EVALUATION OF PRESENT SAFETY LIMITS OF STEEL LATTICE TYPE TELECOMMUNICATION ANTENNA TOWERS IN SRI LANKA.

THIS THESIS IS SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING IN STRUCTURAL ENGINEERING DESIGN

By

G.R.V. PERERA

Supervised By

Dr. M.T.P. Hettiarachchi

Senior Lecturer

Department of Civil Engineering

DEPARTMENT OF CIVIL ENGINEERING

UNIVERSITY OF MORATUWA

SRI LANKA

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By Eng. G.R.V. PERERA

This thesis is submitted to the department of Civil engineering of the University of Moratuwa in partial fulfillment of the requirements for the Degree of M.Eng in Structural Engineering Design.

Department of Civil Engineering
University of Moratuwa
Sri Lanka
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DECLARATION

I hereby declare that the work included in the thesis, in part or whole, has not been submitted for any other academic qualification at any institution.

Eng. G.R.V. Perera

Certified by :

Dr. (Mrs.) M.T.P. Hettiarachchi,
Project Supervisor,
Department of Civil Engineering,
University of Moratuwa,
Sri Lanka.

ABSTRACT

Sri Lanka has made a significant development in the telecommunications sector since the inception of sector reforms in 1991, resulting in a competitive market environment. The results of liberalization have been impressive, with the telecommunications sector growing at one of the fastest paces in Asia. Along with above rapid growth of telecommunication industry, the numbers of antenna towers also have been increased from about 400 (in 1990) up to nearly 5100 towers during the last two decades.

During the above boom period of development, some aspects of safety and reliability seem to have been overlooked. This report provides detailed discussion on the technical aspects of steel lattice antenna tower designs, codes of practice and different factors of safety. Post-collapse assessments of four incidences of recently collapsed tall antenna towers in Sri Lanka are also included in this report.

Several shortcomings existing in currently available technical specifications, tender bidding processes and construction were also highlighted. The possible solutions and methods for eliminating above mentioned shortcomings are also discussed in detail.

The void that exists in telecommunication industry due to the absence of properly qualified structural engineering experts are also highlighted. Further to that, the resulting negative effects such as neglecting public safety, lower reliability of telecommunication network, high possibility of accidents occurring, etc. are discussed in detail.

The cost of construction vs safety of antenna towers is discussed with a desk study. Effectiveness of some common practices and beliefs which are influencing current antenna tower constructions are also discussed.

Concluding remarks along with several basic recommendations are supplied for correcting the present mistakes while making more reliable telecommunication networks as well as ensuring public safety.

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1.0 Introduction

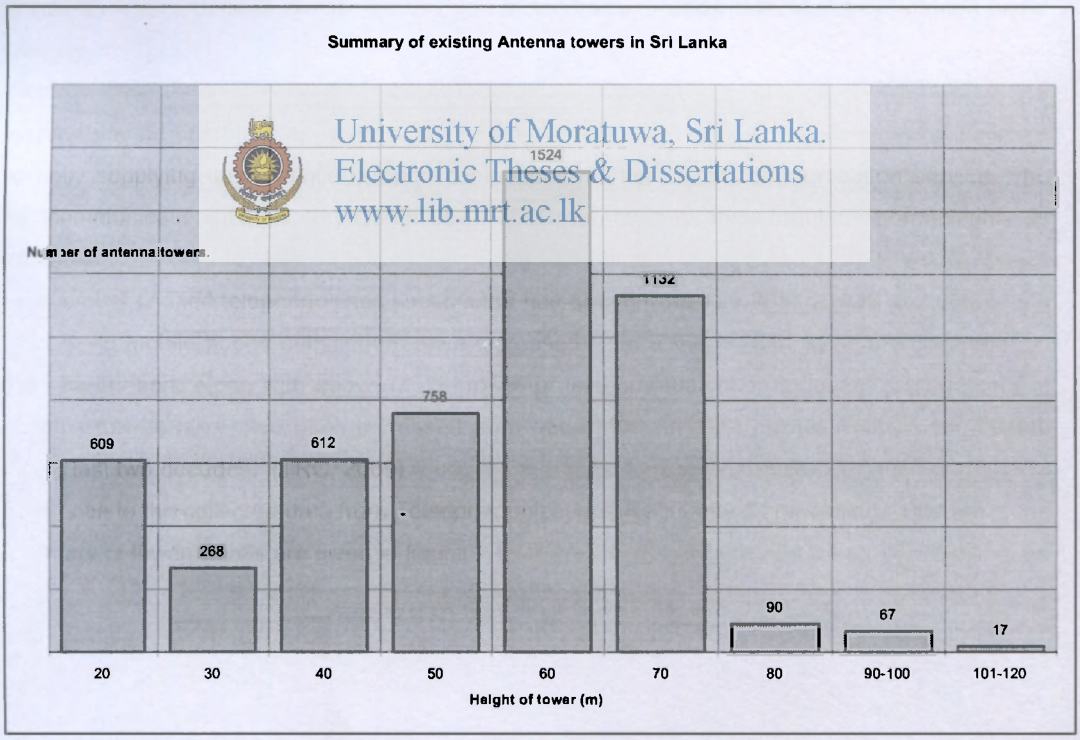
1.1 Background

Sri Lanka has made significant strides in telecommunications liberalization since the inception of sector reforms in 1991, resulting in a competitive market environment. The results of liberalization have been impressive, with the telecommunications sector growing at one of the fastest paces in Asia.

Several private operators as well as government (Sri Lanka Telecom - SLT) organizations are recently supplying their service in open competitive market of telecommunication service. The Telecommunications Regulatory Commission (TRC) is acting as their regulatory organization in Sri Lanka.

The number of fixed telephone lines subscribers has grown from 121,388 in 1990 to 2,086,774 in 2007 while mobile phone subscribers have increased from a mere 2644 to nearly 6.0 million in the same period. Along with above rapid growth of telecommunication industry, the numbers of antenna towers also have been increased from about 400 (in 1990) up to nearly 5100 towers during last two decades. (TRC, 2009)

Reference to the collected data from Telecommunications Regularity Commission - Sri Lanka, the summary of tower details are given in figure 1.1,



.Figure 1.1 - Summary of existing antenna towers in Sri Lanka

1.2 Different types of antenna towers

Antenna towers include any type of structures (i.e Chimneys, concrete structures, etc.) which carries telecommunication antennas, the scope of this report is limited to steel lattice structures and tubular monopoles.

There are three main types of common antenna structures,

- Steel lattice self supporting structures
- Steel lattice or tubular guyed mast structures
- Tubular monopole structures

These structures are further categorized into "Greenfield structures" and "Roof top" according to their place of installation.

1.3 Structural behaviour and safety of antenna towers

The steel lattice type structures are generally considered as one of the most complex and unpredictable type of structures. The principal design criteria of any antenna tower is the pressure due to wind. Self standing antenna structures are basically functioning as vertical cantilever structures. Therefore the items which contribute to an increase of wind loads on the tower such as shielding area of antennas, shielding area and shape of tower itself, installation height of ancillaries from ground level, etc. are considered as primary design criteria of any antenna tower designs.

The importance level of the tower in specific communication network, location of construction, the level of possible damage that may happen to humans in the event of any unexpected collapse and quality of steel fabrication are also considered as another set of primary level design criteria. As the antenna towers are a primary component of vital telecommunication links and usually located in populated locations such as towns and villages, it is always important to adopt correct engineering design of structures and ensure safety of the structure itself as well as the public.

1.4 Main objectives of this study

- Evaluation of engineering codes of practices and identify the correct method and factors of safety that should be used in antenna tower designs in Sri Lanka.
- Understand the relationship between cost of antenna tower and its structural design
- Identify the common mistakes and ill-practices that are currently being practised in Sri Lanka and their effect on safety of the structures.

1.5 Methodology

This research consisted of three types of studies,

1. **Literature review** – Finding the existing literature that is relevant to the topic and objectives of this research work
2. **Field study** - Collecting, evaluating and studying about the details/data available in present practice
3. **Desk study** - Studying and evaluating different criteria which relate to design and safety of antenna towers.

1.6 The arrangement of main chapters,

a. **Chapter 1.0 - Introduction.**

LITERATURE REVIEW

b. **Chapter 2.0 - Literature review.**

FIELD STUDY

c. **Chapter 3.0 - Basic details of design of steel lattice antenna towers**
Brief discussion about the main features of steel lattice antenna towers, correct method of designs and available engineering code of practices. It also includes overview about several computer software (for tower designs) which are available and adopted in present market,

d. **Chapter 4.0 - An overview of present practice of design and detailing of antenna towers**
Learn briefly about history of antenna tower designs, code of practices, etc. Identify the different loading and their effect on tower, factors of safety imposed by different codes of practices, advantages and limitations of steel antenna structures, detailing methods and preparation drawings, methods of testing and verifications.

e. **Chapter 5.0 - Review of reported collapse of antenna towers in Sri Lanka**
Brief overview about several reported collapses of antenna towers in Sri Lanka and discussion about the assessment of possible reasons for each of those failures.

f. **Chapter 6.0 – Failure analysis of antenna tower**
This chapter includes the model analysis of 60m high steel lattice antenna tower and structural behavior of its members under different loading situations

g. **Chapter 7.0 - Various other factors which affect tower designs**
Discussion about the various other factors (technical as well as non-technical) that can affect the safety of antenna towers. This discussion includes brief discussions on

Technical specification, Process of tender bidding and technical evaluation, Testing and verification, Qualification and experience of people involved, Quality of construction, Post Maintenance procedures, etc.

DESK STUDY

h. **Chapter 8.0 - Design of antenna tower to BS8100**
Study about the designing of antenna towers according to the BS8100. Learn the extent of resulting effects when designing towers for different design loads.

i. **Chapter 9.0 - Study of the influence of loading types on steel lattice tower design**
Study and discussion about the effect of different design loading on final steel weight/cost of the tower (according to BS8100)

j. **Chapter 10.0 - Discussion on the effect of tower design on final cost of construction**
Discussion about effect of final cost due to different design criteria.

k. **Chapter 11.0 – Review of several technical specifications**
Brief overview about the (technical) inputs and the quality of several technical specifications that have been included in recent antenna tower supply tender documents.

l. **Chapter 12.0 – Some statistics and overview of current tower design practice.**
Provides some statistics about antenna tower distribution in Sri Lanka and brief overview about some shortcomings which exist in current practice of antenna tower designs and construction that include a review of few design reports of existing antenna towers in Sri Lanka.
This chapter also includes some comments about the selection of suitable factors of safety which are applicable for the conditions in Sri Lanka, etc.

m. **Chapter 13.0 – Concluding remarks and Recommendations**

Some background data and information are also provided in annex (A).

2.0 Literature review

2.1 Introduction

Steel lattice towers and masts are familiar to everybody as these structures are situated in the open landscape as well as in the middle of our cities. While the tall masts and towers are mainly for broadcasting of radio and TV, the small masts, towers and poles are primarily used for mobile communication networks.

However, most of the general public is unaware of the engineering challenges and specialisms behind these common structures. Even most professionals who are practising in engineering field have very little knowledge about structural behavior of above antenna towers and masts. The above void of knowledge is mainly because of the scarcity of literature on above subject, limited number of employment opportunities available in telecommunication industry for those with civil engineering background, etc. Therefore, the only available channel for transferring the expertise on above subject is from senior engineer to the junior engineer.

2.2 Structure type and code of practice

Although the steel lattice type antenna towers are highly efficient structures, they are extremely complex type of structures too. McKittrick, (2010) has categorized the steel lattice masts and towers under structure complexity level 4, which is the category that included most complex structures types, such as shell structures, Chimneys, complex bridges, etc. After the above categorization of structure types, he has further highlighted the necessity of employing of staff with mix of senior professionals and graduates for such (the structures which are included in complexity level 4 category) design and construction works. Therefore, it is on accepted norm that the necessity of all steel lattice antenna towers to be designed, constructed and maintained under proper control of qualified structural engineering experts.

Andersen (2002), discussed the analysis and design of masts and towers, required special knowledge and experience, the special problems related to these structures, contradictory theories, the effect of overall structural layout on the loading on the structure, etc. He has also discussed the dynamic nature of the wind and the sensitiveness of the antenna towers to the dynamic loads. He also has given a brief introduction to the problems related to the analysis and design, as well as the some practical examples have been mentioned.

Wood, (2007) presented the results from simple drag force experiments on a range of standard telecommunication antennas and head frames tested in isolation and in a variety of antenna mounting configurations. According to his conclusion, the along-wind drag coefficients are reasonably independent of wind direction, but from the directional results and flow visualization, it is evident that shielding effects are complex and significant. He has also found that the torsional component is generally small and could be estimated by applying the along-wind drag at an eccentricity of about 5% of the frontal width of the head frame. His findings provide good verification about the accuracy of present practice on influence of along wind and cross wind drag coefficients on antenna towers.

Some of existing old antenna towers in Sri Lanka are designed according to earlier versions of American code of practice for antenna towers (i.e - EIA222C, EIA222D, EIA222E or EIA222F) or other similar engineering design codes of practices. However, those towers may not be reliable enough when comparing with the requirements which are imposed by the recent codes of practices. Sullins and Salim (2007) discussed the current feasibility and factor of safety on design wind and earthquake load of two existing antenna towers, which were designed for previous version of antenna design code. Two towers were analyzed using the TIA-222-F for wind and ice loadings. They have also discussed the computer analysis of antenna towers, several deficiencies that exist when analyzing antenna towers with general engineering software compared to the other software which are specialized for tower analysis. They also discussed the level of factors of safety those available in existing towers under current loadings and according to recent code of practice.
Moskal and Raghu (2006) have explained the differences in the basic design philosophies of the standard (Revision F) and the new Revision G of TIA/EIA222 codes. They also have discussed the impetus behind this major revision triggered by the latest understanding and state-of-the-art practices of the current codes and standards in the building industry.

2.3 Different methods of structural analysis

Although the several popular methods are available for idealizing the structures (such as simple truss modeling, etc.) for purpose of structural analysis of steel lattice antenna tower designs, the level of accuracy of such assumptions also an important factor for complex structural form like steel lattice antenna towers. Da Silva et al(2002), have discussed the impact between the traditional methods of structural analysis (simple truss behaviour) and other structural solution (i.e - all the steel element connections are considered as simple or hinged) that are involved in the designs of steel telecommunication and transmission towers. The investigation on a 40m high steel tower has been used to show that the maximum stresses and displacements for the structural modeling based on the two investigated methodologies (simple truss element and combined beam and truss element modeling), lead to similar results. They have done further comparisons of the two above mentioned design methods on an existing 75m high steel telecommunication tower too. The above results of analysis and the difference between actual behaviour and the results of theoretical analysis of antenna towers, well reflect the level of accuracy existing in present design methodology and the practice. Therefore, whatever the analysis or designing methods adopted, the design engineer should always ensure to keep some allowance for accommodating of possible errors that may happen between such theoretical idealization and actual practice.

Da Silva et al (2005) has also proposed an alternative structural analysis modeling strategy for the steel tower design considering all the actual structural forces and moments combining three-dimensional beam and truss finite elements. Comparisons of the two common design methods (1.Simple truss behaviour and 2. Semi-rigid connections) with above method is presented.
According to their conclusion *"The proposed methodology, less conservative than usual analysis methods, uses a combined solution of three-dimensional beam and truss finite element to model the structural behaviour of tower structures under several loading conditions".*

However, other than the discussion presented about different methods that can be use for analysis of steel lattice type towers and their level of conservativeness, They also have given an idea about the extra factor of safety that available due to adoption of conservative approach (Finite element method) of tower designs in present practice.

Lee, and McClure (2007) also have tried to compare the results of full-scale destructive tests with results of elastoplastic large deformation analysis of a lattice steel tower structure using finite element analysis. Their report provides good informative facts about the limits and level of accuracy between theoretical analysis and full scale test results. As a summary, when considering the maximum load-bearing capacity and the distribution of the failure members, they observed a good agreement between the numerical solutions of model and the experimental results. Therefore, it proves that the numerical model is a reliable method for predicting the ultimate behavior of the lattice steel tower structures.

2.4 Dynamic loads

As the wind load being the primary load on any steel lattice type antenna tower, the dynamic loads due to turbulent flow of wind on antenna towers cannot be neglected. Peil and Behrens (2007) have discussed occurrence of significantly incorrect estimation of the dynamic part of the wind load, particularly in highly turbulent flow. The consequences due to different approaches of the aerodynamic admittance function on the fluctuations of the wind loads are studied. Their analysis has been associated with full scale measurements on a 344m guyed mast too. However, they have discussed several shortcomings in assessing dynamic wind effects in the present design procedures. Some important remarks given by them as conclusion notes are as follows,

1. *Particularly with regard to the life time of critical constructional details of high and slender structures, the dynamic wind loads due to lateral turbulence have to be included in the calculation.*
2. *If higher-order terms of wind speed fluctuations are neglected, this will only produce minor errors taking as a basis wind events with turbulence intensities < 15%. Theoretical investigations show, however, that the error for estimating the variance of the fluctuating wind force process can reach values of about 20%, if higher turbulence intensities of nearly 25% occur.*

Likos and Salim (2005) discuss concerns and uncertainties regarding the current physical condition of the tower network and the associated performance of key towers during environmental loading events (seismic, wind & ice). After detailed analysis of the condition of respective telecommunication network and related structures, they have issued a report with long list of suggestions and recommendations. However, their final recommendations about the maintenance of towers can be considered as fully valid recommendations for all antenna towers in Sri Lanka too. Some of their recommendations are as follows,

1) *The CI system should be used to rank guyed towers in the MoDOT network. Once an initial CI is assigned to each tower, subsequent inspections and maintenance should be performed on a schedule as follows (from TAI/EIA 222-G):*
   a) *At a minimum of three-year intervals for guyed masts and five-year intervals for self-supporting structures.*

b) After severe wind, ice, or earthquake loadings

c) Shorter inspection intervals are required for structures in corrosive atmospheres or subject to frequent vandalism.

d) After a change in type, size, or number of appurtenances such as antennas, transmission lines, platforms, ladders, etc.

e) After any structural modifications

f) After any change in serviceability requirements or land use surrounding the structure

2) Decisions regarding repair to towers identified as deficient should be made in consultation with and external Tower Design, Analysis and Maintenance Consultant

3) Conduct more detailed dynamic modeling to address the following issues:

(a) The models for the towers were based on the available drawings. Some field measurements were collected to verify the drawings to fill-in the missing data. It is recommended that additional field measurements be collected exactly represent the towers as they exist in field;

(b) All attachments shown on drawings were included in the models. The existing towers have additional attachments that were not incorporated in the models. It is recommended that the analyses be performed with all attachments as per the field conditions;

Amiri and Boostan (2000) have done investigation of the dynamic behavior of self- supporting towers with four legs. They have studied about 10 existing self-supporting telecommunication towers with heights varying from 18 to 67 m. Finally, they have provided informative discussion about the behaviour of steel lattice towers under dynamic loadings while highlighting the necessity of considering earthquake loads in tower analysis and designs.

Ngoa and Letchford (2008) have done a study of topographic effects on gust wind speed. Four major wind-loading codes (ASCE/SEI 7-05, AS/NZS 1170.2: 2002, AIJ: 2004, and CEN TC 250) were reviewed and a combined terrain/height and topographic multiplier for each code were derived. Detailed comparisons of topographic effects between codes were presented too. Their concluding remarks are as follows,

"In contrast with AS/NZS 1170 and CEN TC 250, ASCE/SEI 7-05 and AIJ: 2004 show that wind speed-up effects upwind of the crest are quite different between types of topography and further research is needed to clarify these differences. This study has shown that significant differences in speed-up effects between four major wind-loading codes exist. These differences occur for: lower and upper limiting slopes, types of topography; hills, ridges and escarpments, and for regions of application of speedup effects both in the vertical and horizontal extent. Therefore, further research on speedup effects exploring these discrepancies is required."

Abraham et al (2005), have done investigation about the steel lattice towers those have collapsed during cyclones with lesser wind speeds than their design basic wind speeds. They have also presented case studies of failure analysis to identify the causes of possible failure of two microwave latticed towers, which collapsed in cyclonic wind conditions.

According to their investigations, the cyclonic basic wind speeds were lower than the limiting basic wind speeds but also observed that both the towers collapsed under respective cyclone conditions. By reviewing above tower collapses, they suggested to consider an extra margin of safety against the additional turbulence induced dynamic peak loads for the design of these towers along with the wind speed profiles corresponding to local terrain conditions.

Above case study provides valuable information relevant to our study on evaluation of present safety limits of antenna towers in Sri Lanka too. The observations about both of referred tower collapses (in India). are similar to the observations recoded in recent collapses of antenna towers at Mihintale and Horowpatana, Sri Lanka. Therefore, adopting of extra margin of safety against additional turbulence induced dynamic peak loads may be a good practice for Sri Lanka too. However, further research and detail investigation on above subject is highly recommended.

2.5 Foundations, Loads on foundations and durability

Unlike general civil structures such as buildings, etc, the uplifting force will be one of primary consideration in foundation design of any steel lattice type antenna towers. Therefore, structural analysis of the structure, design as well as detailing of such foundations to be done with sufficient accuracy. Savory et al.(2008) have presented a comparison between the wind-induced foundation loads measured on a type L6 transmission line tower during a field study in the UK and those computed values using the UK Code of Practice for lattice tower and transmission line design (BS8100). They explained that their analysis shows excellent agreement between the Code calculations and the measured results, within the overall accuracy of the field data. Therefore, above works provides good verification about the accuracy of calculation and designing methods provided in British standard code of practice for steel lattice towers - BS8100.

Abdalla (2002) has done a case study for the investigation of 51 defective foundations of self-supported and guyed antenna towers. The factors affecting the durability of tower anchorages and foundations were discussed in details. After that, the precautions necessary for preventing failure due to corrosion of buried tower components and deterioration of anchor blocks and foundations are also discussed. Abdalla provides informative discussion about the deterioration of antenna tower foundations and guy anchors which are usually a forgotten part of any antenna tower maintenances.

2.6 Cyclones vs Sri Lanka

As the telecommunication network is a basic component in every field (i.e – financial, communication, transport, military, etc.) in the modern world, such networks must be designed to withstand any disastrous events. Especially, after major natural disastrous events like Tsunami, Cyclone or Flood, the main infrastructure such as roads, electricity and communication networks must function as a first step before starting of any relief or rescue missions. Therefore, above main infrastructure are considered as post-disaster type structures during their design stage itself and make every effort to ensure them to withstand (at least to be exist without total collapse) after possible disastrous events.

Therefore, the studying about the cyclone and their probability of affecting Sri Lanka is an important factor that has to be considered during the evaluation of safety on antenna towers. Jayawardane (2006) has explained about the vulnerability of happening low-frequency high impact events in Sri Lanka with extensive damages. He also discussed the eastern and north-eastern parts of Sri Lanka's vulnerability to tropical cyclones and occasional cyclone impacts in some parts of north-central and north-western provinces. However, according to Jayawardana, as the most of tropical storms developed in the south-west or south-east Bay of Bengal may become a cyclone storm (67-117km/hr) or cyclone (above 118km/hr) just after passing Sri Lanka's latitudinal region and hence Sri Lanka is less vulnerable to direct impact of a cyclone. However, he also have mentioned about major cyclones which occurred in the years 1907, 1922, 1978 and 2000.

IS:875 (Part 3) – 1987 provides details of selection of design wind speed as follows,

Clause 5.3 –Design Wind Speed (Vz)

Design Wind Speed (Vz) The basic wind speed (Vb) for any site shall be obtained from Fig. 1 and shall be modified to include the following effects to get design wind velocity at an height (Vz) for the chosen structure,

a) Risk level;

b) Terrain roughness, height and size of structure; and

c) Local topography.

Clause 5.3.1 – Risk Coefficient (k1)

Figure 1 gives basic wind speeds for terrain Category 2 as applicable at 10 m above ground level based on 50 years mean return period. The suggested life period to be assumed in design and the corresponding k1 factors for different class of structures for the purpose of design is given in Table 1. In the design of all buildings and structures, a regional basic wind speed having a mean return period of 50 years shall be used except as specified in the note of Table 1

Figure 1.0 – Basic design wind speeds in India

Therefore, our neighbor country India is using considerably different design wind speed values and other preliminary factors when compared with the values which are currently practicing in Sri Lanka. Some of them can be tabulated as follows,

Item	*Description*	*Indian practice*	*Sri Lankan Practice*
1	*Basic wind speed - Figure 1*	*39 m/s*	*33 – 39 m/s*
2	*Risk coefficient (K1) – Table 1*	*1.06*	*Depends on the code*

Table 1: Risk coefficients for different classes of structures in different wind speed zones [*Clause 5.3.1*]

Class of Structure	Mean Probable design life of structure in years	k_1 factor for Basic Wind Speed (m/s) of					
		33	39	44	47	50	55
All general buildings and structures	50	1.0	1.0	1.0	1.0	1.0	1.0
Temporary sheds, structures such as those used during construction operations (for example, formwork and false work), structures during construction stages, and boundary walls	5	0.82	0.76	0.73	0.71	0.70	0.67
Buildings and structures presenting a low degree of hazard to life and property in the event of failure, such as isolated towers in wooded areas, farm buildings other than residential buildings, etc.	25	0.94	0.92	0.91	0.90	0.90	0.89
Important buildings and structures such as hospitals, communication buildings, towers and power plant structures	100	1.05	1.06	1.07	1.07	1.08	1.08

Jayasinghe (2008), has explained about the possibility to increasing tropical cyclones with the global warming which is gradually happening at present. He has also given the incidence of typical tracks of tropical cyclones around the world. (Please refer Figure 2). According to figure 2 below, It can be seen that Sri Lanka lies within the areas where tropical cyclones can occur. Then, the three wind speed zones of Sri Lanka where different basic wind speeds have been allocated for normal structures and post disaster structures were explained too. Those values are given in Table 1 below.

	Normal	Post disaster
	3(s) *m/s*	*3(s)m/s*
Zone 1	49	54
Zone 2	42	47
Zone 3	33	38

Table 1: *The three second gust velocities used for different areas of Sri Lanka*

He also has discussed Indian practice on design wind speeds used in cyclone prone zones which is based on according to IS: 875 (Part 3) - 1987. He indicated that three second gust wind velocity recommended for south eastern coast of India was 47 m/s. for south western coast of India It was 39 m/s. He further indicates that the gust wind speeds used to check the serviceability in almost all major cities of Australia are about 38 m/s in at least one critical direction (reference to AS 1170 - Part 2, 1989).

Therefore, He has been made an argument that the wind speeds used in indla, America and Australia in areas of similar cyclone risk may be more and hence the value of 33 m/s adopted in zone 3 of Sri Lanka could be an underestimate. In his conclusion, it is explained that rather than learning by mistakes, it would be better to fall in line with the tried and tested practices adopted in other countries. Therefore, he has suggested to use at least 38 m/s basic wind speed for designs related to Sri Lanka.

Although the discussion on above paper basically targeted for high rise buildings, it also describes many important facts about selection criterion of the design wind speed. The writer's argument may be more valid for slender and unpredictable complex structural types like steel lattice antenna towers than buildings.

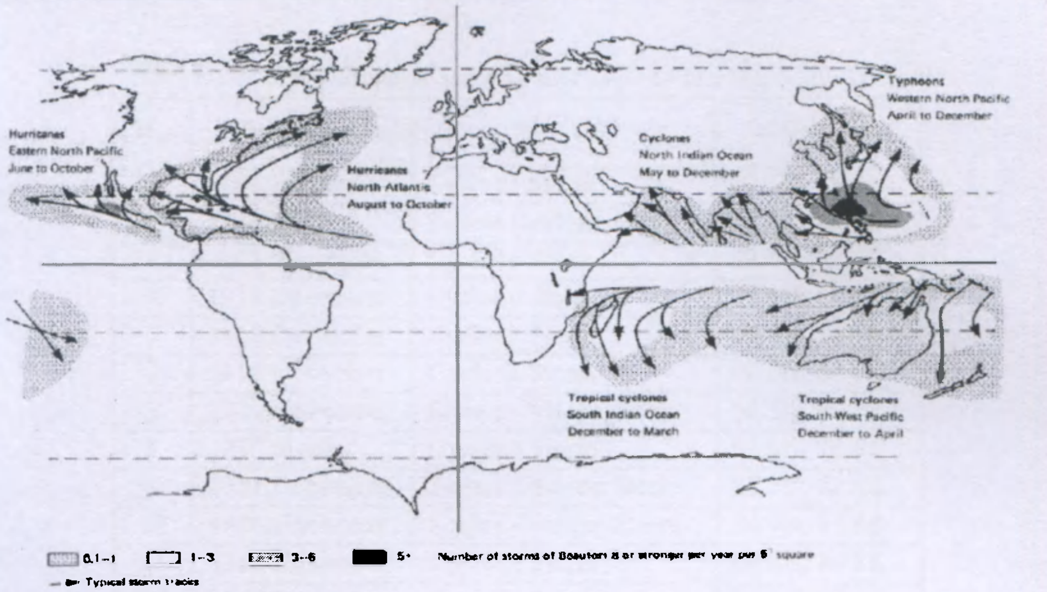


Figure 3: Typical tracks of tropical cyclones in the world. North North Central and Eastern provinces of Sri Lanka are highly vulnerable for cyclonic effects in the months of May to December

Figure 2.0 – Typical tracks of tropical cyclones in the world

Lewangamage et al.(2009), describes the Bay of Bengal as one of the places with the severest wind actions on the planet earth. They also indicated that due to the diminutive size of the island, most of its parts may fall into danger of getting adverse affects by cyclones. As the most of the economic and social centers that are located in the coast line and hence they are densely populated and highly industrialized as well, They have explained how the sudden cyclone strike in the coastal area will lead to severe disasters that force the society into disarray.

They also explained why the East and Northeast coastal areas of island having high tendency of being affected by tropical cyclone than other areas. After that, the cyclones that have gone through the island since 1900 are also given (Please refer Table 2 below). However, the primary details on two recent cyclones were given as follows,

"Among those cyclones, the cyclone that occurred in 1978 was the strongest and most devastative one. During this cyclone, the maximum wind speed of northerly 145km/h was recorded at Batticalloa. The same cyclone indicated satellite estimations of '222 km/h of maximum wind speed. Satellite disturbance summary of Washington reported a maximum wind speed of 206 km/hr"

"There after, the Cyclone in year 2000 was the strongest tropical cyclone to strike Sri Lanka since 1978. It was strengthened under fconductive conditions to reach a top wind speed of 75 mph (120 km/h). This cyclone hit Eastern Sri Lanka at its peak strength and weakened slightly while crossing the island before hitting and dissipating over Southern India."

Table 2 1. Time, situation and origin of cyclone in 1900 – 2000 periods

No	Year/Month	Situation	Origin
1	1906 January	Cyclone Storm	07.5N, 84.5E
2	1907 March	Severe Cyclone Storm	08.5N, 86.5E
3	1908 December	Cyclone Storm	07.5N, 83.5E
4	1912 December	Cyclone Storm	05.5N, 82.5E
5	1913 December	Cyclone Storm	06.5N, 85.5E
6	1919 December	Cyclone Storm	08.0N, 86.0E
7	1922 November	Severe Cyclone Storm	08.5N, 88.5E
8	1925 March	Cyclone Storm	05.0N, 78.5E
9	1931 December	Severe Cyclone Storm	07.5N, 82.5E
10	1964 December	Severe Cyclone Storm	04.9N, 93.0E
11	1966 November	Cyclone Storm	08.0N, 84.0E
12	1967 December	Cyclone Storm	04.0N, 89.0E
13	1978 November	Severe Cyclone Storm	06.5N, 92.5E
14	1980 December	Cyclone Storm	10.5N, 91.5E
15	1992 December	Severe Cyclone Storm	07.5N, 87.2E
16	2000 December	Severe Cyclone Storm	07.5N, 90.0E

It has also indicated that strong winds and gales are occurring more often than cyclones and many parts of Sri Lanka suffer from these kinds of extreme wind conditions right throughout the year.

Mallawaarachchi and Jayasinghe(2008) have discussed the general belief that Sri Lanka is in a disaster free zone and how it may no longer be valid. They used the records of past disasters which happened in Sri Lanka, including damage due to those events to validate their argument. They have explained that, ***"there will be no guarantee that natural disasters will not happen again. They could repeat in the future, may be with lower magnitudes or intensity. This indicates that some kind of disaster preparedness is of great importance today"***.

They also explained about the higher vulnerability of Sri Lanka to cyclones, especially the North and East with reference to the typical cyclone tracks in the world in Figure 2 above. In November 1978 and December 2000, there were two severe tropical cyclones that swept in from the Bay of Bengal across the Northern, North Central and Eastern provinces of Sri Lanka with resulting wind speed reaching up to 150 kmph. The writers also have provided some statistics about damages that had happened due to above two disastrous events for purpose of highlighting the extent of influences of such events.

With considering all aspects that discussed in this chapter, we can summarize the facts as follows,

It is important to understand and practice that the steel lattice type antenna structures are to be considered as special type of structures (such as shell structures or chimneys, etc) and need to be designed and modified accordingly. Although, there is several different structure idealization methods are available for structural analyzing, the final results will not have considerable difference. However, the use of correct computer software which has specially designed for steel lattice tower analysis may able to provide better accuracy.

When considering the effect of dynamic loads, it is always recommended to have sufficient safety margin (about 15% - 25%, that depending on the extent of affecting heavy wind fluctuations on the structure) on design strength of the members. Above safety margin can be utilized to accommodate the error of estimating the variance of fluctuating wind force and particularly with regard to the life time of critical constructional details of high and slender antenna towers.

The foundation of antenna towers to be designed and detailed with proper care about its uplifting forces, durability, etc. As the antenna towers are being a one of primary component in most important system, they are to be designed as post-disaster type structures. But the design wind speeds and factors of safety which are currently practicing in Sri Lanka are questionable when considering the statistics on past cyclones which have affected to Sri Lanka and the comparatively higher design wind speed values that are practicing in other countries with similar conditions. (i.e - India and Australia)

Therefore, we may need to have more technical research and discussions on above subject and correct the error (if any) without further delay.

FIELD STUDY

3.0 Basic details of design of steel lattice antenna towers

3.1 Self supporting/self standing structures

Steel lattice towers have provided an economic solution to the communication industry over many years. Most early towers were generally square in plan and constructed of bolted angle sections. The design of such structures evolved rapidly with the advent of electricity transmission lines whose towers were designed for maximum efficiency (i.e. Lowest weight of tower). Generally, each type of electricity transmission line tower was subjected to full scale test to destruction for ensuring the calculated design capacity and avoiding of immature mistakes in steel fabrication detailing, etc.

Typically lattice towers vary in face width from top to bottom and depending on the form of the structure, different bracing patterns are adopted appropriate to the loading to be carried. Heights of steel tower vary from 10m – 200m with the taller structure using built-up angle members for their legs in the bottom panels.

In terms of the number used, self standing lattice towers are used more extensively than guyed masts up to a height of about 150m. Above 150m height, the number used rapidly decline. It may be due to the increase of cost more rapidly with it's height. The main advantage of self standing lattice structures lie in their good torsional rigidity and in the elimination of stays (guy wires) with the related savings in the area of the site.

Due to above advantages and cost effectiveness, the self standing steel lattice towers are the common choice in the mobile communication networks. The height range of 10-80 meters is generally used in above networks. While the triangular towers are used for lightly loaded structures, square type heavy duty towers are adopted in heavily loaded or the locations where extreme weather conditions exist. (i.e. Hill tops, Coastal areas, etc.)

3.2 Steel lattice type guyed mast or cable stayed masts

The design and construction of guyed lattice masts is based on and has developed from classical beam and bridges, so that bracings, joints and other items follow the established practice with only minor modifications to suit particular conditions and for attaching feeders and antennas.

However, unlike self supporting structures, as guyed masts consist of steel cables/ wire ropes as its main structural element, non-linear analysis of the structure should be done for deciding its behavior and dynamic response under its design wind loading. Although the guy mast towers having more advantage on initial cost of construction, etc. the facts such as the larger land requirement, comparatively lower torsional rigidity and high cost of maintenance is making the choice of self standing tower more feasible in the range of 10-100 meters heights. However, for the towers with more than 100m heights, the guyed masts always tend to be the most economical solution.

But, as the scope of this research is limited to only self supported steel lattice antenna towers, details about steel lattice type guy masts will be not discussed further.

3.3 Design codes of practices - Brief history and versions currently in practice

- An American Trades body, the Electronics Industries Association (EIA) produced its own standard EIA-222, for steel antenna towers and antenna supporting structures. The first version of this was published in 1964 and the current version is ANSI/TIA-222-G (2005).
- The German code, DIN4131, for steel radio towers and masts was first published in 1969 and has been regularly updated. The current version was published in 1991.
- United Kingdom produced a standard for loading of lattice towers, BS8100 Part1, in 1986. Currently there are four (04) separate parts as follows,
    1. BS8100, Part 1 – Code of practice for loading, (1986)
    2. BS8100, Part 2 - Guide to the background and use of part 1 (above) (1986)
    3. BS8100, Part 3 - Code of practice for strength assessment of members of lattice towers and masts (1999)
    4. BS8100, Part 4 - Code of practice for loading of guyed masts (1995)

- The Canadian Standards Association (CSA-S37) published their first standard in 1965. The current version was published in 2001.
- The Australian Standards first produced a Code AS3995, for design of steel lattice towers and masts in 1991. The latest revision was issued in 1994.
- Euro code , 1993-1997 – (Part 3 – Design of steel structures, towers, mast and chimneys)

Other than above specially issued codes for steel lattice towers and masts, following codes of practice are also still popular among the antenna tower designers. All of those codes are either code of practice for electricity transmission line structures or wind loadings on structures.

- CP3 : Chapter V : Part2 : 1972 – Code of basic data for the design of buildings, published by British standards institution. (This standard is obsolete).
- ASCE 10-97, Design of lattice steel transmission structures – a standard published by the American Society of Civil Engineers in 1991. This was to develop a version of the " Guide for design of steel Transmission towers, Manuals and reports on engineering practice – No 52", first published in 1971 by the same above institution.
- IS 802 (Part1/Sec1), Code of practice for use of structural steel in overhead transmission line towers published by The Bureau of Indian standards in 1995. While the above IS 802 deals with materials, loads and stresses in overhead transmission line towers, The IS 875 (Part3) – Indian code of practice for wind loads on building and structures, (first published in 1964) deals about the wind loads. The most recent revision of IS 875 was issued in 1987.
- Although Sri Lanka has no code of practice of its own that related with towers or wind loads, The Ministry of Local Government, Housing and Construction has prepared and published a design manual called " Design of Buildings for High winds - Sri Lanka" in 1980. This document contains some useful design data such as wind speed distribution within the island, recommendations for design wind speed for different category of structures, density of air, etc.
- Similar codes may be available in other counties like China, South Africa, Poland, Russia, etc. but there is no evidence about use of those codes for any antenna tower designs in Sri Lanka.

3.4 Common computer software

Although, there are many general structural engineering computer software available in practice, none of them provide the in-built capacity of designing structural members according to accepted antenna tower design codes. On other hand, there are several other computer software programs, which are for antenna tower and related structure designs. However, if we are going to use firstly explained type of software (i.e – STAAD Pro, SAP2000, etc.), then we should be careful about the applying of all required FOS's and other design data (for example, all nodes are to be pin jointed, etc.) to the computer model. After the process of structural analysis, the results can be sorted, grouped and use for designing each of members/member groups according to the respective engineering code of practice. The designing of members has to be done using a separately developed computer program or spreadsheet program (i.e – Excel, Lotus 123, etc.).

On the other hand, if we use latter explained type of software, then it will have more flexibility on both structural analysis as well as member design processes, resulting in more economized structure with comparatively in short designing period and less possibility of mistakes. Such computer programs usually have useful in-built data such as different types of panels, antenna details, cables, etc too. Therefore, such computer software can makes the antenna tower designing process more efficient and accurate.

Some of popular antenna tower design computer software which are currently in practice are listed below,

Item	Name of software	Supporting code of practices
1	MS TOWER	BS8100, EIA22-G, EIA222-F, AS3995, etc.
2	TOWER	EIA222-G, EIA222-F, CSA S37-01
3	RISA TOWER	EIA222-G
4	I TOWER	BS8100, EIA22-G, EIA222-F, Eurocode (ENV 1993-3-1:1997)
3	STAAD.TOWER	EIA222-G, EIA222-F

4.0 An overview about present practice of design and detailing of antenna towers

4.1 Tall steel lattice tower designs - Brief history

Other than the German code DIN4131(1), it seems no specialized National Standard covering the structural design of communication structures was available before 1980. (Smith, 2006). The structures were designed based on the general loading code of practice, as a result the specific requirement for forms of structure were frequently not considered although this has both positive and negative effects, as far as safety was considered, by ignoring the dynamic effect of wind loading and the distribution of wind over the height of the structure often resulted in an underestimate of the structural response.

However, this was to a certain degree offset by the use of conservative design criteria, based on general codes for steel design that did not properly account for the behavior of light slender lattice frame. The exception to above design rules was in the design of transmission line towers where the need for economy in design was essential due to the multiple uses of individual designs to form a transmission line. This led to the full scale testing to destruction of test towers.

In present practice, there are several well developed codes of practices and theories are available. In addition, the use of computers provide higher accuracy in analysis of complex structures and detailing.

4.2 Different design loads and their methods of application

Wind resistance and drag factor

The design of antenna structures is mainly governed by the pressure due wind. The pressure of wind on the structure is created due to the wind resistance on the tower body as well as the other ancillaries (Antennas, feeder cables, platforms, etc.) which are mounted on the tower. However, the wind resistance is directly related to design wind velocity, shadowing area of the tower and other ancillaries, drag coefficient and air density. But the drag coefficient and the wind shielding area of the tower and the ancillaries will be varied for different application angles of the wind.

Although all above engineering codes of practices uses the same theory of fluid dynamics for calculating wind resistance on the tower, the method of load application and adoption of safety factors have some differences.

The general procedure is the wind resistance on each section of tower is calculated separately. Then each load is applyied to the center of each section or several of its nodes accordingly. Similarly the wind resistance on each of ancillaries will be calculated and applied to the relevant locations as point load. When the large ancillaries, like large diameter Microwave dish antennas with random (i.e-a cylindrical cover) which are projecting outside of the tower is available, the resulting torsional moment also needs to be considered.

But when the numbers of ancillaries are limited as well as their wind shielding area are not significant that compared to the wind shielding area of the tower, then both (ancillary as well as tower) wind shielding areas will consider together for calculations of the wind resistance.

Usually the wind resistance on antennas are obtained from wind tunnel test results that are usually supplied by antenna manufactures themselves with their technical specifications of antennas. Otherwise the design engineer should have to decide appropriate value with help of literature.

Basic loads on antenna tower

Basic loads on any common antenna tower will be as follows,

- Wind load on tower itself.
- Wind load and torsional moments induced by different antennas, etc.
- Wind load on cable tray (with cables) and climbing ladder,
- Wind load and weight of working platforms and resting platforms,
- Weight of antennas, cables, self weight of the tower.
- Loads in tower erection and antenna mounting stages.
- Any other special loads (if any)

Load combinations

After calculation of basic wind loads for each above items, the different load combinations to be adopted for idealizing the actual design environment of the tower. Usually any tower provides its highest wind shielding area in its cross wind (diagonal) directions. Therefore, as a usual practice any tower should be analysed for design wind loads from both its face and cross (diagonal) wind directions separately. When the situation of the ancillaries are located in unsymmetrical pattern, the tower should be analyzed and checked with applying wind loads from all its face and diagonal directions separately. (for example, for a square shaped tower- all 45 degree angles around the tower while the triangular shaped tower - for each 60 degree angles around the tower.)

Other than the above primary wind loads and their combinations, the loads such as self weight and weight of the ancillaries, erection loads and any other special loads also to be considered and included in to above load combinations as appropriately.

4.3 Different factors of safety.

Generally, antenna towers are designed for ultimate wind load while ensuring the serviceability requirements in service wind loads. According to the Policy of construction and maintenance of antenna towers and similar structures published by Telecommunication Regularity Commission - Sri Lanka in 2009, all antenna structures to be designed and detailed as Post disaster type of structures. It also has recommended to considering ultimate wind speed (3 second gust wind) as 180km per hour, while service wind speed is taking 120km per hour or 140km per hour by most of net work operators. But there exist some towers which are operating as key towers in some important communication links has designed for higher ultimate wind speed such as 210km per hour too.

Unlike general reinforced concrete and steel designs, for antenna towers we adopt many different factors of safeties (FOS) in different stages of their design process. Some of them are as follows,

- FOS on quality of material / design strength
- FOS on workmanship in fabrications
- FOS for importance of the tower (in network, location of installed, etc.)
- FOS for wind load respect to the surrounding terrain or location of installed.

- FOS on dead load
- FOS on category of usage (Civil telecommunication, military, Navigation, etc.)
- FOS on wind respect to the height of installed (tower itself or/and ancillaries)

However, all previously discussed (in sec 2.3) engineering code of practices are usually providing sufficient guidance notes and recommendations for selecting of above FOS's.

4.4 Designing methods

The structural behavior of any self standing antenna tower can be idealized as similar to simple vertical cantilever, and then the resulting tension and compression on leg members as well as forces on other bracing members can be calculated accordingly.

However, the structure can be analyzed accurately for different load combinations that the methods depending on the complexity of the structure and structural form. Although the simple, small lattice structures are capable of analysis by using more conservative (above mentioned) manual approaches, the complex, large lattice structures are need to use more sophisticated approaches such as FEM, etc. While the guyed mast structures need complex non-linear analysis, the simple mono pole structures can be analyzed by using primary theories of structural engineering. However, the antenna structures are generally designed with approach of elastic analysis. The possible reason for above practice may be for allocating more safety region for such unpredictable structures.

Usually above structural analysis can be easily done with the help of computers, but it always advisable to verifying above analysis results that obtain from the computers along with the simple manual calculations too.

As the lattice structures, the members are usually assumed to be bearing tension and compression loads only. Therefore, each member is need to provide sufficient cross sectional area for bearing design tension load as well as selecting correct member size/type (L/r ratio) to avoiding become slender in design compression loads. As the load reversal is the inherent nature of this type of structures, all joints need to be detailed accordingly.

4.5 Advantages and limitations

When we are dealing with special structural forms such as steel lattice structures, we have to be more careful about their capabilities as well as limitations too. Unlike other basic structural forms such as simple beams and column structures, Slabs or heavy stone arch bridges, the structural form of steel lattice structures having its own advantages as well as strict limitations. Some of them are as follows,

4.5.1 Advantages

- As the steel lattice structure being an extremely efficient structural form, we can have very economical structures with maximum utilizing of its members and materials.
- Transport of structure can be done very economically with de-assembling it to pieces.
- We can make tall structures even in areas where having limited accessibility such as hills, top of tall buildings, deep in forests, marshy areas, etc.
- It is easy for routine maintenance as well as for replacements,
- Simple to construct with commonly available tools, equipment and know how.

4.5.2 Disadvantages & Limitations

- As the steel lattice structure being an extremely efficient structural form, it is weak for tolerating the exceedence of its design loads than other structural forms such as beam-column structures, slabs, etc..
- As the steel lattice structures are assembled mostly with simple bolted connections, the actual behavior of such connection cannot be accurately idealized in our designs. Therefore, the predicted behavior of the structure that obtained through common FEM analysis software may not have guarantee as the 100% true behavior of the actual structure.
- As the steel lattice structure being an extremely efficient structural form, the failure of single member may result in overloading of other adjacent members. The result will be progressive failure of adjacent structural members and finally the collapse of the whole structure with no prior warnings.
- Aesthetically not much adoptable to the neighboring environment with compared to other structural forms such as buildings, bridges, etc.
- Easily make damages or collapse with vandalism, etc.
- Immature errors in design stage cannot be easily traceable and may leads to total failure of the structure too.
- Poor workmanship (for example poor quality of welding, etc.) may cause structure unsafe than other structural forms.
- These types of structures need extreme care during construction stage as well as in routine maintenances too.

4.6 Detailing of structural joints and drawings

Steel lattice structures idealizing as totally pin jointed space frames during their idealizing for structural analysis. But in actual practice, they will be jointed with nut and bolts.

When we following the British design code of practice (BS8100), the part 3 of above code contain necessary guidance notes on the rules and procedures about the designing of individual members and joints. Further to above, for designing of bolted joints, etc. above code (BS8100) also referring BS5950 – Code of practice for design of steel buildings.

Similarly, if we use American code (ANS/TIA 222-G or EIA222-F), then it refers into ASCE 10-90 – (i.e - Code of practice for design of lattice steel transmission structures) for member designs.

All other design codes which described in section 3.2 above, also having their own, well described methods of rules and procedures about the designing of individual members and joints.

After the structural analysis and member designs the process of detailing and preparation of erection drawing will be started. During this process all joints, base plates, non-structural items such as ladder, platforms, etc. will have to be detailed to suit to the structural requirements as well as considering the practical aspects. As the steel lattice towers are sensitive and complex structures, it has prime importance of designing all the structural joints (Leg to leg joints, Leg to bracing joints and other joints) accurately. As the load reversal is inherent nature of any antenna structures, each principal joints to be checked for its load bearing capacity (both in tension and compression).

Further to that all structural drawings, tower erection drawings to be properly detailed with including all necessary information (such as member size, Grade of steel, type and size of bolts, etc.). It is essential to certify above all structural drawings and tower erection drawings preferably by design engineer himself or other well qualified fabrication engineer.

