Construction 15

Zibby Kieloch, João B.G.F. Silva, Mauro Gomes Baleeiro,
Mark Lancaster, Marcin Tuzim, and Piotr Wojciechowski

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Z. Kieloch (✉)
Winnipeg, Canada
e-mail: zkieloch@hydro.mb.ca

J.B.G.F. Silva • M.G. Baleeiro • M. Lancaster • M. Tuzim • P. Wojciechowski

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15.1 Introduction

This chapter will address practical aspects of constructing overhead transmission lines. Various aspects of material procurement, inventory control, construction supervision and engineering support during construction are addressed in Chapter 3 "Planning and Management Concepts" of the Green Book and are not addressed here.

Material contained in this Chapter is intended to provide a concise picture of the most common construction activities and installation techniques used in installation of an overhead transmission line. Special attention is being paid to construction activities requiring either high degree of accuracy or those posing high safety risks to construction crews. This Chapter does not address custom type design applications requiring very specialized and rarely used techniques or equipment, as these issues are being addressed by other chapters dealing with either design approaches or material requirements.

15.2 Construction Surveys

Placement of transmission line structures in specific locations as determined during the tower spotting process is critical from legal, environmental and technical perspectives. Field surveys are needed to:

- Establish the limits of the transmission line right-of-way,
- Establish transmission line centre line,
- Identify structure locations including individual legs, anchors, foundations,
- Mark locations/zones where special construction techniques are required (i.e. use of mats to protect the soil or areas requiring hand clearing),
- Identify danger tress for removal.

Accurate locations of structures and their components in the field are important to allow for ease of installation and to provide safe operational performance as intended.

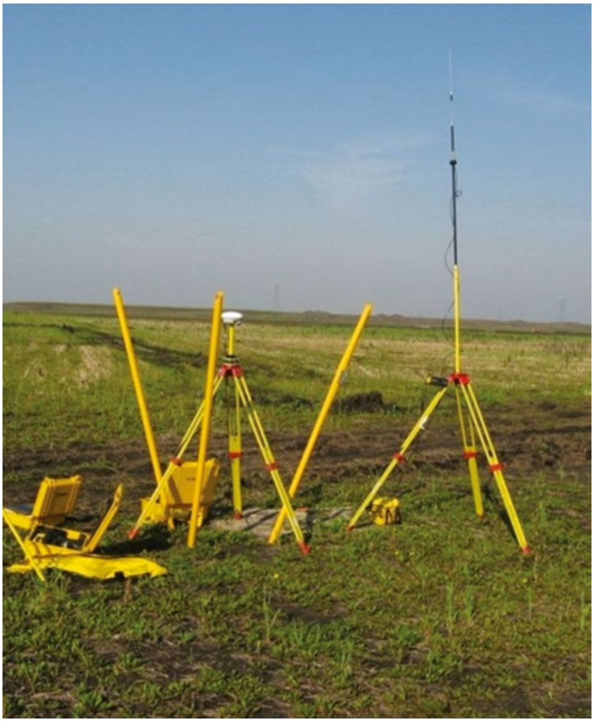

Figure 15.1 Modern electronic equipment used in transmission line surveys.

In the past, field surveys required mostly optical instruments, various manual calculations and intensive labour resources. Presently, some of these tasks are simplified thanks to the use of computerized tools and instruments such as total station equipment or real time kinematics GPS systems based on satellite signals (Figure 15.1). Subsequently, the speed of surveying and the accuracy of work have both improved significantly.

15.3 Right-Of-Way Clearing and Site Access

Transmission line right-of-way may require removal of trees and shrubs to allow for construction activities. In many cases, vegetation is allowed within a transmission line right-of-way providing it is controlled and does not lead to operational problems (i.e. tree contacts with an energized conductor leading to line outages).

Various techniques are used in the right-of-way clearing depending on site specific requirements and license conditions. They range from the use of shear blades to remove most of the vegetation to the use of chain saws to remove individual trees. In some cases, vegetation clearing is done at the structure locations only. In other cases, no vegetation clearing is allowed at all and so called “tree canopy” towers are used with the conductor hanging above the tree tops.

In some cases, selective clearing is used to minimize negative effects on the environment. This may be required at the stream, lake or river crossing or at any environmentally sensitive locations. Selective clearing may be done by hand clearing using chain saws or by use of specialized equipment such as feller-bunchers (Figure 15.2).

Removal of the cut trees/vegetation will depend on the conditions of the project licence. In some cases, trees are cut and sold as merchantable timber. In other cases, trees and shrubs are chipped/mulched down and disposed at the job site or within the right-of-way.

Access to a new transmission line right-of-way needs to be provided for the construction activities. In many cases, temporary access roads are developed to bring in required materials and construction equipment. In some cases, these temporary access roads are within a right-of-way and they continue to be used later by asset owners for maintenance purposes.

Site access may be limited to specific periods of time due to either environmental constrains or terrain conditions. In some areas with poor terrain such as swamps or permafrost, access may be restricted to winter months only with frozen conditions allowing the use of heavy equipment. An example of such conditions is shown in the photograph below (Figure 15.3).

Other measures to help gain access to the transmission line construction site include the use of soil mats to minimize damage to the soil or the use of helicopters. In very remote areas, difficult terrain conditions or areas with severe restrictions to vehicular traffic, helicopters may be the only option. In order to use helicopters for transportation, special provisions need to be made at the design stage. Often, additional lifting brackets may be required in the tower design (Figure 15.4).

Figure 15.2 Feller buncher used to remove danger trees at the edge of right-of-way.

Figure 15.3 Transportation of heavy construction equipment over a frozen lake.

Figure 15.4 Steel tower lifted by a helicopter and transported to the installation site.

15.4 Foundations

15.4.1 Introduction

This chapter will highlight the main challenges encountered during installation of transmission structure foundations.

Foundations are the most critical components of an overhead transmission line system. They are responsible for transfer of the line loads from the structure onto the soil. They also provide stability of the supporting structure and protection from extensive deformations. Failure of foundations can have catastrophic consequences to the overall transmission line system - often causing prolonged line outages and requirements for extensive rebuilds. In comparison, failures of other components, such as hardware or structural members, can be localized and may not result in line outages at all.

Selection of foundation and anchor options for a given project is done at the design stage. Various foundation design options include:

- Spread footings (concrete, steel or lumber),
- Drilled concrete with reinforcing steel,
- Piles (driven type, screw type, concrete, micropiles, single or group arrangements),
- Direct imbedded foundations,
- Anchors (helical screw, grouted, plate, single or in a group).

In many cases, especially when a transmission line traverses large and diverse environment, foundation designers develop multiple foundation design options allowing the installer to choose the most suitable option as determined at the specific site.

Cigré TB 308 provides a comprehensive overview of various foundation options. TB 308 also contains a foundations installation guide, a review of health and safety concerns as well as an assessment of the environmental impacts and various mitigation measures.

Cigré TB 281 deals with the installation of micropiles and ground anchors which might be good foundation choices in terrain with poor soil conditions or difficult access.

An additional source of good information on foundation installation is the IEEE 977 Standard.

15.4.2 Excavation

The foundation installation process starts with excavation. Usually, a trial pit is excavated at a structure site to identify the soil conditions. In case of guyed towers, multiple pits may be required. Selection of the foundation type is the responsibility of the contractor. However, the final decision generally resides with the site engineer/supervisor who has the right to override the contractor's selection (in cooperation with the foundation designer).

Once the foundation option has been selected, the full excavation process (if applicable) can begin. The work must be performed in a manner ensuring due stability of the foundation holes, surroundings (trees, roads, buildings, etc.) and safety of people.

Hydraulic excavators, such as the one shown in Figure 15.5 are often used for the excavation in normal soils such as clay. Excavations with unshielded walls may only be performed in un-saturated soils and while maintaining safe wall inclination.

In more loose soils, internal sheeting, as shown in Figure 15.6, can be used to keep open access to the excavation hole. The main load-bearing elements of the structure are steel or wooden puncheons, while the elements protecting the soil from falling are made of boards or steel sheets.

The excavated material is removed and stock-piled. It can be later used as a fill but not as compacting material.

If in the course of the foundation works the excavation is made too deep, it should not be filled with the excavation material, but a concrete or condensed gravel substructure up to the foundation depth needs to be installed. During installation, water should be prevented from entering the foundation excavation. When required, an appropriate drainage system is used to lower the ground water level without causing decrease in the load-bearing parameters of the surrounding soils or negative impact on the environment or surrounding infrastructure.

Figure 15.5 Hydraulic excavator during the work of strengthening the foundation of 110 kV OHL.

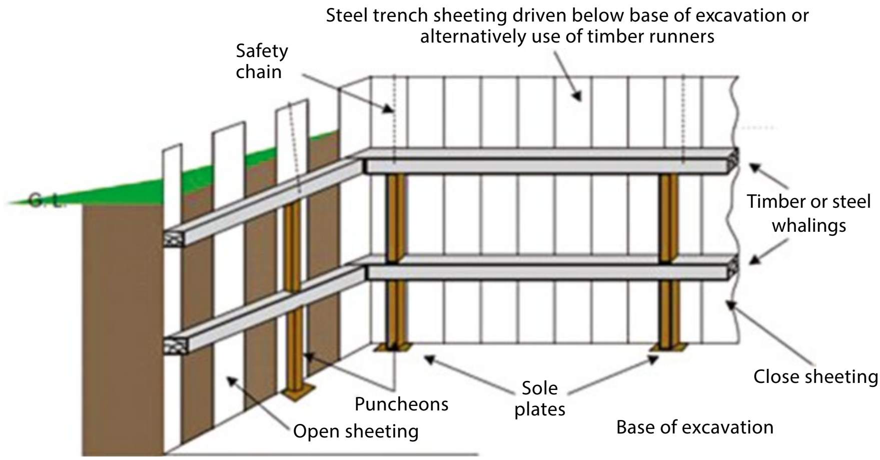

Figure 15.6 A view of an properly made excavation sheeting.

