## **Evaluation of a Cable-Stayed Roof Design**

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by

Michael Scott Woods

B.S., Civil and Environmental Engineering MIT, 1997

Submitted to the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of

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> > at the

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### Abstract

This thesis presents a tool for evaluating the performance of a cable-stayed roof, proposed for a new Civil and Environmental Engineering Department building. The CEE building (as designed by the author and the other members of his team as part of the 1998 M.Eng. High-Performance Group Project) is introduced, the relevant design criteria are listed, and a design of the roof is described. Then, the basis and implementation (in Matlab) of the analytical model are presented. Lastly, the model is used to evaluate the roof design and propose changes.

Thesis Supervisor: Prof. Jerome J. Connor Title: Professor, Civil and Environmental Engineering

# **Table of Contents**

1	Intro	duction	6
	1.1	The Building	7
2	Desig	n Criteria	9
	2.1	Loads	9
	2.2	Strength	10
	2.3	Deflection	10
	2.4	Stability	11
3	Initia	l Roof Design	12
	3.1	The Roof System	12
		3.1.1Cables	14
		3.1.2Piers	20
		3.1.3Roof Truss	23
	3.2	Design Improvements	23
	3.3	Construction	24
4	Anal	ytical Model	26
	4.1	Basis and Implementation of the Model	26
5	Case	Study Using the Analysis Engine	31
	5.1	Deflection Under Service Dead Load	31
	5.2	Deflection Under Snow (Live), Wind, and Dead Load	32
	5.3	Cable Stresses	33
	5.4	Correcting the Design	34
6	Conc	lusion	35
Re	eferen	ces	.37
A	pend	ix A: Purpose & Guiding Principles for the New CEE Building	38
A	pend	ix B: Matlab Code for Pier Geometry (muse.m & Ww.m)	39
A	- ppend	ix C: Matlab Code for Roof Evaluation (engine.m & infile_r1.m)	41
Δ.	nond	iv D. Mast I gading Data & Mast Design Data	51
4 M J	Pulu	ia Di must Douving Data & mast Dosign Data	

# **List of Figures**

Figure 1.1: Proposal for the New CEE Building (by Thu Nguyen)	7
Figure 3.1: Perspective View of the Roof Truss, Cables, and Piers	13
Figure 3.2: Elevation View of the New CEE Building Drawn to Scale	13
Figure 3.3: Calculation of Vertical Deflection from Cable Elongation	15
Figure 3.4: Calculation of Cable Elongation	16
Figure 3.5: Cable Layout & Cable Deflection Data Spreadsheet	18
Figure 3.6: Points Establishing Pier Geometry (Key for muse.m Program)	20
Figure 3.7: Plan View Showing Column & Pier Locations	21
Figure 3.8a: Forces on the Pier.	22
Figure 3.8b: Forces on the Pier.	23
Figure 4.1: Beam Segment Forces and Displacements	27
Figure 4.2: Cables with Pre-Stress.	29
Figure 5.1: Deformation Due to Service Dead Load	31
Figure 5.2: Deformation Due to Full, Service Load	32

# **List of Tables**

 Table 1: Factored Load Combinations for Determining Required Strength in ACI Code
 9

Table 2: Cable Pre-Tensioning19

 Table 3: Coordinates of Points Establishing Pier Geometry
 21

Table 4: Displacements at Cable Connection Points (Full, Service Load--Both Sides) 33

Table 5: Cable Forces and Stresses34

### Chapter 1 Introduction

This thesis is concerned with the analysis of a cable-stayed roof which is part of a design proposed for a new MIT Civil and Environmental Engineering Department building. The cablestayed roof is the centerpiece of a creative and visible high performance structural system. This type of roof is relevant to a civil engineering building because it illustrates the power, elegance, and responsibility of civil engineering. Moreover, the resemblance to "half a cable-stayed bridge" is obvious and intentional.

The field of cable-stayed structures is an area of recent development in design and construction techniques. The use of this technology in the CEE Department's signature building would emphasize MIT's role in the development and use of state-of-the-art technology.

The cable-stayed roof represents a technical challenge, as the cables are required if the building's roof is to remain stable. Without the cables, the roof truss would need to be connected to the piers with a rigid connection which would need to resist a very large moment. The cables reduce displacements along the length of the roof by sharing the load that the space truss roof would otherwise carry alone.

Using cable-stays on the roof is also a construction challenge. One way to construct it would be to treat it like a bridge design, using the cantilever method. Construction would start at the mast or pier where some sections of the truss roof would be installed and connected to the innermost cables. Then construction would proceed moving outward from the pier in both directions as truss components and then cables were added. Cable tensions would be adjusted during this process to obtain a desired roof shape (flat or cambered) in the final product. Alternatively, the building underneath could be used as a staging area, where large sections of the truss could be

assembled then hoisted into place and connected to the cables.

This thesis is concerned with evaluating the performance of the roof. Of primary interest is the deflection of the roof and the stiffness requirements for various vertical load resisting components of the system. Matlab code is provided which enables a designer to vary all aspects of the system's geometry, the shear and bending stiffness of the roof, and the cable stiffness and pre-tensioning.

#### 1.1 The Building

MIT's Civil and Environmental Engineering Department is proposing the development of a new and unified building complex to house its academic, research, and administrative activities. A major goal for the CEE Department is to ensure that its visions and aspirations for the future directions of the profession are embodied and visible in the physical appearance of the complex. Thus the CEE Department is requesting a conceptual design for a showcase facility built with the most modern and advanced construction and technology to house the most modern educational and research technology.(Appendix A)

In answer to the Department's request, the Master of Engineering design team produced the design sketched below. (Sketch by Thu Nguyen.) [1]



Figure 1.1: Proposal for the New CEE Building

The complex is comprised of two rectangular buildings. In this thesis we are concerned with the larger building in particular, with its cable-stayed roof. It is a six-story building reaching 90 ft. at the underside of the roof truss. The truss height is 10 ft. The tops of the pier masts rise to 50 ft. above the truss roof, or 150 ft. above the ground. The mast tops are located a horizontal distance of 80 ft. from the left end of the building in the above figure. The masts are inclined at 60° with respect to the ground. The lower half of the lambda-shaped pier is in the form of an equilateral triangle with its apex 75 ft. above the ground. There is one lambda-shaped pier on each of the long sides of the building. Beams connecting the piers through the volume of the building provide lateral resistance.

The roof is 240 ft. long and 75 ft. wide. A dome projects through a circular hole in the space truss to the right of the pier in the above sketch. The presence of this circular hole in the roof should be accounted for if this design is developed beyond the conceptual phase. The space truss projects beyond the edges of the building.

On each of the long sides of the building is a set of twelve cables in a vertical plane which run from the mast top to points along the 240 ft. edge of the building. Lateral bracing for the space truss is provided by other cables.

### Chapter 2 Design Criteria

#### 2.1 Loads

Snow (or live), dead, wind, and earthquake loads are relevant to the design of the entire roof system including the lateral bracing. The loads used to generate an initial design [1] are as follows: snow/live load of 30 psf, an assumed dead load of 75 psf, wind pressure from 21 to 26 psf, and earthquake loading of 382 kips in the long direction (191 kip/pier) and 220 kips in the short (transverse) direction. The factored load combinations from the ACI code are used because they are more conservative than the Massachusetts Building Code.[2,3]

Condition	Factored load or load effect U
Basic	U=1.4D+1.7L
Winds	U=0.75(1.4D+1.7L+1.7W)
	U=0.75(1.4D+1.7W)
	U=0.9D+1.3W
	U=1.4D+1.7L
Earthquake	U=0.75(1.4D+1.7L+1.87E)
	U=0.75(1.4D+1.87E)
	U=0.9D+1.43E
	U=1.4D+1.7L

Table 1: Factored Load Combinations for Determining Required Strength in ACI Code

For the evaluation contained in this thesis, the only loads of interest are the vertical loads applied to the flat rectangular roof, i.e. snow, wind, and dead loads. The vertical wind load applied at the rooftop is 20.8 psf calculated according to the codes. In the analysis, conceptually, the roof is split in half along its long axis so that we examine one half of the roof, one plane of cables, and one pier. Hence, we are interested in the values per half of the roof, per unit length along the roof. These values are: 1.125 kip/foot of snow, 0.78 kip/foot of wind, and 2.81 kip/foot of dead load. These values can be factored according to Table 1 when using the analysis program for design.

#### 2.2 Strength

All structures are subjected to loads during their lifetimes which they must be able to resist in order to be safe. The roof must not fail under the loads given in section 2.1. While the focus of this thesis is on the deflection of cable-stayed roof designs due to various point and continuous loadings, the strength and stressing of the cables is discussed in some detail. The strength-based design of the piers is outlined in chapter 3 which concerns an initial design proposal. The strength of the roof truss is not addressed in this thesis. (See reference 1 for more details.)

#### **2.3 Deflection**

Serviceability is of utmost concern in this thesis. It is important to limit deflections at points along the roof to acceptable values. Deflection criteria for the roof are based on current engineer-ing practice, according to the formulas below. [4]

$$\Delta_{live, \, service} \le \frac{L}{360} \tag{2.3.1}$$

$$\Delta_{live + dead, service} \le \frac{L}{240} \tag{2.3.2}$$

The maximum allowable deflection, found using equation 2.3.1, for the right- and leftmost points of the roof are 3.6" and 4.4" respectively. Equation 2.3.2 is not an issue since cable pretensioning is used to eliminate dead load deflection.

### 2.4 Stability

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This thesis is concerned with overturning of the roof due to pivoting about its pinned connection to a beam running between the piers. Member buckling and global buckling of the truss are not treated.

### Chapter 3 Initial Roof Design

What follows, in this chapter, is a description of the roof system designed for the new CEE Department building. [1] The performance of this design and some alternatives will be evaluated in chapter 5, using the analysis engine of chapter 4.

#### 3.1 The Roof System

For the most part, the roof and the building it covers are structurally separate; indeed, the gravity load of the roof is not resisted by the framing of the six story building at all. This aspect of the design is discernible in three ways, as figures 3.1 and 3.2 show. First, the piers/masts stand just outside the 240' long exterior walls of the six-story building. Second, there is a bank of windows all around the sixth floor. Third, the top floor is free of columns. Lateral bracing of the piers might be integrated into frame of the six story building in a further design stage.

Massive, reinforced-concrete piers support the space truss roof, while steel cables connected to the mast resist a portion of the vertical loads acting on the roof. A lambda-shaped pier on each of the long sides of the building rises 150' vertically to the point where the cables are attached. The two piers support the entire weight of the roof system as well as the moments (in the x-y plane in all of the following figures) resulting from the non-symmetric cable layout and location of the point of attachment of the roof truss. The lateral bracing system of the masts consists of beams passing between the two lambda-shaped piers.



Figure 3.1: Perspective View of the Roof Truss, Cables, and Piers

As this is a conceptual design some loads are assumed and connections simplified. However, the design proves a useful test case for the analysis model in chapter 4.

The next *design* stage would involve the generation of a computer model for the *entire* building which would suggest changes beyond the conceptual design, such as linking the piers to the six story building for greater lateral reinforcement or altering the kinds of connections between elements.



Figure 3.2: Elevation View of the New CEE Building Drawn to Scale

#### 3.1.1 Cables

Twenty-four 50 ksi steel cables counteract deflection and resist a portion of the load applied to the roof truss. Twelve cables are attached to the top of each mast and connect to points along the 240' edge of the roof adjacent to the mast. As these cables are arranged in a vertical plane, they only resist vertical forces applied to the roof. The cables are prestressed so that there is no deflection in the roof due to dead load.

The mast top is located 50 ft. above the roof (or 150 ft. above the ground) and 80 ft. from the left-hand side of the roof truss. (Figure 3.2) Since the roof truss modules are 6 ft., the cables are attached to the truss at intervals which are multiples of 6 ft.. For aesthetic reasons, the attachment points of the leftmost six cables are spaced at 18 ft., while for the other six the spacing is 24 ft.

The means of calculating the vertical deflection and vertical stiffness of the cables (vertical stiffness is the force required for a unit vertical deflection at the cable connection point) are illustrated in figures 3.3 and 3.4. Equations 3.1.1 through 3.1.8, developed from these figures, are used in the cable deflection data spreadsheet (Figure 3.5) and in the analysis model of chapter 4.



Figure 3.3: Calculation of Vertical Deflection from Cable Elongation

$$\frac{e}{\sin\theta} \cong \Delta = VerticalDeflection$$

(3.1.1)



Figure 3.4: Calculation of Cable Elongation

$$Tension \cdot \sin\theta = F_{vert} \tag{3.1.2}$$

$$T = \frac{F_{vert}}{\sin\theta} \tag{3.1.3}$$

$$k = \frac{EA}{L} \tag{3.1.4}$$

$$e = \frac{T}{k} = \frac{L}{EA} \cdot \frac{F_{vert}}{\sin\theta}$$
(3.1.5)

 $k_{vert} \cdot \Delta = F_{vert} \tag{3.1.6}$ 

$$\Delta \cong \frac{e}{\sin\theta} = \frac{L}{EA} \cdot \frac{F_{\nu}}{\left(\sin\theta\right)^2}$$
(3.1.7)

$$k_{vert} = \frac{EA}{L} \cdot (\sin\theta)^2$$
(3.1.8)

The cable deflection data spreadsheet (Figure 3.5) shows the cable locations and calculates the length, stiffness, and sine of the angle (with respect to the roof) of each cable given its area and material properties. Tension, stress, elongation, and vertical deflection of the point of attachment to the roof truss are also determined, given the vertical force which each cable is to resist. The magnitude of the vertical forces result is determined by distributing the roof loads to the cables using tributary areas and neglecting irregularities in uniform loads caused by the presence of the dome.

One can see that the spreadsheet in figure 3.5 does not account for a strength reduction factor, thus a factored cable stress greater than 45 ksi (or 0.9 \* 50 ksi) would be unacceptable. For example, if we wanted the cable system to resist all of the factored live and dead load, we see from the data that we would need to redesign the twelfth cable.

The prestress of the cable system is designed to equilibrate the unfactored roof dead load, hence roof deflection due to service dead load is eliminated. (See Table 2) The cables must also be strong enough to bear all of the factored dead load and at least a portion of the factored live load.

It is important to decide how much of the live load will be born by the cables and how much by the roof truss, keeping in mind that both sides of the roof must be loaded for the roof truss to carry any load. That is, the truss contributes stiffness when loads are applied to both sides of the pin connection of the truss to the piers, such that the resulting moments are balanced.

