European Commission
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ANGELHY

Innovative solutions for design and strengthening of telecommunications and transmission lattice towers using large angles from high strength steel and hybrid techniques of angles with FRP strips

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REPORT ON STRUCTURAL TYPOLOGIES FOR TELECOMMUNICATION AND TRANSMISSION TOWERS

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TABLE OF CONTENTS

A. TELECOMMUNICATION TOWERS....1
A.1 Introduction....1
A.2 Square lattice towers....2
A.3 Triangular lattice towers....4
A.4 Polygonal towers....6
A.5 Lattice towers with angle steels members....8
A.6 Lattice towers with tubular members....12
A.7 Guyed masts....16
A.8 Types of Antennas....19
B. TRANSMISSION TOWERS....21
B.1 Introduction....21
B.2 Structural typologies of transmission towers....23
B.3 Structural typologies of lattice towers....26
B.3.1 General structure....26
B.3.2 Typologies of lattice towers....31
B.3.3 Functions of the transmission towers....37
B.4 Outlook....39
List of Figures....41
List of Tables....41
References....44

A. TELECOMMUNICATION TOWERS

A.1 Introduction

The communication industries have seen a tremendous increase in last years which has resulted in the need for installation of towers to enhance the coverage area and network consistency.

Lattice telecom towers are free standing towers composed of three or four legs and a bracing pattern of their vertical or inclined walls. They resist their own self-weight, the self-weight of the antennas and cables they carry, imposed loads and meteorological loads, especially wind loading.

The tower types are all based on a reinforced concrete foundation and they bear antennas, microwave mirrors, antenna and microwave mirror links, waveguides and the vertical ladder for waveguides. The tower members are entirely hot-dip-galvanized and for this purpose welding must be avoided and all connections must be done by hot-dip-galvanized screws. Welding is allowed only for the construction of the towers' footings, the sections of the climbing stair and the lightning arrester of the towers.

Lattice towers are specifically provided for heights ranging from 20m to 80m. Towers are rated heavy or light, according to their design load. Lattice telecom towers have one advantage over pole type towers. The weight of the lattice tower is distributed over a greater area, which reduces the loads on the foundation and on the ground. The modules of the lattice telecom tower can be assembled one piece at a time and so do not require the use of heavy cranes. A lattice tower can be easily installed even on rough terrain.

The towers may be distinguished in following categories:

I. By plan:
- Square Lattice Towers
- Triangular Lattice Towers

II. By cross section type of legs
- Lattice towers with tubular profile members
- Lattice towers with angle steel members

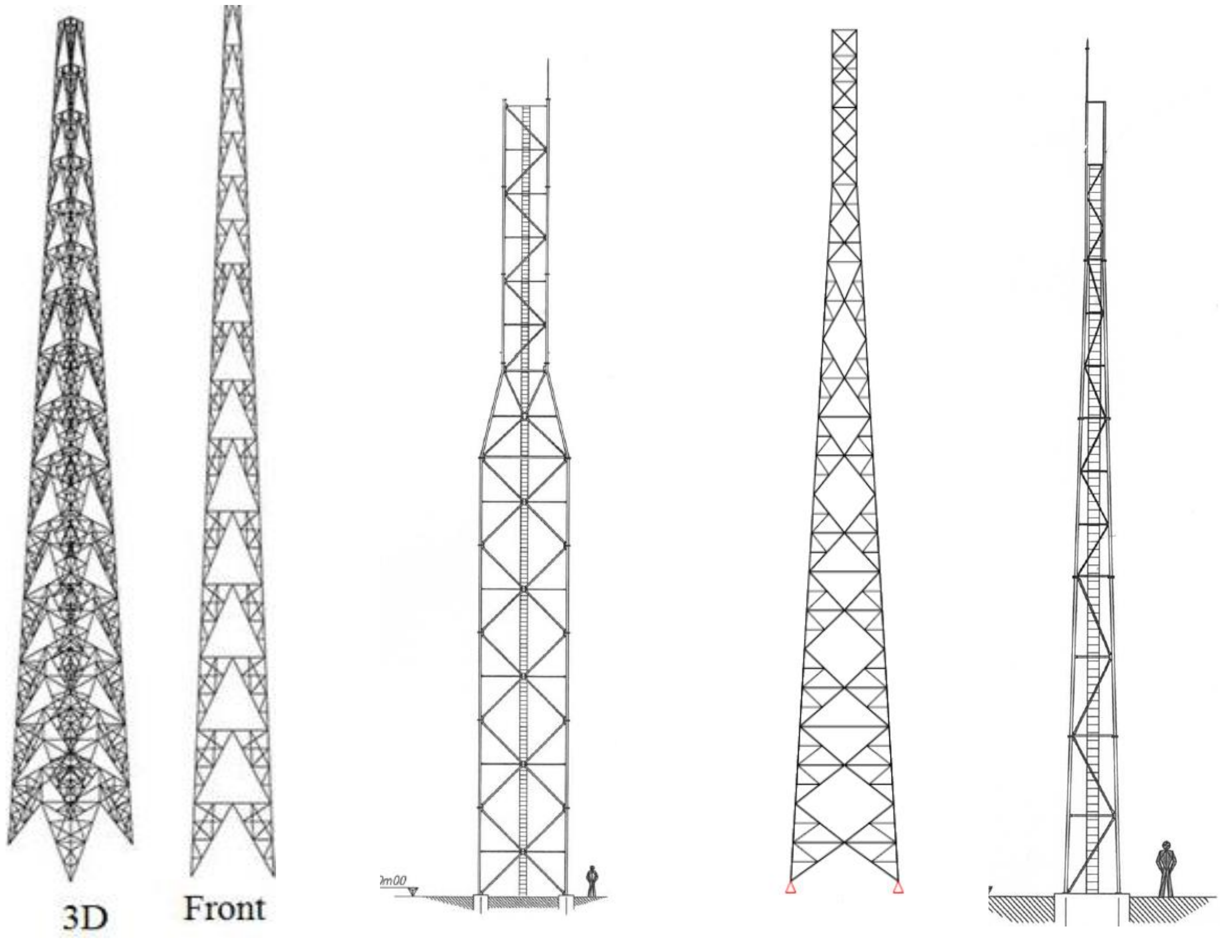
III. Guyed masts

IV. Polygonal towers

A.2 Square lattice towers

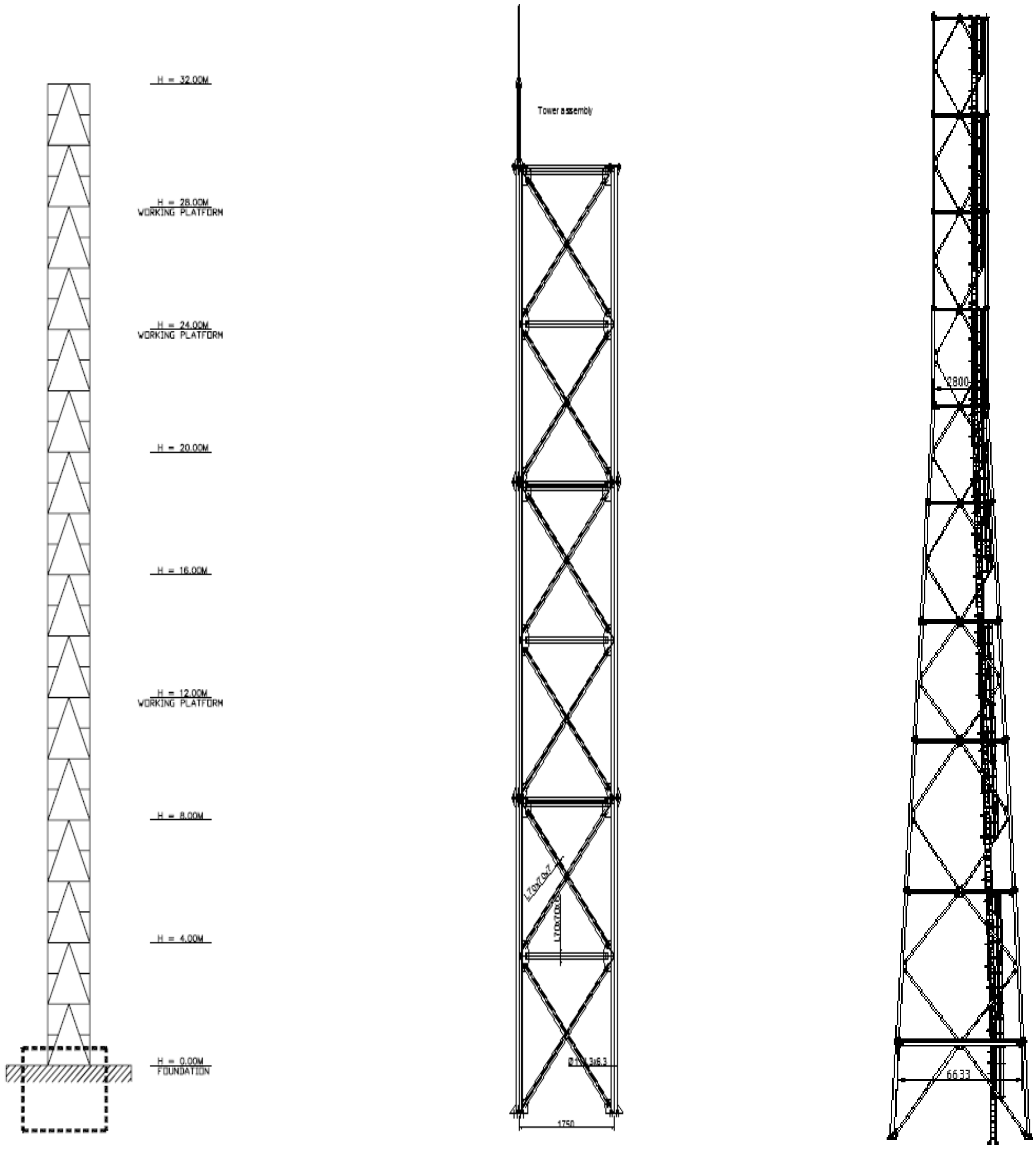
Square lattice towers are square in plan. They are composed of four legs connected by various types of bracings (Figure A2.1). Depending on the height of the tower, the legs may be inclined from the base to the top, may be vertical from the base to the top, or may be inclined from the base up to a certain height and then continue vertical to the top. The inclined part is up to 40 m and then continues to vertical, but this depends on the design. The primary bracing patterns range from inverted V-type, X-type or N-type. Primary bracing is complemented by secondary bracings in various patterns that reduce the buckling length of legs and primary bracing members.

Tower legs and bracings may consist of angle cross sections or tubular cross sections, each one with its own advantages. Angle sections are easier to connect and allow a faster assembly of the overall structure. On the other side, tubular sections attract less wind loading and have better buckling characteristics. Cross section dimensions of the tower members depend on the overall height of the tower and their position within the tower. Angle members are usually hot rolled, but may be cold formed for lighter and shallow towers.



(a) (b) (c) (d)

Figure A2.1: *continued*

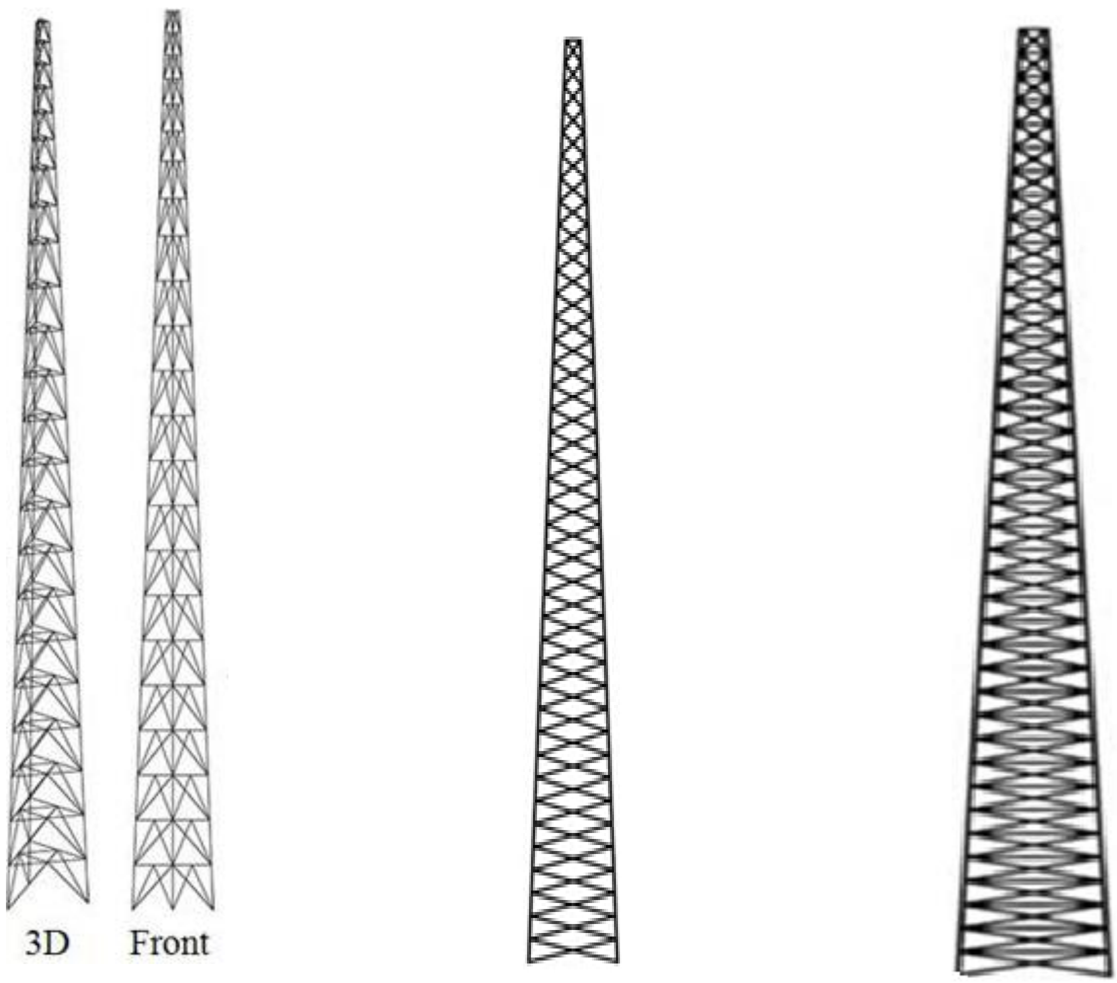


(e) (f) (g)

