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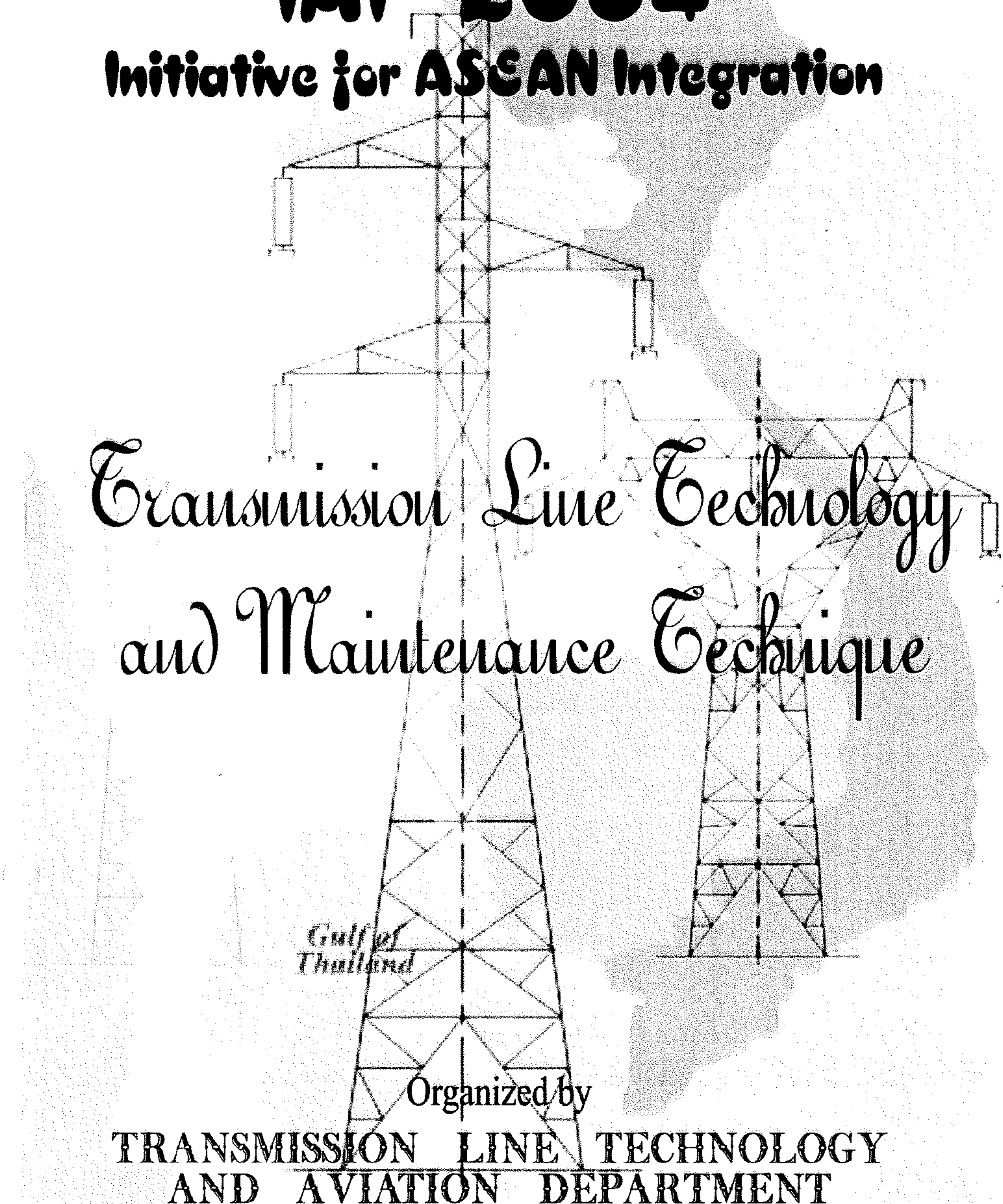

Transmission Line Technology and Maintenance Technique

Organized by

TRANSMISSION LINE TECHNOLOGY AND AVIATION DEPARTMENT

TRANSMISSION SYSTEM BUSINESS

CONTENTS

CHAPTER 1

Transmission Line Introduction

1. Introduction

1.1. Transmission Line Description

Electric transmission lines are used to transmit large blocks of power from the generating plants to the load centers and from large substations to distribution stations. They are generally operated at higher voltages and are designed for greater capacity and reliability than are electric distribution lines.

Various types of structures are used to support the transmission lines. They can be single-pole, double-pole or lattice structures. They can be wood, steel or concrete.

Electric transmission lines are most generally three phase alternating current line, but occasionally, a direct current line can be cost justified. The conductors are generally aluminum or steel reinforced aluminum and each phase can be a single conductor or a bundle of conductors.

1.2. Voltage Levels

The following is a listing of some of the nominal phase to phase voltage levels for the different transmission categories:

- **Sub-Transmission**

  69 kV

  115 kV

- **Transmission**

  138 kV

  230 kV

Bulk-Transmission

345 kV

500 kV

2. General Design Considerations

When one undertakes the assignment to design an electric transmission line, many items must be considered. Included in this list of things to consider are: Safety, Reliability, Appearance and Cost.

Common Corridors (highways, other power lines)

Distance of Structures from Road Crossings and Intersections

Farming Activities

- **Lightening Protection**

Lightening activity in the proximity of a power line can cause line outages. With the installation of an overhead ground wire as a shielding device, a measure of protection can be provided. The level of desired reliability will influence the following:

Distance of Shielding

Angle of Shielding

Level of Grounding

2.3. Appearance

The route of a power line will have a large impact on its overall appearance requirements. A line passing through a residential neighborhood should have a different level of ascetics than one routed through an industrial complex. Items that may influence the appearance of a line are:

- **Right-of-Way Clearing**

The level of right-of-way clearing will have a drastic impact on the overall appearance of the line. But it also impacts line reliability and future maintenance requirements. As a result, compromises are needed in this area.