Cable deflection data
Final cable geometry
If load is taken as 1.4D+1.7L (2808 kip/roof)

II IOau IS	taken t		.76 (2000	Kip/1001)										
Cable	x	mast x	mast y	length (ft)	sin theta	E (ksi)	A (in^2)	EA/L	F vert	Tension	elong (ft)	defl vert (in)	Cable stress (ksi)	F horiz at mast
1	0	80	50	94.3	0.53	29000	4.9	1506	105	199	0.13	2.99	40.55	-168.48
2	18	80	50	79.6	0.63	29000	4.9	1784	105	168	0.09	1.80	34.23	-130.57
3	36	80	50	66.6	0.75	29000	4.9	2134	105	140	0.07	1.05	28.63	-92.66
4	54	80	50	56.4	0.89	29000	4.9	2521	105	119	0.05	0.64	24.22	-54.76
5	72	80	50	50.6	0.99	29000	4.9	2806	105	107	0.04	0.46	21.76	-16.85
6	90	80	50	51.0	0.98	29000	4.9	2787	105	107	0.04	0.47	21.92	21.06
7	120	80	50	64.0	0.78	29000	4.9	2219	70	90	0.04	0.62	18.29	56.00
8	144	80	50	81.2	0.62	29000	9.6	3428	140	228	0.07	1.30	23.76	179.71
9	168	80	50	101.2	0.49	29000	9.6	2751	140	284	0.10	2.51	29.60	247.10
10	192	80	50	122.7	0.41	29000	9.6	2270	140	344	0.15	4.47	35.88	314.50
11	216	80	50	144.9	0.35	29000	9.6	1921	140	407	0.21	7.36	42.38	381.89
12	240	80	50	167.6	0.30	29000	9.6	1661	140	471	0.28	11.40	49.03	449.28
									1404					1186.22
If load is	taken a	us D+L (1	890 kip/rc	oof)									<u> </u>	
Cable	х	mast x	mast y	length (ft)	sin theta	E (ksi)	A (in^2)	EA/L	F vert	Tension	elong (ft)	defl vert (in)	Cable stress (ksi)	F noriz at mast
1	0	80	50	94.3	0.53	29000	4.9	1506	71	134	0.09	2.01	27.34	-113.00
2	18	80	50	79.6	0.63	29000	4.9	1784	71	113	0.06	1.21	23.08	-00.04
3	36	80	50	66.6	0.75	29000	4.9	2134	/1	95	0.04	0.71	19.30	-02.40
4	54	80	50	56.4	0.89	29000	4.9	2521	71	80	0.03	0.43	10.33	-30.92
5	72	80	50	50.6	0.99	29000	4.9	2806	/1	72	0.03	0.31	14.07	-11.30
6	90	80	50	51.0	0.98	29000	4.9	2/8/	/1	12	0.03	0.32	14.70	14.20
1	120	80	50	64.0	0.78	29000	4.9	2219	44	50 154	0.03	0.39	16.07	121.60
8	144	80	50	81.2	0.62	29000	9.6	3428	95	154	0.05	0.88	20.02	121.00
9	168	80	50	101.2	0.49	29000	9.0	2/51	95	192	0.07	1.70	20.03	212.80
10	192	80	50	122.7	0.41	29000	9.0	2270	95	233	0.10	3.02	24.28	258 40
11	216	80	50	144.9	0.35	29000	9.0	1921	95	213	0.14	4.90 7 7	33.18	304.00
12	240	80	50	107.0	0.50	29000	9.0	1001	93	516	0.19	1.12	55.10	801.00
Ifloodic	tokon	No. L. (540	kin/roof)						943					001.00
Cable	v	mast v	mast v	length (ft)	sin theta	E (ksi)	A (in^2)	EA/L	F vert	Tension	elong (ft)	defl vert (in)	Cable stress (ksi)	F horiz at mast
1	Ô	80	50	94 3	0.53	29000	4.9	1506	20	38	0.03	0.57	7.70	-32.00
2	18	80	50	79.6	0.63	29000	4.9	1784	20	32	0.02	0.34	6.50	-24.80
3	36	80	50	66.6	0.75	29000	4.9	2134	20	27	0.01	0.20	5.44	-17.60
4	54	80	50	56.4	0.89	29000	4.9	2521	20	23	0.01	0.12	4.60	-10.40
5	72	80	50	50.6	0.99	29000	4.9	2806	20	20	0.01	0.09	4.13	-3.20
6	90	80	50	51.0	0.98	29000	4.9	2787	20	20	0.01	0.09	4.16	4.00
7	120	80	50	64.0	0.78	29000	4.9	2219	15	19	0.01	0.13	3.92	12.00
8	144	80	50	81.2	0.62	29000	9.6	3428	27	44	0.01	0.25	4.57	34.56
9	168	80	50	101.2	0.49	29000	9.6	2751	27	55	0.02	0.48	5.69	47.52
10	192	80	50	122.7	0.41	29000	9.6	2270	27	66	0.03	0.86	6.90	60.48
11	216	80	50	144.9	0.35	29000	9.6	1921	27	78	0.04	1.42	8.15	73.44
12	240	80	50	167.6	0.30	29000	9.6	1661	27	91	0.05	2.19	9.43	86.40
		50	50					-	270					230.40

**Table 2: Cable Pre-Tensioning** 

Chapter 4 describes an *analysis* model for the cable-truss interaction, but for design purposes the vertical load is divided between the truss and cables as follows: the cables carry all the factored dead load plus half the factored live load, while the truss supports half the live load. One can see from the spreadsheet in figure 3.5 that the cables deflect 0.57 in. and 2.19 in. under service live load at the left- and right-hand sides respectively; even without the bending stiffness of the space truss this is more than adequate. (The limiting values are 3.6 in. and 4.4 in.. Section 2.3) Looking at Case II. of the mast loading data (Appendix D) it can be seen that the greatest cable stress is 41 ksi, which is below the reduced cable strength of 45 ksi (0.9 \* 50 ksi). Thus the cable system of figure 3.2 (Described in figure 3.5) meets both strength and deflection criteria.

#### **3.1.2 Piers**

The first step in designing the masts supporting the cables and truss is to decide on its exact shape and location with respect to the building. The arrangement selected involves raising the mast to 150' (in order to generate reasonably steep cable angles) and angle it at 60 degrees (to reduce moments in the mast due cable-stays pulling at point A) and placing the mast such that point A has a horizontal coordinate of 80' from the left-hand side of the building. A Matlab program, muse.m, is used to generate coordinates of points on the masts as the angle and height of the elements are varied (Appendix B, Fig. 3.6, & Table 3); this information is used to enter the mast geometry in SAP2000 (Figs. 3.1 & 3.2). The pier footing locations are shown in figure 3.7. One can evaluate the structural effects of changes in the geometry of the mast and roof truss easily, with the arrangement of spreadsheets in figure 3.5 and appendix D.



Figure 3.6: Points Establishing Pier Geometry (Key for muse.m Program)

Point	Х	Y	Z
А	80	150	0
В	114.6	90	0
С	108.9	100	0
D	166.6	0	0
E	123.3	75	0
G	80	0	0

**Table 3: Coordinates of Points Establishing Pier Geometry** 



Figure 3.7: Plan View Showing Column & Pier Locations

The loads acting on one of the two lambda-shaped piers can be found in appendix D (Mast Loading Data). The cables and space truss (attached via pinned connections to the underside of a beam between the two piers, point c) transmit horizontal and vertical forces to the masts. The moments, shear forces, and axial forces which result are calculated on this spreadsheet.

Three gravity load cases are examined: A. Live load applied uniformly over the roof, B. Live load applied only to the cables on the right-hand side which pull the mast top in that direction, and C. Live load applied only to the cables that pull the mast top to the left. All member forces, moments, and reactions in the mast are calculated for Case II. A.B.C., where it is assumed

that the cables resist all the dead load and half the live load on the structure. (Appendix D: Mast Design Data & Figs. 3.8a,b)



Figure 3.8a: Forces on the Pier (Key for "Mast Design Data" Appendix D)

These values are used to calculate an estimate of the pier dimensions. [1] The resulting section has an effective depth of 7' and a width of 4', f'c = 5000 psi and fy = 60,000. This section would require both negative and positive reinforcement to resist changes in direction of moment that result from different load scenarios.

Similar means are employed using the earthquake load to estimate the dimensions of the five or six beams that join the two piers and act as lateral bracing. Approximate dimensions for those members are 3.5'x3.5'.



Figure 3.8b: Forces on the Pier (Use with "Mast Design Data" Appendix D)

#### 3.1.3 Roof Truss

The roof truss is connected with simple connections to the underside of a beam passing between the two masts and to the 24 cables. Additional tension members running from the foundation to the corners of the roof and/or from the top of the six story building laterally brace and stabilize the roof. A circular opening in the roof truss is intended to accommodate a dome. The truss forms a flat 240'x75' roof. It is assumed to weigh 75 psf of roof surface. As mentioned in section 3.1.1, the roof truss is intended to carry half of the roof live load, while the cables carry resist the rest of the live and other vertical loads.

#### **3.2 Design Improvements**

As the building is designed, the roof and piers do not carry much of the load, compared to the sixstory building frame. In the next design phase, it is recommended that one or more floors be suspended from the roof truss. This will make tension elements of the vertical elements in those floors, and allow the lower level columns to be more slender. The additional cost of suspending the upper stories from the roof truss and cables may be offset by two benefits gained by reducing the number and size of vertical members: Costs are reduced since there are fewer beam-column connections in the six story building and flexibility results from the larger bay sizes.

Given that the lateral bracing system of the masts consists of beams passing though the volume covered by the roof truss, the beams would be integrated with the floors of the six story building in a more detailed design. It is also likely that pin-connections between the concrete pier components would really be constructed as rigid joints, although this is more difficult to design. Furthermore, we assume for our conceptual design that each set of twelve cables forms a vertical plane and is connected along an edge of the space truss. In reality, the space truss would project beyond the exterior walls of the building, the cables would be attached some distance in from the edge, and the plane could be non-vertical (inducing biaxial bending in the masts).

#### **3.3 Construction**

One way to construct the cable-stayed roof truss would be to treat it like a bridge design, and use the cantilever method. Construction would start at the mast or pier where some sections of the truss roof would be installed and connected to the innermost cables. Then construction would proceed moving outward from the pier in both directions as truss components and then cables were added. Cable tensions would be adjusted during this process to obtain a desired roof shape (flat or cambered) in the final product.

Alternatively, the six-story building frame could be used as a staging area, where large sections of the truss could be assembled then hoisted into place and connected to the cables.

The effects of loads resulting from the cantilever method of construction can be evaluated

using the analysis model presented in this thesis. (Chapters 4 & 5, Appendix C) One can create an input file for the cable and truss geometry and erection loads of each construction stage and run the program to see the resulting tensions and deflections.

### Chapter 4 Analytical Model

This chapter describes the analytical model of the roof system. The model is implemented as a Matlab program that reads information about the roof geometry and materials from input files. The roof is then modeled as a beam with constant shear (GA) and bending (EI) stiffness supported at one point by the pier and at other points by the cables. The roof is simply connected to the pier, hence at least two cables are required to make the structure stable under all load scenarios. Any number of vertical load combinations can be applied to the roof simultaneously; these load combinations can have different locations and magnitudes. The deflection response of the roof is then calculated and plotted. The resulting cable tensions are determined as well.

The geometric and material properties of the cable-stayed roof system can all be changed by simply modifying the input file. Scenarios in which location, number, cross-sectional area, and pre-stress of the cables are different can be analyzed. The dimensions of the roof truss and the location of its connection to the pier can be varied. The pier position, shape, and dimensions can be changed as well.

Finally a plot of the pier can be superimposed on the plot of the deflected shape of the roof, for a sense of the scale of the deflections.

#### 4.1 Basis and Implementation of the Model

The model evaluates the roof behavior by considering it to be a long beam with a simple support at its connection to the pier, and vertical tension-only springs where the cables are connected. The Matlab code for this analysis engine and a sample input file are found in appendix C.

The roof is divided into segments, with nodes as specified in the input file. Nodes are

located at cable connection points. By specifying additional "zero-area cables", the user causes more nodes to be generated. Doing this results in a better plot of the deformed shape of the roof and a more accurate solution of the roof deformation, because uniform loads are distributed to the node points in the Matlab implementation; in the case where we have many cables, as with the roof designed in chapter 3, the addition of additional nodes causes only slight improvements in the solution

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**Figure 4.1: Beam Segment Forces and Displacements** 

The stiffness of the roof beam segments is based on figure 4.1, and results in equations 4.1.1. [5] The two columns and rows of the stiffness matrix associated with F and u are not used, as the axial forces and displacements (*along* the roof truss) are not considered in this evaluation.

$$\begin{bmatrix} \frac{D_s}{L} & 0 & 0 & \frac{-D_s}{L} & 0 & 0 \\ 0 & \frac{12D_B^*}{L^3} & \frac{6D_B^*}{L^2} & 0 & \frac{-12D_B^*}{L^3} & \frac{6D_B^*}{L^2} \\ 0 & \frac{6D_B^*}{L^2} & \frac{(4+a)D_B^*}{L} & 0 & \frac{-6D_B^*}{L^2} & \frac{(2-a)D_B^*}{L} \\ \frac{-D_s}{L} & 0 & 0 & \frac{D_s}{L} & 0 & 0 \\ 0 & \frac{-12D_B^*}{L^3} & \frac{-6D_B^*}{L^2} & 0 & \frac{12D_B^*}{L^3} & \frac{-6D_B^*}{L^2} \\ 0 & \frac{6D_B^*}{L^2} & \frac{(2-a)D_B^*}{L} & 0 & \frac{-6D_B^*}{L^2} & \frac{(4+a)D_B^*}{L} \end{bmatrix}$$

$$(4.1.1a)$$

where:

$$a = \frac{12D_B}{L^2 D_T},$$
 (4.1.1b)

$$D_B^* = \frac{1}{1+a} \cdot D_B,$$
 (4.1.1c)

and

$$D_S = EA, D_B = EI, and D_T = GA.$$
 (4.1.1d)

The roof stiffnesses, EI and GA, are read from an input file. EA is not used.

These element stiffness matrices are combined in a global stiffness matrix, then cable vertical stiffnesses (Section 3.1.1) are added along the diagonal, and the vertical deflection at the simple support (point c of Fig. 3.8a) is set to zero. Iteration in the program ensures that cables only provide stiffness when they are in tension. Because of the preloading of the cables, the cables provide stiffness even when the roof is deflected above the flat position--up to the point where there is still some tension in the cable. That the prestressed cables operate in this fashion, can be verified by running the analysis engine using an input file with no loads applied to the roof, but with prestressed cables. The roof will deflect upwards such that the resulting cable tensions are zero.



**Figure 4.2: Cables with Pre-Stress** 

The cables stiffnesses are a function of area, material stiffness, and pre-tensioning. Figure 4.2 is used to derive the stiffness of a prestressed cable, for use in the analysis engine, below:

$$L = L_0 + \frac{P_0}{k_0} = L_0 + \left(\frac{P_0}{EA}\right) L_0$$
(4.1.2)

$$L_0 = \frac{L}{1 + \frac{P_0}{EA}}$$
(4.1.3)

$$\frac{1}{k_0} = \frac{L_0}{EA} = \frac{L}{EA + P_0} \tag{4.1.4}$$

$$k = k_0 = \frac{EA + P_0}{L}$$
(4.1.5)

The applied loads are distributed to the nodes, that is, a vector with nodal shear forces and moments is constructed. This vector--VM in the code--is adjusted for the cable pre-stress before displacements are calculated. The nodal rotations and vertical displacements along the roof are calculated, as are cable tensions and stresses.

The vertical displacements and allowable vertical displacements are plotted. In the plot, node points (where there are cables or zero-area "cables") appear as circles connected by a curve (generated by cubic spline interpolation) while the deflection limits are shown as straight lines, crossing where the space truss roof is pin-connected to the pier.

There are two items which must be manually verified by the user to ensure that the solution of the analysis engine is correct. First, the Matlab program will pause for the user to verify that the two columns of the matrix check show the same values; if they do not, then the structure is unstable. Second, after the program finishes iterating to ensure that cables contribute no stiffness to the roof unless they are in tension, the user must check that preloops (the number of iterations completed) is less than maxloops (the number of iterations before the program stops iterating). The variable maxloops must be increased.

### Chapter 5 Case Study Using the Analysis Engine

The following case study of the roof designed in chapter 3 demonstrates the usefulness of the analysis model in the evaluation of a cable-stayed roof design. The roof is evaluated and altered when necessary, to meet performance criteria. The example file, infile\_r1.m (Appendix C) contains all the relevant data for the roof including the three, service (unfactored) loads: dead, snow, and live. The matrix containing cable data includes several zero-area "cables" as described in section 4.1

#### 5.1 Deflection Under Service Dead Load

In section 3.1.1, cable prestresses were selected with the goal of eliminating deflections due to service dead load. The deflected shape of the roof with only dead loads present is shown in the following plot from Matlab:



Figure 5.1: Deformation Due to Service Dead Load

It is clear from the figure, that while the roof is well within the deflection limit, the prestress towards the ends is overcompensating. Reducing by 25% the pretensioning of a few cables near the ends, leads to a shape which is almost a straight line, with a deflection of at most 0.09 inches from level.

#### 5.2 Deflection Under Snow (Live), Wind, and Dead Load

Testing the roof with the new cable prestresses and maximum service loads (snow, wind, and dead) leads to the deformed shape in figure 5.2:



Figure 5.2: Deformation Due to Full, Service Load

It can be seen from figure 5.2 and table 4 that the deflection is kept within acceptable limits. The deflection criteria are also met for the cases when snow and wind forces (in addition to dead load, which is always applied along the entire length of the roof) are applied to only the right or left side of the roof. When the wind load is directed upward (along the entire roof or either side) with no other live/snow load the roof deflects less than the allowable.

Cable	X Coordinate	Vertical Displacement (ft)	Rotation (ft/ft)
1	0	-0.0424	0.0005
2	18	-0.0337	0.0005
3	36	-0.0241	0.0006
4	54	-0.0142	0.0005
5	72	-0.0052	0.0004
6	90	0.0009	0.0002
7	120	-0.0066	-0.0008
8	144	-0.0324	-0.0013
9	168	-0.0681	-0.0016
10	192	-0.1075	-0.0016
11	216	-0.1448	-0.0015
12	240	-0.1786	-0.0014

 Table 4: Displacements at Cable Connection Points (Full, Service Load--Both Sides)

#### **5.3 Cable Stresses**

The governing factored load case for the cables is 1.4D+1.7L (5.85 kip/foot downward) from table 1. (Even under the factored loads the roof meets the deflection criteria set section 2.3 for service load alone.) Table 5 shows that the cable stresses are less than the allowable 45 ksi. (Section 3.1.1) In cases when load types are applied along the whole length of the truss, and in cases when they are only applied to one side of the support, the most highly-stressed cable never

exceeds 33 ksi.

