United States
Department of
Agriculture

Rural
Electrification
Administration

REA Bulletin 62-1

Design Manual for High Voltage Transmission Lines

Revised August 1980

FOREWORD

This revision of REA Bulletin 62-1, "Design Manual for High Voltage Transmission Lines," provides engineering personnel with comprehensive information on wood pole transmission lines through 230 kV. This publication is an excellent reference of fundamental engineering guidelines, minimum requirements and basic recommendations. The subject area includes structural and electrical aspects of line design as well as explanations and illustrations.

Numerous cross-references and examples, along with the latest in design philosophy, should be of great benefit to all engineers and engineering firms, and particularly helpful to relatively inexperienced engineers beginning careers in transmission line design.

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Index:
DESIGN, SYSTEM:
Design Manual for High Voltage Transmission Lines
TRANSMISSION FACILITIES:
Design Manual for High Voltage Transmission Lines

REA BULLETIN 62-1

DESIGN MANUAL FOR

HIGH VOLTAGE TRANSMISSION LINES

ENGINEERING STANDARDS DIVISION

RURAL ELECTRIFICATION ADMINISTRATION

U.S. DEPARTMENT OF AGRICULTURE

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TABLE OF CONTENTS

LIST OF TABLES

This is an extensive revision of the issue dated September 1972 (Reprinted September 1975). The principal changes consist of reorganizing and expanding the publication, updating it to conform to the 1977 edition of the National Electrical Safety Code* (NESC), limiting the scope to line designs of 230 kV and below, and inserting metric quantities. An extensive appendix of useful data has also been included. Information previously covered on EHV voltages will be included in other publications.

*American National Standards Institute (ANSI), Standard C2. Throughout this publication the National Electrical Safety Code shall be referred to as the NESC.

I. GENERAL

A. Purpose and Scope

The primary purpose of this bulletin is to furnish engineering information for use in designing wood pole-type transmission lines of 230 kV and below. It is assumed that standard REA structures will be used in conjunction with the data in this bulletin. Where nonstandard construction is used, factors not covered herein may have to be considered and modification in the design criteria given in this bulletin may be appropriate.

Since the REA program is national in scope, it is necessary that its standards be adaptable to various conditions and local requirements. The engineer should investigate local weather information, soil conditions, operation of existing lines, local regulations, environmental requirements and evaluate all known pertinent factors in arriving at design recommendations. It is desirable to keep structures simple and low in first cost. Good line design should result in high continuity of service, long life of physical equipment, low maintenance cost, safe operation and acceptability from an environmental standpoint.

B. National Electrical Safety Code

Much of the material in this bulletin is based on the requirements of the 1977 edition of the National Electrical Safety Code*. It is REA's policy that all transmission lines meet as a minimum the requirements for Grade B construction as defined in the NESC. Since, however, the NESC is a safety code and not a design guide, much additional information and design criteria are given in this bulletin.

C. Responsibility

The responsibility of the borrower is to provide or obtain all engineering services necessary for sound and economical design. Due concern for the environment in all phases of construction and cleanup should be exercised.

D. Environmental Criteria

REA borrowers must follow the provisions of REA Bulletin 20-21, "National Environmental Policy Act". This publication references

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*American National Standards Institute (ANSI), Standard C2. Throughout this publication the National Electrical Safety Code shall be referred to as the NESC.

additional directives and instructions relative to the protection of the environment.

It is recommended that the criteria in the following publication be followed in the design, construction and operation of transmission systems.

> "Environmental Criteria for Electric Transmission Systems" - Issued jointly by the Secretary of Agriculture and the Secretary of Interior.

II. TRANSMISSION LINE DOCUMENTATION

A. Purpose

The purpose of this chapter is to provide information regarding design documentation for REA-financed transmission lines.

B. General

Approval requirements for transmission line designs are outlined in REA Bulletin 40-6, "Construction Methods and Purchase of Materials and Equipment." Engineering design information includes design data, sample calculations, and plan-profile.

C. Design Data Summary

Sample Form 265, Transmission Line Design Data Summary, which is included in Appendix A, has been prepared to aid in the presentation of the design data summary. Where design data is required by Bulletin 40-6, the design data summary, or equivalent, will be expected. A suggested outline of information to be included in a design data book necessary to support the design data summary, is also given in Appendix A. Generally, all the information indicated should be provided; however, some judgment should be used in including more or less information as appropriate.

D. Plan-Profile Sheets

Where plan-profile sheets are required to be submitted to REA, it is strongly recommended that if the line is of considerable length, that one should not wait until all the sheets are completed before submitting them, but rather that they be submitted as they are completed in reasonable minimum length increments (16-48 km - 10-30 miles - minimum).

III. TRANSMISSION LINE LOCATION AND ENGINEERING SURVEY AND RIGHT-OF-WAY ACTIVITIES

A. Route Selection

Transmission line routing requires thorough investigation and study of several different routings to assure that the most practical route is selected, taking into consideration both the environmental criteria and cost of construction.

In order to select and identify environmentally acceptable transmission line routes, it is necessary to identify all requirements imposed by state and federal legislation. Environmental considerations are generally outlined in REA Bulletin 20-21 and the joint USDA-USDI publication "Environmental Criteria for Electric Transmission Systems." State public utility commissions and departments of natural resources may also designate avoidance and exclusion areas which must be considered in the routing process.

Maps are developed in order to identify the avoidance and exclusion areas and other requirements which might impinge on the line route. Ideally, all physical and environmental considerations should be plotted on one map so that the engineer can easily use this information for route evaluation. However, when there is a large number of areas to be identified, more than one map may have to be prepared for clarity. The number of constraint maps which the engineer must refer to in order to analyze routing alternatives should be kept to a minimum.

Typical physical, biological and human environmental considerations are listed in Table III-1. Suggested sources for such information are also included in the table. The order in which the considerations appear is not intended to imply any priority.

For large projects, photogrammetry is contributing substantially to route selection and the designing of lines. The locating of preliminary corridors is improved when high altitude aerial photographs or satellite imagery are used to rapidly and accurately inventory existing land use. Once the preferred and alternate corridors have been selected (primarily from land use), the engineer should consult geological survey maps, county soil, plat and road maps in order to produce small scale maps which will be used to identify additional obstructions and considerations for the preferred transmission line.

On most projects, the line lengths are short and benefits of

TABLE III-1

LINE ROUTING CONSIDERATIONS

	Sources
Physical	
o Highways	USGS, State & County Highway Department Maps
o Streams, Rivers, Lakes	USGS, Army Corps of Engineers, Flood Insurance Maps (H.E.W.)
o Railroads	USGS, Railroad
o Airstrips	USGS, Federal Aviation Administration
o Topography (Major Ridge Lines, Floodplains, etc.)	USGS, Flood Insurance Maps (H.E.W.), Army Corps of Engineers
o Transmission Lines	USGS, Local Utility System Maps
Biological	
o Woodlands	USGS, USDA - Forest Service
o Wetlands	USGS, Army Corps of Engineers, U.S. Fish and Wildlife Service
o Waterfowl, Wildlife Refuge Areas, Endangered Species & Critical Habitat Areas	USDI - U.S. Fish & Wildlife Service, State Fish and Game Office
Human Environmental	
o Rangeland o Cropland o Urban Development o Industrial Development o Mining Areas o Recreation or Aesthetic Areas	USGS Aerial Survey, Satellite Mapping, County Planning Agencies, State Planning Agencies, State Soil Conservation Service, Mining Bureau, U.S. Bureau of Land Management
o Prime or Unique Farmland	USGS Soil Surveys, USDA-Soil Conservation Service, State Department of Agriculture, County Extension Agent
o Irrigation (Existing & Potential)	Irrigation district maps, applications for electrical service, aerial survey, state departments of agriculture and natural resources, water management districts
o Historic and Archeological Sites	National Register of Historic Sites (existing), State Historic Preservation Officer (proposed), State Historic and Archeological Societies
Other	
o Federal, State and County Controlled Lands	USGS, State Maps, U.S. Park Service, Bureau of Land Management, State Department of Natural Resources, County Maps, etc.

high altitude photograph and satellite imagery quickly diminish. The engineer should consult other entities which may have previously used aerial photographs. Such entities include county planning agencies, pipeline companies, county highway departments, and land development corporations. A preliminary field survey should also be made to locate possible new features which do not appear on USGS maps of aerial photographs.

Final route selection, whether it be a large or small project, is a matter of judgment and requires sound evaluation of divergent requirements, including costs of easements, cost of clearing, ease of maintenance as well as what effect the line may have on the environment. Public relations and public input are necessary in the corridor selection and preliminary survey stages.

B. Reconnaissance and Preliminary Survey

Once the best route has been selected and a field examination made, aerial photos of the corridor should be reexamined to determine what corrections will be necessary for practical line location. Certain carefully located control points should then be established from an aerial reconnaissance.

Once these control points have been made, a transit line using stakes with tack points should be laid in order to fix the alignment of the line. A considerable portion of this preliminary survey usually turns out to be the final location of the line.

C. Right-of-Way

A right-of-way agent (or Borrower's representative) should accompany or precede the preliminary survey party in order to acquaint the property owners with the purpose of the project, the survey, and to secure permission to run the survey line. He should also be responsible for determining property boundaries crossed and maintaining good public relations. He should avoid making any commitments for individual pole locations before structures are spotted on the plan and profile sheets. However, if the landowner feels particularly sensitive about placing a pole in a particular location along the alignment, then the agent should deliver that information to the engineer, and every reasonable effort should be made by the engineer to accomodate the landowner.

As the survey proceeds, a right-of-way agent should begin a check of the records for faulty titles, transfers, joint owners, foreclosed mortgages, etc., against the ownership information ascertained from the landowners. This phase of the work requires close coordination between the engineer and the right-of-way agent. The overall importance of this phase is for the right-of-way agent to deliver to the engineer important information he has gained as a field person. The right-of-way agent at this time must also be thinking of any access easements necessary to construct the line. Permission may also have to be obtained to cut danger trees located outside, or for that matter, inside the right-of-way. Costly details, extravagent misuse of survey time and effort, and misunderstanding on the part of the landowners are to be avoided.

D. Line Survey

Immediately after the alignment of a line has been finalized to the satisfaction of both the engineer and the borrower, a survey should be made to map the route of the line. The results of the survey will be plan-profile drawings which will be used to spot structures. The accuracy of the survey should be to third order.

Long corridors can usually be mapped by photogrammetry at less cost than equivalent ground surveys. The photographs will also contain information and details which could not otherwise be discovered or recorded. Aerial survey of the corridor can be done rapidly, but the proper conditions for photography occur only on a comparatively few days during the year. In certain areas, photogrammetry is impossible. It cannot be used where high conifers conceal the ground or in areas such as grass-covered plains that contain no discernible objects. The necessary delays and overhead costs inherent in air mapping usually prevent their use for short lines.

When using aerial photogrammetry to develop plan-profile drawings, proper horizontal and vertical control should first be established in accordance with accepted methods. From a series of overlapping aerial photographs, a plan of the transmission line route can be made. The plan may be in the form of an orthophoto or it may be a planimetric map (see Chapter X). The overlapping photos also enable the development of profile drawings. The tolerance of plotted ground elevations to the actual ground profile will depend on photogrammetric equipment, flying height, and accuracy of control points.

If the use of photogrammetry for topographic mapping is not applicable for a particular line, then transit and tape or various electronic instruments for measuring distances should be used to make the route survey. This survey will generally consist of placing stakes at 30.5 meter (100 foot) intervals with the station measurement suitably marked on the stakes. It will also include the placement of intermediate stakes to note the station at property lines and reference points as required. These stakes should be aligned by transit between the hub stakes set on the preliminary survey. The survey party shall keep notes showing property lines and topographic features of obstructions that would influence structure spotting. Colored ribbon or strips of cloth should be attached at all fence crossings and to trees at regular intervals along the route wherever possible, so as to facilitate the location of the route by others.

As soon as the horizontal control survey is sufficiently advanced, a level party should start taking ground elevations along the center line of the survey. Levels should be taken at every 30.5 meter (100 foot) stations and at all intermediate points where breaks in the ground contour appear. Wherever the ground slopes more than 10 percent across the line of survey, side shots should be taken for a distance of at least 3 meters (10 feet) beyond the outside conductor's normal position. These elevations to the right and left of the center line should be plotted as broken lines. These broken lines represent sidehill profiles and are necessary in spotting structures to assure proper ground clearance under all conductors, and proper pole lengths and setting depths for multiple-pole structures.

E. Drawings

As soon as the route survey has been obtained, the plan and profile should be prepared. The information on the plan and profile should include the alignment, stationing, calculated courses, fences, trees, roads, ditches, streams and swamps. The vertical and plan location of telecommunications, transmission and other electric lines should be included since they effect the proposed line. Also, to be shown are railroads and river crossings, property lines, with the names of the property owners, along with any other features which may be of value in the right-of-way acquisition, design, construction and operation of the line. Chapter X discusses structure spotting on the plan-profile.

Structure spotting should begin after all of the topographic and level notes are plotted on the plan and profile sheets. Prints of the drawings should be furnished to the right-of-way agent for checking property lines and for recording easements. One set of prints certified as to the extent of permits, easements, etc., that have been secured by the borrower should be returned to the engineer. Prints of plan and profile drawings, with structure spotting complete, should be reviewed and approved by REA in accordance with Chapter II.

F. Rerouting

During the final survey, occasions may arise where considerations should be given to rerouting small segments of the line due to the inability of the right-of-way agent to satisfy the demands of a property owner. In such instances, the engineer should ascertain the costs and public attitudes towards all reasonable alternatives. The engineer should then decide to either satisfy the property owner's demands, relocate the line, initiate condemnation proceedings, or take other action as appropriate.

G. Clearing Right-of-Way

The first actual work to be done on a transmission line is usually clearing the right-of-way. When clearing, it is important that the environment be considered. It is also important that the clearing be done in such a manner that will not interfere with the construction, operation or maintenance of the line. In terrain having heavy timber, prior partial clearing may be desirable to facilitate surveying. Preferably, all right-of-way for a given line should be secured before starting construction.

See Chapter V for a discussion of right-of-way width.

H. Responsibility

The engineer is responsible to coordinate right-of-way clearing, structure staking and construction of the project in such a manner that no unnecessary delays will result.

I. Permits, Easements, Licenses, Franchises, and Authorizations

The following is a list of permits, easements, licenses, franchises, and authorizations that may be necessary.

1. Private property: Easement from owner and permission to cut danger trees.

2. Railroad: Permit or agreement.

3. Highway: Permit from state.

4. Other public bodies: Authorization.

5. City, County or State: Permit.

6. Joint and common use pole: Permit or agreement.

7. Wire crossing: Permission of utility.

8. Navigable stream: Permit of U.S. Army Corps of Engineers.
9. U.S. Government property: Permit.
10. Airport and airways: Coordinate with Federal Aviation Agency.
11. Federal Energy Regulatory Commission, DOE: License.
12. U.S. Forest Service: Permit.
13. National Park Service: Permit.
14. Indian Tribal Reservation: Easement.

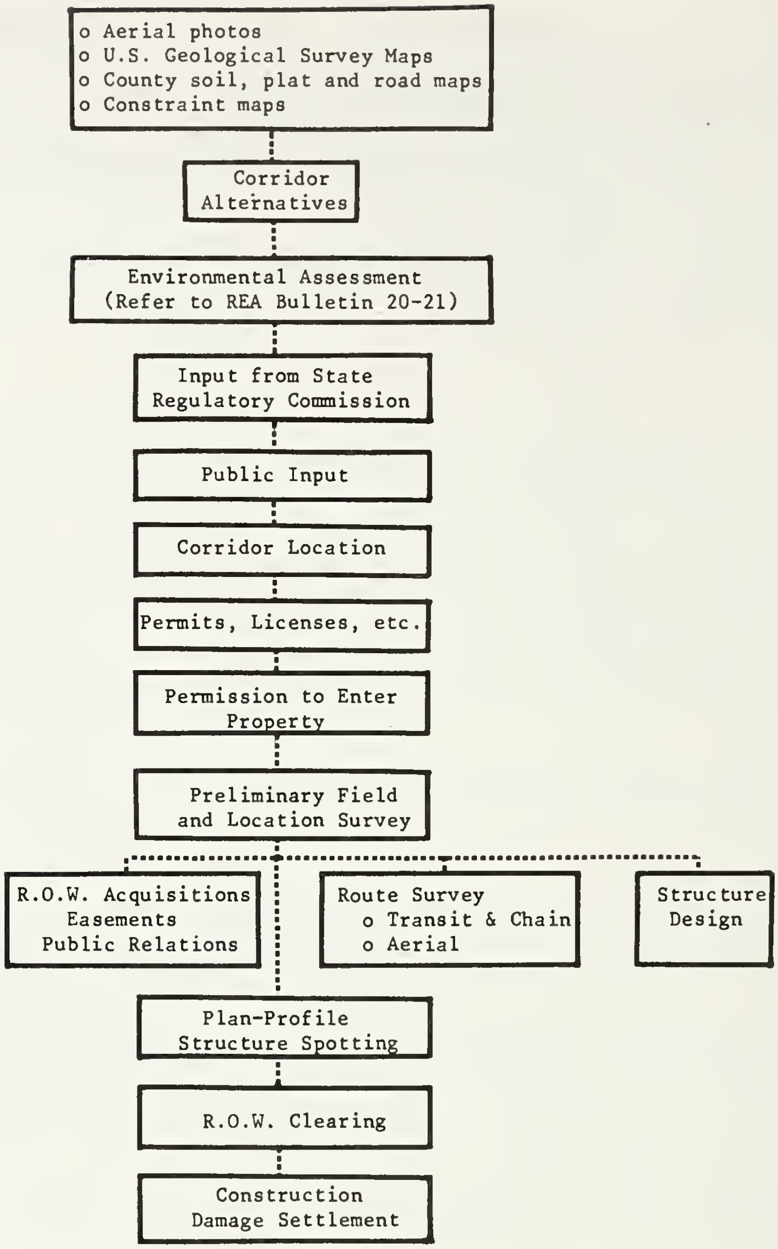


FIGURE III-1

FLOW CHART OF RIGHT-OF-WAY ACTIVITIES

1. Depending on the State, input may occur at different points in the flow diagram.

2. Preliminary cost analysis, structure and conductor selection occurs previously (not shown).

SAMPLE SPECIFICATION FOR PREPARATION OF PROFILE AND MAPPING OBTAINED BY AERIAL PHOTOGRAPHY METHODS FOR TRANSMISSION LINES

Item I. Aerial Photography

Aerial photography shall be suitable for use in the preparation of proposed items and data to be furnished. Negative scale shall be 1" = ____' and shall be exposed using a certified precision aerial camera.

Item II. Contact Prints

One set of contact prints shall be furnished at a scale of 1" = ____' and shall provide stereo coverage of the entire proposed route.

Item III. Photo Control Surveys

A. A closed circuit traverse shall be established using angle measuring instruments reading directly to one second and electronic distance measuring instruments. The resultant accuracies shall be suitable for use in computing distances and angles for the field establishment of centerline using targeted points. All traverses shall close within third order or better before adjustment.

B. Rebars shall be set in the ground and referenced near locations where the centerline crosses public roads and other public rights of way. Prior to aerial photography, targets shall be placed over the rebars.

C. All vertical control shall be based on mean sea level datum and all level circuits shall close within third order or better before adjustments. All level lines to establish elevations shall be closed in accordance with accepted methods.

Item IV. Planimetric Mapping

A. Planimetric pencil drafted manuscripts shall be prepared 500' either side of the tentative centerline unless otherwise noted by ___________________________. Manuscripts shall show the location of roads, fences, timber, drainage features, railroads, buildings and other pertinent features which may affect centerline location. Apparent land corners shall be shown where visible in the photographs. The manuscripts shall be to a scale of 1" = ______.

B. An area within a 500' radius of each major Point of Inflection (P.I.) and river location shall show contours at intervals of 5'.

Item V. Profile

After completion of the planimetric mapping, blue line copies of the pencil manuscript will be sent to ______________________ for final location of centerline. Profiles shall be read along the centerline and 15' left and right of centerline at intervals of 1" = ___ft.

The photogrammetric profile shall be within ± ___ft. of true ground profile.

Item VI. Drafting

A. Plan profile sheets shall be prepared in the form of ink tracings on "Mylar" base material to a scale of 1" = ___ft. horizontal and 1" = ___ft. vertical.

B. Sheets shall conform to format furnished by ______________ __________. Sheets shall contain 2000' overlap with adjoining sheets. All lettering shall be ___ size Leroy or smaller.

C. All sectional information, highways, railroads, rivers and major transmission lines will be identified. All P.I.'s will be shown with a 1/8" circle.

D. The profile view shall show stations at 1000' intervals on the vertical lines. The elevation shall be shown at 100' intervals on the horizontal lines at both ends of the drawing.

E. The following information relative to each pole line crossed by centerline:

1. Its station.
2. Distance from centerline to first pole on either side of centerline.
3. The scaled angle the pole line makes with the centerline.
4. The elevation of the tops of poles one span on each side of centerline.
5. Number of wires crossed.
6. Elevation of top wire at highest elevation

within 20' on each side of centerline.
Temperature at which measurement was taken.

F. The following information relative to each railroad right-of-way crossed:

1. *The station at which the centerline crosses the centerline of each track. The number of tracks being crossed shall also be shown.*

2. *Elevation of top of the highest rail crossed.*

3. *The scaled angle the rails make with the centerline.*

4. *Distance and direction from centerline to nearest signal tower, bridge, culvert, or other railroad landmark.*

5. *Name of railroad crossed.*

G. The station at the point of crossing of all fence lines and crop lines. Show location by symbol in both plan and profile views.

H. Calculated stationing and grid coordinate of each angle point in the centerline and the calculated magnitude of each angle.

I. Location and direction of flow of any ditch wash or creek that is on the right-of-way strip although it may not cross the centerline.

J. Calculated station and identification of all hubs, iron pipes, and iron rods installed in the centerline.

K. Location and identification on the right-of-way strip of swamps, rock formations, or other unusual ground conditions that show up in the aerial pictures.

L. Location of all trees.

M. The centerline shall be dimensioned on the plan view by scale to the nearest quarter section line, section line, or fence line crossed.

N. Show the location and identify all apparent section corners (outlined and numbered by township and range), township lines, municipality limits, and county lines through which the right-of-way passes.

O. The profile shall show P.I.'s by a triangular symbol with 1/4" base and 1/2" height.

Item VII. General

A. All distances determined for control surveys and centerline stationing shall be based on ________________ Plane Coordinate System.

B. Copies of reference notes of target points, traverse and vertical control shall be furnished.

Item VIII. Items to be Delivered to the Owner

A. One (1) set stereo contact prints.

B. List of coordinates, stations and angles of all P.I.'s.

C. Two (2) sets of bluelines of pencil manuscripts at a scale of 1" = ____ft.

D. One (1) set of final drafted plan and profile sheets at a scale of 1" = ____ft. horizontal, 1" = ____ft. vertical.

IV. CLEARANCES TO GROUND, TO OBJECTS UNDER THE LINE, AND TO CROSSING CLEARANCES

The minimum vertical clearances for REA-financed AC transmission line designs of 230 kV and below are listed in the tables below. These clearances meet or exceed the minimum clearances given in the 1977 edition of the NESC. If the 1977 edition has not been adopted in a particular locale, the clearances and the conditions found in this chapter should be reviewed to insure that they meet the more stringent of the applicable requirements.

Clearances less than those specified in the tables shall not be used without prior REA approval.

