ANALYSIS OF ANTENNA SUPPORTING STRUCTURES

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

EARTHQUAKE ENGINEERING
(With Specialization in Soil Dynamics)

By

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CANDIDATE'S DECLARATION

I, hereby, declare that the work, which is being presented in this dissertation, entitled "**ANALYSIS OF ANTENNA SUPPORTING STRUCTURES**", in partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** in **EARTHQUAKE ENGINEERING** with specialization in **SOIL DYNAMICS**, submitted in the department of Earthquake Engineering, IIT ROORKEE, is an authentic record of my own work carried out for a period from July, 2002 to January, 2003 under the super vision of Dr. D. K. Paul, Professor, Department of Earthquake Engineering, IIT Roorkee and Dr. Yogendra Singh, Assistant Professor, Department of Earthquake Engineering , IIT Roorkee.

I have not submitted the matter embodied in this dissertation for the award of any other degree or diploma.

Dated: 28th February 2002 **(Prasad S R Jallipalli)**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

The antennas for communication with artificial earth satellites have a complicated structure, which include high-precision mechanisms for guidance of the antennas working with the computers. Design of such large antennas for wind is rather complex. During operational condition and for proper communication, under a high design wind speed the antenna supporting structure should satisfy the stringent requirements of the antenna.

In this dissertation, a paraboloidal 18-meter diameter dish antenna is considered for the analysis of antenna supporting structures. Finite element software ANSYS is used to carryout the analysis. Solid45 and mass21 elements are used to generate the mathematical model of supporting structure. Different structural configuration with truncated conical pedestal with and without ribs have been considered. Natural frequencies and maximum displacements on pedestal top have been observed to asses the suitability of supporting structure under varying soil conditions. It has been observed that the ribs do not have any significant impact on the frequency of the supporting structure. However, to achieve the displacement limits these are essential. It has been found that the stringent limits on displacement and frequency cannot be satisfied with pedestals on soil, these can be satisfied only with pedestals on hard rock.

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Chapter 1

INTRODUCTION

Generally satellite earth station requires fully steerable dish shaped antenna for fixed satellite services. These antennas receive or radiate electromagnetic waves. High precision stability is required to perform its functions smoothly even under adverse atmospheric conditions. To ensure confidence on the durability of antenna performance, design of its supporting structure should be done with utmost care. So supporting structure design should consider various factors such as type of loads coming on the structure, suitability of available materials for construction, site conditions and above all engineering skill to satisfy stringent requirements of supporting structure even under adverse environmental considerations. A rational approach to the design of an antenna supporting structure on soil media should consider flexible characteristics of soil medium and foundation. In this dissertation, the effect of flexibility of soil on supporting structure is studied. The analysis is carried out using ANSYS 5.4 software.

1.1 STRUCTURAL DETAILS

A typical supporting structure for an 18 m diameter antenna [1] shown in Fig. 1.1 is in the form of a RCC truncated conical pedestal resting on a raft slab is shown in Fig.1.2. The diameter of conical shell at the top is 4400 mm c/c and at the bottom is 8800 mm c/c. The wall thickness of the conical shell is 500 mm. A circular slab and a ring beam are provided at the top of the pedestal. Similarly a ring beam and a circular slab with central opening of 1000 mm are provided at the mid-height of pedestal. This conical shaped pedestal is also provided with RCC ribs.

1.2 LOADS ON SUPPORTING STRUCTURE

Usually antennas are located at higher elevations and open terrains at which the wind force is predominant. Hence antennas are subjected to high wind loads. This wind load generates drag, lift, moment and torque in antennas. Ultimately these

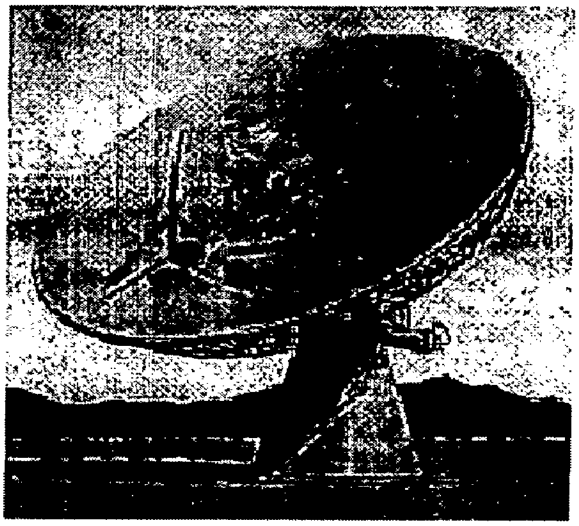
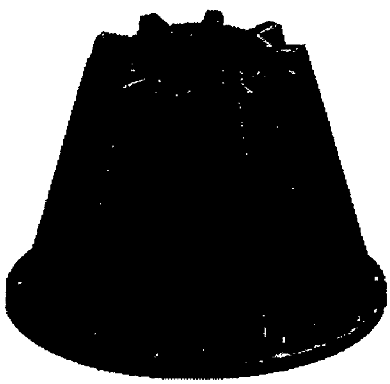


Fig. 1.1 18 m diameter earth station antenna with pedestal



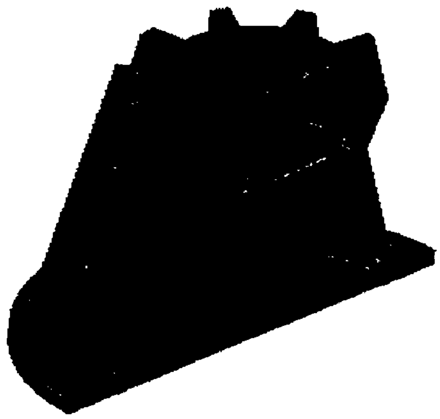


Fig. 1.2 Antenna supporting structure and its cross-section

loads act on supporting structure along with the dead load of antenna and play an important role in the design of antenna supporting structure. Maximum loads developed on antenna should be considered for the design of the supporting structure. Hence wind load governs the design of antenna supporting structures.

1.3 DESIGN CRITERIA OF SUPPORTING STRUCTURE

For smooth functioning of satellite services, the pointing and tracking of antennas with high precision is required even under high wind loads. Wind loads depends on terrain, type of structure, height of structure, topography etc. Design wind load on supporting structure can be derived from IS: 875 (Part 3)–1987 [2] The design requirements of antenna are specified as

(i) The lateral displacement of the pedestal top should be limited to 0.0004 degree when subjected to a wind speed of 100 km/h.

(ii) The natural frequency of the supporting structure for the antenna should be more than 20 Hz.

These criteria are quite stringent to satisfy and a proper design for supporting structure is required.

1.4 OBJECTIVES OF DISSERTATION

(i) To work out a suitable supporting structure so as to meet the stringent design criteria of antenna system.

(ii) Modeling of the antenna supporting structure and adjacent soil to determine the natural frequency and maximum lateral displacement

(iii) To study the behavior of the antenna supporting structure on different soil conditions.

1.5 ORGANIZATION OF DISSERTATION

Dissertation is divided into five chapters. The first chapter introduces the problem and defines the objectives of the study.

Chapter-2 gives the details of elements used for the generation of model and meshing options available in the software.

Chapter-3 deals with the study of behavior of supporting structure under fixed condition at the base of raft. Various supporting structure configurations are analyzed to select most suitable model to suit the design.

Chapter-4 incorporates, the influence of flexibility of soil on the behaviour of supporting structure. An attempt has been made to introduce piles below the raft of supporting structure to increase its natural frequency and minimize lateral displacement.

In Chapter-5 conclusions of the study are drawn.

