DESIGN OF NEXT GENERATION ANTENNA MOUNT IN TELECOMMUNICATION TOWERS WITH LOW EFFECTIVE PROJECTED AREA

By

RUBEN GREGORY PUTHOTA DOMINIC SAVIO

Presented to the Faculty of the Graduate School of

The University of Texas at Arlington in Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

August 2015

Acknowledgements

Firstly, I would like to thank my professor Dr. Dereje Agonafer who has been an immense presence in my graduate studies guiding me to complete thesis and mold me into a professional student with his own experience.

I want to sincerely thank CommScope Inc. for giving me the opportunity to work on their project and develop that into a thesis. I am also thankful to industry mentors Mr. Tom Palmer and Mr. Al Skrepcinski for their overall help to finish my thesis.

I also like to thank all EMNSPC lab members and mechanical department who supported me throughout my graduate studies and helped me get through it all, particularly Betsegaw Gebrehiwot one of the PhD students, who was like a mentor and a brother to me, inspired a lot with his urge to learn and willingness to share his knowledge.

I take this opportunity to show my gratitude to Dr. Haji Sheikh and Dr. Ratan Kumar for being there as my committee members and also thank them for their valuable comments on my thesis and the work I put in.

Finally, I am also grateful to my parents Mr&Mrs Dominic Savio, brother Amal Kennedy, sister-in-law Tina and friend Kanimozhi for their unconditional love, patience, financial backing and mental support to complete my thesis and also my life in general.

July 23, 2015

Abstract

DESIGN OF NEXT GENERATION ANTENNA MOUNT

IN TELECOMMUNICATION TOWERS WITH

LOW EFFECTIVE PROJECTED AREA

Ruben Gregory Puthota Dominic Savio, MS

The University of Texas at Arlington, 2015

Supervising Professor: Dereje Agonafer

Design of new antenna mount with low effective projected area (EPA) and high load carrying capacity for telecommunication towers is the purpose of this thesis. The main aim is to reduce the EPA of the mount against the wind pressure direction at the desired elevation from ground by reducing the mount frame structure parts compared to the previous mount designs used in the market. The model in itself has to withstand its dead weight, operator's weight along with five antenna-radio units. The new model has been designed with a single horizontal frame and four supporting structure for EPA reduction and also the EPA is calculated through Image Processing using MATLAB tool which has not been done previously for mounting structures in the telecommunication field. The stress and deformation results calculated using ANSYS 15.0 workbench tool and results are analyzed for von-mises stress criterion.

Table of Contents

List of Illustrations

List of Tables

Chapter 1

INTRODUCTION

1.1. Wireless communication

Wireless communication, one of the most important inventions that the entire 20th century is said to be surviving with it. Nikola Tesla is considered more like the father of wireless communication since it all started with his ideology that he proposed to the entire world. Tesla was born on july 10th 1856 in Croatia who had a great photographic memory. Telsa is still one of the most underrated among the list of inventors like Thomas Edison, Marconi and Benjamin Franklin. In his own words [15], “If in a thunderstorm hit earth’s surface, it creates concentric wave that travels along earth’s crust and comes back to the original place where it started. Earth’s crust is a conductor of electrical energy because of the abundance in ion particles and hence we should destroy distance as our senses can only tell about things nearer but how to know things that are far away. We should be able to transmit information that is far away and the wireless power transmission concept should be able to provide free power to all humans who should be able to have power just like they breather air”.

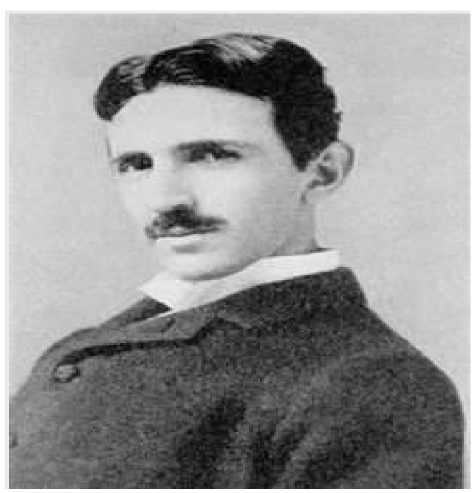

Figure 1.1 Nikola Tesla [9]

In 1890s Tesla built the first model to demonstrate the wireless transmission of electrical energy where he used a transmitter and a portable receiver at a national level electrical conference at St. Louis [9]. The first telecommunication tower called the Wardenclyffe tower [1] was built on long island in 1901 by Tesla with the funding from businessman J.P. Morgan to test Tesla's idea of wireless power transmission and wireless communication at high altitudes where the air is conductive because it's thinner [9]. But the first proper telecommunication station, the Telefunken radio station was built at Sayville, Long Island in 1912 [4].

Wireless communication is one of the fastest growing parts of the communications industry. The cellular systems usage has been growing in an exponential rate over the last decade and it has been estimated that there could be currently 2 billion users worldwide and counting. The demand in cellular systems, laptops worldwide increases the need and speed of the wireless network. Thus the wireless systems started to see an evolution from First generation (1G-pcs) usage of analog communications to Second generation (2G-TDMA/CDMA) systems which moved from analog to digital which also increased the speed in communication. The 2G systems later in the 2000s evolved to 3G (WYMAX/EVDO) systems which had higher frequency band and faster compared to the previous generation systems [2]. The current and emerging need of wireless network means that the technology involving the Mechanical engineering, Electrical engineering, Information Engineering, Automation Engineering also has to be evolved [14].

The evolution in the Mechanical side of wireless communication industry includes the design Antenna-Radio units and wireless mounting systems without failure. The increase in demand of the frequency band in turn increases the number of Antenna-Radio units mounted on a telecommunication tower and so the weight of the whole unit is also higher. Presently the wireless Mount structure holds four Antenna-Radio units to form one sector. Three such sectors are fixed at the same elevation from the ground level on the tower to produce an interference of 360^{o} for the signal frequency. This thesis is based on the future need of increased bandwidth which could increase the count of the Antenna-Radio units to five. The increased antenna-radio units will definitely increase the number of structures used for the design of mount in order to have a better weight carrying capacity thus increasing the EPA. One of the major parts of the design process is to calculate and reduce the EPA as low as possible but also without compromising the mechanical stability of the mount [14].

1.2. Telecommunication Towers

Telecommunication towers comprises of various mechanical steel structures and electronic units that are used to achieve wireless communication for people. Towers are basically used for all kinds of wireless communication, telephone connections, radio and television broadcasting.

Different types of telecommunication tower structures are fielded around the globe such as, monopole, self-supporting and guyed etc. Most commonly used tower structures are the self-supporting ones.

Figure 1.2 Monopole Tower [13]

Figure 1.3 Self-supporting Tower [13]

Figure 1.4 Guyed Tower [13]

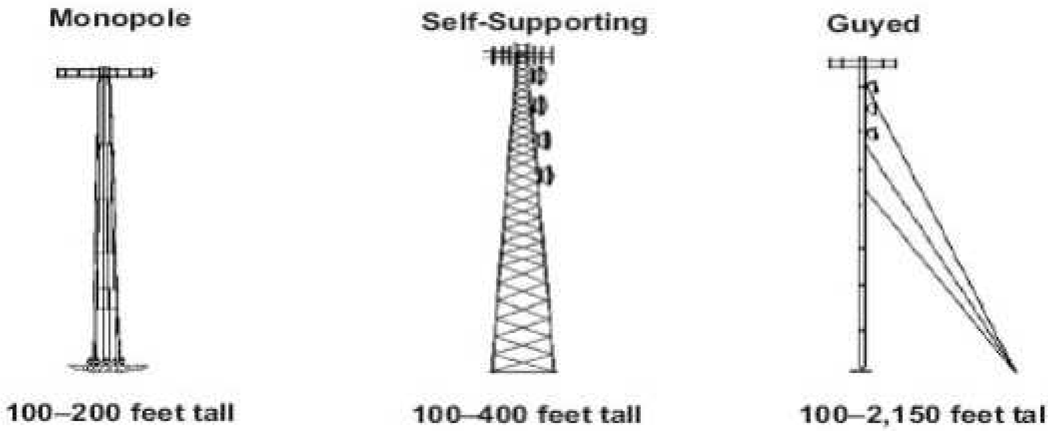

Figure 1.5 Types of telecommunication towers [7]

Towers can vary in height between 100ft to 2000ft and also depends on the site whether it is a hill or plain area [11]. Telecommunication towers are manufactured in huge parts and are erected on site using cranes and could take a month to complete depending on the tower structure [11]. Towers carry Antennas and Remote radio units to produce electrical signals and transmit them for usage.

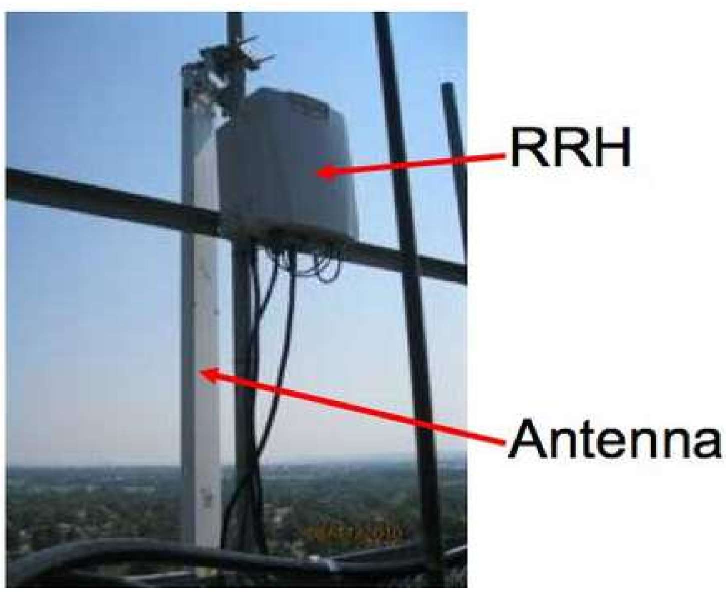

Figure 1.6 Antenna-Radio units

One of those advanced antenna mount designs to be used to avoid solar radiation is shown below.

Figure 1.7 Antenna Solar panel protector

1.3. Antenna-RRU mounting structures

As discussed earlier, a tower will be built to carry on antennas and radio units that generate signals needed for wireless communication. To fix all those antenna units we need proper mechanical mounting structures that could hold all the equipment. As the evolution of wireless communication goes on growing the need to build better mounts are also necessary and mounting structure are also evolving based on the increase in number of antenna units and its weight. Some of the antenna mounts are shown in the images. There are different types of antenna mounting structures based on the requirement. Antenna mounts varies with different numbers of antenna units like two, three or even four units.

Figure 1.8 Antenna mount carrying four antenna units

Antenna mounts consists of different structures and assembled parts that acts as a bridge between antenna-radio units and tower legs. Basically, a mounting structure comprises of main frame structures those hold all the antenna, antenna vertical pipes, radio units, cables and also main supporting structures that holds the entire frame to connect them to the tower leg. The connections and the parts used are all well designed to hold frames, antennas, radio units and fiber optic cables [10]. There are separators used to hold all frame structures without bumping into other closely fixed sector's frame elevated at the same height.

Figure 1.9 Antenna mount carrying three antenna units

Figure 1.10 Connector plates and bolts

Figure 1.11 Separator flanges

All the mounting frames are fixed to tower legs using strong plate structures and some of the connectors for specific mounting structures will be flexible enough to tilt or pivot the entire structure to help adjust radio signal frequency and direction.

Figure 1.12 Tower leg connectors

1.4. Image Processing

Image processing is one of the methods that can be used to calculate projected area of mount structures. Image processing has become a major research oriented area that is used vastly from photography to various fields like computer vision, astrology and engineering imaging [12]. One of the areas that use image processing is the differentiation of different wavelength waves.

