**PDHonline Course E538 (4 PDH)**

# Transmission Line Design - Volume 2

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# Transmission Line Design Volume II - Clearances

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This course is based on a USDA document, "Design Manual for High Voltage Transmission Lines", United States Department of Agriculture, Rural Utilities Service December, 2015.

# Introduction

The primary purpose of this series of courses is to furnish engineering information for use in designing transmission lines. Good line design should result in high continuity of service, long life of physical equipment, low maintenance costs, and safe operation. These courses presents a generalized "how to" guide for the design of a high voltage transmission line.

The engineering information in this course is for use in design of transmission lines for voltages 230 kV and below. Designs should be adapted to various conditions and local requirements. Engineers should investigate local weather information, soil conditions, operation of existing lines, local regulations, and environmental requirements and evaluate known pertinent factors in arriving at design recommendations.

This course is based on the requirements of the National Electrical Safety Code® (NESC®). However, since the NESC is a safety code and not a design guide, additional information and design criteria are provided in this course as guidance to the engineer. The additional design criteria are based on practices of many utilities in the United States.

This series includes five volumes. For the best understanding of the material, they should be studied in order. The volumes are generally divided into the following categories.

Volume I. This volume is an introduction to transmission line design and addresses siting issues, plan and profile drawings, loading, and distribution underbuild.

Volume II. This volume is all about clearances. Ground clearances, horizontal clearances, clearances from other live parts, and clearances to supporting structures are addressed.

Volume III. This volume discusses the materials involved in transmission line design and construction including insulators, conductors and hardware.

Volume IV. This volume in the series is concerned with the structural aspects of transmission line design and includes foundations and guyed structures.

Volume V. The final volume in the series is concerned with the structural aspects of transmission line design and includes single-pole structures and H-frame structures.

# Chapter 1
# Clearances to Ground, to Objects under the Line and at Crossings

Recommended design vertical clearances for transmission lines of 230 kV and below are listed in the Tables 1 through 3. These clearances exceed the minimum clearances calculated in accordance with the latest edition of the NESC. If the latest edition has not been adopted in a particular locale, clearances and the conditions found in this chapter should be reviewed to ensure that they meet the more stringent of the applicable requirements.

Clearance values provided in the following tables are recommended design values. In order to provide an additional cushion of safety, recommended design values exceed the minimum clearances in the 2012 NESC.

In most cases, the clearances in Tables 1 through 3 exceed NESC requirements. Check the latest version of the NESC for actual requirements.

**Assumptions**

- Fault Clearing and Switching Surges. Clearances in tables 1, 2, 3, and 4 are recommended for transmission lines capable of clearing line-to-ground faults and voltages up to 230 kV. For 230 kV, the tables apply for switching surges less than or equal to 2.0; for higher switching surges on 230 kV transmission lines see the alternate clearance recommendations in the NESC.

- Voltage. Listed in the chart that follows are nominal transmission line voltages and the assumed maximum allowable operating voltage for these nominal voltages. If the expected operating voltage is greater than the value given below, the clearances in this course may be inadequate. Refer to the latest edition of the NESC for guidance.

| Nominal Line-to-Line Voltage (kV) | Maximum Line-to Line Operating Voltage (kV) |
|---|---|
| 34.5 | * |
| 46 | * |
| 69 | 72.5 |
| 115 | 121 |
| 138 | 145 |

| | |
|---|---|
| 161 | 169 |
| 230 | 242 |
| *Maximum operating voltage has no effect on clearance requirements for these nominal voltages. | |

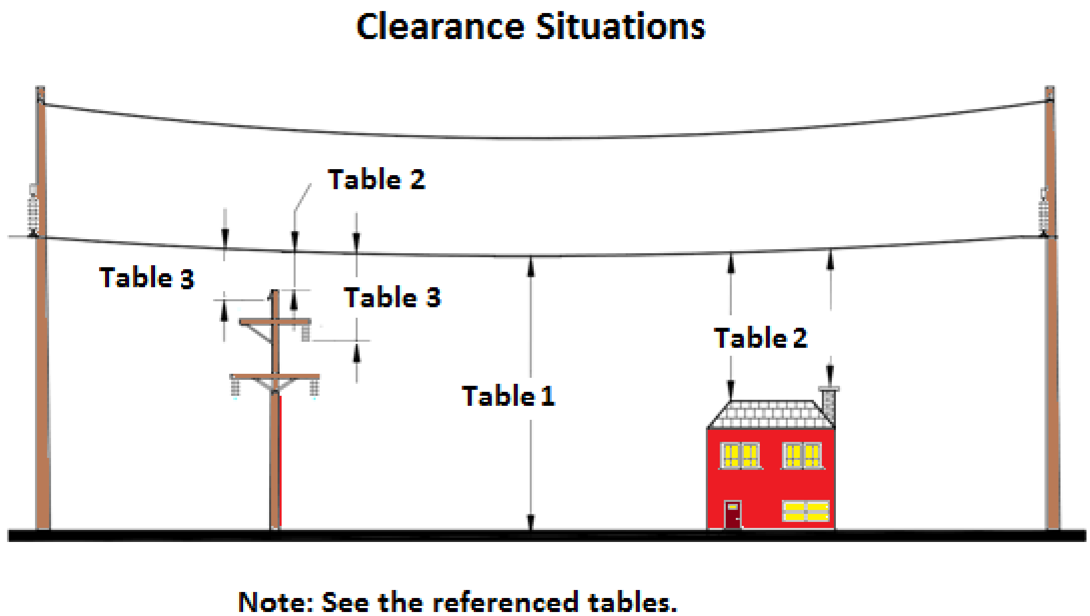



Figure 1

**Design Vertical Clearance of Conductors**

The recommended design vertical clearances under various conditions are provided in Table 1.

The clearances apply to a conductor at final sag for the conditions ‘a’ through ‘c’ listed below. The condition that produces the greatest sag for the line is the one that applies.

a) Conductor temperature of 32F, no wind, with the radial thickness of ice for the applicable NESC loading district.

b) Conductor temperature of 167F. A lower temperature may be considered where justified by a qualified engineering study. Under no circumstances should a design temperature be less than 120F.

c) Maximum design conductor temperature, no wind. For high voltage bulk transmission lines of major importance to the system, consideration should be given to the use of 212F as the maximum design conductor temperature.

According to the National Electric Reliability Council criteria, emergency loading for lines of a system would be the line loads sustained when the worst combination of one line and one generator outage occurs. The loads used for condition "c" should be based on long range load forecasts.

Sags of overhead transmission conductors are predicted fairly accurately for normal operating temperatures. However, it has consistently been observed that sags for ACSR (Aluminum Conductor Steel Reinforced) conductors can be greater than predicted at elevated temperatures. If conductors are to be regularly operated at elevated temperatures, it is important that sag behavior be well understood. Current knowledge of the effects of high temperature operation on the long term behavior of conductors and associated hardware (splices, etc.) is probably limited; however, and a clear understanding of the issues involved is essential.

The traditional approach in predicting ACSR conductor sag has been to assume that the aluminum and steel share only tension loads. But as conductor temperature rises, aluminum expands more rapidly than steel. Eventually the aluminum tension will reduce to zero and then go into compression. Beyond this point the steel carries the total conductor tension. These compressive stresses generally occur when conductors are operated above 176F to 200F.

Greater sags than predicted at these elevated temperatures may be attributed to aluminum being in compression which is normally neglected by traditional sag and tension methods. AAC (All Aluminum Conductors) and AAAC (All Aluminum Alloy Conductor) or ACSR conductors having only one layer of aluminum or ACSR with less than 7 percent steel should not have significantly larger sags than predicted by these traditional methods at higher operating temperatures.

Altitude Greater than 3300 Feet

If the altitude of a transmission line (or a portion thereof) is greater than 3300 feet, an additional clearance as indicated in Table 1 must be added to the base clearances given.

Spaces and Ways Accessible to Pedestrians Only

Pedestrian-only clearances should be applied carefully. If it is possible for anything other than a person on foot to get under the line, such as a person riding a horse, the line should not be considered to be accessible to pedestrians-only and another clearance category should be used. It is expected that this type of clearance will be used rarely and only in the most unusual circumstances.

Clearance for Lines along Roads in Rural Districts

If a line along a road in a rural district is adjacent to a cultivated field or other land falling into Category 3 of Table 1, the clearance-to-ground should be based on the clearance requirements of Category 3 unless the line is located entirely within the road right-of-way and is inaccessible to vehicular traffic, including highway right-of-way maintenance equipment. If a line meets these two requirements, its clearance may be based on the "along road in rural district" requirement. To avoid the need for future line changes, it is strongly recommended that the ground clearance for the line should be based on clearance over driveways. This should be done whenever it is considered likely a driveway will be built somewhere under the line. Heavily traveled rural roads should be considered as being in urban areas.

Reference Component and Tall Vehicles/Boats

There may be areas where it can be normally expected that tall vehicles/boats will pass under the line. In such areas, it is recommended that consideration be given to increasing the clearances given in Table 1 by the amount by which the operating height of the vehicle/boat exceeds the reference component. The reference component is that part of the clearance component which covers the activity in the area which the overhead line crosses.

For example, truck height is limited to 14 feet by state regulation, thus the reference component for roads is 14 feet. However, in northern climates sanding trucks typically operate with their box in an elevated position to distribute the sand and salt to icy roadways. The clearances in Table 1 are to be increased by the amount the sanding truck operating height exceeds 14 feet. In another example, the height of farm equipment may be 14 feet or more. In these cases, these clearances should be increased by the difference between the known height of the oversized vehicle and the reference height of 14 feet.

Reference heights for Table 1 are given below.

| Item | Description | Reference height |
|---|---|---|
| 1.0 | Track rails | 22.0 |
| 2.0 | Streets, alleys, roads, driveways, and parking lots | 14.0 |
| 3.0 | Spaces and ways--pedestrians only | 10.0 |
| 4.0 | Other lands traversed by vehicles | 14.0 |
| 5.0 | Water areas--no sail boating | 12.5 |

| | | |
|---|---|---|
| 6.0 | Water areas—sail boating<br>Less than 20 acres | 16.0 |
| | 20 to 200 acres | 24.0 |
| | 200 to 2000 acres | 30.0 |
| | Over 2000 acres | 36.0 |
| 7.0 | Areas posted for rigging or launching sailboats | See NESC Table |



Clearances over Water

Clearances over navigable waterways are governed by the U.S. Army Corps of Engineers and therefore the clearances over water provided in Table 1 apply only where the Corps does not have jurisdiction.

Clearances for Sag Templates

Sag templates used for spotting structures on a plan and profile sheet should be cut to allow at least one foot extra clearance than given in Table 1, in order to compensate for minor errors and to provide flexibility for minor shifts in structure location.

Where the terrain or survey method used in obtaining the ground profile for the plan and profile sheets is subject to greater unknowns or tolerances than the one foot allowed, appropriate additional clearance should be provided.

**Design Vertical Clearance of Conductors to Objects under the Line**

The recommended design vertical clearances to various objects under a transmission line are given in Table 2.

The clearances in Table 2 apply under the same loading and temperature conditions as previously outlined. See NESC Figures 234-1(a) and 234-1(b) and 234-1(c) for transition zones between horizontal and vertical clearance planes. See Chapter 2 for horizontal clearances.

Lines Over Buildings

Although clearances for lines passing over buildings are shown in Table 2, it is recommended that lines not pass directly over a building if it can be avoided.

Clearances to Rail Cars

The NESC has defined the clearance envelope around rail cars as shown in Figure 2 (NESC Figure 234-5):

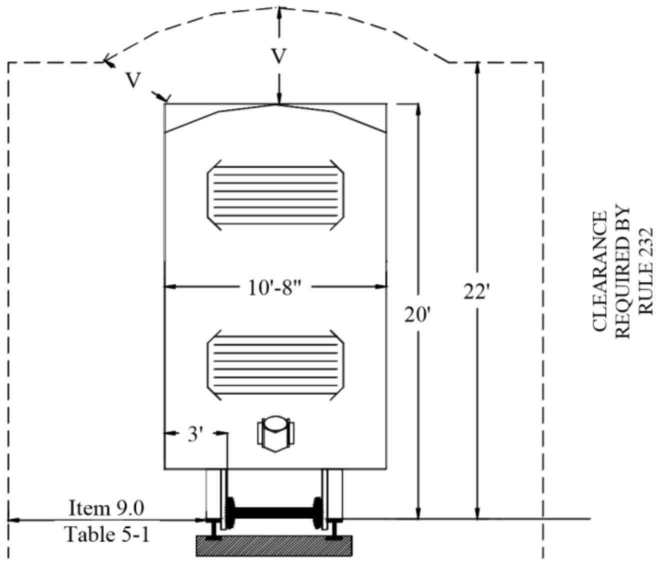



Figure 2

Note: This figure is from IEEE C2-2012, National Electric Safety Code® (NESC®), Copyright IEEE 2012. All rights reserved.

To simplify the design process, Figure 3, which defines the recommended clearances, may be used:

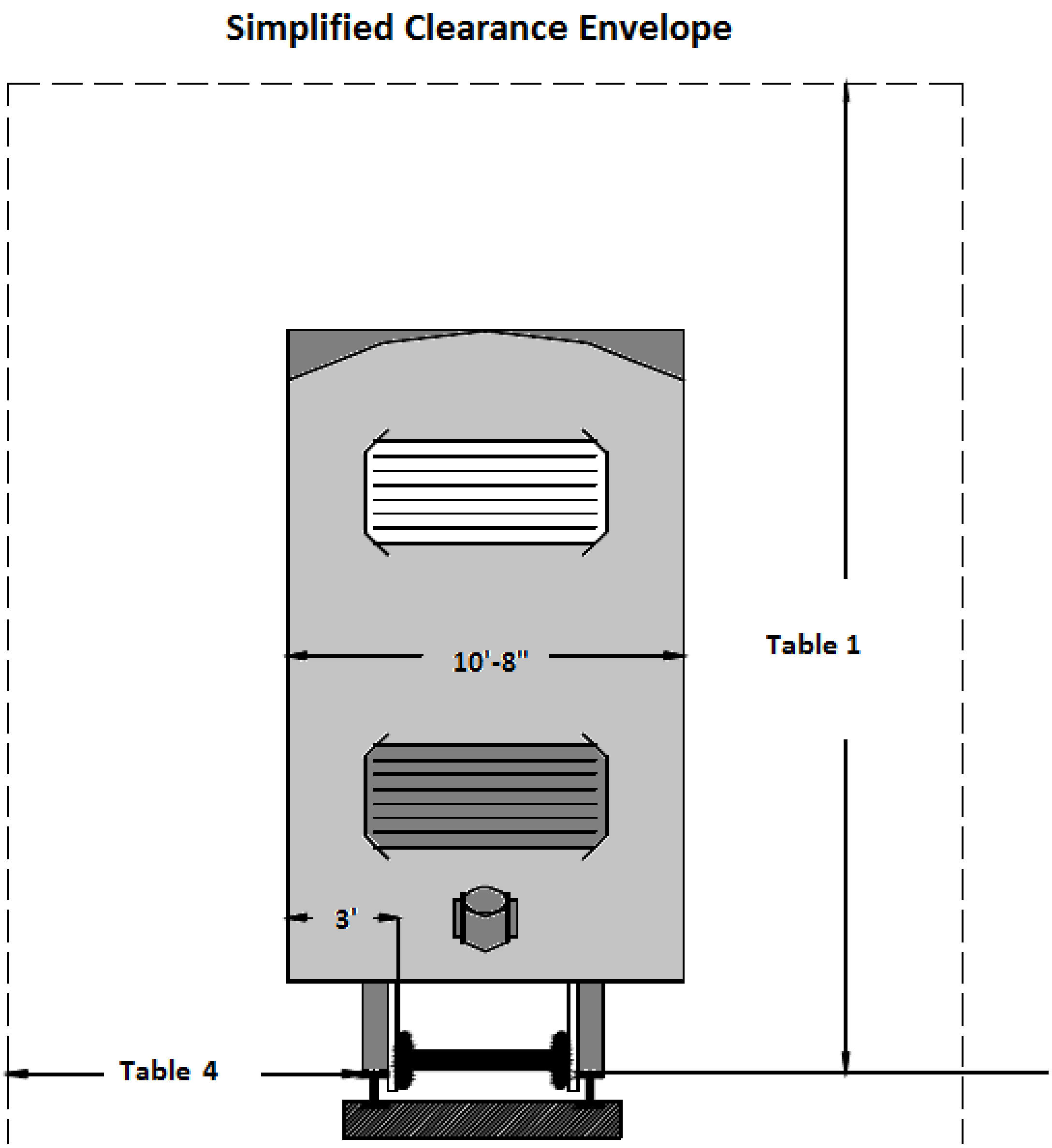



Figure 3

In cases where the base of the transmission line is below that of the railroad bed, the designer may be required to install taller poles or to offset further from the track than is indicated by the NESC clearance envelope.

Lines over Swimming Pools

Clearances over swimming pools are for reference purposes only. Lines should not pass over or within clearance 'A' of the edge of a swimming pool or the base of the diving platform. Clearance 'B' should be maintained in any direction to the diving platform or tower.

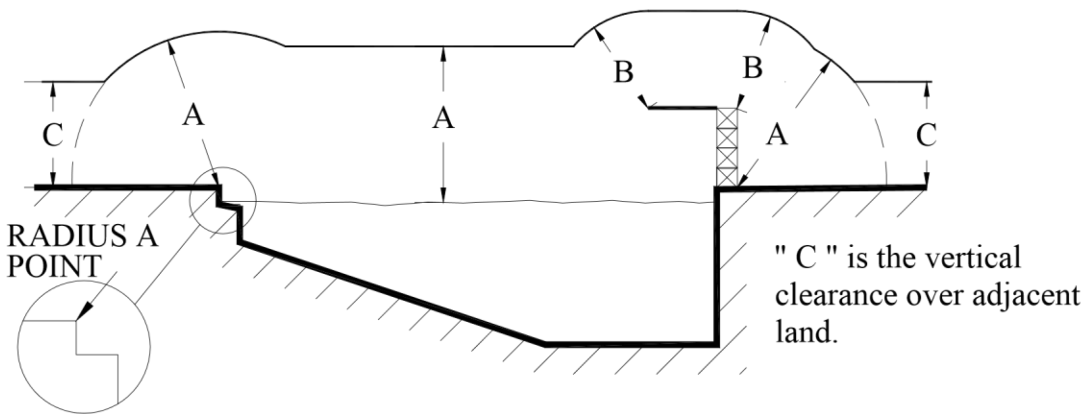



**Figure 4**



**Table 1**

**Recommended Design Vertical Clearances of Conductors above Ground, Roadways, Rails, or Water Surface (Feet) (See Notes A, F & G) (Applicable NESC Rules 232a, 232b, And Table 232-1)**

**Line conditions under which the NESC states vertical clearances shall be met (Calculations are based on Maximum Operating Voltage):**

- 32F, no wind, with radial thickness of ice, if any, specified in Rule 250B of the NESC for the loading district concerned.
- Maximum conductor temperature for which the line is designed to operate, with no horizontal displacement

| **Nominal Voltage, Phase to Phase ($kV_{LL}$)** | **34.5 & 46** | **69** | **115** | **138** | **161** | **230** |
|---|---|---|---|---|---|---|
| Max. Operating Voltage, Phase to Phase ($kV_{LL}$) | ---- | 72.5 | 120.8 | 144.9 | 169.1 | 241.5 |
| Max. Operating Voltage, Phase to Ground ($kV_{LG}$) | ---- | 41.8 | 69.7 | 83.7 | 97.6 | 139.4 |

| | NESC Basic Clear.(Note F) | Clearances in feet | | | | | |
|---|---|---|---|---|---|---|---|
| 1.0 Track rails | 26.5 | 29.2 | 29.7 | 30.6 | 31.1 | 31.5 | 32.9 |
| 2.0 Roads, streets, etc., subject to truck traffic | 18.5 | 21.2 | 21.7 | 22.6 | 23.1 | 23.5 | 24.9 |
| 3.0 Driveways, parking lots, and alleys | 18.5 | 21.2 | 21.7 | 22.6 | 23.1 | 23.5 | 24.9 |
| 4.0 Other lands cultivated etc., traversed by vehicles, industrial and commercial areas (Note B) | 18.5 | 21.2 | 21.7 | 22.6 | 23.1 | 23.5 | 24.9 |
| 5.0 Spaces and ways accessible to pedestrians only (Note C) | 14.5 | 17.2 | 17.7 | 18.6 | 19.1 | 19.5 | 20.9 |
| 6.0 Water areas – no sail boating | 17.0 | 19.7 | 20.2 | 21.1 | 21.6 | 22.0 | 23.4 |
| 7.0 Water areas – sail boating suitable (Notes D & E) | | | | | | | |
| Less than 20 acres | 20.5 | 23.2 | 23.7 | 24.6 | 25.1 | 25.5 | 26.9 |
| 20 to 200 acres | 28.5 | 31.2 | 31.7 | 32.6 | 33.1 | 33.5 | 34.9 |
| 200 to 2000 acres | 34.5 | 37.2 | 37.7 | 38.6 | 39.1 | 39.5 | 40.9 |
| Over 2000 acres | 40.5 | 43.2 | 43.7 | 44.6 | 45.1 | 45.5 | 46.9 |
| 8.0 Public or private land and water areas posted for rigging or launching sailboats (Note E) | | | | | | | |
| Less than 20 acres | 25.5 | 28.2 | 28.7 | 29.6 | 30.1 | 30.5 | 31.9 |
| 20 to 200 acres | 33.5 | 36.2 | 36.7 | 37.6 | 38.1 | 38.5 | 39.9 |
| 200 to 2000 acres | 39.5 | 42.2 | 42.7 | 43.6 | 44.1 | 44.5 | 45.9 |
| Over 2000 acres | 45.5 | 48.2 | 48.7 | 49.6 | 50.1 | 50.5 | 51.9 |
| ***ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE***: | | | | | | | |
| Additional feet of clearance per 1000 feet of altitude above 3300 feet | | 0.00 | 0.02 | 0.05 | 0.07 | 0.08 | 0.12 |

**Notes:**

(A) For voltages exceeding 98 kV alternating current to ground, or 139 kV direct current to ground, the NESC states that either the clearance shall be increased or the electric field, or the effects thereof, shall be reduced by other means, as required, to limit the current due to electrostatic effects to 5.0 milliampere (mA), rms, if the largest anticipated truck, vehicle or equipment under the line were short circuited to ground. The size of the anticipated truck, vehicle, or equipment used to determine these clearances may be less than but need not be greater than that limited by Federal, State, or local regulations governing the area under the line. For this determination, the conductors shall be at final unloaded sag at 120F.

