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 applied 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 90 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.
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 (ANSITIA 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.