Figure A2.1: Square Lattice towers

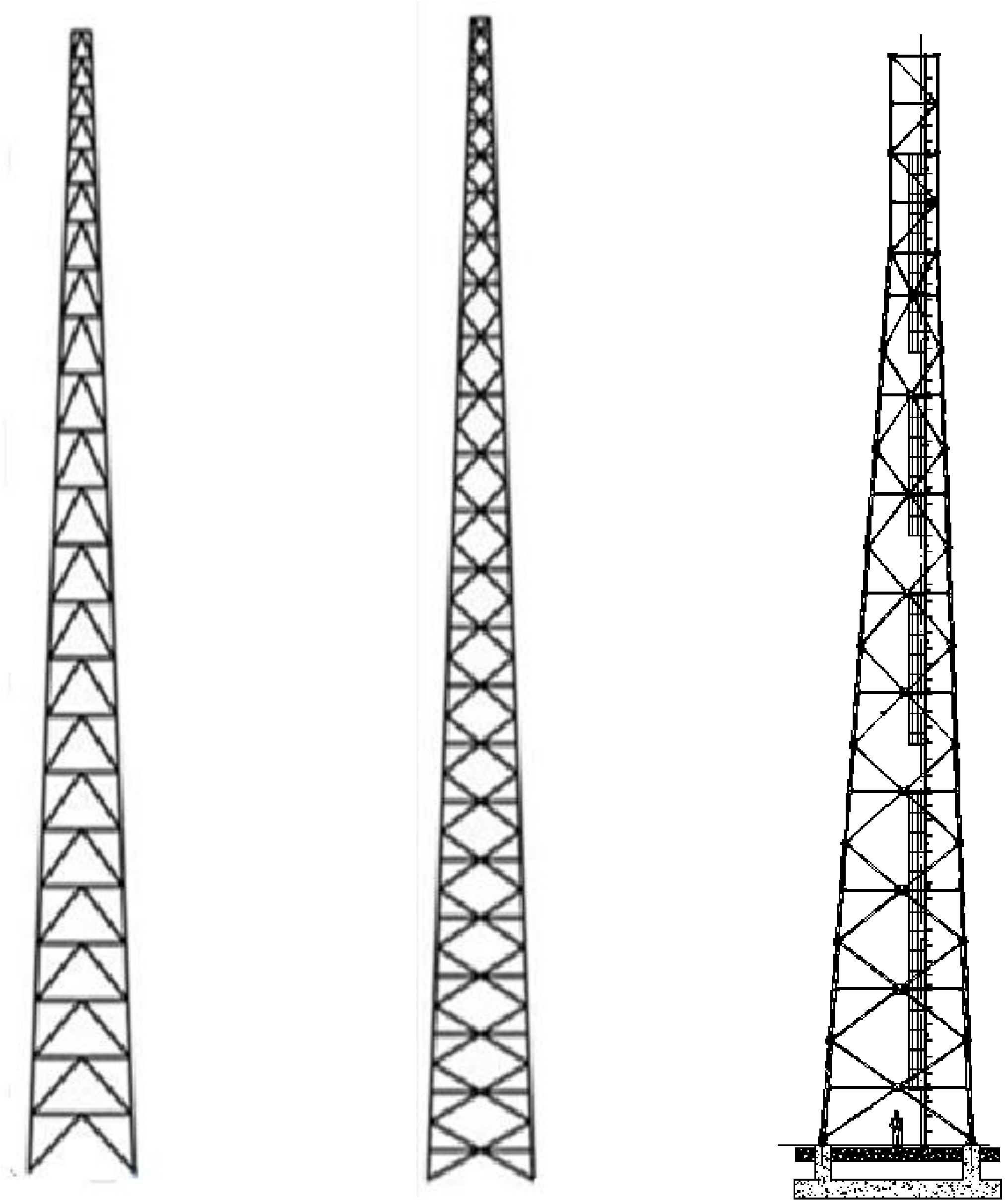
A.3 Triangular lattice towers

Triangular lattice towers have in plan the form of an equilateral triangle. They are composed of three legs at an angle of 120^0 connected by various types of bracings (Figure A3.1). The legs are mostly inclined from the base to the top, but for smaller heights they may be vertical from the base to the top or be inclined up to a certain height and then continue vertical. The primary bracing patterns range from inverted V-type, X-type or N-type. Primary bracing is complemented by secondary bracings in various patterns that reduce the buckling length of legs and primary bracing members. Triangular tower are torsional stiffer than square towers. However, there is a restriction in the selection of cross sections for leg members to tubular sections that is associated to enhanced assembly effort. Alternatively, cross sections for legs may be angle sections of special type, in which the angle legs are not at a 90 degree angle but at a 60 degree angle. Such cross sections require special fabrication. These types of towers are another alternative for general telecommunication uses. They are designed, manufactured and supplied with a variety of accessories. The support can either be anchor type (Figure A3.1a to e) or stub type (Figure A3.1f).



(a) (b) (c)

Figure A3.1: *continued*



(d) (e) (f)

Figure A3.1: Triangular lattice towers

A.4 **Polygonal towers**

Polygonal towers are self-supported towers of variable width with height up to 30m. Depending on the needs, this type of structures will also be used for the production of towers of 25m, 20m and 15m. The variation of the diameter in dependence of the height is shown in Figure A4.1. The shape of the cross section is a polygon with eight, ten, or sixteen sides (octagonal, decagonal, decahexagonal shape), or it can be circular. Polygonal shapes are easier to produce than tubular ones, since they are formed through bending of plates and welding of the seam.

Level	Mean diameter d
(m)	(mm)
0.5	860.00
1.5	837.14
2.5	814.29
3.5	791.43
4.5	768.57
5.5	745.71
6.5	722.86
7.5	700.00
8.5	677.14
9.5	654.29
10.5	631.43
11.5	608.57
12.5	585.71
13.5	562.86
14.5	540.00
15.5	517.14
16.5	494.29
17.5	471.43
18.5	448.57
19.5	425.71
20.5	402.86
21.5	380.00
22.5	357.14
23.5	334.29
24.5	311.43
25.5	292.50
26.5	168.30
27.5	168.30
28.5	168.30
29.5	168.30

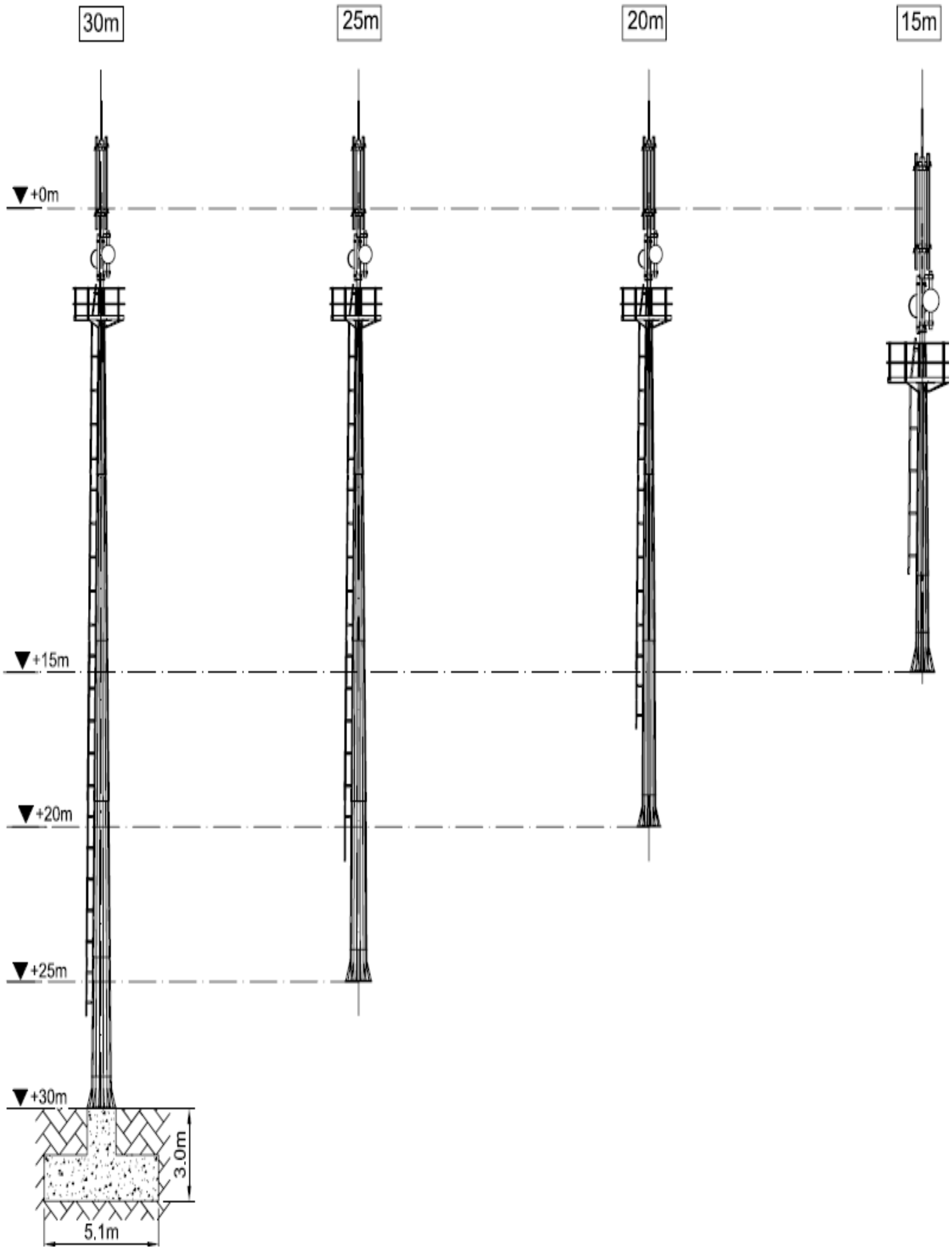


Figure A4.1: *continued*

Figure A4.1: Polygonal Towers

A.5 **Lattice towers with angle steels members**

The dimensions of the towers base with square plan is between 1.50m*1.50m and 12.5m*12.5m. (Figure A5.1a) and the foundation of the structure is a concrete slab C20/25 connecting the legs of the tower. The bottom level of the foundation block is between 1.8m and 2.50m below the ground level. (Figure A5.1b)

At certain distances along the height, diaphragms are provided that act as platform decks. The diaphragm types for square towers with angle members are indicatively shown in Figure A5.2a and b. They consist of UPN or angle sections, forming a rectangular shape which inscribes a rotated square shape, also made of angle sections. The dimensions range from 1.50m*1.50m to 12.5m*12.5m.