Fences and large permanent metallic structures in the vicinity of the line will be grounded in accordance with the owner's grounding units for the structure concerned to meet the 5.0 milliampere requirement. There should be adequate ground clearance at crossings and along the right-of-way to meet the minimum requirement of 5 mA due to the electrostatic field effects on the anticipated vehicles under the transmission line. Consideration should be given to using the 5.0 mA rule to the conductor under maximum sag condition of the conductor.

(B) These clearances are for land traversed by vehicles and equipment whose overall operating height is less than 14 feet.

(C) Areas accessible to pedestrians only are areas where riders on horses or other large animals, vehicles or other mobile units exceeding 8 feet in height are prohibited by regulation or permanent terrain configurations or are not normally encountered nor reasonably anticipated. Land subject to highway right-of-way maintenance equipment is not to be considered as being accessible to pedestrians only.

(D) The NESC states that "for uncontrolled water flow areas, the surface area shall be that enclosed by its annual high-water mark. Clearances shall be based on the normal flood level; if available, the 10 year flood level may be assumed as the normal flood level. The clearance over rivers, streams, and canals shall be based upon the largest surface area of any one mile-long segment which includes the crossing. The clearance over a canal, river, or stream normally used to provide access for sailboats to a larger body of water shall be the same as that required for the larger body of water."

(E) Where the U.S. Army Corps of Engineers or the state, has issued a crossing permit, the clearances of that permit shall govern.

(F) The NESC basic clearance is defined as the reference height plus the electrical component for open supply conductors up to 22 kVL-G.

(G) An additional 2.5 feet of clearance is added to the NESC clearance to obtain the recommended design clearances. Greater values should be used where survey methods to develop the ground profile are subject to greater unknowns.

Note: Section G adds 2.5 feet to the NESC Clearances in this table. "Adders" are included in several of the charts and the numbers provided herein are representative of standard utility practice but each utility should select their own adders.

**Table 2**

**Recommended Design Vertical Clearances From Other Supporting Structures (See Note B), Buildings and Other Installations (Feet)**

**(Applicable NESC Rules: 234a, 234b, 234c, 234d, 234e, 234f, 234i, Tables 234-1, 234-2, 234-3)**

**Line conditions under which the NESC vertical clearances shall be met (Calculations are based on Maximum Operating Voltage.):**

- 32F, no wind, with radial thickness of ice, if any, specified in Rule 250B of the NESC for the loading district concerned.
- Maximum conductor temperature for which the line is designed to operate, with no horizontal displacement

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Nominal Voltage, Phase to Phase ($kV_{LL}$)** | | **34.5 & 46** | **69** | **115** | **138** | **161** | **230 (E)** |
| Max. Operating Voltage, Phase to Phase | ($kV_{LL}$) | ---- | 72.5 | 120.8 | 144.9 | 169.1 | 241.5 |
| Max. Operating Voltage, Phase to Ground | ($kV_{LG}$) | ---- | 41.8 | 69.7 | 83.7 | 97.6 | 139.4 |
| | NESC Basic Clear.(Note D) | Clearances in feet | | | | | |
| 1.0 From a lighting support, traffic signal support, or supporting structure of a second line | 5.5 | 7.5 | 7.5 | 8.2 | 8.6 | 9.1 | 10.8 |
| 2.0 From buildings not accessible to pedestrians | 12.5 | 14.7 | 15.2 | 16.1 | 16.6 | 17.0 | 18.4 |
| 3.0 From buildings – accessible to pedestrians and vehicles but not truck traffic | 13.5 | 15.7 | 16.2 | 17.1 | 17.6 | 18.0 | 19.4 |
| 4.0 From buildings – over roofs, ramps, and loading docks accessible to truck traffic | 18.5 | 20.7 | 21.2 | 22.1 | 22.6 | 23.0 | 24.4 |
| 5.0 From signs, chimneys, billboards, radio & TV antennas, flagpoles, banners, tanks & other installations **not accessible to personnel**. | 8.0 | 10.2 | 10.7 | 11.6 | 12.1 | 12.5 | 13.9 |
| 6.0 From bridges – not attached (Note C ) | 12.5 | 14.7 | 15.2 | 16.1 | 16.6 | 17.0 | 18.4 |
| 7.0 From grain bins probe ports | 18.0 | 20.2 | 20.7 | 21.6 | 22.1 | 22.5 | 23.9 |
| 8.0 Clearance in any direction from swimming pool edge and diving platform base **(Clearance A, Figure 4-4)** | 25.0 | 27.2 | 27.7 | 28.6 | 29.1 | 29.5 | 30.9 |
| Clearance in any direction from diving structures **(Clearance B, Figure 4-4)** | 17.0 | 19.2 | 19.7 | 20.6 | 21.1 | 21.5 | 22.9 |
| ***ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE***: | | | | | | | |
| Additional feet of clearance per 1000 feet of altitude above 3300 feet | | 0.00 | 0.02 | 0.05 | 0.07 | 0.08 | 0.12 |

| ***Notes:*** |
|---|
| (A) An additional 2.0 feet of clearance is added to NESC clearance to obtain the recommended design clearances. Greater values should be used where the survey method used to develop the ground profile is subject to greater unknowns.<br><br>(B) Other supporting structures include lighting supports, traffic signal supports, a supporting structure of another line, or intermediate poles in skip span construction.<br><br>(C) If the line crosses a roadway, then Table 1, line 2.0 clearances are required.<br><br>(D) The NESC basic clearance is defined as the reference height plus the electrical component for open supply conductors up to 22 $kV_{LG}$ except row '1.0' where voltage reference is 50 $kV_{LG}$<br><br>(E) For 230 kV, clearances may be required to be higher if switching surges are greater than 2.0 per unit. See NESC Tables 234-4 and 234-5. |

<u>Examples of Clearance Calculations</u>

The following examples demonstrate the derivation of the vertical clearances shown in Tables 1 and 2.

To determine the vertical clearance of a 161 kV line crossing a road (category 2.0 of Table 1), the clearance is based on NESC Table 232-1 and NESC Rule 232.

NESC Vertical Clearance = NESC Basic Clearance (Table 232-1) + 0.4* ($kV_{L-G}$ – 22) / 12
= 18.5 feet + .4(97.6-22) / 12 feet
= 18.5 feet + 2.52 feet
= 21.02 feet

Note: See Note 1 in Tablw 1 about the "adder"

Recommended Clearance = NESC Vertical Clearance + Adder
= 21.02 feet + 2.5 feet
= 23.52 feet (23.5 feet in Table 1)

To determine the vertical clearance of a 230 kV line over a building roof not accessible to pedestrians (category 2.0 of Table 2), the clearance is based on NESC Table 234-1 and NESC Rule 234.

NESC Vertical Clearance = NESC Basic Clearance (Table 234-1) + .4($kV_{L-G}$ – 22)/12
= 12.5 feet + .4(139-22)/12 feet
= 12.5 feet + 3.9 feet
= 16.4 feet

Recommended Clearance = NESC Vertical Clearance + Adder
= 16.4 feet + 2.0 feet

= 18.4 feet (18.4 feet in Table 2)

**Design Vertical Clearance between Conductors Where One Line Crosses Over or Under Another**

Recommended design vertical clearances between conductors when one line crosses another are provided in Table 3. The clearance values in Table 3 are for transmission lines which are known to have ground fault relaying. The clearances should be maintained at the point where the conductors cross, regardless of where the point of crossing is located on the span.

**Table 3**

**Recommended Design Vertical Clearances in Feet Between Conductors where the Conductors of One Line Cross Over the Conductors of Another and where the Upper and Lower Conductors Have Ground Fault Relaying**

Voltage between circuits = Voltage line to ground Top Circuit + Voltage line to ground Bottom Circuit (Calculations are based on the maximum operating voltage.)

The NESC requires that clearances not be less than that required by application of a clearance envelope developed under NESC Rules 233A1 & 233A2. Structure deflection shall also be taken into account. Recommended values in this table are to be adders applied for the movement of the conductor and deflection of structures, if any.

| | | | Upper Level Conductor (Note F) | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Nominal Voltage, Phase to Phase kV $_{L-L}$** | | | **34.5 & 46** | **69** | **115** | **138** | **161** | **230** |
| Max. Operating Voltage, Phase to Phase | | ($kV_{LL}$) | ---- | 72.5 | 120.8 | 144.9 | 169.1 | 241.5 |
| Max. Operating Voltage, Phase to Ground | | ($kV_{LG}$) | ---- | 41.8 | 69.7 | 83.7 | 97.6 | 139.4 |
| | NESC Basic Clear. (Note H) | ($kV_{LG}$) | Clearances in feet | | | | | |
| **Lower Level Conductor** | | | | | | | | |
| 1. Communication | 5.0 | | 6.7 | 7.2 | 8.1 | 8.6 | 9.0 | 10.4 |
| 2. OHGW (Note G) | 2.0 | | 3.7 | 4.2 | 5.1 | 5.6 | 6.0 | 7.4 |
| 3. Distribution conductors | 2.0 | | 3.7 | 4.2 | 5.1 | 5.6 | 6.0 | 7.4 |
| 4. Transmission conductors of lines that have ground fault relaying. Nominal line–to-line voltage in kV. (Note F) | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 230 kV | 2.0 | 139.4 | | | | | | 11.3 |
| 161 kV | 2.0 | 97.6 | | | | | 8.5 | 9.9 |
| 138 kV | 2.0 | 83.7 | | | | 7.6 | 8.1 | 9.5 |
| 115 kV | 2.0 | 69.7 | | | 6.7 | 7.1 | 7.6 | 9.0 |
| 69 kV | 2.0 | 41.8 | | 4.8 | 5.6 | 6.2 | 6.7 | 8.1 |
| 46 kV and below | 2.0 | 26.4 | 3.8 | 4.3 | 5.2 | 5.7 | 6.2 | 7.6 |

***Notes*:**

(A) The conductors on other supports are assumed to be from different circuits

(B) **This table applies to lines with ground fault relaying.**

(C) The NESC requires that the clearance shall be not less than that required by application of a clearance envelope developed under NESC Rule 233A2 to the positions on or within conductor movement envelopes developed under Rule 233A1 at which the two wires, conductors or cables would be closest together. For purposes of this determination, the relevant positions of the wires, conductors, or cables on or within their respective conductor movement envelopes are those which can occur when (1) both are simultaneously subjected to the same ambient air temperature and wind loading conditions and (2) each is subjected individually to the full range of its icing conditions and applicable design electrical loading.

(D) An additional 1.5 feet of clearance is added to NESC clearance to obtain the recommended design clearances. Greater values should be used where the survey method used to develop the ground profile is subject to greater unknowns.

(E) ***ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE***

Total altitude = Correction for upper conductors + Correction for correction factor lower conductors

For upper conductors use correction factor from Table 1 of this course.
For lower conductors:
Categories 1, 2, 3 above use no correction factors
Category 4 uses correction factors from Table 1 of this course

(F) **The higher voltage line should cross over the lower voltage line**

(G) If the line on the lower level has overhead ground wire(s), this clearance will usually be the limiting factor at crossings.

(H) The NESC basic clearance is defined as the reference height plus the electrical component for open supply conductors up to 22 $kV_{L-G}$.

The clearances apply for an upper conductor at final sag for the conditions ‘a’ through ‘c’. The condition that produces the greatest sag for the line is the one that applies.

a) A conductor temperature of 32F, no wind, with a radial thickness of ice for the loading district concerned.

b) A conductor temperature of 167F. A lower temperature may be considered where justified by a qualified engineering study. Under no circumstances should a design temperature be less than 120F.

c) Maximum conductor temperature, no wind. The same maximum temperature used for vertical clearance to ground should be used.

At a minimum the NESC requires:

1. the upper and lower conductors are simultaneously subjected to the same ambient air temperature and wind loading conditions and
2. each is subjected individually to the full range of its icing conditions and applicable design electrical loading.

Altitude Greater than 3300 Feet

If the altitude of the crossing point of the two lines is greater than 3300 feet, additional clearance as indicated in Table 3 is added to the base clearance given.

Differences in Sag Conditions between Lower and Upper Conductors

The reason for the differences in sag conditions between the upper and lower conductor at which the clearances apply is to cover situations where the lower conductor has lost its ice while the upper conductor has not, or where the upper conductor is loaded to its thermal limit while the lower conductor is only lightly loaded.

Examples of Clearance Calculations

The following example demonstrates the derivation of the vertical clearance of a category in Table 3 of this course.

To determine the vertical clearance of a 161 kV line crossing a distribution conductor (item 3 of Table 3), the clearance is based on NESC Table 233-1 and NESC Rule 233.

NESC Vertical Clearance = NESC Basic Clearance (Table 233-1) + .4($kV_{L-G}$ – 22)/12
= 2.0 feet + .4(97.6-22)/12 feet
= 2.0 feet + 2.5 feet
= 4.5 feet

Recommended Clearance = NESC Vertical Clearance + Adder
= 4.5 feet + 1.5 feet
= 6.0 feet (6.0 feet in Table 3)

**Design Vertical Clearance between Conductors of Different Lines at Non-crossing Situations**

If the horizontal separation between conductors (see Chapter 2) cannot be achieved, then the clearance requirements in the previous section should be attained.

Example of Line-to-Ground Clearance

A portion of a 161 kV line is to be built over a field of oats that is at an elevation of 7200 feet. Determine the design line-to-ground clearance. Because the altitude of the 161 kV line is greater than 3300 feet, the basic clearance is to be increased by the amount indicated in Table 1.

The calculation follows: (7200-3300) * 0.08 / 1000 = 0.32 feet

The recommended design clearance over cultivated fields for a 161 kV line is 23.5 feet. Therefore, the recommended clearance, taking altitude into account, is 23.8 feet.

0.32 feet + 23.5 feet = 23.8 feet

An additional one foot of clearance should be added for survey, construction and design tolerance.

Example of Conductor Crossing Clearances

A 230 kV line crosses over a 115 kV line in two locations. At one location the 115 kV line has an overhead ground wire which, at the point of crossing, is 10 feet above its phase conductors. At the other location the lower voltage line does not have an overhead ground wire. Determine the required clearance between the 230 kV conductors and the 115 kV conductors at both crossing locations. Assume that the altitude of the line is below 3300 feet. Also assume that the sag of the overhead ground wire is the same as or less than the sag of the 115 kV phase conductors. The 230 kV line has ground fault relaying.

The first step in the solution is to determine if the line being crossed over has automatic ground fault relaying. We are able to determine that the lower line has automatic ground fault relaying.

From Table 3, (item 4), the required clearance from a 230 kV conductor to a 115 kV conductor is 9.0 feet. From Table 3, (item 2), the required clearance from the 230 kV conductor to the overhead ground wire is 7.4 feet; adding 10 feet for the distance between the overhead ground wire (OHGW) and the 115 kV phase conductors, the total required clearance is 17.4 feet.

When the lower circuit has an overhead ground wire, clearance requirements to the overhead ground wire govern and the required clearance between the upper and lower phase conductor is

17.4 feet. Where there is no overhead ground wire for the 115 kV circuit, the required clearance between the phase conductors is 9.0 feet. It is important to note that the above clearances are to be maintained where the upper conductor is at its maximum sag condition and the lower conductor is at 60F initial sag.

**Vertical Clearances to Vegetation**

The best practice is usually to remove all substantive vegetation (such as trees and vines) under and adjacent to the line. In certain areas, such as canyons, river crossings, or endangered species habitat, vegetation can be spanned.

# Chapter 2
# Horizontal Clearances from Line Conductors to Objects and right-of-Way Width

The preliminary comments and assumptions in Chapter 1 of this course also apply to this chapter.

**Minimum Horizontal Clearance of Conductor to Objects**

Recommended design horizontal clearances of conductors to various objects are provided in Table 4 and minimum radial operating clearances of conductors to vegetation in Table 5. The clearances apply only for lines that are capable of automatically clearing line-to-ground faults.

Clearance values provided in Table 4 are recommended design values. In order to provide an additional margin of safety, the recommended design values exceed the minimum clearances in the NESC. Clearance values provided in Table 5 are minimum operating clearances to be used by the designer to determine appropriate design clearances for vegetation maintenance management.

**Conditions under Which Horizontal Clearances to Other Supporting Structures, Buildings and Other Installations Apply**

- Conductors at Rest (No Wind Displacement): When conductors are at rest the clearances apply for the following conditions:
    - 167F but not less than 120F, final sag,
    - The maximum operating temperature the line is designed to operate, final sag,
    - 32F, final sag with radial thickness of ice for the loading district (0 in., ¼ in., or ½ in.).

- Conductors Displaced by 6 PSF Wind: The clearances apply when the conductor is displaced by 6 lbs. per sq. ft. at final sag at 60F. See Figure 5.