- **Size and Type of Structures**

The size and type of structures can often be adjusted when a line passes through a sensitive area.

- **Type and Color of Finishes**

There are times when a change in the color or type of finish on the structures will reduce the impact of a power line that must pass through a sensitive area.

2.4. Overall Cost of Line

A good engineering design will always include an economic analysis. The least expensive line is not always the best line, but the cost of each improvement must be evaluated and justified. Items to consider are:

- **Time-Value of Money**

Money has time-value. That is, money received or spent today has more value than the same quantity of money will have a year from now. The difference in the two values is the interest on the money.

4. Conductors

4.1. Conductor Designations

The following is a list of the more commonly used aluminum conductors accompanied by their designation:

AAC	All Aluminum Conductor
	All aluminum conductor with no steel for support.
AAAC	All Aluminum Alloy Conductor
	Conductor with only aluminum alloy strands.
ACAR	Aluminum Conductor Aluminum Alloy Reinforced
	Aluminum conductor with one or more strands of aluminum alloy.
ACSR	Aluminum Conductor Steel Reinforced
	Aluminum conductor with one or more strands of steel.
ACSS	Aluminum Conductor Steel Supported
	Aluminum conductor totally supported by the strands of steel.
AW	Alumoweld
	Conductor made up of aluminum coated steel strands.

4.2. Conductor Selection

There are many things to consider besides the overall cost of the conductor and associated cost of the supporting structures when one is in the process of selecting a conductor for a transmission line. Some of the more important considerations are Power Flow, Line Loss, Voltage Drop, Corona, Span & Sag Requirements, and Vibration Considerations.

- **Power Flow**

  Power flow is a function of line impedance. Therefore, to achieve the desired level of power flow, the conductor must be of adequate size to allows that level of flow.

- **Line Loss**

  The line loss is a function of the square of the current and the line impedance. Thus, the cost of the lost power over the life of the line must be compared to the added cost of increasing the size of the wire to reduce the loss. Also, because of the skin effect of AC current flow, the line loss can be somewhat reduced by expanding the overall diameter of the wire without increasing the amount of metal. In earlier days, this was accomplished by using a hemp core conductor or a twisted I-bean core conductor.

- **Voltage Drop**

  The voltage drop along a line is a function of the line current and the line impedance (in accordance with Ohm's Law). Thus, to maintain the voltage at the load point to an

4.4. Conductor Tension Limits

Tension limits are established for various loading condition to prevent overloading and also to reduce the occurrence of vibration at low wind velocities. Several standards have been established. The values expressed in the table are in terms of the % of the Rated Tensile Strength (RTS) of the conductor.

Standard	Zone Loading	Initial, Unloaded	Final, Unloaded	Extreme Wind	Extreme Ice
NESC	60% RTS	35% @ 60°F	25% @ 60°F	N / S	N / S
ALCOA	50% RTS	33.3%@Zone°F	25% @Zone°F	N / S	N / S
NW Utility	40% RTS	25% @ 0°F	20% @ 0°F	50% @ 60°F	50% @ 32°F
SW Utility	40% RTS	25% @Zone°F	20% @Zone°F	50% @ 60°F	N / A

5.2. Ruling Span

The discussion on conductor sag and tension thus far has dealt with a single span. In practice, however, a power line is made up of a series of spans suspended on insulator strings that are free to move.

Rather than doing all of the conductor sag and tension calculations on the entire series of spans, it is helpful to find an equivalent length span that will react the same to temperature and loading changes as the series of spans will react. The various sag and tension calculations can then be made on this equivalent span. This equivalent span is called the ruling span.

5.3. Sag & Tension Calculations

Because of its ease, the parabola approximation is generally used for the initial design calculations. Once all of the ruling spans are determined, the sag and tension calculations should be redone using the catenary equation.

- **Calculation Procedure**

  Typically, a set of tension limits are established for a variety of loading conditions. Then the designer must determine which loading condition is the controlling condition for each ruling span district. Once the controlling condition is established for a ruling span district, the designer will calculate an array of conductor sags and tensions for various temperatures and loading conditions.

  Alternatively, a sag is specified for a given temperature and loading condition. Then the array of conductor sags and tensions for various temperatures and loading conditions will be calculated for the ruling span.

- **Computer Programs**

Although many Sag & Tension computer programs were written by various Utility Companies in the 1970's, the standard of the industry is the Alcoa Sag-10 Program. In this program, various tension limits, and even sag limits, can be specified. The program then determines which limit is the controlling one and then develops a table of sags and tensions for the various loading conditions.

5.4. Inclined Span

When the attachments on the two sides of a span are not at the same height, modifications to the equations are needed to calculate the various sag and tension relationships. Also, when several suspension spans ascend a steeply inclined hillside, special procedures are needed during the sagging and clipping operations to produce plumb structures and insulator strings. This is especially true for wood pole structures because of the extreme flexibility of the wood poles.

- **Ruling Span Correction**

  To calculate the ruling span for a series of inclined spans, the slope span distances should be used. It will be observed that the rise must be at least 10% of the span for it to have a significant difference in the ruling span calculation.

  > Note: These slope distances are used only for the ruling span calculation. A different equivalent span length should be used in the sag and tension program for the calculation of the stringing sag.

