ANALYSIS OF ANTENNA STRUCTURE

By

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Ahmedabad 382481
May 2006

ANALYSIS OF ANTENNA STRUCTURE

Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Civil Engineering
(Computer Aided Structural Analysis & Design)

By

Parikh Snehal Ashokbhai
(04MCL009)

Guide
Dr. PVBAS Sarma

NIRMA UNIVERSITY
INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING
Ahmedabad 382481
May 2006

CERTIFICATE

This is to certify that the Major Project entitled "**Analysis and Design of Antenna Structure**" submitted by **Mr. Parikh Snehal Ashokbhai (04MCL009)**, towards the partial fulfillment of the requirements for the degree of **Master of Technology in Civil Engineering** (**Computer Aided Structural Analysis and Design**) of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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ABSTRACT

Complex real life structural analysis problems can now be handled easily using a galore of powerful and high speed digital computer hardware, packed and zapped with the bewitching computer graphic facilities. The engineering ingenuity helps in actually zeroing down on the keen issues related to design of complex structure with respect to the given design specifications. In addition to that, better insight into the behavior of the structural aspects can be now explored, up to the hilt.

Satellite Communication Earth Station Antennas are subjected to wind loads and dead loads and have severe restrictions on their surface RMS depending on their frequency of operation. In order to cover the landmass for different satellite locations the antenna structures are made steerable: 0 to 360 degrees in azimuth and 0 to 90 degrees in elevation. Hence to have a standardized design usually the earth station antennas are steerable as said above and use servo motors. One of the restrictions of the servo motor is the servo loop frequency should be lower than the natural frequency of the antenna. Hence estimation of the natural frequency of the antenna is necessary. Calculation of natural frequencies and mode shapes is also the first step to estimate the dynamic analysis of antenna subjected to earthquake loads.

In this piece of work, it is proposed to carryout the static and dynamic analysis of an antenna structure used for the satellite communication. The antenna has to perform successfully for a wind speed of 80 KMPH for different elevation angles between 0 to 90 degrees. As per the electrical specifications, the RMS of the reflector surface has to be within the specified limit.

For a wind speed of 200 KMPH, the antenna will be stored and locked in zenith position and the stresses in the structure members should withstand the wind load of 200 KMPH in this position with a factor of safety of 2.

For static analysis, the major specifications are:

- Survivalibility of structural members for 200 KMPH wind speed in zenith position. The stresses should be within the permissible limit of the maximum allowable stress limit for the aluminum material of 200 N/mm^2.

- The overall RMS value of deflection for other elevation angles to be less than 1 mm to have satisfactory electrical performance.

Wind load on antenna structure is generally not calculated by using any Indian Standard Code. The Wind load on the antenna structure is calculated based on the paper entitled "CALCULATION OF WIND FORCES AND PRESSURES ON ANTENNAS" by Edward Cohen and Joseph Vellozzi presented at ANNALS OF THE NEW YORK ACADEMY OF SCIENCES on June 26, 1964. The paper is the work based on several wind tunnel tests made on different diameter antennas and results are presented for pressure distribution as a % of chord length for various angles of attack. The pressure distribution on the reflector for the various angles of attack is taken from Fig.25 of the paper.

In this piece of work, wind force calculations, for operational wind speed condition of 80 KMPH, are carried out for the different elevation angles ranging from 0 to 90 degrees for an 11 meter diameter antenna. The azimuth angle is kept constant as 0 degrees. The RMS values are found out and a comparison is done to find the critical position of the antenna structure. Wind force calculations, for survival wind speed condition of 200 KMPH, are carried out for the zenith position only and stresses are checked to fall under the allowable stresses of the material.

Different components of the whole antenna structure like hub, yoke, elevation module, azimuth module and pedestal are modeled. Linear Static Analysis as per IS 1893 (Part-1): 2002 and Time History Analysis is done for different components along with the whole antenna structure. For Time History Analysis, BHUJ Earthquake Response Spectrum is used for time Vs acceleration response details. Frequencies and time periods are found out for the same. Also, the stresses are checked for being less than the permissible limits. STAAD Pro software is used for the modeling and analysis of whole antenna structure.

INDEX

LIST OF FIGURE

LIST OF TABLES

LIST OF CHARTS

NOTATIONS

ɑ	=	Angle of incidence (degrees)
τ	=	Angle of location of symmetry (degrees)
Cp	=	Resultant pressure coefficient
p	=	Wind pressures (N/mm^2)
F	=	Wind force (N)
ρ	=	Density of air (N/mm^2)
v	=	Wind velocity (m/sec^2)
g	=	Acceleration due to gravity (m/sec^2)
A	=	Area of panel (mm^2)
$\theta_{1,}\ \theta_2$	=	Slope of the node on the backup structure (degrees)
θ	=	Angle of the node w.r.t. the X axis (degrees)
δ	=	Displacement of the node (mm)
AZ	=	Azimuth (degrees)
EL	=	Elevation (degrees)
RMS	=	Root Mean Square (mm)
A_h	=	design horizontal seismic coefficient
Z	=	Zone factor
I	=	Importance Factor
R	=	Response Reduction Factor
Sa/g	=	Average response acceleration coefficient
E	=	Young's Modulus

1. INTRODUCTION

1.0 INTRODUCTION

Complex real life structural analysis problems can now be handled easily using a galore of powerful and high speed digital computer hardware, packed and zapped with the bewitching computer graphic facilities. The engineering ingenuity helps in actually zeroing down on the keen issues related to design of complex structure with respect to the given design specifications. In addition to that, better insight into the behavior of the structural aspects can be now explored, up to the hilt.

Satellite Communication Earth Station Antennas are subjected to wind loads and dead loads and have severe restrictions on their surface RMS depending on their frequency of operation. In order to cover the landmass for different satellite locations the antenna structures are made steerable: 0 to 360 degrees in azimuth and 0 to 90 degrees in elevation. Hence to have a standardized design usually the earth station antennas are steerable as said above and use servo motors. One of the restrictions of the servo motor is the servo loop frequency should be lower than the natural frequency of the antenna. Hence estimation of the natural frequency of the antenna is necessary. Calculation of natural frequencies and mode shapes is also the first step to estimate the dynamic analysis of antenna subjected to earthquake loads.

1.1 BACKGROUND

Antenna is the system of wires or other conductors used to transmit or receive radio or other electromagnetic waves; sometimes called an aerial. The idea of using an antenna was developed by Guglielmo Marconi (c.1897). In a transmitting antenna, the signal from an electronic circuit causes electrons in the antenna to oscillate; these moving electric charges generate electromagnetic radiation, which is transmitted through the air and space. Distribution of the waves depends on the design of the antenna; the transmitting antennas of a radio station might be designed to emit waves in all directions, while an antenna used for radar or space communications would be designed to focus the waves in a single direction. In a receiving antenna electromagnetic waves cause the electrons to oscillate, inducing a signal that can be detected by an electronic circuit.

The earth station antenna is used for various purposes like for the Broadcasting on Television, Remote Sensing, Military Activity, and many more. The earth station antenna plays a vital role in the communication for transmissing and receiving signals from satellite. The International calls are done with the help of satellite communication only. In today's context, various countries are trying to enter into the space technologies. For these kinds of advancements, the antenna plays very important role. All the wireless technologies depend on the signals which are transmitted or received by the antennas only. One most common use of the antenna is for the mobile phone signals.

The earth station antennas are usually large in diameter ranging from 11 meter to 20 meter depending upon the requirement of gain with a focal length to diameter ratio (f/D) = 0.4. In order to have a light weight structure, the reflector surface is usually made from Aluminum Alloy backup structures with a reflector sheet as Aluminum. A white paint is put on the reflecting surface for reflection. A feed is mounted with a tripod or quadripod on the antenna structure which receives the energy for receiving signals and transmits the energy for transmitting signals.

1.2 OBJECTIVE OF WORK

The earth station antenna is transmitting and receiving the signals or waves to and from the satellite. For reception and transmission of signals or waves, the antenna is to be focused towards the satellite in the steady or fixed position. Special care is to be taken to design the antenna structure such that it serves the purpose and function properly. Slight tilt of an antenna results in the loss of signals because the satellites are at very far distance, so by tilting slightly on the ground will cause very large slanting on the satellite which will made the satellite out of focus. So the stability of the antenna is the most important thing. The structural design of the antenna should be sound enough to make the antenna very stiff. The support structure should also help in the stability of the whole structure.

The objective of the work is to study the behavior of the antenna structure and to analyze the structure with respect to wind forces and earthquake forces for the static and dynamic analysis respectively. The RMS values and stresses for the different wind load intensities are to be studied for the different antenna positions. Linear Static Analysis and Time History Analysis are done as per IS 1893 (Part-1): 2002 and as per BHUJ Earthquake Response Spectrum respectively. STAAD Pro software is used for the analysis.

1.3 ORGANIZATION OF REPORT

Accordingly in the treatise, chapter-1 introduces the background, objective and scope of work of the study.

Chapter-2 gives the details of literature review.

Chapter-3 incorporates the theoretical aspects regarding the fundamentals of an Antenna Structure

Chapter-4 deals with the basic theoretical aspects of Wind loads including the terminology and Calculation of overall RMS values.

Chapter-5 deals with wind load analysis of an 11m Earth Station Antenna Structure and computation of RMS values and Stresses for different wind load conditions for different antenna positions.

Chapter-6 deals with the theoretical aspects of finite element modeling including the elements used in the modeling of an Antenna Structure.

Chapter-7 deals with the static analysis of whole antenna structure with soil mass and raft foundation and its components like hub, sub-reflector, EL- Module, AZ-Module, Pedestal etc as per IS 1893 (Part-1):2002.

Chapter-8 deals with the time history analysis of whole antenna structure with soil mass and raft foundation and its components like hub, sub-reflector, EL-Module, AZ-Module, Pedestal etc considering BHUJ earthquake response spectrum.

2. LITERATURE REVIEW

2.1 GENERAL

Literature survey is essential to review the work done in the area of performance based engineering. To take up the specific need to perform the analysis, the literature like technical papers, journals and books need to be referred. The prime important in the review was to understand the analysis and different concept of performance based engineering.

2.2 LITERATURE REVIEW

Edward Cohen and Joseph Vellozzi [1]:

Wind forces undoubtedly play a significant role in the design and operation of large steerable antennas, and the need for satisfactory estimates of these forces is becoming increasingly evident. Although much remains to be learned, many of the gross features of the wind loading have been established. A resolution of the problem of predicting wind forces on antennas depends upon improved knowledge of the variation of pressures and local velocities on the reflector and its supporting framework, integrated loadings, and ground effect for both solid and porous conditions.

The purpose of this paper is to present the results of a recent aerodynamic study of these aspects of the problem and to indicate possible applications of this information in determining wind loads on antennas. Although it is recognized that the problem is basically of a dynamic nature, attention in this paper is restricted to static effects, i.e., the effects of fluctuations of the natural wind and of the unsteadiness of the flow around the instrument are not considered. It is necessary to bear in mind that the data presented represent only reasonably estimate at best and to realize that, in some cases, considerable reliance must be placed on judgment and experience in applying this information in design.

C. Richards [2] has given the details of design of Antenna Structures which links with the performance of antenna and the relation between the frequency of operation with the RMS value of deflection and other related parameters.

It also gives a methodology for calculation of wind loads and methodology for estimation of RMS values of deflection.

Design Document for 11 Meter Steerable Antenna System [3] has given the procedure for the calculation of Wind Forces with the Design of the supporting structure also.

This document has also given the footing design for the antenna structure. Static analysis as well as Dynamic analysis is carried out for the design of the antenna structure. Drive equipment and bearing analysis is also given in this document. Deflection, Stress and pointing error analysis are also described in this document.

Preliminary Design Report for 11 m Antenna System [4] has given the Design for the Wind Load Analysis for different antenna components. It also describes the stiffness and natural frequency analysis and pointing error analysis. It has given the specifications for the bearings, motors, etc. It has also given the manufacturing process for reflector panels, dies and mount. The report describes the test plan and the project schedule for the erection of the antenna structure.

Design document for 6.3 meter Limited Antenna System [5] gives the specification, general description of structural and mechanical antenna components. It also gives the calculation of wind loads, structural analysis of components, design checks of antenna structural components, RMS and Pointing error calculation, mechanical system design, foundation design, line of action for the erection etc.

Prof. P. C.Vasani [6]:

Soil-structure interaction plays an important role in the behavior of foundations. For structures like beams, piles, mat foundations and box cells it is very essential to consider the deformational characteristics of soil and flexural properties of foundations. It can be seen that when interaction is taken into account, the true design values arrived-at may be quite different from those worked out without considering interaction. In general in most of the cases interaction causes reduction in critical design values of the shear and moments etc. However, there may be quite a few locations where the values show an increase. Because of these possibilities have their own roles to play in economy and safety of structure. Several studies have indicated that the maximum bending moment in a foundation raft or beam could be substantially affected by interaction with superstructure. Reduction as high as 80% is reported in certain cases. The rigidity of foundation raft relative to soil is of extremely high values of bending moments in relative rigid rafts as compared to those in flexible rafts. An elastoplastic analysis also indicates a similar trend, although to a much lesser degree. Unequal settlement is the severest cause for cracking and even failure of superstructures. On the other hand, rigidity of superstructure helps in reducing differential settlements. Of course, to realize this, only interactive analysis has to be carried out.

IDE Toshiyuki, HAMAMOTO Naokazu, and OGAWA Takaya [7]:

A folding parabola antenna with flat facets designed for portable earth stations of satellite communications systems using the S-band is proposed. High-data-rate satellite communications systems using low power terminals and/or measurement of satellite antenna properties require the use of portable, high-gain antenna. The reflector of this proposed antenna is constructed of flat facets, enabling it to be easily folded and carried. An experimental model of the antenna with a diameter of 68cm has a gain of 21dBi at 2.5 GHz.

P.M. Rao, N. Sreedhanam and P.K. Jain [8]:

Meteorological and Earth resources data is transmitted from various Sun-synchronous and Geostationary remote sensing satellites, in various frequency bands with different spatial and spectral resolutions. The system design of the Earth station is done to meet the required data reception quality specifications. The link design parameters are worked out to meet overall margins. The signal reception from these satellites is among any frequency in L/S/C/X bands. To make a single Earth station compatible for data reception from different satellites, the receive system design has to cater for the multi-mission data reception requirements. The operational procedures for regular data collection are to be streamlined along with periodical testing procedures for Ground station system checkout.

This paper deals with the detailed design considerations for establishing the Earth station with the multi-mission capabilities and its adaptability for any class of satellites.

3. FUNDAMENTALS OF ANTENNA STRUCTURE

3.1 INTRODUCTION

Antenna is the system of wires or other conductors used to transmit or receive radio or other electromagnetic waves; sometimes called an aerial. The idea of using an antenna was developed by Guglielmo Marconi (c.1897). In a transmitting antenna, the signal from an electronic circuit causes electrons in the antenna to oscillate; these moving electric charges generate electromagnetic radiation, which is transmitted through the air and space. Distribution of the waves depends on the design of the antenna; the transmitting antennas of a radio station might be designed to emit waves in all directions, while an antenna used for radar or space communications would be designed to focus the waves in a single direction. In a receiving antenna electromagnetic waves cause the electrons to oscillate, inducing a signal that can be detected by an electronic circuit.

The dish-shaped microwave antenna is highly directional; it uses a parabolic reflector to focus received signals on a small antenna element. Phased array antennas, used for long range radar and radio astronomy, are composed of large groupings of individual antennas; they may be electronically aimed by changing the relative phase of the signal at each element.

The antenna system is designed for structural and mechanical reliability simplified installation and is ideal for satellite communication earth station works. The Antenna is structurally designed to withstand wind loads, to meet the pointing errors and stability conditions.

3.2 GENERAL DESCRIPTION OF ANTENNA STRUCTURES

3.2.1 Main Reflector:

The main reflector consists of number of panels, which include inner and outer panels. The mid radius is considered such that the areas of all the panels should match as equal.

The material of the skin and reinforcing frame is aluminum alloy which has higher corrosion resistance and yield strength that of low carbon steel. The thickness of the skin is generally 2mm. The skin is riveted to the frame. The reflector panels are mounted on the radial trusses with stud and cleat and can be adjusted to achieve required profile. The surface accuracy of the main reflector is measured with the high accuracy measuring tape and a wild theodilite. After measurement the adjusting studs are tightened firmly in order to keep the original surface accuracy of the main reflector.

3.2.2 Back-Up Structures:

The back-up structure is designed to give better support to the panel to limit the deformations and stresses within acceptable limits. The back-up structure is composed of center hub and number of truss members installed radially around the center hub and sub-reflector support as shown in figure 3.1. The center hub is a cylindrical steel structure which accommodates low noise amplifier and composite feed. The greater part of the truss members is fabricated from Aluminum Tubes. The center hub and truss members have mechanical strength to maintain high surface accuracy in the operating conditions. The truss members are designed so that they can be divided into suitable sizes for transportation, assembly, and dismantling and are bolted together by high tensile strength bolts.

3.2.3 Yoke Structure:

The Yoke Structure consisting of two yoke arms, two elevation bearings, mounting bases for drive mechanisms and handrail is installed on the main azimuth axis by azimuth drive mechanism as shown in the figure 3.1. The two arms of the Yoke Structure house the main elevation bearings which transfer the total load of the reflector and back up structure through the azimuth bearing to the main conical mount. The elevation bearings are self-aligning ball bushing bearings installed in pillow blocks located on the Yoke Structure arms. The self-aligning capability of the bearings allows easy installation without any involved alignment procedures. The bearings are designed to withstand the maximum loads encountered under the specified environmental conditions. The bearings are grease lubricated.

3.2.4 Conical Mount:

The conical mount has two conical steel bases which are assembled together with high tensile strength bolts. The complete assembly is bolted down to the concrete foundation base with the anchor bolts. The wave-guide and cable from the equipment building are installed inside the conical mount and a hatch is provided to gain access to them.

An azimuth slew ring bearing is bolted into the upper conical mount section and support the radial loads, thrust loads over turning moments due to wind loads, eccentric loads and seismic loads. The azimuth bearing is designed to withstand the specified environmental conditions and is grease lubricated.

3.2.5 DRIVE MECHANISM:

The drive mechanism for EL axis consists of screw actuator, a torque limiter coupling, speed reducer, an AC motor with manual handle. The self-locking arrangement is used to prevent the antenna from moving when the drive is not operating.

The Antenna is driven around the azimuth axis through a bull gear integral with slew ring bearing and a pinion mounted on a planetary gearbox. The gear box is driven by an AC motor. The gear box is mounted on the yoke and rotates along with it, the pinion rolling over the slew ring gear for continuous motion of 0 to 360.

The elevation drive screw actuator assembly is mounted on the yoke structure and pushes against the rear face of the center hub. The elevation drive assembly ensures that the dish is fully steerable over the elevation range +5 degrees to +90 degrees.

The drive mechanisms are grease lubricated and are fitted with a torque limiter coupling between the screw jack and cyclo speed reducer. The torque limiter coupling prevents excessive torque load from the motor being applied directly to the screw jack. Limit switches are provided in each drive mechanism. Lightning protection is also provided for the system.

3.2.6 Shaped Reflector For Better Efficiency:

The Cassegrain system describes above produces a coherent phase distribution in the aperture plane of the main reflector. In addition, the main reflector amplitude distribution is tapered, i.e., the aperture energy density is high near the center and low near the edge. To maximize signals to noise ratios. Modern communication satellite antenna systems seek as one design criterion, to produce maximum antenna gain. A tapered illumination as described above does not accomplish this.

Maximum main reflector antenna gain results when a uniform energy density is produced in the aperture. For a given primary feed system amplitude pattern, uniform energy density in the main reflector aperture can be achieved by a process of shaping. In the shaping process, the sub-reflector and main reflector curves are caused to deviate from the true hyperbolic and parabolic profiles. Computer design techniques are used to arrive at the shapes necessary to produce uniform amplitude illumination. The shaping process is, in general, unique. Each problem of main reflector diameter focal length and primary feed system amplitude must be newly exercised by the computers.

3.2.7 Sub-Reflectors:

The sub-reflector of the feed system is specially shaped reflecting surface. The sub-reflector vertex has a central mounting pad for an optical alignment mirror which serves as a target for alignment the sub-reflector to the antenna as shown in the figure 3.1.

3.2.8 Antenna Feed Systems:

The primary feed assembly consists of corrugated conical horn, a tapered wave guide, polarizer section, a duplexer and a transmit reject filter.
The corrugated horn produces axially symmetrical low side lobe radiation pattern and low Polarization response. This performance contributed to the improvement of illumination efficiency and spill over energy from the reflector element. In addition, it will be to the excellent cross Polarization characteristics as antennas with the frequency re-use feed. The aperture of the horn is covered with random mode of glass reinforced Teflon sheet which allows the feed to be pressurized initially with dry air.

The polarizer is integrated for two purposes. When the linear Polarization mode is in operation, the polarizer physically rotates the orientation of the waves to align them with the duplexer ports. In the circular Polarization mode, the half section of the polarizer physically charges the Polarization mode from the "**linear to circular"** for transmission and from "**circular to linear"** for reception. When operating its phase shift plane is inclined at 45 degrees to the input port of the duplexer, the phase shift plane of the remained section is aligned parallel to the port.

The duplexer combines and separates transmitting (6 GHz band) and receiving (4 GHz band) signals polarized orthogonally to each other. The reject filter is connected at the receiving port to **"isolate the transmitting signals"** from the receiving port.

3.3 DIFFERENT COMPONENTS OF ANTENNA STRUCTURE

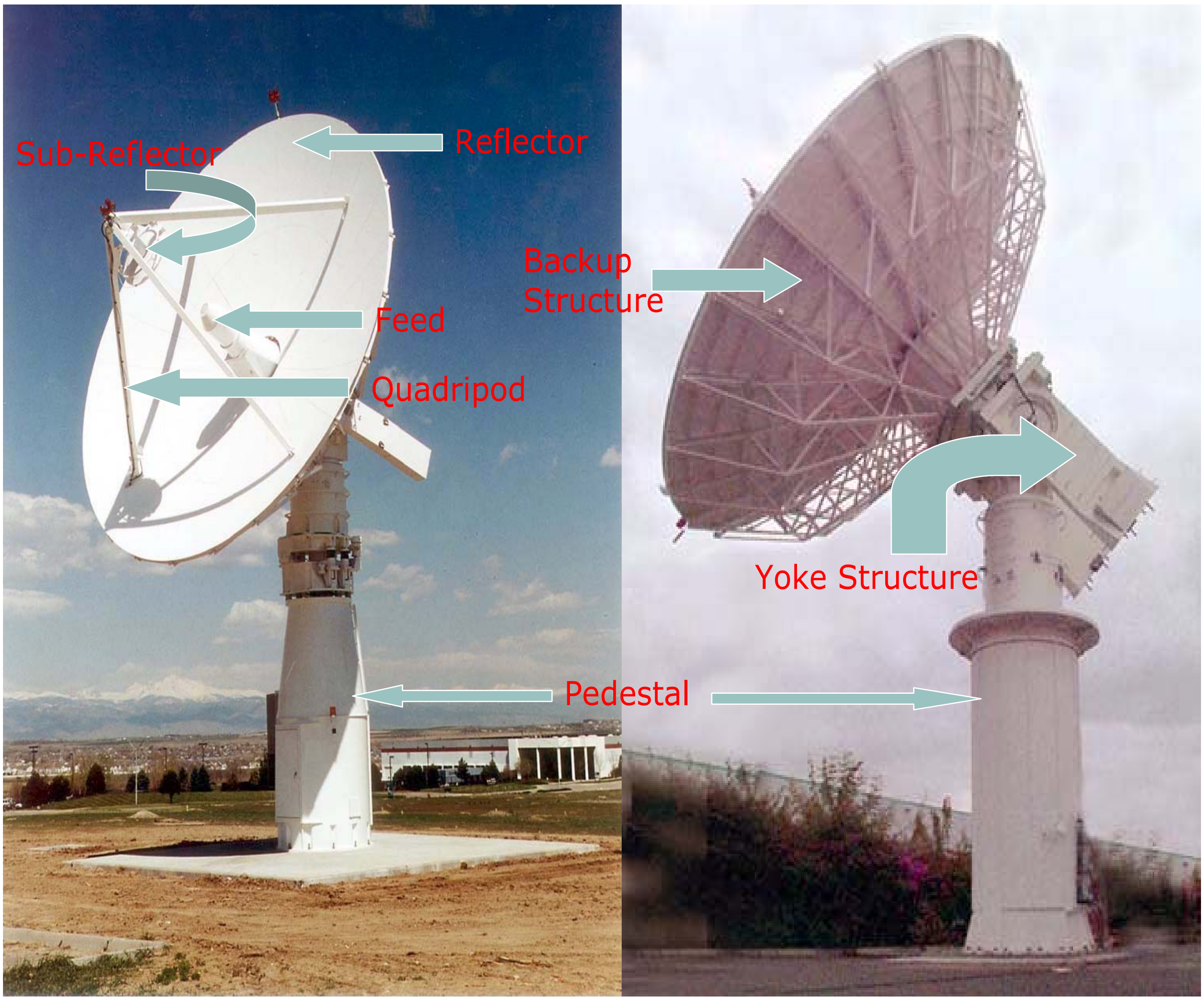


FIGURE 3.1 VARIOUS COMPONENTS OF AN ANTENNA STRUCTURE

4. FUNDAMENTALS OF WIND LOAD CALCULATIONS

4.1 CALCULATION OF WIND LOAD

Wind forces undoubtedly play a significant role in the design and operation of large steerable antennas, and the need for satisfactory estimate of these forces is becoming increasingly evident. Although much remains to be learned, many of the gross features of the wind loading have been established. A resolution of the problem of predicting wind forces on antennas depends upon improved knowledge of the variation of pressures and local velocities on the reflector and its supporting framework, integrated loading, and ground effect for both solid and porous conditions.

4.1.1 Wind Load on Reflector

The Wind load on the antenna structure is calculated based on the paper titled **"CALCULATION OF WIND FORCES AND PRESSURES ON ANTENNAS"** by Edward Cohen and Joseph Vellozzi presented at ANNALS OF THE NEW YORK ACADEMY OF SCIENCES on June 26, 1964. The pressure distribution on the reflector for the various angles of attack is taken from Fig.25 of the paper. This figure is reported in reproduced in Fig: 4.1 of this report. Because the wind load is applied as a pressure distribution, the overall force coefficients are computed from this pressure distribution.

4.1.2 Wind Load on Backup Structure and Quadripod

The wind load on the backup structure is conservatively computed by calculating projected length of the member in the wind direction and correspondingly calculating the projected area for each member by multiplying with width of the member. The projected area is multiplied with the wind pressure to obtain the force on the member. No advantage is taken of shielding effect of the reflector or other adjacent trusses.

4.1.3 Wind Load on Sub-Reflector

The wind load on the sub-reflector is taken as a percentage of the load on the main reflector.

4.1.4 Wind Load on Hub and Mount Assembly

The wind load on the Hub and Mount assembly is conservatively computed by calculating the projected length of the member in the wind direction and correspondingly calculating the projected area for each member by multiplying with the width of the member. The projected area is multiplied with the wind pressure to obtain the force on the member. No advantage is taken of shielding effect of the reflector or other adjacent trusses.

4.1.5 Wind Load on Panels

The panels are analyzed for strength as well as for RMS calculation. For strength calculation load equivalent to 200 KMPH front wind is applied on the panels, while for RMS calculation load equivalent to 80 KMPH front wind is applied on the panels.

4.2 GENERAL THEORY & TERMINOLOGY

The wind is assumed to flow only in horizontal direction. Hence the angle α, which the wind makes with the plane of reflector rim (the angle of attack), is a function of the altitude and azimuth angles relative to wind stream. For every azimuth and elevation angle combination, angle of incidence is worked out using,

$$\alpha = \mathrm{Sin}^{-1}(\mathrm{Cos}\ (AZ) * \mathrm{Cos}\ (EL))$$

The aerodynamic characteristics of paraboloidal reflectors with sharp edges are greatly affected by such parameters as depth to diameter ratio (h/d), surface solidity ratio *(Φ),* and surface geometry. Laboratory tests proved that coefficient of lift, drag and side force is a function of angle of attack. Line of symmetry on a reflector renders these coefficients identical on either side. The angle of location of symmetry (τ) for a given set of azimuth and elevation angle can be calculated using following expression.

$$\tau = \tan^{-1} (\mathrm{Sin}\ (EL) * \mathrm{Sin}\ (AZ) / \mathrm{Cos}\ (AZ))$$

Having known the line of symmetry and leading and trailing edge percentage chord length for each panel at CG location is calculated. The CG of each panel is calculated using polar co-ordinates in the term of starting and ending radius of panel and single suspended center as follows,

$$CG = [(R_2^3 - R_1^3) / (R_2^2 - R_1^2)] * [(2/3) * \mathrm{Sin} / \theta]$$

Where,

R1 = Starting radius of panel
R2 = Ending radius of panel
θ = Angle suspended by CG point with horizontal at the center of the reflector.

Then percentage of chord is calculated using the following formula:

$$\% \text{ of chord} = (AB/BC) * 100 \qquad \text{(Refer Figure 4.2)}$$

Referring to the curve given by Edward Cohen for Percentage of chord versus Resultant pressure coefficient (Cp), for different percentage of chord for each panel, resultant pressure coefficients are calculated by interpolation.

The expression used for calculation of wind pressures and wind forces are summarized as below:

$$p = (1/2) * \rho * v^2 / g$$
$$F = A * p * Cp$$

Where

ρ = Density of air

v = Wind velocity

g = Acceleration due to gravity

Cp = Resultant pressure coefficient

A = Area of panel

The loads on each node are resolved in vertical and radial direction as follows.

$Fv = F * \cos(\theta_1)$

$Fr = F * \sin(\theta_1)$

Where, θ_1 is the slope of the node on the backup structure.
The forces are resolved in global X, Y and Z direction as follows:

$X = Fr * \cos(\theta)$

$Y = Fv * \sin(\theta)$

$Z = Fv$

Where, θ is the angle of the node w.r.t. the X axis.

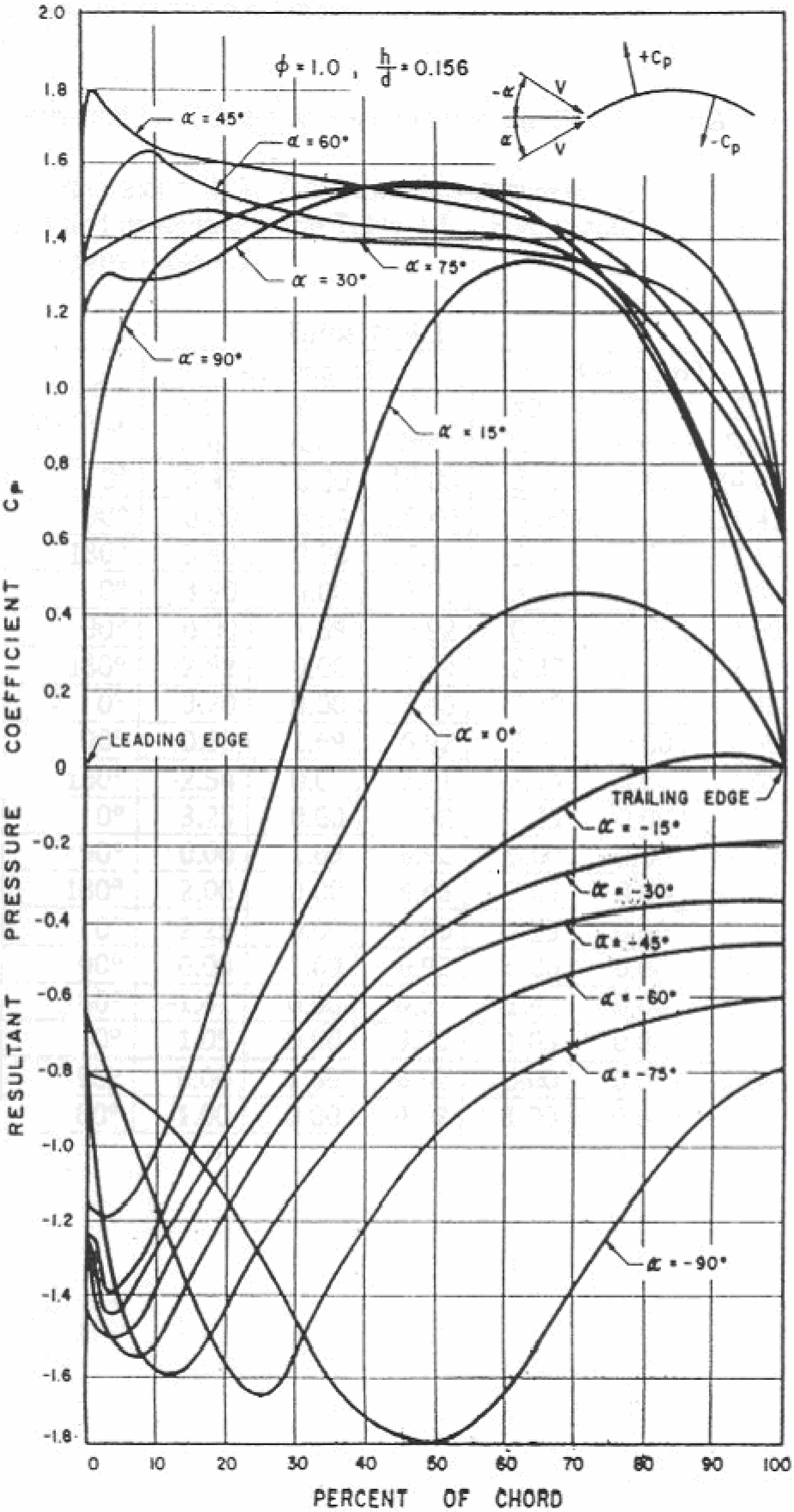


FIGURE 4.1 Chordwise pressure profiles.

