216.6	1.176
8	24375	213.9	1.081	202.7	1.024	219.6	1.110	26388	230.0	1.074	218.9	1.022	235.7	1.100
10	29000	237.7	1.010	226.6	0.962	243.5	1.034	31012	253.9	1.008	242.7	0.964	259.6	1.031
12	32617	255.9	0.966	244.7	0.924	261.6	0.988	34630	272.1	0.968	260.9	0.928	277.8	0.988

Note:

- -w1 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #1 & #2.
- -w3 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #3.
- -w4 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #4.
- -Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
PANEL WEIGHT AND THE WEIGHT OF THE BACKUP STRUCTURE.
DEFLECTION DUE TO DEAD LOAD ONLY.

Elastic Modulus, E = 29000 ksi
Triangular Unit Size = 60 ft
Depth, h = 6 ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	10272	170.9	4.25	157.6	3.92	177.8	4.42	12620	174.5	3.53	161.1	3.26	181.3	3.67
3-1/2	10857	174.0	4.09	160.6	3.78	180.9	4.25	13205	177.5	3.43	164.1	3.17	184.4	3.57
4	11495	177.4	3.94	164.0	3.64	184.2	4.09	13842	180.9	3.34	167.5	3.09	187.7	3.46
5	12967	185.0	3.64	171.6	3.38	191.9	3.78	15315	188.5	3.14	175.2	2.92	195.4	3.26
6	14639	193.7	3.38	180.3	3.15	200.6	3.50	16987	197.2	2.97	183.9	2.76	204.1	3.07
8	18338	212.9	2.96	199.5	2.78	219.7	3.06	20686	216.4	2.67	203.0	2.51	223.3	2.76
10	22962	236.7	2.63	223.4	2.48	243.6	2.71	25310	240.3	2.42	226.9	2.29	247.1	2.49
12	26580	254.9	2.45	241.5	2.32	261.8	2.52	28928	258.4	2.28	245.0	2.16	265.3	2.34

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	13243	177.4	3.42	164.0	3.16	184.3	3.55	13243	179.9	3.47	166.5	3.21	186.8	3.60
3-1/2	13828	180.5	3.33	167.1	3.09	187.3	3.46	13828	183.0	3.38	169.6	3.13	189.8	3.51
4	14465	183.8	3.25	170.4	3.01	190.7	3.37	14465	186.3	3.29	173.0	3.05	193.2	3.41
5	15938	191.5	3.07	178.1	2.85	198.3	3.18	15938	194.0	3.11	180.6	2.89	200.9	3.22
6	17610	200.2	2.90	186.8	2.71	207.0	3.00	17610	202.7	2.94	189.3	2.75	209.6	3.04
8	21309	219.4	2.63	206.0	2.47	226.2	2.71	21309	221.9	2.66	208.5	2.50	228.7	2.74
10	25933	243.2	2.40	229.8	2.26	250.1	2.46	25933	245.7	2.42	232.3	2.29	252.6	2.49
12	29550	261.4	2.26	248.0	2.14	268.2	2.32	29550	263.9	2.28	250.5	2.165	270.7	2.34

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	15472	189.1	3.12	175.7	2.90	196.0	3.23	16478	195.4	3.03	182.0	2.82	202.3	3.13
5	16944	196.8	2.97	183.4	2.76	203.6	3.07	17950	203.1	2.89	189.7	2.70	209.9	2.99
6	18616	205.5	2.82	192.1	2.64	212.3	2.91	19622	211.8	2.76	198.4	2.58	218.6	2.85
8	22315	224.6	2.57	211.2	2.42	231.5	2.65	23321	230.9	2.53	217.5	2.38	237.8	2.60
10	26939	248.5	2.36	235.1	2.23	255.3	2.42	27946	254.8	2.33	241.4	2.21	261.6	2.39
12	30557	266.7	2.23	253.3	2.12	273.5	2.29	31563	273.0	2.21	259.6	2.10	279.8	2.26

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	6							8						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
6	20676	218.9	2.70	205.5	2.54	225.8	2.79	22689	234.7	2.64	221.3	2.49	241.5	2.72
8	24375	238.1	2.49	224.7	2.35	244.9	2.57	26388	253.9	2.46	240.5	2.33	260.7	2.52
10	29000	262.0	2.31	248.6	2.19	268.8	2.37	31012	277.7	2.29	264.3	2.18	284.6	2.34
12	32617	280.1	2.19	266.7	2.09	287.0	2.25	34630	295.9	2.18	282.5	2.08	302.7	2.23

Note:

- w1 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #1 & #2.
- w3 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #3.
- w4 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #4.
- Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
PANEL WEIGHT AND THE WEIGHT OF THE BACKUP STRUCTURE.
DEFLECTION DUE TO DEAD LOAD ONLY.

Elastic Modulus, E = 29000 ksi
Triangular Unit Size = 70 ft
Depth, h = 6 ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	10272	195.8	9.02	180.2	8.30	203.8	9.39	12620	199.3	7.47	183.6	6.89	207.3	7.77
3-1/2	10857	198.9	8.67	183.2	7.99	206.9	9.01	13205	202.3	7.25	186.7	6.69	210.3	7.54
4	11495	202.2	8.32	186.6	7.68	210.2	8.65	13842	205.7	7.03	190.1	6.50	213.7	7.30
5	12967	209.9	7.66	194.3	7.09	217.9	7.95	15315	213.3	6.59	197.7	6.11	221.3	6.84
6	14639	218.6	7.07	203.0	6.56	226.6	7.32	16987	222.0	6.19	206.4	5.75	230.0	6.41
8	18338	237.7	6.13	222.1	5.73	245.7	6.34	20686	241.2	5.52	225.6	5.16	249.2	5.70
10	22962	261.6	5.39	246.0	5.07	269.6	5.56	25310	265.1	4.96	249.4	4.66	273.1	5.10
12	26580	279.8	4.98	264.1	4.70	287.8	5.12	28928	283.2	4.63	267.6	4.38	291.2	4.76

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3-1/2	13828	205.2	7.02	189.6	6.49	213.2	7.30	13828	207.7	7.11	192.1	6.57	215.7	7.38
4	14465	208.6	6.82	193.0	6.31	216.6	7.08	14465	211.1	6.90	195.4	6.39	219.0	7.16
5	15938	216.2	6.42	200.6	5.96	224.2	6.66	15938	218.7	6.49	203.1	6.03	226.7	6.73
6	17610	224.9	6.04	209.3	5.62	232.9	6.26	17610	227.4	6.11	211.8	5.69	235.4	6.33
8	21309	244.1	5.42	228.5	5.07	252.1	5.60	21309	246.6	5.48	230.9	5.13	254.6	5.65
10	25933	268.0	4.89	252.3	4.60	275.9	5.03	25933	270.4	4.93	254.8	4.65	278.4	5.08
12	29550	286.1	4.58	270.5	4.33	294.1	4.71	29550	288.6	4.62	273.0	4.37	296.6	4.75

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	15472	213.8	6.54	198.1	6.06	221.8	6.78	16478	220.0	6.32	204.3	5.87	227.9	6.55
5	16944	221.4	6.18	205.8	5.75	229.4	6.41	17950	227.6	6.00	212.0	5.59	235.6	6.21
6	18616	230.1	5.85	214.5	5.45	238.1	6.05	19622	236.3	5.70	220.7	5.32	244.3	5.89
8	22315	249.3	5.29	233.7	4.95	257.3	5.46	23321	255.5	5.18	239.9	4.87	263.5	5.35
10	26939	273.1	4.80	257.5	4.52	281.1	4.94	27946	279.3	4.73	263.7	4.47	287.3	4.86
12	30557	291.3	4.51	275.7	4.27	299.3	4.63	31563	297.5	4.46	281.9	4.23	305.5	4.58

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	6							8						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
6	20676	243.4	5.57	227.8	5.21	251.4	5.75	22689	258.8	5.40	243.2	5.07	266.8	5.56
8	24375	262.6	5.10	246.9	4.79	270.6	5.25	26388	278.0	4.98	262.4	4.70	286.0	5.13
10	29000	286.4	4.67	270.8	4.42	294.4	4.80	31012	301.9	4.61	286.2	4.37	309.8	4.73
12	32617	304.6	4.42	289.0	4.19	312.6	4.53	34630	320.0	4.37	304.4	4.16	328.0	4.48

Note:

- -w1 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #1 & #2.
- -w3 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #3.
- -w4 is the total dead load (panel weight and backup structure weight) supported by each truss for geometric layout #4.
- -Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

LAR - Wind Loads and Deflections
WIND LOAD ACTS ON THE MAIN SUPPORT STRUCTURE ALONE.

Elastic Modulus, E =		29000	ksi
Depth, h =		6	ft
Operational:	6.58	psf	
Survival:	22.8	psf	

Max Unit Angle	Max Unit Angle	Triangular Unit Size	Total Area per Triangular Unit (ft^2)					
			9	12	15	18	21	(m)
(rad)	(deg)		30	40	50	60	70	(ft)
1.26	72	Layout #1	414.6	737.1	1152	1659	2257	
1.26	72	Layout #2	414.6	737.1	1152	1659	2257	
1.05	60	Layout #3	377.6	671.2	1049	1510	2056	
1.47	84	Layout #4	433.6	770.8	1204	1734	2361	

Geometric Layout	Wind Load (lbs/ft)*					
	30	40	50	60	70	(ft)
1 & 2	30.3	40.4	50.5	60.6	70.7	
3	27.6	36.8	46.0	55.2	64.4	
4	31.7	42.3	52.8	63.4	74.0	

Top/ Bottom Chord:

Pipe Diameter	Wt of Pipe	A	I	d = h/2	I+Ad^2
(in)	(lbs/ft)	(in^2)	(in^4)	(in)	(in^4)
3	7.58	2.23	3.02	36	2893.1
3-1/2	9.11	2.68	4.79	36	3478.1
4	10.79	3.17	7.23	36	4115.6
5	14.62	4.30	15.2	36	5588.0
6	18.97	5.58	28.1	36	7259.8
8	28.55	8.40	72.5	36	10959
10	40.48	11.9	161	36	15583
12	49.56	14.6	279	36	19201

Web Pipe:
Pipe Spacing = 10 ft

Pipe Diameter	Wt of Pipe	Wall Thickness	I	Total Weight of Web Pipes (lbs/ft)				
				30	40	50	60	70
(in)	(lbs/ft)	(in)	(in^4)	(ft)	(ft)	(ft)	(ft)	(ft)
1-1/4	1.68	0.140	8709	3.30	3.13	3.03	2.96	2.91
1-1/2	2.27	0.145	9020	4.45	4.23	4.09	4.00	3.93
2	3.65	0.154	9580	7.16	6.80	6.58	6.43	6.33
2-1/2	5.79	0.203	12628	11.4	10.8	10.4	10.2	10.0
3	7.58	0.216	13437	14.9	14.1	13.7	13.4	13.1
3-1/2	9.11	0.226	14059	17.9	17.0	16.4	16.1	15.8
4	10.79	0.237	14743	21.2	20.1	19.4	19.0	18.7
5	14.62	0.258	16050	28.7	27.2	26.3	25.8	25.3
6	18.97	0.280	17418	37.2	35.3	34.2	33.4	32.9
8	28.55	0.322	20031	56.0	53.2	51.4	50.3	49.5

* Assuming wind load is acting perpendicular to the entire triangular unit.

THE LARGE ADAPTIVE REFLECTOR
WIND LOAD ACTS ON THE BACKUP STRUCTURE ALONE.
DEFLECTION DUE TO WIND LOAD.

Elastic Modulus, E =	29000	ksi
Triangular Unit Size =	30	ft
Depth, h =	6	ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	1-1/4							1-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	11602	30.3	0.042	27.6	0.038	31.7	0.044	11913	30.3	0.041	27.6	0.038	31.7	0.044
3-1/2	12187	30.3	0.040	27.6	0.036	31.7	0.042	12498	30.3	0.039	27.6	0.036	31.7	0.042
4	12825	30.3	0.038	27.6	0.034	31.7	0.039	13136	30.3	0.037	27.6	0.034	31.7	0.039
5	14297	30.3	0.034	27.6	0.031	31.7	0.035	14608	30.3	0.033	27.6	0.031	31.7	0.035
6	15969	30.3	0.030	27.6	0.028	31.7	0.032	16280	30.3	0.030	27.6	0.028	31.7	0.032
8	19668	30.3	0.025	27.6	0.022	31.7	0.026	19979	30.3	0.024	27.6	0.022	31.7	0.026
10	24293	30.3	0.020	27.6	0.018	31.7	0.021	24604	30.3	0.020	27.6	0.018	31.7	0.021
12	27910	30.3	0.017	27.6	0.016	31.7	0.018	28221	30.3	0.017	27.6	0.016	31.7	0.018

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	12473	30.3	0.039	27.6	0.035	31.7	0.041	15521	30.3	0.031	27.6	0.028	31.7	0.033
3-1/2	13058	30.3	0.037	27.6	0.034	31.7	0.039	16106	30.3	0.030	27.6	0.027	31.7	0.031
4	13696	30.3	0.035	27.6	0.032	31.7	0.037	16744	30.3	0.029	27.6	0.026	31.7	0.030
5	15168	30.3	0.032	27.6	0.029	31.7	0.033	18216	30.3	0.027	27.6	0.024	31.7	0.028
6	16840	30.3	0.029	27.6	0.026	31.7	0.030	19888	30.3	0.024	27.6	0.022	31.7	0.025
8	20539	30.3	0.024	27.6	0.021	31.7	0.025	23587	30.3	0.021	27.6	0.019	31.7	0.021
10	25163	30.3	0.019	27.6	0.018	31.7	0.020	28212	30.3	0.017	27.6	0.016	31.7	0.018
12	28781	30.3	0.017	27.6	0.015	31.7	0.018	31829	30.3	0.015	27.6	0.014	31.7	0.016

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	16330	30.3	0.030	27.6	0.027	31.7	0.031	16330	30.3	0.030	27.6	0.027	31.7	0.031
3-1/2	16915	30.3	0.029	27.6	0.026	31.7	0.030	16915	30.3	0.029	27.6	0.026	31.7	0.030
4	17552	30.3	0.028	27.6	0.025	31.7	0.029	17552	30.3	0.028	27.6	0.025	31.7	0.029
5	19025	30.3	0.025	27.6	0.023	31.7	0.027	19025	30.3	0.025	27.6	0.023	31.7	0.027
6	20697	30.3	0.023	27.6	0.021	31.7	0.024	20697	30.3	0.023	27.6	0.021	31.7	0.024
8	24396	30.3	0.020	27.6	0.018	31.7	0.021	24396	30.3	0.020	27.6	0.018	31.7	0.021
10	29020	30.3	0.017	27.6	0.015	31.7	0.017	29020	30.3	0.017	27.6	0.015	31.7	0.017
12	32638	30.3	0.015	27.6	0.014	31.7	0.016	32638	30.3	0.015	27.6	0.014	31.7	0.016

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	18859	30.3	0.026	27.6	0.023	31.7	0.027	20165	30.3	0.024	27.6	0.022	31.7	0.025
5	20331	30.3	0.024	27.6	0.022	31.7	0.025	21638	30.3	0.022	27.6	0.020	31.7	0.023
6	22003	30.3	0.022	27.6	0.020	31.7	0.023	23309	30.3	0.021	27.6	0.019	31.7	0.022
8	25702	30.3	0.019	27.6	0.017	31.7	0.020	27009	30.3	0.018	27.6	0.016	31.7	0.019
10	30327	30.3	0.016	27.6	0.015	31.7	0.017	31633	30.3	0.015	27.6	0.014	31.7	0.016
12	33944	30.3	0.014	27.6	0.013	31.7	0.015	35250	30.3	0.014	27.6	0.013	31.7	0.014

Note:

- w1 is the wind load acting on geometric layout #1 & #2.
- w3 is the wind load acting on geometric layout #3.
- w4 is the wind load acting on geometric layout #4.
- Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
WIND LOAD ACTS ON THE BACKUP STRUCTURE ALONE.
DEFLECTION DUE TO WIND LOAD.