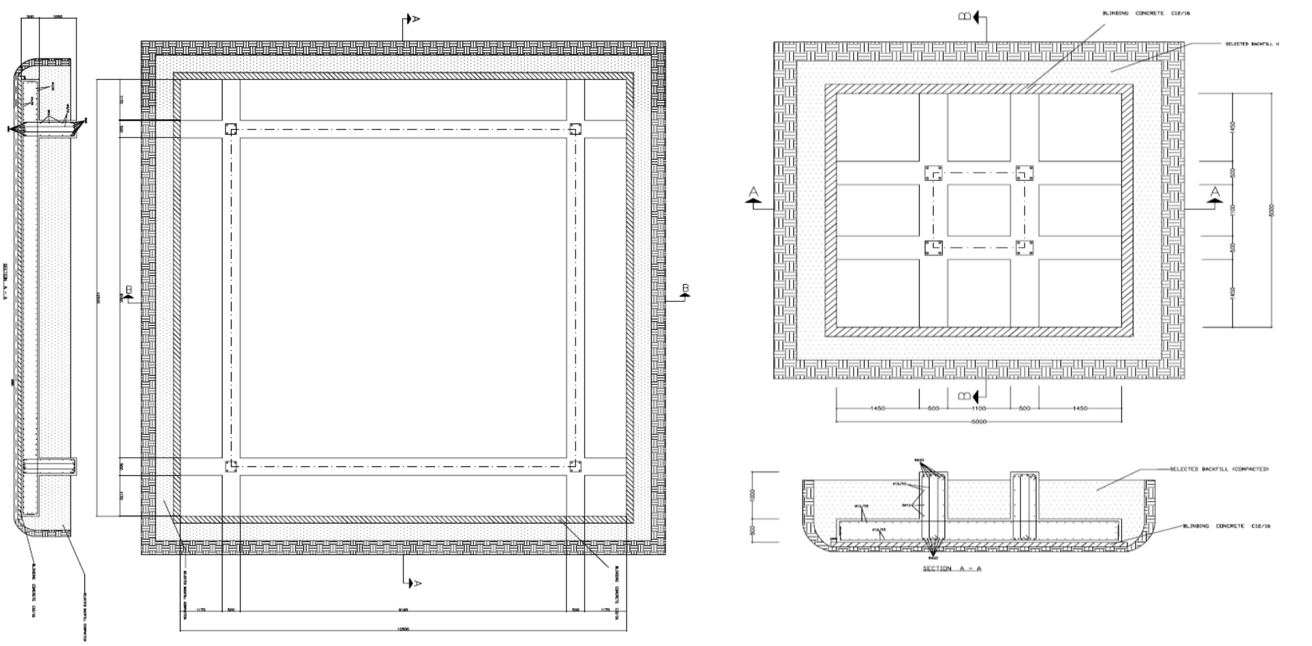
Triangular lattice towers have dimensions at the base between 2.57*2.57*2.57m and 6.4*6.4*6.4m and the bottom level of the foundation block is 2m below the ground level. The legs are made of 60 degrees hot rolled angle profiles and the bracings are made of typical hot rolled angles (Figure A5.3c).

The cross sections (Figure A5.3 a and b) of the structural system contains:

- Angle legs from L80.8 to 200.20
- Angle vertical diagonal-bracings from L70.7 to 110.10
- Angle secondary bracings from L25.5 to 55.5
- Horizontals from UPN 80 to UPN 100
- Horizontal diagonals from UPN and angle sections

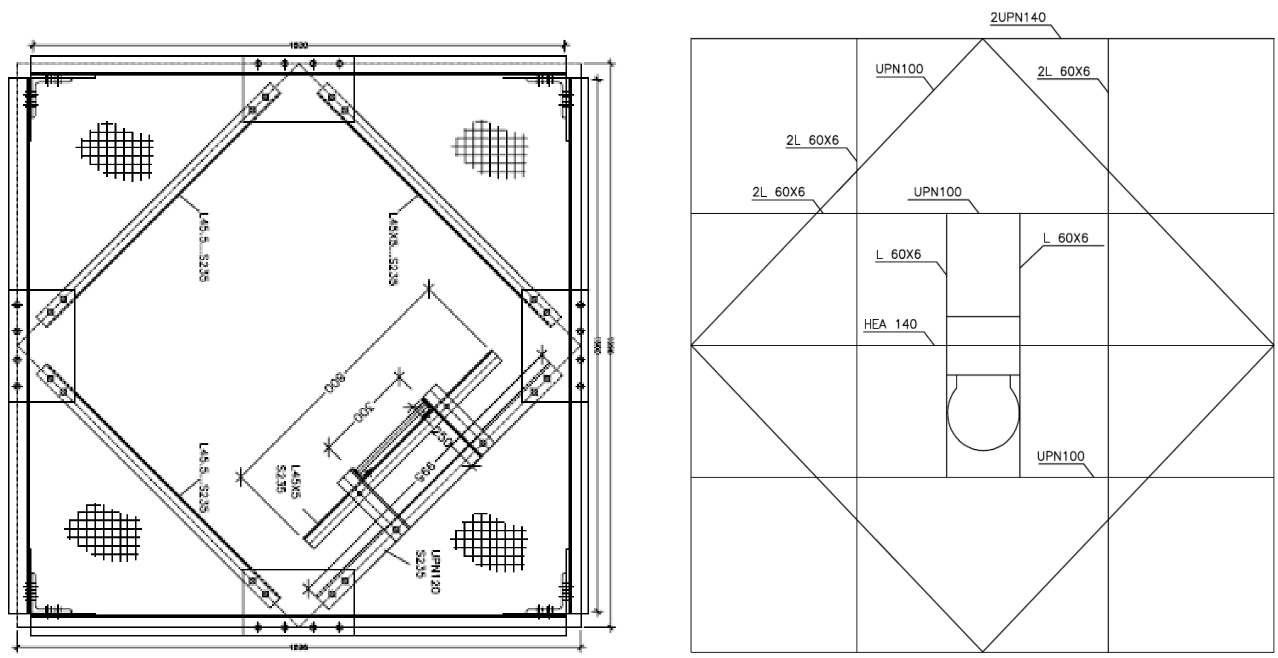
All towers have:

- Vertical access stair, safety ring and devices against back fall
- Resting platforms are placed at certain distances along the height
- Vertical holsters for feeders, electrical cables, night beacon and lightening system
- There are at least 4 triple band antennas symmetrically placed, typically installed at the upper part and parabolic antennas installed at various heights with diameters ranging from 0.3m to 3.2m (Figure A5.4a). Typical installation of the antennas and microwave are shown in Figure A5.4b.



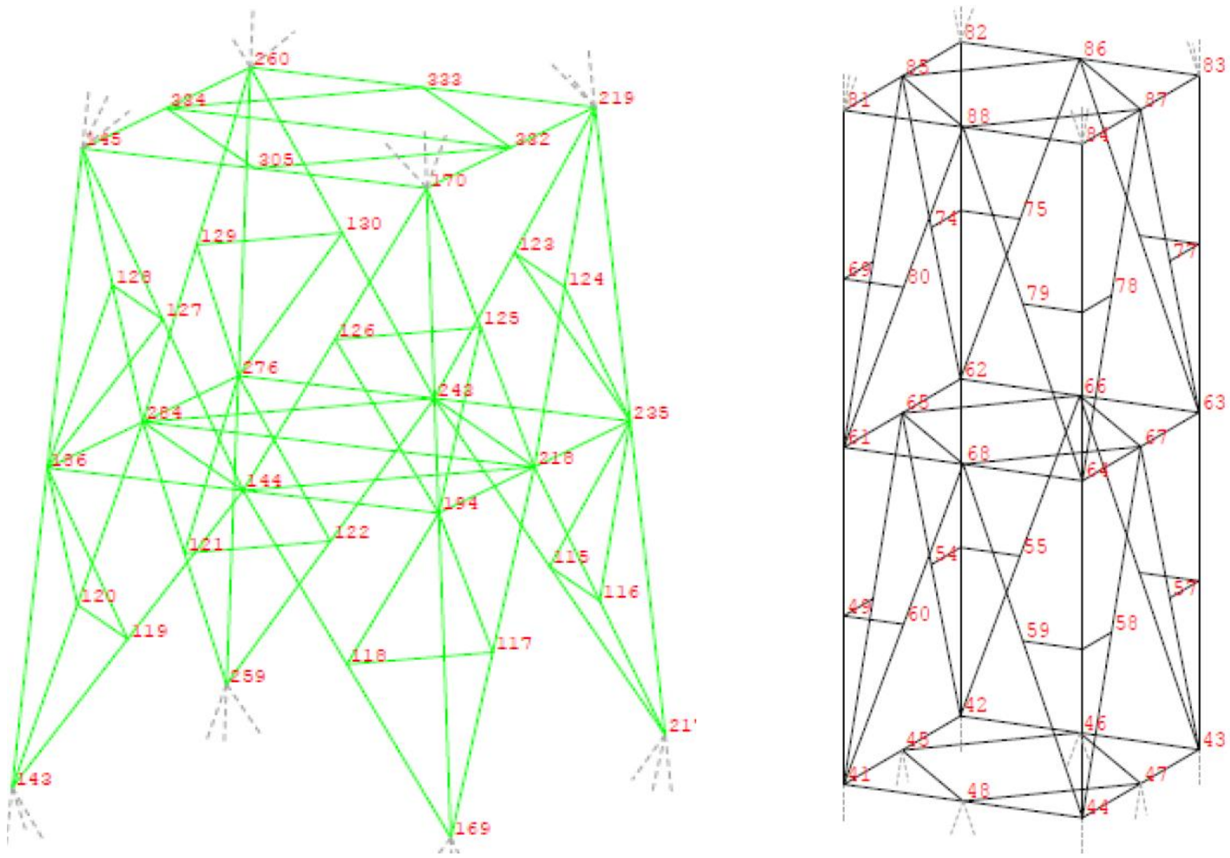
(a) (b)

Figure A5.1: Foundation plan view of towers with angle members

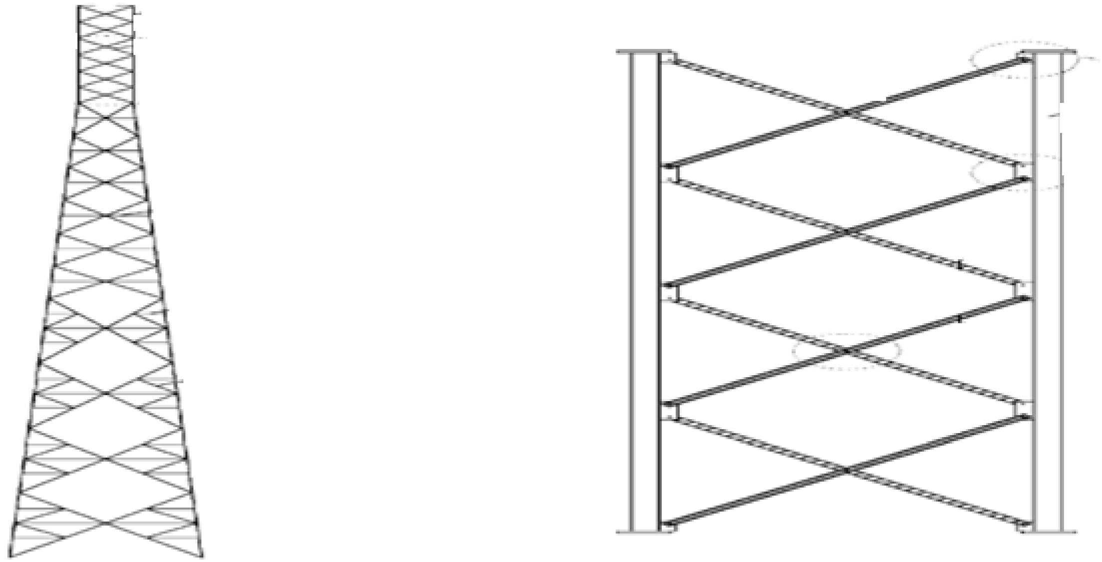


(a) (b)