4.7 Use of different types of steel and bolts

Usually high tensile steel were used for legs members while either only mild steel or combination of both high tensile and mild steel were used in bracing members.

In present market, it is commonly available the high tensile steel of tensile strengths (fy) with fy=330 to 420N/mm^2 and the mild steel of tensile strength ranging fy=230–250 N/mm^2.

M16 M20 and M24 nut & bolts of ISO grade 4.6, 5.6 and 8.8 were usually adopted for structural connections while M12 bolts have been used only for non-structural jointing. Although the bolt grade 10.6 or the bolt size M30 are not common in antenna tower designs, they are also readily available in the market.

As the antenna towers are outdoor structures those are usually experiencing different and changing climatic conditions, almost all recent structures are hot dip galvanized and painted. While the hot dip galvanizing alone will provide minimum 15 years for prevention on possible corrosion, proper painting on top of galvanized members can extend above period to another 10 -15 years (total 25-30 years).

4.8 Testing and verification

Usually steel lattice structures (pylons) designed for electricity transmission lines are designing for their maximum efficiency. For Transmission line pylons, where repetition is the norm, any saving in weight can have significant economic advantage. Therefore, each type of tower will be generally subjected to full-scale test (i.e - Prototype testing) to destruction at the testing bays.

Above full-scale testing will ensure,

- Avoidance of any immature detailing, etc.
- Guarantee about the ultimate design load carrying capacity.
- Verification of the design calculations,

However, for antenna towers such full-scale test to destruction is usually not carried out. Therefore, following precautions should be taken for ensure the structure to be safe in its operations,

- Designing according to accepted design code of practice,
- Detailing all joints and other members accurately,
- Strict quality controlling of materials and workmanship in the process of manufacturing.
- Ensure proper tower erection/construction with qualified personnel.

During the period of operation and maintenance,

- Ensure proper routine maintenance of the structure
- When it is needed to install any additional antennas or other ancillaries that are not included in the original design configuration of antennas, the structural feasibility should be verified that prior to mounting such antennas, etc.

5.0 Review of reported collapse of antenna towers in Sri Lanka

There were three incidents of tall antenna tower collapses reported during the last decade in Sri Lanka. But proper investigation and assessment for finding the root cause for such collapse was done for one of above incidents only. Others were not allowed to be inspected by outsiders by their owners. Therefore, following reviews has been done by help of the photographs of above collapsed structures and from the comments of those tower designers, owners, etc. only.

5.1 - 70m high antenna tower at Beliatta – (Owner -: Mobitel),

Basic data - This is a four legged steel lattice structure, designed for 10sqm antenna area. Design wind speed was 120km/hr (operational) and 160km/hr (survival), designed and manufactured in Sri Lanka. The collapsed tower was located in land next to several houses of the village

General information

This tower collapsed during its steel lattice tower erection stage in year 2005. Both University of Moratuwa and University of Peradeniya were consulted for carrying out an engineering assessment for finding the possible reason for such collapse. Ultimately, it has been agreed that as the most possible reason for above tower collapse is improper erection procedures adopted. The main suspected reason was the unsafe tower erection procedure that was adopted by the tower erection contractor. The 70m tall tower has been erected without providing any of inner plan bracings, etc. (This is a usual practice of electrical transmission tower/pylon erectors for making more space to lifting materials/panels from inside of the tower). During the careful inspection of the remains of collapsed tower, above inner plan bracings were found missing. Apart from missing plan bracings, the use of temporary guy ropes in unsymmetrical manner also were noted.

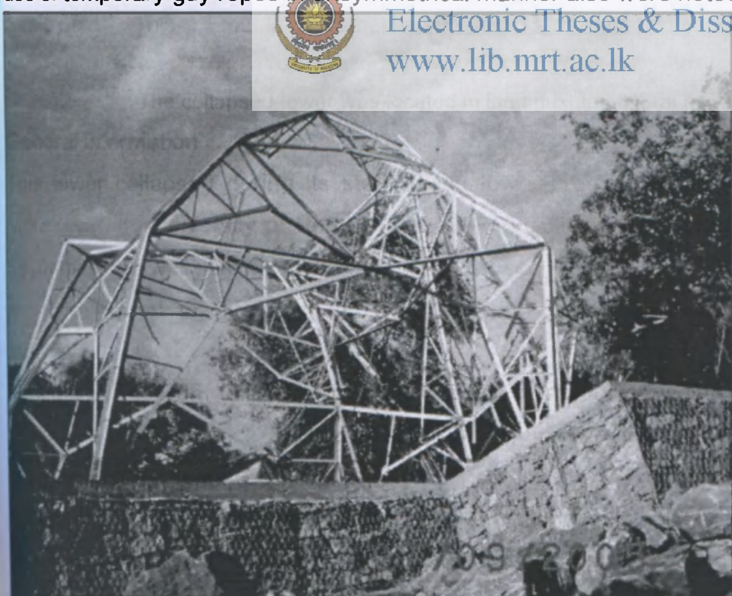


Photo 5.1, Beliatta 70m antenna tower collapse

Discussion

As per the study and assessment report of University of Moratuwa, the tower collapsed due to the incorrect tower erection procedures adopted. The assessment included re-modeling of the tower structure with and without plan bracings. Both models were checked for their stability under 80km/hr wind. According to the available details of collapsed structure, it collapsed due to buckling of leg members. There is no evidence available about the tension failure of any leg members. The steel lattice structures usually collapse with no prior warnings when its main leg or bracing member fails in compression.

Although both post-collapsed assessment reports from University of Moratuwa and University of Peradeniya have suggested that the root cause for above collapse as incorrect tower erection procedures, some other engineers have also raised an argument which suspecting the root cause for above collapse as not considering of tower erection loads as a separate loading case in original tower design. (Which is usual practice exists in design of other steel structures such as buildings, etc.) But, it may be a weak argument that reference to the steel lattice structures, which are be totally pin jointed, fully triangulated structures by nature. Therefore, the construction of such special structures should be carrying out to the correct procedures and without violating the basic assumptions of the steel lattice type structures. Otherwise we may not able to utilizing the advantages of such special structural forms and may lead to uneconomical, heavy and more complex structure.

However, the above tower collapse was a good example for showing the danger of adopting of such erroneous practices in sensitive structure such as tall communication towers.

5.2 - 70m high antenna tower at Mihintale – (Owner -: Sri Lanka Telecom).

Basic data - This is also a four legged steel lattice structure, designed for 10sqm antenna area. Design wind speed was 120km/hr (operational) and 160km/hr (survival), designed and manufactured in Sri Lanka. The tower was located in Mihintale SLT office premises, that next to Mihintale Anuradhapura main road.

General information

This tower collapsed after few years of its construction, in year 2007. The client has not only allowed anyone to inspect the site, but immediately removed the debris too. However, we were able to receive some photograph taken by SLT engineer immediately after the above collapse. According to the information available, it is believed that the tower collapsed due to Tornado situation. Even from the photos of collapsed structure, it shows the sign of twisting around its own axis during the collapse.

Discussion

According to SLT engineers, there were no reports on overloading of antennas on above structure, or any other special / unusual activities (prior to collapse) which can be suspected as that direct connection with above tower collapse. However, as the tower has collapsed in day time, the people who are working in SLT premises provides clear evidences of sudden tornado situation that has been associated with above collapse.

Reference to the explanation received from the department of meteorology- Sri Lanka, The Tornadoes are short term (it usually last for 5 to 15 minutes) but very powerful local windy situation which affects small areas only. Usually tornados having wind speed of 140 to 250km/hr and circulating around its own axis forming dangerous vortex of wind. Furthermore, the month that the tower has been collapsed was also identified as the period of having high risk of occurring tornados to above area by the department of meteorology. Therefore, the collapse of above tower can be easily explained from the fact that its design survival wind speed is 180km/hr.

Photo 5.2 – Mihintale tower collapse

However, there is no evidence of any tension failures of any main members but exists evidences of several compression failures (buckling of members). This tower also collapsed at second panel that similar to above Beliatta tower collapse. The pattern of collapsed structure gives some indication of twisting of the structure in its own axis during the collapse. This may give us good evidence for suspecting that the twisting of structure may have happened as a result of the powerful tornado.

However, we are not able to make any conclusion about above collapse, because it was not allowed for any proper post-collapse investigations. But, it may not be economical to designing antenna towers for extremely rare climatic condition, like hitting by tornado, etc. However, the design engineers should make sure to provide necessary structural members (i.e -: belt members, plan bracings, etc.) to any steel lattice antenna towers for ensuring to provide extra capacity for withstanding under turbulent wind condition and heavy twisting forces that may generate by tornados. Although, antenna towers are not designing to withstand under tornado situations, above mentioned good member detailings may able to provide extra strength for heavy twisting forces up to some extent.

5.4 - 70m high antenna tower at Horowpatana – (Owner -: Sri Lanka Telecom),

Basic data - This is also a four legged steel lattice structure, designed for 10sqm antenna area. Design wind speed was 120km/hr (operational) and 160km/hr (survival), designed and manufactured in Sri Lanka. The tower was located in Horowpatana SLT premises.

General information

This tower collapsed after few years of its construction, in May 2010. The client has not only allowed anyone to inspect the site. However, we were able to receive some photograph taken by Mobitel engineer after one day from the collapse. According to the information available, it believes the tower was collapsed due to direct hit by a Tornado. Even the from the photos of collapsed structure, it shows the sign of twisting around its own axis during the collapse. Another antenna tower which is about 60m tall, lightly loaded but constructed before the collapsed tower exists unharmed a few meters away from the collapsed structure.

Discussion

According to information avaialble, although there were no clear evidence on overloading of antennas to above structure, or any other special / unusual activities (prior to collapse) which can be suspected as that direct connection with above tower collapse, except a cable tray with about 1000mm wide. But in the original design report, the width of cable tray was assumed as 400mm. However, as the tower has collapsed in day time, the people who worked in SLT premises are providing clear evidences about the direct hit by tornado situation. Although the respective post-collapse investigations are not completed yet, while considering the available data, we can reasonably assume that above antenna tower has been collapsed due to direct hit by tornado. The overloading due to large cable tray may have provided significant contribution to generate heavy twisting forces in the tower structure, but it may not be the only reason for above tower collapse.

Summary

Unlike the collapse pattern of Mihintale tower, the Gampaha tower collapsed from the first panel itself. But there is a similarity also exists in all above collapsed towers, that the all structures shows fail of leg members at their node points. This may be a good indication for developing an argument that the "triggering point of the above all collapses has happened by initial failure of main bracing members and panels but not due to fail of leg members".

However, we cannot make any final conclusion about above collapse, because it also has not allowed for any proper post-collapse investigations. But the above tower collapse was a good example for most likely result of blind loading to complex and high sensitive structural forms (i.e – Steel lattice structures, etc.) as well as requirement of more attention on design and structural stability of key structures like "Hub towers" in any important communication networks.

As a summary, following lessons can be learned from above post-collapse assessments,

1. It needs to do proper post-collapse investigations about any collapse/damage of the structures. Because they will provide good opportunities for learning from failures.
2. Overloading to be totally avoided in complex, unpredictable type of structures like antenna towers. The antenna tower owners should work closely with structural engineering experts for every doubtful activities which are in relation with steel lattice antenna towers.
3. Although it may not be economically feasible for designing antenna towers to withstand in unpredictable and rare occurrences like hitting by tornados, etc, a good steel detailing can be used to ensure those structures to be more stronger in bearing of twisting loads.
4. The construction of steel lattice type structures (antenna towers, etc.) to be done more carefully while maintaining their basic requirements such as well trangulated forms of space frames in all stages of construction. Therefore, the construction of any tall tower to be done under well qualified personnel who having sufficient past experiences on similar works.
5. All above collapses are having direct relationship with blind loading of antennas without proper recommendation obtained from qualified structural engineer.
6. There are some evidences exist about faulty structural detailing on some members too.

However, the importance of true involvement of structural engineers on design, construction and maintenance on antenna towers to be identified without further delay. Then, we may able to avoid many expensive damages and further antenna tower collapses in future.

6.0 Failure analysis of a steel lattice type tower for different loading conditions.

6.1 Introduction

Although we can control most technical issues that are influencing the tower design and safety of towers (i.e - with following standard codes of practices, etc.), there are few other items which also having high influence on safety of the tower and its designs. Structural behavior of the steel lattice tower under different load configuration is a one of such gray area in tower designs which having high impact to the safety of antenna towers. As explained by McKittrick (2010), steel lattice type structure is an extremely complex type of structure and therefore, its structural behavior under different loading conditions will be similarly complex. In such situation, any activities which may acting beyond the limits of original design loading of the structure to be carried out methodically as well as with extreme care.

However, most of the technical personal who are involved in operation and maintenance of antenna towers in Sri Lanka are having a common practice of using a simple thumb rule for evaluating the feasibility of mounting new antennas or changing of antenna configuration on existing towers. According to above thumb rule, the antenna tower is approximating in to a simple vertically cantilevered pole structure. Then the feasibility of new arrangement of antennas will be evaluated with simply comparing the new (proposed) base moment against the original design base moment of the tower. As above method is being simple and not involving any time consuming (as well as expensive) structural analysis process, it has become well established and widely used practice among the technical personals of most of telecommunication operators in Sri Lanka. In this chapter, the accuracy of above thumb rule and its application has been investigated with using 60m high steel lattice tower (FEM model) under different loading arrangements.

6.2 Method of analysis and loading

Basic assumptions during the use of above mentioned thumb rule are as follows,

1. Steel lattice type structure can be idealized in to simple vertically cantilevered steel pole,
2. The most influencing forces are compression and tension forces on main leg members and resulting leg reactions on foundation (uplift and down thrust)
3. As the horizontal shear force on foundation is small (usually about 5.0% of the uplift/down thrust force) when compared with design uplift and down trust forces, the resulting effect of horizontal shear force on reinforced concrete foundation due to any change of antenna configuration can be neglected. (As R/F concrete structures are usually designed with including large factor of safety)
4. Therefore, the antenna loads on steel lattice structure can be safely changed or altered if we could carefully maintaining the same design bending moment at the tower base in every such occasion.

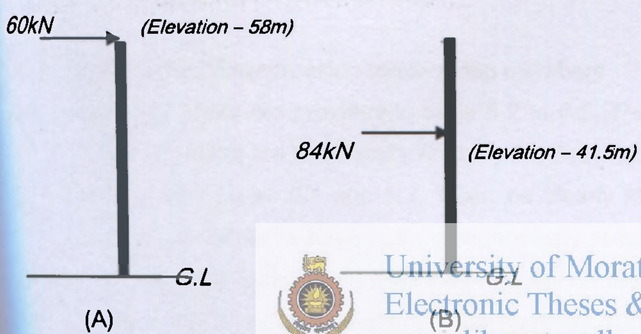
A 60m high steel lattice tower was selected for above analysis. The structural modeling and FEM analysis was done in PLS TOWER software. The above antenna tower has been originally designed for bearing 60kN of horizontal antenna load (due to wind pressure) at top of (58m) the structure.

Therefore, with using the thumb rule, the different base moments was calculated as follows,

Loading

Loading pattern (A) - A single antenna load at top of the tower,
(i.e - 60kN load at elevation 58.0m elevation)

Loading pattern (B) - A single antenna load, which is generating similar moment at base of the tower applied to the middle of same tower, (i.e - 84kN load at elevation 41.5m elevation). The calculation is as follows,



BM at base,

Loading (A) = 60kN x 58m

= 3480 kNm

Loading (B) = 84kN x 41.5m

= 3486 kNm

All other basic design conditions (wind speed, terrain category, etc) were applied similar to both above situations. Each antenna loads were applied as four equal nodal loads (Leg-leg joint) at above elevations. All nodes which used for test loading were located in levels of mid X-bracings and their heights are indicated in table 6-1.

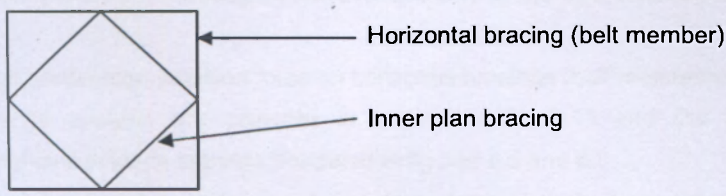
Table 6-1

Input data		Basic output	
Loading height	Load	BM at base of the tower	Shear force
(m)	(kN)	(kNm)	(kN)
59	59	3480	59
55	63.3	3480	63.3
51	68.2	3480	68.2
41.56	83.7	3480	83.7
32	107	3480	107

6.3 The result of tower analysis and evaluation

The tower model was analyzed, with PLS-Tower software for all above loading arrangements that listed in table 6-1. The final analysis results are provided in table 6-2 to 6-15.

Note:- The figure 6.0 provides further graphical illustration about basic input data and resulting member forces (by using colour code) for each above loading situations.



Plan View (at mid level of X panel)

6.3.1 Design tension/compression force on leg members

The results of analysis are provided in table 6-2 to 6-5. The behavior of maximum compression and tension loads of the leg are graphically illustrated in figures 6.1 and 6.2.

According to above figure 6.1 and 6.2, it can be clearly identified that the leg compression/tension forces in mid-tower sections have been comparatively reduced when the height of antenna load was lowered. On the other hand, even if we had maintained the same bending moment at tower base on each load case, the mid sections of the tower have not 100% agreed for its idealized behavior into a simple pole structure.

In addition, the table 6-3 and 6-5 explains that the compression/tension force on leg members are reduced about 30-35% of its original loading (i.e- when the antenna load at 59m level) when antenna load located at 32m level. Similarly, figure 6.1 and 6.2 are well illustrating the complex distribution of member capacities in each section. In this example, capacity of the leg to leg connection (shear and bearing capacity) has been become the governing criteria of the tower design capacity at 30-40m height range. The minimum leg compression capacity can be identified in 10-20m heights.

6.3.2 Design tension/compression force on X panels

The results of analysis are provided in table 6-6 to 6-9. The behavior of maximum compression and tension loads of the structural members of X panels are graphically illustrated in figures 6.3 and 6.4.

According to above figure 6.3 and 6.4, the compression forces on X panels which located below the antenna load have been increased significantly when antenna load changes/increases. In addition, the table 6-7 and 6-8 explaining that the above increase of compression forces are in the range of 20-35% from its original loading. Even, some of above overloaded X panels have exceeded their design L/R capacity (compression capacity) and may capable of leading in to total collapse of the structure.

Therefore, from above details we can explain about the efficient and complex nature of distributing antenna load among the structural members of triangulated lattice structure. On the other hand, due to the result of antenna load increases, the shear force on the structure also has been increased. As the X panels being a main structural element which located in all four outer faces of the tower, the above increase of shear force may have directly affected to the load on the X panels. Even the compression force on some X panels are exceeded their design capacity too (Pl refer fig 6.4).
In addition, the load on X panel which are located at the level of antenna load has been increased by about 80-100% of its original load. However, the X panels which located above the antenna load are remained lightly loaded, because they were loaded only by the wind force on the structural elements.

6.3.3 Design tension/compression force on horizontal bracings (belt members)

The results of analysis are provided in table 6-10 to 6-13 and the behavior of maximum compression/tension loads are also illustrated in figures 6.5 and 6.6.
Although the horizontal bracing members show comparatively less sensitivity about change of antenna load and location, the belt member which is located at the level of antenna load has been loaded very severely. Above isolated increase of compression/tension load on structural members may have happened due to the localized effect of the antenna load distribution on steel lattice structure. However, as per the figure 6.6, we can identify that some of above new member forcers are in the verge of reaching to their design compression capacity.

6.3.4 Design tension/compression force on inner plan bracings

The results of analysis are provided in table 6-14 to 6-15. The behavior of maximum compression and tension loads are also illustrated in figures 6.7 and 6.8.

According to the above details, the change of antenna load/location has not made considerable effect on inner plan bracings.

6.4 Discussion

According to the results of tower analysis and evaluation of the behavior of member forces in different loading situations, above steel lattice tower has been showed more complex behavior than its simple idealized pole structure. In each occasion, the steel lattice structure has been distributed the antenna loads among its triangulated structural members along its load path, very effectively and complex manner. Unlike other common structures, the steel lattice structures are usually designed and detailed with ensuring the maximum optimizing (ensuring to about 75-90% utilized from their design capacity) of its main structural members. Therefore, most of main structural members will not have much excess load bearing capacity available for keeping the structure safe in the event of any overloading.
On the other hand, as the steel lattice tower being a very efficient structural form, it can also very easily be unstable and leading to total structural failure when it is overloaded. In addition, the tall steel lattice tower collapses are usually happens as sudden, progressive collapses with providing no prior warnings. Therefore, any tall steel lattice tower may easily lead to total collapse even when few main

structural components (such as leg or main X bracings) are failed and its triangulated structural load path has obstructed.

Therefore, idealizing of steel lattice antenna tower in to simple vertical cantilever pole may not considered to be safe engineering practice due to following reasons,

1. Although we are trying to maintain the same design bending moment at base of the tower, mid panels of the structure may able to be unstable due to excessive loads. According to the details explained in 6.3.2, the main members of X panels may able to be failed due to excessive compression or tension forces.
2. As observed in 6.3.3, there is a possibility of failing the horizontal bracing members (belt members) due to localized overloading of structural members on the heights where the antennas are mounted.
3. As we are maintaining the original design bending moment at base, uplifting or down thrust loads on foundation may not be affected. However, the horizontal shear force on concrete column will be increased severely due to increase of the antenna load.

Therefore, the use of above thumb rule may not be advisable and cannot be considered as a safe engineering practice for evaluating of loads on complex structural types like steel lattice antenna towers. The more accurate and reliable methods such as FEM analysis with help of computers modeling or other well accepted method should be used for evaluating above structures for their load carrying capacity and associated modifications. With the help of recent high speed computers and specialized software packages which are designed for steel lattice tower design and detailing, any tall steel lattice antenna tower with complex antenna configurations can be evaluated very easily. In addition, the different hi-tech tools and modern graphic interface that included in recent FEM analysis software have made them very user-friendly, accurate as well as easy to learn.

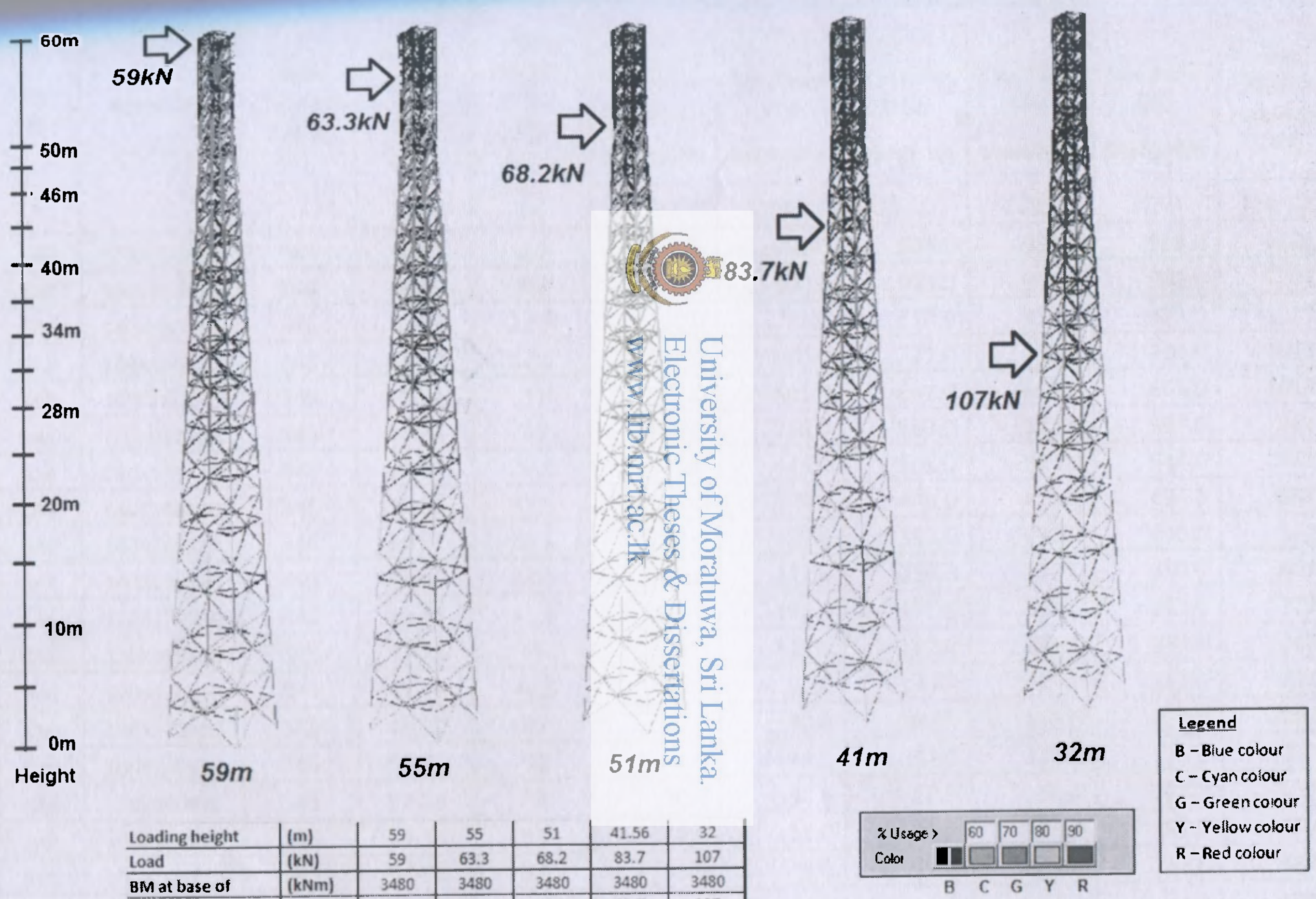
However, it is clear that the excessive cost and time delays that may arise during the detail structural evaluations for each change of antenna configurations may not be easily accepted in actual practice. Therefore the above primary concerns such as excessive cost, need of long time for such detail analysis and less flexibility for making frequent changes in antenna configurations should be addressed with more practical solutions as appropriately. So following solutions can be suggested as reliable as well as more adoptable answers for above problems,

- The owners of tower can make request from their suppliers to design structures with considering many given standard antenna configurations in initial stage itself. The possible different standard antenna configurations can be easily formulated by studying the different antenna configurations already available in existing towers.
- For existing antenna towers, feasibility of several different antenna configurations can be checked and verified in single process of structural evaluation. In addition, the required re-strengthening arrangements (if any) for above existing towers can be discussed during above evaluations as appropriately.

- Employing of well experience (about antenna tower design and detailing) structural engineer to maintenance team of every service provider/antenna tower owner. Then he can maintain a library of FEM models for relevant standard antenna towers and easily check and verify the feasibility of modifying any of above existing antenna configuration. The initial cost for license of computer software and training of the structural engineer may be negligible when compared to the financial risk associated to the business as a result of any unexpected collapse of a tower.

Therefore, instead of using unreliable thumb rules, more professional approach may need for assessment of loading and modification of complex structural form like steel lattice antenna towers. It will help to increase the reliability of any telecommunication network and the safety of both antenna tower itself as well as on public.

Figure 6.0 - Effect of different loading on 60m tower.



Loading height	(m)	59	55	51	41.56	32
Load	(kN)	59	63.3	68.2	83.7	107
BM at base of	(kNm)	3480	3480	3480	3480	3480
Shear	(kN)	59	63.3	68.2	83.7	107

Table 6-2
Different maximum tension forces on each leg sections (kN).

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of the leg	Mid height of the leg	Antenna load /Height from ground level					Available member capacities		
						Ten. Force (kN) 107kN/32m	Ten. Force (kN) 84kN/41m	Ten. Force (kN) 68kN/51m	Ten. Force (kN) 63kN/55m	Ten. Force (kN) 59kN/59m	Net tension capacity (kN)	Ten. Conn. Shear capacity (kN)	Ten. Conn. Bearing capacity (kN)
				m	m	*LT32*	*LT41*	*LT51*	*LT55*	*LT59*	*Ten. Cap*	*Shear cap*	*Bearing cap*
Leg1	SAE	160X160X12	345	0-5	2.5	976.0	981.0	984.0	985.0	986.0	1208.3	1875.7	1846.7
Leg2	SAE	160X160X12	345	5-10	7.5	876.0	892.0	903.0	906.0	909.0	1208.3	1875.7	1846.7
Leg3	SAE	160X160X10	345	10-15	12.5	762.0	791.0	810.0	816.0	822.0	1013.3	1406.8	1154.2
Leg4	SAE	160X160X10	345	15-20	17.5	649.0	692.0	721.0	731.0	739.0	1013.3	1406.8	1154.2
Leg5	SAE	160X160X10	345	20-24	22	542.0	601.0	641.0	654.0	665.0	1013.3	1406.8	1154.2
Leg6	SAE	140X140X10	345	24-28	26	440.0	516.0	567.0	583.0	597.0	861.5	1406.8	1154.2
Leg7	SAE	140X140X10	345	28-31	29.5	349.0	443.0	506.0	526.0	544.0	861.5	937.9	769.4
Leg8	SAE	140X140X10	345	31-34	32.5	263.0	374.0	449.0	473.0	494.0	861.5	937.9	769.4
Leg9	SAE	140X140X10	345	34-37	35.5	220.0	305.0	393.0	422.0	446.0	861.5	937.9	769.4
Leg10	SAE	140X140X10	345	37-40	38.5	183.0	231.0	336.0	370.0	399.0	861.5	937.9	769.4
Leg11	SAE	120X120X10	345	40-43	41.5	148.0	153.0	277.0	317.0	352.0	717.3	937.9	769.4
Leg12	SAE	120X120X10	345	43-45	44	119.0	119.0	222.0	269.0	310.0	717.3	937.9	769.4
Leg13	SAE	120X120X10	345	45-48	46.5	92.0	92.0	164.0	219.0	267.0	717.3	937.9	769.4
Leg14	SAE	120X120X10	345	48-50	49	70.0	70.0	109.0	172.0	227.0	717.3	937.9	769.4
Leg15	SAE	100X100X10	345	50-52	51	48.0	48.0	52.0	120.0	179.0	557.9	937.9	769.4
Leg16	SAE	100X100X10	345	52-54	53	30.0	30.0	30.0	69.0	132.0	557.9	937.9	769.4
Leg17	SAE	100X100X10	345	54-56	55	14.0	14.0	14.0	18.0	82.0	557.9	937.9	769.4
Leg18	SAE	100X100X10	345	56-58	57	5.0	5.0	5.0	6.0	42.0	557.9	937.9	769.4
Leg19	SAE	100X100X10	345	58-60	59	0.0	0.0	0.0	0.0	4.0	557.9	937.9	769.4

Table 6-3 :- Different maximum tension forces on leg sections.
(As a percentage of the Tension capacity of each leg section)

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Top height of panel	Mid height of the leg	Antenna load /Height from ground level					Net Ten. capacity (kN)
						Ten. Force (% of Net ten. cap) 107kN/32m	Ten. Force (% of Net ten. cap) 84kN/41m	Ten. Force (% of Net ten. cap) 68kN/51m	Ten. Force (% of Net ten. cap) 63kN/55m	Ten. Force (% of Net ten. cap) 59kN/59m	
				m	m	*LT32*	*LT41*	*LT51*	*LT55*	*LT59*	*Ten. Cap*
Leg1	SAE	160X160X12	345	0-5	2.5	80.8	81.2	81.4	81.5	81.6	100
Leg2	SAE	160X160X12	345	5-10	7.5	72.5	73.8	74.7	75.0	75.2	100
Leg3	SAE	160X160X10	345	10-15	12.5	75.2	78.1	79.9	80.5	81.1	100
Leg4	SAE	160X160X10	345	15-20	17.5	64.1	68.3	71.2	72.1	72.9	100
Leg5	SAE	160X160X10	345	20-24	22	53.5	59.3	63.3	64.5	65.6	100
Leg6	SAE	140X140X10	345	24-28	26	51.1	59.9	65.8	67.7	69.3	100
Leg7	SAE	140X140X10	345	28-31	29.5	40.5	51.4	58.7	61.1	63.1	100
Leg8	SAE	140X140X10	345	31-34	32.5	30.5	43.4	52.1	54.9	57.3	100
Leg9	SAE	140X140X10	345	34-37	35.5	25.5	35.4	45.6	49.0	51.8	100
Leg10	SAE	140X140X10	345	37-40	38.5	21.2	26.8	39.0	43.0	46.3	100
Leg11	SAE	120X120X10	345	40-43	41.5	20.6	21.3	38.6	44.2	49.1	100
Leg12	SAE	120X120X10	345	43-45	44	16.6	16.6	31.0	37.5	43.2	100
Leg13	SAE	120X120X10	345	45-48	46.5	12.8	12.8	22.9	30.5	37.2	100
Leg14	SAE	120X120X10	345	48-50	49	9.8	9.8	15.2	24.0	31.6	100
Leg15	SAE	100X100X10	345	50-52	51	8.6	8.6	9.3	21.5	32.1	100
Leg16	SAE	100X100X10	345	52-54	53	5.4	5.4	5.4	12.4	23.7	100
Leg17	SAE	100X100X10	345	54-56	55	2.5	2.5	2.5	3.2	14.7	100
Leg18	SAE	100X100X10	345	56-58	57	0.9	0.9	0.9	1.1	7.5	100
Leg19	SAE	100X100X10	345	58-60	59	0.0	0.0	0.0	0.0	0.7	100

Figure 6.1 - Design force on main leg members for different antenna locations/loads

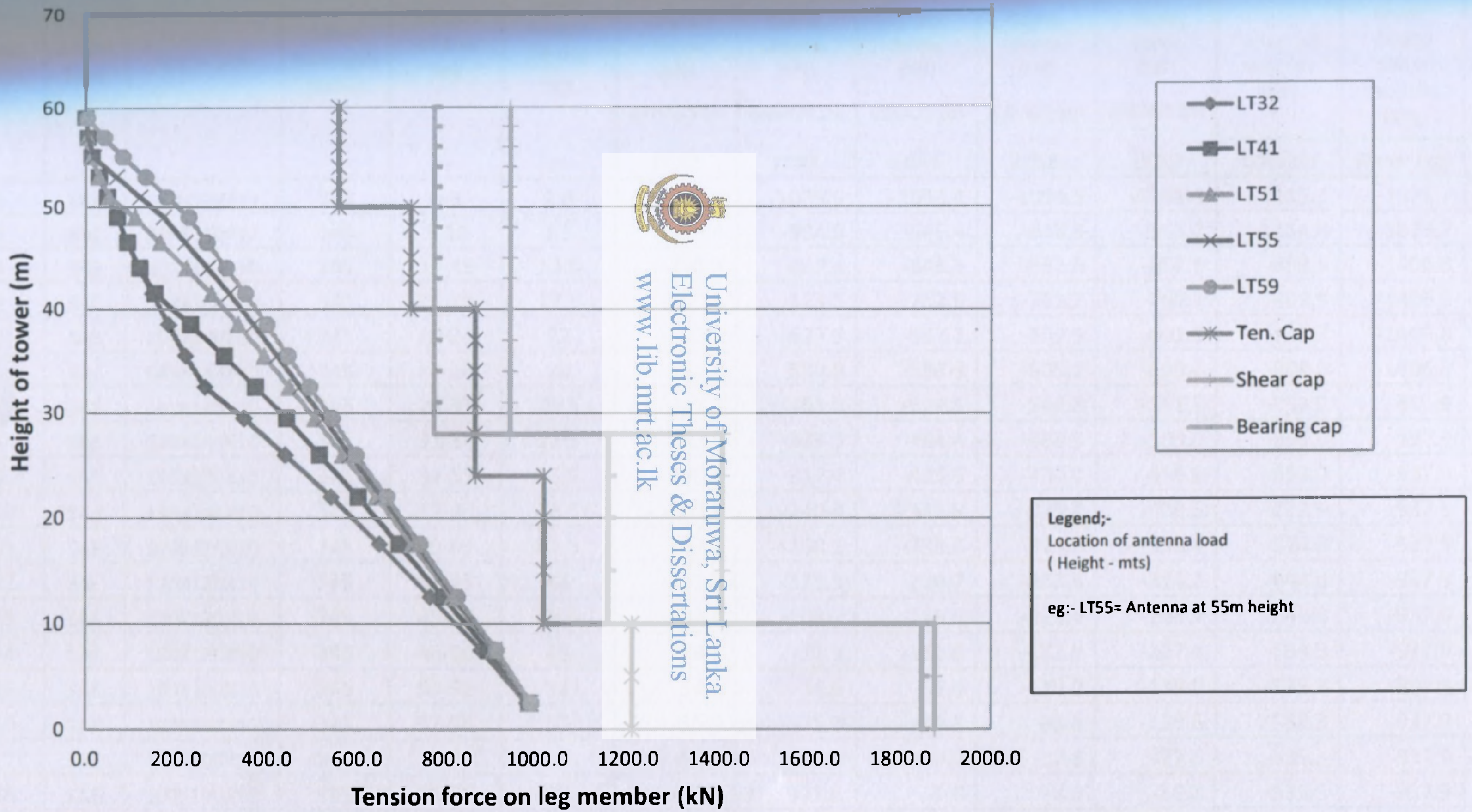


Table 6-4

Different maximum compression forces on each leg sections (kN).

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of the leg	Mid height of the leg	Antenna load /Height from ground level					Available member capacities		
						Comp. Force (kN) 107kN/32m	Comp. Force (kN) 84kN/41m	Comp. Force (kN) 68kN/51m	Comp. Force (kN) 63kN/55m	Comp. Force (kN) 59kN/59m	Comp. L/R capacity (kN)	Comp. Conn. Shear capacity (kN)	Comp. Conn. Bearing capacity (kN)
				m	m	*LC32*	*LC41*	*LC51*	*LC55*	*LC59*	*L/R Cap*	*Shear cap*	*Bearing cap*
Leg1	SAE	160X160X12	345	0-5	2.5	-1024.9	-1029.9	-1033.4	-1034.5	-1035.4	-1115.1	-1875.7	-1846.7
Leg2	SAE	160X160X12	345	5-10	7.5	-919.4	-934.9	-945.4	-948.8	-951.7	-1114.8	-1875.7	-1846.7
Leg3	SAE	160X160X10	345	10-15	12.5	-798.9	-827.4	-846.5	-852.6	-857.9	-860.6	-1406.8	-1154.2
Leg4	SAE	160X160X10	345	15-20	17.5	-680.5	-723.5	-752.5	-761.7	-769.7	-809.9	-1406.8	-1154.2
Leg5	SAE	160X160X10	345	20-24	22	-567.7	-627.3	-667.2	-679.9	-691.0	-842.3	-1406.8	-1154.2
Leg6	SAE	140X140X10	345	24-28	26	-461.8	-537.8	-588.9	-605.2	-619.4	-808.0	-1406.8	-1154.2
Leg7	SAE	140X140X10	345	28-31	29.5	-367.3	-461.6	-524.6	-544.8	-562.3	-853.0	-937.9	-769.4
Leg8	SAE	140X140X10	345	31-34	32.5	-282.9	-389.5	-464.4	-488.3	-509.0	-853.0	-937.9	-769.4
Leg9	SAE	140X140X10	345	34-37	35.5	-240.4	-317.4	-405.6	-434.0	-458.6	-853.0	-937.9	-769.4
Leg10	SAE	140X140X10	345	37-40	38.5	-200.5	-240.4	-345.8	-379.4	-408.5	-712.9	-937.9	-769.4
Leg11	SAE	120X120X10	345	40-43	41.5	-163.1	-160.1	-283.8	-323.8	-358.4	-574.8	-937.9	-769.4
Leg12	SAE	120X120X10	345	43-45	44	-131.8	-131.5	-226.7	-273.6	-314.2	-644.8	-937.9	-769.4
Leg13	SAE	120X120X10	345	45-48	46.5	-102.4	-102.7	-166.6	-221.4	-268.9	-644.8	-937.9	-769.4
Leg14	SAE	120X120X10	345	48-50	49	-78.1	-77.9	-110.0	-172.9	-227.4	-694.5	-937.9	-769.4
Leg15	SAE	100X100X10	345	50-52	51	-54.6	-54.6	-55.0	-119.0	-178.0	-535.3	-937.9	-769.4
Leg16	SAE	100X100X10	345	52-54	53	-35.3	-35.3	-35.3	-66.8	-129.6	-535.3	-937.9	-769.4
Leg17	SAE	100X100X10	345	54-56	55	-17.9	-17.9	-17.9	-17.8	-77.6	-535.3	-937.9	-769.4
Leg18	SAE	100X100X10	345	56-58	57	-7.6	-7.6	-7.6	-8.0	-36.8	-535.3	-937.9	-769.4
Leg19	SAE	100X100X10	345	58-60	59	-0.7	-0.7	-0.7	-1.0	-0.6	-535.3	-937.9	-769.4

Table 6-5 :- Different maximum compression forces on leg sections.
(As a percentage of the L/R capacity of each leg section)

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Top height of panel	Mid height of the leg	Antenna load /Height from ground level					Comp. L/R capacity (kN)
						Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	
						107kN/32m	84kN/41m	68kN/51m	63kN/55m	59kN/59m	
				m	m	*LC32*	*LC41*	*LC51*	*LC55*	*LC59*	*L/R Cap*
Leg1	SAE	160X160X12	345	0-5	2.5	91.9	92.4	92.7	92.8	92.9	100
Leg2	SAE	160X160X12	345	5-10	7.5	82.5	83.9	84.8	85.1	85.4	100
Leg3	SAE	160X160X10	345	10-15	12.5	98.6	102.1	104.4	105.2	105.8	100
Leg4	SAE	160X160X10	345	15-20	17.5	84.0	89.3	92.9	94.1	95.0	100
Leg5	SAE	160X160X10	345	20-24	22	67.4	74.5	79.2	80.7	82.0	100
Leg6	SAE	140X140X10	345	24-28	26	57.2	66.6	72.9	74.9	76.7	100
Leg7	SAE	140X140X10	345	28-31	29.5	43.1	54.1	61.5	63.9	65.9	100
Leg8	SAE	140X140X10	345	31-34	32.5	33.2	45.7	54.4	57.2	59.7	100
Leg9	SAE	140X140X10	345	34-37	35.5	28.2	37.2	47.6	50.9	53.8	100
Leg10	SAE	140X140X10	345	37-40	38.5	28.1	33.7	48.5	53.2	57.3	100
Leg11	SAE	120X120X10	345	40-43	41.5	28.4	27.9	49.4	56.3	62.3	100
Leg12	SAE	120X120X10	345	43-45	44	20.4	20.4	35.2	42.4	48.7	100
Leg13	SAE	120X120X10	345	45-48	46.5	15.9	15.9	25.8	34.3	41.7	100
Leg14	SAE	120X120X10	345	48-50	49	11.2	11.2	15.8	24.9	32.7	100
Leg15	SAE	100X100X10	345	50-52	51	10.2	10.2	10.3	22.2	33.3	100
Leg16	SAE	100X100X10	345	52-54	53	6.6	6.6	6.6	12.5	24.2	100
Leg17	SAE	100X100X10	345	54-56	55	3.3	3.3	3.3	3.3	14.5	100
Leg18	SAE	100X100X10	345	56-58	57	1.4	1.4	1.4	1.5	6.9	100
Leg19	SAE	100X100X10	345	58-60	59	0.1	0.1	0.1	0.2	0.1	100

Figure 6.2 - Design force on main leg members for different antenna locations/loads

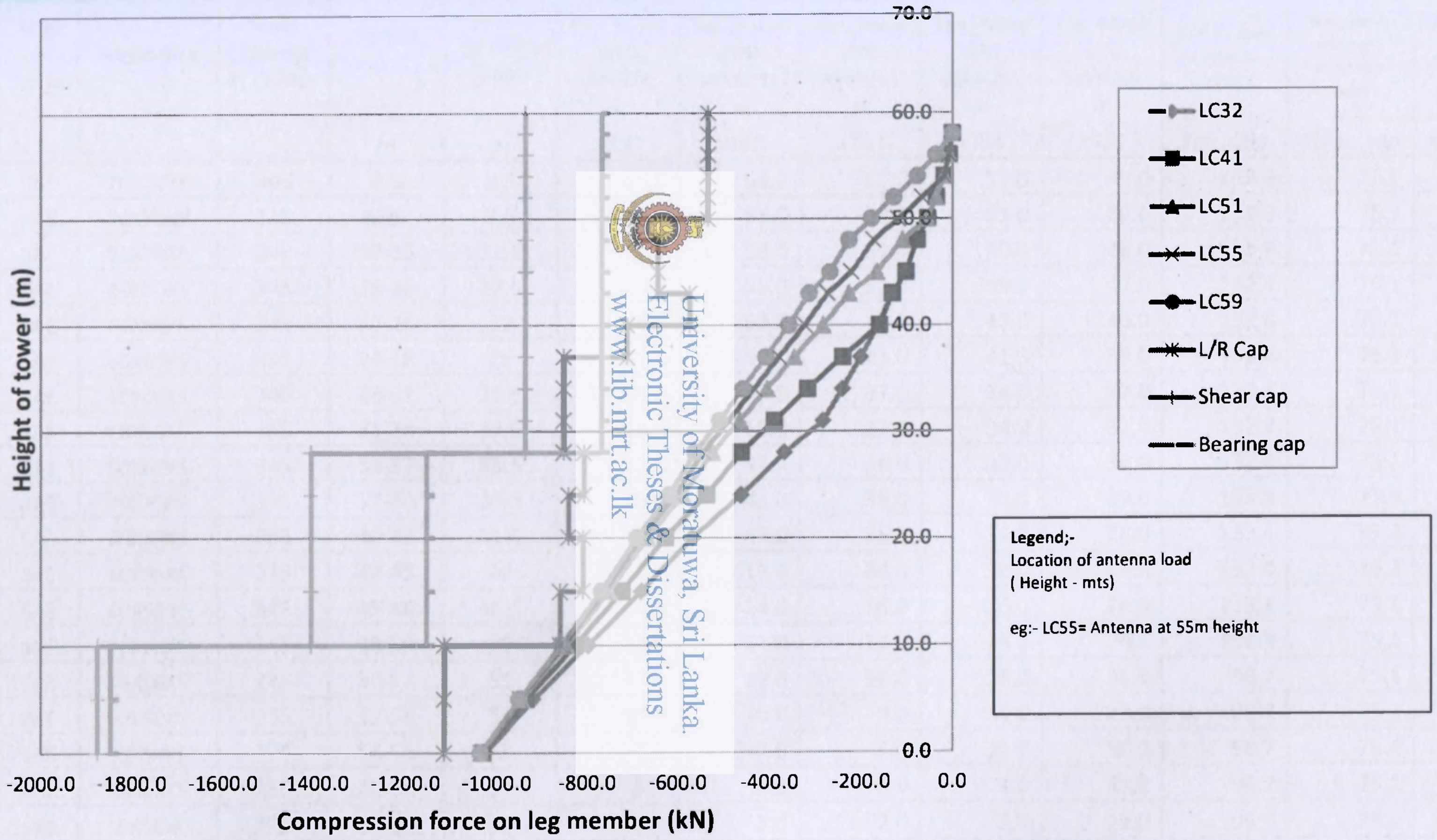


Table 6-6

Different maximum tension forces on X panels (kN).