Elastic Modulus, E =	29000	ksi
Triangular Unit Size =	40	ft
Depth, h =	6	ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	1-1/4							1-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	11602	40.4	0.176	36.8	0.160	42.3	0.184	11913	40.4	0.171	36.8	0.160	42.3	0.184
3-1/2	12187	40.4	0.167	36.8	0.152	42.3	0.175	12498	40.4	0.163	36.8	0.152	42.3	0.175
4	12825	40.4	0.159	36.8	0.145	42.3	0.166	13136	40.4	0.155	36.8	0.145	42.3	0.166
5	14297	40.4	0.143	36.8	0.130	42.3	0.149	14608	40.4	0.140	36.8	0.130	42.3	0.149
6	15969	40.4	0.128	36.8	0.116	42.3	0.134	16280	40.4	0.125	36.8	0.116	42.3	0.134
8	19668	40.4	0.104	36.8	0.094	42.3	0.108	19979	40.4	0.102	36.8	0.094	42.3	0.108
10	24293	40.4	0.084	36.8	0.076	42.3	0.088	24604	40.4	0.083	36.8	0.076	42.3	0.088
12	27910	40.4	0.073	36.8	0.067	42.3	0.076	28221	40.4	0.072	36.8	0.067	42.3	0.076

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	12473	40.4	0.163	36.8	0.149	42.3	0.171	15521	40.4	0.131	36.8	0.120	42.3	0.137
3-1/2	13058	40.4	0.156	36.8	0.142	42.3	0.163	16106	40.4	0.127	36.8	0.115	42.3	0.132
4	13696	40.4	0.149	36.8	0.136	42.3	0.156	16744	40.4	0.122	36.8	0.111	42.3	0.127
5	15168	40.4	0.134	36.8	0.122	42.3	0.141	18216	40.4	0.112	36.8	0.102	42.3	0.117
6	16840	40.4	0.121	36.8	0.110	42.3	0.127	19888	40.4	0.103	36.8	0.093	42.3	0.107
8	20539	40.4	0.099	36.8	0.090	42.3	0.104	23587	40.4	0.086	36.8	0.079	42.3	0.090
10	25163	40.4	0.081	36.8	0.074	42.3	0.085	28212	40.4	0.072	36.8	0.066	42.3	0.076
12	28781	40.4	0.071	36.8	0.065	42.3	0.074	31829	40.4	0.064	36.8	0.058	42.3	0.067

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	16330	40.4	0.125	36.8	0.114	42.3	0.131	16330	40.4	0.125	36.8	0.114	42.3	0.131
3-1/2	16915	40.4	0.121	36.8	0.110	42.3	0.126	16915	40.4	0.121	36.8	0.110	42.3	0.126
4	17552	40.4	0.116	36.8	0.106	42.3	0.121	17552	40.4	0.116	36.8	0.106	42.3	0.121
5	19025	40.4	0.107	36.8	0.098	42.3	0.112	19025	40.4	0.107	36.8	0.098	42.3	0.112
6	20697	40.4	0.099	36.8	0.090	42.3	0.103	20697	40.4	0.099	36.8	0.090	42.3	0.103
8	24396	40.4	0.084	36.8	0.076	42.3	0.087	24396	40.4	0.084	36.8	0.076	42.3	0.087
10	29020	40.4	0.070	36.8	0.064	42.3	0.073	29020	40.4	0.070	36.8	0.064	42.3	0.073
12	32638	40.4	0.062	36.8	0.057	42.3	0.065	32638	40.4	0.062	36.8	0.057	42.3	0.065

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	18859	40.4	0.108	36.8	0.098	42.3	0.113	20165	40.4	0.101	36.8	0.092	42.3	0.106
5	20331	40.4	0.100	36.8	0.091	42.3	0.105	21638	40.4	0.094	36.8	0.086	42.3	0.099
6	22003	40.4	0.093	36.8	0.084	42.3	0.097	23309	40.4	0.087	36.8	0.080	42.3	0.091
8	25702	40.4	0.079	36.8	0.072	42.3	0.083	27009	40.4	0.076	36.8	0.069	42.3	0.079
10	30327	40.4	0.067	36.8	0.061	42.3	0.070	31633	40.4	0.064	36.8	0.059	42.3	0.067
12	33944	40.4	0.060	36.8	0.055	42.3	0.063	35250	40.4	0.058	36.8	0.053	42.3	0.060

Note:

- w1 is the wind load acting on geometric layout #1 & #2.
- w3 is the wind load acting on geometric layout #3.
- w4 is the wind load acting on geometric layout #4.
- Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
WIND LOAD ACTS ON THE BACKUP STRUCTURE ALONE.
DEFLECTION DUE TO WIND LOAD.

Elastic Modulus, E = 29000 ksi
Triangular Unit Size = 50 ft
Depth, h = 6 ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	12473	50.5	0.499	46.0	0.454	52.8	0.522	15521	50.5	0.401	46.0	0.365	52.8	0.419
3-1/2	13058	50.5	0.477	46.0	0.434	52.8	0.498	16106	50.5	0.386	46.0	0.352	52.8	0.404
4	13696	50.5	0.454	46.0	0.414	52.8	0.475	16744	50.5	0.372	46.0	0.338	52.8	0.389
5	15168	50.5	0.410	46.0	0.374	52.8	0.429	18216	50.5	0.342	46.0	0.311	52.8	0.357
6	16840	50.5	0.370	46.0	0.337	52.8	0.386	19888	50.5	0.313	46.0	0.285	52.8	0.327
8	20539	50.5	0.303	46.0	0.276	52.8	0.317	23587	50.5	0.264	46.0	0.240	52.8	0.276
10	25163	50.5	0.247	46.0	0.225	52.8	0.259	28212	50.5	0.221	46.0	0.201	52.8	0.231
12	28781	50.5	0.216	46.0	0.197	52.8	0.226	31829	50.5	0.196	46.0	0.178	52.8	0.204

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	16330	50.5	0.381	46.0	0.347	52.8	0.398	16330	50.5	0.381	46.0	0.347	52.8	0.398
3-1/2	16915	50.5	0.368	46.0	0.335	52.8	0.385	16915	50.5	0.368	46.0	0.335	52.8	0.385
4	17552	50.5	0.355	46.0	0.323	52.8	0.371	17552	50.5	0.355	46.0	0.323	52.8	0.371
5	19025	50.5	0.327	46.0	0.298	52.8	0.342	19025	50.5	0.327	46.0	0.298	52.8	0.342
6	20697	50.5	0.301	46.0	0.274	52.8	0.314	20697	50.5	0.301	46.0	0.274	52.8	0.314
8	24396	50.5	0.255	46.0	0.232	52.8	0.267	24396	50.5	0.255	46.0	0.232	52.8	0.267
10	29020	50.5	0.214	46.0	0.195	52.8	0.224	29020	50.5	0.214	46.0	0.195	52.8	0.224
12	32638	50.5	0.191	46.0	0.174	52.8	0.199	32638	50.5	0.191	46.0	0.174	52.8	0.199

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	18859	50.5	0.330	46.0	0.300	52.8	0.345	20165	50.5	0.309	46.0	0.281	52.8	0.323
5	20331	50.5	0.306	46.0	0.279	52.8	0.320	21638	50.5	0.288	46.0	0.262	52.8	0.301
6	22003	50.5	0.283	46.0	0.258	52.8	0.296	23309	50.5	0.267	46.0	0.243	52.8	0.279
8	25702	50.5	0.242	46.0	0.220	52.8	0.253	27009	50.5	0.230	46.0	0.210	52.8	0.241
10	30327	50.5	0.205	46.0	0.187	52.8	0.215	31633	50.5	0.197	46.0	0.179	52.8	0.206
12	33944	50.5	0.183	46.0	0.167	52.8	0.192	35250	50.5	0.177	46.0	0.161	52.8	0.185

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	6							8						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
6	24678	50.5	0.252	46.0	0.230	52.8	0.264	27291	50.5	0.228	46.0	0.208	52.8	0.238
8	28377	50.5	0.219	46.0	0.200	52.8	0.229	30990	50.5	0.201	46.0	0.183	52.8	0.210
10	33002	50.5	0.189	46.0	0.172	52.8	0.197	35614	50.5	0.175	46.0	0.159	52.8	0.183
12	36619	50.5	0.170	46.0	0.155	52.8	0.178	39232	50.5	0.159	46.0	0.144	52.8	0.166

Note:

- w1 is the wind load acting on geometric layout #1 & #2.
- w3 is the wind load acting on geometric layout #3.
- w4 is the wind load acting on geometric layout #4.
- Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
WIND LOAD ACTS ON THE BACKUP STRUCTURE ALONE.
DEFLECTION DUE TO WIND LOAD.

Elastic Modulus, E = 29000 ksi
Triangular Unit Size = 60 ft
Depth, h = 6 ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	12473	60.6	1.24	55.2	1.13	63.4	1.30	15521	60.6	1.00	55.2	0.91	63.4	1.04
3-1/2	13058	60.6	1.19	55.2	1.08	63.4	1.24	16106	60.6	0.96	55.2	0.88	63.4	1.01
4	13696	60.6	1.13	55.2	1.03	63.4	1.18	16744	60.6	0.92	55.2	0.84	63.4	0.97
5	15168	60.6	1.02	55.2	0.93	63.4	1.07	18216	60.6	0.85	55.2	0.77	63.4	0.89
6	16840	60.6	0.92	55.2	0.84	63.4	0.96	19888	60.6	0.78	55.2	0.71	63.4	0.81
8	20539	60.6	0.75	55.2	0.69	63.4	0.79	23587	60.6	0.66	55.2	0.60	63.4	0.69
10	25163	60.6	0.62	55.2	0.56	63.4	0.64	28212	60.6	0.55	55.2	0.50	63.4	0.57
12	28781	60.6	0.54	55.2	0.49	63.4	0.56	31829	60.6	0.49	55.2	0.44	63.4	0.51

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	16330	60.6	0.95	55.2	0.86	63.4	0.99	16330	60.6	0.95	55.2	0.86	63.4	0.99
3-1/2	16915	60.6	0.92	55.2	0.83	63.4	0.96	16915	60.6	0.92	55.2	0.83	63.4	0.96
4	17552	60.6	0.88	55.2	0.80	63.4	0.92	17552	60.6	0.88	55.2	0.80	63.4	0.92
5	19025	60.6	0.81	55.2	0.74	63.4	0.85	19025	60.6	0.81	55.2	0.74	63.4	0.85
6	20697	60.6	0.75	55.2	0.68	63.4	0.78	20697	60.6	0.75	55.2	0.68	63.4	0.78
8	24396	60.6	0.63	55.2	0.58	63.4	0.66	24396	60.6	0.63	55.2	0.58	63.4	0.66
10	29020	60.6	0.53	55.2	0.49	63.4	0.56	29020	60.6	0.53	55.2	0.49	63.4	0.56
12	32638	60.6	0.47	55.2	0.43	63.4	0.50	32638	60.6	0.47	55.2	0.432	63.4	0.50

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	18859	60.6	0.82	55.2	0.75	63.4	0.86	20165	60.6	0.77	55.2	0.70	63.4	0.80
5	20331	60.6	0.76	55.2	0.69	63.4	0.80	21638	60.6	0.72	55.2	0.65	63.4	0.75
6	22003	60.6	0.70	55.2	0.64	63.4	0.74	23309	60.6	0.66	55.2	0.60	63.4	0.69
8	25702	60.6	0.60	55.2	0.55	63.4	0.63	27009	60.6	0.57	55.2	0.52	63.4	0.60
10	30327	60.6	0.51	55.2	0.46	63.4	0.53	31633	60.6	0.49	55.2	0.45	63.4	0.51
12	33944	60.6	0.46	55.2	0.42	63.4	0.48	35250	60.6	0.44	55.2	0.40	63.4	0.46

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	6							8						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
6	24678	60.6	0.63	55.2	0.57	63.4	0.66	27291	60.6	0.57	55.2	0.52	63.4	0.59
8	28377	60.6	0.55	55.2	0.50	63.4	0.57	30990	60.6	0.50	55.2	0.46	63.4	0.52
10	33002	60.6	0.47	55.2	0.43	63.4	0.49	35614	60.6	0.43	55.2	0.40	63.4	0.45
12	36619	60.6	0.42	55.2	0.39	63.4	0.44	39232	60.6	0.39	55.2	0.36	63.4	0.41

Note:

- w1 is the wind load acting on geometric layout #1 & #2.
- w3 is the wind load acting on geometric layout #3.
- w4 is the wind load acting on geometric layout #4.
- Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

THE LARGE ADAPTIVE REFLECTOR
WIND LOAD ACTS ON THE BACKUP STRUCTURE ALONE.
DEFLECTION DUE TO WIND LOAD.