A. Assumptions

The clearances given in the tables below (unless otherwise stated) are based on the following assumptions:

1. Fault Clearing

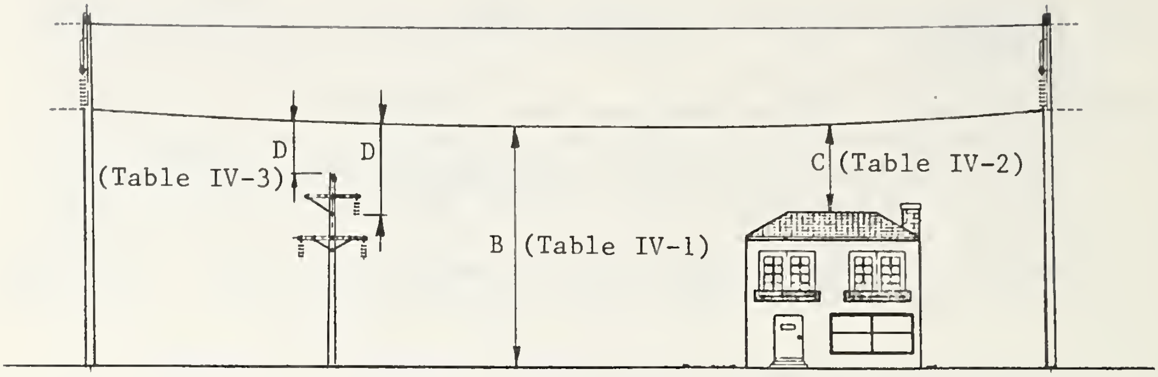
The clearances apply only for lines that are capable of automatically clearing line-to-ground faults.

2. Voltage

Listed below are nominal transmission line voltages and the assumed maximum allowable operating voltage for each level. If the expected operating voltage is greater than the value given below, the clearances in this bulletin may be inadequate. Refer to the 1977 edition of the NESC for guidance.

Nominal Line-to-Line Voltage (kV)	Maximum Line-to-Line 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.



Letters refer to sections in this chapter covering clearance indicated.

FIGURE IV-1: CLEARANCE SITUATIONS COVERED IN THIS CHAPTER

B. Minimum Vertical Clearance of Conductors

The required minimum vertical clearances under various conditions are given in Table IV-1.

1. Conditions Under Which Clearances Apply

The clearances apply to a conductor at final sag for the condition below yielding the greatest sag for the line.

a. A conductor temperature of $0^{\circ}C$ ($32^{\circ}F$), no wind, with the radial thickness of ice for the applicable loading district;

b. A conductor temperature of $75^{\circ}C$ ($167^{\circ}F$)*;

c. Maximum design conductor temperature, no wind, under emergency loading conditions**. For high voltage bulk transmission lines of major importance to the system, consideration should be given to the use of $100^{\circ}C$ ($212^{\circ}F$) as the maximum design conductor temperature.

*A lower temperature may be considered where justified by a qualified engineering study. Under no circumstances should a design temperature be less than $49^{\circ}C$ ($120^{\circ}F$).

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

2. Altitude Greater than 1000 Meters (3300 Feet)

If the altitude of a transmission line or portion thereof is greater than 1000 meters (3300 feet), an additional clearance as indicated in Table IV-1 must be added to the base clearances given.

3. Spaces and Ways Accessible to Pedestrians Only

These 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.

4. 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 IV-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. For lines qualifying to be built to this requirement, it is strongly recommended that if it is considered likely a driveway will be built somewhere under the line, or that loaded vehicles may be crossing under the line, the ground clearance for the line should be based on clearance over driveways. Heavily traveled rural roads should be considered as being in urban areas.

5. Tall Vehicles

In those areas where it can be normally expected that vehicles with an overall operating height greater than 4.3 meters (14 feet) will pass under the line, it is recommended that consideration be given to increasing the clearances given in Table IV-1 by the amount by which the vehicle's operating height exceeds 4.3 meters (14 feet).

6. Clearances Over Water

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

TABLE IV-1

MINIMUM VERTICAL CLEARANCE OF
CONDUCTORS-TC-GROUND IN METERS (FEET)

CLEARANCE REQUIRED WHEN CONDUCTORS CROSS OVER:	Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	16i	230
1. Railroad tracks	9.4 (31.0)	9.7 (31.7)	9.8 (32.1)	10.0 (32.6)	10.4 (34.0)
2. Roads, streets, alleys, parking lots or drive-ways	7.0 (23.0)	7.2 (23.7)	7.4 (24.1)	7.5 (24.6)	7.9 (26.0)
3. Land that may be traversed by vehicles such as cultivated, grazing, forest, orchards, etc. (B)	7.0 (23.0)	7.2 (23.7)	7.4 (24.1)	7.5 (24.6)	7.9 (26.0)
4. Spaces and ways accessible to pedestrians only (C)	5.5 (18.0)	5.7 (18.7)	5.9 (19.1)	6.0 (19.6)	6.4 (21.0)
5. Water areas not suitable for sailboating or where sailboating is not per-mitted (E)	5.5 (18.0)	5.7 (18.7)	5.9 (19.1)	6.0 (19.6)	6.4 (21.0)
6. Water areas suitable for sailboating including lakes, ponds, reservoirs, rivers, streams, and canals with unobstructed surface area of (D) (E)					
a. Less than 8.09 ha (A) (20 acres)	7.0 (23.0)	7.2 (23.7)	7.4 (24.1)	7.5 (24.6)	7.9 (26.0)
b. 8.09 to 80.9 ha (20 to 200 acres)	9.4 (31.0)	9.7 (31.7)	9.8 (32.1)	10.0 (32.6)	10.4 (34.0)
c. 80.9 to 809.4 ha (200 to 2000 acres)	11.3 (37.0)	11.5 (37.7)	11.6 (38.1)	11.8 (38.6)	12.2 (40.0)
d. Over 809.4 ha (2000 acres)	13.1 (43.0)	13.3 (43.7)	13.5 (44.1)	13.6 (44.6)	14.0 (46.0)
7. Land and water areas for rigging and launching sailboats (E)	Clearance above ground shall be 1.5 meters (5 feet) greater than in No. 6 above for the water area served by the launching site.				

TABLE IV-1

MINIMUM VERTICAL CLEARANCE OF
CONDUCTORS-TO-GROUND IN METERS (FEET), CONT.

CLEARANCE REQUIRED WHEN CONDUCTORS RUN ALONG THE TRAVELED WAY OR ADJACENT LAND AND WITHIN THE LIMITS OF THE RIGHT-OF-WAY BUT DO NOT OVERHANG:	Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	161	230
8. Roads in rural districts (F)	6.4 (21.0)	6.6 (21.7)	6.8 (22.1)	6.9 (22.6)	7.3 (24.0)
9. Streets or alleys in urban districts	7.0 (23.0)	7.2 (23.7)	7.4 (24.1)	7.5 (24.6)	7.9 (26.0)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:					
Additional meters of clearance per 1000 meters of altitude above 1000 meters (same value also represents additional feet of clearance per 1000 feet of altitude above 3300 feet)	0	.02	.04	.05	.09

Notes:

(A) 1 hectare = .4047 acres.

(B) These clearances are for land traversed by vehicles and equipment whose overall operating height is less than 4.3 meters (14 feet).

(C) Areas accessible to pedestrians only are areas where vehicular traffic is not encountered or reasonably anticipated. Land subject to highway right-of-way maintenance equipment shall not be considered as being accessible to pedestrians only.

(D) The surface area and corresponding clearance shall be based upon the uncontrolled 10 year flood level, or for controlled impoundments, upon the design high water level. The clearance over rivers, streams, and canals shall be based upon the surface area of the largest 1.6 kilometer (1 mile) long segment which includes the crossing and which has the greatest surface area. The clearance over a canal or similar waterway providing 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 has issued a crossing permit, the clearances of that permit shall govern.

(F) Heavily traveled roads, even if they are located in rural areas, should be considered as being in urban areas.

7. Clearances for Sag Templates

Sag templates used for spotting structures on a plan and profile sheet should be cut to allow at least .3 meters (1 foot) extra clearance than given in Table IV-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 0.3 meters (1 foot) allowed, appropriate additional clearance should be provided.

C. Minimum Vertical Clearance of Conductors to Objects Under the Line (not including conductors of other lines)

The required minimum vertical clearances to various objects under a transmission line are given in Table IV-2.

1. Conditions Under Which Clearances Apply

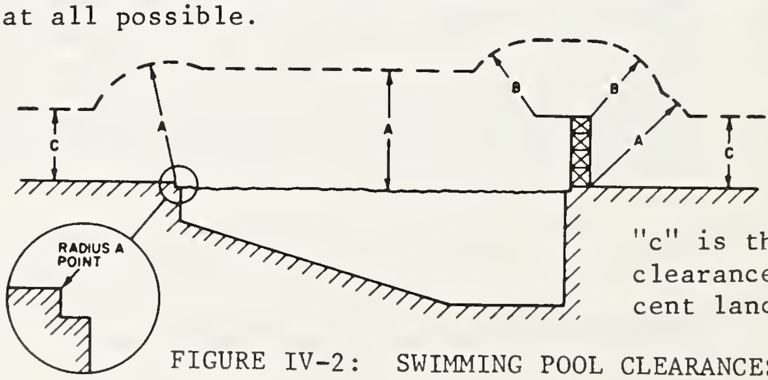
The clearances in the table must be met if the horizontal clearance requirements to the same objects are not met (see Chapter V). The clearances in the table apply under the same loading and temperature conditions as outlined in section IV.B.1 above.

2. Lines Over Buildings

Although clearances for lines passing over buildings are given, it is recommended that lines not pass directly over a building if it can be at all avoided.

3. Lines Over Swimming Pools

Clearances over swimming pools are given for reference purposes only. Lines should not pass over or within 7.6 meters (25 feet) of the edge of a swimming pool if at all possible.



"c" is the vertical clearance over adjacent land.

FIGURE IV-2: SWIMMING POOL CLEARANCES

TABLE IV-2

MINIMUM CONDUCTOR CLEARANCES
TO OBJECTS UNDER LINES, METERS (FEET)
(Applies only to lines with
automatic ground fault relaying)

CLEARANCES WHEN CONDUCTORS CROSS OVER:	Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	161	230
1. Building roofs or projections not accessible to pedestrians	4.0 (13.0)	4.2 (13.7)	4.3 (14.1)	4.5 (14.6)	4.9 (16.0)
2. Building roofs, balconies or projections accessible to pedestrians	5.5 (18.0)	5.7 (18.7)	5.9 (19.1)	6.0 (19.6)	6.4 (21.0)
3. Signs, chimneys, radio & television antennas, tanks, bridges and other installations not classified as buildings or bridges.	3.4 (11.0)	3.6 (11.7)	3.7 (12.1)	3.9 (12.6)	4.3 (14.0)
4. Lighting supports, traffic signals, or a supporting structure of another line	2.5 (8.0)	2.7 (8.7)	2.8 (9.1)	2.9 (9.6)	3.4 (11.0)
5. Swimming pools Clearance A*	8.6 (28.0)	8.8 (28.7)	8.9 (29.1)	9.0 (29.6)	9.5 (31.0)
Clearance B*	5.8 (19.0)	6.0 (19.7)	6.2 (20.1)	6.3 (20.6)	6.7 (22.0)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:					
Additional meters of clearance per 1000 meters of altitude above 1000 meters (same value also represents additional feet of clearance per 1000 feet of altitude above 3300 feet.)	0	.02	.04	.05	.09

*See Figure IV-2.

D. Minimum Vertical Clearance Between Conductors Where One Line Crosses Over or Under Another

The required minimum vertical clearances between conductors when one line crosses another are given in Table IV-3. When a transmission line is crossed over that is known to have ground fault relaying, the values from section 4 of the table should be used. If it is not known whether the transmission line crossed over has ground fault relaying, the values from section 5 of the table should be used. The clearances given should be maintained at the point where the conductors cross, regardless of where on the span the point of crossing is.

1. Conditions Under Which Clearances Apply

a. Upper Conductor

The clearances apply for an upper conductor at final sag for that condition below that yields the greatest sag for the line in question.

(1) A conductor temperature of $0^{o}C$ ($32^{o}F$), no wind, with a radial thickness of ice for the loading district concerned.

(2) A conductor temperature of $75^{o}C$ ($167^{o}F$)*.

(3) Maximum conductor temperature, no wind, under emergency loading conditions**. The same maximum temperature used for vertical clearance to ground should be used.

b. Lower Conductor

The lower conductor sag to be used in conjunction with Table IV-3 is the initial sag at $16^{o}C$ ($60^{o}F$), no wind. If such a sag value is not available, the best available estimates of such sags should be used.

2. Altitude Greater than 1000 Meters (3300 Feet)

If the altitude of the crossing point of the two lines is greater than 1000 meters (3300 feet), additional clearance as indicated in Table IV-3 must be added to the base clearance given.

*See first note on Page IV-2.
**See second note on Page IV-2.

TABLE IV-3

MINIMUM VERTICAL CLEARANCE IN METERS (FEET) BETWEEN CONDUCTORS WHERE THE CONDUCTORS OF ONE LINE CROSS OVER THE CONDUCTORS OF ANOTHER WHERE UPPER CONDUCTOR HAS GROUND FAULT RELAYING

CLEARANCE REQUIRED BETWEEN UPPER AND LOWER LEVEL CONDUCTORS:	Upper Level Conductor (A) Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	161	230
Lower Level Conductor					
1. Communication lines	2.2 (7.0)	2.4 (7.7)	2.5 (8.1)	2.6 (8.6)	3.1 (10.0)
2. Overhead ground wire (B)	1.5 (5.0)	1.7 (5.7)	1.9 (6.1)	2.0 (6.6)	2.5 (8.0)
3. Distribution conductors	1.5 (5.0)	1.7 (5.7)	1.9 (6.1)	2.0 (6.6)	2.5 (8.0)
4. Transmission conductors of lines that have ground fault relaying. Nominal line-to-line voltage in kV.					
a. 69 and below	1.5 (5.0)	1.7 (5.7)	1.9 (6.1)	2.0 (6.6)	2.5 (8.0)
b. 115		1.9 (6.3)	2.1 (6.8)	2.2 (7.3)	2.7 (8.7)
c. 138			2.2 (7.3)	2.4 (7.7)	2.8 (9.1)
d. 161				2.5 (8.2)	2.9 (9.6)
e. 230					3.4 (11.0)

5. Transmission conductors of lines that do not have ground fault relaying. Nominal voltage in kV.	Nominal Line-to-Line Voltage in kV					
	34.5-46	69	115	138	161	230
a. 46 and below	1.5 (5.0)	1.5 (5.0)	1.7 (5.7)	1.9 (6.1)	2.0 (6.6)	2.5 (8.0)
b. 69		1.8 (5.8)	2.0 (6.4)	2.1 (6.9)	2.3 (7.3)	2.7 (8.7)
c. 115			2.5 (8.0)	2.6 (8.5)	2.8 (8.9)	3.2 (10.3)
d. 138				2.9 (9.3)	3.0 (9.8)	3.4 (11.1)
e. 161					3.2 (10.6)	3.7 (11.9)
f. 230						4.4 (14.4)

TABLE IV-3

MINIMUM VERTICAL CLEARANCE IN METERS (FEET)
BETWEEN CONDUCTORS WHERE THE CONDUCTORS OF
ONE LINE CROSS OVER THE CONDUCTORS OF ANOTHER
WHERE UPPER CONDUCTOR HAS GROUND FAULT RELAYING, CONT.

ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:

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

For upper conductors use correction factor from Table IV-1.

For lower conductors:

Categories 1, 2 and 3 above use no correction factors.

Category 4 uses correction factors from Table IV-1.

Category 5 uses the following:

	Nominal Line-to-Line Voltage in kV					
	34.5-46	69	115	138	161	230
Additional meters of clearance per 1000 meters above 1000 meters. (Same value also represents additional feet of clearance per 1000 feet of altitude above 3300 feet.	0	.03	.07	.10	.12	.20

Notes:

(A) The higher voltage line should cross over the lower voltage line.

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

3. Differences in Sag Conditions Between Lower and Upper Conductors

The reason for the difference 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.

E. Minimum Vertical Clearance Between Conductors of Different Lines at Noncrossing Situations

If the horizontal separation between conductors as set forth in Chapter V is not met, then the clearance requirements in section IV.D above must be met.

Example IV-1: Minimum 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 2200 meters (7200 feet). Determine the minimum line-to-ground clearance.

Solution

1. Additional clearance for altitude:

   Because the altitude is greater than 1000 meters (3300 feet), the basic clearance must be increased by the amount indicated in Table IV-1, which is .05 meters per 1000 meters above 1000 meters, or .05 feet per 1000 feet above 3300 feet.

$$\frac{(2200 - 1000)(.05)}{1000} = .06 \text{ meters}$$

$$\frac{(7200 - 3300)(.05)}{1000} = .195 \text{ feet (round to .20 feet)}$$

2. Total clearance:

   Assuming the line meets the assumptions given in A of this chapter, from Table IV-1 the required minimum clearance over cultivated field for a 161 kV line is 7.5 meters (24.6 feet).

   Total clearance over field:

   .06m + 7.5m = 7.56m

   .20ft. + 24.6ft. = 24.8ft.

(The sag template should be drawn for at least .3m (1ft.) additional).

Example IV-2: 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 3.05 meters (10 feet) above its phase conductors. At the other location the lower voltage line does not have overhead ground wires. 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 1000 meters (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.

Solution

The first step in the solution is to determine if the line that is crossed over has automatic ground fault relaying. Let us assume that we are unable to make such a determination and therefore to be safe, we must assume that the line does not have such relaying.

From Table IV-3, section 5, the required clearance from the 230 kV conductor to the 115 kV conductor is 3.2 meters (10.3 feet). From Table IV-3, section 2, the required clearance from the 230 kV conductor to the overhead ground wire is 2.5 meters (8.0 feet); adding 3.05 meters (10 feet) for the distance between the OHGW and the 115 kV phase conductors, we get a total required clearance of 5.55 meters (18 feet).

When the lower circuit has an overhead ground wire, the clearance requirements to the overhead ground wire govern and the required clearance between the upper and lower phase conductor is 5.5 meters (18 feet).

Where there is no overhead ground wire for the 115 kV circuit, the required clearance between the phase conductors is 3.2 meters (10.3 feet).

It should be stressed that the above clearance values must be maintained where the upper conductor is at its maximum sag condition as defined in section IV.D.1.a above, and the lower conductor is at 16°C (60°F) initial sag.

V. HORIZONTAL CLEARANCE FROM LINE CONDUCTORS TO OBJECTS AND RIGHT-OF-WAY WIDTH

The preliminary comments and assumptions (see section IV.A) of Chapter IV also apply to this chapter.

A. Minimum Horizontal Clearance of Conductor to Objects

The required minimum horizontal clearance of conductors to various objects are given in Table V-1. The clearances apply only for lines that are capable of automatically clearing line-to-ground faults.

1. Conditions Under Which Clearances Apply

The clearances apply when the conductor is displaced by a .29 kilopascals (6 pounds per square foot) wind, at 16°C (60°F). The sag value to be used is the final sag at 16°C (60°F) with .29 kilopascals (6 pounds per square foot) of wind. See Figure V-1.

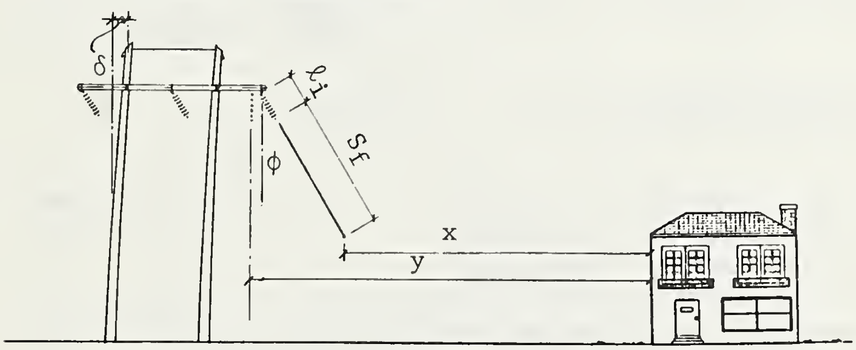


FIGURE V-1: HORIZONTAL CLEARANCE REQUIREMENT

ϕ = conductor swing out angle in degrees under .29 kilopascals (6 lbs/sq. ft.) of wind.

S_f = conductor final sag at 16°C (60°F) with .29 kilopascals (6 lbs/sq. ft.) of wind.

x = clearance required per Table V-1 (include altitude correction if necessary).

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

y = total horizontal distance from insulator suspension point (conductor attachment point for post insulators) to structure.

δ = structure deflection with a .29 kilopascals (6 lbs/sq. ft.) wind.

TABLE V-1

MINIMUM HORIZONTAL CLEARANCE
FROM CONDUCTORS TO OBJECTS NEAR THE LINE
IN METERS (FEET)

CLEARANCE TO:	Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	161	230
1. Buildings, bridges, signs, chimneys, and television antennas, tanks containing nonflammables, and other installations not classified as buildings.	3.4 (11.0)	3.6 (11.7)	3.7 (12.1)	3.9 (12.6)	4.3 (14.0)
2. Lighting supports, traffic signals, or supporting structures of another line.	1.9 (6.0)	2.1 (6.7)	2.2 (7.1)	2.3 (7.6)	2.8 (9.0)
3. Rail of railroad tracks.	4.9 (16.0)	5.1 (16.7)	5.2 (17.1)	5.4 (17.6)	5.8 (19.0)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:					
Additional meters of clearance per 1000 meters of altitude above 1000 meters (same value also represents additional feet of clearance per 1000 feet of altitude above 3300 feet).	0	.02	.04	.05	.09

2. Altitude Greater Than 1000 Meters (3300 Feet)

If the altitude of the transmission line or portion thereof is greater than 1000 meters (3300 feet), an additional clearance as indicated in Table V-1 must be added to the base clearance given.

3. Total Horizontal Clearance to Point of Insulator Suspension to Object

As can be seen from Figure V-1, the total horizontal clearance value (y) is:

$$y = (\ell_i + S_f) \sin \phi + x + \delta \qquad \text{Eq. V-1}$$

where symbols are as defined above.

The factor "δ" indicates that structure deflection must be taken into account. Generally, for single pole wooden structures, it can be assumed that the deflection under .29 kilopascals (6 lbs/sq. ft.) of wind will not exceed 5 percent of the structure height above the groundline. For unbraced H-frame structures the same assumption can be made. For braced H-frame structures, the deflection under .29 kilopascals (6 lbs/sq. ft.) of wind will be considerably less than that for a single pole structure, and is often assumed to be insignificant.

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

The conductor swing angle (ϕ) under .29 kilopascals (6 lbs/sq. ft.) of wind can be determined from the formulae.

$$\phi = \tan^{-1}\left(\frac{(d_c)(F)}{1000\ w_c}\right) \quad \text{(Metric) Eq. V-2}$$

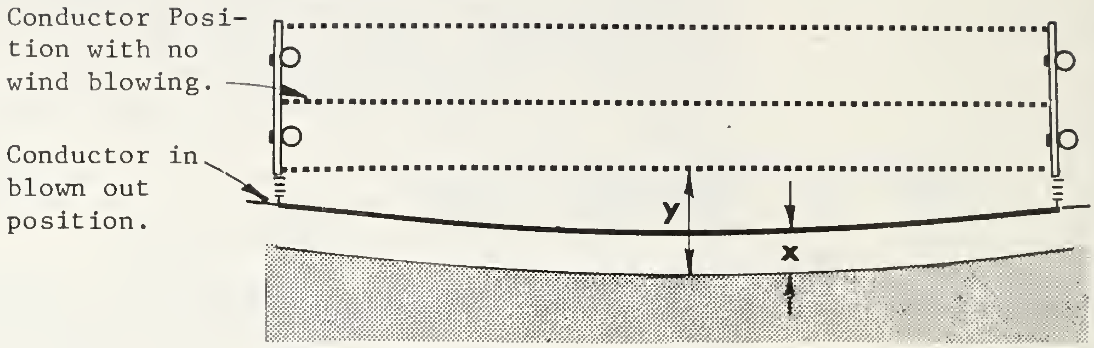
$$\phi = \tan^{-1}\left(\frac{(d_c)(F)}{12\ w_c}\right) \quad \text{(English) Eq. V-3}$$

where:

d_c = conductor diameter in millimeters (inches).
w_c = weight of conductor in Newtons per meter (lbs. per foot)(for standard gravity 1kg = 9.81N).
F = wind force. Use .29 kPa (6 lbs/sq. ft.) for this case.

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 V-2.

Top View of a Line



x = clearance required per Table V-1

y = total horizontal clearance

FIGURE V-2: A TOP VIEW OF A LINE SHOWING TOTAL HORIZONTAL CLEARANCE REQUIREMENTS

B. Right-of-Way (ROW) Width

For transmission lines, a right-of-way is necessary so that an environment can be established and maintained that allows the line to be operated and maintained safely and reliably. The determination of the right-of-way width is a task that requires the consideration of a variety of judgmental, technical, and economic factors. Given below for guidance in this task are several methods that may be of use in making this determination.