FINITE ELEMENT MODELLING

2.1 GENERAL

Finite element method [3] is a powerful tool in structural analysis of simple to complicated geometries. In recent years with the coming of fast computers the job of performing finite element analysis of a complicated geometry has become easy. ANSYS [4,5,6,7,8 & 9] is one of the powerful software tools for finite element analysis. Any complicated geometry can be analyzed easily using ANSYS. This chapter describes the finite elements and techniques used to model and study the behavior of antenna supporting structures.

2.2 ELEMENTS USED FOR THE MODELLING

2.2.1. Solid45 3-D solid element

Solid45 has been used for the three-dimensional modeling of solid structure. The element is defined by eight nodes having three degrees of freedom at each node with translations in the X, Y and Z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. The geometry, node locations, and the coordinate system for this element are shown in Fig. 2.1

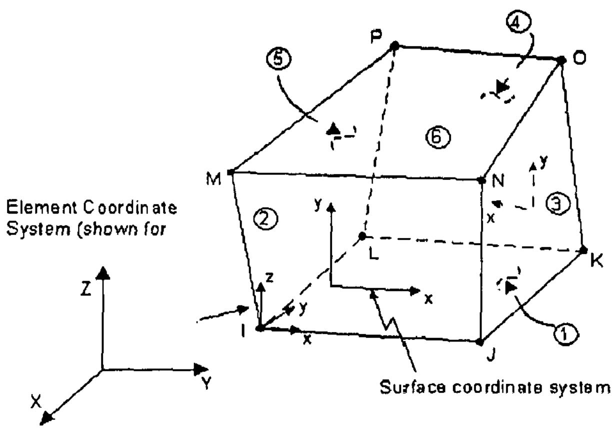


Fig. 2.1. Solid45 element

Solid45 element is used to generate mathematical model of the antenna supporting structure along with soil below it.

2.2.2 Mass 21 element

Mass21 element is a point element or is defined by a single node concentrated having up to six degrees of freedom with translations in the X, Y and Z direction and rotations about the nodal X, Y and Z-axes. It is used to model the mass of antenna on supporting structure for free vibration analysis.

2.3. MESHING

Two meshing options are available in ANSYS. (i) Free mesh and (ii) mapped mesh.

Mapped mesh is adopted in meshing the mathematical model of antenna supporting structure. Mapped mesh has a regular pattern, with obvious rows of elements. In mapped mesh element size can be controlled so that mesh density can be maintained as per requirements of analysis. Number of elements used for the generation of finite element model will be less for mapped mesh than free mesh.

Fig. 2.2 shows the pattern of free and mapped meshing.

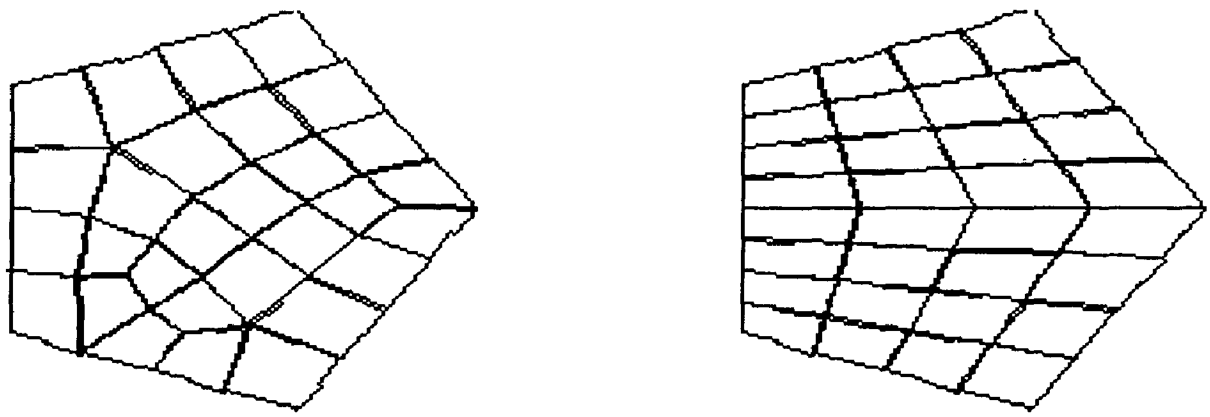


Fig. 2.2 Free and mapped meshes

STUDY OF SUPERSTRUCTURE

As mentioned in first chapter, the antenna supporting structure is to be designed considering the effect of supporting soil. However, to study the behavior and work out a suitable structural configuration, the superstructure is first considered independently with fixed base conditions. The effect of soil is considered in the next chapter.

3.1 GEOMETRY OF SUPPORTING STRUCTURE

The height of supporting structure is 11 m from the base of the circular raft slab to the top of the pedestal. The diameter of circular raft slab is 12 m. The height of the conical shell is 10.4 m. The outer diameter of conical shell at the top is 4.9 m. The outer diameter of conical shell at its bottom is 9.30 m. The wall thickness of conical shell is 0.5 m. Similarly circular slabs are provided at the top and mid-height of the pedestal the cross-sectional details are shown in Fig. 1.1. The thickness of circular slabs is 0.5 m. The proposed depth of foundation is 3 m below original ground level. These dimensions are shown in Fig. 3.1

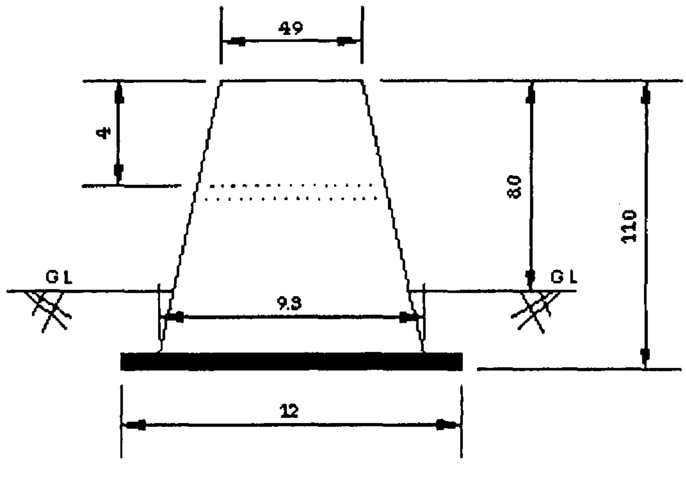


Fig. 3.1 Elevation of pedestal (all dimensions are in meters)

3.2 MATERIAL PROPERTIES

The material properties considered for the supporting structure are

(i) Elastic modulus of concrete = 2.73861×10^{10} N/m^2. (M30 grade)

(ii) Density of concrete = 2500 kg/m^3

(iii) Poisson's ratio = 0.15

3.3 LOADS ON SUPPORTING STRUCTURE

The elevation axis of antenna is at 4 m above the pedestal top. The maximum loads acting on the antenna at this level at operational conditions at a wind speed of 100 Km/h are as given below.

(i) Maximum elevation axis drag = 197 kN.

(ii) Maximum elevation axis lift = 154 kN

(iii) Maximum elevation axis moment = 507 kN m

(iv) Max wind torque at elevation axis = 811.4 kN m

(v) Dead load of antenna = 467.5 kN.

The directions of these maximum loads are shown in Fig. 3.2. These loads on the antenna supporting structure are furnished by the manufacturer.