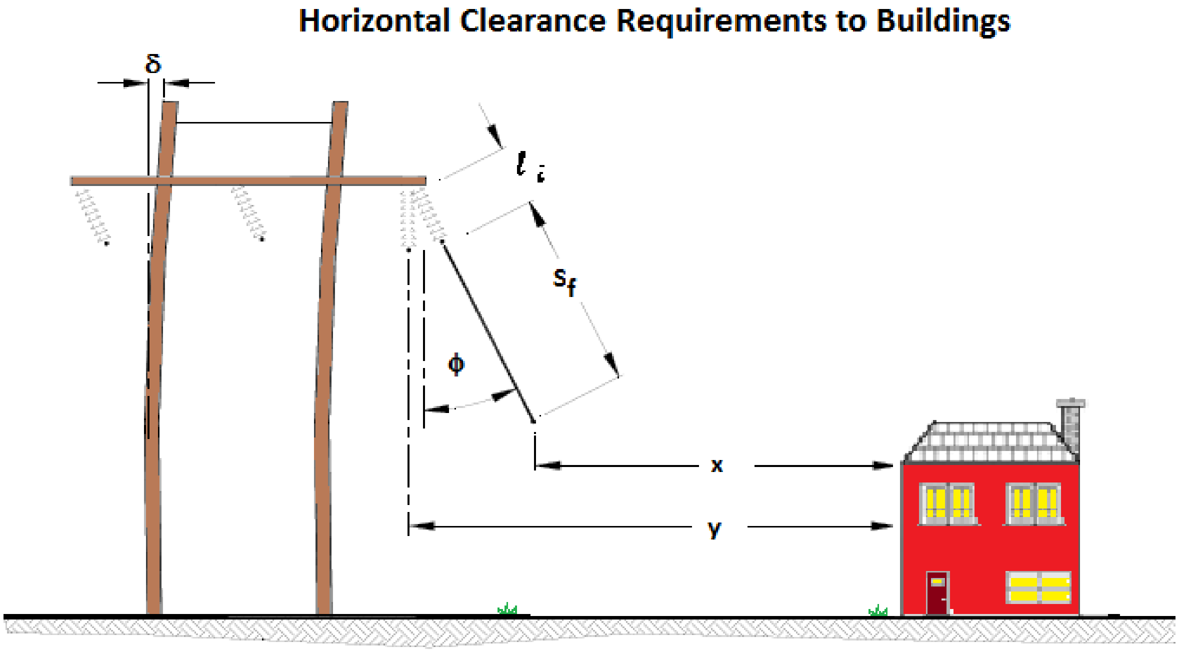



Figure 5

Where,

ϕ = conductor swing out angle in degrees under 6 PSF of wind

Sf = conductor final sag at 60F with 6 PSF. of wind

x = horizontal clearance required per Table 4 for conductors displaced by 6 PSF wind (include altitude correction if necessary)

ℓi = insulator string length (ℓi = 0 for post insulators or restrained suspension insulators).

y = total horizontal distance from insulator suspension point (conductor attachment point for post insulators) to structure with conductors at rest

δ = structure deflection with a 6 PSF Wind

**Table 4**

## Recommended Design Horizontal Clearances (Feet) from Conductors at Rest and Displaced by 6 PSF Wind to other Supporting Structures, Buildings and other Installations

## (NESC Rules 234b, 234c, 234d, 234e, 234f, 234i, Tables 234-1, 234-2, 234-3)

**Conditions under which clearances apply**:

**No wind**: When the conductor is at rest the clearances apply at the following conditions: (a) 120F, final sag, (b) the maximum operating temperature the line is designed to operate, final sag, (c) 32F, final sag with radial thickness of ice for the loading district (1/4 in. for Medium or 1/2 in. Heavy).

**Displaced by Wind**: Horizontal clearances are to be applied with the conductor displaced from rest by a 6 PSF wind at final sag at 60°F. The displacement of the conductor is to include deflection of suspension insulators and deflection of flexible structures.

The clearances shown are for the displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance. See Equation 5-1.

**Clearances are based on the Maximum Operating Voltage**

| | NESC Basic Clear | 34.5 & 46 | 69 | 115 | 138 | 161 | 230 |
|---|---|---|---|---|---|---|---|
| **Nominal voltage, Phase to Phase, $kV_{L-L}$** | | **34.5 & 46** | **69** | **115** | **138** | **161** | **230** |
| Max. Operating Voltage, Phase to Phase, $kV_{L-L}$ | | ---- | 72.5 | 120.8 | 144.9 | 169.1 | 241.5 |
| Max. Operating Voltage, Phase to Ground, $kV_{L-G}$ | | ---- | 41.8 | 69.7 | 83.7 | 97.6 | 139.4 |
| **Horizontal Clearances - (Notes 1,2,3)** | NESC Basic Clear | Clearances in feet | | | | | |
| 1.0 From a lighting support, traffic signal support or supporting structure of another line | | | | | | | |
| **At rest (NESC Rule 234B1a)** | 5.0 | 6.5 | 6.5 | 7.2 | 7.6 | 8.1 | 9.5 |
| **Displaced by wind (NESC Rule 234B1b)** | 4.5 | 6.2 | 6.7 | 7.6 | 8.1 | 8.5 | 9.9 |
| 2.0 From buildings, walls, projections, guarded windows, windows not designed to open, balconies, and areas accessible to pedestrians | | | | | | | |
| **At rest (NESC Rule 234C1a)** | 7.5 | 9.2 | 9.7 | 10.6 | 11.1 | 11.5 | 12.9 |
| **Displaced by wind (NESC Rule 234C1b)** | 4.5 | 6.2 | 6.7 | 7.6 | 8.1 | 8.5 | 9.9 |
| 3.0 From signs, chimneys, billboards, radio, & TV antennas, tanks & other installations not classified as buildings | | | | | | | |
| **At rest (NESC Rule 234C1a)** | 7.5 | 9.2 | 9.7 | 10.6 | 11.1 | 11.5 | 12.9 |
| **Displaced by wind (NESC Rule 234C1b)** | 4.5 | 6.2 | 6.7 | 7.6 | 8.1 | 8.5 | 9.9 |
| 4.0 From portions of bridges which are readily accessible and supporting structures are not attached | | | | | | | |
| **At rest (NESC Rule 234D1a)** | 7.5 | 9.2 | 9.7 | 10.6 | 11.1 | 11.5 | 12.9 |
| **Displaced by wind (NESC Rule 234D1b)** | 4.5 | 6.2 | 6.7 | 7.6 | 8.1 | 8.5 | 9.9 |
| 5.0 From portions of bridges which are ordinarily inaccessible and supporting structures are not attached | | | | | | | |
| **At rest (NESC Rule 234D1a)** | 6.5 | 8.2 | 8.7 | 9.6 | 10.1 | 10.5 | 11.9 |
| **Displaced by wind (NESC Rule 234D1b)** | 4.5 | 6.2 | 6.7 | 7.6 | 8.1 | 8.5 | 9.9 |

**Conditions under which clearances apply**:

**No wind**: When the conductor is at rest the clearances apply at the following conditions: (a) 120F, final sag, (b) the maximum operating temperature the line is designed to operate, final sag, (c) 32F, final sag with radial thickness of ice for the loading district (1/4 in. for Medium or 1/2 in. Heavy).

**Displaced by Wind**: Horizontal clearances are to be applied with the conductor displaced from rest by a 6 PSF wind at final sag at 60F under extreme wind conditions (such as the 50 or 100-year mean wind) at final sag at 60F. The displacement of the conductor is to include deflection of suspension insulators and deflection of flexible structures.

The clearances shown are for the displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance. See Equation 5-1.

**Clearances are based on the Maximum Operating Voltage**

| **Nominal voltage, Phase to Phase, $kV_{L-L}$** | **34.5 & 46** | **69** | **115** | **138** | **161** | **230** |
|---|---|---|---|---|---|---|
| Max. Operating Voltage, Phase to Phase, $kV_{L-L}$ Max. | ---- | 72.5 | 120.8 | 144.9 | 169.1 | 241.5 |
| Operating Voltage, Phase to Ground, $kV_{L-G}$ | ---- | 41.8 | 69.7 | 83.7 | 97.6 | 139.4 |

| **Horizontal Clearances - (Notes 1,2,3)** | NESC Basic Clear | Clearances in feet | | | | | |
|---|---|---|---|---|---|---|---|
| 6.0 Swimming pools – NESC Rule 234E | | | | | | | |
| **Clearance in any direction from swimming pool edge** (Clearance A, Figure 4) | 25.0 | 27.2 | 27.7 | 28.6 | 29.1 | 29.5 | 30.9 |
| **Clearance in any direction from diving structures** (Clearance B, Figure 4) | 17.0 | 19.2 | 19.7 | 20.6 | 21.1 | 21.5 | 22.9 |
| 7.0 From grain bins loaded with permanently attached conveyor | | | | | | | |
| **At rest** **(NESC Rule 234F1b)** | 15.0 | 17.2 | 17.7 | 18.6 | 19.1 | 19.5 | 20.9 |
| **Displaced by wind** **(NESC Rule 234C1b)** | 4.5 | 6.7 | 7.2 | 8.1 | 8.6 | 9.0 | 10.4 |
| 8.0 From grain bins loaded with a portable conveyor. Height 'B' of highest filling or probing port on bin must be added to clearance shown. Clearances for 'at rest' and not displaced by the wind. See NESC Figure 234-4 for other requirements. **Horizontal clearance envelope (includes area of sloped clearance per NESC Figure 234-4b)** | | $H_t$ = (24+B) + 1.5B (See Note 3 and Fig. 11) | | | | | |
| 9.0 From rail cars (Applies only to lines parallel to tracks) See Figure 234-5 and section 234I of the NESC | | | | | | | |
| **Clearance measured to the nearest rail** | | 14.1 | 14.1 | 15.1 | 15.6 | 16.0 | 17.5 |
| **ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE** | | | | | | | |
| Additional feet of clearance per 1000 feet of altitude above 3300 feet | | 0.02 | 0.02 | 0.05 | 0.07 | 0.08 | 0.12 |

***Notes:***

1. Clearances for categories 1-5 in the table are approximately 1.5 feet greater than NESC clearances.
2. Clearances for categories 6 to 9 in the table are approximately 2.0 feet greater than NESC clearances.
3. "B" is the height of the highest filling or probing port on a grain bin. Horizontal clearance is for the highest voltage of 230 kV.

**Considerations in Establishing Radial and Horizontal Clearances to Vegetation**

The designer should identify and document clearances between vegetation and any overhead, ungrounded supply conductors, taking into consideration transmission line voltage, the effects of ambient temperature on conductor sag under maximum design loading, and the effects of wind velocities on conductor sway. Specifically, the designer should establish clearances to be achieved at the time of vegetation management work and should also establish and maintain a set of clearances to prevent flashover between vegetation and overhead ungrounded supply conductors. As a minimum, these clearances should apply to all transmission lines operated at 200 kV phase-to-phase and above and to any lower voltage lines designated as critical.

The designer should determine and document appropriate clearance distances to be achieved at the time of transmission vegetation management work based upon local conditions and the expected time frame in which the Transmission Owner plans to return for future vegetation management work. Local conditions may include, but are not limited to: operating voltage, appropriate vegetation management techniques, fire risk, reasonably anticipated tree and conductor movement, species types and growth rates, species failure characteristics, local climate and rainfall patterns, line terrain and elevation, location of the vegetation within the span, and worker approach distance requirements.

The designer should determine and document specific radial clearances to be maintained between vegetation and conductors under all rated electrical operating conditions. These minimum clearance distances are necessary to prevent flashover between vegetation and conductors and will vary due to such factors as altitude and operating voltage. These specific minimum clearance distances should be no less than those set forth in the Institute of Electrical and Electronics Engineers (IEEE) Standard 516-2003, Guide for Maintenance Methods on Energized Power Lines. Where transmission system transient overvoltage factors are not known, clearances shall be derived from IEEE 516-2003, phase-to-ground distances, with appropriate altitude correction factors applied. Where transmission system transient overvoltage factors are known, clearances shall be derived from IEEE 516-2003, phase-to-phase voltages, with appropriate altitude correction factors applied. Table 5 contains radial clearances determined from IEEE 516-2003, where transmission system transient overvoltage factors are not known.

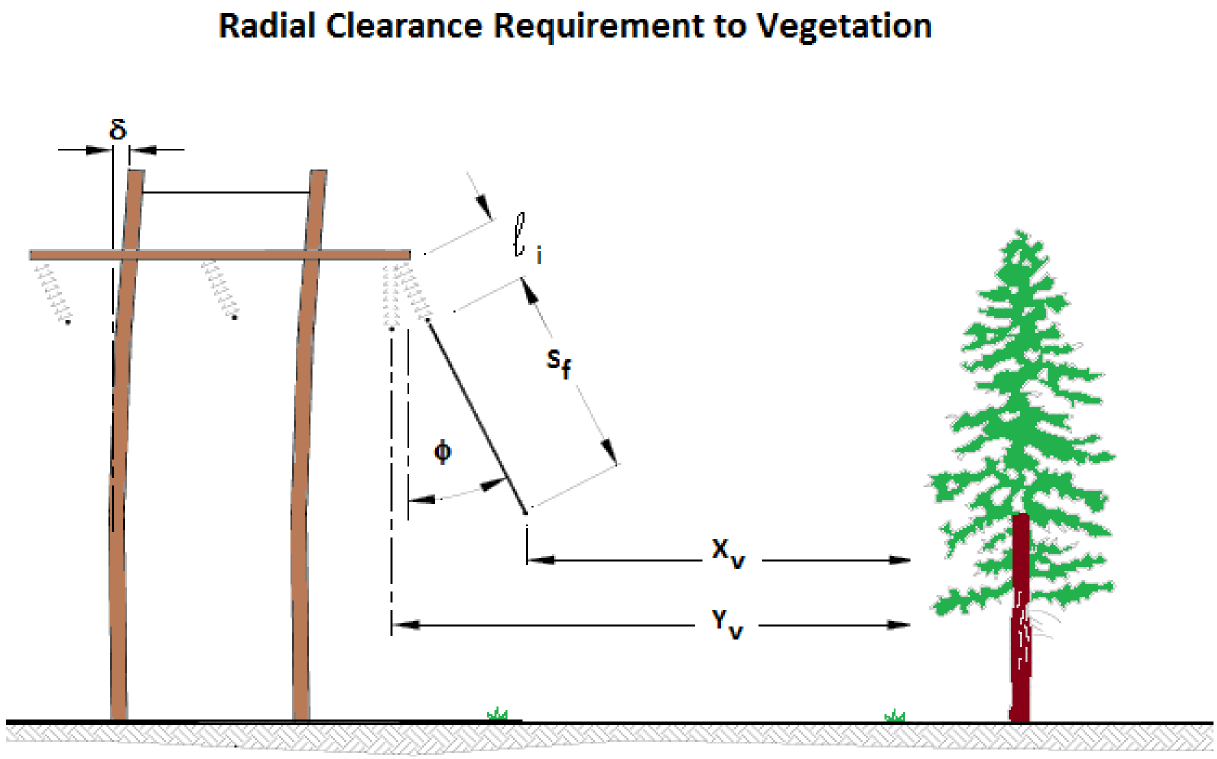



**Figure 6**

Where,

$\phi$ = conductor swing out angle in degrees under all rated operating conditions

Sf = conductor final sag at all rated operating conditions

$x_v$ = radial clearance (include altitude correction if necessary)

ℓi = insulator string length (ℓi = 0 for post insulators or restrained suspension insulators).

$y_v$ = horizontal clearance at the time of vegetation management work

$\delta$ = structure deflection at all rated operating conditions

**Table 5**

## Radial Operating Clearances (Feet) from IEEE 516 for use in Determining Clearances to Vegetation from Conductors

**Conditions under which clearances apply**:

**Displaced by Wind**: Radial operating clearances are to be applied at all rated operating conditions. The designer should determine applicable conductor temperature and wind conditions for all rated operating conditions. The displacement of the conductor is to include deflection of suspension insulators and deflection of flexible structures.

The operating clearances shown are for the displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance. See Equation 5-1.

**Clearances are based on the Maximum Operating Voltage**.

**Nominal voltage, Phase to Phase, $kV_{L-L}$** **34.5** **69**[1] **115**[1] **138**[1] **161**[1]
**230**[1,2]
**& 46**[1]

Max. Operating Voltage, Phase to Phase, $kV_{L-L}$ Max. Operating Voltage, Phase to Ground, $kV_{L-G}$ ---- 72.5 120.8 144.9
169.1 241.5

**Radial Table 5 IEEE Standard 516 Operating Clearances** ---- 41.8 69.7 83.7 97.6
139.4

**Operating clearance at all rated operating conditions**
**Design adder for survey and installation tolerance**
**Design adder for vegetation**

Clearances in feet

**ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE**
Additional feet of clearance per 1000 feet of altitude above 3300 feet

1.8 1.8 1.9 2.3 2.5
2.7
1.5 feet for all voltages
Determined by designer (see Note 3 below)

0.02 0.02 0.05 0.07 0.08 0.12

*Notes*:

1. These clearances apply to all transmission lines operated at 200 kV phase-to-phase and above and to any lower voltage lines designated as critical.
2. The 230 kV clearance is based on 3.0 Per Unit switching surge.
3. The design adder for vegetation, applied to conductors displaced by wind, should account for reasonably anticipated tree movement, species types and growth rates, species failure characteristics, and local climate and rainfall patterns. The design adder for vegetation, applied to conductors at rest, should account for worker approach distances in addition to the aforementioned factors.

**Clearances to Grain Bins**

The NESC has defined clearances from grain bins based on grain bins that are loaded by permanent or by portable augers, conveyers, or elevator systems.

In NESC Figure 234-4(a), the horizontal clearance envelope for permanent loading equipment is graphically displayed and shown Figure 7.

P = probe clearance, item 7, Table 2
H = horizontal clearance, item 7, Table 4
T = transition clearance
$V_1$ = vertical clearance, item 2&3, Table 2
$V_2$ = vertical clearance, Table 1

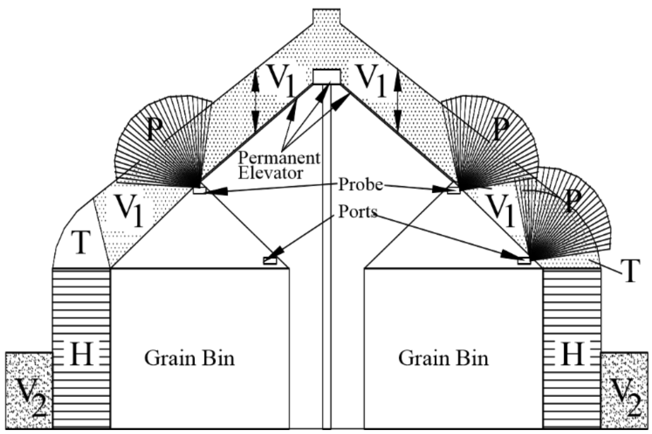



**Figure 7**

Note: This figure is from IEEE C2-2012, National Electric Safety Code® (NESC®), Copyright IEEE 2012. All rights reserved.