In very dense soils, heavy duty excavators are used. In rock, hydraulic hammers or explosives may be required.

Other construction equipment used in excavations include: trucks, energy generators, vibration plates, jumping jacks, vibration hammers, levelers, etc.

15.4.3 Concrete and Reinforcement Works

Concrete foundations are used on overhead transmission lines worldwide. Their popularity is due to ease of design, ease of obtaining base materials (cement, sand, water) and low installation costs.

15.4.3.1 Reinforcement

Foundation stub angles get positioned in the excavation prior to insertion of steel reinforcement. Proper alignment of the steel stub angles is critical in successful tower installation and can be achieved by the use of rigid steel leg templates reproducing the position of all four tower legs in relation to each other or by the use of independent concrete slabs to which individual stub angle is attached.

The reinforcement bars/rods should be free from visible defects and damage, clear from excessive amounts of rust, mud and other dirt. The bars should be joined by means of tie wire or welding. To ensure proper setbacks, plastic distance holders providing minimum distance between the reinforcement and the formwork are used. An additional procedure increasing the firmness of ready-made reinforcement cages and protecting it from canting during installation or concrete works, is to use additional inclined bars along and across the mounted reinforcement cases.

15.4.3.2 Concrete Mixing and Placement

The concrete used in foundation works may be mixed directly on site or brought in or from the concrete mixing plant. If mixed at the job site, the following measures must be taken:

- Proper storage for cement, sand, stone, aggregate, and water is required,
- Silos used for bulk storage of cement should be weatherproof and protected from dust pollution,
- Bagged cement should be stored to prevent it becoming damp and used in the same order as delivered,
- Cement that is adversely affected by damp should not be used,
- Aggregate storage areas should have adequate drainage,
- Water should be protected against contamination.

If produced at the concrete mixing plant, mixing of the concrete should be done with the use of machines preventing its fractions from separating and its consistency from changing. For longdistance transport of concrete mixes, truck concrete mixers with low rotation speed should be used to prevent segregation of the materials. For short-distance transport on site, conveyor pumps are often used.

Normally, concrete should be placed within two hours after the initial loading in a truck mixer or agitators, or within one hour if non-agitating equipment is used. These periods may be extended or shortened, depending on climatic conditions and whether accelerating admixtures or retarding admixtures have been used. Before the concrete is placed, all rubbish should be removed from the formwork and the faces of the form in contact with the concrete should be cleaned and treated with a suitable release agent.

The quality of the concrete mix can be checked at the job site using a slump test which involves filling a steel cone with concrete mix, removing the cone and then measuring the concrete shape slump. Additional tests include preparation of concrete cubes for strength testing at the lab after 7 and 28 days to verify adequate strength.

The free drop height of the concrete mix should be made as small as possible. It should not exceed 100 cm. The thinner the mix, the smaller should be the height of its drop. With liquid mixes, the height should not exceed 50 cm. In higher trenches, concrete should be placed with the use of tubes, sleeves or chutes. Whatever the method used, the last stretch to be filled with concrete (50 cm) must be vertical and not sloping as this prevents separation of the mix.

15.4.3.3 Concrete Consolidation

Consolidation of the concrete mix is the last procedure but one (before curing) that determines the quality of both the concrete itself and the structure made of that concrete. For this reason:

- the mix must be consolidated until it is compact and homogenous,
- the excavation must be tightly filled, and the reinforcement – precisely coated,
- the surface of the structure should be as smooth and pore-free as possible.

The most widespread method of concrete consolidation is vibration. In practice, internal or external vibrators are used. Vibration lasts for 10–30 seconds, which depends on the consistency and composition of the concrete mix as well as the type and parameters of the vibrator. Vibration should be discontinued as soon as the cement wash appears on the concrete surface.

15.4.3.4 Concrete Curing

Proper concrete curing in essential in achieving desired mechanical parameters. The concrete, particularly in the summer time, requires proper humidity to be maintained. Unrestricted water evaporation can lead to undesired concrete shrinking. Therefore concrete must be protected from water loss due to extensive wind and temperature, using a special curing compound, covering with foil or pouring with water. During rain fresh concrete shall be protected from direct effects of rainwater. During winter the proper maturing conditions for concrete shall be ensured by:

- external warming of the foundation by means of e.g. straw batts, styrofoam,
- using chemical concrete additives shortening the concrete bonding time or increasing its temperature,
- heating the water or the aggregates,
- use of heating rods inside and outside the foundation,
- increasing the cement content, that increases the hydratation temperature.

Concrete works in temperatures below −10 °C is not recommended.

15.4.4 Drilling and Blasting

In some soil conditions, foundation excavation is done by the means of drilling and blasting methods. In stable materials drilling should be to the full depth of the excavation. According to IEEE 977, inspection of the drilling and blasting activity should include monitoring to ensure that survey controls such as tower center monuments, survey hubs, reference points and benchmarks are not distorted or lost.

During such drilling and blasting, work safety procedures must be followed. When blasting are done near existing infrastructures (ie. OHL) or inhabitants, a “heave mat” should be placed over the blast area. This mat prevents or minimizes the danger of rocks impacting existing infrastructures.

15.4.5 Assembly and Setting of Foundations

Accurate placement of foundations and anchors is extremely important to achieve proper installation of the structures while maintaining legal commitments to the affected land owner. Additionally, incorrect installations may lead to undesired visual effects. It is always recommended to use proper surveying techniques.

In order to ensure proper steel tower stub anchor installations in the concrete foundations, steel templates are used. They are usually made of steel angles that are welded to the reinforcement or steel trench sheeting of the foundation. There are ready made holes in templates in order to provide temporary connection with the anchor of the tower. Sometimes, when the foundations are very big, steel truss constructions are used as templates. It is recommended to place and measure all foundations anchors of the tower at one time.

Each country has its own installation tolerances based on their own experiences and local regulations. Some of the tolerances are presented in Cigré TB 308 (Figure 15.7).

15.4.6 Backfilling

Proper compaction of the backfilling is crucial for achieving desired uplift resistance. Most failures of foundations take place due to the tower leg being pulled out and not pressed down (see Figure 15.8). The main principle of using proper backfill is to achieve soil characteristics close to those of natural soil.

The following methods are used to obtain the appropriate condition of the backfill:

- Backfilling should be done by placing backfill in layers,
- Use of proper backfill material which is easy to compact,
- Modification of the structure of the backfill by application of an additive for draining of the moisture (e.g. lime),
- “Fixing” the particulates of cohesionless soil (reducing its deformability) by chemical stabilization, joining with additives, e.g. cement,
- Separating the soil and broken stone levels or reinforcing them by means of reinforcement (e.g. geosynthetics).

The most popular method used in the construction of the overhead power lines is compacting of the backfill. Cohesionless backfill should be placed in layers, approximately 25–35 cm thick, each compacted by vibration plates, jumping jacks or vibration hammers. A commonly used practice enhancing condensation is to damp the filling soil by pouring it with water and its simultaneous compaction. Another method of increasing the load-bearing capacity is the stabilization with cement.

Cohesive soils shall be condensed in layers every 20–25 cm, using non-hammering methods, e.g. tamping rollers after fragmentation of the agglomerated soil or vibration plates instead of hammer-type methods. Damping the filling soil with water is a gross mistake.

The compaction index, typically in the range of 0.96-0.98, is often specified by the foundation designers to be achieved during installation.

15.4.7 Foundation Installation Challenges

Installation of transmission structure foundations presents various challenges and problems. Some of them are:

Country	Face Dimensions	Diagonal Dimensions	Rake of Stub	Stub Levels	Twist of Stub in plan
Belgium (Elia)	Linearly from ± 0 to 10 mm for 0 to 5 m face or diagonal dimensions, then ± 10 to 15 mm for 5 to 15 m face or diagonal dimension.		≤ 5 mm / m	Max. difference between highest and lowest stub ≤ 2 to 5 mm varying linearly between 0 and 12 m face dimensions.	≤ 5 mm / m
France (EDF)	± 10 mm	± 15 mm	Angles ≤ 100 mm 10 mm / m Angles > 100 mm 5 mm / m	Max. difference between each pair of stubs 10 mm.	-0.01< tgα < + 0.02 + towards centre of tower.
Ireland (ESB)	± 5 mm	± 10 mm	Nil – Bottom panel of tower used as stub setting template.	Max. difference in level between all 4 stubs 3 mm; Max. difference between mean level of pairs of diagonally opposite stubs 3 mm.	Nil – Bottom panel of tower used as stub setting template.
Italy (ABB)	± 12 mm or ± 0.2% of face or diagonal dimension.		0.3°	Difference in levels between one stub and a plane passing through other 3 stubs ± 3 mm or 0.1%.	0.5°
Norway (Stanett)	Use of Holding Down Bolts with holes 8 to 10 mm larger than bolt diameter, horizontal tolerance ± 4 / 5mm, vertical maximum difference 3 mm.				
Spain (Red Electrica)	± 0.1% of face dimension	± 0.15% of diagonal dimension	± 5 mm /m	Max. difference in level between all 4 stubs ± 0.01% of diagonal; Max. difference between mean level of pairs of diagonally opposite stubs ±.0.15%.	Not defined
(Iberdrola)	± 6 mm or ± 0.1% of face dimension	± 6 mm or ± 0.1% of diagonal dimension	± 5 mm /m	Max. difference in level between all 4 stubs 3 mm or ± 0.01% of diagonal; Max. difference between mean level of pairs of diagonally opposite stubs 3 mm or ±.0.1%.	1% of width of steel frame
UK (NGT)	± 10 mm or ± 0.1% of face dimension	± 15 mm or ± 0.1% of diagonal dimension	1:100 from hip slope	Max. difference in level between all 4 stubs 10 mm or ± 0.05% of diagonal; Max. difference between mean level of pairs of diagonally opposite stubs 6 mm.	1° about longitudinal axis
USA (GAI)	± 0.1% of face dimension	± 0.1% of diagonal dimension	± 1.6 mm / 300 mm	Max. tolerance from the top of each stub 0.1% of face or diagonal dimension; Max. difference between mean levels of diagonally opposite stubs 0.1% of diagonal dimension.	Not defined

Figure 15.7 Foundation setting tolerances.

Figure 15.8 Foundation uplift. The right hand foundation is intact.

15.4.7.1 Safety

During all installation foundation stages (excavation, reinforcing, concreting, back-filling) good safety procedures must be followed in order to avoid human injuries and equipment damage.

15.4.7.2 Environmental Requirements

Special measures are required to minimize negative impact on environment and surroundings.

15.4.7.3 Logistical Problems

- Delays in delivery of the concrete,
- Improper backfill material,
- Malfunctioning of the equipment,
- Encounter of unexpected conditions: underground infrastructure, war explosives, big rocks, unstable soil, high ground water levels, etc.,
- Inexperienced construction personnel causing installation errors.

15.4.7.4 Extreme Weather Conditions

- Heavy snow or rain,
- Flooding,
- extreme cold or heat.

15.4.8 Foundation Failures

Transmission structure foundation failures may occur as a result of either poor design or incorrect installation. Typical causes of such failures include:

- Mistakes in design calculations,
- Improperly collected or assumed soil strength parameters,

- Faulty materials used,
- Improper backfilling,
- Insufficient reinforcement or piles.

Additionally, transmission foundation failures can occur due to the failure of other line components such as an insulator or a hardware string.

The catastrophic failure of a single foundation can lead to cascading failures of several structures, especially if a transmission line has no provisions for anti-cascading or "stop" type structures.

The following are two examples of foundation failures.

15.4.8.1 Failure of a 220 kV OHL

The failure started at a tension tower. Over 7 km of OHL was destroyed (Figures 15.9 and 15.10).

Figure 15.9 Destroyed tension tower of a 220 kV OHL.

Figure 15.10 A view of the destroyed suspension towers of a 220 kV OHL.

Figure 15.11 Tension tower destroyed and moved down about 14 m on a 110 kV OHL.

Figure 15.12 Landslide causing destruction of a road, a house and a tower on a 110 kV OHL.

15.4.8.2 Failure of a 110 kV OHL

Failure caused by a landslide (bad geotechnical design). 1.3 km of OHL was destroyed (Figures 15.11 and 15.12).

15.5 Structure Assembly and Erection

15.5.1 Introduction

This Section provides an overview of all the activities involved in the erection of HV Transmission Line structures, addressing the typical installation techniques, equipment and safety requirements, as well as general advice regarding the best and most common industry practices used to achieve safe and cost effective installation.

15.5.1.1 Structure Types

The installation techniques may vary according to the structure types and may be better suited or be more effective in regard to cost and time, for one type or another. This Section focuses on the installation of guyed and self-supporting steel lattice tower types, designed and manufactured using steel angles and plates, with bolted joints, corresponding to the vast majority of the high and extra-high voltage transmission lines built up around the world. This construction type is the most common in all parts of the world.

Cigré TB 416 provides examples of various alternate and innovative structure designs used worldwide.

15.5.1.2 Preparation Work

Prior to commencement of tower installation, the following preparation work must be done:

- All structural design drawings including structure layout, erection, and bill of materials must be available,
- Plan and profile drawings identifying structure types and their locations must be available,
- Structure and anchor foundations must be in place, with their cast in metallic inserts clean and ready for erection start up, observing the minimum time lapse for concrete curing, as applicable,
- All the steel must be made available.

15.5.1.3 Logistics, Site Facilities and Mobilization

A good logistical planning and execution at site is essential for the success of the tower installation activities, as multiple resources are applied simultaneously at multiple spots, organized in a logical sequence. Large quantities of steel angles of different sizes are usually delivered by "the like pieces" to a marshaling yard (usually called "cemetery"). They need to be re-bundled by "component" prior to the transportation to their erection sites.

15.5.1.4 Equipment and Tools

The typical equipment and tools used for HV transmission structures assembly and erection can be grouped into 4 basic categories:

- Small Individual and portable tools, suitable for the manual tower erection activities. The ordinary individual or portable tools for work at height consist of the fork wrenches and torque wrenches used by the linemen. A handheld electric-rechargeable battery screw driver is also used for the tower preassembling on the ground.
- Medium-light equipment and tools, for the partly mechanized tower erection activities. The medium-light category comprises small equipment and heavier tools mainly used for pulling ropes and lifting the tower pieces and sections, or tensioning the guy wires, such as hoists, handheld devices such as the come-alongs, small stand-alone motorized winches, together with sets of fiber or nylon ropes, sets of anchors, pulleys and hooks or equivalent, or hydraulic light

truck-mounted types; also steel or aluminum truss-type beams to be attached to the tower legs or masts and work as gin poles; ladders.
- Heavy equipment, for the extensively mechanized tower erection activities. In general, the heavy equipment determines the installation method, and vice-versa; it can be one or multiple gin poles, mobile-cranes, preferably the "all terrain" types on wheels, or giant helicopters, known as "sky-cranes".
- Auxiliary stuff. A radio communication system is extensively used; grounding devices are mandatory to be in place, prior to commencement of any tower erection work; theodolites are used to control leveling, alignment and plumbing.

15.5.1.5 Safety Requirements

Tower erection is amongst the activities posing the highest safety risks to the construction crews and therefore it requires special individual and collective protection and strict compliance to the safety rules. As a general safety rule, every piece of equipment, tools, ropes, pulleys, hooks, safety clamps, etc, need to be inspected, calibrated and have their nominal capacity tested and certified, prior to be released to the sites and/or put into service.

Laws and Regulations

Special provisions concerning the management of risks and safe work procedures at height apply to the tower erection activities, according to the local laws and regulations for each country.

Labor Qualification

The assembly and erection of any tower requires team work, where each member of the team performs a specific task that has to be perfectly orchestrated with the others. Only professionals who are well trained and certified to work at height shall be hired to perform such a job.

Individual and Collective Protection

It is mandatory that the employer provides and ensures that all his/her employees properly uses and continuously keep their individual and collective protection devices, know and abide to the local legislation, guidance and codes of practices, whenever working at the tower sites, as applicable.

Weather Condition Restrictions

As another safety rule, the tower erection activities shall not be performed or has to be discontinued whenever subject to the risk of lightning or under rainfall, snowfall, fog or haze.

15.5.2 Installation Techniques

Provided that the preparation work has been properly done as above, and the towers have been sorted out to their spots in a sequence, complete with their legs, extensions, bodies and accessories, according to the construction lists, then the installation work shall commence. Special attention has to be paid to prevent damage to the steel and to the galvanizing coat, by splitting the tower members, and/or preassembled sections, preferably over a timber bed and providing them with proper rigging with fiber or nylon ropes during the lifting and temporary guy wiring processes. No tower element shall be bent or eventually subjected to undue straining during erection. As a generally accepted practice, the tower joints shall not have their bolts tightened to the prescribed torque at first, so that a minimal degree of freedom is allowed in order to accommodate the necessary corrections in the level, verticality and/or alignment of each tower section. A surveyor with the theodolite has to be positioned along the tower axis line to control and command these corrections during the entire tower erection process.

There are four main methods of erection of steel lattice transmission towers which are described below:

15.5.2.1 Manual Erection Piece by Piece: the Build-up or Piecemeal Method

This method consists of building up the tower, member by member, from bottom upwards. The tower members are laid down serially on the ground according to the sequence and closest possible to their erection positions, to avoid time loss.

For self-supporting towers, the erection procedure starts with the preparation and positioning of the first four leg segments together with their relative step bolts, joint plates and splices; then lifted and tilted to the right angle, bolted to the foundation stubs and hold their upper end firmly in their positions, by a temporary guy wire anchoring system. Linemen climb up the leg segments and stay positioned to proceed forward with the tower erection. Subsequently, bracings and diagonals are rigged, lifted and rendered to the linemen to be located at their respective joint plates, then inserting as many bolts, washers and nuts that corresponds to the assembly drawings and to the joint holes, and tightened, in order to complete the first section, i.e., the base frame of the tower. The same procedure is repeated for the following sections until the tower is completely erected.