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height	Mid height of the X panel	Antenna load /Height from ground level					Available member capacities		
						Ten. Force (kN) 107kN/32 m	Ten. Force (kN) 84kN/41 m	Ten. Force (kN) 68kN/51 m	Ten. Force (kN) 63kN/55 m	Ten. Force (kN) 59kN/59 m	Net tension capacity (kN)	Ten. Conn. Shear capacity (kN)	Ten. Conn. Bearing capacity (kN)
				m	m	*XT32*	*XT41*	*XT51*	*XT55*	*XT59*	*Ten. Cap*	*Shear cap*	*Bearing cap*
X BZ1	SAE	70X70X5	345	0-5	2.5	65.0	58.0	52.0	51.0	49.0	158.9	75.1	77.1
X BZ2	SAE	70X70X5	345	5-10	7.5	67.0	58.0	53.0	51.0	49.0	158.9	75.1	77.1
X BZ3	SAE	70X70X5	345	10-15	12.5	68.0	58.0	52.0	50.0	48.0	158.9	75.1	77.1
X BZ4	SAE	60X60X5	345	15-20	17.5	70.0	58.0	51.0	49.0	47.0	132.4	75.1	77.1
X BZ5	SAE	60X60X5	345	20-24	22	64.0	52.0	45.0	42.0	40.0	132.4	75.1	77.1
X BZ6	SAE	60X60X5	345	24-28	26	65.0	52.0	43.0	41.0	38.0	132.4	75.1	77.1
X BZ7	SAE	60X60X5	345	28-31	29.5	58.0	46.0	37.0	34.0	32.0	132.4	75.1	77.1
X BZ8	SAE	60X60X5	345	31-34	32.5	58.0	46.0	37.0	34.0	31.0	132.4	75.1	77.1
X BZ9	SAE	60X60X5	345	34-37	35.5	21.0	47.0	36.0	33.0	30.0	132.4	75.1	77.1
X BZ10	SAE	70X70X5	345	37-40	38.5	20.0	48.0	36.0	32.0	29.0	158.9	75.1	77.1
X BZ11	SAE	60X60X5	345	40-43	41.5	18.0	49.0	36.0	32.0	28.0	132.4	75.1	77.1
X BZ12	SAE	60X60X5	345	43-45	44	15.0	15.0	34.0	30.0	26.0	132.4	75.1	77.1
X BZ13	SAE	60X60X5	345	45-48	46.5	14.0	14.0	36.0	30.0	26.0	132.4	75.1	77.1
X BZ14	SAE	60X60X5	345	48-50	49	11.0	11.0	34.0	28.0	24.0	132.4	75.1	77.1
X BZ15	SAE	50X50X5	235	50-52	51	12.0	12.0	36.0	36.0	35.0	96.7	75.1	72.1
X BZ16	SAE	50X50X5	235	52-54	53	10.0	10.0	9.0	34.0	33.0	96.7	75.1	72.1
X BZ17	SAE	50X50X5	235	54-56	55	7.0	7.0	7.0	30.0	30.0	96.7	75.1	72.1
X BZ18	SAE	50X50X5	235	56-58	57	5.0	5.0	5.0	4.0	27.0	96.7	75.1	72.1
X BZ19	SAE	50X50X5	235	58-60	59	2.0	2.0	2.0	2.0	23.0	96.7	75.1	72.1

Table 6-7 :- Different maximum tension forces on X panels (kN).
(As a percentage of the tension capacity of each X panel)

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height	Mid height of the X panel	Antenna load /Height from ground level					Net Ten. capacity (kN)
						Ten. Force (% of Net ten. cap) 107kN/32m	Ten. Force (% of Net ten. cap) 84kN/41m	Ten. Force (% of Net ten. cap) 68kN/51m	Ten. Force (% of Net ten. cap) 63kN/55m	Ten. Force (% of Net ten. cap) 59kN/59m	
				m	m	*XT32*	*XT41*	*XT51*	*XT55*	*XT59*	*Ten. Cap*
X BZ1	SAE	70X70X5	345	0-5	2.5	40.9	36.5	32.7	32.1	30.8	100
X BZ2	SAE	70X70X5	345	5-10	7.5	42.2	36.5	33.4	32.1	30.8	100
X BZ3	SAE	70X70X5	345	10-15	12.5	42.8	36.5	32.7	31.5	30.2	100
X BZ4	SAE	60X60X5	345	15-20	17.5	52.9	43.8	38.5	37.0	35.5	100
X BZ5	SAE	60X60X5	345	20-24	22	48.3	39.3	34.0	31.7	30.2	100
X BZ6	SAE	60X60X5	345	24-28	26	49.1	39.3	32.5	31.0	28.7	100
X BZ7	SAE	60X60X5	345	28-31	29.5	43.8	34.7	27.9	25.7	24.2	100
X BZ8	SAE	60X60X5	345	31-34	32.5	43.8	34.7	27.9	25.7	23.4	100
X BZ9	SAE	60X60X5	345	34-37	35.5	15.9	35.5	27.2	24.9	22.7	100
X BZ10	SAE	70X70X5	345	37-40	38.5	12.6	30.2	22.7	20.1	18.2	100
X BZ11	SAE	60X60X5	345	40-43	41.5	13.6	37.0	27.2	24.2	21.1	100
X BZ12	SAE	60X60X5	345	43-45	44	11.3	11.3	25.7	22.7	19.6	100
X BZ13	SAE	60X60X5	345	45-48	46.5	10.6	10.6	27.2	22.7	19.6	100
X BZ14	SAE	60X60X5	345	48-50	49	8.3	8.3	25.7	21.1	18.1	100
X BZ15	SAE	50X50X5	235	50-52	51	12.4	12.4	37.2	37.2	36.2	100
X BZ16	SAE	50X50X5	235	52-54	53	10.3	10.3	9.3	35.2	34.1	100
X BZ17	SAE	50X50X5	235	54-56	55	7.2	7.2	7.2	31.0	31.0	100
X BZ18	SAE	50X50X5	235	56-58	57	5.2	5.2	5.2	4.1	27.9	100
X BZ19	SAE	50X50X5	235	58-60	59	2.1	2.1	2.1	2.1	23.8	100

Figure 6.3 - Design force on X panels for different antenna locations/loads

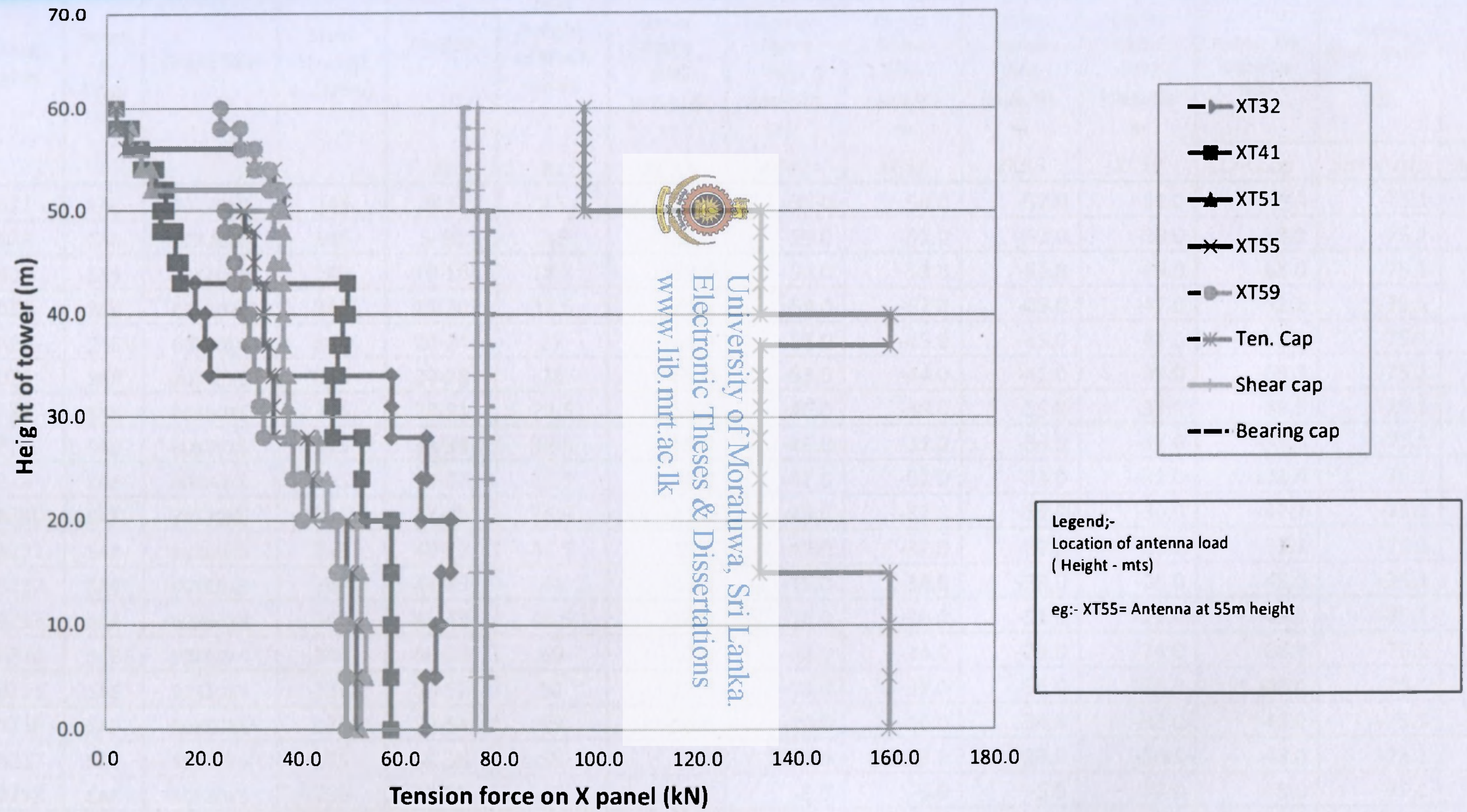


Table 6-9 :- Different maximum compression forces on X panels.

(As a percentage of the comp. capacity of each X panel)

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height	Mid height of the X panel	Antenna load /Height from ground level					Comp. L/R capacity (kN)
						Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	Comp. Force (% of L/R cap)	
						107kN/32m	84kN/41m	68kN/51m	63kN/55m	59kN/59m	
				m	m	*XC32*	*XC41*	*XC51*	*XC55*	*XC59*	*L/R Cap*
X BZ1	SAE	70X70X5	345	0-5	2.5	125.4	110.4	101.1	97.3	95.5	100
X BZ2	SAE	70X70X5	345	5-10	7.5	117.1	101.6	91.2	89.5	86.1	100
X BZ3	SAE	70X70X5	345	10-15	12.5	109.5	93.6	84.1	80.9	77.8	100
X BZ4	SAE	60X60X5	345	15-20	17.5	134.1	113.0	99.6	93.8	90.0	100
X BZ5	SAE	60X60X5	345	20-24	22	109.7	90.8	77.1	73.7	70.3	100
X BZ6	SAE	60X60X5	345	24-28	26	102.7	83.8	69.5	64.8	61.6	100
X BZ7	SAE	60X60X5	345	28-31	29.5	65.9	51.4	42.4	39.1	36.9	100
X BZ8	SAE	60X60X5	345	31-34	32.5	61.8	48.2	38.7	35.6	33.5	100
X BZ9	SAE	60X60X5	345	34-37	35.5	21.7	46.3	36.5	32.5	30.6	100
X BZ10	SAE	70X70X5	345	37-40	38.5	44.0	100.5	77.5	69.1	62.8	100
X BZ11	SAE	60X60X5	345	40-43	41.5	59.1	152.5	115.1	99.6	87.1	100
X BZ12	SAE	60X60X5	345	43-45	44	35.5	33.3	75.5	66.6	57.8	100
X BZ13	SAE	60X60X5	345	45-48	46.5	28.5	28.5	73.2	63.0	52.9	100
X BZ14	SAE	60X60X5	345	48-50	49	17.4	17.4	49.3	42.1	34.8	100
X BZ15	SAE	50X50X5	235	50-52	51	30.2	30.2	86.0	83.7	81.4	100
X BZ16	SAE	50X50X5	235	52-54	53	23.2	23.2	23.2	79.0	76.7	100
X BZ17	SAE	50X50X5	235	54-56	55	18.6	18.6	16.3	69.7	69.7	100
X BZ18	SAE	50X50X5	235	56-58	57	11.6	11.6	11.6	11.6	62.8	100
X BZ19	SAE	50X50X5	235	58-60	59	4.6	4.6	4.6	4.6	53.5	100

Figure 6.4 - Design force on X panels for different antenna locations/loads

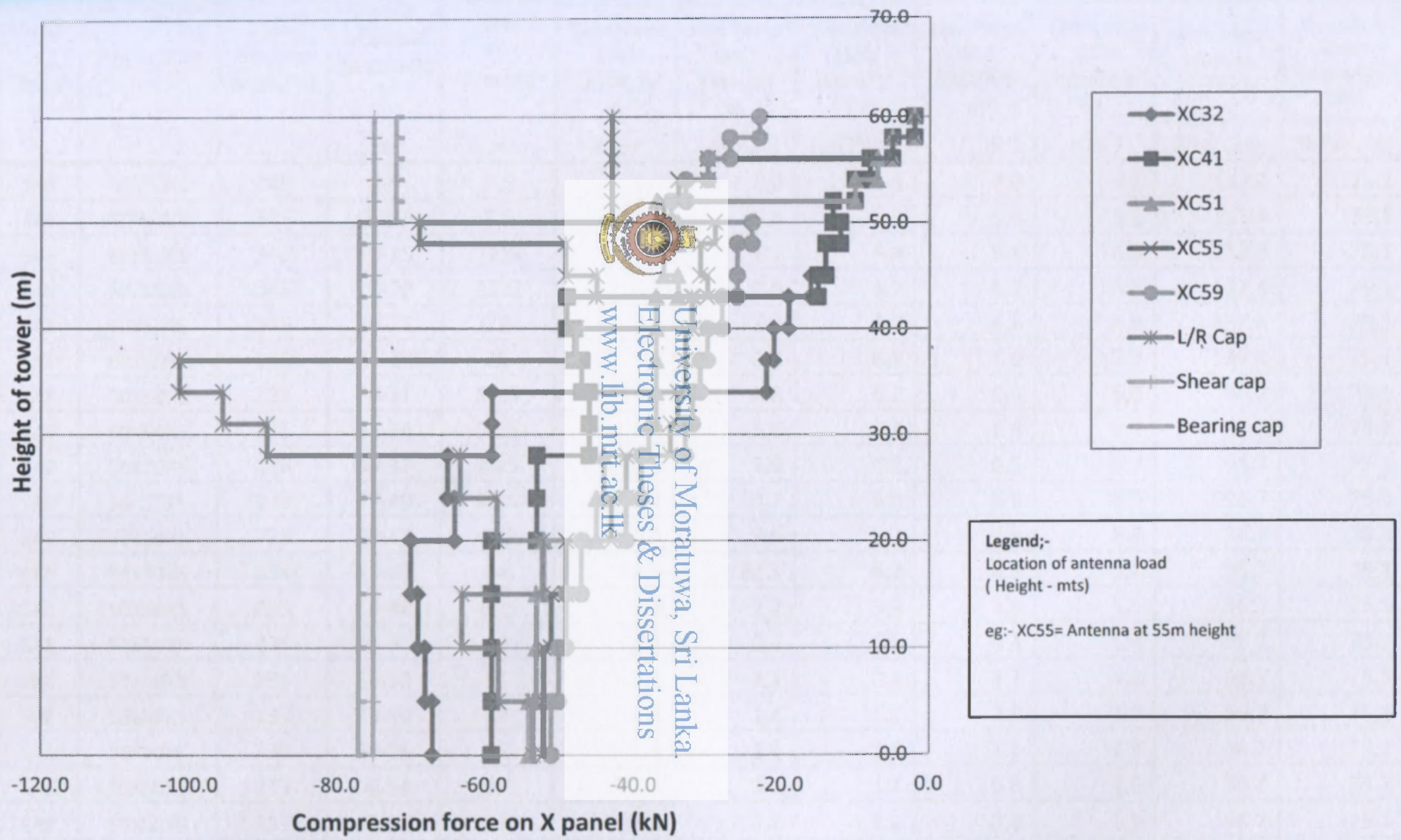


Table 6-10

Different maximum tension forces on Horizontal bracing (kN).

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of panel (X panel)	Level of the H-bracing	Antenna load /Height from ground level					Available member capacities		
						Ten. Force (kN) 107kN/32 m	Ten. Force (kN) 84kN/41 m	Ten. Force (kN) 68kN/51 m	Ten. Force (kN) 63kN/55 m	Ten. Force (kN) 59kN/59 m	Net tension capacity (kN)	Ten. Conn. Shear capacity (kN)	Ten. Conn. Bearing capacity (kN)
				m	m	*HT32*	*HT41*	*HT51*	*HT55*	*HT59*	*Ten. Cap*	*Shear cap*	*Bearing cap*
H1	SAE	60X60X5	345	0-5	2.5	1.0	0.8	1.9	3.0	4.1	132.4	75.1	77.1
Hb1	SAE	60X60X5	345	5-10	7.5	5.2	5.3	5.3	5.3	5.3	132.4	75.1	77.1
Hb2	SAE	60X60X5	345	10-15	12.5	6.6	6.7	6.8	6.8	6.9	132.4	75.1	77.1
Hb3	SAE	60X60X5	345	15-20	17.5	6.2	6.5	6.7	6.7	6.8	132.4	75.1	77.1
Hb4	SAE	60X60X5	345	20-24	22	6.1	6.4	6.7	6.8	6.9	132.4	75.1	77.1
Hb5	SAE	60X60X5	345	24-28	26	5.8	6.4	6.9	7.0	7.2	132.4	75.1	77.1
Hb6	SAE	50X50X5	235	28-31	29.5	4.8	5.6	6.2	6.4	6.5	96.7	75.1	72.1
Hb7	SAE	50X50X5	235	31-34	32.5	4.4	5.6	6.4	6.6	6.9	96.7	75.1	72.1
Hb8	SAE	50X50X5	235	34-37	35.5	27.9	5.0	6.1	6.5	6.7	96.7	75.1	72.1
Hb9	SAE	50X50X5	235	37-40	38.5	3.4	4.7	6.0	6.5	6.9	96.7	75.1	72.1
Hb10	SAE	50X50X5	235	40-43	41.5	3.4	3.6	5.3	5.9	6.3	96.7	75.1	72.1
Hb11	SAE	50X50X5	235	43-45	44	2.7	22.3	4.2	4.9	5.4	96.7	75.1	72.1
Hb12	SAE	50X50X5	235	45-48	46.5	2.6	2.2	3.9	4.8	5.5	96.7	75.1	72.1
Hb13	SAE	50X50X5	235	48-50	49	2.4	2.4	3.2	4.4	5.4	96.7	75.1	72.1
Hb14	SAE	50X50X5	235	50-52	51	2.1	2.1	2.4	3.7	4.8	96.7	75.1	72.1
Hb15	SAE	50X50X5	235	52-54	53	1.4	1.4	16.8	2.0	3.0	96.7	75.1	72.1
Hb16	SAE	50X50X5	235	54-56	55	1.4	1.4	1.0	1.6	2.9	96.7	75.1	72.1
Hb17	SAE	50X50X5	235	56-58	57	1.1	1.1	1.1	15.6	1.6	96.7	75.1	72.1
Hb18	SAE	50X50X5	235	58-60	59	1.1	1.1	1.1	0.8	1.1	96.7	75.1	72.1

Table 6-11 :- Different maximum tension forces on Horizontal bracing (kN).
(As a percentage of the tension capacity of each H bracing)

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of panel (X panel)	Level of the H-bracing	Antenna load /Height from ground level					Net Ten. capacity (kN)
						Ten. Force (% of Net ten. cap)	Ten. Force (% of Net ten. cap)	Ten. Force (% of Net ten. cap)	Ten. Force (% of Net ten. cap)	Ten. Force (% of Net ten. cap)	
						107kN/32m	84kN/41m	68kN/51m	63kN/55m	59kN/59m	
				m	m	*HT32*	*HT41*	*HT51*	*HT55*	*HT59*	*Ten. Cap*
H1	SAE	60X60X5	345	0-5	2.5	0.8	0.6	1.4	2.3	3.1	100
Hb1	SAE	60X60X5	345	5-10	7.5	3.9	4.0	4.0	4.0	4.0	100
Hb2	SAE	60X60X5	345	10-15	12.5	5.0	5.1	5.1	5.1	5.2	100
Hb3	SAE	60X60X5	345	15-20	17.5	4.7	4.9	5.1	5.1	5.1	100
Hb4	SAE	60X60X5	345	20-24	22	4.6	4.8	5.1	5.1	5.2	100
Hb5	SAE	60X60X5	345	24-28	26	4.4	4.8	5.2	5.3	5.4	100
Hb6	SAE	50X50X5	235	28-31	29.5	5.0	5.8	6.4	6.6	6.7	100
Hb7	SAE	50X50X5	235	31-34	32.5	4.6	5.8	6.6	6.8	7.1	100
Hb8	SAE	50X50X5	235	34-37	35.5	28.9	5.2	6.3	6.7	6.9	100
Hb9	SAE	50X50X5	235	37-40	38.5	3.5	4.9	6.2	6.7	7.1	100
Hb10	SAE	50X50X5	235	40-43	41.5	3.5	3.7	5.5	6.1	6.5	100
Hb11	SAE	50X50X5	235	43-45	44	2.8	23.1	4.3	5.1	5.6	100
Hb12	SAE	50X50X5	235	45-48	46.5	2.7	2.3	4.0	5.0	5.7	100
Hb13	SAE	50X50X5	235	48-50	49	2.5	2.5	3.3	4.6	5.6	100
Hb14	SAE	50X50X5	235	50-52	51	2.2	2.2	2.5	3.8	5.0	100
Hb15	SAE	50X50X5	235	52-54	53	1.4	1.4	17.4	2.1	3.1	100
Hb16	SAE	50X50X5	235	54-56	55	1.4	1.4	1.0	1.7	3.0	100
Hb17	SAE	50X50X5	235	56-58	57	1.1	1.1	1.1	16.1	1.7	100
Hb18	SAE	50X50X5	235	58-60	59	1.1	1.1	1.1	0.8	1.1	100

Figure 6.5 - Design force on horizontal bracing for different antenna locations/loads

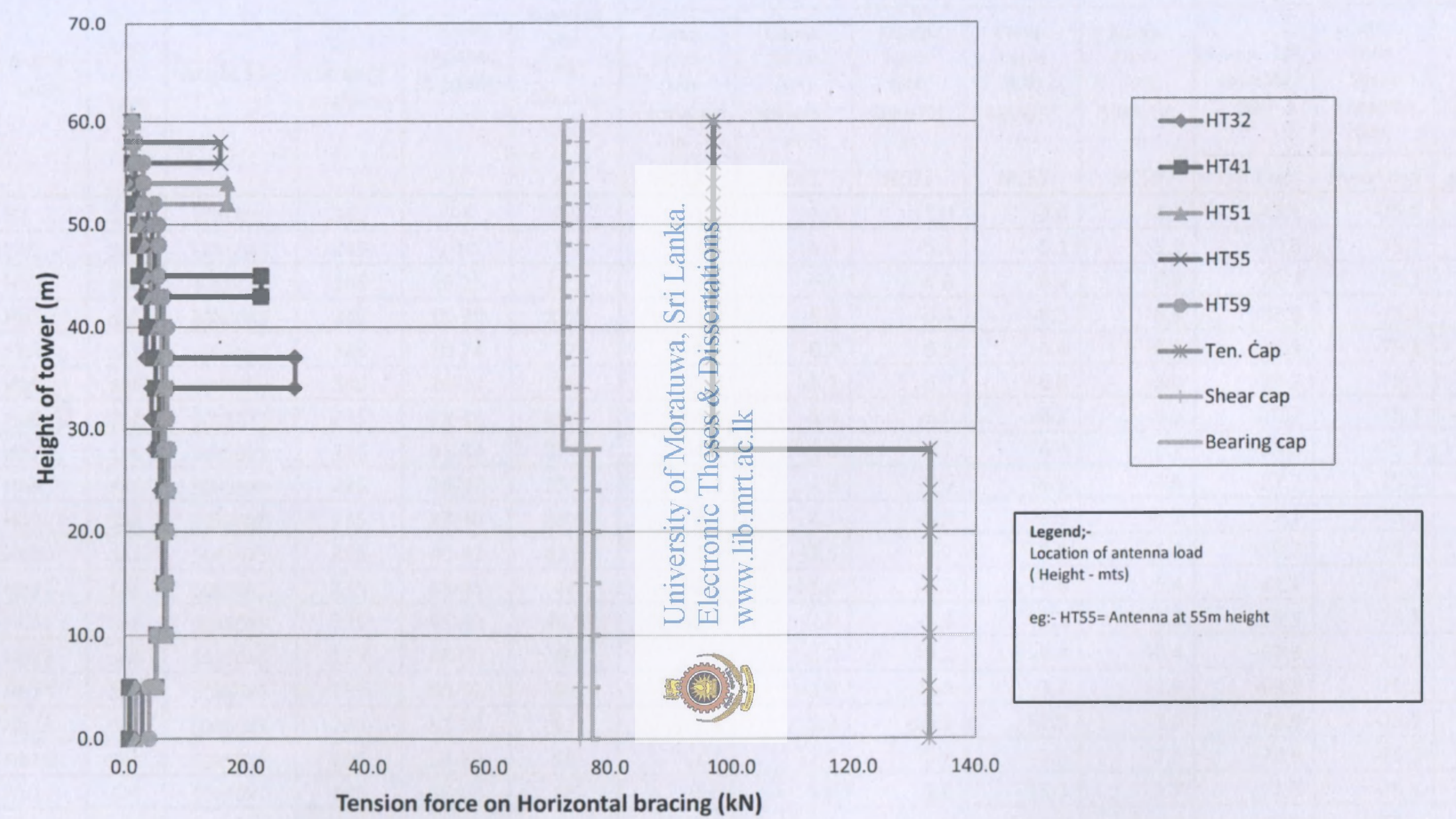


Table 6-12
Different maximum compression forces on Horizontal bracings (kN).

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of panel (X panel)	Level of the H-bracing	Antenna load /Height from ground level					Available member capacities		
						Comp. Force (kN) 107kN/32 m	Comp. Force (kN) 84kN/41 m	Comp. Force (kN) 68kN/51 m	Comp. Force (kN) 63kN/55 m	Comp. Force (kN) 59kN/59 m	Comp. L/R capacity (kN)	Comp. Conn. Shear capacity (kN)	Comp. Conn. Bearing capacity (kN)
				m	m	*HC32*	*HC41*	*HC51*	*HC55*	*HC59*	*L/R Cap*	*Shear cap*	*Bearing cap*
H1	SAE	60X60X5	345	0-5	2.5	-1.2	-1.0	-1.9	-3.0	-4.1	-42.1	-75.1	-77.1
Hb1	SAE	60X60X5	345	5-10	7.5	-5.0	-5.1	-5.1	-5.1	-5.1	-60.3	-75.1	-77.1
Hb2	SAE	60X60X5	345	10-15	12.5	-6.4	-6.5	-6.6	-6.6	-6.6	-70.3	-75.1	-77.1
Hb3	SAE	60X60X5	345	15-20	17.5	-6.0	-6.3	-6.4	-6.5	-6.5	-82.6	-75.1	-77.1
Hb4	SAE	60X60X5	345	20-24	22	-5.8	-6.2	-6.5	-6.6	-6.6	-24.9	-75.1	-77.1
Hb5	SAE	60X60X5	345	24-28	26	-5.6	-6.2	-6.7	-6.8	-6.9	-29.7	-75.1	-77.1
Hb6	SAE	50X50X5	235	28-31	29.5	-4.6	-5.4	-6.0	-6.2	-6.3	-20.2	-75.1	-72.1
Hb7	SAE	50X50X5	235	31-34	32.5	-4.1	-5.4	-6.2	-6.4	-6.7	-23.8	-75.1	-72.1
Hb8	SAE	50X50X5	235	34-37	35.5	-27.3	-4.9	-5.9	-6.3	-6.6	-27.7	-75.1	-72.1
Hb9	SAE	50X50X5	235	37-40	38.5	-3.2	-4.5	-5.9	-6.3	-6.7	-32.7	-75.1	-72.1
Hb10	SAE	50X50X5	235	40-43	41.5	-3.1	-3.5	-5.2	-5.8	-6.2	-39.2	-75.1	-72.1
Hb11	SAE	50X50X5	235	43-45	44	-2.5	-21.8	-4.2	-4.8	-5.4	-47.4	-75.1	-72.1
Hb12	SAE	50X50X5	235	45-48	46.5	-2.4	-2.0	-3.9	-4.7	-5.4	-55.3	-75.1	-72.1
Hb13	SAE	50X50X5	235	48-50	49	-2.2	-2.2	-3.2	-4.4	-5.4	-62.9	-75.1	-72.1
Hb14	SAE	50X50X5	235	50-52	51	-1.9	-1.9	-2.4	-3.7	-4.8	-69.8	-75.1	-72.1
Hb15	SAE	50X50X5	235	52-54	53	-1.3	-1.3	-16.8	-2.0	-3.0	-72.9	-75.1	-72.1
Hb16	SAE	50X50X5	235	54-56	55	-1.2	-1.2	-0.9	-1.6	-2.9	-72.9	-75.1	-72.1
Hb17	SAE	50X50X5	235	56-58	57	-1.0	-1.0	-1.0	-15.6	-1.7	-72.9	-75.1	-72.1
Hb18	SAE	50X50X5	235	58-60	59	-1.0	-1.0	-1.0	-0.7	-1.2	-72.9	-75.1	-72.1

Table 6-13 :- Different maximum compression forces on Horizontal bracings.
(As a percentage of the comp. capacity of each H bracing)

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of panel (X panel)	Level of the H-bracing	Antenna load /Height from ground level					Comp. L/R capacity (kN)
						Comp. Force (% of L/R cap) 107kN/32m	Comp. Force (% of L/R cap) 84kN/41m	Comp. Force (% of L/R cap) 68kN/51m	Comp. Force (% of L/R cap) 63kN/55m	Comp. Force (% of L/R cap) 59kN/59m	
				m	m	*HC32*	*HC41*	*HC51*	*HC55*	*HC59*	*L/R Cap*
H1	SAE	60X60X5	345	0-5	2.5	2.8	2.4	4.5	7.1	9.7	100
Hb1	SAE	60X60X5	345	5-10	7.5	8.3	8.5	8.5	8.5	8.5	100
Hb2	SAE	60X60X5	345	10-15	12.5	9.1	9.2	9.4	9.4	9.4	100
Hb3	SAE	60X60X5	345	15-20	17.5	7.3	7.6	7.7	7.9	7.9	100
Hb4	SAE	60X60X5	345	20-24	22	23.3	24.9	26.1	26.5	26.5	100
Hb5	SAE	60X60X5	345	24-28	26	18.8	20.8	22.5	22.9	23.2	100
Hb6	SAE	50X50X5	235	28-31	29.5	22.8	26.7	29.7	30.7	31.2	100
Hb7	SAE	50X50X5	235	31-34	32.5	17.2	22.7	26.1	26.9	28.2	100
Hb8	SAE	50X50X5	235	34-37	35.5	98.5	17.7	21.3	22.7	23.8	100
Hb9	SAE	50X50X5	235	37-40	38.5	9.8	13.8	18.0	19.3	20.5	100
Hb10	SAE	50X50X5	235	40-43	41.5	7.9	8.9	13.3	14.8	15.8	100
Hb11	SAE	50X50X5	235	43-45	44	5.3	46.0	8.9	10.1	11.4	100
Hb12	SAE	50X50X5	235	45-48	46.5	4.3	3.6	7.1	8.5	9.8	100
Hb13	SAE	50X50X5	235	48-50	49	3.5	3.5	5.1	7.0	8.6	100
Hb14	SAE	50X50X5	235	50-52	51	2.7	2.7	3.4	5.3	6.9	100
Hb15	SAE	50X50X5	235	52-54	53	1.8	1.8	23.0	2.7	4.1	100
Hb16	SAE	50X50X5	235	54-56	55	1.6	1.6	1.2	2.2	4.0	100
Hb17	SAE	50X50X5	235	56-58	57	1.4	1.4	1.4	21.4	2.3	100
Hb18	SAE	50X50X5	235	58-60	59	1.4	1.4	1.4	1.0	1.6	100

Figure 6.6 - Design force on horizontal bracings for different antenna locations/loads

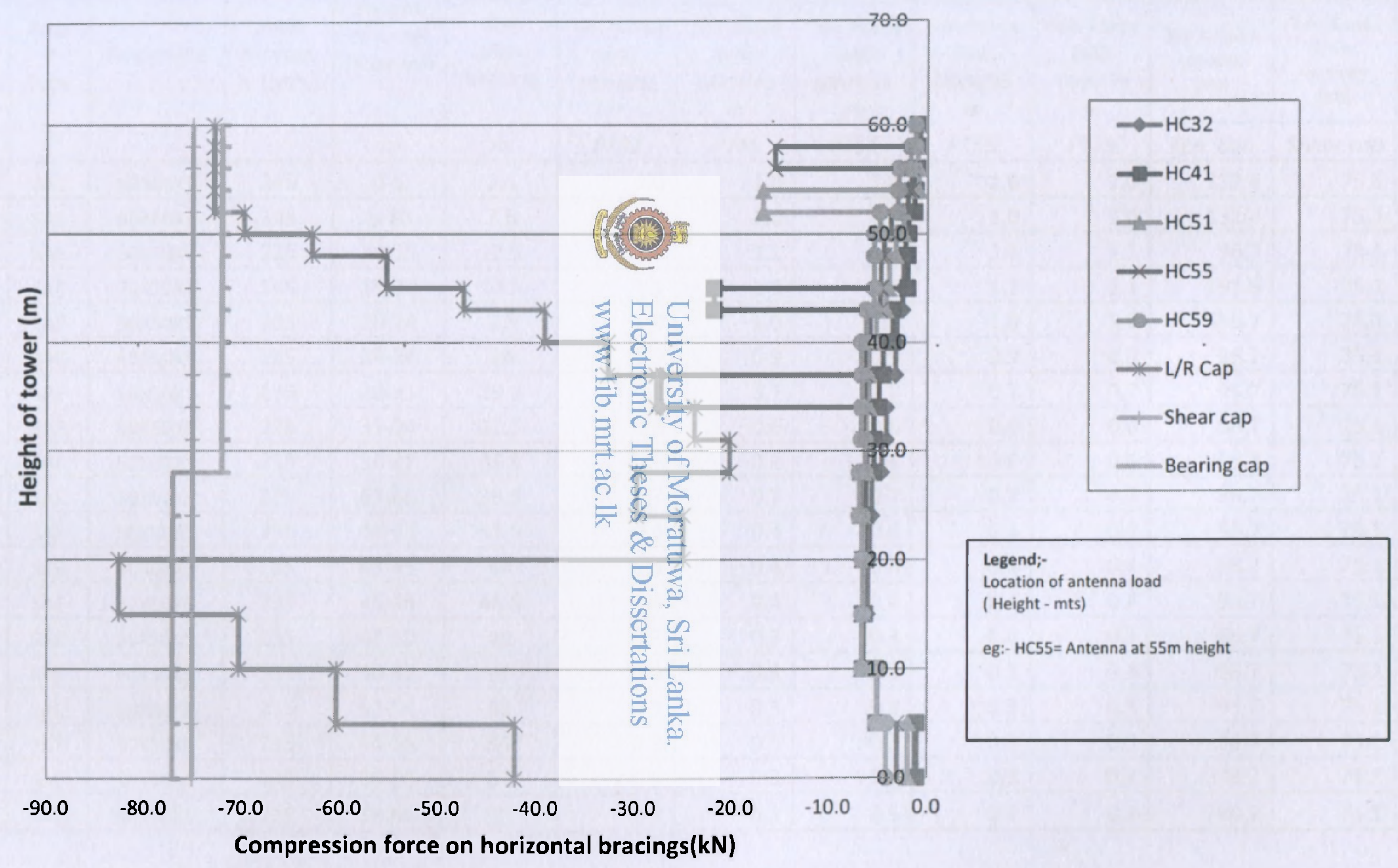


Table 6-14
Different maximum tension force on plan bracings (kN).

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of panel (X panel)	Level of the plan bracing	Antenna load /Height from ground level					Available member capacities		
						Ten. Force (kN) 107kN/32 m	Ten. Force (kN) 84kN/41 m	Ten. Force (kN) 68kN/51 m	Ten. Force (kN) 63kN/55 m	Ten. Force (kN) 59kN/59 m	Net tension capacity (kN)	Ten. Conn. Shear capacity (kN)	Ten. Conn. Bearing capacity (kN)
				m	m	*PT32*	*PT41*	*PT51*	*PT55*	*PT59*	*Ten. Cap*	*Shear cap*	*Bearing cap*
PB1	SAE	60X60X5	345	0-5	2.5	1.0	1.0	1.0	1.0	1.0	132.4	75.1	77.1
PB2	SAE	60X60X5	345	5-10	7.5	1.0	1.0	1.0	1.0	1.0	132.4	75.1	77.1
PB3	SAE	50X50X5	235	10-15	12.5	1.1	1.1	1.1	1.1	1.1	96.7	75.1	72.1
PB4	SAE	70X70X6	345	15-20	17.5	1.1	1.1	1.1	1.1	1.1	191.6	75.1	92.5
PB5	SAE	50X50X5	235	20-24	22	1.0	1.0	1.0	1.0	1.0	96.7	75.1	72.1
PB6	SAE	50X50X5	235	24-28	26	0.9	0.9	0.9	0.9	0.9	96.7	75.1	72.1
PB7	SAE	50X50X5	235	28-31	29.5	0.7	0.7	0.7	0.7	0.7	96.7	75.1	72.1
PB8	SAE	50X50X5	235	31-34	32.5	0.6	0.6	0.6	0.6	0.6	96.7	75.1	72.1
PB9	SAE	50X50X5	235	34-37	35.5	0.6	0.6	0.6	0.6	0.6	96.7	75.1	72.1
PB10	SAE	50X50X5	235	37-40	38.5	0.7	0.7	0.7	0.7	0.7	96.7	75.1	72.1
PB11	SAE	50X50X5	235	40-43	41.5	0.4	0.4	0.4	0.4	0.4	96.7	75.1	72.1
PB12	SAE	50X50X5	235	43-45	44	0.4	0.4	0.4	0.4	0.4	96.7	75.1	72.1
PB13	SAE	50X50X5	235	45-48	46.5	0.4	0.4	0.4	0.4	0.4	96.7	75.1	72.1
PB14	SAE	50X50X5	235	48-50	49	0.3	0.3	0.3	0.3	0.3	96.7	75.1	72.1
PB15	SAE	50X50X5	235	50-52	51	0.3	0.3	0.3	0.3	0.3	96.7	75.1	72.1
PB16	SAE	50X50X5	235	52-54	53	0.3	0.3	0.3	0.3	0.3	96.7	75.1	72.1
PB17	SAE	50X50X5	235	54-56	55	0.3	0.3	0.3	0.3	0.3	96.7	75.1	72.1
PB18	SAE	50X50X5	235	56-58	57	0.3	0.3	0.3	0.3	0.3	96.7	75.1	72.1
PB19	SAE	50X50X5	235	58-60	59	0.3	0.3	0.3	0.3	0.3	96.7	75.1	72.1

Figure 6.7 - Design force on plan bracing for different antenna locations/loads

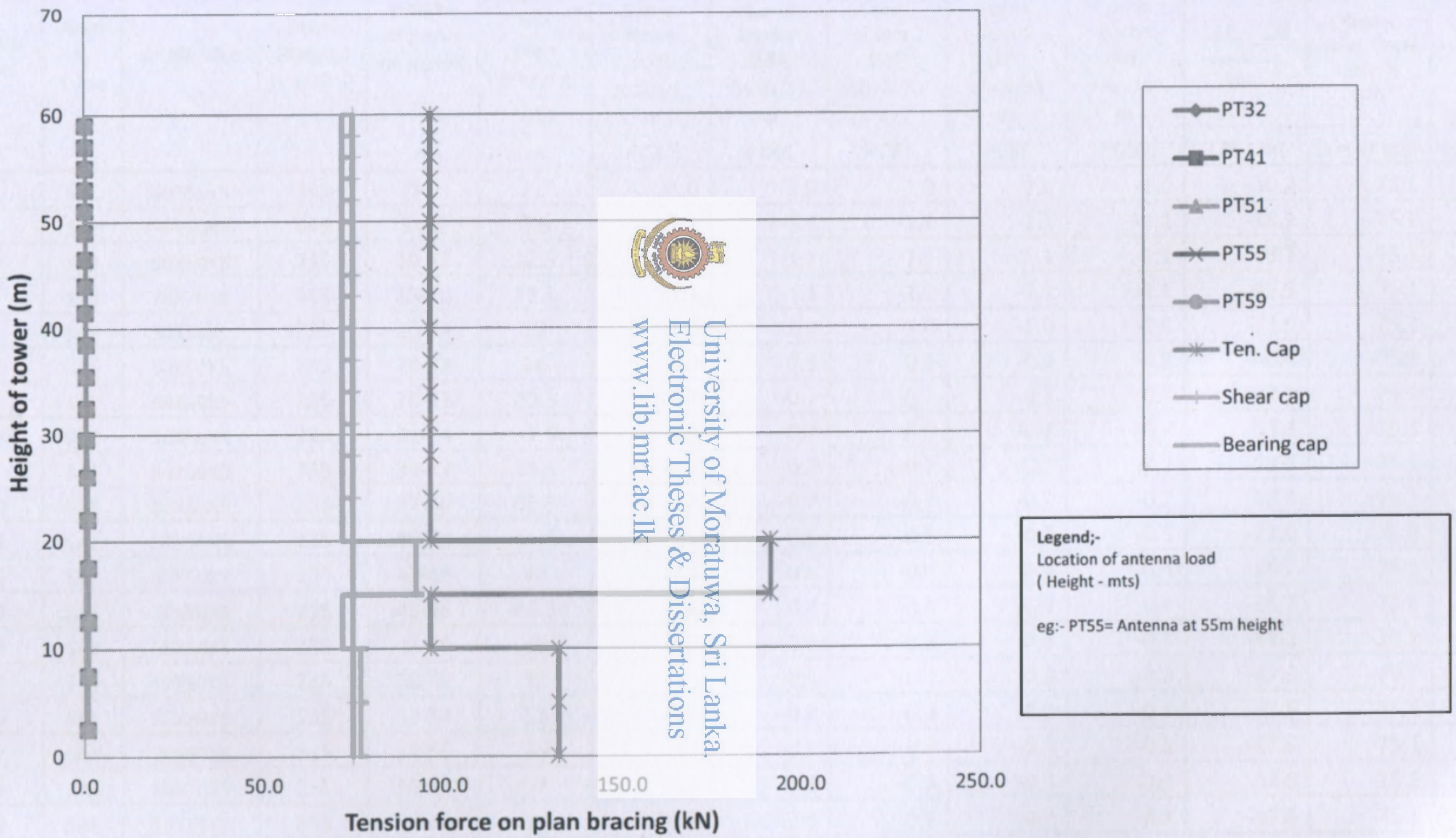
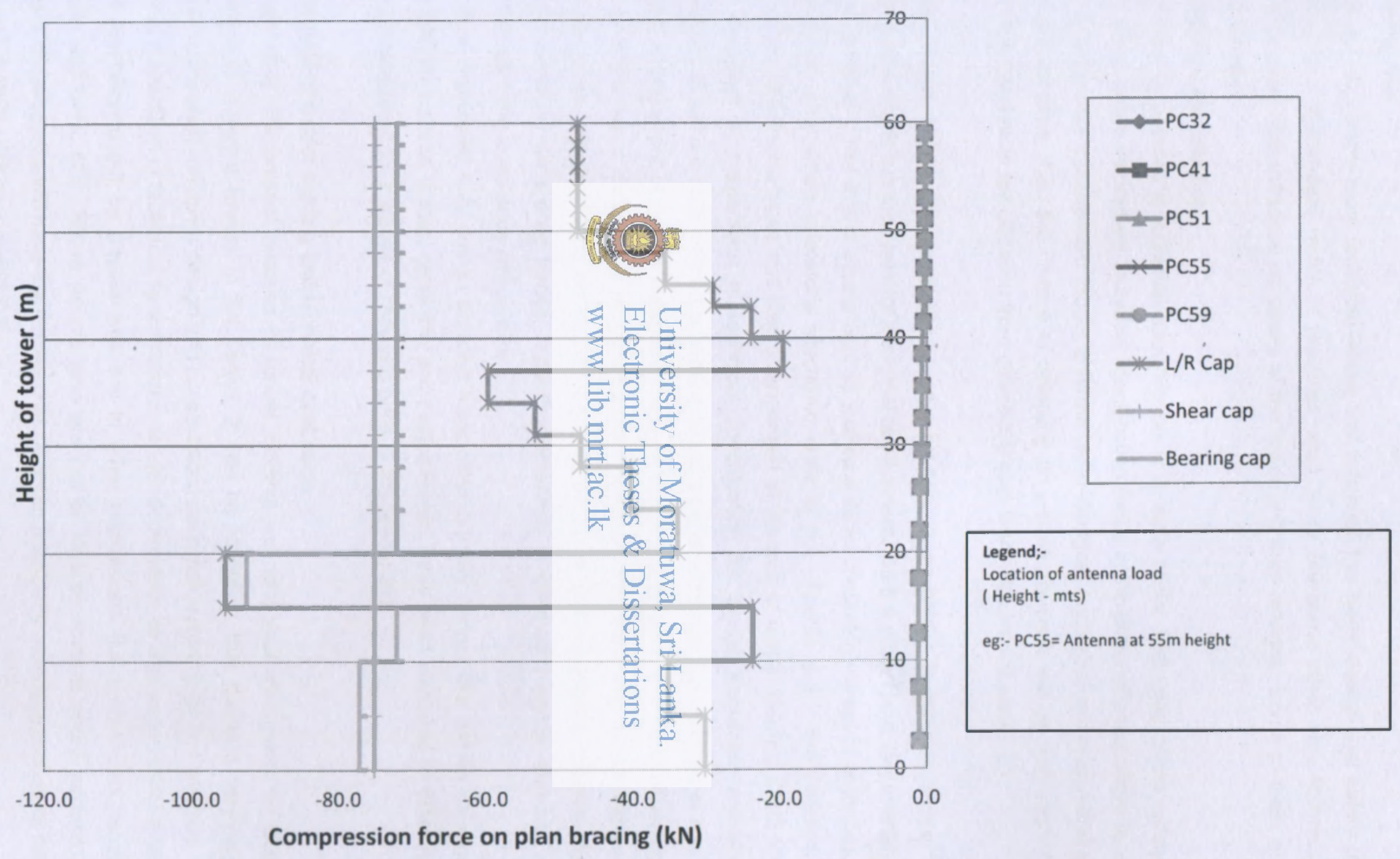


Table 6-15

Different maximum compression forces on plan bracings (kN).

Group Label	Angle Type	Angle Size	Steel Strength (MPa)	Height of panel (X panel)	Level of the plan bracing	Antenna load /Height from ground level					Available member capacities		
						Comp. Force (kN) 107kN/32 m	Comp. Force (kN) 84kN/41 m	Comp. Force (kN) 68kN/51 m	Comp. Force (kN) 63kN/55 m	Comp. Force (kN) 59kN/59 m	Comp. L/R capacity (kN)	Comp. Conn. Shear capacity (kN)	Comp. Conn. Bearing capacity (kN)
				m	m	*PC32*	*PC41*	*PC51*	*PC55*	*PC59*	*L/R Cap*	*Shear cap*	*Bearing cap*
PB1	SAE	60X60X5	345	0-5	2.5	-1.0	-1.0	-1.0	-1.0	-1.0	-30.2	-75.1	-77.1
PB2	SAE	60X60X5	345	5-10	7.5	-1.1	-1.1	-1.1	-1.1	-1.1	-35.2	-75.1	-77.1
PB3	SAE	50X50X5	235	10-15	12.5	-1.1	-1.1	-1.1	-1.1	-1.1	-23.7	-75.1	-72.1
PB4	SAE	70X70X6	345	15-20	17.5	-1.1	-1.1	-1.1	-1.1	-1.1	-95.5	-75.1	-92.5
PB5	SAE	50X50X5	235	20-24	22	-1.0	-1.0	-1.0	-1.0	-1.0	-33.9	-75.1	-72.1
PB6	SAE	50X50X5	235	24-28	26	-0.9	-0.9	-0.9	-0.9	-0.9	-40.4	-75.1	-72.1
PB7	SAE	50X50X5	235	28-31	29.5	-0.7	-0.7	-0.7	-0.7	-0.7	-47.2	-75.1	-72.1
PB8	SAE	50X50X5	235	31-34	32.5	-0.7	-0.7	-0.7	-0.7	-0.7	-53.3	-75.1	-72.1
PB9	SAE	50X50X5	235	34-37	35.5	-0.7	-0.7	-0.7	-0.7	-0.7	-59.7	-75.1	-72.1
PB10	SAE	50X50X5	235	37-40	38.5	-0.7	-0.7	-0.7	-0.7	-0.7	-19.6	-75.1	-72.1
PB11	SAE	50X50X5	235	40-43	41.5	-0.5	-0.5	-0.5	-0.5	-0.5	-23.9	-75.1	-72.1
PB12	SAE	50X50X5	235	43-45	44	-0.4	-0.4	-0.4	-0.4	-0.4	-29.2	-75.1	-72.1
PB13	SAE	50X50X5	235	45-48	46.5	-0.4	-0.4	-0.4	-0.4	-0.4	-35.7	-75.1	-72.1
PB14	SAE	50X50X5	235	48-50	49	-0.3	-0.3	-0.3	-0.3	-0.3	-43.7	-75.1	-72.1
PB15	SAE	50X50X5	235	50-52	51	-0.3	-0.3	-0.3	-0.3	-0.3	-47.6	-75.1	-72.1
PB16	SAE	50X50X5	235	52-54	53	-0.3	-0.3	-0.3	-0.3	-0.3	-47.6	-75.1	-72.1
PB17	SAE	50X50X5	235	54-56	55	-0.3	-0.3	-0.3	-0.3	-0.3	-47.6	-75.1	-72.1
PB18	SAE	50X50X5	235	56-58	57	-0.3	-0.3	-0.3	-0.3	-0.3	-47.6	-75.1	-72.1
PB19	SAE	50X50X5	235	58-60	59	-0.3	-0.3	-0.3	-0.3	-0.3	-47.6	-75.1	-72.1

Figure 6.8 - Design force on plan bracing for different antenna locations/loads



7.0 Various other factors which are affect tower designs

7.1 Introduction

Although we can control most technical issues that influence the tower design and safety of towers (i.e - with following standard codes of practices, etc.), there are some other non- technical issues which also having high influence on safety of the tower and their designs. Some of them are briefly described below,

7.2 Technical specification

Shortcomings in operator's technical specification is a main factor that may affect safety of any antenna tower. When incomplete technical specification exists in the event of competitive tender bids, as well as technically incompetent (about antenna tower designs) personnel are involved in technical evaluation committee, then the chance of selecting an unsafe structure will be very high. (Note -: Several recent technical specification from different clients were attached in annex B)

Generally, during extreme competition of tender bidding, every bidder is trying to supply his best tender proposal which suit the operator's original requirement. On the other hand, the operator needs, simply an antenna tower that is economical as well as safe for mounting his set of antennas. But the problem arises only when operator's electronic crew is not capable (i.e - not finalized, etc) of providing correct antenna types and their arrangement at the time of tender bidding. Then the person who is in-charge of preparation of technical specification for tender document (usually a civil engineer) has to seek a safe method and generalized type of wordings (i.e - 10sqm at top, etc.) for describing arrangement of design antennas area – which is the primary and most important design parameter of the tower design - in proposed tower. However, this will make tender bidders free to choose their own interpretations on design loadings on tower (i.e - Adopting different shapes of antennas to reduce wind drag forces, mounting antennas in different heights, etc) and resulting tender bids will have huge price differences.

