RUS BULLETIN 1724E-200

DESIGN MANUAL FOR
HIGH VOLTAGE TRANSMISSION LINES

ELECTRIC STAFF DIVISION
RURAL UTILITIES SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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4. CLEARANCES TO GROUND, TO OBJECTS UNDER THE LINE AND AT CROSSINGS

4.1 General: Recommended design vertical clearances for RUS-financed transmission lines of 230 kV and below are listed in the Tables 4-1 through 4-3. These clearances exceed the minimum clearances calculated in accordance with the 2002 edition of the NESC. If the 2002 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 2002 NESC.

4.2 Assumptions

4.2.1 Fault Clearing and Switching Surges: Clearances in tables 4-1, 4-2, 4-3, and 5-1 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.

4.2.2 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 bulletin may be inadequate. Refer to the 2002 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.

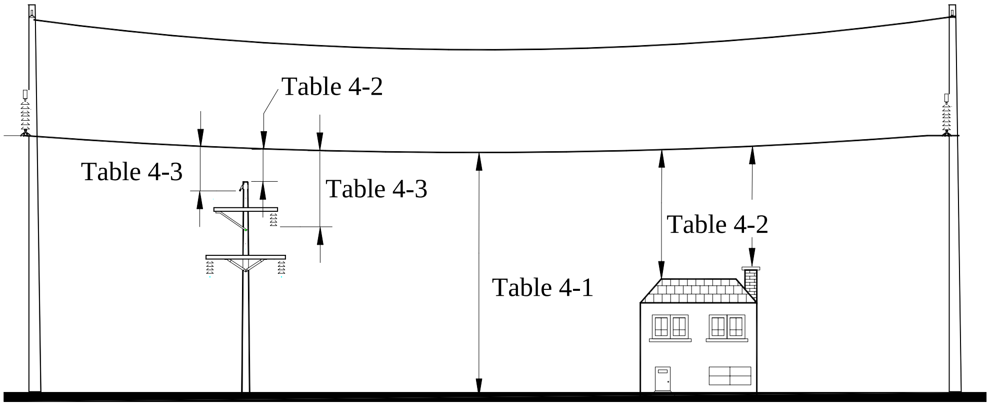


FIGURE 4-1: CLEARANCE SITUATIONS COVERED IN THIS CHAPTER

TABLE 4-2
RUS RECOMMENDED DESIGN VERTICAL CLEARANCES FROM OTHER SUPPORTING STRUCTURES (See Note B), BUILDINGS AND OTHER INSTALLATIONS (in 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.):

- 32°F, 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	7.7	8.2	9.1	9.6	10.0	11.4
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 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, 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		.00	.02	.05	.07	.08	.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.
(B) Other supporting structures include lighting supports, traffic signal supports, or a supporting structure of another line.
(C) If the line crosses a roadway, then Table 4-1, line 2.0 clearances are required.
(D) The NESC basic clearance is defined as the reference height plus the electrical component for open supply conductors up to 22 kV$_{LG}$.
(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.

In the span, phases of different circuits:

NESC Vertical Separation $= 0.75\left[\frac{16}{12} + \frac{.4}{12}(50 - 8.7)\right] + \frac{.4}{12}\left(kV_{LG1} + kV_{LG2} - 50\right)$

= 0.75(1.33+1.37) ft + (.4/12)(69.7+69.7-50) feet
= 2.03 ft. + 2.98 feet

NESC Vertical
Separation in the Span = 5.01 feet

RUS Recommended
Clearance = NESC Vertical Separation + RUS Adder
= 5.01 feet + .5 feet
= 5.51 feet (5.5 feet in RUS Table 6-1)

6.3 Maximum Span as Limited by Conductor Separation Under Differential Ice Loading Conditions

6.3.1 General: 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 paragraph 6.3.2 of 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.

6.3.2 Clearance Recommendations: 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 6-1. These vertical separations in span are recommended in cases where the horizontal separation between conductors (H) is greater than one foot (H ≥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 6-1. 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 1 foot significantly lessens the ice-jump problem. Figure 6-4 indicates the horizontal and vertical components of clearance and their relationship.

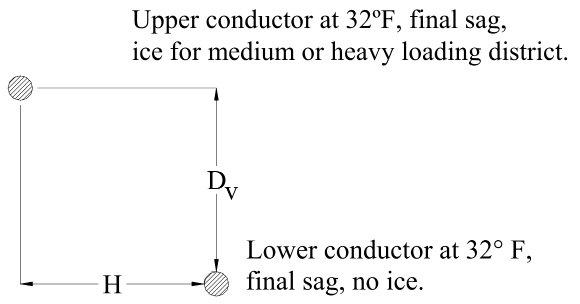


FIGURE 6-2: MINIMUM DISTANCE BETWEEN CONDUCTORS

6.3.3 Conditions Under Which Clearances Apply: RUS recommends that lines be designed so that clearances are considered with the upper conductor at 32°F, 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 32°F, 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 6-1).