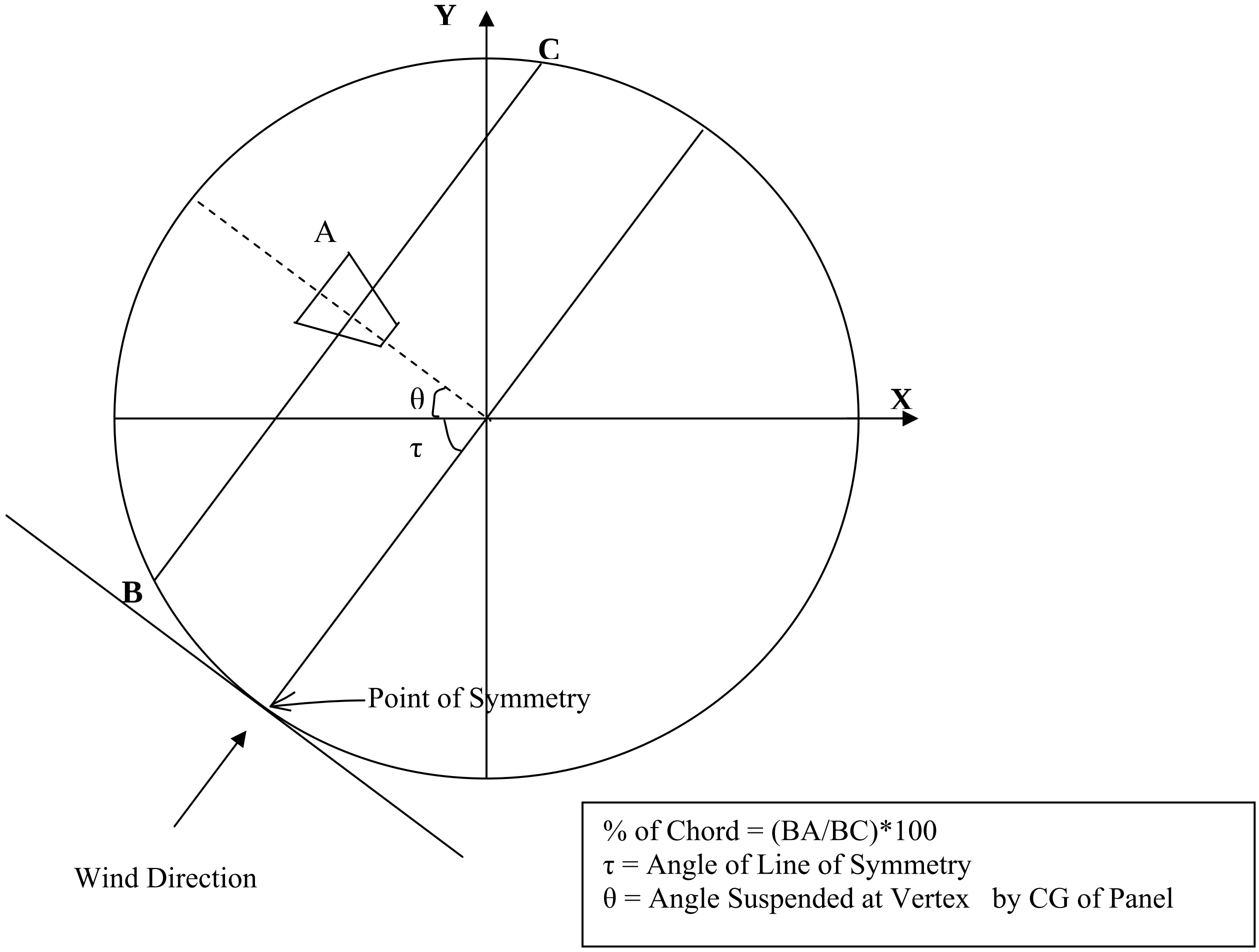


Figure 4.2 Percentage of Chord

FLOW CHART

FOR WIND FORCE CALCULATION ON REFLECTOR OF 11M ANTENNA

$$\alpha = \mathrm{Sin}^{-1}(\mathrm{Cos}\ (AZ) * \mathrm{Cos}\ (EL))$$

$$\downarrow$$

$$\tau = \tan^{-1}\ (\mathrm{Sin}\ (EL) * \mathrm{Sin}\ (AZ) / \mathrm{Cos}\ (AZ))$$

$$\downarrow$$

$$CG = [(R_2^3 - R_1^3) / (R_2^2 - R_1^2)] * [(2/3) * \mathrm{Sin} / \theta]$$

$$\downarrow$$

$$\%\ \text{of chord} = (BA/BC) * 100$$

$$\downarrow$$

$$p = (1/2) \times \rho \times v^2 / g$$

$$\downarrow$$

$$F = A * p * Cp$$

$$\downarrow$$

$$Fv = F * \mathrm{Cos}\ (\theta_1)$$

$$\downarrow$$

$$Fr = F * \mathrm{Sin}\ (\theta_1)$$

$$\downarrow$$

$$X = Fr * \mathrm{Cos}\ (\theta)$$

$$\downarrow$$

$$Y = Fv * \mathrm{Sin}\ (\theta)$$

$$\downarrow$$

$$Z = Fv$$

4.3 SURFACE ACCURACY ANALYSIS

The wind load and gravity load on the model will affect the surface accuracy of the reflector, out of which major effect will be from wind load. Since the deformations caused by the wind load and self-weight varies according to the wind velocity and reflector EL-AZ positions, the analysis has been carried out for two loading conditions and the critical case results are presented.

The allocation of overall RMS value of the reflector is as follows

- ❖ RMS due to fabrication R_f
- ❖ RMS due to alignment R_a
- ❖ RMS due to structural deflection R_s
  (due to wind loads + dead loads)

Overall RMS = $\sqrt{R_f^{\,2} + R_a^{\,2} + R_s^{\,2}}$

- ❖ Usually, allocated fabrication RMS R_f = 0.5
  allocated alignment RMS R_a= 0.5

For the critical positions of the reflector, RMS due to structural deformation is determined based on the corresponding wind force pressure distribution on the reflector panels. The RMS for the backup structure is calculated from the deflections of the nodes on the backup structure directly supporting the reflector panels. The following formula is used to calculate the RMS value (due to structural deflection).

$$\delta \text{ avg.} = \frac{\delta 1 + \delta 2 + \delta 3 + \ldots\ldots\ldots\ldots\ldots}{n}$$

$$\text{RMS } R_s = \frac{\sqrt{[(\delta 1 - \delta \text{avg})^2 + (\delta 2 - \delta \text{avg})^2 + \ \ldots + (\delta \text{n} - \delta \text{avg})^2]}}{n}$$

5. WIND LOAD ANALYSIS

5.1 DETAILS OF AN 11 METER DIAMETER EARTH STATION ANTENNA REFLECTOR AND BACKUP STRUCTURE

5.1.1 Reflector:

The 11 meter diameter earth station antenna consists of total 48 panels which include 24 inner and 24 outer panels.

5.1.2 Backup Structure:

The backup structures are provided to give support to the panels and to limit the stresses and deformations within acceptable limits. At each interface of panels, the total numbers of 24 trusses.

The single truss member of reflector is shown in figure 5.1. The cross sections for (I) Top, Bottom and Circumferential Members and (II) Intermediate Members are shown in figure 5.2. The material used for the trusses and circumferential members are Aluminum.

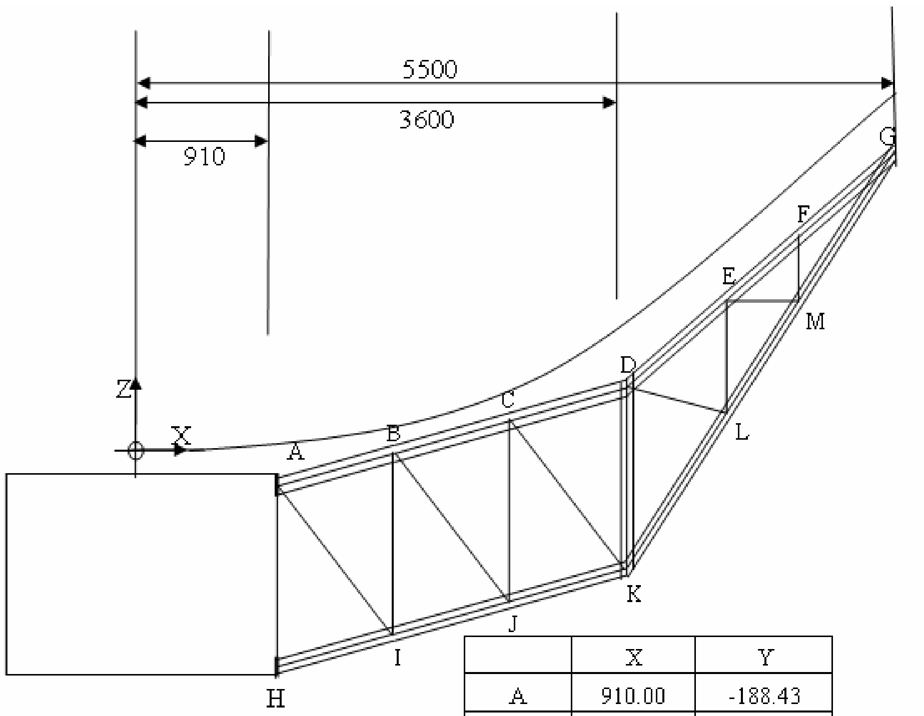
The Beam Numbers and Node Numbers for the truss members are as shown in figure 5.3.

Three Dimensional view of an Antenna Backup Structure is shown in figure 5.4.
The top view of the Antenna Backup Structure with top surface nodes is shown in figure 5.5.

Now for finding out the Wind force as explained in Section 4.2, the pressure coefficient Cp is to be found out first.

5.2 CALCULATION OF WIND PRESSURE COEFFICIENT (Cp) AND AREA

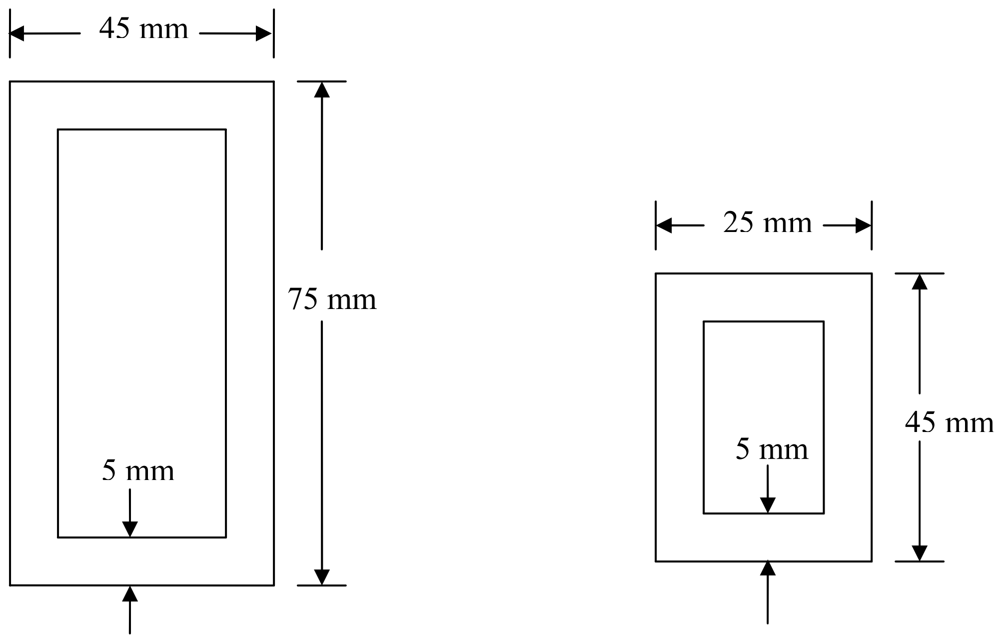
The Wind load on the antenna structure is calculated based on the paper titled **"CALCULATION OF WIND FORCES AND PRESSURES ON ANTENNAS"** by Edward Cohen and Joseph Vellozzi presented at ANNALS OF THE NEW YORK ACADEMY OF SCIENCES on June 26, 1964. The pressure distribution on the reflector for the various angles of attack is taken from Fig.25 of the paper. This figure is reported in reproduced in Fig: 4.1 of this report. Because the wind load is applied as a pressure distribution, the overall force coefficients are computed from this pressure distribution.



	X	Y
A	910.00	-188.43
B	1806.67	44.96
C	2703.33	278.36
D	3600.00	511.75
E	4232.33	882.60
F	4866.66	1253.45
G	5500.00	1624.31
H	910.00	-1225.42
I	1806.67	-956.37
J	2703.30	-687.32
K	3600.00	-418.28
L	4232.33	262.58
M	4866.66	943.44

All Dimensions are in mm

Figure 5.1 Truss Member of Reflector



CROSS-SECTION OF TRUSS MEMBER (TOP, BOTTOM AND CIRCUMFERRENTIAL MEMBER)

CROSS-SECTION OF TRUSS MEMBER (INTERMEDIATE MEMBERS)

Figure 5.2 Cross-Sections of various sizes for different members

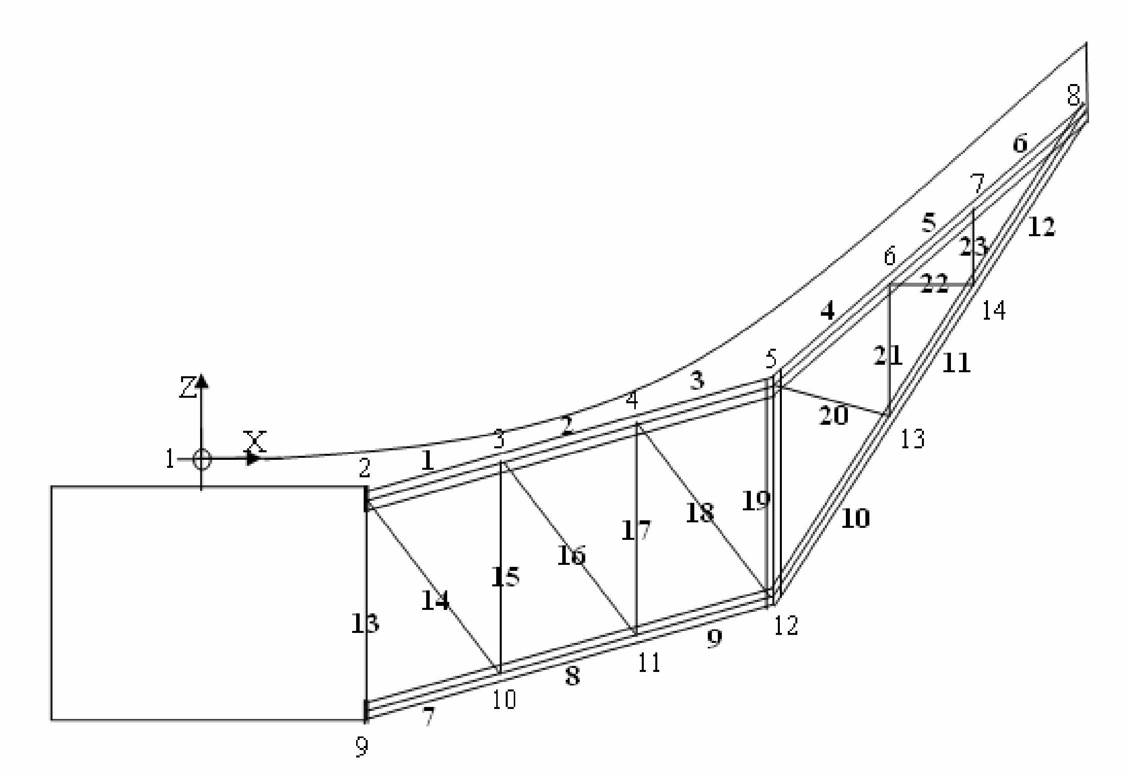


Figure 5.3 Beam and Nodes of Reflector

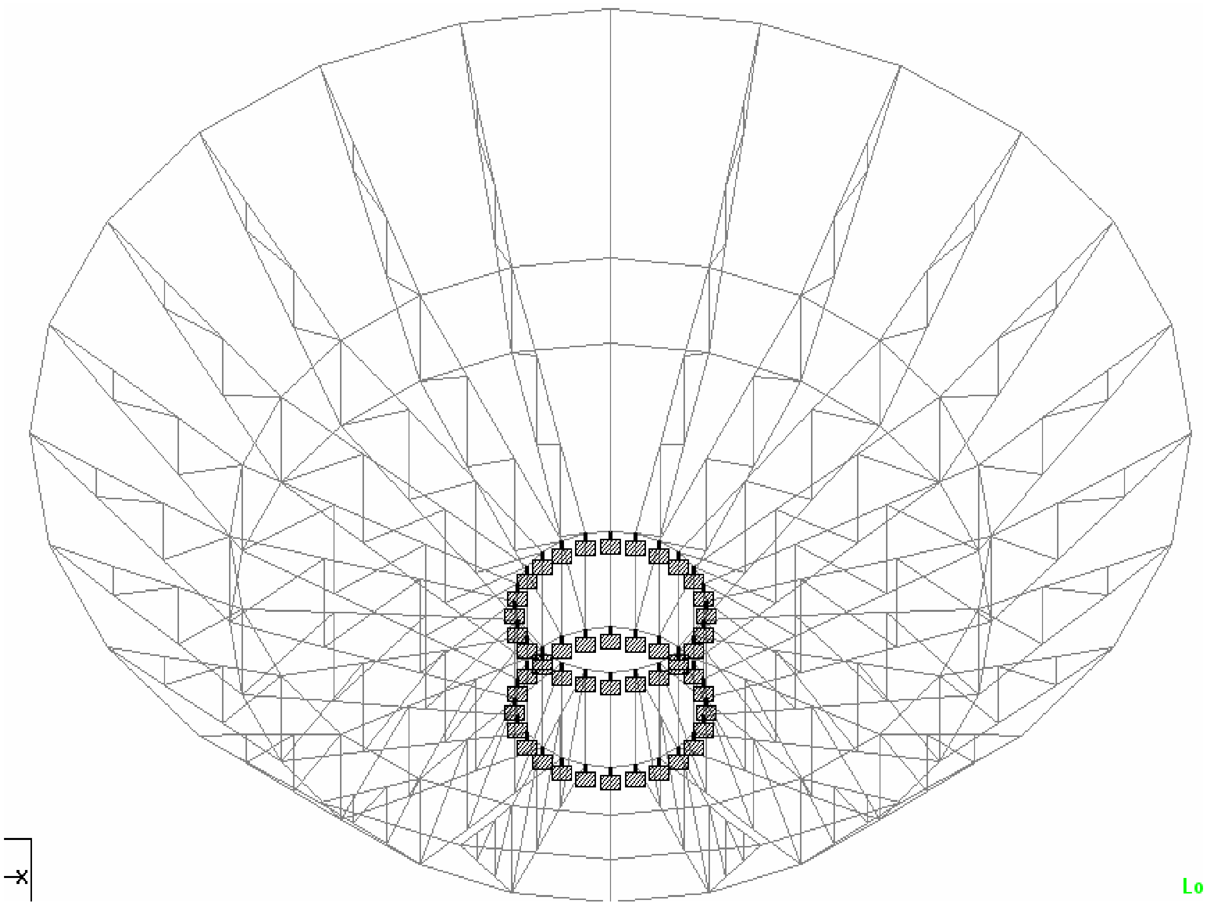


Figure 5.4 3-Dimensional View of Antenna Structure

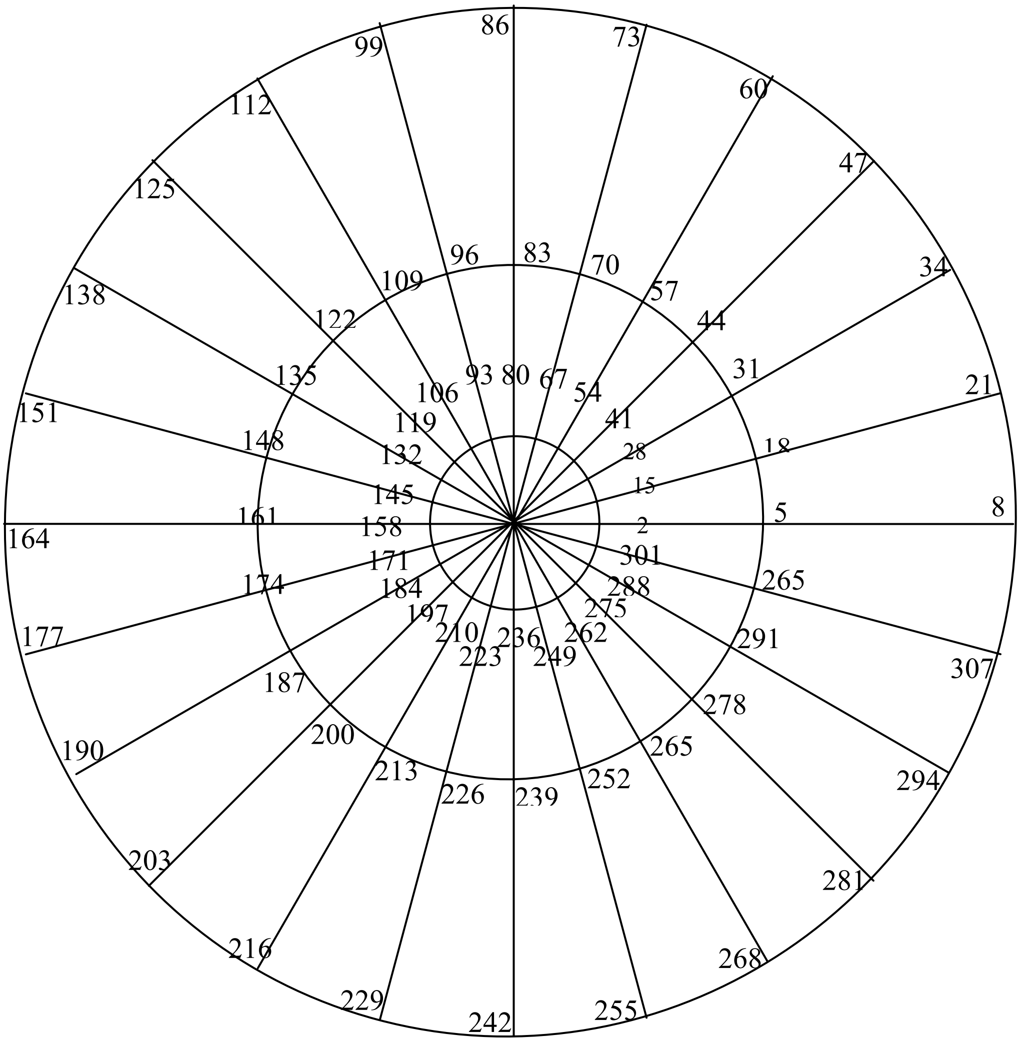


Figure 5.5 Top Surface Nodes in Plan

5.2.1 RESULTANT PRESSURE COEFFICIENT (CP) FOR A WIND SPEED OF 200 KMPH FOR THE ZENITH POSITION OF AN ANTENNA

Here only the top surface of the antenna backup structure is taken into account as shown in the figure 5.5.

From Chart 5.1, the angle α can be found out as

$$\boldsymbol{\alpha = \sin^{-1}(\cos(AZ) * \cos(EL))}$$

For the case of Zenith Position **AZ=0; EL=90**

Therefore $\alpha = 0$

1. For the portion between nodes 5-8-21-18 as shown in figure 5.5.

- For Point 5

  $$\% \text{ of chord} = \frac{5.5 + 3.6}{11.00}\ \%$$
  $$= 82.72\ \%$$

  Now from Fig. 5.1 => see the graph of **α = 0**

  Therefore **Cp = 0.4**

- For Point 8

  $$\% \text{ of chord} = \frac{5.5 + 5.5}{11.00}\ \%$$
  $$= 100\ \%$$

  Now from Fig. 5.1 => see the graph of **α = 0**

  $\therefore$ **Cp = 0.05**

- For Point 21

$$\% \text{ of chord} = \frac{5.5+3.48}{11.00}\ \%$$
$$= 81.64\ \%$$

Now from Fig. 5.1 => see the graph of **α = 0**

$\therefore$ **Cp = 0.41**

- For Point 18

$$\% \text{ of chord} = \frac{5.5+5.32}{11.00}\ \%$$
$$= 98.36\ \%$$

Now from Fig. 5.1 => see the graph of **α = 0**

$\therefore$ **Cp = 0.07**

$$\therefore (Cp)_{average} = \frac{0.4+0.05+0.41+0.07}{4}$$

$(Cp)_{average}$ =0.22

This Cp is the average pressure coefficient for the panel 5-8-21-18.

2. For the portion between nodes 2-5-8-15 as shown in figure 5.5

- For Point 2

$$\% \text{ of chord} = \frac{5.5 + 0.91}{11.00}\ \%$$

$$= 58.27\ \%$$

Now from Fig. 5.1 => see the graph of **α = 0**

$\therefore$ **Cp = 0.4**

- For Point 5

$$\% \text{ of chord} = \frac{5.5 + 3.6}{11.00}\ \%$$

$$= 82.73\ \%$$

Now from Fig. 5.1 => see the graph of **α = 0**

$\therefore$ **Cp = 0.4**

- For Point 8

$$\% \text{ of chord} = \frac{5.5 + 3.48}{11.00}\ \%$$

$$= 81.64\ \%$$

Now from Fig. 5.1 => see the graph of **α = 0**

$\therefore$ **Cp = 0.41**

- For Point 15

$$\% \text{ of chord} = \frac{5.5 + 0.88}{11.00}\%$$

$$= 58\ \%$$

Now from Fig. 5.1 => see the graph of **α = 0**

$$\therefore\ \mathbf{Cp = 0.40}$$

$$\therefore\ (Cp)_{average} = \frac{0.4 + 0.4 + 0.41 + 0.40}{4}$$

$$\mathbf{(Cp)_{average} = 0.40}$$

This Cp is the average pressure coefficient for the panel 5-8-21-18.

Similarly, Cp values are to be found out for all the 48 panels (24 inner panels and 24 outer panels).

Thus Cp value at each panel is found out as follows:

Table 5.1 Cp values at each node for 200 KMPH wind speed for zenith position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	0.22	109-112-125-122	-0.51	213-216-229-226	-0.15
2-5-18-15	0.40	106-109-122-119	-0.18	210-213-226-223	0.00
18-21-34-31	0.28	122-125-138-135	-0.92	226-229-242-239	0.09
15-18-31-28	0.41	119-122-135-132	-0.30	223-226-239-236	0.18
31-34-47-44	0.37	135-138-151-148	-1.05	239-242-255-252	0.34
28-31-44-41	0.41	132-135-148-145	-0.38	236-239-252-249	0.31
44-47-60-57	0.42	148-151-164-161	-1.05	252-255-268-265	0.43
41-44-57-54	0.40	145-148-161-158	-0.43	249-252-265-262	0.37
57-60-73-70	0.43	161-164-177-174	-1.05	265-268-281-278	0.42
54-57-70-67	0.37	158-161-174-171	0.17	262-265-278-275	0.40
70-73-86-83	0.34	174-177-190-187	-1.05	278-281-294-291	0.37
67-70-83-80	0.31	171-174-187-184	-0.38	275-278-291-288	0.41
83-86-99-96	0.09	187-190-203-200	-0.92	291-294-307-304	0.28
80-83-96-93	0.18	184-187-200-197	-0.30	288-291-304-301	0.41
96-99-112-109	-0.15	200-203-216-213	-0.51	304-307-8-5	0.22
93-96-109-106	0.00	197-200-213-210	-0.18	301-304-5-2	0.40

5.2.2 Calculation of area of each panel

- **For Whole Outer panel**

$$\text{Area} = (\Pi r_3^2 - \Pi r_2^2) \quad [r_1=0.910\text{m}, r_2= 3.6\text{m}, r_3=5.5\text{m}]$$
$$= 54.318\text{m}^2$$

Therefore, the area enclosed between the 15 degrees at outer panel is

$$= \frac{15*54.318}{360}$$
$$= 2.26325 \text{ m}^2$$

- **For Whole Inner panel**

$$\text{Area} = (\Pi r_2^2 - \Pi r_1^2) \quad [r_1=0.910\text{m}, r_2= 3.6\text{m}, r_3=5.5\text{m}]$$
$$= 38.11\text{m}^2$$

Therefore, the area enclosed between the 15 degrees at outer panel is

$$= \frac{15*38.11}{360}$$

$$= 1.5879 \text{ m}^2$$

5. 3 CALCULATION OF WIND FORCE AT EACH NODE

Now the Force acting at each node is to be found out.

$$F= A * p * Cp$$

In this p is the wind pressure which can be calculated as

$$p = 0.006*V^2 \quad \text{(V in KMPH)}$$
$$= 0.006*200^2$$
$$= 240 \text{ kg/m}^2$$
$$= 2.3544 \text{ kN/mm}^2$$

- **Wind Force at outer panel nodes**

$$F=2.26325*2.3544*Cp \text{ kN}$$
$$= 5.32859*Cp \text{ kN}$$

- **Wind Force at outer panel nodes**

$$F=1.5879*2.3544*Cp \text{ kN}$$
$$= 3.73855*Cp \text{ kN}$$

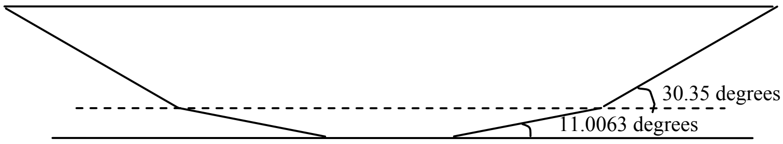


Figure 5.6 Front View of an Antenna Structure

From the above figure

θ_1 = 30.35 degrees

θ_2 = 11.0063 degrees

The wind forces are to be resolved into the components using θ_1& θ_2 by using the equations in table 5.1.

Finally the forces at each node are applied to the respective nodes and the analysis is done to find the RMS values and stresses.

Table 5.2 Forces at each node for 200 KMPH wind speed for zenith position of an Antenna

Wind Force Calculation for V=200 KMPH						
θ=	0,15,30,…	θ1=	30.35	θ2=	14.59	
Node No	Force at each Node (N)	Fv=F*Cos(θ1,θ2)	Fr=F*Sin(θ1,θ2)	X=Fr*Cos(θ)	Y=Fr*Sin(θ)	Fz=Fv
8	572.82	494.33	289.43	289.43	0.00	494.33
21	662.74	571.92	334.86	323.45	86.67	571.92
34	869.23	750.11	439.19	380.35	219.59	750.11
47	1055.73	911.05	533.42	377.20	377.18	911.05
60	1129.00	974.28	570.44	285.24	494.01	974.28
73	1012.43	873.69	511.55	132.42	494.11	873.69
86	569.49	491.45	287.75	0.01	287.75	491.45
99	-76.60	-66.10	-38.70	10.01	-37.38	-66.10
112	-882.55	-761.61	-445.92	222.94	-386.19	-761.61
125	-1901.64	-1641.05	-960.84	679.37	-679.46	-1641.05
138	-2611.01	-2253.20	-1319.26	1142.46	-659.72	-2253.20
151	-2794.18	-2411.27	-1411.81	1363.67	-365.52	-2411.27
164	-2804.17	-2419.89	-1416.86	1416.86	-0.13	-2419.89
177	-2794.18	-2411.27	-1411.81	1363.74	365.27	-2411.27
190	-2611.01	-2253.20	-1319.26	1142.58	659.51	-2253.20
203	-1901.64	-1641.05	-960.84	679.49	679.34	-1641.05
216	-882.55	-761.61	-445.92	223.01	386.15	-761.61
229	-76.60	-66.10	-38.70	10.02	37.38	-66.10
242	569.49	491.45	287.75	-0.04	-287.75	491.45
255	1012.43	873.69	511.55	132.33	-494.14	873.69
268	1129.00	974.28	570.44	285.15	-494.06	974.28
281	1055.73	911.05	533.42	377.13	-377.25	911.05
294	869.23	750.11	439.19	380.31	-219.66	750.11
307	662.74	571.92	334.86	323.44	-86.73	571.92
5	1325.21	1282.48	333.81	333.81	0.00	1282.48
18	1419.80	1374.02	357.64	345.45	92.56	1374.02
31	1630.96	1578.37	410.83	355.79	205.41	1578.37
44	1810.45	1752.07	456.04	322.48	322.46	1752.07
57	1851.00	1791.32	466.25	233.14	403.78	1791.32
70	1645.65	1592.59	414.53	107.30	400.40	1592.59
83	1022.79	989.81	257.63	0.01	257.63	989.81
96	91.64	88.68	23.08	-5.97	22.30	88.68
109	-1046.11	-1012.38	-263.51	131.74	-228.21	-1012.38
122	-2340.92	-2265.44	-589.66	416.92	-416.98	-2265.44
135	-3244.23	-3139.62	-817.20	707.68	-408.65	-3139.62
148	-3548.90	-3434.47	-893.94	863.46	-231.44	-3434.47
161	-3042.50	-2944.40	-766.39	766.39	-0.07	-2944.40
174	-2992.79	-2896.29	-753.86	728.20	195.04	-2896.29
187	-3244.23	-3139.62	-817.20	707.76	408.52	-3139.62
200	-2340.92	-2265.44	-589.66	417.00	416.91	-2265.44
213	-1046.11	-1012.38	-263.51	131.78	228.19	-1012.38
226	91.64	88.68	23.08	-5.98	-22.30	88.68

239	1022.79	989.81	257.63	-0.04	-257.63	989.81
252	1645.65	1592.59	414.53	107.23	-400.42	1592.59
265	1851.00	1791.32	466.25	233.07	-403.82	1791.32
278	1810.45	1752.07	456.04	322.42	-322.52	1752.07
291	1630.96	1578.37	410.83	355.75	-205.47	1578.37
304	1419.80	1374.02	357.64	345.44	-92.62	1374.02
2	752.38	728.12	189.52	189.52	0.00	728.12
15	757.06	732.65	190.70	184.20	49.35	732.65
28	761.73	737.17	191.87	166.17	95.93	737.17
41	754.72	730.38	190.11	134.43	134.42	730.38
54	722.01	698.73	181.87	90.94	157.50	698.73
67	633.22	612.80	159.50	41.29	154.07	612.80
80	453.30	438.68	114.18	0.01	114.18	438.68
93	168.23	162.81	42.38	-10.97	40.93	162.81
106	-163.56	-158.29	-41.20	20.60	-35.68	-158.29
119	-439.28	-425.12	-110.65	78.24	-78.25	-425.12
132	-633.22	-612.80	-159.50	138.13	-79.76	-612.80
145	-754.72	-730.38	-190.11	183.63	-49.22	-730.38
158	-238.33	-230.65	-60.03	60.03	-0.01	-230.65
171	-198.61	-192.21	-50.03	48.33	12.94	-192.21
184	-633.22	-612.80	-159.50	138.14	79.74	-612.80
197	-439.28	-425.12	-110.65	78.25	78.23	-425.12
210	-163.56	-158.29	-41.20	20.60	35.68	-158.29
223	168.23	162.81	42.38	-10.97	-40.93	162.81
236	453.30	438.68	114.18	-0.02	-114.18	438.68
249	633.22	612.80	159.50	41.26	-154.07	612.80
262	722.01	698.73	181.87	90.91	-157.52	698.73
275	754.72	730.38	190.11	134.41	-134.45	730.38
288	761.73	737.17	191.87	166.15	-95.97	737.17
301	757.06	732.65	190.70	184.19	-49.39	732.65

5.4 CALCULATION OF RMS VALUE AND STRESSES

As explained in section 4.3, the RMS value of the structural deformation can be found out using the following equation

$$\text{RMS } (R_s) = \frac{\sqrt{[(\delta 1 - \delta \text{avg})2 + (\delta 2 - \delta \text{avg})2 + \ \ldots. + (\delta \text{n} - \delta \text{avg})2]}}{n}$$

RMS value is found out using the above mentioned formula which is tabulated in the tabular format as shown in Table 5.5.

The Maximum Nodal Displacements and Maximum Stresses are presented in Table 5.3 and 5.4.