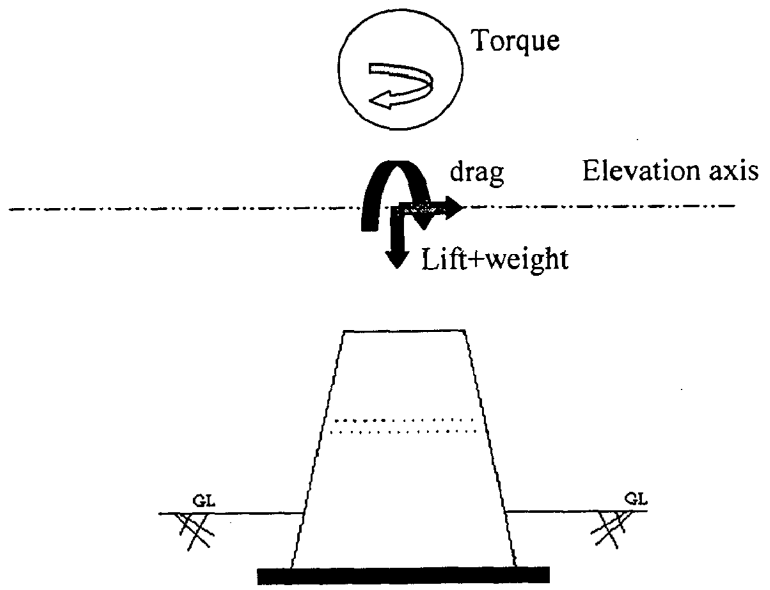


Fig. 3.2 Loads acting on supporting structure

3.4 MODELING OF STRUCTURE

3.4.1 Solid modeling

Cylindrical coordinate system is used to generate the mathematical model of the supporting structure. Taking the advantage of symmetry only one-tenth of supporting structure is modeled. The total model is generated using this one-tenth model by the software. 8 nodded brick element [10] is used to create a 3-D finite element model. Separate solid regions like ring beam, slab, wall of the shaft are interconnected together to behave as a single entity.

3.4.2 Meshing

Of the two meshing options available in the software mapped mesh is used for descritizing the supporting structure as it helps in controlling the density of mesh. Mapped volume mesh contains only hexahedron elements. In addition mapped mesh typically has a regular pattern with obvious rows of elements. Before meshing, the size of element should be decided. The finite element model of supporting structure is given in Fig. 3.6. The number of elements and nodes used for the construction of mathematical model of supporting structure are furnished in Table 3.1.

Table 3.1 Number of elements and nodes in the different models

Model description	Number of elements	Number of nodes
Superstructure without ribs	2940	5101
Superstructure with 10 ribs	3190	5786
Superstructure with 20 ribs	4851	7549

3.4.3 Boundary conditions

In this chapter to study the behavior of superstructure, fixed base response is considered assuming that no interaction exists between the superstructure and the foundation. The influence of soil is considered later in the next chapter. In this analysis all the nodes at the base of raft are fixed against movement in x, y and z directions. This fixidity condition helps to select appropriate superstructure to be used in the analysis with soil mass in next chapters.

3.5 APPLICATION OF LOADS

The loads described in section 3.3 are applied on 20 points, on the center of the ring beam at the pedestal top of the conical shaft as shown in Fig. 3.3. The drag is applied in horizontal direction, the lift and weight of antenna is applied in vertical direction. It should be noted that weight and lift are both acting in downward direction. The moment is replaced by equivalent vertical reactions. As specified drag is to act at 4 m above pedestal top, additional moment due to drag is also considered at the pedestal top. The torque is replaced by equivalent horizontal reactions. Wind load is also considered on the conical shaft. Live load of 500 kg/m^2 and 1000 kg/m^2 are considered at 4 m and 8 m levels respectively.

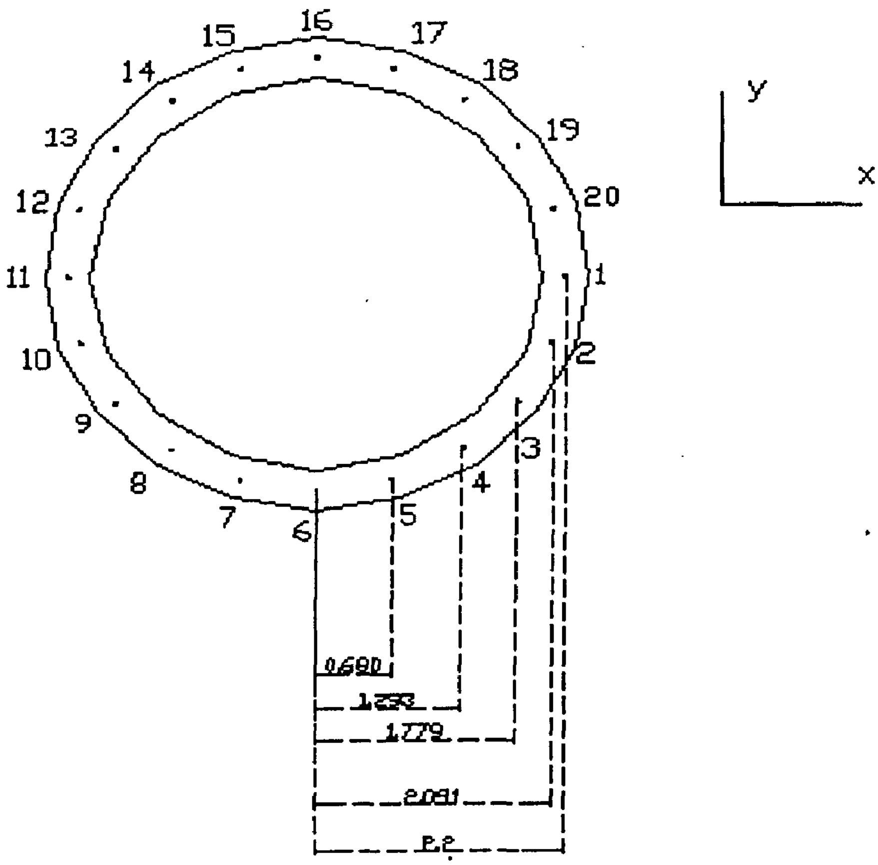


Fig. 3.3. Plan of pedestal top with nodes that are to be loaded

Total vertical load acting on each node = Lift force / 20 + weight of antenna / 20 + equivalent vertical reactions due to moment + equivalent vertical reactions due to moment caused by drag force

Total horizontal load on each node at pedestal top = Drag force / 20 + equivalent horizontal forces due to torque.

3.5.1 Conversion of moment and torque into equivalent vertical and horizontal forces

The moment / torque is converted into equivalent vertical / horizontal forces and applied at 20 points along center of ring beam on top of the pedestal.2

Equivalent vertical force at the i[th] node due to moment is given as $R_i = \frac{M \times X_i}{\sum X_i^2}$

Where X_i is the horizontal distance of the i[th] node from the axis of moment.

Similarly torque will result in horizontal forces in X and Y directions at all the points.

Equivalent horizontal force at the i[th] node due to torque can be obtained as

$$H_{xi} = \frac{T \times X_i}{\sum R_i^2} \quad (3.1)$$

$$H_{yi} = \frac{T \times Y_i}{\sum R_i^2} \quad (3.2)$$

Where, X_i and Y_i are coordinates of i[th] node and $R = \sqrt{X_i^2 + Y_i^2}$

3.5.2 Transfer of drag to the pedestal top

Drag is acting at height of 4 m. This results in horizontal force and moment at the top of the pedestal. The horizontal force is distributed equally on the twenty nodes and the moment is converted into equivalent vertical reactions as described above.

The resultant vertical and horizontal forces applied at top of the pedestal on 20 nodes are shown in Tables 3.2 and Table 3.3 respectively. Negative and positive signs indicate direction of force to be applied.