Cable	1	2	3	4	5	6	7	8	9	10	11	12
Tension (kips)	128	123	131	109	76	49	54	214	281	280	299	313
Stress (ksi)	26	25	27	22	16	10	11	22	29	29	31	33

**Table 5: Cable Forces and Stresses** 

#### **5.4** Correcting the Design

The evaluation tool, engine.m, showed that the prestressing of some cables was higher than necessary and lead to a change in the design. As the tool is used to evaluate other designs, the results tend to suggest improvements--such as changing the cross-sectional areas of cables, cable strength, or the stiffness properties of the roof truss. Re-evaluating an altered design becomes a simple matter of editing the parameters of the input file and running the program.

### Chapter 6 Conclusion

In the design of a showcase structure intended to attract attention to civil and environmental engineering, a structural engineer has a tremendous opportunity for creativity. For that creativity to become a structure that can be built, there must be a means of evaluating its performance before construction. The evaluation tool described in this thesis helps respond to the technical challenges of a cable-stayed roof, in hopes that a simple tool might determine whether to take the design beyond the conceptual stage and into the new CEE building.

The design of the roof for the new CEE building is examined in chapter 5. It is found that, while the roof meets the deflection requirements in section 2.3, it does not meet the desired goal of zero deflection under service dead load because the prestressed cables lift the ends of the roof.

With the level of prestress reduced such that the roof is flat under service dead load, the design behaves well, meeting deflection requirements even when factored load combinations are used to evaluate cable stresses. Under the expected load scenarios, the roof typically deforms with a shape similar to what is shown in figure 5.2. Table 4 gives the vertical displacements and rotations at each point along the truss where cables are attached (when full service load is applied to both sides). When snow/live and wind loads are applied to one side of the truss only, some of nodes on the other side deflect upward as one might expect, but do not exceed the deflection limits.

Cables are found to be stressed at 75% (or less) of the allowable amount. This information, and the fact that the deflection limits are being met, indicates a way to save material. By reducing cable areas and increasing prestress, it is possible to design a roof that is more materialefficient.

This thesis indicates that the proposed conceptual design is adequate (with a reduction of prestress values). However, greater efficiency may be achieved through further changes--evaluating each successive design with the analysis tool provided.

### References

[1] 1998 MIT M.Eng. Group Project Report. Unpublished.

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[3] State Board of Building Regulations and Standards. <u>Massachusetts State Building Code (780 CMR)</u>. 6th ed. Boston: William F. Galvin, Secretary of the Commonwealth, 1997.

[4] Nilson, A. H. and Winter, G. <u>Design of Concrete Structures</u>. 11th ed. New York: McGraw-Hill, Inc., 1991.

[5] Connor, Jerome J. Course notes from 1.571: Structural Analysis and Control. Unpublished.

[6] Englekirk, Robert. <u>Steel Structures: Controlling Behavior Through Design</u>. New York: John Wiley and Sons, 1994, pp. 473-478.

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#### **Appendix A: Purpose & Guiding Principles for the New CEE Building**

### THE CIVIL & ENVIRONMENTAL ENGINEERING BUILDING COMPLEX 12/18/97

#### Purpose and Guiding Principles

In keeping with the unique and defining culture of the Massachusetts Institute of Technology, the Department of Civil and Environmental Engineering is committed to maintaining the excellence of its civil and environmental engineering education and research activities and dedicated to shaping the future of the profession. The forces that are driving change in the discipline include:

> -Increasing emphasis on improved methods for the conceptualization, design, construction, and operation of both new and revitalized buildings and infrastructure systems in order to improve economic productivity, competitiveness, and quality of life for the citizens of the world.

> -Growing commitment to environmental stewardship and sustainable development which is affording higher priority to compatibility between built and natural environments and providing impetus to the continuing evolution of synergistic partnerships among civil and environmental engineering disciplines.

-Rapid advancements in technology, particularly information technology, which hold great potential for dramatically changing and enhancing the processes for realizing civil and environmental facilities.

The CEE Department, to enhance its mission of educating future leaders of the profession and providing them with the skills and systems for life-long learning, personal growth, and service to society, proposes the development of a new and unified building complex to house relevant academic, research, and administrative activities. The complex will consist of one of the following two alternatives:

- 1. A new building located adjacent to and connected to a renovated Parsons Laboratory (Building 48).
- 2. A totally new building on the site of a demolished Parsons Laboratory and the adjacent parking lot.

A major goal of the CEE Department's leadership, is to ensure that its visions and aspirations for the future directions of the profession are embodied and visible in the physical appearance and operating characteristics of the complex. Thus the complex should serve as a showcase facility built with the most modern and advanced construction and environmental technology to house the most modern educational and research technology. Some possible aspects to showcase include: a creative and visible high performance structural system; information technology systems for both building control systems and educational activities; HVAC systems and building materials that contribute to sustainable development; and alternative project delivery systems.

### Appendix B: Matlab Code for Pier Geometry (muse.m & Ww.m)

What follows is the code used to generate coordinates of the points shown in figure 3.5. The code also draws the pier.

muse.m		
% FILE NAME: muse.m % Pier Geometry generation file clear hold on		
% Get input: Ww		
ss = sin(angle_xy_mast*(pi/180)); cc = cos(angle_xy_mast*(pi/180)); tt = tan(angle_xy_mast*(pi/180));		
ht_rooftop = (ht_to_roof + t_roof); ht_mast = (ht_to_roof + t_roof + ht_mast_above); Mast = ( xcoord_A xcoord_A+(ht_mast_above+t_roof)/tt xcoord_A+ht_mast_above/tt	ht_mast ht_to_roof ht_rooftop	0 0 0
xcoord_A+ht_mast/ft xcoord_A+(ht_mast-ycoord_E)/tt xcoord_A+(ht_mast-ycoord_E)/tt-(ycoord_E/tt) )	0 ycoord_E 0	0 0 0

plot(Mast(:,1),Mast(:,2)), grid on

#### Ww.m

% FILE NAME: Ww.m % Input file for muse.m % Units = feet, kips

% Axes defined: % X length % Y height % Z width

% Points defined:

% A top of long mast element

% B where long mast element intersects underside of roof

% C where long mast element intersects top of roof % D bottom of long mast element % E top of short mast element % G bottom of short mast element

% Building geom ht_to_roof t_roof ht_mast_above len_roof wid_roof	etry = 90 = 10 = 50 = 240 = 75	% feet % feet % feet % feet
% Tower geomet angle_xy_mast xcoord_A ycoord_E	ry = 60 = 80 = 75	% wrt ground, value between 0 and 90 % feet % feet (max = ht_to_roof)

### Appendix C: Matlab Code for Roof Evaluation (engine.m & infile\_r1.m)

What follows is the code used evaluate the performance of a cable-stayed roof and an example input file. The input file\_r1.m, contains the data for the design described in chapter 3.

#### engine.m

```
% FILE NAME: engine.m
% Analysis engine for cable-stayed roof evaluation
clear
% Get input:
infile r1
ss = sin(angle_xy_mast*(pi/180));
cc = cos(angle_xy_mast*(pi/180));
tt = tan(angle_xy_mast*(pi/180));
mast_x = xcoord_a;
mast_y = ycoord_a - 100;
num cab = size(cable, 1)
data = zeros(num_cab,5);
data(:,1) = cable(:,1);
% cable length
data(:,2) = sart((mast_x-cable(:,2)).^2 + mast_y^2);
% cable sin theta
data(:,3) = mast_y./data(:,2);
% cable EA/L adjusted for prestress
data(:,4) = (E \ cable*cable(:,3)+cable(:,4))./data(:,2);
% Cable Vertical stiffness: EA/L *sin^2 theta
data(:,5) = data(:,4).*data(:,3).^2
kiter = data(:,5);
% roof stiffness matrix
       = Elxx roof;
Db
Dt
       = GA roof;
       = 12*Db/Dt;
al
% loop for no compression in cable
maxloops = 12;
preloops = 0;
```

```
for ggg=1:maxloops
```

```
% number of uniformly distributed load cases
num_load = size(BB,1);
```

```
Κ
      = zeros(2*(num_cab+1),2*(num_cab+1));
VM
        = zeros(2^{(num cab+1),1)};
found
         = 0:
% FOR LOOP to create global K matrix
for r=2:1:num cab
    % beam member length
    if cable(r,2) < support | found == 1
         anode = cable(r-1,2);
         bnode = cable(r, 2);
         L = bnode-anode;
         a = a1/L^{2};
         Db_star = Db/(1+a);
         k1 = 12^{Db} star/L^{3};
         k^{2} =
                6*Db star/L^2;
         k3 = (4+a)^*Db star/L;
         k4 = (2-a)^*Db star/L;
         member = r-1+found;
         index = 2^{\text{member-1}};
         K(index, index) = K(index, index) + k1;
         K(index, index+1) = K(index, index+1) + k2;
         K(index, index+2) = K(index, index+2) - k1;
         K(index, index+3) = K(index, index+3) + k2;
         K(index+1, index) = K(index+1, index) + k2;
         K(index+1, index+1) = K(index+1, index+1) + k3;
         K(index+1, index+2) = K(index+1, index+2) - k2;
         K(index+1, index+3) = K(index+1, index+3) + k4;
         K(index+2, index) = K(index+2, index) - k1;
         K(index+2, index+1) = K(index+2, index+1) - k2;
         K(index+2, index+2) = K(index+2, index+2) + k1;
         K(index+2, index+3) = K(index+2, index+3) - k2;
         K(index+3, index) = K(index+3, index) + k2;
         K(index+3, index+1) = K(index+3, index+1) + k4;
         K(index+3, index+2) = K(index+3, index+2) - k2;
         K(index+3, index+3) = K(index+3, index+3) + k3;
         % cable stiffness
         K(index+2*found, index+2*found) = K(index+2*found, index+2*found) +
```

kiter(member);

```
% Shear and moment *1*
    for ff = 1:1:num load
         if anode \geq BB(ff,3) \mid bnode \leq BB(ff,2)
         elseif anode >= BB(ff,2) & bnode <= BB(ff,3)
              VM(index) = VM(index) + L^{BB}(ff, 1)/2;
              VM(index+2) = VM(index+2)+L*BB(ff,1)/2;
         elseif anode >= BB(ff,2) & bnode > BB(ff,3)
              loadb = (BB(ff,3)-anode)^*BB(ff,1);
              dist1 = (BB(ff, 3)-anode)/2;
              dist2 = L - dist1;
              VM(index) = VM(index) + loadb*dist2/L;
              VM(index+2) = VM(index+2) + loadb*dist1/L;
         elseif anode < BB(ff,2) & bnode <= BB(ff,3)
              loadb = (bnode-BB(ff, 2))^*BB(ff, 1);
              dist2 = (bnode-BB(ff,2))/2;
              dist1 = L - dist2;
              VM(index) = VM(index) + loadb*dist2/L;
              VM(index+2) = VM(index+2) + loadb*dist1/L;
         elseif anode < BB(ff,2) & bnode > BB(ff,3)
              loadb = (BB(ff,3)-BB(ff,2))^*BB(ff,1);
              dist1 = (BB(ff,3)-BB(ff,2))/2 + (BB(ff,2)-anode);
              dist2 = L - dist1;
              VM(index) = VM(index) + loadb*dist2/L;
              VM(index+2) = VM(index+2) + loadb*dist1/L;
         end
    end
else
    % if the program reaches a segment with the support in it
    anode = cable(r-1,2);
    bnode = support;
                                      % bug: if support = 0
    L = bnode-anode;
    a = a1/L^{2};
    Db star = Db/(1+a);
    k1 = 12*Db star/L^3;
    k^{2} = 6^{*}Db star/L^{2};
    k3 = (4+a)^{*}Db star/L;
    k4 = (2-a)^{*}Db star/L;
    member = r-1+found;
    index = 2^{\text{member-1}};
    K(index, index) = K(index, index) + k1;
    K(index, index+1) = K(index, index+1) + k2;
    K(index, index+2) = K(index, index+2) - k1;
```

```
K(index, index+3) = K(index, index+3) + k2;
```

K(index+1, index) = K(index+1, index) + k2;K(index+1, index+1) = K(index+1, index+1) + k3;K(index+1, index+2) = K(index+1, index+2) - k2;K(index+1, index+3) = K(index+1, index+3) + k4;K(index+2, index) = K(index+2, index) - k1; K(index+2, index+1) = K(index+2, index+1) - k2;K(index+2, index+2) = K(index+2, index+2) + k1;K(index+2, index+3) = K(index+2, index+3) - k2; K(index+3, index) = K(index+3, index) + k2; K(index+3, index+1) = K(index+3, index+1) + k4;K(index+3, index+2) = K(index+3, index+2) - k2;K(index+3, index+3) = K(index+3, index+3) + k3;% cable stiffness K(index+2\*found, index+2\*found) = K(index+2\*found, index+2\*found) +kiter(member); % Shear and moment \*2\* for  $ff = 1:1:num_load$ if anode  $>= BB(ff,3) \mid bnode <= BB(ff,2)$ elseif anode >= BB(ff,2) & bnode <= BB(ff,3)  $VM(index) = VM(index) + L^*BB(ff, 1)/2;$ VM(index+2) = VM(index+2)+L\*BB(ff,1)/2;elseif anode >= BB(ff,2) & bnode > BB(ff,3) $loadb = (BB(ff,3)-anode)^*BB(ff,1);$ dist1 = (BB(ff, 3)-anode)/2;dist2 = L - dist1;VM(index) = VM(index) + loadb\*dist2/L;VM(index+2) = VM(index+2) + loadb\*dist1/L;elseif anode < BB(ff,2) & bnode <= BB(ff,3) $loadb = (bnode-BB(ff, 2))^*BB(ff, 1);$ dist2 = (bnode-BB(ff,2))/2;dist1 = L - dist2;VM(index) = VM(index) + loadb\*dist2/L;VM(index+2) = VM(index+2) + loadb\*dist1/L;elseif anode < BB(ff,2) & bnode > BB(ff,3)loadb =  $(BB(ff,3)-BB(ff,2))^*BB(ff,1);$ dist1 = (BB(ff,3)-BB(ff,2))/2 + (BB(ff,2)-anode);dist2 = L - dist1;VM(index) = VM(index) + loadb\*dist2/L;VM(index+2) = VM(index+2)+ loadb\*dist1/L; end end

```
support_node = member+1;
         found = 1:
         anode = support;
         bnode = cable(r,2);
         L = bnode-anode;
         a = a1/L^{2};
         Db_star = Db/(1+a);
         k1 = 12^{D}b star/L^{3};
         k^{2} = 6^{*}Db star/L^{2};
         k3 = (4+a)^{*}Db_{star/L};
         k4 = (2-a)^{Db_star/L};
         member = r-1+found;
         index = 2^{\text{member-1}};
         K(index, index) = K(index, index) + k1;
         K(index, index+1) = K(index, index+1) + k2;
         K(index, index+2) = K(index, index+2) - k1;
         K(index, index+3) = K(index, index+3) + k2;
         K(index+1, index) = K(index+1, index) + k2;
         K(index+1, index+1) = K(index+1, index+1) + k3;
         K(index+1, index+2) = K(index+1, index+2) - k2;
         K(index+1, index+3) = K(index+1, index+3) + k4;
         K(index+2, index) = K(index+2, index) - k1;
         K(index+2, index+1) = K(index+2, index+1) - k2;
         K(index+2, index+2) = K(index+2, index+2) + k1;
         K(index+2, index+3) = K(index+2, index+3) - k2;
         K(index+3, index) = K(index+3, index) + k2;
         K(index+3, index+1) = K(index+3, index+1) + k4;
         K(index+3, index+2) = K(index+3, index+2) - k2;
         K(index+3, index+3) = K(index+3, index+3) + k3;
         % cable stiffness
         K(index+2*found, index+2*found) = K(index+2*found, index+2*found) +
kiter(member);
         % Shear and moment *3*
         for ff = 1:1:num_load
              if anode >= BB(ff,3) \mid bnode <= BB(ff,2)
              elseif anode >= BB(ff,2) & bnode <= BB(ff,3)
                   VM(index) = VM(index) + L*BB(ff, 1)/2;
                   VM(index+2) = VM(index+2)+L*BB(ff,1)/2;
              elseif anode >= BB(ff, 2) & bnode > BB(ff, 3)
```

```
loadb = (BB(ff,3)-anode)^*BB(ff,1);
```

```
dist1 = (BB(ff,3)-anode)/2;
              dist2 = L - dist1;
              VM(index) = VM(index) + loadb*dist2/L;
              VM(index+2) = VM(index+2) + loadb*dist1/L;
         elseif anode < BB(ff,2) & bnode <= BB(ff,3)
              loadb = (bnode-BB(ff, 2))^*BB(ff, 1);
              dist2 = (bnode-BB(ff,2))/2;
              dist1 = L - dist2;
              VM(index) = VM(index) + loadb*dist2/L;
              VM(index+2) = VM(index+2) + loadb*dist1/L;
         elseif anode < BB(ff,2) & bnode > BB(ff,3)
              loadb = (BB(ff,3)-BB(ff,2))^*BB(ff,1);
              dist1 = (BB(ff,3)-BB(ff,2))/2 + (BB(ff,2)-anode);
              dist2 = L - dist1;
              VM(index) = VM(index) + loadb*dist2/L;
              VM(index+2) = VM(index+2) + loadb*dist1/L;
         end
    end
end
```

```
end
```