For guyed towers, the procedures are similar and need to be adapted to the vertical erection of the tower mast components, anchored all the way up by temporary guy wires, until it reaches the final and definitive guy wire anchoring positions and then the tower head is completed.

Generally, hoisting of members is carried out manually and/or by an auxiliary beam, having ropes and pulleys attached to the tower legs, to work as a gin pole, or even assisted by small standalone winches.

While it is still extensively used in many parts of the world, this is a labor intensive and less productive method in comparison to the others and can only be suitable and advantageous if:

- The use of a heavy equipment, such as a crane or a helicopter, is not available, or is not feasible for technical or economic reasons,
- There is qualified and cheap labor available, in abundance,

- There is not enough flat land near to the tower spot available and cleared for tower and/or tower sections preassembling,
- It is used as a complementary activity in special circumstances and in combination with other methods, such as
  - to erect the upper part of a tower, if its height and weight exceeds the capacity range of a crane,
  - to erect a heavy tower base, especially in case of unequal legs, in preparation for a faster helicopter erection of the remainder parts, particularly in rough terrain with difficult access, or inside to a rainforest with a narrow ROW clearance; for smaller jobs, especially out of sequence,
  - illustration of the Build-up Method as complementary to the Section Method is provided in Figures 15.13, 15.14 and 15.15.

Figure 15.13 Build-up Method - Manual erection of a self-supporting tower aided by gin poles, in a swampy area; no access for cranes; no place for preassembling.

Figure 15.14 Build-up Method - Manual erection of a self-supporting tower aided by gin poles, in a mountainous area; no access for cranes; no place for preassembling.

Figure 15.15 Build-up Method/Complementary -Manual erection of the upper part of a self-supporting tower aided by gin poles; tower height exceeded crane capacity range.

15.5.2.2 Section Pre-assembling on the Ground and Equipment-aided Erection: the Section Method

This method consists of the preassembling of the major sections of the tower on the ground and then to rig and lift them as units, using a gin pole, a mobile crane or a helicopter, up to their final elevation, section by section, until the erection of the entire tower is complete. Hence, it speeds up the erection process and reduces the risk exposure to the construction crews. Prior to commencing, an analysis of the dimensions and weight of the tower components, as well as for the entire tower height, per each type and quantities, needs to be conducted so that the right erection strategy is formulated and the most suitable lifting equipment can be selected.

Using a Gin Pole

The gin pole used consists of a steel or aluminum truss-type beam, approximately 10 m long, and is held in place by means of guys on the side of the tower to be erected. The erection procedures inherent to the Section Method are mostly the same, whether using a gin pole or a mobile-crane. However, the gin pole-aided erection has some limitations and depending upon the size and weight of the tower sections and members, they may have to be split. For instance, a common practice is to divide it in two pairs of legs forming two panels preassembled on the ground that correspond to the opposite faces of the tower section, then lifted, tilted, spliced to the immediately subjacent stubs or leg segments and anchored with temporary guy ropes. In case only one gin pole is being used, to raise the second face of this section, it is necessary to shift the foot of the gin pole on the strut of the opposite side of the tower.

After the two opposite faces are raised, the bracings on the other two sides are fitted and bolted up by the linemen to complete the tower section. The tower sections are lined up and made square to the line, as the erection develops. After completing a tower section, the gin pole needs to slide up to be able to pull up another section. The gin pole is then made to rest on the top strut of the tower section's leg, immediately below the leg splice and properly guyed into position. The last lift raises the top of the towers.

After the tower top is placed and all side bracings have been bolted up, all the guy are removed, except the one which is to be used to lower the gin pole. An illustration of the gin pole-aided erection of guyed and self-supporting towers is provided in Figures 15.16, 15.17, 15.18, and 15.19.

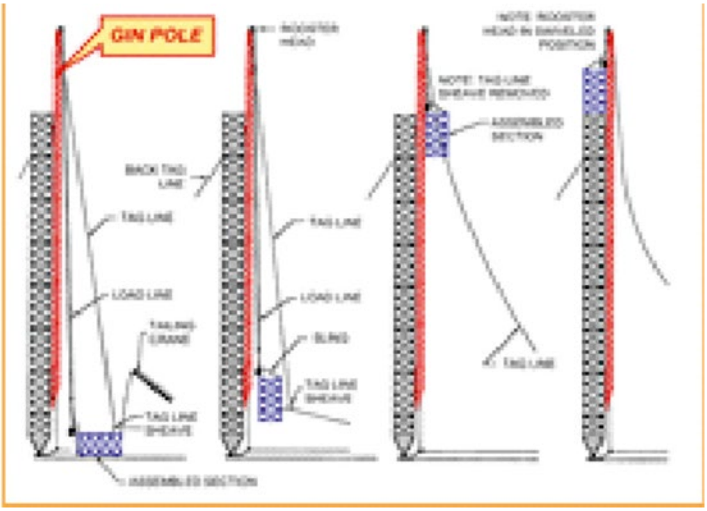

Figure 15.16 Section Method – Illustration of the erection of the central mast of a guyed tower using a gin pole; mast sections were preassembled on the ground.

Figure 15.17 Section Method – a cross arm section of a self-supporting suspension tower is erected using a gin pole.

Figure 15.18 Section Method – a cross arm section of an angle tower is erected using a gin pole.

Figure 15.19 Section Method – a cross arm section of a tower is preassembled on the ground; this method speeds up the erection process.

Using a Mobile-Crane

The Section Method using a Mobile-Crane, preferably an “all-terrain-on-wheels” type, is the most productive for the erection of self-supporting towers, particularly in flat terrain with good access conditions. An illustration of this Method is shown in Figures 15.20, 15.21, and 15.22.

Figure 15.20 Section Method – tower sections preassembling takes place at the tower spot in preparation for erection using a mobile crane.

Figure 15.21 Section Method using a Mobile Crane – a lateral section of a tower is preassembled on the ground and then lifted and mounted on its final position by the crane.

Figure 15.22 Section Method using a Mobile Crane – a cross arm section of an angle tower is preassembled on the ground and then lifted and mounted on its final position by the crane.

Using a Helicopter

The Section Method using a helicopter, as an air-crane, is also very productive for the erection of self-supporting towers, particularly in bad terrain with limited access conditions. Special accessories combining a coupling and guiding system and consisting of angle guides and steel frame corner brackets, need to be installed on both ends of the four corners of the tower sections to be coupled. This coupling system is designed to ease and speed erection, to quickly release the helicopter and to be stand alone, i.e., with no linemen attendance. Linemen will then climb up the tower to bolt up the remaining joints and leg splices, to finalize erection and remove the coupling and guiding accessories. This method is illustrated in Figures 15.23, 15.24, and 15.25.

15.5.2.3 Tower Assembly on the Spot and Mobile-crane Erection: the Tilting and Stand Up Method

This method consists of assembling the whole tower on the ground just aside and/or closest possible to the tower footings, and then tilt and stand it up, as a complete unit, using a mobile-crane, that holds the tower while the linemen crew connects and strings the guy wires to their anchoring positions. This is the most usual and most productive method for the erection of guyed towers, particularly in flat terrain with good access conditions (Figures 15.26, 15.27, 15.28, and 15.29).

In some cases, it may be disadvantageous because it requires plenty of land cleared at the tower spot to allow for the entire tower preassembling. Therefore, it may be subject to restrictions by the land owners in case a large damage to their plantations or tillable areas could occur. Limitations may also apply in case of hilly terrain where the assembly of complete tower on slopping ground may not be possible or, either if it may be difficult to get the crane into position to raise the complete tower. This method may also not be useful if the towers are too large and heavy.

Figure 15.23 Section Method using an Air-Crane – mid sections of a tower are preassembled on the ground and then lifted, flied off and mounted by the S-64 Erickson air-crane; linemen not necessarily required to assist up to this point.

Figure 15.24 Section Method using an Air-Crane – the top beam of the head of a "delta" tower is mounted. No linemen on the tower.

15.5.2.4 Tower Assembly in a Yard, Stand up and Air Transport to the Spot: the Helicopter Method

This method consists of the setup of a batch production line for the entire preassembling of a group of towers, corresponding to the tower row in a line segment as per the construction sequence, altogether in a marshaling yard and prior to erection. Then plan for the helicopter pick up and erection campaign, to properly rig, tilt and lift, tower by tower, as complete units, and fly over the line by the shortest distance up to each tower spot, respectively, where they are placed and left in their final erection positions. For self-supporting towers, there are special coupling and guiding accessory systems, located at the tower stubs, capable of managing the entire tower, in order to allow for a faster release of the helicopter back to another trip, while the linemen finally bolt up the tower leg splices and remove the coupling accessories. For guyed towers, a line crew needs to be on the ground when the helicopter arrives and hovers on the tower spot, to assist with the tower placement on the central pin,

Figure 15.25 Section Method - the head of a "racket" tower is mounted.

Figure 15.26 Tilt and Stand up Method – The entire tower is preassembled on the ground (step 1).

Figure 15.27 Tilt and Stand up Method – The entire tower is tilted, keeping its foot on the ground (step 2).

Figure 15.28 Tilt and Stand up Method – The tilting and lifting of the entire tower continues (step 3).