Although we discussed only design antenna area, other primary factors like terrain category, other basic ancillaries such as ladder, cable tray and platforms, etc. have been identified as other items that can be misinterpreted for purpose of reducing price of the tender bid.

7.3 Process of tender bidding and technical evaluation

With regards to the present process of tender bidding and technical evaluation for Supply and construction of antenna towers in Sri Lanka, it can be identified that there is very little or no technically competent (on tower design and construction) personal involving for this process.

Therefore, preparation of technical specifications, tender documents as well as technical evaluation of tenders are carrying out by people who are in other professions (i.e - Managers, accountants, electronic engineers, etc). Above people who are not or less competent about aspects of tower designs or constructions will have the tendency of selecting financially attractive proposals rather than identifying the safety risk associated in it.

On the other hand, above tendency of long term negligence of civil engineering profession in telecommunication industry has also resulted in lack of competent structural engineers about antenna tower designs or related other structure designs too.

7.4 Testing and verification

Although the tall telecommunication antenna towers are usually not subjected to full-scale test for destruction that similar to the practice in electrical transmission line pylons, several other tests and verifications are practised for controlling the quality of product. Some of them are as follows,

- Validation of structural design by qualified independent consultant engineer,
- Material testing (Steel grade, Chemical composition, etc.)
- Prototype assembly of very first tower of new design for verification purposes (i.e - before starting the process of mass production)
- Verification of galvanized thickness & paint thicknesses,
- Visual inspection of quality of workmanship, galvanizing and painting
- Quality check of welding (X-ray test, ultrasound test or special paint, etc.)
- Cube test of concrete.
- Close Inspection of structure and structural elements after assembly,
- Verticality check of newly erected structures,

Above set of inspection and verification is important for ensuring to have good quality product from the suppliers/contractors.

7.5 Qualification and experience of people involved

When considering the telecommunication companies and mobile phone service providers who are currently operating in Sri Lanka, most of above companies do not have their own in-house civil engineering design capacity. Although most of the above companies are operating in Sri Lanka for last 20 years, the importence of structural engineer to ensuring the safety of their structures and network is still not recognized. According to the information and data collected during this study, the following general facts may explain the situation and quality of above networks,

- Most companies operating large telecommunication network with their own structures.
- Each of above operators owns structures such as tall antenna towers, monopoles, rooftop structures, etc. that are not less than 500 such structures.
- Majority of above structures are located in places where exist high risk for people in the event of collapse. (In rooftops, mid of towns, next to roads, railways or electricity transmission lines, residential areas, etc.)
- But, most of the telecommunication network owners/operators don't have their own in-built civil engineering design capacity.
- Even, the telecommunication network owners/operators who have their own in-built civil engineering design capacity, also utilize their design team only for checking and verification of contractor's/supplier's designs, but not for new designs, etc.
- None of the above mentioned telecommunication network owners/operators have a practice of getting assistance from outside experts for their technical evaluation of tender bids,

- And most of telecommunication network owners/operators usually employ only one (or rarely two) qualified civil engineer, but he will be used mostly for monitoring new constructions and routing maintenances, etc.
- Usually all above telecommunication network owners/operators have been employed small crew of technical officers (qualified as well as non qualified) but mostly with non – civil engineering background.

As described above, it can be clearly understood that the antenna tower industry has a large void of civil engineering professionals. Therefore, with present situation we cannot expect required guarantee on safety of most of antenna structures exist in Sri Lanka.

7.6 Erroneous assessment of design loads and blind use of computer software

The happenings of critical, non-recoverable errors are very common with reference to the construction and maintenance process of telecommunication antenna towers in Sri Lanka recently. One main reason for such mistakes can be identified as the non-involvement of qualified technical staff in to decision making process of such constructions. The critical errors such as mis-judgment of design antenna area as well as the loading due to topography (i.e – antenna tower on coastal areas, Hill tops or top of tall building, etc.) are common in recent practice.

Blind use of computer software for designing of antenna towers also can be seen in some occasions. This is critically affecting events of severe competition among the tower manufacturers for tower supply tenders. Most of such unethical events are accepting by the client without understanding its incorporated level of risk, but motivated from the immediate financial benefits which may highlighting by the supplier.

On the other hand, it can be noted that the contractors are getting benefits from laying unnecessarily large foundations for antenna towers due to non-existences of qualified technical personnel for decision making with responsibility. Usually the non-qualified technical staff always tend to select most safer (un-economical) solution as well as showing high reluctance for getting further assistances from qualified professional. Sometime, there are instances of large mistakes happening due to taking un-safe critical decisions by such non-qualified technical staff who are attached to the telecommunication network owners/operators in Sri Lanka.

7.7 Quality of constructions

As the antenna towers usually located far from another and most of tall towers are in rural/remote areas, monitoring of such construction is a very expensive task. In such environment as well as in the heavy pressure of completing works, the contractors are encouraged to do low quality work and earn extra profit from it. The information received from construction engineers regarding low quality tower foundation works and large number of sites which are pending (for long period) for receive their final approval of completion can be use as good evidences for exists of such low quality works.

During this study, we were noted that the antenna tower erection and foundation constructions are usually obtained by small individual contractors. As their overheads and profit margins are lower compared to other well organized medium level contractors, the main contractors also use to hire these gangs for lower work rates.

This criterion is indirectly providing benefits to the operator too, that supplying lower prices through tender bids. Therefore, in general, the qualities of construction work being comparatively lower than the other constructions.

7.8 Post Maintenance procedures

As mentioned earlier too, usually antenna towers located both in remote sites as well as in town areas. As the most of above structures have direct threat to the people in neighborhood that in the event of collapse, anybody can understand the quality of routine maintenance that is needed for such structures.

Usually, any galvanized steel structure need re-painting in at least every 5 year intervals. Bolt tightening and thorough inspection in every two years. The guyed mast towers need replacement of it's corroded guy wires and re-tensioning of all guy wires (due to creep loss) in every two years.

But, as explained in section 7.5 above, without necessary input from qualified professionals, it cannot be expected to have such proper maintenance procedures, etc. although no disaster has been reported as yet, such luck in the future cannot be guaranteed.

Because, normally any galvanized structure with proper painting can be guaranteed to last about 20 to 30 years with no corrosion (15 years - if galvanized only and no painting). Most of presently available antenna structures in Sri Lanka have been constructed after 1990, therefore we are still enjoying the period which having above guarantee.

7.9 Assessment of antenna configuration and adding of additional antennas or other ancillaries.

While steel lattice antenna structures being one of the most efficient structures, it also having basic shortcoming that of above structure may easily become unstable when it deviates from its original design conditions. Furthermore, these types of structures are very unlikely of showing any prior warning signs or other indications before their sudden collapses.

As discussed in section 6.0, adding additional antennas which beyond the originally designed arrangement of antennas will be very dangerous and may able to make the structure unsafe. On the other hand, we cannot easily evaluate the possible impact on such loading due to additional antennas with any simple calculations other than the completely re-analyzing of the complex structures.

The most of telecommunication operators in Sri Lanka are requesting for different, arbitrary antenna arrangements (For example – 10 m² flat antenna area at top of the tower, to any direction, etc.) in their tower supply tender documents for last decades. Then, their technical personnel who are arranging required antenna configurations on different elevations, directions, etc on each specific tower (in each location.) will totally relying on the simple desktop verification according to that explained in section 6.0 (with simplified rough calculation methods).

According to the facts that discussed in section 6.0, above belief and practice includes huge misjudgments on the true behavior of complex structural form like tall steel lattice towers. Because, during above process of simplification, they have completely neglected about the possible local effects on leg and bracing members, complex nature of the distribution of loads on fully triangulated structural members, etc.

Photo 7.1,

It is important to checking the structural feasibility prior to adding any additional antenna

Therefore, it is essential to use accurate method of structural evaluation prior to any change of antenna loads or configuration in steel lattice type antenna structures.

DESK STUDY

8.0 Design of antenna tower to BS8100 code

8.1 Introduction

The BS8100 – 1986, the British code of practice for steel lattice towers and mast. Above code consist of four separate parts, they are as follows,

- Part 1 – Code of practice for loading
- Part 2 - Guide to the background and use of Part 1
- Part 3 - Code of practice for strength assessment of members of lattice towers and masts
- Part 4 - Code of practice for loading of guyed masts

With reference to above BS8100-Part 1, the required factors of safety can be found. After that, the proposed model of antenna tower can be analyzed and member forces can be found. Each above member should be designed according to above mentioned Part 3 of the code. However, the most of presently available computer software which are specifically prepared for analysis/design of steel lattice structures having their in-built capacity of analysis the model as well as designing each of member according to the selected code of practice.

Use of suitable software will help us to avoiding time consuming, complex calculations in process of analysis of model and calculations of repetitive nature in member designs. However, use of computer software should be done in careful manner by a qualified person who has the capacity to understand the structural behavior as well as capability of interpreting the design results of the modeled tower.

8.2 Different factors of safety

According to BS8100- Part 1, following factor of safeties should be selected.

8.2.1 Factor of safety on required reliability of the structure - (γ_v) and (γ_{DL})

Section 2.1 of BS8100–1:1986 explains the requirement of factors of safety as follows,

"In order to select appropriate safety factors to be applied in design to the loadings defined in this code, consideration should be given to the reliability required of a tower during its intended period of service. The factors adopted should take into account the risk to life in the event of collapse and the potential economic or strategic consequences of failure. The also depend on the quality of materials and workmanship specified and achieved in construction."

Clause 2.2, Classification of required reliability

In clause 2.2.1,

The safety factors to be used, appropriate to the reliability required of a tower, should be selected on the basis of either of the following performance requirements,

a) *The potential hazards resulting from failure of the tower, i.e the environmental conditions near the tower.*
b) *The economic consequences of failure or the usage of the tower*

Clause 2.2.2, further explaining the above mentioned environmental conditions,

The environmental category of the tower should be selected with due consideration of the potential risk to life in the event of the tower's failure. This risk will depend on the location and size of the structure in relation to inhabited buildings, railway or roads and on the possible contingent effect of collapse.

Figure 8.1 indicates categories which should be used to select safety within the range appropriate to the environment of the tower.

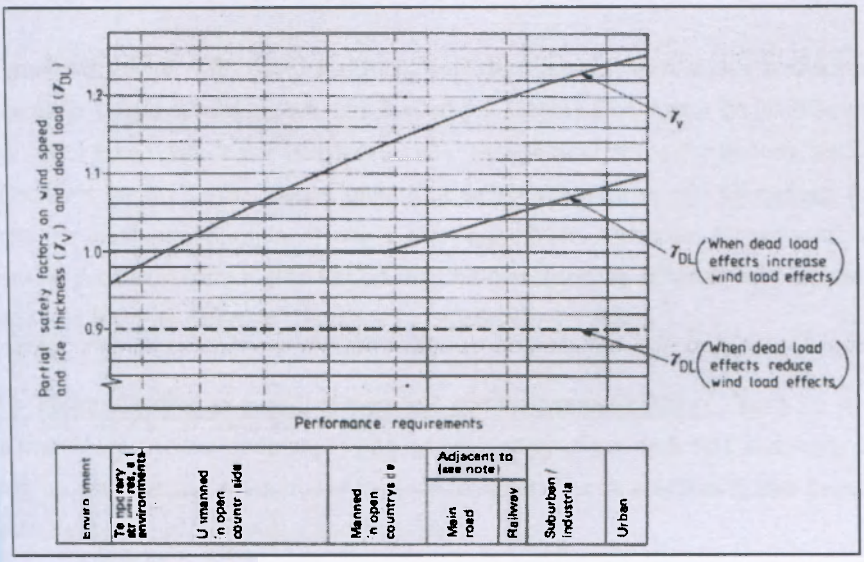


Figure 8.1– (Part of Table 2.1 , BS8100)

Clause 2.2.3, explaining about the economic consequences or usage,

Where the potential risk to life is small, (unmanned towers in open countryside) or the economic consequences of failure are great (a major link in a telecommunications network) the safety factors should be selected with regard to the potential cost in the event of collapse.

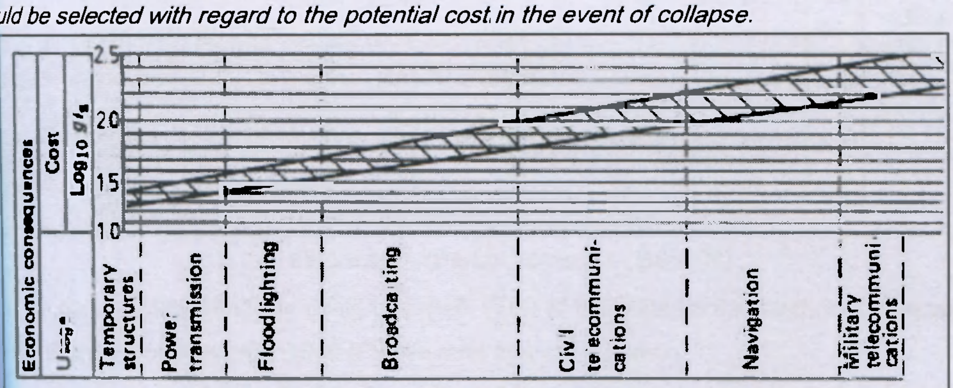


Figure 8.2– (Part of Table 2.1 , BS8100)

Economic consequences

The potential total cost, at net present value, of failure within the design service life should be estimated. This should include the cost of removal and replacement of the tower and its ancillary *attachments and all contingent cost such as loss of revenue, third-party claims and loss of amenity. The ratio, g of this consequential cost to the initial cost of the tower should then be evaluated.*

Figure 2.1 indicates categories of the potential economic consequences of failure, represented as the logarithm of gi_s where i_s is the design service period.

Usage

If the economic consequences of failure cannot be judged, the reliability should be selected on the basis of the tower as indicated in Figure 2.1 (please refer figure 8.2 above)

As explained above, with using the most important aspect from above mentioned Environmental, Economic or usage conditions we can derived the partial safety factor on wind speed (γ_v) and dead loads (γ_{DL}) from figure 2.1 of BS8100-1:1986 (Please refer figure 8.3 above). Although it is generally inappropriate for Sri Lanka, above factors of safety values may not be enough for towers that are planned for locations (or regions) with a risk of cyclones, typhoons, tornados or other local intense storms. In such situations higher values may be necessary to achieve the required reliability (This is reference to the note given on Clause 3.1.1 of BS8100-1:1986).

8.2.2 Factor of safety on quality of materials and the workmanship - (γ_m)

The reliability of a tower depends in part on the quality of the materials and workmanship used in its construction and on the adequacy of the maintenance after its erection. It also depends on the degree of control checking of the design and installation

Therefore, BS8100 has been offered three separate categories of towers (Class A, B and C) and their method of selection (please refer Clause 2.3) which are based on mainly the quality of materials and workmanship.

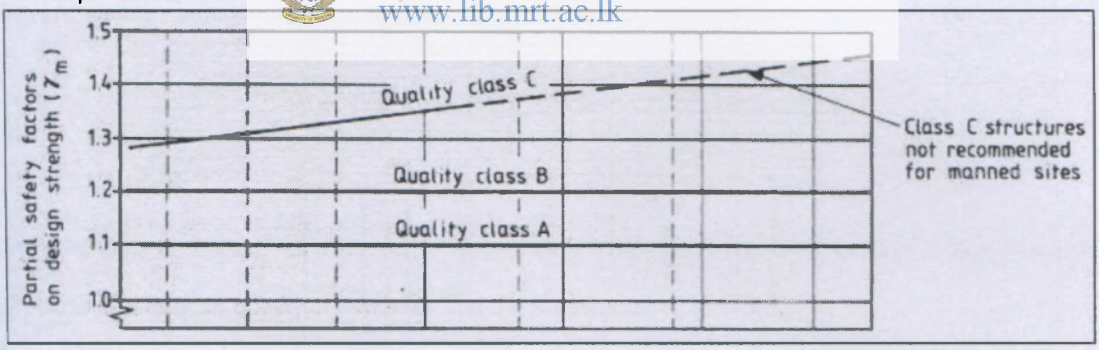


Figure 8.3 – (Part of Table 2.1 , BS8100)

Then, the partial safety factor for design strength (γ_m) of the material (i.e steel, etc.) can be derived from the figure 2.1 of BS8100-1:1986 (Please refer figure 8.3 above).

Furthermore, the methods of selecting γ_v, γ_{DL} and γ_m has been clearly indicated in BS8100-2 with examples. (Please refer figure 8.4 below). According to above figure 2.1 of BS8100-1:1986, for civil telecommunication and broadcasting towers, the partial safety factor on wind speed (γ_v) can be varied in the range of 1.1 to 1.2.

The partial safety factor on design strength (γm), can be selected as 1.2 for the antenna towers that are manufactured in well quality controlled fabrication facilities in Sri Lanka using high quality steel. The safety factor 1.1 is not usually recommended for use for situations other than where it uses UK originated materials (steel) in well quality controlled tower fabrication facilities. When the steel originated from countries such as China, India or other Asia or African region, it is always advisable that the tower designers to use above factor as 1.2 or 1.3, as the extent of quality controlling of such steel manufacturing cannot be guaranteed

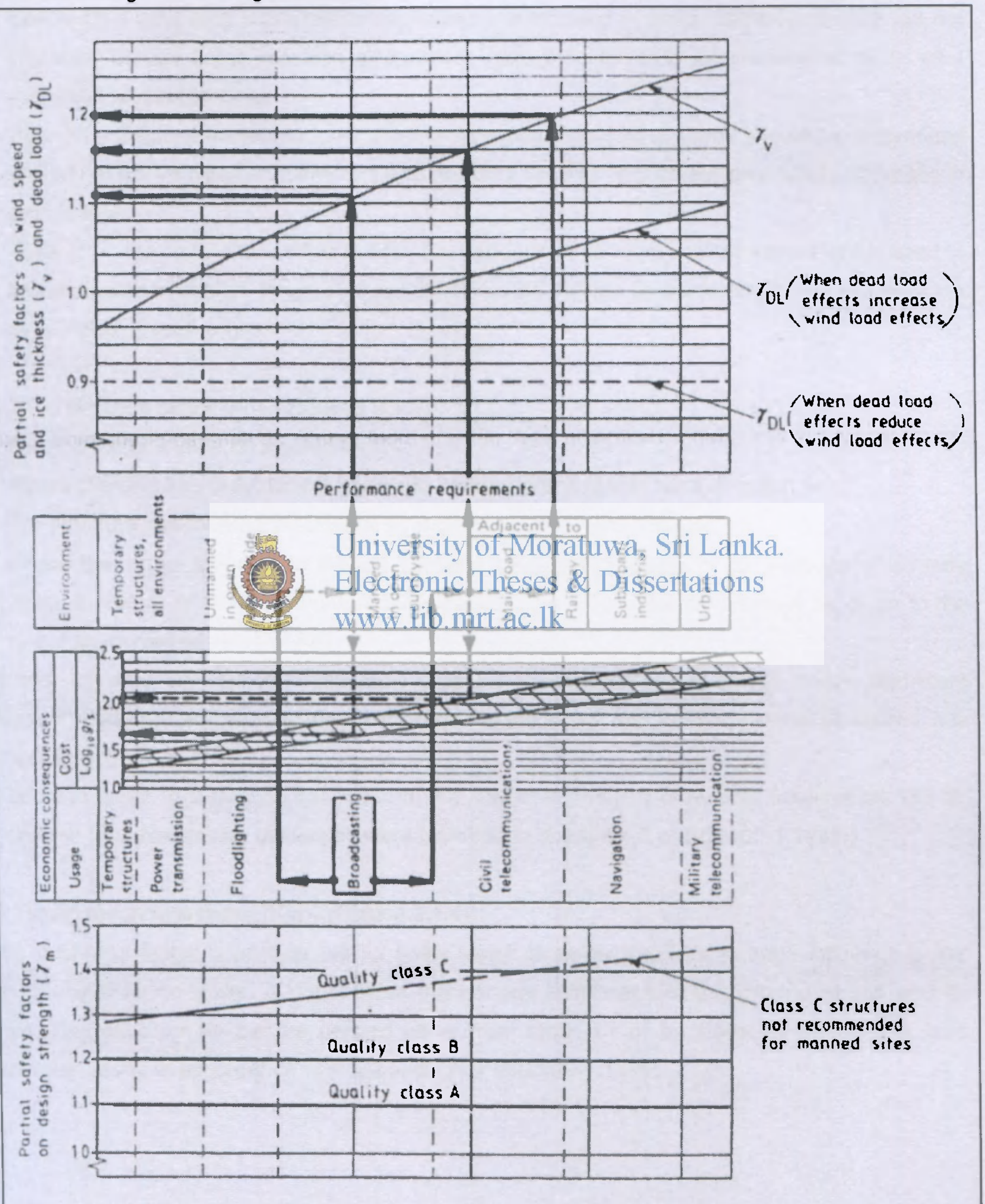


Figure C.2.3 — Example of the use of Figure 2.1 of Part 1

Figure 8.4 – (Figure C.2.3 of BS8100, Part 2)

8.2.3 Factors of safety on meteorological parameters.

This aspect has been discussed in section 3 of BS8100-1:1986,

According to Clause 3.1, three types of atmospheric environments were discussed, they are as follows,

1. Type (a) – Regions of well-conditioned climatic conditions where extremely localized and intense storms can be ignored in design. Basic wind speed will determined from the calculated wind speed of 50 year return period from the measured wind speed data. For Sri Lanka, we have such a wind map published by the Ministry of Housing in 1980. (When such data are not available, Clause 3.1.2 has also given some guidelines for safe assessment of basic wind speed with available data).
2. Type (b) – Regions subject to hurricanes or typhoons. Basic wind speed should be determined similarly to above type (a), combined with the local records of such extreme windy situations in combination.
3. Type (c) – Regions where there is risk of tornados or other local intense storms which need to be considered in design. Basic wind speed should be derived by assessing local records which have included such winds.

8.2.4 Wind direction factor (Kd) – (Clause 3.1.3)

Wind direction factor should be applied for,

- Where the structure provides resistance to the wind varying with wind direction or,
- The structure has marked variation in strength in different directions or,
- Where the terrain adjacent to the site contains steep-sided valleys or excavations which may cause funneling of the wind from certain direction. (i.e - Consideration should be given to the use of an increased value of Kd)

In general, for most of telecommunication antenna tower sites in Sri Lanka where significant variations of wind from any specific direction cannot be identified, and for symmetrical structures, it is safer to use Kd =1.0.

Wind direction factor (Kd) may be derived from the statistical analysis of records taken at the site for wind direction too. (Necessary guidelines were provided in appendix A of BS8100-1:1986.)

8.2.5 Terrain roughness factor (K_R) – (Clause 3.1.4)

Terrain roughness factor is another one of basic factor of safety that having large influence to the design of any antenna tower. It depends of the general roughness of the ground at site and its environs. The value for K_R can be derived either from table 3.1 or by statistical analysis of wind records taken at site in accordance with appendix A of BS8100-1:1986.

Table 3.1 — Terrain characteristics

Category	Terrain description	Terrain roughness factor, K_R	Power law index of variation of wind speed with height, α	Effective height, h_e
				m
I (z_0 = 0.003 m)	Snow-covered flat or rolling ground without obstructions; large flat areas of tarmac; flat coastal areas with off-sea wind	1.20	0.125	0
II (z_0 = 0.01 m)	Flat grassland, parkland or bare soil, without hedges and with very few isolated obstructions	1.10	0.14	0
III (z_0 = 0.03 m)	*Basic open terrain* Typical UK farmland, nearly flat or gently undulating countryside, fields with crops, fences or low hedges, or isolated trees	1.00	0.165	0
IV (z_0 = 0.10 m)	Farmland with frequent high hedges, occasional small farm structures, houses or trees	0.86	0.19	2
V (z_0 = 0.30 m)	Dense woodland, domestic housing typically covering 10 % to 20 % of the plan area	0.72	0.23	10

NOTE 1 z_0 is the terrain aerodynamic roughness parameter (see Appendix B).
NOTE 2 The lower (smoother) of any two possible categories should be adopted where the environs of the site are difficult to define or may change
NOTE 3 The terrain descriptions should apply to environs extending several kilometres upwind from the site.
NOTE 4 Higher (rougher) categories that occur within only a few kilometres upwind from the site, may not be sufficiently extensive to develop an equilibrium wind profile and should not generally be used as a basis for determining the terrain category.
NOTE 5 In urban areas ($z_0 \simeq$ 0.8 m), where towers rise above the general level of the surrounding buildings, category V should be adopted. Specialist advice should be sought where considerations of local accelerations from adjacent high buildings could affect the tower design.

Figure 8.5 – (Table 3.1 of BS8100)

According to table 3.1 (Figure 8.5 above), some general values of K_R, that may recommended for different terrains in Sri Lanka are as follows,

Table 8.1 – Recommendation for Sri Lanka

Terrain category	Description	K_R
I	Large flat area with no obstructions, next to the large reservoir or tank, coastal area with off-sea wind	1.2
II	Large paddy fields, grass lands or bare lands without hedges and with few isolated obstructions	1.1
III	Basic open terrain, fields with crops, village areas	1.0
IV	Not recommend to apply for Sri Lanka	N/A
V	Urban areas where tower rise above the surrounding buildings (when any local acceleration of wind due to adjacent buildings were not exist) or dense wood lands, forests.	0.72

However, it should be noted that,

- When selecting terrain category, the terrain description should apply to environs extending several kilometers upwind from the site.
- The lower (smoother – higher value of K_R) of any two possible categories should be adopted where the environs of the site are difficult to define or may change.

8.2.6 Typical drag (pressure) coefficient (C_N) for individual components. (Ancillaries, etc.)

During the calculation of design wind pressure on different ancillaries, we need to adopt drag coefficient as appropriate to the respective ancillary item. The typical drag coefficients for common ancillaries were given in table 4.1. Usually the antenna manufactures providing wind tunnel test data of their ancillary item. Therefore, the drag coefficient of such ancillaries can be easily calculated too. However, it is important to carefully select the correct drag coefficient for proposed ancillaries on the tower, because the drag coefficient is a factor that having large influence to design load of the tower. (for example, while the drag coefficient of the flat sided section is 2.0, the smooth cylindrical item having value of 0.6)

Table 4.1 — Typical drag (pressure) coefficients for individual components

Member type	Effective Reynolds number $R_e = 1.5 \frac{\bar{V}_z D}{\nu}$	Drag (pressure) coefficient C_N	
		Ice free	Iced
a) Flat-sided sections and plates	All values	2.0	2.0
b) Circular sections and smooth wire	$\leqslant 2 \times 10^5$	1.2	1.2
	4×10^5	0.6	1.0
	$> 10 \times 10^5$	0.7	1.0
c) Fine stranded cable, e.g. aluminium core steel round conductor	*Ice free:* $\leqslant 6 \times 10^4$	1.2	
locked coil ropes	$\geqslant 10^5$	0.9	
spiral steel strand with more than seven wires	*Iced:* $\leqslant 1 \times 10^5$		1.25
	$\geqslant 2 \times 10^5$		1.0
d) Thick stranded cable, e.g. small wire ropes	*Ice free:* $\leqslant 4 \times 10^4$	1.3	
round strand ropes	$> 4 \times 10^4$	1.1	
spiral steel strand with seven wires only (1 × 7)	*Iced:* $\leqslant 1 \times 10^5$		1.25
	$\geqslant 2 \times 10^5$		1.0
e) Cylinders with helical strakes of height up to 0.12D	All values	1.2	1.2

NOTE 1 For intermediate values of R_e, C_N should be obtained by linear interpolation.

NOTE 2 D is the member diameter (in m).

V_z is the factored wind speed relevant to the height z from ground level to the centre of the member (see **3.2.1**) (in m/s);

ν is the kinematic viscosity of air (see **4.2.1**) (in m^2/s).

Figure 8.6 – (Table 4.1 of BS8100)

8.2.7 Gust response factor.

Antenna towers are usually isolated, comparatively smaller structures that rise over the general canopy level of the site. Therefore, the effect of wind gusts (fluctuating loads) will have considerable contribution to the design loadings on these structures.

So, it is essential to consider the effect of wind gust and cross wind response during the designing of any antenna towers. Section 5 explaining the method of applying wind loadings, gust response factor, etc. Generally the gust response factor can be found in the range of 0.85 to 1.8 for antenna towers.

5.2 Wind loading for symmetrical towers

5.2.1 General

For towers free from ancillaries or containing ancillaries complying with the constraints of **4.1.3**, the maximum mean wind load in the direction of the wind per panel height of the tower body, P_{TW}, should be taken as:

$$P_{TW} = \frac{\rho_a}{2} V_z^2 \Sigma R_W$$

The maximum fluctuating load due to turbulence in the direction of the wind, P'_{TW}, should be taken as:

$$P'_{TW} = G \bar{P}_{TW}$$

The maximum fluctuating load due to turbulence in the crosswind direction, where required, P'_{TX} should be taken as:

$$P'_{TX} = K_X \left(\frac{\Sigma R_X}{\Sigma R_W}\right) P'_{TW}$$

where

- G is a gust response factor appropriate to the bending moment or shear force, determined in accordance with **5.2.3** or **5.2.4**, as appropriate;
- ρ_a is the density of the air at the reference temperature and pressure (ρ_a = 1.22 kg/m^3 for the UK when determining P in newtons and with V in metres per second);
- V_z is the mean wind speed at the level of the centre of area of the panel at a height z metres above the site ground level, determined in accordance with **3.2**;
- ΣR_W is the total wind resistance of the structure (and any ancillaries if present) in the direction of the wind over the panel height concerned, determined in accordance with **4.2** or **4.3**, as appropriate;

  NOTE ΣR_W is taken as the wind resistance of the partially-shielded tower body, R_{TS}, when using **5.3**.
- K_X is a factor allowing for crosswind intensity of turbulence and should be taken as 0.5;
- ΣR_X is the corresponding crosswind resistance over the panel height.

These loads should be taken as acting at the level of the centre of area of the faces (including ancillaries if present) within a panel height.

Figure 8.7 – (Clause 5.2 of BS8100)

8.3 Discussion – selecting correct factors of safety

As per above descriptions, many different combinations of FOS's can be found in antenna tower design. Those FOS's will represent the most severe loadings and environmental conditions that may experience to the structure may experience in its design conditions. When we design common tower that to be use in telecommunication networks, we may able to create several categories of above design conditions as follows,

a) **Key towers or special structures**

Towers that are very important in specific communication network (or tower use as Hub of network), towers in highly populated area or possible damage in the event of collapse is very high, any structure associated with uncommon type of structure, structural form or loading arrangement, etc.

Suggested FOS for key towers or special structures (Reference to BS8100)

γ_V	1.23	*Table 2.1*
γ_{DL}	1.1	*Table 2.1*
γ_M	1.1	*To be manufactured.according to Quality class A*
K_d	1.0	*Symmetrical structure*
K_R	1.0 - 1.2	*For terrain category (I) to (III)*
C_N	1.2 - 2.0	*Depends on shape of ancillary*

b) **Heavy-duty structures**

Towers those are located in coastal regions or adjacent to large water body, top of High Mountain, hill or building, heavily loaded structures, etc.

Basic FOS are similar to above (a), but suitable wind speed modifying factor to be adopted for antenna towers which are constructed on buildings or mountains.

c) **Medium-duty structures**

Towers those are located in general flat terrains and averagely loaded, No high damage or unbearable financial loss associated in the event of collapse.

Suggested FOS for medium-duty towers on flat terrains (Reference to BS8100)

γ_V	1.1 - 1.2	*Table 2.1*
γ_{DL}	1.0 - 1.1	*Table 2.1*
γ_M	1.1 - 1.2	*To be manufactured.according to Quality class A or B*
K_d	1.0	*Symmetrical structure*
K_R	1.0	*For terrain category (I)*
C_N	1.2 - 2.0	*Depends on shape of ancillary*

d) **Light-duty structures**

Isolated towers those are located in rural or unmanned regions with few ancillaries, No high damage or unbearable financial loss associated in the event of collapse.

Basic FOS are similar to above (c).

e) **Temporary structures**

Towers or structures those use for temporary and short term events,

Basic FOS are similar to above (c), except it can be adopted, $\gamma_V = 1.0$.

Most of antenna tower users or telecommunication companies usually specify several categories of towers (i.e similar to above) according to their requirements. However the use of correct structure to the correct design environment should be done with proper care.

9.0 Study of the influence of loadings types on steel lattice tower design

The structural behavior of any self standing antenna tower can be simply idealized as similar to vertical cantilever structure; therefore the resulting tension and compression forces on leg members as well as on other bracing members will be increased with increasing of the design antennas area that located on the tower. Generally the weight of tower always is representing the basic cost of construction.

9.1 Design antenna area vs. Tower weight

For purpose of generating a graph that " Antenna area vs Tower weight", several separate antenna towers were designed (of 100m high) for different antenna loads. All other basic design conditions such as tower architecture, loading arrangements (i.e Loaded at top), design wind speed, etc are ensured to have similar for all models. The resulting final estimated weights of towers were plotted against the respective antenna areas (i.e Load) – please refer figure 9.1a below.

Although the antenna towers which having antenna area of 0m², 5m² & 10m² were able to designed with using single angle leg members, the towers with antenna area 15m² and above are designed with star type leg members. Therefore, graph in figure 9.1a shows jump at 10m² antenna area.

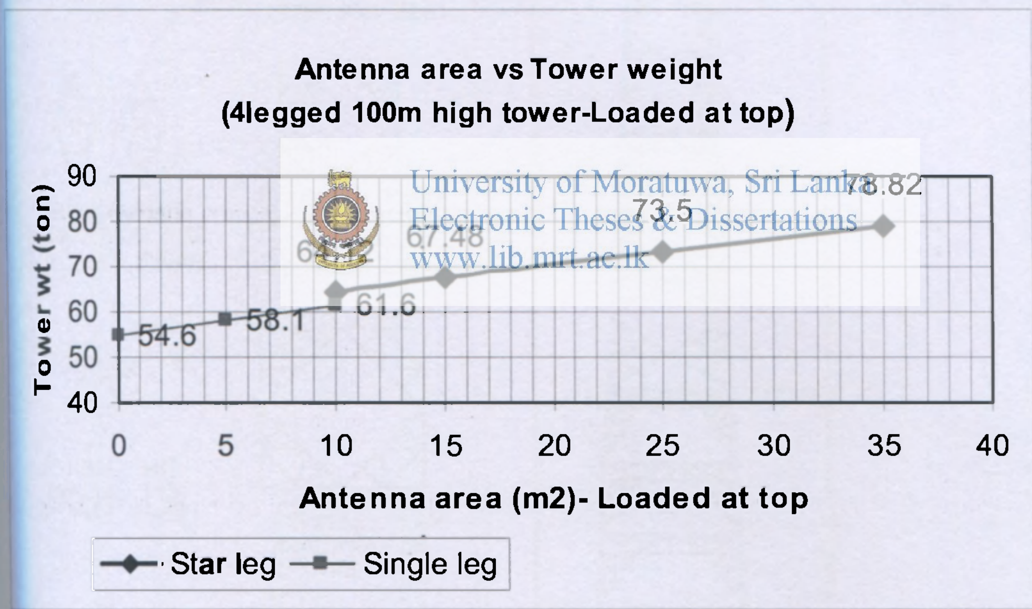


Figure 9.1a - Design antenna area vs. Tower weight chart

The basic inputs are given below. Typical architecture of above antenna towers is presented in figure 9.1b. (Note:- 10m² tower designed for both single as well as star leg types)

(1). Wind speed 120/160 km/hr, (2). Terrain category type III, (3). γ_v = 1.15, (4). γ_m = 1.1,

(5). Kd = 1.0, (6). K_R = 1.0, (7).C_N = 2.0. (8). Base width=11.5m (H/B=100/11.5) (9) fy=345N/mm²

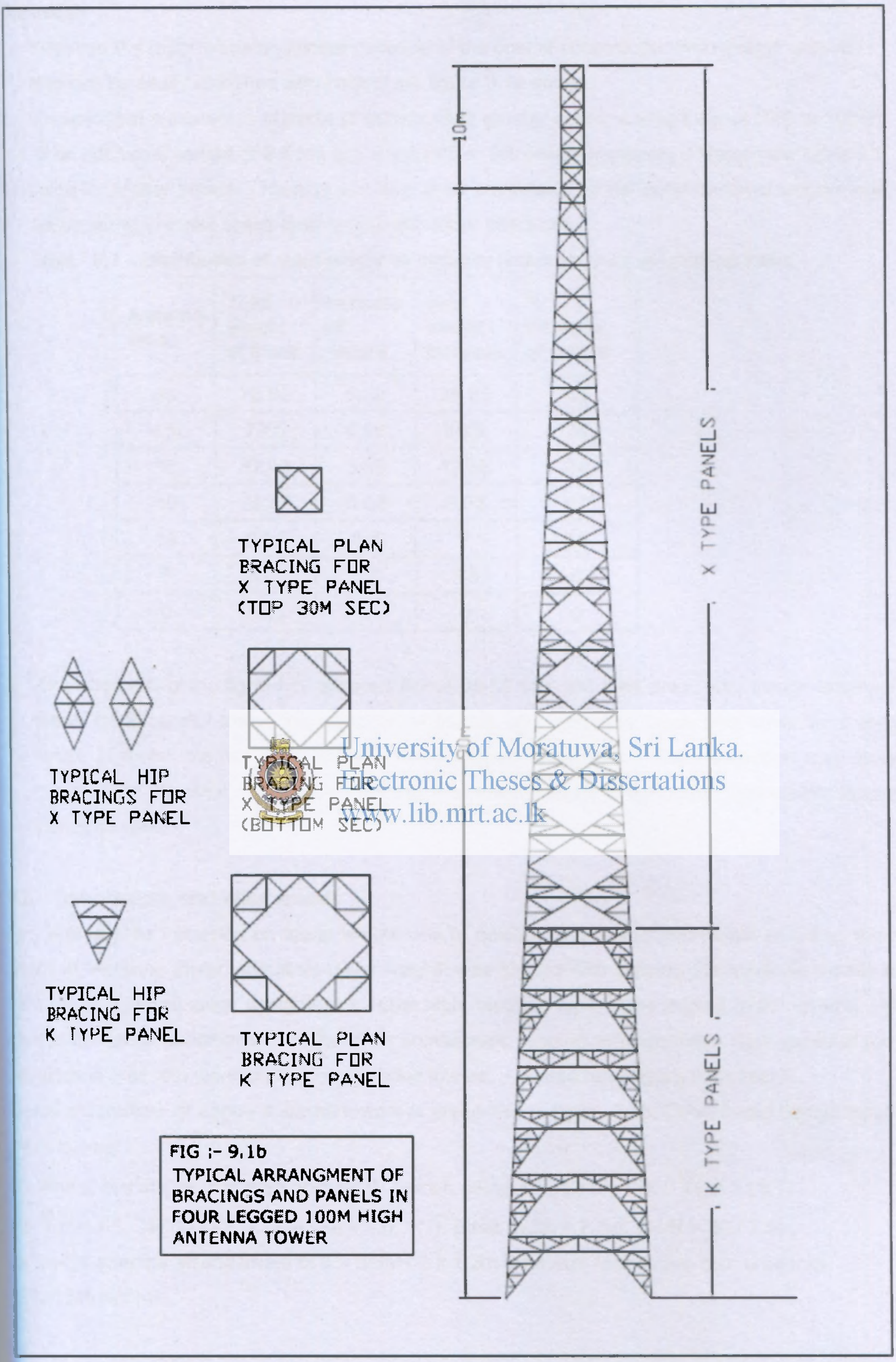


FIG :- 9.1b TYPICAL ARRANGMENT OF BRACINGS AND PANELS IN FOUR LEGGED 100M HIGH ANTENNA TOWER

Discussion

1. However, the (approximately) linear variation of the cost of construction with design antenna area can be easily identified with help of the figure 9.1a above.
2. It is seen that the tower is capable of withstanding greater antenna area (about 50% to 100%) for an additional weight of 3.5 ton to 6.0 ton (6% to 9% weight increase). Please refer table 9.1 below for further details. This may use as a great advantage for the antenna tower owners who are targeting to make share their facility with other operators.

Table 9.1 – Distribution of steel weight vs capacity (antenna area) of antenna tower

Antenna area	Total weight of tower	increase of weight	cum weight increase	% increase of weight
35	78.82	5.32	24.22	44
25	73.5	6.02	18.9	35
15	67.48	3.36	12.88	24
10	64.12	6.02	9.52	17
10	61.6	3.5	7	13
5	58.1	3.5	3.5	6
0	54.6	0	0	0

3. And, when designing light-duty towers (About 05-10 sqm antenna area, etc.) design engineer should more careful about the selection of panels and members those with lower wind drag forces. (Tubular members, K panels, Three legged tower, etc.). Such selection may have considerable effect on further reducing the final tower weight of light-duty, light weight towers than other towers.

9.2 Tower weight and Wind speed

For identifying the influence on tower weight due to design wind speed and height of tower, three graphs of "Antenna tower weight vs tower height" was plotted with utilizing the available details of three similar antenna tower designs (i.e - 60m high, modular type, three legged (pipe) towers) . All other basic design conditions such as tower architecture, loading arrangements (i.e Loaded at top) and antenna area, etc were similar for all above towers. – please refer figure 9.2a below.

Typical architecture of above antenna towers is presented in figure 9.2b, Other basic design inputs are as follows.

(1). Wind speed are as indicated above (2). Terrain category type III, (3). γ_v = 1.15,

(4). γ_m = 1.1, (5). Kd = 1.0, (6). K_R = 1.0, (7). Base width = 7.3m, (H/B = 60 / 7.3) ,

(8). Design antenna arrangement of 6 x GSM+ 3 x 1.2m Diameter Microwave dish antennas.

(9) fy = 345 N/mm^2.

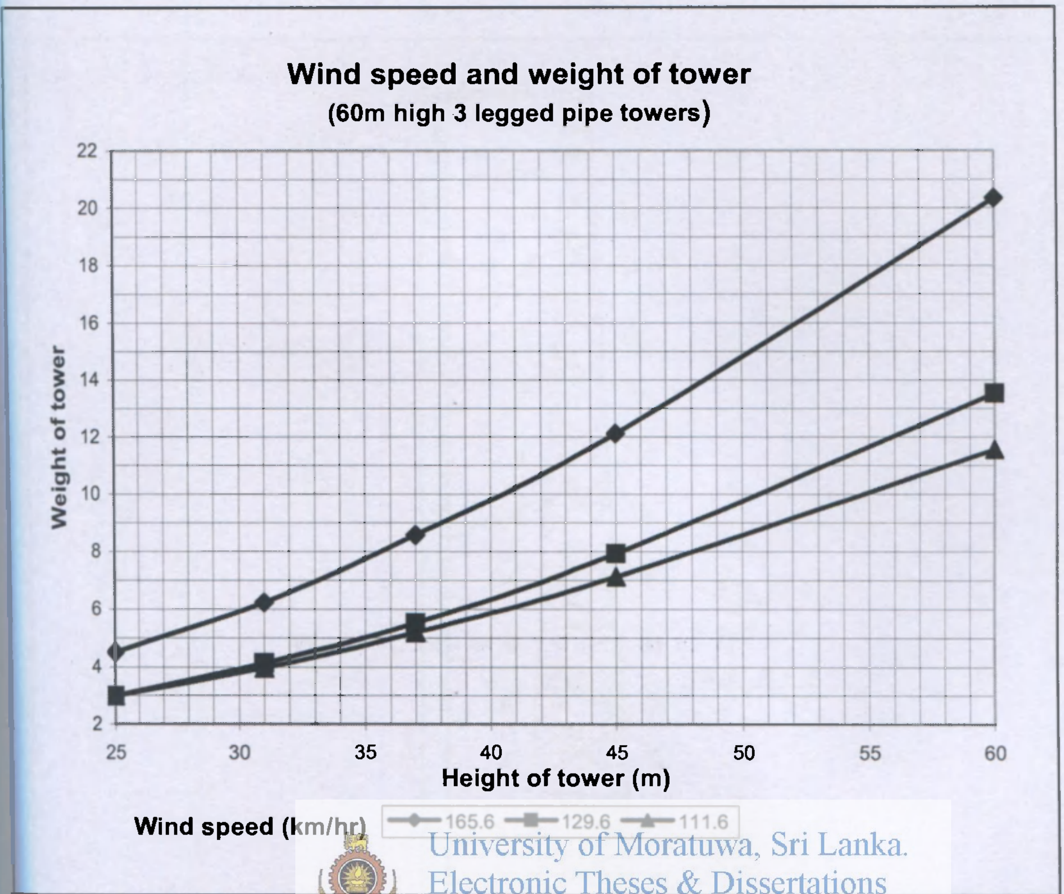


Figure 9.2a - Tower weight vs. Wind speed chart

Discussion

1. As per above Figure 9.2a, It can be identified that, while the design wind speed increases, the tower weight increase more rapidly with respect to the changing of tower height.
   Therefore, above chart clearly indicates that although the use of common tower designs for smaller towers is feasible, for taller towers it is always beneficial for having separate design for each wind speeds.
2. The optimization of any steel lattice antenna tower will mainly depend on several practical aspects such as availability of structural member sizes, choice of architecture (i.e - 3 legged or 4 legged structure, panel types, etc.), joints, allocated time for design and detailing, other limitation that may be imposed by client himself, etc.
   Therefore, when the structure becomes smaller, the chances for extreme optimization also will become less too. On the other hand, the cost benefits which can be obtained from such optimization are also minimum for smaller structures unless there exists a requirement of large quantity of such towers. The narrow difference of the tower weights between each curve (for

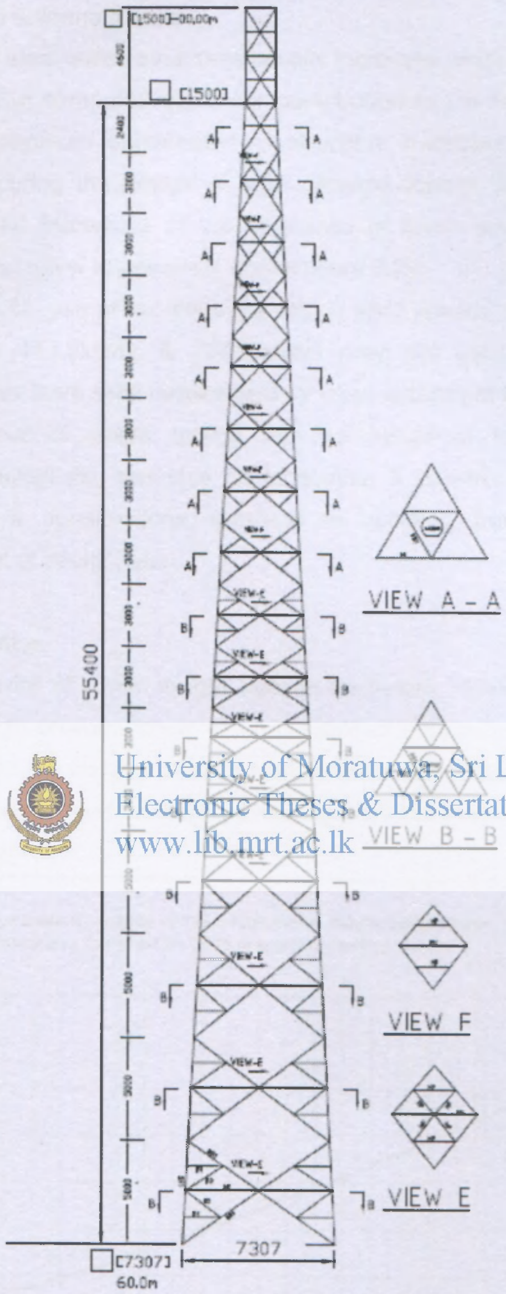


FIGURE 9.2b :- TYPICAL ARRANGMENT OF 60M HIGH, 3 LEGGED (PIPE) ANTENNA TOWER

different wind speeds) in the range of shorter towers in figure 9.2a, clearly explain the above argument.

3. As a result of above described limitations, the shorter antenna towers are usually more rigid than the taller steel lattice antenna towers.
4. As the base width of any steel lattice structures usually increases while increasing of its height, the lower panels will make comparatively larger contribution to the final weight of any such structures. Therefore, maximum optimization of structural members will always leads for attractive cost benefits during the design of taller antenna towers. This explanation is well reflecting by the indicated increasing of the difference of tower weight (for different wind speeds) while the height of tower increases in above figure 9.2a.
5. According to the figure 9.2a, use of two separate design wind speeds which has no significant difference (for example 111.6km/hr & 129.6km/hr) may not usually providing sufficient economical benefits unless there exist requirement for large quantity of towers.

   For such instances, use of single design can be beneficial through other practical considerations such as simplicity, easiness for fabrication & construction, more flexibility on replacing missing items in constructions, simplicity on handling, transport, distributing and storage, reducing the cost of design, etc.