6. Conductor Installation & Operation

6.1. Conductor Stringing & Sagging

The conductor stringing operation involve pulling the conductor into position over stringing sheaves or pulleys, with the aid of a sock line or rope, while maintaining sufficient tension on the wire to prevent it from contacting the ground or other objects under the line.

The sagging operation follows the stringing operation and involves adjusting the tension in the line to obtain the proper sag. It is important to check the sag in more than one span in each ruling span district to assure that the tension over all of the spans has equalized. Also, the spans that are used to check the sag should be nearly level and close to the ruling span in length.

- **Sagging Methods**

There are three sagging methods that warrant discussion. They are the Sighting Method, the Dynamometer Method, and the Stop Watch Method.

Sighting Method

In the sighting method of sagging a conductor, a marker is placed below the attachment point a distance equal to the sag on each of the adjacent structures. A worker then sights between the two markers and when the conductor becomes tangent with the line of sight, it is properly sagged.

This is a very accurate method of sagging the conductor. The major draw back of this method is that it requires climbing both poles to measure down from the conductor attachment elevation. In the few cases where the low point of the sag is below the base of the structure, as may be the case in long canyon crossings, it will require the use of surveying equipment.

Dynamometer Method

This method requires that a dynamometer be placed in series with the conductor and adjusting the tension until the dynamometer reads the prescribed value for the tension.

This method has a severe problem. It requires that the dynamometer be capable of handling the full stringing tension and still be sensitive enough to read the small changes in tension necessary to properly sag the conductor.

Stop Watch Method

The stop watch method (also known as the Traveling Wave Method), makes use of the physics property that the velocity of propagation of a traveling wave along a tight wire is a function of only the tension and the unit mass of the wire. When this is applied to a conductor assumed to be hanging in a parabola, the sag becomes a function of only the time for the wave to travel out and back and is independent of the span.

- **Increased Creep**

An increase in the wire temperature over time will accelerate the rate of metallurgical creep. As with an increase in the thermal elongation, an increase in the creep causes additional sag and a corresponding loss in ground clearance.

- **Wire Annealing**

Depending upon which report one reads, aluminum start to anneal at a temperature around 95°C, maybe even as low as 93°C, and becomes fully annealed when it reached a temperature of around 100°C. When the wire anneals, it loses a substantial amount of its strength. Unless the conductor is totally supported by a steel core or steel messenger, the line is permanently damaged if the wire temperature reaches the level where it becomes annealed.

7. Supporting Structures

7.1. Structure Types & Materials

The various voltage classes typically utilize specific structure type. This is the case because of the varied level of reliability needed and the cost associated with each type of structure. This in no way means that a specific line cannot utilize either a higher level or lower level of reliability structure if the circumstances warrant it.

Listed below is a general categorization of the structure types and materials for various voltage classes:

- **69kV Lines**

  Single Pole Wood

  Single Pole Concrete

- **115kV Lines**

  Single Pole Wood

  Single Pole Concrete

  Single Pole Tubular Steel

- **138kV Lines**

  Single Pole Tubular Steel

  H-Frame Wood

  H-Frame Tubular Steel

- **230kV Lines**

  Single Pole Tubular Steel

  H-Frame Wood

  H-Frame Tubular Steel

tension from equalizing with temperature and loading changes. This has the potential of changing the sag characteristics of the conductor and may cause clearance problems.

- **Supported Post**

The supported post insulator system utilizes an I-String in conjunction with a post insulator. The I-String provides support for the post insulator. The post insulator typically is articulated at the base.

The advantages of the supported post insulator system are that it can handle larger vertical loads than can the post by itself and, since it is articulated at the base, it allow horizontal movement. Thus, the major concerns of the rigid post are eliminated.

9. Foundation Design Concepts

9.1.Direct Embedment Structures

Direct embedment structures rely on the their own dimensions to provide adequate surface area to obtain foundation support for both vertical bearing and overturn resistance.

When the designer determines that a direct embedment pole does not have sufficient bearing area for the native soil to support the structure, the designer can either specify that a better backfill be used or design a bearing plate to be attached to the pole.

9.2.Caisson Foundation Structures

Caisson foundation structures come with a base plate and an anchor bolt cage which are sized to transfer the structure loads to a concrete caisson. The concrete caisson is then sized to transfer both the vertical load and the overturn moment to soil.

9.3 Backfills

Backfills must have sufficient bearing strength to support the vertical loads of the structure and sufficient shear strength to resist the overturn moment of the pole. If the pole will experience uplift, then the backfill must provide sufficient skin friction against the pole to prevent it from being pulled out of the soil.

The designer must specify the type of backfill to be used. Some choices are:

- **Native Backfill**

Native backfill is the soil that was dug out of the structure hole. The holding strength of the native soil can range from very good to very poor. Also, the strength may change from season to season depending upon the amount of moisture entering and leaving the soil.

- **Gravel Backfill**

When the native soil is determined to be inadequate for backfill, it may be appropriate to specify a gravel or crushed rock backfill. A typical size of gravel used for backfill is 3/4 inch minus or 1-1/4 inch minus.

The crushed rook provides a good bearing surface provided the surrounding soil is not too marshy to support the backfill system.

- **Structure Hold-Down Guys**

  Structure hold-down guys are employed on a structure when the structure is in, or nearly in, an uplift condition at least part of the time.

  There are certain conditions where a structure is not needed to maintain ground clearance but is needed to keep the wind span within the design limits. This structure is often in an uplift situation and may need to be anchored to keep it from being pulled out of the ground..