Because the vertical distance from the probe in Table 2, item 7.0, is greater than the horizontal distance, (see Table 4, item 7.0), the user may want to simplify design and use this distance as the horizontal clearance distance as shown below:

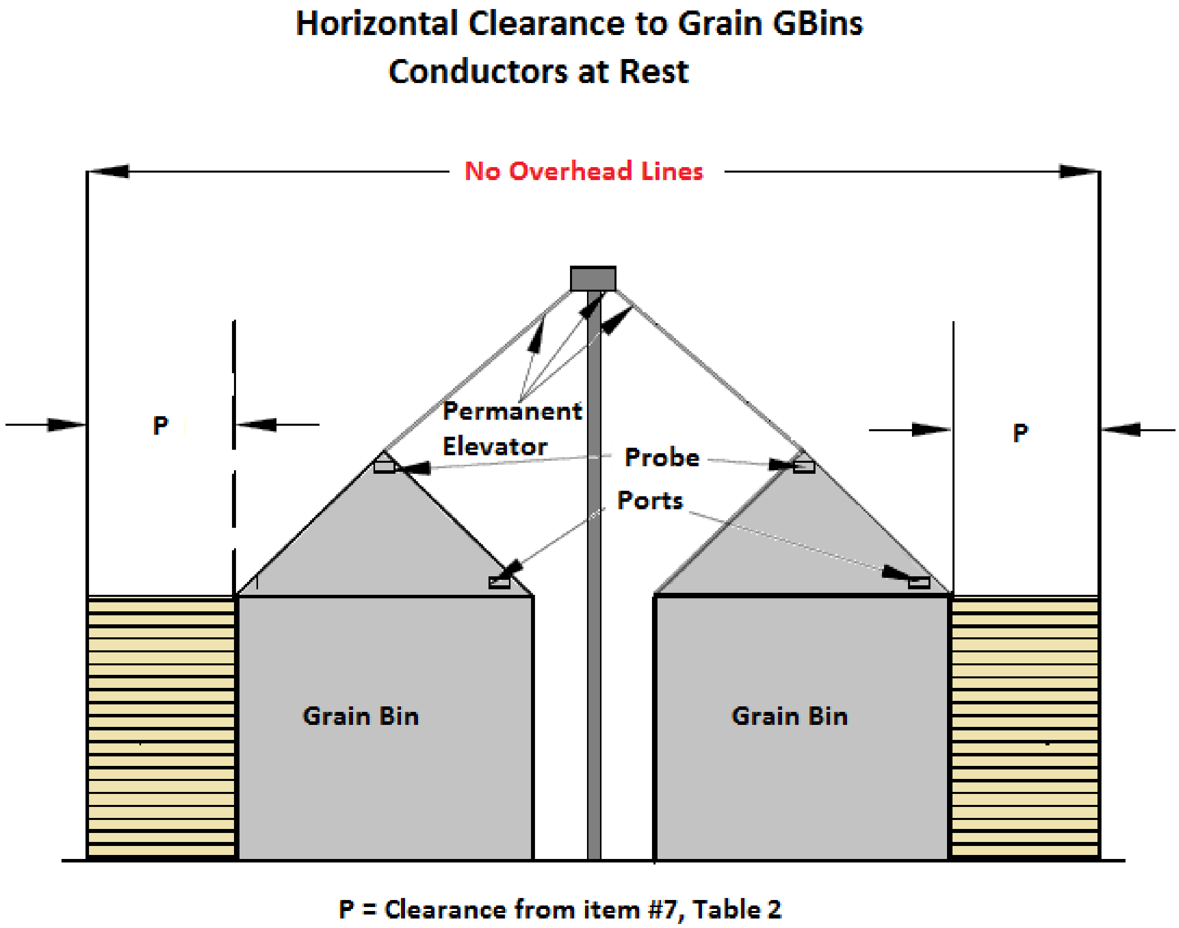

Horizontal Clearance to Grain GBins
Conductors at Rest
No Overhead Lines
P
P
Permanent
Elevator
Probe
Ports
Grain Bin
Grain Bin
P = Clearance from item #7, Table 2

**Figure 8**

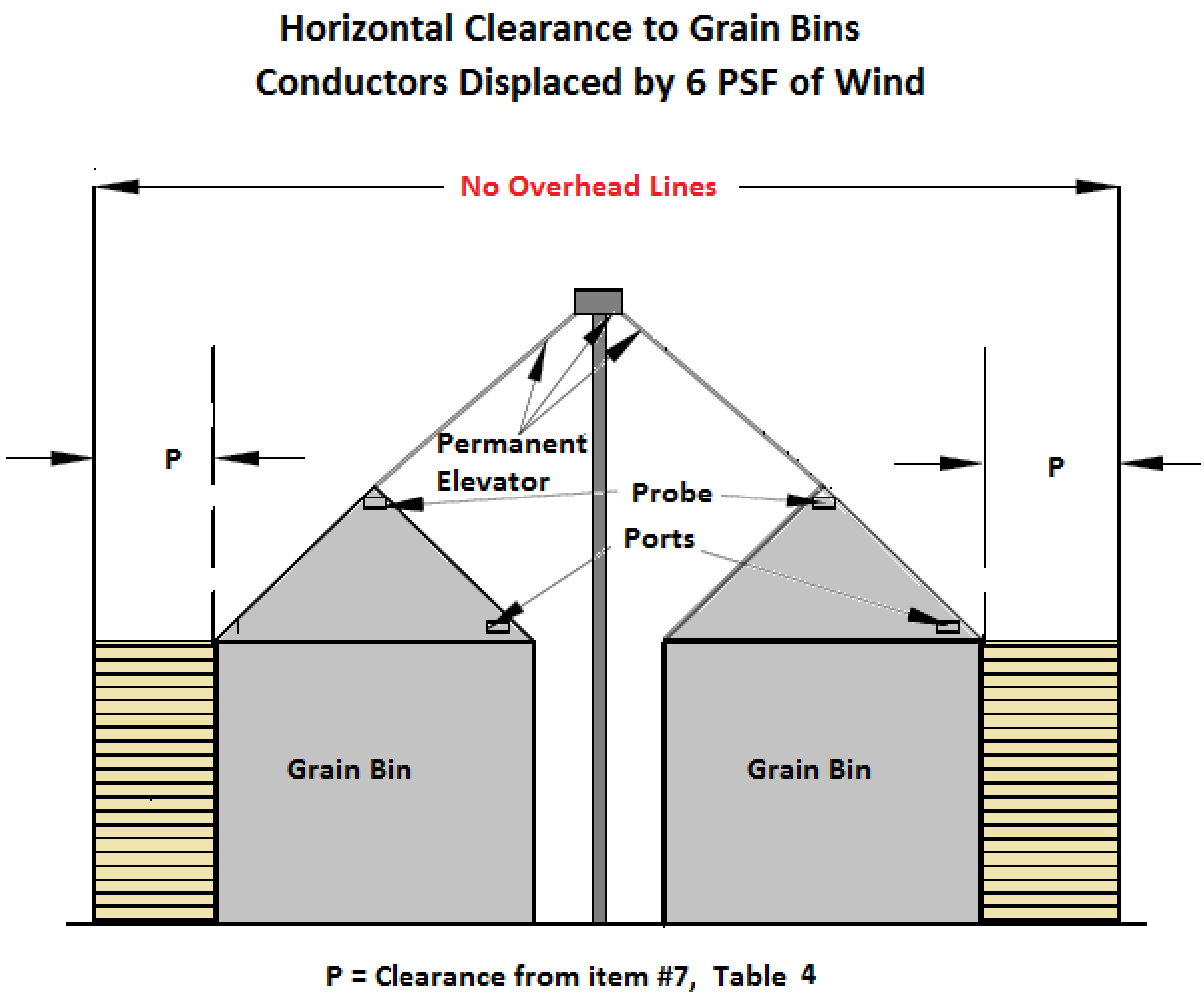



**Figure 9**

The clearance envelope for portable loading equipment from NESC Figure 234(b) is shown in Figure 10.

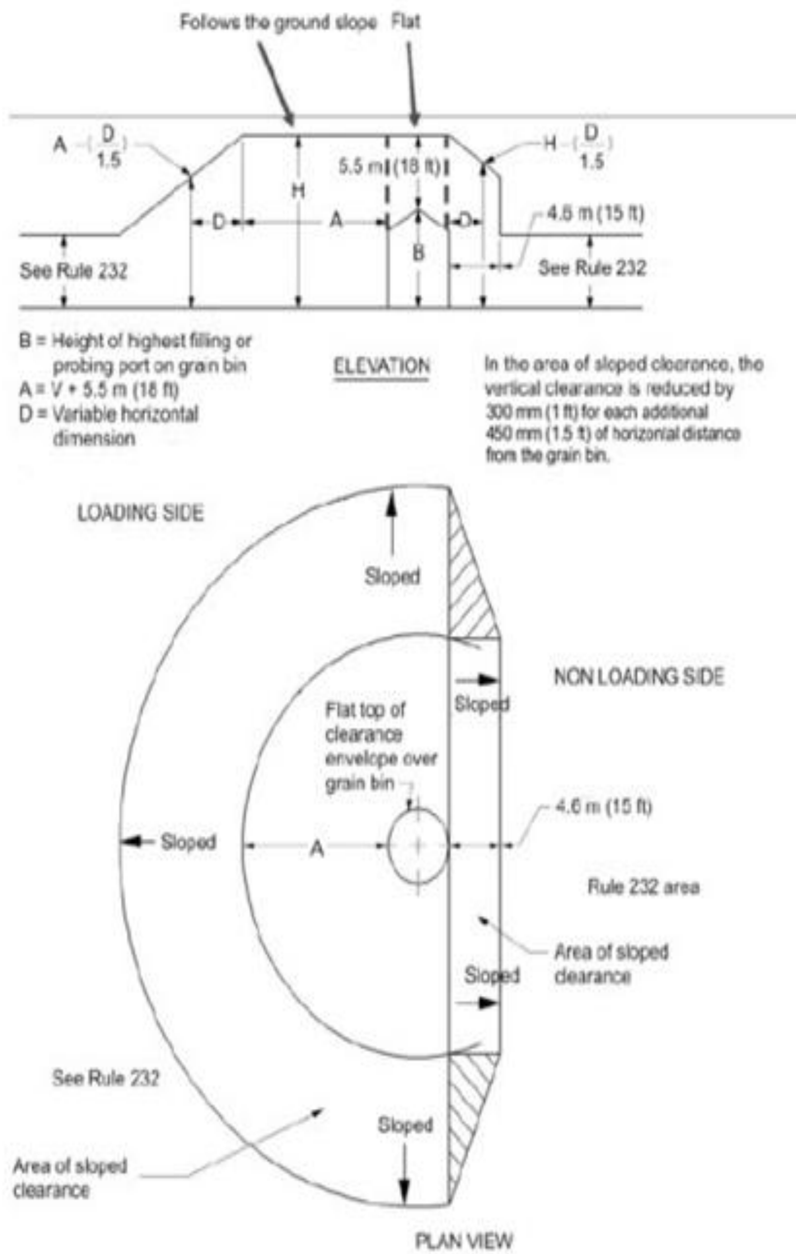



**Figure 10**



In order to simplify the clearance envelope, the horizontal clearances in category 8 of Table 4 are shown as “H” in the drawing below:

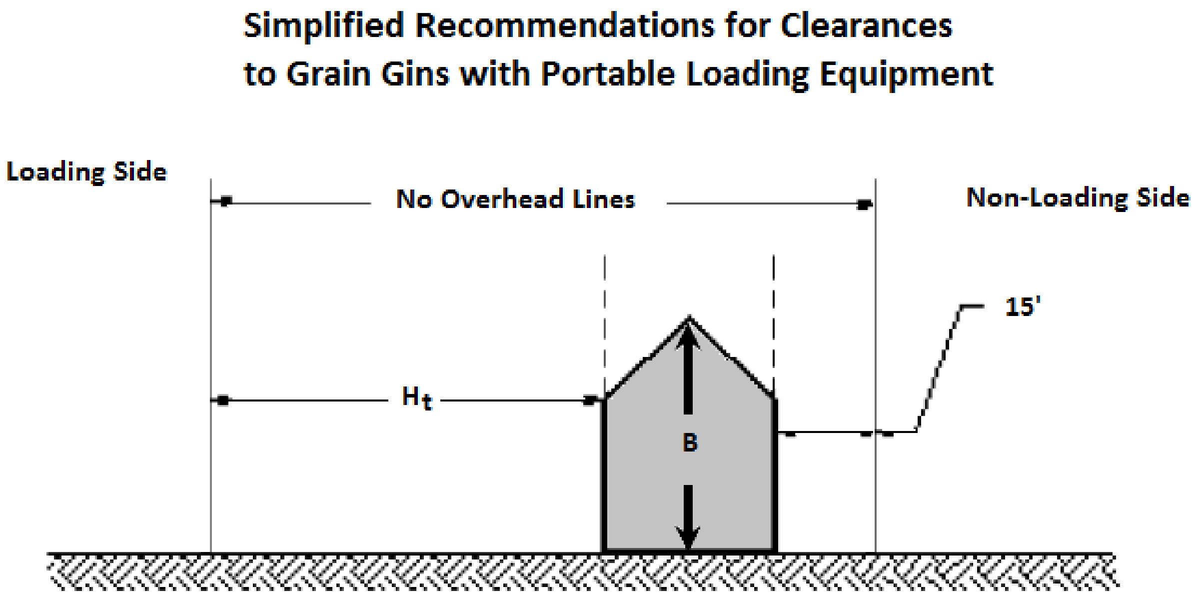



Figure 11

Total Horizontal Clearance = Ht = (24' + B) + 1.5B.

Horizontal clearance is for highest voltage of 230kV.

If the altitude of the transmission line or portion thereof is greater than 3300 feet, an additional clearance as indicated in Table 4 and 5 has to be added to the base clearance given.

Total Horizontal Clearance to Point of Insulator Suspension to Object

As can be seen from Figure 6, the total horizontal clearance (y) is:

$$y = (\ell_i + S_f) * \sin(\phi) + x + \delta$$

Where,

$\phi$ = conductor swing out angle in degrees under 6 PSF of wind

$S_f$ = conductor final sag at 60F with 6 PSF of wind

x = horizontal clearance required per Table 4 for conductors displaced by 6 PSF wind (include altitude correction if necessary)

$\ell i$ = insulator string length ($\ell i$ = 0 for post insulators or restrained suspension insulators).

$\delta$ = structure deflection with a 6 PSF. Wind

The factor "$\delta$" indicates that structure deflection should be taken into account. For post insulators, $\ell i = 0$.

For the sake of simplicity when determining horizontal clearances, the insulator string should be assumed to have the same swing angle as the conductor. This assumption should be made only in this chapter as its use in calculations elsewhere may not be appropriate.

The conductor swing angle ($\phi$) under wind can be determined from the formula.

$$\boldsymbol{\phi = \tan^{-1}\frac{d_c * F}{12 * w_c}}$$

Where,
*dc* = conductor diameter in inches
*wc* = weight of conductor in lbs./ft.
*F* = wind force.

The total horizontal distance (y) at a particular point in the span depends upon the conductor sag at that point. The value of (y) for a structure adjacent to the maximum sag point will be greater than the value of (y) for a structure placed elsewhere along the span. See Figure 12.

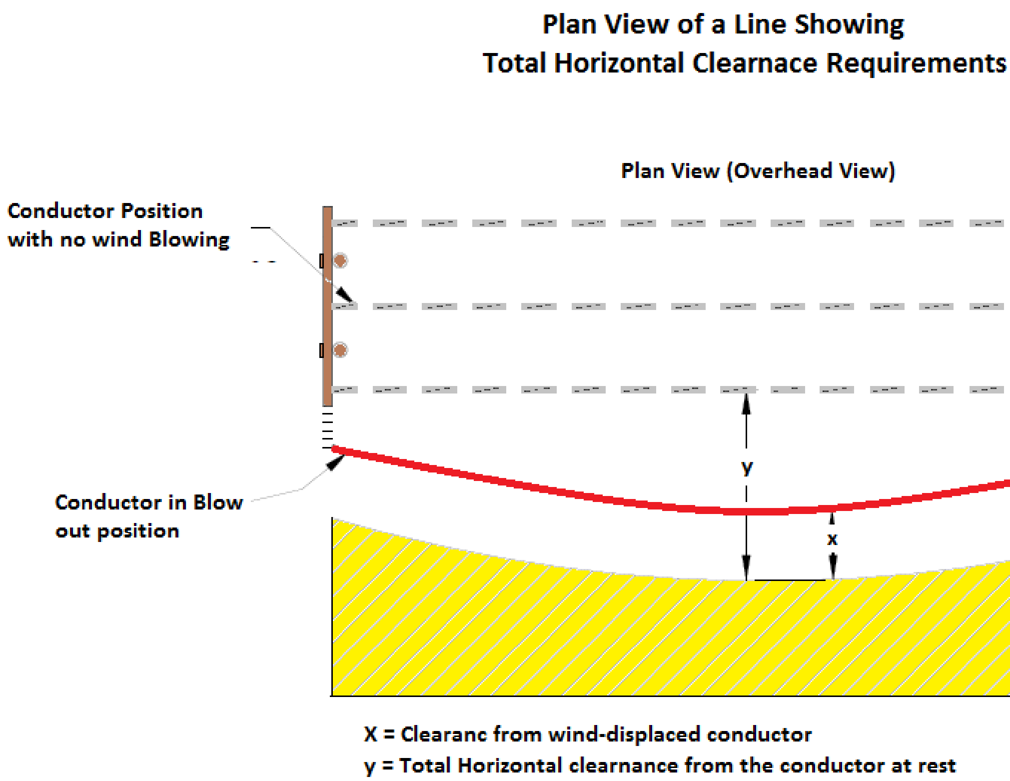



**Figure 12**

Examples of Horizontal Clearance Calculations

The following examples demonstrate the derivation of the horizontal clearance in Table 4 of this course.

To determine the horizontal clearance of a 115 kV line to a building (category 2.0 of Table 4), the clearance is based on NESC Table 234-1 and NESC Rule 234.

At rest:

NESC Horizontal Clear. = NESC Basic Clearance (Table 234-1) + .4($kV_{L-G}$ – 22)/12
= 7.5 feet + .4(69.7-22)/12 feet
= 7.5 feet + 1.59 feet
= 9.09 feet

Recommended Clearance = NESC Horizontal Clearance + Adder
= 9.09 feet + 1.5 feet
y = 10.59 feet (10.60 feet in Table 4)

Conductors displaced by 6 PSF wind:

NESC Horizontal Clear. = NESC Basic Clearance (Table 234-1) + .4($kV_{L-G}$ – 22)/12
= 4.5 feet + .4(69.7-22)/12 feet
= 4.5 feet + 1.59 feet
= 6.09 feet

Recommended Clearance = NESC Horizontal Clearance + Adder
= 6.09 feet + 1.5 feet

x = 7.59 feet (7.6 feet in Table 4)

**Right-of-Way (ROW) Width**

For transmission lines, a right-of-way provides an environment which allows the line to be operated and maintained safely and reliably. Determination of the right-of-way width is a task that requires the consideration of a variety of judgmental, technical, and economic factors.

Typical right-of-way widths (predominantly H-frames) that have been used in the past are shown in Table 6. In many cases a range of widths is provided. The actual width used will depend upon the particulars of the line design.

**Table 6**
**Typical Right-Of-Way Widths**

| ROW Width ft. | Nominal Line-to-Line Voltage in kV | | | | |
|---|---|---|---|---|---|
| | 69 | 115 | 138 | 161 | 230 |
| | 75-100 | 100 | 100-150 | 100-150 | 125-200 |

**Calculation of Right-of-Way Width for a Single Line of Structures on a Right-of-Way**

Right-of-way widths can be calculated using the method described below. The calculated values for right-of-way widths are directly related to the particular parameters of the line design. This method provides sufficient width to meet clearance requirements to buildings of undetermined height or vegetation located directly on the edge of the right-of-way. See Figures 12 and 13.

**Right of Way Width for Single Line of Structures**

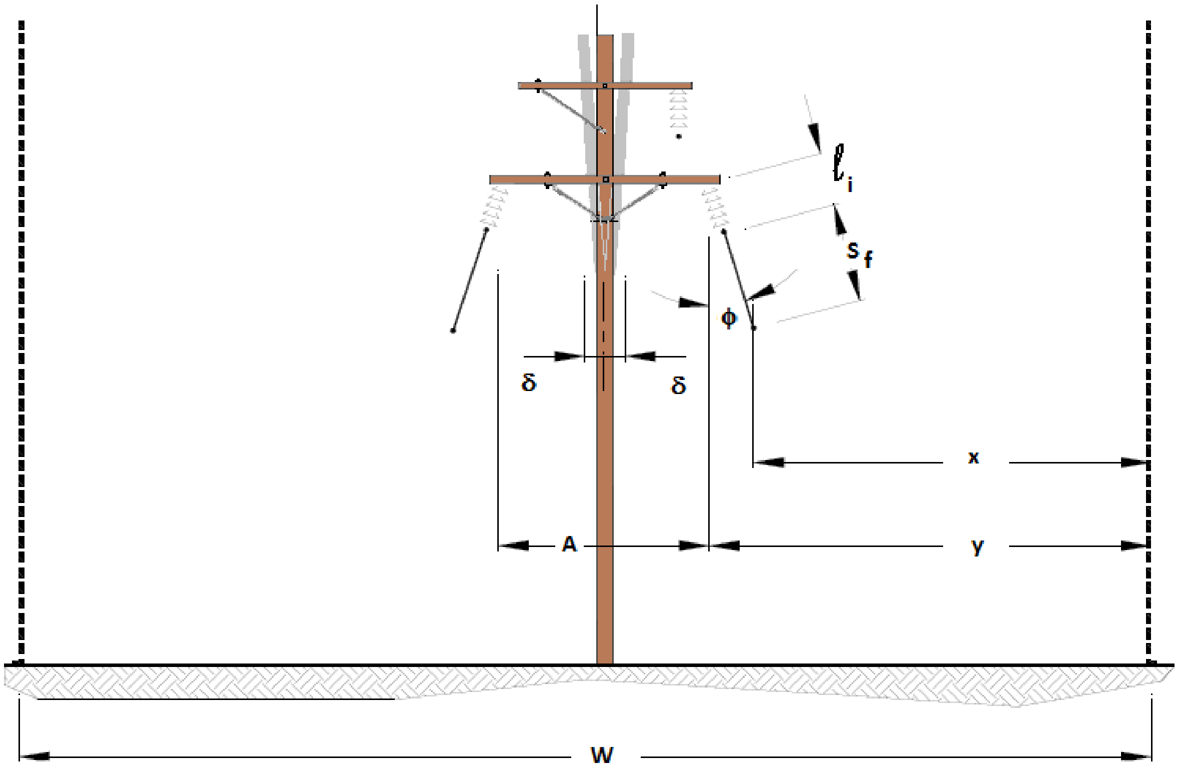



**Figure 13**

$$W = A + 2(l_i + S_f) * \sin(\varphi) + 2\delta + 2x$$

Where,
W = total right-of-way width required
A = separation between points of suspension of insulator strings for outer two phases
*x* = clearance required per Table 4 and appropriate clearance derived from Table 5 (include altitude correction if necessary)
*y* = clearance required per Table 4 and appropriate clearance derived from Table 5 (include altitude correction if necessary)
$S_f$ = conductor final sag at 60F with 6 PSF of wind
$\ell i$ = insulator string length ($\ell i$ = 0 for post insulators or restrained suspension insulators).
δ = structure deflection with a 6 PSF Wind

In some instances, clearance "x" may control. In other instances, clearance "y" may control.