9.3 Tower weight distribution

For understanding the behavior of tower weight against its height, it has designed a separate modular type, 100 meters high antenna tower which capable of supporting 35m² design antenna area on top of the tower. Then the weights of each module tower were also derived. After that, the estimated weights of each tower module were plotted against the respective height of tower – please refer figure 9.3a below.

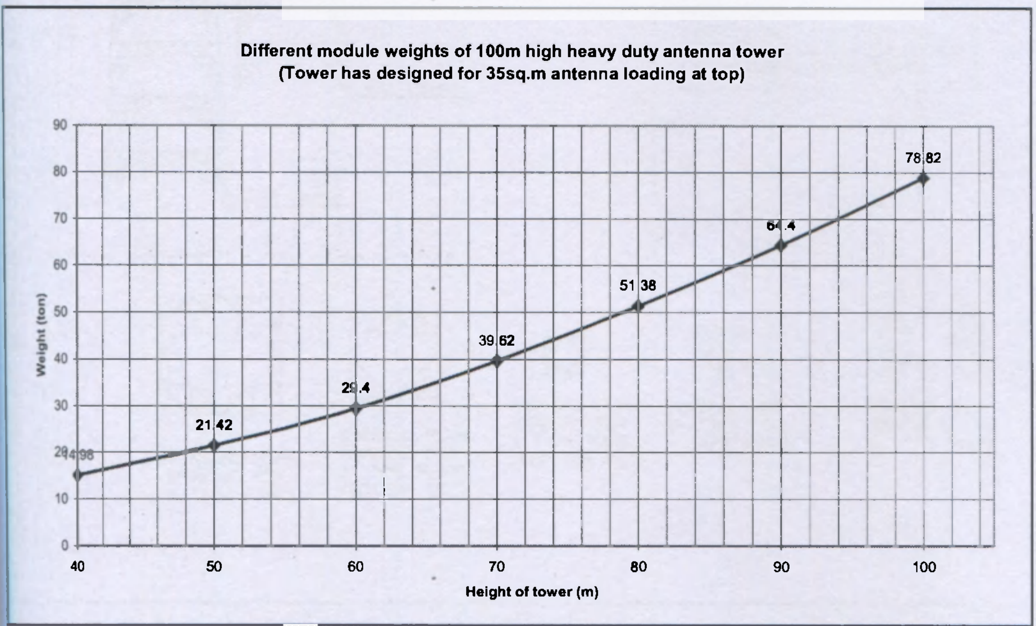


Figure 9.3a - Tower weight vs Height

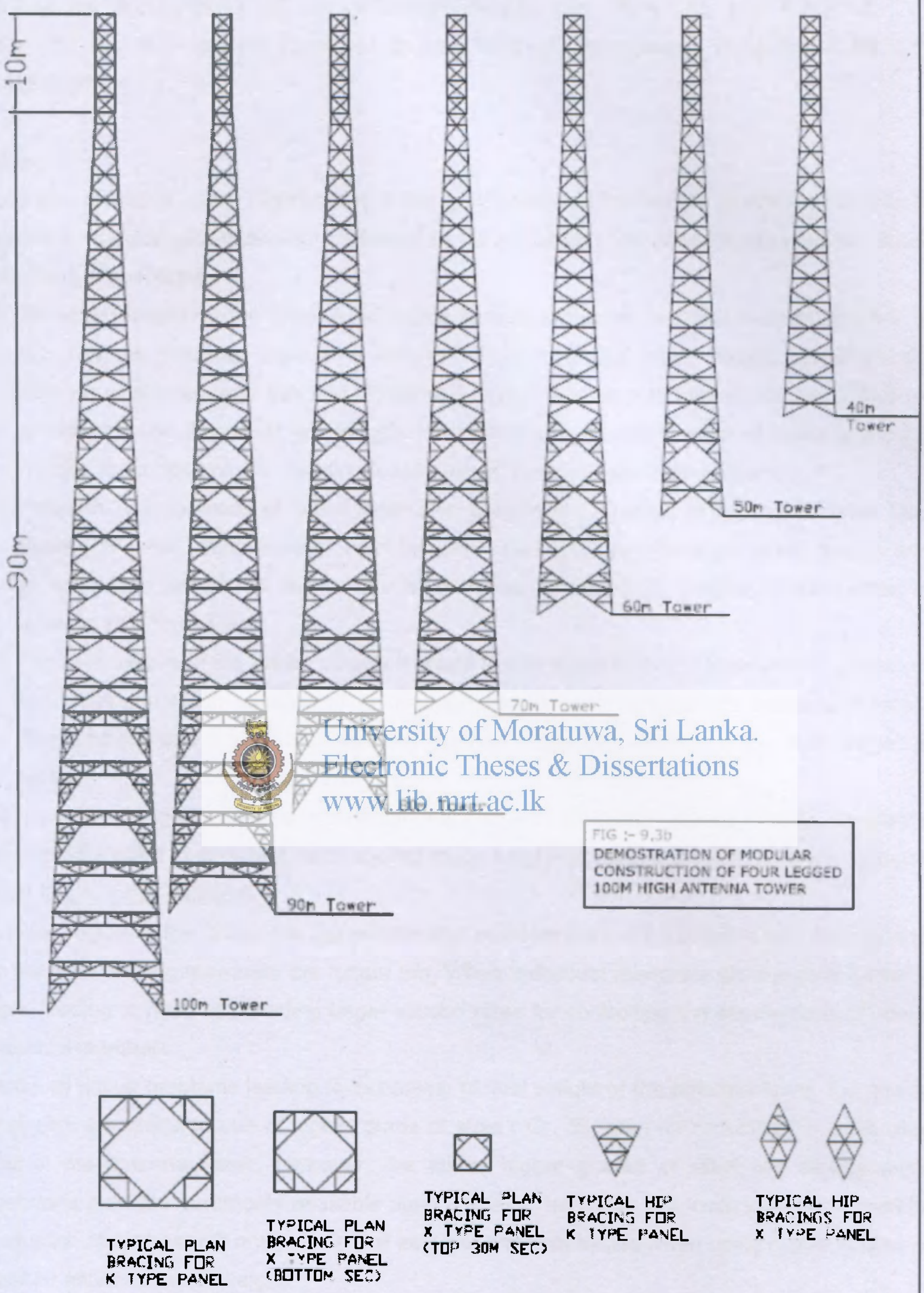


FIG :- 9.3b
DEMOSTRATION OF MODULAR CONSTRUCTION OF FOUR LEGGED 100M HIGH ANTENNA TOWER

Typical architecture of above antenna towers is presented in figure 9.3b, Other basic design inputs are as follows.

(1). Wind speed 120/160 km/hr, (2). Terrain category type III, (3). γ_v = 1.15, (4). γ_m = 1.1, (5). K_d = 1.0, (6). K_R = 1.0, (7). C_N = 2.0. (8). Base width of 100m tower = 11.5m (H/B=100/11.5) (9) f_y=345N/mm^2

Discussion

a. According to above chart, (figure 9.3a) it can be identify that the weight of tower increases in non-linear manner with changing the height of the structure. The possible reasons for above behavior are as follows,

   (1) When we idealizing the tower as a simple vertical cantilever, bending moment at base of the tower is generally increasing with the increase of the tower height. Therefore, for catering to above larger bending moments at lower regions of the tower, the base width of the tower to be increased accordingly. The increasing the base width of tower is a good method for controlling the resulting tension/compression of the leg members.

   However, the increase of base width also creates requirement of having complex face panels for steel lattice towers. Therefore, the lower panels with larger cross section and complex face panels will always heavier than the comparatively smaller, simple panels in upper area of the tower.

   (2) For lower region of the tower, usually it needs to use comparatively larger as well as thicker leg members which catering in to the high tensile and compressive forces generated. Those larger and thicker leg members provide major contribution to the final weight of tower.

b. As the tower weight increases non-linear manner with changing of tower height, it always beneficial for client to selecting best required tower height for each location than using common tower height for all locations.

c. In lower region of the tower, the leg tension and compressions are comparatively high as well as the main bracing members are longer too. When individual members are become longer, it again leading to need of providing larger section sizes for controlling the slenderness of above individual members.

   As the all above problems leading to increasing of final weight of the antenna tower, the design engineers are oblige to use of higher grade of steel (Gr. 55, etc.) for reducing the production cost of the antenna tower. However, the above higher grades of steel are usually more expensive than the commonly available steel grades. Therefore, it is necessary to do careful evaluation of cost-benefit analysis as well as other practical issues when using higher grades of steel for antenna tower designs.

d. If the selection of tower base width will not done properly, the above values in figure 9.3a may be changed. The resulting effects may be as follows,
   (1) If the tower base width will be too narrow, the tension/compression of leg members will be higher. The result will be need of providing larger section sizes for leg members.
   Similarly, the foundation reactions will be increased and cost of foundation will be increased too. But comparatively smaller section sizes can be used for main bracings and other secondary members.
   (2) If the tower base width will be too larger, it may able to use comparatively smaller leg members, but slenderness of main bracings and other secondary members may not be controlled. Then, it may need to use of larger section sizes or more complex face panels as a solution for to satisfy above requirements. On the other hand, too complex structures to be avoided too. Because such structures may lead to increasing the cost of fabrication and handling as well as the constructions mistakes.

9.4 Tower Foundation

Generally, steel lattice towers are having reinforced concrete, individual pad footings as their foundations. But, adopting of comparatively expensive foundation types such as raft foundations, well foundations or pre-cast driven pile foundations are also common practice for locations where the individual pad footings are not feasible. On the other hand, simple, non-reinforced mass concrete footings also possible for very small light weight towers and poles.

When we simply idealizing the antenna tower as vertical cantilever, the bending moment at base of towers or the resulting compression/tension of the tower leg is increase with every increment of tower height or antenna area. However, as the uplifting force, down thrust and punching shear being primary governing parameters for designing of any individual pad footing type antenna tower foundation, understanding the behavior of cost of foundation (i.e- volume of foundation) against design wind speed and height of tower will be advantages.

Therefore, typical foundations were designed for the 15 tower modules which are discussed in section 9.2 above. Three graphs were generated (similar to figure 9.2a) that height of towers against respective volume of foundations. – please refer figure 9.4a below,

The design foundation reactions are as follows

Design ULT Foundation reactions
(Design wind speed 165.6 km/hr)

Tower Height (m)	Total found vol (m3)	Down thrust (kN)	Uplift (kN)	Shear X (kN)	Shear Y (kN)
60	50.5	2450	2293	283	283
45	29.4	1588	1498	192	192
37	21.8	1221	1156	142	142
31	16.5	932	900	108	108
25	12.4	716	694	84	84

Design ULT Foundation reactions

(Design wind speed 129.6 km/hr)

Tower Height (m)	Total found vol (m3)	Down thrust (kN)	Uplift (kN)	Shear X (kN)	Shear Y (kN)
60	29.5	1545	1451	153	153
45	18.3	1055	1002	105	105
37	13.7	807	771	80	80
31	11.2	604	576	62	62
25	9.44	470	450	48	48

Design ULT Foundation reactions

Design wind speed 111.6 km/hr

Tower Height (m)	Total found vol (m3)	Down thrust (kN)	Uplift (kN)	Shear X (kN)	Shear Y (kN)
60	18.2	1125	1042	109	109
45	12.4	776	727	77	77
37	11.2	597	560	58	58
31	10.1	460	430	46	46
25	8.6	359	336	37	37

Other basic design inputs are as follows. (1). Typical Soil bearing capacity = 120 kN/m^2, (2). Angle of repose = 30 deg. (3).Typical individual pad footings - no Ground Water Table (GWT).

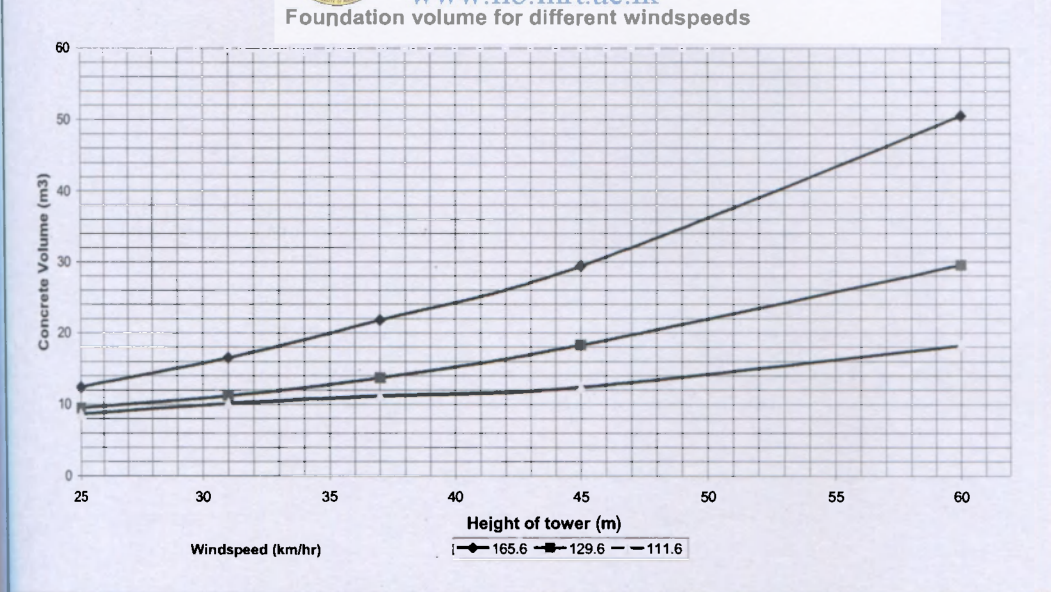


Figure 9.4a - Tower foundation volume (cost) and design wind speed

Discussion

a. Above chart (Figure 9.4a) also showing similar characteristics as it's respective Wind speed vs Tower weight chart (Figure 9.2a) .Therefore, the cost of foundation will increase non-linear manner with changes of the tower height.

b. As the considerable variation exist according to Figure 9.4a, it is advisable to designing separate foundations for each type of tower. The use of common, typical foundation may not be much economical for this situation unless the situations where the variation of concrete volume is not significant.

c. As the usual practice in Sri Lanka, separate foundation design will do for each location according to the recommendations of respective soil investigation. Therefore, the contractor as well as the client always able to getting the benefit of optimization of foundation works. As the most of antenna towers are generally located on difficult locations where having less accessibility, the contractors are also preferred to laying smallest possible foundations and put their effort in to the comparatively more profitable tower erection activity.

d. According to above chart in Figure 9.4a, the tower architecture has not been changed for different design wind speeds. However, If the tower architecture is able to be changed (i.e- changing the base width of towers) then the resulting foundation reactions may be in same range too. In such situation the size of foundation may have not showed large variation as in figure 9.4a.

e. Although the change of the foundation volume roughly proportional to the respective change of foundation reactions, for smaller towers above proportionality may not always exists. Because, when the governing criteria of foundation design being uplift force for the tall towers, for shorter towers the down thrust become the critical criteria.

10.0 Discussion on the effect of tower design on final cost of construction

10.1 Introduction

Steel is the one of the most expensive material use in construction as well as the cost of steel lattice antenna tower depends mainly on the amount of steel used in it. Therefore, the main objective of the good tower design engineer is to developing, structurally safe structure while consuming optimum amount (weight) of steel in to the structure. This can be achieved by designing structures with ensuring maximum efficient – all members utilizing their capacity in maximum level - on its design loading conditions.

The main advantage of selecting complex structural form such as space frame is for efficiently utilizing its materials and as a result made reduce the cost of constructions. Therefore, steel lattice type antenna towers are highly efficient structures when compare with the other general structures which can be used for similar loading arrangements (Concrete and steel monopoles, tall concrete buildings, chimneys, etc.).

On the other hand, all activities included the process of antenna towers construction such as design, fabrication, transport, erection of structures, foundations, painting as well as routing maintenance to be carefully considered during the process of cost optimization. Therefore, in this chapter, I am discussing about some general factors those have direct relationship to the final cost of antenna tower from its design stage to the construction phase.

10.2 Effect of available materials and section sizes

The one of primary limitation that tends to controlling structural design engineer's freedom will be the limited sizes of steel sections available in the market. With this constraint, the design engineer has to find the optimum solution that without sacrificing safety of the structure too.

According to the details of table 10.1, leg members and main bracing members are always having more contribution to the total tower weight. Therefore, the details in table 9.1 clearly demonstrating the need of selecting more efficient member sizes for legs and main bracings in any economical antenna tower designs.

Table 10.1 Distribution of tower weight among its members

Design antenna area	5.0 m2		15.0 m2		25.0 m2		35.0 m2	
	ton	%	ton	%	ton	%	ton	%
Main legs	17.0	30	22.6	33	26.8	37	29.9	38
Main bracings	20.5	35	22.2	33	22.9	30	24.2	30
Redundant members	10.0	17	10.7	16	10.7	15	10.7	14
Non structural members	10.3	18	12.1	18	13.1	18	14.1	18
	57.8	100	67.6	100	73.5	100	78.9	100

(Note:- The details provided in this table are from the same tower designs that used in figure 9.1a)

While selecting different steel sections for tower legs and members, there are several different options as well as constraints are exists. One of above is, If we are planning to manufacture our structures in large manufacturing facilities, as well as our quantity of towers are considerably higher, then the chance of finding large range of steel section sizes is higher too. On the other hand, when we are going to manufacture small quantity of towers, we may have to be satisfied with the limited numbers of locally available section sizes.

Similarly, we can use different grades of steel for our structures too. Usually for tall antenna towers, it is always economical to use high tensile steel (HS) for leg and main bracing members (which carrying comparatively higher loads) while mild steel (MS) for other members such as redundant members, non- structural members, plan bracings and hip bracings, etc.

Use of higher grade nuts and bolts is always being beneficial, because it allowing us to use smaller diameter bolts for structural joints. As a result of using smaller diameter nuts and bolts in joints, we were able to utilizing the cross sectional area of structural members in a more efficient manner.

10.3 Effect of selection of design wind speed

Although the structural design engineers have usually not much control over the selecting of the design wind speed, some clients are demanding to design their structures for unusually higher design wind speeds, without understanding the effect of wind speed on final tower weight. In such situations, it is structural engineer's duty to convincing the client for selecting of correct wind speed with explaining the effect of wind speed on antenna tower design and cost. Therefore, reference to the figure 9.2a and related discussion on previous chapter, the selection of correct wind speed will always ensure the providing of the most cost optimized and safe antenna tower to the client.

10.4 Effect of selecting correct terrain category

Choosing the correct terrain category for antenna tower design also very important in economical as well as in safety aspects. Reference to the section 3 and table 3.1 of BS8100-part1 (figure 8.5), it can be understand that the terrain category having large as well as direct influence to the design wind loading on tower itself and its other accessories. However, as explained in figure 9.2a, the increasing of design wind load will also results to the increase of the final tower weight. Therefore, the selecting of correct terrain category also will always be beneficial for the economical tower design. On the other hand, if we selected incorrect terrain category, it will have considerable negative effects to the safety limits of the tower designs in actual practice.

10.5 Effect on selecting of tower architecture,

Selection of best suited architecture for antenna tower is always beneficial for lowering the final weight of the tower. Apart of that, the practical aspects such as arrangement of ladder and cable tray, working and resting platforms also to be considered during above selections. Providing of correct type of panels or panel heights, plan bracings and hip bracings will making the structure more structurally stable as well as capable of using of smaller member sizes too.

Some type of panels having larger wind shielding area than another type of panel, therefore the blind use of former described panels will tend to increasing wind load on the tower. Therefore the selection of correct type of panels for each level is important task for design engineer.

On the other hand, the aspect of reducing the complexity of the tower also very important factor in fabrications and material handlings. Sometimes, having of slightly over-weighted structure with simple architecture will have more economical (in mass production) than low-weighted complex structure with many small members.

Therefore, the selection of best architecture for antenna tower is important in both safety as well as financial aspects. However, the selection criteria for individual panel or architecture of whole tower is not simple or straight forward task but should be developed only through the work experience and capability of the structural design engineer.

10.6 Effect of arrangement of antennas and other ancillaries

Arrangement of design antennas and other ancillaries is providing the main contribution for loading of the any antenna tower. Design arrangement of antennas could be either actual arrangement (i.e - 6xGSM at 60m level + 2x 1.2m dia MW at.......etc.) or any other idealized antenna arrangement (i.e – 10m2 of equivalent flat area at any direction on top of the tower, etc.). However, most accurate as well as economical solution for antenna tower design can be found when actual arrangement of the antenna is considered. Then the ability of selecting actual wind drag coefficient in each antenna will act beneficial to the tower loading.

The chart for "Effect of the area of antenna vs the tower weight" has been shown in figure 9.1a. According to above figure 9.1a, it demonstrating the nature of increasing the final weight of tower whiles the increase of design antenna area. Apart of above, the table 4.1 of BS8100-part1 indicates the drag pressure coefficients of different shapes of ancillaries. According to above data, while the flat sided items having higher drag coefficient value of 2.0, the drag coefficient value of circular items is 1.2. **As the most of telecommunication antennas and other ancillaries are having circular or spherical shapes, the above mentioned idealizing of the design antennas that having sharp flat faces will be an overestimation. On the other hand, the arrangement of antennas in actual practice will be not always on top of the tower. Usually, while the several numbers of cylindrical shaped GSM panel antennas are fixed on top of the tower, large spherical shaped microwave dish antennas will mount few meters below the GSM panels antennas or middle part of the antenna tower. Therefore, the previously discussed flat antenna arrangement at top, may not be able to provide reasonable idealization for its actual arrangement of antennas. On the other hand, the loading of large antennas to highly unpredictable, complex type of structures such as steel lattice antenna towers that without any proper evaluation can be very dangerous too. The complex nature of structural behavior in steel lattice towers as well as the possible impact of such blind loading has been discussed in chapter 6.0.**

Therefore, the use of design antenna arrangement that will similar to actual arrangement of antennas can be considered as the best, economical as well as safe practice of designing any antenna tower. As the most of telecommunication antenna towers are having typical type of antenna arrangements, it may not be much difficult task for selecting of suitable design antenna arrangement.

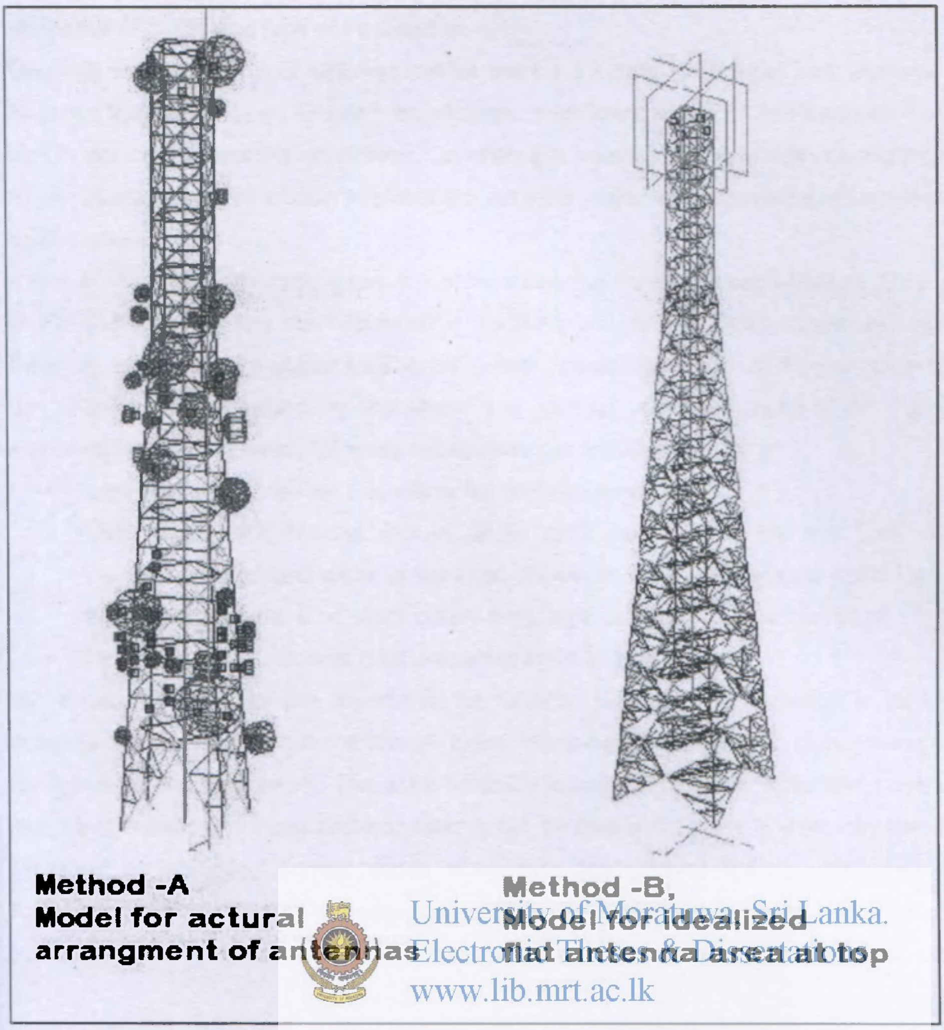


Figure 10.1 – Different method of modeling antennas

10.7 Selecting optimum height of tower

Although the structural engineer has no control over selecting of the tower height, the use of optimum tower height for each specific location having larger influence for controlling the final cost of constructions. It can be very clearly explain by use of the chart, (Tower weight vs tower height) that shown in figure 9.3a . According to above chart, the weight of tower is increasing in non-linear manner while increasing its overall height. Usually the any antenna tower is designing as modular type of tower which having several different modules. (i.e – original 70m tower includes 60m, 50m & 40m module towers too). Therefore, different modules of single design can be use for different locations as appropriately. Apart of above advantage of flexibility of selecting different heights, there are other advantages such as economical in fabrication, storage &.maintenance, etc. also available in modular type of designs.

10.8 Effect of depth and type of Foundation

Generally the foundation of antenna towers will be a simple, individual pad footings. But there are instances that other types like raft foundations, well foundations or pre-cast pile foundations were used in extremely weak soil conditions. Concrete (tie beams) beams which connecting each leg to leg can be usually found in locations where the antenna towers have constructed on sloppy grounds or marshy areas.

Whatever the foundation type used, the main designing criteria of any antenna tower foundation will be that designing for the main foundation reactions of Uplifting, Down thrust and horizontal Shear. Therefore, while the size of pad footing will govern mainly by design uplifting or down thrust force, the size of column will decided by the shear and number of anchor bolts used. For enhancing the resistance for uplifting force, following techniques can be adopted,

- Laying of pad in deeper (usually in 3.0 to 4.0m deep) level,
- Utilizing the soil internal repose angle (with undercutting the soil wall, etc.) where the locations that ground water is not exist. However, where the ground water level is near to the surface, we will have no other option other than having larger pad footings.
- Use of GI screw anchors (Not practicing in Sri Lanka yet)

Use of raft foundation or pile foundation for antenna towers is not common in Sri Lanka, because changing of proposed location is always being more economical option than having very expensive foundation for antenna towers. But, such flexibility is not available for construction of transmission line pylons and therefore raft and pile foundations can be frequently seen in electricity transmission lines. Therefore, by selecting correct depth along with the size of footing, the most cost optimized foundation can be obtained. However, selection of depth of footing will also depends on several other practical aspects such as ground water table, type of soil, bearing capacity, location, etc.

As a conclusion, when considering the antenna towers, the design engineer have large responsibility on optimization of final cost of construction other than the visible commitments such as carrying out engineering design calculations and preparation of drawings. Theoretically, the design engineer should make his contribution to all stages of antenna towers construction (i.e - Planning, Tender bidding, designs, fabrications, constructions, etc.) for having better results. On the other hand, he should have knowledge, work experience and familiar about available fabrication facility and its capabilities too. Then the structural engineer may able to arrange most cost optimized tower architecture while its structural stability and functionality also be ensured.

11.0 Review of technical specifications of recent tower supply tenders.

As indicated earlier section of this report, some of shortcomings in tower design and constructions are starting from the initial stages of the tender biddings. The technical specification will be a one of key items for any tender bidding. It is the main document which provides all technical information to the tender bidders as well as ensures the quality of the product matching against with the requirement. Therefore, several technical specifications those have issued with tender documents for last few years were reviewed and discussed here for identifying their effectiveness. But the scope of details discussed here has been limited only for the items those may direct relationship about the design and cost optimization of tower and its safety. The relevant pages of all technical specifications those discussed below were attached as attachments in annex (A) for any further reference purposes.

11.1. Technical specification of Hutchison – March 2007 - (Attachment A-1)

- This document was attached in the tender document of supplying 40m, 60m & 70m towers (both Greenfield as well as Roof top type towers) for Hutchison telecommunication (pvt) limited, Colombo in March 2007.

- This tender call bids for Supply, deliver and complete construction (erection) of towers in provided locations.

- Under item (3) of SCOPE OF SUPPLY as well as in item (2)- Design codes of TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, the design codes were indicated as follows
  "The American or British structural standards for steel antenna towers and antenna supporting structures to be used"
  Note:- Although above statement has not precisely defined, it having no errors in it.

- Under the heading of "General" in TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, it defines "Manufacturing and workmanship should comply to BS449 or AISC"
  Note:- This statement provides some guidance about the required quality during process of manufacturing and workmanship of the structure.

- Under the headings of "(3) Galvanizing, (4) Steel works, & (5) Bolts, nuts & washers " in TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, further explaining about the quality of product & workmanship that required by the client
  Note:- These statements are satisfactory.

- Under the headings of "(6) Working and resting platforms, (7) Antenna mounting, & (8) Lighting protection and earthing" in TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, also explaining about the quality of product & workmanship that required by the client

Note:- These statements also are satisfactory and comparatively having low influence to the structural behavior of the tower.

- Under the heading of "(2) Wind loading and tolerance" in TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, it defines,

> **2. Wind Loading and Tolerance**
>
> 1 Operational wind speed of 120-km/h and survival wind speed of 160km/h should be used in the design
>
> 2 Twist and swing should not exceed 0.5 ° under extreme wind condition as specified in 1.
>
> 3 Tower Loading and tolerances are as follows
>
> a. Maximum wind exposed area is of antennae any direction shall be at least $20m^2$ for ground towers and $8m^2$ for rooftop towers. The force due to this wind-exposed area shall be applied to the top of the tower in design calculations.
>
> b. The design loading for total weight of antennae shall be at least 15 KN for ground towers and 6 KN for rooftop towers.
>
> 4 A safety factor of 1.7 should be used
>
> 5 The erected tower, under the condition of negligible wind, shall not deviate from the vertical position by more than one eight percent (1/8%) of its height, and shall be straight within 2.5cm of the nominal geometric position. The erected tower shall be free of inherent twists.

Note 1:- Survival wind speed of 160km/hr has been used for all locations, but it should be 180km/hr for any post disaster type structures in wind zone 1 & 2 (Jayasinghe, 2008) as well as according to new policy for antenna structures in Sri Lanka which has been issued by the Telecommunication Regularity Commission-Sri Lanka in 2008.

Note 2:- The limits of twist and deviations described in item 2 of above are operational requirements of the mounted equipments/antennas.

Note 3:- The maximum wind exposed area should be defined as "Effective flat area of $20m^2$".(It indicates to the bidder that the design antenna area of $20m^2$ should be considered as a flat area (i.e - provides highest wind drag coefficient)) Otherwise different suppliers may use different lower drag coefficients during their calculations. Then the actual design loading capacity of tower may be lower than the expected $20m^2$). Therefore, when it providing generalized design antenna area, it should be considered as "Effective flat antenna area" and the drag coefficient factor should be decided accordingly.

On the other hand, if there is a possibility of finalizing actual arrangement of antennas up to reasonable accuracy, then the details of design arrangement of antennas to be provided. The providing of actual arrangement of antennas will always beneficial for obtaining more safer as well as economical results.

Note 4:- Total weight of antennas should be either 15kN or 6kN as indicated. However, this value of 15kN also contributes the other operational loadings such as load applying on structure due to derric (temporary steel lattice pole or boom) in tower erection stage as well as antenna mounting operations, etc. However, as the steel lattice structures are usually capable of bearing more vertical loads, it may enough to consider 15kN (or 6kN for roof tops as indicated) vertically downward load at top of the tower in design stage to accounting all above design conditions.

Note 5:- The intention of using a general safety factor of 1.7 is not clear. Because the overall factor of safety of structure (for wind loads) will be 1.78 (i.e $160^2/120^2 = 1.78$), the factor of safety for material strength to be selected as value of 1.1 to 1.2 as appropriately. The Factors of safety for foundation has been indicated separately in another section of above same document, etc.

Note 6:- The item 5 of above, limit of deviation of erected structure, limit of twisting, etc. are mostly important as the aesthetical aspects. Because, when the steel lattice structure is 100% accurately constructed with supplying all of its members, such slight deviations or twists are not much important factors for its structural stability.

Under the headings of "(9) Climbing ladder, (10) Feeder runaway & horizontal gantry" in TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, explaining the type & its details about climbing ladder & feeder runaway that requested by the client.

Note:- Although above statements are apparently be satisfactory, the feeder runaway to be explained further. Usually the full width of the feeder runaway will be utilized for installing cables. Reference to the cable runaways (cable trays) of existing antenna towers, most of them are extremely congested with cables.

Therefore, the cable tray should essentially be considered as a one of main ancillary item that could contributes considerable loads to the tower structure. Assuming the cable tray is similar to long linear ancillary of having shape of flat plate may be good idealization for any tower designs.

Under the same above heading of "(10) Feeder runaway & horizontal gantry", it should further explain as follows,

"When considering the loadings of the tower, the 600mm wide, cable installed feeder runaway should be idealized as a 600mm wide effective flat area, with solidity ration 1.0 from 3m of the ground level up to the top of the antenna tower"

Otherwise, design engineers may able to use different (i.e - lower) wind drag coefficients and solidity ratios (i.e – less than 1.0) for above idealizations. Such assumptions will make them to achieve some benefits of lowering the final tower weight while reducing the design loading of the tower. We have seen use of such practically incorrect, questionable assumptions during the reviewing of existing antenna tower designs in chapter 10 of this report.

- Under the headings of "(11) Obstruction light, (12) Welding, & (13) Obstruction paint" in TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, also explaining about the quality of product & workmanship that required by the client

  Note:- These statements also are satisfactory and comparatively having low influence to the structural behavior of the tower.

- Under the headings of "(14) Foundation" in TECHNICAL SPECIFICATIONS FOR SELF SUPPORTING TOWERS, also mostly explaining about the quality of foundation & workmanship that required by the client

  Note:- In addition to the above quality aspects, it may necessary to be included some of primary design criterions also in to this section. The primary design criterions those having large influences on design of individual pad footings may be as follows,

  - Standard soil bearing capacity to be assumed for pricing purposes (indicated above)
  - Factors of safety to be considered on design uplifting force for different situations such as, good soil foundations with undercutting possible, when undercutting is not possible, water logged foundations, etc.
  - General factor of safety for overturning, sliding, etc. (for example FOS=1.5)
  - Type and quality of steel reinforcement to be used, (for example f_y=460N/mm^2, etc.)
  - Grade of concrete, (for example Gr 25, etc.)
  - Emphasizing the need of avoid of reinforcement lapping in main column reinforcements and ensuring to provide sufficient anchoring length in to pad footing. (As the antenna tower foundations are designed for catering high uplifting forces, this type of detailing is essential)
  - Use of cone shaped pad footings for large foundations. (to having economical foundations, specially in antenna towers those are located in difficult terrains)
  - Recommendation of minimum width of column to ensuring to proved sufficient space for proper placement of anchor bolts,
  - Other miscellaneous aspects such as minimum cover to reinforcement steel, reinforcement lap length, thickness of screed concrete, casting of test cubes, etc.
  - Factors of safety to be adopted & quality of workmanship on locations where rock anchoring is to be done.

11.2 Technical specification of Mobitel – November 2009 (Attachment A-2)

- This document was attached in the tender document of supplying 70m, 80m & 100m towers (All are Greenfield type towers) for Mobitel Lanka (pvt) limited, Colombo in November 2009.

- This tender call bids for Supply, deliver and complete construction (erection) of towers in provided locations at North province.

- Under the headings of "Design codes " it has defined as follows,

DESIGN CODES

The Following Codes shall be used and shall be fully complied in the designs fabrication and construction,

1.1.1.1.1	Calculation of loading on the Tower: The American "Structural Standard for Steel Antenna Towers and Antenna Supporting structures" EIA 222F:1996 or Equivalent
1.1.1.1.2	Design of Steel Transmission Structures: ASCE 10-90 Design of Structures or Equivalent
1.1.1.1.3	Calculation of Wind loads: BSI CP2 Chapter V Part II 1972 or Equivalent
1.1.1.1.4	Welding: EN970:1997 BS EN 25817:1992 ISO 5817:1992
1.1.1.1.5	Foundation RCC Design: BS8110: Part I: 1985 & BS8007 or Equivalent
1.1.1.1.6	Manufacturing and workmanship shall comply to BS449 or AISC
1.1.1.1.7	Galvanizing of the tower members shall comply with BS EN ISO 1461:1991, ASTM/A123 or equivalent
1.1.1.1.8	The Steel used in the fabrication of tower shall conform to BS EN10025 Grade S275 and S355 as appropriate to Rolling Tolerance to relevant ISO standards.
1.1.1.1.9	All Nuts and Bolts shall be in accordance with ISO 898-1(Hexagonal Bolts) or relevant standards.

Note 1:- Although it has recommended use a design code of EIA 222F:1996 or equivalent, there is a another newly issued (in 2005) version of same code also available - TIA/EIA222-G - with many (new) important features included. Therefore, it is better to request tower designs according to most recent code than old versions.

Note 2:- The purpose of using EIA222F (or TIA/EIA222-G) code in antenna tower design is for calculation of wind loading on steel structure as well as other loadings, therefore recommending again to use of BSI CP2 Chapter V Part II 1972 for calculation of wind loading may make confusing environment. On the other hand, the BSI CP2 Chapter V Part II 1972 code is currently considered as obsolete document as well as it is not a document which targeted to use only for tower designs. Therefore the use of such obsolete, general wind code for design of complex structural forms like steel lattice antenna towers may be questionable.

Note 3:- The loading due to 600mm wide feeder runaway (cable tray) should be further explained as follows, (a detail discussion for similar issue has been done for Hutchision technical specification above)

"When considering the loadings of the tower, the 600mm wide, cable installed feeder runaway should be idealized as a 600mm wide effective flat area, with solidity ration 1.0 from 3m of the ground level up to the top of the antenna tower"

- Under the headings of "TECHNICAL SPECIFICATIONS " it has defined as follows,

WIND LOADING AND TOLERANCE FOR TOWERS/POLES IN ANY NATURE

1.1.1.1.10 The Wind loading on the Towers/Poles shall be calculated in accordance with BSI CP2 Chapter V Part II 1972 or Equivalent and to meet the following:

a) Operational wind speed of 140-km/h and survival wind speed of 180 km/h shall be used in the design for green field towers.

b) Twist and sway for any structure shall not exceed 0.50 under extreme (operational) wind condition as specified.

c) The tower loading figure shall accommodate following equipment and if the Tenderer proposed that the given loadings are insufficient to cater the supplied equipment in this proposal it shall be escalated in the proposed solution document.

   i. Minimum wind exposed area for green field tower in any direction shall be at least $30m^2$ on top of the tower. The force due to this wind-exposed area shall be applied to the top of the tower in design calculations.

d) The top centre of the erected tower/pole, under operational condition, shall not deviate from the vertical position by more than one eighth percent (1/8%) of its height. The erected tower shall be free of inherent twists.

Note 1:- it has again mentioned about the calculation of wind loads according to BSI CP2 Chapter V Part II 1972 or Equivalent,

Note 2:- Survival wind speed of 180km/hr and Operational wind speed of 140km/h has been used for all locations, it is satisfactory

Note 3:- The limits of twist and deviations described in item (b) of above are operational requirements of the mounted equipments/antennas.

Note 4:- The minimum wind exposed area should be defined as "Effective flat area of $30m^2$".(It indicates to the bidder that the design antenna area of $30m^2$ should be considered as a flat area for any direction (i.e - provides highest wind drag coefficient)) Otherwise different suppliers may use different lower drag coefficients during their calculations.

The word "in any direction" is important, then the supplier should oblige to applying above same total loads (due to 30m² antennas at top of tower) for cross wind analysis (wind applying along diagonal direction of the tower) which will be usually the most critical loading pattern.

Note 5:- The details those described under item (d) is aesthetical requirements as similar to that explained in Hutchision technical specification above.

- Under the headings of "TECHNICAL SPECIFICATIONS " it has defined some of basic design criteria are as follows,

TOWER FOUNDATION

1.1.1.1.11 The Design and Construction of the Tower Foundations shall conform to BS8110: Part I: & BS 5950 1985 for Roof Top Towers and BS8110: Part I 1985, BS 5950 & BS 8007 or Equivalent for Green Field Towers.

1.1.1.1.12 Standard soil bearing capacity shall be define as 100kN/m2 for pricing purposes.

1.1.1.1.13 Where the concrete only has to resist the uplift, the weight of concrete shall be 1.5 times the uplift.

1.1.1.1.14 Where the footing is undercut into undisturbed soil, the frustum may be taken for uplift and overturning calculation depending on the repose angle given in the soil report and the total weight of concrete plus the ground frustum shall be at least 1.77 times the uplift.

1.1.1.1.15 The buoyant force due to ground water level shall be taken into account for the foundation design, wherever applicable.

1.1.1.1.16 Where the foundation is designed without considering undercut safety factor for uplifting and overturning shall be taken as 1.5.

Continue ......

Note 1:- The above descriptions are well explained, in addition to above descriptions following items may included too.

- Emphasizing the need of avoid of reinforcement lapping in main column reinforcements and ensuring to provide sufficient anchoring length in to pad footing. (As the antenna tower foundations are designed for catering high uplifting forces, this type of detailing is essential)
- Use of cone shaped pad footings for large foundations. (to having economical foundations, specially in antenna towers those are located in difficult terrains)
- Recommendation of minimum width of column to ensuring to proved sufficient space for proper placement of anchor bolts,
- Other miscellaneous aspects such as minimum cover to reinforcement steel, reinforcement lap length, thickness of screed concrete, casting of test cubes, etc.
- Factors of safety to be adopted & quality of workmanship on locations where rock anchoring is to be done.

11.3. Technical specification of Suntel – December 2008 (Attachment A-3)

- This document was attached in the tender document of supplying 50m, 60m, 70m and 80m towers (All are Greenfield type towers) for Suntel Lanka (pvt) limited, Colombo in December 2008.

- This tender call bids for Supply, deliver and complete construction (erection) of towers in provided locations.
- Under the headings of "General " it has described as follows,

> **1.0 GENARAL**
>
> The specification define the characteristics and performance requirement of the Tower to be purchased
>
> 1.1 For the performance specifications and characteristics witch are not stated in this specification, the relevant standard and\ or recommendations as specified in EIA RS –222C and BS449 shall apply:
>
> 1.2 Manufacturing and workmanship should comply to BS 449 or AISC
>
> 1.3 Minimum distance between legs at the top portion shall be type and 1.8m for 50m,60m,70m and 80m towers.
>
> 1.4 The straight portion at the top shall be 10m for all towers above 50m in height.

Note 1:- Although it has recommended use a design code of EIA RS-222C, there are another four new versions (D, E, F & G) of same code also available. Most recently released version is TIA/EIA222-G which includes many (new) important features. Therefore, it is better to request tower designs according to most recent engineering code than old versions.

- Under the headings of "Design codes " it has described as follows,

> **2.0 DESIGN CODES**
>
> The American "Structural standard for steel Antenna Towers and Antenna supporting Structures" RS222C or The British codes of practices 3 chapter V part 2, 1972 shall be used.

Note 1:- Both EIA222-C code and BSI CP2 Chapter V Part II 1972 are obsolete documents. Therefore, we should use either ANSI/TIA222-G-2005 (Structural standard for Antenna supporting structures and antennas-American) ,or BS8100-1986 (British standard for lattice towers and masts)

- Under the headings of "Wind loading and tolerance " it has described as follows,

> **3.0 WIND LOADING AND TOLERANCE**
>
> 3.1 Operational wind speed of 120 km/h and survival wind speed of 160 km/h should be used in the design
>
> 3.2 Twist and swing should not exceed 0.5 under extreme wind condition as specified in 3.1.
>
> 3.3 The tower-loading :.(wind shield area of 32Sq.m in any one direction at top
> 3.4 A safety factor of 1.7 should be used.
> 3.5 The erected tower, under the condition of negligible wind, shall not deviate from the vertical position by more than one eight percent (1/8%) of its heights, and shall straight within 2.5 cm of the normal Geometric position: the erected tower shall be free of inherent twists.

Note 1:- Survival wind speed of 160km/hr and Operational wind speed of 120-km/h has been used for all locations, but it is not satisfactory for wind zone 2 and 3. On the other hand the new policy for antenna structures of the TRC has been recommended to use 180km/hr wind speed for all antenna structures that considering them as post disaster type structures.

Note 2:- The limits of twist and deviations described in item 3.2 of above are operational requirements of the mounted equipments/antennas.

Note 3:- The tower loading conditions that has described in above item 3.3 should be done in more detailed and precise manner. Otherwise the towers supplier may submit tenders with providing their own different definitions for above design antenna area, etc.
Therefore, above description in item 3.3 should be corrected as follows,
The tower loading -: The minimum **"Effective flat wind shielding area of 32m²"**.(i.e-It indicates to the bidder that the design antenna area of 32m² should be considered as a flat area which provides the highest wind drag coefficient) **for any direction should be applied to the top level of the structure.**

Note 4:- The intension of using a general safety factor (in item 3.4) of 1.7 is not clear. Because the overall factor of safety of structure (for wind loads) will be 1.78 (i.e $160^2/120^2 = 1.78$), the factor of safety for material strength to be selected as value of 1.1 to 1.2 as appropriately. The Factors of safety for foundation has been indicated separately in another section of above same document, etc.

Note 5:- The item 3.5 of above, limit of deviation of erected structure, limit of twisting, etc. are mostly important as the aesthetical aspects. Because, when the steel lattice structure is 100% accurately constructed with supplying all of its members, such slight deviations or twists are not much important factors for its structural stability.

Note 5:- Under the headings of Item 4.0 to 12.0, it described the details of quality of product and workmanship required by the client.

However, it is important to add some further description about the design loading condition of Feeder runaway as follows,

"When considering the loadings of the tower, the 600mm wide, cable installed feeder runaway should be idealized as a 600mm wide effective flat area, with solidity ration 1.0 from 3m of the ground level up to the top of the antenna tower"

Otherwise, tower suppliers may able to use different (i.e - lower) wind drag coefficients and solidity ratios (i.e – less than 1.0) for above idealizations. Such assumptions will make them to achieve some benefits of lowering the final tower weight while reducing the design loading of the tower.

- Under the headings of "(13) Foundation" it mostly explaining about the quality of foundation & workmanship that required by the client

Note:- In addition to the above quality aspects, it may necessary to be included some of primary design criterions also in to this section. The primary design criterions those having large influences on design of individual pad footings may be as follows,

- Standard soil bearing capacity to be assumed for pricing purposes (indicated above)
- Factor of safeties to be considered on design uplifting force for different situations such as, good soil foundations with undercutting possible, when undercutting is not possible, water logged foundations, etc.
- General factor of safety for overturning, sliding, etc. (for example FOS=1.5)
- Type and quality of steel reinforcement to be used, (for example fy=460N/mm^2, etc.)
- Grade of concrete, (for example Gr 25, etc.)
- Emphasizing the need of avoid of reinforcement lapping in main column reinforcements and ensuring to provide sufficient anchoring length in to pad footing. (As the antenna tower foundations are designed for catering high uplifting forces, this type of detailing is essential)
- Use of cone shaped pad footings for large foundations. (to having economical foundations, specially in antenna towers those are located in difficult terrains)
- Recommendation of minimum width of column to ensuring to proved sufficient space for proper placement of anchor bolts,
- Other miscellaneous aspects such as minimum cover to reinforcement steel, reinforcement lap length, thickness of screed concrete, casting of test cubes, etc.
- Factor of safeties to be adopted & quality of workmanship on locations where rock anchoring is to be done.

11.4. Technical specification of Lanka Bell – July 2008 (Attachment A-4)

- This document was attached in the tender document of supplying 50m, 60m, 70m, 80m & 100m towers (All are Greenfield type towers) for Lanka Bell (pvt) limited, Colombo.

- This tender call bids for Supply, deliver and complete construction (erection) of towers in provided locations.

- Under the headings of "Design Codes " it has described as follows,

1.1.1.2 Design Codes

The Following Codes will be used in the designs fabrication and construction

1. Calculation of loading on the Tower: The American "Structural standard for Steel Antenna Towers and Antenna Supporting structures": EIA222F :1996 or Equivalent
2. Design Of Steel Transmission Structures: ASCE 10-90 Design of Structures or Equivalent
3. Calculation of Wind loads: BSI CP2 Chapter V Part II 1972 or Equivalent
4. Welding: EN970:1997 BS EN 25817:1992 ISO 5817:1992
5. Foundation RCC Design: BS8110: Part I: 1985 & BS8007 or equivalent
6. Manufacturing and workmanship should comply to BS449 or AISC
7. Galvanizing of the tower members shall comply with BS EN ISO 1461:1991, ASTM/A123 or equivalent.
8. The Wind loading on the Tower shall be calculated in accordance with BSI CP2 Chapter V Part II 1972 or equivalent
9. The Steel used in the fabrication of tower shall conform to BS EN10025 Grade S275 and S355 as appropriate to Rolling Tolerance to relevant ISO standards.
10. All Nuts and Bolts shall be in accordance with ISO 898-1(Hexagonal Bolts) or relevant standards.