% adjust shear for prestress forces

% (similar means to adjust VM for reaction at support--don't bother)

VM; % This VM represents the applied loads

```
%pause
```

```
presin = (cable(:,4).*data(:,3))';
VM(1:2:2*(num_cab+1)) = VM(1:2:2*(num_cab+1)) + (presin(1:support_node-1) 0
presin(support_node:num_cab))';
```

% now VM is changed for calculations

```
K2 = zeros(2*(num_cab+1)-1,2*(num_cab+1)-1);

K2(1:2*support_node-2, 1:2*support_node-2) = K(1:2*support_node-2,

1:2*support_node-2);

K2(2*support_node-1:2*(num_cab+1)-1, 2*support_node-1:2*(num_cab+1)-1) =

K(2*support_node:2*(num_cab+1), 2*support_node:2*(num_cab+1));

K2(1:2*support_node-2, 2*support_node-1:2*(num_cab+1)-1) =

K(1:2*support_node-2, 2*support_node:2*(num_cab+1)-1) =

K(1:2*support_node-2, 2*support_node:2*(num_cab+1));

K2(2*support_node-1:2*(num_cab+1)-1, 1:2*support_node-2) =

K(2*support_node:2*(num_cab+1), 1:2*support_node-2);
```

```
VM2 = zeros(2*(num_cab+1)-1,1);
VM2(1:2*support_node-2) = VM(1:2*support_node-2);
VM2(2*support_node-1:2*(num_cab+1)-1) =
```

```
VM(2*support_node:2*(num_cab+1));
U2 = K2 \setminus VM2;
% check if K2*U2 = VM2
check = (VM2 K2*U2);
U = zeros(2*(num_cab+1), 1);
U(1:2*support_node-2) = U2(1:2*support_node-2);
U(2^{support node-1}) = 0;
U(2*support_node:2*(num_cab+1)) = U2(2*support_node-1:2*(num_cab+1)-1);
U:
Udispl = U(1:2:2*(num_cab+1));
hold off
x = (cable(1:support_node-1,2)' support cable(support_node:num_cab,2)');
y = 100 + Udispl;
lastpt = cable(num_cab,2);
xi = 0:4:lastpt;
y_i = spline(x, y, x_i);
plot(xi,yi,x,y,'o'), grid on
hold on
plot((0 support lastpt),(100-(support)/360 100 100-(lastpt-support)/360), 'w');
plot((0 support lastpt),(100+(support)/360 100 100+(lastpt-support)/360), 'w');
title('Deformed Shape & Allowable Deformation')
xlabel(`Distance Along Roof (feet)')
ylabel(`Height (feet)')
hold off
Tension = cable(:,4)-data(:,4).*data(:,3).*(Udispl(1:support_node-1)'
Udispl(support_node+1:num_cab+1)')';
changed = 0;
Tens kiter = (Tension kiter)
for jj=1:size(Tension, 1)
    if Tension(jj) < 0 & kiter(jj) > 0
         kiter(jj) = 0;
         changed = 1;
     elseif Tension(jj) > 0 & kiter(jj) <= 0 & data(jj,5) > 0
         kiter(jj) = data(jj,5);
         changed = 1;
     end
end
clear jj
```

```
preloops = preloops +1;
if changed ~= 1
    break
end
end % for no compression in cable
pause
% check if K2*U2 = VM2
check
pause
for hgh=1:size(Tension)
    if Tension(hgh) < 0
         Tension(hgh) = 0;
    end
end
Tension
% (neg. stress values should be viewed as zero stress)
%cable_stress = Tension./cable(:,3) % problem when cable area = zero
U
Udispl
preloops
maxloops
                                   infile_r1.m
% FILE NAME: infile_r1.m
% Input file for engine.m
% Units = feet, kips
% Axes defined:
% X length
% Y height
% Z width
% Points defined:
% a top of long mast element
% c point of connection with roof (pinned connection, top of roof)
% d top of short mast element (pinned connection w/ long element)
```

% Building geometry ht\_to\_roof = 90; % feet

t_roof = 10; % feet % distance between underside of roof & top ht_mast_above = 50; % feet % height of the mast above the roof len_roof = 240; % feet wid_roof = 75; % feet
% Tower geometry angle_xy_mast = 60; % wrt ground, value between 0 and 90 xcoord_a = 80; % feet ycoord_a = 150; % feet ycoord_d = 75; % feet (max = ht_to_roof)
% Stiffnesses E_cable = (29000); % ksi Elxx_roof = 650e5 % kip x ft^2 % El for half of roof GA_roof = 9.3e6 % kip % GA for half of roof
% Roof geometry support = 109; % feet % x coord of point c
% Strengths cable_str = 50 % ksi

11 216 9.6 197 22 228 0 0 12 240 9.6 228 );

% Uniform Load (unfactored dead for half roof = -2.81 k/ft) % Uniform Load (unfactored snow for half roof = -1.125 k/ft) % Uniform Load (unfactored wind for half roof = +/-0.78 k/ft) %(1) (2) (3) % MAGNITUDE(kip/ft) START(ft) END(ft) BB = ( -2.81 240 0 -1.125 240 0 -0.78 0 240 );

# Appendix D: Mast Loading Data & Mast Design Data

The following Excel spreadsheets contain data about the pier design of chapter 3.