Figure 15.29 Tilt and Stand up Method – The tower is lifted and mounted in the central pin, the guy wires are anchored. (step 4).

as well as, to provisionally connect and string the four guy wires to their anchoring position, for a quicker release of the helicopter. This is the most productive method for the erection of either guyed or self-supporting towers, particularly in bad terrain with difficult access conditions. The use of helicopters, however, is expensive, weather-dependent and requires especial arrangements for the fuel supply. Also, more strict and stringent safety and labor regulations governing the aviation industry applies. This method may not be useful if the towers are too large and heavy (Figures 15.30, 15.31, and 15.32).

15.5.3 Bolt Tightening and Finishing

It is a usual industry practice that during the course of erection the bolts and nuts at the tower joints receive a provisional torque, just enough to keep all the members together securely and allow the whole assembly to stand upright. The same procedure is applied to the guy wires. This is a strategy to speed up erection and make efficient use of the bulk erection crew and expensive equipment.

Figure 15.30 Helicopter Method – an entire guyed tower is preassembled on the ground and then lifted and air transported to its erection spot by the helicopter.

Figure 15.31 Helicopter Method – an entire guyed tower is rigged, tilted and then lifted and air transported.

Figure 15.32 Helicopter Method – an entire guyed tower is air transported by the helicopter to its erection spot.

15.5.3.1 Tower Assembly Revision Checking and Tightening of Bolts at the Required Torque

However, as the joints might remain slightly loose, prior to commence the cable stringing, it is mandatory that a second and smaller crew come just behind to perform a check of the tower assemblies. Linemen have to check all the joints, in regard to missing pieces and improper joint assembly and then firmly tighten together the members, plates, fillers, bolts, nuts and washers at the final torque specified in the assembly drawings, using pre-calibrated torque wrenches. The same procedure applies to the guy wires, that are finally adjusted to the proper tension and this is the right time to check the leveling and alignment of the cross arms and verticality of the towers, and provide for necessary corrections, prior to the final tightening of the joints. The tightening shall be carried on progressively from the top downwards, care being taken that all bolts at every level are tightened simultaneously. It is advisable to employ four persons, each covering one leg and the face to his/her right. Tolerance limit for tower verticality shall be a displacement of one in 360 of the tower height.

15.5.3.2 Finishing and Installation of Signaling and Special Devices

If during the tower assembly check it is found any part of the tower members and plates have any damage to their zinc protective coating, then the affected areas must be cleaned and recoated with a rich zinc paint. Signaling and special devices, such as numbering, phase, circuit and danger plates, anti-climbing devices and bird perching guards shall be installed, as applicable, according to the assembly drawings.

15.5.4 Erection Method Selection Criteria

Achieving an optimal selection of the structure assembly and erection method involves a complex decision matrix, as multiple variables exist and affect each other and need to be balanced altogether, at the same time. Overhead transmission line structures vary significantly according to functional and situational factors, and are designed to enable a large spectrum of combination possibilities, in response to these variations. Similarly, their assembly and erection activities are often subject to logistical, local markets supply, land availability, access, safety, legal permits and environmental constraints, so that, there is no universal rule or single solution that would apply to encompass all these variations and constraints, in a cost-effective and timely manner. Therefore, it needs to be customized for each single transmission line project.

However, it's been proven by the practice that, whichever assembly and erection method has been chosen, the smoother is the work, the better, meaning good planning in advance, continuous in sequence, keeping on schedule and having an early warning and problem resolution system in place to prevent slippage. It is of utmost relevance to avoid working out of sequence, moving back and forth with the assembly and erection crews, as experience shows it is one of the major sources of cost overruns and project delays. In particular because the cable stringing activities cannot commence until a reasonably long stretch of the line has all the structures completely erected and revised.

15.5.4.1 Combining Methods

Due to the high cost of mobilization and hourly rates of the heavy equipment, like mobile-cranes and air-cranes, it requires a minimum volume of work to be viable, so that, in the normal course, a decision has to be taken upfront on which method and equipment is best suited to the circumstances, bearing in mind that a later shift from one method to another will be more expensive. Also, it is a good practice to advance the structure preassembling on the ground, before one or another type of equipment comes in. Nevertheless, a combination of different structure assembly and erection methods may lead to an optimal erection plan for longer lines, provided that there are opportunities to improve cost and time, by capturing the advantages of different erection methods in response to different work environments.

15.6 Conductor Stringing

Installation of a bare overhead conductor can present complex problems. Careful planning and a thorough understanding of pull requirements and stringing procedures are needed to prevent damage to the conductor during stringing operations. The selection of stringing sheaves, tensioning methods and measurement techniques are critical factors in obtaining the desired sagging results. Conductor stringing, sagging equipment and techniques are discussed in detail in the IEEE Standard 524. Some basic factors concerning installation are covered in this section.

15.6.1 Preparation

Before conductor stringing can commence, structures must be equipped with required insulator strings and hardware. In the case of suspension structures, complete insulator strings are attached to the structure. Instead of conductor clamps, running blocks with stringing sheaves (pulleys) with large diameter are attached to the bottom of the insulator string to allow for the movement of the conductor through the structure. On dead-end structures, running blocks are attached directly to the take-off (landing) plates on the structure and the dead-end hardware assemblies are installed after the conductor is cut to its required length.

15.6.2 Stringing Methods

There are two basic methods of stringing conductors, categorized as either tension or slack stringing. There are many variations of these methods and the selected method depends primarily on the terrain and the sensitivity to conductor surface damage.

15.6.2.1 Tension Stringing Method

A tension stringing method is the preferred method for installing transmission conductor. Using this method, the conductor reel is mounted on a payoff that is capable

Figure 15.33 Trailer mounted payoffs and a truck mounted bullwheel for tension stringing (Courtesy of Southwire Co.)

of applying braking force to the reel to maintain tension on the conductor. The conductor is then strung (or “reeved”) through a multi-groove bullwheel tensioner so that the conductor is under tension during pulling and is not allowed to contact the ground (Figure 15.33). It is important to coordinate the bullwheel speed with the puller speed to prevent excessive sagging or dynamic loading (jerking) of the conductor during the pull.

In a typical tension stringing operation, blocks (also known as “travelers” or “sheaves”) are attached to each structure or the end of an insulator string. For re-conductoring applications, the existing conductor can be transferred to the blocks at each tower, then connected to the new conductor and used to pull in the new conductor as it is removed. For new construction, a pilot line is pulled through the blocks and used to pull in a heavier pulling line, which is then used to pull the conductor through the blocks. The tension in the conductor is controlled by coordinating the tension puller at the pulling end and the bullwheel tensioner at the conductor payout end of the installation. This installation method keeps the conductor off the ground, minimizing the possibility of surface damage and limiting problems at roadway crossings.

It should be noted that the reels the conductor is shipped on are designed only for transportation and should not be used as a tensioning device. Minimum breaking tension should be applied to the reel on the payoff, just enough to prevent “overspin” when the pull is interrupted or stopped. A common problem in the field is to over tension the conductor due to excessive braking of the payoff reel, thus causing conductor “pull-down” (Figure 15.34). Pull-down can occur in layers under the outer layer, thus making it appear the conductor was not properly wound by the manufacture. For this reason payoff tension should be carefully monitored during pulling.

Figure 15.34 Conductor Pull-Down due to excessive braking force on the payoff (Courtesy of Southwire Co.)

15.6.2.2 Slack or Layout Stringing Method

Slack stringing of a conductor should be limited to lower voltage distribution lines and smaller conductors where some surface damage is tolerable. The conductor reel(s) are placed on reel stands or "jack stands" at the beginning of the stringing location. The conductor is unreeled from the shipping reel and dragged along the ground by means of a vehicle or pulling device. When the conductor is dragged past a supporting structure, pulling is stopped and the conductor is placed in stringing blocks attached to the structure. The conductor is then reattached to the pulling equipment and the pull is continued to the next structure. This method requires heavy traffic in the right-of-way and is not recommended for transmission applications.

15.6.2.3 Helicopter Stringing Method

Conductor stringing using helicopters is rarely used due to high cost. This is usually done in terrain with very difficult relief and access or in locations where environmental constrains prohibit traditional access to a right-of-way.

15.6.3 Tension Stringing Equipment and Setup

Stringing equipment and requirements can vary based on the type of conductor being installed. The customer should always contact the conductor manufacturer for recommended guidelines when installing a conductor for the first time. Stringing equipment typically includes payoffs to support the reel and back-tension the conductor going into the bullwheel, a bullwheel for back-tensioning the conductor during stringing and sagging; blocks (travelers or sheaves) at the structure attachment points to support the conductor; a puller for pulling the conductor through blocks; a means of gripping the conductor; and various other special items of equipment.

During the stringing, it is necessary to use the proper tool to grip the strands of the conductor evenly to avoid damaging the outer layer of wires. The preferred type of grip is often referred to as a basket or Kellems® grip. It is often used because its flexibility and small size make it easily pulled through blocks during the stringing operation. A swivel should be installed between the pulling grip and pulling line, or between grips when double-socked, to allow free rotation of both the conductor and the pulling line (Figure 15.35).

A stringing block consists of one or more sheaves or pulley wheels enclosed in a frame to allow it to be suspended from structures or insulator strings (Figure 15.36). The frame must have some type of latching mechanism to allow insertion and removal of the conductor during the stringing operation. Blocks are designed for a maximum safe working load which must not be exceeded during pulling or sagging. Sheaves are often lined with neoprene or urethane to prevent scratching of conductor in high voltage applications; however, unlined sheaves are also available for special applications. Block diameters and groove design must be properly sized for the conductor being used per the conductor manufacturer's recommendation.