Figure A5.2: Diaphragm types of angle members

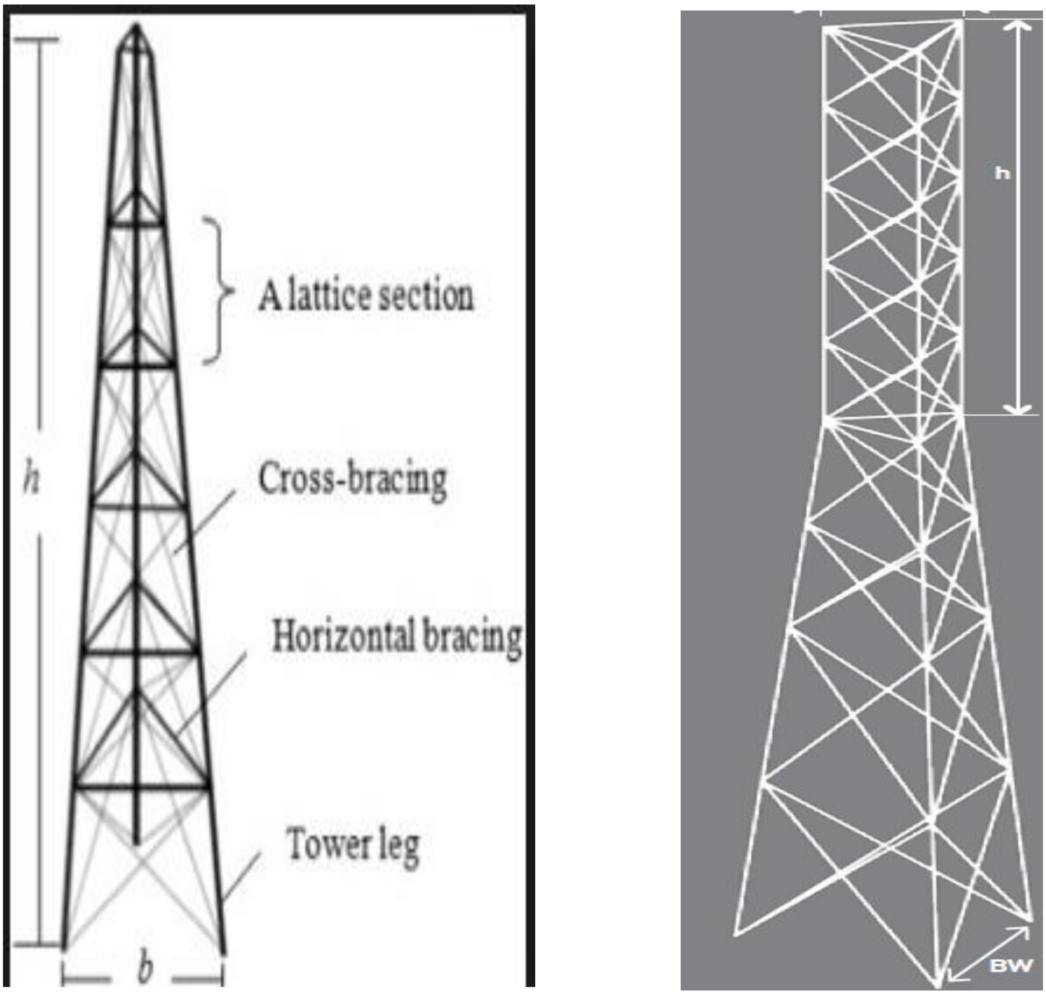


(a)



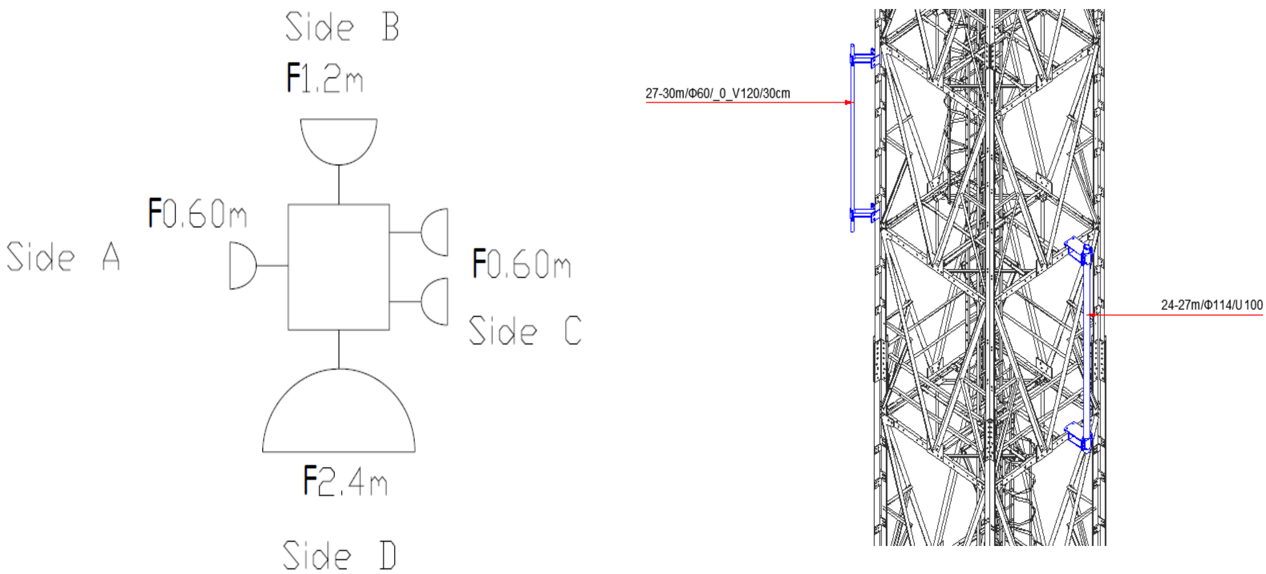
(b)

Figure A5.3: *Continued*



(c)

Figure A5.3: Cross sections of angle members



(a) (b)

Figure A5.4: Details

A.6 **Lattice towers with tubular members**

Square lattice towers have side dimensions at the base between 4.0*4.0m and 10*10m and the bottom level of the foundation block is 2m below the ground level (Figure A6.2).

The diaphragm types for square lattice towers are shown in Figure A6.3 and consist of tubular and angle sections forming a rectangular shape. Inside this shape a rotated square is inscribed.

Triangular lattice towers have dimensions at the base between 1.60*1.60*1.60m to 9*9*9m and the bottom level of the foundation block is 2m below the ground level (Figure A6.1 and A6.2).

The diaphragm types for triangular lattice towers are shown in Figure A6.4, and consist of tubular sections forming a triangular shape. Inside this shape a second triangular shape formation is inscribed. The dimensions range from 1.60*1.60*1.60m to 9*9*9m.

The member diameters are between 42 mm and 127 mm and the thickness of the material is between 4 mm and 14 mm. The connection elements (flanges, angle brackets etc.) have a thickness between 5 mm and 16 mm. Manual welding is permitted and it is compulsory to use coated electrodes type EL 44T (Figure A6.5, Figure A6.6, and Figure A6.7).

All towers have:

- Vertical access stair, safety ring and devices against back fall
- Resting platforms at certain distances along the height
- Vertical holsters for feeders, electrical cables, night beacon and lightening system
- There are at least 4 triple band antennas symmetrically placed, typically installed at the upper part and parabolic antennas installed at various heights with diameters ranging from 0.3m to 3.2m (Figure A5.4).

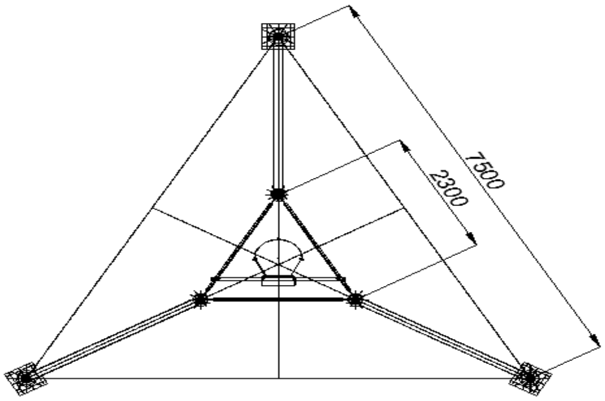


Figure A6.1: Basement plan view of triangular tower and tubular members

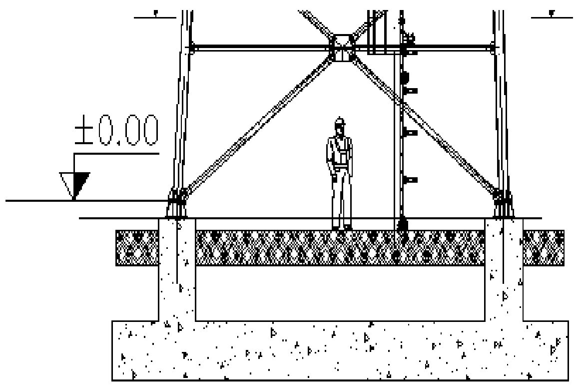


Figure A6.2: Basement plan view of square tower and tubular members

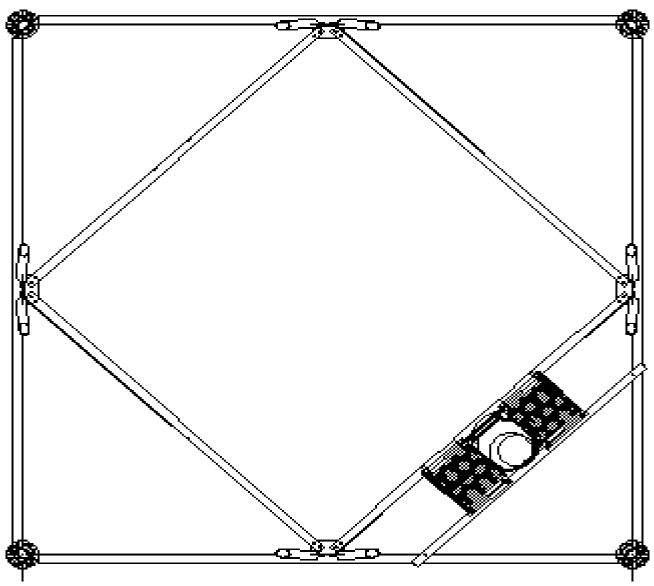


Figure A6.3: Diaphragm types of square tower with tubular members

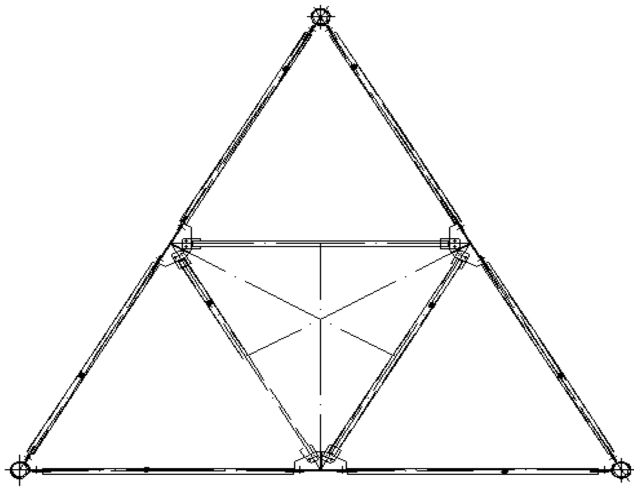


Figure A6.4: Diaphragm types of triangular tower with tubular members

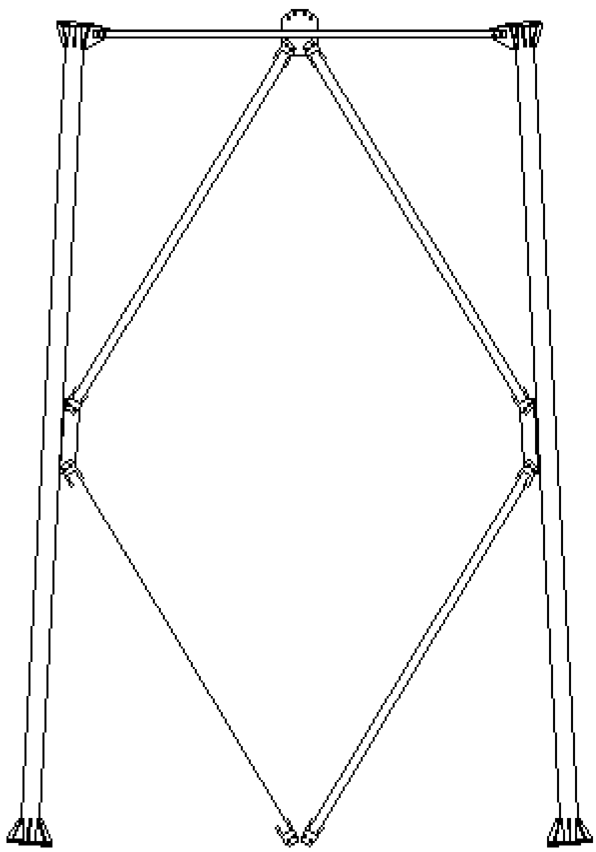


Figure A6.5: Side view of a square tower with tubular members

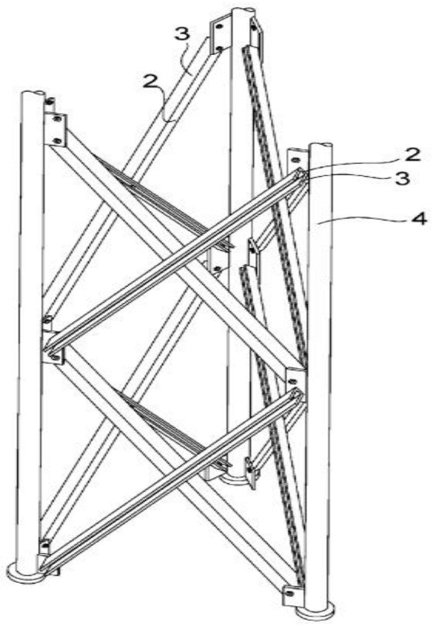
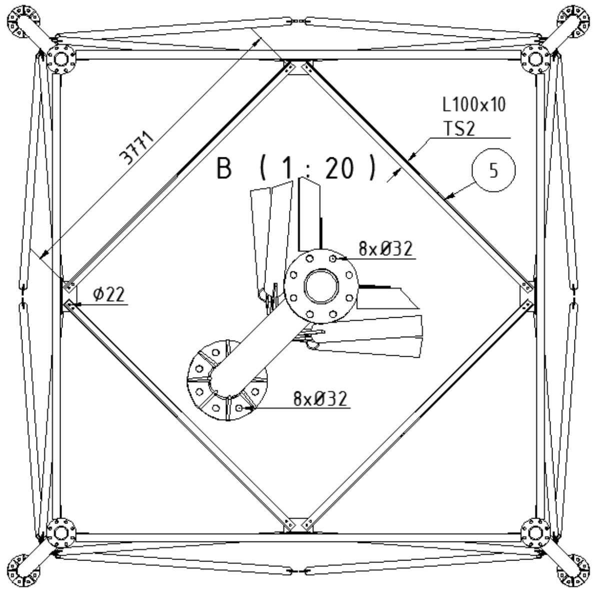