1. Nominal Widths

The following are nominal right-of-way widths that have been used by REA borrowers in the past. In many cases a range of widths is given. The actual width used will depend upon the particulars of the line design. The widths have generally proven to be satisfactory and in most instances provide sufficient width so that if a line structure falls, it will remain within the right-of-way.

	Nominal Line-to-Line Voltage in kV				
	69	115	138	161	230
ROW Width in meters	22-30	30	30-45	30-45	40-60
(feet)	(75-100)	(100)	(100-150)	(100-150)	(125-200)

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

Instead of using the nominal right-of-way width given above, widths can be calculated using either of the two methods below. They yield values that are more directly related to the particular parameters of the line design.

a. First Method

This method provides sufficient width so that if a building of undetermined height is built at any place directly on the edge of the right-of-way, the clearance requirements to buildings given in part A above will be met. Generally, this method yields a narrower width value than in part 1 above.

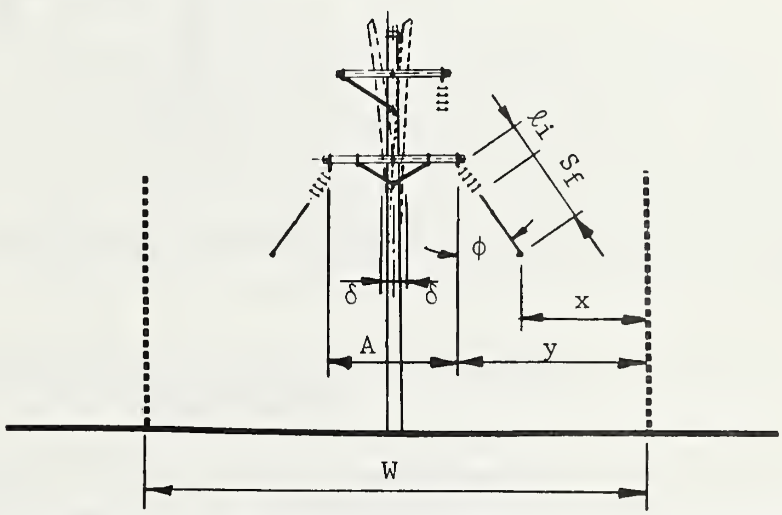


FIGURE V-3: ROW WIDTH FOR SINGLE LINE OF STRUCTURES (FIRST METHOD)

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 V-1 (include altitude correction if necessary).

Other symbols are as previously defined.

The question arises as to what span length (and thus what sag) should the right-of-way width be based upon. There are two ways of approaching this question. One is to use one width for the entire line and to base that width on the maximum span length in the line. The other way is to base the width on a relatively long, but not the longest span, (say the ruling span, for instance) and for those spans that exceed the base span, add additional width as appropriate.

b. Second Method

If there is an extremely low probability of structures being built near the line, the right-of-way width could be based on allowing the phase conductor to blow out to the edge of the right-of-way under extreme wind conditions such as the 50 or 100 year mean wind (see Appendix E).

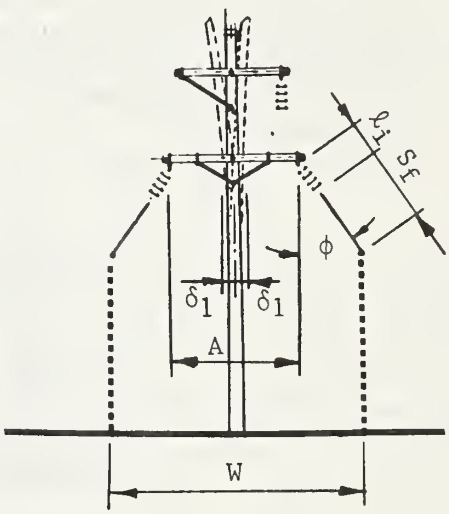


FIGURE V-4: ROW WIDTH FOR SINGLE LINE OF STRUCTURES (SECOND METHOD)

ϕ = conductor swing out angle in degrees at extreme wind conditions

S_f = conductor final sag at extreme wind conditions at the temperature at which the wind is expected to occur.

δ_1 = structure deflection under extreme wind conditions.

Other symbols are as previously defined.

Figure V-4 above illustrates the right-of-way width determination for the second method. From the figure above it can be seen that the formula for the width is:

$$W = A + 2(\ell_i + S_f)\sin\phi + 2\delta_1 \qquad \text{Eq. V-4}$$

where:

ϕ can be determined using Equations V-2/V-3 with a wind force value F for the extreme wind condition (see Appendix E for conversion of wind velocity to wind pressure).

All symbols are as defined above.

As with the previous method, the sags in the calculations can be based on either the maximum span or the ruling span, with special consideration given to spans longer than the ruling span.

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

The right-of-way width requirements for a line next to a road are the same as those given in the two previous sections except that there is no ROW required on the road side of the line as long as the required clearances to existing or possible future structures on the road side of the line are met.

If a line is to be put next to a roadway, consideration should be given to who will pay for the cost of moving the line if the road is widened. Generally, if the line is on the road right-of-way, the borrower would pay to move it, and if it is on private land, the highway department would pay. The choice of putting a line on a road right-of-way would depend on local ordinances and requirements, plus an estimation of the probability of the road being widened.

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

The determination of the right-of-way width where there are two parallel lines on the same right-of-way can be broken into two parts. The distance from the outside phases of the lines to the ROW edge is calculated in the same manner as given in section V.B.2 above. The distance between the lines is governed by three separate sets of requirements, given below, any one of which may be governing.

*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 bulletin.

a. <u>Separation Between Lines as Dictated by Minimum Clearance Between Conductors Carried on Different Lines</u>

The horizontal clearance between a phase conductor of one line to a phase conductor of another line shall meet the largest of (1), (2), or (3), below, under the following conditions: (a) both phase conductors displaced by a .29 kilopascal (6 lbs/sq. ft.) wind at $16^{o}C$ ($60^{o}F$), final sag; (b) if insulators are free to swing, one should be assumed to be displaced by a .29 kPa (6 lbs/sq. ft.) wind while the other should be assumed to be unaffected by the wind (see Figure V-5). The wind direction assumed should be that which results in the greatest separation requirement. It should be noted that in the equations that follow, the $(\delta_1 - \delta_2)$ term, the differential structure deflection between the two lines of structures involved, must be taken into account. See section V.B.2 for further discussion on deflections.

Metric Form

(1) $C_1 = 1.6m + (\delta_1 - \delta_2)$ Eq. V-5

(2) $C_2 = .610 + .0102\left[(kV_{LG_1} + kV_{LG_2}) - 8.7\right] + (\delta_1 - \delta_2)$ Eq. V-6

(3) $C_3 = .00762\left[(kV_{LG_1} + kV_{LG_2}) + (kV_{LG_1} + kV_{LG_2} - 50)\right] + F_c\sqrt{S_f(.3048)}$ Eq. V-7

English Form

(1) $C_1 = 5ft. + (\delta_1 - \delta_2)$ Eq. V-8

(2) $C_2 = 2' + \frac{.4}{12}\left[(kV_{LG_1} + kV_{LG_2}) - 8.7\right] + (\delta_1 - \delta_2)$ Eq. V-9

(3) $C_3 = .025\left[(kV_{LG_1} + kV_{LG_2}) + (kV_{LG_1} + kV_{LG_2} - 50)\right] + F_c\sqrt{S_f}$ Eq. V-10

where:

C_1, C_2, C_3 = clearance requirements between conductors on different lines in meters (feet) (largest value governs).

kV_{LG_1} = maximum line-to-ground voltage in kV of line 1.

kV_{LG_2} = maximum line-to-ground voltage in kV of line 2.

S_f = the final sag of conductor in meters (feet) at 16°C (60°F)
F_c = experience factor; can be 1.4 to 6.7*.
δ_1 = deflection of the upwind structure in meters (feet).
δ_2 = deflection of the downwind structure in meters (feet).

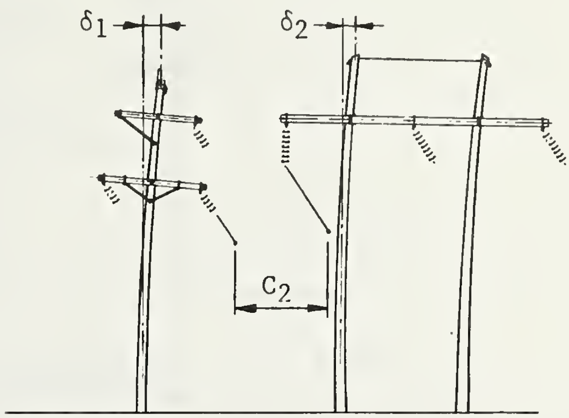


FIGURE V-5: CLEARANCE BETWEEN CONDUCTORS OF ONE LINE TO CONDUCTOR OF ANOTHER LINE

b. <u>Separation Between Lines as Dictated by Minimum Clearance of Conductors From One Line to the Supporting Structure of Another</u>

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 .29 kPa (6 lbs/sq. ft.) wind at 16°C (60°F) final sag must meet:

$$C_4 = 1.9 + .0102(kV_{LG} - 50) + (\delta_1 - \delta_2)$$

(Metric) Eq. V-11

$$C_4 = 6' + \frac{.4(kV_{LG} - 50)}{12} + (\delta_1 - \delta_2)$$

(English) Eq. V-12

where:

kV_{LG} = the maximum line-to-ground voltage in kV.
C_4 = the clearance of conductors of one line to structure of another in meters (feet).
Other symbols as previously defined.

*See Chapter VI for full explanation.

Note that as with the previous set of equations, structure deflection, if significant, should be taken into account.

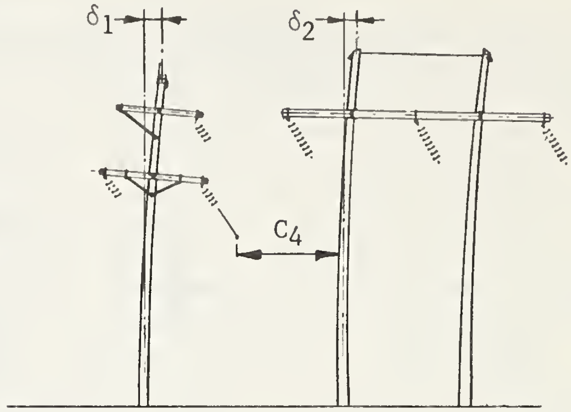


FIGURE V-6: CLEARANCE BETWEEN CONDUCTOR OF ONE LINE AND STRUCTURE OF ANOTHER

The separation between lines will depend upon the spans and sags of the lines as well as how the structures of one line line up with structures of another. In order to avoid the unreasonable task of determining the separation of the 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 the other, the separation required by "b" above 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.

c. Other Factors

Other factors that may determine line spacing are:

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

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

d. Altitude Greater than 1000 Meters (3300 Feet)

If the altitude of the lines is greater than 1000 meters (3300 feet), see Section 23 of the NESC for additional separation requirements.

VI. CLEARANCES BETWEEN CONDUCTORS AND BETWEEN CONDUCTORS AND OVERHEAD GROUND WIRES

The preliminary comments and assumptions (see section IV.A) of Chapter IV also apply to this chapter.

This chapter considers those design limits related to conductor separation. It is assumed that only standard REA 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.

Any one of the following requirements for separation could be the limiting factor for span length. Other factors not covered in this chapter which may limit span length are structure length, insulator strength, and ground clearance.

A. 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.

1. Situations Under Which Maximum Span as Limited by Horizontal Separation Must be Met

If the vertical separation at the structure (regardless of horizontal displacement) of phase conductors of the same or different circuit(s) is less than the appropriate value given in Table VI-1 below, then the requirements in sections VI.A.2, A.3, and A.4 below must be met.

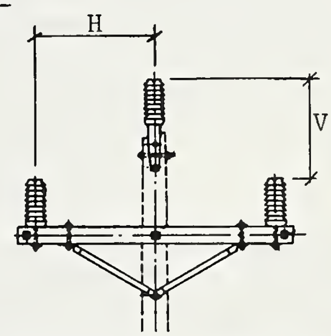


FIGURE VI-1: EXAMPLE OF VERTICAL AND HORIZONTAL SEPARATION VALUES.

2. Horizontal Separation Requirements

The equations below give a sufficient horizontal phase spacing in relation to conductor sag, and thus indirectly to span length, in order to prevent swinging contacts or flashovers between phases of the same or different circuits.

$$H = (.00762)kV + F_c\sqrt{S_f(.3048)} + \ell_i(\sin\phi_{max})$$ (Metric) Eq. VI-1

$$H = (.025)kV + F_c\sqrt{S_f} + \ell_i(\sin\phi_{max})$$ (English) Eq. VI-2

TABLE VI-1

MINIMUM VERTICAL SEPARATION IN METERS (FEET)
BETWEEN PHASES OF THE SAME OR DIFFERENT CIRCUITS
NECESSARY FOR EQUATIONS VI-1 AND VI-2 NOT TO APPLY*

*(The values in this table are not recommended as minimum vertical separations at the structure for nonstandard structures, but are intended only to be used to determine whether or not horizontal separation calculations are required).

	Nominal Line-to-Line Voltage in kV					
MINIMUM VERTICAL SEPARATION	34.5-46	69	115	138	161	230
1. Phases of the Same Circuit	1.2 (4.0)	1.5 (4.8)	2.0 (6.4)	2.2 (7.2)	2.5 (8.0)	3.2 (10.4)
2. Phases of Different Circuits**	1.2 (4.0)	1.6 (5.1)	2.2 (7.0)	2.4 (8.0)	2.7 (8.9)	3.6 (11.7)
ALTITUDE CORRECTION TO BE ADDED TO VALUE IN NO. 2 ABOVE (NONE REQUIRED FOR NO. 1).						
Additional meters of clearance per 1000 meters of altitude above 1000 meters (same value also represents additional feet of clearance per 1000 feet of altitude above 3300 feet).	0	.03	.09	.12	.15	.23

**Assumes both circuits have the same nominal voltage. If they do not, the vertical separation can be determined using the equations below. See Section 23 of the NESC for altitude correction factors.

$$= 1.2 + .0102(kV_{LG_1} + kV_{LG_2} - 50) \quad \text{(Metric) Eq. VI-3}$$

$$= 4ft. + \frac{.4}{12}(kV_{LG_1} + kV_{LG_2} - 50) \quad \text{(English) Eq. VI-4}$$

where:

H = horizontal separation between the phase conductors at the structure in meters (feet).

kV = (for 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 = (for 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.

F_c = the experience factor.

ϕmax = the maximum 6 lb/ft^2 insulator swing angle for the structure in question**.

S_f = the final sag of the conductor at 16^oC (60^oF), no load, in meters (feet).

ℓ_i = the length of the insulator string in meters (feet), $\ell_i = 0$ for post or restrained suspension insulators.

The experience factor (F_c) may vary from a minimum of .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 F_c that have in the past proved to be satisfactory.

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

Any value of F_c in the .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 with horizontal spacing based on an F_c factor of .67; therefore, F_c factor values significantly less than the values listed above may be appropriate. If F_c 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.

---

*It is recommended that if one is unsure of the vector relationship between the phases of different circuits, the voltage between the phases should be taken to be the sum of the two line-to-ground voltages, based on 1.05 times nominal voltage.

**See Chapter VII.

3. Additional Horizontal Separation Equation

The equation below, commonly known as the Percy Thomas formula, may be used in addition to (but not instead of) equations VI-1 and VI-2 for determining the horizontal separation between the phases at the structure. The equation takes into account the weight, diameter, sag, and span length of the conductor.

$$H = (.00762)kV + \frac{(E_c)(d_c)(S_p)}{w_c}(1.74) + \frac{\ell_i}{2}$$ (Metric) Eq. VI-5

$$H = (.025)kV + \frac{(E_c)(d_c)(S_p)}{w_c} + \frac{\ell_i}{2}$$ (English) Eq. VI-6

where:

d_c = conductor diameter in millimeters (inches).
w_c = weight of conductor in N/m (lbs/ft.) (for standard gravity 1 kg = 9.81 N).
E_c = an experience factor. It is generally recommended that (E_c) be larger than 1.25.
S_p = sag of conductor (at 16°C (60°F)), expressed as a percent of span length.

All other symbols are as previously defined.

The Thomas equation may be used to examine the spacings of conductors on lines which have operated successfully in a locality by determining values of E_c. These values of E_c may be helpful in determining other safe spacings.

4. Maximum Span

Equations VI-1 and VI-2 can be rewritten and combined with equation X-1 to yield the maximum allowable span, given the horizontal separation at the structure and the sag and length of the ruling span*.

$$L_{max} = \frac{(RS)}{(.552)}\left(\frac{H - (.00762)kV - \ell_i \sin\phi}{F_c\sqrt{S_{RS}}}\right)^2$$ (Metric) Eq. VI-7

$$L_{max} = (RS)\left(\frac{H - (.025)kV - \ell_i \sin\phi}{F_c\sqrt{S_{RS}}}\right)^2$$ (English) Eq. VI-8

where:

L_{max} = max. span as limited by conductor separation in meters (feet).
RS = length of ruling span in meters (feet).
S_{RS} = sag of the ruling span at 16°C (60°F) final sag in meters (feet).

Other symbols are as previously defined.

*See Chapter IX for a discussion of ruling span.

B. Maximum Span as Limited by Galloping

1. The Galloping Phenomenon

Galloping, sometimes called dancing, is a phenomenon where the transmission line conductors vibrate with very large amplitudes. This 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.

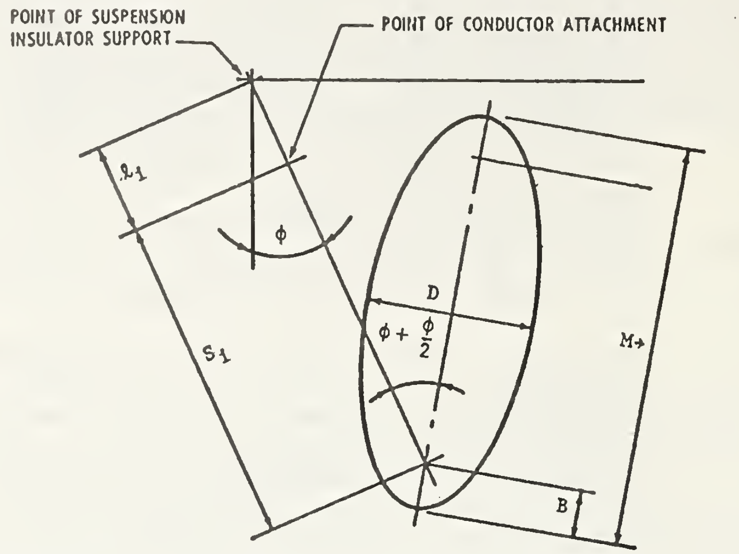
Galloping usually occurs only when a steady, moderate wind blows over a conductor covered by a layer of ice deposited by freezing rain, mist or sleet. The coating may vary from a very thin glaze on one side to a solid three-inch cover and may give the conductor a slightly out-of-round, elliptical, or 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 8 to 72 kilometers per hour (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 190 to 215 meters (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 things that can be done at the design stage of a line to reduce potential conductor contacts caused by galloping, such as shorter spans, or increased phase separation. The H-frame structures provide very good phase spacing for reducing galloping contacts.

2. Galloping Considerations in the Design of Transmission Lines

In areas where galloping is either historically known to occur or is expected, it should be taken into account in the design of the line. The primary tool for doing this is the Lissajous ellipses which give the theoretical envelope of a galloping conductor. To avoid contact between phase conductors or between phase conductors and overhead ground wires, their ellipses should not

FIGURE VI-2: GUIDE FOR PREPARATION OF LISSAJOUS ELLIPSES



	Single Loop		Double Loop	
Angle "ϕ"	$\phi = \tan^{-1}\left(\frac{p_c}{w_c}\right)$			Eq. VI-9
Major Axis "M"	$M = 1.25\,S_1 + .3048$	(Metric) Eq. VI-10	$M = .3048 + \sqrt{\frac{3a(L + \frac{8S_1^2}{3L} - 2a)}{8}}$	(Metric) Eq. VI-14
	$M = 1.25\,S_1 + 1$	(English) Eq. VI-11	$M = 1 + \sqrt{\frac{3a(L + \frac{8S_1^2}{3L} - 2a)}{8}}$	(English) Eq. VI-15
			$a = \sqrt{\left(\frac{L}{2}\right)^2 + S_1^2}$	
Distance "B"	$B = .25\,S_1$	Eq. VI-12	$B = .2M$	Eq. VI-16
Minor Axis "D"	$D = .4M$	Eq. VI-13	$D = 1.104\sqrt{M - .3048}$	(Metric) Eq. VI-17
			$D = 2\sqrt{M - 1}$	(English) Eq. VI-18

where:

p_c = wind load per unit length on iced conductor in N/m (lbs/ft). Assume a .0958 kPa (2 lbs/ft^2) wind.
w_c = weight per unit length of conductor plus 12.7 mm (.5 in.) of radial ice in N/m (lbs/ft) (for standard gravity 1 kg = 9.81 N).
L = span length in meters (feet).
M = major axis of Lissajous ellipses in meters (feet).
S_1 = final sag of conductor with 12.7 mm (.5 in.) of radial ice, no wind, at 0°C (32°F).
D = minor axis of Lissajous ellipses in meters (feet).
ϕ, B } are as defined in figure above.

touch. However, depending upon how frequent and how severe the galloping is expected to be, there may be situations where allowing ellipses to overlap may be the best design choice when economics are considered.

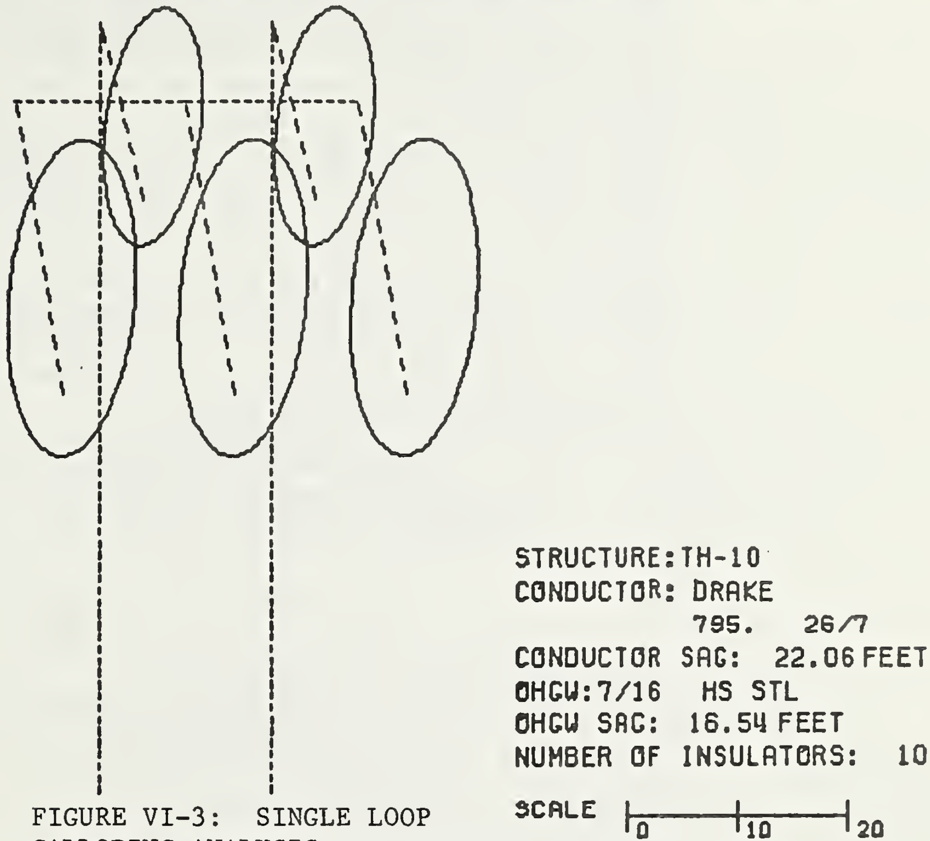


FIGURE VI-3: SINGLE LOOP GALLOPING ANALYSIS

C. <u>Maximum Span as Limited by Conductor Separation Under Differential Ice Loading Conditions</u>

1. <u>General</u>

There is a tendency among conductors covered with ice, for the conductor closest to the ground to drop its ice first. There are two problems caused by this. First, upon unloading its ice, the lower conductor may jump up toward the upper conductor, possibly resulting in a temporary short circuit. Second, after the lower conductor recovers from its initial "jump up", it will 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 during a system disturbance.