6.4 Overhead Ground Wire Sags and Clearances: 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 RUS structures by keeping the sag of the OHGW at 60°F initial sag, no load conditions to 80 percent of the phase conductors under the same conditions.

6.5 Maximum Span as Limited by Galloping

6.5.1 The Galloping Phenomenon: 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.

6.5.2 Galloping Considerations in the Design of Transmission Lines: 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 6-3 and 6-4. 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.

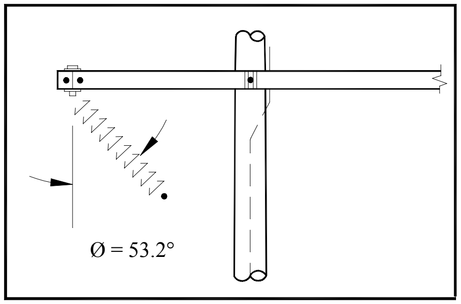
FIGURE 7-6: INSULATOR SWING CHART FOR EXAMPLE 7-9 (continued)

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

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: TH-10
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 0°F)**

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 7-6: INSULATOR SWING CHART FOR EXAMPLE 7-9 (continued)

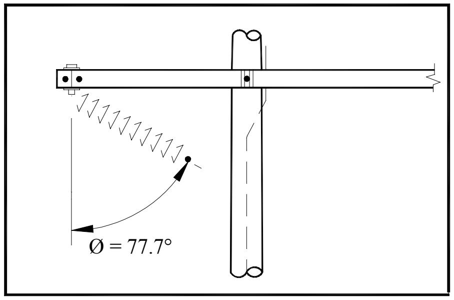
$$VS = \frac{(2)(T)(\sin \theta/2) + (HS)(p_c)}{(w_c)(\tan \phi)} - \frac{W_i}{(2)(w_c)}$$

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	

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

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	

Structure: TH-10
Conductor: 795 26/7 ACSR
Voltage: 161 kV
Insulator Swing Condition:

Ruling span 800 ft.
Loading district: Heavy
No of Insulators: 10
High wind
(F=12.5 psf at 32°F)

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

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

TRANSMISSION LINE DESIGN DATA SUMMARY

I. GENERAL INFORMATION

BORROWER:

DATE:

LINE IDENTIFICATION:

VOLTAGE		LENGTH	
TRANSMISSION	UNDERBUILD	TRANSMISSION	UNDERBUILD
___________kV	___________kV	___________mi .	___________mi.

TYPE OF TANGENT STRUCTURE:

BASE POLE: ____________HT. ____________CL

DESIGNED BY:

II. CONDUCTOR DATA

	TRANSMISSION	OHGW	UNDERBUILD	COMMON NEUTRAL
SIZE *(kcmil or in.)*				
STRANDING				
MATERIAL				
DIAMETER *(in)*				
WEIGHT *(lbs./ft.)*				
RATED STRENGTH *(lbs.)*				

III. DESIGN LOADS (Wires)

		TRANSMISSION *(lbs./ft.)*	OHGW *(lbs./ft.)*	UNDERBUILD *(lbs./ft.)*	COMM.NEUTRAL *(lbs./ft.)*
NESC:__________________LOADING DISTRICT					
a. ICE: _________in.	Vertical.				
b. WIND ON ICED COND. ____psf	Transverse				
c. CONSTANT K ___________	Resultant + K				
HEAVY ICE*(NO WIND)* ______in.	Vertical.				
HIGH WIND*(NO ICE)* ______psf	Transverse				
OTHER					

IV. SAG & TENSION DATA

SPANS AVERAGE*(EST)* ___________ft MAXIMUM*(EST)* ___________ft.. RULING*(EST)* ____________ft.

SOURCE OF SAG-TENSION DATA:	TRANSMISSION		OHGW		UNDERBUILD		COMM.NEUTRAL	
TENSIONS (*% RATED STRENGTH*)	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
NESC								
a. UNLOADED (0° 15° 30°) _____°F								
b. LOADED (0° 15° 30°) _____°F								
MAXIMUM ICE 32 °F								
HIGH WIND (NO ICE) _____°F								
UNLOADED LOW TEMPERATURE _____°F								
SAGS *(FT)*								
NESC DISTRICT LOADED _____°F								
UNLOADED HIGH TEMP(120°FOR OHGW &U.B.)___°F								
MAXIMUM ICE 32°F								
LOADED 1/2” ICE, NO WIND 32°F								

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT:____

CLEARANCES IN FEET	RAILROADS	HIGHWAY	CULTIVATED FIELDS			ADDITIONAL . ALLOWANCE
TRANSMISSION						
UNDERBUILD						

VI. RIGHT OF WAY

WIDTH _____________ FT. *(MIN.)* _____________ FT. *(MAX.)*

APPENDIX E

WEATHER DATA