Blocks used in tension stringing must be free-rolling and capable of withstanding high running or static loads without damage. Proper maintenance is essential. Very high longitudinal tension loads can develop on transmission structures if a block should "freeze" during tension stringing, possibly causing conductor and/or

Figure 15.35 Basket grip and swivel.

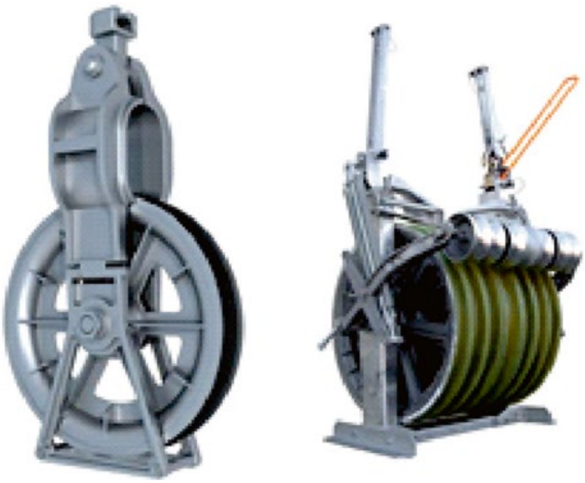

Figure 15.36 Single and multi-grooved, lined blocks (Courtesy of Sherman & Reilly).

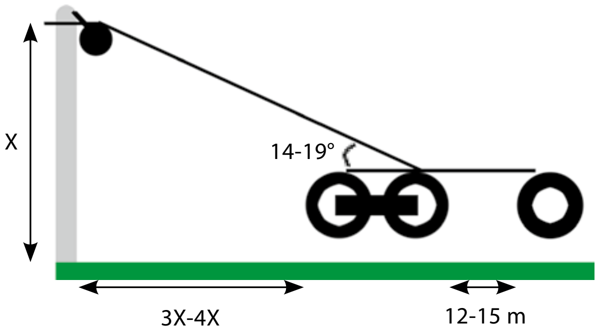

Figure 15.37 Recommended minimum bullwheel and payoff setback.

structure damage and posing safety risk to the construction crews. Significant levels of rotation resistance will also yield tension differences between spans, resulting in incorrect sag.

Equipment setup is generally limited by the terrain available for the payoff and pulling sites. The recommended bullwheel and payoff setup and their minimum setback distances are shown in Figure 15.37. It is important that the angle the conductor passes over on the first "entry" block be large enough to prevent conductor "birdcaging". If the recommended setback cannot be achieved, other methods of maintaining this angle should be used, such as, increasing the diameter of the entry block or lowering the entry block on the structure.

Generally, splices cannot be pulled through blocks. However, some manufacturers have developed splices that can be used for long pulls through blocks. Unless approved for pulling, provision for conductor splicing must be made at the tension site or mid-span sites to avoid pulling splices through the blocks. Failure to follow manufacturer's recommendations for stringing equipment can result in unsafe conditions, equipment damage, or conductor damage. Conductor damage can include scuffing (Corona issues), damage to the outer strands, and damage to the core strands (especially critical for composite core designs).

15.6.4 Conductor Sagging

It is important that the conductors be properly sagged, at the correct stringing tension and reference temperature per the design. A series of several spans, called a line section, is usually sagged in one operation. To obtain the correct sags, and ensure the suspension insulators hang vertically, the horizontal tension in all spans must be equal. Most sagging information is given relative to the conductor temperature. A sagging thermometer should be used to accurately determine the temperature of the conductor (Figure 15.38).

15.6.4.1 Sagging Grips

Once the conductor is pulled in and lying in the blocks, the conductor can be pulled up to design (or "sagging") tension. Generally the conductor is dead-ended to a structure at one end and the slack pulled out of the spans. Next a grip is applied to

Figure 15.38 Sagging Thermometer (Courtesy of Tallman Equipment).

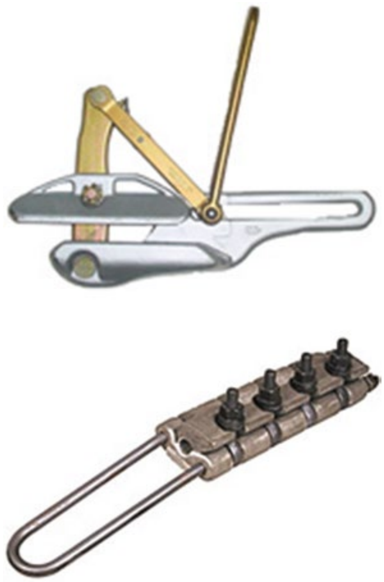

Figure 15.39 Chicago-style and pocketbook grips.

the conductor free end and the grip is attached to a ratcheting tensioning device, like a come-along to pull the conductor up to sag. There are several types of grips available so verify the conductor manufacturer's recommendation. Common grip types include scissor type (Klein "Chicago-style") and pocketbook (Figure 15.39).

Each grip should be sized for the specific conductor it is used with and each grip has a tension rating that should not be exceeded. Grips have specific installation methods which must be followed to ensure proper gripping. When the needed tension cannot be obtained using a single grip, grips can be connected in tandem to achieve a higher rating. However, the grip manufacturer should be consulted as to the proper connection method and the resulting rating. In many instances the rating of tandem grips is less than twice the rating of a single grip.

15.6.4.2 Sagging Methods

There are many different methods available for sagging lines. Two of the most common are the stopwatch method and the transit method. A third method, using a dynamometer, is sometimes used for small conductors over one or two spans but is not recommended for transmission applications as its accuracy diminishes with each span.

The stopwatch method is based on the principle that a mechanical pulse imparted to a tensioned conductor moves at a speed proportional to the square root of tension divided by weight per unit length. Three or five return waves usually provide an accurate measurement of sag. The equation for the stopwatch method can be seen below.

$$D = 0.3067\left(\frac{t}{n}\right)^2 \tag{15.1}$$

D = conductor sag, m.
t = time, sec.
n = number of return waves

By initiating a pulse on a tensioned conductor and measuring the time required for the pulse to move to the nearest termination and back, the tension and sag of the conductor can be determined. This stopwatch method has come into wide use even for long spans and large conductors.

IEEE Standard 524 lists three methods of sagging conductor with a transit: “Calculated Angle of Sight”, “Calculated Target Method” and “Horizontal Line of Sight”. The method best suited to a particular line sagging situation may vary with terrain and line design. While the transit method is considered more accurate, the stopwatch method is favored due to is relative ease and quickness.

15.6.4.3 Sagging Accuracy

Sagging accuracy depends on many factors and it is usually prescribed in construction specification document used in tendering. IEEE Standard 524 suggests that all sags be within the lesser of 13 mm (0.5 in) of the design value for every 30 m (98 ft.) of span length or 152 mm (6 in.) of the design value for any span. Additionally, possible errors in terrain measurement, variations in conductor properties, loading conditions and hardware installation have led some utilities to include up to 1 m (3 ft.) of additional clearance in addition to the required minimum ground clearance.

The type and condition of the structures can also affect sagging accuracy. Certain structure types (such as flexible tubular poles, tall wood poles, etc.) can deflect under sagging tensions. Older structures may have reduced ability to sustain sagging tensions due to damage, corrosion or other environmental effects. In these cases it may be necessary to reinforce structures and crossarms, or temporarily add reinforcement through guying.

Sag adjustment devices such as turnbuckles or sag adjustment plates are often used in the deadend hardware strings to allow for adjusting conductor sags and make necessary sag corrections (Figure 15.40).

15.6.5 Offset Clipping

If conductor is to be sagged in a series of suspension spans where span lengths vary widely or, more commonly, where the terrain is steep, then clipping offset calculations may need to be employed in order to yield vertical suspension strings after

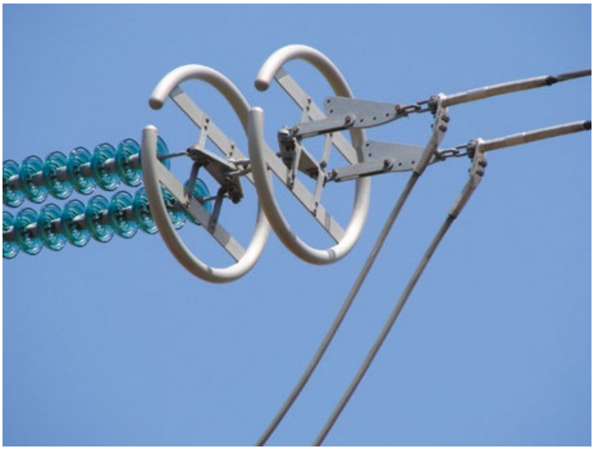

Figure 15.40 Example of a sag adjustment plate used with a dead-end insulator string.

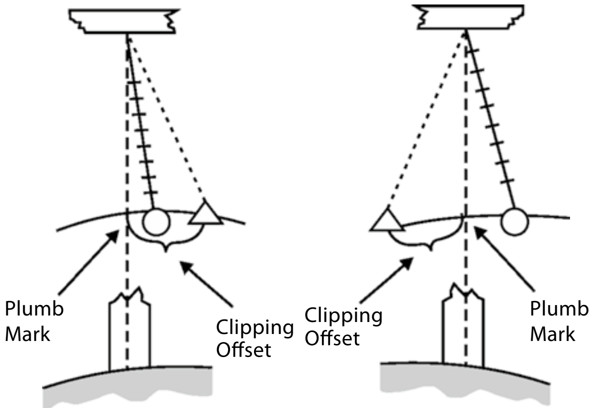

Figure 15.41 Offset clipping example.

installation. More information can be found in the Southwire Overhead Conductor Manual (Figure 15.41).