Elastic Modulus, E =	29000	ksi
Triangular Unit Size =	70	ft
Depth, h =	6	ft

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	2							2-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3	12473	70.7	2.68	64.4	2.44	74.0	2.81	15521	70.7	2.16	64.4	1.96	74.0	2.25
3-1/2	13058	70.7	2.56	64.4	2.33	74.0	2.68	16106	70.7	2.08	64.4	1.89	74.0	2.17
4	13696	70.7	2.44	64.4	2.23	74.0	2.56	16744	70.7	2.00	64.4	1.82	74.0	2.09
5	15168	70.7	2.21	64.4	2.01	74.0	2.31	18216	70.7	1.84	64.4	1.67	74.0	1.92
6	16840	70.7	1.99	64.4	1.81	74.0	2.08	19888	70.7	1.68	64.4	1.53	74.0	1.76
8	20539	70.7	1.63	64.4	1.48	74.0	1.70	23587	70.7	1.42	64.4	1.29	74.0	1.48
10	25163	70.7	1.33	64.4	1.21	74.0	1.39	28212	70.7	1.19	64.4	1.08	74.0	1.24
12	28781	70.7	1.16	64.4	1.06	74.0	1.22	31829	70.7	1.05	64.4	0.96	74.0	1.10

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	3							3-1/2						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
3-1/2	16915	70.7	1.98	64.4	1.80	74.0	2.07	16915	70.7	1.98	64.4	1.80	74.0	2.07
4	17552	70.7	1.91	64.4	1.74	74.0	1.99	17552	70.7	1.91	64.4	1.74	74.0	1.99
5	19025	70.7	1.76	64.4	1.60	74.0	1.84	19025	70.7	1.76	64.4	1.60	74.0	1.84
6	20697	70.7	1.62	64.4	1.47	74.0	1.69	20697	70.7	1.62	64.4	1.47	74.0	1.69
8	24396	70.7	1.37	64.4	1.25	74.0	1.43	24396	70.7	1.37	64.4	1.25	74.0	1.43
10	29020	70.7	1.15	64.4	1.05	74.0	1.21	29020	70.7	1.15	64.4	1.05	74.0	1.21
12	32638	70.7	1.03	64.4	0.93	74.0	1.07	32638	70.7	1.03	64.4	0.93	74.0	1.07

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	4							5						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
4	18859	70.7	1.77	64.4	1.62	74.0	1.86	20165	70.7	1.66	64.4	1.51	74.0	1.74
5	20331	70.7	1.65	64.4	1.50	74.0	1.72	21638	70.7	1.55	64.4	1.41	74.0	1.62
6	22003	70.7	1.52	64.4	1.39	74.0	1.59	23309	70.7	1.44	64.4	1.31	74.0	1.50
8	25702	70.7	1.30	64.4	1.19	74.0	1.36	27009	70.7	1.24	64.4	1.13	74.0	1.30
10	30327	70.7	1.10	64.4	1.00	74.0	1.15	31633	70.7	1.06	64.4	0.96	74.0	1.11
12	33944	70.7	0.99	64.4	0.90	74.0	1.03	35250	70.7	0.95	64.4	0.86	74.0	0.99

Top/ Bottom Chord Diameter	Web Pipe Diameter (in)													
	6							8						
	I	w1	Defl.	w3	Defl.	w4	Defl.	I	w1	Defl.	w3	Defl.	w4	Defl.
(in)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(in^4)	(lbs/ft)	(mm)	(lbs/ft)	(mm)	(lbs/ft)	(mm)
6	24678	70.7	1.36	64.4	1.23	74.0	1.42	27291	70.7	1.23	64.4	1.12	74.0	1.28
8	28377	70.7	1.18	64.4	1.07	74.0	1.23	30990	70.7	1.08	64.4	0.98	74.0	1.13
10	33002	70.7	1.01	64.4	0.92	74.0	1.06	35614	70.7	0.94	64.4	0.86	74.0	0.98
12	36619	70.7	0.91	64.4	0.83	74.0	0.96	39232	70.7	0.85	64.4	0.78	74.0	0.89

Note:

- -w1 is the wind load acting on geometric layout #1 & #2.
- -w3 is the wind load acting on geometric layout #3.
- -w4 is the wind load acting on geometric layout #4.
- -Deflection:

$$\Delta = \frac{5wL^4}{384EI}$$

APPENDIX C: ANSYS INPUT AND OUTPUT FILES

PRELIMINARY DESIGN OF THE SPACE FRAME STRUCTURE

```
create
/title, LAR-Backup Structure , August 06, 1999
! Created by Ya-Ying Chang
!==========================================================================
! LAR
! Finite Element Model for LAR Backing Structure
! Rev Date      Note: Equilateral Triangle (21m)
!
!==========================================================================
!SECTION 1: Definition of elements, materials and sections
!==========================================================================
! Define element type
et,1,pipe16,,,,0,,2
et,2,mass21
!
! Define material properties of steel
mp,ex,1,200                    ! Young's modulus in kN/mm2
mp,dens,1,7.85e-12             ! density in kN-sec^2/mm^4 (w/a =9810 mm/sec^2)
mp,nuxy,1,0.3                  ! Poisson's ratio
mp,gxy,1,79.29                 ! shear ratio in kN/mm2
mp,alpx,1,11.7e-6              ! thermal expansion coeff. / deg. C
!
! Define shapes in mm, mm
! r,no,OD,Tkwall
r,11,168,7.112                          !Top/ Bottom Chords
r,12,168,7.112                          !Web
r,13,0.001825,0.001825,0.001825         !Panel mass per actuator
! Specify coordinate system and material
!==========================================================================
!SECTION 2: Geometry definition
!==========================================================================
!Local systems
local,11,0,,,,-30
local,12,0,10500,-18186.5335,0,-30,10,10
local,13,0,,,,30
!n,1000,0,0,0
local,90,0,10500,-18186.5335,0,,-11,6          !Consider tilt of the space frame
csys,90
n,1,0,0,0
n,2,-5250,0,0
n,3,-10500,0,0
n,4,-15750,0,0
n,5,-21000,0,0
n,6,-2625,0,-1800
n,7,-7875,0,-1800
n,8,-10500,0,-1800
n,9,-13125,0,-1800
n,10,-18375,0,-1800
n,11,-13125,-4546.633375,0
n,12,-11812.5,-2273.3166875,-1800
n,13,-14437.5,-6819.9500625,-1800
n,31,-21000,0,0
n,32,-18375,-4546.63338,0
n,33,-15750,-9093.26675,0
n,34,-13125,-13639.90013,0
n,35,-10500,-18186.5335,0
```

```
n,36,-19687.5,-2273.31669,-1800
n,37,-17062.5,-6819.95006,-1800
n,38,-15750,-9093.26675,-1800
n,39,-14437.5,-11366.58344,-1800
n,40,-11812.5,-15913.21681,-1800
n,41,-10500,-9093.26675,0
n,42,-13125,-9093.26675,-1800
n,43,-7875,-9093.26675,-1800
n,61,-10500,-18186.5335,0
n,62,-7875,-13639.90013,0
n,63,-5250,-9093.26675,0
n,64,-2625,-4546.63338,0
n,65,0,0,0
n,66,-9187.5,-15913.21681,-1800
n,67,-6562.5,-11366.58344,-1800
n,68,-5250,-9093.26675,-1800
n,69,-3937.5,-6819.95006,-1800
n,70,-1312.5,-2273.31669,-1800
n,71,-7875,-4546.633375,0
n,72,-6562.5,-6819.9500625,-1800
n,73,-9187.5,-2273.3166875,-1800
!
type,1
real,11
en,1,1,2
en,2,2,3
en,3,3,4
en,4,4,5
en,5,6,7
en,6,7,8
en,7,8,9
en,8,9,10
en,9,1,6
en,10,6,2
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en,20,3,12
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en,22,11,13
en,23,13,33
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en,125,12,13
en,126,13,38
en,127,10,36
engen,30,2,30,1,23
engen,30,2,30,124,127
engen,30,2,30,31,48
en,79,71,3
en,80,63,72
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en,81,71,72
en,82,71,73
en,83,73,3
en,184,68,72
en,185,72,73
en,186,73,8
en,187,70,6
en,101,2,64
en,102,2,71
en,103,71,64
en,104,71,11
en,105,71,41
en,106,11,41
en,107,4,11
en,108,4,32
en,109,11,32
en,110,41,62
en,111,41,34
en,112,34,62
!
type,2                              !panel
real,13
en,24,1
en,25,2
en,26,3
en,27,4
en,28,11
engen,30,3,30,24,28
nall
eall
/ANG, 1 ,-30.0,XS,1
eplot
/eof
bc
csys,11
nall
nrotat,all
nsel,s,node,,1,61,30
nsel,a,node,,5,65,30
d,1,ux,0,,,,uy,uz
d,61,ux,0,,,,uz
d,31,uz,0
cp,2,all,1,65
cp,next,all,31,5
cp,next,all,61,35
!
nall
eall
/eof
deadL
nall
eall
acel,,,9810
/eof
post
! Postprocessing
```