Figure A6.6: 3D-view of a triangular tower with tubular members



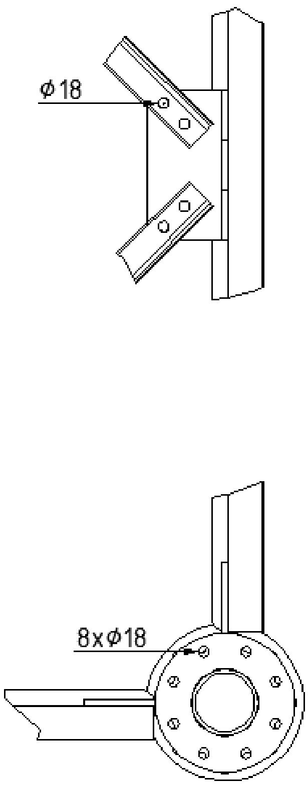
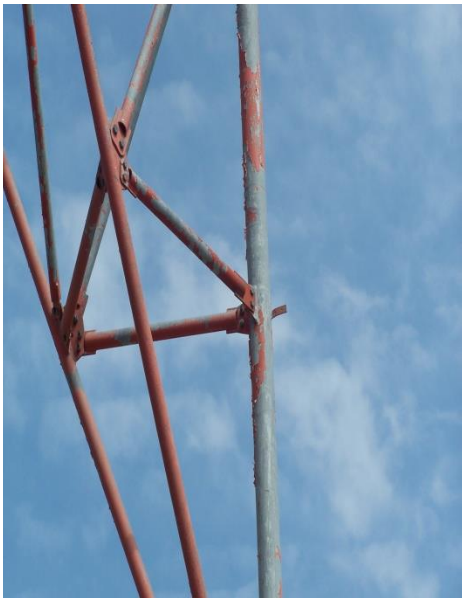


Figure A6.7: *Continued*



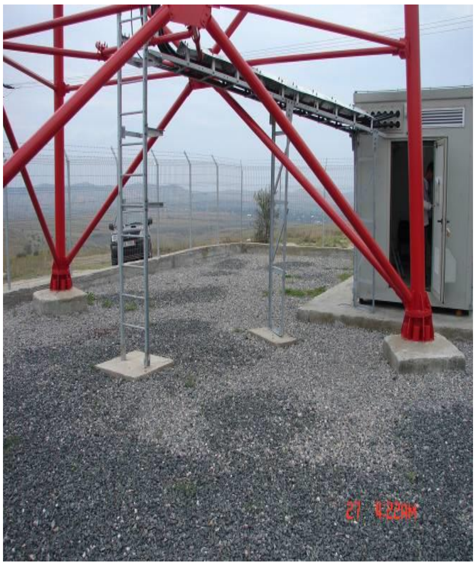
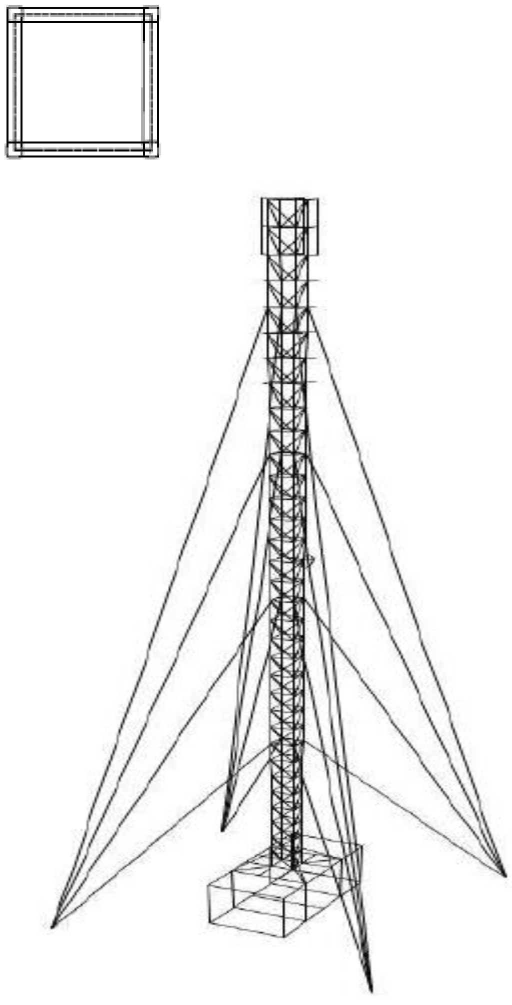


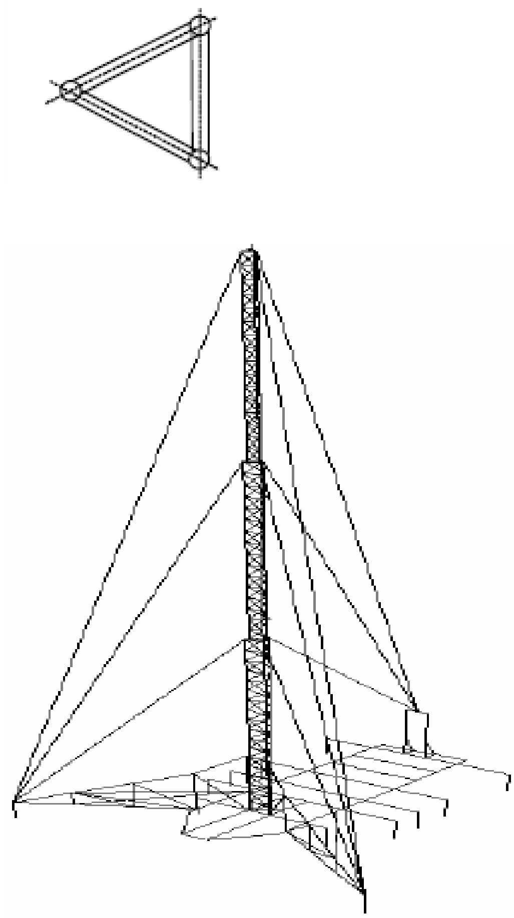
Figure A6.7: Cross sections of tubular members

A.7 Guyed masts

Guyed masts mostly require tailor-made solutions. These structures are supported with a set of steel guyed wires of high strength steel. The guy assembly consists of cables, depending on the system's height. The cables are appropriately pre-stressed. The mast's legs and bracings are made of square hollow sections or angle sections. The masts have a square or triangular plan form and are supported at discrete intervals along the height by guys. The shaft of the mast is made of 3 to 6 m segments assembled at the construction site by bolting. The mast is mounted on a cross-shaped base as shown in the Figures A7.1 and A7.2. The base consists of four 2-dimensional trusses that expand as far as the guys do. The lower end of the guys is anchored to those trusses and suitable counterweights (prefabricated concrete elements) are applied at the same position in order to keep the structure steady. A steel waveguide rack is placed along the full height of the mast. An ascension ladder is provided as well, covering the total height of the mast. For higher masts where the guys are anchored far from the masts base, the trusses do not exist and all guys are anchored separately.

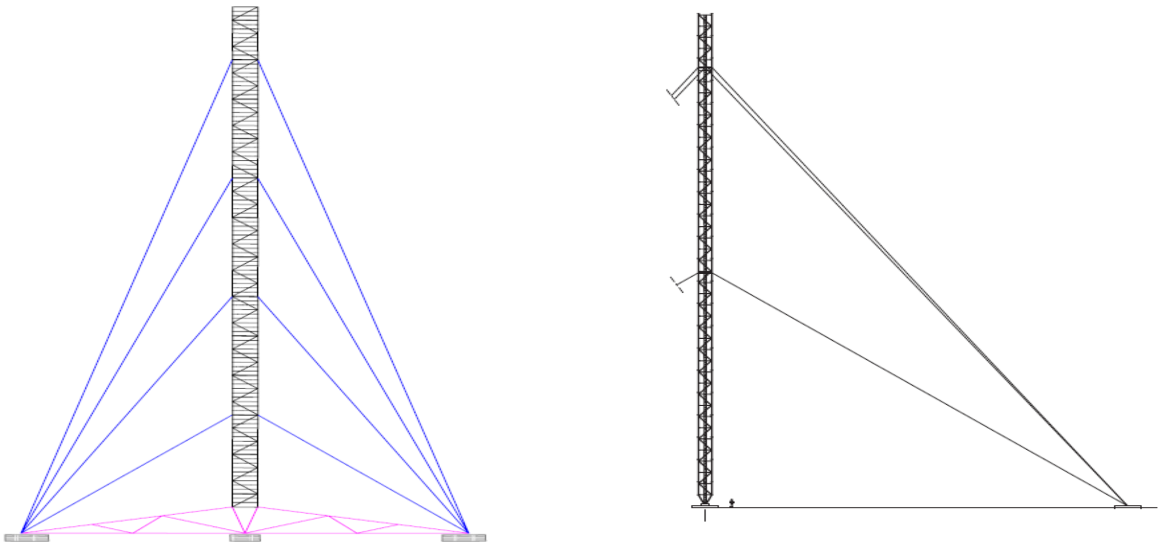


(a) Square mast



(b) Triangular mast

Figure A7.1: *Continued*



(c) Square mast (d) Square or triangular mast

Figure A7.1: Typologies of guyed masts

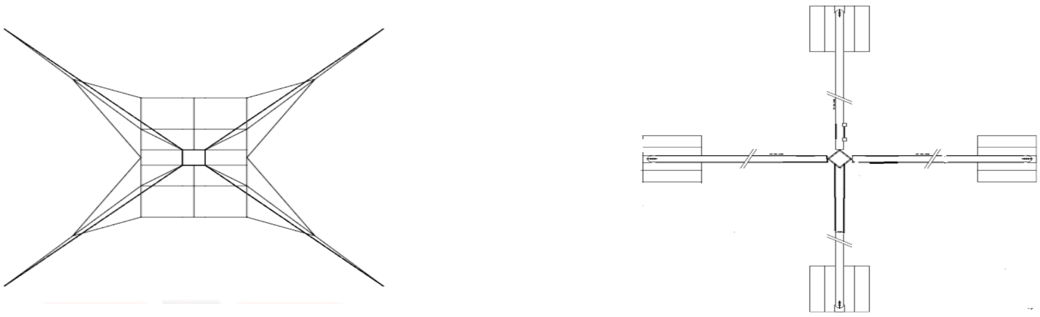
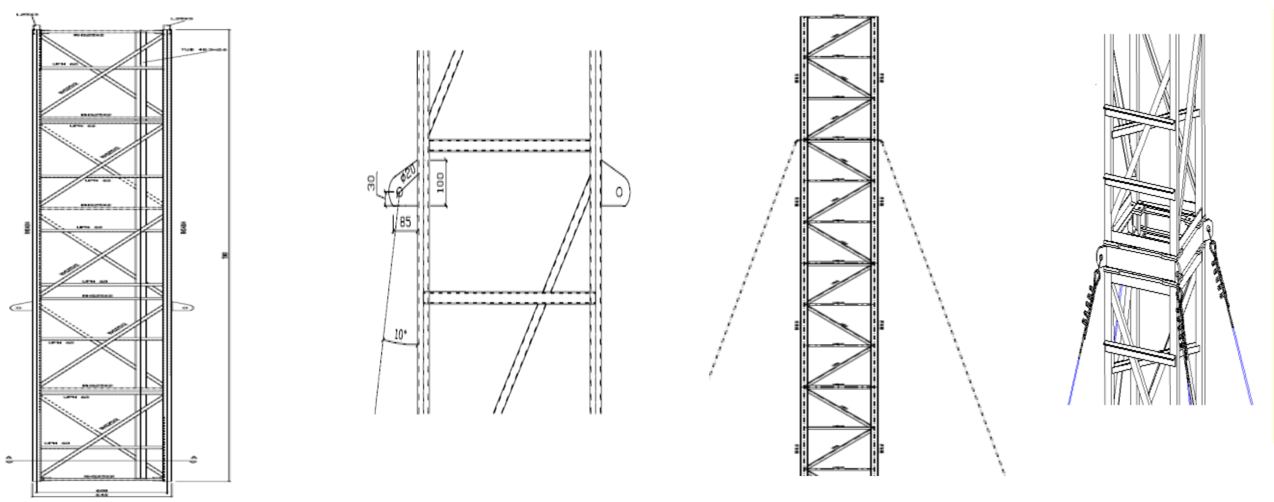
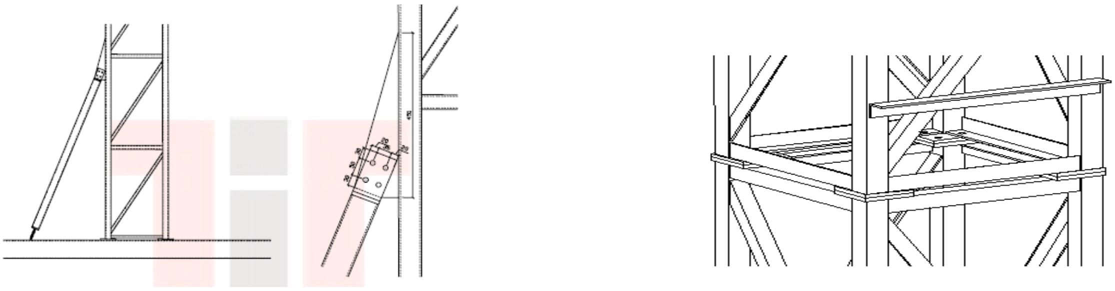


Figure A7.2: Foundation plan view



(a) (b)

Figure A7.3: *Continued*



(c) (d)

Figure A7.3: Views of masts with legs from square hollow sections and bracings from angle steel members

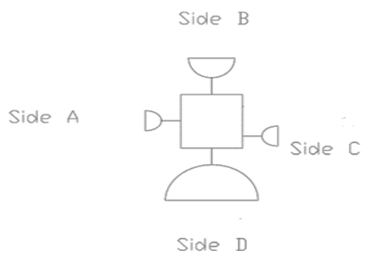
Figure A7.4: Views and details of guyed masts

A.8 Types of Antennas

On the towers, triple band antennas are installed symmetrically, placed typically at the upper part and parabolic antennas are installed at various heights with diameters ranging from 0.3m to 3.7m. The most common types of such installations are shown in the following Table A.1.