- **Insulator Hold-Down Guys**

  Insulator hold-down guys are guys that are attached, through an additional string of insulators, to the conductor clamp on a suspension structure that is in uplift at least part of the time. They are most often used as a last effort correction to an uplift problem when a taller structure or hold down weights are not practical.

The hold-down guys (especially the structure hold-down guys) will prevent the structure from moving with the wind. Therefore the forces in the hold-down guys include the wind forces as well as the uplift force.

10.6. Waist Guys & Bridle Guys

Waist guys are used to shorten the column length on tall, heavily loaded poles.

The waist guy system is made up of down guys that are installed at a point slightly above the mid-point of the pole and extend out in at least three directions around the pole to stabilize the mid-point and thereby shorten the column length. When the structure is made up of multiple poles, bridle guys (much like span guys) are installed between the poles at the waist guy level to eliminate the need to install down guys in that direction.

Waist guys are most often installed on fully deadended structures where the deadend wires and their associated down guys are stabilizing the top of the pole, as well as supporting nearly all of the wind load. As a result, the waist guys will be supporting only the lateral forces which would otherwise be causing buckling. These lateral forces are generally quite small and do not tend to load the guys or pole enough to be concerned about.

10.7. Push Poles

A push pole (or push brace) is sometimes used in place of an angle guy when the right-of-way for an angle guy cannot be obtained. As implied by its name, the push pole goes on the inside of the angle and pushes against the supporting structure, while the angle guy goes on the outside of the angle and pulls against the supporting structure.

The only difference between the force in angle guy and the force in the push pole is that the guy is in tension while the pole is in compression.

10.8. Anchors

The anchor is the device which transfers the guy wire force to the soil. Depending upon the soil type, the anchor will pull against either a cylinder or a cone of soil behind the it.

A general description of some of the more popular anchors follows:

The number of blows is recorded for each of three six-inch intervals. The first is generally considered the seating drive. The sum of the blows for the remaining two intervals is reported as the N value or the Blow Count. The core sample is then retrieved for the purpose of soil classification.

11. Right-of-Way & Permits

The corridor in which the transmission line traverses is often referred to as the right-of-way, deriving its name from having the "right" to place the line there. There are several methods of obtaining permission to place the line in the right-of-way. The main ones are:

11.1. Fee Title

When the utility company already has direct ownership of the land or they purchases the corridor over which the line is to traverse, they have a title of ownership and it is often referred to as having "fee title" for the corridor.

11.2. Property Easement

Most often the utility company will buy a right to use the corridor but not purchase the land itself. This is referred to as having an "easement" for the corridor. The easement is typically perpetual.

The two main advantages of having an easement over fee title are:

In many instances, the property owner can continue to use the property as it was previously being used as long as that uses does not interfere with the power line. A good example is farming.

The property owner continues to pay the property taxes on the corridor. This eliminates the bookkeeping hassle of having to pay taxes on hundreds of parcels of land.

11.3. Permits

Railroads and government entities typically will issue only a permit and not an easement for the power company to construct the line on their property. The permit is typically renewed on a periodic basis.

By issuing only a permit and not a perpetual easement, the owner can revoke the permit, or refuse to renew it when it comes due, when they have a new need for the land themselves.

Typical permits required by the government other than for direct use of their land are:

FAA Permit for the safety of aircraft.

Navigable Water Permit to maintain clearance for boats.

Shoreline Permits for restrict construction near waterways.

Wet Lands Permit to protect wetland animals.

CHAPTER 2

Transmission Line Equipment

1. Aluminium Concrete, Fiberglass, and Steel Structures

Environmental considerations have increased the use of aluminum, concrete, fiberglass, and steel to support electric transmission and distribution circuits. Wood-pole structures have generally proved to be the most economical for distribution and transmission lines operating at voltages through 345 kV. The design of structures to make them compatible with the environment has resulted in the use of materials and colors to comport with the natural surroundings. Aluminum, concrete, fiberglass, and steel structures, properly used, may reduce the widths of rights-of-ways required for distribution and transmission lines.

1.1. Aluminum Structures. Ornamental street lighting is one of the most common applications of aluminum poles. The hollow-tubular street-lighting poles give a pleasing appearance. The poles are lightweight, making them easy to handle and install. The hollow pole facilitates the installation of the low-voltage cables supplying the lamps from underground electric distribution circuits.

1.2. Concrete Poles. Poles manufactured with concrete are used for street lighting and for distribution and transmission lines. Concrete poles h ave been used to improve the aesthetics of overhead circuits and are preferred where the life of wooden poles is unduly shortened by decay and woodpeckers. Compared to wood poles, concrete poles have disadvantages of being more expensive, lower in insulation level, more difficult to climb, heavier to handle, and more difficult to drill when necessary to install equipment. Concrete has advantages, compared to wood, of long life and availability on demand.

Hollow-type concrete poles are made by putting the concrete materials and steel reinforcing rods into a cylinder of the desired length and taper. Revolving the cylinder in a lathe-like machine for a period of 10 to 15 min then forces the concrete materials to the outside, thereby forming the hollow pole when the concrete cures. The hollow-type pole is lighter than the solid-type pole and provides a means for making connections throuh the pole to underground cables or services. The hollow-type poles are commonly used for ornamental street-lighting installations served from underground electric circuits.

The hollow-spun prestressed-concrete poles have a high-density concrete shell completely encasing a reinforcing cage containing prestressed high-tensile steel wires. Prestressing produces poles with a high strength-to-weight ratio that can be used for distribution and transmission lines. Table 1 lists typical data for hollowspun prestressed-concrete poles equivalent to class 1 wood poles.