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/format,,,,4
/output,prel_r,rst
prrsol
csys,0
esel,u,type,,2
etable,fxi,smisc,1
etable,fyi,smisc,2
etable,fzi,smisc,3
etable,mxi,smisc,4
etable,myi,smisc,5
etable,mzi,smisc,6
etable,fxj,smisc,7
etable,fyj,smisc,8
etable,fzj,smisc,9
etable,mxj,smisc,10
etable,myj,smisc,11
etable,mzj,smisc,12
pretab,fxi,fyi,fzi,mxi,myi,mzi
pretab,fxj,fyj,fzj,mxj,myj,mzj
etable,eras
esel,s,type,,2
etable,fxi,smisc,1
etable,fxj,smisc,2
pretab,fxi,fxj
/output
/output,prel_d,dsp
prdisp
/output
nsel,all
esel,all
/eof
main
/clear
/prep7
*use,create
*use,bc
eplot
*use,deadl
/eof
```

Preliminary Design

No tilt.

Date: August 11, 1999

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
	[kN]	[kN]	[kN]	[kN-mm]	[kN-mm]	[kN-mm]
1	0.0	0.0	122.4	0.0	0.0	0.0
31	0.0	0.0	123.1	0.0	0.0	0.0
61	0.0	0.0	123.9	0.0	0.0	0.0

TOTAL VALUES

VALUE	0.0	0.0	369.3	0.0	0.0	0.0

Preliminary Design

No tilt.

Date: August 11, 1999

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	0	0	0	0
2	0.5486	0.5778	-10.36	10.39
3	1.461	0.669	-14.8	14.89
4	2.373	0.5778	-10.36	10.65
5	2.922	-1.88E-09	0	2.922
6	3.35	1.935	-5.597	6.804
7	2.277	1.453	-13.27	13.54
8	1.461	1.006	-14.8	14.91
9	0.6449	1.453	-13.27	13.36
10	-0.4281	1.935	-5.597	5.938
11	1.69	0.7113	-15.77	15.87
12	1.338	1.073	-15.41	15.5
13	1.2	0.8351	-15.41	15.48
31	2.922	-1.88E-09	0	2.922
32	2.147	0.1862	-10.36	10.58
33	1.612	0.9306	-14.8	14.92
34	1.235	1.766	-10.36	10.58
35	1.461	2.53	0	2.922
36	-0.4289	1.934	-5.597	5.937
37	0.5252	1.245	-13.27	13.34
38	1.32	0.7619	-14.8	14.88
39	1.341	-0.1678	-13.27	13.34
40	1.46	-1.338	-5.597	5.937
41	1.461	1.108	-15.77	15.87
42	1.323	0.6221	-15.41	15.48
43	1.598	0.6221	-15.41	15.5
61	1.461	2.53	0	2.922
62	1.687	1.766	-10.36	10.65
63	1.31	0.9306	-14.8	14.89
64	0.7747	0.1862	-10.36	10.39
65	0	0	0	0
66	1.462	-1.338	-5.597	5.938
67	1.58	-0.1678	-13.27	13.36
68	1.602	0.7619	-14.8	14.91
69	2.396	1.245	-13.27	13.54
70	3.351	1.934	-5.597	6.804
71	1.232	0.7113	-15.77	15.83
72	1.721	0.8351	-15.41	15.53
73	1.584	1.073	-15.41	15.53

MAXIMUM ABSOLUTE VALUES

	UX	UY	UZ	USUM
NODE	70	35	41	41
VALUE	3.351	2.53	-15.77	15.87

Preliminary Design

Tilt angles of -11 (radial) and 6 (tangential) degrees

Date: August 11, 1999

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
	[kN]	[kN]	[kN]	[kN-mm]	[kN-mm]	[kN-mm]
1	0.0	0.0	122.4	0.0	0.0	0.0
31	0.0	0.0	123.1	0.0	0.0	0.0
61	0.0	0.0	123.9	0.0	0.0	0.0
TOTALVALUES						
VALUE	0.0	0.0	369.3	0.0	0.0	0.0

Preliminary Design

Tilt angles of -11 (radial) and 6 (tangential) degrees

Date: August 11, 1999

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	0.0	0.0	0.0	0.0
2	-0.5	-1.1	-10.0	10.0
3	-0.1	-1.9	-14.2	14.3
4	1.2	-1.3	-9.9	10.1
5	2.6	-0.4	0.0	2.6
6	2.6	1.1	-6.0	6.7
7	0.8	-0.6	-13.0	13.1
8	-0.1	-1.6	-14.3	14.3
9	-0.8	-0.6	-12.7	12.8
10	-1.1	1.2	-5.3	5.6
11	0.1	-2.1	-15.1	15.3
12	-0.2	-1.7	-14.8	14.9
13	-0.3	-1.9	-14.7	14.8
31	2.6	-0.4	0.0	2.6
32	1.1	-1.8	-10.0	10.2
33	0.2	-1.7	-14.2	14.3
34	0.3	0.0	-9.9	9.9
35	1.5	2.5	0.0	2.9
36	-0.6	0.9	-5.7	5.8
37	-0.5	-1.1	-12.8	12.9
38	0.0	-1.9	-14.1	14.3
39	0.4	-2.4	-12.5	12.7
40	1.2	-2.1	-4.7	5.3
41	0.0	-1.7	-15.1	15.2
42	-0.1	-1.9	-14.7	14.8
43	0.1	-1.9	-14.8	14.9
61	1.5	2.5	0.0	2.9
62	0.8	0.0	-9.8	9.9
63	-0.1	-1.6	-14.1	14.2
64	-0.3	-1.6	-10.0	10.1
65	0.0	0.0	0.0	0.0
66	1.2	-2.3	-4.5	5.2
67	0.3	-2.5	-12.3	12.6
68	0.1	-1.9	-14.1	14.3
69	1.0	-1.2	-13.0	13.1
70	2.4	1.0	-6.1	6.7
71	-0.3	-2.0	-15.1	15.2
72	0.4	-1.8	-14.8	14.9
73	0.2	-1.5	-14.9	15.0

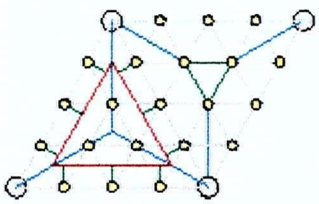
MAXIMUM ABSOLUTE VALUES

NODE	6	35	11	11
VALUE	2.6	2.5	-15.1	15.3

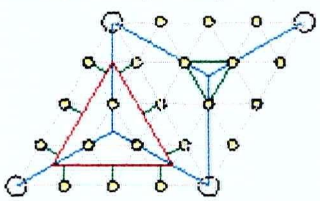
APPENDIX D: ALTERNATIVE CONFIGURATIONS

ALTERNATIVE CONFIGURATION COMBINATIONS

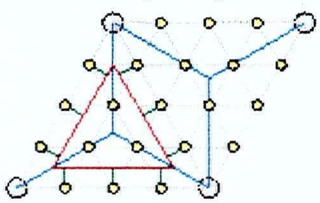
Combination #1: (#1 & #24)



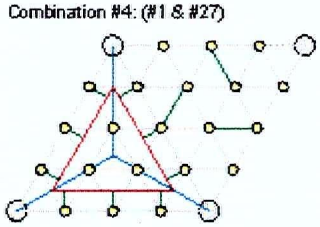
Combination #2: (#1 & #25)



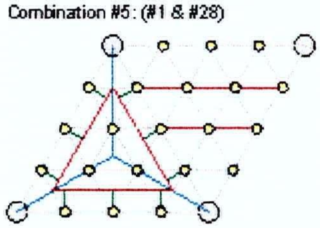
Combination #3: (#1 & #26)



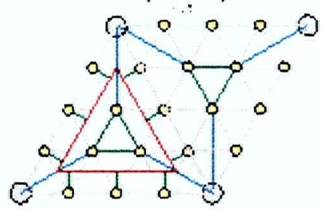
Combination #4: (#1 & #27)



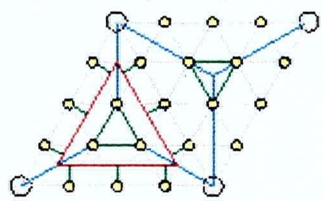
Combination #5: (#1 & #28)



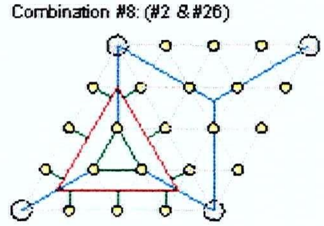
Combination #6: (#2 & #24)



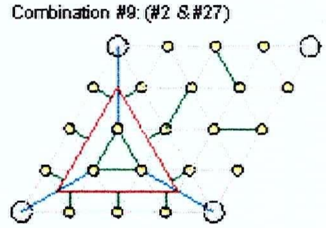
Combination #7: (#2 & #25)



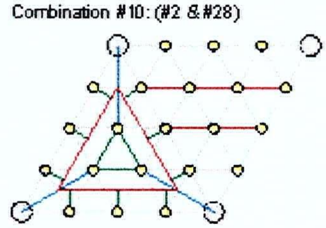
Combination #8: (#2 & #26)



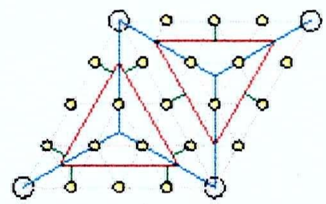
Combination #9: (#2 & #27)



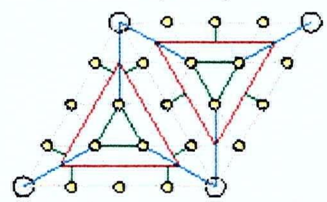
Combination #10: (#2 & #28)



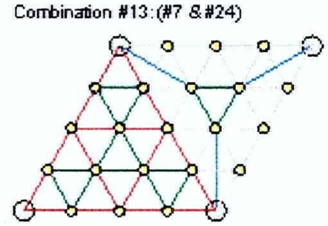
Combination #11: (#3 & #4)



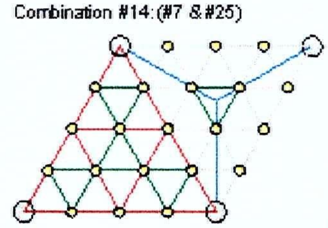
Combination #12: (#5 & #6)



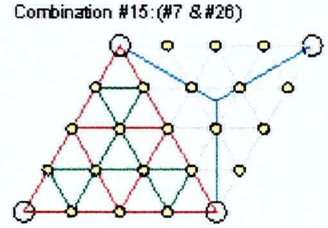
Combination #13: (#7 & #24)



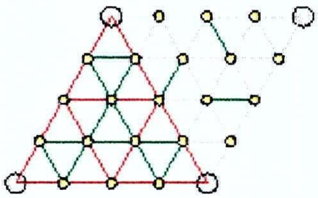
Combination #14: (#7 & #25)



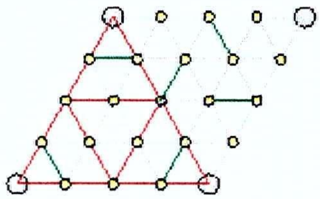
Combination #15: (#7 & #26)



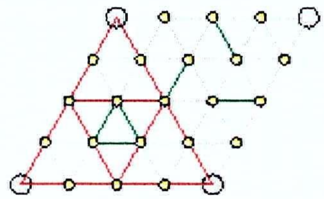
Combination #16: (#7 & #27)



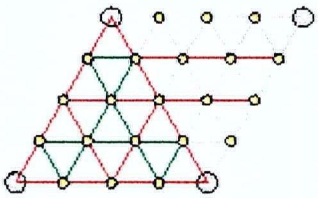
Combination #21: (#8 & #27)



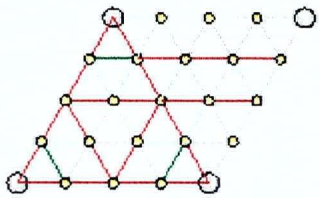
Combination #26: (#9 & #27)



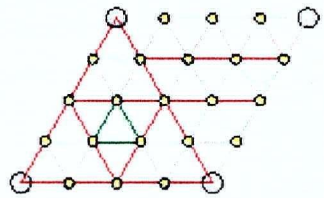
Combination #17: (#7 & #28)



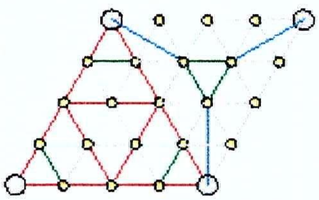
Combination #22: (#8 & #28)



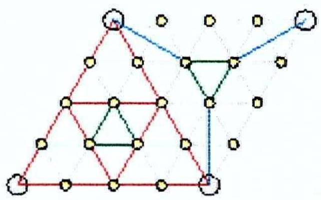
Combination #27: (#9 & #28)



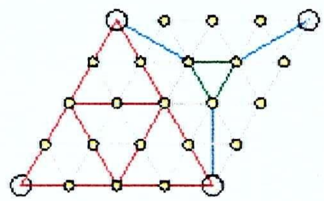
Combination #18: (#8 & #24)



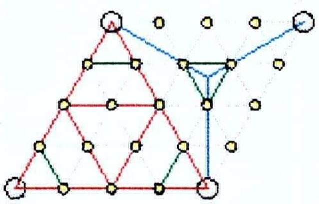
Combination #23: (#9 & #24)



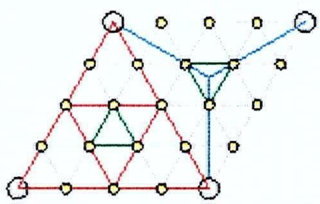
Combination #28: (#10 & #24)



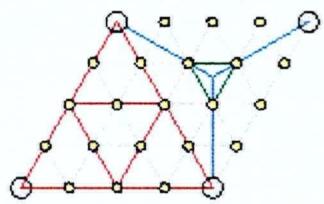
Combination #19: (#8 & #25)



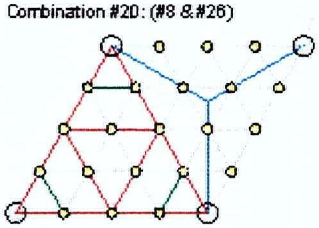
Combination #24: (#9 & #25)



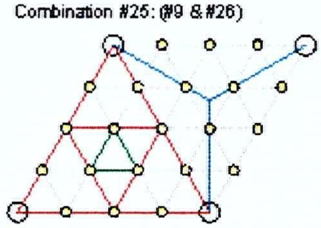
Combination #29: (#10 & #25)



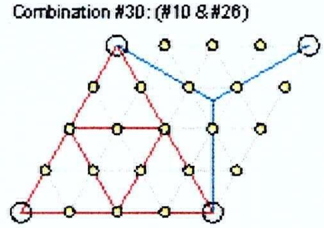
Combination #20: (#8 & #26)



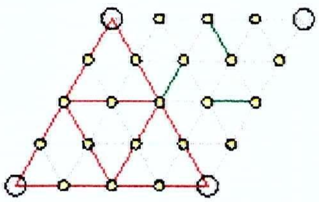
Combination #25: (#9 & #26)



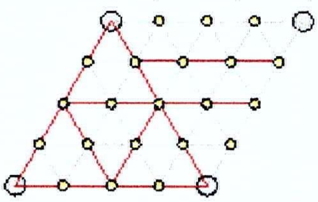
Combination #30: (#10 & #26)



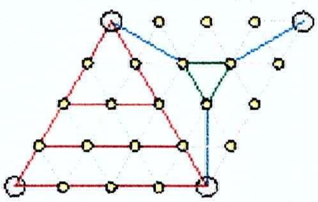
Combination #31: (#10 & #27)



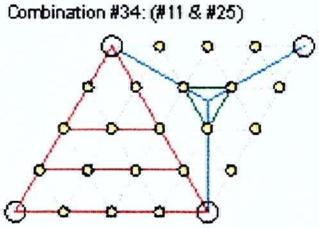
Combination #32: (#10 & #28)



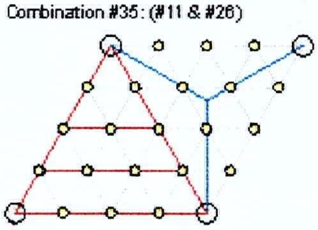
Combination #33: (#11 & #24)



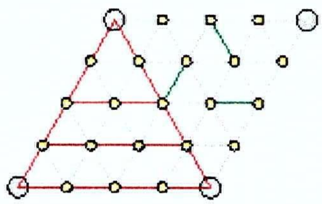
Combination #34: (#11 & #25)



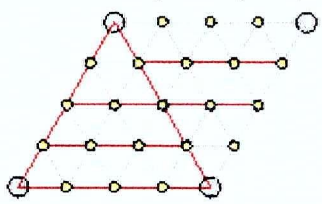
Combination #35: (#11 & #26)



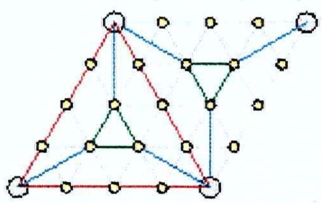
Combination #36: (#11 & #27)



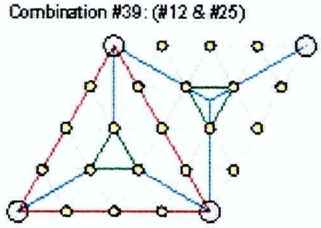
Combination #37: (#11 & #28)



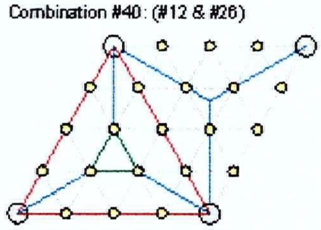
Combination #38: (#12 & #24)



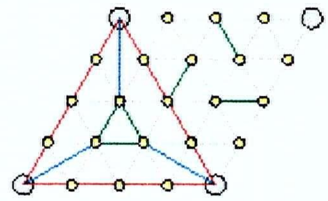
Combination #39: (#12 & #25)



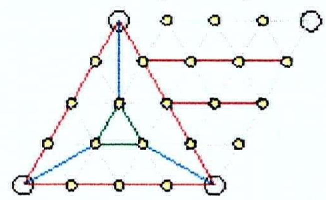
Combination #40: (#12 & #26)



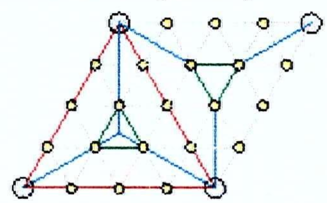
Combination #41: (#12 & #27)



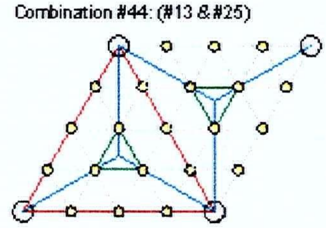
Combination #42: (#12 & #28)



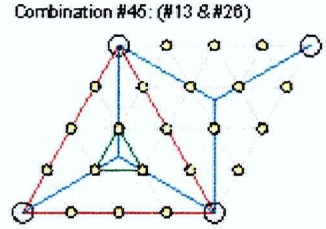
Combination #43: (#13 & #24)



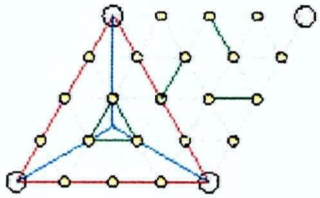
Combination #44: (#13 & #25)



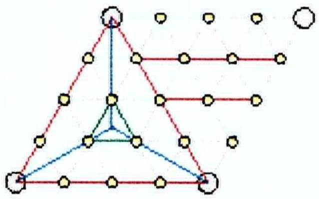
Combination #45: (#13 & #26)



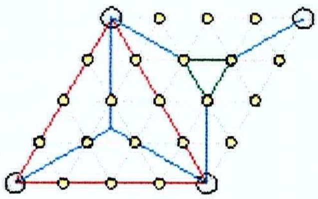
Combination #46 (#13 & #27)



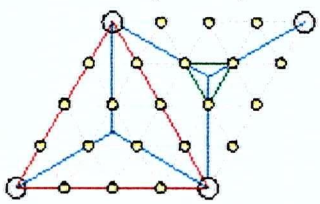
Combination #47 (#13 & #28)



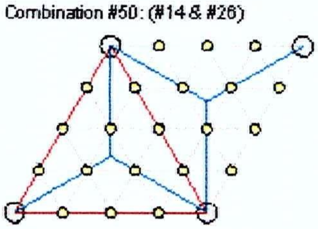
Combination #48: (#14 & #24)



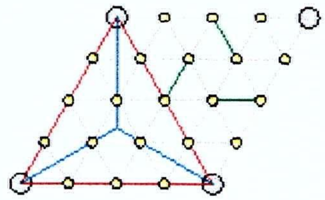
Combination #49: (#14 & #25)



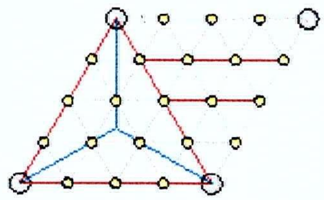
Combination #50: (#14 & #26)



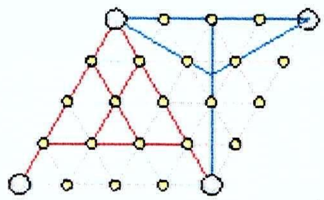
Combination #51: (#14 & #27)



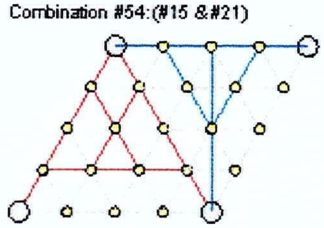
Combination #52: (#14 & #28)



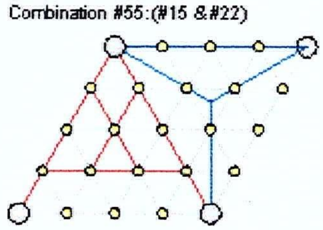
Combination #53: (#15 & #20)



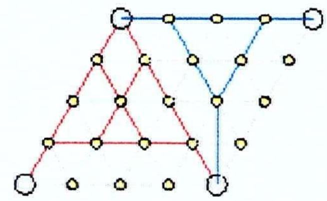
Combination #54: (#15 & #21)



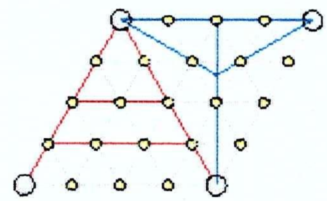
Combination #55: (#15 & #22)



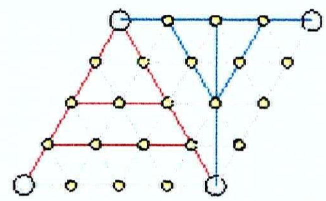
Combination #56: (#15 & #23)



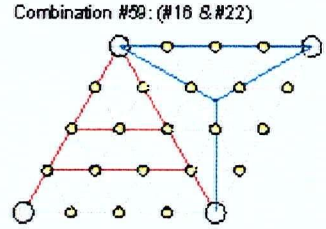
Combination #57: (#16 & #20)



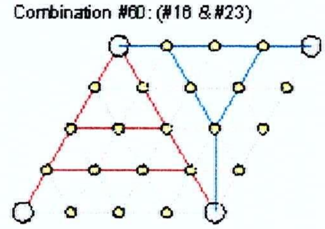
Combination #58: (#16 & #21)



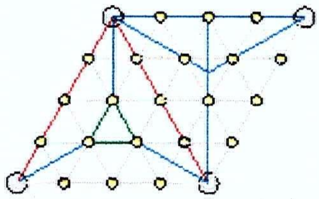
Combination #59: (#16 & #22)



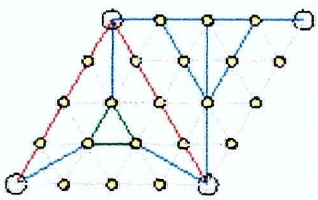
Combination #60: (#16 & #23)



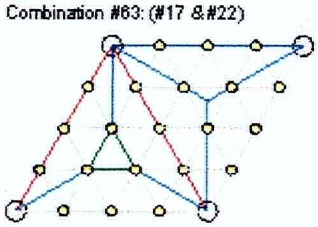
Combination #61: (#17 &#20)



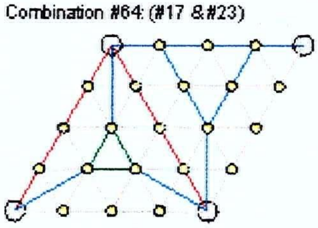
Combination #62: (#17 &#21)



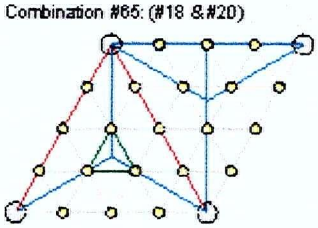
Combination #63: (#17 &#22)



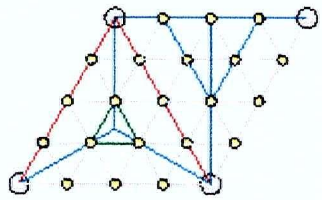
Combination #64: (#17 &#23)



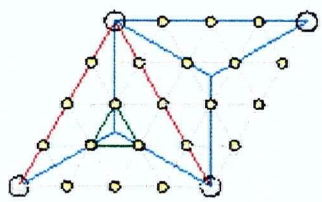
Combination #65: (#18 &#20)



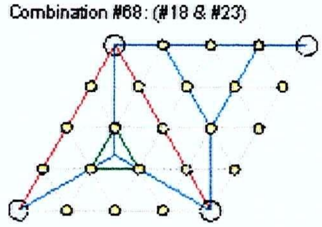
Combination #66: (#18 & #21)



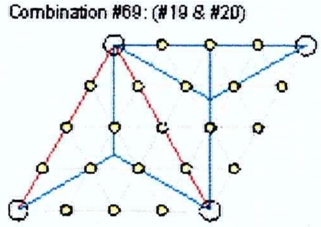
Combination #67: (#18 & #22)



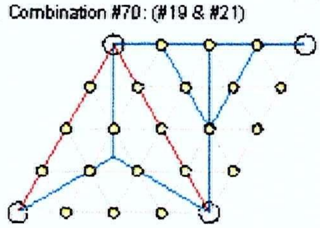
Combination #68: (#18 & #23)



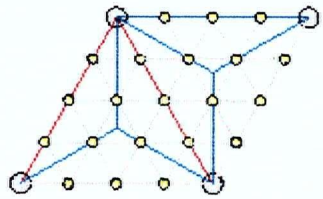
Combination #69: (#19 & #20)



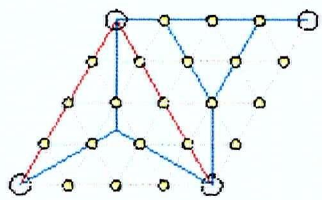
Combination #70: (#19 & #21)



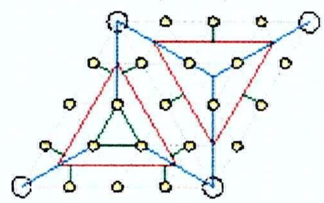
Combination #71: (#19 &#22)



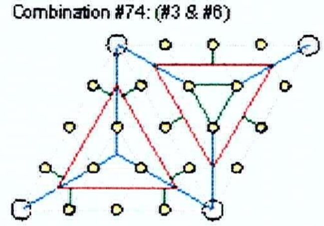
Combination #72: (#19 &#23)



Combination #73: (#4 & #5)



Combination #74: (#3 & #6)



APPENDIX E: ANSYS INPUT AND OUTPUT FILES

ANSYS INPUT FILES AND OUTPUT FILES FOR CONFIGURATIONS:
COMBO #31, COMBO #37, DRAO#1, AND THE BRIDGING SYSTEM

Input file for Combination #31