Table 3.2 Vertical forces to be applied on 20 nodes for static analysis

Node No.	Lift (kN)	Weight (kN)	Equivalent forces due to moment (kN)	Equivalent forces due to drag (kN)
1	-7.7	-23.375	-23.06	-35.84
2	-7.7	-23.375	-21.92	-34.06
3	-7.7	-23.375	-18.65	-28.98
4	-7.7	-23.375	-13.55	-21.06
5	-7.7	-23.375	-7.130	-11.07
6	-7.7	-23.375	0.000	0.000
7	-7.7	-23.375	7.130	11.07
8	-7.7	-23.375	13.55	21.06
9	-7.7	-23.375	18.65	28.98
10	-7.7	-23.375	21.92	34.06
11	-7.7	-23.375	23.06	35.84
12	-7.7	-23.375	21.92	34.06
13	-7.7	-23.375	18.65	28.98
14	-7.7	-23.375	13.55	21.06
15	-7.7	-23.375	7.130	11.07
16	-7.7	-23.375	0.000	0.000
17	-7.7	-23.375	-7.130	-11.07
18	-7.7	-23.375	-13.55	-21.06
19	-7.7	-23.375	-18.65	-28.98
20	-7.7	-23.375	-21.92	-34.06

Table 3.3 Horizontal forces to be applied on 20 nodes for static analysis

Node No.	Drag (kN)	Force due to torque (kN)
1	9.85	0
2	9.85	-11.41
3	9.85	-21.69
4	9.85	-29.85
5	9.85	-35.08
6	9.85	-36.91
7	9.85	-35.08
8	9.85	-29.85
9	9.85	-21.65
10	9.85	-11.41
11	9.85	0.00
12	9.85	11.41
13	9.85	21.69
14	9.85	29.85
15	9.85	35.08
16	9.85	36.91
17	9.85	35.08
18	9.85	29.85
19	9.85	21.69
20	9.85	11.41

3.5.3 Wind load on conical pedestal

The wind load has been calculated as per IS: 875 (Part 3) –1987.

A design wind speed of 100 km/h (27.7 m/s) has been specified.

Design wind pressure $p_z = 0.6 \times V_z^2 = 0.6 \times 27.7 \times 27.7 = 460.374$ N/m^2.

Wind force on supporting structure $F = C_t \times Pd \times A_e$

Where,

C_t = force coefficient = 0.7 (for circular plan shapes)

P_d = design wind pressure

A_e = effective area of the object normal to the wind direction

This wind load can be assigned as pressure load in the software. These forces are applied on the pedestal as shown in Fig 3.4 and Fig 3.5.

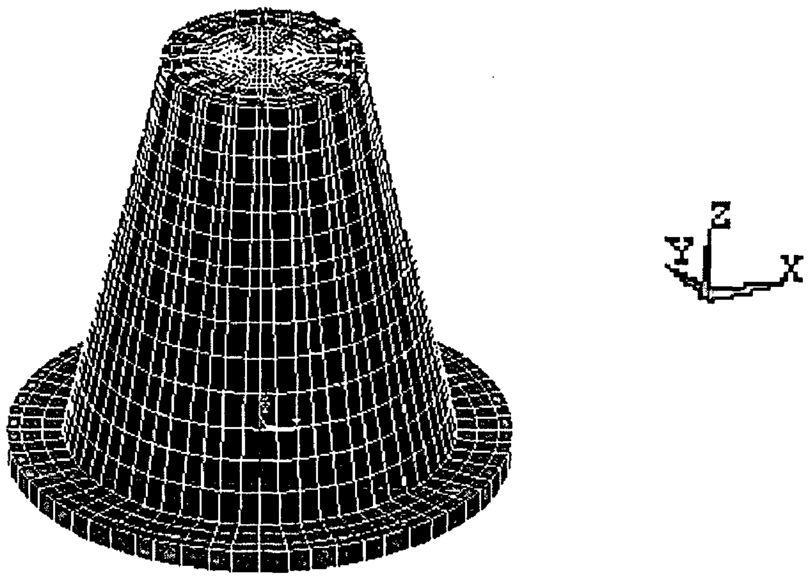


Fig. 3.4 Application of resultant vertical and horizontal forces on pedestal top

3.6 MODELING OF ANTENNA MASS

The mass of antenna is concentrated at 4m above the pedestal top. The mass of antenna affects the behavior of supporting structure. So in order to consider the effect of antenna on supporting structure, solid cylinder of height 4m and 1.5m radius is created. The structural properties of this cylinder is kept as

$E= 2.7\times10^{13}$ N/m^2 and density = 0.

These values are selected to nullify the effect of cylinder on supporting structure. The modulus of elasticity is given a value about 1000 times the value of concrete to avoid the vibration of cylinder and the density is taken zero to avoid the mass contribution of the cylinder. The mass of antenna is placed at the center of cylinder using mass21 element at the top. The finite element model of this arrangement is shown in Fig. 3.6.

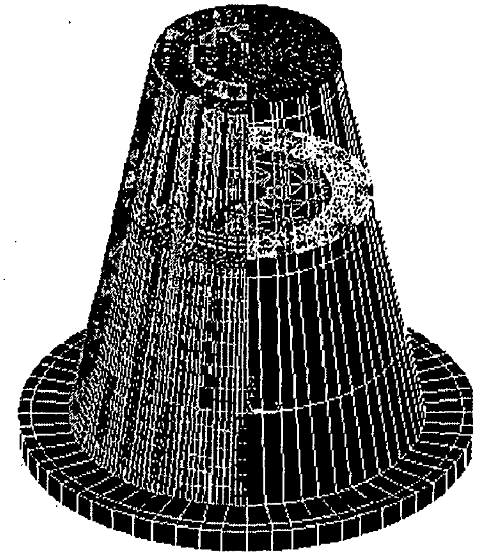


Fig. 3.5 Live load and wind load on conical pedestal applied as pressure loads

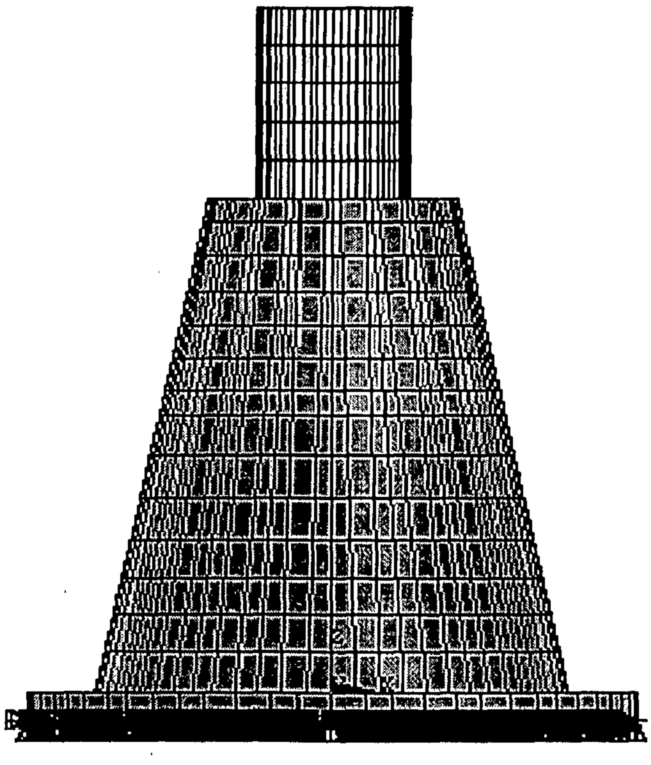


Fig. 3.6. Modeling of antenna mass on supporting structure

3.7 STATIC ANALYSIS

First the supporting structure model without ribs is analyzed. The loads acting on the supporting structure are applied as explained in section 3.3... and static analysis is carried out using frontal solver technique which is available in the software. The maximum stresses obtained in the structure are given in Table 3.4. It is observed from the Table 3.4 maximum normal stresses in X, Y and Z - directions obtained in the supporting structure are within permissible limits. So nominal reinforcement is enough for this model according to IS 456-2000 [11] under operational loading conditions.