### Mast Loading Data

Final ca	ible geo	metry												
Case I.	Assur	e cables	take enti	re load										
Load is	Load is taken as 1.4D+1.7L (2808 kip/roof) Hence, Load=67% dead load effect & 33% live load effects.													
Cable	X	mast x	mast y	length (ft)	sin theta	E (ksi)	A (in^2)	EA/L	F vert	Tension	clong (ft)	defi vert (in)	Cable stress (ksi)	F horiz at mast
1	0	80	50	94.3	0.53	29000	4.9	1506	105	199	0.13	2.99	41	-168
	18	80 80	50	/9.5	0.63	29000	4.9	2134	105	168	0.09	1.80	34	-131
4	54	80	50	56.4	0.89	29000	4.9	2521	105	119	0.05	0.64	24	-55
5	72	80	50	50.6	0.99	29000	4.9	2806	105	107	0.04	0.46	22	-17
7	120	80 80	50	64.0	0.98	29000	4.9	2/8/	105	107	0.04	0.47	22	21
8	144	80	50	81.2	0.62	29000	9.6	3428	140	228	0.07	1.30	24	180
9	168	80	50	101.2	0.49	29000	9.6	2751	140	284	0.10	2.51	30	247
11	216	80	50	144.9	0.41	29000	9.6	1921	140	407	0.13	4.47	30 42	314
12	240	80	50	167.6	0.30	29000	9.6	1661	140	471	0.28	11.40	49	449
	14641186													
B. Live	e load a	pplied to	right sid	e only	I.e. remove	LL effect	s from cabl	es that p	ull mast	to the left				
Cable	x	mast x	mast y	length (ft)	sin theta	E (ksi)	A (in^2)	EA/L	F vert	Tension	clong (ft)	defi vert (ia)	Cable stress (ksi)	F horiz at mast
	18	80 80	50 50	94.3 79.6	0.53	29000 29000	4.9	1506	70	133	0.09	2.00	27	-113
3	36	80	50	66.6	0.75	29000	4.9	2134	70	94	0.04	0.70	19	-62
4	54	80	50	56.4	0.89	29000	4.9	2521	70	79	0.03	0.43	16	-37
5	90	80 80	50	50.6	0.99	29000 29000	4.9 4.9	2806	105	107	0.03	0.31	15	-11
7	120	80	50	64.0	0.78	29000	4.9	2219	70	90	0.04	0.62	18	56
8	144	80	50	81.2	0.62	29000	9.6	3428	140	228	0.07	1.30	24	180
9	168 192	80 80	50 50	101.2	0.49	29000 29000	9.6 9.6	2751	140	284 344	0.10	2.51	30	247
ii	216	80	50	144.9	0.35	29000	9.6	1921	140	407	0.21	7.36	42	382
12	240	80	50	167.6	0.30	29000	9.6	1661	140	471	0.28	11.40	49	449
									140					1340
C. Live	: load a	pplied to	left side	only	I.e. remove	LL effect	s from cabl	es that p	ull mast	to the right				
Cable	x	mast x	mast y	length (ft)	sin theta	E (ksi)	A (in^2)	EA/L	F vert	Tension	elong (ft)	defi vert (in)	Cable stress (ksi)	F horiz at mast
2	18	80	50	79.6	0.63	29000	4.9	1784	105	168	0.13	2.99	41 34	-108
3	36	80	50	66.6	0.75	29000	4.9	2134	105	140	0.07	1.05	29	-93
4	54	80 80	50	56.4	0.89	29000	4.9	2521	105	119	0.05	0.64	24	-55
6	90	80	50	51.0	0.98	29000	4.9	2787	70	72	0.03	0.40	15	-17
7	120	80	50	64.0	0.78	29000	4.9	2219	47	60	0.03	0.42	12	38
8	144	80 80	50	81.2	0.62	29000	9.6	3428	94	152	0.04	0.87	16	120
10	192	80	50	122.7	0.49	29000	9.6	2270	94	230	0.10	2.98	24	210
11	216	80	50	144.9	0.35	29000	9.6	1921	94	272	0.14	4.92	28	255
12	240	80	50	167.6	0.30	29000	9.6	1661	94 1113	314	0.19	7.62	33	300
			_											
Case II.	. Assur	ne cables	take ent	ire DL but o	aly half LL	Hence I	and=8067.d	and lond	effect 8	2062 live l	and affects			
Case II. Load is A. Live	. Assur taken a lond a	ne cables s 1.4D+1. pplied to	take enti 71./2 (235 both side	ire DL but o 60 kip/roof) es	nly haif LL	Hence, L	oad=80% d	ead load	effect &	: 20% live	oad effects.			
Case II. Load is A. Live Cable	Assur taken a tond a x	ne cables s 1.4D+1. pplied to mast x	take enti 71_/2 (235 both side mast y	ire DL but o 60 kip/roof) es length (ft)	sin theta	Hence, L E (ksi)	oad=80% d	ead load	F vert	20% live l	elong (ft)	defi vert (in)	Cable stress (ksl)	F horiz at mast
Case II. Load is A. Live Cable 1 2	Assur taken av tlond a tlond a x 0 18	ne cables s 1.4D+1. pplied to mast x 80 80	take enti 71./2 (235 both side mast y 50 50	ire DL but of 60 kip/roof) es length (ft) 94.3 79.6	sin theta 0.53 0.63	Hence, L E (ksi) 29000 29000	oad=80% d A (im^2) 4.9 4.9	EA/L 1506 1784	F vert 88 88	20% live 1 Tension 166 140	elong (ft) 0.11 0.08	defl vert (in) 2.50 1.50	Cable stress (ksl) 34 29	F horiz at mast -141 -109
Case II. Load is A. Live Cable 1 2 3	Assur taken au tlond a x 0 18 36	ne cables s 1.4D+1. pplied to mast x 80 80 80	take enti 71_/2 (235 both side mast y 50 50 50	ire DL but o (0 kip/roof) es length (ft) 94.3 79.6 66.6	sin thetn 0.53 0.63 0.75	Hence, L E (ksi) 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134	F vert 88 88 88 88	: 20% live   Tension 166 140 117	elong (ft) 0.11 0.08 0.06	defi vert (in) 2.50 1.50 0.88	Cable stress (ksi) 34 29 24	F horiz at mast -141 -109 -78
Case II. Load is A. Live Cable 1 2 3 4 5	Assur taken av t lond a x 0 18 36 54 72	ne cables s 1.4D+1. pplied to mast x 80 80 80 80 80	take enti 7L/2 (235 hoth side mast y 50 50 50 50	ire DL but of 60 kip/roof) es length (ft) 94.3 79.6 66.6 56.4 50.6	sin theta 0.53 0.63 0.75 0.89	Hence, L E (ksi) 29000 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2521	F vert 88 88 88 88 88	20% live   Tension 166 140 117 99	elong (ft) 0.11 0.08 0.06 0.04	defi vert (in) 2.50 1.50 0.88 0.53 0.30	Cable stress (kd) 34 29 24 20 18	F horiz at mast -141 -109 -78 -46
Case II. Load is A. Live Cable 1 2 3 4 5 6	Assur taken av t lond a x 0 18 36 54 72 90	ne cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80	take enti 71_/2 (235 both side mast y 50 50 50 50 50 50	re DL but of 0 kip/roof) es length (ft) 94.3 79.6 66.6 56.4 50.6 51.0	niy haif LL sin theta 0.53 0.63 0.75 0.89 0.99 0.98	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000	oad=80% d <b>A (in^2)</b> 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2521 2806 2787	F vert 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 89 90	elong (ft) 0.11 0.08 0.06 0.04 0.03 0.03	defi vert (in) 2.50 1.50 0.88 0.53 0.39 0.39	Cable stress (koi) 34 29 24 20 18 18	F horiz at mast -141 -109 -78 -46 -14 18
Case II. Load is A. Live Cable 1 2 3 4 5 6 7	Assur taken ar tond a tond a x 0 18 36 54 72 90 120	me cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80 80	take enti 71_/2 (235 both side mest y 50 50 50 50 50 50 50	re DL but o 0 kip/roof) est length (ft) 94.3 79.6 66.6 56.4 50.6 51.0 64.0	sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000	oad=80% d 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2521 2806 2787 2219	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 89 90 76	elong (ft) 0.11 0.08 0.06 0.04 0.03 0.03 0.03	defl vert (in) 2.50 1.50 0.88 0.53 0.39 0.39	Cable stress (kol) 34 29 24 20 18 18 18	F horiz at mast -141 -109 -78 -46 -14 18 47
Case II. Load is A. Live Cable 1 2 3 4 5 6 7 8 8	Assur taken au tond a tond a x 0 18 36 54 72 90 120 144	ne cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80 80 80 80	take enti 71_/2 (235 both side mast y 50 50 50 50 50 50 50 50 50 50 50	re DL but o (0 kip/roof) es length (ft) 94.3 79.6 66.6 56.4 50.6 51.0 64.0 81.2 1012	sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.40	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2521 2806 2787 2219 3428 2751	F vert 88 88 88 88 88 88 88 88 88 88 118	20% live 1 Tension 166 140 117 99 89 90 76 191 238	elong (ft) 0.11 0.08 0.06 0.04 0.03 0.03 0.03 0.03 0.06	defl vert (in) 2.50 1.50 0.88 0.33 0.39 0.39 0.52 1.09 2.10	Cable stress (koi) 34 29 24 20 18 18 15 20 25 20 25 20 25	F horiz at mast -141 -109 -78 -46 -14 18 47 150 202
Case II. Load is A. Live Cable 1 2 3 4 5 6 7 8 9 10	Assur taken av cload a cload a x 0 18 36 54 72 90 120 120 144 168 192	me cables <u>s</u> 1.4 <u>D+1</u> . <u>pplied to</u> mast x 80 80 80 80 80 80 80 80 80 80	take ent 71/2 (235 both alds mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	re DL but o (0 kip/roof) es length (ft) 94.3 79.6 66.6 56.4 50.6 51.0 64.0 81.2 101.2 101.2 122.7	aly half LL sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.49 0.41	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2521 2806 2787 2219 3428 2751 2270	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 89 90 76 191 238 288	elong (ft) 0.11 0.08 0.06 0.04 0.03 0.03 0.03 0.03 0.06 0.09 0.13	defi vert (in) 2.50 1.50 0.88 0.53 0.39 0.39 0.52 1.09 2.10 3.74	Cable stress (kci) 34 29 24 20 18 18 15 20 25 30	F horiz at mast -141 -199 -78 -44 -14 18 47 -150 207 263
Case II. Load is A. Live Cable 1 2 3 4 5 5 6 7 7 8 9 10 11	Assur taken av taken av taken av 0 18 36 54 72 90 120 144 168 192 216	me cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80	take entit 71/2 (235 both elde mast y 50 50 50 50 50 50 50 50 50 50 50 50 50 5	re DL but or to kip/roof) es length (ft) 94.3 79.6 66.6 56.4 50.6 51.0 64.0 81.2 101.2 101.2 122.7 144.9	aly half LL sin theta 0.53 0.63 0.75 0.89 0.98 0.78 0.78 0.62 0.49 0.41 0.35	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2806 2787 2219 3428 2751 2270 1921	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 89 90 76 191 238 288 341	elong (ft) 0.11 0.08 0.06 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defi vert (in) 2.50 1.50 0.88 0.53 0.59 0.52 1.09 2.10 3.74 6.16	Cable stress (koi) 34 29 24 20 8 18 15 20 25 30 35	F horiz at mast -141 -109 -78 -14 -14 -14 -18 -14 -15 -15 -15 -15 -15 -15 -15 -15 -15 -15
Case II. Load is A. Live Cable 1 2 3 4 5 6 7 8 9 10 11 12	Assur taken a taken a taken a taken a 0 18 36 54 72 90 120 144 168 192 216 240	me cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80 80 80 80	take entit 71./2 (235 <b>both side</b> mass y 50 50 50 50 50 50 50 50 50 50 50 50 50 5	tre DL bet or bip/toof) er length (ft) 94.3 79.6 66.6 66.6 51.0 64.0 81.2 101.2 122.7 144.9 167.6	aiy haif LL sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.49 0.41 0.35 0.30	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2521 2806 2787 2219 3428 2751 2270 1921 1661	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 89 90 76 191 238 288 341 394	elong (ft) 0.11 0.08 0.06 0.04 0.03 0.03 0.03 0.03 0.05 0.09 0.13 0.18 0.24	defl vert (in) 2.50 1.50 0.88 0.33 0.39 0.39 0.52 1.00 2.10 3.74 6.16 9.54 ∰	Cable stress (cd) 34 24 24 18 18 15 20 25 30 35 34	F horiz at mast -141 -78 -46 -46 -47 -14 -14 -14 -14 -14 -13 -20 -20 -20 -20 -20 -20 -20 -20 -20 -20
Case II. Load is A. Live Cable 1 2 3 4 5 6 7 8 9 10 11 11 2	Assur taken a taken a taken a 0 18 36 54 72 90 120 144 168 192 216 240	me cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80 80 80 80	take entit 7L/2 (235 Tooth side mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	ire DL but o 10 kip/roof) est length (R) 94.3 79.6 66.6 56.4 50.6 51.0 64.0 81.2 101.2 102.7 144.9 167.6	niy haif LL sin theta 0.53 0.63 0.75 0.89 0.99 0.99 0.98 0.78 0.62 0.49 0.41 0.35 0.30	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d A (im*2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2521 2806 2787 2219 3428 2751 2270 1921 1661	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 89 90 76 191 238 288 341 394	eload effects. elong (ft) 0.11 0.08 0.04 0.03 0.03 0.03 0.03 0.06 0.09 0.13 0.18 0.24	defl vert (in) 2.50 1.50 0.88 0.33 0.39 0.52 1.09 2.10 3.74 6.16 9.54 ∰	Cable stress (kol) 34 29 20 18 15 25 25 35 35 44	F horiz at mast -141 -109 -78 -14 18 -14 18 46 -14 18 47 150 207 263 3200 3306 3306 3376 993
Case II. Load is A. Live Cable 2 3 4 5 5 6 7 7 8 9 10 11 12 8. Live Cable	Assur taken an taken an taken an x 0 18 366 54 72 90 120 144 168 192 216 240 taken an x 0 18 18 36 54 72 90 120 144 162 182 120 144 192 216 240 240 240 240 240 240 240 240	ne cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80	take entit 71_/2 (235 both side mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	ire DL but o: 10 kip/roof) est length (R) 94.3 79.6 66.6 56.4 50.6 51.0 64.0 81.2 101.2 102.7 122.7 144.9 167.6 e only	aiy haif LL ain theta 0,53 0,63 0,75 0,89 0,99 0,98 0,78 0,62 0,49 0,41 0,35 0,30 Lc. remove	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	EA/L 1506 1784 2134 2806 2787 2219 3428 2751 2270 1921 1661	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 80 76 191 238 341 394 to the left Tension	elong (ft) 0.11 0.08 0.06 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (in) 2.50 0.88 0.53 0.39 0.39 2.10 2.10 3.74 6.16 9.54	Cable stress (kcl) 34 29 24 20 18 15 20 25 30 35 41	F horiz at mast -141 -19 -78 -46 -14 18 47 150 207 263 320 376 993 F horiz -1
Case II. Load is A. Live Cable 2 3 4 5 6 6 7 8 9 10 11 12 2 8. Live Cable	Assur taken av load a x 0 18 36 54 72 90 120 144 168 192 216 240 total av x 0 120 144 168 192 216 240 x 0 x 0 18 x 0 x x x x x x x x x x x x x	ne cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80	Eake entit 71_7 (235 both side mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	ire DL bet of 10 kip/roof) sength (ft) 94.3 79.6 666.6 56.4 50.6 51.0 64.0 81.2 101.2 122.7 144.9 167.6 e only length (ft) 94.3 79.6 51.0	aiy haif LL sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.49 0.49 0.49 0.41 0.35 0.30 Le. remove sin theta 0.53	Hence, L E (ksi) 29000 2900 290000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 2000000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 6.9 9.6 9.6 9.6 9.6 9.6 9.6 9	EA/L 1506 1784 2134 2806 2787 2219 3428 2751 2270 1921 1661 1921 1661 EA/L 1506	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	: 20% live   Tension 166 140 117 99 90 76 191 238 248 341 394 to the left Tension 133	ioad effects. elong (ft) 0.11 0.08 0.06 0.03 0.03 0.03 0.06 0.09 0.13 0.13 0.24 elong (ft) 0.09	defl vert (in) 2.50 1.50 0.88 0.53 0.39 0.52 1.09 2.10 3.74 5.16 9.54 ∰ defl vert (in) 2.00	Cable stress (ici) 34 29 24 20 18 18 15 20 25 30 35 44 Cable stress (ici)	F horiz at mast -141 -19 -78 -46 -14 18 47 750 207 203 320 376 993 376 -993 F boriz at mast
Case II. Load is A. Live Cable 1 2 3 4 5 6 7 8 8 9 10 11 12 12 B. Live Cable 1 2 2	. Assum taken au taken au taken au taken au x 0 18 36 54 72 90 120 144 168 192 216 240 2216 240 x 0 18 8 8 18 19 2216 240 19 2216 240 19 2216 240 19 2216 240 240 216 240 216 240 216 216 216 216 216 216 216 216	me cables <u>s</u> 1.4D+1. <u>pplied</u> to mast x 80 80 80 80 80 80 80 80 80 80	Eake entit 71_7 (235 both side mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	ire DL bet of 10 kip/roof) statements 10 kip/roof) 10	aly haif LL sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.99 0.98 0.78 0.62 0.41 0.35 0.30 Lc. remove sin theta 0.53 0.63 0.63	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9	EA/L 1506 1784 2134 2521 2806 2787 2219 3428 2751 2270 1921 1661 1661 cs that p EA/L	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	: 20% live   Tension 166 140 117 99 89 90 76 191 238 248 341 394 to the left Tension 133 112	ioad effects, elong (ft) 0.11 0.08 0.06 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (in) 2.50 1.50 0.88 0.53 0.39 0.39 0.39 2.10 3.74 6.16 9.54 § defl vert (in) 2.00 1.20	Cable stress (6cl) 4 29 20 18 15 20 25 30 33 4 Cable stress (Ld) 21 22 23 4 24 24 25 25 25 25 25 25 25 25 25 25	F horiz at meet -141 -109 -78 -46 -14 -18 -18 -150 205 205 205 205 205 205 205 205 205 2
Case II. Load is A. Live Cable 1 2 3 4 5 6 7 8 9 10 11 12 8. Live Cable 1 2 2 3 4 4 5 5 6 7 8 8 9 10 11 12 2 2 3 4 4 3 4 4 3 4 3 4 4 4 3 3 4 4 4 5 5 6 6 7 7 8 8 8 9 10 10 10 10 10 10 10 10 10 10 10 10 10	- Assur taken a taken a x 0 0 18 36 54 72 90 120 144 168 192 216 240 240 2 2 6 3 6 5 4 5 4 5 5 4 5 5 4 5 5 4 5 5 4 5 5 6 5 5 6 5 5 6 5 5 5 5 5 5 5 5 5 5 5 5 5	me cables <u>s</u> 1.4D+1. <u>pplied to</u> mast x 80 80 80 80 80 80 80 80 80 80	take entit 71/2 (235 both side mast y 50 50 50 50 50 50 50 50 50 50	Te DL. bert o i0 kip/roof) se Hength (ft) 94.3 79.6 66.6 56.4 50.6 51.0 64.0 81.0 64.0 81.0 102.2 102.7 144.9 167.6 167.6 94.3 79.6 66.6 50.4 50.6 50.4 50.6 50.4 50.6 50.4 50.6 50.	aiy haif LL ain theta 0.53 0.63 0.75 0.89 0.99 0.98 0.99 0.98 0.78 0.62 0.41 0.35 0.30 Lc. remove ain theta 0.53 0.63 0.75 0.89	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d           A (im^2)           4.9           4.9           4.9           4.9           4.9           6           9.7           4.9           4.9           4.9           4.9           4.9           4.9           4.9	Earl load EA/L 1506 1784 2521 2806 2787 2219 3428 2751 2270 1921 1661 1661 1661 1784 2134 2521	F vert 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 147 99 89 90 76 191 238 288 341 394 to the left Tension 133 112 94 70	elong (ft) 0.11 0.08 0.06 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (ls) 1.50 0.39 0.39 0.52 1.09 2.10 3.74 6.16 9.54 defl vert (ls) 2.00 1.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.37 0.37 0.37 0.39 0.39 0.39 0.39 0.35 0.39 0.37 0.39 0.37 0.39 0.39 0.37 0.39 0.37 0.00 0.0	Cable stress (kcl) 34 29 24 29 24 29 24 25 35 25 35 25 35 25 35 25 35 25 35 25 35 25 35 25 35 25 25 25 25 25 25 26 26 26 26 26 26 26 26 26 26	F horiz at mast -141 -109 -78 -46 -14 18 47 150 203 320 330 330 3320 376 993 F boriz at mast -113 -87 -62 -37
Case II. Load is A. Live Cable 1 2 3 4 5 6 6 7 7 8 9 9 10 11 12 12 B. Live Cable B. Live Cable 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	- Assur taken a taken a x 1 0 0 18 36 54 72 90 120 144 168 192 216 240 216 240 216 240 54 54 54 54 54 54 54 54 54 54	ne cables s 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80	take entit 71/2 (235 both side mast y 50 50 50 50 50 50 50 50 50 50	Te DL bet o (0 kip/roof) st length (R) 94.3 79.6 66.6 56.4 50.6 51.0 64.0 81.2 101.2 122.7 101.2 122.7 167.6 6.6 6.6 6.6 6.6 6.6 6.6 6.6	aly half LL sin theta 0.53 0.63 0.75 0.89 0.98 0.98 0.78 0.62 0.49 0.41 0.35 0.30 0.49 0.41 0.35 0.30 0.53 0.55 0.59 0.59 0.59 0.53 0.55	Hence, L. E (ksii) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	ad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9	ead loac EAAL 1506 1784 2134 2232 2787 2219 3428 2751 2270 1921 1661 1506 1784 2134 2134 22521 2260	Effect 8 F vert 88 88 88 88 88 88 88 88 88 8	20% live 1 Tension 166 140 117 99 89 90 76 191 238 341 394 to the left Tension 133 112 94 79 71	elong (ft) 0.11 0.08 0.06 0.03 0.03 0.03 0.03 0.05 0.13 0.18 0.24 elong (ft) 0.09 0.06 0.09 0.13 0.13 0.13 0.24	defl vert (la) 1.50 1.50 0.88 0.53 0.39 0.52 1.09 2.10 3.74 6.16 9.54 ∰ 2.00 1.20 0.70 0.43 0.43 0.43	Cable stress (kol) 34 29 24 29 24 29 24 25 30 35 41 Cable stress (kal) 27 23 19 16 15	F horiz at mast -141 -199 -78 -46 -14 18 47 750 263 320 376 993 F horiz at mast -113 -87 -62 -37 -11