There are two ways of choosing the length (and thus the sag) on which the right-of-way width is based. One is to use a width based on the maximum span length in the line. The other way is to base the width on a relatively long span, (the ruling span, for instance), but not the longest span. For those spans that exceed this base span, additional width is added as appropriate.

**Right-of-Way Width for a Line Directly Next to a Road**

The right-of-way width for a line next to a road can be calculated based on the two previous sections with one exception. No ROW is needed on the road side of the line as long as the appropriate clearances to existing or possible future structures on the road side of the line are met.

If a line is to be placed next to a roadway, consideration should be given to the possibility that the road may be widened. If the line is on the road right-of-way, the utility would generally be expected to pay for moving the line. If the right-of-way is on private land, the highway department should pay. Considerations involved in placing a line on a road right-of-way should also include evaluation of local ordinances and requirements.

**Right-of-Way Width for Two or More Lines of Structures on a Single Right-of Way**

To determine the right-of-way width when the right ROW contains two parallel lines, start by calculating the distance from the outside phases of the lines to the ROW edge. The distance between the two lines is governed by the two criteria provided below. If one of the lines involved is an EHV line (345 kV and above), the National Electrical Safety Code should be referred to for additional applicable clearance rules not covered in this course.

**Separation between Lines as Dictated by Minimum Clearance between Conductors Carried on Different Supports**

The horizontal clearance between a phase conductor of one line to a phase conductor of another line shall meet the larger of C1, or C2 below, under the following conditions:

a) Both phase conductors displaced by a 6 PSF wind at 60F, final sag;

b) If insulators are free to swing, one should be assumed to be displaced by a 6 lbs/sq. ft. wind while the other should be assumed to be unaffected by the wind (see Figure 14).

The assumed wind direction should be that which results in the greatest separation requirement. It should be noted that in the equations the ‘δ1-δ2’ term, (the differential structure deflection between the two lines of structures involved), is to be taken into account. An additional 1.5 feet have been added to the NESC clearance to obtain design clearances '$C_1$'and '$C_2$'.

$$C_1 = 6.5 + (\delta_1 - \delta_2) \qquad \text{(NESC Rule 233B1)}$$

$$C_2 = 6.5 + \frac{.4}{12} * \left[(kV_{LG1} + kV_{LG2}) - 22\right] + (\delta_1 - \delta_2) \qquad \text{(NESC Rule 233B1)}$$

Where:

$C_1, C_2$ = clearance requirements between conductors on different lines in feet (largest value governs)

$kV_{LG1}$ = maximum line-to-ground voltage in kV of line 1

$kV_{LG2}$ = maximum line-to-ground voltage in kV of line 2

$\delta_1$ = deflection of the upwind structure in feet

$\delta_2$ = deflection of the downwind structure in feet

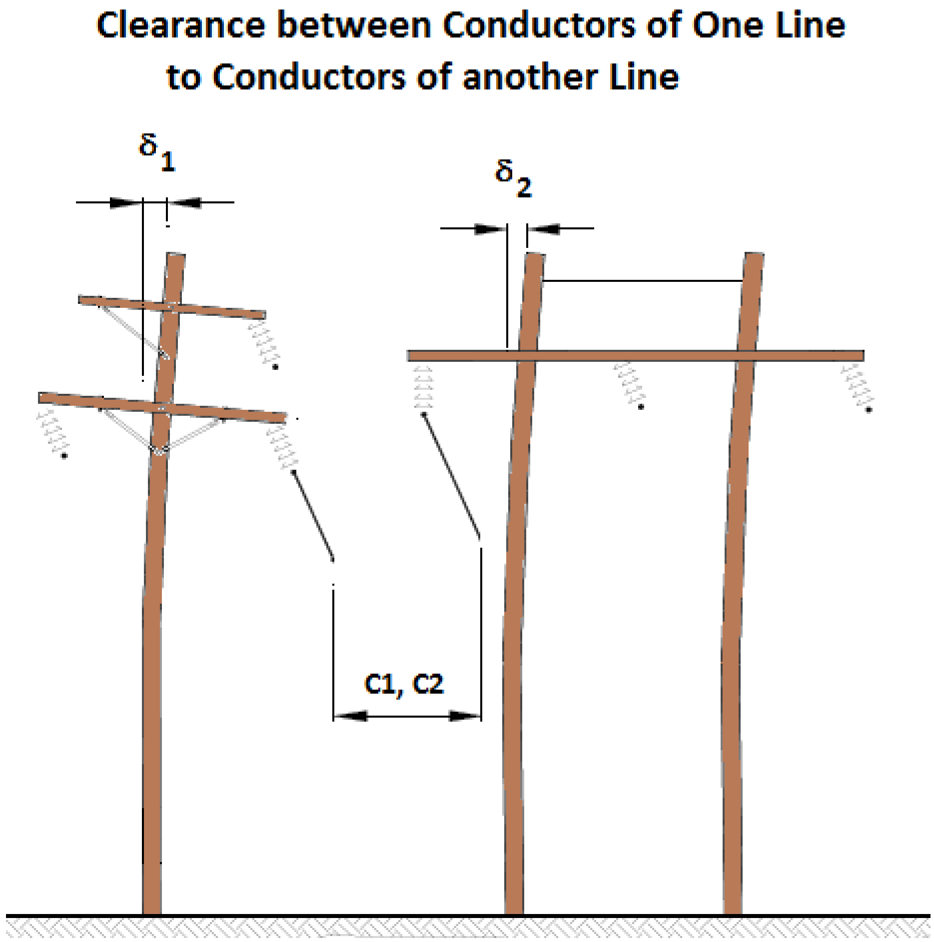



Figure 14

**Separation between Lines as Dictated by Minimum Clearance of Conductors from One Line to the Supporting Structure of Another**

The horizontal clearance of a phase conductor of one line to the supporting structure of another when the conductor and insulator are displaced by a 6 PSF wind at 60F final sag should meet,

$$C_3 = 6' + \frac{.4}{12}(kV_{LG} - 22) + (\delta_1 - \delta_2)$$

Where,
*kV* = the maximum line-to-ground voltage in kV
δ = structure deflection with a 6 PSF wind

Additional 1.5 feet have been added to the NESC clearance and included in the equation to obtain the design clearance ‘$C_3$’.

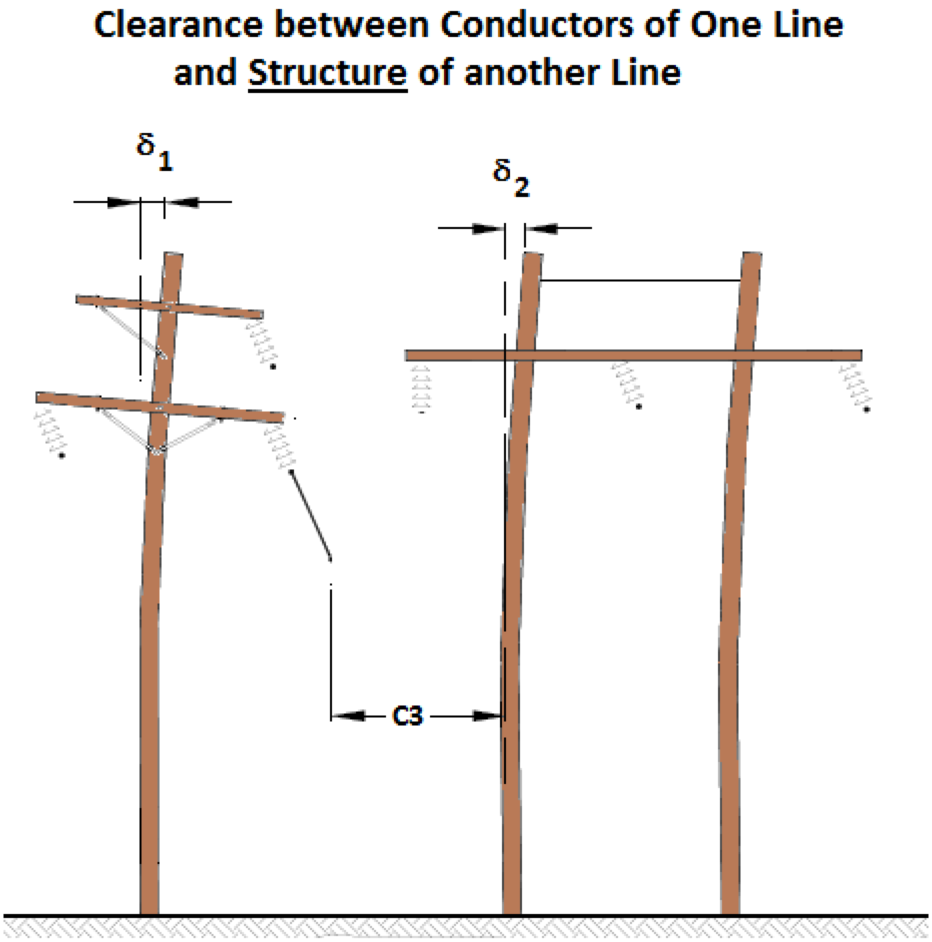



**Figure 15**

The separation between lines will depend upon the spans and sags of the lines as well as how structures of one line match up with structures of another. In order to avoid the unreasonable task of determining separation of structures span-by-span, a standard separation value should be used, based on a worst case analysis. Thus if structures of one line do not always line up with those of the other, the separation determined as shown above and should be based on the assumption that the structure of one line is located next to the mid-span point of the line that has the most sag.

**Other Factors**

Galloping should be taken into account in determining line separation. In fact, it may be the determining factor in line separation. See Chapter 3 for a discussion of galloping.

Standard phase spacing should also be taken into account. For example, if two lines of the same voltage using the same type structures and phase conductors are on a single ROW, a logical separation of the two closest phases of the two lines should be at least the standard phase separation of the structure.

If the altitude at which the lines included in the design are installed greater than 3300 feet, NESC Section 23 rules provide additional separation requirements.

# Chapter 3
# Clearances between Conductors and Between Conductors and Overhead Ground Wires

The preliminary comments and assumptions of Chapter 1, also apply to this chapter. This chapter considers design limits related to conductor separation. It is assumed that only standard structures will be used, thus making it unnecessary to check conductor separation at structures. Therefore, the only separation values left to consider are those related to span length and conductor sags.

Maximum span lengths may be controlled by conductor separation. Other factors which may limit span length, but are not covered in this chapter, are structure strength, insulator strength, and ground clearance.

**Maximum Span as Limited by Horizontal Conductor Separation**

Sufficient horizontal separation between phases is necessary to prevent swinging contacts and flashovers between conductors where there is insufficient vertical separation.

If the vertical separation - regardless of horizontal displacement - of phase conductors of the same or different circuits at the structure is less than the appropriate values provided in Table 7, then the recommendations in this section should be met.

**Example of Vertical and Horizontal Separation Values**

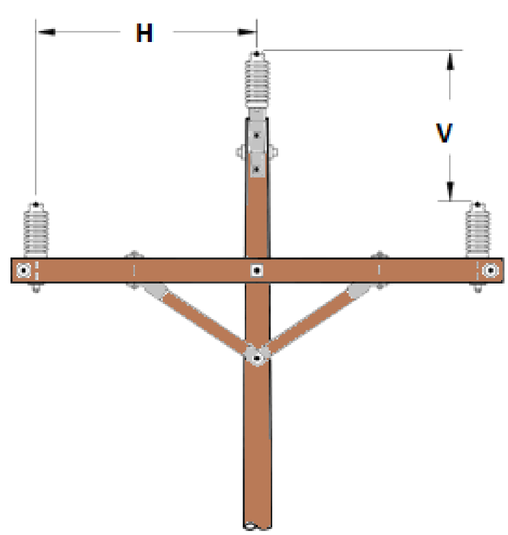



Figure 16

**Horizontal Separation Recommendations**

The following equation gives an horizontal phase spacing (relative to conductor sag, and thus indirectly to span length) that should be sufficient to prevent swinging contacts or flashovers between phases of the same or different circuits.

$$H = (0.025) * kV + F_c \sqrt{S_f} + \ell_i * (\sin\varphi_{max})$$

Where,
*H* =horizontal separation between the phase conductors at the structure in feet.
*kV* = (phases of the same circuit) the nominal line-to-line voltage in 1000's of volts for 34.5 and 46 kV and 1.05 times the nominal voltage in 1000's of volts for higher voltages
*kV* = (phases of different circuits) 1.05 times the magnitude of the voltage vector between the phases in 1000's of volts. kV should never be less than 1.05 times the nominal line-to-ground voltage in 1000's of volts of the higher voltage circuit involved regardless of how the voltage vectors add up. The voltage between the phases should be taken as the sum of the two line-to-ground voltages, based on 1.05 times nominal voltage.
$F_C$ = experience factor
$Ø_{max}$ = maximum 6 PSF insulator swing angle for the structure in question.
$S_f$ = final sag of the conductor at 60F, no load, in feet
$\ell_i$ = length of the insulator string in feet,
$\ell_i$ = 0 for post or restrained suspension insulators
*V* = vertical separation between phase conductors at the structure in feet

The experience factor ($F_C$) may vary from a minimum of 0.67 to a maximum of 1.4, depending upon how severe the wind and ice conditions are judged to be. The following are values of Fc that have proved to be satisfactory in the past.

Fc = 1.15 for the light loading zone
Fc = 1.2 for the medium loading zone
Fc = 1.25 for the heavy loading zone

Any value of Fc in the 0.67 to 1.4 range may be used if it is thought to be reasonable and prudent. There has been significant favorable experience with larger conductor sizes that have horizontal spacing based on an Fc factor of 0.67. Therefore, Fc factor values significantly less than the values listed above may be appropriate. If Fc values less than those given above are used, careful attention should be paid to galloping as a possible limiting condition on the maximum span length.

**Table 7**

**Recommended Vertical Separation in Feet Between Phases of the Same or Different Circuits Attached to the same Standard Structure**

| **Nominal voltage, Line-to-Line Voltage in kV** | **34.5 & 46** | **69** | **115** | **138** | **161** | **230** |
|---|---|---|---|---|---|---|
| Max. Operating Voltage, Phase to Phase, kV | ---- | 72.5 | 120.8 | 144.9 | 169.1 | 241.5 |
| Max. Operating Voltage, Phase to Ground, kV | ---- | 41.8 | 69.7 | 83.7 | 97.6 | 139.4 |
| Vertical Separation | Separation in feet | | | | | |
| **Minimum Vertical Separation at Support** | | | | | | |
| 1. Phases of the same circuit (Note A) (Based on NESC Table 235-5) | 3.2 | 4.0 | 5.6 | 6.4 | 7.2 | 9.6 |
| 2. Phases of different circuits (Notes B & D) (Based on NESC Table 235-5,footnote 7 criteria for different utilities) | 3.3 | 4.9 | 8.2 | 9.1 | 10.1 | 12.8 |
| 3. Phase conductors and overhead ground wires (Based on NESC 235C and 233C3) | 2.5 | 2.9 | 3.9 | 4.3 | 4.8 | 6.4 |
| **Minimum Vertical Separation in Span** | | | | | | |
| 4. Phases of the same circuit (Notes A & G) (Based on NESC Table 235-5 and NESC 235C2b(1)), H ≥ 1.0 ft., Figure 17 | 2.5* | 3.3 | 4.9 | 5.7 | 6.5 | 9.0 |
| 5. Phases of different circuits (Notes C, D & G) (Based on NESC Table 235-5, footnote 7 criteria for different utilities NESC Rule 235C2b.), H ≥ 1.0 ft. | 4.2 | 5.2 | 7.0 | 7.9 | 8.9 | 11.7 |
| 6. Phase conductors and overhead ground wires (H ≥ 1.0 ft., Figure 17), Notes D & G | 1.9** | 2.2** | 3.2 | 3.7 | 4.1 | 5.6 |
| | *75% of corresponding value in Line 1.<br>**75% of corresponding values in Line 3. | | | | | |

***Altitude correction to be added to values above***
Clearance values in table above shall be increased 3% for each 1,000 ft. in excess of 3,300 ft. above mean sea level.

***Notes:***

(A) There are no NESC values specified for vertical separation of conductors of the same circuit for voltages above 50 kV line-to-line.

(B) Assumes both circuits have the same nominal voltage. If they do not, the vertical separation can be determined using Equation 6-2 below.

$$V = \frac{40}{12} + \frac{0.4}{12} * (kV_{LG1} + kV_{LG2} - 8.7) + \frac{6}{12} * (Note\ D)$$

Where:

$kV_{LG1}$ = Line to ground voltage circuit one, kilovolts.

$kV_{LG2}$ = Line to ground voltage circuit two, kilovolts.

(C) Assumes both circuits have the same nominal voltage. If they do not, the vertical separation can be determined using Equation 6-2a below.

$$V = 0.75[\frac{40}{12} + \frac{0.4}{12} * (50 - 8.7)] + \frac{0.4}{12} * (kV_{LG1} + kV_{LG2} - 50) + \frac{6}{12} * (Note\ D)$$

(D) An additional 0.5 feet of clearance is added to the NESC clearance to obtain the recommended design clearances.

(E) The values in this table are not recommended as minimum vertical separations at the structure for non-standard structures. They are intended only to be used on standard structures to determine whether or not horizontal separation calculations are required.

(F) The upper conductor is at final sag at the maximum operating temperature and the lower conductor is at final sag at the same ambient conditions as the upper conductor without electrical loading and without ice loading; **or**, the upper conductor is at final sag at 32º with radial ice from either the medium loading district or the heavy loading district and the lower conductor is at final sag at 32ºF.

(G) In areas subjected to icing, an additional 2.0 feet of clearance should be added to the above clearances when conductors or wires are directly over one another or have less than a one foot horizontal offset.

## Additional Horizontal Separation Equation

The equation below, commonly known as the Percy Thomas formula, may be used in addition to (but not instead of) the previous equation for determining the horizontal separation between the phases at the structure. This equation takes into account the weight, diameter, sag, and span length of the conductor.

$$\mathbf{H = 0.025kV + \frac{E_c * d_c * S_p}{w_c} + \frac{\ell_i}{2}}$$

Where,
*$d_c$ = conductor diameter in inches*
*$w_c$ = weight of conductor in lb/ft*
*$E_c$ = an experience factor. It is generally recommended that Ec be larger than 1.25*
*$S_p$ = sag of conductor at 60F, expressed as a percent of span length*
*$\ell_i$ = length of the insulator string in feet*

By using the Thomas formula to determine values of Ec, the spacing of conductors on lines which have operated successfully in a locality can be examined. These values of Ec may be helpful in determining other safe spacings.

Maximum Span Based on Horizontal Separation at the Structure
The maximum allowable span, given the horizontal separation at the structure and the sag and length of the ruling span can be found by,

$$\mathbf{L_{max} = RS * \frac{H - 0.025kV - (\ell_i * \sin \phi_{max})}{F_c * \sqrt{S_{RS}}}}$$

Where,
$L_{max}$ = maximum span as limited by conductor separation in feet
RS = length of ruling span in feet
$S_{RS}$ = sag of the ruling span at 60F final sag in feet
H =horizontal separation between the phase conductors at the structure in feet.
kV = (phases of the same circuit) the nominal line-to-line voltage in 1000's of volts for 34.5 and 46 kV and 1.05 times the nominal voltage in 1000's of volts for higher voltages
$F_C$ = experience factor
$Ø_{max}$ = maximum 6 PSF insulator swing angle for the structure in question.