Table 5.3 Maximum Nodal Displacement values for 200 KMPH wind speed for zenith position of an Antenna

		Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	86	3 DL+WL	**28.028**	0.173	0.376	28.031	0	0	0.006
Max Y	164	3 DL+WL	0.636	**27.679**	1.176	27.711	0	0	0.005
Max Z	190	3 DL+WL	13.488	24.022	**1.294**	27.58	0	0	0.005
Max Rst	112	3 DL+WL	24.36	13.976	0.3	**28.086**	0	0	0.006

Table 5.4 Maximum Stresses for 200 KMPH wind speed for zenith position of an Antenna

			Max Compressive			Max Tensile		
Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
168	1 BACKUP	936.16	1.34	0.00	2.00			
398	1 BACKUP	936.16	1.34	0.00	1.00			
129	1 BACKUP	926.54				-1.27	0.00	1.00
175	1 BACKUP	926.54				-1.27	0.00	1.00
226	2 WIND	936.17	95.86	0.00	1.00	0.00	0.00	0.00
364	2 WIND	926.55				-91.59	0.00	1.00
364	3 DL+WL	936.17	96.00	0.00	1.00	91.45	936.17	1.00
226	3 DL+WL	936.17	96.00	0.00	1.00	91.42	936.17	1.00

Table 5.5 RMS value for 200 KMPH wind speed for zenith position of an Antenna

Node No	Resultant Displacement Δ	Δ average	Δ-Δ average	(Δ-Δ average)^2
2	0.00	1.32	-1.32	1.75
5	0.74	1.32	-0.58	0.34
8	1.59	1.32	0.27	0.07
15	0.00	1.32	-1.32	1.75
18	0.81	1.32	-0.51	0.26
21	1.72	1.32	0.40	0.16
28	0.00	1.32	-1.32	1.75
31	0.97	1.32	-0.35	0.12
34	2.03	1.32	0.70	0.50
41	0.00	1.32	-1.32	1.75
44	1.13	1.32	-0.19	0.04
47	2.33	1.32	1.00	1.01
54	0.00	1.32	-1.32	1.75
57	1.22	1.32	-0.10	0.01
60	2.48	1.32	1.15	1.33
67	0.00	1.32	-1.32	1.75
70	1.17	1.32	-0.15	0.02
73	2.45	1.32	1.12	1.26
80	0.00	1.32	-1.32	1.75
83	0.95	1.32	-0.37	0.14

86	2.10	1.32	0.78	0.60
93	0.00	1.32	-1.32	1.75
96	0.71	1.32	-0.62	0.38
99	1.72	1.32	0.40	0.16
106	0.00	1.32	-1.32	1.75
109	1.03	1.32	-0.29	0.08
112	2.20	1.32	0.87	0.76
119	0.00	1.32	-1.32	1.75
122	1.66	1.32	0.33	0.11
125	3.34	1.32	2.01	4.06
132	0.00	1.32	-1.32	1.75
135	2.15	1.32	0.83	0.68
138	4.28	1.32	2.95	8.72
145	0.00	1.32	-1.32	1.75
148	2.31	1.32	0.99	0.98
151	4.57	1.32	3.24	10.53
158	0.00	1.32	-1.32	1.75
161	2.23	1.32	0.91	0.82
164	4.47	1.32	3.14	9.88
171	0.00	1.32	-1.32	1.75
174	2.20	1.32	0.87	0.76
177	4.42	1.32	3.09	9.57
184	0.00	1.32	-1.32	1.75
187	2.11	1.32	0.79	0.63
190	4.21	1.32	2.89	8.34
197	0.00	1.32	-1.32	1.75
200	1.65	1.32	0.33	0.11
203	3.33	1.32	2.01	4.03
210	0.00	1.32	-1.32	1.75
213	1.03	1.32	-0.29	0.08
216	2.19	1.32	0.87	0.75
223	0.00	1.32	-1.32	1.75
226	0.70	1.32	-0.62	0.39
229	1.71	1.32	0.39	0.15
236	0.00	1.32	-1.32	1.75
239	0.95	1.32	-0.38	0.14
242	2.09	1.32	0.77	0.59
249	0.00	1.32	-1.32	1.75
252	1.17	1.32	-0.15	0.02
255	2.44	1.32	1.12	1.25
262	0.00	1.32	-1.32	1.75
265	1.22	1.32	-0.10	0.01
268	2.47	1.32	1.15	1.32
275	0.00	1.32	-1.32	1.75
278	1.13	1.32	-0.19	0.04
281	2.32	1.32	1.00	1.00
288	0.00	1.32	-1.32	1.75
291	0.97	1.32	-0.35	0.13
294	2.03	1.32	0.70	0.49
301	0.00	1.32	-1.32	1.75
304	0.81	1.32	-0.51	0.26
307	1.72	1.32	0.40	0.16

Based on the formula given in section 4.3, the RMS due to structural deformation is calculated.

RMS = 1.27

5.5 CALCULATION OF PRESSURE COEFFICIENTS, WIND FORCES, MAXIMUM NODAL DISPLACEMENTS, MAXIMUM STRESSES AND RMS VALUE FOR 80 KMPH WIND SPEED IN DIFFERENT EL-AZ POSITION

5.5.1 EL-0 AZ-0 Position

Table 5.6 Cp values at each node for 80 KMPH wind speed for EL-0 AZ-0 position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	1.01	109-112-125-122	1.01	213-216-229-226	1.01
2-5-18-15	1.47	106-109-122-119	1.47	210-213-226-223	1.47
18-21-34-31	1.01	122-125-138-135	1.01	226-229-242-239	1.01
15-18-31-28	1.47	119-122-135-132	1.47	223-226-239-236	1.47
31-34-47-44	1.01	135-138-151-148	1.01	239-242-255-252	1.01
28-31-44-41	1.47	132-135-148-145	1.47	236-239-252-249	1.47
44-47-60-57	1.01	148-151-164-161	1.01	252-255-268-265	1.01
41-44-57-54	1.47	145-148-161-158	1.47	249-252-265-262	1.47
57-60-73-70	1.01	161-164-177-174	1.01	265-268-281-278	1.01
54-57-70-67	1.47	158-161-174-171	1.47	262-265-278-275	1.47
70-73-86-83	1.01	174-177-190-187	1.01	278-281-294-291	1.01
67-70-83-80	1.47	171-174-187-184	1.47	275-278-291-288	1.47
83-86-99-96	1.01	187-190-203-200	1.01	291-294-307-304	1.01
80-83-96-93	1.47	184-187-200-197	1.47	288-291-304-301	1.47
96-99-112-109	1.01	200-203-216-213	1.01	304-307-8-5	1.01
93-96-109-106	1.47	197-200-213-210	1.47	301-304-5-2	1.47

Table 5.7 Forces at each node for 80 KMPH wind speed for EL-0 AZ-0 position of an Antenna

Wind Force Calculation for V=80 KMPH for EL-0 AZ-0 Position						
θ=	0,15,30,…	θ1=	30.35	θ2=	14.59	
Node No	**Force at each Node (N)**	**Fv=F*Cos(θ1,θ2)**	**Fr=F*Sin(θ1,θ2)**	**X=Fr*Cos(θ)**	**Y=Fr*Sin(θ)**	**Fz=Fv**
8	428.42	369.71	216.47	216.47	0.00	369.71
21	428.42	369.71	216.47	209.09	56.02	369.71
34	428.42	369.71	216.47	187.47	108.23	369.71
47	428.42	369.71	216.47	153.07	153.06	369.71
60	428.42	369.71	216.47	108.24	187.46	369.71
73	428.42	369.71	216.47	56.03	209.09	369.71
86	428.42	369.71	216.47	0.01	216.47	369.71
99	428.42	369.71	216.47	-56.01	209.09	369.71
112	428.42	369.71	216.47	-108.22	187.47	369.71
125	428.42	369.71	216.47	-153.05	153.08	369.71
138	428.42	369.71	216.47	-187.46	108.25	369.71
151	428.42	369.71	216.47	-209.09	56.04	369.71
164	428.42	369.71	216.47	-216.47	0.02	369.71
177	428.42	369.71	216.47	-209.10	-56.00	369.71

190	428.42	369.71	216.47	-187.48	-108.21	369.71
203	428.42	369.71	216.47	-153.08	-153.05	369.71
216	428.42	369.71	216.47	-108.26	-187.45	369.71
229	428.42	369.71	216.47	-56.05	-209.08	369.71
242	428.42	369.71	216.47	-0.03	-216.47	369.71
255	428.42	369.71	216.47	55.99	-209.10	369.71
268	428.42	369.71	216.47	108.20	-187.48	369.71
281	428.42	369.71	216.47	153.04	-153.09	369.71
294	428.42	369.71	216.47	187.45	-108.26	369.71
307	428.42	369.71	216.47	209.08	-56.06	369.71
5	866.58	838.63	218.28	218.28	0.00	838.63
18	866.58	838.63	218.28	210.85	56.49	838.63
31	866.58	838.63	218.28	189.04	109.14	838.63
44	866.58	838.63	218.28	154.35	154.35	838.63
57	866.58	838.63	218.28	109.15	189.04	838.63
70	866.58	838.63	218.28	56.50	210.84	838.63
83	866.58	838.63	218.28	0.01	218.28	838.63
96	866.58	838.63	218.28	-56.48	210.85	838.63
109	866.58	838.63	218.28	-109.13	189.05	838.63
122	866.58	838.63	218.28	-154.34	154.36	838.63
135	866.58	838.63	218.28	-189.03	109.16	838.63
148	866.58	838.63	218.28	-210.84	56.51	838.63
161	866.58	838.63	218.28	-218.28	0.02	838.63
174	866.58	838.63	218.28	-210.85	-56.48	838.63
187	866.58	838.63	218.28	-189.05	-109.12	838.63
200	866.58	838.63	218.28	-154.37	-154.33	838.63
213	866.58	838.63	218.28	-109.17	-189.03	838.63
226	866.58	838.63	218.28	-56.52	-210.84	838.63
239	866.58	838.63	218.28	-0.03	-218.28	838.63
252	866.58	838.63	218.28	56.47	-210.86	838.63
265	866.58	838.63	218.28	109.11	-189.06	838.63
278	866.58	838.63	218.28	154.33	-154.38	838.63
291	866.58	838.63	218.28	189.02	-109.17	838.63
304	866.58	838.63	218.28	210.84	-56.53	838.63
2	438.16	424.03	110.37	110.37	0.00	424.03
15	438.16	424.03	110.37	106.61	28.56	424.03
28	438.16	424.03	110.37	95.58	55.18	424.03
41	438.16	424.03	110.37	78.04	78.04	424.03
54	438.16	424.03	110.37	55.19	95.58	424.03
67	438.16	424.03	110.37	28.57	106.61	424.03
80	438.16	424.03	110.37	0.01	110.37	424.03
93	438.16	424.03	110.37	-28.56	106.61	424.03
106	438.16	424.03	110.37	-55.18	95.59	424.03
119	438.16	424.03	110.37	-78.04	78.05	424.03
132	438.16	424.03	110.37	-95.58	55.19	424.03
145	438.16	424.03	110.37	-106.61	28.57	424.03
158	438.16	424.03	110.37	-110.37	0.01	424.03
171	438.16	424.03	110.37	-106.61	-28.55	424.03
184	438.16	424.03	110.37	-95.59	-55.17	424.03
197	438.16	424.03	110.37	-78.05	-78.03	424.03
210	438.16	424.03	110.37	-55.20	-95.58	424.03
223	438.16	424.03	110.37	-28.58	-106.60	424.03
236	438.16	424.03	110.37	-0.02	-110.37	424.03
249	438.16	424.03	110.37	28.55	-106.61	424.03
262	438.16	424.03	110.37	55.17	-95.59	424.03
275	438.16	424.03	110.37	78.03	-78.06	424.03
288	438.16	424.03	110.37	95.57	-55.20	424.03
301	438.16	424.03	110.37	106.60	-28.58	424.03

Table 5.8 Maximum Nodal Displacements for 80 KMPH wind speed for EL-0 AZ-0 position of an Antenna

		Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	267	3 DL+WL	**0.283**	0.135	0.445	0.545	0	0	0
Max Y	209	3 DL+WL	0.253	**0.16**	0.485	0.57	0	0	0
Max Z	8	3 DL+WL	0.272	0.006	**0.629**	0.685	0	0	0
Max Rst	8	3 DL+WL	0.272	0.006	0.629	**0.685**	0	0	0

Table 5.9 Maximum Stresses for 80 KMPH wind speed for EL-0 AZ-0 position of an Antenna

			Max Compressive			Max Tensile		
Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corn er	Stress N/mm2	Dist mm	Corn er
93	1 BACKUP	926.54	2.97	0.00	1.00			
461	1 BACKUP	926.54	2.97	0.00	2.00			
185	1 BACKUP	926.54				-2.97	0.00	1.00
369	1 BACKUP	926.54				-2.97	0.00	1.00
62	2 WIND	1157.70	2.06	1157.70	2.00	0.00	0.00	0.00
99	2 WIND	936.16				-2.82	0.00	1.00
467	3 DL+WL	936.16	4.89	0.00	1.00	-3.14	936.16	3.00
187	3 DL+WL	926.54	2.05	0.00	1.00	-3.41	926.54	1.00

Table 5.10 RMS value for 80 KMPH wind speed for EL-0 AZ-0 position of an Antenna

Node No	Resultant Displacement Δ	Δ average	Δ-Δ average	(Δ-Δ average)^2
2	0.00	0.33	-0.33	0.11
5	0.41	0.33	0.09	0.01
8	0.69	0.33	0.36	0.13
15	0.00	0.33	-0.33	0.11
18	0.41	0.33	0.08	0.01
21	0.68	0.33	0.35	0.12
28	0.00	0.33	-0.33	0.11
31	0.40	0.33	0.08	0.01
34	0.65	0.33	0.33	0.11
41	0.00	0.33	-0.33	0.11
44	0.39	0.33	0.06	0.00
47	0.62	0.33	0.29	0.09
54	0.00	0.33	-0.33	0.11
57	0.37	0.33	0.04	0.00
60	0.56	0.33	0.24	0.06
67	0.00	0.33	-0.33	0.11
70	0.34	0.33	0.02	0.00
73	0.50	0.33	0.17	0.03
80	0.00	0.33	-0.33	0.11

83	0.32	0.33	-0.01	0.00
86	0.43	0.33	0.11	0.01
93	0.00	0.33	-0.33	0.11
96	0.34	0.33	0.02	0.00
99	0.50	0.33	0.18	0.03
106	0.00	0.33	-0.33	0.11
109	0.37	0.33	0.04	0.00
112	0.57	0.33	0.24	0.06
119	0.00	0.33	-0.33	0.11
122	0.39	0.33	0.06	0.00
125	0.62	0.33	0.29	0.09
132	0.00	0.33	-0.33	0.11
135	0.40	0.33	0.08	0.01
138	0.66	0.33	0.33	0.11
145	0.00	0.33	-0.33	0.11
148	0.41	0.33	0.08	0.01
151	0.68	0.33	0.35	0.12
158	0.00	0.33	-0.33	0.11
161	0.41	0.33	0.09	0.01
164	0.69	0.33	0.36	0.13
171	0.00	0.33	-0.33	0.11
174	0.41	0.33	0.08	0.01
177	0.68	0.33	0.35	0.12
184	0.00	0.33	-0.33	0.11
187	0.40	0.33	0.08	0.01
190	0.65	0.33	0.33	0.11
197	0.00	0.33	-0.33	0.11
200	0.39	0.33	0.06	0.00
203	0.62	0.33	0.29	0.09
210	0.00	0.33	-0.33	0.11
213	0.37	0.33	0.04	0.00
216	0.56	0.33	0.24	0.06
223	0.00	0.33	-0.33	0.11
226	0.34	0.33	0.02	0.00
229	0.50	0.33	0.17	0.03
236	0.00	0.33	-0.33	0.11
239	0.32	0.33	-0.01	0.00
242	0.43	0.33	0.11	0.01
249	0.00	0.33	-0.33	0.11
252	0.34	0.33	0.02	0.00
255	0.50	0.33	0.18	0.03
262	0.00	0.33	-0.33	0.11
265	0.37	0.33	0.04	0.00
268	0.57	0.33	0.24	0.06
275	0.00	0.33	-0.33	0.11
278	0.39	0.33	0.06	0.00
281	0.62	0.33	0.29	0.09
288	0.00	0.33	-0.33	0.11
291	0.40	0.33	0.08	0.01
294	0.66	0.33	0.33	0.11
301	0.00	0.33	-0.33	0.11
304	0.41	0.33	0.08	0.01
307	0.68	0.33	0.35	0.12

Based on the formula given in section 4.3, the RMS due to structural deformation is calculated.

RMS = 0.25

5.5.2 EL-15 AZ-0 Position

Table 5.11 Cp values at each node for 80 KMPH wind speed for EL-15 AZ-0 position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	0.98	109-112-125-122	1.44	213-216-229-226	1.41
2-5-18-15	1.34	106-109-122-119	1.41	210-213-226-223	1.40
18-21-34-31	1.12	122-125-138-135	1.44	226-229-242-239	1.40
15-18-31-28	1.34	119-122-135-132	1.43	223-226-239-236	1.40
31-34-47-44	1.25	135-138-151-148	1.41	239-242-255-252	1.38
28-31-44-41	1.35	132-135-148-145	1.44	236-239-252-249	1.39
44-47-60-57	1.32	148-151-164-161	1.51	252-255-268-265	1.36
41-44-57-54	1.37	145-148-161-158	1.44	249-252-265-262	1.39
57-60-73-70	1.36	161-164-177-174	1.39	265-268-281-278	1.32
54-57-70-67	1.39	158-161-174-171	1.44	262-265-278-275	1.37
70-73-86-83	1.38	174-177-190-187	1.40	278-281-294-291	1.25
67-70-83-80	1.39	171-174-187-184	1.44	275-278-291-288	1.35
83-86-99-96	1.40	187-190-203-200	1.44	291-294-307-304	1.12
80-83-96-93	1.40	184-187-200-197	1.43	288-291-304-301	1.34
96-99-112-109	1.41	200-203-216-213	1.44	304-307-8-5	0.98
93-96-109-106	1.40	197-200-213-210	1.41	301-304-5-2	1.34

Table 5.12 Forces at each node for 80 KMPH wind speed for EL-15 AZ-0 position of an Antenna Structure

Wind Force Calculation for V=80 KMPH for EL-15 AZ-0 Position						
θ=	0,15,30,…	θ1=	30.35	θ2=	14.59	
Node No	**Force at each Node (N)**	**Fv=F*Cos(θ1,θ2)**	**Fr=F*Sin(θ1,θ2)**	**X=Fr*Cos(θ)**	**Y=Fr*Sin(θ)**	**Fz=Fv**
8	418.83	361.43	211.62	211.62	0.00	361.43
21	447.07	385.80	225.89	218.19	58.46	385.80
34	504.08	435.01	254.70	220.58	127.35	435.01
47	547.78	472.71	276.78	195.71	195.71	472.71
60	570.69	492.49	288.35	144.18	249.72	492.49
73	584.23	504.17	295.19	76.41	285.13	504.17
86	592.97	511.71	299.61	0.01	299.61	511.71
99	599.52	517.36	302.92	-78.39	292.60	517.36
112	608.21	524.86	307.31	-153.64	266.14	524.86
125	614.23	530.06	310.35	-219.43	219.47	530.06
138	607.46	524.22	306.93	-265.80	153.49	524.22
151	622.38	537.09	314.47	-303.75	81.42	537.09
164	619.18	534.33	312.85	-312.85	0.03	534.33
177	595.20	513.64	300.74	-290.50	-77.81	513.64
190	605.86	522.84	306.12	-265.13	-153.03	522.84
203	614.23	530.06	310.35	-219.48	-219.42	530.06
216	608.21	524.86	307.31	-153.69	-266.12	524.86
229	599.52	517.36	302.92	-78.44	-292.59	517.36

242	592.97	511.71	299.61	-0.04	-299.61	511.71
255	584.23	504.17	295.19	76.36	-285.14	504.17
268	570.69	492.49	288.35	144.14	-249.74	492.49
281	547.78	472.71	276.78	195.68	-195.74	472.71
294	504.08	435.01	254.70	220.55	-127.39	435.01
307	447.07	385.80	225.89	218.18	-58.50	385.80
5	818.10	791.72	206.07	206.07	0.00	791.72
18	847.47	820.14	213.47	206.20	55.25	820.14
31	907.10	877.85	228.49	197.88	114.24	877.85
44	954.91	924.12	240.53	170.09	170.08	924.12
57	982.87	951.18	247.58	123.80	214.40	951.18
70	1000.10	967.86	251.92	65.21	243.33	967.86
83	1010.49	977.90	254.53	0.01	254.53	977.90
96	1017.71	984.90	256.36	-66.34	247.62	984.90
109	1028.38	995.22	259.04	-129.51	224.35	995.22
122	1038.63	1005.14	261.62	-184.98	185.01	1005.14
135	1035.90	1002.50	260.94	-225.97	130.49	1002.50
148	1053.06	1019.10	265.26	-256.21	68.68	1019.10
161	1050.61	1016.73	264.64	-264.64	0.02	1016.73
174	1025.88	992.81	258.41	-249.61	-66.86	992.81
187	1034.30	1000.95	260.53	-225.64	-130.24	1000.95
200	1038.63	1005.14	261.62	-185.02	-184.97	1005.14
213	1028.38	995.22	259.04	-129.55	-224.32	995.22
226	1017.71	984.90	256.36	-66.38	-247.61	984.90
239	1010.49	977.90	254.53	-0.04	-254.53	977.90
252	1000.10	967.86	251.92	65.17	-243.34	967.86
265	982.87	951.18	247.58	123.76	-214.43	951.18
278	954.91	924.12	240.53	170.06	-170.11	924.12
291	907.10	877.85	228.49	197.86	-114.28	877.85
304	847.47	820.14	213.47	206.19	-55.29	820.14
2	399.28	386.40	100.58	100.58	0.00	386.40
15	400.40	387.49	100.86	97.42	26.10	387.49
28	403.02	390.02	101.52	87.92	50.76	390.02
41	407.13	394.00	102.55	72.52	72.51	394.00
54	412.18	398.88	103.82	51.91	89.91	398.88
67	415.88	402.47	104.76	27.12	101.19	402.47
80	417.52	404.06	105.17	0.00	105.17	404.06
93	418.19	404.71	105.34	-27.26	101.75	404.71
106	420.18	406.63	105.84	-52.91	91.66	406.63
119	424.40	410.72	106.90	-75.59	75.60	410.72
132	428.44	414.62	107.92	-93.46	53.97	414.62
145	430.68	416.79	108.49	-104.79	28.09	416.79
158	431.43	417.52	108.67	-108.67	0.01	417.52
171	430.68	416.79	108.49	-104.79	-28.07	416.79
184	428.44	414.62	107.92	-93.47	-53.95	414.62
197	424.40	410.72	106.90	-75.60	-75.58	410.72
210	420.18	406.63	105.84	-52.93	-91.65	406.63
223	418.19	404.71	105.34	-27.28	-101.75	404.71
236	417.52	404.06	105.17	-0.01	-105.17	404.06
249	415.88	402.47	104.76	27.10	-101.19	402.47
262	412.18	398.88	103.82	51.90	-89.92	398.88
275	407.13	394.00	102.55	72.50	-72.53	394.00
288	403.02	390.02	101.52	87.91	-50.77	390.02
301	400.40	387.49	100.86	97.42	-26.12	387.49

Table 5.13 Maximum Nodal Displacements for 80 KMPH wind speed for EL-15 AZ-0 position of an Antenna

		Horizontal	Horizont al	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	151	3 DL+WL	**0.234**	0.033	0.715	0.753	0	0	0
Max Y	73	3 DL+WL	0.064	**0.175**	0.58	0.609	0	0	0
Max Z	151	3 DL+WL	0.234	0.033	**0.715**	0.753	0	0	0
Max Rst	151	3 DL+WL	0.234	0.033	0.715	**0.753**	0	0	0

Table 5.14 Maximum Stresses for 80 KMPH wind speed for EL-15 AZ-0 position of an Antenna

			Max Compressive			Max Tensile		
Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
191	1 BACKUP	936.16	1.62	0.00	1.00			
375	1 BACKUP	936.16	1.62	0.00	1.00			
129	1 BACKUP	1180.57				-1.39	0.00	1.00
451	1 BACKUP	1180.57				-1.39	0.00	1.00
269	2 WIND	1157.69	2.63	1157.69	1.00	0.00	0.00	0.00
260	2 WIND	936.17				-3.67	0.00	1.00
237	3 DL+WL	936.16	4.44	0.00	1.00	-4.16	936.16	1.00
191	3 DL+WL	936.16	4.36	0.00	1.00	-4.22	936.16	1.00

Table 5.15 RMS value for 80 KMPH wind speed for EL-15 AZ-0 position of an Antenna

Node No	Resultant Displacement Δ	Δ average	Δ-Δ average	(Δ-Δ average)^2
2	0.00	0.36	-0.36	0.13
5	0.33	0.36	-0.02	0.00
8	0.32	0.36	-0.04	0.00
15	0.00	0.36	-0.36	0.13
18	0.35	0.36	-0.01	0.00
21	0.36	0.36	0.00	0.00
28	0.00	0.36	-0.36	0.13
31	0.39	0.36	0.03	0.00
34	0.44	0.36	0.08	0.01
41	0.00	0.36	-0.36	0.13
44	0.43	0.36	0.07	0.00
47	0.52	0.36	0.16	0.03
54	0.00	0.36	-0.36	0.13
57	0.45	0.36	0.10	0.01
60	0.57	0.36	0.21	0.05
67	0.00	0.36	-0.36	0.13
70	0.47	0.36	0.12	0.01
73	0.61	0.36	0.25	0.06
80	0.00	0.36	-0.36	0.13

83	0.49	0.36	0.13	0.02
86	0.64	0.36	0.29	0.08
93	0.00	0.36	-0.36	0.13
96	0.50	0.36	0.14	0.02
99	0.67	0.36	0.32	0.10
106	0.00	0.36	-0.36	0.13
109	0.51	0.36	0.16	0.02
112	0.70	0.36	0.35	0.12
119	0.00	0.36	-0.36	0.13
122	0.52	0.36	0.16	0.03
125	0.72	0.36	0.37	0.14
132	0.00	0.36	-0.36	0.13
135	0.52	0.36	0.17	0.03
138	0.74	0.36	0.38	0.14
145	0.00	0.36	-0.36	0.13
148	0.53	0.36	0.18	0.03
151	0.75	0.36	0.40	0.16
158	0.00	0.36	-0.36	0.13
161	0.53	0.36	0.17	0.03
164	0.75	0.36	0.39	0.15
171	0.00	0.36	-0.36	0.13
174	0.52	0.36	0.16	0.03
177	0.73	0.36	0.37	0.14
184	0.00	0.36	-0.36	0.13
187	0.52	0.36	0.16	0.03
190	0.73	0.36	0.37	0.14
197	0.00	0.36	-0.36	0.13
200	0.52	0.36	0.16	0.03
203	0.72	0.36	0.37	0.13
210	0.00	0.36	-0.36	0.13
213	0.51	0.36	0.15	0.02
216	0.70	0.36	0.35	0.12
223	0.00	0.36	-0.36	0.13
226	0.50	0.36	0.14	0.02
229	0.67	0.36	0.32	0.10
236	0.00	0.36	-0.36	0.13
239	0.49	0.36	0.13	0.02
242	0.64	0.36	0.29	0.08
249	0.00	0.36	-0.36	0.13
252	0.47	0.36	0.12	0.01
255	0.61	0.36	0.25	0.06
262	0.00	0.36	-0.36	0.13
265	0.45	0.36	0.10	0.01
268	0.57	0.36	0.21	0.04
275	0.00	0.36	-0.36	0.13
278	0.43	0.36	0.07	0.00
281	0.51	0.36	0.16	0.02
288	0.00	0.36	-0.36	0.13
291	0.39	0.36	0.03	0.00
294	0.44	0.36	0.08	0.01
301	0.00	0.36	-0.36	0.13
304	0.35	0.36	-0.01	0.00
307	0.35	0.36	0.00	0.00

Based on the formula given in the section 4.3, the RMS due to structural deformation is calculated.

RMS = 0.27

5.5.3 EL-30 AZ-0 Position

Table 5.16 Cp values at each node for 80 KMPH wind speed for EL-30 AZ-0 position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	0.90	109-112-125-122	1.49	213-216-229-226	1.46
2-5-18-15	1.30	106-109-122-119	1.44	210-213-226-223	1.43
18-21-34-31	1.02	122-125-138-135	1.54	226-229-242-239	1.44
15-18-31-28	1.33	119-122-135-132	1.46	223-226-239-236	1.43
31-34-47-44	1.17	135-138-151-148	1.51	239-242-255-252	1.41
28-31-44-41	1.36	132-135-148-145	1.47	236-239-252-249	1.41
44-47-60-57	1.28	148-151-164-161	1.27	252-255-268-265	1.37
41-44-57-54	1.39	145-148-161-158	1.48	249-252-265-262	1.40
57-60-73-70	1.37	161-164-177-174	1.27	265-268-281-278	1.28
54-57-70-67	1.40	158-161-174-171	1.48	262-265-278-275	1.39
70-73-86-83	1.41	174-177-190-187	1.51	278-281-294-291	1.17
67-70-83-80	1.41	171-174-187-184	1.47	275-278-291-288	1.36
83-86-99-96	1.44	187-190-203-200	1.54	291-294-307-304	1.02
80-83-96-93	1.43	184-187-200-197	1.46	288-291-304-301	1.33
96-99-112-109	1.46	200-203-216-213	1.49	304-307-8-5	0.90
93-96-109-106	1.43	197-200-213-210	1.44	301-304-5-2	1.30

Table 5.17 Forces at each node for 80 KMPH wind speed for EL-30 AZ-0 position of an Antenna

Wind Force Calculation for V=80 KMPH for EL-30 AZ-0 Position						
θ=	0,15,30,…	θ1=	30.35	θ2=	14.59	
Node No	**Force at each Node (N)**	**Fv=F*Cos(θ1,θ2)**	**Fr=F*Sin(θ1,θ2)**	**X=Fr*Cos(θ)**	**Y=Fr*Sin(θ)**	**Fz=Fv**
8	382.59	330.16	193.31	193.31	0.00	330.16
21	407.64	351.78	205.97	198.95	53.31	351.78
34	466.25	402.36	235.58	204.02	117.79	402.36
47	522.26	450.69	263.88	186.59	186.59	450.69
60	564.14	486.83	285.04	142.53	246.85	486.83
73	592.59	511.39	299.42	77.51	289.21	511.39
86	607.73	524.45	307.06	0.01	307.06	524.45
99	618.65	533.87	312.58	-80.89	301.94	533.87
112	629.31	543.07	317.97	-158.97	275.38	543.07
125	644.76	556.40	325.78	-230.34	230.37	556.40
138	649.02	560.08	327.93	-283.98	163.99	560.08
151	592.01	510.88	299.12	-288.92	77.44	510.88
164	540.32	466.28	273.01	-273.01	0.03	466.28
177	592.01	510.88	299.12	-288.94	-77.39	510.88
190	649.02	560.08	327.93	-284.01	-163.93	560.08
203	644.76	556.40	325.78	-230.39	-230.33	556.40

216	629.31	543.07	317.97	-159.02	-275.35	543.07
229	618.65	533.87	312.58	-80.94	-301.92	533.87
242	607.73	524.45	307.06	-0.04	-307.06	524.45
255	592.59	511.39	299.42	77.45	-289.23	511.39
268	564.14	486.83	285.04	142.48	-246.87	486.83
281	522.26	450.69	263.88	186.56	-186.62	450.69
294	466.25	402.36	235.58	204.00	-117.83	402.36
307	407.64	351.78	205.97	198.94	-53.34	351.78
5	769.91	745.08	193.93	193.93	0.00	745.08
18	799.51	773.73	201.39	194.53	52.12	773.73
31	868.48	840.48	218.76	189.46	109.38	840.48
44	933.80	903.68	235.22	166.33	166.32	903.68
57	981.62	949.97	247.26	123.64	214.13	949.97
70	1013.96	981.27	255.41	66.11	246.71	981.27
83	1032.24	998.95	260.01	0.01	260.01	998.95
96	1045.97	1012.24	263.47	-68.18	254.50	1012.24
109	1059.24	1025.09	266.82	-133.39	231.08	1025.09
122	1078.43	1043.66	271.65	-192.07	192.10	1043.66
135	1086.81	1051.76	273.76	-237.07	136.90	1051.76
148	1032.78	999.48	260.15	-251.28	67.35	999.48
161	982.22	950.54	247.41	-247.41	0.02	950.54
174	1032.78	999.48	260.15	-251.29	-67.31	999.48
187	1086.81	1051.76	273.76	-237.10	-136.85	1051.76
200	1078.43	1043.66	271.65	-192.11	-192.06	1043.66
213	1059.24	1025.09	266.82	-133.44	-231.05	1025.09
226	1045.97	1012.24	263.47	-68.22	-254.49	1012.24
239	1032.24	998.95	260.01	-0.04	-260.01	998.95
252	1013.96	981.27	255.41	66.07	-246.72	981.27
265	981.62	949.97	247.26	123.60	-214.16	949.97
278	933.80	903.68	235.22	166.30	-166.35	903.68
291	868.48	840.48	218.76	189.44	-109.41	840.48
304	799.51	773.73	201.39	194.52	-52.16	773.73
2	387.31	374.82	97.56	97.56	0.00	374.82
15	391.87	379.24	98.71	95.35	25.55	379.24
28	402.23	389.26	101.32	87.75	50.66	389.26
41	411.54	398.27	103.66	73.30	73.30	398.27
54	417.48	404.02	105.16	52.58	91.07	404.02
67	421.37	407.78	106.14	27.48	102.52	407.78
80	424.51	410.82	106.93	0.00	106.93	410.82
93	427.32	413.54	107.64	-27.85	103.97	413.54
106	429.93	416.07	108.30	-54.14	93.79	416.07
119	433.67	419.69	109.24	-77.24	77.25	419.69
132	437.78	423.67	110.27	-95.50	55.14	423.67
145	440.78	426.56	111.03	-107.24	28.75	426.56
158	441.90	427.65	111.31	-111.31	0.01	427.65
171	440.78	426.56	111.03	-107.25	-28.73	426.56
184	437.78	423.67	110.27	-95.51	-55.13	423.67
197	433.67	419.69	109.24	-77.25	-77.23	419.69
210	429.93	416.07	108.30	-54.16	-93.78	416.07
223	427.32	413.54	107.64	-27.87	-103.97	413.54
236	424.51	410.82	106.93	-0.01	-106.93	410.82
249	421.37	407.78	106.14	27.46	-102.53	407.78
262	417.48	404.02	105.16	52.57	-91.08	404.02
275	411.54	398.27	103.66	73.29	-73.31	398.27
288	402.23	389.26	101.32	87.74	-50.67	389.26
301	391.87	379.24	98.71	95.34	-25.57	379.24

Table 5.18 Maximum Nodal Displacements for 80 KMPH wind speed for EL-30 AZ-0 position of an Antenna

		Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	138	3 DL+WL	**0.278**	0.076	0.781	0.833	0	0	0
Max Y	59	3 DL+WL	0.1	**0.188**	0.492	0.536	0	0	0
Max Z	190	3 DL+WL	0.27	0.09	**0.781**	0.831	0	0	0
Max Rst	138	3 DL+WL	0.278	0.076	0.781	**0.833**	0	0	0

Table 5.19 Maximum Stresses for 80 KMPH wind speed for EL-30 AZ-0 position of an Antenna

			Max Compressive			Max Tensile		
Beam	**L/C**	**Length mm**	**Stress N/mm2**	**Dist mm**	**Corner**	**Stress N/mm2**	**Dist mm**	**Corner**
191	1 BACKUP	936.16	2.08	0.00	2.00			
375	1 BACKUP	936.16	2.08	0.00	1.00			
208	1 BACKUP	926.55				-1.92	0.00	1.00
346	1 BACKUP	926.55				-1.92	0.00	1.00
246	2 WIND	1157.70	2.74	1157.70	1.00	0.00	0.00	0.00
352	2 WIND	936.17				-3.87	0.00	1.00
375	3 DL+WL	936.16	4.96	0.00	1.00	-4.49	936.16	1.00
214	3 DL+WL	936.17	4.84	0.00	1.00	-4.53	936.17	1.00

Table 5.20 RMS for 80 KMPH wind speed for EL-30 AZ-0 position of an Antenna

Node No	**Resultant Displacement Δ**	**Δ average**	**Δ-Δ average**	**(Δ-Δ average)^2**
2	0.00	0.35	-0.35	0.12
5	0.27	0.35	-0.09	0.01
8	0.22	0.35	-0.14	0.02
15	0.00	0.35	-0.35	0.12
18	0.29	0.35	-0.07	0.00
21	0.25	0.35	-0.11	0.01
28	0.00	0.35	-0.35	0.12
31	0.34	0.35	-0.02	0.00
34	0.33	0.35	-0.02	0.00
41	0.00	0.35	-0.35	0.12
44	0.39	0.35	0.03	0.00
47	0.44	0.35	0.08	0.01
54	0.00	0.35	-0.35	0.12
57	0.43	0.35	0.08	0.01
60	0.53	0.35	0.17	0.03
67	0.00	0.35	-0.35	0.12
70	0.46	0.35	0.11	0.01
73	0.61	0.35	0.25	0.06
80	0.00	0.35	-0.35	0.12

83	0.49	0.35	0.14	0.02
86	0.67	0.35	0.32	0.10
93	0.00	0.35	-0.35	0.12
96	0.52	0.35	0.16	0.03
99	0.72	0.35	0.37	0.14
106	0.00	0.35	-0.35	0.12
109	0.54	0.35	0.18	0.03
112	0.77	0.35	0.42	0.18
119	0.00	0.35	-0.35	0.12
122	0.55	0.35	0.20	0.04
125	0.82	0.35	0.47	0.22
132	0.00	0.35	-0.35	0.12
135	0.56	0.35	0.21	0.04
138	0.83	0.35	0.48	0.23
145	0.00	0.35	-0.35	0.12
148	0.53	0.35	0.18	0.03
151	0.78	0.35	0.43	0.18
158	0.00	0.35	-0.35	0.12
161	0.51	0.35	0.16	0.02
164	0.73	0.35	0.38	0.15
171	0.00	0.35	-0.35	0.12
174	0.53	0.35	0.18	0.03
177	0.78	0.35	0.43	0.18
184	0.00	0.35	-0.35	0.12
187	0.56	0.35	0.21	0.04
190	0.83	0.35	0.48	0.23
197	0.00	0.35	-0.35	0.12
200	0.55	0.35	0.20	0.04
203	0.82	0.35	0.47	0.22
210	0.00	0.35	-0.35	0.12
213	0.53	0.35	0.18	0.03
216	0.77	0.35	0.42	0.18
223	0.00	0.35	-0.35	0.12
226	0.51	0.35	0.16	0.03
229	0.72	0.35	0.37	0.13
236	0.00	0.35	-0.35	0.12
239	0.49	0.35	0.14	0.02
242	0.67	0.35	0.31	0.10
249	0.00	0.35	-0.35	0.12
252	0.46	0.35	0.11	0.01
255	0.60	0.35	0.25	0.06
262	0.00	0.35	-0.35	0.12
265	0.43	0.35	0.08	0.01
268	0.52	0.35	0.17	0.03
275	0.00	0.35	-0.35	0.12
278	0.39	0.35	0.03	0.00
281	0.43	0.35	0.08	0.01
288	0.00	0.35	-0.35	0.12
291	0.33	0.35	-0.02	0.00
294	0.33	0.35	-0.02	0.00
301	0.00	0.35	-0.35	0.12
304	0.29	0.35	-0.07	0.00
307	0.25	0.35	-0.11	0.01

Based on the formula given in the section 4.3, the RMS due to structural deformation is calculated.