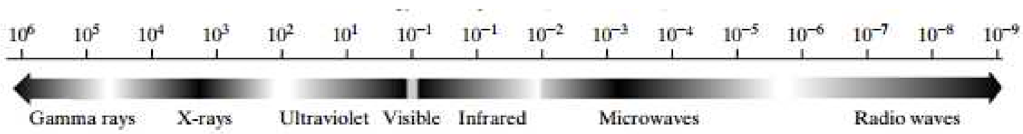

Figure 1.13 Arrangement of electromagnetic spectrum based on energy per photon [2]

According to Jain [3], digital image processing is an application of function that transform a two dimensional image using a computer. The main five purpose of image processing are visualization, Image sharpening, Image retrieval, pattern measurement and Image recognition [8]. There are two types of Image processing, one the analog and the other digital. Analog Image processing is used for obtaining hard copies in photographs and printouts. Digital Image processing uses computer to process images and one of the biggest flied it is being used is on producing proper satellite images. The procedure followed to attain the RGB image is to compress the image at first, pre-processing method for noise filtering, edge extraction. Then the RGB image is converted to Grey scale image for further measurements or calculations based on requirements. One of the advanced techniques in image processing is to use parallel processing, network based processing and artificial intelligence [12]. Some of the current researches where Image processing is used are brain imaging, cancer imaging and a lot more medical related areas.

Chapter 2

ANTENNA-RADIO UNIT MOUNT DESIGN THEORY [6]

In this chapter, we discuss about all the design requirements, parameters, the telecommunication standard data to be used in order to design the new Antenna-radio unit mounting structure to mount antennas on telecommunication towers. The design of antenna mount structure should be eligible to be mounted on different kinds of telecommunication towers irrespective of their leg structures. The mounting structure should be easy to use without any complicated assembly parts, so that it is mountable using cranes and humans who work on bolt-nut connections.

2.1. Design Factors

The design of new mounting structures has to be done with care not only because the structures need to support antenna and radio units that make our modern communication possible but also the people who work on and around the tower need to conduct their work safely. Hence the following factors need to be considered while designing the mounting structures:

- Effective Projected Area (EPA)

The antenna-radio mounting assembly can be as high as 70m to 100m above ground and all of the assembly is expected to be placed within 3m to 3.6m vertical space. At such height, the wind blows at higher speed than it does close to the ground. To reduce the wind force applied on the antenna-radio mounting structure, it is important to minimize the area where wind force is applied to the mounting structure (i.e. the EPA). If the EPA of the mount is reduced then the weight of the structure that needs to support the antenna-radio assembly could also be reduced.

- Weight carrying capacity

A radio-antenna unit is expected to weigh as much as 1330N. A sector may carry up to five antenna-radio units and also adding the operating human weight which could be 2224N, the mounting structure for the sector should be designed to carry 8896N dead load.

- Weight of the mounting structure

The antenna-radio mounting structures are mounted on to the telecommunication towers by skilled operators using different methods. Currently existing mounting structures, which are made of hot-dip galvanized carbon steel, are heavy and could become heavier in the coming years since the structure will be expected to carry more number of and heavier telecommunication equipment. So the design of new mounting structures should consider an installation which may involve mounting the members up 70m to 100m above ground. If possible materials other than steel which are lighter but able to provide structural support to the antenna-radio assembly and sustain the elements should be considered.

- Cost

Effort should be made to minimize the life-cycle cost of the new design (purchase, transportation, etc) and the cost of the new design should not increase significantly compared to existing mounting structures.

- Specifications

The antenna mount design should meet the ANSI/TIA 222 rev-G standards [6] developed for telecommunication towers. The parameters and wind load condition data should be used as per the standards. The materials to be selected should always maintain ASME standard.

2.2 Design parameters and Standard calculation [6].

2.2.1. Parameters

- The mounting structure must be designed within a vertical space limit of 10ft. Mostly wireless companies rent space on telecommunication towers to setup their antenna-radio units for network coverage. Since the renting space is itself a huge business, in order to tackle the cost rates and due to multiple industrial usage of tower space, industries set a vertical space limit so that they can stay within limits and cut down cost effects.

- The new model of the mount should not have a horizontal frame member that exceeds a length span of 14.5 ft. This parameter is to maintain the horizontal limit close to what they use right now with current models.

- Stand-off distance between tower legs and horizontal frame of that of the mounting structure varies for different mounts. In this case, the mount should be designed in such a way that the stand-off distance must be 42 inches.

- On the horizontal frame, the antenna units that are fixed on vertical tubes must be evenly spread within 14.5 ft. The equal spacing between antennas are to maintain the integrity and avoid interference between frequency signals that help achieve better wireless communication.

- Every single antenna vertical pipe will have to carry 2 remote radio units (RRU) and must be fixed on them to avoid wind load acting from the front face normal to the horizontal frame. The RRUs can be placed anywhere on the vertical tube but must be careful in mounting so that they do not bounce onto mounting structures due to external wind loads. It is always safer to have certain gap between RRU and other mounting structure parts.

2.2.2 Standard calculation for wind force [6]

In general to calculate the force, we need the pressure and the area exposed to that pressure. In the case of the telecommunication towers, the wind force acting against the mounting structures are calculated by wind pressure multiplied with the effective projected area (EPA) of the structure in the plane of the windward direction.

$$\text{Wind force} = \text{Wind pressure} * \text{EPA} \quad (1)$$

Effective projected area is defined as the projected area of a body in a desired 2-D plane multiplied with the body's drag coefficient.

$$\text{EPA} = \text{Projected area} * C_d \quad (2)$$

To get the wind pressure and EPA of telecommunication tower parts there are certain standard formulae calculated by the telecommunication standards EIA/TIA 222 rev-G. In this study we calculate the EPA for the mounting structure for wind force acting normal to the mounting structure frame.

2.2.2.1. Effective projected area of mounting structure to the windward face normal to the azimuth of the frame (EPA_N) [6]

$$(EPA)_N = (EPA)_{MN} + (EPA)_{FN} \quad (3)$$

Where,

$(EPA)_{MN}$	Effective projected area of the mount frame structure	
	$C_{as}*(A_f + R_{rf}*A_r)$	4
C_{as}	$1.58 + 1.05(0.6-\varepsilon)^{1.8}$ for $\varepsilon \le 0.6$	5
C_{as}	$1.58 + 2.63(\varepsilon-0.6)^{2.0}$ for $\varepsilon > 0.6$	6
A_f	Projected area of flat components of the mount frame structure	
R_{rf}	$0.6 + 0.4*\varepsilon^2$	7

ε	Solidity ratio of mounting frame without antennas and mounting pipes	
	$= (A_f+A_r)/A_g$	8
A_r	Projected area of round components of mounting frame	
A_g	Gross area of the frame if it were a solid defined by the largest outside dimensions of all the flat and round components	
$(EPA)_{FN}$	Effective projected area of the supporting structure of the mount frame	
	$= 0.5[\ 2.0*A_{fs}+1.2*A_{rs}]$	9
A_{fs}	Projected area of flat components of the supporting structures	
A_{rs}	Projected area of all round components without shielding factor	

2.2.2.2 Wind pressure calculation [6]

The pressure of the wind against the mounting structure in any direction is calculated by,

$$\text{Pressure (P)} = G_H *q_z \qquad 10$$

Where,

G_H is the Gust response factor and q_z is the velocity pressure.

Gust Effect Factor:

Gust Effect Factor can be expressed by the following equation,

$$G_h = 0.85+0.15[(h/150)-3.0] \qquad \text{h, in feet} \qquad 11$$

Where, h is the height of structure. Gust factor in this case for mounting structures are considered to be 1.1 since we use pole structures in the mount model. For guyed masts the factor is considered to be 0.85.

Velocity Pressure:

According to the EIA/TIA-222 Rev G standard the velocity pressure itself is calculated by,

$$q_z = 0.00256*K_z *K_{zt} *K_d *V^2*I \qquad (\text{lb/ft}^2) \qquad 12$$

K_z	Velocity pressure coefficient
K_{zt}	Topographic factor
K_d	Wind direction probability factor
V	Wind speed for loading condition, mph
I	Importance factor

Velocity Pressure Coefficient

Based on exposure category, velocity pressure coefficient (K_z) is determined by,

$$K_z = 2.01*(Z/Z_g)^{2/\alpha}, \qquad 13$$

$K_{zmin} \leq K_z \leq 2.01$ where, Z is the height above ground level, α is the 3-second gust wind speed power law exponent and Z_g is the nominal height of atmospheric boundary layer. Exposure category can be classified into B, C and D.

- B is for structures built in urban and suburban areas with closely spaced obstructions.
- C is for structures built in open terrain with scattered obstructions with heights less than 30ft. The category includes flat, open countru, grasslands and shorelines.
- D is for flat and shorelines exposed to wind flowing over open water for a distance of at least 1 mile. Exposure D extends inland to a distance of 660ft or ten times the height of the structure.

Table 2.1 Exposure category

Exposure Category	Z_g	α	K_{zmin}	K_e
B	1200 ft	7.0	0.70	0.90

Table 2.2 Exposure category-continued

C	900 ft	9.5	0.85	1.00
D	700 ft	11.5	1.03	1.10

Topographic Factor

The wind speed-up effect is included in the calculation of wind loads by,

$$K_{zt} = [1+(K_e*K_t/K_h)]^2 \qquad 14$$

Where,

K_h Height reduction factor, $K_h = e^{(f.z/H)}$

e Natural log base = 2.718

K_e Terrain constant (table 1)

K_t Topographic constant (table 2)

f Height attenuation factor (table 2)

Z Height above ground level

H Height of crest above terrain

K_{zt} is 1.0 for topographic category 1 and can be used for the new mounting structure since the design is for category 1 which means no abrupt changes in the topography like flat terrains.

Table 2.3 Topographic category

Topographic category	K_t	f
2	0.43	1.25
3	0.53	2.00
4	0.72	1.50

Table 2.4 Wind probability factor

Structure type	Wind probability factor, K_d
Latticed structures with triangular and square cross section	0.85
Tubular pole structures	0.95

The basic wind speed to be considered for the model is 85 mph and the importance factor for the new mounting structure with a wind load without ice loading should be considered as 1.00 based on industry data.

But in general importance factor depends on the classification of structures based on hazard level. Structures are classified into I, II and III starting from low hazard to human life and damage towards high level damage progressively. Importance factors based on that are,

Table 2.5 Importance factor

Structure class	Wind load without ice	Wind load with ice
I	0.87	N/A
II	1.00	1.00
III	1.15	1.00

Thus, by following all the standard values and formulae we calculate the wind pressure to be used for the new design of mounting structures for antenna-radio units used in telecommunication towers.

Table 2.6 Wind pressure details [6]

Z(ft)	K_z	G_H	V(mph)	q_z (lb/ft^2)	P (psi)
250	1.53	1.1	85	26.97	0.206
225	1.50	1.1	85	26.37	0.201
200	1.46	1.1	85	25.73	0.196
160	1.39	1.1	85	24.55	0.187
120	1.31	1.1	85	23.10	0.176
100	1.26	1.1	85	22.23	0.169
80	1.20	1.1	85	21.21	0.162
60	1.13	1.1	85	19.97	0.152
40	1.04	1.1	85	18.33	0.140
33	1	1.1	85	17.57	0.134
30	1	1.1	85	17.57	0.134
25	1	1.1	85	17.57	0.134
20	1	1.1	85	17.57	0.134
15	1	1.1	85	17.57	0.134
0	1	1.1	85	17.57	0.134

These values are the input for the whole design that will be carried out in the following chapters.

Chapter 3

EFFECTIVE PROJECTED AREA CALCULATION

3.1. Methodology

Image processing is the technique used here to calculate EPA for mounting structures for wind force acting normal to the frame. Image processing can be done using a lot of software but in this case we use MATLAB programming tool [17]. The basic idea is to use images and calculate the number of pixels in them to use them find the area of that image. MATLAB codes are easier way to approach an image and get all the details that can be derived from that image.

Usually they manually calculate all the projected area of different parts of mounting structures and then use them in all the standard formulae to obtain EPA. This method acts as a perfect alternative to calculate EPA quicker than manual one and accuracy level is close too. The verification of the method using an example will be explained in the later part of the chapter 3. But this explains why we choose this method to replace the current manual one and the detailed version of the method will be explained in the following sections.

3.2. Flowchart

The flowchart below shows the Image Processing concept which is implemented using MATLAB R2014a tool in calculating EPA of mounting structure with windward face acting on the normal face. The important note before having the model in CREO parametric will always be making the software's background screen white in color. While creating a background plate as a reference area for the structure, it is advisable to use dark colors on it and all the parts of the mount model with a lighter color to create a contrast between them. Rendering options in CREO parametric 3.0 [18] enable us to work on reducing reflections or glossiness of colors used in case of shadows occurring on the model due to default room light settings. Some of the options available in CREO parametric 3.0 [18] are shown below in pictures.