**Maximum Span Based on Vertical Separation**

Since vertical separation is related to the relative sags of the phase conductors involved, and since sags are related to span length, a maximum span as limited by vertical separation can be determined. The formula for the maximum span as limited by vertical separation is:

$$L_{max} = RS * \sqrt{\frac{D_v - B}{S_t - S_u}}$$

Where,
*Lmax* = maximum allowable span in feet
*Dv* = required vertical separation at mid-span in feet
*B* = vertical separation at supports in feet
$S_l$ = sag of lower conductor in feet without ice
*Su* = sag of upper conductor wire in feet with ice
*RS* = ruling span in feet

Example of Clearance Calculations

The following example demonstrates the derivation of the vertical separation at a support for phases of different circuits in Table 7 of this course.

To determine the vertical separation of a 115 kV line to another 115 kV circuit, the clearance is based on NESC Table 235-5 and NESC Rule 235.

At the support, phases of different circuits:

NESC Vertical Separation = 40 inches / 12 in/ft + .4*($kV_{L-G}$ + $kV_{L-G}$ – 8.7) / 12 ft.
= 3.333 + .4(69.7+69.7-8.7) / 12
= 7.69 feet

Recommended Vertical Separation = NESC Vertical Separation + suggested Adder
= 7.69 + 0.5
= 8.19 feet (8.2 feet in Table 7)

In the span, phases of different circuits:

NESC Vertical Separation $= 0.75 + \left[\frac{40}{12} + \frac{0.4}{12} * (50 - 8.7)\right] + \frac{0.4}{12} * (kV_{LG1} + kV_{LG2} - 50)$
= 0.75 * (3.33+1.37) + (.4/12) * (69.7 + 69.7 - 50)
= 3.53 + 2.98
= 6.51 feet

Recommended Clearance = NESC Vertical Separation + suggested Adder
= 6.51 + 0.5
= 7.01 feet (7.0 feet in Table 7)

**Maximum Span as Limited by Conductor Separation under Differential Ice Loading Conditions**

There is a tendency among conductors covered with ice, for the conductor closest to the ground to drop its ice first. Upon unloading its ice the lower conductor may jump up toward the upper conductor, possibly resulting in a temporary short circuit. After the lower conductor recovers from its initial ice-jump it may settle into a position with less sag than before, which may persist for long periods of time. If the upper conductor has not dropped its ice, the reduced separation may result in a flashover between phases.

The clearance recommendations provided in this section are intended to insure that sufficient separation will be maintained during differential ice loading conditions with an approach towards providing clearance for the ice-jump.

The minimum vertical distance ($D_v$) in span between phase conductors, and between phase conductors and overhead ground wires under differential ice loading conditions, are provided in Table 7. These vertical separations in span are recommended in cases where the horizontal separation between conductors (H) is greater than one foot ($H \geq 1.0$ ft). When conductors or wires are directly over one another or have less than a 1 foot horizontal offset, it is recommended that an additional 2 feet of clearance be added to the values given in Table 7. The purpose of this requirement is to improve the performance of the line under ice-jump conditions. It has been found that a horizontal offset of as little as one foot significantly lessens the ice-jump problem. Figure 17 indicates the horizontal and vertical components of clearance and their relationship.

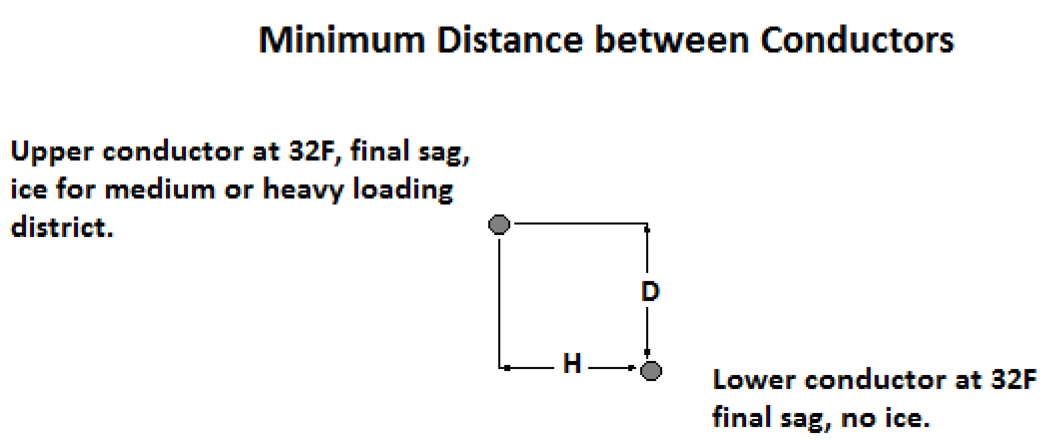



Figure 17

Lines should be designed so that clearances are considered with the upper conductor at 32F, final sag, and a radial thickness of ice equal to the ice thickness from either the medium loading district or the heavy loading district. The lower conductor should be at 32F, final sag, no ice. The designer is reminded to check clearances for the upper conductor at the maximum operating temperature (no wind) and the lower conductor at ambient temperature (see Note F of Table 7).

In addition to checking clearances between the overhead ground wire (OHGW) and phase conductors under differential ice loading conditions, it is also important that the relative sags of the phase conductors and the OHGW be coordinated so that under more commonly occurring conditions, there will be a reasonably low chance of a mid-span flashover. Adequate midspan separation is usually assured for standard structures by keeping the sag of the OHGW at 60F initial sag, no load conditions to 80 percent of the phase conductors under the same conditions.

**Maximum Span as Limited by Galloping**

*Galloping*, sometimes called dancing, is a phenomenon where the transmission line conductors vibrate with very large amplitudes. This movement of conductors may result in:

1. Contact between phase conductors or between phase conductors and overhead ground wires, resulting in electrical outages and conductor burning,
2. Conductor failure at support point due to the violent stress caused by galloping,
3. Possible structure damage, and
4. Excessive conductor sag due to the overstressing of conductors.

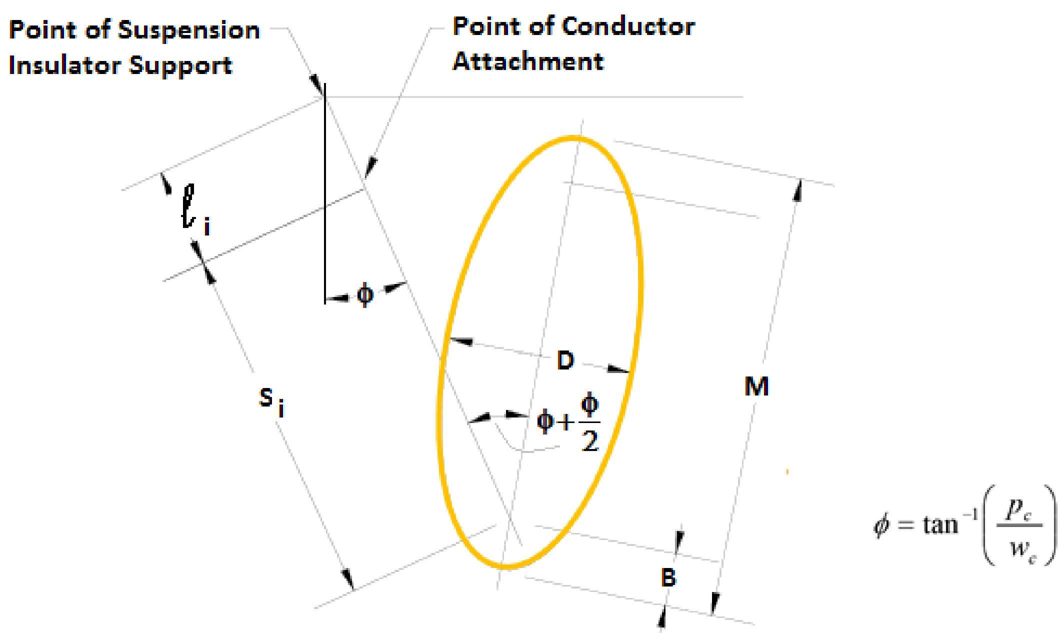
Galloping usually occurs only when a steady, moderate wind blows over a conductor covered by a layer of ice deposited by freezing rain, mist or sleet. The coating may vary from a very thin glaze on one side to a solid three-inch cover and may give the conductor a slightly out-of-round, elliptical, or quasi-airfoil shape. The wind blowing over this irregular shape results in aerodynamic lift which causes the conductor to gallop. The driving wind can be anything between 5 to 45 miles per hour at an angle to the line of 10 to 90 degrees and may be unsteady in velocity or direction.

During galloping, the conductors oscillate elliptically at frequencies on the order of 1-Hz or less with vertical amplitudes of several feet. Sometimes two loops appear, superimposed on one basic loop. Single-loop galloping rarely occurs in spans over 600 to 700 feet. This is fortunate since it would be impractical to provide clearances large enough in long spans to prevent the possibility of contact between phases. In double-loop galloping, the maximum amplitude usually occurs at the quarter span points and is smaller than that resulting from single-loop galloping.

There are several measures that can be incorporated at the design stage of a line to reduce potential conductor contacts caused by galloping, such as designing the line to have shorter spans, or increased phase separation. The H-frame structures provide very good phase spacing for reducing galloping contacts.

In areas where galloping is either historically known to occur or is expected, designers should indicate design measures that will minimize galloping and galloping problems, especially conductor contacts. The primary tool for assuring absence of conductor contacts is to superimpose Lissajous ellipses over a scaled diagram of the structure to indicate the theoretical path of a galloping conductor. See Figures 18 and 19. To avoid contact between phase conductors or between phase conductors and overhead ground wires, none of the conductor ellipses should touch one another. However, if galloping is expected to be infrequent and of minimal severity, there may be situations where allowing ellipses to overlap may be the favored design choice when economics are considered.

## Guide for Preparation of Lissajous Ellipses




| | Single Loop | Double Loop |
|---|---|---|
| **Major Axis** | $M = 1.25\,S_i + 1.0$ | $M = 1.0 + \sqrt{\frac{3a\left(L + \frac{8S_i^2}{3L} - 2a\right)}{8}}$ where $a = \sqrt{\left(\frac{L}{2}\right)^2 + S_i^2}$ |
| **Distance 'B'** | $B = 0.25\,S_i$ | $B = 0.2M$ |
| **Minor Axis** | $D = 0.4M$ | $D = 2\sqrt{M - 1.0}$ |

**Figure 18**

Where:

*pc* = wind load per unit length on iced conductor in lbs/ft. (Assume a 2 PSF wind )

*wc* = weight per unit length of conductor plus 1/2 in. of radial ice, lbs/ft

*L* = span length in feet

*M* = major axis of Lissajous ellipses in feet

*Si* = final sag of conductor with 1/2 in. of radial ice, no wind, at 32F, in feet.

*D* = minor axis of Lissajous ellipses in feet

*B,Ø* = as defined in figure above

**Single Loop Galloping Analysis**

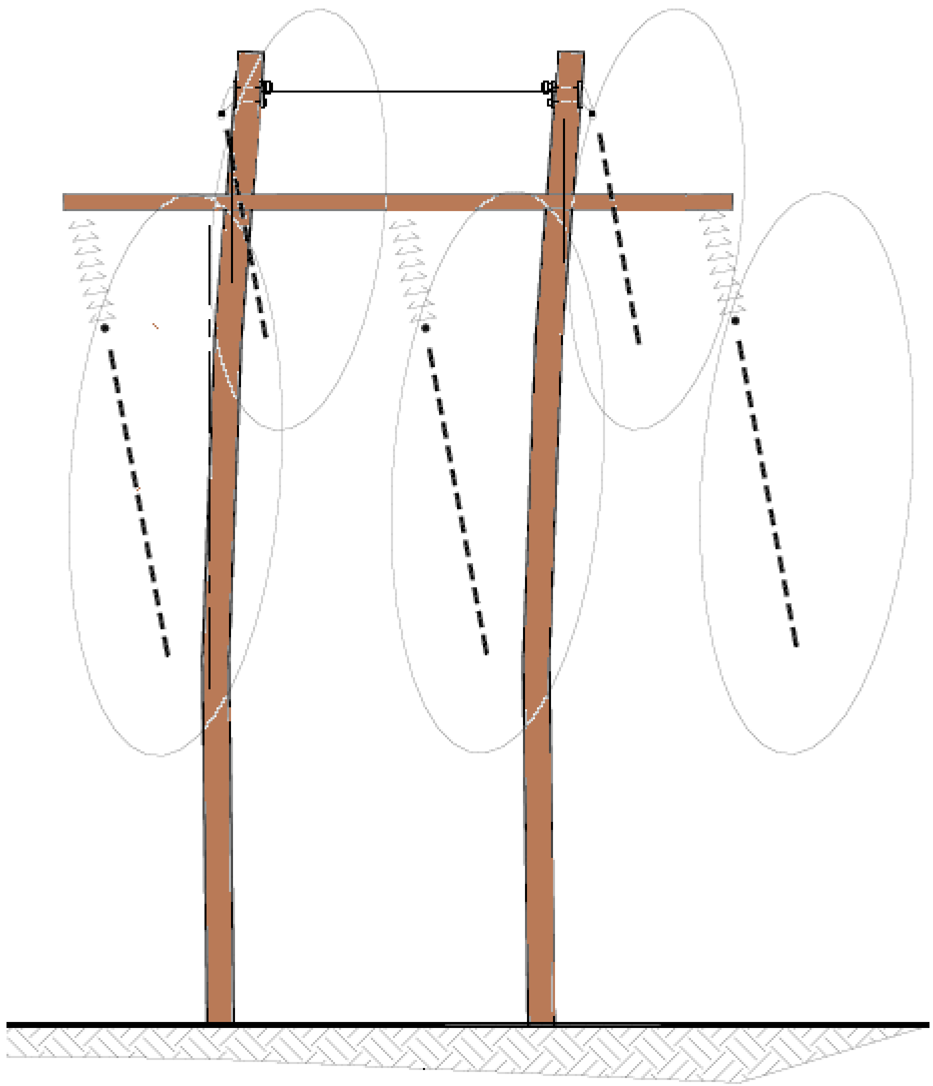


**Figure 19**

**Clearance between Conductors in a Crossarm to Vertical Construction Span**

Conductor contacts in spans changing from crossarm to vertical type construction may be reduced by proper phase arrangement and by limiting span lengths. Limiting span lengths well below the average span lengths is particularly important in areas where ice and sleet conditions can be expected to occur. See Figure 20.

**Proper Phase Arrangements from Horizontal (Crossarm) to Vertical Construction**

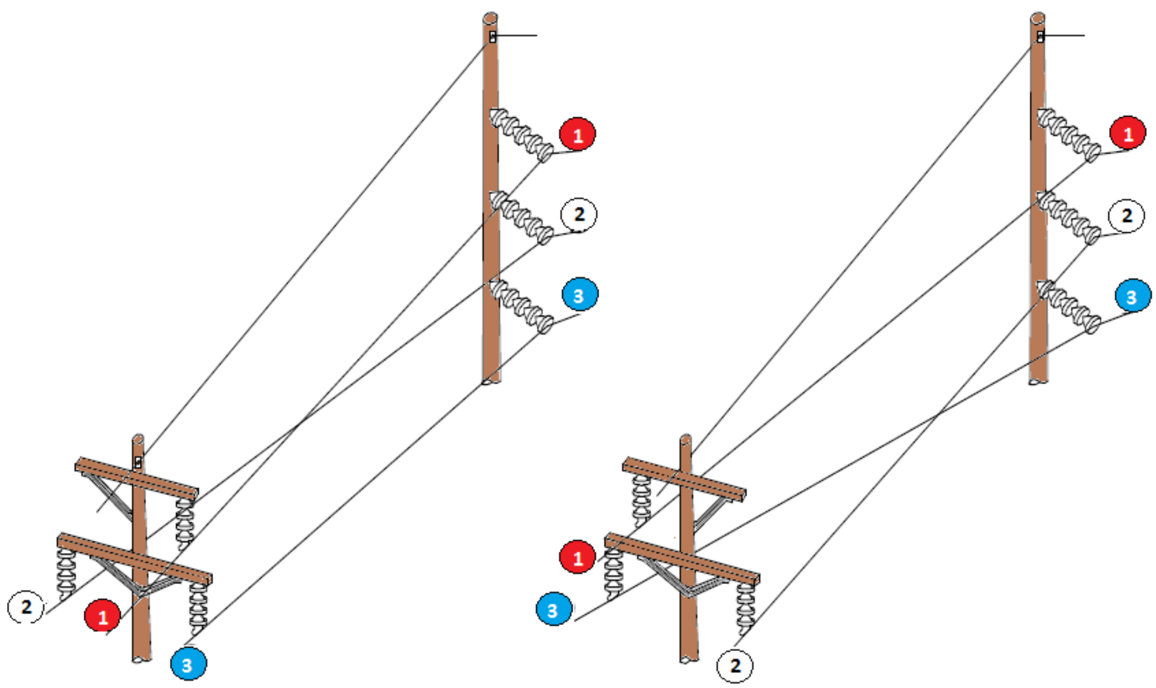



**Figure 20**

# Chapter 4
# Insulator Swing and Clearances of Conductors from Supporting Structures

Suspension insulator strings supporting transmission conductors, either at tangent or angle structures, are usually free to swing about their points of support. Therefore, it is necessary to ensure that when the insulators do swing, clearances are maintained to structures and guy wires. The amount of swing varies with such factors as: conductor tension, temperature, wind velocity, insulator weight, ratio of weight span to wind span, and line angle.

The force due to line angle will cause suspension strings to swing in the direction of the line angle of the structure. Wind blowing on the conductor span will exert a force in the direction of the wind. These two forces may act either in the same or opposite direction. The algebraic sum of the two forces determines the net swing direction. Line angle forces and wind forces also interact with the vertical forces of the conductor weight and insulator string weight. The vector sum of these forces determines the net angle from the vertical axis to which the insulator string will swing. This net insulator swing angle should be calculated for several key weather conditions so that corresponding phase-to-ground clearances may be checked on a particular pole-top arrangement.

The purpose of this chapter is to explain how insulator swing application guides called swing charts are prepared.

**Clearances and Their Application**

Table 8 provides information on three sets of clearances that can ensure proper separation between conductors and structures or guys under various weather conditions. Figure 21 illustrates the various situations in which the clearances are to be applied.

**Table 8**

**Recommended Minimum Clearances in Inches at Conductor to Surface of Structure or Guy Wires**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Nominal voltage, Phase to Phase, kV** | **34.5** | **46** | **69** | **115** | **138** | **161** | **230** |
| **Standard Number of 5-3/4"x10" Insulators on Tangent Structures** | **3** | **3** | **4** | **7** | **8** | **10** | **12** |
| Max. Operating Voltage, Phase to Phase, kV | 34.5 | 46 | 72.5 | 120.8 | 144.9 | 169.1 | 241.5 |
| Max. Operating Voltage, Phase to Ground, kV | 19.9 | 26.6 | 41.8 | 69.7 | 83.7 | 97.6 | 139.4 |
| | Clearance in inches | | | | | | |
| **No Wind Clearance (Not NESC)** | | | | | | | |
| Min. clearance to structure or guy at no wind in inches Notes A, B | 19 | 19 | 25 | 42 | 48 | 60 | 71 |
| **Moderate Wind Clearance (NESC Table 235-6)** | | | | | | | |
| Min. clear. to structure at 6 PSF of wind (inches). Notes C, D | 9 | 11 | 16 | 26 | 30 | 35 | 50 |
| Min. clear. to jointly used structures and a 6 PSF of wind in inches. Notes C, D | 11 | 13 | 18 | 28 | 32 | 37 | 52 |
| Min. clearance to anchor guys at 6 PSF in inches Notes C, D | 13 | 16 | 22 | 34 | 40 | 46 | 64 |
| **High Wind Clearance (Not NESC)** Min. clearance to structure or guy at high wind ( inches) | 3 | 3 | 5 | 10 | 12 | 14 | 20 |

***Notes***:
(A) If insulators in excess of the standard number for tangent structures are used, the no wind clearance value shown should be increased by 6 in. for each additional bell. If the excess insulators are needed for contamination purposes, this additional clearance is not necessary. For non-ceramic suspension insulators, the no wind clearance should be, at minimum, the length of the insulator plus 2".

(B) For post insulators, the no wind clearance to structure or guy is the length of the post insulator.

(C) A higher wind may be assumed if deemed necessary.