15.6.6 Conductor Creep and Pre-stressing

Upon completion of conductor stringing, a time of up to several days may elapse before the conductor is tensioned to design sag. Since the conductor tension during the stringing process is normally well below the initial sagging tension, and because the conductor remains in the stringing sheaves for only a few days or less, any elongation due to creep is normally neglected. The conductor should be sagged to the initial stringing sags listed in the stringing tables. However, if the conductor tension is excessively high during stringing, or the conductor is allowed to remain in the blocks for an extended period of time, an abnormal amount of creep will occur. If this occurs, the stringing tables should be corrected to compensate for the additional creep elongation.

When installing a new conductor that will be spliced into an aged, existing conductor it is sometimes beneficial to pre-stress the new conductor to match the aged creep of the existing conductor. The pre-stressing tension is normally much higher than the unloaded design tension for a conductor. The degree of stabilization is dependent upon the time maintained at the pre-stressing tension. After pre-stressing, the tension on the conductor is reduced to stringing or design tension limits. At this reduced tension, the creep or plastic elongation of the conductor has been temporarily halted, reducing the permanent elongation due to strain and creep for a defined period of time. By tensioning an ACSR (Aluminum Conductor Steel Reinforced) conductor to levels approaching 50 % of its rated breaking strength for 1–2 hours, creep elongation will be temporarily halted. For an ACSS (Aluminum Conductor Steel Supported) conductor, the hold time is substantially less and greatly improves the conductors self-damping capability.

15.6.7 Crossings

When a conductor installation is required to cross a highway, river, rail or other sensitive area advanced planning is required. Permits should be sought from the AHJ (Authority Having Jurisdiction) over the crossing. Coordination with local authorities, rail, shipping and other entities must be made, especially where the installation requires disruption of commercial or public transportation.

Crossings often involve installation of temporary intermediate structures, long pulls and high tensions. Custom, high strength conductors and composite core conductors are often used. In many cases conductor and connector selection can mitigate tension and long pull concerns.

When stringing is done over the existing power lines, these lines should be de-energized for safety reasons. When this is not possible, additional safety measures are needed which may include the use of insulating blankets and presence of "safety watch" on the job site.

15.6.8 Grounding

Care should be taken to ensure that the conductor is isolated from all electrical influences during the installation procedure. This includes incidental contact with nearby energized sources, static voltage buildup during pulling and induced voltage from nearby energized lines. All equipment should be properly grounded. The conductor should be grounded, usually with a running ground, and all blocks should be grounded at structures.

15.7 Insulators, Hardware and Fittings

15.7.1 Insulators

Insulators are the most important element of the strings connecting the electrical parts (conductors) with grounded structures. They are made of dielectric materials and have dual purpose by providing an adequate level of electrical insulation for the given voltage and sufficient mechanical strength to support mechanical loads.

Insulators come in different types as shown in Figure 15.42.

Construction techniques will vary depending on the insulator type used.

15.7.1.1 Handling

Cigré TB 184 provides a full overview of composite insulator handling techniques. However, most of the rules from the brochure also apply to other types of insulators (especially long-rod types).

Insulators should be delivered to the construction site in wooden crates protecting them from damage during transportation and handling. At delivery, the crates must be thoroughly checked for any damage. If cracks, dents or other damage to the crate are found, each insulator should be examined for damage. Any unit with exposed core or damaged sealing of the triple point should be immediately rejected and replaced. Crates containing insulators should be stored above the ground in a dry and covered area. Lids should remain closed to prevent entrance of rodents and to protect insulators against weather elements.

Insulators should be delivered to a job site in their original packaging. Direct contact with the ground must be avoided to ensure that clean units without any mechanical damage are installed on the transmission line. A good solution to protect insulators after removing them from crates is application of a wrap-on shield. The use of a wrap-on shield helps to prevent the insulator from damage during installation or tower painting. The wrap-on must be set up to allow the air flow, so that it keeps the insulator from getting mouldy.

15.7.1.2 Assembling Strings

Before installation, each insulator must be re-checked for damage. If any cuts, exposure of the core, torn cover, puncture or split is detected, that insulator must be rejected and removed from the construction site to ensure it is not accidentally used.

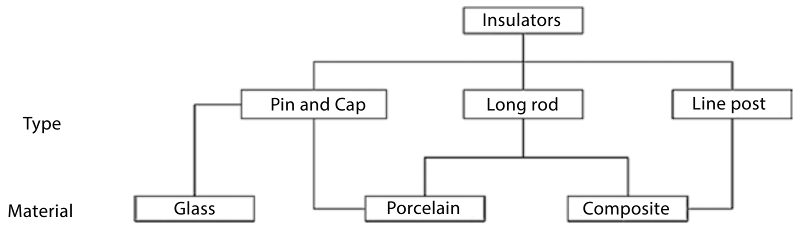

Figure 15.42 Main types of insulators.

Moving insulators should be performed manually. Extra care should be taken when lifting and moving long insulators so that no additional bending or twisting to the unit is introduced. Under no circumstances can the insulators be pulled on the ground or carried by a rope tied under the shed.

Assembly of insulator strings should be done as closely to the tower as possible. A plastic foil or canvas should be spread out so that the assembly is not carried directly on the ground. Any stones and other hard objects that may cause damage to the housing of the insulator must be removed.

All the components should be assembled without the use of excessive force. After assembling the string, one should check if the pins and the nut are set up correctly. Nuts and bolts should be checked for proper tightness. Any dirt or contamination should be removed with soft cloth.

It is important to install Corona (grading) rings in the proper position to achieve the desired protection. Installation procedures should be followed to avoid installing the Corona rings upside-down.

15.7.1.3 Installation

Lifting ropes should be attached to the earth-end insulator metal fitting only. Ropes should not have contact with the silicon housing of composite insulators. To tighten the screws, use the manufacturer's recommended torque. When installing, insulators must not be subjected to bending or torsional loads. It is forbidden to walk, sit or climb on the insulators and their Corona rings. During installation special ladders or temporary bridges must be used.

Ladders, tools, blocks and other equipment, should be kept away from the housing of an insulator string to avoid mechanical damage.

Insulators damaged during hardware assembly should always be replaced and removed from the site.

15.7.2 Conductor Hardware

15.7.2.1 Suspension Strings

Suspension strings can be installed from a bucket truck or by using mounting ladders suspended from the crossarm. The length of the ladder should be properly matched to the length of the suspension string to allow the installer to work in a standing position. Strings should be pulled using lifts securely attached to a crossarm and providing a uniform load transfer to both vertical walls of the crossarm. The place of attachment of a conductor in the suspension clamp must be clearly marked and cleared. Care shall be taken to transfer the conductor from the stringing travellers to the suspension clamp accurately to ensure that the suspension clamp is centered on the conductor contact point mark.

15.7.2.2 Dead-End Strings

The dead-end strings should be assembled near the tower using necessary protection methods to prevent direct contact with the ground to avoid contamination or damage. When fitting the string particular attention should be paid to:

- Proper alignment of arcing devices and protective rings,

- Turning screws to the ground,
- Correct assembling of locking pins.

Once assembled, the deadend string must be connected to the insulator string on one side, and on the other to the hook rope of the tensioning system. Next, the dead-end string must be tied to the crossarm of the tension tower. For safety reasons, the installer must be standing on the shaft of the tower and not on the crossarm.

15.7.3 Vibration Control Devices

Vibration dampers, spacers and spacer dampers are mounted on the conductor using either bolted clamps or preformed rods, depending on design. Vibration dampers must be installed at the specified distance from each suspension clamp, in accordance with manufacturer's installation instructions to provide optimum damping performance. They must also be installed in the vertical position, directly below the conductor. Spacers and spacer-dampers must be installed along the conductor in specific locations, in accordance with the installation spacing charts, to provide optimum damping performance.

Installation of vibration control devices should be carried out on aerial work platforms or from cable trolley carts. During installation, special attention should be paid in order not to distort the conductor bundle. The manufacturer's recommended tightening torques should be used when tightening the bolts to avoid conductor damages. Bolt heads should point downwards so that it is easy to validate the installation from the ground.

15.7.4 Warning Devices

Warning devices on high voltage lines are required in the zones where there is air traffic. They come as coloured balls or cones usually mounted on ground wires and glowing elements mounted on phase conductors. These devices must be placed in specific location along the wire/conductor to satisfy local regulations.

To protect birds against collisions with overhead wires, various warning devices, often called bird diverters, are being used. Common designs are flapping discs or spiral rods attached and distributed along to the overhead wire. Similarly to vibration control devices, bird diverters can be installed using lifts/cranes or cable trolley carts.

15.7.5 Conductor Fittings

Conductor fittings used with transmission line overhead conductors include full tension deadends, full tension joints, jumper terminals, and repair sleeves. These fittings are needed to provide for continuity of the conductor.

The most common conductor fittings are of a compression type involving one or more sleeves. The sleeves are pressed onto the conductor by means of applying

Figure 15.43 Simultaneous installation of multiple implosive type sleeves.

mechanical pressure using hydraulic dies. They require filler compound to be inserted into the sleeve prior to compressing to provide corrosion protection.