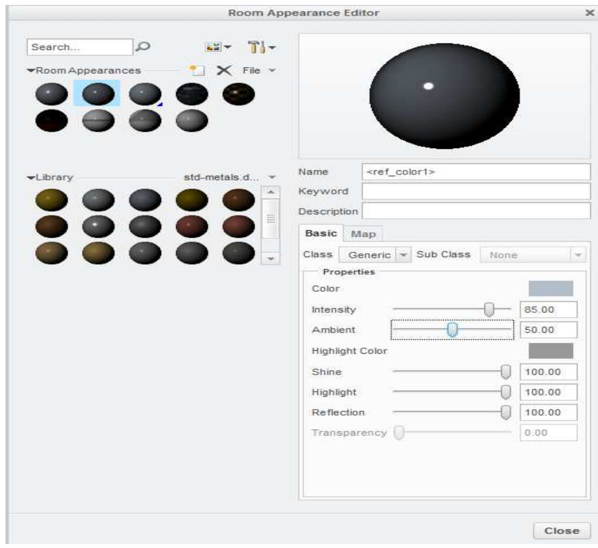

Figure 3.1 Rendering options without changes [18]

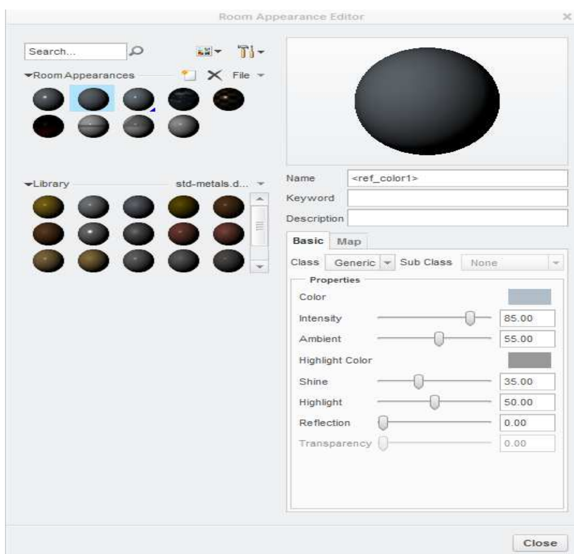

Figure 3.2 Rendered settings [18]

Different parts of horizontal frame and supporting structures of the mounting structure for their respective area calculations are selected individually by hiding the other parts of the model and screenshots must be shot including the background plate.

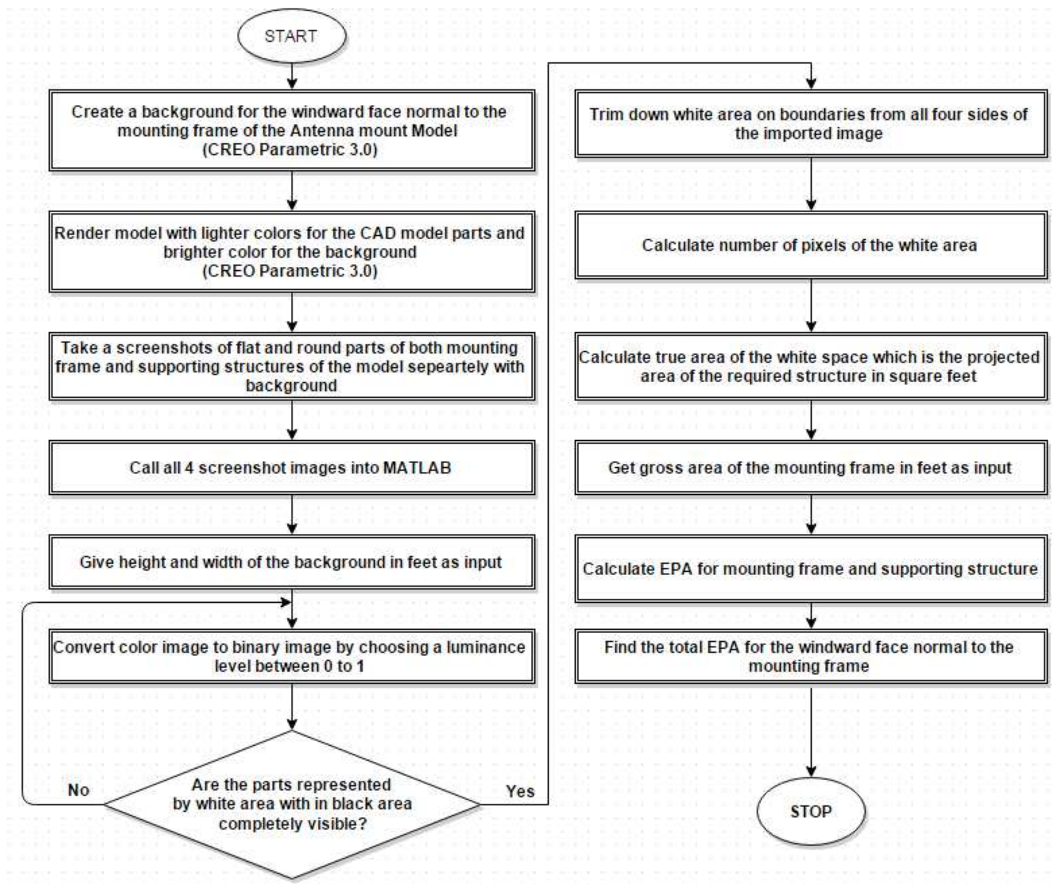

Figure 3.3 Flowchart for EPA calculation

Using MATLAB, 4 different RGB images to calculate Af, Ar, Afs and Ars and are converted to binary images with an appropriate luminous value. The program creates a binary number matrix for each image with 0 represented by black color (background plate) and 1 by white color (parts of the model and software background). While getting a screenshot there is a possibility of having an excessive boundary layer that will be represented by white color which is trimmed off. Trimming off the boundaries is a big step in the entire program. MATLAB identifies each column and row and tries to calculate the sum of the first column. Then MATLAB will start to compare the sum of the first column with the next column and it proceeds. If the sum of other columns is equal to that of the first most one, that column will be deleted. This process stops when the sum of a particular column is less than that of the first one. Now the process starts again from the last column in the reverse way and stops until the sum of column is less than that of the last column. The same procedure is followed for all the rows and thus the excessive boundaries with value 1 are deleted.

The background plate's area is called in as an input by MATLAB and pixel number of all 4 images are counted and saved in the memory. Then, percentage white pixels to whole image are obtained using MATLAB codes. Now, MATLAB multiplies the percentage with the area of the background plate which was called in earlier which gives us all the white region values. These white region areas represent the projected area of flat, round parts of horizontal and supporting structures of the mounting structures. After getting all the projected area, the MATLAB gets gross area dimensions as input. All calculated areas and input gross area are then used in their respective formulae mentioned above in chapter 2 to calculate the total EPA of the mounting structure with windward direction acting along the azimuth's normal face. The software tool gives an alternative to calculate the projected area of an assembly instead of hand calculation where we still have to check every single part's detail to calculate their projected area which takes more time, especially for mounting structures with lot of parts. This method is also helpful to quickly calculate the projected area of faces in different angles to the windward direction if needed.

3.3. Verification of the Method

The methodology of calculating EPA using image processing through MATLAB tool was explained in detail in the section above. Though theoretically explained, the method required verification for one of the mounting structure which is currently being used in the market. To verify the method, we requested a cad model of an existing model from CommScope Incorporation and they sent us one of their own models SF-QV 14-B. The exact methodology is followed for the model and the EPA result of SF-QV 14-B obtained from MATLAB is compared with the manufacturer's value [5].

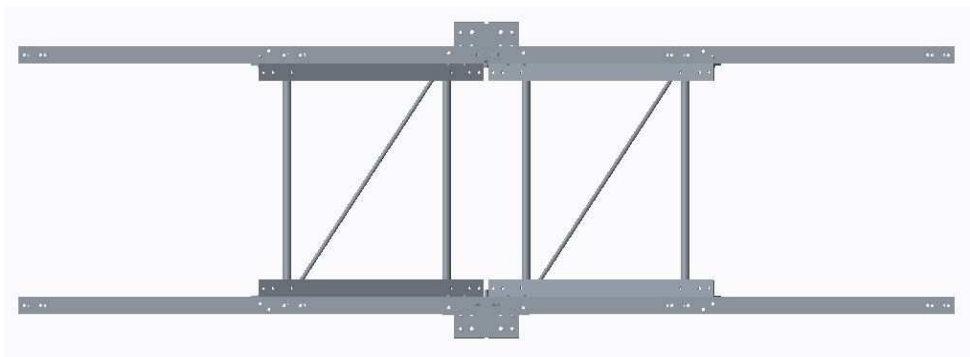

Figure 3.4 SF-QV 14-B mount structure [5]

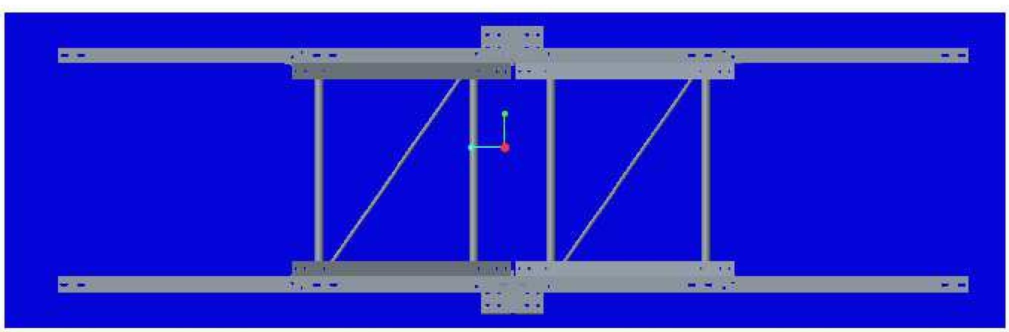

Figure 3.5 SF-QV 14-B mount with background plate [18]

The binary images of the flat and round frame, supporting structures are also shown in this chapter below.

Figure 3.6 Binary image of frame structure

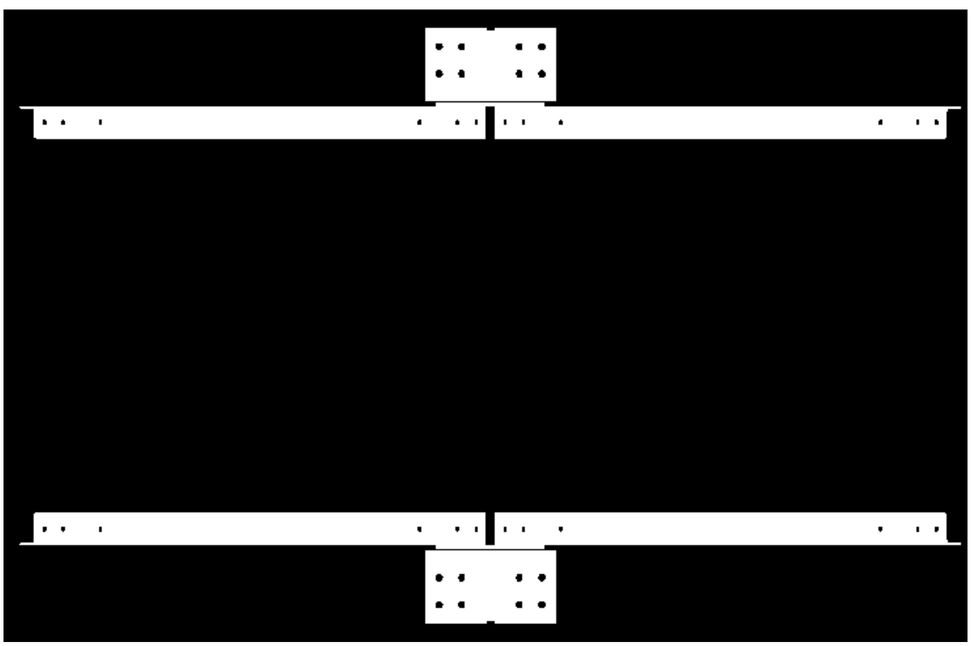

Figure 3.7 Binary image of flat members of supporting structure [17]