```
create
/title, LAR-Backing Structure (Combo#31), Dec 14, 1998
! Created by Ya-Ying Chang
!==========================================================================
! LAR
! Finite Element Model for LAR Backing Structure
!
!==========================================================================
!SECTION 1: Definition of elements, materials and sections
!==========================================================================
!
! Define element type
et,1,pipe16,,,,0,,2
et,2,mass21
!

! Define material properties of steel
mp,ex,1,200                     ! Young's modulus in kN/mm2
mp,dens,1,7.85e-12          ! density in kN-sec^2/mm^4 (w/a =9810 mm/sec^2)
mp,nuxy,1,0.3               ! Poisson's ratio
mp,gxy,1,79.29              ! shear ratio in kN/mm2
mp,alpx,1,11.7e-6           ! thermal expansion coeff. / deg. C
!
! Define shapes in mm, mm
! r,no,OD,Tkwall
r,11,168,7.112                                    !Top/ Bottom Chords
r,12,168,7.112                                    !Web
r,13,0.001825,0.001825,0.001825          !Panel mass per actuator
!
! Specify coordinate system and material
!==========================================================================
!SECTION 2: Geometry definition
!==========================================================================
! Define nodes
! Assuming 5.25m Flat Panels, 21m Triangular Unit
!
!node,#,x,y,z
!csys,0
local,11,0,,,,,-11,6
n,1,7875,4547,0                   ! Center points (top)
n,2,13125,4547,0
n,3,10500,9093,0
n,4,13125,-4547,0                 ! Cantilever truss points (top)
n,5,18375,13640,0
n,6,0,9093,0
n,7,11813,-2273,-1829             ! Cantilever truss points (bottom)
n,8,17063,11367,-1829
n,9,2625,9093,-1829
n,10,0,0,0                        ! Top chord
n,11,20,0,0
n,12,5250,0,0
n,13,10500,0,0
n,14,15750,0,0
n,15,20980,0,0
n,20,21000,0,0
```

```
n,21,20990,17,0
n,22,18375,4547,0
n,23,15750,9093,0
n,24,13125,13640,0
n,25,10510,18169,0
n,30,10500,18187,0
n,35,10,17,0
n,34,2625,4547,0
n,33,5250,9093,0
n,32,7875,13640,0
n,31,10490,18169,0
n,40,2635,0,-1829                    ! Bottom chord
n,41,7875,0,-1829
n,42,10500,0,-1829
n,43,13125,0,-1829
n,44,18365,0,-1829
n,45,19683,2282,-1829
n,46,17063,6820,-1829
n,47,15750,9093,-1829
n,48,14438,11367,-1829
n,49,11818,15905,-1829
n,50,9183,15905,-1829
n,51,6563,11367,-1829
n,52,5250,9093,-1829
n,53,3938,6820,-1829
n,54,1318,2282,-1829
n,60,6563,6820,-1829
n,61,9188,2273,-1829
n,62,11813,2273,-1829
n,63,14438,6820,-1829
n,64,13125,9093,-1829
n,65,7875,9093,-1829
mat,1                                ! Circular HSS
type,1
real,11
en,1,10,11
en,2,11,12
en,3,12,13
en,4,13,14
en,5,14,15
en,6,15,20
en,11,20,21
en,12,21,22
en,13,22,23
en,14,23,24
en,15,24,25
en,16,25,30
en,21,30,31
en,22,31,32
en,23,32,33
en,24,33,34
en,25,34,35
en,26,35,10
en,33,1,13
en,34,2,13
en,35,2,23
```

```
en,36,3,23
en,37,3,33
en,38,1,33
en,41,40,41
en,42,41,42
en,43,42,43
en,44,43,44
en,45,45,46
en,46,46,47
en,47,47,48
en,48,48,49
en,50,50,51
en,51,51,52
en,52,52,53
en,53,53,54
en,55,40,54
en,56,44,45
en,57,49,50
en,30,4,13                              ! Cantilever sections
en,31,5,23
en,32,6,33
en,91,4,7
en,92,7,13
en,93,7,42
en,94,5,8
en,95,8,23
en,96,8,47
en,97,6,9
en,98,9,33
en,99,9,52
en,135,52,60
en,136,60,61
en,137,61,42
en,138,42,62
en,139,62,63
en,140,63,47
en,141,47,64
en,142,64,65
en,143,65,52
type,1
real,12
en,61,11,40                             ! Truss webs
en,62,12,40
en,63,12,41
en,64,13,41
en,65,13,42
en,66,13,43
en,67,14,43
en,68,14,44
en,69,15,44
en,71,21,45
en,72,22,45
en,73,22,46
en,74,23,46
en,75,23,47
en,76,23,48
```

```
en,77,24,48
en,78,24,49
en,79,25,49
en,81,31,50
en,82,32,50
en,83,32,51
en,84,33,51
en,85,33,52
en,86,33,53
en,87,34,53
en,88,34,54
en,89,35,54
en,121,33,60
en,122,1,60
en,123,1,61
en,124,13,61
en,125,13,62
en,126,2,62
en,127,2,63
en,128,23,63
en,129,23,64
en,130,3,64
en,131,3,65
en,132,33,65
type,2                              ! Panels
real,13
en,101,10
en,102,12
en,103,13
en,104,14
en,105,20
en,106,22
en,107,23
en,108,24
en,109,30
en,110,32
en,111,33
en,112,34
en,113,1
en,114,2
en,115,3
en,116,4
en,117,5
en,118,6
! Define boundary conditions
nall
eall
local,90,0,,,,-30
nrotat,all
d,10,uz,0,,30,10
d,20,uy,0,,30,10
d,30,ux,0
/view,,0,-1,1
/pbc,all,1
eplot
/eof
```