Linemen use bucket trucks to eliminate the need for pole steps when fiberglass poles are located in areas accessible to trucks. Fiberglass poles are too expensive to be used extensively for overhead distribution circuits, but fiberglass rods have been used for insulator supports, eliminating the need for crossarms. Armless construction using fiberglass components is used extensively to enhance the appearance of overhead lines. Fiberglass components are reasonably priced and economically acceptable where the appearance of the facilities is important.

1.4. Steel Structures. Steel towers have been used extensively to support subtransmission line and transmission-line conductors. Towers of this type are required for 765-kV three-phase ac transmission lines. The size of transmission-line towers should be kept to the minimum feasible to preserve the environment and minimize the conflict with other use of the land. Galvanized steel eliminates the need to paint the towers for several years, reducing maintenance costs. Steel is free from damage by woodpeckers and bacteria.

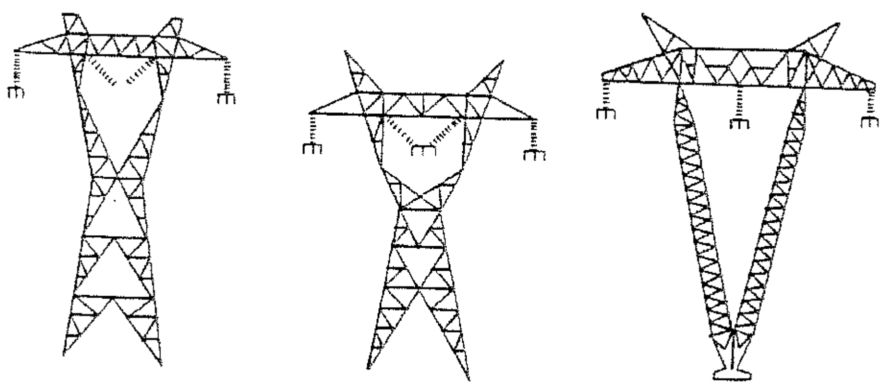

Figure 1 Standard tower designs.

Steel transmission-line towers are of either the rigid or the flexible type. The rigid tower is firm in all directions, whereas the flexible tower is free to deflect in the direction of the line. Rigid towers, in order to be rigid, must have three or more legs, but the flexible construction consists of only two legs. Rigid towers can resist the same strain in all directions. Flexible towers can resist strain only transversely or across the line and have very little strength in the direction of the line. They will give or deflect if there is any unbalance in conductor pull; in fact, they depend largely on the conductors to hold them in position.

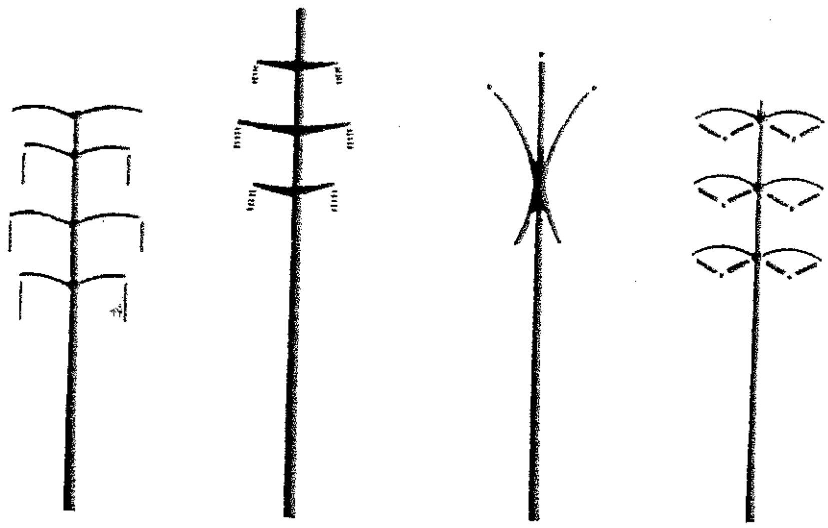

Figure 4 Inconspicuous steel transmission-structure designs.

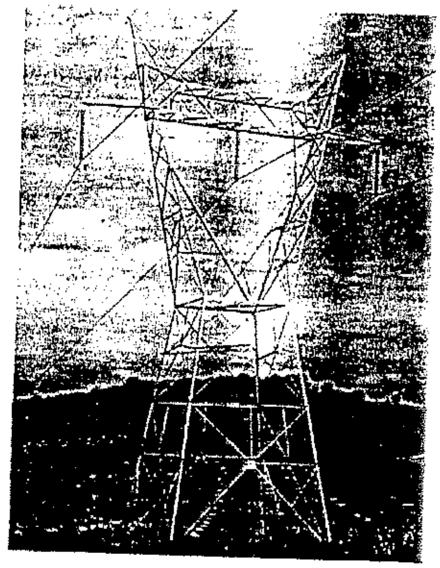

Figure 5 Four-legged rigid-type 230-kV transmission tower.

The cost of structure assembly of steel H-frame structures is estimated to be approximately 50 percent of that for standard rigid-latticework steel towers for this type of circuit; it is also less than that of wood-pole structures as a result of the reduced number of structures. The smaller number of structures minimizes the number of insulators and the line hardware required and reduces the labor costs to string, sag, and clip in the conductors. The total cost for the construction of this type of line is approximately the same for rigid and flexible steel towers.

When an aluminum conductor is stranded, the central strand is often made of steel, which serves to reinforce the cable. Such reinforcement gives great strength for the weight of conductor. Reinforced aluminum cable called ACSR (aluminum conductor steel-reinforced) is therefore especially suited for long spans.