(D) The following values should be added as appropriate where the altitude exceeds 3300 feet

**Additional inches of clearance per 1000 feet of altitude above 3300 feet**

| Voltage, kV | **34.5** | **46** | **69** | **115** | **138** | **161** | **230** |
|---|---|---|---|---|---|---|---|
| Clearance to structure | 0 | 0 | 0.14 | 0.43 | 0.57 | 0.72 | 1.15 |
| Clearance to anchor guy | 0 | 0 | 0.17 | 0.54 | 0.72 | 0.90 | 1.44 |

No-Wind Clearance

The no wind clearance provides a balanced insulation system in which the insulating value of the air gap is approximately the same as that of the insulator string for a tangent structure.

Conditions at which no-wind clearances are to be maintained follow:

- Assume no wind.
- Assume a temperature of 60F. See Figure 21 for conductor condition. The engineer may also want to evaluate clearances at cold conditions (such as -20F initial sag) and hot conditions (such as 167F final sag).

Moderate Wind Clearance

This clearance is the minimum clearance that should be maintained under conditions that are expected to occur occasionally. A typical condition may be the wind that reoccurs no less than once every two years (probability of occurrence no more than 50 percent). Clearance values for moderate wind clearance conditions will have a lower flashover value than clearance values for the no-wind condition. These lower clearance values are acceptable because under moderate wind conditions, the specified clearance will be sufficient to withstand most of the severe voltage stress situations for wind conditions that are not expected to occur often.

Refer to Table 8 for minimum clearances from conductor to structure and guys, and for additional clearance required at altitudes above 3,300 feet.

Conditions at which moderate wind clearances are to be maintained follow:

- Assume a wind of at least 6 PSF blowing in the direction shown in Figure 8. Higher wind pressures can be used if judgment and experience deem them to be necessary. However, the use of excessively high wind values could result in a design that is overly restrictive and costly. It is recommended that wind pressure values of no higher than 9 PSF (60 mph) be used for the moderate wind clearance design unless special circumstances exist.
- Temperature conditions under which the clearances are to be maintained depend upon the type of structure. A temperature of no more than 32F should be used for tangent and small angle structures where the insulator string is suspended from a crossarm. A lower temperature value should be used where such a temperature can be reasonably expected to occur in conjunction with the wind value assumed. It should be borne in mind, however, the insulator swing will increase at lower temperatures because conductor tensions increase. Therefore, in choosing a temperature lower than 32F, one should

weigh the increase in conservatism of line design against the increase or decrease in line cost. NESC Rule 235.B.2 requires a temperature no higher than 60F final tension.

A temperature of 60F should be used for angle structures where the force due to change in direction of the conductor holds the insulator string away from the structure. Even if the maximum conductor temperature is significantly greater than 60F, a higher temperature need not be used as an assumed wind value of 40 mph (6 PSF)) has quite a cooling effect.

Assume final sag conditions for 60F temperature and initial sag conditions for 32F.

High Wind Clearance

This is the minimum clearance that should be maintained under high wind conditions that are expected to occur very rarely. The clearances provide enough of an air gap to withstand up to a 60 Hz flashover. Choice of such values is based on the philosophy that under very rare high wind conditions, the line should not flashover due to the 60 Hz voltage.

Conditions under which high wind clearances are to be maintained are:

- The minimum assumed wind value should be at least the 10year mean recurrence interval wind blowing in the direction shown in Figure 21. More wind may be assumed if deemed appropriate.

- The temperature assumed should be that temperature at which the wind is expected to occur. The conductor should be assumed to be at final tension conditions.

To determine the velocity of the wind for a 10 year return period, the following factors should be applied to the 50 year peak gust wind speed.

| **V = 85 to100 mph, Continental U.S.** | **Alaska** | **V > 100 mph (hurricane)** |
|---|---|---|
| 0.84 | 0.87 | 0.74 |

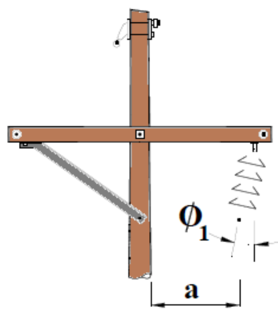
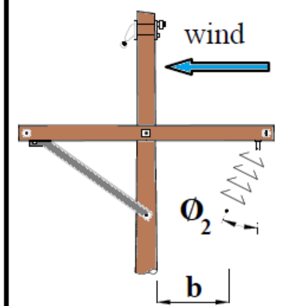
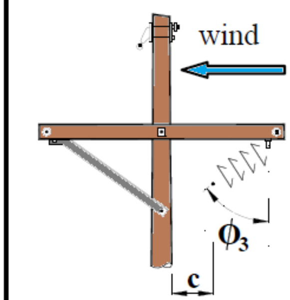
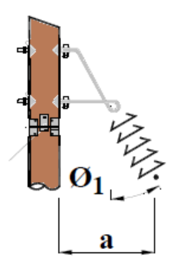
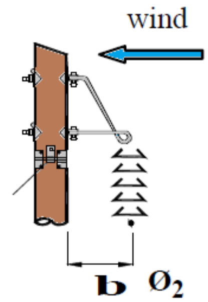
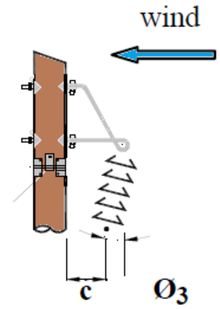
| Illustration of Structure Insulator Swing Angle Limits and Conditions under which they Apply (excludes Backswing) | | | |
|---|---|---|---|
| **TANGENT AND SMALL ANGLE STRUCTURES** | **No Wind Insulator Swing** | **Moderate Wind Insulator Swing** | **High Wind Insulator Swing** |
| **Conditions* at which clearances are to be maintained** |  |  |  |
| • Line angle<br>• Wind force<br>• Temperature<br>• Conductor tension | Force due to line angle (if any)<br>0<br>60ºF<br>Final tension | Force due to line angle (if any)<br>6 psf minimum<br>32ºF or lower<br>Initial tension | Force due to line angle (if any)<br>10 year mean wind, recommended value<br>Temp. at which wind value is expected<br>Final tension |
| **MEDIUM AND LARGE ANGLE STRUCTURES**<br><br>**Conditions* at which clearances are to be maintained** |  |  |  |
| • Line angle<br>• Wind force<br>• Temperature<br>• Conductor tension | Force due to line angle (if any)<br>0<br>60ºF<br>Final tension | Force due to line angle (if any)<br>6 psf minimum<br>32ºF or lower<br>Initial tension | Force due to line angle (if any)<br>10 year mean wind, recommended value<br>Temp. at which wind value is expected<br>Final tension |

**Figure 21**

In the figure above,
a = No wind clearance
b = Moderate wind clearance

c = High wind clearance

Example of Clearance Calculations

The following examples demonstrate the derivation of the minimum clearance to anchor guys at 6 PSF.

To determine the minimum clearance of a 115 kV line to an anchor guy (Table 8) at 6 PSF, the clearance is based on NESC Table 235-6 and NESC Rule 235E.

NESC Clearance in any direction = NESC Basic Clearance (Table 235-6) + .25($kV_{L-L}$ – 50)
= 16 + .25 * (120.8-50)
= 16 + 17.7
= 33.7 inches (clearance in Table 8 is 34 inches)

**Backswing**

Insulator swing considerations are illustrated in Figure 21. For angle structures where the insulator string is attached to the crossarm, the most severe condition is usually where the force of the wind and the force of the line angle are acting in the same direction. However, for small angle structures, it is possible that the limiting swing condition may be when the wind force is in a direction opposite of that due to the force of the line angle. This situation is called backswing, as it is a swing in a direction opposite of that in which the insulator is pulled by the line angle force. Figure 22 illustrates backswing.

When calculating backswing, it is necessary to assume those conditions that would tend to make the swing worse, which usually is low conductor tension or small line angles. It is recommended that the temperature conditions for large angle structures in Figure 21 be used, as they result in lower conductor tensions.

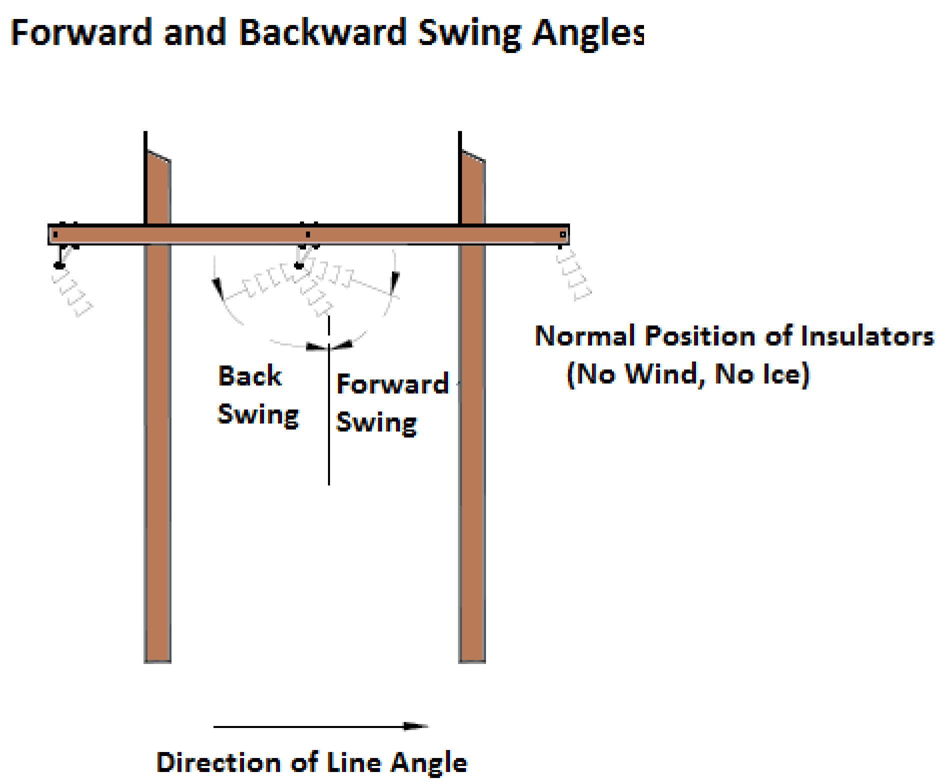



Figure 22

**Structure Insulator Swing Values**

Table 9 provides the allowable insulator swing angle values for some of the most often used standard tangent structures. These values represent the maximum angle from the vertical that an insulator string of the indicated number of standard bells may swing in toward the structure without violating the clearance category recommendation indicated at the top of each column. For tangent structures, the most restrictive angle for the particular clearance category for the entire structure is given. Thus, for an asymmetrical tangent structure where the allowable swing angle depends upon whether the insulators are assumed to be displaced to the right or left, the use of the most restrictive value means that the orientation of the structures with respect to the line angle need not be considered. For certain angle structures the insulator string has to be swung away from the structure in order to maintain the necessary clearance. These situations usually occur for large angle structures where the insulator string is attached directly to the pole or to a bracket on the pole and where the force due to the change in direction of the conductors is relied upon to hold the conductors away from the structure.

| Table 9<br>Allowable Insulator Swing Angle Values in Degrees<br>(For Insulator String with Ball Hooks) | | | | |
|---|---|---|---|---|
| **Structure and Voltage** | **Number of Insulators** | **No Wind Swing Angle** | **Moderate Wind Swing Angle** | **High Wind Swing Angle** |
| 69 kV<br>Tangent Suspension | 4 | 21.3 | 41.4 | 74.9 |
| Wishbone | 4 | 41.7 | 61.2 | 82.6 |
| H-Frame | 4 | 35.6 | 61.2 | 85.6 |
| 115 kV – H-Frame | 7 | 28.3 | 58.7 | 80.8 |
| 161 kV – H-Frame | 10 | 16.4 | 53.2 | 77.7 |
| 230 kV – H-Frame | 12 | 16.5 | 47.5 | 74.8 |

### Line Design and Structure Clearances

Insulator swing has a key effect on acceptable horizontal to vertical span ratios. Under a given set of wind and temperature conditions, an insulator string on a structure will swing at an angle toward the structure a given number of degrees. The angle of this swing is related to a ratio of horizontal to vertical forces on the insulator string. A relationship between the horizontal span, the vertical span, and if applicable, the line angle can then be developed for the structure, conductor, and weather. Horizontal and vertical spans are explained in Figure 24.

The acceptable limits of horizontal to vertical span ratios are plotted on a chart called an insulator swing chart. Such a chart can be easily used for checking or plotting out plan and profile sheets. Figures 23 and 25 show simplified insulator swing charts for the moderate wind condition only. There is one significant difference between the chart for tangent structures, and the chart for angle (running corner) structures. In Figure 23 for a typical tangent structure, the greater the vertical span for a fixed horizontal span the less swing occurs. The reverse is true for chart of Figure 25 for a typical angle structure. This occurs because the swing chart in Figure 25 is for a large angle structure where the force of the line angle is used to pull the insulator string away from the structure. As such, the less vertical force there is from the weight span, the greater the horizontal span can be.

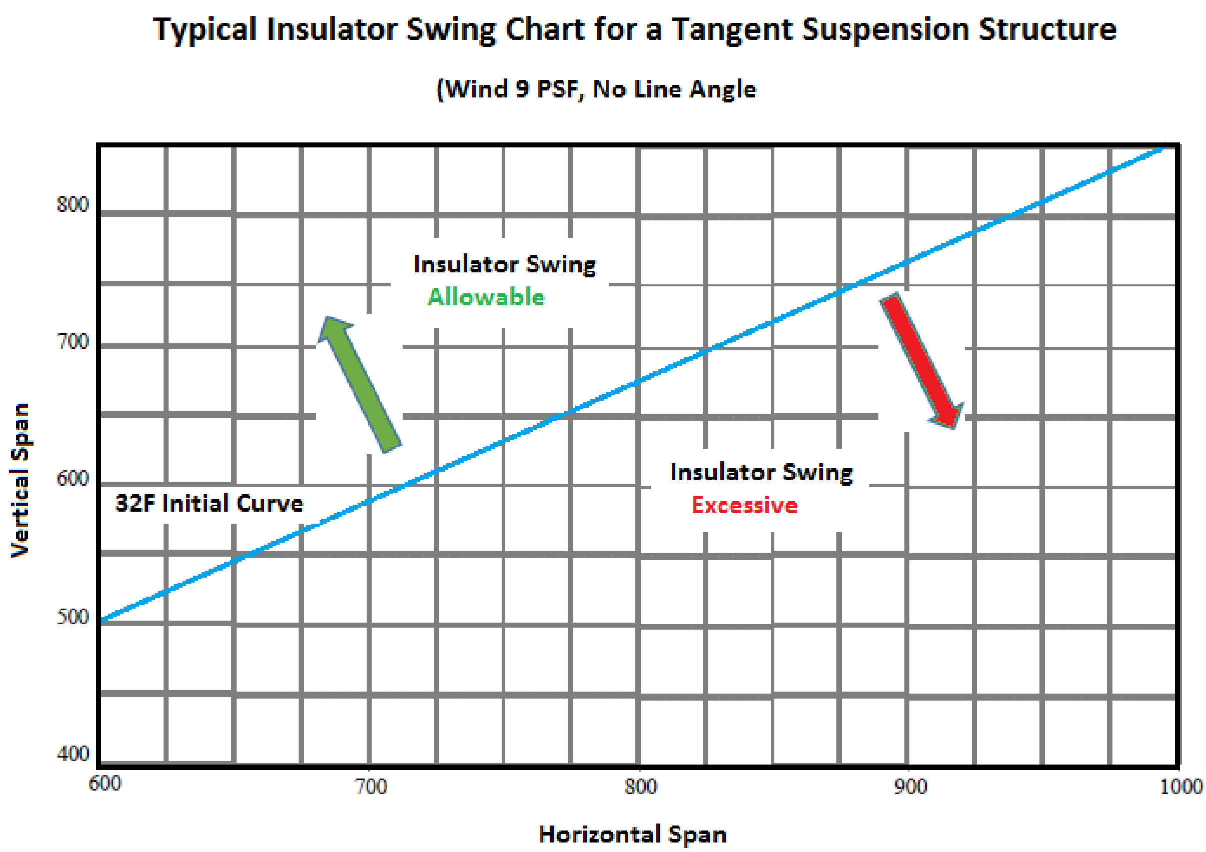

Typical Insulator Swing Chart for a Tangent Suspension Structure
(Wind 9 PSF, No Line Angle
Vertical Span
800
700
600
500
400
600
700
800
900
1000
Horizontal Span
Insulator Swing
Allowable
Insulator Swing
Excessive
32F Initial Curve

Figure 23

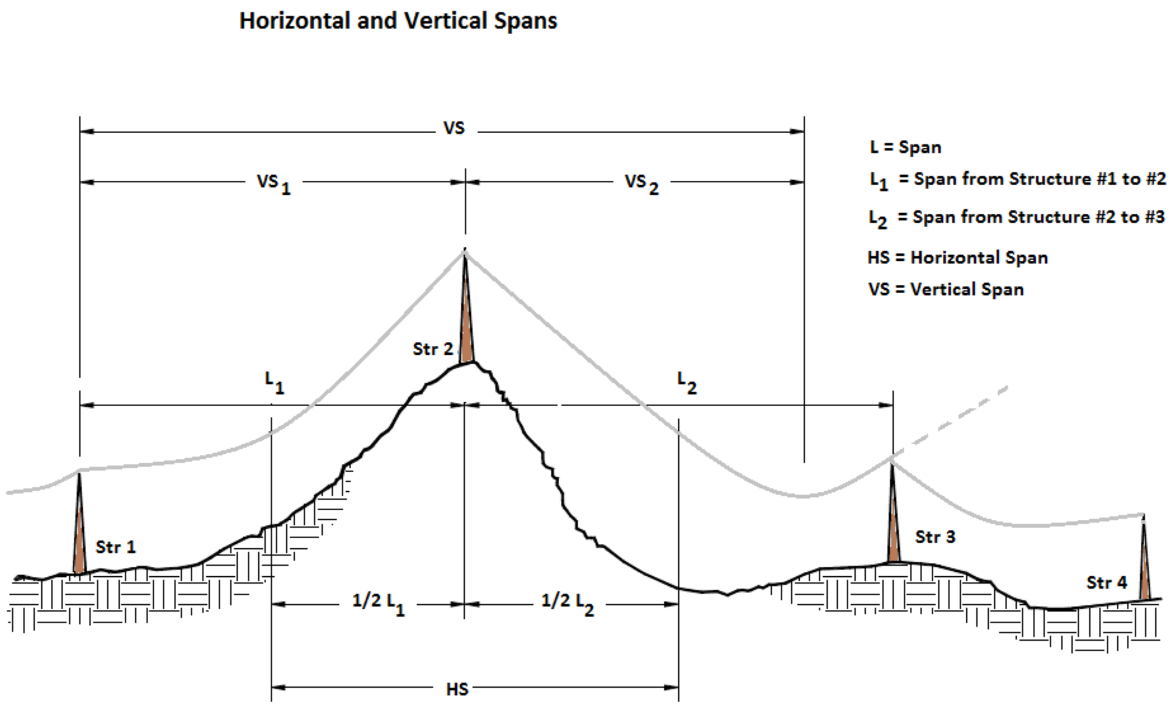



Figure 24

The 'no wind' insulator swing criteria will not be a limiting condition on tangent structures as long as the line direction does not change and create an angle in the line. If an angle is turned, it is possible that the 'no wind' condition might control. The other two criteria may control under any circumstance. However, the high wind criteria will be significant in those areas where unusually high winds can be expected. Thus, all three conditions specified need to be checked.