Case II Load is A Live A Live Cable 1 1 2 3 3 4 5 6 6 7 7 8 8 9 9 9 9 9 10 11 12 2 8 Live Cable 1 1 2 3 3 4 4 5 5 6 6 1 7 7 8 8 8 9 9 9 9 10 11 2 2 3 3 4 4 5 5 6 6 6 1 1 2 2 3 3 4 4 5 5 6 6 6 1 1 2 2 3 3 4 4 5 5 6 6 6 1 1 2 2 3 3 4 4 5 5 6 6 6 1 1 2 2 3 3 4 4 5 7 7 8 9 10 10 10 10 10 10 10 10 10 10 10 10 10	■ Assume taken av taken av ■ load a av 0 0 18 366 54 72 90 120 144 168 192 216 240 ■ * * * * * * * * * * * * *	me cableing s 1.4D+1. pplied to mast x x 80 80 80 80 80 80 80 80 80 80	take entit 71./2 (235 both side mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	Two DL best or 10 kip/roof) and and and and and and and and	aly half LL in theta 0.53 0.63 0.75 0.89 0.98 0.78 0.78 0.78 0.78 0.78 0.75 0.89 0.98 0.78 0.41 0.35 0.30 0.41 0.35 0.30 0.53 0.63 0.75 0.89 0.98 0.41 0.35 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.30 0.39 0.98 0.98 0.98 0.98 0.98 0.98 0.41 0.35 0.30 0.98 0.30 0.30 0.53 0.63 0.75 0.89 0.99 0.988 0.9888 0.988 0.988 0.988	Hence, L. E (sai) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9	ead loac EA/L 1506 1784 2134 2232 2787 2219 3428 2751 1661 1506 1784 2230 1506 1784 2232 2270 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 2200 20	Effect 8 F vert 88 88 88 88 88 88 88 88 88 8	20% live ] Tension 166 140 117 99 90 76 191 238 248 341 394 to the left Tension 133 112 94 79 71 102 90 70 70 70 70 70 70 70 70 70 7	elong (ft) 0.04 0.04 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (fs) 2.50 1.50 0.83 0.39 0.52 2.10 3.74 6.16 9.54 0.02 0.75 0.02 0	Cable stress (Eci) 34 29 20 18 18 18 20 20 20 35 30 35 30 35 30 35 30 35 30 35 30 35 30 35 30 35 30 30 35 30 30 30 30 30 30 30 30 30 30	F horiz at meet -141 -190 -78 -44 -14 -14 -13 -13 -13 -113 -113 -87 -62 -37 -11 -87 -62 -37 -11 -87 -87 -87 -87 -87 -87 -87 -87
Case II A. Live Cable I A. Live Cable 1 2 3 3 4 5 6 6 7 7 8 8 9 10 11 2 2 8 . Live Cable 5 6 6 7 7 8 8 9 10 11 12 2 3 3 4 4 5 5 6 6 7 7 7 8 8 9 10 10 10 10 10 10 10 10 10 10 10 10 10	■ Assume taken av taken av ■ load a av 0 0 18 366 54 72 90 120 144 168 192 216 240 ■ * * 0 18 192 216 240 ■ * * * * * * * * * * * * *	me cables a 1.4D+1. pplied to mast x 80 80 80 80 80 80 80 80 80 80	take entit 11/2 (235 10-06 aldd mast y 50 50 50 50 50 50 50 50 50 50	Te DL bet o (0 kip/roof) state (0 kip/roof) state (0 kip/roof) (0	aly half LL sin theta 0.53 0.63 0.75 0.89 0.98 0.78 0.62 0.49 0.49 0.41 0.35 0.30 Lc. remove sin theta 0.53 0.59 0.98 0.75 0.89 0.98 0.75 0.98 0.98 0.75 0.99 0.98 0.75 0.89 0.98 0.75 0.99 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.98 0.75 0.89 0.98 0.75 0.89 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.49 0.55 0.30 0.55 0.59 0.59 0.49 0.49 0.49 0.49 0.49 0.55 0.50 0.50 0.50 0.75 0.30 0.57 0.63 0.75 0.89 0.78 0.63 0.78 0.78 0.78 0.78 0.63 0.78 0.99 0.99 0.78 0.63 0.78 0.99 0.99 0.78 0.63 0.78 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.98 0.99 0.98 0.99 0.98 0.98 0.98 0.98 0.99 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.78 0	Hence, L E (ksi) 29000 29000 29000	oad=80% d 4.9 4.9 4.9 4.9 4.9 4.9 4.9 5.6 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9	ead loac EAAL 1506 1784 2134 2306 2787 2219 3428 2751 2270 1921 1661 1506 1784 2134 22751 2270 1921 1501 2270 1921 1921 1661 1784 2134 22751 2275 2219	Effect 8 8 88 88 88 88 88 88 88 88 88 88 88 88	20% live ) Tension 166 140 117 99 80 76 191 238 248 341 394 to the left Tension 133 112 94 79 71 90 76 107 107 107 107 107 107 107 107	elong (ft) 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.0	defi vert (la) 1.50 1.50 0.53 0.39 0.52 1.09 2.10 3.74 6.16 9.54 2.00 1.20 0.20 0.20 0.37 0.39 0.39 0.52 0.39 0.39 0.39 0.52 0.39 0.39 0.39 0.52 0.39 0.39 0.39 0.39 0.52 0.39 0.37 0.39 0.39 0.37 0.39 0.37 0.37 0.39 0.37 0.37 0.37 0.39 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.37 0.30 0.20 0.37 0.37 0.20 0.20 0.20 0.37 0.52 0.00 0.52 0.00 0.52 0.00 0.52 0.00 0.52 0.00 0.52 0.00 0.52 0.00 0.52 0.00 0.52 0.00 0.52 0.00 0.20 0.20 0.52 0.00 0.20 0.52 0.00 0.20 0.52 0.00 0.20 0.52 0.00 0.52 0.00 0.00 0.20 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.000000 0.00000000	Cable stress (kcl) 34 29 24 20 18 15 25 35 25 35 25 35 25 35 25 35 25 35 25 35 25 35 25 35 25 35 25 25 35 25 25 25 25 25 25 25 25 25 2	F horiz at mast -141 -199 -73 -46 -14 18 47 150 263 330 330 330 330 376 993 F boriz at mast -113 -37 -52 -37 -11 18 47 -14 -14 -14 -14 -14 -14 -14 -14
Case II a. Live Load is a A. Live Cable 1 2 3 3 4 4 5 6 6 7 7 8 9 10 11 11 11 11 12 2 3 8 6 6 10 11 11 12 2 3 8 9 10 11 11 12 2 3 8 9 10 10 11 11 2 2 3 1 4 4 5 5 6 6 6 7 7 8 9 10 10 10 10 10 10 10 10 10 10 10 10 10	Assumption of the second secon	me cablefail 1.10-1.1 pplied to mast x = 1.00-1.1 80 80 80 80 80 80 80 80 80 80 80 80 80 8	take entit 1/2/2 (235 both side mast y 50 50 50 50 50 50 50 50 50 50	Te DL bet of 10 kip/roof) est length (R) 9 943 79.6 6 666 56.4 51.0 64.0 81.2 102.7 144.9 167.6 6 666 56.4 50.6 51.0 64.0 81.2 10.	aly half LL also heta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.41 0.35 0.30 Le. remove ain theta 0.53 0.53 0.53 0.53 0.53 0.54 0.54 0.54 0.54 0.55 0.89 0.99 0.98 0.78 0.53 0.55 0.89 0.99 0.98 0.78 0.53 0.53 0.55 0.89 0.99 0.98 0.78 0.53 0.53 0.55 0.89 0.99 0.99 0.98 0.78 0.53 0.53 0.55 0.89 0.99 0.98 0.53 0.55 0.89 0.99 0.98 0.53 0.55 0.59 0.58 0.55 0.59 0.58 0.57 0.59 0.58 0.57 0.59 0.58 0.57 0.59 0.58 0	Hence, L E (ksi) 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000 29000	oad=80% d 4.9 4.9 4.9 4.9 4.9 4.9 4.9 5.6 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9	ead loac EAAL 1506 21784 2334 2426 2787 2219 23428 2751 2270 1921 1661 1506 1784 2134 2521 1784 2134 22806 2787 2219 3428 2751	Leffect 8 8 88 88 88 88 88 88 88 88 88 88 88 88	20% live 1 Tension 166 140 117 99 89 90 76 191 238 341 394 to the left Tension 133 112 94 79 71 90 76 191 238	elong (ft) 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.0	defl vert (0=) 1.50 1.50 0.88 0.53 0.39 0.52 1.09 2.10 3.74 6.16 9.54 0.52 2.00 1.20 0.70 0.43 0.39 0.52 1.09 2.10 0.37 0.15 0.52 1.09 0.15 0.52 1.09 0.15 0.15 0.52 1.09 0.52 1.09 0.15 0.15 0.52 1.09 0.15 0.15 0.39 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.54 1.00 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.05 1.09 0.52 1.09 0.05 1.00 0.52 1.09 0.05 1.00 0.52 1.00 0.07 0	Cable stress (kcl) 34 29 24 8 18 15 25 30 35 41 Cable stress (ksl) 77 23 19 16 16 5 18 18 18 15 20 25	F horiz at mast -141 -109 -78 446 -14 18 47 750 203 320 330 330 330 376 993 F horiz at mast -113 -87 -62 -37 -11 18 47 -52 -37 -11 18 47 -15 -52 -52 -52 -11 -11 -11 -12 -52 -52 -52 -52 -52 -52 -52 -52 -52 -5
Case III A. Live A. Live Cable 1 1 3 3 3 4 4 5 6 6 7 7 8 8 9 9 10 11 12 12 2 3 3 4 4 5 5 6 6 6 8 9 9 10 11 12 2 3 3 3 4 4 5 7 7 7 8 8 9 9 10 12 2 3 8 9 9 10 10 10 10 10 10 10 10 10 10 10 10 10	Assumption of the second secon	me cablefail (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	take entit 71.2 (233 both add mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	Ire DL bet of (0 kip/roof) est length (R) length (R) 379.6 66.6 56.4 51.0 64.0 81.2 101.2 122.7 144.9 167.6 66.6 56.4 56.4 50.6 56.4 50.6 51.0 64.0 81.2 122.7 142.9 167.6 56.4 50.6 51.0 64.0 81.2 122.7	aly half LL sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.41 0.35 0.30 Lc. remove sin theta 0.53 0.53 0.53 0.59 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.99 0.98 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.75 0.89 0.78 0.62 0.41 0.33 0.53 0.53 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.58 0.59 0.58 0.58 0.58 0.59 0.58 0.59 0.58 0.59 0.58 0.59 0.58 0.59 0.58 0.59 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.89 0.98 0.75 0.41 0.53 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0.75 0.41 0.58 0	Hence, L E (ksi) 29000 2900 290000 290000 29000 29000 29000 29000 29000 29000 29000 290000	oad=80% d A (im^2) 4.9 4.9 4.9 4.9 4.9 4.9 5.6 9.6 9.6 9.6 9.6 9.6 9.6 9.6 9	kead loac EAAL 1506 1784 2134 2521 2806 2787 2219 3428 2751 1661 1784 2521 219 219 219 219 219 219 219 219 219 2	Effect 8 F vert 8 88 88 88 88 88 88 88 88 88 88 88 88	20% live Tension 166 140 117 99 90 76 191 238 288 384 394 to the left Tension 133 112 94 79 71 190 76 191 238 288 133	eiong (ft) 0.01 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.09 0.13 0.24 0.24 0.24 0.04 0.03 0.06 0.04 0.03 0.06 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (fs) 2.50 0.88 0.39 0.52 1.09 2.10 3.74 6.16 9.54 0.02 0.70 0.73 0.39 0.52 0.74 0.52 0.75 0.55 0.39 0.52 0.39 0.52 0.59 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0.50 0.55 0	Cable stress (kcl) 34 29 20 28 28 28 20 29 20 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 35 35 25 25 25 25 25 25 25 25 25 2	F horiz at mast -141 -169 -78 -78 -74 -14 -14 -14 -14 -14 -14 -14 -1
Case III A Live A Live Cable 1 1 3 3 3 4 4 5 6 6 7 7 8 8 9 9 10 11 11 2 2 3 3 4 4 5 6 6 6 8 9 9 10 11 12 2 7 8 8 12 2 8 12 2 3 3 12 2 7 7 7 7 8 8 9 9 10 12 2 7 8 10 10 10 10 10 10 10 10 10 10 10 10 10	Assumption of the second secon	ne cable is 1.4D-1.1 pplied to mast x 800 800 800 800 800 800 800 800 800 80	take entit 71_2 (235 10 minut y 50 50 50 50 50 50 50 50 50 50 50 50 50	Tre DL best or 10 kip/roof) 10 kip/roof) 11 sength (ft) 11 sength (ft) 11 sength (ft) 12 constant 12 c	aly half LL sin theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.49 0.55 0.89 0.49 0.49 0.49 0.49 0.49 0.49 0.55 0.30 0.55 0.53 0.54 0.53 0.53 0.54 0.55 0.54 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55 0.54 0.55	Hence, L E (ksi) 29000	sad=30% id           A (ia^2)           4.9           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6           9.6	ead load EAAL 1506 2787 2521 2806 2787 2219 3428 2270 1921 1661 1506 1784 2521 2270 219 2219 3428 2751 2219 3428 2787 2219 3428 2787 2219 3428 2787 2219 3428 2787 2219 3428 2787 2219 2270 219 2270 219 219 219 219 219 219 219 219 219 2270 219 219 2270 219 219 2270 2270 2270 2279 2279 2279 2279 227	i effect d 88 88 88 88 88 88 88 88 88 88 88 88 88	: 20% live : 20% live : <b>Tession</b> 166 160 160 167 99 90 07 191 191 288 341 133 112 133 112 134 79 90 07 6 137 137 132 132 132 132 132 132 132 132	elong (ft) 0.01 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.04 0.03 0.03 0.04 0.04 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.05 0.03 0.05 0.03 0.05 0.04 0.03 0.05 0.03 0.05 0.03 0.05 0.03 0.05 0.03 0.05 0.04 0.05	defl vert (ls) 2.00 2.00 0.88 0.39 0.52 1.00 2.10 3.74 6.16 2.00 1.20 0.20 0.20 1.20 0.374 0.31 0.39 0.52 1.00 0.374 0.16 0.31 0.39 0.52 1.00 0.374 0.16 0.53 0.39 0.52 1.00 0.53 0.39 0.52 1.00 0.53 0.39 0.52 1.00 0.53 0.39 0.52 1.00 0.53 0.39 0.52 1.00 0.53 0.55	Cable stress (kol) 34 29 24 20 18 15 25 35 24 25 35 24 25 35 26 27 27 27 27 27 27 27 27 27 27	F horiz at mast -141 -199 -78 46 -14 18 47 150 263 3200 376 993 F horiz at mast -113 -87 -62 -37 -11 18 47 -15 -37 -62 -37 -11 11 18 47 -37 -37 -37 -37 -37 -37 -37 -37 -37 -3
Case III A. Live A. Live Cable 1 2 3 4 4 5 5 6 6 7 7 8 8 9 9 10 11 11 12 <b>B. Live</b> Cable 1 1 2 3 3 4 4 5 5 6 6 7 7 8 8 9 9 9 10 11 11 12 2 3 3 4 4 5 5 6 6 7 7 8 8 8 9 9 9 10 10 11 12 12 12 12 12 12 12 12 12 12 12 12	Assumption of the second secon	ne cables i 14D-11 pplied to mast x mast x 800 800 800 800 800 800 800 800 800 800	take entit 71.2 (233 soth adda 500 500 500 500 500 500 500 500 500 500	<b>Ire DJ. bet of</b> 19 kip/roof) ■ ■ Iength (R) 9 943 666 666 6640 812 1022 1012 1227 144.9 167.6 <b>c only</b> ■ ngth (R) 94.3 79.6 66.6 51.0 81.2 1022 122.7 144.9 167.6 564.4 50.6 51.0 81.2 1022 1022 1022 1022 1022 1025	aiy haif LL in theta 0.53 0.63 0.75 0.89 0.99 0.98 0.78 0.62 0.49 0.41 0.35 0.59 0.59 0.99 0.98 0.78 0.35 0.30 0.53 0.53 0.53 0.53 0.53 0.53 0.55 0.89 0.99 0.98 0.49 0.53 0.59 0.58 0.59 0.59 0.58 0.58 0.59 0.58 0.58 0.58 0.59 0.58 0.58 0.58 0.59 0.59 0.58 0.59 0.59 0.59 0.58 0.59 0.59 0.59 0.59 0.59 0.59 0.58 0.59 0.58 0.59 0.59 0.59 0.59 0.59 0.59 0.58 0.59 0	Hence, L E (basi) 29000	add=80%         d           A         (ia*2)           4         9           9         6           9         6           9         6           9         6           9         6	EA/IL 1506 1784 2231 2201 22521 2270 2279 1921 1651 1661 1784 22806 2787 2219 3428 22521 2270 1921 1661	i effect 3 8 88 88 88 88 88 88 88 88 88 88 88 88	20% live i 20% live i Tension 166 160 140 140 149 99 90 90 90 90 90 90 90 90 9	elong (ft) 0.11 0.08 0.04 0.03 0.03 0.03 0.03 0.03 0.09 0.13 0.24 elong (ft) 0.09 0.04 0.09 0.03 0.09 0.03 0.09 0.03 0.00 0.03 0.03	defl vert (0=) 1.50 1.50 0.39 0.39 0.52 1.09 2.10 3.74 6.16 9.54 ∰ 0.39 0.70 0.70 0.43 0.39 0.52 1.09 1.00 0.37 0.39 0.37 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09 0.52 1.09	Cable stress (kcl) 34 29 24 18 18 15 20 25 30 35 41 Cable stress (ksl) 27 23 39 16 15 15 27 23 39 16 15 27 23 35 41 25 25 25 25 25 25 25 25 25 25	F horiz at mast -141 -199 -78 446 -14 18 47 150 207 263 3200 376 993 F boriz at mast F boriz at mast -113 -57 -52 -37 -11 18 47 -10 -23 -37 -23 -37 -13 -57 -23 -14 -14 -14 -14 -14 -14 -14 -14
Case III A Live Load is in Load 1 and 1 a	Assumption of the second secon	ne cable ne cable 1.4Dr-1. pplied to 800 800 800 800 800 800 800 80	take entit 17.12 (233 josth elde mast y mast y 50 50 50 50 50 50 50 50 50 50	Ire DL best or 10 kip/rocf) 30 kip/rocf) 31 kip/rocf 31 kip/sec 32 kip/sec 32 kip/sec 33 kip/sec 34 kip/se	sin these 0.53 0.53 0.53 0.53 0.53 0.53 0.55 0.59 0.59 0.98 0.88 0.78 0.99 0.98 0.88 0.75 0.99 0.98 0.80 0.75 0.33 0.33 0.33 0.33 0.35 0.35 0.35 0.3	Hence, L E (ksi) 29000	A (is*?)         49           4.9         49           4.9         49           4.9         49           4.9         49           4.9         50           9.6         9.6           9.6	EA/IL 1506 1784 2231 2201 22521 2270 22787 2219 3428 2751 2270 1921 1661 1784 2521 2259 3428 2521 2219 3428 2259 121 1661	Effect 3 F vert 88 88 88 88 88 88 88 88 88 8	20% live i 20% live i Tension 166 140 140 140 140 147 99 99 90 00 76 191 288 841 394 133 133 133 133 133 133 133 13	elong (ft) 0.01 0.02 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (fs) 2.50 0.88 0.39 0.52 1.09 2.10 3.74 6.16 9.54 2.00 0.70 0.70 0.70 0.70 0.70 0.70 0.71 0.43 0.39 0.52 0.74 0.43 0.39 0.52 0.74 0.53 0.74 0.53 0.74 0.53 0.74 0.74 0.74 0.74 0.74 0.74 0.74 0.74 0.75 0	Cable stress (kcl) 34 29 20 28 18 18 20 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 35 35 35 35 35 35 35 35 35 3	F horiz at mast -141 -197 -141 -141 -14 -14 -14 -14 -14 -
Case III A Live Load is A Live Cable 1 2 4 3 4 4 5 5 6 6 6 7 7 8 8 9 10 11 11 12 2 8 Live Cable 1 2 2 3 3 4 4 5 6 6 6 7 7 8 8 9 10 10 11 12 2 3 3 4 4 5 5 6 6 6 7 7 7 8 9 10 10 11 12 2 3 3 4 4 5 5 6 6 6 7 7 7 8 9 10 10 11 12 2 3 3 4 4 5 5 6 6 6 6 7 7 7 7 8 9 10 10 10 10 10 10 10 10 10 10 10 10 10	Assumption of the second secon	ne cable: ne cable: 1.14D-1.1 80 80 80 80 80 80 80 80 80 80	take entit T/L2 (235 S0 S0 S0 S0 S0 S0 S0 S0 S0 S0	Tre DL best or 10 kip/roof) 21 kip/roof) 21 kip/roof) 21 kip/roof) 21 kip/roof 21 kip/roof 22 rist 22 r	iy haf LL in the construction of the construction	Hence, L E (bst) 290000 29000 29000 29000 29000 29000 29000 29000 29000 29000	add=807. d         (a*2)           4.9         4.9           4.9         4.9           4.9         4.9           4.9         9.6           9.6         9.6           9	EAAL 1506 1784 2134 2134 2134 2134 2134 2134 2134 213	Effect 3 F vert 88 88 88 88 88 88 88 88 88 8	20% live 1 Tension 166 140 140 140 140 147 9 9 9 0 76 191 238 8 288 248 241 394 79 79 71 7 10 238 244 133 112 258 244 133 112 12 19 9 0 0 76 191 238 248 248 248 248 248 248 248 248 248 24	elong (ft) 0.01 0.02 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.09 0.04 0.09 0.04 0.09 0.04 0.09 0.02 0.09 0.03 0.02 0.09 0.03 0.03 0.04 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.05 0.04 0.05 0.04 0.03 0.05 0.04 0.05	defl vert (la) 250 1.50 0.88 0.53 0.59 0.52 1.09 2.10 3.74 6.16 9.54 0.53 0.39 0.52 1.09 1.20 0.20 1.20 0.37 4.53 0.39 0.53 2.00 1.20 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.39 0.53 0.55 0.57 0.57 0.57 0.57 0.57 0.57 0.57 0.57 0.57 0.57 0.57 0.57 0.57 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.54 0.55 0.	Cable stress (6d) 34 29 24 20 18 15 20 25 30 35 41 Cable stress (6d) Cable stress (6d)	F horiz at mast -141 -199 -78 -46 -14 -18 -14 -19 -78 -20 -20 -20 -20 -20 -20 -20 -20 -20 -20
Case III A Live Losd is Losd is Losd is Live Cable 1 2 2 3 4 4 5 5 6 6 7 7 8 8 9 9 10 0 111 12 2 10 10 10 10 10 10 10 10 10 10 10 10 10	Assumption of the second secon	ne cable ne cable 1.14D-1.1 mast x 80 80 80 80 80 80 80 80 80 80	take entit T/L2 (235) beth aldel mast y \$0 \$0 \$0 \$0 \$0 \$0 \$0 \$0 \$0 \$0	Ire DL best or 10 kip/roof) == length (ft) 9 943 564 566 566 560 64.0 81.2 102.2 101.2 102.2 101.2 102.2 101.2 102.2 04.3 79.6 564 56.4 56.6 51.0 64.0 81.2 102.2 10	in the set of the set	Hence, L E (ksi) 290000 29000 29000 29000 29000 29000 29000 29000 29000 29000	A (in*2) 49 49 49 49 49 49 49 49 49 49	Eadload EAAL 1506 2134 2234 2234 2234 2237 2219 2270 1921 1661 1506 1506 22787 2270 1921 1661 1506 1521 2270 1921 1661 1506 1521 2270 1921 1661 1526 1526 1527 15	Leffect 3 F vert 88 88 88 88 88 88 88 88 88 8	20% live 166 140 140 140 140 140 140 140 140	elong (ft) 0.11 0.08 0.06 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (la) 2.60 2.80 0.39 0.39 0.52 1.09 2.10 3.74 6.16 9.54 2.00 1.20 0.20 1.20 0.30 0.37 4.61 0.37 0.37 0.43 0.31 0.39 0.52 2.00 1.20 0.37 0.52 2.00 1.20 0.37 0.43 0.37 0.43 0.37 0.52 0.52 0.70 0.43 0.37 0.52 0.52 0.70 0.43 0.52 0.52 0.52 0.52 0.70 0.43 0.52 0.52 0.52 0.52 0.70 0.43 0.52 0.54 0.55 0	Cable stress (kcl) 34 29 24 20 18 15 20 25 35 41 Cable stress (kd) 55 15 15 15 15 15 15 15 15 27 23 35 41 Cable stress (kd) 35 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 25 35 41 27 27 27 27 27 27 27 27 27 27	F horiz at mast -141 -199 -78 -46 -14 14 47 150 263 320 376 993 F boriz at mast 47 -11 -14 167 -141 -141