2.3. Steel Conductors. Steel wire is used to a limited extent where minimum construction expense is desired. Steel wire, because of its high tensile strength of 160,000 lb/in^2, permits relatively long spans, therefore requires few supports. Bare steel wire, however, rusts rapidly and is therefore very short-lived. Steel is also a poor conductor compared with copper, being only about 10 to 15 percent as good. Galvanized steel conductors are commonly used for shield or static wires in transmission and subtransmission lines. Most guy wires are galvanized steel stranded cables.

2.4. Copperweld Steel Conductors. The disadvantages of short life and low conductivity of steel led to the development of the copperwelded steel conductor. In this conductor a coating of copper is securely welded to the outside of the steel wire. The copper acts as a protective coating to the steel wire, thus giving the conductor the same life as if it were made of solid copper. At the same time, the layer of copper greatly increases the conductivity of the steel conductor, while the steel gives it great strength. This combination produces a very satisfactory yet inexpensive line conductor. Its chief field of application is for overhead primary conductors in rural lines, for guy wires, and for overhead ground wires.

The conductivity of copperweld conductors can be raised to any desired percentage, depending on the thickness of the copper layer. The usual values of conductivity of wires as manufactured are 30 and 40 percent.

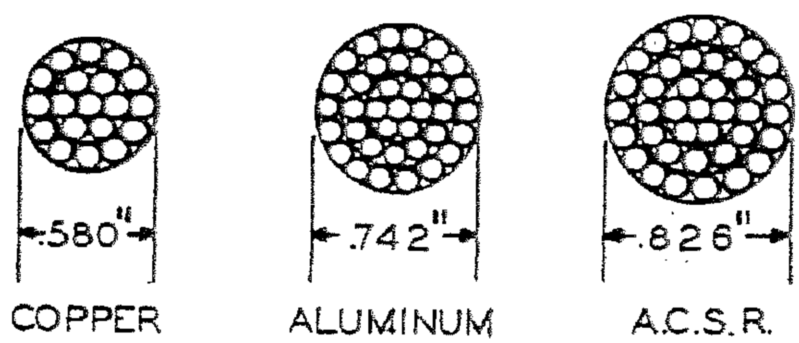

Figure 6 Relative cross sections of copper, aluminum, and ACSR conductors having equal current-carrying capacities.

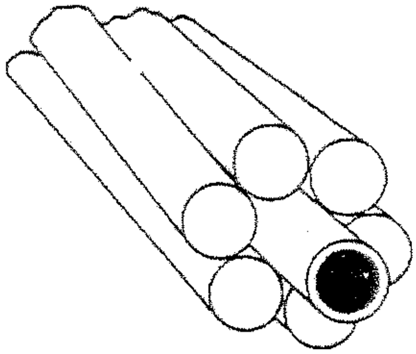

Figure 9 ACSR cable with steel strand covered with layer of welded aluminum. The layer of aluminum on the steel strand prevents electrolytic corrosion between strands, prevents rusting of the steel strand, and increases the conductivity of the steel strand by a substantial amount.

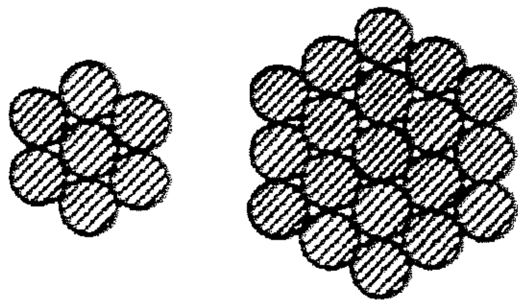

Figure 10 Sketches showing arrangement of wires in 7- and 19-stand conductors. The wires are arranged in concentric layers about a central core.

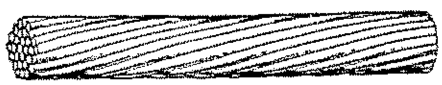

Figure 11 Typical stranded cable.

2.7. Wire Sizes. Wire sizes are ordinarily expressed by numbers. There are, however, several different numbering methods, so that in specifying a wire size by number it is also necessary to state which wire gauge or numbering method is used. The most used wire gauge in the United States is the Brown and Sharpe gauge, also called American wire gauge (AWG).

- **American Wire Gauge.** The American standard wire gauge is shown in Fig. 13. This cut is full size, so that the widths of the openings on the rim of the gauge correspond to the diameters of the wires whose numbers stand opposite the openings. Note that the greater the number of the wire, the smaller the wire is. That came about by numbering the wire by the number of steps required in the wire-