Table 3.4. Maximum stresses observed under operational loading conditions.

Model No.	Maximum normal stress in X-direction (N/m^2)	Maximum normal stress in Y-direction (N/m^2)	Maximum normal stress in Z-direction (N/m^2)	Comments
1	$37.9986\times10^4 N/m^2$	$52.89\times10^4 N/m^2$	$15.4\times10^5 N/m^2$	Maximum stresses in x, y and z directions are less than permissible value $30\times10^6 N/m^2$

The maximum lateral displacement is also calculated from the static analysis, which is one of the stringent requirements of supporting structure. The displacements occurring on the pedestal in the lateral direction are shown by displacement contours due to operational loading conditions in Fig. 3.7. Maximum lateral displacement is observed on the pedestal top and is equal to 0.101×10^{-3} m. Therefore, rotation angle for a pedestal height of 11.0 m comes to be 0.000526 degree, which is more than stipulated rotation value (0.0004 degree). Hence the pedestal without ribs did not satisfy displacement criteria.

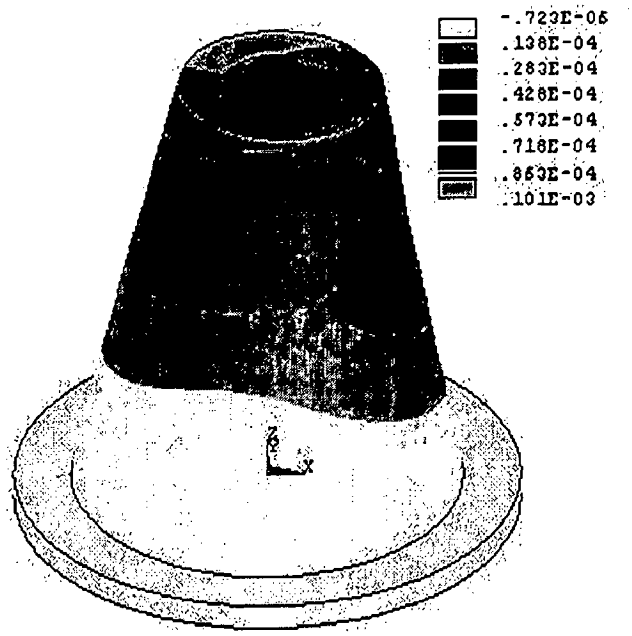


Fig. 3.7 Displacement contours on supporting structure

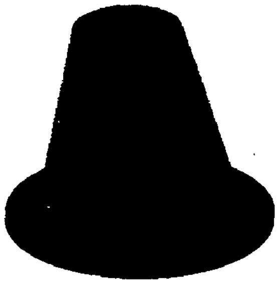
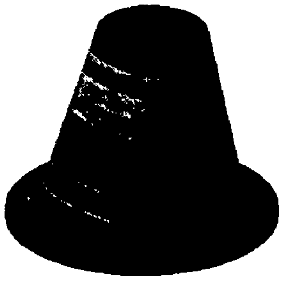
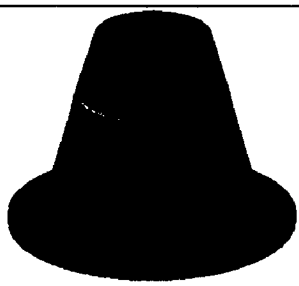
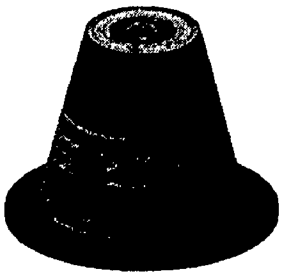
3.8 FREE VIBRATION ANALYSIS

Free vibration analysis is carried out on the supporting structure without ribs using subspace iteration method. Fro the analysis the fundamental frequency of this model is observed as 31.972 Hz. Which is more than stipulated limit 20 Hz. Hence the supporting structure without ribs satisfied frequency criteria. Modes and mode of vibration obtained from the analysis are given in Table 3.5. It is observed from the Table 3.5 first two modes are equal and are having rocking modes of vibration. Third mode of vibration is in vertical direction and fourth mode of vibration is torsion i.e., rotation about vertical axis of the supporting structure.

3.9 STUDY OF SUPERSTRUCTURE WITH RIBS

From the static and modal analysis results of supporting structure without ribs, it is inferred that it is not satisfying the displacement design criteria though it is satisfying frequency criteria. But the supporting structure should satisfy stringent design criteria

Table 3.5 Modes and mode shapes of pedestal without ribs

Mode No.	Frequency (Hz)	Mode shape	Mode of vibration	Comments
1	31.972		X-direction	The fundamental frequency of supporting structure in fixed condition is more than 20 Hz
2	31.972		Y-direction	
3	66.497		Z-direction	
4	69.089		Torsion	

even with soil below it. Hence to increase the performance of structure the conical structure with ribs is considered for further analysis because generally ribs increase the stiffness of the structure. First 10 ribs of uniform size are placed on the pedestal. Static analysis and modal analysis is performed on the model. The results obtained are furnished in Table 3.6.

Table 3.6 Results for pedestal with 10 ribs of uniform size $1\times 0.5\ m^2$

Description of ribs	No of ribs	Lateral displacement(m)	Rotation angle (degree)	Natural frequency (Hz)
Uniform ribs of size $1 \times 0.5m^2$	10	0.82×10^{-4}	0.00042	30.928

Results in the Table 3.6 show resistance to lateral displacement of supporting structure is increased for the model with 10 number of ribs of uniform size $1\times 0.5\ m^2$ but its natural frequency is reduced to 30.927 Hz. It is an uncommon behavior. Usually ribs are added to increase the stiffness of the supporting structure so that natural frequency increases but for this model it is decreased. To analyze the reason for this uncommon behavior, static analysis for this model has been carried out by applying an arbitrary horizontal force (25 kN) on top of pedestal. The application of load and stress distribution is shown in Fig. 3.8. High stresses are observed at bottom of pedestal and the ribs, which are in the direction of load, are only subjected to high stresses. The top portion of the ribs does not have significant stress. Similarly the ribs at larger angles from the direction of load develop less stress. Therefore in case of uniform ribs, the rate of increase of stiffness is less than rate of increase of mass. Hence causing decrease in frequency. So a parametric study has been carried out by using tapered ribs and also by increasing the number of ribs to 20.