The clearance requirements given below 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".

2. Clearance Requirements

The minimum distance between phase conductors and between phase conductors and overhead ground wires under differential ice loading conditions are given in Table VI-2. Note that an additional .6 meter (2 feet) of clearance must be added to the values given in Table VI-2 when conductors or wires are directly over one another or have less than a .3 meter (1 foot) horizontal offset. 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 .3 meter (1 foot) significantly lessens the ice jump problem. The figure below illustrates the manner in which the minimum distance is to be measured. Also indicated are the horizontal and vertical components of clearance and their relationship.

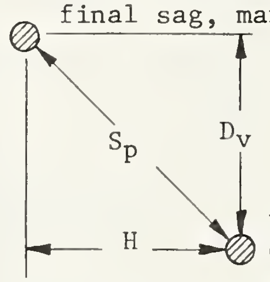


FIGURE VI-4: MINIMUM DISTANCE BETWEEN CONDUCTORS (SP)

where:

SP = minimum distance between conductors as required by Table VI-2.
D_V = vertical component of clearance.
H = horizontal component of clearance.

From Figure VI-4, it can be seen that the relationship of the clearance components are:

$$D_V = \sqrt{(SP)^2 - (H)^2} \qquad \text{Eq. VI-19}$$

a. Conditions Under Which Clearances Apply

(1) Upper conductor at $0^\circ C$ ($32^\circ F$), final sag, with a radial thickness of ice equal to the maximum thickness of ice that can be reasonably expected for the geographical area in question. Typically 25.4 mm (1 inch) for short and medium spans; 12.7 mm (.5 inches) for unusually long spans.

(2) Lower conductor at $0^\circ C$ ($32^\circ F$), final sag, no ice.

TABLE VI-2

MINIMUM SEPARATION IN ANY DIRECTION BETWEEN PHASE CONDUCTORS AND BETWEEN PHASE CONDUCTORS AND OVERHEAD GROUND WIRES IN METERS (FEET) UNDER DIFFERENTIAL ICE LOADING CONDITIONS

	Nominal Voltage in kV_{LL}						
MINIMUM SEPARATION BETWEEN:	34.5	46	69	115	138	161	230
1. Phase conductors of the same circuit.	.28 (.87)	.37 (1.2)	.56 (1.8)	.92 (3.0)	1.1 (3.6)	1.3 (4.2)	1.9 (6.0)
2. Phase conductors and overhead ground wires.	.16 (.52)	.21 (.70)	.32 (1.0)	.55 (1.8)	.64 (2.1)	.77 (2.5)	1.1 (3.5)

If one conductor is located directly above another or has less than a .3 meter (1 foot) horizontal offset, .6 meter (2 feet) of clearance in addition to that specified in the table above must be maintained.

b. Maximum Span

For a structure with a given horizontal offset between phases, equation VI-19 can be used to determine what the vertical separation at the mid-span point must be in order to meet the total separation requirement. 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:

$$L_{max} = (RS)\sqrt{\frac{D_u - B}{S_\ell - S_u}} \qquad \text{Eq. VI-20}$$

where:

L_{max} = maximum allowable span in meters (feet).
D_u = required vertical separation at mid-span in meters (feet).
B = vertical separation at supports in meters (feet).
S_ℓ = sag of lower conductor in meters (feet) without ice.
S_u = sag of upper conductor wire in meters (feet) with ice.
RS = ruling span in meters (feet).

D. Overhead Ground Wire Sags and Clearances

In addition to checking clearances between the 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 during a system disturbance. Adequate mid-span separation is usually assured for standard REA structures by keeping the sag of the OHGW at 16°C (60°F) initial sag, no load conditions to 80 percent of the phase conductors under the same conditions.

E. 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 VI-5.

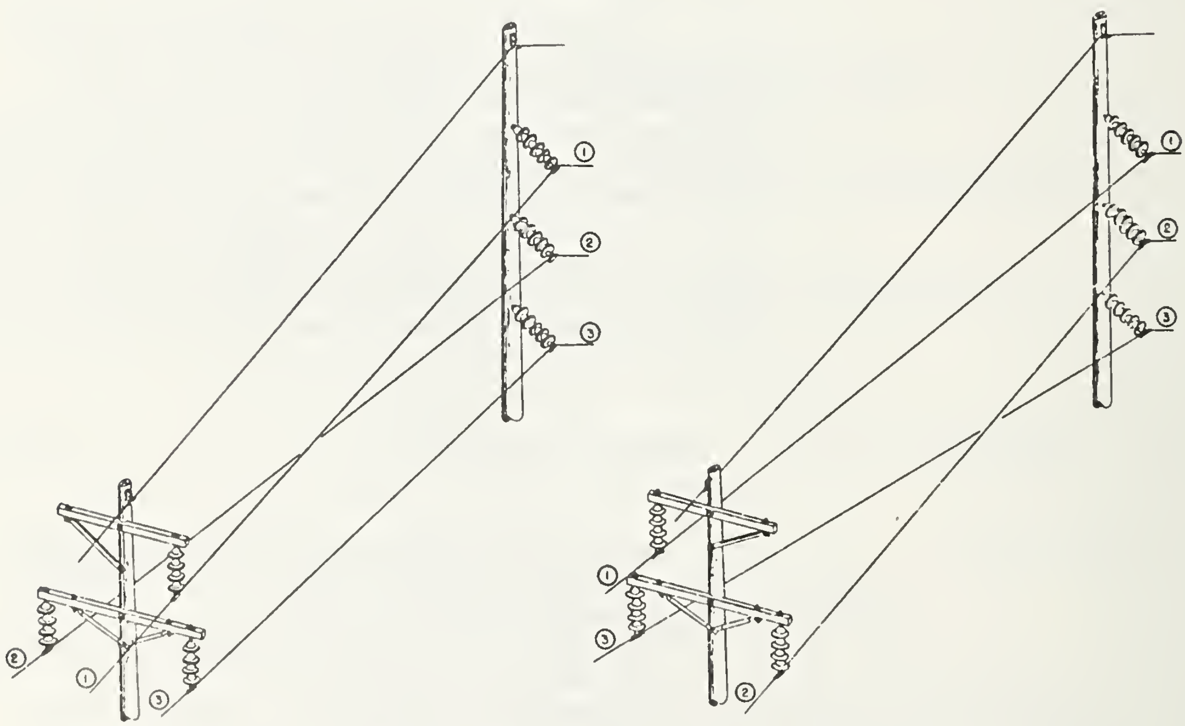


FIGURE VI-5: PROPER PHASE ARRANGEMENTS FOR CROSSARM TO VERTICAL CONSTRUCTION.

VII. INSULATOR SWING AND CLEARANCES OF CONDUCTORS FROM SUPPORTING STRUCTURES

A. Introduction

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 insure that when the insulators do swing, reasonable clearances are maintained to structures and guy wires. The amount by which the string will swing varies with such factors as: conductor tension, temperature, wind velocity, and the ratio of the vertical to horizontal spans.

The purpose of this chapter is to explain how and on what basis insulator swing application guides called swing charts are prepared. Chapter X explains how these charts are used in laying out a line.

B. Clearances and Their Application

Table VII-1 gives three sets of clearances that have been established in order to insure proper separation between conductors and structures or guys under various conditions. Figure VII-1 illustrates the various situations in which the clearances are to be applied.

1. No Wind Clearance

a. Clearance

This is the minimum clearance that must be maintained between the conductor and structure or guys under conditions that are expected to exist for long periods of time. It provides a balanced insulation system where the insulating value of the air gap is approximately the same as that of the insulator string (does not include extra insulators used at angle structures).

b. Conditions at Which Clearance is to be Maintained

(1) Wind

No wind shall be assumed to be blowing.

(2) Temperature

A temperature of 16°C (60°F) shall be assumed with the conductor at its final sag condition.

2. Moderate Wind Clearance

a. Clearance

This is the minimum clearance that must be maintained under conditions that are expected to occur only occasionally. The air gap values given have a lower flashover value than that of the insulator string length normally used at the various voltages. This condition is acceptable because: (1) although the air gap flashover value is less than that of the insulator string, it is still quite high and should be sufficient to withstand most of the severe voltage stress situations, and (2) the clearances are to be maintained at conditions that are not expected to occur often. It should be pointed out that there are different clearance requirements to the structure than to anchor guys. Also, note that Table VII-1 requires that additional clearance must be provided if the altitude is above 1000 meters (3300 feet).

b. Conditions at Which Clearance is to be Maintained

(1) Wind

A wind of at least .29 kPa (6 lb/ft^2) blowing in the direction shown in Figure VII-1 shall be assumed. Higher wind pressures can be used if judgment and experience deem it to be necessary (see Appendix E for a correlation of wind pressure to velocity). 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 .43 kPa (9 lbs/ft^2), 97 kph (60 mph) be used unless very special circumstances exist.

(2) Temperature

The temperature conditions at which the clearances are to be maintained depend upon the type of structure. For tangent and small angle structures where the insulator string is suspended from a crossarm, a temperature of no more than $0^{\circ}C$ ($32^{\circ}F$) should be used. 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, that the insulator swing problem for this situation becomes worse as the temperature decreases. Therefore, in choosing a temperature lower than $0^{\circ}C$

($32^{o}F$), one should weigh the increase in conservatism of line design against the increase or decrease in line cost.

For angle structures where the insulator string is dependent upon the force due to the change in direction of the conductor to hold it away from the structure, a temperature of $16^{o}C$ ($60^{o}F$) should be used. Even if the maximum conductor temperature is significantly greater than $16^{o}C$ ($60^{o}F$), a higher temperature need not be used as an assumed wind value of 64.5 kph (40 mph) (.29 kPa (6 lbs/ft^2)) has quite a cooling effect.

The conductor shall be assumed to be at final sag conditions for the $16^{o}C$ ($60^{o}F$) temperature and at the initial sag conditions for the $0^{o}C$ ($32^{o}F$).

3. High Wind Clearance

a. Clearance

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

b. Conditions Under Which Clearance is to be Maintained

(1) Wind

The assumed wind value shall be at least at the 10-year mean recurrence internal wind (see Appendix E) blowing in the direction shown in Figure VII-1. More wind may be assumed if deemed appropriate.

(2) Temperature

The temperature assumed should be that temperature at which the extreme wind is expected to occur and the conductor shall be assumed to be at final sag conditions.

TABLE VII-1

MINIMUM CLEARANCES IN METERS (INCHES) AT CONDUCTOR TO SURFACE OF STRUCTURE OR GUY WIRES*

	Nominal Voltage in kV_{LL} — Standard Number of 5-3/4" x 10" Insulators on Tangent Structures								
	34.5	46	69	115	138	161	230		
	3	3	4	7	8	10	12	13	14
NO WIND CLEARANCE									
- Min. clearance to structure or guy at no wind in meters (inches) (A)(B)	.48 (19)	.48 (19)	.64 (25)	1.07 (42)	1.22 (48)	1.52 (60)	1.80 (71)	1.96 (77)	2.11 (83)
MODERATE WIND CLEARANCE (NESC)									
- Min. clearance to structure at .29 kPa (6 lbs/ft^2) of wind in meters (inches) (C)(D)	.30 (12)	.30 (12)	.41 (16)	.66 (26)	.77 (30)	.89 (35)	1.27 (50)	1.32 (52)	1.42 (56)
- Min. clearance to anchor guys at .29 kPa (6 lbs/ft^2) of wind in meters (inches) (C)(D)	.33 (13)	.40 (16)	.56 (22)	.88 (35)	1.04 (41)	1.19 (47)	1.65 (65)	1.65 (65)	1.65 (65)
HIGH WIND CLEARANCE									
- Min. clearance to structure or guy at high wind in meters (inches)	.08 (3)	.08 (3)	.13 (5)	.25 (10)	.30 (12)	.36 (14)	.51 (20)	.51 (20)	.51 (20)

(A) If insulators in excess of the standard number for tangent structures are used, the no wind clearance value given should be increased by .15 m (6 in.) for each additional bell. If the excess insulators are needed for contamination purposes, only the additional clearance is not required.

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

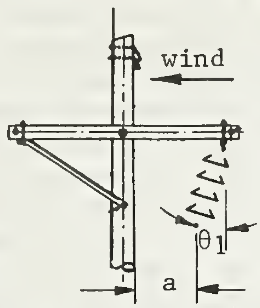
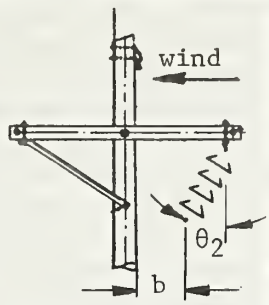
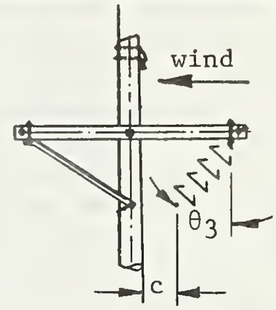
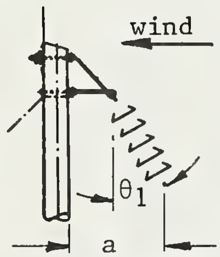
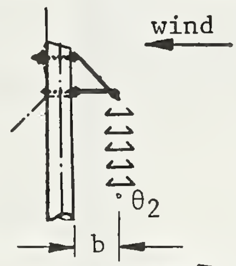
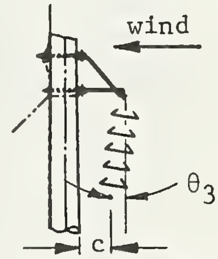
(C) More wind may be assumed if deemed necessary.

(D) The following values should be added as appropriate where the altitude exceeds 1000 meters (3300 feet).

		34.5-46	69	115	138	161	230
Additional mm of clearance per 1000 m above 1000 m (additional in. of clearance per 1000 ft. above 3300 feet)	Clearance to Structure	0	11 (.14)	36 (.43)	48 (.57)	60 (.72)	96 (1.2)
	Clearance to Anchor Guys	0	14 (.17)	45 (.53)	60 (.72)	75 (.89)	120 (1.4)

*Values are intended for wood structures only. For nonwooden structures, somewhat larger clearances may be appropriate.

FIGURE VII-1: ILLUSTRATION OF STRUCTURE INSULATOR SWING ANGLE LIMITS AND CONDITIONS* UNDER WHICH THEY APPLY (EXCLUDES BACKSWING)

	No Wind Insulator Swing	Moderate Wind Insulator Swing	High Wind Insulator Swing
TANGENT, SMALL AND MEDIUM ANGLE STRUCTURES.			
Conditions* at which clearances are to be maintained:	Force due to line angle (if any).	Force due to line angle (if any).	Force due to line angle (if any).
Wind Force (F)	0	.29 kPa (6 lb/ft^2) minimum.	10 yr. mean wind, min. recommended value.
Temperature	16°C (60°F)	0°C (32°F) or <u>lower</u>	Temp. at which wind value is expected.
Conductor Condition	Final sag.	Initial sag.	Final sag.
LARGE ANGLE STRUCTURES.			
Conditions* at which clearances are to be maintained:	Force due to line angle.	Force due to line angle.	Force due to line angle.
Wind Force (F)	0	.29 kPa (6 lb/ft^2) minimum.	10 yr. mean wind, min. recommended value.
Temperature	16°C (60°F)	16°C (60°F)	Temp. at which wind value is expected.
Conductor Condition	Final sag.	Final sag.	Final sag.

a = No wind clearance.
b = Moderate wind clearance.
c = High wind clearance.

*See text for full explanation of conditions.

C. Backswing

The combinations of wind direction and direction of force due to line angle that are usually the most severe and that govern insulator swing considerations are given in Figure VII-1. As can be seen, 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 those angle structures that are asymmetrical; that is, the maximum insulator swing to the left is different of that to the right, 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 would most likely occur where the line angle is small and tensions are low. 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 VII-2 illustrates backswing.

When one is calculating backswing, one must assume those conditions that would tend to make the swing worse, which would be relatively low conductor tension. It is recommended that the temperature conditions given for large angle structures in Figure VII-1 be used, as they result in lower conductor tensions.

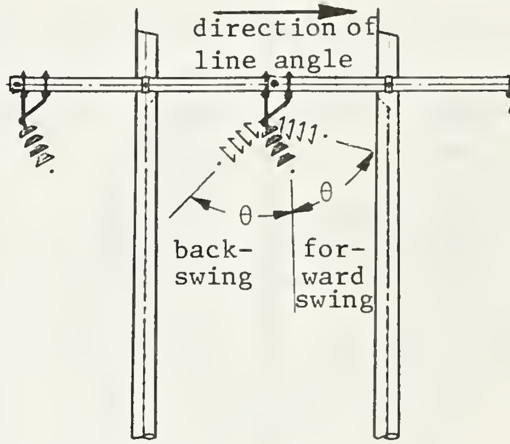


FIGURE VII-2: FORWARD AND BACKWARD SWING ANGLES

D. Structure Insulator Swing Values

Table VII-2 gives the allowable insulator swing values for some of the most often used standard REA structures. (See Appendix D for the list of assumptions used in determining the insulator swing values and for a complete list of insulator swing values). The values given 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 requirement 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 (TS-1 for instance) 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. Those swing angle values that have an asterisk (*) next to them represent a situation where 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 VII-2

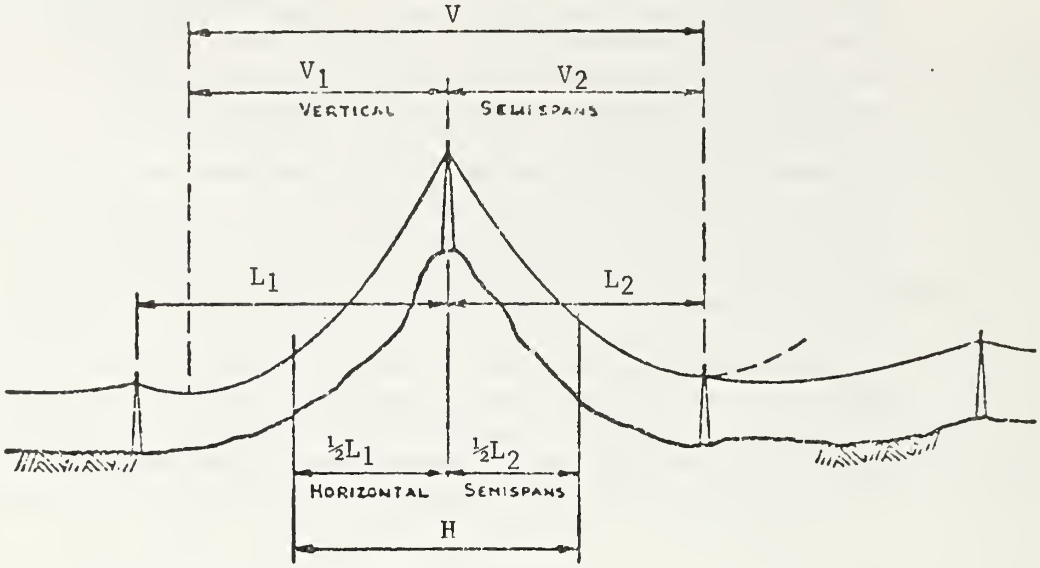
INSULATOR SWING VALUES FOR SOME COMMONLY USED STRUCTURES
(See Appendix D for Complete List)

Tangent Structures

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	Mod. Wind Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
69 kV				
TS-1, TS-1X	4	21.3	41.4	74.9
TSZ-1, TSZ-2	4	41.7	61.2	82.6
TH-1, TH-1C	4	35.6	61.2	85.6
115 kV				
TH-1A	7	28.3	58.7	80.8
161 kV				
TH-10	10	16.4	53.2	77.7
230 kV				
TH-230	12	16.5	47.8	74.8

Angle Structures

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	Mod. Wind Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
69 kV				
TS-3	4	10.2*	4.6	24.4
115 kV				
TH-4A	8	51.2*	27.4*	8.1*
TH-11B	7	53.5	76.5	97.3
161 kV				
TH-12	10	43.9	71.7	91.4
TH-13	11	33.3	10.3*	7.7
230 kV				
TH-231B	12	48.9	67.2	91.3
TH-233	13	34.8*	17.7*	4.4



L = span,

L_1 = span from structure 1 to 2
L_2 = span from structure 2 to 3

HS = horizontal span

VS = vertical span

Span

Span is the horizontal distance from one structure to an adjacent structure along the line.

Vertical Span

The vertical span (sometimes called the wind span) is the horizontal distance between the maximum sag points of two adjacent spans. The maximum sag point of a span may actually fall outside the span. The vertical span lengths times the weight of the loaded conductor per foot will yield the vertical force per conductor bearing down upon the structure and insulators.

Horizontal Span

The horizontal span (sometimes called the wind span) is the horizontal distance between the mid-span points of adjacent spans. Thus, twice the horizontal span is equal to the sum of the adjacent spans. The horizontal span length times the wind force per foot on the conductor will yield the total horizontal force per conductor on the insulators and structure.

FIGURE VII-3: HORIZONTAL AND VERTICAL SPANS

E. Effect of Clearance Requirements on Line Design

The key effect of the insulator swing requirements on line design is that it determines the horizontal to vertical span* ratios that are acceptable. Assuming that under a given set of wind and temperature conditions an insulator string on a structure may swing in toward the structure a given number of degrees, the angle can be related to a ratio of horizontal to vertical forces on the insulator string. This, in turn, can be related to a relationship between the horizontal span, the vertical span, and if applicable, the line angle.

For convenience sake the acceptable limits of horizontal to vertical span ratios are plotted on a chart called an insulator swing chart. This chart can then be easily used for checking or plotting out plan and profile sheets. Figures VII-4 and VII-5 show simplified insulator swing charts (for one swing condition only). It should be pointed out that there is one significant difference between the two charts. While for the chart in Figure VII-4 the greater the vertical span is for a fixed horizontal span the better off we are; the reverse is true for the chart of Figure VII-5. This is because the swing chart in Figure VII-5 is for a large angle structure where the force of the line angle is used to pull the insulator string away from the structure so that the less vertical force we have, the greater the horizontal span can be.

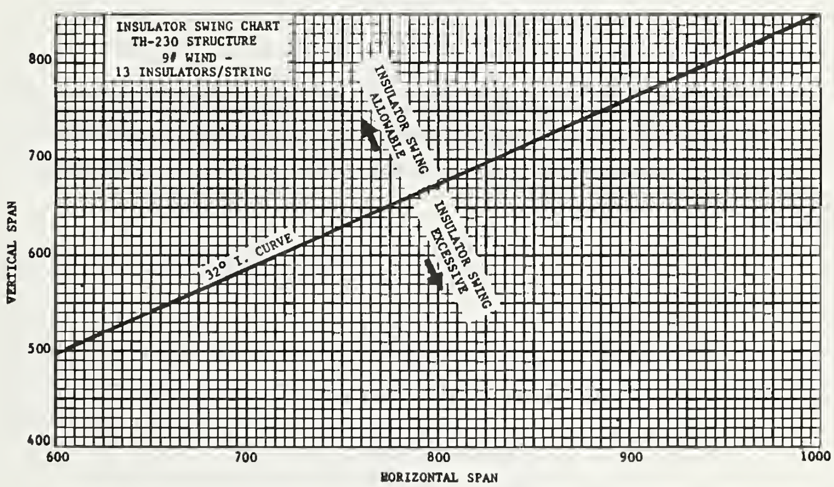


FIGURE VII-4: TYPICAL INSULATOR SWING CHART FOR A TANGENT STRUCTURE (Moderate Wind Swing Condition Only, No Line Angle Assumed)

*See Figure VII-3 for explanation of horizontal and vertical spans.