Note 1:- Although it has recommended use a design code of EIA 222F:1996 or equivalent, there is a another newly issued (in 2005) version of same code also available - TIA/EIA222-G - with many (new) important features included. Therefore, it is better to request tower designs according to most recent code than old versions.

Note 2:- The purpose of using EIA222F (or TIA/EIA222-G) code in antenna tower design is for calculation of wind loading on steel structure as well as other loadings, therefore recommending again (in item 3 & 8) to use of BSI CP2 Chapter V Part II 1972 for calculation of wind loading may make confusing environment. On the other hand, the BSI CP2 Chapter V Part II 1972 code is currently considering as obsolete document as well as it is not a document which targeted to use only for tower designs. Therefore the use of such obsolete, general wind code for design of complex structural forms like steel lattice antenna towers may be questionable.

- Under the headings of "Design Criteria and Tolerances" it has described as follows,

1.1.1.3 Design Criteria and Tolerances.

1. **Operational wind speed of 140 km/h and survival wind speed of 180 km/h is used in design.**
2. Maximum wind exposed area is of antenna for any direction shell be as per the Table 1.1
3. The design loading for total weight of antennae is 15kN for Green Field.
4. A safety factor of 1.7 is used.
5. Twist and swing should not exceed 0.5 ° under extreme wind condition as specified above (CL 1.1.2.2 – 1).
6. The erected tower under the condition of negligible wind, will not deviate from the vertical position by more than one eight percent (1/8%) of its height and shell be straight within 2.5cm of the nominal geometric position. The erected tower will be free of inherent twists.
7. The height of straight portions of towers will be according to the Table 1.1
8. Tower fabrication tolerances will be, ±0.75mm for centers location of holes, ±1.5mm for overall length of members and ±1.5mm for bolt holes.

1.1.1.1 Tower Types

1.1.1.1.1 Table 1.1 -Tower Height and Loading Details

Tower Type	Height (m)	Antenna loading at the tower in any direction (m^2)	Location of the sector antenna on the tower (m)	Location of the M/w antenna on the tower (m (m)
Green Field Tower	50	16	50-45	45-35
	60	16	60-55	55-45
	70	16	70-65	65-55
	80	16	80-75	75-65
	100	16	100-95	95-85

Note 1:- Survival wind speed of 180km/hr and Operational wind speed of 140-km/hr has been used for all locations, Therefore it will be satisfactory for all three wind zones. On the other hand it also agrees with the recommendations given in new policy for antenna structures by the TRC that considering those are as post disaster type structures.

Note 2:- The limits of twist and deviations described in item 5 of above are operational requirements of the mounted equipments/antennas.

Note 3:- The tower loading conditions that has described in above item 2 & table 1.1 should be done in more detailed and precise manner. Otherwise the towers supplier may submit tenders with providing their own different definitions (which may not providing the worse design loading arrangement for tower structure) for above design antenna area, etc. Therefore, above description in item 2 may be corrected as follows,

Total wind shielding area of the antennas will be equal to 16m2
Above antennas includes 6 nos of 0.5mx2.5m panel antennas arranged at top (attachment A-04a) and 2 x 1.8m and 1 x 2.0m diameter dish antennas that may arranged in to any direction (attachment A-04b & A-04c). The mounting arrangement and heights of all above antennas will be according the table 1.1

Note 4:- The purpose of using a general safety factor (in item 4) of 1.70 is not clear. Because the overall factor of safety of structure (for wind loads) will be 1.65 (i.e $180^2/140^2 = 1.65$), the factor of safety for material strength to be selected as value of 1.1 to 1.2 as appropriately. The Factors of safety for foundation has been indicated separately in another section of above same document, etc.

Note 5:- The item 6 of above, limit of deviation of erected structure, limit of twisting, etc. are mostly important as the aesthetical aspects. Because, when the steel lattice structure is 100% accurately constructed with supplying all of its members, such slight deviations or twists are not much important factors for its structural stability.

Note 5:- All other sections of above technical specification described the details of quality of product and workmanship required by the client.
However, it is important to add some further description about the design loading condition of Feeder runaway as follows,

"When considering the loadings of the tower, the 500mm wide, cable installed feeder runaway should be idealized as a 500mm wide effective flat area, with solidity ratio of 1.0 from 3m of the ground level up to the top of the antenna tower"

Otherwise, tower suppliers may able to use different (i.e - lower) wind drag coefficients and solidity ratios (i.e – less than 1.0) for above idealizations. Such assumptions will make them to achieve some benefits of lowering the final tower weight while reducing the design loading of the tower.

- Under the headings of "1.1.2 Technical Specifications for Tower Foundations" it mostly explaining about the quality of foundation & workmanship that required by the client

Note:- In addition to the above quality aspects, it may necessary to be included some of primary design criterions also in to this section. The primary design criterions those having large influences on design of individual pad footings may be as follows,

- Standard soil bearing capacity to be assumed for pricing purposes (indicated above)
- Factor of safeties to be considered on design uplifting force for different situations such as, good soil foundations with undercutting possible, when undercutting is not possible, water logged foundations, etc.
- General factor of safety for overturning, sliding, etc. (for example FOS=1.5)
- Type and quality of steel reinforcement to be used, (for example fy=460N/mm2, etc.)
- Grade of concrete, (for example Gr 25, etc.)
- Emphasizing the need of avoid of reinforcement lapping in main column reinforcements and ensuring to provide sufficient anchoring length in to pad footing. (As the antenna tower foundations are designed for catering high uplifting forces, this type of detailing is essential)
- Use of cone shaped pad footings for large foundations. (to having economical foundations, specially in antenna towers those are located in difficult terrains)
- Recommendation of minimum width of column to ensuring to proved sufficient space for proper placement of anchor bolts,
- Other miscellaneous aspects such as minimum cover to reinforcement steel, reinforcement lap length, thickness of screed concrete, casting of test cubes, etc.
- Factors of safety to be adopted & quality of workmanship on locations where rock anchoring is to be done.

11.5. Technical specification of Safaricom (Kenya) – January 2010 (Attachment A-5)

- This document was attached in the tender document of supplying 50m, 60m, 80m Greenfield towers & 21m rooftop towers for Safaricom limited, Kenya.

- This tender call bids for Supply, deliver and complete construction (erection) of towers in provided locations.

- As a general details, it has described as follows,

1.1.1. Loading

Objectives

The objective of this section is to provide minimum design criteria for self supporting steel lattice towers and monopoles

Service life

The expected service life of towers and monopoles shall be 25 years. The design, choice of fabrication materials, fabrication methods, installation accessories, all safety factors and tower/monopole loadings shall all be made to conform to standards for this to be achieved.

Note 1:- It explains the objective of the loading criterion given in above technical specification as the minimum required design criteria for self standing towers and monopoles. Therefore, the tendorers can provide suitable families of towers to suit above minimum criteria.

- Under the headings of "Design loads" it has described as follows,

For the basic wind speeds in Kenya, the following table shall be used as a guide

Location	Description	Basic Wind Speed, m/s	
1	Nairobi, Central Province & southern half of Eastern Province including Machakos, Thika & Nyeri	28	Region 1
2	Coast Province including Voi, Malindi & Mombasa	31	
3	Southern half of Rift Valley Province including Nakuru, Naivasha, Narok, Rumuruti, Nanyuki & Magadi	36	Region 2
4	North Eastern Province, Northern half of Eastern & Rift Valley Provinces including Eldoret, Kitale & Kericho	45	Region 3
5	Nyanza & Western Provinces including Kisumu, Kakamega, Busia & Kisii	46	

The basic wind speed shall be read from this table whereas the design wind speed shall be obtained from methods given in BS CP3: Chapter V: Part 2.

Note 1:- The basic wind speed for different region of Kenya has given as a guideline. It will help to decide design wind speed for given regions.

- Under the headings of "Loading " it has described as follows,

> There will be two types of towers for every region: namely normal duty and heavy duty.
>
> The towers shall be designed to cater for the following antenna equipment
>
> **NORMAL DUTY**: 6 Nos. 2.6m long GSM and 1.2 m Ø M/W @ top. and 2 nos. 1.2m Ø M/W just below.
>
> **HEAVY DUTY**: 6 nos. GSM @ top. and 4 nos 1.8m Ø M/W 5m below. and 4 nos. 1.8m Ø MW 10m further below.
>
> NOTE: Heavy Duty towers shall always be four legged.

Note 1:- The proposed arrangements of antennas were given. This may be the best way of obtaining most economized structures for large quantity of tower requirements.

Note 2:- If the samples of GSM and MW antennas were given, the details will be more completed. Otherwise the drag coefficients of above two types of antennas to be given.

Note 3:- The design loading due to cable tray has not included above or any other sections of the technical specification.

> The deflection of the structure shall not exceed the maximum allowable sway of ±0.50 degrees at the centre of the top most MW position. at 80% of the basic wind speed as stated in table above.

Note 3:- The operational requirements were given above in slightly different wordings,

> *Minimum Dead and Live Load:*
>
> The dead loads to be considered in design shall include self weight of tower/monopole. GSM and M/W antenna. feeder cables. mounting brackets. fixtures and fittings and access ladder and platforms. An allowance of about 5% of the structure weight shall be made for galvanising and fasteners.
>
> The live loads to be considered shall include workers climbing for installation / inspection

- Under the headings of "Tower designs " it has described as follows,

> All steel structures shall be designed in accordance with BS5950. Tower designs shall also conform to BS 8100
>
> The tower shall be designed to resist the most onerous combination of loading resulting from wind acting on towers. ancillaries. antennae and feeders.

Note 1:- The above two sentences clearly described the code of practice and load combination to be adopted.

> At the time of submission of a new tower monopole type never deployed in Safaricom Limited network before for Safaricom Limited's approval with SoC, the contractor shall submit a bound structural analysis & design report, including the tower structural drawings and models in soft copy either in STAAD *pro*, Prokon or STRAP programmes, for each new tower to be supplied. Tower structural drawings shall indicate region, material strengths, dimensions, member sizes, platform positions, ladder, design load and any other relevant notes. These calculations must clearly indicate both the net (as obtained from structural analysis) and gross weight of tower.
>
> If vendor bids for a tower that has been deployed in the Safaricom Limited network before, reference to approved documents should be made and drawings of tower submitted with these SoCs. These structural drawings shall indicate region, material strengths, dimensions, member sizes, platform positions, ladder, design load and any other relevant notes.
>
> All structural design (drawings and calculations) submitted to Safaricom Limited, must be clearly marked to show they have been approved for use in Kenya by a Structural Engineer registered by Kenya's Engineers Registration Board or IEK.

Note 2:- The client is asking all the details and computer model of each towers for their own evaluations.

Note 3:- In one aspect, it can argue as the wise choice of requesting tender bidders to submit computer models of above proposed towers in software (i.e STAAD Pro, Prokon or STRAP) which are available with client in his facility. But the use of more specific software those are using only for designing of steel lattice antenna towers will be always advantage – as discussed in earlier sections of this report.

Note 4:- It has clearly requested that the each drawings should have to be well detailed with all basic details.

Note 5:- All structural drawing are requested to be validated by a structural engineer registered in Kenya's Engineering Registration Board or IEK. (In Sri Lanka, this type of validation of design calculations by local experts is not always requested.)

- Under the headings of "Modular requirement " it has described as follows,

> **1.1.2. Modular Requirement**
>
> The tower shall be of lattice bolted construction, square or triangular in geometric cross section. The tower shall be made up of 5m or 6m modular sections enabling complete flexibility over the height requirements.

Note 2:- This is very useful for operation and maintenance aspects of the structures.

- Under the headings of "Foundation designs " it has described as follows,

> **1.1.3. Footprint Requirement and Foundation Design**
>
> The footprint shall be the smallest possible meeting the loading requirements specified in this document.
>
> The foundation designs and drawings shall also be submitted with these SoCs. For each tower to be supplied, the vendor shall provide the following options for tower foundations namely ground raft for soil bearing capacity of 200 kpa, underground raft and separate pads for soil bearing capacity 120 to 150 kpa and underground raft for soil bearing capacity of 80 to 100 kpa.
>
> All structural designs for foundations (drawings and calculations) must be submitted to Safaricom Limited with the SoC and be clearly marked to show they have been approved for use in Kenya by a Structural Engineer registered by Kenya's Engineers Registration Board or IEK.

- Note 1:- In addition to the above described basic requirements, it may necessary to be included some other primary design criterions too. The primary design criterions those having large influences on design of individual pad footings may be as follows,

  - Standard soil bearing capacity to be assumed for pricing purposes (indicated above)
  - Factor of safeties to be considered on design uplifting force for different situations such as, good soil foundations with undercutting possible, when undercutting is not possible, water logged foundations, etc.
  - General factor of safety for overturning, sliding, etc. (for example FOS=1.5)
  - Type and quality of steel reinforcement to be used, (for example fy=460N/mm2, etc.)
  - Grade of concrete, (for example Gr 25, etc.)
  - Emphasizing the need of avoid of reinforcement lapping in main column reinforcements and ensuring to provide sufficient anchoring length in to pad footing. (As the antenna tower foundations are designed for catering high uplifting forces, this type of detailing is essential)
  - Use of cone shaped pad footings for large foundations. (to having economical foundations, specially in antenna towers those are located in difficult terrains)
  - Recommendation of minimum width of column to ensuring to proved sufficient space for proper placement of anchor bolts,
  - Other miscellaneous aspects such as minimum cover to reinforcement steel, reinforcement lap length, thickness of screed concrete, casting of test cubes, etc.
  - Factors of safety to be adopted & quality of workmanship on locations where rock anchoring is to be done.

- Under the headings of "Tower member requirement " it has described as follows,

> **1.1.4. Tower Member Requirement**
>
> Leg members, main and secondary bracings shall be manufactured from hot rolled steel sections, either in angle or tubular hollow sections. For the coastal region, angular sections shall be preferred to tubular hollow sections.

Note 1:- It has clearly requested not to use tubular hollow sections for coastal regions. Generally the tubular hollow members are having higher tendency for heavy corrosion due to the reasons such as they are having comparatively thinner members, usually inside of members are not well galvanized, more welded joints, etc.

- Under the headings of "Structural steelwork " it has described as follows,

> **1.1.5. Structural Steelwork**
>
> All structural steelwork shall be in accordance with BS4360 Grades 50C, 40B & 50B
>
> Hot rolled angled sections shall conform to BS4848: Part 4: 1972.
>
> Hot rolled structural hollow sections shall be to BS4848: Part 2: 1972.
>
> All bolts shall be in accordance with BS4190 and each supplied complete with single nut, single coil spring washer and flat washer.
>
> Fabrication shall be generally carried out in accordance with the requirements of BS5950
>
> All welding shall be performed before the galvanizing process and shall conform to BS5135.
>
> All steelwork shall conform to structural loading requirements, structural steel specifications and local market availability.

Note 1:- Basic requirements are described above sufficiently

11.6. Technical specification of Orange (France/Africa) –December 2008(Attachment A-6)

This document was attached in the tender document of Design, Manufacture, Delivery of Towers and Masts (Both Greenfield and Roof top type structures) for Orange Telecommunication limited, Kenya.

- Under the headings of "Design " it has described as follows,

> ***Design***
>
> *Two (2) standard / code are allowed:*
>
> - *EIA/TIA-222-G with addendum G1*
> - *NV 65 - DTU P06-002 version of 2000*
>
> *Per consequence the following calculation rules for steel constructions shall be used*
>
> - *AISC- LRFD 99 – Load and Resistance Factor Design Specification for Structural Steel Building*
> - *P 22.701 CM 66 Rules and addition 80: Metal construction rules – Calculation rules for steel constructions edited in 1966*
>
> *These Standards / Codes shall be imperatively used to design standard tower. Using equivalent or others Standard/Code for standard tower is not allowed.*
>
> *The tower should be designed in such a manor that the connections are not the critical or weakest link.*

Note 1:- Only two design codes are allowed.

Note 2:- The towers were requested to be designed in such a way that the connections are not the critical or weakest link.

- Under the headings of "Design notes " it has described as follows,

> **Design note**
>
> The structure's design note is to be supplied to Purchaser for each tower or mast delivered. The design note will include a hypothesis note defining the base values of the wind and the various coefficients taken into account (site, dimension, height, dynamic and drag, etc.) and the surfaces considered and the type of links at the bearings and between the bars. The name, the origin and the characteristics of the software used shall be specified.
>
> The stability and the solidity of the structure will be checked according the allowed standard / code
>
> - E.g :With the wind pressures corresponding to the extreme wind of NV65.
>
> The dimensions of the pylon's and mast's anchorage and the checking of mast fatigue may be carried out as per the Recommendations on the calculation of the mast structure for the lighting of open spaces
>
> - published in CTICM's Metal Construction report, no. 4 of 2000.
> - AISC – LRFD 99

Note 1:- It requested to include all the technical details in each report of tower as seperate notes. This will make sure that all necessary design details will included in to design report and submitted to the client. Therefore, No hidden factors, etc. are allowed to be used by the supplier for his designs.

- Under the headings of " Wind " it has described as follows,

Wind

The impacts of the wind will be considered on the pylon's structure, the ladder, the platforms, the cable paths, the antenna and their accessories.
The tower and mast will be adapted to the wind zone encountered.

	EIA/TIA-222-G1 (3 Sec Gust wind speed at 10 m height)	NV 65 (10 Min Ave wind speed at 10 m height)
Wind Area A	Basic wind speed :149,7 Km/h	Normal speed: 103,0 Km/h Extrem speed: 136,1 Km/h
Wind Area B	Basic wind speed :162,5 Km/h	Normal speed: 112,7 Km/h Extrem speed: 149,1 Km/h
Wind Area C	Basic wind speed :181,8 Km/h	Normal speed: 126,0 Km/h Extrem speed: 166,6 Km/h
Wind Area D	Basic wind speed :197,9 Km/h	Normal speed: 137,9 Km/h Extrem speed: 182,5 Km/h
Wind Area E	Basic wind speed :228,5 Km/h	Normal speed: 159,2 Km/h Extrem speed: 210,6 Km/h
Wind Area F	Basic wind speed :251,0 Km/h	Normal speed: 174,4 Km/h Extrem speed: 230,7 Km/h

For exposed site, the superior class should be taken

- E.g: Wind Area B is corresponding to Wind Area A for exposed site

(For TIA-222-G the Exposure Categories as per 2.6.5 are to be followed)
The Tower height will be limited for the wind area D, E, F
Note: the wind speed are given for 10m height

Note 1:- Design Wind speeds for different categories were clearly given.

- Under the headings of "Antenna Effective projected area " it has described as follows,

Antennas Effective Projected Area (EPA)

Antenna Effective Projected Area (EPA) includes only the load for the antennas (GSM and MW).
Feeder, cable tray, platform, (etc..) impacts are not included in the EPA value.
The tenderer shall consider the following typical values for the antennas Effective Projected Area (EPA) for the tower (greenfield site).

- The typical values are: 6 sqm and 300 Kg, 12 sqm and 600 Kg, 20 sqm and 1100 Kg, 25 sqm and 1300 Kg
- The location is : 1.1 In the last 3 meters for the 6sqm
  In the last 5 meters for the 12 sqm
  In the last 10 meters for the 20 and 25 sqm

The tenderer shall consider the following typical values for the antennas Effective Projected Area (EPA) for the tower (rooftop site).

- The typical values are: 6 sqm and 300 Kg, 12 sqm and 600 Kg
- The location is :
  - In the last 3 meters for the 6sqm
  - In the last 5 meters for the 12 sqm

The tenderer shall consider the following typical values for the antennas Effective Projected Area (EPA) for the pole (rooftop site).

- The typical values are: 2 sqm and 100 Kg
- The location is :
  - In the last 2 meters

Note 1:- The design antenna area and their location of loading have been clearly indicated. All antenna areas are supplied as Effective projected areas (EFA).

- Under the headings of "Transmission lines " it has described as follows,

Transmission lines (Feeder)

The manufacturer will consider a width for a wind projected area of at least 50cm for the tower and a weight of 16 Kg / meter for feeders, with the except of the towers up to 36m with a EPA of 6sqm, in this case 350mm can be used for the feeder projected area.

In specific case (on purchaser request), a second cable ladder could be added. The position should be studied to limit the wind load.

For the pole, the manufacturer will consider a width for a wind projected area of at least 25 cm for the pole.

Note 1:- The design area of feeder line have been clearly indicated as Effective projected areas (EFA).

- Under the headings of "Tilt, Twist and Sway " it described as follows

1.1.2 Tilt, Twist and sway

The maximum authorised tilt, twist and sway for the tower and mast will be of: (See #13 for loading tables)

± 1°at the top for pole 2sqm load

- ± 1°at the top for tower 6sqm load
- ± 1°at 2,5 m of the top for tower·12sqm load (Cast 1)
- ± 30' at 2,5 m of the top for tower 12sqm load (Case 2)
- ± 20' at 5 m of the top for tower 20 and 25 sqm load

Note 3:- The necessary details are clearly defined above

- Under the headings of "Foundation " it described as follows

1.1.3 Foundation

The tower shall be compatible with the different soil quality (defined in chapter 7.1.1 of "Civil works and Tower installation –annex"

To summarize, the typical soil quality are:

- 200 kPa
- 150 kPa
- 100 kPa
- 50 kPa

These values are given in ELU (Ultimate limit)

Note 3:- The necessary details are clearly defined above and in separate chapter.

- Under the headings of "Other parameters " it described as follows

1.1.4 Other parameters

For design with EIA/TIA -222G with addendum, the following parameters shall be considered:

- Exposure category: C
- Topographic category: 1
- Classification of structure: 2

For design with NV65, the following parameters shall be considered:

- Site effect: normal
- No cliff effect

Note 3:- All other parameters relevant to two design codes were clearly defined above.

- Under the headings of "Report " it described as follows

> **1.2 Report**
>
> The report shall include:
> - The parameters defined for the design calculation
> - The impact of the accessories (ladder, work platform, feeder, ..)
> - Steel quality
> - Ratio of the admissible resistance for the element of tower part (critical part)
> - Anchorage of the tower (number, repartition and diameter)
> - Reference of the tool for design

Note 3:- All details required that included in report were clearly defined above.

- Under the headings of "Type of equipment to be installed for tower " it has described details of Cable ladder and Access ladder as a mandatory requirements.

  Note 3:- All bidders were forced to supply above important service requirements according to the given details.

- Under the several different headings all other details (width at the top, quality of materials, workmanship, labeling, documentation, etc) were described accordingly.

  Note 3:- All precautions were taken for the quality of product to be keeping in one category. All required details were provided to the bidders and therefore, no allocations for supply the products with different qualities.

Note: - When comparing with all other technical specifications which are reviewed here, the technical specification issued by Orange can be considered as well detailed, technically accurate document.

12.0 Some statistics and overview of current tower design practice

12.1 The statistics, influence on public safety and reliability.

Reference to the collected data from Telecommunications Regularity commission - Sri Lanka, the summary of tower details are given in figure 12.1 and 12.2

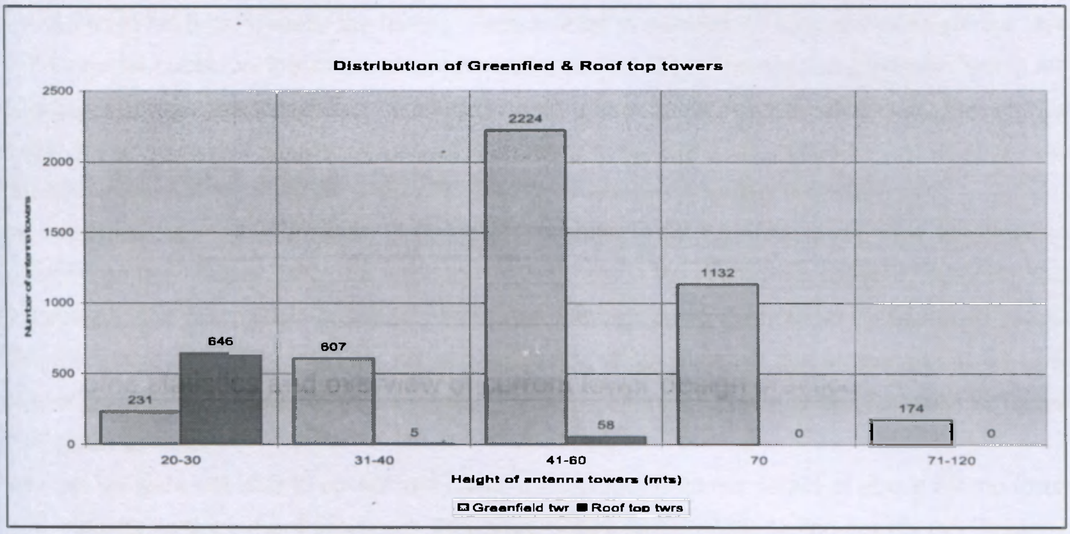


Figure 12.1 – Distribution of Greenfield and Roof top antenna towers in Sri Lanka

According to the figure 12.1, most of rooftop type towers (i.e:- 646 towers) are 20-30m heights, while 63 numbers of roof top towers are in height range of 31-60m. Therefore, in general, we can assume all above roof top type towers are located in places where high risk to the general public.

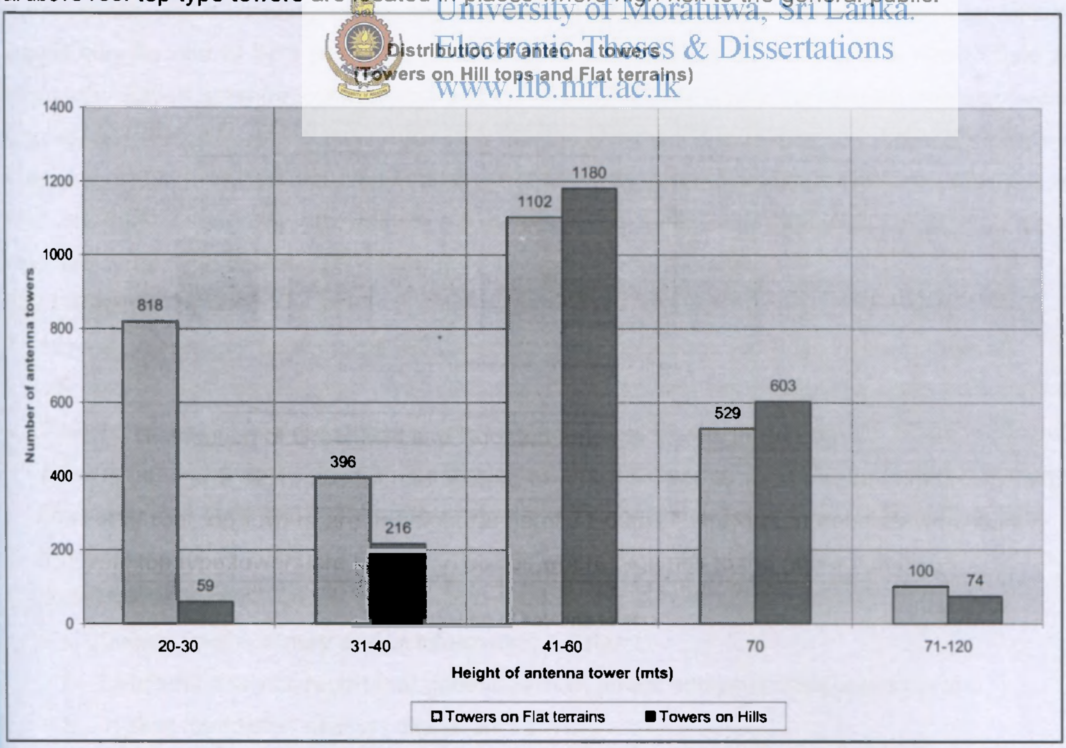


Figure 12.2 – Distribution of antenna towers in hill tops and flat terrains in Sri Lanka

Although the complete data about the location of the antenna towers is not easily obtain from TRC, (due to security reasons, etc.) we were able to approximately sort out available data for getting the idea about the number of hill top towers available in Sri Lanka. The summery of above data is presented in figure 12.2.

According to above figure 12.2, approximately 50% of antenna towers which are beyond 30m height are located in hill tops. Usually the towers which located in isolated hill tops are having lesser threat to the general public on the event of sudden collapse, but those towers are generally having more coverage in respective telecommunication net works than other towers. Therefore, the structural design of hill top towers should be done with specially considering the adverse effect of wind due to hill, impotence level of the antenna tower in respective telecommunication network, etc.

On the other hand, the antenna tower which located in flat terrains should be designed with considering the available risk to the public (when required) in the event of unexpected collapse, etc.

According to the information collected during this research work, there is no evidence on adopting different factors of safety for hill top tower designs and other towers in current practice in Sri Lanka. Most of the antenna towers which are currently located in hill tops are originally designed for install in general flat terrains.

Although we were not able to collect and check the installed antenna details of above hill top towers, while considering the current practice in Sri Lanka, It may also possible to find heavily over loaded hill top antenna towers, without considering any resulting effects of structural stability, etc.

12.2 Review of some existing tower design reports

The reviewing (while carefully comparing each other) of similar works which are done by different experts may be one of best practice available for further learning. Therefore, in a narrow field like telecommunication antenna tower design and constructions which have very limited opportunities for learning, reviewing of existing design report is always worth for further learning. Other than my own works, I was able to collect about eight different antenna tower design reports (including calculations) which are from several different sources. All above design reports are related to the antenna towers which are currently in operation. The summary of my review is as follows,

12.2.1 General

- All reviewed design reports were self supporting steel lattice towers and tubular monopoles.
- The steel lattice tower heights were in the range of 10-100m while monopoles were 6-15 meters.
- While the most of reviewed antenna tower designs have been done using MS TOWER computer software, few of designs were found those had done by using STAAD Pro, (structural analysis only) one of general structural engineering design software along with computer worksheets for member designs.
- Usually most of reviewed design reports consist of four (04) separate chapters,
  1. Design brief / primary design information & data
  2. Structural analysis report that generated from (tower analysis) computer software,
  3. Typical foundation design calculation
  4. Detailed line diagram of the tower and foundation drawings

- No tower erection drawings/ detail drawings were included in any tower design reports
- As a usual practice, the tower is connected to the foundations by anchor bolts. In some cases, towers are also available with stub angles and cleats being adopted.
- No design calculations were available for critical details such as leg to leg joints or base plate to leg joints.
- No design calculations included for non structural parts such as working platforms, resting platforms, climbing ladder, cable tray, antenna mounting brackets, etc.

12.2.2 Code of practice

- Majority of above designs were done in accordance with BS8100 :1986 and others for TIA/EIA222-F (TIA/EIA222-G has been published very recently)

12.2.3 Wind speed

- It has identified that the all reviewed tower designs have been done for two different design wind speed categories (Survival/Operation), such as 180/140 kilometers per hour or 160/120 kilometers per hour.

12.2.4 Factors of safety (FOS)

- FOS for material strength were taken as 1.1 as well as 1.0
- FOS for wind were taken the values from 1.0 to 1.15 (When designed for BS code)
- Terrain type/category is considered as general flat terrain in every above design report,

12.2.5 Loading (antenna and other ancillaries)

- Design wind shielding area of the antennas was assumed in several different ways in different design reports. There are as follows,
  1. Large flat areas at top of the tower that are on each of faces of the tower. (i.e - while four areas in square shaped towers, three areas in triangular towers)
  2. Large, single Microwave dish antenna at top of the tower which matching to the required total area of the antennas.
  3. Flat area of antennas that similar to above (1), but were distributed in top 10-15 meter area of the tower.
  4. GSM panel antennas and microwave dish antennas arranged in specific configuration that may be either given by the client himself in his tender document or assumed generalized configuration of the tower supplier, etc.
- Climbing ladder and cable tray were usually assumed as arranged internally
- The wind shielding area of cable tray was either assumed as flat, strip of area or several individual cables of 50mm diameter. Every time, the cable tray and climbing ladder were idealized as continuous from 3m level to top of the tower.
- Usually working platforms and resting platforms were not separately identified. When the instances that the working platforms were included, there wind shielding area was in range of 1-3 square meters while the resting platform is range of 0.3-0.5 square meters.

12.2.6 Materials

- Usually high tensile steel were used for legs members while either only mild steel or combination of both high tensile and mild steel were used in main bracing members. Redundant and other members are usually consist from mild steel sections.
- High tensile grades, of tensile strengths fy=330N/mm^2, 345N/mm^2, 390N/mm^2, and 420N/mm^2 while the mild steel of tensile strength ranging fy=230–250 N/mm2 were used in different designs.
- M16 and M20 nut and bolts of ISO grade 5.6 and 8.8 were usually adopted for structural connections while M12 bolts have been used only for non-structural joints.
- Usually M20, M24, M30 and M36 size anchor bolts are used in steel lattice towers. The grades of steel are grade 50 (fy=355N/mm^2). None of antenna tower designs were found with foundation stub type connection.
- The reviewed designs of Monopole structures were fabricated only by using mild steel seamless pipes of their diameters in 200mm to 300mm range. (But there also exists monopole structures of height range of 20 to 45 meters, which uses specially designed thick hollow sections as their structural body.)
- Typical foundations are always found to be an individual pad footing, of grade 25 reinforced concrete, that has been designed for 100–200 kN/m^2 soil bearing capacity.

12.2.7 Discussion on review of existing tower design reports

While the majority of tower and monopole were found that designed according to BS8100, few reports were found those designed using EIA222-F code of practice. The reviewed design reports were included several reports of three local tower suppliers, one supplier from Thailand, etc. All reviewed design reports were approved by the respective clients (Telecommunication network operators) and corresponded to the several existing antenna towers in Sri Lanka.

The common features that have been identified in reviewed design reports were as follows,

1. Incomplete design reports

   In some reports, only the result sheets which have generated from tower analysis computer software were attached. As a common practice, the design of base plate, anchor bolts, leg to leg joints were not included.

2. Availability of ill-practices and purposely done mistakes

   Following mistakes were found on some referred design reports.

   - While the calculating of wind loads, some of tower suppliers were assumed the cables in the cable tray as several individual cables which are fixed in space. But, it was a ill-practice which has done for the purpose of reducing wind drag of the feeder cables. In actual practice, the feeder cables are usually stacked very close to each other in the full width of the cable tray, therefore, it should reasonable to idealized the cables and cable tray as a long flat strip of plate like ancillary which exist from top to bottom of the tower.

- On another event, some of design factors were taken making contradictory arguments with respect to the recommendations given in respective code of practice. For example, the safety factor for material strength has taken as 1.0, while the BS8100 clearly recommends to assume it as either 1.1, 1.2 or 1.3. (Above recommendations were given respect to the steel quality that available in UK, therefore, when we working with non-UK originate steels, it is recommended to select factor of safety 1.2 or 1.3 only)

3. Blind use of computer software for design of towers & monopoles

The blind use of computer software was another shortcoming that observed during the data/information collection for this study. The critical incidences like existing of structural members those were loaded more than 95% of their theoretical loading capacity are very common in some of reviewed reports. Even, in one of above report, it has observed that the exist of several structural members which are exceeded of their capacity indicated design loads. The above ill-practice may able to cause huge effects to tower design due to the following shortcomings,

- I have observed that some of popular computer software is having some internal mistakes and shortcomings. (i.e;- Not identifying the exceed of limit of L/r ratio of some minor members, Not capable of identifying number of bolts needed in (pipe) leg to (pipe) leg joint – tension bolts, etc.). Therefore, when some one does blind use of computer software for tower designs, above errors will never be able to identify correctly.
- The threat of non-identifying possible human errors (for example typing mistakes such as 10 tons instead of 100 tons in input data, etc) in the computer model of antenna tower.

4. Erection drawings which are having no proper approval from the design engineer

As a usual practice, the structural engineer himself (or other qualified fabrication engineer) should provide his signature on each of erection drawings that to ensuring the correct detailing of the tower and its members according to the structural design. This practice is not following as a very strict rule in present business of tower supply. According to the information gathered during this study, there are evidences of non-correctable mistakes those happened due to above ill-practice.

As the most of the above mistakes and ill-practices are still happening due to the shortcoming exists in the process of technical assessment by the client, the safety of antenna towers and the financial risk that taken by client is questionable with existence of above type of critical mistakes and errors.

12.3 Design wind speed

Sri Lanka has been divided into three zones where different basic wind speeds have been allocated for normal structures and post disaster structures (MLGHC-SL-1980 and Jayasinghe-2008). The further details about above different zones and wind speeds were discussed in Chapter 2.0 under the literature review.

In Sri Lanka, all telecommunication network operators/owners having a present practice of using two classes of wind speeds,

item	Wind zone / Province	Operational m/s (km/hr)	Survival m/s (km/hr)
1	Zone 3 – Western, South, Sabaragamuwa, Central, North-west & Uva.	33.3 (120)	44.4 (160)
2	Zone 1 & 2 – Other North and Eastern provinces including North-central	39 (140)	50 (180)

Table 12.1

But, when we considering the antenna towers as post-disaster type structures, above present practice of wind speeds is not matching to the recommendations which given in MLGHC-SL-1980, above design manual recommends following basic wind speeds,

Table 1: Normal and post disaster wind speeds for 3 different wind zones in Sri Lanka

Zone	Wind speed (ms^{-1}) Normal	Post disaster
Zone 1	49	54
Zone 2	42	47
Zone 3	33	38

Although the basic wind speed of 38m/s (140km/hr) will be reasonable value for post disaster type building structures, as discussed in the literature review (Jayasinghe 2008), the validity of same argument for antenna structures to be critically evaluated further. Some parameters which have critical influence on antenna towers are as follows,

1. Unlike the massive reinforced concrete structures like buildings, the antenna towers are comparatively thinner, flexible type of structures which may having comparatively higher respond to the wind gust effect.
2. Survival of antenna towers and associated telecommunication and broadcasting links will be an essential item for proper management of post-disaster activities after the possible future disaster like major cyclone, etc.

3. Initial extra cost that may need to having such extra-heavy duty antenna towers (at least for key locations) will be not in unbearable range with compared to the similar extra cost may needed for other structures like buildings or bridges.
4. As the steel lattice type antenna towers are being very complex and highly load sensitive structural forms (Mckittrick-2010), the risk of possible collapse will be comparatively higher than the other structures.
5. In addition to all above, if we considering about the usual locations that most of antenna towers are constructed, the available threat of damaging to the lives and properties of public on the event of any possible collapse also not negligible.

On the other hand, reference to the discussions (Mallawaarachchi and Jayasinghe-2008). (Lewangamage et al.-2009) in literature review, the threat of major cyclones or local tornados to the Sri Lanka will be not in negligible range. According to the previous records such major cyclones have been occurred in the years 1907, 1922, 1978 and 2000. In addition, the value of basic wind speed that has used in Indian practice (IS:875 – 1987) is 39m/s for the location next to the Sri Lanka.
Therefore, the accuracy of basic wind speed values which are currently practicing in Sri Lanka should be critically re-evaluated with special consideration of their adoptability on antenna towers. After that the necessary precautions and other mitigatory actions to be taken (at least key towers) for ensuring the reliability and level of safety of the telecommunication networks in Sri Lanka accordingly.

12.4 Design code of practice and selection of design parameters

Reference to the Chapter 3 and 4, although we don't have our own design code of practice for design and detailing of antenna towers, there exists several other documents that can be adopted for design conditions in Sri Lanka. The most popular code of practices among Sri Lankan telecommunication networks are British (BS8100) and American (EIA 222) standards.

The BS8100 is a limit state type code of practice for lattice towers which having four separate parts for loading (1986), Guide to the background and use of part 1 (1986), Strength assessment of members of lattice towers and masts (1999) and for loading of guyed masts (1995). As discussed in chapter 3 and 7, BS8100 provides proper guidelines for complete design and detailing of any kind of steel lattice structures.

Although the EIA 222 used an "allowable stress" format up to it's revision F (1996), the latest revision G (2005), has been adopted the "load and resistance factor design" procedure. The TIA/EIA 222-G code of practice also provides complete guideline for design and detailing of steel antenna towers and antenna supporting structures.

Both above documents provides complete guidance for all important design parameters such as selection of design basic wind speed, terrain category, different factors of safety, reliability categories, etc. As the TIA/EIA222-G being the newly revised code of practice, it may have incorporated with most recent theories/data on wind engineering. Therefore the antenna tower designers believes as the design of antenna towers accordance with TIA/EIA 222-G provide more economical solutions than the BS8100.

For example, when BS8100 provides more conservative value of 2.0 as a typical drag (pressure) coefficient (C_N) for Flat-sided sections and plates (Please refer Table 4.1 of BS8100-1: 1986), similar force coefficients were given in TIA/EIA 222-G with reference to Aspect ratio of the respective member. Therefore, while the value of force coefficient being 2.0 for Flat antenna with aspect ratio > 25 it provides further lower force coefficient values of 1.4 & 1.2 for aspect ratios of 7 and 2.5 (or lower) respectively (Table 2-8 of TIA/EIA222-G). As the primary design load being the pressure of wind on its antennas and tower body of any antenna towers, above type of precise definitions will always beneficial for obtaining further optimized designs.

However, reference to the discussions under above item 12.2, the misinterpretation or incorrect use of design parameters those given in above codes of practice is very common practice in Sri Lanka. The encouragement for such ill-practices provides by various reasons such as incomplete technical specifications, employing of incompetent technical staff, fierce competition between suppliers, etc. But, the result of above ill-practices will make dangerously reducing of the factor of safety and reliability of the antenna towers as well as the respective telecommunication networks.

Therefore, the necessary precautions to be taken for avoiding any incorrect use and misinterpretation of design parameters, etc. The technical specifications for antenna tower design and construction to be precisely defined and modified to suit the recent code of practices. It is essential to make necessary arrangements for all design reports and construction procedures/methods to be verified by the professional structural engineering experts before their further implementations.

12.5 Other factors which have considerable influences on design and safety of antenna towers

The need of correctly defined technical specification has discussed in earlier paragraph. If the primary parameters and engineering code of practice has well defined in the technical specification, the possibility of ill-practices during designing process can be minimized. However, we may never be able to expect total elimination of such practices, especially in the situations like a fierce competition among tower suppliers in present market. Therefore, the proper verification of each and every technical document in any tender bid proposal should be an essential task. The importance of having proper technical guidance and inputs in to technical evaluation and tender bidding process have been discussed in details under Chapter 7.0.

It is important to carry out above verification of technical reports by help of qualified and well experienced structural engineering experts on antenna towers and related structures.

Test and verification will be another important factor that may critically influence the safety of the antenna towers. Although the tall telecommunication antenna towers are usually not undergoing for full-scale test for destruction that similar to the practice in electrical transmission line pylons, several other indirect tests and verifications are available for controlling the quality of product. Other than the validation of structural designs, the verification of quality of product such as Material testing (Steel grade, Chemical composition, etc.), Prototype assembly, Verification of Galvanized thickness and paint thicknesses, Visual inspection of quality of workmanship, Quality check of welding (X-ray test, ultrasound test or special paint, etc.), Cube test of concrete, Close Inspection of structure and structural elements after assembly, etc., can be done accordingly.

The use of qualified technical staff for above mentioned events about the process of testing and verification, also having prime importance for guaranteeing the better quality of product.

As described under Chapter 7.0, The qualification of technical staff employed for construction and maintenance will be high impact on the overall safety as well as the quality of the structures (as well as the reliability of the network). In addition to above safety and quality it also having direct impact on some financial parameters like unnecessary delay of projects, uncontrollable project overhead and high cost of maintenance.

According to the discussed facts on item 6 of Chapter 7.0, although the telecommunication industry of Sri Lanka operates with more than 5100 different types of antenna structures, those including large numbers of 40m to 120m tall, extremely complex engineering structures like steel lattice antenna towers, the utilizing of structural engineering knowledge being kept minimum. As a result of that, the use of many ill-practices has become a common practice in process of tower designs as well as in constructions. As I felt, the situation has becomes further complicated with the influences of large crew of non-qualified technical staff who are presently enjoying the benefits of above industry. Usually those technical staff members having, untold reluctant for employing/hire any well-qualified technical staff for their companies. Therefore, while the minimizing the opportunities for generating new jobs for qualified staff, the discouraged qualified professionals are having tendency of transferring in to other more attractive fields of constructions like building, roads & bridges, etc.

Therefore, it can be easily identified the void exists on professional inputs from civil/structural engineering professionals and technicians with reference to the antenna tower construction and maintenance industry. Therefore, with present situation we cannot expect required guarantee on safety of most of antenna structures exist in Sri Lanka.

As the necessity of structural engineer's input has not been currently identified as the essential item for the tender bid preparation, the details of proposed antennas and their loading arrangement will always being incomplete in most of the tender bids. While being not aware of the real importance of providing correct antenna arrangement, as an usual practice in Sri Lanka the call of tender bid for antenna towers specifying the required antenna arrangement as,

"Flat area of antennas (for example 15m2) at top of the tower"

But the actual antenna arrangement may be as follows,

"6 x GSM panel antennas at 1.0m below the top and 2 x 2m diameter MW antennas at 10-15m below the top of tower which are directed to north and east directions"

Those two different load criteria's are not compatible to each other. Their directions of loading, wind drag coefficients, etc, are different. Therefore, the resulting antenna towers may not match for their actual antenna loadings. Therefore, the overall factor of safety of such tower will be totally different than its expected value.

Similarly, the loading of additional antenna which is other than its originally designed arrangement of antennas, will be a task that should be done with proper care. But, there are many reported occasions that large, heavy antennas were fixed to existing steel lattice towers without any assessment for its structural stability under new loads. We have also discussed one of similar event under the reviewing of recently collapsed antenna towers, in Chapter 5.0.

The critical errors such as mis-judgment of design antenna area, loading due to topography (i.e – antenna tower on coastal areas, Hill tops or top of tall building, etc.) are to be avoided. Any antenna tower to be designed for its actual arrangement of antennas (& location), rather than designing it for approximate, generalized flat antenna area at top (and for flat terrain).

Reference to the Chapter 5.0, The reason for collapse of Beliatta 70m tower was identified as erroneous tower erection procedure while the Mihintale and Horowpatana towers were collapsed due to sudden tornado situation. According to the available information, the most possible reason for collapse of Gampaha tower is overloading. However, the designing of antenna towers for withstanding to very rare disastrous events like tornados will not be feasible. But the other errors can be totally eliminated with proper supervision of the work in construction/operational stage.

Avoid disastrous events like Beliatta tower collapse, the well detailed tower erection method statement can be obtained from the tower supplier.

If the loading of antennas and modification of structural members will be done under recommendation of structural engineer, unexpected collapses of any antenna towers (i.e:- due to overloading, etc.) can be easily avoided. **The best solution will be of employing a structural engineer by the each telecommunication network operator/owner. Then the above structural engineer can keep computer model of all antenna towers in respective network and provide strong and accurate guidance's whenever necessary.** As the antenna towers are usually supplied in modular type designs, any large telecommunication networks consist with different module towers of few basic designs. Therefore, above idea of having computer model of each and every tower will be a practically feasible solution.

12.6 Influence of different factors of safety on cost of antenna tower

Generally the weight of tower always represents the basic cost of construction. Therefore, we can easily identify the (approximately) linear variation of the cost of construction with design antenna area with help of the above figure 9.1a. in Chapter 9.0.

According to the figure 9.2a, the behaviour of steel weight with different wind speeds can be identified. In addition, the applicability of design optimization for taller towers and its low impact on shorter towers can be explained from above figure 9.2a.

Figure 9.3a is clearly explaining the non-linear behaviour of the tower weight with changing of its height, Therefore, it always beneficial for client to selecting best required tower height for each location than using common tower height for all locations.

The Figure 9.4a showing the non-linear behaviour of the foundation cost vs the tower height. Above figure reflect the need of designing separate foundations for each type of tower. The use of common, typical foundation may not be much economical for this situation unless the variation of concrete volume is not significant.

We can summarize the above results as follows, about 50% of their designed load conditions unless it facing for cyclone storm (67-117km/hr) or cyclone (above 118km/hr).

4. Except the key towers (hub towers) which are using as hubs of the telecommunication links, other antenna towers are usually lightly loaded with few GSM panels antennas and one (or two) medium size microwave dish antenna.
5. As the majority of present antenna towers are still in good condition (i.e :- less than 15 years old), no secondary problems like severe corrosion, fatigue failures, etc. are exists yet.
6. Although we designing antenna towers for elastic conditions of the steel, in actual practice the steel also having considerable range of plastic behaviour, before it fails.
7. The older codes of practices may have over-estimated the wind loading and other design factors with compared to their actual values. Therefore, the previous structures may have more load carrying capacity than their previously estimated values.

According to above review of design reports and other details which discussed above, lot of existing antenna towers in Sri Lanka can be suspected as having shortcomings in their original design, etc. But, those structure are still survive without any noticeable damages or defects, The one of most possible reason for above contradictory situation, that " we are still fortunate enough for not occurring the expected high wind conditions (i.e - design wind condition which can reach wind speed up to 140 - 180km/hr) like major cyclone or other similar climatic conditions in recent past".
Therefore, we are still not too late for correcting such errors and ensure the safety and reliability.