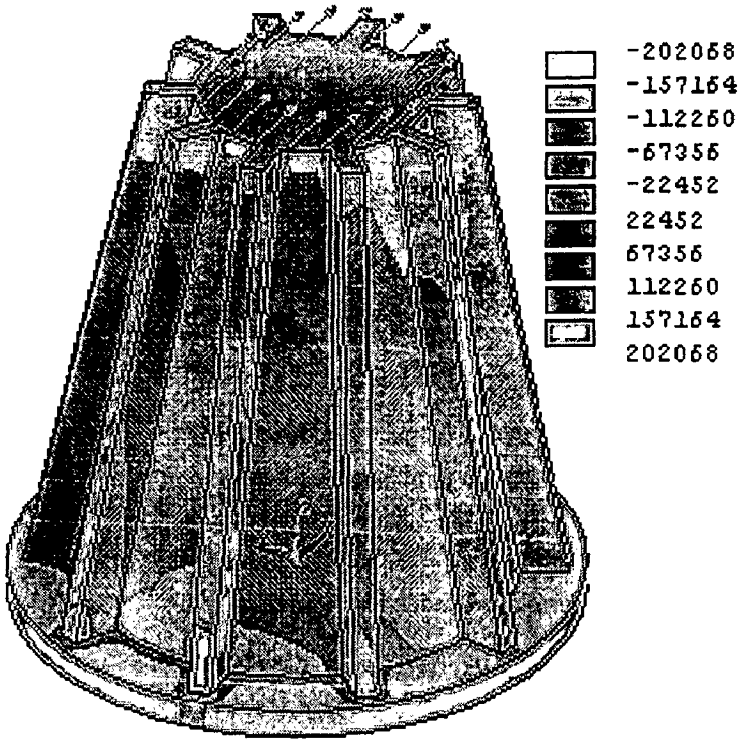


Fig. 3.8 Stress contours on pedestal in z-direction

3.10 PARAMETRIC STUDY

In order to get the most suitable model for analysis on soil mass, a parametric study has been carried out, by changing the structural details of the ribs. Several patterns of ribs on the conical pedestal are considered. By observing the results obtained for free vibration and static analysis in the Table 3.7. We can notice that ribs are playing very important role in lateral displacement but these are not so important for frequency as the change in frequency for different rib patterns is not significant. Considering both frequency and displacement, model with 20 tapered ribs of size 1×0.5 m^2 at bottom and 0.5×0.5 m^2 at top is most suitable model as it has maximum frequency and displacement almost equal to the minimum displacement of pedestal with 20 uniform ribs of size 1×0.5 m^2.

Table 3.7 Results observed for different patterns of ribs on the conical pedestal

Description of model	Number of ribs	Maximum Lateral displacement (m)	Rotation angle (Degree)	Natural frequency (Hz)
Tapered ribs of size 1 × 0.5 m^2 at bottom and 0.1 × 0.5 m^2 at top	10	0.96×10^{-4}	0.0005	33.887
Tapered ribs of size 1× 0.5 m^2 at bottom and 0.1×0.5 m^2 at top	20	0.707×10^{-4}	0.000368	33.918
Uniform ribs of size 1 × 0.5 m^2	20	0.516×10^{-4}	0.000268	29.923
Tapered ribs of size 1× 0.5 m^2 at bottom and 0.2 × 0.5 m^2 at top.	10	0.938×10^{-4}	0.000484	33.51
Tapered ribs of size 1 × 0.5 m^2at bottom and 0.3 × 0.5 m^2 at top	10	0.931×10^{-4}	0.000485	33.145
Tapered ribs of size 1 × 0.5 m^2 at bottom and 0.5 × 0.5 m^2 at top	10	0.893×10^{-4}	0.000465	32.451
Tapered ribs of size 1 × 0.5 at bottom and 0.5 × 0.5 at top	20	0.587×10^{-4}	0.000305	32.338

3.11 CONCLUSIONS

The supporting structure without ribs is not satisfying the stringent requirements of supporting structure. When we add ribs of uniform size, decrease in frequency is observed. Based on the stress contours observed along the height of pedestal for certain amount of horizontal load on pedestal top, a parametric study is carried out by changing the cross-sectional dimensions of ribs and their number on the pedestal top. Based on this study it is concluded that ribs are playing an important role in reducing the lateral displacement of pedestal top, and the ribs with tapered section are resulting in increase in frequency of pedestal. Based on parametric study results, 20 number of tapered cross-sectional ribs of size 1×0.5 m^2 at bottom and 0.5×0.5 m^2 at top and 20 number of uniform ribs of size 0.5×0.5 m^2 are showing better performance with respect to minimum displacement criteria. With respect to the frequency criteria tapered rib model is having higher frequency than uniform rib model. From economy considerations also, tapered rib model is preferable.

STUDY OF SOIL EFFECTS

Based on the frequency and displacement for the model with 20 tapered ribs of cross-section 1×0.5 m^2 at bottom and 0.5×0.5 m^2 at top the most suitable model, selected, in previous chapter is now analyzed with the soil mass. The supporting structure hereby in this work refers to the above model unless and until a change in configuration is specified.

4.1 MODELING OF SOIL

Structural response of any structure depends on foundation support conditions and nature of soil below it. A structure always has finite dimensions and its mathematical model with number of degrees of freedom can always be constructed. The soil on the other hand 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 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 assumed as fixed.

4.2 FINITE ELEMENT MODELING OF SOIL

The soil adjacent to raft is modeled using 8-noded brick element. The element is assumed to be isotropic. Taking the advantage of symmetry of a supporting structure only one tenth of supporting structure along with soil is modeled and total model is generated using this one tenth of supporting structure. The finite element mesh used for analysis is shown in Fig. 4.1. The size of the element is increased in the radial direction. The number of elements and nodes used for the construction of mathematical model of soil mass for 30 m radius and 20 m depth of soil mass are 15490 and 18008 respectively.

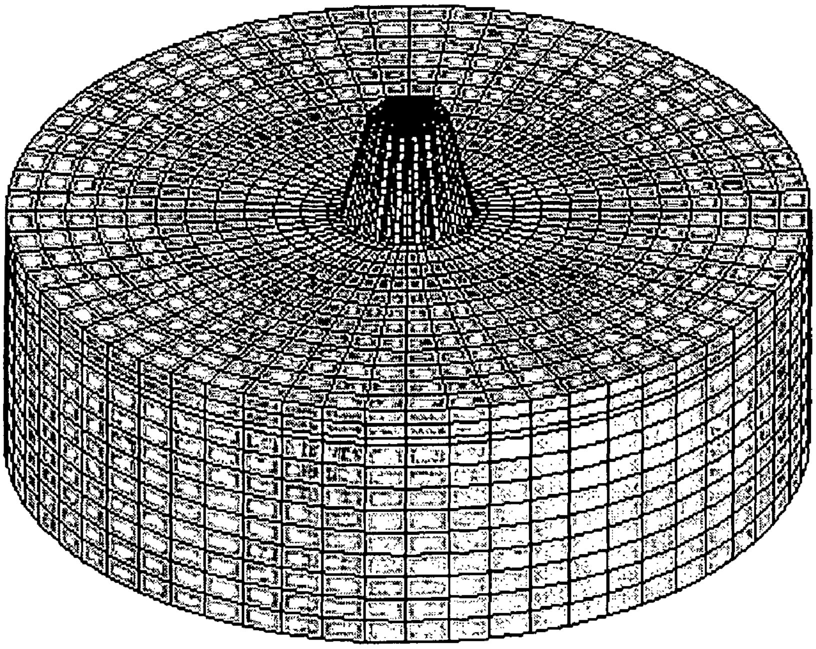


Fig. 4.1 Finite element model of supporting structure with soil mass

4.2.2 Boundary conditions

As the supporting structure plan is circular in shape, the finite element model of soil mass is modeled as a solid cylinder. The outer vertical surface and base of the soil mass is restrained in X, Y and Z directions.

4.2.3 Soil properties

Usually the stiffness of soil differs considerably depending on the degree of consolidation and shear wave velocity of soil. The soil modeled below raft is assumed to be homogeneous for the analysis. The soil properties considered for the analysis is expressed by using shear wave velocity, density of soil and Poisson's ratio. Using these soil properties, elastic modulus of soil was calculated using the following relation and given as material property of soil element in the software.

$$V_s = \sqrt{\frac{E}{2\rho(1+\upsilon)}} \tag{4.1}$$

Where,

E = elastic modulus of soil.

ρ = density of soil.

υ = Poisson's ratio of soil.