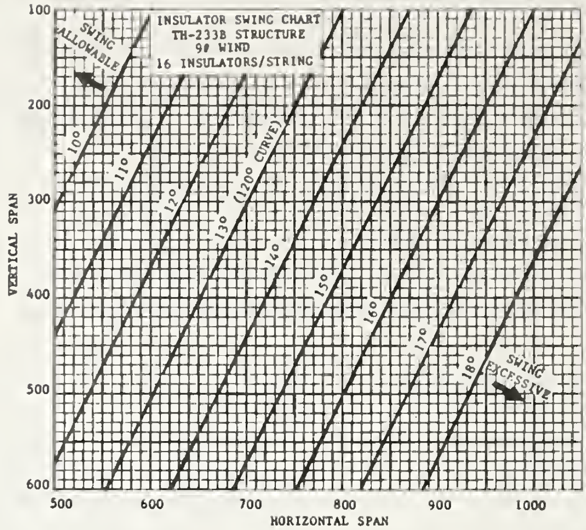


FIGURE VII-5: TYPICAL INSULATOR SWING CHART FOR A LARGE ANGLE STRUCTURE (Moderate Swing Condition Only)

The no wind insulator swing criteria will not be a limiting condition on tangent structures as long as there is no angle turned. 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 only be significant in those areas where unusually high winds can be expected.

F. Formulae for Insulator Swing

The following general formulae 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.

$$\tan \phi = \frac{(2)(T)(\sin \tfrac{1}{2}\theta) + (HS)(p_c)}{(VS)(w_c) + (\tfrac{1}{2})(W_i)} \qquad \text{Eq. VII-1}$$

$$p_c = \frac{(d_c)(F)}{1000} \qquad \text{(Metric) Eq. VII-2}$$

$$p_c = \frac{(d_c)(F)}{12} \qquad \text{(English) Eq. VII-3}$$

where:

ϕ = angle with the vertical through which the insulator string swings, in degrees.
θ = line angle, in degrees.
T = conductor tension, in Newtons (pounds).
HS = horizontal span, in meters (feet).
VS = vertical span, in meters (feet).

p_c = wind load per unit length of bare conductor in Newtons per meter (pounds per foot).
w_c = weight per unit length of bare conductor in Newtons per meter (pounds per foot).
W_i = weight of insulator string (wind pressure neglected), in Newtons (pounds). (See Appendix C for insulator string weights).
d_c = conductor diameter in millimeters (inches).
F = wind force in Pa (lbs/ft^2).

In order for the formula to be used properly, the following sign conventions must be followed:

Condition	Sign Assumed
Wind:	
Blowing insulator toward structure	+
"(2)(T)($\sin\frac{1}{2}\theta$)" term (force on insulator due to line angle):	
Pulling insulator toward structure	+
Pulling insulator away from structure	-
Insulator swing angle ϕ:	
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	-

G. Insulator Swing Charts

Insulator swing charts similar to those in Figures VII-4 and VII-5 can be computed by using the formula below and the maximum angle of insulator swing values as limited by clearance to structure.

$$VS = \frac{(2)(T)(\sin\frac{1}{2}\theta) + (HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)} \qquad \text{Eq. VII-4}$$

The symbols and sign conditions are the same as those given for Equation VII-1. Equation VII-4 above is Equation VII-1 solved for VS.

There is one situation where the equation above will yield an erroneous result. This is when the sign of the "$(2)(T)(\sin\frac{1}{2}\theta) + (HS)(p_c)$" term is different from the sign of the angle ϕ, when the standard sign conventions above are used. What is happening is the net horizontal force is in a direction opposite of that in which the insulator must swing. When such a situation occurs, it is a relatively simple matter of judgment what is in fact acceptable.

A proper understanding of what is involved in making an insulator swing chart can be obtained by carefully following the examples given at the end of the chapter.

H. Excessive Angles of Insulator Swing

If upon spotting a line a structure has excessive insulator swing, one or more of the steps outlined in section X.D.5 of Chapter X may be required.

Example VII-1: Tangent Structure

For the condition given below, calculate the insulator swing chart. Assume that it is desired to turn slight angles with the tangent structure given.

Given:

1. Voltage: 161 kV
   Structure: TH-10
   Conductor: 795 kcmil 26/7 ACSR
   Insulation: Standard (10 bells)

2. NESC heavy loading district
   High winds - .599 kPa (12.5 psf)
   R.S.: 244 m (800 ft.)

3. Conductor Tensions

   a. .29 kPa (6 psf) wind
      -17.7°C (0°F) 27,775 N (6,244 lbs.)
      initial tension

   b. No wind
      15.6°C (60°F) 20,608.6 N (4,633 lbs.)
      final tension

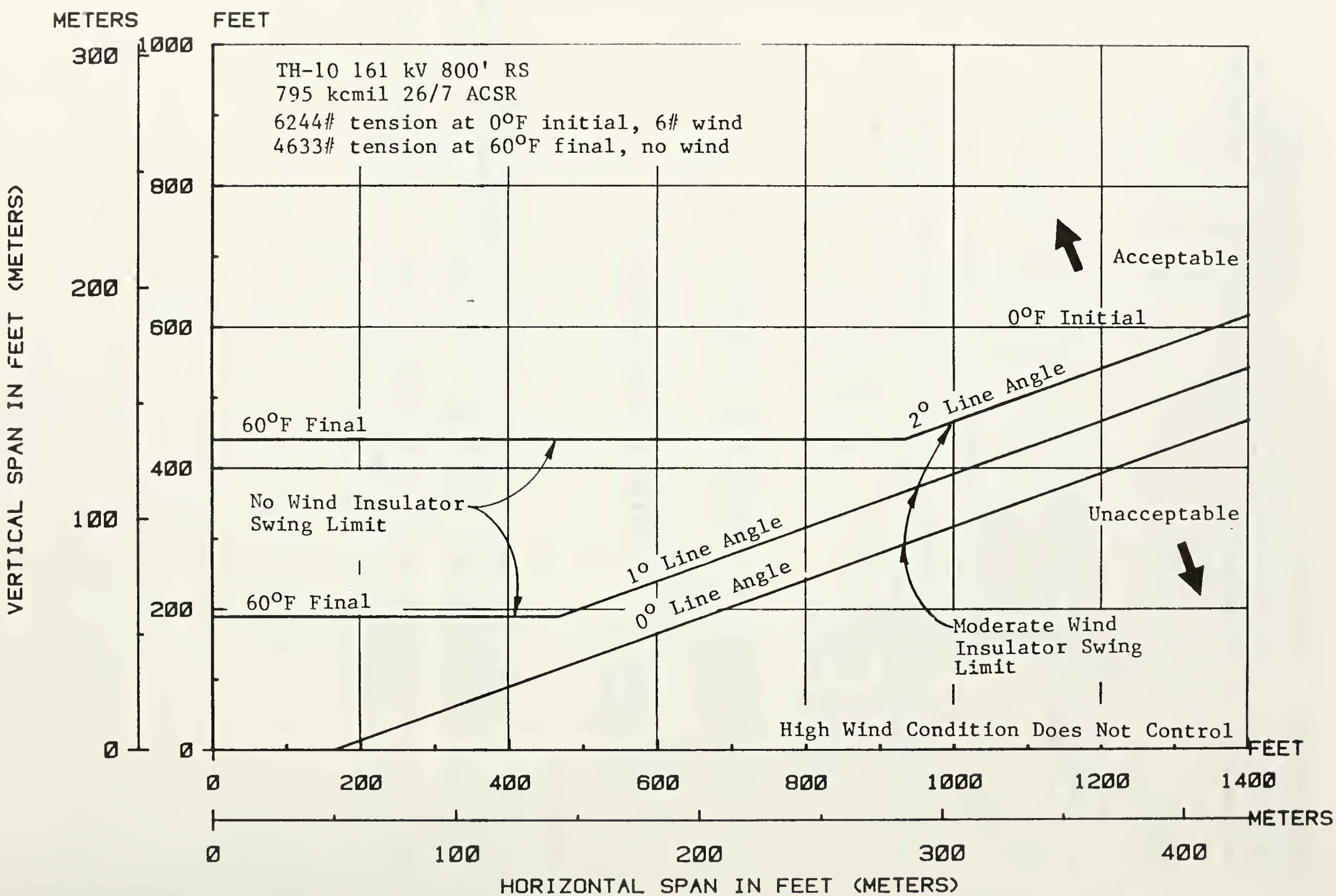
   c. .599 kPa (12 psf) wind
      0°C (32°F) 46,261.5 N (10,400 lbs.)
      final tension

Solution

Using the information on conductor sizes and weights, allowable swing angles, and insulator string weights from the appendices, the following calculation tables and the swing chart in Figure VII-6 can be determined.

Note that the high wind condition does not control, but that for some conditions, when angles are turned, the no wind condition does control.

FIGURE VII-6: INSULATOR SWING CHART FOR EXAMPLE VII-1

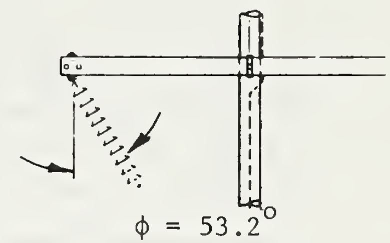


INSULATOR SWING CALCULATIONS

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

θ		HS=200	HS=400	HS=800	HS=1000
$\theta = 0^o$	$\theta = 0^o$	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)	110.80	221.60	443.20	554.00
	(a + b)	110.80	221.60	443.20	554.00
	c) (w_c)(tan φ)	1.460	1.460	1.460	1.460
	d) (a + b)/c	75.77	151.53	303.07	378.83
	e) W_i/(2)(w_c)	61.70	61.70	61.70	61.70
	d − e = VS	14.07	89.83	241.37	317.13
$\theta = 1^o$	$\theta = 1^o$	HS=200	HS=400	HS=800	HS=1000
	sin θ/2	.008727	.008727	.008727	.008727
	a) (2)(T)(sin θ/2)	108.98	108.98	108.98	108.98
	b) (HS)(p_c)	110.80	221.60	443.20	554.00
	(a + b)	219.78	330.58	552.18	662.98
	c) (w_c)(tan φ)	1.460	1.460	1.460	1.460
	d) (a + b)/c	150.29	226.05	377.59	453.35
	e) W_i/(2)(w_c)	61.70	61.70	61.70	61.70
	d − e = VS	88.59	164.35	315.89	391.65
$\theta = 2^o$	$\theta = 2^o$	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)(p_c)	110.80	221.60	443.20	554.00
	(a + b)	328.75	439.55	661.15	771.95
	c) (w_c)(tan φ)	1.460	1.460	1.460	1.460
	d) (a + b)/c	224.80	300.57	452.10	527.87
	e) W_i/(2)(w_c)	61.70	61.70	61.70	61.70
	d − e = VS	163.10	238.87	390.40	466.17

ϕ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



SKETCH

Structure TH-10 Ruling Span 800 ft.

Conductor 795 26/7 ACSR Loading Dist. (L, M, (H))

Voltage 161 kV No. of Insulators 10

Type of Insulator Swing Moderate wind

6 (F) lbs. Wind 0 °F

Cond. Dia. (d) 1.108

ϕ = 53.2 °

p_c = .554 lbs/ft.

w_c = 1.0940 lbs/ft.

T = 6,244 lbs.

W_i = 135 lbs.

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

INSULATOR SWING CALCULATIONS

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

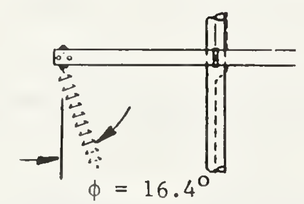
	θ	1°	2°		
	sin θ/2	.008727	.017452		
a)	(2)(T)(sin θ/2)	80.86	161.71		
b)	(HS)(p_c)	0	0		
	(a + b)	80.86	161.71		
c)	(w_c)(tan φ)	.32	.32		
d)	(a + b)/c	251.13	502.25		
e)	W_i/(2)(w_c)	61.70	61.70		
	d − e = VS	189.43	440.55		

	θ				
	sin θ/2				
a)	(2)(T)(sin θ/2)				
b)	(HS)(p_c)				
	(a + b)				
c)	(w_c)(tan φ)				
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 φ)				
d)	(a + b)/c				
e)	W_i/(2)(w_c)				
	d − e = VS				

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

φ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



SKETCH

Structure TH-10 Ruling Span 800 ft.
Conductor 795 26/7 ACSR Loading Dist. (L, M, (H))
Voltage 161 kV No. of Insulators 10
Type of Insulator Swing no wind
0 (F)lbs. Wind 60 °F

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

Cond. Dia.(d) 1.108

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

INSULATOR SWING CALCULATIONS

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

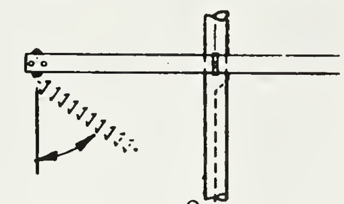
θ = 0°	$\theta = 0^o$	HS=200	HS=400	HS=800	HS=1000
	sin θ/2	0	0	0	0
	a) (2)(T)(sin θ/2)	0	0	0	0
	b) (HS)(p_c)	230.80	461.60	923.20	1154.00
	(a + b)	230.80	461.60	923.20	1154.00
	c) (w_c)(tan φ)	5.02	5.02	5.02	5.02
	d) (a + b)/c	46.00	92.00	183.99	229.99
	e) W_i/(2)(w_c)	61.70	61.70	61.70	61.70
	d - e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

θ = 1°	$\theta = 1^o$	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 φ)	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°	$\theta = 2^o$	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	923.20	1154.00
	(a + b)	593.81	824.61	1286.21	1517.01
	c) (w_c)(tan φ)	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

ϕ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.

SKETCH



Structure TH-10 Ruling Span 800 ft.

Conductor 795 26/7 ACSR Loading Dist. (L, M, H)

Voltage 161 kV No. of Insulators 10

Type of Insulator Swing high wind

12.5 (F) lbs. Wind 32 °F

ϕ = 77.7 °

p_c = 1.154 lbs/ft.

w_c = 1.0940 lbs/ft.

T = 10,400 lbs.

W_i = 135 lbs.

Cond. Dia. (d) 1.108

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

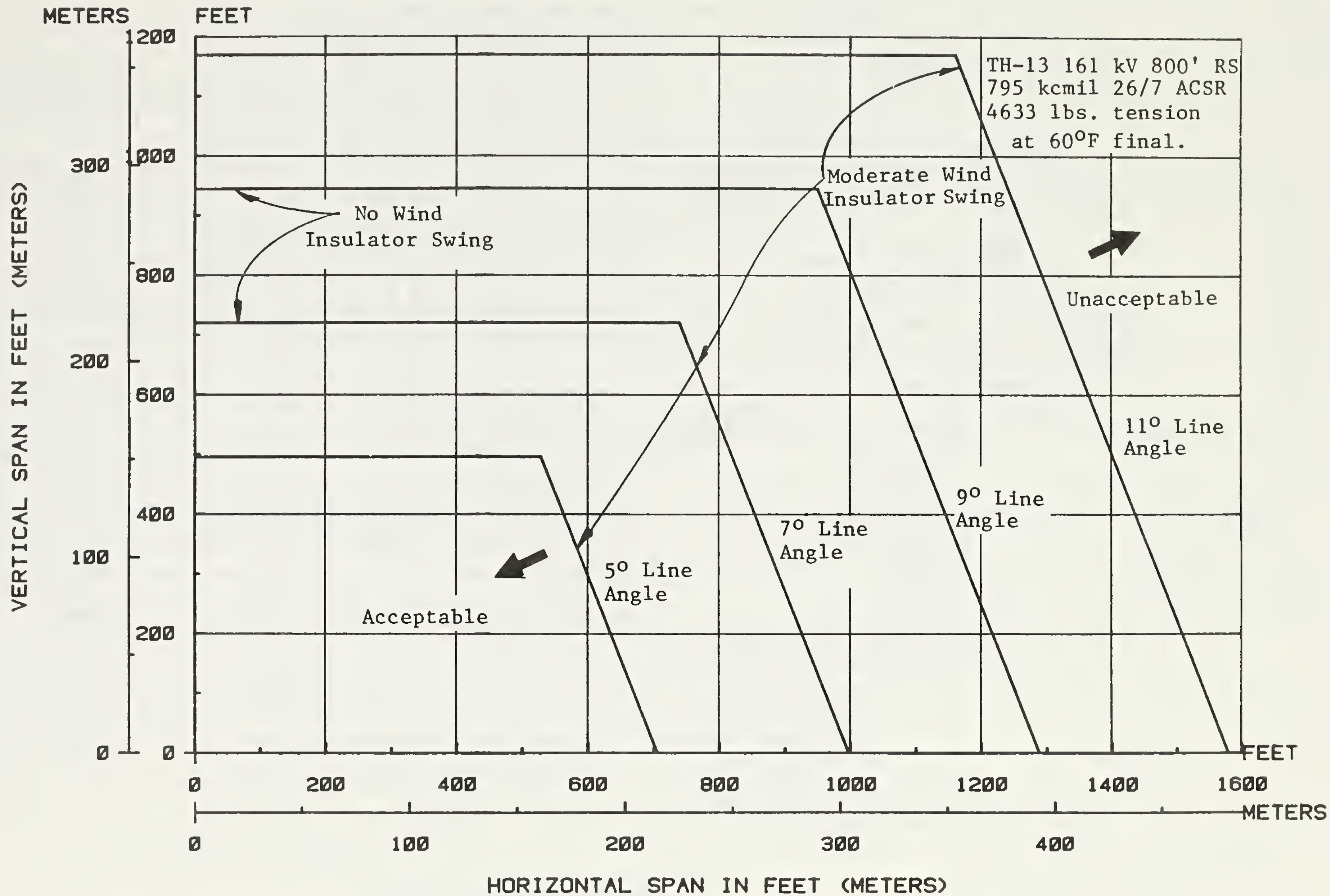
Example VII-2: Large Angle Structure

For a TH-13, calculate the insulator swing chart. Assume the same conditions as in Example VII-1.

Solution

Using the information on conductor sizes, weights, allowable swing angles and insulator string weights from the appendices, the following conductor tables and swing chart in Figure VII-8 can be determined.

FIGURE VII-8: INSULATOR SWING CHART FOR EXAMPLE VII-2



INSULATOR SWING CALCULATIONS

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

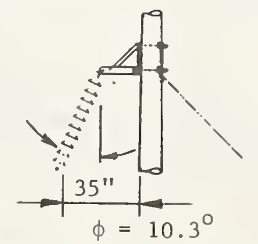
θ = 5°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	.043619	.043619	.043619	.043619
a) (2)(T)(sin θ/2)	-404.18	-404.18	-404.18	-404.18
b) (HS)(p_c)	110.80	221.60	443.20	554.00
(a + b)	-293.38	-182.58	39.02	149.82
c) (w_c)(tan ϕ)	-.20	-.20	-.20	-.20
d) (a + b)/c	1475.64	918.33	(1)	(1)
e) W_i/(2)(w_c)	67.18	67.18		
d − e = VS	1408.46	851.15		

θ = 7°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	.061049	.061049	.061049	.061049
a) (2)(T)(sin θ/2)	-565.68	-565.68	-565.68	-565.68
b) (HS)(p_c)	110.80	221.60	443.20	554.00
(a + b)	-454.88	-344.08	-122.48	-11.68
c) (w_c)(tan ϕ)	.20	-.20	-.20	-.20
d) (a + b)/c	2287.95	1730.65	616.03	(1)
e) W_i/(2)(w_c)	67.18	67.18	67.18	
d − e = VS	2220.77	1663.46	548.85	

θ = 9°	H=200	H=400	H=800	HS=1000
sin θ/2	.078459	.078459	.078459	.078459
a) (2)(T)(sin θ/2)	-727.00	-727.00	-727.00	-727.00
b) (HS)(p_c)	110.80	221.60	443.20	554.00
(a + b)	-616.20	-505.40	-283.80	-173.00
c) (w_c)(tan ϕ)	-.20	-.20	-.20	-.20
d) (a + b)/c	3099.40	2542.09	1427.48	870.17
e) W_i/(2)(w_c)	67.18	67.18	67.18	67.18
d − e = VS	3032.21	2474.91	1360.29	802.99

(1) Sign of "(a + b)" is different from that of "c". This horizontal span value is unacceptable.

ϕ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



SKETCH

Structure TH-13 Ruling Span 800 ft.
Conductor 795 26/7 ACSR Loading Dist. (L, M, (H))
Voltage 161 kV No. of Insulators 11
Type of Insulator Swing moderate wind
6 (F) lbs. Wind 60 °F

ϕ = 10.3* °
p_c = .5540 lbs/ft.
w_c = 1.0940 lbs/ft.
T = 4,633 lbs.
W_i = 147 lbs.

Cond. Dia. (d) 1.108

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

*According to the sign convention, this is a negative angle.

INSULATOR SWING CALCULATIONS

CONTINUED FROM PRECEDING SHEET

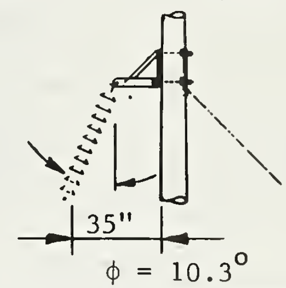
$$VS = \frac{\pm(2)(T)(\sin\theta/2) + (HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)}$$

	$\theta = 11^o$	HS=200	HS=400	HS=800	HS=1000
	$\sin\theta/2$	.095846	.095846	.095846	.095846
a)	$(2)(T)(\sin\theta/2)$	-888.11	-888.11	-888.11	-888.11
b)	$(HS)(p_c)$	110.80	221.60	443.20	554.00
	$(a + b)$	-777.31	-666.51	-444.91	-334.11
c)	$(w_c)(\tan\phi)$	-.20	-.20	-.20	-.20
d)	$(a+b)/c$	3909.73	3352.42	2237.81	1680.50
e)	$W_i/(2)(w_c)$	67.18	67.18	67.18	67.18
	$d - e = VS$	3842.54	3285.24	2170.62	1613.32

	θ				
	$\sin\theta/2$				
a)	$(2)(T)(\sin\theta/2)$				
b)	$(HS)(p_c)$				
	$(a + b)$				
c)	$(w_c)(\tan\phi)$				
d)	$(a+b)/c$				
e)	$W_i/(2)(w_c)$				
	$d - e = VS$				

	θ				
	$\sin\theta/2$				
a)	$(2)(T)(\sin\theta/2)$				
b)	$(HS)(p_c)$				
	$(a + b)$				
c)	$(w_c)(\tan\phi)$				
d)	$(a+b)/c$				
e)	$W_i/(2)(w_c)$				
	$d - e = VS$				

ϕ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



SKETCH

Structure TH-13 Ruling Span 800 ft.

Conductor 795 26/7 ACSR Loading Dist. (L, M, (H))

Voltage 161 kV No. of Insulators 11

Type of Insulator Swing moderate wind (continued)

6 (F) lbs. Wind 60 °F

ϕ = 10.3* °
p_c = .5540 lbs/ft.
w_c = 1.0940 lbs/ft.
T = 4,633 lbs.
W_i = 147 lbs.

Cond. Dia. (d) 1.108

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

*According to the sign convention, this is a negative angle.

INSULATOR SWING CALCULATIONS

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

	θ	5°	7°	9°	11°
	$\sin\theta/2$	.043619	.061049	.078459	.095849
a)	$(2)(T)(\sin\theta/2)$	-404.18	-565.68	-727.00	-888.11
b)	$(HS)(p_c)$	0	0	0	0
	$(a + b)$	-404.18	-565.68	-727.00	-888.11
c)	$(w_c)(\tan\phi)$	-.72	-.72	-.72	-.72
d)	$(a+b)/c$	562.43	787.17	1011.66	1235.84
e)	$W_i/(2)(w_c)$	67.18	67.18	67.18	67.18
	$d - e = VS$	495.25	719.98	944.47	1168.66

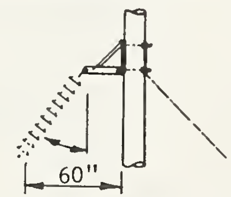
	θ				
	$\sin\theta/2$				
a)	$(2)(T)(\sin\theta/2)$				
b)	$(HS)(p_c)$				
	$(a + b)$				
c)	$(w_c)(\tan\phi)$				
d)	$(a+b)/c$				
e)	$W_i/(2)(w_c)$				
	$d - e = VS$				

	θ				
	$\sin\theta/2$				
a)	$(2)(T)(\sin\theta/2)$				
b)	$(HS)(p_c)$				
	$(a + b)$				
c)	$(w_c)(\tan\phi)$				
d)	$(a+b)/c$				
e)	$W_i/(2)(w_c)$				
	$d - e = VS$				

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

ϕ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.