Table A.1: Antennas and microwaves on different heights and types of towers

Typologies of towers	Height	Radio anntennas	Microwave	Installation Heights		
				A	B	C
Guyed masts	40	4	6 Φ1.20m	37	35	33
	37	4	6 Φ1.20m	34	32	30
	34	4	6 Φ1.20m	31	29	27
	31	4	6 Φ1.20m	28	26	24
	28	4	6 Φ1.20m	25	23	21
Light Lattice Towers	66	4	8 Φ3.0m	63	60	
	60	4	8 Φ3.0m	57	54	
	54	4	8 Φ3.0m	51	48	
	48	4	8 Φ3.0m	45	42	
	42	4	8 Φ3.0m	39	36	
	36	4	8 Φ3.0m	33	30	
	30	4	8 Φ3.0m	27	24	
Heavy Lattice Towers	66	4	8 Φ1.8m	63	60	
	60	4	8 Φ1.8m	57	54	
	54	4	8 Φ1.8m	51	48	
	48	4	8 Φ1.8m	45	42	
	42	4	8 Φ1.8m	39	36	
	36	4	8 Φ1.8m	33	30	
	30	4	8 Φ1.8m	27	24	
1.60 x 1.60	32	4	1 Φ2.4m, 1 Φ1.2m, 3Φ0.6m	28		
Polygonal	30	4	2 Φ0.6m	27		
	25	4	2 Φ0.6m	21		



DIAMETER MICROWAVES	***WEIGHT***
Φ3.7 m	**4.50 kN**
Φ3.0 m	**3.50 kN**
Φ2.4 m	**2.30 kN**
Φ1.8 m	**1.90 kN**
Φ1.2 m	**0.80 kN**
Φ0.6 m	**0.50 kN**
Φ0.3 m	**0.40 kN**

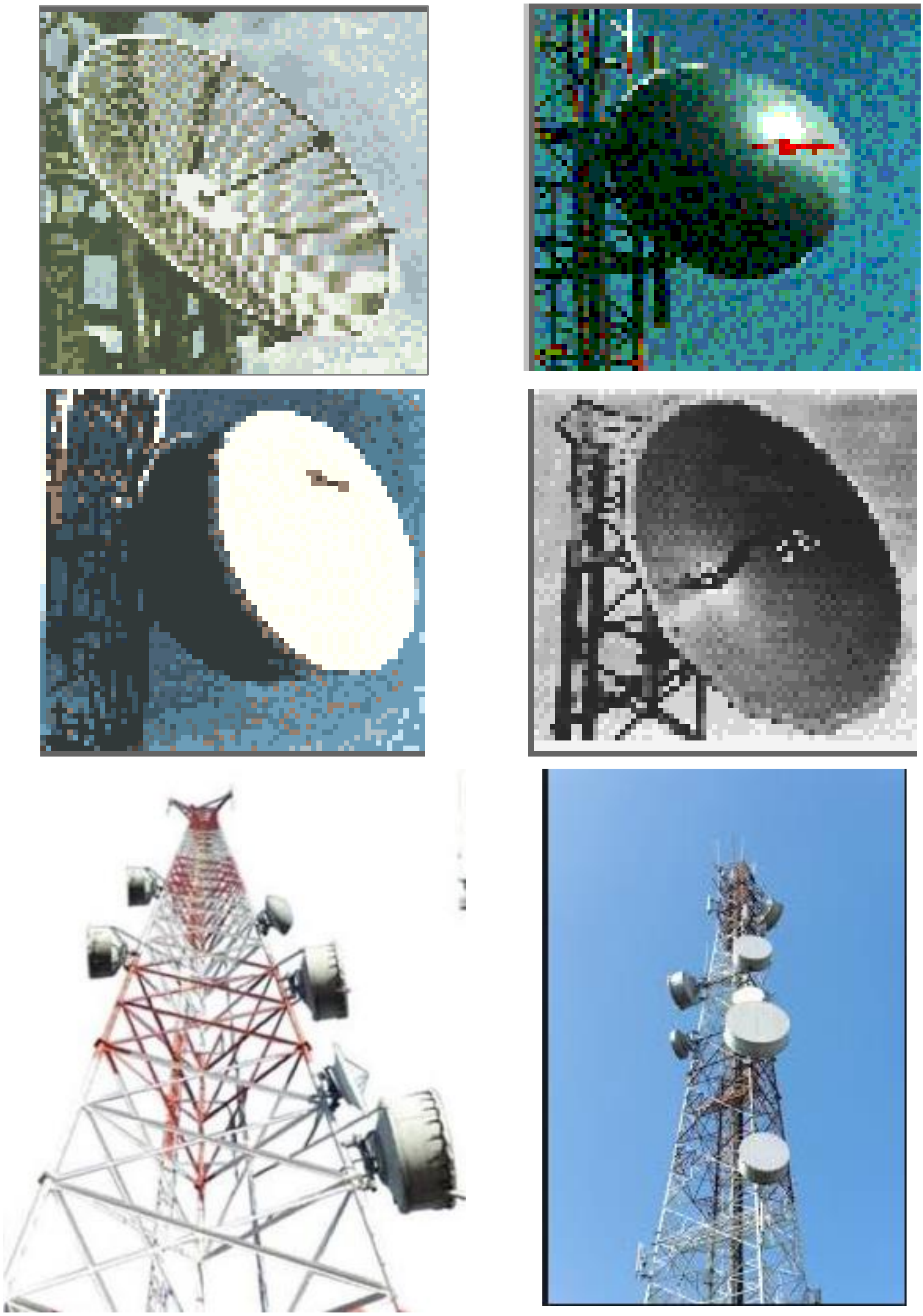


Figure A8.1: Types of antennas

B. TRANSMISSION TOWERS

B.1 Introduction

Transmission towers have been built since the very beginning of the 20th century with the upcoming need to transport electrical energy from the production location to the consumers. A transmission tower consists in a tall self-supporting structure which carries electrical overhead lines. These lines are part of high-voltage CD or AC systems. The function of the supporting structures consists on one hand in the safe transfer of the conductor loads to the ground and on the other hand in ensuring a safety distance between the conductors and the ground as well as between the conductors. The height of the towers or pylons depends on the voltage of the power lines and generally varies in a range between 15 m for low voltage (≤ 1 kV) and 70 m for extra-high voltage lines (> 110 kV). For special purposes, supporting structures exceeding a height of 100 m are realized. These extreme heights are necessary to span obstacles in the axis of the power line such as woods or rivers. The supporting structures of overhead lines can be made of different materials and they can have several typologies: tubular steel towers, steel lattice towers, wooden and concrete pylons. For extra-high voltage lines, mainly steel lattice towers are used nowadays. A typical lattice transmission tower structure is shown in Figure B1.1.

Figure B1.1: Typical structure for a transmission tower for two 110kV circuits

The first regular transmission tower in Europe was erected in 1905 between Moosburg and Munich in Germany. The so called "Moosberg-München power line" was a two-circuit 50kV high-voltage line with conductors made of copper. Each circuit was supported by one cross arm.

The tallest transmission towers in Europe are a group of four lattice transmission towers known as the Elbe Crossing 2 in Schleswig-Holstein, Germany. The towers provide overhead lines for four 380 kV three-phase AC circuits across the river Elbe and two of them have a height of 227 m [7].

They have a base of 45 m x 45 m, a total weight of 980 tons and a span of 1.170 km (Figure B1.2). The dimensions allow the towers to be the sixth high in the world.

Figure B1.2: Elbe Crossing 2 transmission towers

B.2 Structural typologies of transmission towers

As stated in Chapter B.1, different structural typologies of transmission towers are used in dependency of the power line voltage. In this chapter, a brief overview of the types and the materials for transmission towers is given.

- Wood pylons

Wood pylons have a limited height of approximately 30 m. In Europe, they are mainly used for low (≤ 1 kV) and medium voltage circuits (≤ 50 kV). In the USA and Canada, wooden pylons are still used up to a voltage of 345 kV [2]. The wooden pylon consists in one or multiple (H- or K-form) wooden pole with a cross arm on top that carries the conductor and the earth wire (Figure B2.1). The insulators can be installed in a standing or hanging position.

Figure B2.1: Wooden pylon for a mean voltage circuit in the USA

- Tubular steel pylons

Tubular steel pylons are predominantly established for the support of medium voltage circuits. The steel tubes are assembled to the pylon in the work shop and the pylon is transported to the construction site where it is finally erected. The conductors are supported by cross arms connected to the steel pole.

Figure B2.2: Compact pylon for a 100-kV circuit

Over the last years, tubular steel poles have become popular also for high and extra-high voltage lines. The so called “Compact pylons” (Figure B2.2) allow a reduction of the grid width for the same pole height or a reduction of the pole height for the same grid width. In addition, they have a smaller base than conventional lattice towers. However, they are still more expensive than lattice towers and the connection of the different steel tubes requires low tolerances which make out of the mounting phase a complex task.

- Concrete pylons

Concrete pylons are used for operating voltages less than 30 kV. The typology is like the wooden pylons: the conductors are supported by concrete cross arms connected to the concrete pole (Figure B2.3(a)). The poles are prefabricated in the concrete work shop and mounted on the construction site.

Only in exceptional cases, concrete pylons with a height over 60 m are erected for supporting high and extra-high operating voltage circuits. These concrete pylons resemble to chimneys and are made of in-situ concrete (Figure B2.3(b)).

(a) (b)

Figure B2.3: (a) Concrete pylons for 20 kV; (b) Concrete pylons for 500 kV

- Lattice towers

Lattice towers are used for all ranges of voltages and they are the most common towers types for high-voltage transmission lines. Lattice towers are mainly made of hot-dip galvanized steel angle profiles which are assembled to form a framework (Figure B2.4). The steel angle profiles are applied as single angle members and/or built-up angles. Hereby the star battened connection is the most commonly used for the leg members whereas the back-to-back configuration is mainly used for the primary diagonals. A detailed description of the design of lattice tower is given in section B.3.1.

The erection of the tower is made on the construction site. First the different modules are preassembled in lying position, then lifted with a crane and finally bolted by assembly operators. Alternatively, the whole tower can be mounted in lying position and then be raised by cable pull. This operation requires a big assembling area and it is therefore only rarely applied. In mountains area, the different modules are often place by helicopter since the mounting area is too confined for cranes. In these cases, often aluminium is used to reduce the weight of the structure. This solution is however more expensive than the steel solution and in addition, aluminium has a lower Young's Modulus than steel that must be account for in the design [7].

Different typologies of lattice towers are currently used all over the world. The typology differs between the continents and the corresponding operating voltage of the power lines. The different designs of lattice towers are described in section B.3.2, where the focus is put on the European market.

Figure B2.4: Lattice tower for 380-kV circuit

B.3 Structural typologies of lattice towers

B.3.1 General structure

Steel lattice towers for transmission lines are made of hot-dip galvanized and bolted steel angles profiles which are assembled to form a framework. The bolted connections and gusset plates allow a modular construction of the tower and simplifies its erection at the construction site (Figure B3.1).