Case III A Live Load is Live Cable 1 2 2 3 3 4 4 5 6 6 7 7 8 8 9 9 10 0 11 11 12 2 8 <b>B</b> Live Cable 1 12 12 2 3 3 4 4 5 6 6 7 7 8 8 9 9 10 0 11 11 12 2 2 3 3 4 4 5 6 6 6 7 7 8 8 9 9 10 10 11 12 12 2 7 8 8 9 9 10 10 11 12 12 2 7 8 8 9 9 10 10 11 12 12 2 7 8 8 9 9 10 11 12 12 2 7 8 8 9 9 10 11 12 12 2 7 7 8 8 9 9 10 11 12 12 2 7 7 8 8 9 9 10 11 12 12 12 12 12 12 12 12 12 12 12 12	Assur taken av s load a 18 36 54 72 900 120 144 168 36 240 240 240 240 240 240 240 240	ne cables 1.4De-1.1 mast x 80 80 80 80 80 80 80 80 80 80	take entit T/L2 (235) mast y 50 50 50 50 50 50 50 50 50 50	Ire DL best or 0 kip/rocf) = = length (R) 9 9 9 9 9 9 9 9 9 9 9 9 9	is the set of the set	Hence, L E (dsai) 290000 29000 29000 29000 29000 29000 29000 29000 29000	A (in*2) 4 (	EarL 1506 1784 2134 2521 2806 2787 2139 2270 1921 1661 1506 2787 2270 1784 2322 2270 1784 2322 2270 1784 2219 2270 1784 2270 2219 2270 270	I effect 3 F vert 88 88 88 88 88 88 88 88 88 8	209: live 7 Tension 1666 140 140 140 140 140 140 140 140	elong (ft) 0.08 0.08 0.06 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.09 0.09 0.09 0.03 0.03 0.03 0.04 0.02 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (fs) 2.50 0.88 0.39 0.52 1.09 2.10 3.74 6.16 9.54 2.00 0.70 0.52 0.70 0.52 0.55 0	Cable stress (kcl) 34 29 24 20 28 18 18 18 20 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 30 25 35 40 25 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 25 25 25 25 25 25 25 25	F horiz at mast -141 -193 -184 -14 -18 -14 -18 -14 -18 -13 -13 -13 -13 -13 -13 -13 -13
Case III And is Losd is Losd is Cable 1 1 2 3 3 4 4 5 6 6 6 7 7 8 9 9 10 11 11 2 2 3 3 4 4 5 6 6 6 7 7 8 8 9 10 11 12 2 8 <b>Live</b> 5 6 6 6 7 7 8 8 9 10 11 2 2 3 3 4 4 5 6 6 6 6 7 7 8 8 9 10 11 2 2 3 3 4 4 5 6 6 6 7 7 8 8 9 10 11 12 2 3 3 4 4 5 6 6 6 6 7 7 8 8 9 10 11 12 2 3 3 4 4 5 6 6 6 6 7 8 8 9 10 11 12 2 3 3 4 4 5 6 6 6 7 8 8 9 10 11 11 2 2 3 3 4 4 5 6 6 6 7 8 8 8 9 10 11 11 2 2 7 8 8 9 10 11 11 12 2 7 7 8 8 8 9 10 11 11 12 2 7 7 8 8 8 9 9 10 11 11 12 2 7 7 8 8 8 9 9 10 11 11 12 2 7 7 8 8 8 9 9 10 11 11 12 2 7 7 8 8 8 8 9 9 10 11 11 12 2 7 7 8 8 8 8 9 9 10 11 11 12 2 7 7 8 8 8 8 8 9 9 10 11 11 12 2 7 7 8 8 8 8 9 9 10 11 11 12 2 2 3 3 4 4 5 6 6 6 6 7 7 7 7 8 8 8 8 9 10 11 11 12 2 2 3 3 4 4 5 6 6 6 7 7 7 7 7 8 8 8 8 9 9 10 11 11 12 2 2 3 3 3 4 4 5 5 6 6 7 7 7 7 8 8 8 8 8 8 9 9 10 11 11 12 2 2 7 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	Assur taken a staken a taken a take	ne cable ne cable 1.4D-1.1 80 80 80 80 80 80 80 80 80 80	take entit TL2 (23) both atdd mast y 50 50 50 50 50 50 50 50 50 50	Tre DL best or 10 kip/roof) 21 bip/roof) 21 bip/roof) 21 bip/roof 21 bip/roof 22 bip/roof	ig hear LL in the set 0.53 0.53 0.57 0.59 0.49 0.43 0.53 0.55 0.59 0.50	Hence, L E (ksi) 290000 29000 29000 29000 29000 29000 29000 29000 29000 29000	A (ia*2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	Eadload EAAL 1506 2787 1784 2134 2521 2270 1921 1521 1526 1784 22751 2270 1921 1526 1784 2270 1526 1784 2280 2287 219 2275 1526 152	Leffect 3 F vert 88 88 88 88 88 88 88 88 88 8	20% live: Tension 160 160 160 161 17 288 361 191 228 394 191 228 394 101 228 394 101 228 394 101 228 394 102 288 394 102 288 394 102 288 394 102 288 394 102 288 394 102 288 394 102 288 394 102 288 394 102 288 394 102 288 394 102 288 394 102 102 102 102 102 102 102 102	elong (ft) 0.01 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.04 0.04 0.05 0.04 0.05 0.04 0.05	defl vert (la) 2.50 1.50 0.88 0.53 0.39 0.52 1.09 2.10 3.74 6.16 9.54 ∰ defl vert (la) 2.00 1.20 0.70 0.43 0.31 0.39 0.52 1.09 2.10 3.74 6.16 9.54 ∰ defl vert (la) 3.74 6.16 9.54 ∰	Cable stress (ksl) 34 29 24 20 20 20 25 25 25 25 27 27 27 27 27 27 27 27 27 27	F hortz at mast -141 -109 -78 -44 131 -141 -19 -78 -113
Case III And in Live Cable 1 1 2 3 4 4 5 6 6 7 7 8 8 9 9 0 10 11 12 2 3 3 4 4 5 6 6 7 7 8 8 8 Live 7 8 8 9 9 0 10 11 12 2 3 3 4 4 5 5 6 6 7 7 8 8 8 10 1 2 2 3 8 8 10 1 2 2 3 3 4 4 5 5 6 6 7 7 8 8 9 9 0 10 11 2 3 3 4 4 5 6 7 7 8 8 9 9 0 10 11 12 2 3 3 4 4 5 6 7 7 8 8 9 9 0 10 11 12 2 3 3 4 4 5 6 7 7 8 8 9 9 0 10 11 12 2 3 3 4 4 5 6 7 8 8 8 9 9 10 11 12 2 3 8 8 8 10 10 10 10 10 10 10 10 10 10 10 10 10	■ Assur taken av = load a x x 0 0 18 366 54 72 220 120 120 120 120 122 240 240 240 240 240 240 240 2	ne cables i 1.4De.11 mast x 800 800 800 800 800 800 800 80	take entities 71.2 (23) 600 still mast y 500 500 500 500 500 500 500 50	Tre DL best or 10 kip/roof) set length (ft) 9 943 564 566 566 560 610 610 610 610 812 1022 10	iy haf LL. in the set of the set	Hence, L           E (ksi)           29000	A (im <sup>2</sup> 2) 49 49 49 49 49 49 49 49 49 49 49 49 49	Eadload EAAL 1506 2134 2234 2234 2230 3428 2751 1661 1784 2134 2270 1921 1661 1784 2134 2270 1526 1784 22751 2270 2139 3428 22751 1526 1784 22751 1527 1527 1527 1527 1527 1527 152	Leffect 3 F vert 88 88 88 88 88 88 88 88 88 88 88 88 81 117 71 71 71 71 71 71 71 71 71 71 71 7	20% live Teaslon 166 of 140 140 140 140 140 140 140 140	elong (ft) 0.04 effects. 0.08 0.06 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.09 0.04 0.09 0.06 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.02 0.03 0.02 0.03 0.03 0.03 0.04 0.03 0.05 0.09 0.13 0.24 0.09 0.03 0.05 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.05 0.04 0.04 0.05 0.04 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.04 0.05 0.0	defl vert (la) 2 200 3 37 4 4 4 4 4 4 4 4 5 4 5 4 5 4 5 4	Cable stress (ks) 34 29 24 20 18 15 25 35 41 Cable stress (ks) 55 15 15 15 15 15 15 15 15 15	F horiz at mast -141 -199 -73 -46 -14 18 47 150 263 3300 376 993 F boriz at mast F boriz at mast 47 -11 18 47 -52 -37 -11 18 47 -52 -37 -11 18 47 -52 -52 -57 -11 18 47 -52 -57 -57 -57 -57 -57 -57 -57 -57
Case III And in Live A Live Cable I 1 2 3 4 5 6 6 7 7 8 9 9 10 11 12 2 3 4 4 5 6 6 7 7 8 8 9 9 10 11 11 2 2 3 4 4 5 5 6 6 7 7 8 8 9 9 10 11 2 2 3 4 4 5 5 6 6 7 7 8 8 9 9 10 11 2 2 3 4 4 5 5 6 6 7 7 7 8 8 9 9 10 11 12 2 3 4 4 5 5 6 7 7 8 8 9 9 10 11 12 2 3 4 4 5 5 6 7 7 8 8 9 9 10 11 12 2 3 4 4 5 5 6 7 7 8 8 9 9 10 11 12 2 3 4 4 5 5 6 7 7 8 8 9 9 10 11 12 2 3 4 4 5 5 6 7 7 8 8 9 9 10 11 11 2 3 4 4 5 7 7 8 8 9 9 10 11 11 2 2 3 4 4 5 7 7 8 8 9 9 10 11 11 12 2 3 4 4 5 5 6 7 7 8 8 8 9 9 10 11 11 12 2 3 4 4 5 7 7 8 8 9 9 10 11 11 12 2 3 4 4 5 6 7 7 8 8 8 9 9 10 11 11 2 2 3 4 4 5 5 6 7 7 8 8 8 9 9 10 11 11 2 2 3 4 4 5 8 8 8 9 9 10 11 11 2 2 3 4 4 5 6 7 7 8 8 8 9 9 10 11 12 2 3 4 5 6 7 7 8 8 8 9 9 10 11 11 12 2 3 4 5 6 7 7 8 8 8 9 9 10 11 11 2 2 3 4 5 8 8 8 9 10 11 11 2 2 3 4 5 8 8 8 8 9 10 11 11 12 2 3 4 5 8 8 8 8 8 8 8 8 8 8 8 8 9 10 11 11 12 2 3 8 8 8 8 8 8 8 8 8 8 9 10 11 11 11 1 1 1 1 1 1 1 1 1 1 1 1 1	Assuur taken av i cond av i cond av i cond av x x x x x x x x x x x x x	me cableser mat cableser mast x 800 800 800 800 800 800 800 800 800 80	take entit 71.2 (235) both aldd mast y 500 500 500 500 500 500 500 500 500 50	Ire DL best or 10 kip/rocf) 30 kip/rocf) 31 bigstress 31 bigstress 31 bigstress 32 bigstress 31 bigstress	is the set of the set	Hence, L E (ksi) 290000 29000 290	A (in*2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	Eadload EAAL 1306 2184 2134 22521 2270 1921 1921 1661 1784 2134 2275 12270 1921 1661 1784 22134 2275 12270 1784 2219 2220 2219 2220 2219 2229 229 2229	Leffect 3 F vert 88 88 88 88 88 88 88 88 88 8	20% live: Tension 166 166 167 179 90 98 98 98 98 98 98 98 98 98 98	elong (ft) 0.01 0.02 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (hs) 2.50 0.88 0.53 0.39 0.52 1.09 2.10 3.74 6.16 9.54 2.00 0.70 0.52 0.55 0	Cable stress (kcl) 34 29 24 20 28 18 18 18 20 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 30 25 25 25 25 25 25 25 25 25 25	F horiz at mast -141 -199 -48 -44 -14 -18 -14 -14 -14 -14 -14 -14 -14 -14
Case III And is in Live Cable 1 1 2 3 3 4 4 5 5 6 6 7 7 8 9 10 0 11 11 11 12 12 13 14 5 5 6 6 7 7 7 8 8 14 15 12 12 13 14 15 12 13 14 15 15 14 15 15 14 15 15 14 15 15 14 15 15 14 15 15 14 15 15 14 15 15 14 15 15 14 15 15 15 14 15 15 15 14 15 15 15 15 15 15 15 15 15 15 15 15 15	A Assur taken av i cond a i cond a x x x x x x x x x x x x x	ne cablered in the cablered in	take entities TL2 (23) both side mast y 500 500 500 500 500 500 500 50	Ire DL best of 0 kip/rocf) 30 kip/rocf) 31 31 31 31 31 31 31 31 31 31	iy haf LL in the set 0.53 0.53 0.57 0.59 0.50 0	Hence, L           F (kai)           29000      29000      29000 <tr< td=""><td>A (in*2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9</td><td>Isoc           EAAL           1506           2134           2321           2321           2321           2428           2751           2270           1921           1661           1784           2134           2230           214           2321           2661           2787           2219           3428           2751           1214           2214           2134           2134           2134           2214           2151           1506           1784           2134           2134           2214           2300           2134           2214           2300           2314           2300           2314           2300           2314           2302</td><td>Leffect 3 F vert 88 88 88 88 88 88 88 88 88 8</td><td>20% live: Tension 166 160 140 140 140 140 140 140 140 14</td><td>elong (ft) 0.01 0.02 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.09 0.06 0.09 0.06 0.09 0.00 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.09 0.03 0.03 0.03 0.02 0.03 0.02 0.03 0.03 0.02 0.03 0.02 0.03 0.03 0.02 0.03 0.03 0.02 0.03 0.03 0.02 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.03 0.04 0.03 0.02 0.03 0.03 0.04 0.03 0.02 0.03 0.02 0.03 0.03 0.04 0.03 0.04 0.03 0.06 0.03 0.06 0.03 0.06 0.03 0.06 0.03 0.03 0.06 0.03 0.03 0.06 0.03 0.03 0.06 0.03 0.03 0.03 0.04 0.03 0.04 0.03 0.05 0.03 0.04 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03</td><td>defl vert (in) 2.50 1.50 0.88 0.53 0.39 0.52 2.10 1.09 2.10 1.09 2.10 1.09 2.10 1.09 2.10 1.09 2.20 0.73 0.41 0.31 0.31 0.39 0.52 1.09 2.20 0.74 6.16 9.54 8 0.31 0.39 0.52 1.09 2.20 0.73 0.42 0.55</td><td>Cable stress (ksl) 34 29 24 20 28 29 20 28 29 20 29 20 20 20 20 20 20 20 20 20 20</td><td>F hortz at mast -141 -169 -78 -14 18 -14 -19 -78 -113 -113 -113 -113 -113 -113 -113 -113 -113 -117 -113 -117 -1</td></tr<>	A (in*2) 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9 4.9	Isoc           EAAL           1506           2134           2321           2321           2321           2428           2751           2270           1921           1661           1784           2134           2230           214           2321           2661           2787           2219           3428           2751           1214           2214           2134           2134           2134           2214           2151           1506           1784           2134           2134           2214           2300           2134           2214           2300           2314           2300           2314           2300           2314           2302	Leffect 3 F vert 88 88 88 88 88 88 88 88 88 8	20% live: Tension 166 160 140 140 140 140 140 140 140 14	elong (ft) 0.01 0.02 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.09 0.06 0.09 0.06 0.09 0.00 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.09 0.03 0.03 0.03 0.02 0.03 0.02 0.03 0.03 0.02 0.03 0.02 0.03 0.03 0.02 0.03 0.03 0.02 0.03 0.03 0.02 0.03 0.03 0.03 0.03 0.03 0.04 0.03 0.03 0.03 0.04 0.03 0.02 0.03 0.03 0.04 0.03 0.02 0.03 0.02 0.03 0.03 0.04 0.03 0.04 0.03 0.06 0.03 0.06 0.03 0.06 0.03 0.06 0.03 0.03 0.06 0.03 0.03 0.06 0.03 0.03 0.06 0.03 0.03 0.03 0.04 0.03 0.04 0.03 0.05 0.03 0.04 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03	defl vert (in) 2.50 1.50 0.88 0.53 0.39 0.52 2.10 1.09 2.10 1.09 2.10 1.09 2.10 1.09 2.10 1.09 2.20 0.73 0.41 0.31 0.31 0.39 0.52 1.09 2.20 0.74 6.16 9.54 8 0.31 0.39 0.52 1.09 2.20 0.73 0.42 0.55	Cable stress (ksl) 34 29 24 20 28 29 20 28 29 20 29 20 20 20 20 20 20 20 20 20 20	F hortz at mast -141 -169 -78 -14 18 -14 -19 -78 -113 -113 -113 -113 -113 -113 -113 -113 -113 -117 -113 -117 -1
Case III Active Cable is 1 active Cables 1 active 3 a 4 4 5 5 6 6 7 7 8 9 9 10 11 12 2 3 3 4 4 5 5 6 6 7 7 8 8 9 9 10 11 12 2 2 3 3 4 4 5 5 6 6 6 7 7 8 8 9 9 10 11 12 2 2 2 3 3 3 4 4 5 5 6 6 6 7 7 8 8 9 9 10 10 11 2 2 2 3 3 3 4 4 5 5 6 6 6 7 7 8 8 9 9 10 10 11 2 2 2 3 10 11 12 2 2 3 10 11 12 2 2 3 10 11 12 2 2 3 10 11 12 2 2 3 10 11 12 2 2 3 10 11 12 2 2 10 11 12 2 2 10 10 11 12 2 2 2	A Assuur taken au i coad a x t coad a x t coad a x t source y on 18 192 216 240 144 168 240 216 240 18 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 240 16 216 216 216 216 216 216 216	ne cables in 1.4D-1.1 1.4D-1.1 mast x x 800 800 800 800 800 800 800 80	take entities 71/2 (238) 964b afdd mast y 500 500 500 500 500 500 500 500 500 50	Tre DL best or 10 kip/roof) 10 kip/roof) 11 sength (ft) 11 sength (ft) 12 sength (ft) 12 control (ft)	iy haf LL in the set of the set	Hence, L E (dsi) 25000 2500	A (in*2) 4 (in*	lsad         lsad           EAAL         1506           1784         2134           2132         2521           2219         3428           22787         22781           1261         1902           1921         1921           1661         1784           2334         2521           23428         2787           2219         3428           3428         2751           1561         1921           1661         1921           1661         1921           1661         1921           22787         22787           2219         3428           2218         22787           2219         3428           2219         3428           22787         22787           2219         3428           3428         22751	Leffect 8 88 88 88 88 88 88 88 88 88 88 88 88 8	20% live: Teaston 166 05 140 140 140 140 140 140 140 140	elong (ft) 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.04 0.09 0.04 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.03 0.02 0.09 0.03 0.02 0.09 0.03 0.02 0.03 0.02 0.03 0.02 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.02 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.06 0.09 0.06 0.03 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.05 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.04 0.03 0.04 0.04 0.03 0.04 0.04 0.04 0.04 0.04 0.03 0.06 0.04 0.04 0.04 0.04 0.05 0.04 0.04 0.05 0.05	defl vert (la) 2.00 0.88 0.39 0.52 1.00 2.10 3.74 6.16 9.54 0.20 1.20 0.20 1.20 0.20 1.20 0.374 0.43 0.31 0.39 0.52 1.00 1.20 0.374 0.43 0.31 0.39 0.52 1.09 0.52 0.53 0.54 0.55 0.55 0.55 0.55 0.55 0.59 0.52 0.70 0.43 0.52 1.00 0.55 0.55 0.55 0.55 0.57 0.57 0.57 0.63 0.55 0.55 0.55 0.57 0.55 0.57 0.55 0.57 0.55	Cable stress (ksl) 34 29 24 20 18 15 25 35 24 25 35 24 27 27 23 35 27 27 27 23 35 26 27 27 27 23 35 26 27 27 23 35 26 27 27 23 35 26 26 26 27 27 23 35 26 26 26 26 26 25 25 25 25 25 25 25 25 25 25	F hortz at maet -141 -199 -73 46 -14 18 47 150 203 320 3300 3300 3300 3300 3300 3300 3500 376 993 F hortz at maet 47 197 263 320 376 993 F hortz at maet 47 197 263 320 376 993 -111 -157 -253 -113 -157 -57 -57 -57 -57 -57 -57 -57 -
Case III And is in Live Cable 1 2 2 3 3 4 4 5 5 6 6 7 7 8 9 9 10 0 11 11 12 12 13 3 4 4 5 5 6 6 7 7 8 8 9 9 10 10 11 12 12 13 3 4 4 5 5 6 6 7 7 8 8 9 9 10 10 11 12 12 13 3 4 4 5 5 6 6 7 7 8 8 9 9 10 10 11 12 12 13 3 4 4 5 5 6 6 7 7 8 8 9 9 10 10 11 12 12 13 14 5 5 6 6 7 7 8 8 9 9 10 10 11 12 12 13 14 5 5 6 6 7 7 7 8 8 9 9 10 10 11 12 12 13 14 15 5 6 6 7 7 7 8 8 9 9 10 10 11 12 12 13 14 15 5 6 6 7 7 7 8 8 9 9 10 10 10 11 12 12 13 14 15 14	A Assur taken a i coad a x x x x y y y y y y y y y y y y y	me cables is 1.4De.1 mast x 80 80 80 80 80 80 80 80 80 80 80 80 80	take entit 71.2 (23) both side mast y 50 50 50 50 50 50 50 50 50 50 50 50 50	Ire DL best or 10 kip/rocf) 30 kip/rocf) 31 bigstress 31 bigstress 31 bigstress 32 bigstress 31 bigstress	is the set of the set	Hence, L E (bas) 29000 2900	A (in*3) 4 (	ead load EA/L 1306 EA/L 1306 2521 2521 2521 22787 2219 2219 2229 2219 2229 2219 222	Leffect 3 88 88 88 88 88 88 88 88 88 88 88 88 88	20% live Teadon 166 140 140 140 140 140 140 140 140	elong (ft) 0.01 0.05 0.03 0.03 0.03 0.03 0.03 0.03 0.03	defl vert (hs) 2.50 0.58 0.59 0.59 0.52 1.09 2.10 3.74 6.16 9.54 ∰ 0.52 2.00 0.70 0.52 0.55	Cable stress (ks) 24 25 25 26 27 20 25 30 35 20 25 30 35 20 25 30 35 20 25 30 35 20 25 20 25 30 25 25 30 25 25 20 25 25 20 25 25 20 25 25 25 25 25 25 25 25 25 25	F hortz at mast 
Case II Ac Live Cable is 1 Cable is 3 Cable 1 Cable 3 Cable 9 10 Cable 8 Live Cable 7 R 8 B Live Cable 7 Cable 7 Cable 1 1 1 2 2 3 3 4 4 5 5 6 6 7 7 8 8 9 10 11 1 12 2 3 3 4 4 5 5 6 6 7 7 8 8 9 10 10 11 12 12 12 12 12 12 12 12 12 12 12 12	A Assur taten a taten a ta	ne cables ne cables 1.4D-1.1 mast x 80 80 80 80 80 80 80 80 80 80	take entities T/L2 (238) both aldel mast y 500 500 500 500 500 500 500 50	Ire DL best of 0 kip/rocf) == == == == == == == == == =	iy haf LL in the set 0.53 0.53 0.57 0.59 0	Hence, L E (ksi) 29000 2900	A (in*2) 49 49 49 49 49 49 49 49 49 49 49 49 49	Eard load Eard 1 1506 2134 2134 23521 23521 23521 23521 23521 23521 23521 23521 2570 1921 16611 1506 1522 2787 2219 2219 2210 2219 2210 2219 2210 2215 2210 1921 16611 1056 2215 2210 2215 2210 2215 2210 2215 2210 2215 2210 2215 2210 2215 2210 2215 2210 2215 2210 2215 2	Effect 8 8 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 88 118 11	220% live: 2 Tension 160 160 160 161 161 162 183 161 162 163 163 163 163 163 163 163 163	elong (ft) 0.08 0.08 0.08 0.04 0.03 0.03 0.03 0.03 0.03 0.03 0.13 0.13 0.13 0.24 elong (ft) 0.04 0.03 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.03 0.04 0.05 0.04 0.05 0.04 0.05	defl vert (in) 2.50 1.50 0.88 0.53 0.39 0.52 1.09 2.10 3.74 6.16 9.54 0.31 0.39 0.52 1.20 0.70 0.43 0.31 0.39 0.52 1.09 2.10 0.74 6.16 9.54 0.53 0.39 0.52 1.09 0.52 0.52 0.55 0	Cable stress (ks) 34 29 24 20 18 18 18 20 20 30 30 30 30 30 30 30 30 30 3	F horiz at mast -141 -199 -78 -44 -44 -44 -14 18 -13 -13 -13 -13 -13 -13 -13 -13