SKETCH



$\phi = 33.3°$

Structure TH-13 Ruling Span 800 ft.

Conductor 795 26/7 ACSR Loading Dist. (L,M,(H))

Voltage 161 kV No. of Insulators 11

Type of Insulator Swing no wind

0 (F)lbs. Wind 60 °F

ϕ = 33.3* °
p_c = 0 lbs/ft.
w_c = 1.0940 lbs/ft.
T = 4,633 lbs.
W_i = 147 lbs.

Cond. Dia.(d) 1.108

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

*According to sign convention, this is a negative angle.

INSULATOR SWING CALCULATIONS

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

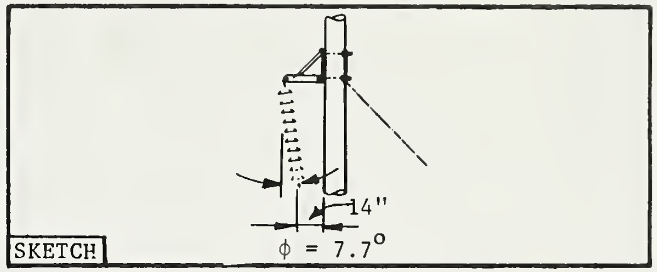
θ = 5°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	.043619	.043619	.043619	.043619
a) (2)(T)(sin θ/2)	-907.28	-907.28	-907.28	-907.28
b) (HS)(p_c)	230.80	461.60	923.20	1154.00
(a + b)	-676.48	-445.68	15.92	246.72
c) (w_c)(tan φ)	.15	.15	.15	.15
d) (a + b)/c			107.61	1667.97
e) W_i/(2)(w_c)	(1)	(1)	67.18	67.18
d - e = VS			40.42	1600.78

θ = 7°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	.061049	.061049	.061049	.061049
a) (2)(T)(sin θ/2)	-1269.81	-1269.81	-1269.81	-1269.81
b) (HS)(p_c)	230.80	461.60	923.20	1154.00
(a + b)	-1039.01	-808.21	-346.61	-115.81
c) (w_c)(tan φ)	.15	.15	.15	.15
d) (a + b)/c				
e) W_i/(2)(w_c)	(1)	(1)	(1)	(1)
d - e = VS				

θ = 9°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	.078459	.078459	.078459	.078459
a) (2)(T)(sin θ/2)	-1631.95	-1631.95	-1631.95	-1631.95
b) (HS)(p_c)	230.80	461.60	923.20	1154.00
(a + b)	-1401.15	-1170.35	-708.75	-477.95
c) (w_c)(tan φ)	.15	.15	.15	.15
d) (a + b)/c				
e) W_i/(2)(w_c)	(1)	(1)	(1)	(1)
d - e = VS				

(1) Direction of force "(a + b)" is away from structure while insulator string can be allowed to swing in toward structure. High wind does not limit.

φ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



Structure TH-13 Ruling Span 800 ft.
Conductor 795 26/7 ACSR Loading Dist. (L, M, (H))
Voltage 161 kV No. of Insulators 11
Type of Insulator Swing high wind
12.5 (F) lbs. Wind 32 °F

φ =	7.7 °
p_c =	1.154 lbs/ft.
w_c =	1.0940 lbs/ft.
T =	10,400 lbs.
W_i =	147 lbs.

Cond. Dia. (d) 1.108

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

VIII. INSULATION AND INSULATORS

A. Insulator Types

The two main types of insulators used on transmission lines today are suspension bells and pin/post units. Several suspension units must be connected in a string to achieve the insulation level desired, while with post insulators, a single unit with the desired rating is used. See Figures VIII-1 and VIII-2.

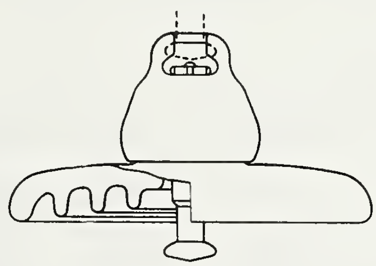


FIGURE VIII-1: A STANDARD SUSPENSION BELL

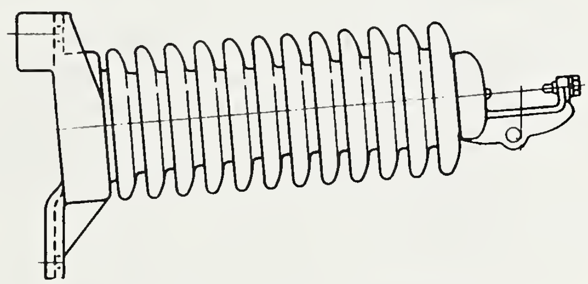


FIGURE VIII-2: A TYPICAL HORIZONTAL POST INSULATOR (FOR 69 kV LINES)

B. Standard REA Insulation Levels

Given below are the standard REA insulation levels. Less insulation than indicated may not be used without special approval from REA. However, under certain special circumstances as discussed in subsequent sections, more insulation may be warranted.

1. Suspension Insulation

a. Tangent and Small Angles

Table VIII-1 indicates the standard number of

5-3/4 x 10" suspension insulators to be used per phase on wood tangent and small angle structures. Also given are the electrical characteristics of the insulator strings.

TABLE VIII-1

REA INSULATION STANDARDS
(SUSPENSION AT TANGENT
AND SMALL ANGLE STRUCTURES)

Flashover Characteristics in kV

Nominal L-L Voltage in kV	No. of 5-3/4x10" Bells	Low Freq. Dry	Low Freq. Wet	Pos. Impulse	Neg. Impulse	Total Leakage Distance in m (in.)
34.5	3	215	130	355	340	.876 (34.5)
46	3	215	130	355	340	.876 (34.5)
69	4	270	170	440	415	1.17 (46)
115	7	435	295	695	670	2.04 (80.5)
138	8	485	335	780	760	2.34 (92)
161	10	590	415	945	930	2.92 (115)
230	12	690	490	1105	1105	3.51 (138)

b. Angles

For angle structures where the conductor tension is depended upon to pull the insulator string away from the structure, one more insulator bell than used on tangent structures should be used. The sole exception to this is 34.5 kV where no additional bells are used.

c. Deadends

In situations where the insulator string is in line with the conductor; that is, where the conductor is deadended on to an insulator string, two more bells than used on tangent structures should be used. The sole exception to this is 34.5 kV where one additional bell is used.

2. Post Insulators

Given below are the electrical characteristics for horizontal post insulators that may be used on REA systems.

TABLE VIII-2

REA INSULATION STANDARDS
(POSTS AT TANGENT AND SMALL ANGLE STRUCTURES)

Flashover Characteristics in kV

L-L kV	Low Freq. Dry	Low Freq. Wet	Pos. Impulse	Neg. Impulse	Total Leakage Distance in m (in.)
34.4	125	115	210	260	.73 (29)
46					
69	200	180	330	425	1.35 (53)
115	380	330	610	780	2.54 (100)

C. Electrical Characteristics

Low frequency dry flashover ratings are generally the most common flashover values referred to when comparing insulators because the values are the most easily and accurately tested for. However, it is probably the least significant of the electrical characteristics of an insulator as flashover (60 Hz) of an insulator in service almost never occurs under normal dry operating conditions. When comparing different types of insulators (e.g. post vs suspension), the other characteristics such as impulse and wet flashover do not necessarily follow the same pattern as the low frequency dry flashover ratings. Since for voltages up to 230 kV the most severe stress on the insulation is usually caused by lightning, the most important flashover characteristic is the impulse flashover values as the wave shape used to make the test most closely imitates the shape of a lightning surge.

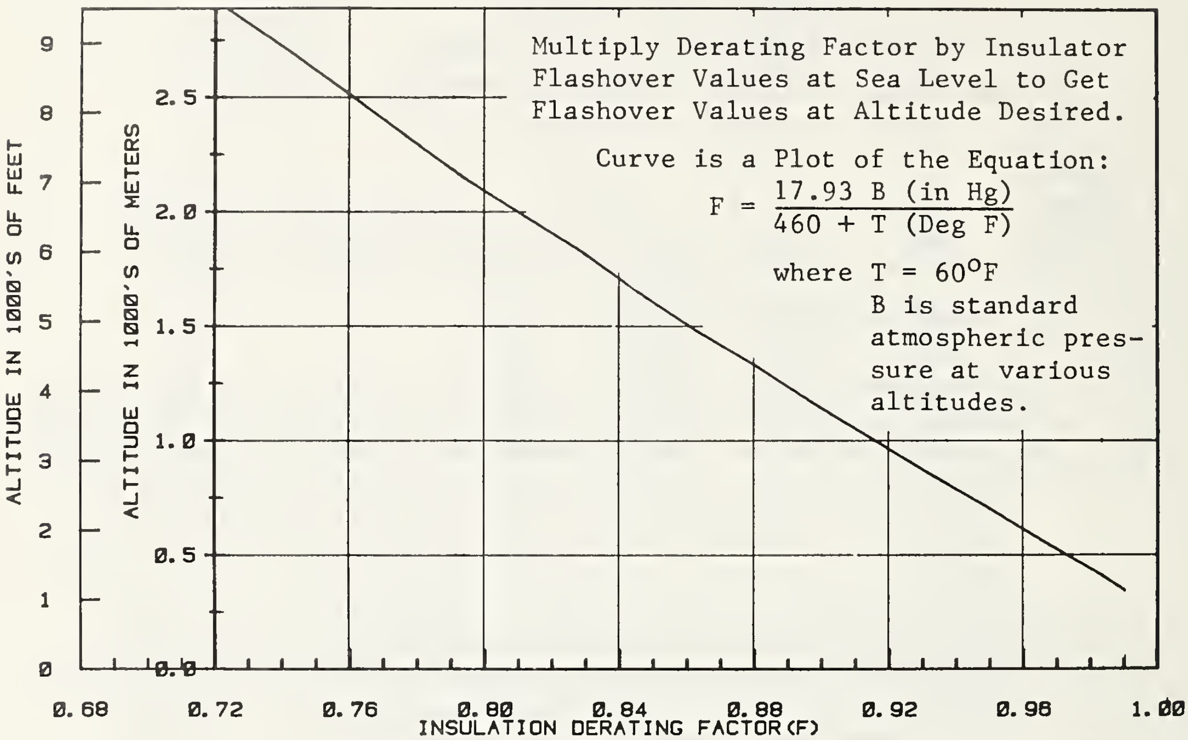
D. High Altitude Considerations

1. General

As altitude increases, the insulation value of air decreases so that an insulator at a high elevation will flashover at a lower voltage than the same insulator at sea level. Figure VIII-3 below gives the derating factors for insulator flashover values as a function of altitude. The derating factors apply to both the low frequency flashover values and the impulse flashover values.

For example, if the low frequency dry flashover value of seven standard insulator bells is 435 kV, then at an altitude of 1800 meters (6000 feet), it will be 435 kV x .827 = 360 kV (where .827 is obtained from Figure VIII-3).

FIGURE VIII-3
INSULATION DERATING FACTOR
VS. ALTITUDE IN 1,000's OF
METERS (FEET) (230 kV AND BELOW)



In addition to increasing the number of insulators for higher altitude, it is also necessary to increase the structure air gap clearances. This could result in either a decreased allowable insulator swing angle or a larger crossarm (see Chapter VII for details).

2. Insulation Design for High Altitudes

The following is a guide for determining when additional insulation should be used to compensate for higher altitudes.

a. Lines with Relatively Small Changes in Altitude

When the insulation derating factor for the line altitude is at a value less than approximately 90 percent of the insulation value at sea level (see Figure VIII-3), then additional insulation should be added to bring the insulation level up to at least 90 percent of the sea level value.

b. Lines with Significant Elevation Changes

(1) Elevation Changes Less than 1500 Meters (5000 Feet)

If the elevation change in a line from its low point to its highest point is less than 1500 meters (5000 feet), it is recommended that insulation for the entire length of the line be based on the weighted average altitude of the line by applying the procedure given in "a" above to that altitude.

(2) Elevation Changes Greater than 1500 Meters (5000 Feet)

Where the elevation change is greater than 1500 meters (5000 feet), the following two steps should be taken:

(a) The entire line insulation should be upgraded for the minimum altitude of the line using the procedure in "a" above.

(b) In sections of line where the altitude of the line increases to the point where the insulation value is less than approximately 90 percent of the insulation value at the minimum line altitude, additional insulation should be used in that section. Thus on the same line there may be different numbers of insulator bells at different points along its length.

E. Lightning Considerations

1. General

Transmission lines are subjected to three types of voltage stress that may cause flashover of the insulation: power frequency voltage, switching surges, and lightning surges. Flashovers due to power frequency voltages are primarily a problem in contaminated conditions and are discussed in section VIII.F. Of the remaining two causes of flashovers, lightning is the more severe for lines of 230 kV and below.

2. Lightning Flashover Mechanism

When lightning strikes a transmission line, it can either hit the overhead ground wire or the phase conductors. If a phase conductor is hit, there will almost certainly be a flashover of the insulation. Thus to avoid this near certainty of a flashover, an overhead ground wire (OHGW) is used to intercept the lightning strokes. In order that a shielding failure* not occur, the shielding angle, which is the angle measured from the vertical between the OHGW and the phase conductors (see Figure VIII-4 below), should be kept at 30^{o} or less. On H-frame structures where there are two overhead ground wires used, the center phase may be considered to be properly shielded even if the shielding angle to it is greater than 30^{o}. For structures whose height is in excess of 28 meters (92 feet), shielding angles of less than 30^{o} as indicated in Table VIII-3 should be used. In situations where there is an unusually high exposure to lightning, such as at river crossings, an even smaller shielding angle may be warranted.

TABLE VIII-3

REDUCED SHIELDING ANGLE VALUES

Structure Height in Meters (Feet)	Recommended Shielding Angle in Degrees
28 (92)	30
30 (99)	26
35 (116)	21

If a lightning stroke strikes an overhead ground wire, a traveling current wave will be set up which will in turn induce a traveling voltage wave. This voltage wave will generally increase in magnitude as it travels down the wire until it reaches a structure where the reflection of the traveling wave from the ground (the OHGW is grounded at every structure) will prevent the voltage from increasing further. If the traveling voltage wave at the structure is sufficiently high, a "back flashover" across the insulation from the ground wire or overhead ground wire to the phase conductor will occur. The factors that determine whether or not a back flashover will

*A shielding failure is where the lightning stroke misses the overhead ground wire and hits the phase conductor.

occur are the amount of insulation, the footing resistance (for the higher the footing resistance, the higher the voltage rise at the structure), and the span length.

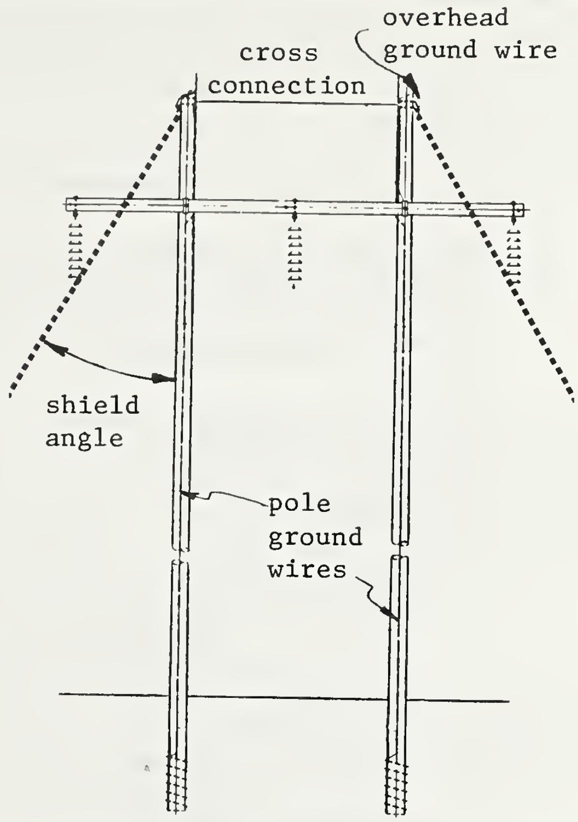


FIGURE VIII-4: SHIELDING ANGLE AND POLE AND OVERHEAD GROUND WIRES

3. Designing for Lightning

a. Overhead Ground Wires

Except where the isokeraunic level is below 20 (see Figure E-1 in Appendix E which gives the number of thunderstorm days per year or "isokeraunic level"), all lines should have overhead ground wires which should be grounded at every structure by way of a structure ground wire. At H-frame structures, the OHGW's should each be connected to a structure ground wire and to one another so that if one structure ground breaks, both overhead ground wires will still be grounded.

In areas where the isokeraunic level is 20 or less, an overhead ground wire should still be used for a distance of .8 kilometer (.5 mile) out of a substation.

b. Line Insulation (All Wood Structures)

The REA standard levels of insulation have proven to provide satisfactory performance. Only under the most unusual of conditions should extra insulation be considered.

c. Line Insulation (Structures with Steel Arms)

When steel arms or all steel structures are used in areas where there is a high isokeraunic level, consideration should be given to the use of one additional suspension bell beyond the standard REA insulation levels.

d. Footing Resistance

(1) General

For satisfactory lightning performance of a line, low footing resistance is essential. Exactly what value of footing resistance is acceptable or unacceptable is not a simple matter as it depends upon several variables. Previous successful experience with a similar line in similar cirstances can be one guide. The following may be useful in determining what lightning outage rate a given footing resistance would yield.

(a) Transmission Line Reference Book, 345 kV and Above, Palo Alto, Calif., Electric Power Research Institute, 1975.

(b) "Estimating Lightning Performance of Transmission Lines," J. M. Clayton and F. S. Young. IEEE Transactions on Power Apparatus and Systems, November 1964, pp. 1102-1110.

A lightning outage rate of 1 to 4 per 160 km (100 miles) per year is acceptable with the lower number more appropriate for lines in the 161 to 230 kV range.

Generally, experience has shown that the footing resistance of individual structures of the line especially within .8 kilometer (.5 mile) of the substation should be less than 30 ohms.

(2) Measuring Footing Resistance

It is recommended that as a line is built that the footing resistance of the ground connection be measured and recorded on a spot check basis. If footing resistance problems are expected, more readings should be made. If experience indicates that the lightning outage rate is not acceptable, these readings can be useful in taking remedial measures.

Footing resistance should not be taken immediately after a rain when the soil is moist.

(3) High Footing Resistance

If footing resistance higher than desired is encountered, driven rods may be used to reduce it. If the earth's resistivity is very high, counterpoise rather than driven rods may be required. See reference (b) above for guidance in the selection of counterpoise.

F. Contamination Considerations

If a line is to be built near a seacoast, an industrial district, or at other locales where airborne contaminants may build up on insulators, the problem of contamination induced flashovers must be considered.

1. Contamination Flashover Mechanism

When the layer of contaminants on an insulator is moistened by fog, dew, light rain, or snow, it will become more conductive and the leakage current along the surface of the insulator will greatly increase. Where the current density is the greatest (for suspension insulators near the pin and for post insulator at the points of least diameter), heat caused by the increased leakage current will evaporate the moisture causing the formation of a dry band. These bands usually have a higher resistance than the adjacent moistened area which means that they will support almost all the voltage across them. This will result in the breakdown of the air and an arc forming across the dry band. The arc will cause the moisture film at the dry band edges to dry out enlarging the dry band, eventually to the point where the band is just below the air breakdown value and if an increase in precipitation occurs causing a lowering of contaminant resistance, a second breakdown would occur. If conditions are right, a cycle of repeated and ever-increasing surges will be set up which will result in several discharges joining together, elongating and bridging the entire insulator and resulting in a power arc.

2. Effect of Insulator Orientation

The orientation of the insulators has an effect on contamination performance. Vertical strings of suspension insulators or vertical post insulators do not wash well in the rain because of the sheltering effects of the insulator skirts. Contaminants will tend to remain on the underside of the insulator which is not immune from the moistening effects of fog or wind blown rain and snow. Horizontally oriented suspension insulators and post insulators have their undersides more thoroughly washed by the rain and therefore tend to fare better in contaminated areas than vertical insulators. Of course, if it does not rain, the better washing does not make a difference. Another advantage of insulators in nonvertical positions is that any ionized gases caused by arcing will not be of any aid in setting up conditions where an arc could jump from one bell to another or along the skirts of a vertical post.

3. Designing for Adverse Contamination Conditions

There are several means available for improving line insulation performance in a contaminated atmosphere.

a. Increased Leakage Distance

One way to compensate for contaminated conditions is to increase the leakage distance of the insulation. The leakage distance is the distance along the surface of the insulators from the top of the string (or post) to the energized hardware, not including any metal such as insulator caps and pins.

Table VIII-4 gives recommended leakage distances for various levels of contamination. The increased leakage distance can be obtained by either adding additional standard insulator bells (using a longer post insulator) or by using fog insulators which have more leakage distance for the same overall insulator length. The additional leakage distance on fog insulators is obtained by having more and/or deeper skirts on the underside of the insulator bell. The shape of the insulator, in addition to the leakage distance has an effect on contamination performance especially when fog units are being used. Therefore,

TABLE VIII-4

SUGGESTED LEAKAGE DISTANCES FOR CONTAMINATED AREAS

Pollution Level	Environment	Equivalent Amount NaCl mg/cm^2	Suggested Leakage Distance mm/kV rms L-G (in/kV)
Very light	Areas without industries and with low density of houses equipped with heating plants; areas with some density of industries or houses but subject to frequent winds and/or rainfall. All areas must be situated far from the sea or at a high altitude and must in any case not be exposed to winds from the sea.	0-0.03	NA-25 mm (NA-1.0 in.)
Light	Areas with industries not producing particularly polluting smoke and/or with average density of houses equipped with heating plants; areas with high density of houses and/or rainfall; areas exposed to winds from the sea but not too close to the coast.	0.03-0.06	25-32 mm (1.0-1.25 in.)
Moderate	Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution; areas close to the sea or in any case exposed to relatively strong winds from the sea.	0.06-0.1	38-44 mm (1.5-1.75 in.)
Heavy	Areas generally of moderate extent, subjected to industrial smoke producing particularly thick conductive deposits; areas generally of moderate extent, very strong and polluting winds from the sea.	0.1-.25	50-64 mm (2.0-2.5 in.)

experience with various types of fog units should be taken into account.

One very important factor that should be taken into account in considering contamination problems associated with insulation is previous successful insulation designs being used in the same area or in other areas where there are similar conditions.