```
!==========================================================================
!Section 3: Loads
!==========================================================================
! Load Case 1: Gravity Load
acel,,,9810
/eof
post
! Postprocessing
/format,,,,4
/output,etruss_t,rst
prrsol
csys,0
esel,u,type,,2
etable,fxi,smisc,1
etable,fyi,smisc,2
etable,fzi,smisc,3
etable,mxi,smisc,4
etable,myi,smisc,5
etable,mzi,smisc,6
etable,fxj,smisc,7
etable,fyj,smisc,8
etable,fzj,smisc,9
etable,mxj,smisc,10
etable,myj,smisc,11
etable,mzj,smisc,12
pretab,fxi,fyi,fzi,mxi,myi,mzi
pretab,fxj,fyj,fzj,mxj,myj,mzj
etable,eras
esel,s,type,,2
etable,fxi,smisc,1
etable,fxj,smisc,2
pretab,fxi,fxj
/output
/output,etruss_t,dsp
prdisp
/output
nsel,all
esel,all
/eof
```

Combo #31

No tilt

Date: Dec 20, 1998

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
	[kN]	[kN]	[kN]	[kN-mm]	[kN-mm]	[kN-mm]
10.0	0.0	0.0	139.2	0.0	0.0	0.0
20.0	0.0	0.0	139.2	0.0	0.0	0.0
30.0	0.0	0.0	139.2	0.0	0.0	0.0
TOTAL	VALUES					
VALUE	0.0	0.0	417.6	0.0	0.0	0.0

Combo #31
No tilt
Date: Dec 20, 1998

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	-1.7	2.9	-19.8	20.1
2	-1.6	2.2	-19.8	20.0
3	-1.1	2.6	-19.8	20.0
4	-2.6	2.0	-21.6	21.8
5	-0.5	1.9	-21.6	21.7
6	-1.4	3.8	-21.6	21.9
7	-2.7	2.7	-20.4	20.8
8	-1.0	1.5	-20.4	20.5
9	-0.8	3.6	-20.4	20.8
10	0.0	5.2	0.0	5.2
11	0.0	5.2	-0.1	5.2
12	-0.6	3.9	-13.4	13.9
13	-2.2	2.5	-19.6	19.9
14	-3.8	2.6	-13.6	14.3
15	-4.5	2.6	-0.1	5.2
20	-4.5	2.6	0.0	5.2
21	-4.5	2.6	-0.1	5.2
22	-3.1	2.7	-13.4	14.0
23	-1.1	2.0	-19.6	19.7
24	-0.4	0.5	-13.6	13.6
25	0.0	0.0	-0.1	0.1
30	0.0	0.0	0.0	0.0
31	0.0	0.0	-0.1	0.1
32	-0.8	1.2	-13.4	13.4
33	-1.2	3.2	-19.6	19.9
34	-0.4	4.6	-13.6	14.4
35	0.0	5.2	-0.1	5.2
40	-4.4	2.2	-7.2	8.7
41	-3.2	2.6	-17.6	18.1
42	-2.3	2.7	-19.6	19.9
43	-1.3	2.0	-17.8	17.9
44	0.0	0.4	-7.3	7.3
45	0.3	0.2	-7.2	7.2
46	-0.7	1.1	-17.6	17.6
47	-1.2	1.8	-19.6	19.7
48	-1.1	3.0	-17.8	18.1
49	-0.4	5.0	-7.3	8.8
50	-0.3685	5.305	-7.159	8.918
51	-0.6086	4.078	-17.59	18.07
52	-1.015	3.219	-19.58	19.87
53	-2.153	2.693	-17.79	18.12
54	-4.15	2.393	-7.298	8.73
60	-1.361	3.103	-19.68	19.97
61	-1.946	2.723	-19.64	19.93
62	-2.003	2.428	-19.68	19.93

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
63	-1.371	2.105	-19.64	19.8
64	-1.102	2.189	-19.68	19.83
65	-1.139	2.896	-19.65	19.89

MAXIMUM ABSOLUTE VALUES

NODE	20	50	6	6
VALUE	-4.5	5.3	-21.6	21.9

Combo #31(Tilted)

ANSYS OUTPUT FILE

Date: Dec 20, 1998

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX [kN]	FY [kN]	FZ [kN]	MX [kN-mm]	MY [kN-mm]	MZ [kN-mm]
10	0.00	0.00	140.1	0.00	0.00	0.00
20	0.000	0.000	139.2	0.00	0.00	0.00
30	0.000	0.000	138.3	0.00	0.00	0.00

TOTAL VALUES

VALUE	0.000	0.000	417.6	0.00	0.00	0.00

Combo #31(Tilted) ANSYS OUTPUT FILE

THE FOLLOW DEGREE OF FREEDOMS RESULTS IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	-2.3	0.0	-19.1	19.2
2	-5.8	0.4	-19.0	19.9
3	-2.7	3.2	-19.9	20.4
4	30.7	17.7	-27.6	44.9
5	-1.4	-2.4	-21.5	21.6
6	-3.2	38.9	-27.9	48.0
7	5.8	4.8	-21.4	22.6
8	-2.1	-2.6	-20.0	20.2
9	-2.6	10.6	-21.6	24.2
10	0.5	4.9	0.0	4.9
11	0.5	4.9	-0.1	4.9
12	-1.5	6.1	-13.5	14.9
13	-3.7	-0.7	-18.5	18.8
14	-4.8	11.1	-15.0	19.3
15	-4.2	2.5	-0.1	4.9
20	-4.2	2.4	0.0	4.8
21	-4.1	2.4	-0.1	4.8
22	3.4	4.4	-14.5	15.5
23	-2.6	-1.4	-19.1	19.3
24	5.0	1.7	-14.5	15.5
25	0.0	0.0	-0.1	0.1
30	0.0	0.0	0.0	0.0
31	0.0	0.0	-0.1	0.1
32	1.4	-3.2	-12.8	13.2
33	-2.8	-0.3	-18.7	18.9
34	-4.4	3.9	-13.0	14.2
35	0.4	4.9	-0.1	4.9
40	-4.6	3.4	-6.4	8.6
41	-4.6	-0.7	-16.2	16.9
42	-3.9	-0.7	-18.5	18.9
43	-2.8	4.2	-18.0	18.7
44	-0.6	4.8	-8.1	9.4
45	4.8	1.7	-7.8	9.3
46	0.1	-0.9	-17.4	17.4
47	-2.8	-1.7	-19.0	19.3
48	-0.3	1.1	-18.0	18.1
49	1.9	5.1	-8.5	10.1
50	1.9	2.0	-7.8	8.3
51	0.3	-0.8	-17.2	17.3
52	-2.8	-0.4	-18.7	18.9
53	-5.9	0.8	-16.5	17.6
54	-6.5	2.3	-6.0	9.1
60	-4.2	-1.1	-18.6	19.1
61	-5.0	-1.5	-18.3	19.1
62	-6.1	0.5	-18.7	19.7
63	-4.2	-0.6	-19.0	19.4
64	-2.8	0.1	-19.3	19.5

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
65	-2.8	-0.9	-18.7	19.0

MAXIMUM ABSOLUTE VALUES

	UX	UY	UZ	USUM
NODE	4	6	6	6
VALUE	30.7	38.9	-27.9	48.0

Input file for Combination #37

```
create
/title, LAR-Backing Structure (Combo#37), Dec 14, 1998
!
!===========================================================================
! LAR
! Finite Element Model for LAR Backing Structure
! Rev Date: August 20, 1999       Note: tilt angle increase to 11 degrees
!
!
!===========================================================================
!SECTION 1: Definition of elements, materials and sections
!===========================================================================
!
! Define element type
et,1,pipe16,,,,0,,2
et,2,mass21
!
! Define material properties of steel
mp,ex,1,200                    ! Young's modulus in kN/mm2
mp,dens,1,7.85e-12             ! density in kN-sec^2/mm^4 (w/a =9810 mm/sec^2)
mp,nuxy,1,0.3                  ! Poisson's ratio
mp,gxy,1,79.29                 ! shear ratio in kN/mm2
mp,alpx,1,11.7e-6              ! thermal expansion coeff. / deg. C
!
! Define shapes in mm, mm
! r,no,OD,Tkwall
!
r,11,168,7.112                                          !Top/ Bottom Chords
r,12,168,7.112                                          !Web
r,13,0.001825,0.001825,0.001825             !Panel mass per actuator
!
! Specify coordinate system and material
!===========================================================================
!SECTION 2: Geometry definition
!===========================================================================
! Define nodes
! Assuming 5.25m Flat Panels, 21m Triangular Unit
!
!node,#,x,y,z
local,11,0,,,,,-11,6
n,1,7875,4547,0            ! Center points (top)
n,2,13125,4547,0
n,3,10500,9093,0
n,7,5250,4547,-1800
n,8,10500,4547,-1800
n,9,15750,4547,-1800
n,10,0,0,0                 ! Top chord
n,11,20,0,0
n,12,5250,0,0
n,13,10500,0,0
n,14,15750,0,0
n,15,20980,0,0
n,20,21000,0,0
n,21,20990,17,0
```

```
n,22,18375,4547,0
n,23,15750,9093,0
n,24,13125,13640,0
n,25,10510,18169,0
n,30,10500,18187,0
n,35,10,17,0
n,34,2625,4547,0
n,33,5250,9093,0
n,32,7875,13640,0
n,31,10490,18169,0
n,40,2635,0,-1800                ! Bottom chord
n,41,7875,0,-1800
n,43,13125,0,-1800
n,44,18365,0,-1800
n,45,19683,2282,-1800
n,42,18375,4547,-1800
n,46,17063,6820,-1800
n,47,15750,9093,-1800
n,48,14438,11367,-1800
n,49,11818,15905,-1800
n,50,9183,15905,-1800
n,51,6563,11367,-1800
n,52,5250,9093,-1800
n,53,3938,6820,-1800
n,67,2628,4551,-1800
n,54,1318,2282,-1800
n,60,6563,6820,-1800
n,61,9188,2273,-1800
n,62,11813,2273,-1800
n,63,14438,6820,-1800
n,64,13125,9093,-1800
n,65,7875,9093,-1800
n,71,15750,9093,0
n,72,21000,9093,0
n,73,26250,9093,0
n,74,13125,13640,0
n,75,18375,13640,0
n,76,23625,13640,0
n,77,28875,13640,0
n,81,18375,9093,-1800
n,82,23625,9093,-1800
n,83,15750,13640,-1800
n,84,21000,13640,-1800
n,85,26250,13640,-1800
mat,1              ! Circular HSS
type,1
real,11
en,1,10,11
en,2,11,12
en,3,12,13
en,4,13,14
en,5,14,15
en,6,15,20
en,11,20,21
en,12,21,22
en,13,22,23
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en,14,23,24
en,15,24,25
en,16,25,30
en,21,30,31
en,22,31,32
en,23,32,33
en,24,33,34
en,25,34,35
en,26,35,10
en,27,22,42
en,30,1,34
en,31,1,2
en,32,2,22
en,33,3,33
en,34,3,23
en,41,40,41
en,42,41,43
en,43,43,44
en,44,42,45
en,45,42,46
en,46,46,47
en,47,47,48
en,48,48,49
en,50,50,51
en,51,51,52
en,52,52,53
en,53,54,67
en,54,53,67
en,55,40,54
en,56,44,45
en,57,49,50
en,58,7,67
en,59,9,42
en,97,7,8
en,98,8,9
en,151,47,64
en,152,64,65
en,153,65,52
en,154,71,72
en,155,72,73
en,156,81,82
en,157,74,75
en,158,75,76
en,159,76,77
en,160,83,84
en,161,84,85
en,171,72,75
en,172,72,76
en,173,81,83
en,174,82,85
type,1
real,12
en,61,11,40                 ! Truss webs
en,62,12,40
en,63,12,41
en,64,13,41
```

```
en,65,34,67
en,66,13,43
en,67,14,43
en,68,14,44
en,69,15,44
en,71,21,45
en,72,22,45
en,73,22,46
en,74,23,46
en,75,23,47
en,76,23,48
en,77,24,48
en,78,24,49
en,79,25,49
en,81,31,50
en,82,32,50
en,83,32,51
en,84,33,51
en,85,33,52
en,86,33,53
en,87,34,53
en,88,34,54
en,89,35,54
en,91,7,34
en,92,1,7
en,93,1,8
en,94,2,8
en,95,2,9
en,96,9,22
en,129,23,64
en,130,3,64
en,131,3,65
en,132,33,65
en,133,71,81
en,134,81,72
en,135,72,82
en,136,82,73
en,137,74,83
en,138,83,75
en,139,75,84
en,140,84,76
en,141,76,85
en,142,85,77
type,2              ! Panels
real,13
en,101,10
en,102,12
en,103,13
en,104,14
en,105,20
en,106,22
en,107,23
en,108,24
en,109,30
en,110,32
en,111,33
```