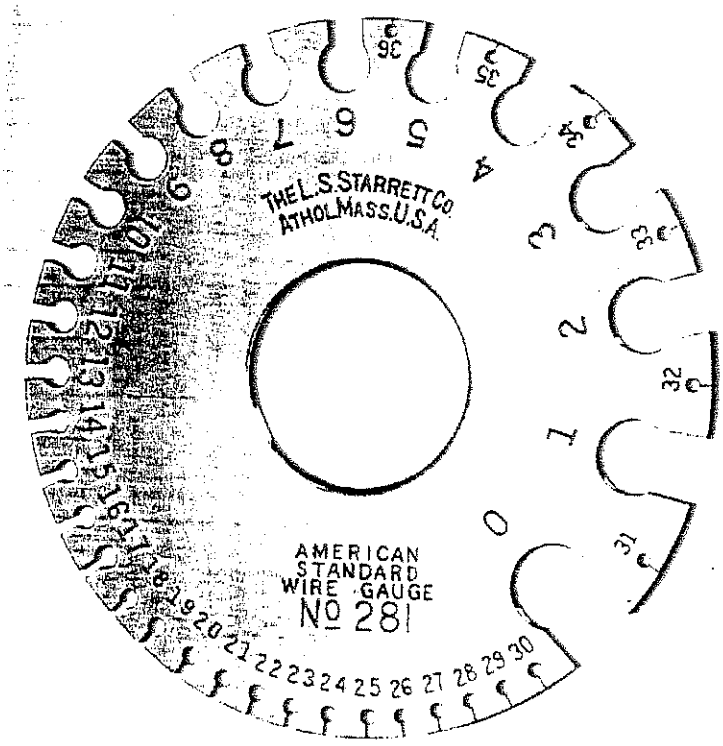

Figure 13 American standard wire gauge. Cut is full size. Widths of openings on rim correspond to diameters of wires whose numbers are opposite the openings.

Vibration Dampers. Line conductors vibrate as a result of aeolian vibration. The vibration has been found to vary from 3 to 150 Hz. Vibration dampers are installed on the conductors to control the vibration and prevent conductor damage. The Stockbridge-type dampers shown in many of the transmission-line pictures throughout the handbook have been used for many years. The elastomeric dampers developed by Alcoa are smaller, lighter, and more efficient than Stockbridge dampers. The elastomeric damper can protect long span lengths from vibration without causing corona on extra-high-voltage transmission lines.

Conductor Spacers. Transmission lines with bundled conductors, that is, two or more conductors per phase, use spacers to keep the conductors from wrapping together. Alcoa spacer dampers are designed with damping mechanisms capable of reducing vibration by converting the mechanical energy of the vibrating conductors into heat in the damping element.

The spacer dampers required to prevent conductor clashing are normally adequate to prevent aeolian vibration.

3. Insulators

An insulator prevents the flow of an electric current and is used to support electrical conductors. The function of an insulator is to separate the line conductors from the pole or tower. Insulators are fabricated from porcelain, glass, fiberglass and polymers.

Porcelain insulators are manufactured from clay. Special clays are selected and mixed mechanically until a plastic-like compound is produced. The clay is then placed in molds to form the insulators. The molds are placed in an oven to dry the clay. When the clay is partially dry, the mold is removed and the drying process is completed. When the insulator is dry, it is dipped in a glazing solution and fired in a kiln. The glaze colors the insulator and provides a glossy surface. This makes the insulator surface self-cleaning.

Large porcelain insulators are made up of several shapes cemented together. Care must be taken when cementing the insulators together to prevent a chemical reaction on the metal parts, causing cement growth. Cement growth can cause stresses on the porcelain great enough to crack the porcelain.

Glass insulators are made from sand, soda, ash, and lime. The materials are properly mixed and melted in an oven until a clear-liquid plastic-like material is produced. The plastic-like compound is placed in a mold and allowed to cool. After the glass insulator is cool, it is placed in an annealing oven.

Fiberglass insulators are manufactured with rods of fiberglass treated with epoxy resins. Rubber-like compounds are applied to the rods to fabricate suspension, deadend, and post-type insulators.

Polymer insulators are formed by using various sizes of silica that are bound together chemically with a resin. The compound's composition is approximately 90 percent silica. Polymer insulators are replacing porcelain, glass and epoxy insulators. Polymer insulators have excellent mechanical and dielectric strength. The insulators are lightweight, virtually nonbreakable and much easier to handle than any other types of insulators. Polymer insulators are less costly than porcelain, glass, or epoxy insulators because of their ease of manufacture. Field tests and current installation success of polymer insulators have proven that they are durable and that they will provide many years of service in an adverse atmosphere.

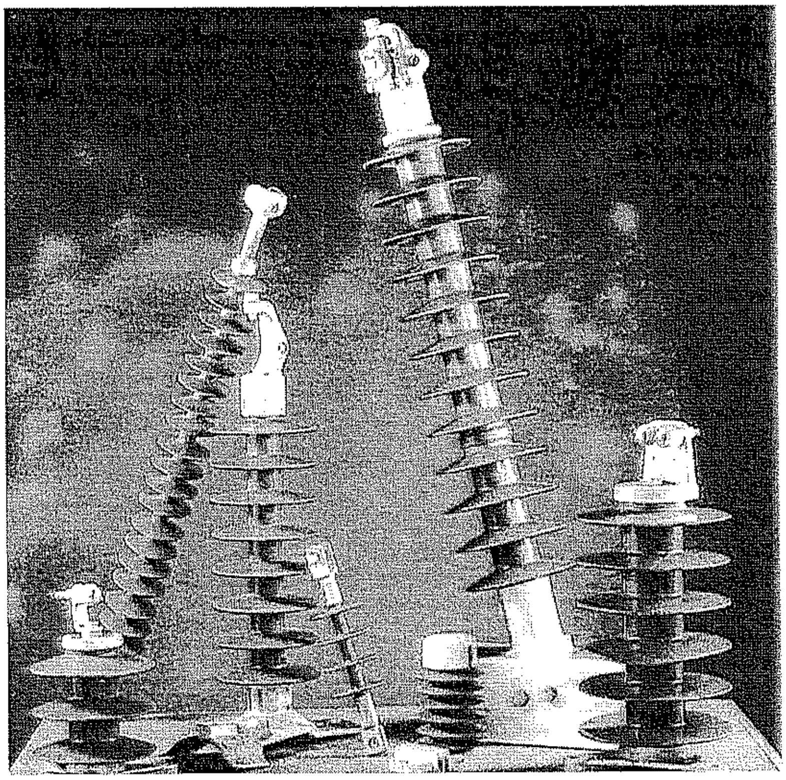

Figure 18 Polymers insulator

3.1. Post-Type Insulators. Post-type insulators are used on distribution, subtransmision, and transmission lines and are installed on wood, concrete, and steel poles. The line-post insulators are manufactured for vertical or horizontal mounting. The line-post insulators are usually manufactured as one-piece solid porcelain units or fiberglass epoxy-covered rods with metal end fittings and rubber weather heds. In some instances the fiberglass rod is combined with a porcelain insulator unit. The insulators are fabricated with a mounting base for curved or flat surfaces, and the top is designed for tying the conductor to the insulator or fitted with a clamp designed to hold the conductor.