Figure B3.1: Modular construction with bolted connections

Welded connections are not used in lattice towers, as they would complicate its mounting. Only in rare cases, built-up angles made of welded single angles are applied in transmission towers.

The galvanization of the angle profiles ensures a corrosion protection over the whole life-time of the transmission tower, which is generally indicated in 80 to 100 years.

In general, the tower structure can be subdivided into four main parts:

- The tower body
- The cross arms
- The earth wire support
- The foundations

The tower body:

The tower body is the main part of the tower. It consists in general of 4 leg members and a primary and secondary bracing system in the vertical and horizontal plane (Figure B3.2).

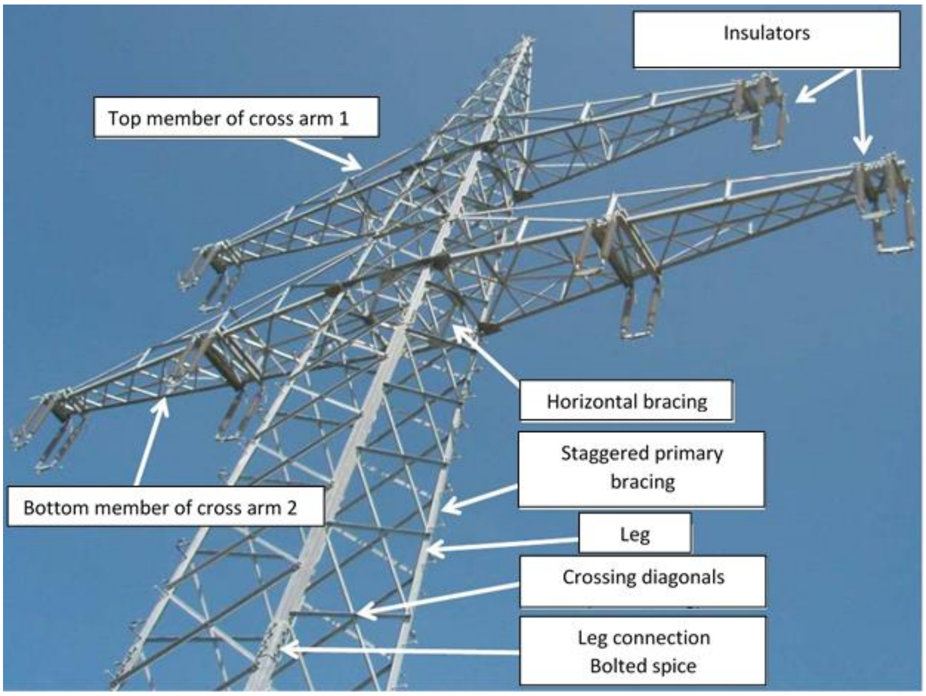


Figure B3.2: Tower body with description of the different elements

The legs run from the foundations of the tower to its top. Single equal leg angle profiles (e.g. L140x10) or built-up angle profiles with smaller angle profiles in star battened configuration are generally applied for the tower legs (e.g. 4 x L80x8). They mainly transfer the self-weight of the structure and therefore the profile size continuously decreases from the lower to the upper modules. Over the height, the tower body is subdivided into several modules which are connected between their leg profiles by bolted splices. This allows a reduction of the delivery length of the leg profiles and a modular mounting of the tower.

The primary bracing system are diagonals that reduce the buckling length of the leg profile and help stabilizing the framework structure (e.g. triangulation) of the tower. They take up the horizontal forces coming from the wind forces acting on the tower body. The diagonals of the primary bracing system are often made of single unequal angle profiles and built-up angle profiles in a back-to-back configuration. They are in general smaller than the leg profiles (e.g. L60x6).

The secondary bracing members are also called redundant members and they are used to reduce the unsupported length of the main legs and primary bracing members to increase buckling stability. In addition, they increase the stiffness of the tower structure. They are commonly made of small equal or unequal angle profiles (e.g. L40x4).

Different lay-outs of the primary and secondary vertical bracing systems are given in Figure B3.3.

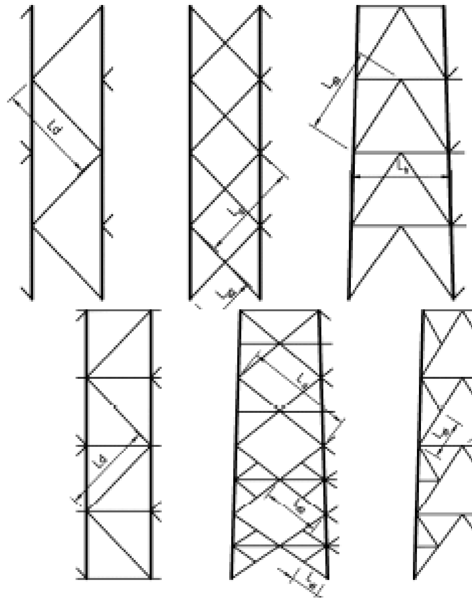


Figure B3.3: Different primary and secondary vertical bracing systems

The type of primary and secondary vertical bracing systems depends on the loads and the height of the tower and commonly varies over the height of the tower. For standard tower geometries as used in Europe, the K-bracing and X-bracing are usually applied for the bottom and the second section of the tower respectively. The upper modules are often braced by a crossing diagonal system. The advantage of the crossing diagonal system consists in the stabilizing effect of the compressed diagonal by the diagonal in tension. A common solution to reduce the buckling length of the legs about the weak axis consist in a staggered bracing system (Figure B3.4). The primary bracings nodes are shifted in two perpendicular framework planes and in this way, the leg profiles are alternately supported in two perpendicular planes.

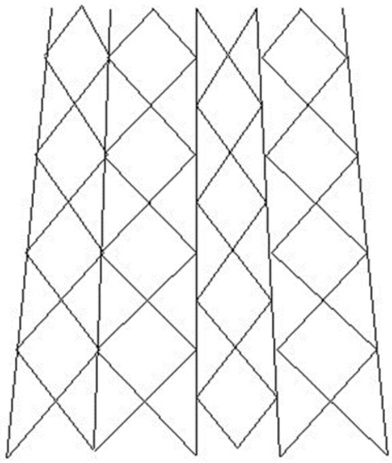


Figure B3.4: Staggered bracing

For large tower bases (ca. 10 m), the primary diagonals of the lower module are often kinked to reduce the buckling length of the bracing systems (Figure B3.5).

High forces raise in the bracing system an additional brace supports are required at the kinked point perpendicular to the framework plane.

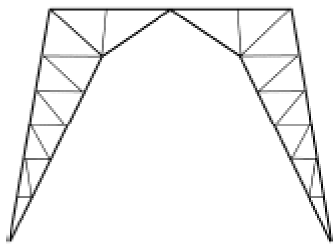


Figure B3.5: Kinked K-bracing

Alternatively, a horizontal bracing can be put at the kinked points to transform the K-bracing into a portal frame system (Figure B3.6). This leads to the loss of the hinge effect of the K-bracing and special verifications become necessary.

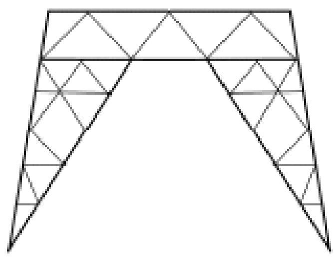


Figure B3.6: Portal frame system

Between two modules and especially in case of a change of the base spreading, the tower is usually stiffened by a horizontal bracing system, also called diaphragm bracing (Figure B3.7).

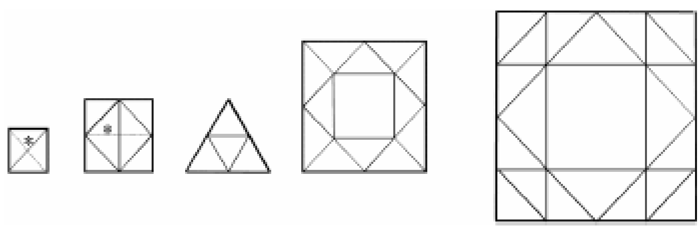


Figure B3.7: Common horizontal bracing systems

The system takes the horizontal forces from wind loading on the tower and transfers them to the four legs. In addition, the horizontal bracing system absorbs the torsional moments generated by an imbalance in the structure (e.g. rupture of one conductor).

The cross arms:

The cross arms are the supporting structure of the insulators and conductors of the power line (Figure B3.8).

Figure B3.8: Cross arms of a lattice tower

They transfer the insulator and conductor loads to the tower body. Depending on the tower type, one, two or even more than three cross arms on the left and right side of the tower are necessary. The length of the cross arms also depends on the tower type and the operating voltage. For high voltage circuits, the clearance between the conductors must be increased and the cross arms become longer. If the three phases of a 380-kV circuit are installed on one single cross arm, the length of the cross arm is about 22 m. This leads to a total width of the transmission tower of approximately 45 m.

The cross arm is constituted of a top and bottom cross arm member which each is connected by bolts to the tower legs. The top and bottom members of the cross arm are braced by a vertical and horizontal system of angle profiles. The size of the angle profiles strongly depends on the tower type and conductor loads. As an alternative to angle profiles, channel profiles are commonly used for the bottom members of cross arms.

The earth wire support:

The earth wire support is the top module of a transmission tower (Figure B3.9) and carries the earth wire. The main role of the earth wire is the protection against lightning. In some cases, the earth wire is made of optical fiber and used as an information transmitter.

Figure B3.9: Earth wire support

The usual heights of the support vary between 5 m and 8 m in function of the tower height and operating voltage of the line. At the earth wire support, the tower legs taper. The legs are commonly braced by a single lattice staggered systems of small single angle profiles (e.g. L50x5). For highly loaded earth wire supports, the bracing is sometimes made of crossing diagonals.

The foundations:

The foundation of the tower depends on the form of the tower, the loading, the type of the soil and the space. The type of foundations which are mainly used in practice are: strip foundations, step foundations, pile foundations and driven pipe pile foundations (Figure B3.10).

Figure B3.10: Step foundation of a lattice tower

The legs are anchored by friction or by separate elements (Figure B3.10, left picture) into the concrete. The elements are usually sticking angles made of common angle profiles.

B.3.2 Typologies of lattice towers

A power grid is several kilometres long and crosses different terrain typologies. The lattice towers are placed in a span of 300 m to 500 m. Depending on the terrain typology, different lattice tower structures are used to overcome the several obstacles (e.g. woods, rivers, railways…) encountered along the grid. In fact, the structure typology differs by the arrangement of the conductors.

In this section, on overview of the different types of lattice towers is given. The different configurations are:

- Anchor portal tower
- Delta tower
- Fir tree tower
- Single plane tower
- Danube tower
- Barrel tower

Anchor portal tower:

Anchor portal towers are a gantry structure supporting the conductor in a switchyard (Figure B3.11). The cross arms are supported by at least two tower bodies. The structure of anchor portal towers is adapted to the high tensions forces in the conductors that need to be anchored in the switchyard [7]. Anchor portals are also used to span over railways as they are less sensitive to vibrations than cross span structures.

Figure B3.11: Anchor portal tower

Delta tower:

In a Delta tower, the cross arm is supported by a V-shaped fork, which offers space for a conductor in the centre line of the tower (Figure B3.12). They are commonly used to support one single circuit (i.e. 3 phases). The delta tower is widely spread in the US, Canada, France, Spain and Italy [7].

Figure B3.12: Delta tower with one circuit

The name dates back to the fact, that the fork with the cross arm resembles the shape of an inverted Delta.

Fir tree tower:

A fir tree tower belongs to the three plane tower typologies. It has three cross arms arranged in three planes on two sides of the tower body. The lower cross arm is longer than the one in the middle which is again longer than the upper cross arm (Figure B3.13). This form is reminiscent of a fir tree. The tower generally carries two circuits whereupon the conductors of each circuit are supported on each side of the cross arms.

Figure B3.13: Fir tree tower

Fir tree towers are tall and the span of the cross arms is reduced. For a 380-kV circuit for instance, the standard height is about 60 m and the span of the cross arm is approximately 20 m. The required width of the protection strip is only 50 m compared to 70 m or 120 m of other tower typologies. Therefore, fire tree towers are mainly erected in areas where the distance of the conductors to the soil is increased and where the width of the protection strip needs to be small (e.g. woods).

Single plane tower:

Single plane towers only have one single cross arm and carry one or two circuits. The phases are supported by the cross arm on the two sides of the tower body (Figure B3.14). The tower is often used in East-Germany for 110-kV circuits.

Figure B3.14: Single plane towers at the airport of Karlsruhe, Germany

The Single Plane tower is used in areas with reduced height prescription like airports. The disadvantage of the tower typology is the wide span of the cross arm (e.g. 40 m) which results in a wide protection strip (e.g. 120 m) and therefore in a huge environmental intervention.

Danube tower:

The Danube tower is the most widely spread tower typology in Europe for 220-kV and 380-kV circuits. The tower has two cross arms arranged in two planes. The lower cross arm is usually longer then the upper one. In general, they support two circuits whose phases are ordered in a triangular shape (Figure B3.15). The upper cross arm carries one phase while the lower one carries two phases.