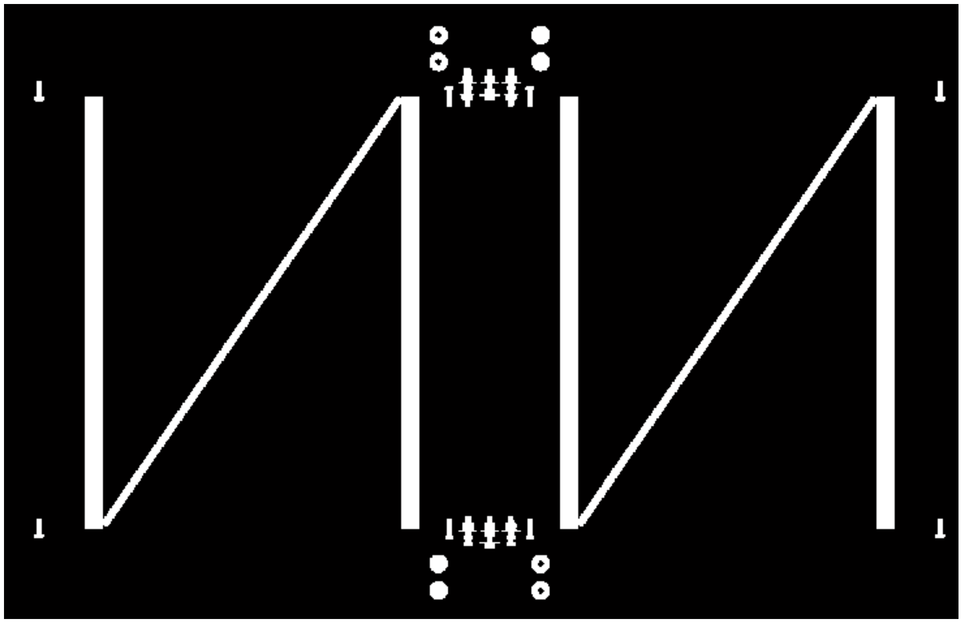

Figure 3.8 Binary image of round members of supporting structure [17]

The EPA values of frame, supporting structures and the entire mounting structure after substituting the projected areas calculated through MATLAB [17] in the standard equations are shared below in the tables.

Table 3.1 Effective projected area [17]

EPA_{MN}	EPA_{FN}	EPA_N
13.28 ft^2	6.27 ft^2	19.59 ft^2

Table 3-2 MATLAB and manufacturer value comparison

EPA_N (MATLAB)	EPA_N (CATALOG) [5]	Error percentage
19.59 ft^2	20.45 ft^2	4.2 %

The results of SF-QV 14-B model [5] from CommScope Inc is calculated using image processing through MATLAB programming tool and compared with the manufacturer value. The calculated result of EPA is 19.59 ft^2 and that of manufacturer's is 20.45 ft^2 [5]. Thus it is clearly understandable that there is only a 4.2 % difference between the values and the difference is considered to be error percentage of the method used. Wind load is measured by EPA multiplied with wind pressure and with this 4.2% difference in EPA will have an impact in wind force calculation. Since EPA and wind force are linearly dependent whatever change in percentage occurs in EPA will be the same in wind load values. So based on the 5% allowable rule used in industries, it is safe to say that anything below 5% is considerable for mounting structure models. Thus it shows that the method is a good enough alternative to manual calculation. More over this method is quick as it saves a lot of time and human error in calculation will also be reduced when compared with manual calculation.

Though the results are acceptable, the error percentage can be improved to have better set of EPA values close to manually calculated value. The error percentage can be taken as one of the limitations of the method used in this project. As discussed earlier the error percentage can be improved with better resolution and pixel density of the computer screen used. The computer screen used in this case is a 23 inches Dell screen with a resolution of 1920 x 1080. As MATLAB converts images to binary images and counts the number of pixels for further are calculation, it is easy to improve results when we have good resolution computer screens through which we snap screenshots of the structures to be used for projected area calculation. Such high resolution screens like 27 inches HP screen with 2560 x 1440 resolution, 24 or 32 inches NEC Multisync with 3840 x 2160 and ACER 28 inches with 3840 x 2160 can be used to improve results.

Chapter 4

NEW ANTENNA MOUNTING STRUCTURE DESIGN

4.1. Mount CAD model

The new model is designed with the all basic requirements and not compensating on any of the design parameters. The mounting structure consists of frame and supporting structures. The number of parts of the frame structure is reduced by having only one horizontal frame structure with plate structures supporting the vertical pipes used to hold antenna and remote radio units. The reduction in assembly parts reduces the EPA of the frame and also the weight of the whole mounting structure. The horizontal frame does not exceed the limit of 14.5 ft and the antenna units are placed on the frame equidistant to each other from one end to the other.

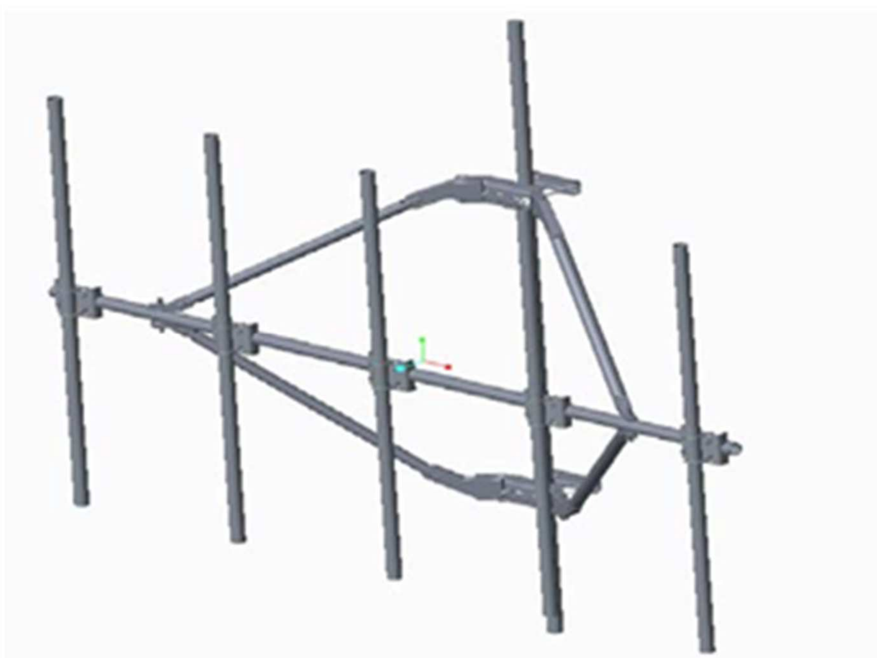

Figure 4.1 Mounting structures with vertical pipes [18]

The frame structure of the mount is connected to the tower through the supporting structures. The use of rectangular plates is required to connect the horizontal frame towards the supporting structures. In this model, we used four main supporting structure pipes to form two different sets of V-frame type structures. They are fixed are at two locations on the frame structure to form a perfect symmetrical body. This is to have a model that is well supported from the tower to carry the dead weight and additional load.
Thus the entire model has reduced a lot of assembly models compared to the other existing models. The V-frames are all connected to the tower using connecting plates that can have additional plates in case if we need to increase the stand-off distance. Currently, this model carries a stand-off distance of 42 inches which is within the design limit.

Figure 4.2 Mounting structure with Antenna-Radio units [18]

The connection plates and vertical pipe connections used to connect antenna units are all shown in the images below.

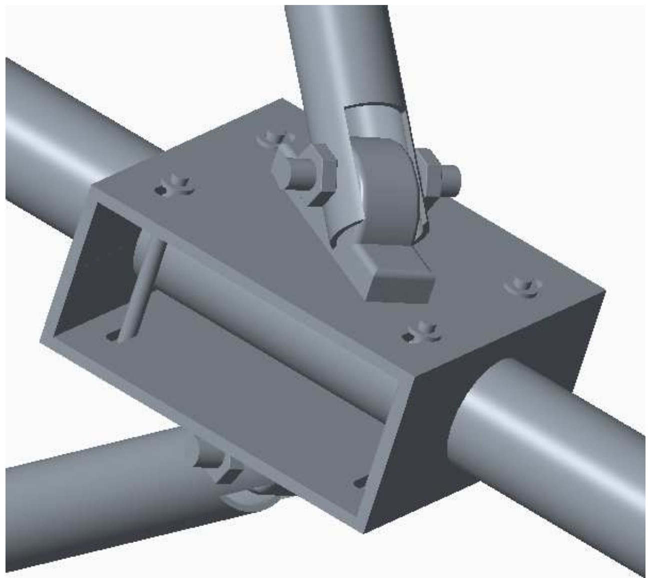

Figure 4.3 Frame and supporting structure connection plate [18]

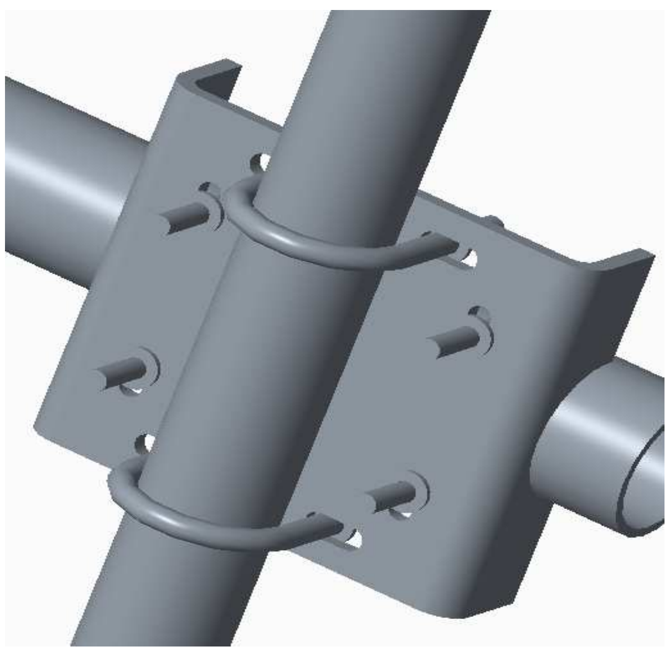

Figure 4.4 Antenna vertical tube connection plate [18]

4.2. Material Data

Material selected for the mounting structure should always satisfy ASME standards. Most of the mount structures are always some of the steel structures with different grades. So, we go by the same selection with steel structures for our mount model. All the steel structures must be galvanized with zinc to avoid rusting problems after installation of the mounting structure. The material properties of all the material used and assumed are provided in the tabular data below in this chapter 4.

Table 4.1 Material property data

Material	Density ($lb\ ft^{-3}$)	Elastic modulus (psi)	Poisson's ratio	Yield strength (psi)
A36-steel	490.06	2.90E+07	0.26	36300
A500-steel	490.06	2.90E+07	0.26	45687
Antenna-material	1.6855	3.48E+07	0.3	1E+06
RRU-material	1.2948	3.48E+07	0.3	1E+06

A36, A500 grade steels are selected because they are currently being used for manufacturing mounting structures and they can also withstand self-weight and dead load applied on them for the dimension used. Our main concern in this project is to design and analyze only the mounting structure. Hence, we are assuming the material properties of antenna and remote radio units used in here. The assumptions of yield strength and Elastic modulus are so high compared to steel structures. The reason behind the selection is that the antenna and radio units must not bend or show max stresses for high wind loads. We are going to study only the mounting structures and hence to avoid other stress concentration distraction we assume high strength materials for antenna-radio units. While assuming the material property it is highly important to use the density properly. As per design parameters, the antenna with 180 lbs and 2 radio units with 60 lbs each should carry a combined load of 300 lbs dead weight. Thus the densities are calculated with the given weight and are used in as material properties. The other main steel material properties are used by referring MatWeb website [20] for this thesis.

4.3. Finite Element Model

Finite element method is used to analyze the mounting structure modelled in CREO parametric 3.0 by using ANSYS 15.0 simulation software. The simulation process is carried out in ANSYS workbench which acts as a graphical unit interface. For this model, we carry out static structural analysis and the work flow of the analysis used is shown in the picture below.