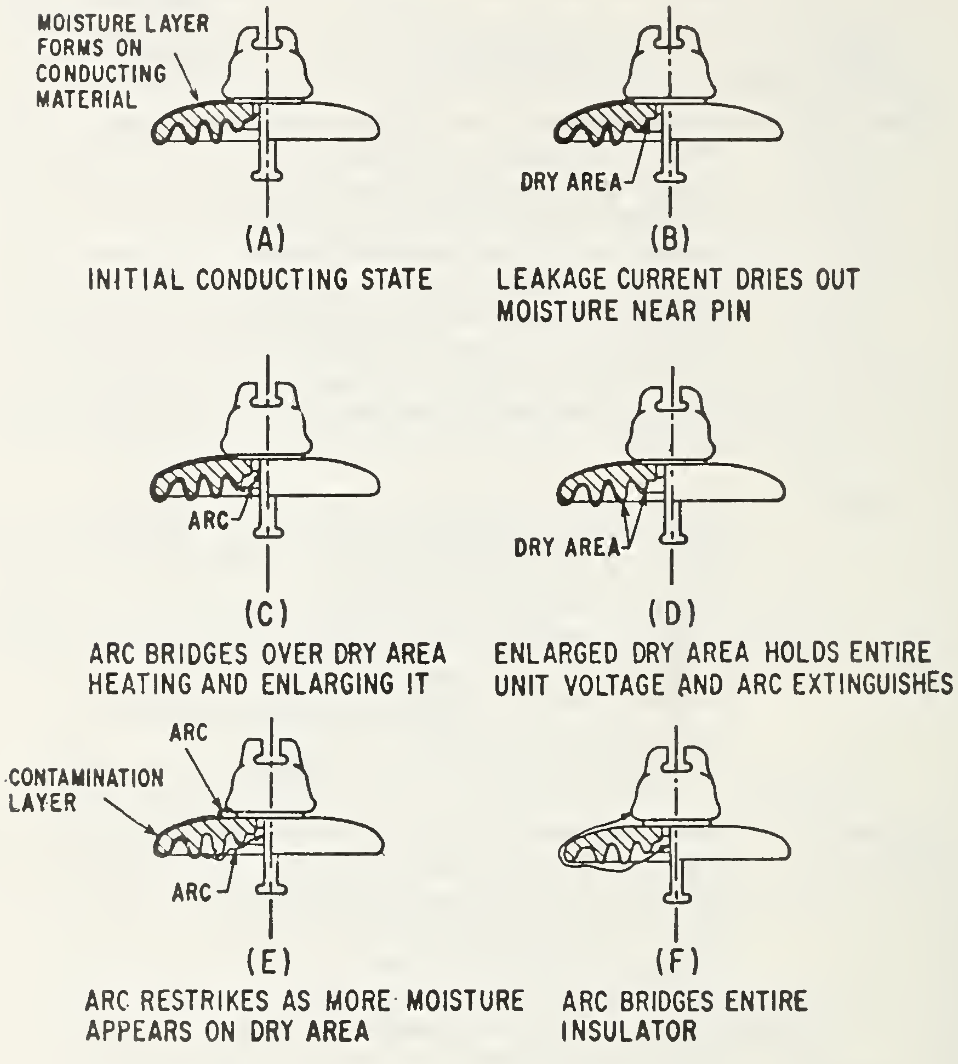


FIGURE VIII-5: THE CONTAMINATION BREAKDOWN PROCESS OF A SINGLE INSULATOR UNIT.

b. Resistance Graded Insulator*

An alternative to increasing the total leakage distance of the insulator string is to use a resistance graded insulator. These insulators have a glaze that permits a small but steady leakage current to flow over their surface. This leakage current gives the insulator much better contamination performance without having to increase leakage distance. In determining whether to use this type of insulator, its advantages and disadvantages as listed below must be weighed against one another.

ADVANTAGES

- No extra leakage distance required.
- No washing, or at least much less washing of insulators required.
- No radio noise (due to more even voltage distribution across string).

DISADVANTAGES

- Higher initial costs.
- Small but continuous power loss.
- They do not always prevent contamination flashovers in very heavily contaminated areas.

The base of the resistance graded insulator should be solidly bonded to the structure ground wire to permit the leakage current to flow easily to the ground.

c. Insulation Washing

The washing of the insulators in order to remove the contaminants is a step that can help. This step should not be used in place of properly designing for contamination but rather should be used in addition to the other steps where it is felt necessary.

*Requires special approval, units not listed in REA Bulletin 43-5, "List of Material Acceptable for Use on Systems of REA Electrification Borrowers."

d. Insulation Greasing

The performance of insulators in a contaminated environment can be improved by coating the surface with a suitable silicone grease. The grease absorbs the contamination and repels water. It is necessary, however, to remove and replace the grease at intervals determined by the degree of contamination. As with washing, the use of a grease should only be considered as a remedial step. Resistance graded insulators should not be greased.

G. Mechanical Considerations

1. Suspension Insulators

Under standard NESC loading district conditions, suspension insulators must not be loaded to more than 50 percent of their M&E* rating. If a heavier loading than the standard NESC loading can be expected to occur with reasonable regularity, then the 50 percent loading limit should be maintained at the higher loading limit. It should be noted that suspension insulators have a "test" value marked on them that is half of the M&E rating value.

Under extreme ice or high wind** (50-year mean recurrence interval wind conditions) the load on the insulator should not exceed 80 percent of the M&E strength of the insulator (160 percent of the "test" value).

Generally, insulators with a 15,000 pound M&E rating will be satisfactory. However, stronger insulators may be needed on long spans with large conductors and at deadends and angles where the insulators carry the resultant conductor tension.

2. Post and Pin Insulators

a. Vertical Post and Pin Insulator Mounted on Crossarms

The maximum transverse load, whether from standard NESC loading district loadings alone or from a combination of loading district loading and the resultant of conductor tension on line angles, must be

---

*M&E strength is a value determined by a combined mechanical and electrical test where the insulator has a voltage impressed across it while a mechanical load is gradually applied to the insulator. See ANSI C29.1.

**See Chapter XI for further discussion of extreme ice and wind.

limited to 2,224 N (500 lbs.) for standard REA structures. It is possible that greater limiting values may be obtained through the use of special structural modifications. The limit will prevent excessive stress on the insulator, the tie wires (if used), insulator pin (if used), and the wood of the crossarm. Structures with double insulator support may be used with a maximum transverse load of 4,448 N (1,000 lbs).

b. Horizontal Post Insulators

(1) Cantilever Loading

Under NESC loading district conditions, horizontal post insulators must not be loaded to more than 40 percent of their ultimate cantilever strength. As with suspension insulators, if a loading more severe than the NESC loading can be expected to occur with reasonable regularity, then the higher loading should be used.

The cantilever load on horizontal post insulators, under extreme ice conditions, must not exceed 70 percent of the ultimate strength.

(2) Tension Loading

When a line angle is turned at a horizontal post structure, some or all of the insulators will be in tension. Under either standard NESC loading conditions or more severe conditions, if deemed warranted, the tension load on the insulator must not exceed 50 percent of the ultimate tension strength of the insulator.

Under extreme loading conditions*, the tension load must not exceed 80 percent of the tension strength of the insulator.

(3) Combined Loading

The loading limits in (1) and (2) above, apply simultaneously. The cantilever loading limit is not affected by the tension limit.

*See Chapter XI for further discussion of extreme ice and wind.

3. Coordination of Insulator Strength with Strength of Associated Hardware

Care should be taken to coordinate the strength of the hardware associated with the insulator with the strength of the insulator itself. See Chapter XV.

TABLE VIII-5

SUMMARY OF INSULATOR LOADING LIMITS

Insulator Type	NESC Loading District Loading	Extreme Loading*
Suspension	50%	80%
	(% of M&E strength)	
Horizontal Post		
Cantilever	40%	70%
Tension	50%	80%
	(% of appropriate rated strength value)	
Vertical Post or Pin Insulator Mounted on the Crossarm	2,224 N (500 lbs.)	—

*See Chapter XI for further discussion.

H. Special Considerations for Horizontal Post Insulators

There are two special considerations that must be mentioned in relation to horizontal post insulators.

1. Insulator Grounding

Where the structure ground wire passes near horizontal post insulators, it must be either stood off from the pole by means of a nonconducting strut or must be solidly bonded to the base of the insulator. This is necessary to avoid radio noise problems.

2. Mechanical Overload Problems

Post insulators mounted on steel, concrete, or in some cases, on wood structures using H-class poles, have in the past experienced cascading mechanical failures due to impact loads because of the relative rigidity of the structures. In order to avoid such occurrences, it is recommended that on rigid structures, the post insulators be equipped with deformable bases, shear pin devices, or other such means of relieving mechanical overloads.

Example VIII-1: Additional Insulation for High Altitudes

A 161 kV line is to be built in an area whose altitude ranges from 1655 m (5430 ft) to 2310 m (7580 ft). Determine how much additional insulation, if any, is necessary.

Solution

The elevation change for the line from its lowest point to its highest point is less than 1500 m (5000 ft), and therefore the insulation should be based on the weighted average altitude. Since we do not know the distribution of the line at the various altitudes, we will have to assume a uniform distribution. Thus:

$$\text{average altitude} = \frac{1655 + 2310}{2} = 1982.5 \text{ m}$$

$$\text{average altitude} = \frac{5430 + 7580}{2} = 6505 \text{ ft.}$$

From Figure VIII-3 the derating factor for an average altitude of 1982.5 m (6505 ft) is .81 and since section VIII.D.2.a indicates that additional insulation is needed if the derating factor is less than .90, additional insulation will be needed here.

Let us try one additional bell at this voltage. One additional bell means a total of 11. From Appendix C, the low frequency dry flashover of 11 bells is 640 kV. Taking into account the derating factor, the low frequency dry flashover value of this string is:

$$(.81)(640 \text{ kV}) = 518 \text{ kV}$$

According to the text, the insulation value should be brought up to approximately 90 percent of the sea level value which for 161 kV is:

$$(.9)(590 \text{ kV}) = 531 \text{ kV}$$

(590 kV is the low frequency dry flashover value of 10 bells at sea level).

Therefore, the addition of one extra bell will not quite bring the insulation level up to the 90 percent of sea level value which would seem to indicate the necessity of adding two extra bells. Some judgment should be exercised as to whether the second additional bell is used. Even though only one bell extra does not quite provide enough additional insulation, it is close and if the expected frequency and severity of lightning storms is not particularly high, it will probably be sufficient.

The final answer is that at least one and possibly two extra bells are necessary depending upon experience and judgment.

Example VIII-2: Maximum Vertical Span Due to Horizontal Post Insulator Strength

A 115 kV line is to be built using horizontal post insulators with a cantilever strength of 12,460 Newtons (2,800 pounds). The conductor to be used is 795 kcmil 26/7 ACSR. Determine the maximum vertical span under a) heavy loading district conditions and b) under an extreme ice load, no wind, and 38 mm (1.5 in.) of radial ice (see Chapter XI for definitions of heavy loading and Chapter IX for information on conductors).

Solution

1. From Appendix B, Conductors, the weights per unit length for the two conditions of the conductor are:

   Heavy loading:

12.7 mm (½ in)	38 mm (1.5 in)
Radial ice:	
2.0938 lbs/ft.	5.9588 lbs/ft.
30.557 N/m	86.962 N/m

   (Metric value converted from English value listed in table).

2. Heavy Loading District:

$$\frac{2800 \text{ lbs}(.40)}{2.0938 \text{ lbs/ft}} = 534.9 \text{ ft.}$$

$$\frac{12460 \text{ N}(.40)}{30.555 \text{ N/m}} = 163.1 \text{ m}$$

   Extreme Ice:

$$\frac{2800 \text{ lbs}(.80)}{5.9588 \text{ lbs/ft.}} = 375.9 \text{ ft.}$$

$$\frac{12460 \text{ N}(.80)}{86.958 \text{ N/m}} = 114.6 \text{ m}$$

   The maximum vertical span is therefore 114.6 m (375.9 ft.)

Example VIII-3: Insulator M&E Ratings

A conductor has a maximum tension under heavy loading district conditions of 46,124 N (10,369 lbs) and under extreme radial ice of 38 mm (1.5 in). It has a maximum tension of 77,728 N (17,474 lbs.). Determine the minimum M&E rating of suspension insulators to be used in tension strings (those insulator strings that are in line with the conductor and bear its full tension).

Solution

1. Under NESC loading district conditions, the insulator can be loaded up to 50 percent of its M&E rating. Therefore:

$$(\text{M\&E rating})(.5) = \text{load}$$

$$\text{M\&E rating} = \frac{\text{load}}{.5}$$

$$\text{M\&E rating} = \frac{46121 \text{ N}}{.5} = 92242 \text{ N}$$

$$\text{M\&E rating} = \frac{10369 \text{ lbs.}}{.5} = 20738 \text{ lbs.}$$

2. Under extreme ice conditions the insulator can be loaded to 80 percent of its M&E rating. Therefore:

$$(\text{M\&E rating})(.8) = \text{load}$$

$$\text{M\&E rating} = \frac{\text{load}}{.8}$$

$$\text{M\&E rating} = \frac{77724 \text{ N}}{.8} = 97155 \text{ N}$$

$$\text{M\&E rating} = \frac{17474 \text{ lbs.}}{.8} = 21843 \text{ lbs.}$$

This case governs.

3. Since insulators are made in discrete M&E values, the lowest standard value that could be used is 111206 N (25000 lbs.).

IX. CONDUCTORS AND OVERHEAD GROUND WIRES

A. Introduction

Of all the components that go into making up a transmission system, nothing is more important than the conductors. There are a surprising number of variables and factors that must be considered when dealing with conductors. Some of these are:

1. Conductor type
2. Conductor size
3. Economic considerations
4. Conductor thermal capacity
5. Conductor tensions
6. Corrosive atmosphere considerations
7. Radio noise
8. Conductor motion considerations

B. Types of Conductors

There are several types of conductors currently available, some of which are used much more extensively than others. Given below is a list and description of many of the conductor types. It should be emphasized that some of the conductors are not listed in REA Bulletin 43-5, "List of Materials Acceptable for Use on Systems of REA Electrification Borrowers," and would require special approval by REA for their use. Those conductor types that are listed are indicated below by an asterisk.

1. ACSR (Aluminum Conductor Steel-Reinforced) 6/1, 26/7, and 54/7 Strandings

   This is the most common type of conductor used today. It is a concentrically stranded conductor composed of one or more layers of hard-drawn 1350 aluminum* wire stranded with a high-strength galvanized steel core. The core may be single wire or stranded depending on the size. Because of the numerous stranding combinations of aluminum and steel wires that may be used, it is possible to vary the proportions of aluminum and steel so as to obtain a wide

*For description of material see section on 1350 aluminum conductors.

range of current carrying capacities and mechanical strength characteristics.

The steel core may be furnished with three different coating weights of zinc. The standard weight zinc coating is the "A" coating. To provide better protection where corrosive conditions are present, a Class "B" or "C" zinc coating may be specified where "C" is the heaviest. Also available is an aluminum coating, aluminized, (not to be confused with an aluminum cladding which is thicker). There is a slight reduction in the conductor rated strengths when the heavier zinc and aluminized coatings are used.

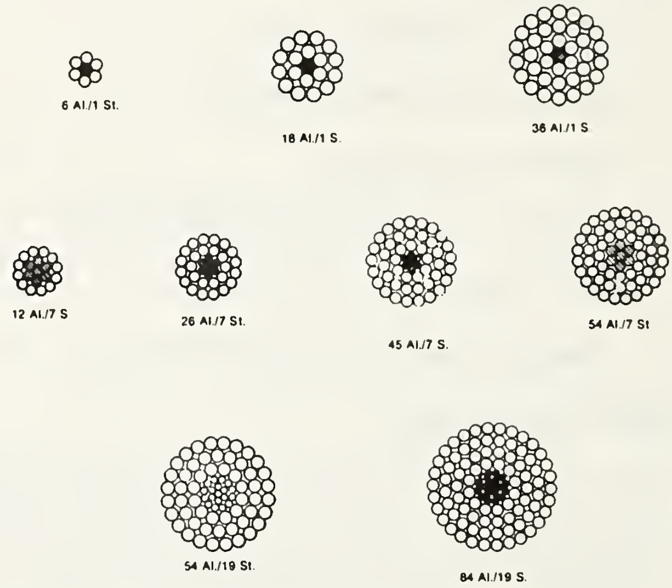


FIGURE IX-1: REA LISTED TYPICAL ACSR STRANDINGS

2. ACSR/AW (Aluminum Conductor, Aluminum-Clad Steel Reinforced)

This type of conductor is similar to conventional ACSR except the core wires are high strength aluminum-clad steel instead of galvanized steel. Aluminum-clad core wire, with its minimum aluminum thickness of 10 percent of the nominal wire radius, provides a greater protection against corrosion than any of the other types of steel core wire, thus making it applicable for use in areas where corrosive conditions are severe. Its tensile strength and stress at 1 percent extension are somewhat less than that for Class "A" galvanized coated steel core wire. However, it has a significantly lower resistivity than galvanized steel core wire which may result in somewhat lower losses.

3. 1350 Aluminum Conductors

This conductor is made up entirely of hard-drawn 1350* aluminum strands. It is usually less expensive than other conductors, but it is not as strong and tends to sag more. It is most useful where electrical loads are heavy and where spans are short and mechanical loads are low.

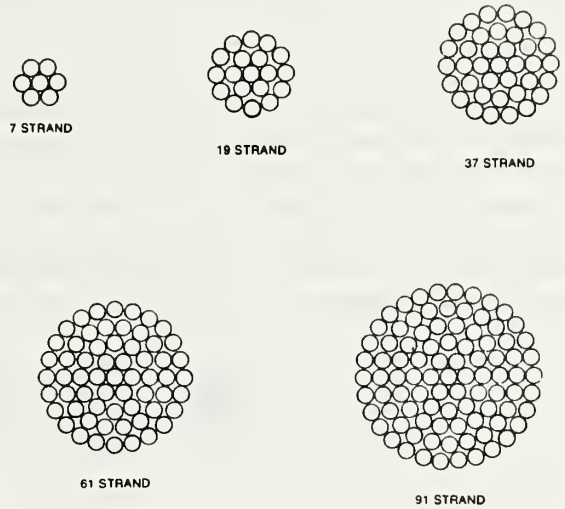


FIGURE IX-2: 1350 ALUMINUM CONDUCTOR STRANDINGS

4. AAAC-6201 (All Aluminum Alloy Conductor - 6201 Alloy)

This type of conductor is composed entirely of 6201-T81 high strength aluminum alloy wires, concentrically stranded and similar in construction and appearance to 1350 aluminum conductors. Its strength is comparable with that of ACSR.

It was developed to fill the need for a conductor with higher strength than that obtainable with 1350 aluminum conductors, but without a steel core.

The constructions were designed to have diameters the same as those of standard sizes and strandings of ACSR. The DC resistance of the 6201 conductors and of the standard ACSR's of the same diameters are approximately the same. This conductor may be used where contamination and corrosion of the steel wires is a problem. It has proven to be somewhat more susceptible to vibration

*1350 aluminum is essentially a pure aluminum (minimum aluminum content 99.5%).

problems than standard ACSR conductors strung at the same tension. The use of conductor sizes smaller than 3/0 ACSR equivalent on suspension type constructions should be avoided because the light weight of the conductor may result in inadequate downward force on the suspension insulators causing radio noise and insulator swing problems.

5. <u>ACAR (Aluminum Conductor Alloy Reinforced)</u>

This type of conductor consists of 1350 aluminum strands reinforced by a core and/or otherwise distributed wires of higher strength 6201 alloy. Because the 6201 reinforcement wires in ACAR may be used in varying amounts, almost any desired property of strength-conductivity between constructions using all 1350 wires and those using all 6201 wires may be achieved. Strength and conductivity characteristics of ACAR are somewhat between those of a 1350 aluminum conductor and a 6201 conductor.

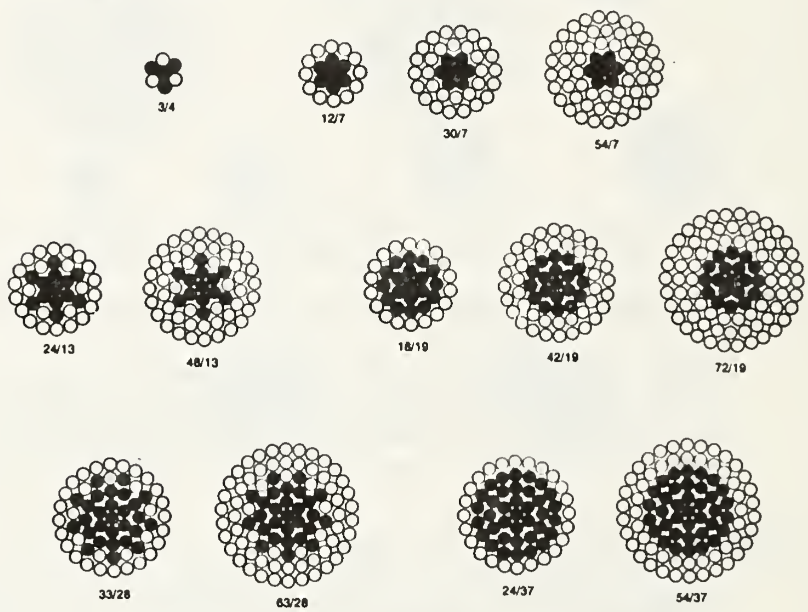


FIGURE IX-3: ACAR STRANDINGS

6. <u>AWAC (Aluminum-Clad Steel Conductor)</u>

This conductor is made up of aluminum-clad steel and 1350 aluminum strands. This conductor includes the aluminum content of the aluminum-clad strands in the total aluminum cross-sectional area. For the same designated size and stranding, the AWAC conductors have a slightly smaller diameter than standard ACSR. For smaller AWAC sizes, the ratio of aluminum-clad to aluminum strands is varied to provide a wide range of rated strengths.

7. ACSR/SD (Aluminum Conductor Steel Reinforced - Self Damping)

This type of special conductor has been in moderately widespread use for several years. It is a concentrically stranded conductor composed of two layers of trapezoidal-shaped wires or two layers of trapezoidal-shaped wires and one layer of round wires of hard-drawn 1350 aluminum stranded with a steel core. The core may be a single wire or stranded depending on the size.

From a performance point of view, the conductor is the same as conventional ACSR except that it is self damping; that is, the conductor is designed to limit aeolian vibration to a safe level. The damping occurs because of the interaction between the two trapezoidal layers and between the trapezoidal layers and the core. To date, experience with this type of conductor has been generally good. It does appear to do a satisfactory job of damping out aeolian vibration. Some special considerations associated with this conductor are that (1) during stringing, special precautions must be taken and procedures followed to avoid difficulties, and (2) it is more expensive per pound than conventional ACSR, but its ability to be strung at higher tensions may result in economic advantages that outweigh its extra cost.

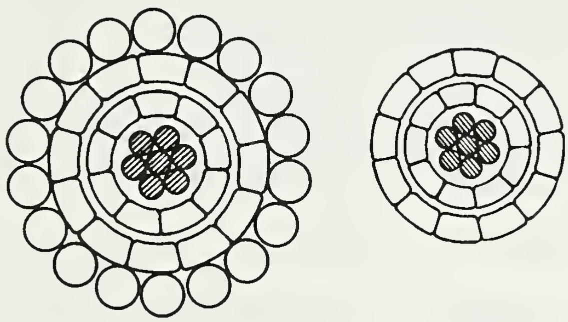


FIGURE IX-4: TYPICAL ACSR/SD STRANDINGS

8. AACSR (Aluminum Alloy Conductor, Steel Reinforced)

This type of conductor is the same as a conventional ACSR conductor except that the 1350 strands have been replaced with higher strength 6201 alloy strands. The resulting greater strength of the conductor allows the sags to be decreased without exceeding the standard conductor percent tension limits. This type of conductor is primarily used at river crossings where sag limitations are important. The higher tensions associated with this type of conductor require that special attention be paid to the possibility of aeolian vibration.

C. Selecting a Conductor Type

Given below are the factors that should be considered when selecting a conductor type.

1. REA Standards

The conductor selected should generally be of a type and stranding listed as being acceptable for use on REA systems. See REA Bulletin 43-5, "List of Materials Acceptable for Use on Systems of REA Electrification Borrowers."

2. Corrosion Considerations

Standard ACSR conductor should not be used in areas of severe corrosion. Rather, a conductor without a steel core wire or one with aluminum-clad core wire should be used. An ACSR conductor with an aluminum coated or a heavier weight zinc coated steel core wire may be considered if experience with such material has been successful.

3. Economics

The relative cost of one conductor type versus another is very important. When comparing costs, one should take into consideration overall line costs. A less expensive conductor with greater sags requiring shorter spans or higher structures compared to a more expensive conductor with lesser sag, may not be the most economical selection when overall line costs are considered.

4. Strength

The strength of the conductor and its ability to sustain the mechanical loads without unreasonable sags must be evaluated.

D. Selection of Conductor Size

1. Minimum Conductor Size

The table below gives the minimum allowable conductor sizes for each of the standard REA transmission voltages. The minimums are based on a combination of radio noise, corona, and mechanical sag and strength considerations. If a conductor type other than ACSR or 6201 AAAC is used, the conductor diameter should not be less than the diameter of the ACSR specified for the particular voltage concerned.