or case II	F vert carried by truss
1	110

For case II F vert carrie 1 229 2 142 3 85

### <u>Mast Design Data</u>

# (Refer to figures 3.7a & 3.7b.)

Mast design				•				
ht_to_roof	90							
t_roof	10							
ht_mast_above	50							
len_roof	240							
wid_roof	75		sin	cos				
angle_xy_mast	60	1.047	0.866	0.5				
xcoord_a	80							
ycoord_d	75							
Roof loads	D	L	1.4D+1.7L					
(kips)	1350	540	2808					
Case I. Assume ca	ibles take ent	ire load						
A. Live load appli	ied to both si	des						
Point	Fx	Fy	Fz	Р	v	Mzz at c	Mzz at d	Mvv at d
а	1186	-1404	0	1809	325	18770	28155	0
b	0	0	0	0	0	0	0	0
c	-1186	0	0	-593	-1027	0	-29650	0
d	0	0	0	0	0		0	0
				1216	-702	18770	-1495	
B. Live load appli	ed to right si	de only						
Point	Fx	Fy	Fz	Р	v	Mzz at c	Mzz at d	Mvv at d
a	1340	-1229	0	1734	546	31522	47283	0
b	0	0	0	0	0	0	0	0
c	-1340	0	0	-670	-1160	0	-33500	0
d	0	0	0	0	0		0	0
C Live load appli	ied to left side	e oniv		1064	-615	31522	13783	
Point	Fx	Fv	Fz	P	v	Mzz at c	Mzz at d	Myy at d
a	639	-1113		1283	-3	-180	-269	0
b	0	0	0	0	0	0	0	0
c	-639	0	0	-320	-553	0	-15975	0
d	0	0	0	0	0		0	0
		<u></u>		964	-557	-180	-16244	
		the DL b			<u></u>			
Case II. Assume c	ables take ei	tife DL o	ut omy nam	LL				

Case II. Assul	he cables take e	Inte DL but o	лиу пап гл					
A. Live load a	pplied to both si	ides						
Point	Fx	Fy	Fz	Р	v	Mzz at c	Mzz at d	Mvv at d
a	993	-1175	0	1514	272	15731	23596	0
b	0	0	0	0	0	0	0	0
с	-993	-229	0	-298	-974	0	-28130	C
d	0	0	0	0	0		0	C
		-1404		1216	-702	15731	-4534	
B. Live load a	pplied to right s	ide only						
Point	Fx	Fy	Fz	Р	v	Mzz at c	Mzz at d	Mvv at d
a	1071	-1087	0	1477	384	22171	33257	0
b	0	0	0	0	0	0	0	C
с	-1071	-142	0	-413	-999	0	-28825	C
đ	0	0	0	0	0		0	C
		-1229		1064	-615	22171	4432	
C. Live load a	pplied to left sid	le only						
Point	Fx	Fy	Fz	Р	V	Mzz at c	Mzz at d	Mvv at d
a	717	-1028	0	1249	107	6174	9261	C
b	0	0	0	0	0	0	0	0
с	-717	-85	0	-285	-663	0	-19152	0
d	0	0	0	0	0		0	0
		-1113		964	-557	6174	-9891	

	Wt. at d	F1	Mzz at d	v	F2	P2	-F1+P2	F1+F2	R1	R2	R3	R4
Case II. A.	-1404	-811	-4534	52	-60	-30	780	-871	754	436	650	-436
Case II. B.	-1229	-710	4432	-51	59	30	739	-650	563	325	666	-325
Case II. C.	-1113	-643	-9891	114	-132	-66	577	-774	671	387	442	-387