Other types of compression sleeves use the energy of a small implosive charge to press the sleeve onto the conductor. These sleeves do not use filler compound and they can be installed simultaneously (Figure 15.43).

In all cases, proper installation procedures must be followed to provide full strength of the fitting and trouble free performance.

15.8 As-Built Inspection

15.8.1 Needs

Commissioning of an overhead transmission line involves an as-built inspection which is needed to confirm full conformance of the installed line components with design drawings and specifications as provided by the line owner. As-built inspections are performed with due diligence, typically by design engineers and before the transmission line is energized, for safety reasons. Typically, they involve design engineers responsible for different line components (electrical, mechanical, civil), contractor's project engineers and asset owners who will be responsible for maintaining the new overhead line. As-built inspections are carried out in two phases: acceptance of the "as-built" documentation and acceptance of the line components (towers, foundations, conductors…).

15.8.2 Documentation Review

Prior to carrying out the as-built inspection in the field, the contractor provides the owner with documentation which may include the following documents:

- Work completion certificates confirming installation meeting all the technical requirements,
- Foundation records: type of foundation installed, size and depth, soil logs (if requested by the owner), foundations test protocols,
- Structure records (i.e. structural deflections, insulator string deflections, guy wire tensions, deviations from the original structure location or orientation),
- Conductor stringing records (temperature, tension, sag checks made),
- Reports of any field measurements performed (i.e. anchor pull-out, foundation deflection, etc.),
- Reports of any material testing done (i.e. inspection of welds),
- As- built documentation,
- Attestations of the materials used,
- Warranty cards of materials and equipment used,
- Instruction for operation of the line.

These documents are to be reviewed and accepted by the Project Engineer and later transferred to the asset owners for maintenance purposes.

15.8.3 Field Inspection

Following review of the above documents, field inspection is performed to assess technical condition of all the line components. The diagnostic procedures constitute the basic source of information concerning the current condition of the line as built.

They include visual inspection, measurements and tests of:

- Foundations: size and placement, condition of the concrete, alignment, type and condition of backfill,
- Support structures: condition of all structural, completeness and tightness of all connections, proper orientation of the circuits/phases, phase and aviation plates, locations of bird nests and foreign elements on the towers, condition of the warning lights, corrosion of any elements,
- Insulation of the line: condition and completeness of the insulation equipment, insulator string deflections,
- Phase conductors and equipment: bird-caging and cracks of phase conductors and jumpers, condition of clamps and joints, location of foreign objects on conductors),
- Vibration control devices: condition, completeness and proper spacing
- OPGW: earthing jumpers, OPGW downleads to connection boxes,

- Grounding system: condition, completeness, connections,
- Crossings: adequacy of conductor clearances, proper offsets, markings of the line crossing with roads and waterways,
- Site conditions: tree clearing, terrain grading, restoration of the existing fences, disposal of materials.

Upon completion of the field inspection, a detailed report is issued capturing all the observations. All deviations and non-conformances are identified and presented to the contractor for corrections. Once all the line components are accepted by the Project Engineer, work completion certificates are issued to the contractor confirming full compliance with all the technical requirements.

15.9 Conclusions

This Chapter has addressed many challenges and risks encounter during installation of an overhead transmission line. It has also presented common construction practices found around the world. Other special construction techniques can be found in the reference documents.

Transmission line construction practices may vary depending on multiple factors, such as design details, availability of manpower resources and construction equipment, geographical location, weather conditions, or past experiences. However, best construction practices have many common elements, including proper logistical planning, safe work procedures, good workmanship, and cost effective solutions.

Success of an overhead line placed in service can be measured based on trouble-free operation of the line and all of its components. This greatly depends on the design effectiveness, proper selection of the components and finally on the best construction techniques and methods used.

15.10 Outlook

The ever changing regulations of how new overhead transmission lines are developed and constructed puts a lot of pressure and high demands on construction companies and their operations. Legal regulations and various conditions prescribed by the transmission line project licence identify numerous restrictions on how and when construction activities can be carried out. In addition, high expectations of the general public and environmentalists force construction companies to adjust their practices in order to minimize the effects on the humans and environment.

These increasing restrictions will be forcing construction companies to change their existing work practices. Improvements to job planning, optimization of the use of available resources, materials management and application of electronic tools will be necessary to stay competitive. Recent advances in Geographic Information Systems (GIS) based technologies offer new tools which can lead to improved productivity and cost efficiencies. Bar coding offers efficiencies in material control.

GPS units can be used for work progress tracking and real-time reporting. New software products offer advanced scheduling and work simulation options to maximize available resources.

New construction equipment will become readily available to help meet the needs of the industry. Helicopters will be utilized more frequently in the areas where access is difficult or restricted. Robotic devices will aid in installations requiring live-line techniques. Various remote sensing and condition assessment techniques will be used frequently to help with upgrading projects.

References

Cigré, TB 184: Composite Insulator Handling Guide (2001)
Cigré, TB 281: Design and Installation of Micropiles and Ground Anchors for OHL Support Foundations (2005)
Cigré, TB 308: Foundation Installation – An Overview (2006)
Cigré, TB 416: Innovative Solutions for Overhead Line Supports (2010)
IEEE, Std 524–2912: Guide to the Installation of Overhead Transmission Line Conductors (2012)
IEEE, Std 977–2010: Guide to Installation of Foundations for Transmission Line Structures (2010)
Thrash, Murrah, Lancaster, Nuckles.: Southwire Overhead Conductor Manual, 2nd ed. (2007)

Zibby Kieloch has MSc in Civil Engineering from Warsaw University of Technology. He has been designing overhead transmission lines at voltages up to 500 kV at Manitoba Hydro, Canada for over 25 years. Most recently, he is responsible for one of the largest HVdc projects in North America – Bipole III Transmission Line Project. He has been a CIGRE member and the Canadian Representative on the Study Committee B2 since 2005, making contributions to a number of Working Groups. Since 2012, he has been the Convenor of the SC B2 Customer Advisory Group. He is also an active member of the Canadian Standards Association technical committees responsible for overhead line design and conductor design standards.

João BGF da Silva obtained his degree in Civil Engineering from the Federal University of Minas Gerais, Brazil, where he was Professor of Steel Structures from 1975 to 2012. At the industry, he has been working in many companies and has been responsible for OHL projects particularly in Brazil and other American countries. Currently, he is the Technical Director of Furnas Trans-Cos being also a member of the Consulting Council of the Brazilian Electric Power Research Center – CEPEL, since 2006. On Cigré, he has been member of the Study Committee B2 – Overhead Lines since 1985. He was Convener of the former WGB2.08 – Transmission Line Structures being nowadays the OHL Components Technical Advisory Group Chairman. He has published more than a hundred articles and brochures devoted to design, construction and performance of high voltage overhead lines. He is an honorary member of Cigré and a holder of the “Cigré Medal” awarded in 2008.

Mauro Gomes Baleeiro Engineer, MBA, Entrepreneur. Executive Education in USA, Switzerland, Japan and South Africa. Head of Sales and Business Development at ABB SBE Power Lines-Brazil (1978–1991) responsible for design, testing and supply of lattice towers to large power transmission projects in Latin America, USA and Middle East. Director of ABB Power Systems-Brazil (1992–2001) & team leader for the 2000 MW Power Interconnection Project between Brazil and Argentina. Co-founder, owner and 1st CEO of DAMP ELECTRIC-Brazil (2004–2009). President & CEO of ALTA ENERGIA S.A. (2010–2013), responsible for the design & construction of 1500 km of the 600 kV Power Line Porto Velho - Araraquara associated to the 6400 MW Madeira River Power Project in Brazil. Co-founder, owner and 1st CEO of ALTIVA HELIMONT (2014), a startup co. dedicated to the intensive use of helicopters for power line towers erection in Brazil.

Mark Lancaster has BSc, BSEE and MBA degrees including the Georgia Institute of Technology, and is a registered Professional Engineer. He is employed at Southwire Company, Carrollton, Georgia, USA where he is Director of Overhead Transmission Engineering. He has been in wire and cable manufacturing, R&D and applications since 1987 and has been active in the development of new HTLS conductors, line monitoring and dynamic line rating, holding 4 US patents in these areas. He is active in industry groups including IEEE Overhead Lines, ASTM International and Cigré and has held several leadership positions in these organizations including Chairman of ASTM B01 Conductors Committee from 2009–2014. He is a co-author of the Southwire Overhead Conductor Manual and contributor to the Cigré Overhead Green Book.

Marcin Tuzim is an engineer who graduated from Warsaw University of Technology. He is employed in ELBUD-PROJEKT Warszawa Ltd. as an assistant designer of high voltage overhead lines. He participated in the design of significant energy investments in Poland (eg. cable and OH high voltage lines and substations).

Piotr Wojciechowski has MSc Eng. degree received from Warsaw University of Technology. He has achieved Certified Project Management Associate level D of IPMA Association. He is employed in Elbud-Projekt Warszawa Ltd. as a Chief Constructor. He has designed several hundred km of Overhead lines: 110, 220, 400 kV and several substations 110/15 kV. He is responsible for designing foundations and construction of towers. He has published over a dozen papers for presentation at various scientific conferences and for technical magazines. He is Poland's Representative on CIGRE Study Committee B2. He is also member of Polish Normalization Committee (group KT-80) and Poland's Representative on CENELEC TC-11 and a member of TC-11 WG 09.