RMS = 0.29

5.5.4 EL-45 AZ-0 Position

Table 5.21 Cp values at each node for 80 KMPH wind speed for EL-45 AZ-0 position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	0.98	109-112-125-122	1.59	213-216-229-226	1.56
2-5-18-15	1.38	106-109-122-119	1.55	210-213-226-223	1.54
18-21-34-31	1.09	122-125-138-135	1.62	226-229-242-239	1.53
15-18-31-28	1.39	119-122-135-132	1.56	223-226-239-236	1.52
31-34-47-44	1.23	135-138-151-148	1.66	239-242-255-252	1.49
28-31-44-41	1.42	132-135-148-145	1.57	236-239-252-249	1.50
44-47-60-57	1.35	148-151-164-161	1.65	252-255-268-265	1.44
41-44-57-54	1.46	145-148-161-158	1.57	249-252-265-262	1.48
57-60-73-70	1.44	161-164-177-174	1.64	265-268-281-278	1.35
54-57-70-67	1.48	158-161-174-171	1.57	262-265-278-275	1.46
70-73-86-83	1.49	174-177-190-187	1.66	278-281-294-291	1.23
67-70-83-80	1.50	171-174-187-184	1.57	275-278-291-288	1.42
83-86-99-96	1.53	187-190-203-200	1.62	291-294-307-304	1.09
80-83-96-93	1.52	184-187-200-197	1.56	288-291-304-301	1.39
96-99-112-109	1.56	200-203-216-213	1.59	304-307-8-5	0.98
93-96-109-106	1.54	197-200-213-210	1.55	301-304-5-2	1.38

Table 5.22 Forces at each node for 80 KMPH wind speed for EL-45 AZ-0 position of an Antenna

Wind Force Calculation for V=80 KMPH for EL-45 AZ-0 Position						
θ=	0,15,30,…	θ1=	30.35	θ2=	14.59	
Node No	**Force at each Node (N)**	**Fv=F*Cos(θ1,θ2)**	**Fr=F*Sin(θ1,θ2)**	**X=Fr*Cos(θ)**	**Y=Fr*Sin(θ)**	**Z=Fv**
8	416.70	359.59	210.54	210.54	0.00	359.59
21	440.14	379.83	222.39	214.81	57.56	379.83
34	492.89	425.35	249.04	215.68	124.52	425.35
47	547.78	472.71	276.78	195.71	195.71	472.71
60	593.07	511.80	299.66	149.84	259.51	511.80
73	624.51	538.93	315.55	81.68	304.79	538.93
86	643.16	555.02	324.97	0.02	324.97	555.02
99	657.02	566.98	331.97	-85.90	320.66	566.98
112	669.80	578.02	338.43	-169.20	293.10	578.02
125	683.66	589.97	345.43	-244.24	244.27	589.97
138	700.18	604.23	353.78	-306.37	176.91	604.23
151	706.04	609.29	356.74	-344.57	92.36	609.29
164	701.24	605.15	354.32	-354.32	0.03	605.15
177	703.91	607.45	355.66	-343.55	-92.02	607.45
190	700.18	604.23	353.78	-306.40	-176.86	604.23

203	683.66	589.97	345.43	-244.28	-244.23	589.97
216	669.80	578.02	338.43	-169.25	-293.07	578.02
229	657.02	566.98	331.97	-85.96	-320.65	566.98
242	643.16	555.02	324.97	-0.05	-324.97	555.02
255	624.51	538.93	315.55	81.62	-304.81	538.93
268	593.07	511.80	299.66	149.79	-259.54	511.80
281	547.78	472.71	276.78	195.68	-195.74	472.71
294	492.89	425.35	249.04	215.66	-124.56	425.35
307	440.14	379.83	222.39	214.80	-57.60	379.83
5	829.43	802.69	208.93	208.93	0.00	802.69
18	854.37	826.82	215.21	207.88	55.70	826.82
31	913.48	884.03	230.10	199.27	115.05	884.03
44	979.21	947.63	246.66	174.42	174.41	947.63
57	1033.10	999.79	260.23	130.12	225.36	999.79
70	1069.77	1035.28	269.47	69.75	260.28	1035.28
83	1094.03	1058.75	275.58	0.01	275.58	1058.75
96	1114.24	1078.31	280.67	-72.63	271.11	1078.31
109	1131.89	1095.39	285.12	-142.54	246.93	1095.39
122	1149.11	1112.06	289.45	-204.66	204.69	1112.06
135	1168.62	1130.94	294.37	-254.92	147.20	1130.94
148	1175.60	1137.69	296.13	-286.03	76.67	1137.69
161	1170.80	1133.05	294.92	-294.92	0.03	1133.05
174	1173.47	1135.63	295.59	-285.52	-76.48	1135.63
187	1168.62	1130.94	294.37	-254.95	-147.16	1130.94
200	1149.11	1112.06	289.45	-204.70	-204.65	1112.06
213	1131.89	1095.39	285.12	-142.59	-246.90	1095.39
226	1114.24	1078.31	280.67	-72.68	-271.10	1078.31
239	1094.03	1058.75	275.58	-0.04	-275.58	1058.75
252	1069.77	1035.28	269.47	69.71	-260.30	1035.28
265	1033.10	999.79	260.23	130.08	-225.39	999.79
278	979.21	947.63	246.66	174.38	-174.44	947.63
291	913.48	884.03	230.10	199.25	-115.08	884.03
304	854.37	826.82	215.21	207.87	-55.74	826.82
2	412.74	399.43	103.97	103.97	0.00	399.43
15	414.23	400.87	104.34	100.79	27.00	400.87
28	420.59	407.03	105.94	91.75	52.97	407.03
41	431.43	417.52	108.67	76.85	76.84	417.52
54	440.03	425.84	110.84	55.42	95.99	425.84
67	445.26	430.90	112.16	29.03	108.34	430.90
80	450.87	436.33	113.57	0.01	113.57	436.33
93	457.22	442.48	115.17	-29.80	111.25	442.48
106	462.08	447.18	116.40	-58.19	100.81	447.18
119	465.45	450.44	117.24	-82.90	82.91	450.44
132	468.44	453.34	118.00	-102.18	59.01	453.34
145	469.56	454.42	118.28	-114.25	30.62	454.42
158	469.56	454.42	118.28	-118.28	0.01	454.42
171	469.56	454.42	118.28	-114.25	-30.60	454.42
184	468.44	453.34	118.00	-102.19	-58.99	453.34
197	465.45	450.44	117.24	-82.91	-82.89	450.44
210	462.08	447.18	116.40	-58.21	-100.79	447.18
223	457.22	442.48	115.17	-29.82	-111.24	442.48
236	450.87	436.33	113.57	-0.02	-113.57	436.33
249	445.26	430.90	112.16	29.01	-108.34	430.90
262	440.03	425.84	110.84	55.41	-96.00	425.84
275	431.43	417.52	108.67	76.83	-76.86	417.52
288	420.59	407.03	105.94	91.74	-52.99	407.03
301	414.23	400.87	104.34	100.78	-27.02	400.87

Table 5.23 Maximum Nodal Displacements for 80 KMPH wind speed for EL-45 AZ-0 position of an Antenna

		Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	151	3 DL+WL	**0.344**	0.026	0.886	0.95	0	0	0
Max Y	59	3 DL+WL	0.158	**0.199**	0.462	0.527	0	0	0
Max Z	164	3 DL+WL	0.342	0.008	**0.89**	0.953	0	0	0
Max Rst	164	3 DL+WL	0.342	0.008	0.89	**0.953**	0	0	0

Table 5.24 Maximum Stresses for 80 KMPH wind speed for EL-45 AZ-0 position of an Antenna

			Max Compressive			Max Tensile		
Beam	**L/C**	**Length mm**	**Stress N/mm2**	**Dist mm**	**Corner**	**Stress N/mm 2**	**Dist mm**	**Corner**
191	1 BACKUP	936.16	2.40	0.00	2.00			
375	1 BACKUP	936.16	2.40	0.00	1.00			
185	1 BACKUP	926.54				-2.45	0.00	1.00
369	1 BACKUP	926.54				-2.45	0.00	1.00
246	2 WIND	1157.70	2.99	1157.70	1.00	0.00	0.00	0.00
260	2 WIND	936.17				-4.18	0.00	1.00
375	3 DL+WL	936.16	5.45	0.00	1.00	-4.73	936.16	1.00
214	3 DL+WL	936.17	5.26	0.00	1.00	-4.78	936.17	2.00

Table 5.25 RMS for 80 KMPH wind speed for EL-45 AZ-0 position of an Antenna

Node No	**Resultant Displacement Δ**	**Δ average**	**Δ-Δ average**	**(Δ-Δ average)^2**
2	0.00	0.38	-0.38	0.14
5	0.25	0.38	-0.13	0.02
8	0.32	0.38	-0.06	0.00
15	0.00	0.38	-0.38	0.14
18	0.27	0.38	-0.11	0.01
21	0.34	0.38	-0.03	0.00
28	0.00	0.38	-0.38	0.14
31	0.32	0.38	-0.06	0.00
34	0.40	0.38	0.03	0.00
41	0.00	0.38	-0.38	0.14
44	0.37	0.38	-0.01	0.00
47	0.46	0.38	0.08	0.01
54	0.00	0.38	-0.38	0.14
57	0.42	0.38	0.04	0.00
60	0.50	0.38	0.13	0.02
67	0.00	0.38	-0.38	0.14
70	0.46	0.38	0.08	0.01
73	0.60	0.38	0.22	0.05

80	0.00	0.38	-0.38	0.14
83	0.50	0.38	0.12	0.01
86	0.68	0.38	0.31	0.09
93	0.00	0.38	-0.38	0.14
96	0.53	0.38	0.15	0.02
99	0.76	0.38	0.38	0.14
106	0.00	0.38	-0.38	0.14
109	0.56	0.38	0.18	0.03
112	0.82	0.38	0.44	0.20
119	0.00	0.38	-0.38	0.14
122	0.58	0.38	0.20	0.04
125	0.88	0.38	0.50	0.25
132	0.00	0.38	-0.38	0.14
135	0.60	0.38	0.22	0.05
138	0.93	0.38	0.55	0.30
145	0.00	0.38	-0.38	0.14
148	0.61	0.38	0.23	0.05
151	0.95	0.38	0.57	0.33
158	0.00	0.38	-0.38	0.14
161	0.61	0.38	0.23	0.05
164	0.95	0.38	0.58	0.33
171	0.00	0.38	-0.38	0.14
174	0.61	0.38	0.23	0.05
177	0.95	0.38	0.57	0.32
184	0.00	0.38	-0.38	0.14
187	0.60	0.38	0.22	0.05
190	0.92	0.38	0.55	0.30
197	0.00	0.38	-0.38	0.14
200	0.58	0.38	0.20	0.04
203	0.88	0.38	0.50	0.25
210	0.00	0.38	-0.38	0.14
213	0.56	0.38	0.18	0.03
216	0.82	0.38	0.44	0.19
223	0.00	0.38	-0.38	0.14
226	0.53	0.38	0.15	0.02
229	0.75	0.38	0.37	0.14
236	0.00	0.38	-0.38	0.14
239	0.50	0.38	0.12	0.01
242	0.68	0.38	0.30	0.09
249	0.00	0.38	-0.38	0.14
252	0.46	0.38	0.08	0.01
255	0.59	0.38	0.22	0.05
262	0.00	0.38	-0.38	0.14
265	0.42	0.38	0.04	0.00
268	0.50	0.38	0.12	0.01
275	0.00	0.38	-0.38	0.14
278	0.37	0.38	-0.01	0.00
281	0.46	0.38	0.08	0.01
288	0.00	0.38	-0.38	0.14
291	0.32	0.38	-0.06	0.00
294	0.40	0.38	0.02	0.00
301	0.00	0.38	-0.38	0.14
304	0.27	0.38	-0.11	0.01
307	0.34	0.38	-0.03	0.00

Based on the formula given in the section 4.3, the RMS of the structural deformation is calculated.

RMS = 0.31

5.5.5 EL-60 AZ-0 Position

Table 5.26 Cp values at each node for 80 KMPH wind speed for EL-60 AZ-0 position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	0.78	109-112-125-122	1.43	213-216-229-226	1.50
2-5-18-15	1.32	106-109-122-119	1.49	210-213-226-223	1.52
18-21-34-31	0.83	122-125-138-135	1.35	226-229-242-239	1.52
15-18-31-28	1.31	119-122-135-132	1.46	223-226-239-236	1.53
31-34-47-44	1.02	135-138-151-148	1.31	239-242-255-252	1.53
28-31-44-41	1.36	132-135-148-145	1.44	236-239-252-249	1.53
44-47-60-57	1.28	148-151-164-161	1.28	252-255-268-265	1.45
41-44-57-54	1.46	145-148-161-158	1.43	249-252-265-262	1.51
57-60-73-70	1.45	161-164-177-174	1.28	265-268-281-278	1.28
54-57-70-67	1.51	158-161-174-171	1.47	262-265-278-275	1.46
70-73-86-83	1.53	174-177-190-187	1.31	278-281-294-291	1.02
67-70-83-80	1.53	171-174-187-184	1.44	275-278-291-288	1.36
83-86-99-96	1.52	187-190-203-200	1.35	291-294-307-304	0.83
80-83-96-93	1.53	184-187-200-197	1.46	288-291-304-301	1.31
96-99-112-109	1.50	200-203-216-213	1.43	304-307-8-5	0.78
93-96-109-106	1.52	197-200-213-210	1.49	301-304-5-2	1.32

Table 5.27 Forces at each node for 80 KMPH wind speed for EL-60 AZ-0 position of an Antenna

Wind Force Calculation for V=80 KMPH for EL-60 AZ-0 Position						
θ=	0,15,30,…	θ1=	30.35	θ2=	14.59	
Node No	**Force at each Node (N)**	**Fv=F*Cos(θ1,θ2)**	**Fr=F*Sin(θ1,θ2)**	**X=Fr*Cos(θ)**	**Y=Fr*Sin(θ)**	**Z=Fv**
8	332.50	286.94	168.00	168.00	0.00	286.94
21	343.16	296.14	173.39	167.48	44.87	296.14
34	394.85	340.74	199.50	172.78	99.75	340.74
47	489.70	422.59	247.43	174.96	174.95	422.59
60	579.75	500.30	292.93	146.47	253.68	500.30
73	633.04	546.29	319.85	82.80	308.95	546.29
86	649.02	560.08	327.93	0.02	327.93	560.08
99	642.63	554.56	324.70	-84.02	313.64	554.56
112	622.38	537.09	314.47	-157.22	272.35	537.09
125	590.94	509.96	298.58	-211.12	211.14	509.96
138	565.90	488.35	285.93	-247.61	142.98	488.35
151	550.44	475.01	278.12	-268.64	72.01	475.01
164	543.52	469.03	274.62	-274.62	0.03	469.03
177	550.44	475.01	278.12	-268.65	-71.96	475.01
190	565.90	488.35	285.93	-247.64	-142.94	488.35
203	590.94	509.96	298.58	-211.15	-211.11	509.96

216	622.38	537.09	314.47	-157.27	-272.32	537.09
229	642.63	554.56	324.70	-84.08	-313.62	554.56
242	649.02	560.08	327.93	-0.05	-327.93	560.08
255	633.04	546.29	319.85	82.74	-308.97	546.29
268	579.75	500.30	292.93	146.43	-253.71	500.30
281	489.70	422.59	247.43	174.93	-174.99	422.59
294	394.85	340.74	199.50	172.76	-99.78	340.74
307	343.16	296.14	173.39	167.47	-44.91	296.14
5	726.55	703.12	183.01	183.01	0.00	703.12
18	735.71	711.99	185.32	179.01	47.96	711.99
31	793.75	768.16	199.94	173.16	99.97	768.16
44	911.78	882.38	229.67	162.41	162.40	882.38
57	1024.26	991.24	258.01	129.01	223.44	991.24
70	1088.02	1052.94	274.06	70.94	264.72	1052.94
83	1107.00	1071.30	278.84	0.01	278.84	1071.30
96	1097.98	1062.58	276.57	-71.57	267.15	1062.58
109	1071.75	1037.19	269.97	-134.97	233.81	1037.19
122	1031.72	998.45	259.88	-183.75	183.78	998.45
135	998.45	966.25	251.50	-217.80	125.77	966.25
148	978.13	946.59	246.39	-237.98	63.79	946.59
161	976.81	945.32	246.05	-246.05	0.02	945.32
174	985.24	953.47	248.17	-239.72	-64.21	953.47
187	998.45	966.25	251.50	-217.82	-125.73	966.25
200	1031.72	998.45	259.88	-183.79	-183.74	998.45
213	1071.75	1037.19	269.97	-135.01	-233.78	1037.19
226	1097.98	1062.58	276.57	-71.62	-267.14	1062.58
239	1107.00	1071.30	278.84	-0.04	-278.84	1071.30
252	1088.02	1052.94	274.06	70.89	-264.74	1052.94
265	1024.26	991.24	258.01	128.97	-223.46	991.24
278	911.78	882.38	229.67	162.38	-162.43	882.38
291	793.75	768.16	199.94	173.14	-100.00	768.16
304	735.71	711.99	185.32	179.00	-48.00	711.99
2	394.04	381.34	99.26	99.26	0.00	381.34
15	392.55	379.89	98.88	95.51	25.59	379.89
28	398.90	386.04	100.48	87.02	50.24	386.04
41	422.08	408.47	106.32	75.18	75.18	408.47
54	444.51	430.18	111.97	55.99	96.97	430.18
67	454.98	440.31	114.61	29.67	110.70	440.31
80	457.97	443.21	115.36	0.01	115.36	443.21
93	455.36	440.67	114.70	-29.68	110.79	440.67
106	449.37	434.88	113.19	-56.59	98.03	434.88
119	440.78	426.56	111.03	-78.50	78.51	426.56
132	432.55	418.60	108.96	-94.35	54.49	418.60
145	427.69	413.90	107.73	-104.06	27.89	413.90
158	433.30	419.33	109.14	-109.14	0.01	419.33
171	434.79	420.77	109.52	-105.79	-28.34	420.77
184	432.55	418.60	108.96	-94.36	-54.47	418.60
197	440.78	426.56	111.03	-78.52	-78.50	426.56
210	449.37	434.88	113.19	-56.61	-98.02	434.88
223	455.36	440.67	114.70	-29.70	-110.79	440.67
236	457.97	443.21	115.36	-0.02	-115.36	443.21
249	454.98	440.31	114.61	29.65	-110.71	440.31
262	444.51	430.18	111.97	55.97	-96.98	430.18
275	422.08	408.47	106.32	75.17	-75.19	408.47
288	398.90	386.04	100.48	87.01	-50.26	386.04
301	392.55	379.89	98.88	95.51	-25.61	379.89

Table 5.28 Maximum Nodal Displacements for 80 KMPH wind speed for EL-60 AZ-0 position of an Antenna

		Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	111	3 DL+WL	**0.307**	0.147	0.652	0.736	0	0	0
Max Y	59	3 DL+WL	0.195	**0.215**	0.459	0.544	0	0	0
Max Z	203	3 DL+WL	0.289	0.102	**0.734**	0.796	0	0	0
Max Rst	125	3 DL+WL	0.3	0.091	0.734	**0.798**	0	0	0

Table 5.29 Maximum Stresses for 80 KMPH wind speed for EL-60 AZ-0 position of an Antenna

			Max Compressive			Max Tensile		
Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
191	1 BACKUP	936.16	2.55	0.00	2.00			
375	1 BACKUP	936.16	2.55	0.00	1.00			
185	1 BACKUP	926.54				-2.81	0.00	1.00
369	1 BACKUP	926.54				-2.81	0.00	1.00
177	2 WIND	1157.69	2.64	1157.69	1.00	0.00	0.00	0.00
168	2 WIND	936.17				-3.92	0.00	1.00
398	3 DL+WL	936.17	5.56	0.00	1.00	-4.49	936.17	2.00
191	3 DL+WL	936.16	5.42	0.00	1.00	-4.52	936.16	2.00

Table 5.30 RMS for 80 KMPH wind speed for EL-60 AZ-0 position of an Antenna

Node No	Resultant Displacement Δ	Δ average	Δ-Δ average	(Δ-Δ average)^2
2	0.00	0.36	-0.36	0.13
5	0.23	0.36	-0.13	0.02
8	0.34	0.36	-0.01	0.00
15	0.00	0.36	-0.36	0.13
18	0.24	0.36	-0.12	0.01
21	0.36	0.36	0.00	0.00
28	0.00	0.36	-0.36	0.13
31	0.28	0.36	-0.08	0.01
34	0.41	0.36	0.06	0.00
41	0.00	0.36	-0.36	0.13
44	0.33	0.36	-0.03	0.00
47	0.50	0.36	0.15	0.02
54	0.00	0.36	-0.36	0.13
57	0.40	0.36	0.04	0.00
60	0.59	0.36	0.23	0.05
67	0.00	0.36	-0.36	0.13
70	0.46	0.36	0.10	0.01
73	0.64	0.36	0.28	0.08
80	0.00	0.36	-0.36	0.13

83	0.50	0.36	0.14	0.02
86	0.72	0.36	0.37	0.13
93	0.00	0.36	-0.36	0.13
96	0.52	0.36	0.16	0.03
99	0.77	0.36	0.42	0.17
106	0.00	0.36	-0.36	0.13
109	0.52	0.36	0.17	0.03
112	0.80	0.36	0.44	0.19
119	0.00	0.36	-0.36	0.13
122	0.52	0.36	0.16	0.03
125	0.80	0.36	0.44	0.19
132	0.00	0.36	-0.36	0.13
135	0.51	0.36	0.15	0.02
138	0.79	0.36	0.44	0.19
145	0.00	0.36	-0.36	0.13
148	0.50	0.36	0.15	0.02
151	0.79	0.36	0.43	0.19
158	0.00	0.36	-0.36	0.13
161	0.50	0.36	0.15	0.02
164	0.79	0.36	0.43	0.18
171	0.00	0.36	-0.36	0.13
174	0.51	0.36	0.15	0.02
177	0.79	0.36	0.43	0.19
184	0.00	0.36	-0.36	0.13
187	0.51	0.36	0.15	0.02
190	0.79	0.36	0.43	0.19
197	0.00	0.36	-0.36	0.13
200	0.52	0.36	0.16	0.03
203	0.80	0.36	0.44	0.19
210	0.00	0.36	-0.36	0.13
213	0.52	0.36	0.16	0.03
216	0.79	0.36	0.44	0.19
223	0.00	0.36	-0.36	0.13
226	0.52	0.36	0.16	0.03
229	0.77	0.36	0.41	0.17
236	0.00	0.36	-0.36	0.13
239	0.50	0.36	0.14	0.02
242	0.72	0.36	0.36	0.13
249	0.00	0.36	-0.36	0.13
252	0.46	0.36	0.10	0.01
255	0.63	0.36	0.27	0.07
262	0.00	0.36	-0.36	0.13
265	0.40	0.36	0.04	0.00
268	0.58	0.36	0.22	0.05
275	0.00	0.36	-0.36	0.13
278	0.33	0.36	-0.03	0.00
281	0.50	0.36	0.14	0.02
288	0.00	0.36	-0.36	0.13
291	0.27	0.36	-0.08	0.01
294	0.41	0.36	0.05	0.00
301	0.00	0.36	-0.36	0.13
304	0.24	0.36	-0.12	0.01
307	0.36	0.36	0.00	0.00

Based on the formula given in the section 4.3, the RMS for the structural deformation is calculated.

RMS = 0.29

5.5.6 EL-75 AZ-0 Position

Table 5.31 Cp values at each panel for 80 KMPH wind speed for EL-75 AZ-0 position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	0.57	109-112-125-122	-0.19	213-216-229-226	0.39
2-5-18-15	1.20	106-109-122-119	0.57	210-213-226-223	0.82
18-21-34-31	0.74	122-125-138-135	-0.62	226-229-242-239	0.95
15-18-31-28	1.21	119-122-135-132	0.35	223-226-239-236	1.08
31-34-47-44	0.99	135-138-151-148	-0.84	239-242-255-252	1.26
28-31-44-41	1.25	132-135-148-145	0.17	236-239-252-249	1.23
44-47-60-57	1.20	148-151-164-161	-0.90	252-255-268-265	1.30
41-44-57-54	1.28	145-148-161-158	0.11	249-252-265-262	1.28
57-60-73-70	1.30	161-164-177-174	-0.90	265-268-281-278	1.20
54-57-70-67	1.28	158-161-174-171	0.64	262-265-278-275	1.28
70-73-86-83	1.26	174-177-190-187	-0.84	278-281-294-291	0.99
67-70-83-80	1.23	171-174-187-184	0.17	275-278-291-288	1.25
83-86-99-96	0.95	187-190-203-200	-0.62	291-294-307-304	0.74
80-83-96-93	1.08	184-187-200-197	0.35	288-291-304-301	1.21
96-99-112-109	0.39	200-203-216-213	-0.19	304-307-8-5	0.57
93-96-109-106	0.82	197-200-213-210	0.57	301-304-5-2	1.20

Table 5.32 Forces at each node for 80 KMPH wind speed for EL-75 AZ-0 position of an Antenna

Wind Force Calculation for V=80KMPH for EL-75 AZ-0 Position						
θ=	0,15,…	θ1=	30.35	θ2=	14.59	
Node No	**Force at each Node (N)**	**Fv=F*Cos(θ1,θ2) (N)**	**Fr=F*Sin(θ1,θ2) (N)**	**X=Fr*Cos(θ) (N)**	**Y=Fr*Sin(θ) (N)**	**Z=Fv (N)**
8	244.05	210.61	123.31	123.31	0.00	210.61
21	278.69	240.50	140.81	136.01	36.44	240.50
34	368.21	317.75	186.04	161.12	93.02	317.75
47	466.78	402.82	235.85	166.78	166.77	402.82
60	532.86	459.84	269.24	134.63	233.16	459.84
73	546.18	471.33	275.97	71.44	266.56	471.33
86	471.58	406.96	238.27	0.01	238.27	406.96
99	286.15	246.93	144.58	-37.41	139.66	246.93
112	43.16	37.25	21.81	-10.90	18.89	37.25
125	-172.11	-148.53	-86.96	61.49	-61.50	-148.53
138	-311.19	-268.55	-157.23	136.16	-78.63	-268.55
151	-370.87	-320.05	-187.39	181.00	-48.52	-320.05
164	-383.66	-331.08	-193.85	193.85	-0.02	-331.08
177	-370.87	-320.05	-187.39	181.01	48.48	-320.05
190	-311.19	-268.55	-157.23	136.18	78.60	-268.55
203	-172.11	-148.53	-86.96	61.50	61.49	-148.53
216	43.16	37.25	21.81	-10.91	-18.89	37.25
229	286.15	246.93	144.58	-37.44	-139.65	246.93
242	471.58	406.96	238.27	-0.03	-238.27	406.96
255	546.18	471.33	275.97	71.39	-266.57	471.33

268	532.86	459.84	269.24	134.58	-233.19	459.84
281	466.78	402.82	235.85	166.74	-166.80	402.82
294	368.21	317.75	186.04	161.10	-93.05	317.75
307	278.69	240.50	140.81	136.01	-36.47	240.50
5	603.70	584.23	152.07	152.07	0.00	584.23
18	639.83	619.20	161.17	155.68	41.71	619.20
31	736.08	712.34	185.41	160.57	92.70	712.34
44	844.75	817.51	212.79	150.47	150.46	817.51
57	914.94	885.44	230.47	115.24	199.59	885.44
70	920.78	891.09	231.94	60.04	224.03	891.09
83	817.40	791.04	205.90	0.01	205.90	791.04
96	570.28	551.89	143.65	-37.17	138.76	551.89
109	250.65	242.57	63.14	-31.57	54.68	242.57
122	-35.28	-34.14	-8.89	6.28	-6.28	-34.14
135	-234.18	-226.62	-58.99	51.08	-29.50	-226.62
148	-329.37	-318.75	-82.97	80.14	-21.48	-318.75
161	-271.88	-263.11	-68.48	68.48	-0.01	-263.11
174	-249.74	-241.69	-62.91	60.77	16.28	-241.69
187	-234.18	-226.62	-58.99	51.09	29.49	-226.62
200	-35.28	-34.14	-8.89	6.29	6.28	-34.14
213	250.65	242.57	63.14	-31.58	-54.67	242.57
226	570.28	551.89	143.65	-37.20	-138.75	551.89
239	817.40	791.04	205.90	-0.03	-205.90	791.04
252	920.78	891.09	231.94	60.00	-224.04	891.09
265	914.94	885.44	230.47	115.20	-199.61	885.44
278	844.75	817.51	212.79	150.44	-150.49	817.51
291	736.08	712.34	185.41	160.56	-92.73	712.34
304	639.83	619.20	161.17	155.67	-41.74	619.20
2	359.65	348.05	90.59	90.59	0.00	348.05
15	361.14	349.50	90.97	87.87	23.54	349.50
28	367.87	356.01	92.66	80.25	46.33	356.01
41	377.97	365.78	95.21	67.32	67.32	365.78
54	382.08	369.76	96.24	48.12	83.35	369.76
67	374.60	362.52	94.36	24.43	91.14	362.52
80	345.82	334.67	87.11	0.00	87.11	334.67
93	284.13	274.97	71.57	-18.52	69.13	274.97
106	207.49	200.80	52.27	-26.13	45.26	200.80
119	136.83	132.42	34.47	-24.37	24.37	132.42
132	77.01	74.53	19.40	-16.80	9.70	74.53
145	41.50	40.16	10.45	-10.10	2.71	40.16
158	111.78	108.18	28.16	-28.16	0.00	108.18
171	121.13	117.22	30.51	-29.47	-7.89	117.22
184	77.01	74.53	19.40	-16.80	-9.70	74.53
197	136.83	132.42	34.47	-24.37	-24.37	132.42
210	207.49	200.80	52.27	-26.14	-45.26	200.80
223	284.13	274.97	71.57	-18.53	-69.13	274.97
236	345.82	334.67	87.11	-0.01	-87.11	334.67
249	374.60	362.52	94.36	24.41	-91.15	362.52
262	382.08	369.76	96.24	48.11	-83.36	369.76
275	377.97	365.78	95.21	67.31	-67.33	365.78
288	367.87	356.01	92.66	80.24	-46.35	356.01
301	361.14	349.50	90.97	87.87	-23.56	349.50

Table 5.33 Maximum Nodal Displacements for 80 KMPH wind speed for EL-75 AZ-0 position of an Antenna

		Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	138	3 DL+WL	**0.546**	0.024	0.796	0.966	0	0	0
Max Y	86	3 DL+WL	0.484	**0.249**	0.607	0.815	0	0	0
Max Z	164	3 DL+WL	0.532	0.004	**0.926**	1.067	0	0	0
Max Rst	164	3 DL+WL	0.532	0.004	0.926	**1.067**	0	0	0

Table 5.34 Maximum Stresses for 80 KMPH wind speed for EL-75 AZ-0 position of an Antenna

			Max Compressive			**Max Tensile**		
Beam	**L/C**	**Length mm**	**Stress N/mm2**	**Dist mm**	**Corner**	**Stress N/mm2**	**Dist mm**	**Corner**
93	1 BACKUP	926.54	2.74	0.00	1.00			
461	1 BACKUP	926.54	2.74	0.00	2.00			
185	1 BACKUP	926.54				-2.99	0.00	1.00
369	1 BACKUP	926.54				-2.99	0.00	1.00
93	2 WIND	926.54	2.70	0.00	1.00	0.00	0.00	0.00
99	2 WIND	936.16				-3.73	0.00	1.00
467	3 DL+WL	936.16	5.43	0.00	1.00	-3.64	936.16	3.00
122	3 DL+WL	936.17	5.35	0.00	1.00	-3.78	936.17	1.00

Table 5.35 RMS for 80 KMPH wind speed for EL-75 AZ-0 position of an Antenna

Node No	**Resultant Displacement Δ**	**Δ average**	**Δ-Δ average**	**(Δ-Δ average)^2**
2	0.00	0.40	-0.40	0.16
5	0.31	0.40	-0.09	0.01
8	0.59	0.40	0.19	0.04
15	0.00	0.40	-0.40	0.16
18	0.33	0.40	-0.07	0.00
21	0.64	0.40	0.24	0.06
28	0.00	0.40	-0.40	0.16
31	0.39	0.40	-0.01	0.00
34	0.75	0.40	0.35	0.12
41	0.00	0.40	-0.40	0.16
44	0.45	0.40	0.05	0.00
47	0.86	0.40	0.46	0.22
54	0.00	0.40	-0.40	0.16
57	0.48	0.40	0.08	0.01
60	0.93	0.40	0.53	0.28
67	0.00	0.40	-0.40	0.16
70	0.48	0.40	0.08	0.01
73	0.90	0.40	0.50	0.25
80	0.00	0.40	-0.40	0.16
83	0.44	0.40	0.04	0.00
86	0.82	0.40	0.42	0.17
93	0.00	0.40	-0.40	0.16
96	0.34	0.40	-0.06	0.00

99	0.67	0.40	0.27	0.07
106	0.00	0.40	-0.40	0.16
109	0.24	0.40	-0.16	0.03
112	0.55	0.40	0.15	0.02
119	0.00	0.40	-0.40	0.16
122	0.30	0.40	-0.10	0.01
125	0.76	0.40	0.36	0.13
132	0.00	0.40	-0.40	0.16
135	0.40	0.40	0.00	0.00
138	0.97	0.40	0.57	0.32
145	0.00	0.40	-0.40	0.16
148	0.45	0.40	0.05	0.00
151	1.06	0.40	0.66	0.44
158	0.00	0.40	-0.40	0.16
161	0.45	0.40	0.05	0.00
164	1.07	0.40	0.67	0.45
171	0.00	0.40	-0.40	0.16
174	0.43	0.40	0.03	0.00
177	1.04	0.40	0.64	0.41
184	0.00	0.40	-0.40	0.16
187	0.40	0.40	0.00	0.00
190	0.96	0.40	0.56	0.31
197	0.00	0.40	-0.40	0.16
200	0.30	0.40	-0.10	0.01
203	0.77	0.40	0.37	0.13
210	0.00	0.40	-0.40	0.16
213	0.24	0.40	-0.16	0.02
216	0.55	0.40	0.15	0.02
223	0.00	0.40	-0.40	0.16
226	0.35	0.40	-0.05	0.00
229	0.67	0.40	0.27	0.07
236	0.00	0.40	-0.40	0.16
239	0.44	0.40	0.04	0.00
242	0.82	0.40	0.42	0.17
249	0.00	0.40	-0.40	0.16
252	0.48	0.40	0.08	0.01
255	0.91	0.40	0.51	0.26
262	0.00	0.40	-0.40	0.16
265	0.48	0.40	0.08	0.01
268	0.93	0.40	0.53	0.28
275	0.00	0.40	-0.40	0.16
278	0.45	0.40	0.05	0.00
281	0.87	0.40	0.47	0.22
288	0.00	0.40	-0.40	0.16
291	0.39	0.40	-0.01	0.00
294	0.75	0.40	0.35	0.12
301	0.00	0.40	-0.40	0.16
304	0.33	0.40	-0.07	0.00
307	0.64	0.40	0.24	0.06

Based on the formula given in the section 4.3, the RMS for structural deformation is calculated.