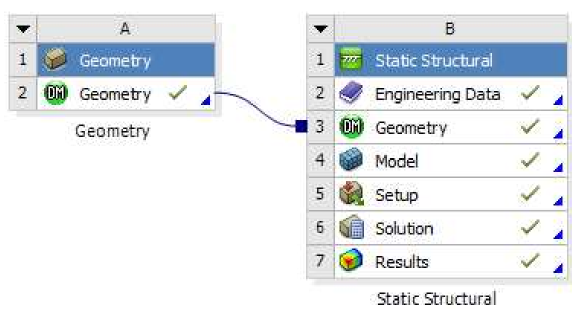

Figure 4.5 Schematic diagram of structural analysis

4.3.1. Importing CAD model

All the required materials are included in the ANSYS workbench library through engineering data. All the required properties like densities, isotropic coefficients, yield strength and ultimate strength can be plugged in from the property chart shown on the left side of the figure below. These materials can then be called into the solver while analyzing easily.

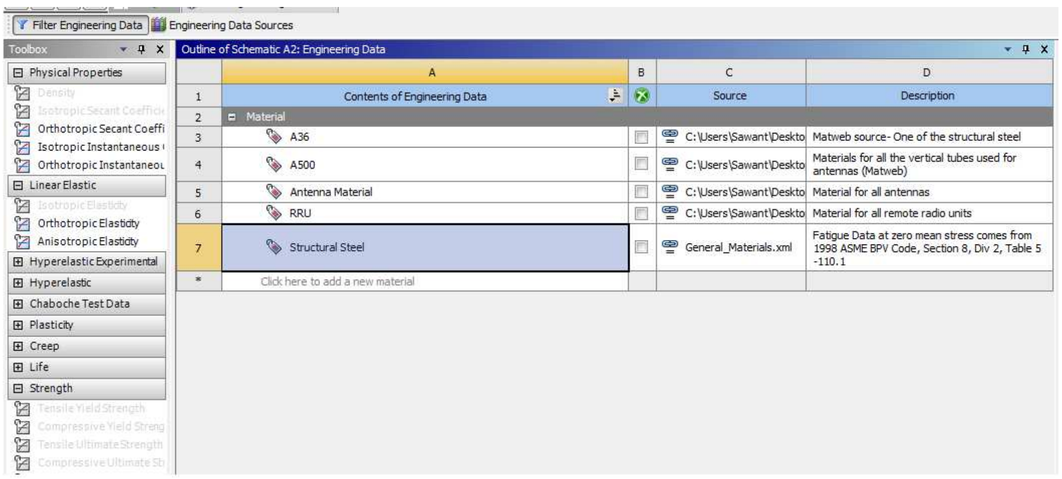

Figure 4.6 Material library in ANSYS workbench 15.0 [19]

The CAD model with assembly parts designed is converted and saved as a STEP file. The STEP file is then imported into ANSYS design modeler to start structural analysis. It is always recommended to turn on the surface bodies, line bodies option in design modeler to import all parts of the assemble model without losing anything. Then generate the model and the whole assembly is created within design modeler. For this assembly mounting structure model we have approximately around 490 parts which includes all the steel tube, pipes, bolts, U-bolts, connection plates and reference tower leg. If necessary the different parts can be color coded differently to differentiate them and also naming them is an option that can be helpful while analyzing in the mechanical solver. The imported model in ANSYS 15.0 [19]can be seen in the below image.

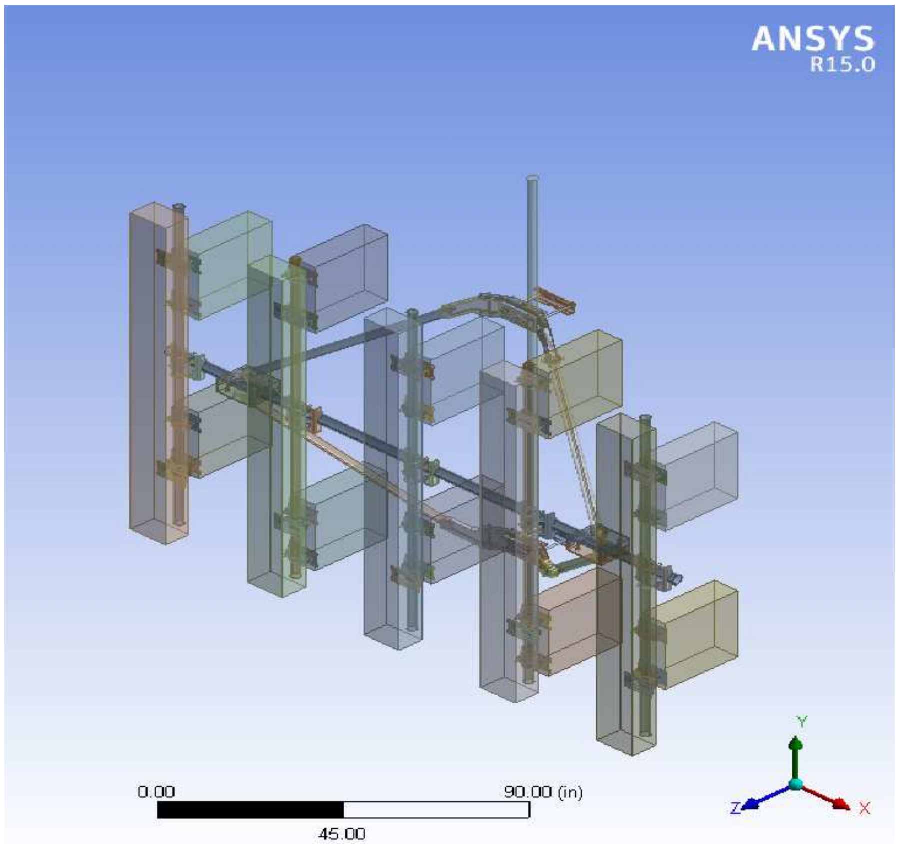

Figure 4.7 Imported geometry model

4.3.2. Contact analysis

After importing and generating the CAD model in ANSYS, it is moved to the mechanical solver where the model is pre-processed to get structural results. When the model is sent to the solver all the contacts between parts are all generated automatically based on assembling of parts in CREO parametric [18]. Before going onto analyze it is always good to check the contacts if there are any unnecessary contacts acting between different parts. For this manual check, ANSYS provides us an option named contact information where the program will run throughout all the contacts and produces a data sheet that has the penetration, gap, type of contact, status and pin-ball radius for each contact. Based on that it is easy to pre-check all the contacts and delete the unwanted contacts. Color codes represented to inform the user that the contacts could be far open or too close or proper. In our model all contact types are bonded and hence a linear type problem. The initial contact information generated helped to delete excessive contacts created and also helped increase pin ball radius for contacts those were open but had to be bonded. By increasing pin ball radius based on the gap information it is easy to make the bonded contact more active than being far open. Finally, checking all the contacts is absolutely necessary so that the model would not have more gaps between parts which will create peak stresses and mislead the analysis.

Color Legend

Red	The contact status is open but the type of contact is meant to be closed. This applies to bonded and no separation contact types.
Yellow	The contact status is open. This may be acceptable.
Orange	The contact status is closed but has a large amount of gap or penetration. Check penetration and gap compared to pinball and depth.
Gray	Contact is inactive. This can occur for MPC and Normal Lagrange formulations. It can also occur for auto asymmetric behavior.

Figure 4.8 Initial contact information

4.3.3. Meshing the Model

Once the model is checked for contacts the next important step to carry out is to mesh the model using different options. There are plenty of meshing methods available in ANSYS 15.0. Each model has to be meshed based on its geometry and structure. There are different types of elements while generating mesh for a body. Tetrahedral, hexahedral (brick) and prism elements are the different types of mesh elements. Brick elements are the best element to be used since it produces an even mesh over a body part and also reduced the count of elements produced.

Some of the element pictures are shown below.

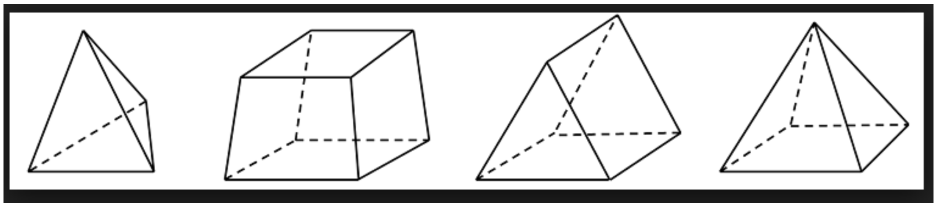

Figure 4.9 Tets, bricks, prism and pyramid mesh elements

While generating mesh for model, there are two strategies to be followed. Using global meshing methods at first and then based on the model requirements local meshing methods can be used.

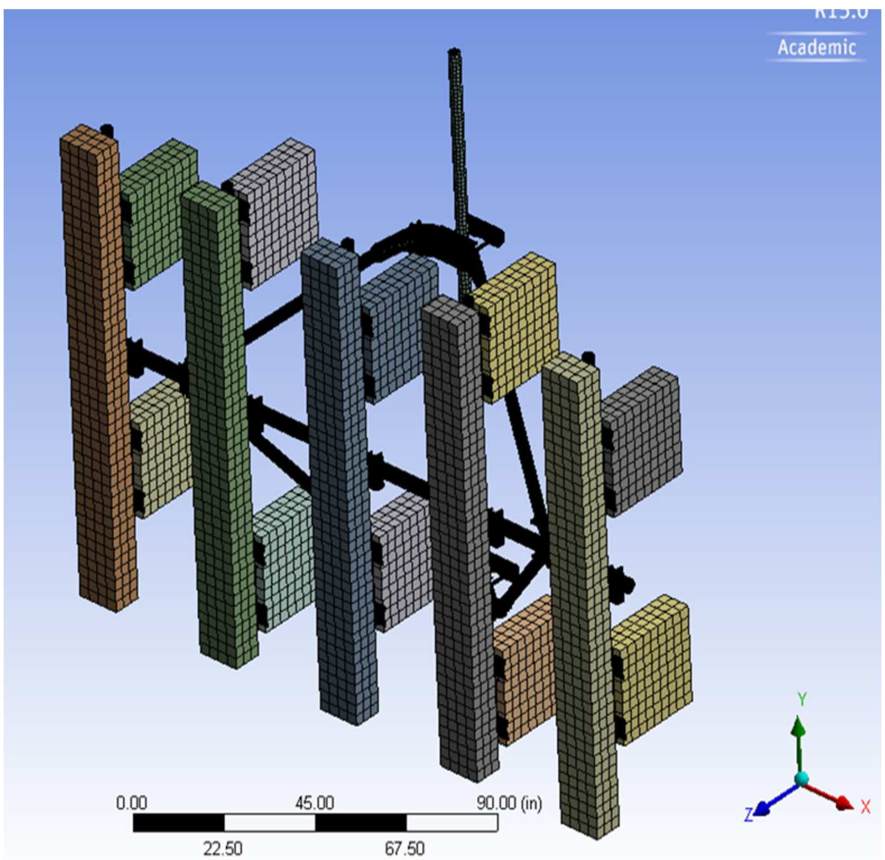

Figure 4.10 Proximity and Curvature mesh method [19]

In this case, one of the advanced mesh method is used as a global method to produce fine number of elements for the entire structure. Proximity and curvature is used for the model because of the round structures and chamfered edges in it. Proximity and curvature method specifically recognizes all the closely placed faces and curved structures and meshes them with finer elements which cannot be achieved using other global mesh methods. The element size gradually grows from 25inches to 0.125 inches based on the size and shape of the structure. The growth rate for all the mesh elements that grows from edges towards the whole body is 1.8 approximately.