4.3 EFFECT OF SOIL

Soil is a semi-infinite medium or unbounded domain so a mathematical model with finite degrees of freedom cannot be constructed. So a parametric study for the various extents of soil is also carried out for the analysis while studying the behavior of supporting structure on soil media. This study helps to know the extent of soil considered adjacent to the structure, is reasonable or not. If the difference between the results obtained, for different extents of soil considered is small, then the results corresponding to the larger dimensions of soil can be taken to analyze the behavior of supporting structure. The soil with shear wave velocity 150 m/s is considered for the parametric study. Density of soil is taken as 1850 Kg/m^3 and Poisson's ratio of soil as 0.3. Free vibration and static analysis are carried out for different extents of soil and results obtained are shown in Table 4.1.

Table 4.1 Results for different extents of soil with a shear wave velocity of 150 m/s.

<table>
<tr><th>S.No</th><th>Radius of soil mass (m)</th><th>Depth of soil mass below ground level (m)</th><th>Maximum lateral displacement (m)</th><th>Rotation angle (Degree</th><th>Natural Frequency (Hz)</th><th>Requirements of supporting structure</th></tr>
<tr><td>1</td><td>24</td><td>20</td><td>0.671×10^{-3}</td><td>0.00349</td><td>7.311</td><td rowspan="3">Frequency should be more than 20 Hz and maximum lateral displacement should be below 0.0004 degree</td></tr>
<tr><td>2</td><td>30</td><td>16</td><td>0.706×10^{-3}</td><td>0.00367</td><td>7.025</td></tr>
<tr><td>3</td><td>30</td><td>20</td><td>0.6978×10^{-3}</td><td>0.00363</td><td>7.125</td></tr>
</table>

By observing the results obtained for different extents of soil considered for the analysis in the Table 4.1, insignificant variation between frequencies and maximum displacements is observed. Hence the extent of soil mass considered is sufficient. The mode shapes and displacement contours observed for supporting structure with soil of shear wave velocity 150 m/s are given in Table 4.2 and Fig. 4.2. However the natural frequency and maximum displacements obtained for supporting structure are far below the stringent requirements of supporting structure. Hence the supporting structure with this configuration is not suitable on soils having shear wave velocity of 150 m/s.

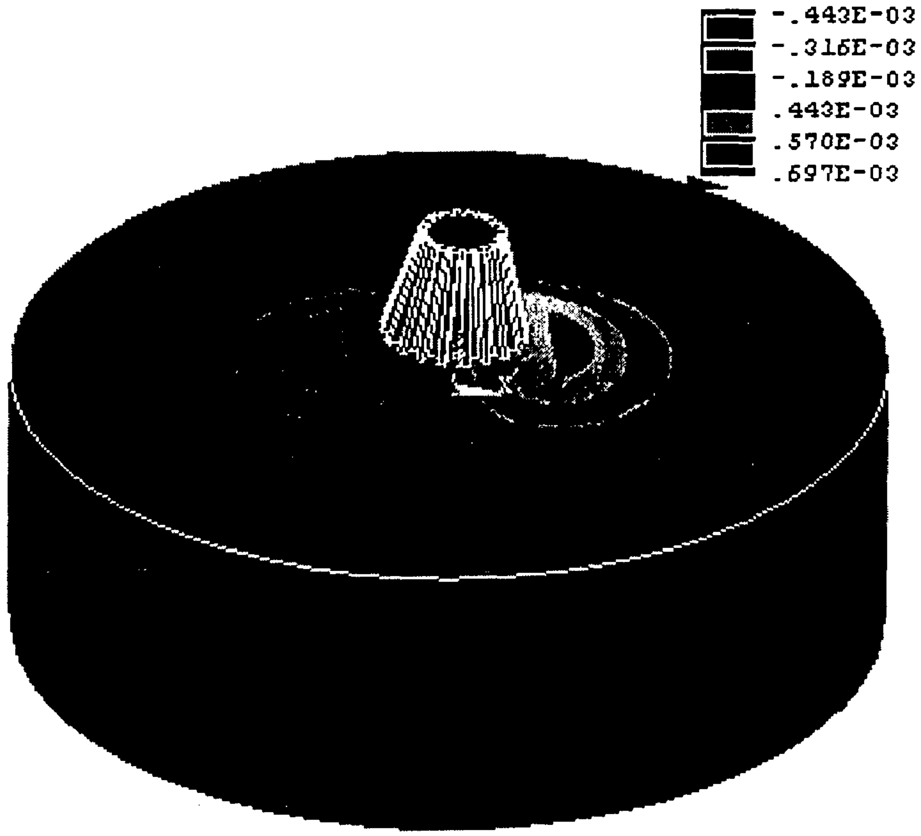
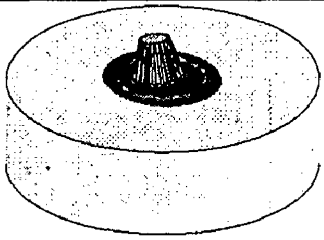
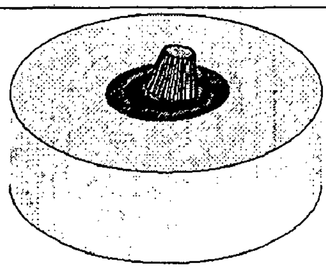
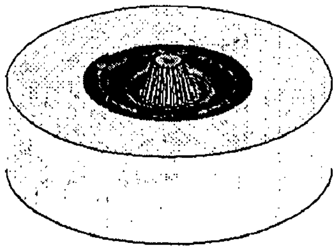
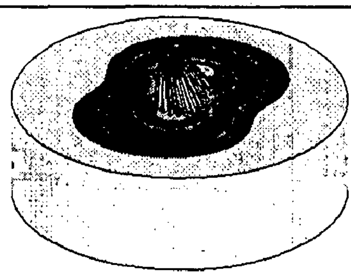


Fig. 4.2 Lateral displacement contours in the soil mass and supporting structure

4.4 RAFT WITH PILES

When the soil at or near the ground surface is not capable of satisfying the requirements of the supporting structure pile foundations can be used [12]. These foundations are commonly used to stiffen the soil beneath the foundations and to control both amplitudes and the natural frequency of the system.

Table 4.2 Frequency and mode shapes of pedestal with soil mass

Mode No.	Frequency (Hz)	Mode shape	Mode of vibration	Comments
1	7.125		X-direction	
2	7.125		Y-direction	
3	10.058		Z-direction	The fundamental frequency of supporting structure on soil is less than 20 Hz
4	15.692		X-direction	

4.4.1 Modeling of piles

The piles are also modeled using 8-node brick element and element is assumed to be isotropic. The plan of arrangement of piles below the raft is shown in Fig. 4.3. RCC piles of uniform circular cross-section are used. The material properties and dimensions of piles used for the analysis are given below.

Length of pile = 15m

Diameter of pile = 1m

Elastic modulus of pile = 273861×10^5 N/m^2

Density of pile = 2500kg/m^3

Poisson's ratio = 0.15

The material properties of soil considered for analysis are the same as in Section 4.3.

4.4.2 Limitations in modeling

The interface between the pile and the soil adjacent to the pile shaft are interconnected by the thin solid 8-node brick elements. The aspect ratio of elements near the pile is kept 5 vertical to 1 horizontal [13]. Interface elements are not used. Arrangement of piles below the raft is done arbitrarily for a parametric study. The material properties considered for piles are arbitrarily chosen.