RMS = 0.35

5.5.7 EL-90 AZ-0 Position

Table 5.36 Cp values at each panel for 80 KMPH wind speed for EL-90 AZ-0 position of an Antenna

Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.	Portion between Nodes	Cp avg.
5-8-21-18	0.22	109-112-125-122	-0.51	213-216-229-226	-0.15
2-5-18-15	0.40	106-109-122-119	-0.18	210-213-226-223	0.00
18-21-34-31	0.28	122-125-138-135	-0.92	226-229-242-239	0.09
15-18-31-28	0.41	119-122-135-132	-0.30	223-226-239-236	0.18
31-34-47-44	0.37	135-138-151-148	-1.05	239-242-255-252	0.34
28-31-44-41	0.41	132-135-148-145	-0.38	236-239-252-249	0.31
44-47-60-57	0.42	148-151-164-161	-1.05	252-255-268-265	0.43
41-44-57-54	0.40	145-148-161-158	-0.43	249-252-265-262	0.37
57-60-73-70	0.43	161-164-177-174	-1.05	265-268-281-278	0.42
54-57-70-67	0.37	158-161-174-171	0.17	262-265-278-275	0.40
70-73-86-83	0.34	174-177-190-187	-1.05	278-281-294-291	0.37
67-70-83-80	0.31	171-174-187-184	-0.38	275-278-291-288	0.41
83-86-99-96	0.09	187-190-203-200	-0.92	291-294-307-304	0.28
80-83-96-93	0.18	184-187-200-197	-0.30	288-291-304-301	0.41
96-99-112-109	-0.15	200-203-216-213	-0.51	304-307-8-5	0.22
93-96-109-106	0.00	197-200-213-210	-0.18	301-304-5-2	0.40

Table 5.37 Forces at each node for 80 KMPH wind speed for EL-90 AZ-0 position of an Antenna

Wind Force Calculation for V=80KMPH for EL-90 AZ-0 Position						
θ=	0,15,…	θ1=	30.35	θ2=	14.59	
Node No	**Force at each Node (N)**	**Fv=F*Cos(θ1,θ2)**	**Fr=F*Sin(θ1,θ2)**	**X=Fr*Cos(θ)**	**Y=Fr*Sin(θ)**	**Z=Fv**
8	91.65	79.09	46.31	46.31	0.00	79.09
21	106.04	91.51	53.58	51.75	13.87	91.51
34	139.08	120.02	70.27	60.86	35.13	120.02
47	168.92	145.77	85.35	60.35	60.35	145.77
60	180.64	155.89	91.27	45.64	79.04	155.89
73	161.99	139.79	81.85	21.19	79.06	139.79
86	91.12	78.63	46.04	0.00	46.04	78.63
99	-12.26	-10.58	-6.19	1.60	-5.98	-10.58
112	-141.21	-121.86	-71.35	35.67	-61.79	-121.86
125	-304.26	-262.57	-153.73	108.70	-108.71	-262.57
138	-417.76	-360.51	-211.08	182.79	-105.55	-360.51
151	-447.07	-385.80	-225.89	218.19	-58.48	-385.80
164	-448.67	-387.18	-226.70	226.70	-0.02	-387.18
177	-447.07	-385.80	-225.89	218.20	58.44	-385.80
190	-417.76	-360.51	-211.08	182.81	105.52	-360.51
203	-304.26	-262.57	-153.73	108.72	108.69	-262.57
216	-141.21	-121.86	-71.35	35.68	61.78	-121.86
229	-12.26	-10.58	-6.19	1.60	5.98	-10.58
242	91.12	78.63	46.04	-0.01	-46.04	78.63
255	161.99	139.79	81.85	21.17	-79.06	139.79
268	180.64	155.89	91.27	45.62	-79.05	155.89
281	168.92	145.77	85.35	60.34	-60.36	145.77

294	139.08	120.02	70.27	60.85	-35.15	120.02
307	106.04	91.51	53.58	51.75	-13.88	91.51
5	212.03	205.20	53.41	53.41	0.00	205.20
18	227.17	219.84	57.22	55.27	14.81	219.84
31	260.95	252.54	65.73	56.93	32.87	252.54
44	289.67	280.33	72.97	51.60	51.59	280.33
57	296.16	286.61	74.60	37.30	64.61	286.61
70	263.30	254.81	66.32	17.17	64.06	254.81
83	163.65	158.37	41.22	0.00	41.22	158.37
96	14.66	14.19	3.69	-0.96	3.57	14.19
109	-167.38	-161.98	-42.16	21.08	-36.51	-161.98
122	-374.55	-362.47	-94.35	66.71	-66.72	-362.47
135	-519.08	-502.34	-130.75	113.23	-65.38	-502.34
148	-567.82	-549.51	-143.03	138.15	-37.03	-549.51
161	-486.80	-471.10	-122.62	122.62	-0.01	-471.10
174	-478.85	-463.41	-120.62	116.51	31.21	-463.41
187	-519.08	-502.34	-130.75	113.24	65.36	-502.34
200	-374.55	-362.47	-94.35	66.72	66.70	-362.47
213	-167.38	-161.98	-42.16	21.09	36.51	-161.98
226	14.66	14.19	3.69	-0.96	-3.57	14.19
239	163.65	158.37	41.22	-0.01	-41.22	158.37
252	263.30	254.81	66.32	17.16	-64.07	254.81
265	296.16	286.61	74.60	37.29	-64.61	286.61
278	289.67	280.33	72.97	51.59	-51.60	280.33
291	260.95	252.54	65.73	56.92	-32.88	252.54
304	227.17	219.84	57.22	55.27	-14.82	219.84
2	120.38	116.50	30.32	30.32	0.00	116.50
15	121.13	117.22	30.51	29.47	7.90	117.22
28	121.88	117.95	30.70	26.59	15.35	117.95
41	120.76	116.86	30.42	21.51	21.51	116.86
54	115.52	111.80	29.10	14.55	25.20	111.80
67	101.31	98.05	25.52	6.61	24.65	98.05
80	72.53	70.19	18.27	0.00	18.27	70.19
93	26.92	26.05	6.78	-1.75	6.55	26.05
106	-26.17	-25.33	-6.59	3.30	-5.71	-25.33
119	-70.28	-68.02	-17.70	12.52	-12.52	-68.02
132	-101.31	-98.05	-25.52	22.10	-12.76	-98.05
145	-120.76	-116.86	-30.42	29.38	-7.88	-116.86
158	-38.13	-36.90	-9.61	9.61	0.00	-36.90
171	-31.78	-30.75	-8.00	7.73	2.07	-30.75
184	-101.31	-98.05	-25.52	22.10	12.76	-98.05
197	-70.28	-68.02	-17.70	12.52	12.52	-68.02
210	-26.17	-25.33	-6.59	3.30	5.71	-25.33
223	26.92	26.05	6.78	-1.76	-6.55	26.05
236	72.53	70.19	18.27	0.00	-18.27	70.19
249	101.31	98.05	25.52	6.60	-24.65	98.05
262	115.52	111.80	29.10	14.55	-25.20	111.80
275	120.76	116.86	30.42	21.50	-21.51	116.86
288	121.88	117.95	30.70	26.58	-15.35	117.95
301	121.13	117.22	30.51	29.47	-7.90	117.22

Table 5.38 Maximum Nodal Displacements for 80 KMPH wind speed for EL-90 AZ-0 position of an Antenna

		Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	138	3 DL+WL	**0.518**	0.016	0.917	1.054	0	0	0
Max Y	277	3 DL+WL	0.189	**0.15**	0.127	0.273	0	0	0
Max Z	151	3 DL+WL	0.514	0.008	**0.993**	1.118	0	0	0
Max Rst	151	3 DL+WL	0.514	0.008	0.993	**1.118**	0	0	0

Table 5.39 Maximum Stresses for 80 KMPH wind speed for EL-90 AZ-0 position of an Antenna

			Max Compressive			Max Tensile		
Beam	**L/C**	**Length mm**	**Stress N/mm2**	**Dist mm**	**Corner**	**Stress N/mm2**	**Dist mm**	**Corner**
191	1 BACKUP	936.16	3.39	0.00	2.00			
375	1 BACKUP	936.16	3.39	0.00	1.00			
185	1 BACKUP	926.54				-3.46	0.00	1.00
369	1 BACKUP	926.54				-3.46	0.00	1.00
260	2 WIND	936.17	2.79	0.00	1.00	0.00	0.00	0.00
254	2 WIND	926.55				-2.18	0.00	1.00
237	3 DL+WL	936.16	5.22	0.00	1.00	-4.05	936.16	1.00
260	3 DL+WL	936.17	5.01	0.00	1.00	-4.25	936.17	1.00

Table 5.40 RMS for 80 KMPH wind speed for EL-90 AZ-0 position of an Antenna

Node No	**Resultant Displacement Δ**	**Δ average**	**Δ-Δ average**	**(Δ-Δ average)^2**
2	0.00	0.33	-0.33	0.11
5	0.14	0.33	-0.19	0.04
8	0.41	0.33	0.08	0.01
15	0.00	0.33	-0.33	0.11
18	0.16	0.33	-0.17	0.03
21	0.43	0.33	0.10	0.01
28	0.00	0.33	-0.33	0.11
31	0.19	0.33	-0.14	0.02
34	0.47	0.33	0.14	0.02
41	0.00	0.33	-0.33	0.11
44	0.24	0.33	-0.09	0.01
47	0.50	0.33	0.17	0.03
80	0.00	0.33	-0.33	0.11
83	0.28	0.33	-0.05	0.00
86	0.55	0.33	0.22	0.05
93	0.00	0.33	-0.33	0.11
96	0.24	0.33	-0.09	0.01
99	0.51	0.33	0.19	0.03
106	0.00	0.33	-0.33	0.11

109	0.33	0.33	0.00	0.00
112	0.65	0.33	0.32	0.10
119	0.00	0.33	-0.33	0.11
122	0.44	0.33	0.11	0.01
125	0.88	0.33	0.55	0.30
132	0.00	0.33	-0.33	0.11
135	0.53	0.33	0.20	0.04
138	1.05	0.33	0.73	0.53
145	0.00	0.33	-0.33	0.11
148	0.56	0.33	0.23	0.05
151	1.12	0.33	0.79	0.62
158	0.00	0.33	-0.33	0.11
161	0.55	0.33	0.22	0.05
164	1.11	0.33	0.78	0.61
171	0.00	0.33	-0.33	0.11
174	0.54	0.33	0.22	0.05
177	1.09	0.33	0.76	0.58
184	0.00	0.33	-0.33	0.11
187	0.52	0.33	0.20	0.04
190	1.04	0.33	0.71	0.51
197	0.00	0.33	-0.33	0.11
200	0.44	0.33	0.11	0.01
203	0.87	0.33	0.55	0.30
210	0.00	0.33	-0.33	0.11
213	0.33	0.33	0.00	0.00
216	0.65	0.33	0.32	0.10
223	0.00	0.33	-0.33	0.11
226	0.24	0.33	-0.09	0.01
229	0.51	0.33	0.18	0.03
236	0.00	0.33	-0.33	0.11
239	0.28	0.33	-0.05	0.00
242	0.55	0.33	0.22	0.05
249	0.00	0.33	-0.33	0.11
252	0.29	0.33	-0.04	0.00
255	0.56	0.33	0.23	0.05
262	0.00	0.33	-0.33	0.11
265	0.28	0.33	-0.05	0.00
268	0.51	0.33	0.18	0.03
275	0.00	0.33	-0.33	0.11
278	0.24	0.33	-0.09	0.01
281	0.50	0.33	0.17	0.03
288	0.00	0.33	-0.33	0.11
291	0.19	0.33	-0.14	0.02
294	0.47	0.33	0.14	0.02
301	0.00	0.33	-0.33	0.11
304	0.16	0.33	-0.17	0.03
307	0.43	0.33	0.10	0.01

Based on the formula given in the section 4.3, the RMS for structural deformation is calculated.

RMS = 0.32

5.6 SUMMARY OF RMS VALUES, MAXIMUM DISPLACEMENT & STRESSES FOR DIFFERENT EL-AZ ANGLES

5.6.1 Summary of the RMS Values (Rs) For Structural Deformation for Different EL-AZ Angles of Antenna

Table 5.41 RMS Values for Structural Deformation for Different EL-AZ Angles

RMS Values (Rs) for different EL-AZ Angles			
For V=80KMPH			
Sr. No:	**AZ Angle**	**EL Angle**	**RMS**
1	0	0	0.25
2	0	15	0.27
3	0	30	0.29
4	0	45	0.31
5	0	60	0.29
6	0	75	0.35
7	0	90	0.31

5.6.1.2 Overall RMS Value

RMS value due to (wind load + dead load) R_s = 0.35 (worst case value)
RMS value due to fabrication R_f = 0.50
RMS value due to alignment R_a = 0.50

$\therefore$ Overall RMS = $\sqrt{R_s{}^2 + R_f{}^2 + R_a{}^2}$

= $\sqrt{0.35^2 + 0.50^2 + 0.50^2}$

= 0.79 < 1 **Hence O.K.**

5.6.2 Summary of Maximum Nodal Displacements For Different EL-AZ Angles of Antenna for Wind Speed of 80 KMPH

Table 5.42 Summary of Maximum Nodal Displacements for Different EL-AZ Angles

Maximum Nodal Displacements

			Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
		Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
EL-0 AZ-0	Max X	267	3 DL+WL	**0.283**	0.135	0.445	0.545	0	0	0
	Max Y	209	3 DL+WL	0.253	**0.16**	0.485	0.57	0	0	0
	Max Z	8	3 DL+WL	0.272	0.006	**0.629**	0.685	0	0	0
	Max Rst	8	3 DL+WL	0.272	0.006	0.629	**0.685**	0	0	0

			Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
		Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
EL-15 AZ-0	Max X	151	3 DL+WL	**0.234**	0.033	0.715	0.753	0	0	0
	Max Y	73	3 DL+WL	0.064	**0.175**	0.58	0.609	0	0	0
	Max Z	151	3 DL+WL	0.234	0.033	**0.715**	0.753	0	0	0
	Max Rst	151	3 DL+WL	0.234	0.033	0.715	**0.753**	0	0	0

			Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
		Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
EL-30 AZ-0	Max X	138	3 DL+WL	**0.278**	0.076	0.781	0.833	0	0	0
	Max Y	59	3 DL+WL	0.1	**0.188**	0.492	0.536	0	0	0
	Max Z	190	3 DL+WL	0.27	0.09	**0.781**	0.831	0	0	0
	Max Rst	138	3 DL+WL	0.278	0.076	0.781	**0.833**	0	0	0

			Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
		Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
EL-45 AZ-0	Max X	151	3 DL+WL	**0.344**	0.026	0.886	0.95	0	0	0
	Max Y	59	3 DL+WL	0.158	**0.199**	0.462	0.527	0	0	0
	Max Z	164	3 DL+WL	0.342	0.008	**0.89**	0.953	0	0	0
	Max Rst	164	3 DL+WL	0.342	0.008	0.89	**0.953**	0	0	0

			Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
		Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
EL-60 AZ-0	Max X	111	3 DL+WL	**0.307**	0.147	0.652	0.736	0	0	0
	Max Y	59	3 DL+WL	0.195	**0.215**	0.459	0.544	0	0	0
	Max Z	203	3 DL+WL	0.289	0.102	**0.734**	0.796	0	0	0
	Max Rst	125	3 DL+WL	0.3	0.091	0.734	**0.798**	0	0	0

			Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
		Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
EL-75 AZ-0	Max X	138	3 DL+WL	**0.546**	0.024	0.796	0.966	0	0	0
	Max Y	86	3 DL+WL	0.484	**0.249**	0.607	0.815	0	0	0
	Max Z	164	3 DL+WL	0.532	0.004	**0.926**	1.067	0	0	0
	Max Rst	164	3 DL+WL	0.532	0.004	0.926	**1.067**	0	0	0

			Horizontal	Horizontal	Vertical	Horizontal	Resultant	Rotational		
		Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
EL-90 AZ-0	Max X	138	3 DL+WL	**0.518**	0.016	0.917	1.054	0	0	0
	Max Y	277	3 DL+WL	0.189	**0.15**	0.127	0.273	0	0	0
	Max Z	151	3 DL+WL	0.514	0.008	**0.993**	1.118	0	0	0
	Max Rst	151	3 DL+WL	0.514	0.008	0.993	**1.118**	0	0	0

5.6.3 Summary of Maximum Stresses for Different EL-AZ Angles of Antenna for Wind Speed of 80 KMPH

Table 5.43 Maximum Stresses for different EL-AZ angles of antenna for Wind Speed of 80 KMPH

FOR 80 KMPH WIND SPEED

				Max Compressive			Max Tensile		
	Beam	L/C	Length mm	Stress	Dist mm	Corner	Stress	Dist mm	Corner
	93	1 BACKUP	926.544	2.965	0	1	0	0	0
	461	1 BACKUP	926.544	2.965	0	2	0	0	0
	185	1 BACKUP	926.544	0	0	0	-2.965	0	1
EL-0 AZ-0	369	1 BACKUP	926.544	0	0	0	-2.965	0	1
	62	2 WIND	1157.698	2.055	1157.698	2	0	0	0
	99	2 WIND	936.162	0	0	0	-2.821	0	1
	467	3 DL+WL	936.162	4.89	0	1	-3.137	936.162	3
	187	3 DL+WL	926.537	2.046	0	1	-3.408	926.537	1

				Max Compressive			Max Tensile		
	Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
	191	1 BACKUP	936.162	1.624	0	1			
	375	1 BACKUP	936.162	1.624	0	1			
EL-15 AZ-0	129	1 BACKUP	1180.574				-1.385	0	1
	451	1 BACKUP	1180.574				-1.385	0	1
	269	2 WIND	1157.691	2.629	1157.691	1			
	260	2 WIND	936.166				-3.665	0	1
	237	3 DL+WL	936.162	4.441	0	1	-4.16	936.162	1
	191	3 DL+WL	936.162	4.361	0	1	-4.215	936.162	1

				Max Compressive			Max Tensile		
	Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
	191	1 BACKUP	936.162	2.08	0	2			
	375	1 BACKUP	936.162	2.08	0	1			
EL-30 AZ-0	208	1 BACKUP	926.549				-1.92	0	1
	346	1 BACKUP	926.549				-1.92	0	1
	246	2 WIND	1157.698	2.739	1157.698	1			
	352	2 WIND	936.167				-3.867	0	1
	375	3 DL+WL	936.162	4.96	0	1	-4.488	936.162	1
	214	3 DL+WL	936.167	4.835	0	1	-4.529	936.167	1

				Max Compressive			Max Tensile		
	Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
	191	1 BACKUP	936.162	2.395	0	2			
	375	1 BACKUP	936.162	2.395	0	1			
EL-45 AZ-0	185	1 BACKUP	926.544				-2.445	0	1
	369	1 BACKUP	926.544				-2.445	0	1
	246	2 WIND	1157.698	2.992	1157.698	1			
	260	2 WIND	936.166				-4.181	0	1
	375	3 DL+WL	936.162	5.449	0	1	-4.733	936.162	1
	214	3 DL+WL	936.167	5.258	0	1	-4.779	936.167	2

				Max Compressive			Max Tensile		
	Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
	191	1 BACKUP	936.162	2.547	0	2			
	375	1 BACKUP	936.162	2.547	0	1			
EL-60 AZ-0	185	1 BACKUP	926.544				-2.814	0	1
	369	1 BACKUP	926.544				-2.814	0	1
	177	2 WIND	1157.691	2.64	1157.691	1			
	168	2 WIND	936.166				-3.924	0	1
	398	3 DL+WL	936.166	5.555	0	1	-4.486	936.166	2
	191	3 DL+WL	936.162	5.422	0	1	-4.515	936.162	2

				Max Compressive			Max Tensile		
	Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
	93	1 BACKUP	926.544	2.736	0	1			
	461	1 BACKUP	926.544	2.736	0	2			
EL-75 AZ-0	185	1 BACKUP	926.544				-2.991	0	1
	369	1 BACKUP	926.544				-2.991	0	1
	93	2 WIND	926.544	2.699	0	1			
	99	2 WIND	936.162				-3.731	0	1
	467	3 DL+WL	936.162	5.432	0	1	-3.639	936.162	3
	122	3 DL+WL	936.166	5.347	0	1	-3.782	936.166	1

				Max Compressive			Max Tensile		
	Beam	L/C	Length mm	Stress N/mm2	Dist mm	Corner	Stress N/mm2	Dist mm	Corner
	191	1 BACKUP	936.162	3.387	0	2			
	375	1 BACKUP	936.162	3.387	0	1			
EL-90 AZ-0	185	1 BACKUP	926.544				-3.459	0	1
	369	1 BACKUP	926.544				-3.459	0	1
	260	2 WIND	936.166	2.793	0	1			
	254	2 WIND	926.548				-2.181	0	1
	237	3 DL+WL	936.162	5.221	0	1	-4.049	936.162	1
	260	3 DL+WL	936.166	5.009	0	1	-4.253	936.166	1

6. THEORETICAL ASPECTS OF FE MODELING

6.1 GENERAL

Finite element method is a powerful tool in structural analysis of simple to complicated structural geometries. In recent years with the coming of fast computers the job of performing finite element analysis of a complicated geometry has become very easy. STAAD Pro 2004 is one of the powerful software tools for this kind of analysis. Many complicated geometry can be analyzed easily using STAAD Pro 2004. This chapter describes the finite elements and techniques used to model and study the behavior of the structure.

6.2 ELEMENTS USED FOR THE MODELLING

6.2.1 Solid Element

Solid elements enable the solution of structural problems involving general three dimensional stresses. There is a class of problems such as stress distribution in concrete dams, soil and rock strata where finite element analysis using solid elements provide a powerful tool.

6.2.2 Plate and Shell Element

The Plate/Shell finite element is based on the hybrid element formulation. The element can be 3-noded (triangular) or 4-noded (quadrilateral). If all the four nodes of a quadrilateral element do not lie on one plane, it is advisable to model them as triangular elements. The thickness of the element may be different from one node to another.

6.2.3 Beam Element

The beam element is assumed to be straight 2 node element of constant doubly symmetric cross-section. The beam is capable of resisting axial force, bending moments about the two principal axes (coincident with the beam local axes), and twisting moment about the centroidal axis. The stiffness properties for a uniform beam element are derived from the differential equations for beam displacements in the engineering beam theory. Lateral deflection is the sum of displacement due to bending strain and the displacement due to shearing strain (computed using effective shear area and G).

6.3 SOLID ELEMENT

Solid elements enable the solution of structural problems involving general three dimensional stresses. There is a class of problems such as stress distribution in concrete dams, soil and rock strata where finite element analysis using solid elements provide a powerful tool.

6.3.1 Theoretical Basis

The solid element used in STAAD is of eight noded isoparametric type. These elements have three translational degrees-of-freedom per node.
By collapsing various nodes together, an eight noded solid element can be degenerated to the following forms with four to seven nodes.

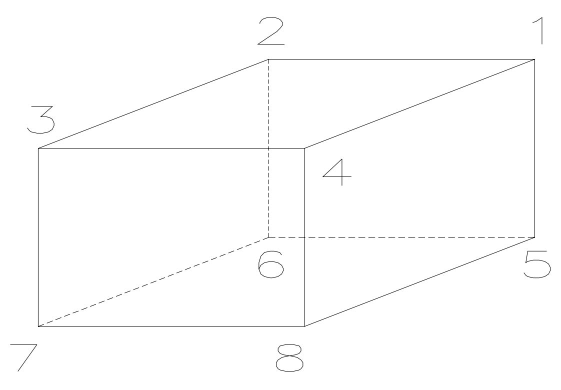


Figure 6.1 8-noded solid element

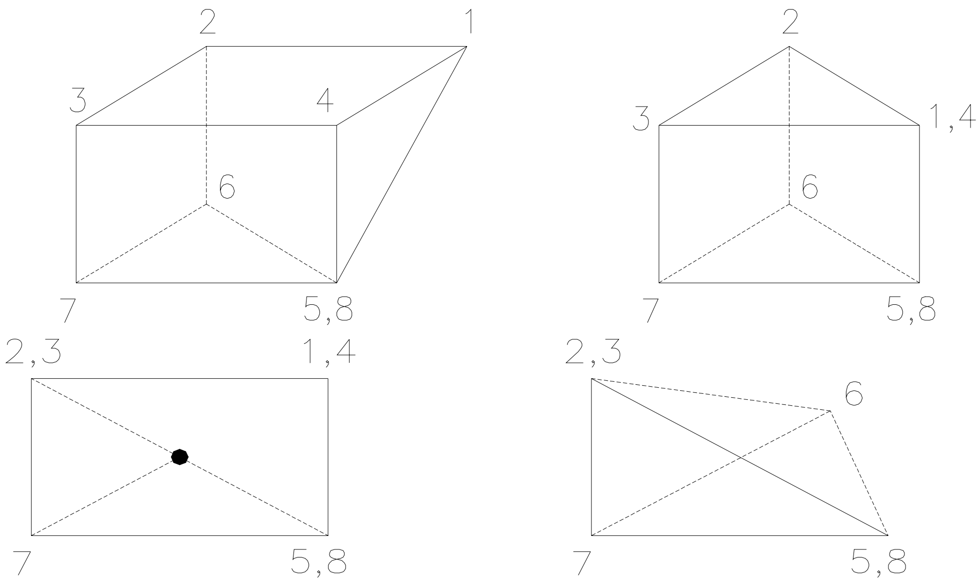


Figure 6.2 Degenerated forms of solid element

The stiffness matrix of the solid element is evaluated by numerical integration with eight Gauss-Legendre points. To facilitate the numerical integration, the geometry of the element is expressed by interpolating functions using natural coordinate system, (r, s, t) of the element with its origin at the center of gravity. The interpolating functions are shown below:

$$x = \sum_{i=1}^{8} hixi, \qquad y = \sum_{i=1}^{8} hiyi, \qquad z = \sum_{i=1}^{8} hizi \tag{6.1}$$

Where x, y and z are the coordinates of any point in the element and xi, yi, zi, i=1......, 8 are the coordinates of nodes defined in the global coordinate system. The interpolation functions hi are defined in the natural coordinate system, (r, s, t). Each of r, s and t varies between -1 and +1. The fundamental property of the unknown interpolation functions hi is that their values in natural coordinate system are unity at node, i, and zero at all other nodes of the element. The element displacements are also interpreted the same way as the geometry. For completeness, the functions are given below:

$$u = \sum_{i=1}^{8} hiui, \qquad v = \sum_{i=1}^{8} hivi, \qquad w = \sum_{i=1}^{8} hiwi \tag{6.2}$$

Where u, v and w are displacements at any point in the element and ui, vi, wi, i=1, 8 are corresponding nodal displacements in the coordinate system used to describe the geometry.

Three additional displacement "bubble" functions which have zero displacements at the surfaces are added in each direction for improved shear performance to form a 33x33 matrix. Static condensation is used to reduce this matrix to a 24x24 matrix at the corner joints.

6.3.2 Local Coordinate System

The local coordinate system used in solid element is the same as the global system as shown below:

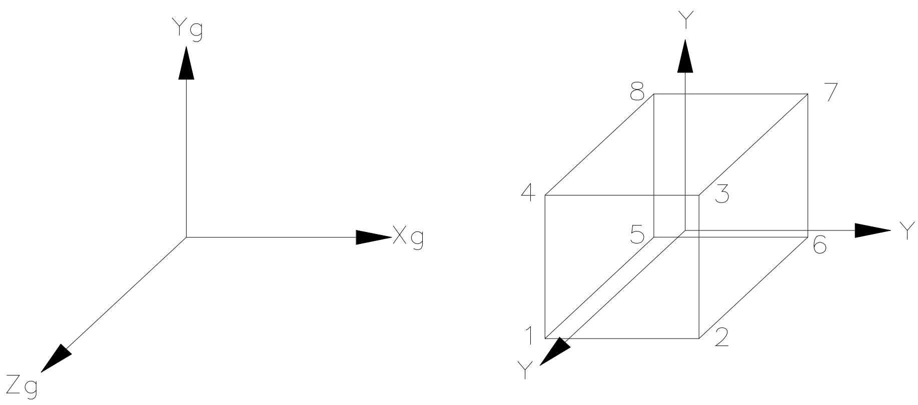


Figure 6.3 Local Coordinate System for solid element

6.3.3 Properties and Constants

Unlike members and shell (plate) elements, no properties are required for solid elements. However, the constants such as modulus of elasticity and Poisson's ratio are to be specified. Also, Density needs to be provided if self weight is included in any load case.

6.3.4 Output of Element Stresses

Element stresses may be obtained at the center and at the joints of the solid element. The items that are printed are:

Normal Stresses: SXX, SYY and SZZ

Shear Stresses : SXY, SYZ and SZX

Principal stresses: S1, S2 and S3.

Von Mises stresses:

$$SIGE = .707\sqrt{(S_1-S_2)^2 + (S_2-S_3)^2 + (S_3-S_1)^2} \qquad (6.3)$$

Direction cosines: 6 direction cosines are printed, following the expression DC, corresponding to the first two principal stress directions.

6.3.5 Solid Element Theoretical Basis

The solid element used in STARDYNE is an eight node isoparametric type or optionally hybrid type. The isoparametric type is the same as in STAAD with the addition of 3 "bubble functions" to improve shear behavior. These elements have three translational degrees-of-freedom per node. By collapsing various nodes together, an eight node solid element can be degenerated to an element with four to seven nodes.

6.3.6 Solid Element Local Coordinate System

The local coordinate system used in solid element is the same as the global system; however stresses may be presented as if JA-JB-JC nodes defined a local system.

6.3.7 Solid Element Properties and Constants

Full 3-D orthotropic properties may be used. Also, Density needs to be provided if self weight is included in any load case.

6.3.8 Output of Solid Element Stresses

Element stresses may be obtained at the center and at the nodes of the solid element. The items that are printed are:

Normal Stresses : SXX, SYY and SZZ

Shear Stresses : SXY, SYZ and SZX

Principal stresses : S1, S2 and S3.

Von Mises stresses : SE

Direction cosines : 6 direction cosines are printed, following the expression DC, corresponding to the first two principal stress directions.

6.3.9 Hybrid Element Formulation, Plate or Solid (STARDYNE)

In the classical displacement formulation, simple polynomials are used to interpolate nodal variables internal to the element. For example, a unit nodal displacement in the x direction induces displacements (£1.0) in the x direction inside of the element. From these interpolated displacements the strains can be found. Then, using the material constants, the element nodal stiffness coefficients and stress matrices can be computed.