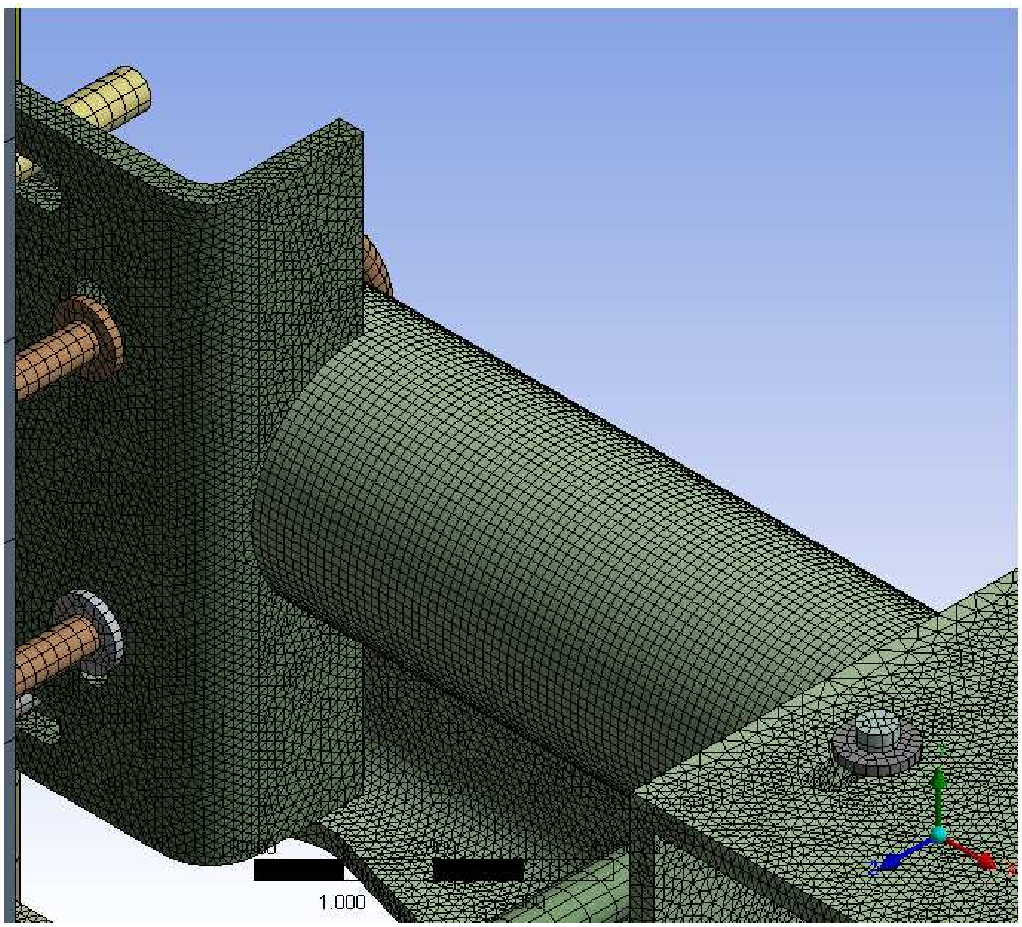

Figure 4.11 Detailed view of the meshed mounting structure [19]

After globally meshing the model, a local mesh method named hex dominant is used on parts which have larger surface to volume ratio. This particular method tries to create better brick elements or hexahedral elements which will reduce the number of element rather than having tetrahedral mesh elements more in number. The main mounting frame structure is locally meshed with a face sizing which creates three elements on its thickness. All the parts those have a stable body structure that is the body doesn't alter from source face to target face are considered as sweep-able bodies and are meshed with brick elements easily. Other parts which are not sweep-able are all meshed with tetra-hedral elements. Thus following all the above stated meshing techniques, we finally generated the model with 6 million element count and 13 million nodes approximately. Once meshing is done, all the contact information should be regenerated because contacts depend on nodes too.

4.3.4. Boundary Conditions

After meshing the entire mounting structure, the model has to have all the boundary conditions before solving the entire analysis. Boundary conditions are all based on the project definition and design parameters. As discussed earlier, the mounting structure has to carry its own weight and a dead load of 2000 lbs which includes antenna-radio unit weight and human load who works up on towers to fix all those bolts. The mounting structure should also withstand a wind load at a height 250 ft above ground level and wind load values are determined using standard formulae and picked from calculated data table shown in chapter 2. All the boundary conditions allotted for this particular mounting structure is discussed in this section.

- The connection plates used to connect all those V-frame type supporting structure to the tower leg are all fixed.

- Since the entire model is fixed at a height of 250 ft from ground level, standard gravitational force acts on the whole structure. Thus, in this model a force of 32.174 ft/s^2 acts on the negative Y direction.

- As the structure is exposed to wind, a pressure of 0.206 psi taken from the previously calculated tabular data strikes against the mount in the direction normal to the frame structure of the mount model. In this case, the 0.206 psi wind pressure acts on the negative Z direction.

- Other important condition of the mount design is to withstand human load of 500 lbs and so the load is added to act on the weakest point of the whole model which is one of the edge of the horizontal frame structure because it could provide more stress on the entire model. So, in directional sense this 500 lbs load acts towards negative Y direction.

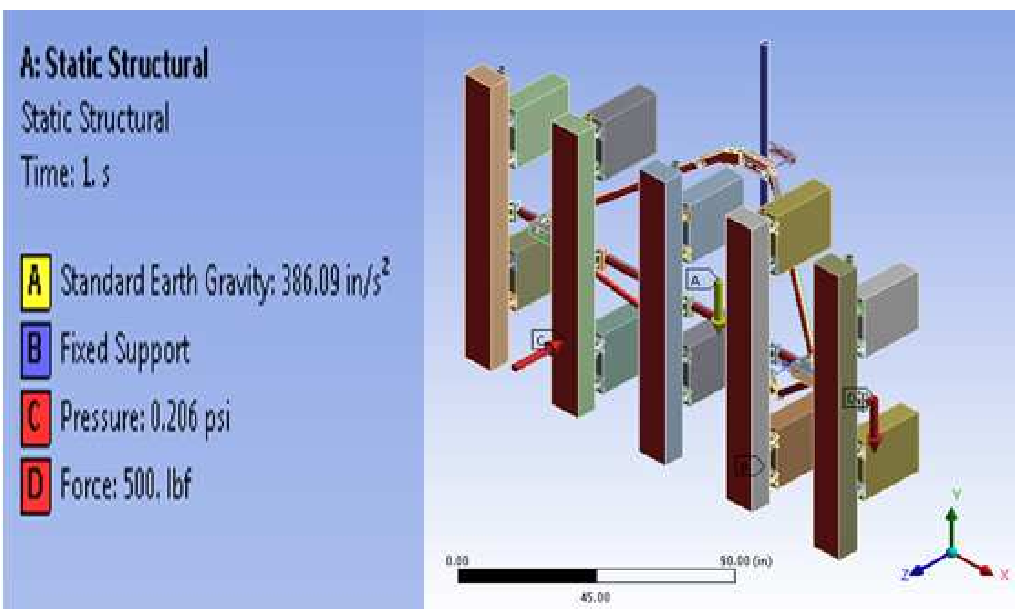

Figure 4.12 Boundary conditions [19]

Chapter 5

RESULTS

5.1. Effective Projected Area results [17]

To calculate the EPA for the new mounting structure projected in windward direction acting normal to the azimuth of the frame, the same image processing method is used since it is verified that the method is good alternative. As per standard calculations EPA for the mount structure is calculated separately for frames and supporting structures.

5.1.1. Effective projected area of frame structures

As discussed in the earlier chapters, snap shots of just frame structures projected onto the reference background plate are taken. Then they are called into MATLAB to get binary images and calculate the projected area which is then substituted in the standard equations to get effective projected area. Before taking snapshots the frame structure which in here the only the horizontal frame is decomposed into two sections based on the shape of the parts. Here, the horizontal frame has flat and round members and projected area calculated separately. Finally the program gives the EPA of the frame structure.

The EPA_{MN} results and binary images are showed below which are calculated through MATLAB codes.

Table 5.1 EPA_{MN} Result

A_f	A_r	EPA_{MN}
2.9ft^2	4.2ft^2	9.9ft^2

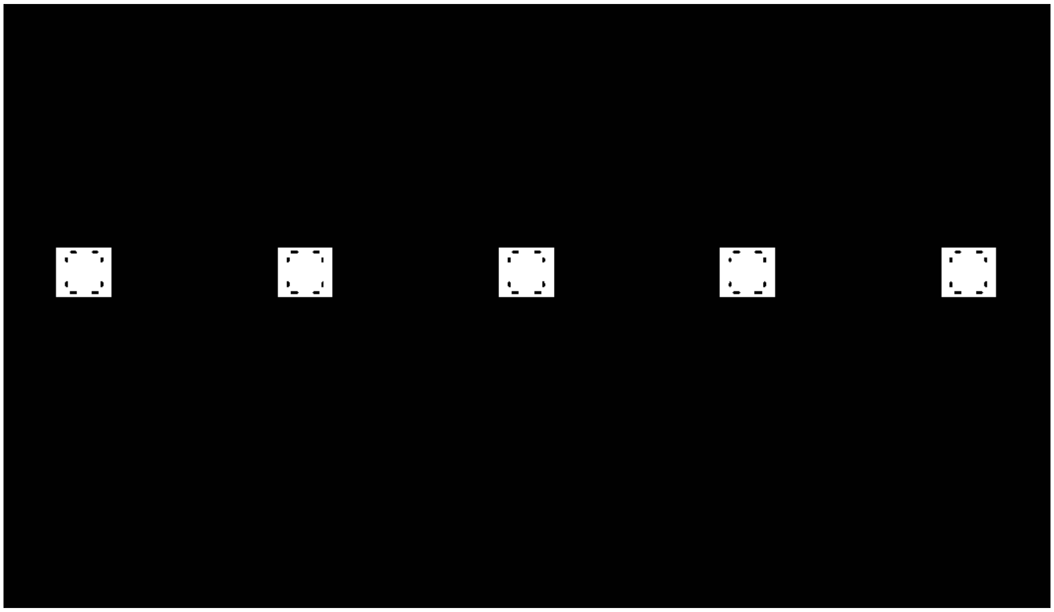

Figure 5.1 Binary image of flat members of frame structure

Figure 5.2 Binary image of round member of frame structure

5.1.2. Effective Projected Area of supporting structures

As we calculate the EPA for frame structure, supporting structures are also disintegrated into two different sections based on the shape that is round and flat members. Projected area is calculated for both flat and round members of the supporting structures and the values are multiplied with their corresponding drag coefficient to calculate the EPA and they are added up to calculate EPA for entire supporting structure. The results and binary images are shown below.