```
en,112,34
en,113,1
en,114,2
en,115,3
en,116,72
en,117,73
en,118,75
en,119,76
en,120,77
! Define boundary conditions
local,90,0,,,,-30
nsel,s,node,,10,30,10
nrotat,all
d,10,uz,0,,30,10
d,20,uy,0,,30,10
d,30,ux,0
nsel,s,node,,71,74,3
nsel,a,node,,23,24,1
local,20,0,,,,30
csys,20
nrotat,all
cp,2,uz,23,71
cp,next,uz,24,74
nsel,s,node,,73,77,4
local,21,0,,,,-30
nrotat,all
d,73,ux,0,,77,4,uz
nall
eall
/view,,0,-1,1
/pbc,all,1
eplot
/eof
load
!=====================================================================
===
!Section 3: Loads
!=====================================================================
===
! Load Case 1: Gravity Load
acel,,,9810
/eof
post
/format,,f,,3
/output,com37,out
/output
/eof
```

Combo #37

No tilt.

Date: Dec 20, 1998

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX [kN]	FY [kN]	FZ [kN]	MX [kN-mm]	MY [kN-mm]	MZ [kN-mm]
10	0.0	0.0	115.7	0.0	0.0	0.0
20	0.0	0.0	129.0	0.0	0.0	0.0
30	0.0	0.0	142.8	0.0	0.0	0.0
73	0.0	0.0	32.9	0.0	0.0	0.0
77	0.0	0.0	43.1	0.0	0.0	0.0

TOTAL VALUES

VALUE	0.0	0.0	463.5	0.0	0.0	0.0

Combo #37
No tilt.
Date: Dec 20, 1998

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	-2.7	4.4	-16.7	17.5
2	-3.2	3.8	-18.0	18.6
3	-1.8	2.4	-20.4	20.6
7	-3.9	2.3	-14.7	15.4
8	-3.4	1.0	-17.7	18.1
9	-2.9	-0.2	-17.2	17.5
10	-2.8	6.1	0.0	6.7
11	-2.8	6.1	0.0	6.7
12	-3.2	5.9	-7.4	10.0
13	-4.0	5.2	-10.4	12.3
14	-4.9	4.3	-7.4	9.9
15	-5.2	3.0	0.0	6.1
20	-5.2	3.0	0.0	6.1
21	-5.2	3.0	-0.1	6.1
22	-3.5	3.2	-16.1	16.8
23	-2.0	1.9	-22.5	22.7
24	-0.8	0.5	-16.1	16.1
25	0.0	0.0	-0.1	0.1
30	0.0	0.0	0.0	0.0
31	0.0	0.0	-0.1	0.1
32	-1.0	1.2	-11.3	11.4
33	-1.7	3.1	-16.5	16.9
34	-2.4	5.1	-12.3	13.5
35	-2.8	6.1	-0.1	6.7
40	-5.2	2.3	-4.0	7.0
41	-4.5	1.3	-9.5	10.6
42	-2.9	-0.7	-16.1	16.4
43	-3.6	0.1	-9.5	10.2
44	-2.8	-1.3	-4.0	5.1
45	-2.6	-1.5	-8.7	9.2
46	-2.8	0.2	-20.6	20.8
47	-2.7	1.4	-22.5	22.7
48	-2.6	2.7	-20.7	21.0
49	-2.0	4.9	-8.7	10.2
50	-2.0	5.4	-6.1	8.4
51	-2.6	4.6	-14.9	15.8
52	-3.0	4.0	-16.5	17.2
53	-3.5	3.3	-15.4	16.2
54	-4.7	2.6	-6.7	8.6
64	-2.8	2.1	-21.5	21.8
65	-3.0	3.5	-18.5	19.1
67	-3.9	2.8	-12.3	13.2
71	0.4	0.8	-22.5	22.5
72	0.3	-0.1	-12.2	12.2

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
73	0.1	0.2	0.0	0.3
74	1.1	-3.0	-16.1	16.4
75	0.9	0.2	-14.0	14.0
76	0.4	-0.2	-8.6	8.6
77	0.1	0.2	0.0	0.2
81	4.0	1.0	-17.5	17.9
82	4.3	-0.7	-6.2	7.6
83	2.0	-0.2	-15.3	15.4
84	2.5	0.8	-11.7	12.0
85	3.0	0.0	-4.5	5.4

MAXIMUMABSOLUTE VALUES

NODE	15	10	47	47
VALUE	-5.2	6.1	-22.5	22.7

Combo #37

Tilt angles of -11 (radial) and 6 (tangential) degrees

Date: Dec 20, 1998

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
	[kN]	[kN]	[kN]	[kN-mm]	[kN-mm]	[kN-mm]
10	0.0	0.0	116.4	0.0	0.0	0.0
20	0.0	0.0	129.2	0.0	0.0	0.0
30	0.0	0.0	142.0	0.0	0.0	0.0
73	0.0	0.0	33.4	0.0	0.0	0.0
77	0.0	0.0	42.5	0.0	0.0	0.0

TOTAL VALUES

VALUE	0.0	0.0	463.5	0.0	0.0	0.0

Combo #37

Tilt angles of -11 (radial) and 6 (tangential) degrees

Date: Dec 20, 1998

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	-2.7	4.4	-16.7	17.5
2	-3.2	3.8	-18.0	18.6
3	-1.8	2.4	-20.4	20.6
7	-3.9	2.3	-14.7	15.4
8	-3.4	1.0	-17.7	18.1
9	-2.9	-0.2	-17.2	17.5
10	-2.8	6.1	0.0	6.7
11	-2.8	6.1	0.0	6.7
12	-3.2	5.9	-7.4	10.0
13	-4.0	5.2	-10.4	12.3
14	-4.9	4.3	-7.4	9.9
15	-5.2	3.0	0.0	6.1
20	-5.2	3.0	0.0	6.1
21	-5.2	3.0	-0.1	6.1
22	-3.5	3.2	-16.1	16.8
23	-2.0	1.9	-22.5	22.7
24	-0.8	0.5	-16.1	16.1
25	0.0	0.0	-0.1	0.1
30	0.0	0.0	0.0	0.0
31	0.0	0.0	-0.1	0.1
32	-1.0	1.2	-11.3	11.4
33	-1.7	3.1	-16.5	16.9
34	-2.4	5.1	-12.3	13.5
35	-2.8	6.1	-0.1	6.7
40	-5.2	2.3	-4.0	7.0
41	-4.5	1.3	-9.5	10.6
42	-2.9	-0.7	-16.1	16.4
43	-3.6	0.1	-9.5	10.2
44	-2.8	-1.3	-4.0	5.1
45	-2.6	-1.5	-8.7	9.2
46	-2.8	0.2	-20.6	20.8
47	-2.7	1.4	-22.5	22.7
48	-2.6	2.7	-20.7	21.0
49	-2.0	4.9	-8.7	10.2
50	-2.0	5.4	-6.1	8.4
51	-2.6	4.6	-14.9	15.8
52	-3.0	4.0	-16.5	17.2
53	-3.5	3.3	-15.4	16.2
54	-4.7	2.6	-6.7	8.6
64	-2.8	2.1	-21.5	21.8
65	-3.0	3.5	-18.5	19.1
67	-3.9	2.8	-12.3	13.2
71	0.4	0.8	-22.5	22.5
72	0.3	-0.1	-12.2	12.2

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
73	0.1	0.2	0.0	0.3
74	1.1	-3.0	-16.1	16.4
75	0.9	0.2	-14.0	14.0
76	0.4	-0.2	-8.6	8.6
77	0.1	0.2	0.0	0.2
81	4.0	1.0	-17.5	17.9
82	4.3	-0.7	-6.2	7.6
83	2.0	-0.2	-15.3	15.4
84	2.5	0.8	-11.7	12.0
85	3.0	0.0	-4.5	5.4

MAXIMUM	ABSOLUTE	VALUES		
NODE	33	13	23	23
VALUE	54.3	62.7	-34.1	70.0

Input file for DRAO#1

```
create
/title, LAR-Backing Structure (DRAO#1), August 14, 1999
!
!==========================================================================
! LAR
! Finite Element Model for LAR Space Frame Structure (Tilted)
! Rev Date      Note
!
!==========================================================================
!SECTION 1: Definition of elements, materials and sections
!==========================================================================
! Define element type
et,1,pipe16,,,,0,,2
et,2,mass21
!
! Define material properties of steel
mp,ex,1,200                  ! Young's modulus in kN/mm2
mp,dens,1,7.85e-12           ! density in kN-sec^2/mm^4 (w/a =9810 mm/sec^2)
mp,nuxy,1,0.3                ! Poisson's ratio
mp,gxy,1,79.29               ! shear ratio in kN/mm2
mp,alpx,1,11.7e-6            ! thermal expansion coeff. / deg. C
!
! Define shapes in mm, mm
! r,no,OD,Tkwall
r,11,168,7.112                          !Top/ Bottom Chords
r,12,168,7.112                          !Web
r,13,0.001825,0.001825,0.001825         !Panel mass per actuator
! Specify coordinate system and material
!==========================================================================
!SECTION 2: Geometry definition
!==========================================================================
! Define nodes
! Assuming 3.5m Flat Panels, 21m Triangular Unit
!
!node,#,x,y,z
local,11,0,,,,,-11,6
n,1,7875,4547,0                         ! Center points (top)
n,2,13125,4547,0
n,3,10500,9093,0
n,4,13125,-4547,0                       ! Cantilever truss points (top)
n,5,18375,13640,0
n,6,0,9093,0
n,7,14438,-2273,-1829               ! Cantilever truss points (bottom)
n,8,15750,13640,-1829
n,9,1313,6820,-1829
n,10,0,0,0                                      ! Top chord
n,11,20,0,0
n,12,5250,0,0
n,13,10500,0,0
n,14,15750,0,0
n,15,20980,0,0
n,20,21000,0,0
n,21,20990,17,0
n,22,18375,4547,0
n,23,15750,9093,0
```

```
n,24,13125,13640,0
n,25,10510,18169,0
n,30,10500,18187,0
n,35,10,17,0
n,34,2625,4547,0
n,33,5250,9093,0
n,32,7875,13640,0
n,31,10490,18169,0
n,40,2635,0,-1829                    ! Bottom chord
n,41,7875,0,-1829
n,42,15750,0,-1829
n,43,13125,0,-1829
n,44,18365,0,-1829
n,45,19683,2282,-1829
n,46,17063,6820,-1829
n,47,13125,13640,-1829
n,48,14438,11367,-1829
n,49,11818,15905,-1829
n,50,9183,15905,-1829
n,51,6563,11367,-1829
n,52,2625,4547,-1829
n,53,3938,6820,-1829
n,54,1318,2282,-1829
n,61,5250,4547,-1829
n,62,14438,2273,-1829
n,63,11813,11367,-1829
mat,1                                    ! Circular HSS
type,1
real,11
en,1,10,11
en,2,11,12
en,3,12,13
en,4,13,14
en,5,14,15
en,6,15,20
en,11,20,21
en,12,21,22
en,13,22,23
en,14,23,24
en,15,24,25
en,16,25,30
en,21,30,31
en,22,31,32
en,23,32,33
en,24,33,34
en,25,34,35
en,26,35,10
en,33,1,34
en,34,2,14
en,35,3,24
en,41,40,41
en,42,41,43
en,43,42,43
en,44,42,44
en,45,45,46
en,46,46,48
```

```
en,47,47,48
en,48,47,49
en,50,50,51
en,51,51,53
en,52,52,53
en,53,52,54
en,55,40,54
en,56,44,45
en,57,49,50
en,30,4,14                                  ! Cantilever sections
en,31,5,24
en,32,6,34
en,37,52,61
en,38,42,62
en,39,47,63
en,91,4,7
en,92,7,14
en,93,7,42
en,94,5,8
en,95,8,24
en,96,8,47
en,97,6,9
en,98,9,34
en,99,9,52
type,1
real,12
en,61,11,40                                 ! Truss webs
en,62,12,40
en,63,12,41
en,64,13,41
en,65,14,42
en,66,13,43
en,67,14,43
en,68,14,44
en,69,15,44
en,71,21,45
en,72,22,45
en,73,22,46
en,74,23,46
en,75,24,47
en,76,23,48
en,77,24,48
en,78,24,49
en,79,25,49
en,81,31,50
en,82,32,50
en,83,32,51
en,84,33,51
en,85,34,52
en,86,33,53
en,87,34,53
en,88,34,54
en,89,35,54
en,121,1,61
en,122,34,61
en,123,2,62
```

```
en,124,14,62
en,125,3,63
en,126,24,63

type,2                              ! Panels
real,13
en,101,10
en,102,12
en,103,13
en,104,14
en,105,20
en,106,22
en,107,23
en,108,24
en,109,30
en,110,32
en,111,33
en,112,34
en,113,1
en,114,2
en,115,3
en,116,4
en,117,5
en,118,6
! Define boundary conditions
local,90,0,,,,-30
nsel,s,node,,10,30,10
nrotat,all
d,10,uz,0,,30,10
d,20,uy,0,,30,10
d,30,ux,0
nall
eall
/view,,0,-1,1
/pbc,all,1
eplot
/eof
load
!========================================================================
!Section 3: Loads
!========================================================================
! Load Case 1: Gravity Load
acel,,,9810
/eof
post
/format,,f,,3
/output,drao_t,out
/output
/eof
!
```

DRAO#1

No tilt.

Date: Dec 20, 1998

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
	[kN]	[kN]	[kN]	[kN-mm]	[kN-mm]	[kN-mm]
10	0.0	0.0	133.8	0.0	0.0	0.0
20	0.0	0.0	133.8	0.0	0.0	0.0
30	0.0	0.0	133.8	0.0	0.0	0.0

TOTAL VALUES

VALUE	0.0	0.0	401.4	0.0	0.0	0.0

DRAO#1

No tilt.

Date: Dec 20, 1998

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	0.6	3.2	-25.0	25.2
2	-2.9	3.9	-25.1	25.6
3	-2.4	0.3	-25.2	25.3
4	-4.4	3.6	-13.5	14.7
5	-1.2	-1.2	-13.4	13.5
6	0.9	4.4	-13.6	14.3
7	-0.6	1.3	-13.3	13.4
8	-1.1	3.4	-13.3	13.8
9	-2.8	2.3	-13.4	13.9
10	0.0	4.9	0.0	4.9
11	0.0	4.9	-0.1	4.9
12	-0.5	4.7	-11.9	12.8
13	-1.9	4.2	-17.4	18.0
14	-3.5	3.3	-13.4	14.3
15	-4.2	2.4	-0.1	4.9
20	-4.2	2.4	0.0	4.9
21	-4.2	2.4	-0.1	4.9
22	-4.0	1.9	-11.9	12.7
23	-3.1	0.9	-17.4	17.7
24	-1.4	0.0	-13.5	13.5
25	0.0	0.0	-0.1	0.1
30	0.0	0.0	0.0	0.0
31	0.0	0.0	-0.1	0.1
32	0.0	0.6	-11.9	11.9
33	0.2	2.1	-17.4	17.6
34	0.4	3.9	-13.4	14.0
35	0.0	4.9	-0.1	4.9
40	-3.9	1.8	-6.4	7.7
41	-2.9	1.7	-15.6	16.0
42	-0.4	1.0	-13.5	13.5
43	-1.3	1.3	-16.7	16.8
44	0.2	0.6	-7.2	7.3
45	0.4	0.5	-6.4	6.4
46	-0.3	1.4	-15.6	15.7
47	-0.9	3.8	-13.5	14.0
48	-0.8	2.9	-16.7	16.9
49	-0.8	4.6	-7.3	8.6
50	-0.8	5.0	-6.4	8.1
51	-1.5	4.2	-15.6	16.2
52	-3.2	2.3	-13.5	14.0
53	-2.6	2.9	-16.7	17.1
54	-3.7	1.9	-7.3	8.4
61	-3.4	1.9	-19.1	19.5
62	0.1	1.0	-19.2	19.2
63	-1.3	4.3	-19.2	19.7

MAXIMUM ABSOLUTE VALUES

NODE	4	50	3	2
VALUE	-4.4	5.0	-25.2	25.6

DRAO#1

Tilt angles of -11 (radial) and 6 (tangential) degrees

Date: Dec 20, 1998

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
	[kN]	[kN]	[kN]	[kN-mm]	[kN-mm]	[kN-mm]
10	0.0	0.0	134.5	0.0	0.0	0.0
20	0.0	0.0	133.8	0.0	0.0	0.0
30	0.0	0.0	133.1	0.0	0.0	0.0

TOTAL VALUES

VALUE	0.0	0.0	401.4	0.0	0.0	0.0

DRAO#1

Tilt angles of -11 (radial) and 6 (tangential) degrees
Date: Dec 20, 1998

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	-46.1	29.8	-40.6	68.3
2	163.1	314.2	-143.0	381.7
3	322.3	-4.9	-3.6	322.4
4	-147.8	322.3	-20.0	355.2
5	148.7	293.3	-141.5	358.0
6	5.8	55.9	-9.2	57.0
7	-72.4	257.4	-35.4	269.7
8	133.0	173.6	-88.9	236.0
9	-34.2	38.8	-9.0	52.6
10	0.1	4.8	0.0	4.8
11	0.1	5.2	-0.2	5.2
12	-1.6	150.0	-40.0	155.2
13	-3.5	276.6	-70.2	285.4
14	-4.7	228.3	-57.0	235.3
15	-4.1	3.3	-0.2	5.3
20	-4.1	2.4	0.0	4.7
21	-3.3	2.8	-0.3	4.3
22	184.6	104.0	-51.9	218.1
23	248.4	136.9	-70.6	292.3
24	154.1	83.8	-46.3	181.4
25	0.5	0.2	-0.2	0.6
30	0.0	0.0	0.0	0.0
31	0.5	-0.3	0.0	0.5
32	59.0	-37.0	-10.8	70.5
33	9.8	-7.7	-16.5	20.7
34	-43.6	26.6	-13.2	52.7
35	-0.2	5.0	-0.1	5.0
40	-4.4	51.3	-15.0	53.7
41	-4.3	205.8	-54.4	213.0
42	-1.8	210.7	-53.9	217.4
43	-2.9	261.3	-66.7	269.6
44	-0.6	114.2	-29.2	117.8
45	100.5	54.7	-27.8	117.7
46	226.5	124.0	-64.0	266.1
47	136.0	77.3	-43.1	162.2
48	203.3	112.9	-60.4	240.2
49	55.0	34.2	-19.9	67.7
50	55.0	-29.6	-6.4	62.8
51	43.9	-26.4	-14.9	53.4
52	-52.2	28.2	-12.6	60.7
53	-29.1	14.6	-15.8	36.2
54	-48.5	26.9	-6.4	55.9
61	-53.8	20.6	-24.3	62.5
62	74.5	249.1	-95.0	276.8
63	220.4	33.0	-21.7	223.9

MAXIMUM ABSOLUTE VALUES				
NODE	3	4	2	2
VALUE	322.3	322.3	-143	381.7

Input file for the Bridging System