13.0 Concluding Remarks and Recommendations

13.1 Conclusion

As discussed in Chapter 3.0, the steel lattice antenna towers have provided economic solution for the communication industry over many years. Other than the economy on cost of structure, the inherent ability of dismantling the lattice towers in to small individual elements, will provides best practical solution for constructing them in difficult non-accessible terrains and locations such as hill tops or top of tall buildings, etc.

However, the principal design criteria of any antenna tower will be the pressure due to wind. The self standing antenna structures are functioning as vertical cantilever structures. Therefore the shielding area of antennas, shielding area and shape of tower itself, ancillary installing height from the general ground level, etc. are consider as primary design criterions of the any antenna tower designs. On the other hand the importance level of the tower in specific communication network, location of construction, the level of possible damages may happen to human in the event of any unexpected collapse and quality of steel fabrication are also consider as another set of primary level design criterions for any antenna towers.

Although the steel lattice structure being an extremely efficient structural form when compared with other structural forms (i.e - such as beam-column structures, slabs, etc,) it also having major inherent weakness which is its extreme sensitivitiness on loads and very limited capability on tolerating the exceedence of its original design loads than other common structural forms. **Therefore, the design, construction and maintenance of any steel lattice antenna towers should be done with extreme care and under the close control of the structural engineering experts.**

As explained above, although a level of tolerating the exceed of original design load is limited in steel lattice antenna towers, there are lot of ill-practices, which can easily make structures overload are still exist in the field antenna tower design and constructions in Sri Lanka. During this research work we were able to identify several critical mistakes and erroneous procedures which could easily make overloading in antenna tower design and constructions in Sri Lanka. Some of critical events are as follows,

1. Technical specifications with errors, mistakes and incomplete details, etc.
2. Mis- interpretation of some of engineering design factors, factors of safety, etc. in antenna tower designs for the purpose of reducing cost of construction.
3. Neglecting of the importance of structural engineers input in preliminary planning stages.
4. Not utilizing the structural engineering knowledge in later stages such as maintenance works, adding of additional antennas, etc.
5. Scarcity of trained professionals and non-existence of encouraging environment in the present telecommunication industry.
6. Blind use of computer software for antenna tower related design works.
7. Adopting of erroneous tower erection and construction procedures.

The one of the reason for existence of above discussed sorrowful situations may be due to the extreme competitiveness and boom in the field of telecommunication and respective construction for last decade. However, now it may be high time for every parties to starting re-assessment of above structures for their true reliability and application of necessary mitigatory actions where necessary.

13.2 Recommendations

As engineers, we cannot expect always to survive our structures with good luck. Although we were fortunate enough for not arising the extreme climatic situation like major cyclone for last decade, there is no any guarantee about not happening such disastrous events in near future. Therefore, it is high time for all telecommunication network operators as well as other related government institutions (Telecommunication Regularity commission-Sri Lanka (TRCSL), Ministry of Defense, etc) to make proper assessment on their true reliability of the related structures as well as the networks on possible day to day operation environments as well as disastrous event like cyclone, etc.

Following basic steps can be recommended for initiating the process of enhancement of safety on telecommunication network and the public.

Structural engineer and his role in evaluation of true structural stability of structures

1. Employing of well experienced structural engineering experts for each telecommunication networks (government, non-government, military, etc.) which consist of their own antenna structures. Also ensuring to provide well structured education and training for structural engineers as well as other related technical personals who involved in design and maintenance of telecommunication structures.
2. Educate all managers and technical personnel (civil and non-civil) who are involving with telecommunication networks about the structural stability of antenna towers and its importance for having reliable network.
3. Ensure to get involved the structural engineer for all parts of tender bidding process (Preparation of technical specifications & tender bid proposals, evaluations of tender bids, etc.) and constructions.
4. Make necessary arrangement to get involving a structural engineer for all day to day operations (Adding new ancillary items or removing of existing ancillaries, structural modifications, etc.) and routine maintenance works. (Repair works, replacement of structural members or cables, etc.).
5. Amendment of currently available civil technical specifications to suit most recent engineering codes of practices. (i.e TIA/EIA222-G, BS8100, AS3600, etc.)
6. Make necessary arrangement to correct estimation of true structural stability under operational condition as well as extreme windy situations (i.e:- Survival condition).
7. Keep full inventory of each antenna tower in network, their arrangement of ancillaries, level of structural stability, physical data, photographs, etc.
8. Make necessary arrangement to replace (or re-strengthening) the structure or reducing of existing loads on the tower which are having unacceptably lower factor of safety on their structural stability.

Design consideration

9. Categorizing the all antenna structures according to their required level of structural stability and reliability. As a guide line following categories can be adopted,
    a. Heavy duty structures for hub towers or towers in populated areas,
    b. Light duty towers for isolated, less populated areas,
    c. Heavy duty Towers for Coastal regions and adjacent to large reservoirs,
    d. Towers for hill tops,
    e. Roof top towers/monopoles,

   In addition, it can be calculated the safe antenna area for each above towers when they are using the locations under other categories. (Factors a,b,c...to be indicated by the supplier). Similar type of chart is currently practicing with steel lattice type steel pylons in electrical transmission line constructions, which shows the capability of one specific tower for bearing loads in different loading conditions such as when use as line tower, 10 degree angle tower, etc.

70m high tower from supplier A

Item	Category	Basic wind speed (km/hr)	Design antenna area (EPA)
1	HD Hub tower	180	30
2	HD normal tower for populated area	180	30 x a
3	HD tower for coastal area	180	30 x b
4	LD tower for isolated, less populated area	180	30 x c
5	Hill top towers	180	30 x d
6	Roof top towers	180	30 x e

10. Make arrangement to design all new towers as post disaster type structures while adopting basic wind speed as 180km/hr (Jayasinghe 2008 and MLGHC-SL-1980). Above requirement is already imposed in new antenna tower policy which has published by TRCSL in 2008.

However, as the several telecommunication network operators are currently operating in this island and more than 5100 antenna towers are already constructed, we cannot expect many new antenna towers to be constructed in future. But, we can expect many operational requirements such as existing towers to be replaced by another strong towers, repairs, modifications, strengthening, etc.

On the other hand, currently the network operators also starting to understand that the true reliability level of their network is less than the expected, due to unreliable structures and also experiencing its negative impacts on their financial conditions. Therefore, the need of having correctly engineered antenna towers, rather than a seeking for low priced, low quality products will also be identified soon. In both above situations, the structural engineers need to learn and practice the correct methods of design and construction of antenna towers and related other structures.

Then the reliability of telecommunication networks as well as job opportunities of structural engineering can be increased.

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ANNEXE

1 SCOPE OF THE SUPPLY

1 Types of Tower

Tower type shall be of 4 legged green field towers, 4 legged roof top towers and poles.

2 General Requirements

The supplier shall be required:

a. To design, supply, deliver and erect the tower.
b. To construct the foundation.
c. To supply and construct working platforms and resting platforms at specified height.
d. To complete with cellular antenna brackets to fix 6 cellular antennae
e. To supply and install 1 No microwave antenna bracket (1.5m high pole)
f. To supply and install lightning protection and earthing system.
g. To supply and install obstruction light system.
h. To test and handover of the tower, lightning protection system, earthing system and obstruction light system.

3 Design codes

The American or British "structural standards for steel antenna towers and antenna supporting structures" to be used.

2 TECHNICAL SPECIFICATIONS FOR SELF SUPPORT TOWERS

General

This specification defines the characteristics and performance requirement of the tower to be purchased.

1 For those performance specifications and characteristics, which are not stated in this specification, the relevant standard and/or recommendations as specified shall apply.
2 Manufacturing and workmanship should comply to BS449 or AISC

1. Design codes

The American or British "structural standards for steel antenna towers and antenna supporting structures" to be used.

2. Wind Loading and Tolerance

1 Operational wind speed of 120-km/h and survival wind speed of 160km/h should be used in the design

2 Twist and swing should not exceed 0.5 ° under extreme wind condition as specified in 1.

3 Tower Loading and tolerances are as follows

a. Maximum wind exposed area is of antennae any direction shall be at least $20m^2$ for ground towers and $8m^2$ for rooftop towers. The force due to this wind-exposed area shall be applied to the top of the tower in design calculations.

b. The design loading for total weight of antennae shall be at least 15 KN for ground towers and 6 KN for rooftop towers.

4 A safety factor of 1.7 should be used

5 The erected tower, under the condition of negligible wind, shall not deviate from the vertical position by more than one eight percent (1/8%) of its height, and shall be straight within 2.5cm of the nominal geometric position. The erected tower shall be free of inherent twists.

3. Galvanizing

1 Galvanizing process should comply with ASTM/A123 or equal in other standard and codes

2 All steel work and fitting used in the assembly of the tower including the platforms, climbing ladder, cable ladders, steel I beam structures used in roof top towers etc, except that used in the concrete foundation, shall be galvanized by the hot dip process after fabrication and before any assembly.

3 If, for manufacturing reasons, contractor proposes to use a treatment other than galvanizing for certain parts of the tower, he shall state specifically the fittings to be so treated and process to be used. Thickness of galvanization shall be more than 610 g/m^2

4 Painting or cadmium plating shall not be used in any instance as a mean of protection against corrosion.

4. Steel work

1 The steel used in the fabrication of the tower shall comply with BS, AISC or an equivalent standard proposed by contractor and agreed by HTLL.

2 Notwithstanding the stress involved, no member of a structures shall be less than 5mm in thickness

3 Tolerance shall be as follows

- ± 0.75mm for location of centers of holes
- ± 1.5mm for overall length of members
- ± 1.5mm for bolt holes

4 Opening of any holes shall not be carried out after galvanizing.

5 All members, before being assembled, shall be straight, unless required to be curvilinear from and shall be free from twist. For the purpose of the specification, "straight" shall mean free from kinks and from gradual bends greater than 1/1000 of member length. Members on site not meeting this condition will be reworked or replaced. Lengths of all members shall be accurate so that when assembled no sagging or twist occurs.

6 No members of the tower shall have any joint by mean of welding.

7 Drawing of all steel parts including tower structural parts detail methods of assembly and list of items shall be provided

5. Bolts, Nuts and Washers

1 Nuts and heads of bolts shall be of the hexagonal type

2 Bolts and nuts shall be in accordance with latest BS, JIS or as specified by contractor and agreed by HTLL

3 Bolts and nuts shall be hot dip galvanized. Thickness of galvanization shall be more than 350 g/m^2

4 To ensure that the full bearing areas of bolts is developed, the thread portion of the bolts shall not extend within the thickness of members being jointed.

6 Spring washers or retaining nuts shall be galvanized by the hot dip process and shall be fully affective after galvanizing. Zinc plating will not be accepted as a substance for galvanizing.

7 After tightening the threaded portion, each bolt shall project through the nut by at least three threads, but the length of the projection shall not exceed 60% of the bolt diameter.

8 Locking nuts for the leg anchoring shall have minimum two (2) nuts and exposed part to have minimum ten (10) threads.

6. Working and Resting Platforms

1 Working platform complete with handrails to provide safe working areas at top of the tower.

Resting platform to be provided at the first 15m levels. All platforms shall have sufficient space for safe working areas and to keep tools.

2 Platform decking shall be expanded metal, fabricated grid or a similar material, adequately supported by steel members of appropriated size.

3 Handrails at a height of one (1) meter, intermediate rails at half meter above the decking and kick rail on the decking. The handrail and kick rail for antenna supporting tower shall be rolled steel angle section of dimensions not less than 5cm x 5cm x 0.5cm. Handrails shall be provided as far as they are consistent with access to the antenna and aircraft warning lights, and shall encompass the ladder and the ladder guard so that free access to the ladder may be gained from the platform. Handrails on working platform shall not be structural member and shall be removable to facilitate the mounting of antenna.

7. Antenna Mounting

At the top of the tower to be provided with cellular antenna mounting structure complete with working platform as specified.

1 Each tower shall be provided with complete six (6) pieces of cellular antenna mounting steelwork to which the antenna may be rigidly attached by means of the mounting hardware supplied as a part of the antenna system

2 Microwave antenna mounting bracket and antenna boom should be provided at height specified when the tower erection commenced.

8. Lightning Protection and Earthing

1 Controlled Early Streamer type lightning capturing terminal to be connected as a direct lightning protection terminal.

2 25*3 mm copper tape should be used as a down conductor. Copper tape should be bonded to the tower properly with using stainless hot dipped galvanized steel straps.

3 All mounting brackets should be galvanized.

4 Tower legs, cable ladders, cable trays should be interconnected with using 25*3 mm copper tape.

5 All terminating points & joints (tape to tape) should be done with using exothermally welded joints (cad weld).

6 Copper radials should be run (10m to the minimum) from each leg with using 25*3 mm copper tapes & 3m copper clad rods should be used in every 3meters.

7 Earth Enhancing Compounds should be used to enhance grounding facility along the radials drawn.

8 Earth pits should be constructed the ending points of all radials & the terminating point of the down conductor.

9 2 ft Earth bar should be provided at the cable bending point of the cable tray.

10 25* 3 mm copper tape should be run around the equipment room & 4 Nos. of 3m copper clad rods should be grounded & clamped to the copper tape at the corners.

11 All equipment, tower & external earth net should be interconnected.

9. Climbing ladder

1 The tower shall be provided complete with climbing ladder vertically from ground level to the top of tower. It shall be galvanized as the same quality for the tower. Ladder should be fixed to the ground with a concrete bases.

2 The ladder shall be fitted with a ladder guard with sufficient caging space ensuring safety. The ladder guard shall commence at a point 2.25m above ground level and above each platform, and shall run continuously to underside of the platform above. A ladder guard shall be constructed of three vertical stringers with horizontal hoops at approximately one (1) meter spacing.

3 Ladder shall continue for a distance of at least 1m above the upper surface of each platform.

4 No structural members of the tower shall protrude into or pass through the space within the ladder guard.

5 Ladder, ladder guards, and ladder supports shall not infringe on the space reserved for the feeder cables.

6 Ladder shall be adequately supported to resist lateral movement

7 Ladder steps shall be rough-surfaced preventing any slipping and hoops shall be painted with the same quality and color scheme of the tower.

10. Feeder Runway and Horizontal Gantry

1 A feeder runway and horizontal gantry shall be provided for the tower. The runway and the gantry are required to support the feeder connecting the antenna with the radio equipment. It must be galvanized and painted with the same quality of the tower members.

2 Each feeder runway shall be located about the center of tower and extending vertically from ground level to the top of tower.

3 The feeder runway members shall be made of angled-iron, with the width of 600mm and horizontal member of 1m apart.

4 The horizontal cable gantry members shall be made of angled-iron. with the width of 600mm and steps spacing of 300mm apart. A total length of ten (10) meter shall be provided for every tower.

11. Obstruction light

1 Tower shall be provided with complete with one (1) obstruction lamp at the tower-top and two (2) at the platform below the top.

2 Obstruction light shall function on full automatic photosensitive basis. Each light shall have its individual control circuit.

3 Obstruction light should have minimum life of 3000 hours

4 A detailed circuit of the automatic photosensitive unit and tower lights shall be provided.

5 Standard shielded cable (Armored Cable) for 10 Amps shall be used.

12. Welding

1 All welding shall be done under approved conditions

2 All welding shall be metal-arc welding complying with BS 1856 for mild steel and BS 2642 for manganese steel whichever is applicable.

13. Obstruction Paints

Tower shall be painted according to ICAO regulations and the tower supplier shall provide the following

- Sigma paint shall be used as per the specifications given with the product.
- Galvanized surface must be free of: DUST,DIRT, GREASE, OIL or WHITE RUST.

- Surface temperature must be above the dew point
- Humidity must be below 90%
- Don't apply in rainy days.
- Total minimum dry film thickness should be 150 μm

14. Tower Foundation

1 Foundation should be designed according to British Standard to withstand all forces, displacements and settlements.

2 The buoyant force due to ground water level shall be taken into account for the foundation design, where considered necessary.

3 Grade of Concrete should be Grade 25.

4 Where back-filling of excavated soil is done, the soil shall be rammed in layers at every 25cm.

5 Where excavated material contains a high proportion of rock, sufficient soil shall be added to enable the backfilling properly compacted. Similarly where the excavated soil is unsuitable for back filling, imported suitable soil or gravel to be used in order to achieve the desired compaction.

6 The concrete placing of foundation may not be preceded until HTLL has approved the excavation and foundation formwork and reinforcement.

7 If any pilling is used as a part of foundation, they shall conform in all aspects to CP 2004

8 For Rooftop towers/ rooftop poles; contractor shall design foundation in such a way to transfer the tower load to the beams and columns of the building and a Charted Structural Engineer shall approve the design.

Following additional procedure to be followed in the tower foundations. (ground/Rooftop)

1. All columns are to be chipped off till the terrace level & reinforcement exposed unless instructed by the structural engineer.
2. Rust in steel to be warded off & cement slurry to be applied on cleaned steel.
3. Lap length of 50d to be given for normal lap & 10d for welded rods.

4. Reinforcement for columns & beams is to be carried out as per Bar Bending Schedule & sufficient cover blocks shall be provided.
5. Shuttering material facing the concrete are to be applied with adequate mould oil in order to get neat form finish.
6. Materials used for concrete should be clean & free from dust.
7. Mix of concrete should be done by volumetric method & 10% more cement shall be used if hand mixed. Concrete shall be placed properly & compacted using vibrator.
8. Curing should be done effectively; making sure the structure is wet for the next 7 days after concreting
9. The threaded portion of the foundation bolts should be covered with wax & polythene papers & tied before and after concreting.
10. Alignment of foundation bolts should be assured before and after concreting and no deviation in this acceptable.
11. All the excess / unwanted material shall be carted away immediately after the work is over. Material shall be properly stacked & unused concrete shall be taken away immediately.
12. Care shall be taken while shifting / uplifting of heavy material to avoid damages / inconvenience to the existing building / structure or to the people. Any consequences arises therein shall be of contractor's responsibility.
13. All the structural steel material shall be in accordance to the relevant B.S Standard.
14. Concrete Samples, Concrete proportion and testing.
15. The Contractor shall ensure testing the concrete 7 days and twenty-eight days after molding. The comprehensive strength of concrete shall be tested by contractor in accordance with latest BS or equivalent standards. Contractor shall furnish test cube specimens in accordance with relevant standards.
16. The tests to be carried out on the various samples at site shall be done in the presence of Certified Structural Engineer and the process to be approved by HTLL Site Development Engineer.

Mobitel (Pvt) Limited

Technical Specification for Supply, Delivery, & Installation of self standing Telecommunication Towers or any Other Structure (M)

SCOPE OF THE SUPPLY

TYPES OF TOWER

1.1.1.1.1 Tower type mainly shall be of four-legged angled-iron for green field but the selected Tenderer will have the flexibility to come up with deferent tower types which they think are more suitable for the given proposal. Tenderer shall quote for other types of structures such as Guy Mast, Portable (Mobile) tower and any other tower available (which can be used in Mobitel Network) in addition to the proposed BOQ if available

1.1.1.1.2 Tenderer shall quote prices according to the following breakdown: Additional price information's shall be provided according to the price formats

TOWER TYPE	QUANTITY
100m, 30m^2 wind exposed area @ top	1
80m, 30m^2 wind exposed area @ top	3
70m, 30m^2 wind exposed area @ top	1

GENERAL REQUIREMENTS

1.1.1.1.3 Design, supply, deliver, construct, install, test and commission self-supporting towers and associated services to fully comply with operational and standard telecommunication requirements

1.1.1.1.4 Supply and construct safe working platforms, ladders, safe guard rails and resting platforms at specified heights

1.1.1.1.5 Supply and construct a circular/square working platform at the top of the green field tower, complete with cellular antenna brackets to fix nine cellular antennas and microwave antenna brackets to fix four microwave antennas per each green field tower supplied irrespective of the location. Cellular and microwave antenna brackets shall be universal type.

1.1.1.1.6 Tenderer shall propose a mechanism to mount two antennas to the same direction at a minimum separation of 1m.

1.1.1.1.7 Supply and install lightning protection and Earthing system with all relevant accessorises as given in the relevant regulations.

1.1.1.1.8 Supply and install solar powered automatic obstruction light system which conforms to IACAO regulations.

1.1.1.1.9 Test and commission the tower, lightning protection system, Earthing system and obstruction light system.

1.1.1.1.10 The contractor shall have a proper insurance scheme against all the damages to the surrounding which is related to construction work including safety of any person on site. This insurance scheme has to be approved by Mobitel prior to the commencement of the project.

1.1.1.1.11 The contractor shall be able to handle all the protests and threats from any party excluding which are from the site owner and the government authorities.

1.1.1.1.12 If the suppliers follow any other standard not specified in this document, the detailed specifications of such standards shall be provided. All such standards shall be agreed by Mobitel prior to actual implementation.

DESIGN CODES

The Following Codes shall be used and shall be fully complied in the designs fabrication and construction,

1.1.1.1.13 Calculation of loading on the Tower: The American "Structural Standard for Steel Antenna Towers and Antenna Supporting structures" EIA 222F:1996 or Equivalent

1.1.1.1.14 Design of Steel Transmission Structures: ASCE 10-90 Design of Structures or Equivalent

1.1.1.1.15 Calculation of Wind loads: BSI CP2 Chapter V Part II 1972 or Equivalent

1.1.1.1.16 Welding: EN970:1997 BS EN 25817:1992 ISO 5817:1992

1.1.1.1.17 Foundation RCC Design: BS8110: Part I: 1985 & BS8007 or Equivalent

1.1.1.1.18 Manufacturing and workmanship shall comply to BS449 or AISC

1.1.1.1.19 Galvanizing of the tower members shall comply with BS EN ISO 1461:1991, ASTM/A123 or equivalent

1.1.1.1.20 The Steel used in the fabrication of tower shall conform to BS EN10025 Grade S275 and S355 as appropriate to Rolling Tolerance to relevant ISO standards.

1.1.1.1.21 All Nuts and Bolts shall be in accordance with ISO 898-1(Hexagonal Bolts) or relevant standards.

QUALITY CONTROL

1.1.1.1.22 The supplier shall provide a scheme of testing for the quality assurance of works to comply with the relevant ISO/BS standards indicating the parameters to be checked and the frequency of testing. All quality assurance related to construction activities shall be complied with ICTAD specifications.

1.1.1.1.23 Any construction related work shall not be carried out without a full time supervision of a qualified technical person by the Tenderer and the CV of such person/persons shall be submitted for Mobitel approval whenever required.

1.1.1.1.24 Any construction related subcontractors' profiles shall be submitted and approved by Mobitel prior to commencement of any implementation work. Subcontractor profile shall include following information:

a) Company Registration

b) Form-48/ Form-20 (Directors' details)

c) Memorandum of Article

d) Organization Chart with Names & contact details.

e) Office addresses & contact details

f) Past experience related telecommunication installation or related fields

g) Company Quality Policy & manual

h) Tools & inventory of other accessories (Vehicle etc)

i) Insurance details specially third party liability

j) Financial status – Last Audited Accounts

k) Individual team details with the names & contact numbers (Team leader detail - mandatory requirement).If team members change during the implementation period vendor shall inform Mobitel.

l) If an international company, Recourse methodology needed.

TECHNICAL SPECIFICATIONS

GENERAL SPECIFICATIONS

1.1.1.1.25 This specification defines the characteristics and performance requirement of any type of tower to be erected.

1.1.1.1.26 For those performance specifications and characteristics, which are not stated in this specification, the relevant standard and/or recommendations shall apply and such standard shall be submitted for Mobitel approval.

WIND LOADING AND TOLERANCE FOR TOWERS/POLES IN ANY NATURE

1.1.1.1.27 The Wind loading on the Towers/Poles shall be calculated in accordance with BSI CP2 Chapter V Part II 1972 or Equivalent and to meet the following:

a) Operational wind speed of 140 km/h and survival wind speed of 180 km/h shall be used in the design for green field towers.

b) Twist and sway for any structure shall not exceed 0.50 under extreme (operational) wind condition as specified.

c) The tower loading figure shall accommodate following equipment and if the Tenderer proposed that the given loadings are insufficient to cater the supplied equipment in this proposal it shall be escalated in the proposed solution document.

   i. Minimum wind exposed area for green field tower in any direction shall be at least $30m^2$ on top of the tower. The force due to this wind-exposed area shall be applied to the top of the tower in design calculations.

d) The top centre of the erected tower/pole, under operational condition, shall not deviate from the vertical position by more than one eighth percent (1/8%) of its height. The erected tower shall be free of inherent twists.

GALVANIZING

1.1.1.1.28 The Galvanizing of the tower members shall comply with BS EN ISO 1461:1991, ASTM/A123 or equivalent.

1.1.1.1.29 The Tenderer shall provide a standard test report for Galvanize properties for Mobitel approval before starting the tower erection for every batch of towers.

1.1.1.1.30 All steel work and fitting used in the assembly of the tower including the platforms, climbing ladder, cable ladders, except that used in the concrete foundation, shall be galvanized by the hot dip process after fabrication and before any assembly.

1.1.1.1.31 If, for manufacturing reasons, contractor proposes to use a treatment other than galvanizing specified in this section for certain parts of the tower, he shall state fittings to be so treated and process to be used specifically and shall get written approval from Mobitel before manufacturing. Thickness of galvanization shall be more than 610 g/m2.

1.1.1.1.32 The entire Steelwork forming portion of the foundation shall be galvanized or else Tenderer shall provide a proper methodology to store such units to prevent corrosion before installations.

1.1.1.1.33 Painting or cadmium plating shall not be used in any instance as a mean of protection against corrosion.

STEEL WORKS

1.1.1.1.34 The Steel used in the fabrication of tower/poles shall conform to BS EN10025 Grade S275 and S355 as appropriate to Rolling Tolerance to relevant ISO standards.

1.1.1.1.35 The slenderness ratio, L/R, of a member in compression shall not exceed:

a) 150 for main members

b) 200 for secondary members

c) 240 for other members

1.1.1.1.36 Members used solely to reduce the effective length of chords and main bracing shall, together with their connectors, be capable of carrying loads equal to 1% of the load in the primary members being supported, or the members being supported, or the members shall have maximum effective slenderness ratio (L/R) of 240, whichever condition is more stringent.

1.1.1.1.37 Notwithstanding the stress involved, no member of structures shall be less than 5mm in thickness.

1.1.1.1.38 All fabrication holes to the connection of tower members shall satisfy the end distance and the edge distance according to the BS 5950.

1.1.1.1.39 All steel used in fabrication of towers shall be tested by using random sample according to the relevant standard mentioned in the RFP.

1.1.1.1.40 Tolerance shall be as follows

a) 0.75mm for location of centers of holes

b) 1.5mm for overall length of members

c) 1.5mm for bolt holes

1.1.1.1.41 Opening of any holes shall not be carried out after galvanizing

1.1.1.1.42 All members, before being assembled, shall be straight, unless required to be curvilinear form and shall be free from twist. For the purpose of the specification, "straight" shall mean free from kinks and from gradual bends greater than 1/1000 of member length. Members on site not meeting this condition will be reworked or replaced. Lengths of all members shall be accurate so that when assembled no sagging or twist occurs.

1.1.1.1.43 No members of the tower shall have any joint by mean of welding.

1.1.1.1.44 Drawing of all steel parts including tower structural parts, detail methods of assembly and list of items shall be provided in both hard and soft copies.

BOLTS, NUTS AND WASHERS

1.1.1.1.45 All Nuts and Bolts shall be in accordance with ISO 898-1(Hexagonal Bolts) or relevant standards.

1.1.1.1.46 All Nuts and Bolts shall Grade 8.8.

1.1.1.1.47 Bolts and nuts shall be hot dip galvanized. Thickness of galvanization shall be more than 350 g/m2.

1.1.1.1.48 To ensure that the full bearing areas of bolts are developed, the thread portion of the bolts shall not extend within the thickness of members being jointed.

1.1.1.1.49 Spring washers or retaining nuts shall be galvanized by the hot dip process and shall be fully affective after galvanizing. Zinc plating will not be accepted as a substance for galvanizing.

1.1.1.1.50 After tightening the threaded portion, each bolt shall project through the nut by at least three threads, but the length of the projection shall not exceed 60% of the bolt diameter.

1.1.1.1.51 Locking nuts for the leg anchoring shall have minimum two (2) nuts and exposed part to have minimum ten (10) threads.

WORKING AND RESTING PLATFORMS

1.1.1.1.52 Top working platforms shall be of circular/square external type and complete with handrails to provide safe working areas and to keep tools at the top.

1.1.1.1.53 Resting platforms shall be provided at intervals of 15m.

1.1.1.1.54 Platform decking shall be expanded metal, fabricated grid or a similar material, adequately supported by steel members of appropriate size. Grid size shall be max of 50mm×50mm.

1.1.1.1.55 Handrails at a height of one (1) meter, intermediate rails at half meter above the decking and kick rail on the decking. The handrail and kick rail for antenna supporting tower shall be rolled steel angle section of dimensions not less than 5cm x 5cm x 0.5cm. Handrails shall be provided as far as they are consistent with access to the antenna and aircraft warning lights, and shall encompass the ladder and the ladder guard so that free access to the ladder may be gained from the platform. Handrails on working platform shall not be a structural member and shall be removable to facilitate the mounting of antenna.

1.1.1.1.56 Further Tenderer shall assure the safety of such platforms decking and hand rails.

ANTENNA MOUNTING

1.1.1.1.57 At the top of the tower to be provided with cellular antenna mounting structure complete with working platform as specified with easy access shall be provided for maintenance of such installed equipment.

1.1.1.1.58 Each tower shall be provided with complete nine (09) numbers of cellular antenna mounting steelwork to which the antenna may be rigidly attached by means of the mounting hardware supplied as a part of the antenna system.

1.1.1.1.59 Each tower shall be provided with four (04) numbers of 1200mm dia. Microwave antenna mounting bracket and antenna boom shall be provided at heights specified when the tower erection commenced.

CLIMBING LADDER

1.1.1.1.60 A climbing ladder shall be provided for the complete tower running vertically from ground level to the top of the tower. It shall be galvanized to meet the same standards as for Tower. The width of the ladder shall be at least 400mm.

1.1.1.1.61 The ladder shall be fitted with a ladder guard with sufficient caging space ensuring safety. The ladder guard shall commence at a point 2.25m above ground level and shall run continuously to underside of the platform above. A suitable access method shall be provided for each platform level. A ladder guard shall be constructed of three vertical stringers with horizontal hoops at approximately one (1) meter spacing.

1.1.1.1.62 Ladder guards shall continue for a distance of at least 1m above the upper surface of each platform.

1.1.1.1.63 No structural members of the tower shall protrude into or pass through the space within the ladder guard.

1.1.1.1.64 Ladder, ladder guards, and ladder supports shall not infringe on the space reserved for the feeder cables.

1.1.1.1.65 Ladder shall be adequately supported to resist lateral movement

1.1.1.1.66 Ladder steps with the interval of 300mm shall be rough-surfaced preventing any slipping and vertical stringers, hoops shall be painted with the same quality and colour scheme of the tower.

FEEDER RUNWAY AND HORIZONTAL GANTRY

1.1.1.1.67 A feeder runway and horizontal gantry linking the radio Equipment shall be provided for the tower. The runway and the gantry are required to support the feeder connecting the antenna with the radio equipment. It must be galvanized and painted to the same standards of the tower members.

1.1.1.1.68 Each feeder runway shall be located about the centre of tower and extend vertically from horizontal gantry level to the top of tower.

1.1.1.1.69 The feeder runway members shall be made of angled-iron, with the width of 600mm and horizontal member of 1m apart.

1.1.1.1.70 The horizontal cable gantry members shall be made of angled-iron, with the width of 600mm and steps spacing of 300mm apart.

1.1.1.1.71 Each horizontal gantry shall be supported by 62mm outer diameter heavy duty (above 3.5mm thickness) hot dipped galvanized GI pipes at intervals of 3000mm.

1.1.1.1.72 All the above mentioned structures shall be supported to the main structure or the ground with necessary arrangement.

OBSTRUCTION LIGHT

1.1.1.1.73 The successful Tenderer shall refer to local regulations in respect to obstruction lighting system implementation.

1.1.1.1.74 Tower shall be provided with one (1) obstruction lamp at the tower-top and two (2) at the platform below the top

1.1.1.1.75 Obstruction light shall function on full automatic photosensitive basis. Each light shall have its individual control circuit.

1.1.1.1.76 Obstruction light (solar powered) shall have minimum life of 120,000 hours.

1.1.1.1.77 A detailed circuit of the automatic photosensitive unit and tower lights shall be provided.

1.1.1.1.78 Standard shielded cable for 10 Amps shall be used.

WELDING

1.1.1.1.79 All welding shall be done under approved conditions and provide solution to protect from corrosion by means of approved paints.

1.1.1.1.80 All welding procedures shall be in accordance with the requirements of EN 970:1997 BS EN25817:1992 ISO 5817:1992

FINISHING PAINTS

1.1.1.1.81 Tower shall be painted according to ICAO regulations and the tower supplier shall provide the following

1.1.1.1.82 Two layer of Lead Oxide type anti corrosion paint (Sigma Universal Primer and Sigma multi primer with recommended chemicals by manufacturer) or equivalent for primary coating;

1.1.1.1.83 Two layer of Enamel paint (gloss) of high quality (Sigma Marine Paint with recommended chemicals by manufacturer) for the finishing coat.

1.1.1.1.84 Details of the primary coating and Enamel paint to be furnished, including the type, model, manufacturer, colour codes etc.

TOWER FOUNDATION

1.1.1.1.85 The Design and Construction of the Tower Foundations shall conform to BS8110: Part I: & BS 5950 1985 for Roof Top Towers and BS8110: Part I 1985, BS 5950 & BS 8007 or Equivalent for Green Field Towers.

1.1.1.1.86 Standard soil bearing capacity shall be define as 100Kn/m2 for pricing purposes.

1.1.1.1.87 Where the concrete only has to resist the uplift, the weight of concrete shall be 1.5 times the uplift.

1.1.1.1.88 Where the footing is undercut into undisturbed soil, the frustum may be taken for uplift and overturning calculation depending on the repose angle given in the soil report and the total weight of concrete plus the ground frustum shall be at least 1.77 times the uplift.

1.1.1.1.89 The buoyant force due to ground water level shall be taken into account for the foundation design, wherever applicable.

1.1.1.1.90 Where the foundation is designed without considering undercut safety factor for uplifting and overturning shall be taken as 1.5.

1.1.1.1.91 The horizontal resistance to the load shall be considered as acting at 2/3 H depth, where H is depth of the face in meters. The fraction between the foundation and the underlying ground may be regarded as assisting to resist horizontal displacement. When the angle of shearing resistance is not less than 300, this friction may be calculated as one seventh (1/7) of the net vertical reaction under the foundation. For other values of the angle, this friction may be taken as one-sixth (1/6) times net vertical reaction times tangent of the angle.

1.1.1.1.92 Where contractor has provided in this tender proposal for foundations in uniform soil, and on excavation at the site encounters rock-layer near the surface, he may amend the foundation design to utilize rock layer or bedrock as part of the foundation. However, designs related to any proposed variation in the foundation shall be submitted to Mobitel in writing before they are undertaken in the site. In this case, any variation shall be evaluated by considering the difference between the standard and the total actual construction.

1.1.1.1.93 Where back-filling of excavated soil is done, the soil shall be rammed at each 30 cm level. Tenderer shall arrange compaction test wherever requested by Mobitel at no cost to Mobitel. All back-filling and testing shall follow ICTAD specifications.

1.1.1.1.94 Contractor shall provide adequate means of drainage of rain water near tower foundations where, in the opinion of Mobitel, such is necessary to prevent erosion.

1.1.1.1.95 The concrete placing of foundation shall not proceed until Mobitel has being informed about the excavation, reinforcement and foundation formwork. All concreting work shall be informed to Mobitel two days prior to placing concrete.

1.1.1.1.96 If any piling is used as a part of foundation, they shall conform in all aspects to CP2004 or BS 8007.

1.1.1.1.97 For Roof Top towers, Poles, Shelters the beam network for foundation shall be designed and constructed in such a way to distribute the tower loads among the load bearing columns of the building and to provide effective restraint under wind conditions.

1.1.1.1.98 Contractor shall submit the concrete cube test reports according to the ICTAD specification.

1.1.1.1.99 The Tenderer shall be able to address all the disturbances which are not addressed in the soil report. No additional payment will be paid for any design revision in the excavation phase and the contractor shall have contingency plans for such issues.

1.1.1.1.100 All soil reports for green field sites shall be done up to at least 10m depth where water table is below 3m from EGL. All rock surfaces which used for rock anchoring to be tested with penetration test up to 3m depth. All soil reports where water table is above 3m level form EGL, one bore hole shall continue up to bed rock level and others shall terminate at 10m level. Tenderer shall provide two bore hole test results per site including foundation recommendation with soil parameters which are relevant to foundation designs.

PART III

TECHNICAL SPECIFICATIONS

FOR

GREEN FIELD

SELF- SUPPORT TOWER

1.0 GENARAL

The specification define the characteristics and performance requirement of the Tower to be purchased

1.1 For the performance specifications and characteristics witch are not stated in this specification, the relevant standard and\ or recommendations as specified in EIA RS –222C and BS449 shall apply:

1.2 Manufacturing and workmanship should comply to BS 449 or AISC

1.3 Minimum distance between legs at the top portion shall be type and 1.8m for 50m,60m,70m and 80m towers.

1.4 The straight portion at the top shall be 10m for all towers above 50m in height.

2.0 DESIGN CODES

The American "Structural standard for steel Antenna Towers and Antenna supporting Structures" RS222C or The British codes of practices 3 chapter V part 2, 1972 shall be used.

3.0 WIND LOADING AND TOLERANCE

3.1 Operational wind speed of 120 km/h and survival wind speed of 160 km/h should be used in the design

3.2 Twist and swing should not exceed 0.5 under extreme wind condition as specified in 3.1.

3.3 The tower-loading :.(wind shield area of 32Sq.m in any one direction at top

3.4 A safety factor of 1.7 should be used.

3.5 The erected tower, under the condition of negligible wind, shall not deviate from the vertical position by more than one eight percent (1/8%) of its heights, and shall straight within 2.5 cm of the normal Geometric position; the erected tower shall be free of inherent twists.

4.0 GALVANIZING

4.1 Galvanizing process should comply with either BS729 or ASTM/A123 or equal in other standard and codes (please quote if others).

4.2 All steelwork and fitting use in the assembly of the tower including the platforms, climbing ladder, cable ladder, except that used in the concrete foundation, shall be galvanized by the hot dipped process after fabrication and before any assembly.
If for manufacturing reasons, Contractor proposes to use a treatment other than galvanizing for certain part of the tower, he shall state specifically the fittings to be so treated and process to be used. Thickness of galvanization shall be more than 610 g/m2

4.3 Steelwork forming portion of the foundation shall be galvanized down to a distance of not less than Thirty (30) cm under the surfaces of the concrete. This steel work may be completely galvanized provided that the design of the foundation does not rely on a bond between the concrete and the encased steelwork.

4.4 Painting or cadmium plating shall not be used in any instance as a mean of protection against corrosion.

5.0 STEEL WORK

5.1 The steel used in fabrication of the tower shall comply with BS, JIS or an equivalent standard proposed by contractor and agreed by SUNTEL.

5.2 The slenderness ratio, 1/r, of a member in compression shall not exceed:

(a) 150 for main members
(b) 200 for secondary members
(c) 240 for other members

Members used solely to reduce the effective length of chords and main bracing shall, together with their connectors, be capable of carrying loads equal to 1% of the load in the primary members being supported, or the members being supported, or the members should have maximum

Effective slenderness ratio (1/r) of 240, whichever condition is more stringent.

5.3 Not withstanding the steel involved, no member of structure shall be less than 5mm (Five) in thickness.

5.4 Tolerance shall be as follows:

- ± 0.75 mm for Location of centers of holes
- ± 1.5 mm for overall length of members
- ± 1.5 mm for bolt holes

5.5 Opening of any holes shall not be carried out after galvanizing.

5.6 All members, before being assembled, shall be straight, unless required to be curvilinear from and shall be free from twist. For the purpose of the specification, "straight" shall mean free from Kinks and from gradual bends greater than 1/1000 of member length. Members on site not meeting this condition will be reworked or replaced. Length of all members shall be accurate so that when assembled no sagging or twist occurs.

5.7 No members of the tower shall have any joint by means of welding.

5.8 Drawings of all steel parts including tower structural parts detail methods of assembly and list of items shall be provided.

5.9 Appreciate soil conditions shall be prescribed. Safe values of ground water level and soil conditions shall be provided.

6.0 BOLTS, NUT AND WASHERS.

6.1 Nuts and heads of bolts shall be of the hexagonal type and should be Grade 8.8

6.2 Bolts and nuts shall be in accordance with latest BS, JIS or as specified by contractor and agreed by SUNTEL.

6.3 Bolts and nuts shall be hot dip galvanized. Thickness of galvanization shall be more than 350 g/m2

6.4 To ensure that the full bearing area of bolt is developed, the thread portion of the bolts shall not extend within the thickness of members being jointed

6.5 Spring washers or retaining nuts shall be galvanized by the hot dip process and shall be fully effective after the galvanizing. Zinc plating will not be accepted as a substance for galvanizing.

6.6 After tightening the threaded portion, each bolt shall project through the nut by at least three threads, but the length of the projection shall not exceed 60% of the bolt diameter.

6.7 Locking nuts for the leg anchoring shall have maximum Two (02) nuts and exposed part to have minimum ten (10) threads.

7.0 WORKING AND REST PLATFORMS

7.1 Resting platform to be provided at the first 15m levels. All the platforms shall have sufficient space for safety working areas and to keep tools.

7.2 Platform decking shall be expended metal, fabricated grid or similar material, adequately supported by steel members of appropriated size.

7.3 Handrails at a height of One (01) meter, intermediate rails at half meter above the decking and kick-rail on the decking. The handrail and kick-rail for antenna supporting tower shall be rolled steel angle sections of dimensions not less than 5mm x 5mm x 0.5mm. Handrails shall be provided as far as they are consistent with access to the antennas and aircraft warning lights, and shall encompass the ladder and the ladder guard so that free access to the ladder may be gained from the platform. Handrails on working platform shall not be structural member and shall be removable to facilitate the mounting of antenna.

8.0 ANTENNA MOUTING

The microwave antenna mounting bracket should be provided at height (will provide construction Stage). As per the BOQ

9.0 CLIMBING LADDER

9.1 The tower shall be provided complete with climbing ladder vertically from ground level to the top of the tower. It shall be galvanize as the same quality for the tower.

9.2 The ladder shall be fitted with a ladder guard with sufficient caging space ensuring safety. The ladder guard shall commence at a point 2.25m above ground level and above each platform, and shall run continuously to underside of the platform above. A ladder guard shall be constructed of three vertical stringers with horizontal hoops at approximately One (01) meter spacing.

9.3 Ladder shall continue for a distance of at last 1.0m above the upper surface of each platform.

9.4 No structural members of the tower shall provide into or pass through the space with in the ladder guard.

9.5 Ladder, ladder guards and ladder supports shall not infringe on the space reserved for the ladder cable feeder cables.

9.6 Ladder shall be adequately support to resist lateral moment.

9.7 Ladder steps shall be rough-surfaced preventing any slipping and hoops shall be painted with the same quality and color scheme of the tower.

10.0 FEEDER RUNWAY AND HORIZONTAL GANTRY

A feeder runway and horizontal gantry shall be provided for the tower. The runway and gantry are required to support the feeder connecting the antenna with the radio equipment. It must be galvanized and painted with the same quality of the tower members.

Each feeder runway shall be located about the center of tower and extending vertically from ground level to the top of the tower.

The feeder runway members shall be made of angled-iron, with the width of 600mm and horizontal members of 1.0m apart.

The horizontal cable gantry members shall be made of angled-iron, with the width of 600mm and steps spacing of 300mm apart. A total length of Ten (10) meter. Cable gantry shall be fixed to the shelter and proper pendulum poles shall be provided to prevent lateral movement.

11.0 WELDING

All welding shall be done under approval conditions.

All welding shall be metal-arc welding comply with BS 1856 for mild steel and BS 2642 for manganese steel whichever is applicable.

.0 OBSTRCTION PAINTS

Tower shall be painted according to ICAO regulations and the tower supplier shall prove the following:

Two layer of Led Oxide type anticorrosion paint or equivalent for primary coating,
Two layer of Enamel paint (gloss) of high quality for the finishing coat.

Detail for the primary coating and Enamel paint to be finished, including the type, model, manufacture, colour codes etc.

13.0 TOWER FOUNDATION

In the design of foundation footings for green field towers, a typical foundation is defined as:

13.1 To resist vertical uplift force the weight of concrete in any footing shall be as follows:

13.2 Where concrete only must reset the uplift, the weight of concrete shall be 1.5 times the uplift.

13.3 Where the footing is undercut into undisturbed soil, the frustum may be taken as extending 30° beyond the vertical and the total weight of concrete plus the ground frustum shall be at least 1.75 times uplift.

13.4 The buoyant force due to ground water level shall be taken into account for the foundation design, where considered necessary.

13.5 The horizontal resistance to the load shall be considered as acting at 2/3 H depth, where H is depth of the face in meters. The friction between the foundation and the underlying ground may be regards as assisting to resist horizontal displacement. When the angle of shearing resistant is not less than 30°, this friction may be calculated as one seventh (1/7) of the net vertical reaction under the foundation. For other values of the angle, this friction may be taken as one – sixth (1/6) times net vertical reaction times tangent of the angle.

13.6 Where contractor has provided in this tender proposal for actual foundations as any proposed variation in the foundation shall not be accepted to SUNTEL in after undertaken the site.

Back-filling: should be done with excavated soil and the soil shall be rammed at each 25 cm layers and shall achieve a minimum dry density of 17kN /m^3. Contractor should implement the soil compaction test and soil dry density test whenever it is requested by Suntel and test reports to be submitted before start the tower erection.

13.7 Where excavated material contains a high proportion of rock, sufficient soil shall be added to enable the back filling property compacted. Contractor shall regard the ground surface or near tower foundations where, in the opinion of SUNTEL, such is necessary to ensure adequate drainage and /or to prevent corrosion.
The concrete placing of foundation may not be preceded until the excavation , reinforcement and foundation framework has been approved by SUNTEL. For

approval contactor should inform the each concrete placing to Suntel at least two days before.

13.8 contractors should submit the concrete cube test reports to the each stage of concrete placing according to the BS of concrete test.

14. Quality Control

14.1. The contractor shall provide the scheme of testing subject to the approval of customer for the quality assurance of work to comply with the relevant standard indicating the parameters to be checked and the frequency of testing.

14.2 Any construction related work shall not carry out without a full time supervision of qualified technical representative of the contractor.

1.1.1.1 Tower Types

Tower Height and Loading Details

Tower Type	Height (m)	Antenna loading at the tower in any direction (m^2)	Location of the sector antenna on the tower (m)	Location of the M/w antenna on the tower (m (m)
Green Field Tower	50	16	50-45	45-35
	60	16	60-55	55-45
	70	16	70-65	65-55
	80	16	80-75	75-65
	100	16	100-95	95-85

1.1.1.2 General Specifications

1. The design, supply, deliver, construct, install, testing and commissioning of self-supporting towers associated services.
2. The construction of the foundation and erection of the tower.
3. Supply and construct working platforms and resting platforms at specified height
4. Supply and construct working platform at the top of the tower or, any other level under special conditions, complete with sector antenna brackets to fix six numbers (06 nos.) of sector antennae.
5. Supply and installation of obstruction light system
6. Test and commission of the tower and obstruction light system

1.1.1.3 Design Codes

The Following Codes will be used in the designs fabrication and construction

1. Calculation of loading on the Tower: The American "Structural standard for Steel Antenna Towers and Antenna Supporting structures": EIA222F :1996 or Equivalent
2. Design Of Steel Transmission Structures: ASCE 10-90 Design of Structures or Equivalent
3. Calculation of Wind loads: BSI CP2 Chapter V Part II 1972 or Equivalent
4. Welding: EN970:1997 BS EN 25817:1992 ISO 5817:1992
5. Foundation RCC Design: BS8110: Part I: 1985 & BS8007 or equivalent
6. Manufacturing and workmanship should comply to BS449 or AISC
7. Galvanizing of the tower members shall comply with BS EN ISO 1461:1991, ASTM/A123 or equivalent.
8. The Wind loading on the Tower shall be calculated in accordance with BSI CP2 Chapter V Part II 1972 or equivalent

9. The Steel used in the fabrication of tower shall conform to BS EN10025 Grade S275 and S355 as appropriate to Rolling Tolerance to relevant ISO standards.

10. All Nuts and Bolts shall be in accordance with ISO 898-1(Hexagonal Bolts) or relevant standards.

1.1.1.4 Quality Control

1. Being a TSP we will provide a scheme of testing subject to the approval of customer for the quality assurance of works to comply with the relevant standards indicating the parameters to be checked and the frequency of testing.

2. Any construction related work will be carried out with a full time supervision of a Engineer/supervisor.

1.1.1.5 Specifications Technical for Self Supporting Towers.

1.1.1.6 General

This specification defines the characteristics and performance requirement of the towers to be erected.