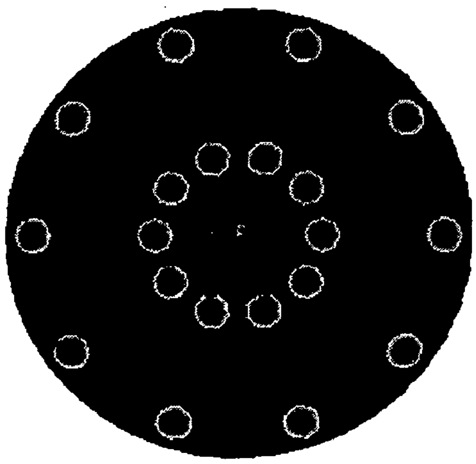


Fig. 4. 3 Pattern of arrangement of piles below raft.

4.4.3 Effect of piles

Static and Free vibration analysis is carried out along with soil and piles, for supporting structure without ribs. Results obtained are furnished in the Table 4.3.

Natural frequency of supporting structure has increased and maximum lateral displacement decreased when piles are used. As observed from Table 4.3, provision of piles does not satisfy the stringent requirements of the supporting structure.

Table 4.3 Results for supporting structure with piles

Description	Natural frequency (Hz)	Maximum lateral displacement (m)	Rotation angle (Degree)
Supporting structure with RCC piles below the raft	13.335	0.25×10^{-3}	0.0013

4.5 PARAMETRIC STUDY WITH DIFFERENT SOILS

As the requirements of the supporting structure with a soil mass of shear velocity 150 m/s is still not satisfied, a parametric study has been carried out by changing the material properties of soil below the supporting structure. The material properties of the soil to be considered for the analyses and the results obtained after carrying out free vibration and static analysis are given in Table 4.4.

Table 4.4 Maximum lateral displacement and fundamental frequency of supporting structure for different shear wave velocities of soil.

Shear wave velocity (m/s)	Maximum lateral displacement (m)	Rotation angle (Degree)	Natural frequency (Hz)	Permissible limits	
				Frequency (Hz)	Rotation angle (Degree)
300	0.227×10^{-3}	0.002480	14.1360	Should be more than 20.	Should be less than 0.0004
600	0.101×10^{-3}	0.000526	24.1412		
1200	0.879×10^{-4}	0.000457	22.8960		
2000	0.759×10^{-4}	0.000390	30.1550		

Usually the shear wave velocity of dense soils ranges from 200 to 300 m/s. In the Table 4.4 it is seen that the supporting structure did not show satisfactory results with the soil of shear wave velocity 300 m/s. Hence it can be concluded that the supporting structure with present configuration is not suitable to be constructed on soil medium. Now, the behavior of supporting structure is analyzed by considering the properties of rock. The shear wave velocity of rock varies from 1000 m/s to 3500 m/s. The supporting structure can rest on the rock and embedment of structures is not needed. So for shear wave velocities of 1200 m/s and 2000 m/s study of behavior of supporting structure is carried out without embedment. From the Table 4.4, it can be seen that for shear wave velocity of 1200 m/s the frequency criteria is satisfied but the displacement is above the specified limit whereas with shear wave velocity of 2000 m/s both these criteria are satisfied. Since the displacement in this case is marginally lower than the specified permissible limit. The supporting structure with 20 number of ribs of size 1×0.5 m^2 is analyzed on rock with a shear wave velocity of 2000 m/s as it have shown better performance than the tapered ribs with respect to displacement criteria in fixed condition. With this data the results tabulated in Table 4.5 satisfy the permissible limits criteria The maximum displacement and mode shapes observed for the supporting structure with 20 numbers of uniform ribs on pedestal are shown in Table 4.5 and Fig. 4.4.

Table 4.5 Results for supporting structure with 20 number ribs of uniform size 1×0.5 m^2 on rock

Maximum lateral displacement (m)	Rotation Angle (Degree)	Natural frequency (Hz)	Comments
0.718×10^{-4}	0.000358	27.241	Stringent requirements are satisfied.

4.6. CONCLUSIONS

The study of antenna supporting structure founded on soil with different shear wave velocities has shown that the frequency and displacement criteria cannot be satisfied for pedestals on soil. This type of footing is possible only on hard rock.

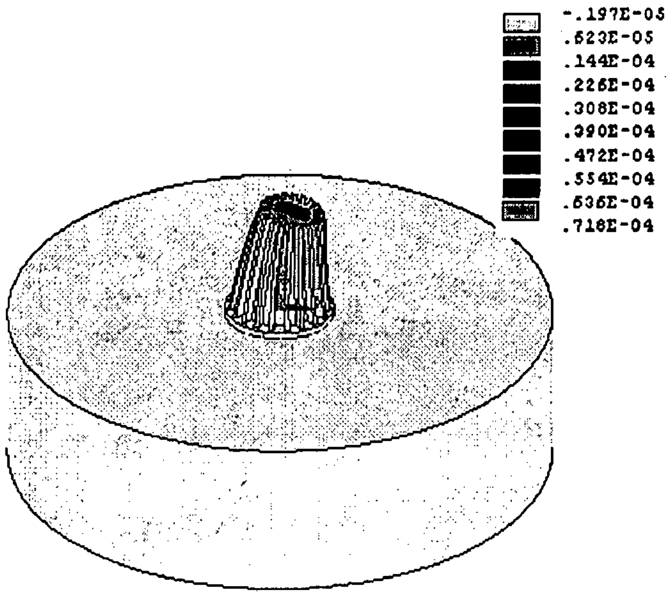
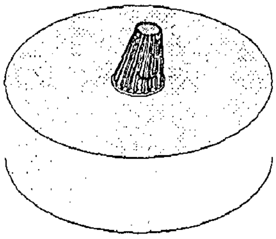
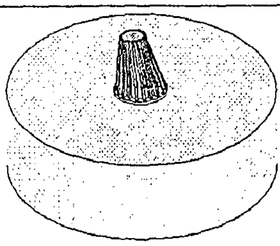
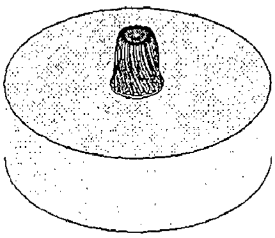
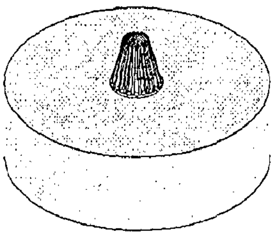
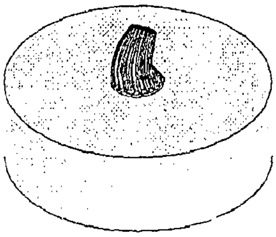


Fig. 4.4 Displacement contours of supporting structure on rock under antenna operational loading

Table 4.6 Modes and mode shapes of supporting structure 20 ribs of size 1×0.5 m^2

Mode No.	Frequency (Hz)	Mode shape	Mode of vibration	Comments
1	27.241		X-direction	
2	27.241		Y-direction	
3	45.419		Torsion	The fundamental frequency of supporting structure on rock is more than 20 Hz
4	64.147		Z-direction	
5	68.29		X-direction	

CONCLUSIONS AND SCOPE FOR FUTURE WORK

Truncated conical pedestals with and without ribs founded on soil or rock with varying shear wave velocity have been studied. Their suitability as antenna supporting structure subjected to stringent frequency and displacement design criteria under severe wind loading have been studied. The following conclusions have been drawn.

1. Ribs do not have any significant effect on frequency as the contribution to mass nullifies the contribution to stiffness.
2. The ribs significantly reduced the deflection.
3. The stress distribution shows that only bottom portion of ribs is effective under lateral load. Hence tappered ribs provide an economical solution.
4. It is not possible to achieve the stringent design criteria with pedestals on soil. It can be achieved with pedestals on rock.

In future studies other alternatives in terms of material (steel) and structural configurations may be studied to achieve the frequency and deflection with antenna supporting structures on soils.

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