In the hybrid formulation two sets of interpolation functions are used. The first to interpolate displacements along the element boundary and the second to interpolate stress fields inside of the element. Consequently, there is a rather complex relationship between the nodal displacements and stresses inside of the element. STARDYNE offers a choice between the classical displacement and the hybrid elements. The QUADH header selects the hybrid quads and CUBEH selects the hybrid cubes.

Hybrid elements, in general, yield slightly better accuracy if they are only slightly distorted from rectangular or parallelogram shapes. If there are areas in the model where severely distorted elements must be used, select the QUADB and CUBEG types.

The classical displacement elements converge to the correct answers "from below". This means that as the finite element mesh gets denser the model gets more flexible and approaches to the correct answers (assuming that loads and boundary conditions are unchanged). The hybrid elements, on the other hand, can converge either from above or below. All of the finite elements in STARDYNE are convergent.

6.4 PLATE AND SHELL ELEMENT

The Plate/Shell finite element is based on the hybrid element formulation. The element can be 3-noded (triangular) or 4-noded (quadrilateral). If all the four nodes of a quadrilateral element do not lie on one plane, it is advisable to model them as triangular elements. The thickness of the element may be different from one node to another.

"Surface structures" such as walls, slabs, plates and shells may be modeled using finite element. For convenience in generation of a finer mesh of plate/shell element within a large area, a MESH GENERATION facility is available.

6.4.1 Geometry Modeling Considerations

The following geometry related modeling rules should be remembered while using the plate/shell element.

1) The program automatically generates a fifth node "O" (center node - see Fig. 6.4) at the element center.

2) While assigning nodes to an element in the input data, it is essential that the nodes be specified either clockwise or counter clockwise (Fig. 6.4). For better efficiency, similar elements should be numbered sequentially.

3) Element aspect ratio should not be excessive. They should be on the order of 1:1, and preferably less than 4:1.

4) Individual elements should not be distorted. Angles between two adjacent element sides should not be much larger than 90 and never larger than 180.

6.4.2 Element Load Specification

Following load specifications are available:

1) Joint loads at element nodes in global directions.

2) Concentrated loads at any user specified point within the element in global or local directions.

3) Uniform pressure on element surface in global or local directions

4) Partial uniform pressure on user specified portion of element surface in global or local directions

5) Linearly varying pressure on element surface in local directions.

6) Temperature load due to uniform increase or decrease of temperature.

7) Temperature load due to difference in temperature between top and bottom surfaces of the element.

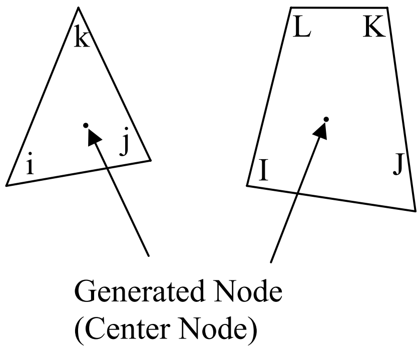


Figure 6.4

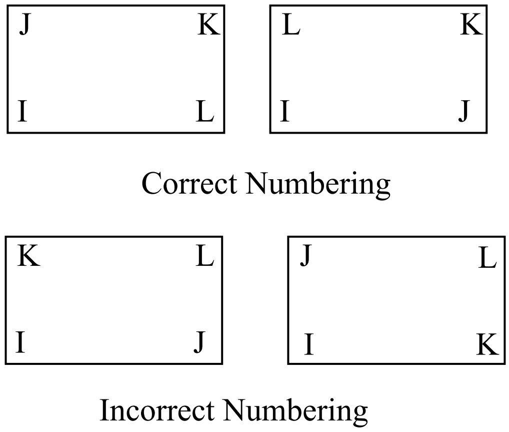


Figure 6.5

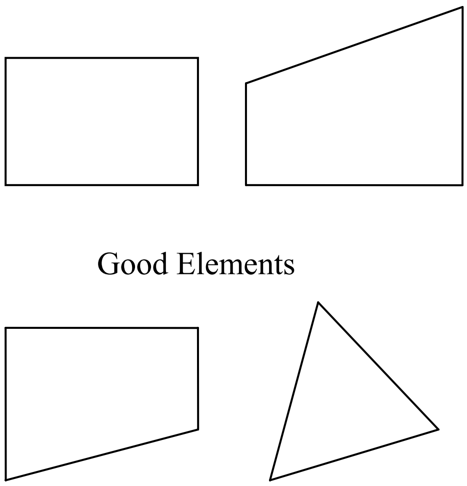


Figure 6.6

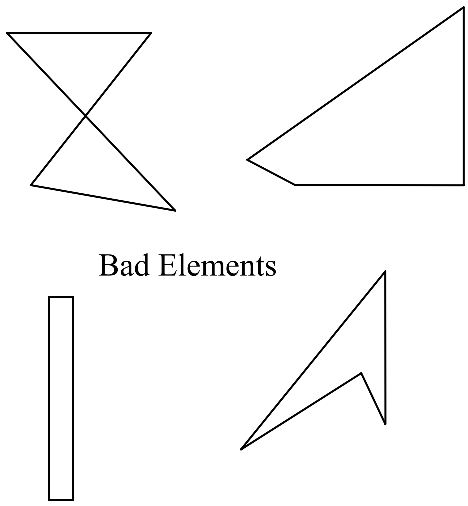
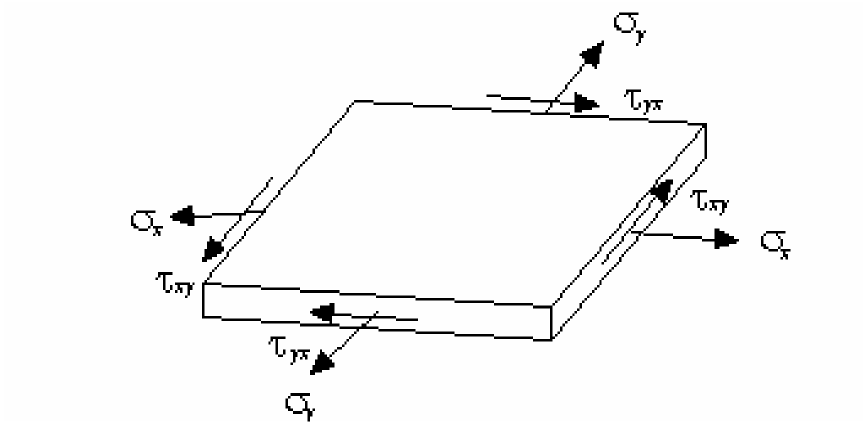


Figure 6.7

6.4.3 Theoretical Basis

The STAAD plate finite element is based on hybrid finite element formulations. A complete quadratic stress distribution is assumed. For plane stress action, the assumed stress distribution is as follows.

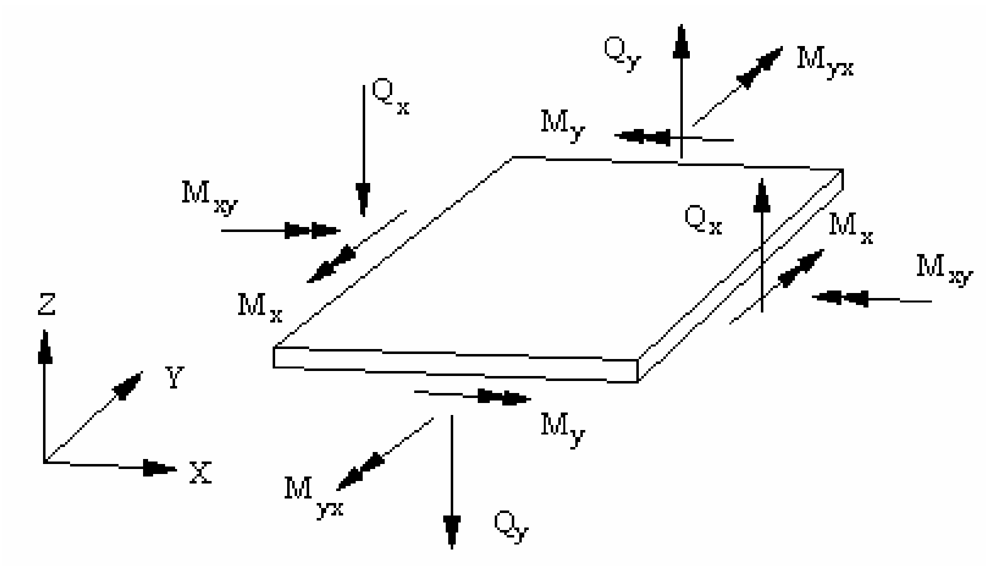


Complete quadratic assumed stress distribution:

$$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{pmatrix}=\begin{bmatrix}1 & x & y & 0 & 0 & 0 & 0 & x^2 & 2xy & y^2 & 0 & 0\\ 0 & 0 & 0 & 1 & x & y & 0 & y^2 & 0 & 0 & x^2 & 2xy\\ 0 & -y & 0 & 0 & 0 & -x & 1 & -2xy & -y^2 & 0 & 0 & -x^2\end{bmatrix}\begin{pmatrix}a_1\\ a_2\\ a_3\\ \vdots\\ \varepsilon\end{pmatrix}$$

a_1 through a_{12} = constants of stress polynomials.

The following quadratic stress distribution is assumed for plate bending action:



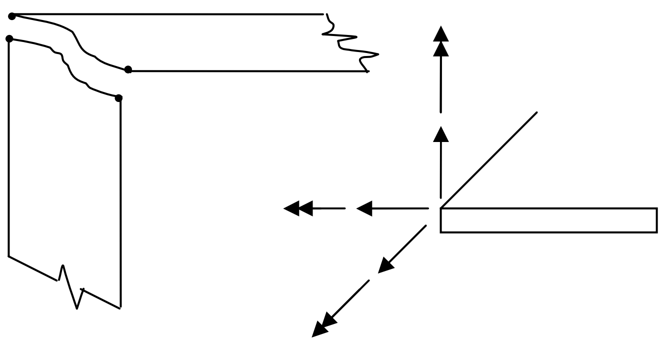
Complete quadratic assumed stress distribution:

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \\ Q_x \\ Q_y \end{Bmatrix} = \begin{bmatrix} 1 & x & y & 0 & 0 & 0 & 0 & 0 & 0 & x^2 & xy & y^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & x & y & 0 & 0 & 0 & 0 & 0 & 0 & x^2 & xy & y^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & -xy & 0 & 0 & 0 & 0 & -xy & x^2 & y^2 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & 0 & 0 & 0 & -x & 0 & 2y \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & -y & 0 & 0 & 0 & x & y & 2x & 0 \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \\ . \\ . \\ a_{17} \end{Bmatrix}$$

a_1 through a_{17} = constants of stress polynomials.

The distinguishing features of this finite element are:

1) Displacement compatibility between the plane stress component of one element and the plate bending component of an adjacent element which is at an angle to the first (see Fig. below) is achieved by the elements. This compatibility requirement is usually ignored in most flat shell/plate elements.



2) The out of plane rotational stiffness from the plane stress portion of each element is usefully incorporated and not treated as a dummy as is usually done in most commonly available commercial software.

3) Despite the incorporation of the rotational stiffness mentioned previously, the elements satisfy the patch test absolutely.

4) These elements are available as triangles and quadrilaterals, with corner nodes only, with each node having six degrees of freedom.

5) These elements are the simplest forms of flat shell/plate elements possible with corner nodes only and six degrees of freedom per node. Yet solutions to sample problems converge rapidly to accurate answers even with a large mesh size.

6) These elements may be connected to plane/space frame members with full displacement compatibility. No additional restraints/releases are required.

7) Out of plane shear strain energy is incorporated in the formulation of the plate bending component. As a result, the elements respond to Poisson boundary conditions which are considered to be more accurate than the customary Kirchoff boundary conditions

8) The plate bending portion can handle thick and thin plates, thus extending the usefulness of the plate elements into a multiplicity of problems. In addition, the thickness of the plate is taken into consideration in calculating the out of plane shear.

9) The plane stress triangle behaves almost on par with the well known linear stress triangle. The triangles of most similar flat shell elements incorporate the constant stress triangle which has very slow rates of convergence. Thus the triangular shell element is very useful in problems with double curvature where the quadrilateral element may not be suitable.

10) Stress retrieval at nodes and at any point within the element.

6.4.4 Element Local Coordinate System

The precise orientation of local coordinates is determined as follows:

1) Designate the midpoints of the four or three element edges IJ, JK, KL, and LI by M, N, O and P respectively.

2) The vector pointing from P to N is defined to be the local x- axis. (In a triangle, this is always parallel to IJ).

3) The cross-product of vectors PN and MO (for a triangle, ON and MK) defines the local z-axis, i.e., z = PN x MO.

4) The cross-product of vectors z and x defines the local y- axis, i.e., y = z x x.

The sign convention of output force and moment resultants is illustrated in Fig. 6.9.

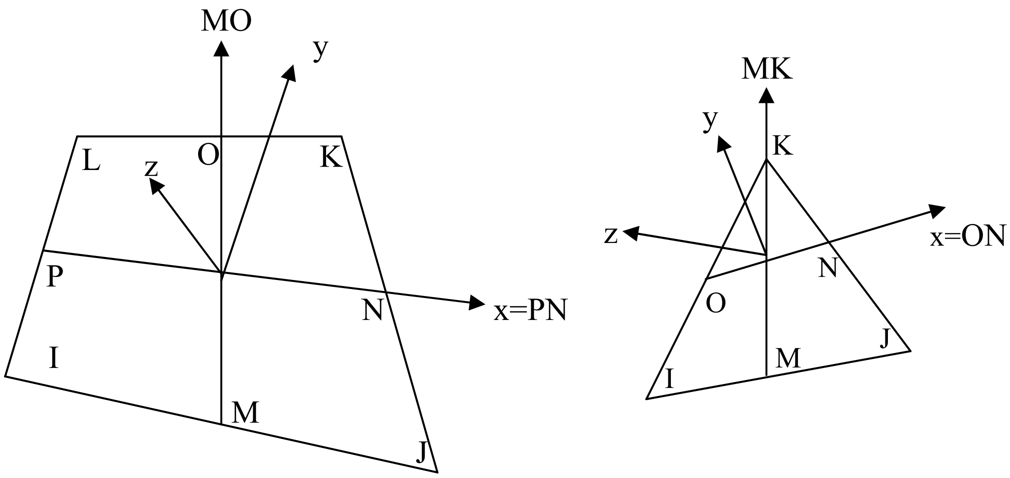


Figure 6.8

6.4.5 Out Put of Element Forces

ELEMENT FORCE outputs are available at the following locations:

A. Center point of the element.

B. All corner nodes of the element.

C. At any user specified point within the element.

Following are the items included in the element stress output.

SQX, SQY	Shear stresses (Force/ unit len./unit thk.)
SX, SY, SXY	Membrane stresses (Force/unit len./unit thk)
MX, MY, MXY	Bending moments per unit width (Moment/unit len.)
SMAX, SMIN	Principal stresses (Force/unit area)
TMAX	Maxim. shear stress (Force/unit area)
ANGLE	Orientation of the principal plane (Degrees)
VONT, VONB	Von Mises stress

$$VM = 0.707\sqrt{(SMAX - SMIN)^2 + SMAX^2 + SMIN^2}$$

Notes:

1. All element stress output is in the local coordinate system. The direction and sense of the element stresses are explained in Fig. 1.13.

2. To obtain element stresses at a specified point within the element, the user must provide the coordinate system for the element. Note that the origin of the local coordinate system coincides with the center node of the element.

3. Principal stresses (SMAX & SMIN), the maximum shear stress (TMAX), the orientation of the principal plane (ANGLE), and the Von Mises stress (VONT & VONB) are also printed for the top and bottom surfaces of the elements. The top and the bottom surfaces are determined on the basis of the direction of the local z-axis.

Sign Convention of Element Forces

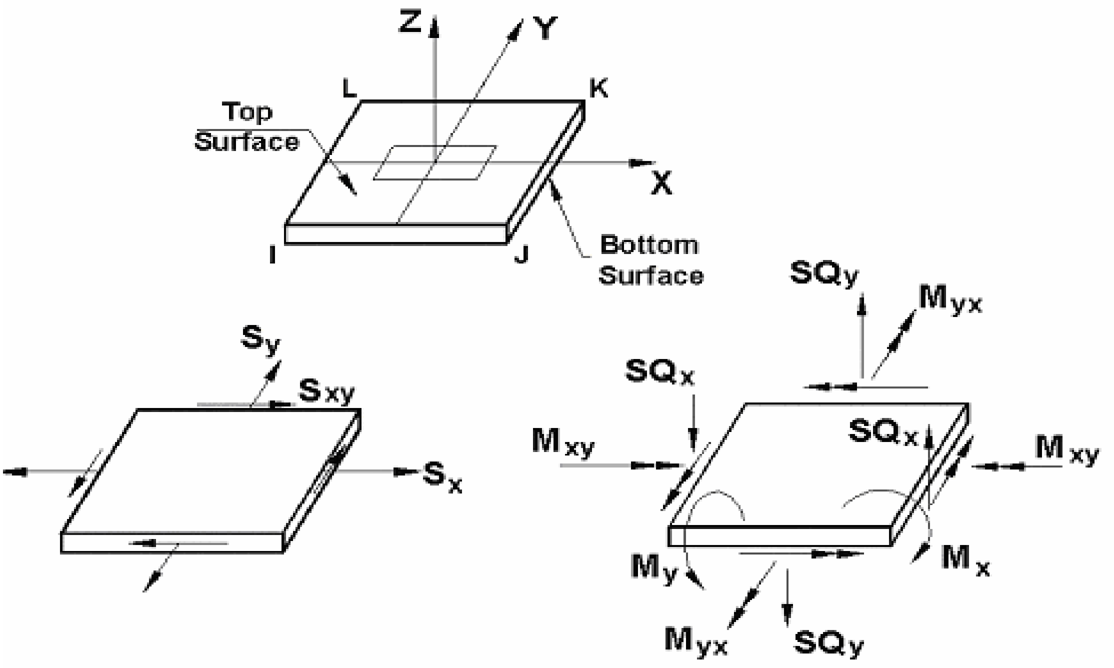
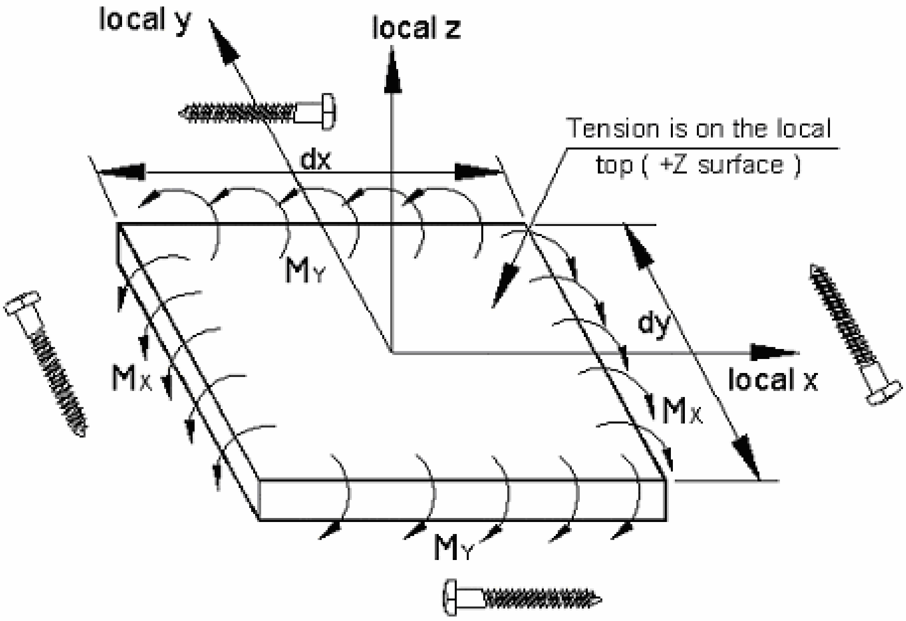
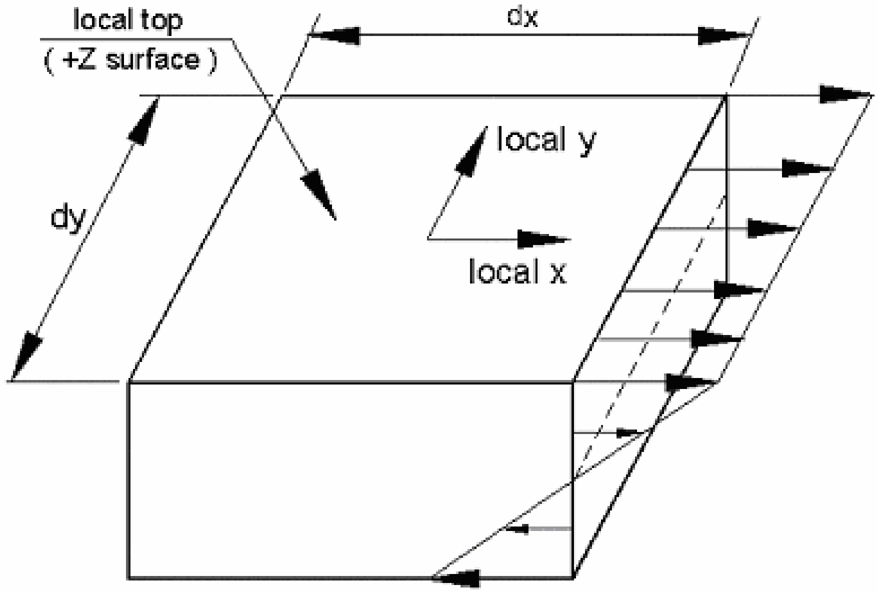


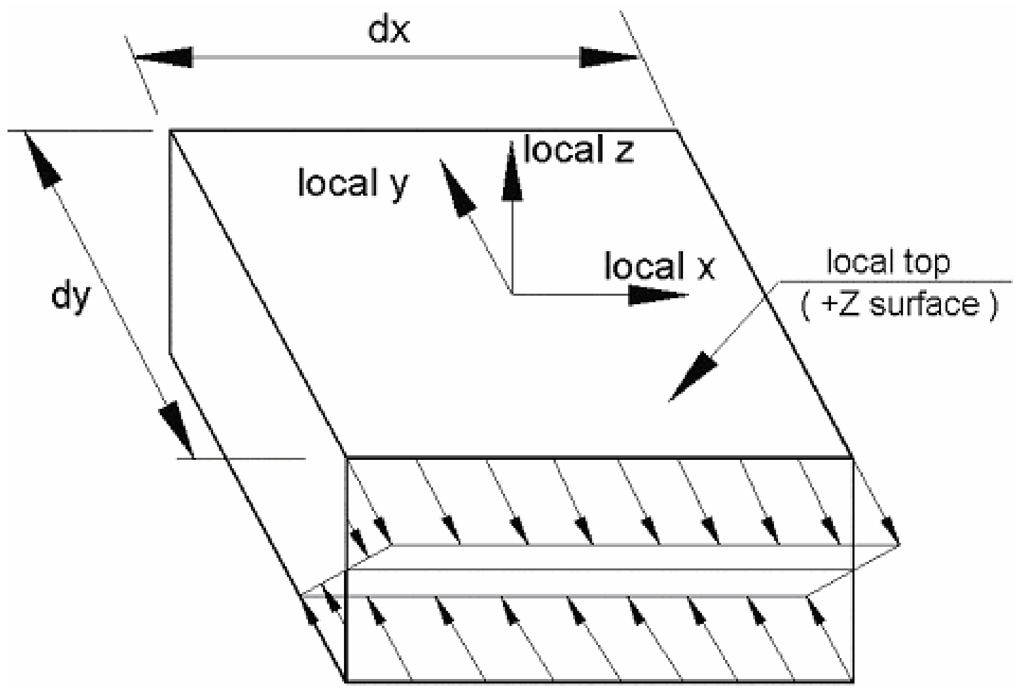
Figure 6.9



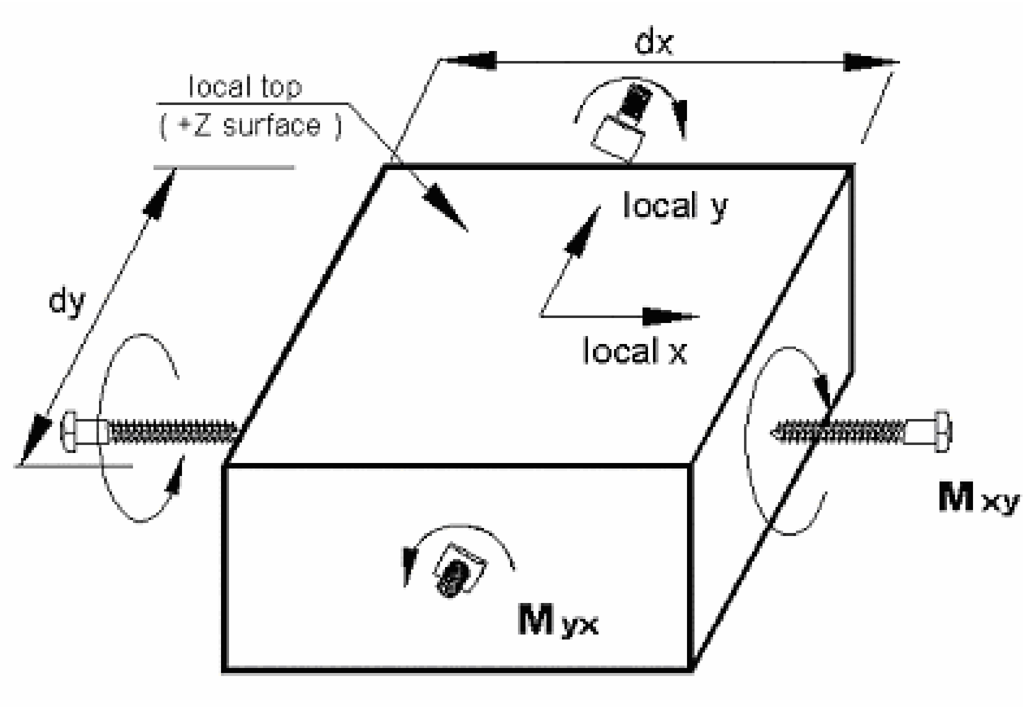
M_x is the Bending Moment on the local x face, the local x-face is the face perpendicular to the local x-axis;
M_y is the Bending Moment on the local y face, the local y-face is the face perpendicular to the local y-axis



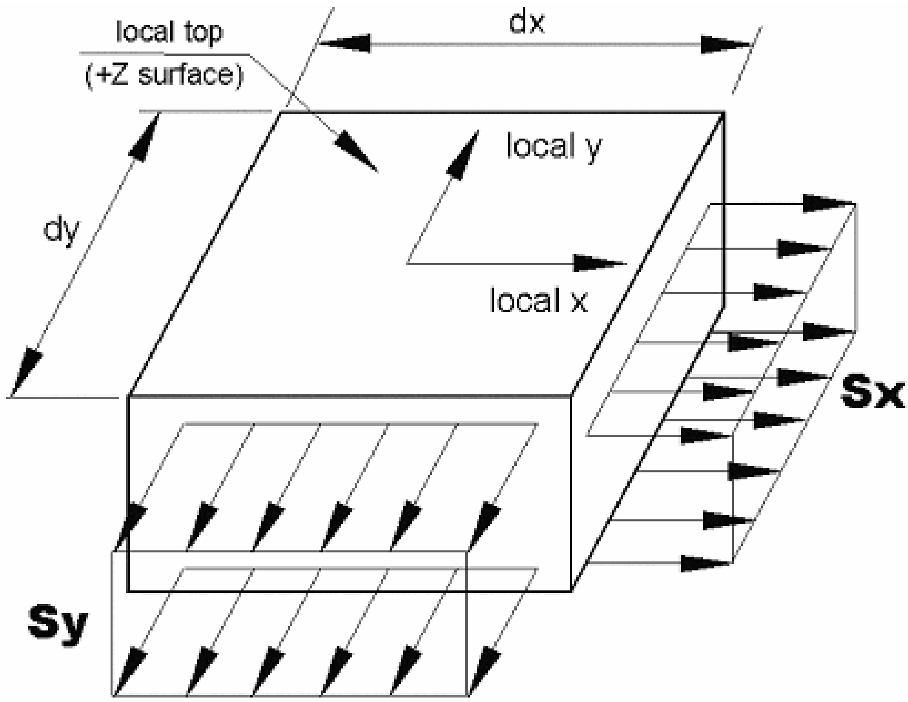
STRESS CAUSED BY M_x



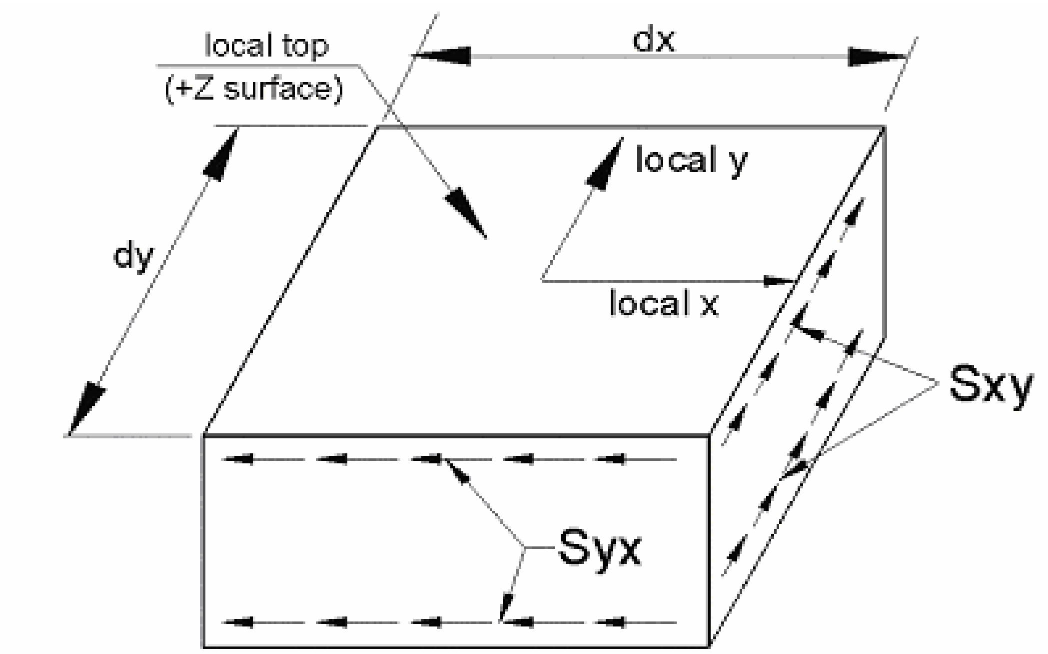
Stress Caused by M_y



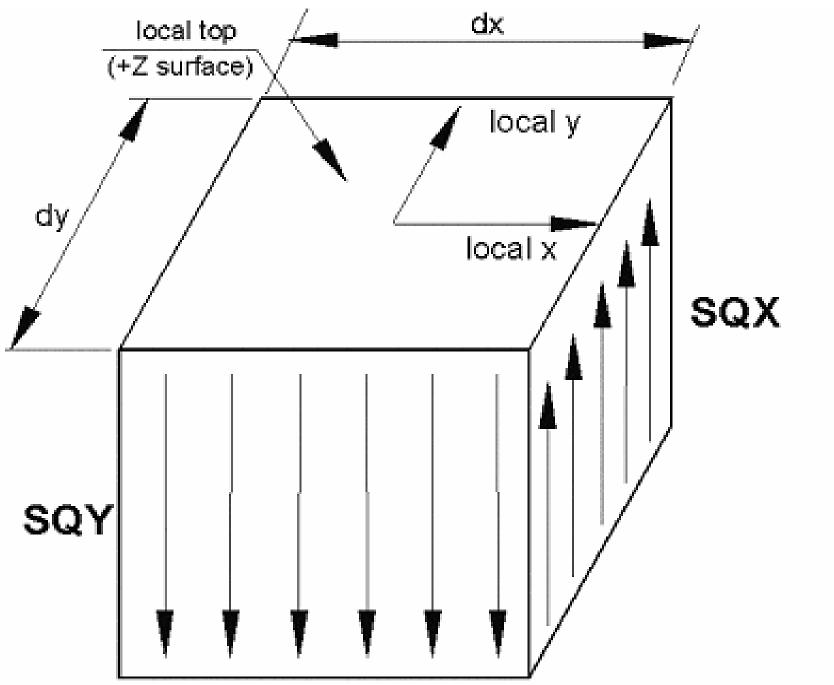
TORSION



Membrane Stresses Sx and Sy



In plane shear stresses Sxy and Syx



Out-of plane shear stresses (SQX and SQY)

Please note the following few restrictions in using the finite element portion of STAAD:

1) Both frame members and finite elements can be used together in a STAAD analysis. The ELEMENT INCIDENCES command must directly follow the MEMBER INCIDENCES input.

2) The self weight of the finite elements is converted to joint loads at the connected nodes and is not used as an element pressure load.

3) Element stresses are printed at the centroid and joints, but not along any edge.

4) In addition to the stresses, the Von Mises stresses at the top and bottom surface of the element are also printed.

6.4.6 Element Numbering

During the generation of element stiffness matrix, the program verifies whether the element is same as the previous one or not. If it is same, repetitive calculations are not performed. The sequence in which the element stiffness matrix is generated is the same as the sequence in which elements are input in element incidences.

Therefore, to save some computing time, similar elements should be numbered sequentially. Figure below shows examples of efficient and non-efficient element numbering.

However the user has to decide between adopting a numbering system which reduces the computation time versus a numbering system which increases the ease of defining the structure geometry.