Table 5.2 EPA_{FN} Result

A_{fs}	A_{rs}	EPA_{FN}
4ft^2	4.7ft^2	6.8ft^2

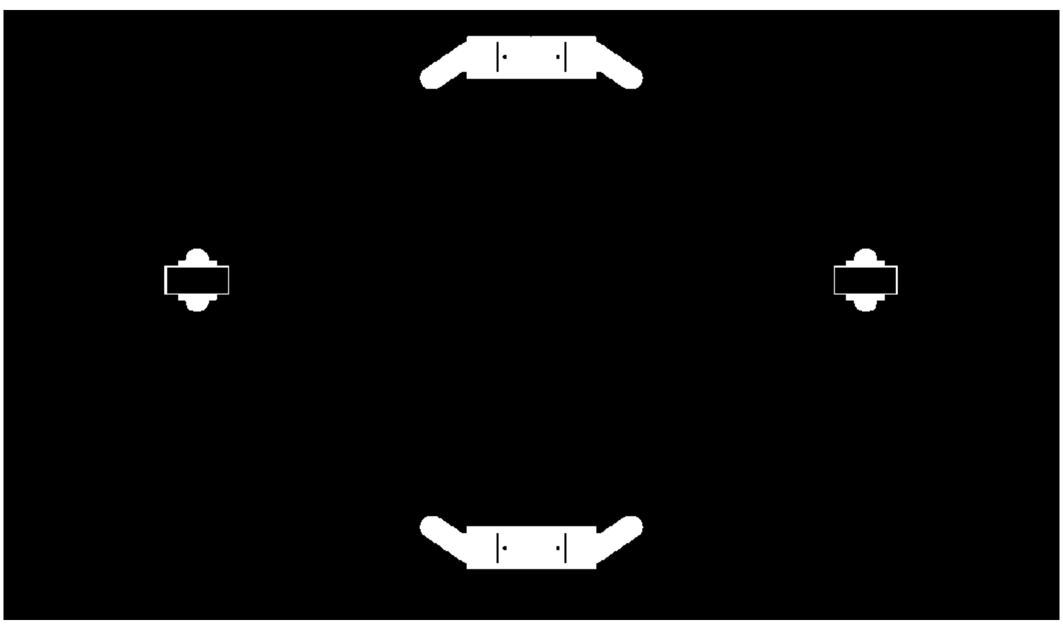

Figure 5.3 Binary image of flat members of supporting structures

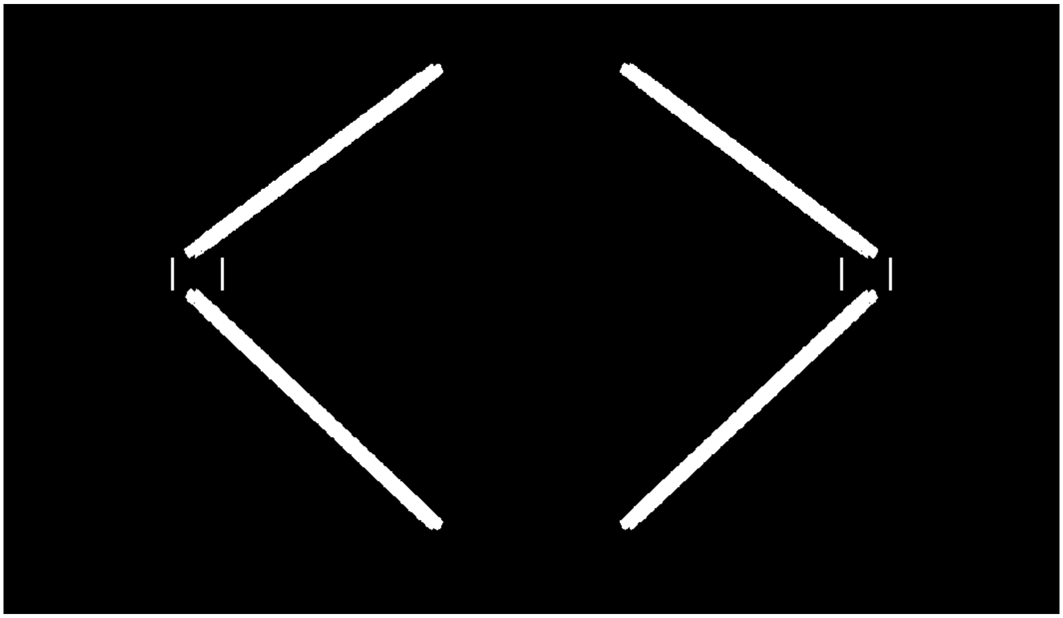

Figure 5.4 Binary image of round members of supporting structures

And, finally both effective projected areas of frame and supporting structures are summed to calculate the overall EPA of the mounting structure projected in the windward direction acting normal to the azimuth of the frame.

Table 5.3 EPA_N Result

EPA_{MN}	EPA_{FN}	EPA_N
9.9ft^2	6.8ft^2	16.7ft^2

The EPA_N calculated for mounting structure is about 16.7ft^2 which does not exceed the maximum limit that is 64ft^2. Also the new mount has a lower EPA when compared the currently used mounting structure by CommScope Inc. The results are better than most of the mount structures and hence it is the first success for the model and it gave way to go on work on finite element analysis.

5.2. Finite Element Analysis Results [19]

Finite element analysis is carried out for the mount model in ANSYS workbench 15.0 with all the boundary conditions we got from EIA/TIA 222 rev G standards. The stress, deformation and strain results are analyzed and elaborately discussed in this chapter.

5.2.1. Stress and Strain Results

After defining the material properties, contacts between parts and meshing the geometry, we define the boundary conditions before starting to run the simulation. For this model stress results were analyzed and since the materials used are all steel structures which are ductile and also the mounting structure having multiaxial loadings, it is safe to analyze the equivalent von-mises stress instead of normal and shear stresses individually. Von-mises stress is nothing but a logical way to sum of all the directional stresses. Von-mises stress results can be further compared to the yield strength to verify whether the entire model satisfies von-mises stress criterion.

$$\sigma v = \frac{[(\sigma 1-\sigma 2)\text{^}2+(\sigma 2-\sigma 3)\text{^}2+(\sigma 3-\sigma 1)\text{^}2]}{2}\text{^}1/2 \geq \sigma y \qquad 15$$

Where, σ_1, σ_2 and σ_3 are principle stresses of the model on all three directions, σ_v represents the von-mises stress and σ_y represents the yield strength. Von-mises criterion can be stated as the model will fail when the von-mises stress exceeds the yield strength.

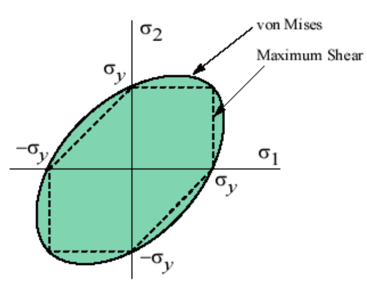

Figure 5.5 Von-Mises and maximum shear stress criterion [16]

The stress results for the mounting structure is shown and discussed below.

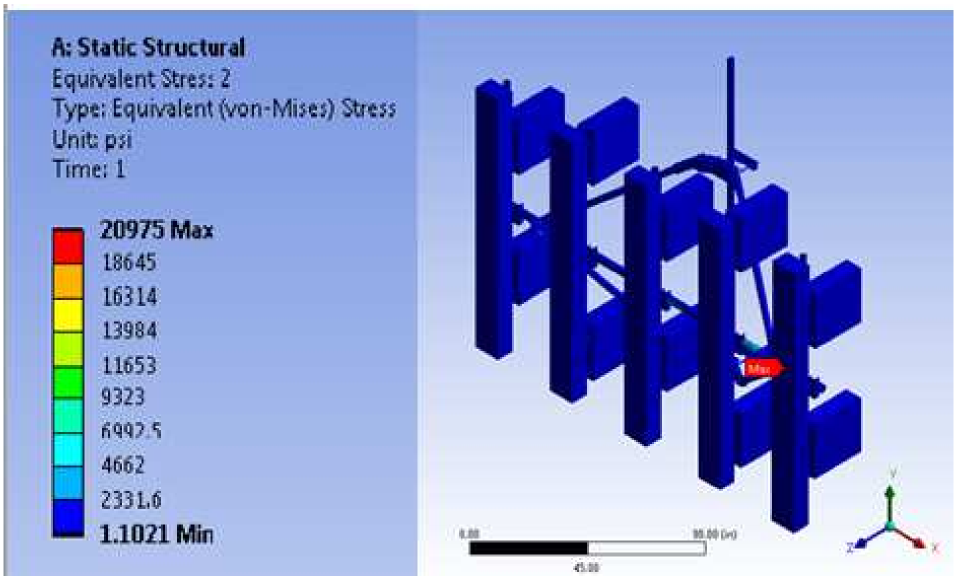

Figure 5.6 Maximum von-mises stress point [19]

As shown in the figure 5-6 above the results are clear that most of the model does not experience a stress beyond 2331.6 psi which are represented by dark blue color. Though there are points where higher stress occurs and particularly in this image the max point is not visible. For that, a zoomed version of the area of concern in different views is shown below.

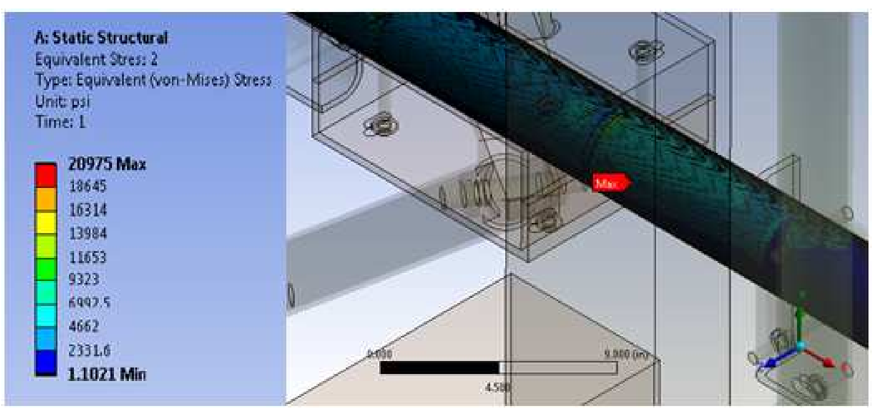

Figure 5.7 Detailed view of max stress point [19]

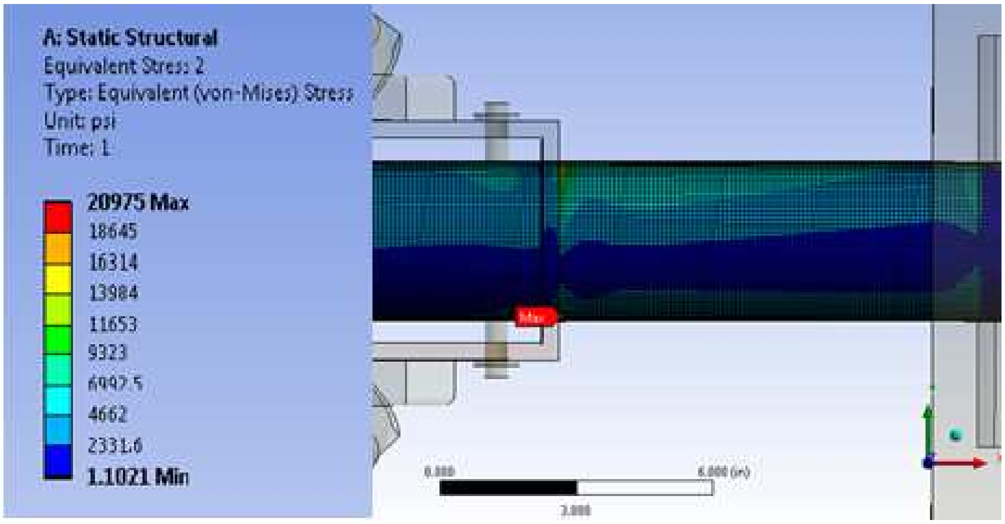

Figure 5.8 Detailed front view of the max stress point [19]

From the figures, it is clear that the max stress occurs at the junction of the horizontal frame and the supporting structures where there will be a lot of tension and compression force due to wind pressure and human load acting on different directions. The max stress is around 21ksi on the horizontal frame but since the material used is A500 the von-mises stress is lower than its yield strength which is 45ksi. The factor of safety can be calculated for the model using the formula,

$$F.S. = \sigma_y/\sigma_v \qquad 16$$

Thus, safety factor of 2.2 is obtained for this model and so it can be said that the mounting structure is mechanically stable for the loading conditions.

The strain results are also calculated as stress and equivalent strain points are shown in the images below. As per hooke's law, max strain points will occur at the same stress points since the materials are ductile and have elastic properties.

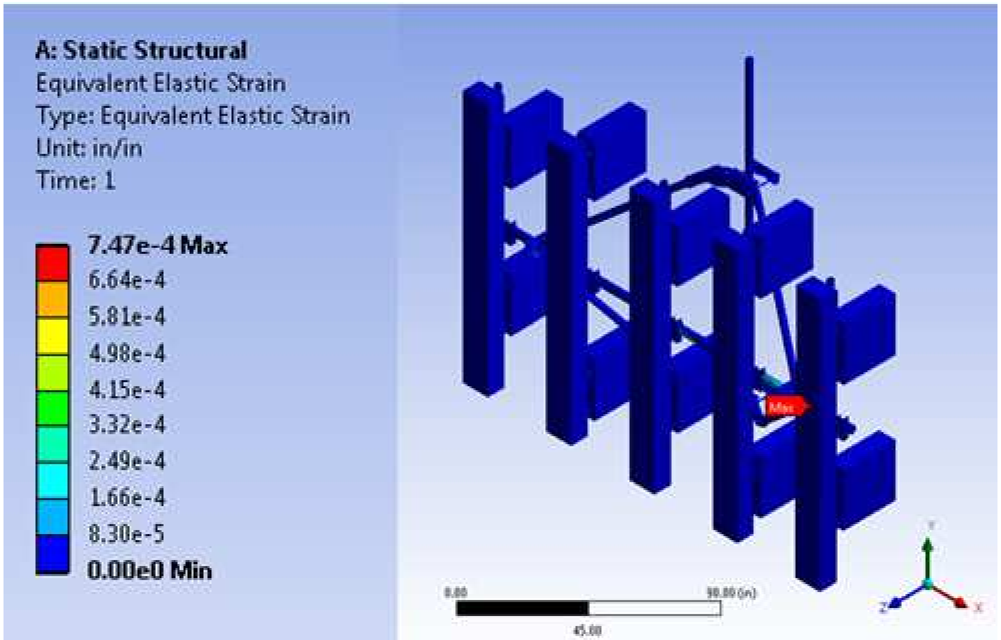

Figure 5.9 Strain result [19]

Just like the maximum stress point, strain results are also not visible and hence the zoomed views of the max strain points are shown below.