```
create
/title, LAR-Backup Structure , August 06, 1998
! Created by Ya-Ying Chang
!==========================================================================
! LAR
! Finite Element Model for LAR Backing Structure
! Rev Date       Note: Equilateral Triangle (21m)
!
!==========================================================================
!SECTION 1: Definition of elements, materials and sections
!==========================================================================
! Define element type
et,1,pipe16,,,,0,,2
et,2,mass21
!
! Define material properties of steel
mp,ex,1,200                 ! Young's modulus in kN/mm2
mp,dens,1,7.85e-12          ! density in kN-sec^2/mm^4 (w/a =9810 mm/sec^2)
mp,nuxy,1,0.3               ! Poisson's ratio
mp,gxy,1,79.29              ! shear ratio in kN/mm2
mp,alpx,1,11.7e-6           ! thermal expansion coeff. / deg. C
!
! Define shapes in mm, mm
! r,no,OD,Tkwall
r,11,168,7.112                        !Top/ Bottom Chords
r,12,168,7.112                        !Web
r,13,0.001825,0.001825,0.001825       !Panel mass per actuator
! Specify coordinate system and material
!==========================================================================
!SECTION 2: Geometry definition
!==========================================================================
!Local systems
local,11,0,,,,-30
local,12,0,10500,-18186.5335,0,-30,10,10
local,13,0,,,,30
!n,1000,0,0,0
local,90,0,10500,-18186.5335,0,,-11,6
csys,90
n,1,0,0,0
n,2,-5250,0,0
n,3,-10500,0,0
n,4,-15750,0,0
n,5,-21000,0,0
n,6,-2625,0,-1800
n,7,-7875,0,-1800
n,8,-10500,0,-1800
n,9,-13125,0,-1800
n,10,-18375,0,-1800
n,11,-13125,-4546.633375,0
n,31,-21000,0,0
n,32,-18375,-4546.63338,0
n,33,-15750,-9093.26675,0
n,34,-13125,-13639.90013,0
n,35,-10500,-18186.5335,0
n,36,-19687.5,-2273.31669,-1800
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```
n,37,-17062.5,-6819.95006,-1800
n,38,-15750,-9093.26675,-1800
n,39,-14437.5,-11366.58344,-1800
n,40,-11812.5,-15913.21681,-1800
n,41,-10500,-9093.26675,0
n,61,-10500,-18186.5335,0
n,62,-7875,-13639.90013,0
n,63,-5250,-9093.26675,0
n,64,-2625,-4546.63338,0
n,65,0,0,0
n,66,-9187.5,-15913.21681,-1800
n,67,-6562.5,-11366.58344,-1800
n,68,-5250,-9093.26675,-1800
n,69,-3937.5,-6819.95006,-1800
n,70,-1312.5,-2273.31669,-1800
n,71,-7875,-4546.633375,0
n,72,-7875,-13639.90013,-1800
!Bridging system
n,201,-5250,-9093.26675,0
n,202,0,-9093.26675,0
n,203,5250,-9093.26675,0
n,204,-2625,-9093.26675,-1800
n,205,2625,-9093.26675,-1800
n,211,-7875,-13639.90013,0
n,212,-2625,-13639.90013,0
n,213,2625,-13639.90013,0
n,214,7875,-13639.90013,0
n,215,-5250,-13639.90013,-1800
n,216,0,-13639.90013,-1800
n,217,5250,-13639.90013,-1800
!
type,1
real,11
en,1,1,2
en,2,2,3
en,3,3,4
en,4,4,5
en,5,6,7
en,6,7,8
en,7,8,9
en,8,9,10
en,9,1,6
en,10,6,2
en,11,2,7
en,12,7,3
en,13,3,8
en,14,3,9
en,15,9,4
en,16,4,10
en,17,10,5
en,18,3,11
en,19,11,33
en,20,8,11
en,21,11,38
en,22,10,36
en,23,8,38
```

```
engen,30,2,30,1,23
engen,30,2,30,31,48
en,79,71,3
en,80,68,71
en,81,71,8
en,82,70,6
en,83,68,8
!
type,1
real,11
en,501,201,202
en,502,202,203
en,503,204,205
en,504,201,204
en,505,204,202
en,506,202,205
en,507,205,203
en,511,211,212
en,512,212,213
en,513,213,214
en,514,215,216
en,515,216,217
en,516,211,215
en,517,215,212
en,518,212,216
en,519,216,213
en,520,213,217
en,521,217,214
en,522,204,215
en,523,205,217
en,524,202,212
en,525,202,213
type,2                              !panel
real,13
en,24,1
en,25,2
en,26,3
en,27,4
en,28,11
engen,30,3,30,24,28
en,508,202
en,532,212
en,533,213
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/eof
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/clear
/prep7
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*use,bc
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*use,deadl
/eof
```

Bridging System

No tilt.

Date: Dec 20, 1998

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
	[kN]	[kN]	[kN]	[kN-mm]	[kN-mm]	[kN-mm]
1	0.0	0.0	130.2	0.0	0.0	0.0
31	0.0	0.0	116.8	0.0	0.0	0.0
61	0.0	0.0	143.2	0.0	0.0	0.0
201	-0.2	0.1	0.0	0.0	0.0	0.0
203	0.2	0.1	14.9	0.0	0.0	0.0
211	0.2	-0.1	0.0	0.0	0.0	0.0
214	-0.2	-0.1	25.3	0.0	0.0	0.0
TOTAL VALUES						
VALUE	0.0	0.0	430.5	0.0	0.0	0.0

Bridging System

No tilt.

Date: Dec 20, 1998

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UX [mm]	UY [mm]	UZ [mm]	USUM [mm]
1	0.0	0.0	0.0	0.0
2	0.5	0.6	-11.5	11.5
3	1.9	1.4	-16.3	16.5
4	3.2	0.8	-11.3	11.7
5	3.7	0.5	0.0	3.8
6	3.7	3.1	-6.1	7.8
7	2.7	2.5	-14.9	15.4
8	1.8	2.1	-16.4	16.6
9	1.1	2.3	-14.7	15.0
10	0.1	2.7	-6.0	6.6
11	2.2	1.4	-18.4	18.6
31	3.7	0.5	0.0	3.8
32	3.2	0.8	-11.4	11.8
33	2.1	1.7	-16.5	16.7
34	2.1	3.3	-11.6	12.2
35	2.4	4.1	0.0	4.7
36	0.0	2.7	-6.1	6.6
37	0.8	2.0	-14.9	15.1
38	1.4	1.4	-16.6	16.7
39	1.4	0.5	-15.1	15.2
40	1.3	-0.9	-6.2	6.4
41	2.2	1.7	-19.8	20.0
61	2.4	4.1	0.0	4.7
62	2.4	3.2	-14.9	15.4
63	2.1	1.3	-20.5	20.7
64	0.7	0.3	-14.0	14.0
65	0.0	0.0	0.0	0.0
66	1.3	-0.9	-8.0	8.2
67	1.6	0.7	-19.0	19.1
68	1.8	1.7	-20.5	20.7
69	2.6	2.4	-18.4	18.8
70	3.7	3.1	-7.5	8.9
71	1.9	1.2	-19.7	19.8
201	-0.3	-0.6	-20.5	20.5
202	-0.5	0.3	-11.2	11.2
203	-0.6	1.0	0.0	1.2
204	2.9	-0.9	-16.0	16.2
205	3.2	1.2	-5.7	6.7
211	0.9	1.5	-14.9	15.0
212	0.6	-0.3	-13.2	13.2
213	0.1	0.6	-8.2	8.2
214	-0.2	0.3	0.0	0.4
215	1.5	-0.1	-14.3	14.3
216	2.0	-0.3	-11.1	11.3
217	2.5	0.8	-4.3	5.1

MAXIMUM ABSOLUTE VALUES

NODE	6	35	68	68
VALUE	3.723	4.084	-20.54	20.69

APPENDIX F: CONNECTION RESISTANCE

FORMATETTED SPREADSHEET FOR
CONNECTION RESISTANCE CALCULATION

PROJECT	LAR	SECTION	1
TITLE	Weld Resistance	DATE	3/02/00
FILE	Truss_1.xls	TIME	11:08 AM

Case 1: Typical Warren Truss

INPUTS					
yield strength	Fy	=			350 Mpa
angle	θ_1	=			34.4 deg
MEMBER SELECTION					
Chord: 168x4.8					
diameter	d_0	=			168 mm
thickness	t_0	=			4.78 mm
area	A_0	=			2460 mm^2
mass	Mc	=			19.3 kg/m
parameter check	Chk1	=	if(d_0/t_0<50,"O.K.","Too slender")	=	O.K.
Web: 73x3.8					
diameter	d_1	=			73 mm
thickness	t_1	=			3.81 mm
area	A_1	=			828 mm^2
mass	Mw	=			6.5 kg/m
parameter check	Chk2	=	if(d_1/t_1<50,"O.K.","Too slender")	=	O.K.
Resistance Calculation					
At Panel Point B					
effective length (chord)	KLc	=			4725 mm
effective length (web)	KLw	=			2387 mm
	A	=	d_1/(2*SIN(θ_1*PI()/180))	=	65 mm
	B	=	d_1/(2*SIN(θ_1*PI()/180))	=	65 mm
	C	=	SIN(θ_1*PI()/180)^2/SIN(2*θ_1*PI()/180)	=	0.34
	D	=	d_0/2	=	84 mm
eccentricity	e	=	C*(A+B+g)-D	=	-31 mm
gap	g	=			25 mm
	g'	=	g/t_0	=	5
	C_K	=			0.26
	Nop	=			-300.00 kN
	n	=	Nop/(A_0*Fy)*1000	=	-0.35
	fn'	=	1+0.3*n-0.3*n^2	=	0.86
connection resistance	N_1	=	CK*(t_0/t_1)*(1/sin(θ_1*pi()/180))*fn'*A_1*Fy/1000	=	144 kN
web comp. resistance	Cr	=			172 kN
comp. Force in web	CFw	=			141.5 kN
resistance check	Chk3	=	if(min(N1,Cr)>CFw,"O.K.","Failure")	=	O.K.
eccentricity check	Chk4	=	if(e/d0>=-0.55,if(e/d0<=0.25,"O.K.","Select e"),"Select e")	=	O.K.
punching shear	N_{ps}	=	Fy/sqrt(3)*t_0*pi()*d_1*(1+SIN(θ_1*PI()/180))/(2*SIN(θ_1*PI()/180)^2)/1000	=	543.0 kN
Weight Calculation					
chord length required	lenc	=			36.75 m
web length required	lenw	=			25.46 m
total weight of chords	Wc	=	lenc*Mc	=	709 kg
total weight of webs	Ww	=	lenw*Mw	=	166 kg
total weight	W	=	Wc+Ww	=	875 kg

Note:

- C_K is taken from Figure 3.14 of "Design Guide for Hollow Structural Section Connections" by Packer & Henderson.
- Cr is taken from Section 4 of "Steel Handbook of Construction", sixth ed.

	PROJECT	LAR	SECTION	1
	TITLE	Weld Resistance	DATE	3/02/00
	FILE	Truss_1.xls	TIME	11:49 AM

Case 1: Typical Warren Truss

INPUTS					
yield strength	Fy	=			350 Mpa
angle	θ_1	=			34.4 deg
MEMBER SELECTION					
Chord: 168x4.8					
diameter	d_0	=			168 mm
thickness	t_0	=			4.78 mm
area	A_0	=			2460 mm^2
mass	Mc	=			19.3 kg/m
parameter check	Chk1	=	if(d_0/t_0<50,"O.K.","Too slender")	=	O.K.
Web: 89x3.8					
diameter	d_1	=			88.9 mm
thickness	t_1	=			3.81 mm
area	A_1	=			1020 mm^2
mass	Mw	=			8.0 kg/m
parameter check	Chk2	=	if(d_1/t_1<50,"O.K.","Too slender")	=	O.K.
Resistance Calculation					
At Panel Point C					
effective length (chord)	KLc	=			4725 mm
effective length (web)	KLw	=			2387 mm
	A	=	d_1/(2*SIN(θ_1*PI()/180))	=	79 mm
	B	=	d_1/(2*SIN(θ_1*PI()/180))	=	79 mm
	C	=	SIN(θ_1*PI()/180)^2/SIN(2*θ_1*PI()/180)	=	0.34
	D	=	d_0/2	=	84 mm
eccentricity	e	=	C*(A+B+g)-D	=	-22 mm
gap	g	=			25 mm
	g'	=	g/t_0	=	5
	C_K	=			0.26
	Nop	=			-300.00 kN
	n	=	Nop/(A_0*Fy)*1000	=	-0.35
	fn'	=	1+0.3*n-0.3*n^2	=	0.86
connection resistance	N_1	=	CK*(t_0/t_1)*(1/sin(θ_1*pi()/180))*fn'*A_1*Fy/1000	=	177 kN
web comp. resistance	Cr	=			172 kN
comp. Force in web	CFw	=			70.7 kN
resistance check	Chk3	=	if(min(N1,Cr)>CFw,"O.K.","Failure")	=	O.K.
eccentricity check	Chk4	=	if(e/d0>=-0.55,if(e/d0<=0.25,"O.K.","Select e"),"Select e")	=	O.K.
punching shear	N_{ps}	=	Fy/sqrt(3)*t_0*pi()*d_1*(1+SIN(θ_1*PI()/180))/(2*SIN(θ_1*PI()/180)^2)/1000	=	661.3 kN
Weight Calculation					
chord length required	lenc	=			36.75 m
web length required	lenw	=			25.46 m
total weight of chords	Wc	=	lenc*Mc	=	709 kg
total weight of webs	Ww	=	lenw*Mw	=	204 kg
total weight	W	=	Wc+Ww	=	913 kg

Note:

- C_K is taken from Figure 3.14 of "Design Guide for Hollow Structural Section Connections" by Packer & Henderson.
- Cr is taken from Section 4 of "Steel Handbook of Construction", sixth ed.