1. The safety factor used in the designs may be waived as and when necessary at the sole discretion of Customer

2. Being a TSP we will furnish all such documents (drawings, specifications, construction schedule etc.,), which are necessary at the implementation of project. (Specially for the Towers, will provided erection drawings for each tower and every design)

1.1.1.7 Design Criteria and Tolerances.

1. Operational wind speed of 140 km/h and survival wind speed of 180 km/h is used in design.

2. Maximum wind exposed area is of antenna for any direction shell be as per the Table 1.1

3. The desing loading for total weight of antennae is 15kN for Green Field.

4. A safety factor of 1.7 is used.

5. Twist and swing should not exceed 0.5 ° under extreme wind condition as specified above (CL 1.1.2.2 – 1).

6. The erected tower under the condition of negligible wind, will not deviate from the verical position by more than one eight percent (1/8%) of its height and shell be sraight within 2.5cm of the nominal geometric position. The erected tower will be free of inherent twists.

7. The height of sraight portions of towers will be according to the Table 1.1

8. Tower frabrication tolerances will be, ±0.75mm for centers location of holes, +1.5mm for overall length of members and ±1.5mm for bolt holes.

1.1.1.8 Steel Works

1. Manufacturing and workmanship will be accordance with BS or an equivalent standard of structural steel fabrication.

2. The slenderness ratio (l/r) of main members in compression will not exceed 150; secondary members in compression will not exceed 200 and 240 for others.

3. Opening of any holes may not be carried after galvernizing.

4. All members, before being assembled will be free from kinks and from gradual bends greater than 1/1000 of member lengh, unless required to be corvilinear shape. Length of all members will be acurate so that when assembled no sagging or twist occurs. Members of site not meeting this condition will be reworked or replaced No members of the tower will have any joints by mean of welding and members will not cut or damaged after galvernizing.

1.1.1.9 Galvanizing

1. All steel work and fitting used in the assembly of the tower including the platforms, climbing ladder, cable ladders, except that used in the concrete foundation, will be galvanized by the hot dip process after fabrication and before any assembly.
2. Steelwork forming portion of the foundation shall be galvanized down to a distance of not less than thirty (30) cm under the surface of the concrete.
3. Customer can be carried out the coating thickness check of galvanize whenever required from the approved company or institute.

1.1.1.10 Bolts, Nuts and Washers

1. Bolts and nuts will be hot dip galvanized. Thickness of galvanization shall be more than 350 g/m^2
2. To ensure that the full bearing areas of bolts are developed, the thread portion of the bolts will extend within the thickness of members being jointed.
3. Spring washers or retaining nuts shall be galvanized by the hot dip process and shall be fully affective after galvanizing.
4. After tightening the threaded portion, each bolt will project through the nut by at least three threads.
5. Locking nuts for the leg anchoring shall have minimum two (2) nuts and exposed part to have minimum ten (10) threads.
6. Torque test would be carried on site in front of the customer.

1.1.1.11 Working and Resting Platforms

1. Working platforms will be of Internal or external type and complete with handrails to provide safe working areas and to keep tools at the top.
2. Resting platforms will be provided at intervals of 15m.
3. Platform decking would be expanded metal, fabricated grid or a similar material, adequately supported by steel members of appropriated size.
4. Handrails at a height of one (1) meter, intermediate rails at half meter above the decking and kick rail on the decking. The handrail and kick rail for antenna supporting tower shall be rolled steel angle section of dimensions not less than 5cm x 5cm x 0.5cm.

1.1.1.12 Antenna Mounts

Cellular antenna mounting structure Complete with working platform as specified above 11.2.2.6, will be provide at the top of the tower.

1. Each tower willl be provided with complete six (06) numbers of sector antenna mounting steelwork to which the antenna may be rigidly attached by means of the mounting hardware supplied as a part of the antenna system.
2. Each tower will be provided with three (04) numbers of antenna brackets and booms to accommodate 1.2mm dia. microwave antennas at heights specified.

1.1.1.13 Climbing Ladder

1. A climbing ladder will be provided the complete tower running vertically from ground level to the top of tower. It will be galvanized to meet the same standards as for Tower. The width of the ladder will be 400mm.
2. The ladder will be fitted with a ladder guard with sufficient caging space (diameter 750 mm) ensuring safety. The ladder guard will commence at a point 2.25m above ground level and above each platform, and would run continuously to underside of the platform above. A ladder guard will be constructed of three vertical stringers with horizontal hoops at approximately one (1) meter spacing.
3. Ladder will continue for a distance of at least 1m above the upper surface of each platform.
4. No structural members of the tower will protrude into or pass through the space with in the ladder guard.
5. Ladder will be adequately supported to resist lateral movement and shall be firmly fixed to a rigid base at the bottom.
6. Ladder rungs will be flattened at the end where they are welded to the vertical members so as to safely support the weight of climbers and rough-surfaced preventing any slipping and hoops
7. Climbing ladder bottom will be concreted according to proper size.

1.1.1.14 Feeder Runway and Horizontal Gantry

1. A Galvanized feeder runway and horizontal gantry linking the radio equipment will be provided for the tower.
2. Each feeder runway will be located about the center of tower and extend vertically from horizontal gantry level to the top of tower.
3. The feeder runway members would be made of angled-iron, with the width of 400mm and horizontal member of 1m apart.
4. The horizontal cable gantry will be made of angled-iron, with a width of 400mm and steps spacing of 300mm apart of shall be provided to link to link the tower with the shelter. Cable gantry shall not be fixed to the shelter and proper pendulum poles shall be provided to prevent lateral movement.
5. Pendulum pole size of the horizontal cable gantry will be 50mm dia. Circular and Intervals will be at every 3m c/c.

1.1.1.15 Finishing Paints

Tower shall be painted according to ICAO regulations and the tower TSP shall provide the following

1. Two layers of Primer (Sigma Universal Primer and Sigma Multi Primer or Equivalent) for primary coating;
2. Two layers of Enamel paint (gloss) of high quality (Sigma Marine Paint or Equivalent) for the finishing coat.
3. Detail of the primary coating and Enamel paint to be furnished, including the type, model, manufacturer, color codes etc.
4. TSP should not use any other paints or coating specifications with out having approval of customer.

1.1.2 Technical Specifications for Tower Foundations.

1. In the design of Footings for Green Field Towers, a typical standard foundation is defined as;
2. A foundation designed for a bearing capacity of 100 kN/m2
3. Where concrete only must resist the uplift, the weight of concrete shall be 1.7 times the uplift in 140km/h wind speed.
4. Where the footing is undercut into undisturbed soil, the frustum may be taken as extending 30o beyond the vertical and the total weight of concrete plus the ground frustum shall be at least 2.0 times the uplift in 140km/h wind speed.
5. Foundation designs carried out in accordance with the CL 1.1.3 – 1, shall be modified depending on the results of proper soil investigations, in order to achieve the most economical solution.

6. At the completion of construction works the ground profile shall be restored back to its original state.

7. The buoyant force due to ground water level shall be taken into account for the foundation design, where considered necessary.

8. The horizontal resistance to the load shall be considered as acting at 2/3 H depth, where H is depth of the face in meters. The fraction between the foundation and the underlying ground may be regarded as assisting to resist horizontal displacement. When the angle of shearing resistance is not less than 30o, this friction may be calculated as one seventh (1/7) of the net vertical reaction under the foundation. For other values of the angle, this friction may be taken as one-sixth (1/6) times net vertical reaction times tangent of the angle.

9. Where TSP has provided in this tender proposal for foundations in uniform soil, and on excavation at the site encounters rock-layer near the surface, he may amend the foundation design to utilize rock layer or bedrock as part of the foundation. However, any proposed variation in the foundation shall be submitted to Ericsson in writing before they are undertaken in the site. In this case, any variation of the contracted price shall not be accepted.

10. Where back filling of the excavated area, the soil shall be rammed at each 25 cm thick layer and shall achieve a minimum dry density of 17 kN/m3 . TSP should implement the soil Compaction test and soil dry density test whenever it is requested by Ericsson and test reports to be provided before start the tower erection.

11. TSP shall provide adequate means of drainage of rainwater near tower foundations where, in the opinion of Ericsson and Mobitel, such is necessary to prevent erosion.

12. The concrete placing of foundation may not be preceded until Ericsson and Mobitel have approved the excavation, reinforcements and foundation formwork. For the approvals TSP should inform the each concrete placing to Ericsson at least two days before.

13. If any piling is used as a part of foundation, they shall conform in all aspects to CP2004.

14. TSP should submit the concrete cube test reports for the each stage of concrete placing according to the BS of concrete testing.

15. For Roof Top towers, the beam network for foundation shall be designed in such a way to distribute the tower loads among the load bearing columns of the building and to provide effective restraint under survival wind conditions.

SAFARICOM LIMITED

TECHNICAL SPECIFICATIONS

&

COMPLIANCE DOCUMENT

FOR

TOWERS, MONOPOLES & STUB TOWERS

DATE **January 2010**

PREPARED BY **Technical Operations Support & Logistics Department**

PART 1 – TECHNICAL SPECIFICATIONS

Introduction: The following are specifications for **self supporting** steel lattice towers, monopoles and stub towers to be ordered by Safaricom Limited.

1.1. TOWERS & MONOPOLES

1.1.1. Loading

Objectives

The objective of this section is to provide minimum design criteria for self supporting steel lattice towers and monopoles

Service life

The expected service life of towers and monopoles shall be 25 years. The design, choice of fabrication materials, fabrication methods, installation accessories, all safety factors and tower/monopole loadings shall all be made to conform to standards for this to be achieved.

Design Loads

For the basic wind speeds in Kenya, the following table shall be used as a guide:

Location	**Description**	**Basic Wind Speed, m/s**	
1	Nairobi, Central Province & southern half of Eastern Province including Machakos, Thika & Nyeri	28	Region 1
2	Coast Province including Voi, Malindi & Mombasa	31	
3	Southern half of Rift Valley Province including Nakuru, Naivasha, Narok, Rumuruti, Nanyuki & Magadi	36	Region 2
4	North Eastern Province, Northern half of Eastern & Rift Valley Provinces including Eldoret, Kitale & Kericho	45	Region 3
5	Nyanza & Western Provinces including Kisumu, Kakamega, Busia & Kisii	46	

The basic wind speed shall be read from this table whereas the design wind speed shall be obtained from methods given in BS CP3: Chapter V: Part 2.

There will be two types of towers for every region: namely normal duty and heavy duty.

The towers shall be designed to cater for the following antenna/equipment:

NORMAL DUTY: 6 Nos. 2.6m long GSM and 1.2 m ∅ M/W @ top, and 2 nos. 1.2m ∅ M/W just below.

HEAVY DUTY: 6 nos. GSM @ top, and 4 nos 1.8m ∅ M/W 5m below, and 4 nos. 1.8m ∅ MW 10m further below.

NOTE: Heavy Duty towers shall always be four legged.

The deflection of the structure shall not exceed the maximum allowable sway of ±0.50 degrees at the centre of the top most MW position, at 80% of the basic wind speed as stated in table above.

Monopoles shall be designed to cater for 6 Nos. 2.6m long GSM and 0.6m ∅ MW @ top and in addition shall be designed to meet all tower specifications including deflection criteria for region under consideration. Monopoles shall be made from galvanised hollow steel pipes or high strength steel, heavy duty, thick steel tubes or flanged steel tubes.

Minimum Dead and Live Loads

The dead loads to be considered in design shall include self weight of tower/monopole, GSM and M/W antenna, feeder cables, mounting brackets, fixtures and fittings and access ladder and platforms. An allowance of about 5% of the structure weight shall be made for galvanising and fasteners.

The live loads to be considered shall include workers climbing for installation / inspection

Tower Design

All steel structures shall be designed in accordance with BS5950. Tower designs shall also conform to BS 8100

The tower shall be designed to resist the most onerous combination of loading resulting from wind acting on towers, ancillaries, antennae and feeders.

At the time of submission of a new tower/monopole type never deployed in Safaricom Limited network before for Safaricom Limited's approval with SoC, the contractor shall submit a bound structural analysis & design report, including the tower structural drawings and models in soft copy either in STAAD *pro*, Prokon or STRAP programmes, for each new tower to be supplied. Tower structural drawings shall indicate region, material strengths, dimensions, member sizes, platform positions, ladder, design load and any other relevant notes. These calculations must clearly indicate both the net (as obtained from structural analysis) and gross weight of tower.

If vendor bids for a tower that has been deployed in the Safaricom Limited network before, reference to approved documents should be made and drawings of tower submitted with these SoCs. These structural drawings shall indicate region, material strengths, dimensions, member sizes, platform positions, ladder, design load and any other relevant notes.

All structural design (drawings and calculations) submitted to Safaricom Limited, must be clearly marked to show they have been approved for use in Kenya by a Structural Engineer registered by Kenya's Engineers Registration Board or IEK.

1.1.2. Modular Requirement

The tower shall be of lattice bolted construction, square or triangular in geometric cross section. The tower shall be made up of 5m or 6m modular sections enabling complete flexibility over the height requirements.

1.1.3. Footprint Requirement and Foundation Design

The footprint shall be the smallest possible meeting the loading requirements specified in this document.

The foundation designs and drawings shall also be submitted with these SoCs. For each tower to be supplied, the vendor shall provide the following options for tower foundations namely ground raft for soil bearing capacity of 200 kpa, underground raft and separate pads for soil bearing capacity 120 to 150 kpa and underground raft for soil bearing capacity of 80 to 100 kpa.

All structural designs for foundations (drawings and calculations) must be submitted to Safaricom Limited with the SoC and be clearly marked to show they have been approved for use in Kenya by a Structural Engineer registered by Kenya's Engineers Registration Board or IEK.

All the above shall be applicable to all foundations, including those already deployed in the Safaricom Limited network.

1.1.4. Tower Member Requirement

Leg members, main and secondary bracings shall be manufactured from hot rolled steel sections, either in angle or tubular hollow sections. For the coastal region, angular sections shall be preferred to tubular hollow sections.

1.1.5. Structural Steelwork

All structural steelwork shall be in accordance with BS4360 Grades 50C, 40B & 50B.

Hot rolled angled sections shall conform to BS4848: Part 4: 1972.

Hot rolled structural hollow sections shall be to BS4848: Part 2: 1972.

All bolts shall be in accordance with BS4190 and each supplied complete with single nut, single coil spring washer and flat washer.

Fabrication shall be generally carried out in accordance with the requirements of BS5950

All welding shall be performed before the galvanizing process and shall conform to BS5135.

All steelwork shall conform to structural loading requirements, structural steel specifications and local market availability.

1.1.6. Safety and Access

Platforms & walkways shall be manufactured of heavy duty steel floor grating complete with safety hand railing for safe access to all corners of tower.

Structure shall be complete with an internal un-caged ladder fully compliant with BS4211, with a "cable fall arrest system" running vertically for the full height of the tower.

Another option to the usage of the fall-arrest system is the usage of a caged ladder fully compliant with BS4211. This shall consist of hoops and stringers. These will start off at 2.0m from the start of the ladder, either at its start or at the rest platforms.

Tower shall be fitted with platforms every 10m, square in plan, to surround the cable well and ladder complete with hand and knee rails and toe slip guards. The 2 topmost platforms shall be work platforms providing access to up to each tower leg and the others shall be rest platforms. Handrail systems must be sturdy enough for safe latching of personal safety equipment. Flooring shall be of the open mesh variety and shall include an open area for the continuation of the access ladder at all heights. The rest platforms shall be in full accordance with BS 4211.

Monopoles shall be fitted with ladders and working platforms in full accordance with these specifications. Each monopole shall be supplied with the ladder and one work platform that can be fitted at any height within at least the top 6m of the monopole.

1.1.7. Warranty - Protective Surface Finish

After fabrication all structural steel shall be corrosion free and hot dip galvanized to give a minimum coating of 85 microns in accordance with BS729. Galvanization shall have a warranty period equivalent to the service life of the structure stated in 1.1.1 above.

Bolts shall be spun galvanized.

The steelwork consisting of the cable well and the ladder shall not be painted at all.

All earthing connections on the tower shall be left blank, without any coating of any sort. Only the bare galvanized steel shall show at the connection point and shall be in the form of a window measuring 10cm x 10cm minimum.

No item of the earthing system of the tower shall be painted, including lightning arrestor connecting wires, or flat bars and connections.

1.1.8. Tower Anchoring Systems

Anchor bolt size and material grading shall be as per design calculations for the height of the tower.

Anchor bolts shall be either forged or fabricated to create the shape required for anchoring.

The anchor bolts shall be hot dip galvanized over the full length and the thread. After galvanizing the thread must be tested using a galvanized nut to ensure correct thread functioning.

During storage, delivery and installation the threads must be greased and protected from damage due to knocking, denting, or deforming.

Anchor bolt design shall be such as protrusion from the base will allow the thread to extend 50mm minimum after all the fastening nuts and washers are in place. The protrusion must also allow for leveling differences of the tower leg base plates.

The tower anchoring system shall be such that it can be used for both pad and raft type concrete foundations without requiring any modifications.

1.2.STUB TOWERS

1.2.1. Loading

Service life

The expected service life of stub towers shall be 25 years. The design, choice of fabrication materials, fabrication methods, installation accessories, all safety factors and stub tower loadings shall all be made to conform to standards for this to be achieved.

Design Load

The objective of this section is to provide minimum design criteria for stub towers.

Stub towers are a category of supporting structures that are used for rooftop installations higher than 6m. These are centralized structures capable of supporting all the required antennas for the BTS.

The criteria of the design of the stub tower shall follow that of the masts, aforementioned.

The stub tower loading shall take into account loads due to the support structure, mounting brackets, fixtures, fittings and 3 people climbing the structure for inspection/installation. In addition, the stub tower shall be designed for 6 Nos. 2.6m long GSM antenna installed at the top and 2 nos. 0.6m ∅ MW below for which the deflection shall not exceed the maximum allowable sway of ±0.50 degrees from the position at centre of MW antenna, at 80% basic wind speed. The design shall fully comply with BS 5950, BS CP3: Chapter V: Part 2 and tower specifications. The wind speed to be used shall be as stated in tower specifications

Stub Tower Design

All steel structures shall be designed in accordance with BS5950. Tower designs shall also conform to BS 8100

The tower shall be designed to resist the most onerous combination of loading resulting from wind acting on towers, ancillaries, antennae and feeders.

At the time of submission of a new stub tower type never deployed in Safaricom Limited network before for Safaricom Limited's approval with SoC, the contractor shall submit a bound structural analysis & design report, including the tower structural drawings and models in soft copy either in STAAD *pro,* Prokon or STRAP programmes, for each new tower to be supplied. Tower structural drawings shall indicate region, material strengths, dimensions, member sizes, platform positions, ladder, design load and any other relevant notes. These calculations must clearly indicate both the net (as obtained from structural analysis) and gross weight of tower.

If vendor bids for a tower that has been deployed in the Safaricom Limited network before, reference to approved documents should be made and drawings of tower submitted with these SoCs. These structural drawings shall indicate region, material strengths, dimensions, member sizes, platform positions, ladder, design load and any other relevant notes.

As a general guideline, stub towers shall be of lightest possible weight meeting loading criteria. Stub towers should be 3 legged with the footprint not exceeding 1.8m.

All structural design (drawings and calculations) submitted to Safaricom Limited, must be clearly marked to show they have been approved for use in Kenya by a Structural Engineer registered by Kenya's Engineers Registration Board.

1.2.2. Modular Requirement

The stub tower shall be of lattice bolted construction, square or triangular in geometric cross section. The tower shall be made up of 3m modular sections enabling complete flexibility over the height requirements.

1.2.3. Footprint Requirement

The footprint shall be the smallest allowable depending on the Loading requirements specified in this document.

1.2.4. Tower Member Requirement

Leg members, main and secondary bracings shall be manufactured from hot rolled steel sections, either in angle or tubular hollow sections. For the coastal region, angular sections shall be preferred to tubular hollow sections.

1.2.5. Structural Steelwork

All structural steelwork shall be in accordance with BS4360 Grades 50C, 40B & 50B.

Hot rolled angled sections shall conform to BS4848: Part 4: 1972.

Hot rolled structural hollow sections shall be to BS4848: Part 2: 1972.

All bolts shall be in accordance with BS4190 and each supplied complete with single nut, single coil spring washer and flat washer.

Fabrication shall be generally carried out in accordance with the requirements of BS5950

All welding shall be performed before the galvanizing process and shall conform to BS5135.

All steelwork shall conform to structural loading requirements, structural steel specifications and local market availability.

1.2.6. Safety and Access

The stub tower shall be provided with a safe access ladder for the total height of the structure to enable access and maintain ease of installations. The tower shall also be provided with a Safaricom Limited approved method of securing personnel in the event of accidental falling.

Platforms & walkways shall be manufactured of heavy duty steel floor grating complete with safety hand railing for safe access to all corners of tower.

Stub Tower shall be complete with an internal un-caged ladder fully compliant with BS4211, with a "cable fall arrest system" running vertically for the full height of the tower.

Another option to the usage of the fall-arrest system is the usage of a caged ladder fully compliant with BS4211. This shall consist of hoops and stringers. These will start off at 2.0m from the start of the ladder, either at its start or at the rest platforms.

Stub tower shall be fitted with platforms every 10m, square in plan, to surround the cable well and ladder complete with hand and knee rails and toe slip guards. The topmost platform shall be a work platform providing access to up to each tower legs and the others shall be rest platforms. Handrail systems must be sturdy enough for safe latching of personal safety equipment. Flooring shall be of the open mesh variety and shall include an open area for the continuation of the access ladder at all heights. The rest platforms shall be in full accordance with BS 4211.

1.2.7. Warranty - Protective Surface Finish

After fabrication all structural steel shall be corrosion free and hot dip galvanized to give a minimum coating of 85 microns in accordance with BS729.

Bolts shall be spun galvanized.

The steelwork consisting of the cable well and the ladder shall not be painted at all.

All earthing connections on the tower shall be left blank, without any coating of any sort. Only the bare galvanized steel shall show at the connection point and shall be in the form of a window measuring 10cm x 10cm minimum.

No item of the earthing system of the tower shall be painted, including lightning arrestor connecting wires, or flat bars and connections.

Design, Manufacture, Delivery of Towers and Masts

Specifications

Purpose

The purpose of these specifications is to define the Services of design, manufacture of towers and masts.
They can only be applied accompanied by an additional request precisely defining on a case-by-case basis the height of the mast or tower to be designed, manufactured, delivered and implemented in accordance with the following instructions as well as the radiotelephony equipment intended for installation.

1 Reference documents

The supply, delivery and assembly will be in compliance with laws, decrees, orders, circulars and instructions issued by Purchaser in their most recent form regarding the designated site.

It is the Service Provider responsibility to comply with the standards, technical regulations, and professional regulations in force and to respect industry best practice.

Not all of the reference documents are referred to in these Specifications but they are applicable to all Services. They are supposed to be known to all parties (particularly the documents referred to in Appendix 1).

In the event of regulatory provisions, which contradict the definitions of functional and technical requirements contained in the present document, it is the responsibility of the service provider to inform Purchaser. The same applies in the event that new regulations and standards come into force.

In the absence of special provisions in these Specifications, the standards in force apply.
The supply and installation of anti-fall and anti-intrusion equipment and lightening protection must be in compliance with the manufacturers' technical datasheets. The same applies for the application of the paint for daytime marking or environmental integration.
The list of the main reference documents is shown in appendix 1.

Purchaser assumes no legal responsibility for any error or damage resulting from the use of this document.

The content of this specification is subject to revision by Purchaser without notice.

The design and manufacturing of the tower shall be based on recognized principles of structural design conforming to standard practices followed in the field. Soundness of the design and the execution of the work are fully under the Provider responsibility.

2 SUBJECT

This "Tower specification" document describes specifications to be applied for the design, structural analysis, and manufacturing and packing of self supporting towers, guyed pylon and pole, used for telecommunication network (Greenfield and rooftop site).

It concerns:

- Latticed self supporting tower, square cross section with angle leg member
- Latticed self supporting tower, triangular cross section with angle leg member
- Latticed self supporting tower, triangular cross section with tubular leg member
- Guyed pylon, square cross section with angle leg member
- Guyed pylon, triangular cross section with angle leg member
- Guyed pylon, triangular cross section with tubular leg member
- Self supporting pole.

3 Design

Two (2) standard / code are allowed:

- EIA/TIA-222-G with addendum G1
- NV 65 - DTU P06-002 version of 2000

Per consequence the following calculation rules for steel constructions shall be used

- AISC- LRFD 99 – Load and Resistance Factor Design Specification for Structural Steel Building
- P 22.701 CM 66 (Rules) and addition 80: Metal construction rules – Calculation rules for steel constructions edited in 1966

These Standards / Codes shall be imperatively used to design standard tower. Using equivalent or others Standard/Code for standard tower is not allowed.

The tower should be designed in such a manor that the connections are not the critical or weakest link.

3.1 Design note

The structure's design note is to be supplied to Purchaser for each tower or mast delivered. The design note will include a hypothesis note defining the base values of the wind and the various coefficients taken into account (site, dimension, height, dynamic and drag, etc.) and the surfaces considered and the type of links at the bearings and between the bars. The name, the origin and the characteristics of the software used shall be specified.

The stability and the solidity of the structure will be checked according the allowed standard / code

- E.g :With the wind pressures corresponding to the extreme wind of NV65.

The dimensions of the pylon's and mast's anchorage and the checking of mast fatigue may be carried out as per the Recommendations on the calculation of the mast structure for the lighting of open spaces

- published in CTICM's Metal Construction report, no. 4 of 2000.
- AISC – LRFD 99

3.1.1 Wind

The impacts of the wind will be considered on the pylon's structure, the ladder, the platforms, the cable paths, the antenna and their accessories.

The tower and mast will be adapted to the wind zone encountered.

	EIA/TIA-222-G1 (3 Sec Gust wind speed at 10 m height)	NV 65 (10 Min Ave wind speed at 10 m height)
Wind Area A	Basic wind speed :149,7 Km/h	Normal speed: 103,0 Km/h Extrem speed: 136,1 Km/h
Wind Area B	Basic wind speed :162,5 Km/h	Normal speed: 112,7 Km/h Extrem speed: 149,1 Km/h
Wind Area C	Basic wind speed :181,8 Km/h	Normal speed: 126,0 Km/h Extrem speed: 166,6 Km/h
Wind Area D	Basic wind speed :197,9 Km/h	Normal speed: 137,9 Km/h Extrem speed: 182,5 Km/h
Wind Area E	Basic wind speed :228,5 Km/h	Normal speed: 159,2 Km/h Extrem speed: 210,6 Km/h
Wind Area F	Basic wind speed :251,0 Km/h	Normal speed: 174,4 Km/h Extrem speed: 230,7 Km/h

For exposed site, the superior class should be taken

- E.g: Wind Area B is corresponding to Wind Area A for exposed site

(For TIA-222-G the Exposure Categories as per 2.6.5 are to be followed)

The Tower height will be limited for the wind area D, E, F

Nota: the wind speed are given for 10m height

3.1.2 Ice and snow

Impact of ice and snow shall be integrated only in the design for tower in Armenia and Moldova

3.1.3 Antennas Effective Projected Area (EPA)

Antenna Effective Projected Area (EPA) includes only the load for the antennas (GSM and MW). Feeder, cable tray, platform, (etc..) impacts are not included in the EPA value.

The tenderer shall consider the following typical values for the antennas Effective Projected Area (EPA) for the tower (greenfield site).

- The typical values are: 6 sqm and 300 Kg, 12 sqm and 600 Kg, 20 sqm and 1100 Kg, 25 sqm and 1300 Kg
- The location is :
  - o In the last 3 meters for the 6sqm
  - o In the last 5 meters for the 12 sqm
  - o In the last 10 meters for the 20 and 25 sqm

The tenderer shall consider the following typical values for the antennas Effective Projected Area (EPA) for the tower (rooftop site).

- The typical values are: 6 sqm and 300 Kg, 12 sqm and 600 Kg
- The location is :
  - o In the last 3 meters for the 6sqm
  - o In the last 5 meters for the 12 sqm

The tenderer shall consider the following typical values for the antennas Effective Projected Area (EPA) for the pole (rooftop site).

- The typical values are: 2 sqm and 100 Kg
- The location is :
  - o In the last 2 meters

3.1.4 Transmission lines (Feeder)

The manufacturer will consider a width for a wind projected area of at least 50cm for the tower and a weight of 16 Kg / meter for feeders, with the except of the towers up to 36m with a EPA of 6sqm, in this case 350mm can be used for the feeder projected area.

In specific case (on purchaser request), a second cable ladder could be added. The position should be studied to limit the wind load.

For the pole, the manufacturer will consider a width for a wind projected area of at least 25 cm for the pole.

3.1.5 Tilt, Twist and sway

The maximum authorised tilt, twist and sway for the tower and mast will be of: (See #13 for loading tables)

- ± 1°at the top for pole 2sqm load
- ± 1°at the top for tower 6sqm load
- ± 1°at 2,5 m of the top for tower 12sqm load (Cast 1)
- ± 30' at 2,5 m of the top for tower 12sqm load (Case 2)
- ± 20' at 5 m of the top for tower 20 and 25 sqm load

3.1.6 Seismic resistant reinforcement

The impact shall be studied only for Armenia
The supplier shall describe its solution

3.1.7 Foundation

The tower shall be compatible with the different soil quality (defined in chapter 7.1.1 of "Civil works and Tower installation –annex"

To summarize, the typical soil quality are:

- 200 kPa
- 150 kPa
- 100 kPa
- 50 kPa

These values are given in ELU (Ultimate limit)

3.1.8 Height

Please see per tower type

3.1.9 Other parameters

For design with EIA/TIA -222G with addendum, the following parameters shall be considered:

- Exposure category: C
- Topographic category: 1
- Classification of structure: 2

For design with NV65, the following parameters shall be considered:

- Site effect: normal
- No cliff effect

3.2 Report

The report shall include:

- The parameters defined for the design calculation
- The impact of the accessories (ladder, work platform, feeder, ..)
- Steel quality
- Ratio of the admissible resistance for the element of tower part (critical part)
- Anchorage of the tower (number, repartition and diameter)
- Reference of the tool for design

4 Type of equipment to be installed for tower

The equipments described in this chapter are mandatory.

4.1 CABLE LADDER

A “vertical” cable ladder support system, 50 cm width minimum must be provided to support coaxial cable.

The cable ladder support system shall offer at minimum a depth of 150mm with any tower part (to have the possibility to install 2 layers of 1”5/8 feeders)

The horizontal coaxial cable support shall be in steel angle profile.

The distance between the cable connection points in “vertical” position shall not exceed 100 cm.

The “vertical” cable ladders support will be on the same plane in “vertical” position.

The “vertical” cable ladder support (and associated coaxial cable) shan’t impede the movement of the personnel during climbing on access ladder and on working platform.

For lattice structures, all feeders shall be accessible in any point from the access ladder.

4.2 Access LADDER

All the aerial support structures of a height of more than 3m must be fitted with a straight ladder or a parrot ladder (masts only) fixed permanently on the support.
A ladder shall be supplied with each tower; the ladder shall be installed “vertically” all along the tower height. These movable ladders are forbidden where the drop is less than 2m.
Slanting ladders are forbidden.

Geometry and characteristic conditions must be comply with ANSI/TIA-222-G paragraph 12.5 and all relevant annex and addendum with the following deviations:

- Step bolts solution is rejected for latticed self supporting tower
- Anti-slip rungs and constant space of 250 to 300mm,
- Diameter of rungs: 20 mm minimum
- Width between posts: 400mm, NFE 85-010 or parrot rungs with anti-slide system
- Resistance of the posts and the rungs: paragraphs 6 and 7 of the standard NF E 85010,

The tower cross-section shall be designed to include the ladder with its accessories. As well the design of the tower and ladder system shall allow putting down a foot without any difficulty.

According to the tower size, the access ladder could be inside or outside the tower

Distance between the ladder (rung) and any obstacle must be minimum 200 mm.

A free circulation column of diameter 70cm is required for the full height, without circulation of antennas in the electromagnetic field and particularly in the hyperbolic beam field.

5 Stand Alone Tower

5.1 Height

The supplier shall propose tower with the following height:

- 24 m
- 36m
- 45m
- 55m
- 65 m
- 75m

The supplier could adapt slightly the height to be fully adapted with its manufacturing process and for the transportation (container size)

5.2 Width at the top

For tower with a load of 20 or 25 sqm, the width at the top of tower shall be at least of 1.5 meter.
The tower shall accept MW dishes with diameter between 1.8 and 4.6 meters

5.3 Structure

5.3.1 Structure of the pylons and masts

The basic steel of the metal structure elements will comply with NF EN 10 025, EN 10 027 and NF A 35 503 (for galvanised parts).
The hollow sections will be supplied as per the standards NF EN 10210
The pylons and mast will be made of one or several elements, according to the requested height.

Equivalent standards from AISC could be used in accordance with AISC – LRFD -99

The steel quality and chemical composition shall be suitable for galvanization and compliant with relevant Standards.

For cold area (Armenia and Moldova), the steel shall be compatible with the potential cold (-40'C)

5.3.1.1 Cutting

Cuttings will be carried out compulsorily in the factory prior to galvanisation. The Service Provider will ensure that the corners and edges, likely to cause a risk to personnel on the site, are rounded off as much as possible.

5.3.1.2 Boring

Boring will be carried out compulsorily in the factory prior to galvanisation. Drilling on the field is strictly forbidden.
See also on this subject the remark regarding anti-corrosion protection

5.3.1.3 Welding

Welding joints will be carried out compulsorily in the factory prior to galvanisation and must comply with the standards of the NF P 22 470 series (cambered cords are not permitted, i.e. for flange plate connections welding must be full strength full penetration welds on both the inside and outside of the pipe connection).

5.3.1.4 Bolting

Bolts should be HR galvanised and will be chosen by the service provider:

- prestress torque controlled by dynamometric key as per NF E 27 701 and NF E 27 711
- non-prestress with steel as per NF EN 20 898 and "PAL" type brake nuts
- non-prestress in stainless steel as per NF EN ISO 3506 adapted to atmospheric conditions concerning corrosion.

<u>All bolts and nut (with the same size) shall be in the same resistance class</u>

5.3.2 Assembling

Tower on site shall be assembled by nuts, bolts washer compliantly with the relevant standards.

Assembling the tower elements and accessories on the field shall be carried out without any need for welding, drilling or specific tools.

Self supporting tower elements shall be gathered with bolts, nut and by flange or covering.

The Connections envisaged to be carried out on-site, during implementation will be designed in:

- solid flanges and bolts (Axial connection with a minimum of 6 bolts in tension per flange)
- gussets and bolts on the member (Shear connection with bolts in shear) ,

- fish-plate gussets, welded gussets, bent gussets or cross members and diagonals.

The vertically of the tower shall be perfect, only a tolerance of 1/200 of total height is permitted.

5.3.3 Instructions regarding handling

The technical file will describe the handling methods of all of the elements prior to implementation, during assembly and during erection.

5.3.4 Instructions regarding storage

The technical file will describe the methods recommended for storing the elements to be implemented, so that none should suffer particular damage in its surface treatment or in its structure.

5.4 *Labelling system*

Codifying of the equipment shall be ensured enabling the manufacturing run to be monitored.
Each pylon or mast shall include a signage plate with indelible indication of:

- The name of the manufacturer
- Its address
- Its telephone number
- The month and year of manufacture, : (Month & year mm/yyyy)
- The height of the support (m),
- The type of pylon or mast,
- The number of the manufacture run (serial number)
- The maximum load at the top (m²)
- BWS (reference EIA/TIA 222G (km/hr)
- Grade of steel used

5.5 Rest platforms

Rest platform shall be provided every 15 m (maximum).

There may be 2 types:

- ***either identical to the work platforms***
- or simply made up of footrests (foldable or not) not creating any obstruction to circulation.

This solution is possible in the case where the worker remains connected to the safety system and is particularly suited to the monopole pylons and lattice-type pylons with small sections.

Rest platforms shan't be an obstacle on the climbing path.

The rest platform may be fixed on the ladder (retractable rest platform are accepted).

Safety conditions must comply with applicable standards.

5.6 MAINTENANCE PROCEDURE

The Supplier shall provide a standard maintenance procedure applicable for their towers within "Basic Documentation package". Standard maintenance procedure must include at least:

- Frequency and type of inspection (methodology and tools)
- Structure inspection
- Bolts inspection
- Aviation warning light inspection
- Checks for signs of abnormal movements at connections
- Check for signs of rust. Paint, Anti-corrosive protection inspection
- Check for signs of cracks on concrete foundations
- Check for soil erosion in vicinity of foundations
- Recommendations

5.7 CO2 emission

For each proposed tower, the supplier shall specify:

- CO_2 emission to manufacture the equipment.
- CO_2 emission to recycle the equipment.

6 Documentation

1 soft copy of all following documentation shall be provided to FT/Orange purchasing department:

- The Designer shall be responsible for all calculations designed to ensure the proper use of telecommunication equipment (Antennas, feeders, etc....) taking into account all extreme cases according to Standard/Code.
- Static design calculation. The Designer shall submit for approval to FT/Orange the design calculations for each standard or specific tower (structure and foundation) proposed:

  6.1.1 To demonstrate the stiffness of the tower fully loaded and at basic wind speed (extreme speed for NV65)

6.1.2 The maximum twist and sway at the top of the tower, at operational wind speed

6.1.3 To give the maximum stresses on the base of the tower for basic and operational wind speed.

The data sheet description of the tower must contain the following information:

- Tower drawing (sketch) showing:
  - 6.1.4 Tower type (Self-supporting / guyed pylon, ...)
  - 6.1.5 Typical applications (Wind speed, EPA, tilt/sway...)
  - 6.1.6 Main dimensions (Height, footprint...)
- Foundation quantities for standard (200 KPa ELU) soil and minimum soil quality (100 KPa ELU)
- Tower foundation drawings with proposed implementation
- Grounding termination drawings
- Tower outline with:
  - 6.1.7 Tower type (Self-supporting / guyed pylon ..)
  - 6.1.8 Typical applications (Wind speed, EPA, tilt/sway...)
  - 6.1.9 All measurements (Face width, maximum tower height, etc...)
  - 6.1.10 Dimensions of tower base (Footprint)
  - 6.1.11 Cross-section with internal bracing at each tower segment-structural steelwork detail
- Bracing system, type of bracing
- Coaxial support members and spacing details
- Antennas support pipes
- Overall tower weight and weight of sectional steel
- Maximum length of tower steel members
- Detailed manufacturing drawings (applicable when Designer is not the Manufacturer / Supplier is only Designer)
- Complete list of all elements, organized per section.

The Designer shall undertake:

- To supply "Liability Insurance" certificate
- To report any changes to FT/Orange
- To supply reference of design and calculation software used
- To supply design and calculation report
- To supply standard maintenance procedure
- To supply installation documents.

7 Summary of all potential configurations

The potential configurations are for:

- All the tower types
- All the heights
- All the loads
- All the wind areas
- All the maximum deflections (tilt /twist/ sway)

8 Foundation and civil works for tower

The so-called "special" foundations will be the subject of a special study and are not referred to in these specifications.

8.1 Foundation type

The choice of the foundation system will be made according to the type of ground encountered and defined by the manufacturer on the basis of a geotechnical study submitted to Purchaser.

8.1.1 Soil parameter

The presumptive data soil parameters to design standard foundations are listed below:. Rock, cohesive soils, saturated or submerged soils are not considered for the standard foundations.

These soils quality are reached for a depth between 1.2 and 3 meters

Presumptive Data Soil Parameters (Standard EIA222G) to design standard foundations									
Soil Type	N (blows/m)	φ (deg)	γ (kN/m3)	c (kPa)	Ultimate bearing (kPa)		Sf (kPa)	K (kN/m3)	ε50
					Shallow Fnds	Deep Fnds			
"Presumptive" soil parameters for **standard design**	30	26	17	30	200	NA for standard design	24	30000	NA
"Presumptive" soil parameters for **soil1 design**	30	26	17	20	150	NA for standard design	24	30000	NA
"Presumptive" soil parameters for **soil2 design**	20	18	17	15	100	NA for standard design	20	25000	NA

Where:
N = Standard penetration value
φ = Angle of internal friction
γ= Effective unit weight of soil
c = Cohesion
Sf = Ultimate skin friction
k = Lateral modulus of soil reaction
ε50 = Strain at 50% of ultimate compression

Effective unit weight of concrete = 25 kN/m3
Concrete ultimate cube strength at 28 days = 21,1MPa
Shallow Foundations = Isolated foundations such as pier and pads and mats
Deep Foundations = Drilled piers, piles and drill and bell foundations
Frost depth: NA except for Moldova and Armenia

For EIA/TIA 222 G1, the ultimate bearing value shall be considered before the application of the:

- factor of safety (equal to 2 – EIA /TIA 222 G1 -Chapter 9.4)
- resistance factor (EIA /TIA 222 G1 chapter 9.4.1)
- Safety factor against compression force = 3.0

For NV65, the ultimate bearing value in the above table is corresponding to ELU (Etat limite ultime – ultimate limit)

Supplier Response: Compliant or not Compliant

8.1.2 Foundation design

Foundations to build shall be designed for the conditions existing at the site and the current norms:

- Foundation safety factor according to EIA/TIA-222 G1
- ACI 318 RM (1999), EIT codes: reinforced concrete structures
- DTU 13.12 for superficial foundation
- Fascicule (leaflet) 62 titre V: technical rules for design and foundation calculation
- BAEL 91 modfied 99: for constructions in reinforced concrete,
- Leaflet 62 Title V for the foundations,
- Quality assurance:
  - Conduct strength test of concrete during construction
  - Control slump of concrete sample
  - Inspect concrete batching, mixing and delivery operations
  - Report location of test with method stored and curing procedure

The choice of the foundation type should be determined to limit the global cost for FT/ Orange and in accordance with the soil parameters and pylon design

The tenderer establishes his note of calculation; determine efforts of uprising, of compression and the horizontal efforts in foot of the pylon for size its massif.

Foundation types acceptable are:
- single pad (with or without stub columns)
- independent pads (with or without stub columns)

For specific foundations (e.g: on piles or belled pier), it is necessary to have a previous agreement from the purchaser

The eposed top surface of the pad should be sloped to avoid stagnant water.

The calculation notes shall specifying the ultimate design factors and factors of safety, justifying the recommended solution will be provided to THE PURCHASER..
The report shall be in soft copy
The report shall include:
- calculations
- drawings for the tower foundations
- reinforcement bars location
- size
- weight
- anchor bolt locations
- layout drawing

Supplier Response: Compliant or not Compliant

8.1.2.1 Seismic foundation design

The impact shall only be considered for Armenia unless specifically requested by the service provider.
Supplier Response: Compliant or not Compliant
The supplier shall explain the specific foundation

8.1.2.2 Foundation design in cold area

The impact shall be studied only for Armenia and Moldova
The service provider shall describe the needed modification for these cold areas
Supplier Response: Compliant or not Compliant
The supplier shall explain the specific modifications

8.2 Excavation

From the start of the excavation the service provider will carry out the burying of the earthing plate (see chapter on lightning protection) taking particular care to protect against possible concrete splashes, the tin-coated copper strands welded to the plate. Immediately after burying the earthing plate the service provider will carry out the installation, on the excavation floor, of over site concrete whose thickness will have been

mentioned in the design note. In order to optimise the installation of the anchorage crosses, it is recommended to ensure the levelness of this over site concrete.
The service provider will carry out, if necessary during the reinforcing and pouring works, protection of the excavation walls (for example: polyane, lagging, etc.)

The arable ground should be separate and kept on the site. This arable ground should be levelled on the site at the end of the site construction.
Supplier Response: Compliant or not Compliant

8.3 Concrete

The concrete used for the foundations should be standardised concrete issued by central office. If ready mixed concrete is not readily available, concrete may be mixed on site using an appropriate concrete mixer under skilled supervision, with 2 sets of cubes tests taken for crush testing at 7 and 28 days. Its characteristics will be defined by the design note supplied by the manufacturer

The civil engineering works concerning the foundations will take into account the following points:

- In order to prevent the stagnation of water, the upper part of each block will be floated, finished without bug-holes and sloping,
- The top of the foundation (or stub column) will rise above the ground by at least 7cm at any point,
- The horizontal edges of the top of the foundation (or stub column) will be chamfered by any appropriate means to be chosen by the service provider,
- In order to avoid the risk of deterioration of any metal part in contact with the concrete, an elastomer sealing joint will be installed everywhere or freely, such risks exist (for example: base of the pylon at the exit of the block) and it will be the same for any attachment fitting in the masonry.
- Minimum concrete protecting steel reinforcement from corrosion
    - Concrete deposited against ground: 75 mm
    - Formed surfaces exposed to weather or in contact with ground: 50 mm

Supplier Response: Compliant or not Compliant

8.3.1 Installation of the anchorage

With high pylons and masts, anchorage and template hardware will be supplied, which correspond to the attachment holes already made in the support structure, to be incorporated into the foundation blocks. The anchorage and sealing devices will also be included in the basic supply. Particular attention will be paid to this operation on which the verticality of the pylon depends.
Supplier Response: Compliant or not Compliant

8.3.2 Reinforcement

All of the reinforcing elements and its characteristics, such as, for example, and not limited to, colours, types, sections, moulding and quantities, etc., will be defined by the manufacturer and implemented in compliance with these guidelines.
Supplier Response: Compliant or not Compliant

8.3.3 Formwork

The upper part of each block will be formworked in such a way that the concrete rises above the ground by at least 7cm and at most 16cm.
Where the ground slopes, the formwork will be carried out by taking account of the constraints exercised during the pouring.
Supplier Response: Compliant or not Compliant

8.3.4 Remind of basic rules

Concrete works

Concrete works shall follow local and international standards. Every charge of concrete will be accompanied by report, test specimen procedure and results. A copy of such document will be included in the site documentation. Tests to be verified by a civil engineer on a site-by-site basis.

For early loading condition, the 7 day strength test is required.

Materials

The materials to be used in the concrete shall be compliant to meet the defined requirements in calculation note and shall be specified on the civil construction drawings:
Strength
Slump

The materials to used should be
Cement: TIS 15-2532 (1989) 150, Portland Cement Type I
Water: Fresh, clean
Aggregates: For Normal Weight Concrete: TIS 566-2528 (1985)
Vapor Barrier: 0.25 mm thick clear polyethylene film. for very low temperature (Armenia and Moldova

Admixtures

Suitable admixtures may be used in concrete mixes, if required, with the prior approval of the Engineer.
Do not use admixture containing calcium chloride
Use admixtures in accordance with Suppliers instructions
Use only admixtures in work used in establishing design mix
Retarders, accelerators, and other admixtures may be used to produce quality of concrete specified under prevailing placing conditions
Use only admixture indicated in design mix submitted for review
If more than one admixture is used in concrete, add separately 1n accordance with Supplier's instruction to prevent interference with admixture deficiency or concrete quality

Production of Concrete

Site-Mixed Concrete

Mix in batch mixer capable of combining aggregates, cement, and water into uniform mass

Discharge concrete without segregation

Temperature

If temperature on site more than 30°C the temperatu re of concrete to be measured

If water or aggregate is heated above 37°C, combine water with aggregate in mixer before cement is added

Do not mix cement with water or mixtures of water and aggregate having temperature greater than 37°C

Do not revive concrete once it has set

Do not re-use spilled concrete

Execution

The procedures for placing of the concrete shall be as follows:

Inspection

Inspection sub-grade for conditions detrimental to work and for specified compacted density

Verify anchors, seats, plates, reinforcement,

Do not proceed with work until unsatisfactory conditions are corrected.

Preparation for Placing Concrete

Remove hardened concrete and foreign materials

Remove water from completed formwork

Verify that reinforcement is secured in place

Verify that expansion joint material, anchors, and other embedded items are in place

Before placing concrete, clean reinforcement of foreign particles or coatings

Curing

After placement, protect concrete from premature drying, excessively hot temperature, and mechanical injury.

Maintain concrete with minimal moisture loss at relative constant temperature for period necessary for hydration and hardening.

Continue curing for seven days minimum or when average compressive strength of job-cured cylinders has reached 70 % of specified strength, moisture retention measures may be terminated.

Supplier Response: Compliant or not Compliant

9 Tower installation

9.1 Securing the work site

The Service Provider will mark out and signal all of its intervention area so as to prohibit access by inadvertence. All safety measures necessary to secure its intervention will be implemented by the Service Provider.
Supplier Response: Compliant or not Compliant

9.2 Assembly

On site, the following will be carried out according to their design:
- blank flanges and bolts (with a minimum of 6 bolts per flange)
- gussets and bolts on the chord frame,
- fish-plate gussets, welded gussets, bent gussets or cross members and diagonals.

The assembly of various elements making up the pylon will be carried out totally respecting the manufacturer's provisions in particular and a not limited to, as regards the assembly and bolt torque scheduling.
Supplier Response: Compliant or not Compliant

9.3 Erection

If the pylon is assembled entirely on the ground, the Service Provider will carry out erection of the pylon in compliance with the manufacturer's provisions.

If the tower is erected using manual labour, the Service Provider will carry out erection of the pylon in compliance with the manufacturer's provisions.

All safety measures necessary for securing its operation will be implemented by the service provider

The Service Provider will ensure the perfect verticality of the pylon for which a tolerance of 1/200 of total height is permitted.
Supplier Response: Compliant or not Compliant

9.4 Attaching

The Service Provider will ensure the assembly and erection of the pylon or its mast(s) in compliance with the manufacturer's provisions.

In the case of guyed elements, the Service Provider will assure Purchaser of the compatibility of the struts that it plans to implement with the radio constraints of the site.
Supplier Response: Compliant or not Compliant