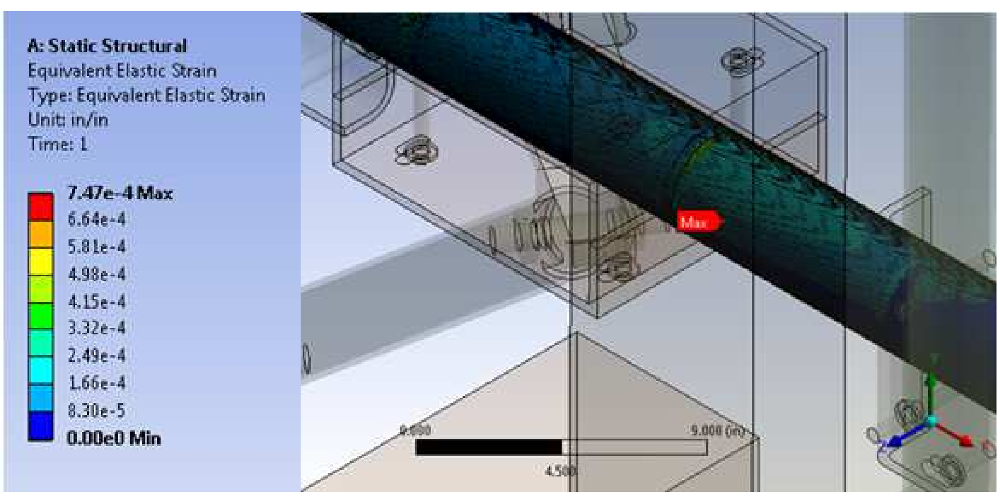

Figure 5.10 Detailed view of max-strain point on frame structure [19]

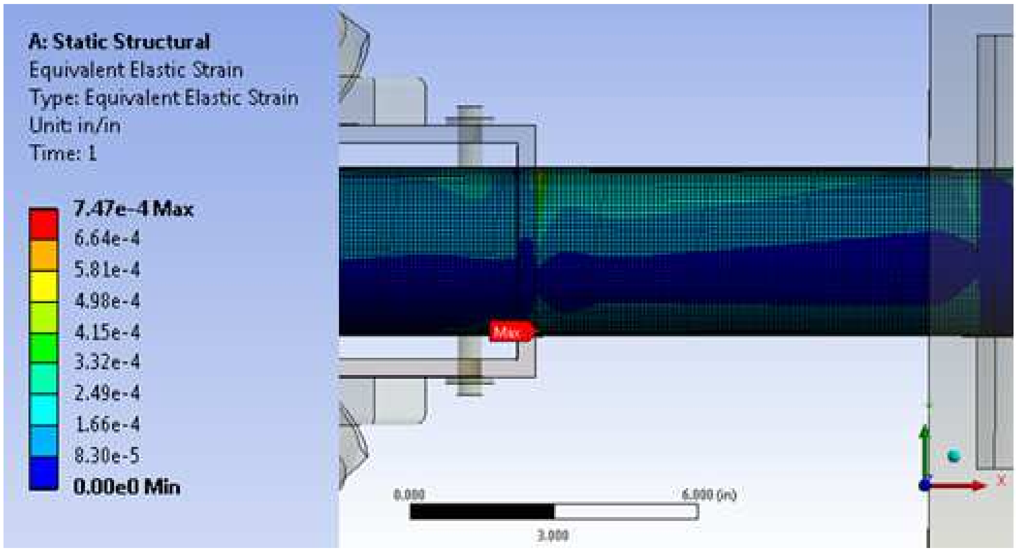

Figure 5.11 Detailed front view of max strain point on frame structure [19]

Results show that the max strain occurs at the same spot as the stress and the max value is 7.4E-04 and lies within the yield range of the material used. Thus the model is stable enough for all given load conditions.

5.2.2. Total Deformation Result

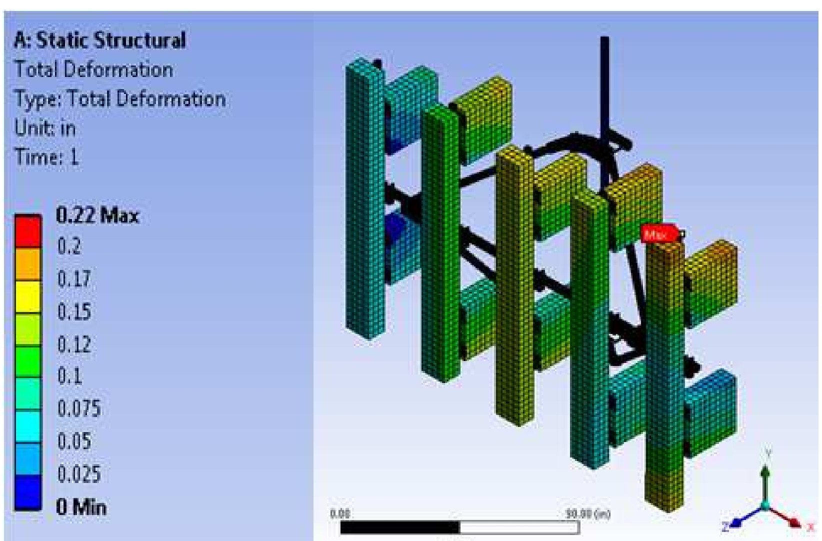

Figure 5.12 Total Deformation (True scale) [19]

The deflection results are analyzed for the model since there are multiple loads and it is important to check these results. From the results it is clear that the maximum deformation occurs at the vertical tubes holding all the weight of antenna-radio unit of 300 lbs on the side where human load acts. But the max deformation is way low and hence will not affect the mounting structure when it is applied with a human load at the weakest point of the entire frame structure. Also we have additional tiebacks connecting the outer most vertical pipes towards the tower legs and they act as additional support to reduce the deflection further. Thus the deformation results also show that the mounting structure designed is perfectly stable.

In the true scale image of deformation 0.22in deflection is not clear enough for the viewer to see and so the results effects are magnified by 66 times and now it is visible where the 0.22in deflection occurs.

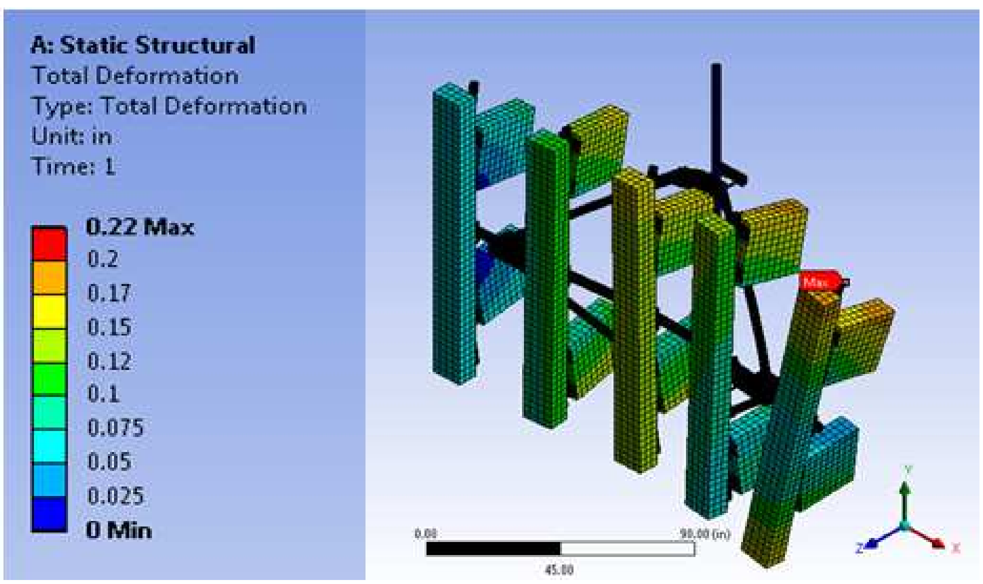

Figure 5.13 Magnified view of the deformation [19]

Chapter 6

Conclusion

The EPA along the windward face normal to the azimuth face of the mounting structure has been successfully calculated using Image Processing through MATLAB R2014a software which has not been done previously in the telecommunication field. The calculated EPA 16.7 ft^2 which compared to the other sample mounts used in the market is much lesser. The minimized EPA helps to reduce the Wind load acting on the structure and reduces the weight of the Mounting structure itself. One limitation of the method is that a computer screen with a good resolution and a higher PPI should be considered so that the pixels of the image are much higher and more accurate.

The max deformation and Stress results calculated are 0.22in and 21ksi respectively which shows that the mount structure is stable and also the frame will have tie backs extending from the tower legs which will further reduce the deflection and stress values acting on the mounting structure. Validation for the simulated results can be done by experimental analysis for the model by assembling the whole mounting structure and then with the help of a wind tunnel results can be measured. The next analysis to be carried out will be for the same model with high wind pressures to check its stability under bad weather conditions and have a dynamic load analysis. Vibration analysis can also be done for the mount but for that the vibration data for the towers is also required. The Mounting structure analysis for transient load conditions can to be simulated as a future work.

References

1. A Green Road. (2013,). Free energy wardenclyffe tower wireless energy demonstration project, wireless communication through earth, rain making machine. Retrieved from http://agreenroad.blogspot.com/2013/06/nikola-tesla-free-energy-wardenclyffe.html
2. Goldsmith. A (2005). In cambridge university press (Ed.), *Wireless communicaion* (pp. 237-240)
3. Jain. A (1989). *Digital imale processing* Prentice Hall.
4. Audio Engineering Society. (2002). The telefunken radio station at sayville, long island. Retrieved from http://www.aes.org/aeshc/docs/recording.technology.history/sayville.html
5. CommScope Incorporation. (2013). *CommScope inc catalog* (5th edition ed.,)
6. Committees (Ed.). (2006). *EIA/TIA 222 rev-G standard*. Arlingotn: TIA standards and Engineering publications.
7. Elcosh Company. (2011). Types of telecommunication towers. Retrieved from http://www.elcosh.org/index.php
8. Engineers Garage. (2012). Image processing. Retrieved from http://www.engineersgarage.com/articles/image-processing-tutorial-applications?
9. ENT Journal. (november 27, 2012,). Nikola tesla and his discovery of wireless technology. Retrieved from https://entjournal.wordpress.com/2012/11/27/nikola-tesla-and-his-discovery-of-wireless-technology/
10. Fiber Optics Associations. (2015). Fibre optic cables. Retrieved from http://www.thefoa.org/user/

11. Ishtiaq Muhammad. (2012). *Manufacturing and erection of telecommunication towers* (B.E Mechanical Engineering).

12. R.G.a.R. Woods. (2006). *Digital image processing* (3rd Edition ed.) Prentice Hall.

13. Tower direct. (2-015). Selfsupporting towers. Retrieved from http://towerdirect.net/used-190-self-supporting-towers/

14. Ruben Gregory Puthota. (2015). Next generation antenna mounts. *International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems,* San Francisco, CA. 1.

15. *Nikola tesla and his vision.* . (2012, sep 28). [Video/DVD] Youtube: LaboratoryTesla.

16. efunda. (2015). Failure criteria for ductile materials. Retrieved from http://www.efunda.com/formulae/solid_mechanics/failure_criteria/failure_criteria.cfm

17. Mathworks. (2014). *Matlab r2014a* (8.3rd ed.)

18. PTC. (2014). *Creo parametric 3.0* (3.0th ed.)

19. Canonsburg, P., U.S. (2015). *ANSYS workbench* (15.0th ed.)

20. MatWeb. (2015). Online material information. Retrieved from http://www.matweb.com/

Biographical Information

Ruben Gregory is a Mechanical engineer graduate student at University of Texas at Arlington who completed his studies in summer, 2015. He had a great opportunity to work for couple of company projects with CommScope Incorporation and his area of interest has always been design engineering and the thesis work speaks about the interest. Ruben graduated from SKCET, India as an undergraduate in mechanical engineering in 2011 during which did an internship for a year with BHEL, India a power plant equipment manufacturing company. Ruben Gregory lives in Arlington, Texas, USA. In future, Ruben would love to work for oil-based industry as a Design engineer and gain, improve knowledge with industrial experiences.