Line-post insulators designed for vertical mounting are mounted on crossarms. This type of construction is often used for long-span rural distribution circuits. Armless construction using post-type insulators permits the construction of subtransmission and transmission lines on narrow rightsof-way and along city streets.

Post-type insulators have been used to construct circuits that operate at voltages through 345 kV. Lines constructed with post-type insulators are clean-looking and aesthetically acceptable to the public.

Strain insulators are used where a pull must be carried as well as insulation provided. Such places occur wherever a line is dead-ended-at corners, at sharp curves, or at extra long spans, as at river crossings or in mountainous country. In such places the insulator not only must be a good insulator electrically, but also must have sufficient mechanical strength to counterbalance the forces due to the tension of the line conductors.

Strain insulators are built in the same way as suspension insulators except that they are made stronger mechanically. Furthermore, when a single string is not able to withstand the pull, two or more strings are arranged in multiple.

Glass suspension insulators have been used on the circuits in many cases. Glass is used more commonly in countries other than the United States. Glass insulators can be used interchangeably with porcelain insulators wherever their strength and voltage characteristics are adequate.

The development of extra-high-voltage (EHV) bundle-conductor transmission circuits resulted in heavy and cumbersome installations when porcelain suspension insulators were used. To solve that problem, the Ohio Brass Co. developed the Hi-Lite suspension insulator, which has a long epoxy-fiberglass rod of extremely high mechanical and dielectric strength with weather sheds of rubber. A heavy silicone grease is used as an interface between the rod and the weather sheds. Forged-steel end attachments are swaged to the rod under pressure. The insulators are manufactured with maximum design tension ratings of 10,000, 20,000, 40,000, and 80,000 lb. A single Hi-Lite suspension insulator can replace four parallel strings of porcelain or glass suspension insulators. The synthetic-material insulators weigh only 5 to 10 percent of the weight of the suspension insulators they replace. A 500-kV Hi-Lite insulator weighs 40 lb, and a 765-kV insulator weighs 65 lb. The synthetic-material insulators are less susceptible to mechanical damage.

TABLE 2 Approximate Number of 10-in Porcelain or Glass Disk Insulators Required in Suspension String for Various Line Voltages

Line voltage volts	Number of suspension units required in string	Line voltage volts	Number of suspension units required in string
13,200	2	138,000	8, 9, or 10
23,000	2 or3	154,000	9, 10, or 11
34,500	2 or3	230,000	12 to 16
69,000	4 or5	345,000	18 to 20
88,000	5 or6	500,000	24 to 28
110,000	6, 7, or 8	765,000	30 to 35

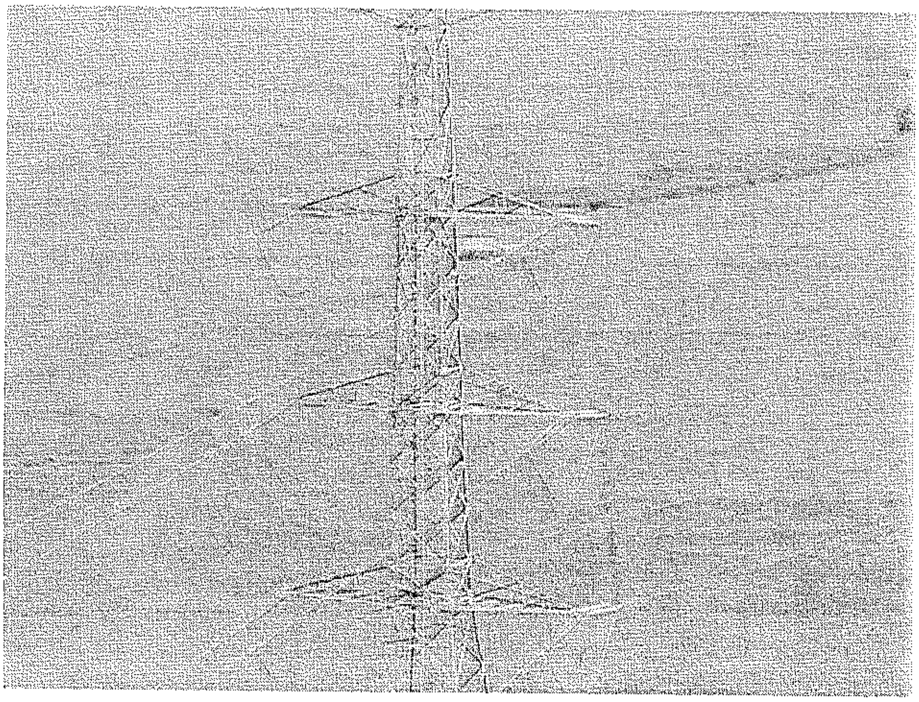

Figure 21 Two parallel strings of suspension insulators used to serve as strains insulators at 230 kV tower.

Figure 22 Two parallel strings of suspension insulators at 115 kV tower.