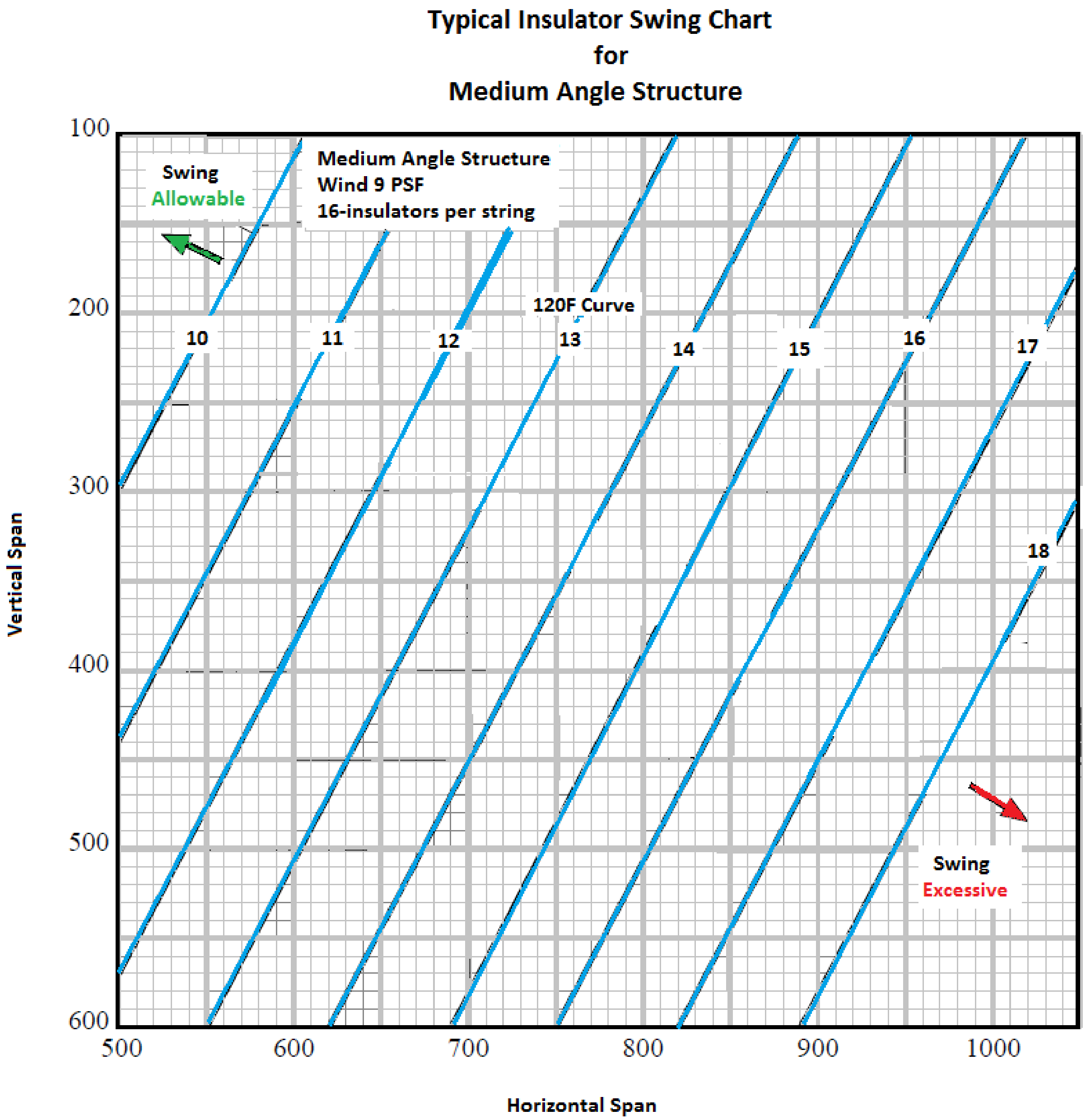



**Figure 25**

(Moderate Wind Swing Condition, 9 PSF assumed instead of minimum NESC 6 PSF)

**Formulas for Insulator Swing**

The formulas in the following equations can be used to determine the angle of insulator swing that will occur under a given set of conditions for either tangent or angle structures.

$$\tan \phi = \frac{2 * T * \sin\left(\frac{\theta}{2}\right) + HS * p_c}{VS * w_c + \frac{1}{2} * W_i}$$

$$p_c = \frac{d_c * F}{12}$$

Where,
Ø = angle with the vertical through which the insulator string swings, in degrees
θ = line angle, in degrees
T = conductor tension, pounds
HS = horizontal span, feet
VS = vertical span, feet
$p_c$ = wind load per unit length of bare conductor in pounds per foot
$w_c$ = weight per unit length of bare conductor in pounds per foot
$W_i$ = weight of insulator string (wind pressure neglected), in pounds.
$d_c$ F = conductor diameter in inches wind force in $lbs/ft^2$

In order to use the equation properly, the following sign conventions are to be followed:

| Condition | Sign Assumed |
|---|---|
| *Wind - Blowing insulator toward structure* | + |
| *"(2)(T)(sin ϑ/2)" term (force on insulator due to line angle):* *Pulling insulator toward structure* | + |
| *Pulling insulator away from structure* | - |
| *Insulator swing angle* *Angle measured from a vertical line through point of insulator support in toward structure* | + |
| *Angle measured from a vertical line through point of insulator support away from structure* | - |

**Insulator Swing Charts**

Insulator swing charts similar to those in Figures 23 and 25 can be developed by using the following and the maximum angle of insulator swing values as limited by clearance to structure.

$$\mathbf{VS} = \frac{\mathbf{2 * T * sin\left(\frac{\theta}{2}\right) + HS * p_c}}{\mathbf{w_c * tan\,\phi}} - \frac{\mathbf{W_i}}{\mathbf{2 * w_c}}$$

The symbols and sign conditions are the same as those previously provided.

**Excessive Angles of Insulator Swing Examples**

Example #1

For an H-Frame tangent structure, develop the insulator swing chart. Assume that it is desired to turn slight angles with the tangent structure and the insulator string assembly uses the ball hook.

Given:

Voltage: 161 kV

Structure: H-Frame

Conductor: 795 kcmil 26/7 ACSR

Insulation: Standard (10 bells)

NESC heavy loading district

High winds: 14 PSF

Ruling Span: 800 ft.

Conductor Tensions

6 PSF wind

0F

6,244 lbs. initial tension

No wind

60F

4,633 lbs. final tension

12.5 PSF wind

32F

10,400 lbs. final tension

Using the information on conductor sizes and weights, allowable swing angles and equations the calculation tables and the swing chart in Figure 26 are created.

Example #2

On the plan and profile drawings, the engineering is checking insulator swing for the H-frame structure in the previous example. For a certain H-frame structure with no line angle, the horizontal span is 800 feet. Determine the minimum vertical span.

Same Information as the previous example.

From Figure 26, for a horizontal span of 800 feet, the vertical span must be greater than 241 feet (see also tables for Figure 27). Many programs which are used to develop plan-profile drawings will automatically check insulator swing or will use insulator swing as a parameter in the spotting of structures.

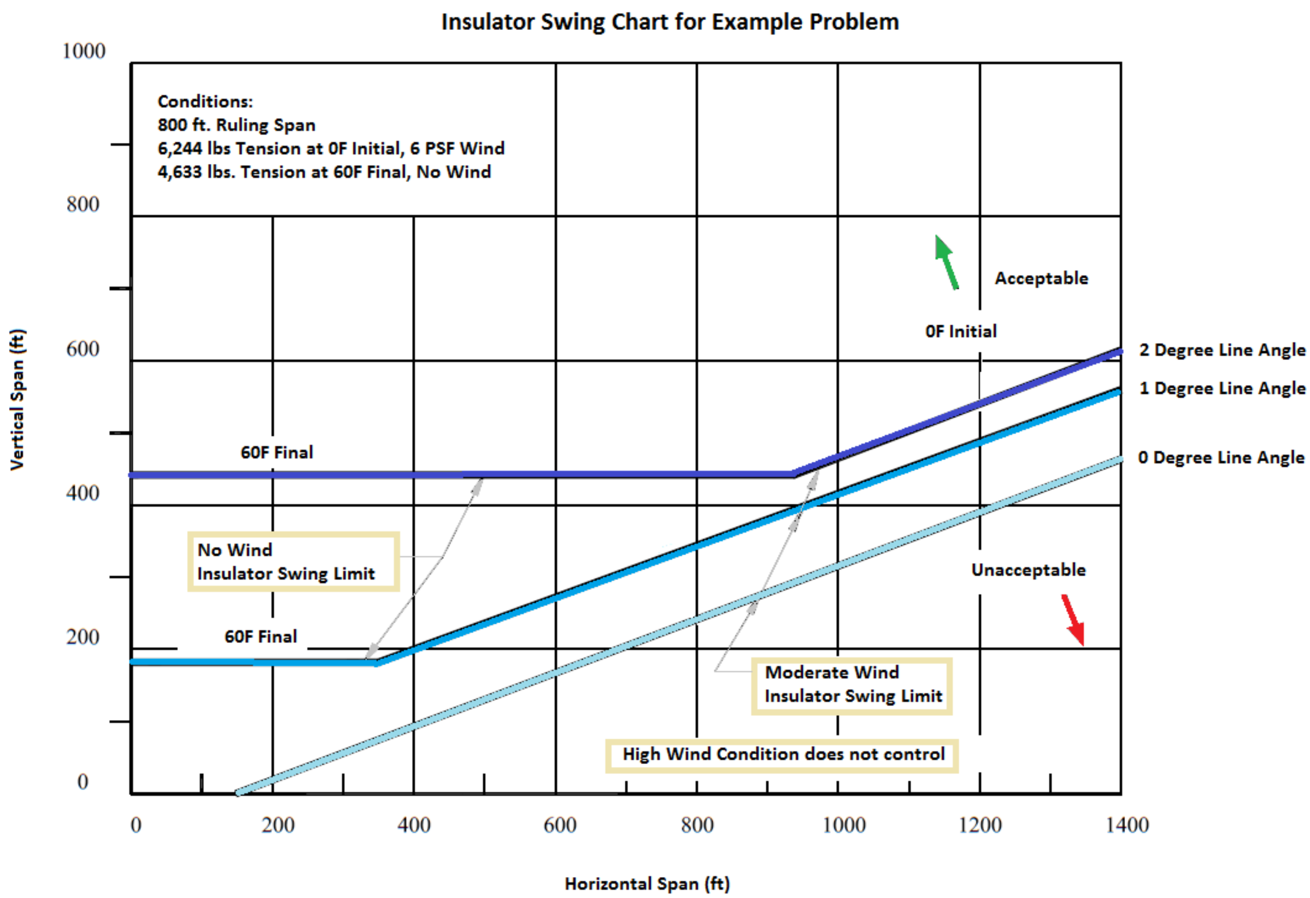


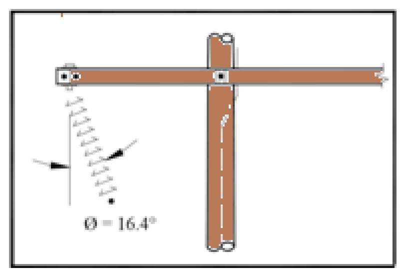

Figure 26

$$VS = \frac{2 * T * \sin\left(\frac{\theta}{2}\right) + HS * p_c}{w_c * \tan\phi} - \frac{W_i}{2 * w_c}$$

*Note: for the no wind case, vertical span is independent of horizontal span. It is only dependent upon line angle.*

| Θ | 1° | 2° | |
|---|---|---|---|
| sin θ/2 | .00872 | .01745 | |
| a) (2)(T)(sin θ/2) | 80.26 | 161.71 | |
| b) (HS)($p_c$) | 0 | 0 | |
| a + b = | 80.26 | 161.71 | |
| c) ($w_c$)(tan Ø) | 0.32 | 0.32 | |
| d) (a + b)/c | 251.13 | 502.25 | |
| e) $W_i$/(2)($w_c$) | 61.70 | 61.70 | |
| d – e = VS | 189.43 | 440.55 | |
| **Θ** | | | |
| sin θ/2 | | | |
| a) (2)(T)(sin θ/2) | | | |
| b) (HS)($p_c$) | | | |
| a + b = | | | |
| c) ($w_c$)(tan Ø) | | | |
| d) (a + b)/c | | | |
| e) $W_i$/(2)($w_c$) | | | |
| d – e = VS | | | |
| **Θ** | | | |
| sin θ/2 | | | |
| a) (2)(T)(sin θ/2) | | | |
| b) (HS)($p_c$) | | | |
| a + b = | | | |
| c) ($w_c$)(tan Ø) | | | |
| d) (a + b)/c | | | |
| e) $W_i$/(2)($w_c$) | | | |
| d – e = VS | | | |
| | | | |

Ø = angle with the vertical through which insulator string swings.
θ = line angle
T = conductor tension
HS = horizontal span
VS = vertical span
$p_c$ = wind load on conductors
$w_c$ = weight of conductor/ft.
$W_i$ = weight of insulator string




Structure: H-Frame
Conductor: 795 26/7 ACSR
Voltage: 161 kV
Insulator Swing Condition: No wind

Ø = 16.4°
$p_c$ = 0 lbs./ft
$w_c$ = 1.0940 lbs./ft
T = 4,633 lbs
$W_i$ = 135 lbs

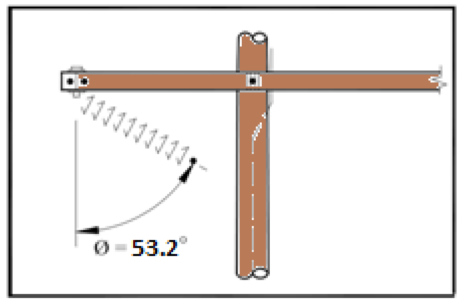
Conductor dia: 1.108

$p_c = \frac{(d)(F)}{12}$

**Figure 27**

| **θ = 0°** | HS=200 | HS=400 | HS=800 | HS=1000 |
|---|---|---|---|---|
| sin θ/2 | 0 | 0 | 0 | 0 |
| a) (2)(T)(sin(θ/2) | 0 | 0 | 0 | 0 |
| b) (HS)(pc) | 110.80 | 221.60 | 443.20 | 554.00 |
| a + b = | 110.80 | 221.60 | 443.20 | 554.00 |
| c) (wc)(tan Ø) | 1.460 | 1.460 | 1.460 | 1.460 |
| d) (a + b)/c | 75.77 | 151.53 | 303.07 | 378.83 |
| e) Wi/(2)(wc) | 61.70 | 61.70 | 61.70 | 61.70 |
| d – e = VS | 14.07 | 89.83 | 241.37 | 317.13 |
| **θ = 1°** | HS=200 | HS=400 | HS=800 | HS=1000 |
| sin θ/2 | .008727 | .008727 | .008727 | .008727 |
| a) (2)(T)(sin(θ/2) | 1.08.98 | 108.98 | 108.98 | 108.98 |
| b) (HS)(pc) | 110.80 | 221.60 | 443.20 | 554.00 |
| a + b= | 219.78 | 330.58 | 552.18 | 662.98 |
| c) (wc)(tan Ø) | 1.460 | 1.460 | 1.460 | 1.460 |
| d) (a + b)/c | 150.29 | 226.05 | 377.59 | 453.35 |
| e) Wi/(2)(wc) | 61.70 | 61.70 | 61.70 | 61.70 |
| d – e = VS | 88.59 | 164.35 | 315.89 | 391.65 |
| **θ = 2°** | HS=200 | HS=400 | HS=800 | HS=1000 |
| sin θ/2 | .017452 | .017452 | .017452 | .017452 |
| a) (2)(T)(sin θ/2) | 217.95 | 217.95 | 217.95 | 217.95 |
| b) (HS)(pc) | 110.80 | 221.60 | 443.20 | 554.00 |
| a + b = | 328.75 | 439.55 | 661.15 | 771.95 |
| c) (wc)(tan Ø) | 1.460 | 1.460 | 1.460 | 1.460 |
| d) (a + b)/c | 224.80 | 300.57 | 452.10 | 527.87 |
| e) Wi/(2)(wc) | 61.70 | 61.70 | 61.70 | 61.70 |
| d – e = VS | 163.10 | 238.87 | 390.40 | 466.17 |
| | | | | |

Ø = angle with the vertical through which insulator string swings.
θ = line angle
T = conductor tension
HS = horizontal span
VS = vertical span
$p_c$ = wind load on conductors
$w_c$ = weight of conductor/ft.
$W_i$ = weight of insulator string




Structure: H-Frame
Ruling span 800 ft.
Conductor: 795 26/7 ACSR
Loading district: Heavy
Voltage: 161 kV
No of Insulators: 10
Insulator Swing Condition:
Moderate wind (F=6 PSF at 0F)

Ø = 53.2°
$p_c$ = 0.554 lbs./ft
$w_c$= 1.0940 lbs./ft
T= 6,244 lbs
$W_i$= 135 lbs

Conductor dia: 1.108

$p_c = \frac{(d)(F)}{12}$

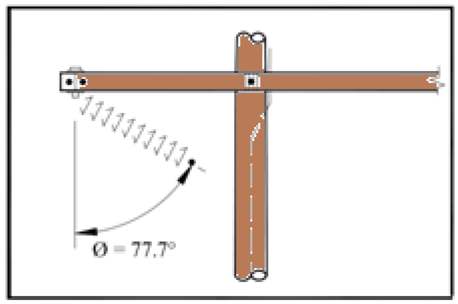
Figure 28

| θ = 0° | HS=200 | HS=400 | HS=800 | HS=1000 |
|---|---|---|---|---|
| sin θ/2 | 0 | 0 | 0 | 0 |
| a) (2)(T)(sin θ/2) | 0 | 0 | 0 | 0 |
| b) (HS)($p_c$) | 230.80 | 461.60 | 923.20 | 1154.00 |
| a + b = | 230.80 | 461.60 | 923.20 | 1154.00 |
| c) ($w_c$)(tan Ø) | 5.02 | 5.02 | 5.02 | 5.02 |
| d) (a + b)/c | 46.00 | 92.00 | 183.99 | 229.99 |
| e) $W_i$/(2)($w_c$) | 61.70 | 61.70 | 61.70 | 61.70 |
| d – e = VS | -15.70 | 30.30 | 122.29 | 168.29 |

| θ = 1° | HS=200 | HS=400 | HS=800 | HS=1000 |
|---|---|---|---|---|
| sin θ/2 | .008727 | .008727 | .008727 | .008727 |
| a) (2)(T)(sin θ/2) | 181.51 | 181.51 | 181.51 | 181.51 |
| b) (HS)($p_c$) | 230.80 | 461.60 | 923.20 | 1154.00 |
| a + b = | 412.31 | 643.11 | 1104.71 | 1335.51 |
| c) ($w_c$)(tan Ø) | 5.02 | 5.02 | 5.02 | 5.02 |
| d) (a + b)/c | 82.17 | 128.17 | 220.17 | 266.17 |
| e) $W_i$/(2)($w_c$) | 61.70 | 61.70 | 61.70 | 61.70 |
| d – e = VS | 20.47 | 66.47 | 158.47 | 204.47 |

| θ = 2° | HS=200 | HS=400 | HS=800 | HS=1000 |
|---|---|---|---|---|
| sin θ/2 | .017452 | .017452 | .017452 | .017452 |
| a) (2)(T)(sin θ/2) | 363.01 | 363.01 | 363.01 | 363.01 |
| b) (HS)($p_c$) | 230.80 | 461.60 | 923.01 | 1154.00 |
| a + b = | 593.81 | 824.61 | 1286.21 | 1517.01 |
| c) ($w_c$)(tan Ø) | 5.02 | 5.02 | 5.02 | 5.02 |
| d) (a + b)/c | 118.35 | 164.35 | 256.34 | 302.34 |
| e) $W_i$/(2)($w_c$) | 61.70 | 61.70 | 61.70 | 61.70 |
| d – e = VS | 56.65 | 102.65 | 194.64 | 240.64 |
| | | | | |

Ø = angle with the vertical through which insulator string swings.
θ = line angle
T = conductor tension
HS = horizontal span
VS = vertical span
$p_c$ = wind load on conductors
$w_c$ = weight of conductor/ft.
$W_i$ = weight of insulator string




Structure: H-Frame
Ruling span 800 ft.
Conductor: 795 26/7 ACSR
Loading district: Heavy
Voltage: 161 kV
No of Insulators: 10
Insulator Swing Condition:
High wind (F=12.5 PSF at 32F)

Ø = 77.7°
$p_c$ = 1.154 lbs./ft
$w_c$= 1.0940 lbs./ft
T= 10,400 lbs
$W_i$= 135 lbs

Conductor dia: 1.108

$p_c = \frac{(d)(F)}{12}$

Figure 29

# Summary

The primary purpose of this series of courses is to furnish engineering information for use in designing transmission lines. Good line design should result in high continuity of service, long life of physical equipment, low maintenance costs, and safe operation. These courses presents a generalized "how to" guide for the design of a high voltage transmission line.

This second course in transmission line design has addressed ground clearances, horizontal clearances, clearances from other live parts, and clearances to supporting structures are addressed.

This series includes five volumes. For the best understanding of the material, they should be studied in order.



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