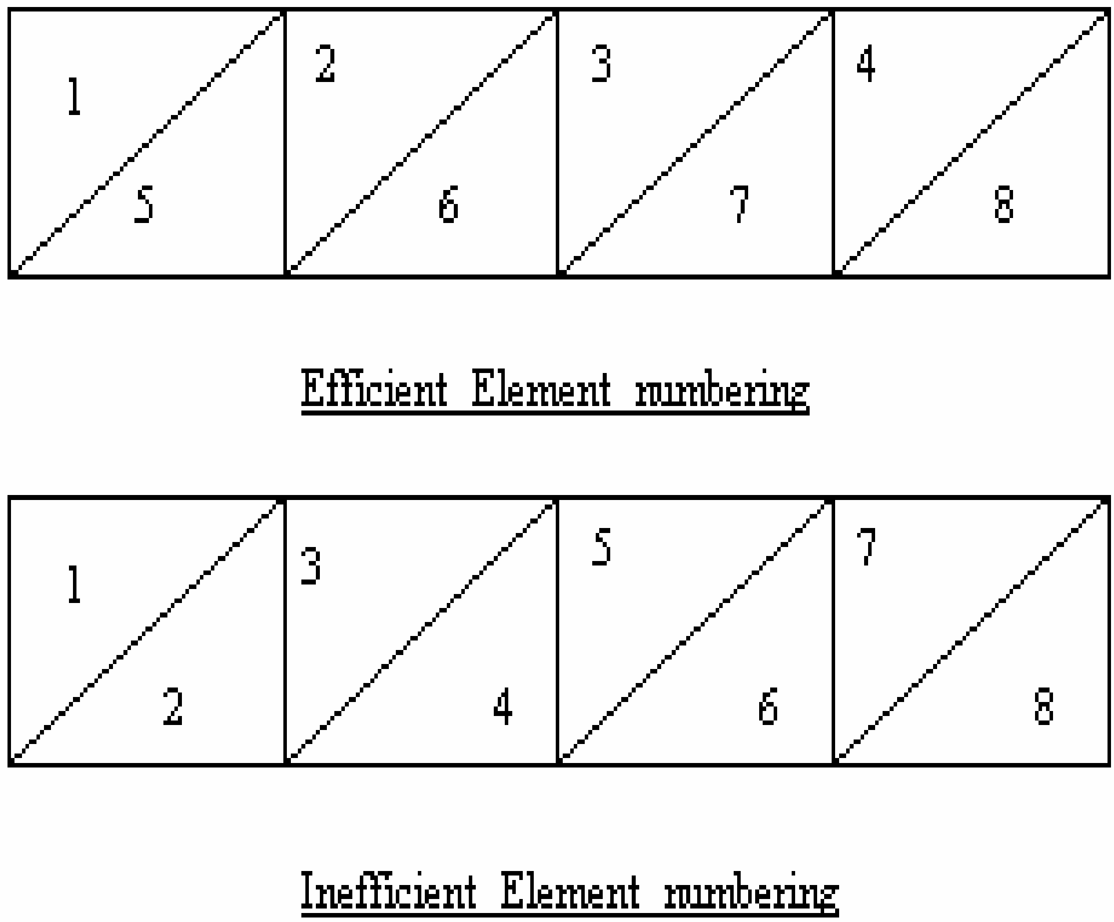


Figure: 6.10 Finite Element Numbering

6.5 BEAM ELEMENT

The beam element is assumed to be straight 2 node element of constant doubly symmetric cross-section. The beam is capable of resisting axial force, bending moments about the two principal axes (coincident with the beam local axes), and twisting moment about the centroidal axis. The stiffness properties for a uniform beam element are derived from the differential equations for beam displacements in the engineering beam theory. Lateral deflection is the sum of displacement due to bending strain and the displacement due to shearing strain (computed using effective shear area and G).

The beam element is really the sum of 4 uncoupled elements, axial, torsion, shear & bending in x-y, and shear & bending in x-z. Any combination can be created via member releases, or setting cross-section properties to zero, or TRUSS, etc. options.

Assumptions

- Linear, elastic, homogeneous.
- Small strains and displacements.
- Plane sections remain plane.
- No coupling of axial, torque and bending.
- Shear deformation are included.
- Geometric and elastic properties constant along length

7. STATIC ANALYSIS OF ANTENNA STRUCTURE AS PER IS 1893 (PART-1): 2002

7.1 METHODOLOGY

For the purpose of determining seismic forces, the country is classified into four seismic zones as shown in figure 1 of IS 1893 (Part-I): 2002.

The design horizontal seismic coefficient A_h for a structure shall be determined by the following expression:

$$A_h = \frac{Z}{2} . \frac{I}{R} . \frac{Sa}{g}$$

Provided that for any structure with T $\leq$ 0.1 s, the value of A_h will not be taken less than Z/2 whatever be the value of I/R.

Where

Z = Zone factor given in Table 2 of IS 1893 (Part-I): 2002, is for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the determination of Z is used so as to reduce the Maximum Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE).

I = Importance Factor, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance (Table 6 of IS 1893 (Part-I): 2002).

R = Response Reduction Factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.0 (Table 7 of IS 1893 (Part-

I): 2002). The values of R for buildings are given in Table 7 of IS 1893 (Part-I): 2002.

Sa/g = Average response acceleration coefficient for rock or soil sites as given by Fig. 2 and Table 3 of IS 1893 (Part-I): 2002 based on appropriate natural periods and damping of the structure. These curves represent free field ground motion.

7.2 ANTENNA STRUCTURE

7.2.1 Geometry Of An Antenna Structure

The height of an earth-station antenna structure up to centre of main-reflector is 9.2 meter. A typical structure of an 11.00 m diameter earth-station antenna resting on a raft slab is shown fig.7.1. The dimension of the different components of an Antenna Structure is shown below.

❖ Main Reflector & Backup Structure:
  - Diameter of reflector: 11 meter
  - Shape: Parabolic
  - Radial 24 inner and 24 outer trusses around the center hub
  - Circumferential stiffeners at outer and intermediate level as shown in figure 7.1
  - Aluminum skin provided on backup structure- generally 2 mm thick
  - Quadripod & Sub-reflector
  - Feed

❖ EL Module:
  - 1450 * 1850 * 1025 mm
  - Box like structure

❖ AZ Module

- Diameter: 1450 mm
- Cylindrical structure

❖ Pedestal

- Total Height : 4500 mm
- 2250 mm conical, 2250 mm cylindrical
- Top Diameter of Conical Portion: 1450 mm
- Bottom Diameter of Conical Portion: 2300 mm

7.2.2 Material Properties

Material properties considered for an Antenna Structure is as shown below.

❖ Concrete:

- Young's Modulus (E): 21718.456 N/mm^2
- Density : 2.35616e-005 N/mm^3
- Poisson Ratio : 0.17

❖ Steel:

- Young's Modulus (E): 20500.00 N/mm^2
- Density : 768195e-005 N/mm^3
- Poisson Ratio : 0.30

❖ Aluminum:

- Young's Modulus (E): 68947.576 N/mm^2
- Density : 2.66018e-005 N/mm^3
- Poisson Ratio : 0.33

7.2.3 SECTIONAL PROPERTIES

The sectional properties for the sections used for main-reflector is as shown below:

- Tube Section-75*45*5 mm

- Tube Section-25*45*5 mm

7.2.4 Modeling Of An Antenna Structure

7.2.4.1 STAAD Pro Modeling

The 3-Dimensional Modeling of an Antenna Structure is as shown in figure 7.1

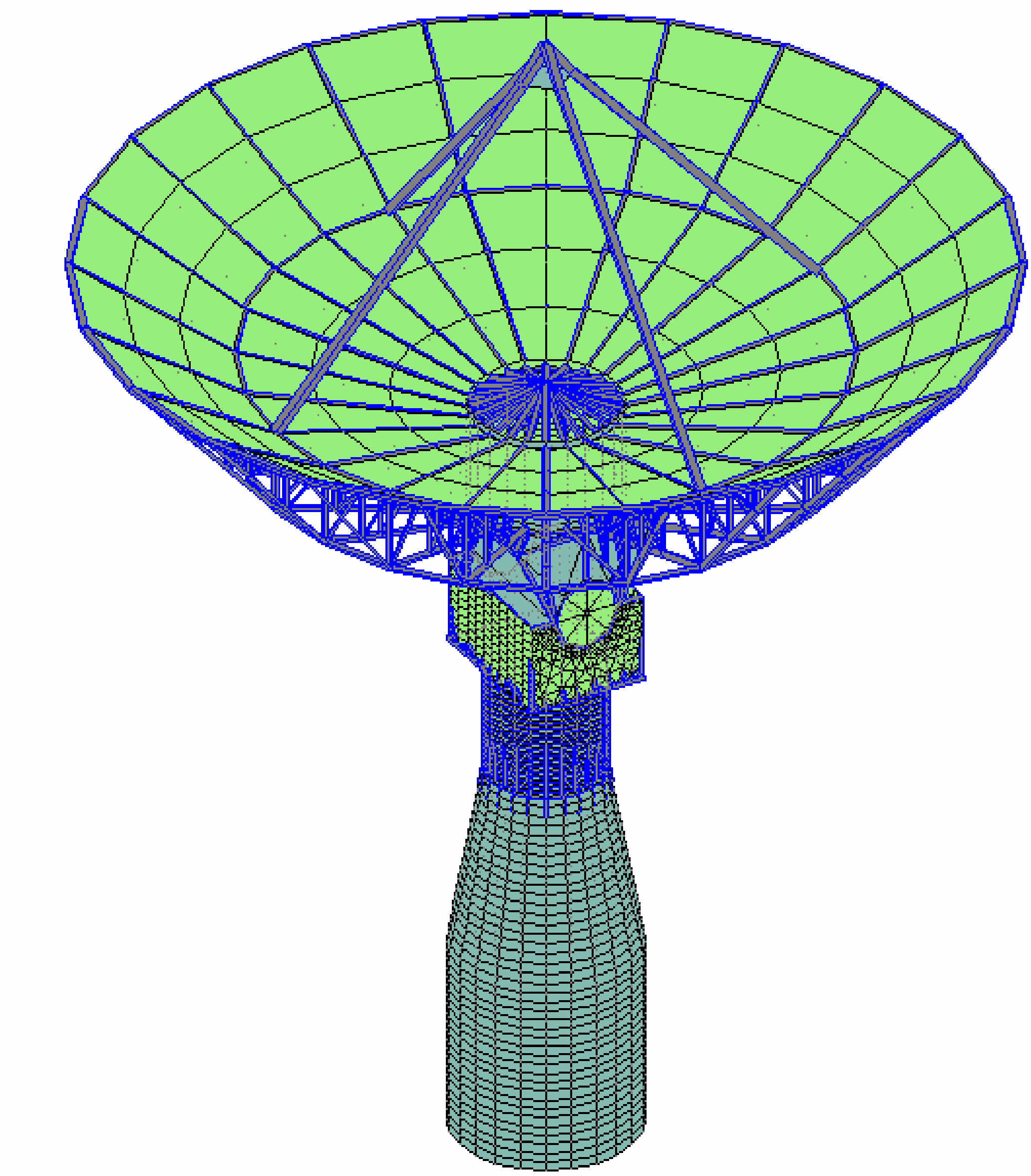


FIGURE 7.1 3-DIMENSIONAL MODELING OF AN ANTENNA STRUCTURE

7.2.4.2 Boundary Condition

In this analysis all the nodes at the base are fixed against movement in X, Y and Z directions.

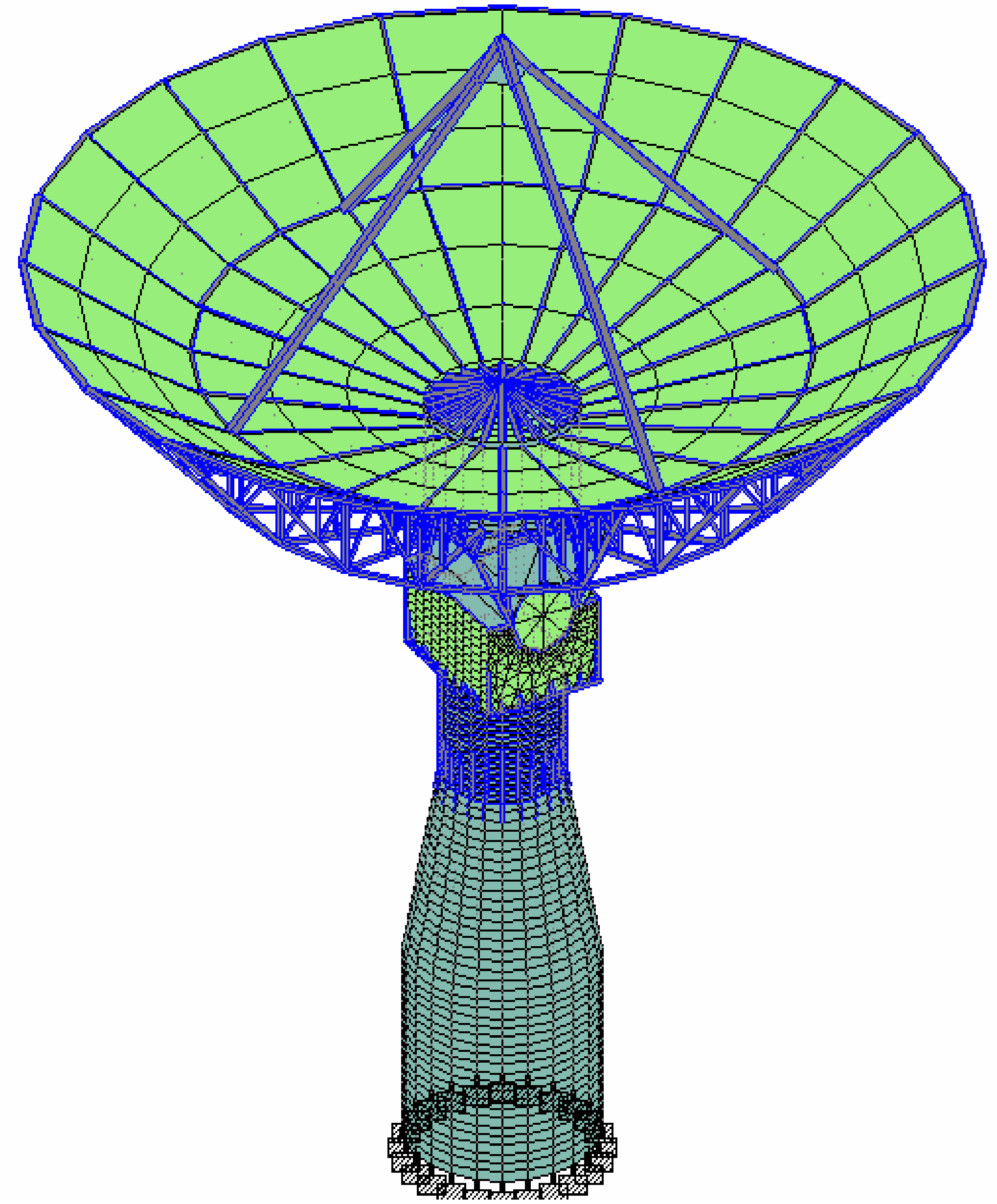


FIGURE 7.2 ANTENNA STRUCTURE WITH FIXED BASED BOUNDARY CONDITION

7.2.5 STATIC ANALYSIS OF ANTENNA STRUCTURE AS PER “IS 1893 (PART-1): 2002”

Static Analysis was carried out as per IS 1893 (Part-1): 2002 for 11 meter diameter earth-station antenna. The frequency and time period for different modes are as follows:

TABLE 7.1 FREQUENCY RESULTS OF AN ANTENNA STRUCTURE FROM STAAD Pro

Mode No.	Frequency [Hz]	Period [sec]
1	2.802	0.357
2	3.376	0.296
3	7.000	0.143

7.2.6 Comparative Study of Frequencies

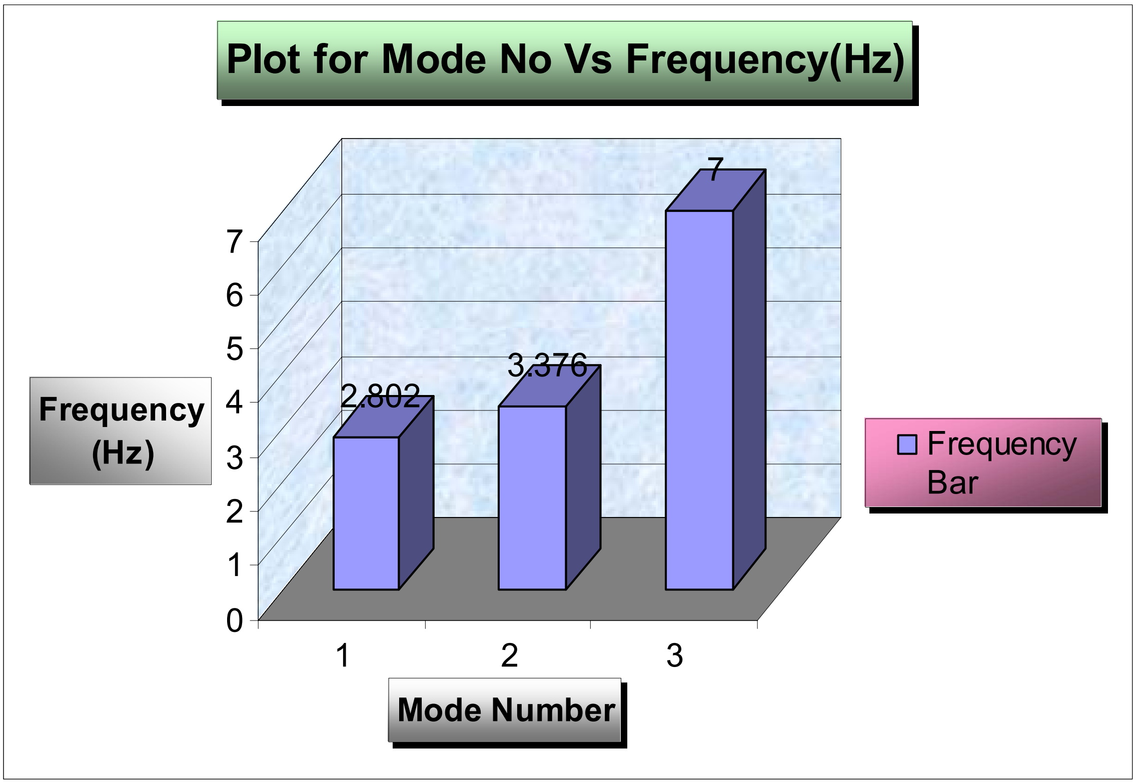
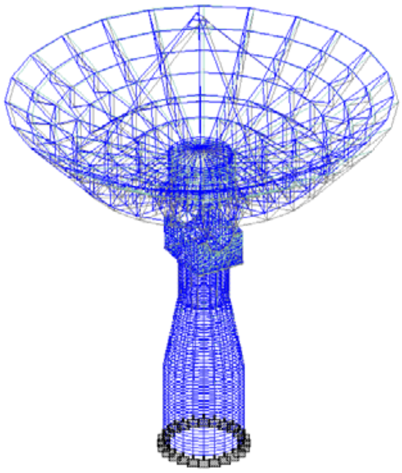
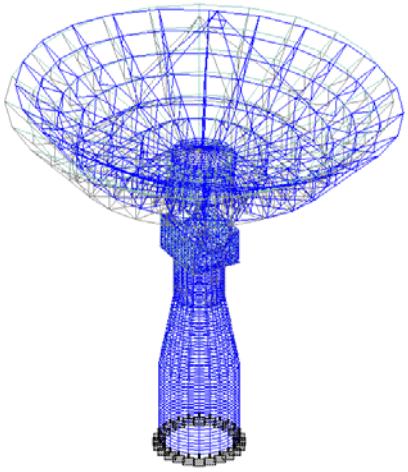
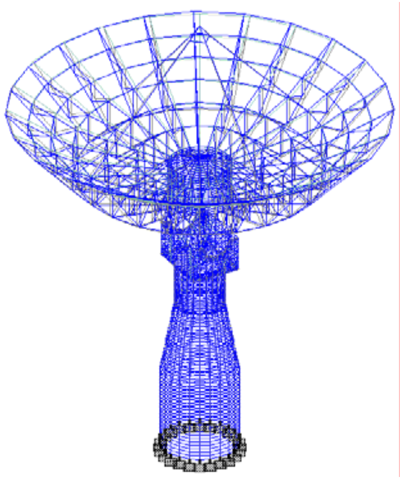


CHART 7.1 MODE NUMBER Vs FREQUENCY (Hz) FOR AN ANTENNA STRUCTURE FOR STATIC ANALYSIS

TABLE 7.2

MODES AND MODE SHAPES OF AN ANTENNA STRUCTURE FROM STAAD Pro

Mode No.	Frequency [Hz]	Mode Shape	Mode of Vibration
1	2.802		Y-direction
2	3.376		X-Direction
3	7.000		Torsion

7.3 RAFT

The role of a typical raft foundation is to transmit the load coming from the superstructure to the soil beneath without causing distress to any of the components of the superstructure or foundation.

Generally, the raft is analyzed by the conventional method in which it is assumed to be rigid, resulting in uniform and linearly varying contact pressure distribution depending on whether the raft supports symmetric or eccentric loads. Thus, soil-structure interaction is an important aspect in the process of predicting overall structural response. Size of the raft is decided from the conversion and frequency criteria.

7.3.1 Finite Element Modeling of Raft

The raft was modeled using 8-noded brick element. The element was assumed to be isotropic. The size of element was taken similar throughout the modeling. Figure 7.3 shows the mathematical model of raft for 6.9m * 6.9m * 0.5m.

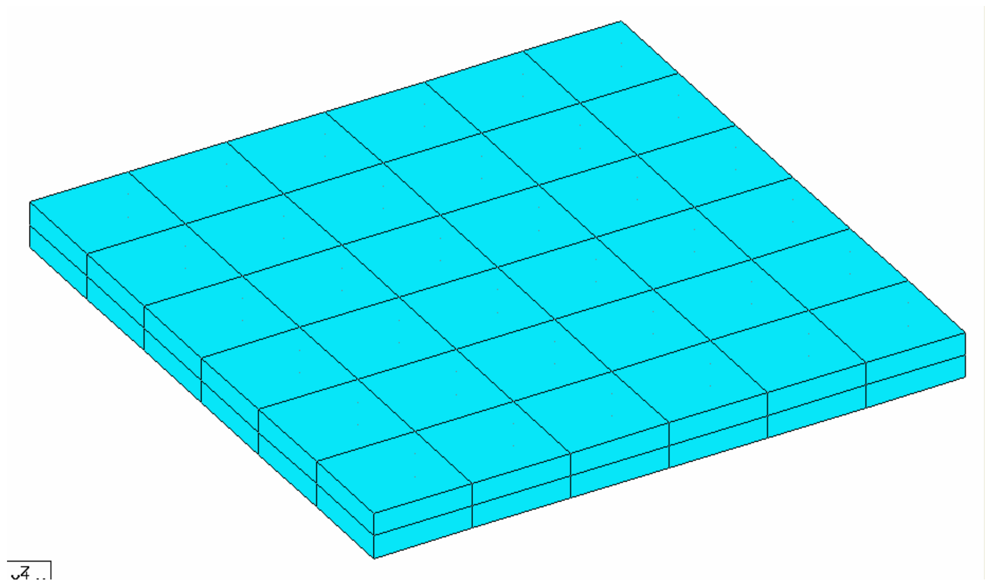


FIGURE 7.3 FINITE ELEMENT MODELING OF RAFT

7.3.2 Material Properties

The material properties considered for raft are

- Concrete:
  - Young's Modulus (E): 21718.456 N/mm^2
  - Density : 2.35616e-005 N/mm^3
  - Poisson Ratio : 0.17

7.4 SOIL

Structural response of any structure mainly depends on the foundation support conditions and the nature of soil below it. Always, a structure has finite dimensions and its mathematical model with number of degrees of freedom can always be constructed.

On the other hand, the soil is a semi-infinite medium, or an unbounded medium and construction of its mathematical model is quite difficult. Therefore the influence of subsoil on the dynamic response of the structure is to be properly accounted for to arrive at satisfactory results. The soil adjacent to the structure has a considerable effect on the structure than the soil in the far field.

The soil near the structure can be modeled with finite element idealization to consider the properties of soil and the soil boundaries at far field are to be constrained w.r.t all the translational D.O.F. From the conversion and frequency criteria size of the mathematical model of soil is decided as 13.8 m * 13.8 m * 13.8 m.

7.4.1 Finite Element Modeling Of Soil

The soil adjacent to raft was modeled using 8-noded brick element. The element was assumed to be isotropic. The size of the element was taken similar throughout the modeling.

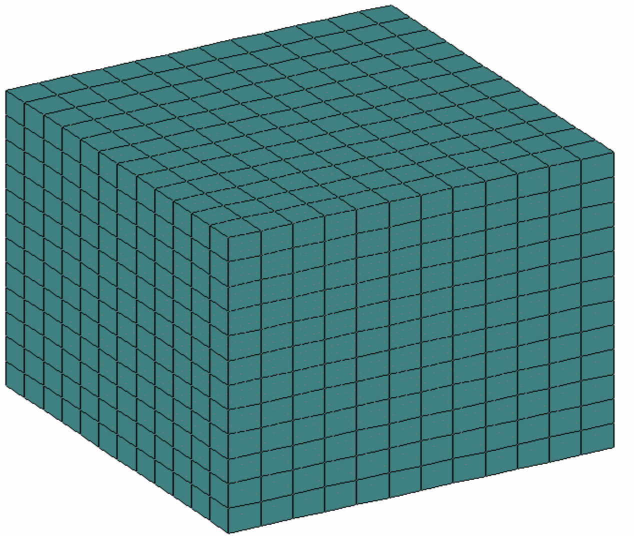


FIGURE 7.4 FINITE ELEMENT MODELING OF SOIL

7.4.2 Material Properties

The material properties considered for raft are

❖ Elastic Modulus of Soil : $1.1*10^5$ kN/m^2

- Mass Density of Soil : 1.85 g/cm^3
- Poisson Ratio : 0.17
- Damping : 0.05

7.4 STRUCTURE AS A WHOLE

In this piece of work, the theoretical approach is to study elements of the structure in the component approach and then take all components together for the system approach. This system approach of all the components of the structure when taken together along with the soil mass gives the whole scenario.

This whole scenario of predicting the natural frequency of the entire system by incorporating the flexibility of a large volume of soil mass is very useful in determining the natural frequencies of the entire structural system. First few modes are the high-energy modes, which are having maximum amplitude and our study particularly from the point of view of bending, compression and torsional mode.

7.5.1 Finite Element Modeling Of Whole Antenna Structure with Soil Mass

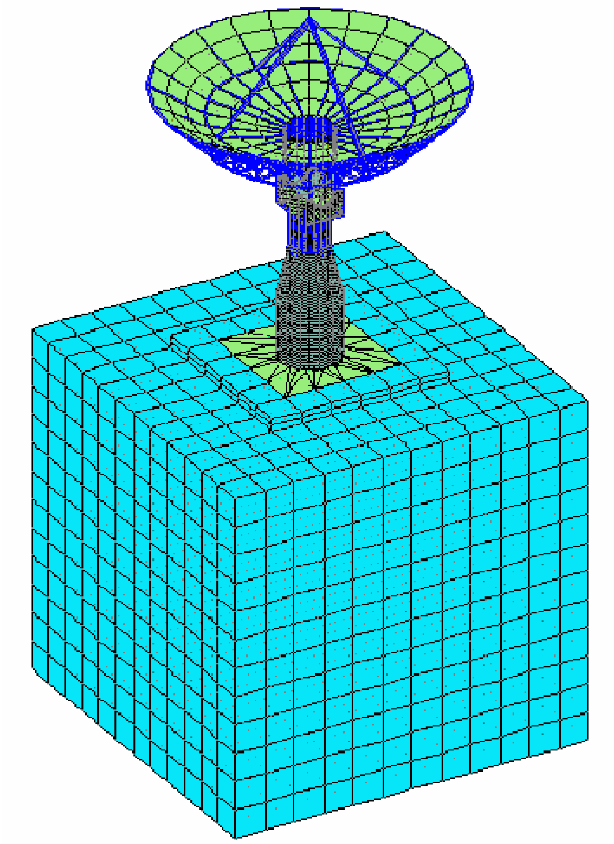


FIGURE 7.5 FINITE ELEMENT MODELING OF WHOLE STRUCTURE WITH SOIL MASS

7.5.2 Linear Static Analysis Of Whole Structure

Linear Static Analysis was carried out on the whole structure. The frequency and time period for different modes are as follows:

TABLE 7.3FREQUENCY RESULTS FROM STAAD Pro

Mode	Frequency Hz	Period (seconds)
1	2.546	0.393
2	2.651	0.377
3	2.721	0.368

7.5.3 Comparative Study Of Frequencies For Soil For Linear Static Analysis

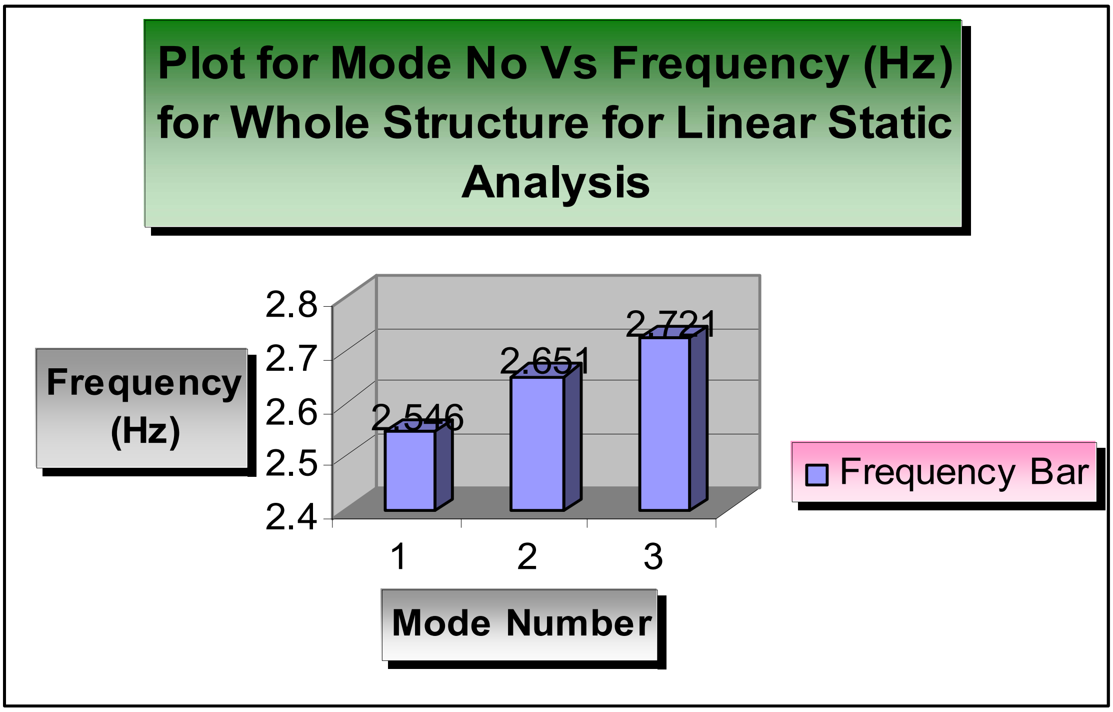
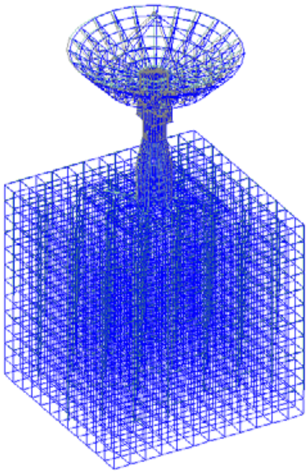
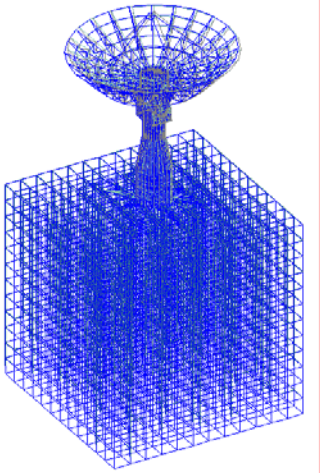
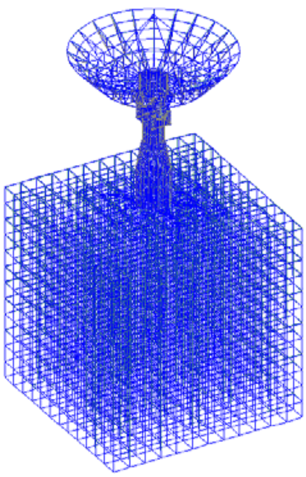


CHART 7.2 MODE NUMBER Vs FREQUENCY (Hz) FOR WHOLE STRUCTURE FOR STATIC ANALYSIS

TABLE 7.4

MODES AND MODE SHAPES OF AN ANTENNA STRUCTURE FROM STAAD Pro

Mode No.	Frequency [Hz]	Mode Shape	Mode of Vibration
1	2.546		Y-Direction
2	2.651		X-Direction
3	2.721		Torsion

7.6 BEAM AND PLATE STRESSES FOR ANTENNA SRUCTURE AND WHOLE ANTENNA STRUCTURE FOR STATIC ANALYSIS AS PER "IS 1893 (PART-1):2002"

7.6.1 Antenna Structure

- Maximum Beam Stress: 114.27 N/mm^2
- Maximum Plate Stress: 126.00 N/mm^2
  (Max. Von Mises Stress)

7.6.2 Whole Antenna Structure

- Maximum Beam Stress: 89.90 N/mm^2
- Maximum Plate Stress: 87.10 N/mm^2
  (Max. Von Mises Stress)

8. TIME HISTORY ANALYSIS OF ANTENNA STRUCTURE

8.1 INTRODUCTION

Problems of dynamics can be categorized as either *wave propagation problems* or *structural dynamics problems*. In wave propagation problems the loading is often an impact or an explosive blast. The excitation, and hence the structural response, are rich in high frequencies. In such problems we are usually interested in the effects of stress waves. Thus the time duration of analysis is usually short and is typically of the order of a wave traversal time across a structure.

Problems of structural dynamics can be subdivided into broad classifications. In one, we ask for *natural frequencies of vibration* and the corresponding mode shapes. In other classification, we ask how structure moves with time under prescribed loads and/or motions of its supports; that is, we ask for a ***time-history analysis*****.** Two popular methods of time-history analysis are *modal methods* and *direct integration methods.* ("Time history" is a commonly used term referring to the record of the variation of a quantity over some interval of time.)

Methods of structural dynamics are largely independent of finite element analysis because these methods presume the availability of stiffness, mass and damping matrices but do not demand that they arise from a finite element discretization.

In this piece of work, an attempt was made to study the given structure in its totality particularly in the dynamic analysis domain. The theoretical approach was carried out for elements of the structure in the component approach and then takes all components together for the system approach. This system approach of all the components of the structure when taken together along with the soil mass gives the whole scenario.

8.2 FORCING FUNCTION USED IN TIME HISTORY ANALYSIS

8.2.1 Bhuj Earthquake

A Mw 7.7 earthquake struck the KUTCH region of Gujarat state in western India at 8:46 a.m. in January 26, 2001. This was the most damaging earthquake in the last fifty years in India. Figure 8.1 shows the corrected displacement time histories recorded at Ahmedabad (comp: N 78^0 E). Figure 8.2 shows the elastic response spectra for the three-recorded components of ground motion for 5 percent damping for the same component.