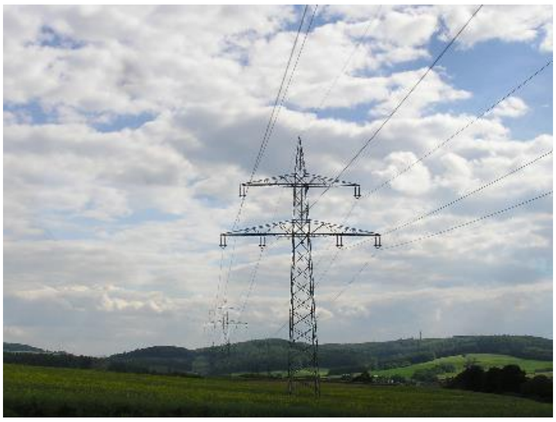


Figure B3.15: Danube tower

The Danube tower is a good economical compromise between the width of the Single Plane tower and the height of the Barrel tower. The first Danube tower for a 100-kV line was erected in 1927 in the Danube Valley near to Regensburg in Germany, therefrom its name [9].

Barrel tower:

Barrel towers have a similar typology than Fir Tree towers. They have three cross arms in three planes and the commonly carry two circuits (Figure B3.16). The median cross arm is longer than the lower and upper cross arms and each cross arm supports 2 phases on each side of the tower body.

Figure B3.16: Barrel tower

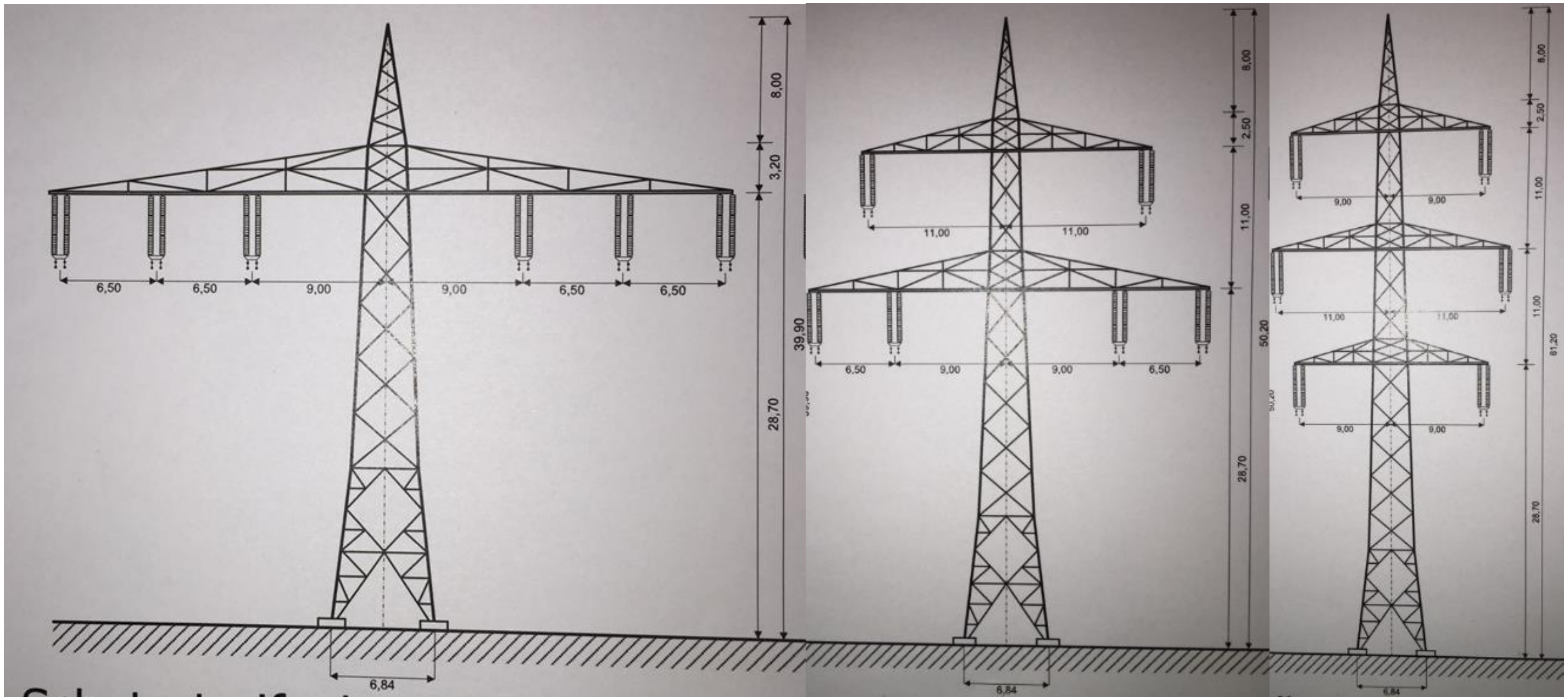
As it is the case for Fir Tree towers, Barrel towers are tall (e.g. 60 m) with a reduced span of the cross arms (e.g. 20 m) and they are applied in areas where big heights and reduced protections strips widths are required (e.g. woods). It is the standard tower typology in the National Grid in the UK.

For some specific applications, special lattice tower typologies have been developed. A brief overview of the most impressive one is given in Figure B3.17.

(a) (b) (c)

Figure B3.17: (a) Hyperbolic tower geometry, Nischni Nowgorod, Russia; (b) 227 m high lattice towers, Elbkreuzung 2, Germany; (c) Special design of transmission towers, Island

The most expanded typologies in Europe for lattice transmission towers of high and extra-high operating voltages are the Single Plane tower, the Danube tower and the Barrel tower. The standard dimensions of these tower typologies for a 380-kV circuit are described in Figure B3.18.



(a) (b) (c)

Figure B3.18: Standard tower dimensions for a 380-kV line: (a) Single Plane; (b) Danube; (c) Barrel

B.3.3 Functions of the transmission towers

The transmission towers can be categorized by the way they support the line conductors [10]. In fact, the line grid is composed of transmission towers with different functions to ensure a safe support of the line conductors and to ensure a redundant power line guidance.

Transmission towers can be classified as follows:

- Suspension tower
- Dead-end tower

Suspension tower:

A suspension tower has vertical hanging isolators that carry the conductors (Figure B3.19). The tower is only subjected to the dead-weight loads coming from the conductors and the tower itself and transverse forces caused by wind loading. As the tower does not get any tension forces from the conductors, its design result in lighter structures than for dead-end towers.

Figure B3.19: Suspension tower

Dead-end tower:

Dead-end towers are located at the extremities of each power line, for long spans, at the positions where the line change its direction and in regular distance of a straight line to reduce the cascading tower failures after conductor failure (redundancy).

A dead-end tower uses horizontal strain insulators at the end of the conductors (Figure B3.20). In-line dead-end towers have two sets of strain insulators supporting the line in each direction, with a jumper between the two segments [7]. The tower is subjected to the tension loads in the conductors in addition to the self-weight loads and wind loads. As they transfer the tension forces in the conductors, their tower structure is heavier (e.g. bigger angle profiles and denser bracing systems) and more expensive than for suspension towers.

Figure B3.20: Dead-end towers

B.4 Outlook

The design of transmission towers has nearly remained unchanged over the last one hundred years. Nowadays, steel lattice towers are by far the most applied transmission tower structures in Europe and the rest of the world.
During the last decade however, research has been carried in the field of compact transmission towers. The results are slender monopole transmission towers made of steel tubes (Figure B4.1). Their advantages in comparison to lattice towers are a reduced soil sealing due to smaller foundation areas and a well-accepted visual appearance. Their drawbacks are the high costs, the complex mounting, the corrosion, maintenance, dismantling, the flexibility of use and the disposal.

Figure B4.1: Compact tower

Nevertheless, it is expected, that compact towers will become a potential alternative to lattice transmission towers in the upcoming years.

A new generation of transmission towers is the “like-tubular” lattice tower “VITRUVIO” (Figure B4.2). It has been developed by the Italian steel constructor COLOMBO S.p.A. together with the Italian network operator TERNA.

Figure B4.2: The new “VITRUVIO“ lattice tower in shape of a monopole tower

The octagonal section of the tower is composed by two interconnected structures having a square section placed at 45° (Figure B4.3). The diameter of the section is equivalent to the one of the compact monopole towers.
To safe weight and costs, hot-rolled angle profiles in high strength steel S420M and S460M have been used for the eight leg members.

Figure B4.3: The octagonal section of the “VITRUVIO” tower

All the connections are bolted type and allow an easy assembling of the structure. The erection of the tower can be realized with traditional methods: preassembling by section on the ground and later assembling of the tower by crane or helicopter.
The Vitruvio tower can be enveloped in an external steel cover made of hot-dip galvanized steel panels. The special connection system of the panels is without bolts (Figure B4.4).

Figure B4.4: Dressed tower

The foundation of the tower are single blocks, like for monopole towers, using stubs for connections.

In future, the main part of the electric energy will come from renewable sources, like wind or solar energy and new power lines will be installed to transport the energy from the location of production to the end-consumers (e.g. “Energiewende” in Germany). In addition, older existing lines will be upgraded (from 220 kV to 380 kV) to be inserted in the new grid. This means that existing lattice transmission towers will be reinforced to carry heavier conductors in addition to the new towers that will be built. For the reinforcement of the existing towers, high-strength steel can be used to reduce the weight of the reinforcement measures. For the new towers for the 380 kV-line, single heavy angle profiles can be used for the legs to reach a height of 70 m to 100 m with at the same time sufficient stability. The use of single heavy angle profiles will reduce the time of erection (no need to assemble built-up angles for the legs) and the total weight of the structure.

List of Figures

A. TELECOMMUNICATION TOWERS

Figure A2.1: Square Lattice towers....3
Figure A3.1: Triangular lattice towers....5
Figure A4.1: Polygonal Towers....7
Figure A5.1: Foundation plan view of towers with angle members....9
Figure A5.2: Diaphragm types of angle members....9
Figure A5.3: Cross sections of angle members....11
Figure A5.4: Details....11
Figure A6.1: Basement plan view of triangular tower and tubular members....12
Figure A6.2: Basement plan view of square tower and tubular members....12
Figure A6.3: Diaphragm types of square tower with tubular members....13
Figure A6.4: Diaphragm types of triangular tower with tubular members....13
Figure A6.5: Side view of a square tower with tubular members....13
Figure A6.6: 3D-view of a triangular tower with tubular members....14
Figure A6.7: Cross sections of tubular members....15
Figure A7.1: Typologies of guyed masts....17
Figure A7.2: Foundation plan view....17
Figure A7.3: Views of masts with legs from square hollow sections and bracings from angle steel members....18
Figure A7.4: Views and details of guyed masts....18
Figure A8.1: Types of antennas....20

B. TRANSMISSION TOWERS

Figure B1.1: Typical structure for a transmission tower for two 110kV circuits....21
Figure B1.2: Elbe Crossing 2 transmission towers....22
Figure B2.1: Wooden pylon for a mean voltage circuit in the USA....23
Figure B2.2: Compact pylon for a 100-kV circuit....23
Figure B2.3: (a) Concrete pylons for 20 kV; (b) Concrete pylons for 500 kV....24
Figure B2.4: Lattice tower for 380-kV circuit....25
Figure B3.1: Modular construction with bolted connections....26
Figure B3.2: Tower body with description of the different elements....27
Figure B3.3: Different primary and secondary vertical bracing systems....28
Figure B3.4: Staggered bracing....28
Figure B3.5: Kinked K-bracing....29
Figure B3.6: Portal frame system....29
Figure B3.7: Common horizontal bracing systems....29
Figure B3.8: Cross arms of a lattice tower....30
Figure B3.9: Earth wire support....30
Figure B3.10: Step foundation of a lattice tower....31
Figure B3.11: Anchor portal tower....32
Figure B3.12: Delta tower with one circuit....32
Figure B3.13: Fir tree tower....33
Figure B3.14: Single plane towers at the airport of Karlsruhe, Germany....33
Figure B3.15: Danube tower....34
Figure B3.16: Barrel tower....34
Figure B3.17: (a) Hyperbolic tower geometry, Nischni Nowgorod, Russia; (b) 227 m high lattice towers, Elbkreuzung 2, Germany; (c) Special design of transmission towers, Island....35

Figure B3.18: Standard tower dimensions for a 380-kV line: (a) Single Plane; (b) Danube; (c) Barrel........36
Figure B3.19: Suspension tower........37
Figure B3.20: Dead-end towers........38
Figure B4.1: Compact tower........39
Figure B4.2: The new “VITRUVIO“ lattice tower in shape of a monopole tower........39
Figure B4.3: The octagonal section of the “VITRUVIO” tower........40
Figure B4.4: Dressed tower........40

List of Tables

A. TELECOMMUNICATION TOWERS

Table A.1: Antennas and microwaves on different heights and types of towers 19

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A. TELECOMMUNICATION TOWERS

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