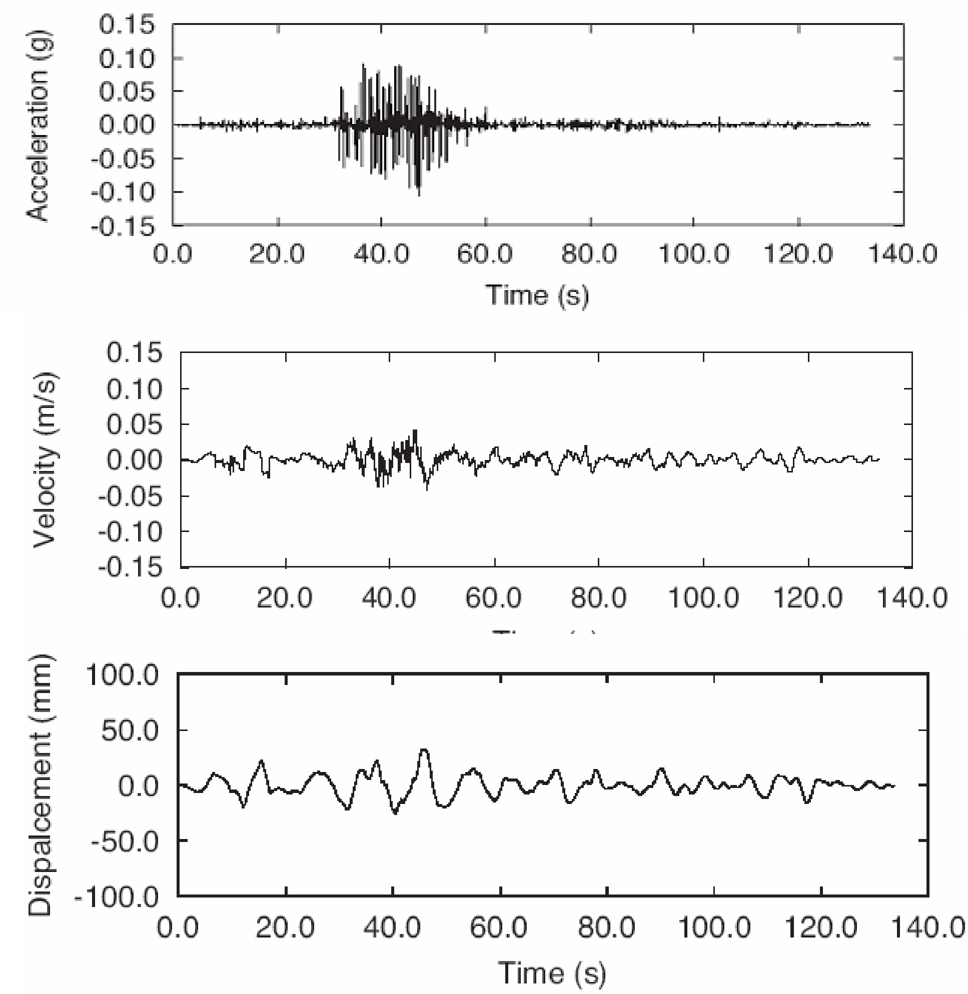


FIGURE 8.1 CORRECTED ACCELERATION AND DERIVED VELOCITY AND DISPLACEMENT TIME HISTORIES RECORDED AT AHMEDABAD (COMP: N78^0 E)

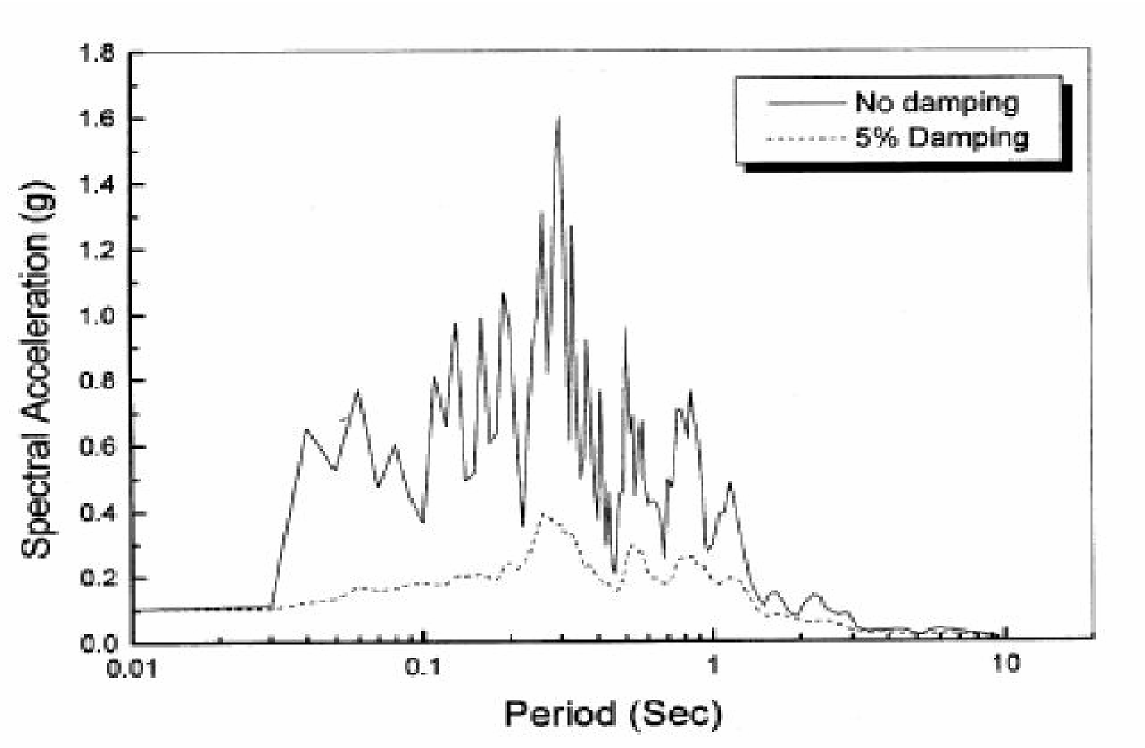


FIGURE 8.2 RESPONSE SPECTRA OF THE GROUND ACCELERATION TIME HISTORIES AT AHMEDABAD FOR N 78 E COMPONENT

8.3 ANTENNA STRUCTURE

8.3.1 Geometry Of An Antenna Structure

The geometry of an Antenna Structure is kept constant as considered in the previous chapter.

8.3.2 Material Properties

The material properties for an Antenna Structure are kept constant as considered in the previous chapter.

8.3.3 Sectional Properties

The sectional properties for an Antenna Structure are kept constant as considered in the previous chapter.

8.3.4 Modeling Of An Antenna Structure

8.3.4.1 *STAAD Pro Modeling*

The 3-Dimensional Modeling of an Antenna Structure is as shown in figure 7.1

8.3.4.2 Boundary Condition

In this analysis all the nodes at the base are fixed against movement in X, Y and Z directions.

8.3.5 Time History Analysis Of Antenna Structure

Time History Analysis was carried out for 11 meter diameter earth-station antenna. The frequency and time period for different modes are as follows:

Mode No.	Frequency [Hz]	Period [sec]
1	2.79	0.358
2	3.37	0.297
3	6.99	0.143

TABLE 8.1 FREQUENCY RESULTS FROM STAAD Pro

8.3.6 Comparative Study Of Frequencies

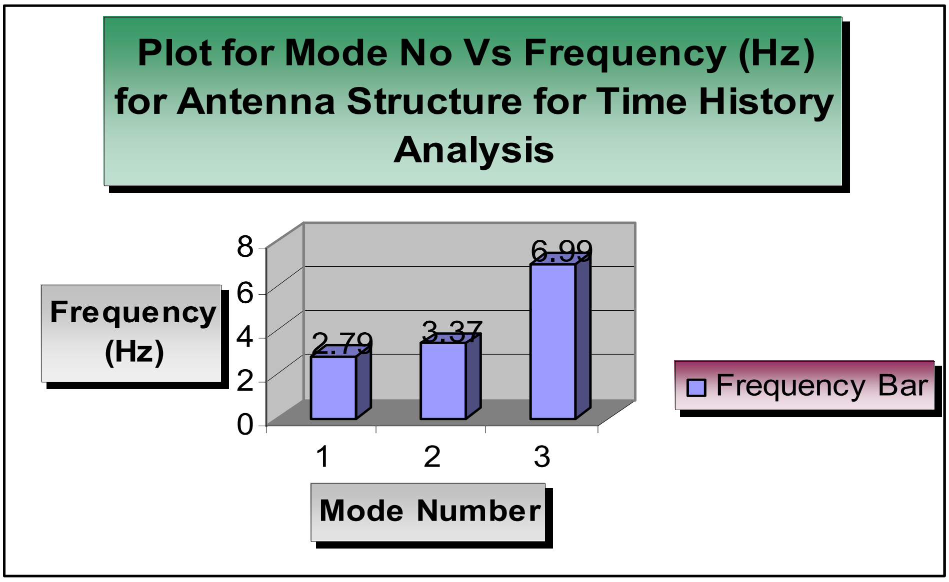
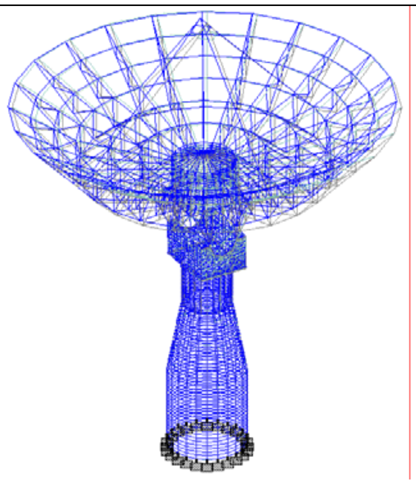
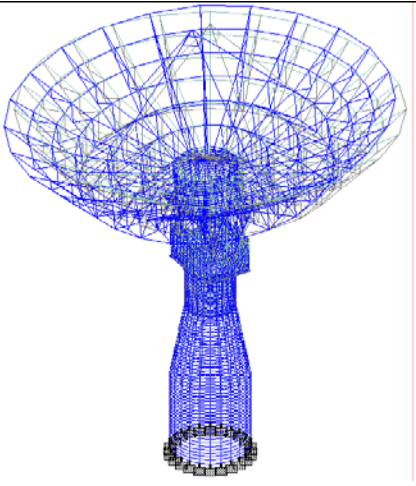
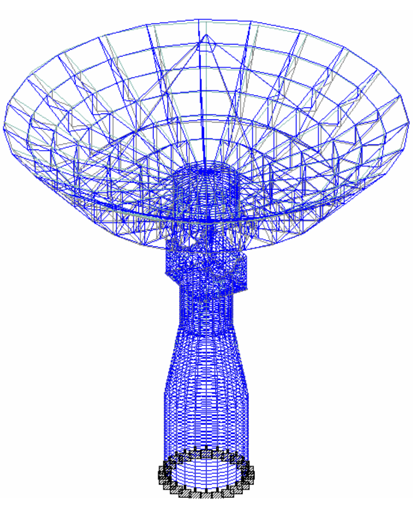


CHART 8.1 MODE NUMBER Vs FREQUENCY (Hz) FOR ANTENNA STRUCTURE FOR TIME HISTORY ANALYSIS

TABLE 8.2

MODES AND MODE SHAPES OF AN ANTENNA STRUCTURE FROM STAAD Pro

Mode No.	Frequency [Hz]	Mode Shape	Mode of Vibration
1	2.79		Y-direction
2	3.37		X-Direction
3	6.99		Torsion

8.4 RAFT

8.4.1 Finite Element Modeling Of Raft

The Raft is modeled as explained in the previous chapter.

8.4.2 Material Properties

The material properties for the raft are kept constant as considered in the previous chapter.

8.5 SOIL

Size, material properties and boundary condition used in the modeling of soil are kept same as explained in previous

8.5.1 Finite Element Modeling Of Soil

The soil adjacent to raft was modeled using 8-noded brick element. The element was assumed to be isotropic. The size of the element was taken similar throughout the modeling as considered in the previous chapter.

8.5.2 Material Properties

The material properties of soil are kept constant as considered in the previous chapter.

8.6 STRUCTURE AS A WHOLE

8.6.1 Finite Element Modeling Of Whole Antenna Structure with Soil Mass

Finite Element modeling of Antenna Structure with Soil Mass is done as considered in the previous chapter.

8.6.2 Time History Analysis Of Whole Structure

The frequency and time period for different modes are as follows:

Mode	Frequency Hz	Period (seconds)
1	2.546	0.393
2	2.651	0.377
3	2.721	0.368

Table 8.3 Frequency Results from STAAD Pro

8.6.3 Comparative Study Of Frequencies For Soil For Time History Analysis

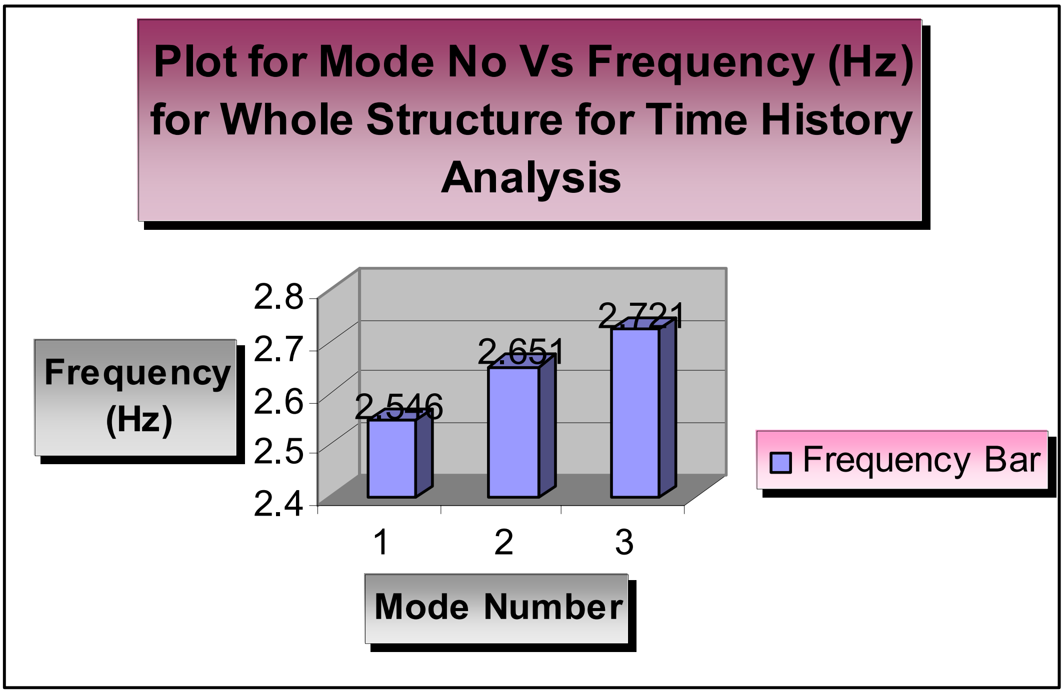
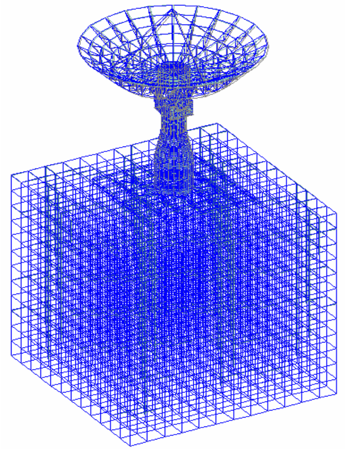
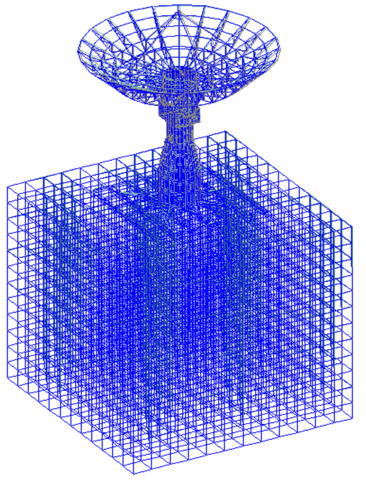
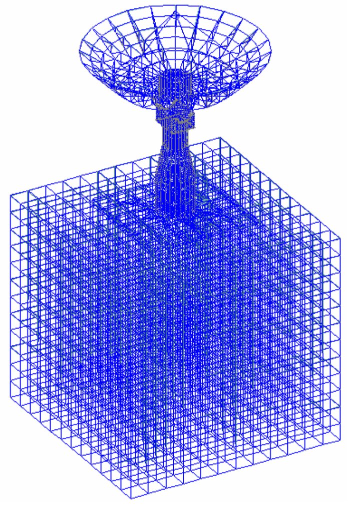


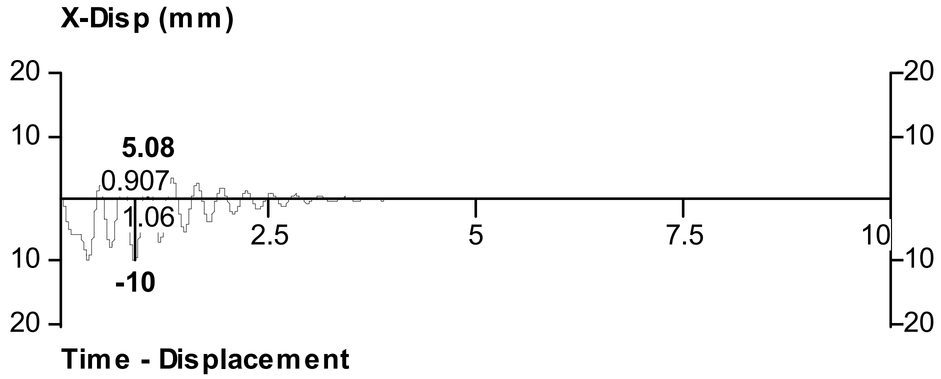
CHART 8.2 MODE NUMBER Vs FREQUENCY (HZ) FOR WHOLE STRUCTURE FOR TIME HISTORY ANALYSIS

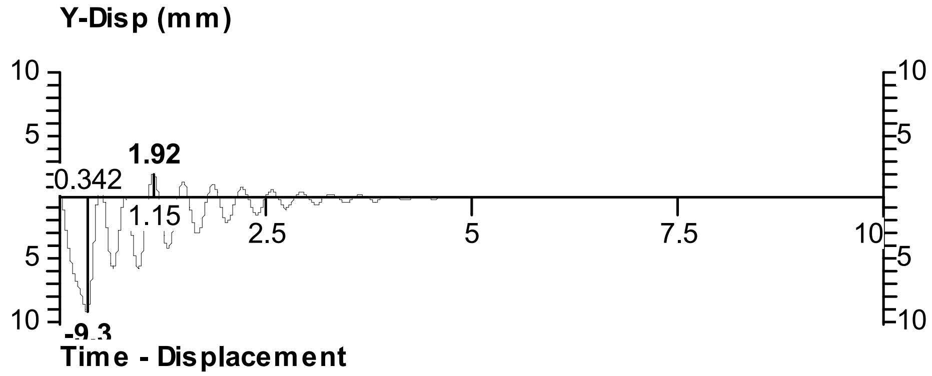
TABLE 8.4

MODES AND MODE SHAPES OF AN ANTENNA STRUCTURE FROM STAAD Pro

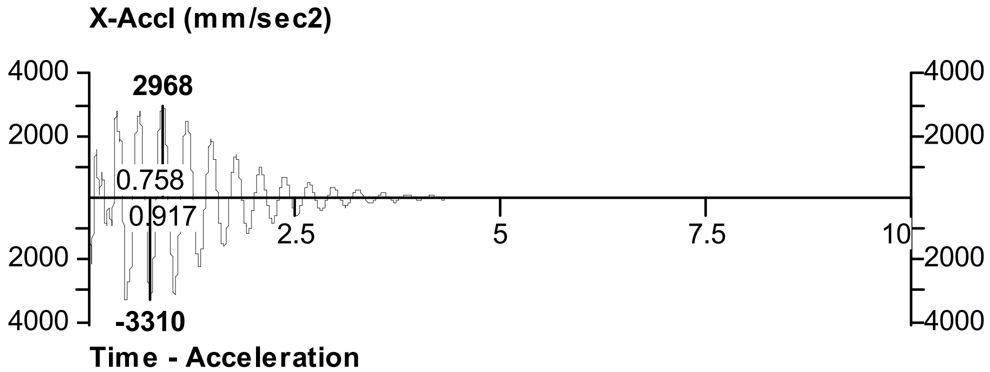
Mode No.	Frequency [Hz]	Mode Shape	Mode of Vibration
1	2.546		Y-Direction
2	2.651		X-Direction
3	2.721		Torsion

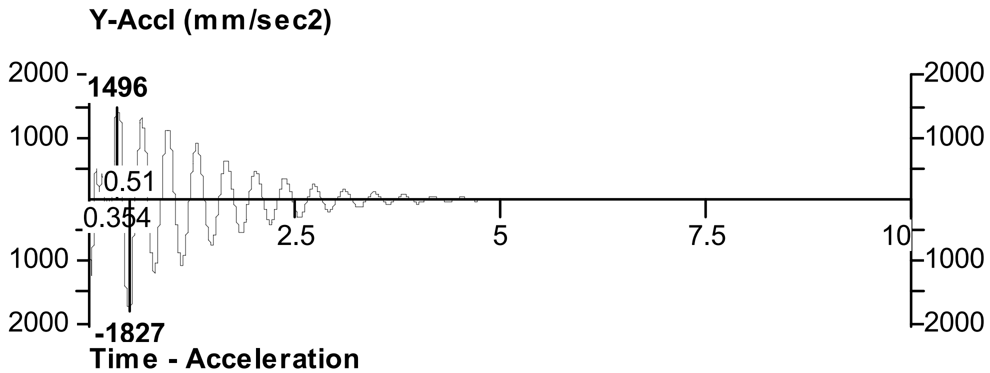
8.7 PLOT FOR TIME Vs DISPLACEMENT AT MAXIMUM NODAL DISPLACEMENT POINT (NODE NO: 318) FOR ANTENNA STRUCTURE

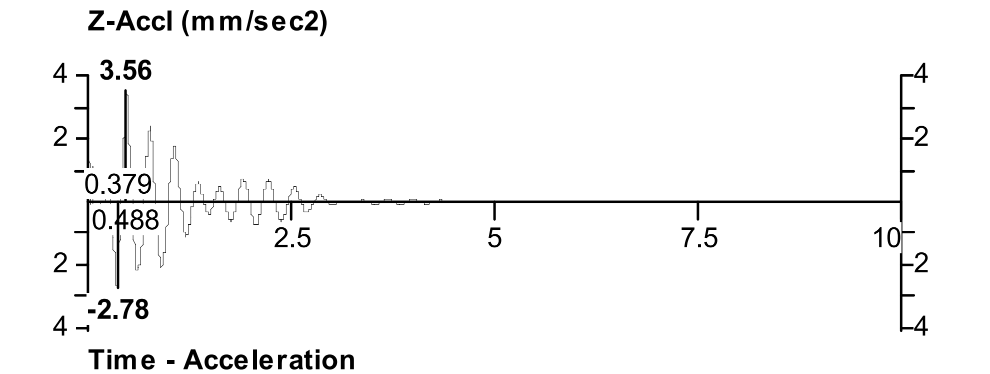




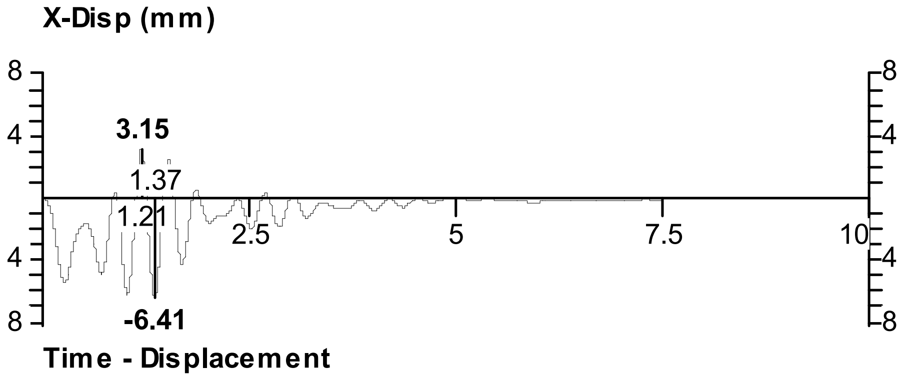
8.8 PLOT FOR TIME Vs ACCELERATION AT MAXIMUM NODAL DISPLACEMENT POINT (NODE NO: 318) FOR ANTENNA STRUCTURE

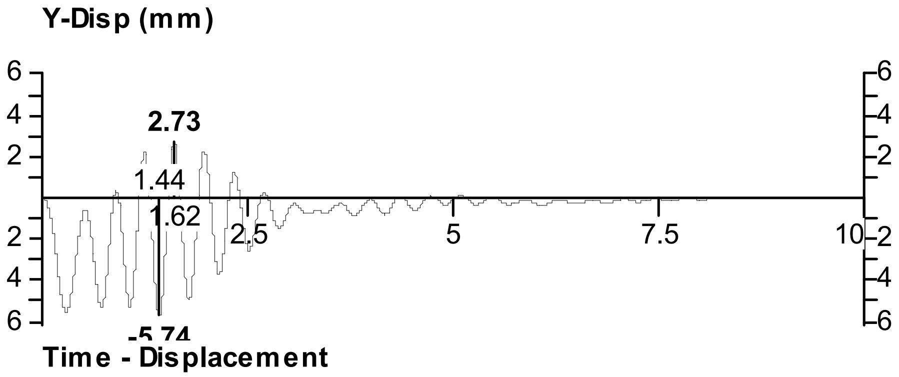


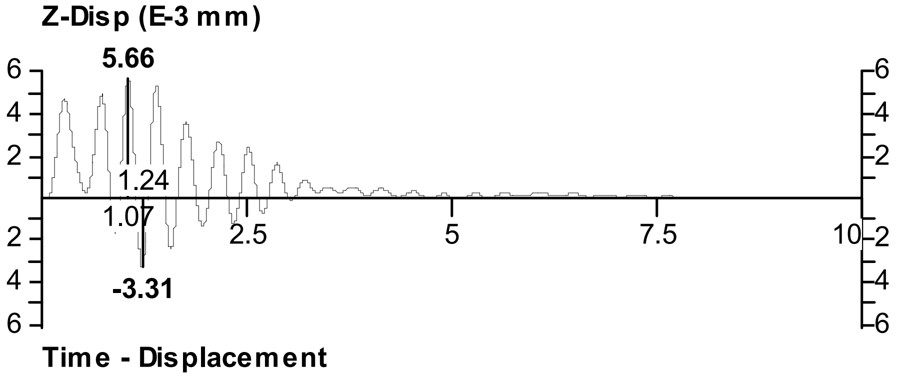




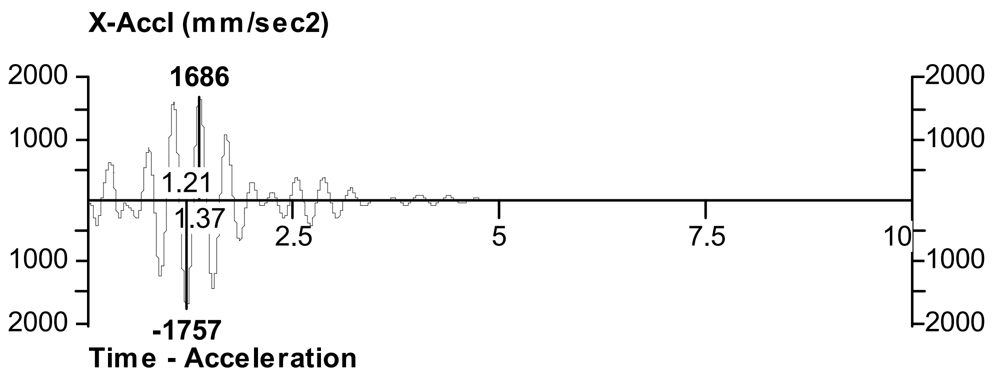
8.9 PLOT FOR TIME Vs DISPLACEMENT AT MAXIMUM NODAL DISPLACEMENT POINT (NODE NO:318) FOR WHOLE ANTENNA STRUCTURE

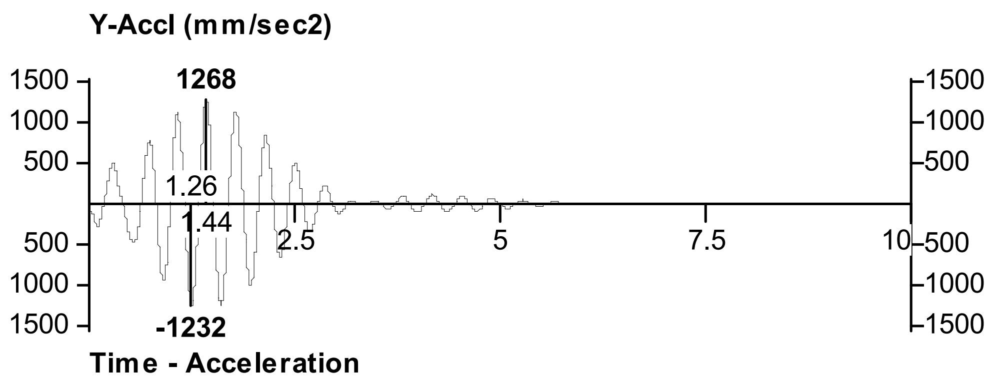


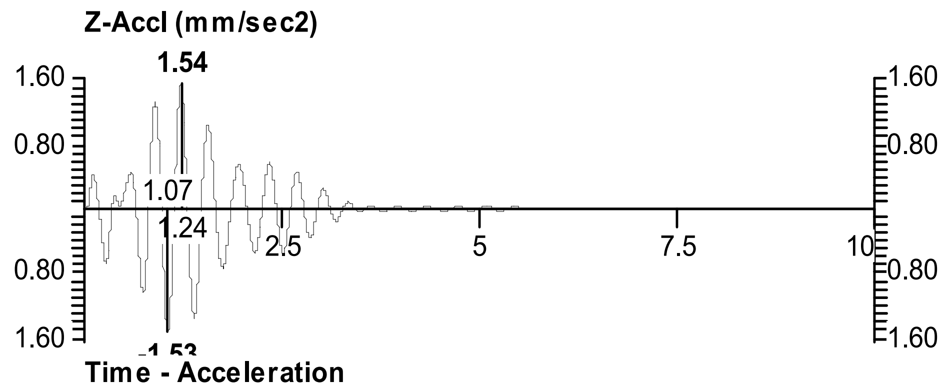




8.10 PLOT FOR TIME Vs ACCELERATION AT MAXIMUM NODAL DISPLACEMENT POINT (NODE NO: 318) FOR WHOLE ANTENNA STRUCTURE







8.11 BEAM AND PLATE STRESSES FOR ANTENNA SRUCTURE AND WHOLE ANTENNA STRUCTURE FOR TIME HISTORY ANALYSIS

8.11.1 Antenna Structure

- Maximum Beam Stress: 131.60 N/mm^2

- Maximum Plate Stress: 146.00 N/mm^2
  (Max. Von Mises Stress)

8.11.2 Whole Antenna Structure

- Maximum Beam Stress: 79.49 N/mm^2

- Maximum Plate Stress: 71.60 N/mm^2
  (Max. Von Mises Stress)

9. RESULTS, CONCLUSIONS AND FUTURE SCOPE OF WORK

9.1 RESULTS AND CONCLUSIONS:

1. The structural analysis of antenna is mainly divided into two aspects:

    - Wind Load Analysis
    - Earthquake Load Analysis

2. The design is basically a displacement based design. Though there is a good factor of safety on maximum stresses for survival wind speed of 200 KMPH. The section size is selected based on RMS value of deflection.

3. The maximum overall R.M.S. value of the reflector for 80 KMPH wind load is 0.788 mm, which is well below the required value of 1.0 mm.

4. For wind load analysis, the maximum peak stress value with in the reflector is 96 N/mm^2. The maximum allowable stress limit for the aluminum material is 200 N/mm^2.

5. The analysis results shows that the reflector is well safe for the **RMS** and **Stress** aspects for the operational and survival cases for wind loads.

6. Static analysis is done as per "IS 1893 (Part-1):2002". The results are as follows:

    Antenna Structure

    - Maximum Beam Stress : 114.27 N/mm^2
    - Maximum Plate Stress : 126.00 N/mm^2
      (Max. Von Mises Stress)

Whole Antenna Structure

- Maximum Beam Stress : 89.90 N/mm^2
- Maximum Plate Stress : 87.10 N/mm^2

  (Max. Von Mises Stress)

7. Time History analysis is done by using BHUJ Earthquake Response Spectrum. The results are as follows:

   Antenna Structure

   - Maximum Beam Stress : 131.60 N/mm^2
   - Maximum Plate Stress : 146.00 N/mm^2

     (Max. Von Mises Stress)

   Whole Antenna Structure

   - Maximum Beam Stress : 79.49 N/mm^2
   - Maximum Plate Stress : 71.60 N/mm^2

     (Max. Von Mises Stress)

8. The servo motor frequency is 2.0 Hz. So the structral frequencies should be more than 2.0 Hz.

   The frequency results are as follows:

   - **Static Analysis as per "IS 1893 (Part-1):2002"**
     - Antenna Structure : 2.79
     - Whole Antenna Structure : 2.55

   - **Time History Analysis**
     - Antenna Structure : 2.80
     - Whole Antenna Structure : 2.55

   Here, all the frequencies are greater than that of the servo motor; hence the structure is safe from frequency point of view.

8. The stresses from Static Analysis and Time History Analysis are well within the permissible limits. Thus, the structure is safe from the stress point of view.

9.2 FUTURE SCOPE OF WORK

1. Detailed studies can still be carried out for different configurations of massive concrete pedestals, from the optimum design point of view.

2. For the bad soil, the raft should be replaced by piles and whole model should be studied along with the pile cap and pile group.

3. Computer program can be generated to customize the response studies for the whole model using Matlab.

4. Computer program can be generated for the calculation of the wind forces for the antenna of given parameters.

REFERENCES

1. Edward Cohen and Joseph Vellozzi, *"CALCULATION OF WIND FORCES AND PRESSURES ON ANTENNAS"*, Annals of the New York Academy of Sciences, Volume 116, Art 1, June 26, 1964.

2. Richards C., "*Mechanical Engineering in Radar and Communication*"

3. Comsat Systems Pvt. Ltd., Hyderabad., *"Design Document for 11 Meter Steerable Antenna System"*, Prepared for Ministry of Home Affairs, October 2001.

4. Electronics Corporation of India Limited, Hyderabad., *"Preliminary Design Report for 11 m Antenna System LUCKNOW and BIAK-II"*, Prepared for ISTRAC, Bangalore., 2001

5. Comsat Systems Pvt. Ltd., Hyderabad., *"Design Document for 6.3 Meter Limited Steerable Antenna System*", Prepared for SAC, ISRO, Ahmedabad, 1994.

6. Prof. P.C. Vasani, *Interactive Analysis Models For Soil And Structures*

7. IDE Toshiyuki, HAMAMOTO Naokazu, and OGAWA Takaya, *A Folding Parabola Antenna with Flat Facets,* Journal of the National Institute of Information and Communications Technology Vol.50 Nos.3/4 2003

8. P.M. Rao, N. Sreedhanam and P.K. Jain, *Ground Station System Design For Meteorological And Earth Resources Data Reception*, National Remote Sensing Agency, Hyderabad 500 037

9. Indian Standard IS:1893 (Part 1) 2002 Criteria For Earthquake Resistant Design of Structures

APPENDIX-A

LIST OF USEFUL WEBSITES

1. www.ecil.co.in
2. www.comsat-systems.com
3. www.viasat.com
4. www.soople.com