TABLE IX-1

REA MINIMUM CONDUCTOR SIZES

kV_{LL}	ACSR	AAAC - 6201
34.5	1/0	123.3 kcmil
46	2/0	155.4 kcmil
69	3/0	195.7 kcmil
115	266.8 kcmil	312.8 kcmil
138	336.4 kcmil	394.5 kcmil
161	397.5 kcmil	465.4 kcmil
230	795. kcmil	927.2 kcmil

2. Voltage Drop Considerations

Not only must the conductor be sufficiently large to meet the requirements of Section 1 above, but it must also meet the system voltage drop requirements. Typically the conductor would have to have sufficiently low impedance so that under a given set of electrical loading conditions, the voltage drop would not exceed approximately 5 percent*. In general, it is the longer lines where voltage drop becomes a factor. Voltage drop can be evaluated by either running a load flow computer program or by using the estimating tables in REA Bulletin 62-5, "Electrical Characteristics of REA Alternating Current Transmission Line Designs."

3. Thermal Capability Considerations

When sizing a phase conductor, the thermal capability of the conductor (ampacity) must also be considered. The conductor should be able to carry the maximum expected long-term load current without overheating. Generally, a conductor is assumed to be able to heat up to 75°C (167°F) without any long-term decrease in strength. Above that temperature, there may be a decrease in strength depending on how long the conductor remains at the elevated temperature. A conductor's ampacity depends not only upon its assumed maximum temperature, but also on the wind and sun conditions that are assumed. See Appendix B for ampacity tables.

*This value will vary depending upon individual system planning criteria.

4. Economic Considerations

Economics is an important factor in determining conductor size. Rarely would the minimum conductor sizes given in Table IX-1 be the most economical in the long run. The additional cost of a larger conductor may be more than offset by the present worth of the savings resulting from the lower losses during the entire life of the conductor. A proper economic analysis should consider the following factors for each of the conductor sizes considered:

a. The total per kilometer (mile) cost of building the line with the particular conductor being considered.

b. The present worth of the energy losses associated with the conductor.

c. The capital cost per kilowatt of loss of the generation substation and transmission facilities necessary to supply the line losses.

d. Load growth.

The results of an economic conductor analysis can often be best presented and understood when presented in a graphical form as shown in Figure IX-5.

At an initial load of approximately 200 MW, 1272 kcmil becomes more economical than 795 kcmil. 954 kcmil is not economical at any load level included on the graph.

5. Standardization and Stocking Considerations

In addition to the above factors, the problem of standardization and stocking must be considered. A proliferation of conductor sizes in use on a power system is undesirable because of the expense of stocking many sizes. When a conductor is electrically and economically optimum, but is not a standard size already in use on the system, the additional cost and complications of having one more conductor size to stock should be weighed against the advantages of using an optimum conductor.

E. Overhead Ground Wires (OHGW)

1. Types Available

a. High Strength or Extra High Strength Galvanized Steel Wires

For high strength wires the allowable sizes are 3/8" and 7/16", while for extra high strength wires, the

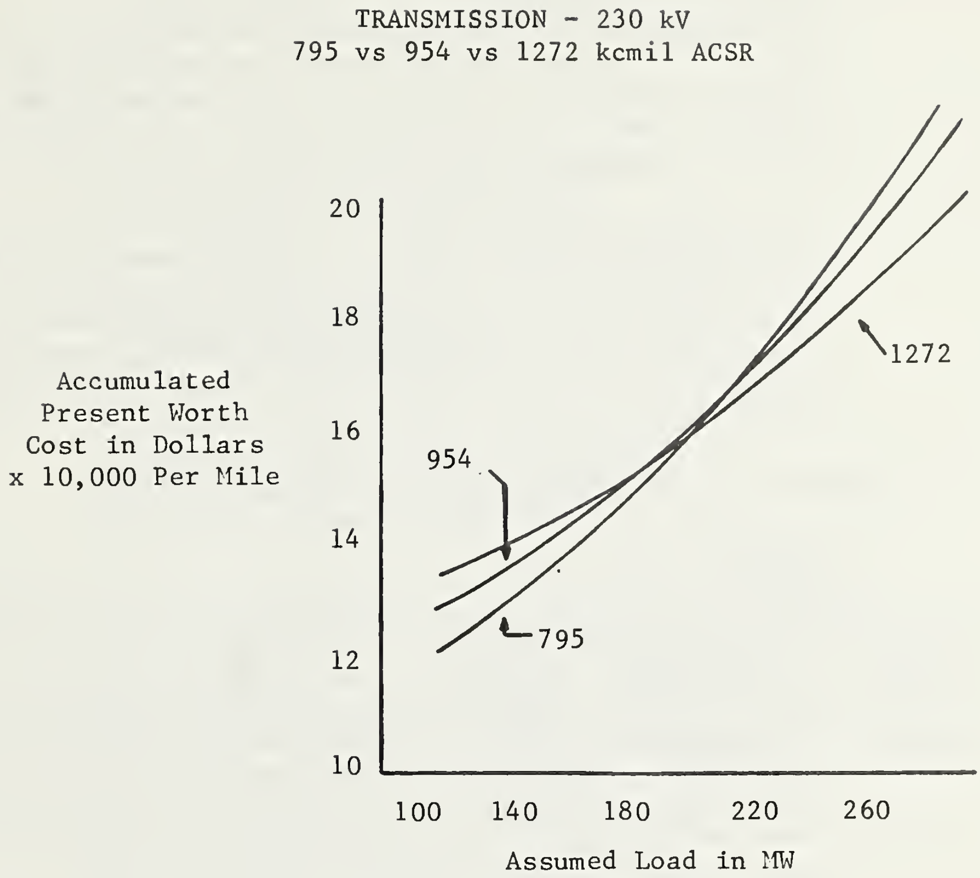


FIGURE IX-5: RESULTS OF A TYPICAL ECONOMICAL CONDUCTOR ANALYSIS

allowable sizes are 5/16", 3/8", and 7/16". Note that 1/4" strand is not acceptable for use as overhead ground wires as is also Siemens Martin grade wires of all sizes. Overhead ground wires must not have brazed or welded joints; that is, they must meet the requirements of ASTM Specification A-363. Steel wires are available in three weights of zinc coating. The standard weight is designated as A and the greater weights are designated B and C.

b. Aluminum-Clad Steel Strand

Instead of a thin coating of zinc, this material has a thick cladding of aluminum which makes it more resistant to corrosion and gives it greater conductivity.

The sizes of this material that may be used as overhead ground wires are 7 x .106", 7 No. 9AWG, 7 No. 8AWG, and 7 No. 7AWG. The material must be in accordance with ASTM Specification B416.

2. Selecting a Size and Type

Selecting an overhead ground wire size and type is dependent upon only a few factors, the most important of which is how the sag of the OHGW coordinates with that of the phase conductors. Other factors that may have to be considered are corrosion resistance and conductivity.

If a line is to be located in a seacoast region or in another location where there is a highly corrosive atmosphere, aluminum-clad steel wire should be considered. If the OHGW is to be used to carry any type of communication signal, or if large magnitudes of lightning stroke currents are expected, a higher conductivity than normal may be desirable.

F. Conductor and Overhead Ground Wire Design Tensions

1. General

Throughout the life of a transmission line, the conductor tensions may vary between 10 and 60 percent or more of rated conductor strength due to change in loading and temperature. Most of the time, however, the tension will vary within relatively narrow limits, inasmuch as ice, high winds, and extreme temperatures are relatively infrequent in many areas. Such normal tensions may actually be more important in determining the life of the conductor than higher tensions which are experienced infrequently.

2. Conductor Design Tensions

Given below in Table IX-2 are REA maximum conductor tension values for ACSR and 6201 AAAC conductors that must be observed for the ruling span. It should be stressed that the values given are maximum design values. If deemed prudent, tensions less than those specified or loadings greater than the standard loading condition (tension limit "B3" of the table) may be used. However, unless the occurrences of loadings in excess of the NESC loading are frequent, it is unwise to base the selection of a "maximum loading" condition on a single or very infrequent case of excessive loading. Mountainous areas above 1200 meters (4000 feet) in which ice is expected should be considered to be in the heavy loading district even if they are not.

In open areas where steady winds are encountered, aeolian vibration can be a problem especially if conductor tensions are high. Generally, lower tensions at conditions at which aeolian vibration is likely to occur, can reduce vibration problems (see section IX.I for further discussion).

TABLE IX-2

REA CONDUCTOR AND OVERHEAD GROUND
WIRE TENSION AND TEMPERATURE LIMITS*

A. Temperatures

1. Tension limits 1, 2 and 3 below must be met at the following temperatures:

Heavy loading district	-17.8°C (0°F)
Medium loading district	-9.4°C (15°F)
Light loading district	-1.1°C (30°F)

2. Limit 4 must be met at the temperature at which the extreme wind is expected.

3. Limit 5 must be met at 0°C (32°F).

B. Tension Limits in Percent of Conductor Rated Strength

Tension Condition (See text for explanation)	Phase Cond.	OHGW High Strength Steel	OHGW Extra High Strength Steel
1. Max. initial unloaded	33.3**	25	20
2. Max. final unloaded	25***	25	20
3. Standard loaded (usually NESC district loading)	50	50	50
4. Max. extreme wind (A)	70****	80	80
5. Max. extreme ice (A)	70****	80	80

Note:
(A) These limits are for tension only. When conductor stringing sags are to be determined, limits 1, 2 and 3 should be considered as long as tensions at conditions 4 and 5 are satisfactory.

*Tension limits do not apply for self-damping and other special conductors.

**In areas prone to aeolian vibration, a value of approximately 20 percent at the average annual minimum temperature is recommended, if vibration dampers or other means of controlling vibration are not used (see section IX.I.2, page IX-19, for further details).

***For 6201 AAAC, a value of 20 percent is recommended.

****For ACSR only. 6201 Aluminum use 60 percent.

Explained below are the several conditions at which maximum conductor tension limits are specified.

a. Initial Unloaded Tension

The initial unloaded tension refers to the state of the conductor when it is initially strung and is under no ice or wind load.

b. Final Unloaded Tension

After a conductor has been subject to the assumed ice and wind loads, and/or long time creep*, it receives a permanent or inelastic stretch. The tension of the conductor in this state, when it is again unloaded, is called the final unloaded tension.

c. Standard Loaded Tension

The loaded tension refers to the state of a conductor when it is loaded to the assumed simultaneous ice and wind loading** for the National Electrical Safety Code (NESC) loading district concerned (see Table XI-1, Chapter XI for definition of and loads associated with loading districts). To the vector resultant of the transverse and vertical loads, the following constants must be added to get total load:

	Heavy	Medium	Light
N/m	4.4	2.9	.73
(lbs/ft)	.30	.20	.05

The initial and final sags and tensions for "standard loaded" condition will be the same unless creep is the governing factor, if the "standard loaded" condition is the maximum mechanical load used in the calculations. If another condition such as extreme ice is the maximum mechanical load, then the initial and final sags and tensions for the "standard loaded" condition can be significantly different from one another. In this case, it is important that the loaded tension limits be set for initial conditions.

d. Extreme Wind Tension

The extreme wind tension refers to the state of the conductor when it has a wind blowing on it of a value not less than the 50-year mean recurrence interval

*Creep is the inelastic elongation of a conductor which occurs with time under load.

**The NESC also requires that a constant be added to the vector sum of the ice and wind loads.

wind (see Appendix E). No ice should be assumed to be on the conductor.

e. Extreme Ice Tension

The tension in a conductor when it is loaded with what is considered to be an extreme amount of ice for the area concerned is called the extreme ice tension. It should be assumed that there is no wind blowing when the ice is on the conductor. Values of 25 to 50 mm (1 to 2 in.) of radial ice are commonly used as extreme ice loads.

3. Controlling Conditions

For a given ruling span, usually only one of the tension limit conditions will control the design of the line and the others will have relatively little significance insofar as line tensions are concerned.

If the conductor loading under extreme ice or wind loads is greater than under the "standard loaded" condition, calculated sag and tension values at other conditions could be somewhat different from what they would be if the "standard loaded" condition were the maximum case. In these situations stringing sags should be based upon limits 1, 2, and 3 only, as long as tensions at conditions 4 and 5 are satisfactory.

4. Overhead Ground Wire (OHGW)

To avoid unnecessarily high mechanical stresses in the OHGW, supporting structures, and guys, the OHGW should not be strung with any more tension than is necessary to coordinate its sags at different conditions with the phase conductors. See Chapters VI and VIII.

G. Ruling Span

1. Why a Ruling Span?

If all spans in a section of line between deadends are of the same length, uniform ice and wind loads will result in equal conductor tension in all spans. But, span lengths usually vary in any section of line, with the result that temperature change and ice and wind loads will cause conductor tensions to become greater in the longer spans and less in the shorter spans when compared to the tensions of loaded uniform spans. The movement of the insulator strings and/or the flexing of the structures will tend to reduce this unequal tension. It is possible, however, for conductor tension in long spans to reach a value greater than desired unless the line is spotted and the conductor strung to limit this undesirable condition.

A ruling span is an assumed uniform design span which approximately portrays the mechanical performance of a section of line between its deadend supports. The use of a ruling span in the design of a line assumes that flexing of the structure and/or insulator string deflection can occur at the intermediate supporting structures so as to allow for the equalization of tension in the conductor between adjacent spans to the ruling span tension. The purpose of a ruling span in the design and construction of a line is to provide a uniform span length which is representative of the various lengths of spans between deadends so that sags and clearances can be calculated for structure spotting and conductor stringing.

2. Calculations of the Ruling Span

On a line where all spans are equal, the ruling span is the same length as the line spans. Where spans vary in length, the ruling span is between the shortest and the longest span lengths on the line, but is mainly determined by the longer spans.

a. Approximate Method

A generally satisfactory method for estimating the ruling span is to take the sum of the average span plus two-thirds of the difference between the maximum span and the average span. However, some judgment must be exercised in using this method as a large difference between the average and maximum span may cause a substantial error in the ruling span value.

$$RS = L_{avg} + 2/3(L_{max} - L_{avg}) \qquad \text{Eq. IX-1}$$

where:

RS = ruling span in meters (feet).
L_{avg} = average span in meters (feet).
L_{max} = maximum span in meters (feet).

b. Exact Method

The following is the exact formula for determining the ruling span.

$$RS = \sqrt{\frac{L_1^3 + L_2^3 + L_3^3 + \ldots + L_n^3}{L_1 + L_2 + L_3 + \ldots + L_n}} \qquad \text{Eq. IX-2}$$

where:

L_1, L_2, L_3, etc. = the different span length in the line in meters (feet).

Other symbols as previously defined.

3. Establishing a Ruling Span

As can be seen from Equation IX-2, the exact value of the ruling span can only be calculated after the structures have been spotted and all the span lengths determined. However, the ruling span must be known in advance of structure spotting. Thus the ruling span must at first be estimated.

When following any procedure for estimating ruling span, it should be borne in mind that the estimation of a ruling span is as much of an intuitive process based on experience, judgment, and trial and error as it is a quantitative procedure. A good starting point for estimating ruling span is the height of the base structure*. After assuming a base structure height, subtract the minimum ground clearance value from the height of the lowest phase conductor above ground, at the structure; the allowable sag as limited by ground clearance is the result. Using this sag value and tables of sags for various ruling span lengths, a ruling span length can be chosen whose sag is approximately equal to the allowable sag for the base structure height. Or in other words, a ruling span is chosen to be approximately equal to the level ground span**. If the terrain is flat or rolling, the above approximation should be followed. However, if it is rough, the ruling span should be somewhat greater than the level ground span.

The ruling span value initially chosen should be checked to see that it coordinates reasonably well with the minimum span values as limited by such factors as structure strength, conductor separation, galloping, etc. Also, Equation IX-1 should be used in conjunction with estimated maximum and average span values to further check the reasonableness of the estimated ruling span. If the initial estimate does not check out, the value should be changed and the procedure repeated.

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*The base structure is the structure that is expected to occur most often throughout the line.

**The level ground span is the maximum span as limited by line to ground conductor clearance for a particular height structure.

If possible, the ruling span should be used throughout the length of the line, as deadending for the purpose of changing ruling spans is costly. In cases where the spans in one extended section of line are consistently and considerably longer or shorter than in another section of line, more than one ruling span may be unavoidable. It is a common practice to permit long spans to double the average span without deadends, provided conductor tension limits are satisfactory. In addition, short spans should not be less than approximately one-half of the ruling span. After the plan and profile sheets are plotted, the validity of the estimated ruling span value should be checked by comparing it to the actual value obtained. It is not essential that the estimated ruling span value be equal to the actual value, provided the estimated ruling span results in satisfactory ground clearance and economical structure spotting without excessive conductor tensions. However, if the difference between the estimated and actual ruling span is more than approximately 15 percent, the effects resulting from the difference should be carefully checked.

4. Effects of the "Wrong" Ruling Span

It is important that the actual ruling span be reasonably close to the ruling span value that is used to spot the line. If this is not the case, there may be significant differences between the predicted conductor tensions and clearances, and the actual values. There have been instances where sags greater than predicted resulting from an improper assumed ruling span have caused clearance problems. The table below will be of use in determining how conductor sags differ from the predicted value when there are differences between actual and assumed ruling span. The tension variation is opposite of that of the sags, thus increased sags mean decreased tension and vice versa.

TABLE IX-3

DIRECTION OF DEVIATION OF SAGS FROM PREDICTED VALUES WHEN ACTUAL AND ASSUMED RULING SPAN VALUES ARE SIGNIFICANTLY DIFFERENT (Applies to Unloaded Condition)

	Assumed RS > Actual RS	Assumed RS < Actual RS
Conductor temp. is less than temp. at which conductor was strung.	Actual Sag < Predicted INCREASED TENSIONS	Actual Sag > Predicted CLEARANCE PROBLEMS
Conductor temp. is greater than temp. at which conductor was strung.	Actual Sag > Predicted CLEARANCE PROBLEMS	Actual Sag < Predicted INCREASED TENSIONS

CLEARANCE PROBLEMS - Conductor sags greater than indicated on the plan and profile sheets will result.

INCREASED TENSIONS - Conductor tensions greater than anticipated will result.

H. Determining Conductor Sags and Tensions

The determination of conductor sags and tensions given a set of tension limits as outlined in section IX.F above is a complex and difficult task. This is true because only one of the tension limits may control, and it is not always predictable which limit it will be. In addition, one must work with conductor stress strain curves which for a compound conductor such as ACSR can be rather complex.

The best method of obtaining conductor sag and tension values is to use one of the numerous computer programs written for that purpose. In using a computer program, several factors should be watched:

1. The program should be written so that a check is made of all the limiting conditions simultaneously and the governing condition noted.

2. The program should take into account conductor creep.

3. The tension values given should be average tension values and not tension at support or horizontal tension values.

4. The source of the stress strain data used should be indicated.

If computerized sag tension values are not available either from one's own program or from a manufacturer's, values can be generated using the graphical method given in the following publication:

> "Graphic Method for Sag Tension Calculations for ACSR and Other Conductors" - Publication No. 8, Aluminum Company of America, 1961.

I. Aeolian Vibration

1. General

Overhead conductors of transmission lines are subject to two different types of vibration: aeolian and galloping, both of which are produced by wind. The first type, aeolian vibration, is a high-frequency low-amplitude oscillation generated by a low velocity comparatively steady wind blowing across the conductors. This steady wind will create air vortices or eddies on the lee side of the conductor which will detach at regular intervals from the top and bottom area of the conductor creating a force on the conductor that is alternately impressed from above and below. If the frequency of the forces approximately corresponds to a frequency of a mode of resonant vibration of the span, the conductor will tend to vibrate in many loops in a vertical plane. The frequency of vibration depends mainly on conductor size and wind velocity and is generally between 5 and 100 Hz for wind speeds within the range of 0 to 24 kilometers per hour (15 miles per hour). The peak-to-peak amplitudes of vibration will cause alternating bending stresses great enough to produce fatigue failure in the strands of the conductor or OHGW at the points of attachment. Highly tensioned conductors in long spans are particularly subject to vibration fatigue. This vibration is generally more severe in flat open terrain where steady winds are more often encountered.

The frequency and loop length of the vibration can be determined using the following formulas.

Frequency of the vibration:

$$f = 51.5 \frac{V}{d_c} \quad \text{(Metric) Eq. IX-3}$$

$$f = 3.26 \frac{V}{d_c} \quad \text{(English) Eq. IX-4}$$

where:

f = frequency of conductor vibration in Hertz.
V = transverse wind velocity in kilometers per hour (miles per hour).
d_c = conductor diameter in millimeters (inches).

Loop Length (for a conductor that is assumed to have negligible stiffness):

$$LL = \frac{1}{2f}\left(\frac{(T_{avg})(g)}{w_c}\right) \qquad \text{Eq. IX-5}$$

where:

LL = loop length in meters (feet).
T_{avg} = average conductor tension in Newtons (pounds).
w_c = weight of conductor in Newtons per meter (pounds per foot)(For standard gravity 1 kg = 9.81 N).
g = 9.81 m/sec^2 (32.2 ft/sec^2).
Other symbols as previously defined.

2. Designing for Vibration Problems

If an area is expected to have aeolian vibration problems, there are several measures given below that may be taken in order to mitigate possible problems. The measures are not necessarily mutually exclusive; more than one measure may be used simultaneously.

a. Reduced Tension

The two line design variables that have the greatest effect upon a line's vibration characteristics are conductor tension and span length. Singly or in combination, these two variables can be reduced to the point where the level of vibration, without any vibration damping devices, will not be damaging. For similar sag characteristics, conductors of different types, with their different characteristics, may require a different degree of vibration protection.

A rule of thumb that has proved generally successful in eliminating vibration problems is to keep the conductor tension for short and medium length spans under initial unload conditions at the average annual minimum temperature to approximately 20 percent or less of the conductor's rated strength. For long spans, a somewhat lower percent tension limit should be used. Due to their vibration characteristics, 6201 AAAC and 1350 aluminum conductors should be held to tensions somewhat lower than the 20 percent value, even for relatively short spans.

b. Armor Rods

Armor rods, in addition to reinforcing the conductor at the support points, do provide a small amount of damping of aeolian vibration. In lines with lower conductor tension and shorter spans, this damping may provide adequate protection against conductor strand fatigue. See Chapter XV.

c. Cushioned Suspensions

Cushioned suspensions combine armor rods with a resilient cushioning of the conductor. They do provide somewhat more damping than armor rods, but the degree of damping is still relatively small compared to vibration dampers (see below and Chapter XV).

d. Dampers

Stockbridge and other types of dampers are effective devices for controlling vibration (see Chapter XV for a description). The selection of damper sizes and the best placement of them in the spans should be determined by the damper or conductor manufacturer on the basis of the tension, weight, and diameter of the conductor and the expected range of wind velocities. The length of the suspension clamp and the effect of the armor rods or cushioned suspensions should also be considered. With new efficient damper designs and usual conductor tensions and span lengths, one damper is installed near one span support joint. For long spans, additional dampers may be required.

J. Galloping

See Chapter VI for details.

K. Maximum Possible Single Span

For a given span length, as the sag is increased, the tension at the support will decrease until a point is reached where the tension will begin to increase due to the weight of the conductor. This point occurs when the sag is equal to .337 times the span length. The relationship between span length and tension can be expressed as:

$$L_{max} = 1.33 \frac{T}{w_c} \qquad \text{Eq. IX-6}$$

where:

T = resultant tension at support, Newtons (pounds).
L_{max} = maximum span, meters (feet).

The above formulas can be used to determine the maximum possible span given a maximum tension at supports. This is most useful when dealing with river crossings, etc.

L. Sag and Tension Relationships

The relationships given below are useful for understanding the sag tension relationships for conductors:

1. Level Span Sags

The approximate "parabola method", Equation IX-7 below, is helpful in solving some sag and tension problems in span lengths below 300 meters (1,000 feet) or where sag is less than 5 percent of the span length.

$$S = \frac{w_c L^2}{8T_h} \qquad \text{Eq. IX-7}$$

where:

S = sag at center of span in meters (feet).
L = span length in meters (feet).
T_h = horizontal tension in Newtons (pounds).

The exact formula for determining sags is:

$$S = \frac{T_h}{w_c}\left(\cosh \frac{w_c L}{2T_h} - 1\right) \qquad \text{Eq. IX-8}$$

2. Inclined Span Sags

See Figure IX-6 for method of determining inclined span sags.

3. Tension

The conductor tension in a level span varies from a maximum value at the point of support to a minimum value at mid-span point.

The tension at the point of support is:

$$T = T_h + w_c S = T_h \cosh \frac{w_c S}{2T_h} \qquad \text{Eq. IX-9}$$

The value that is generally referred to, when the "tension" of a conductor is indicated, is usually the

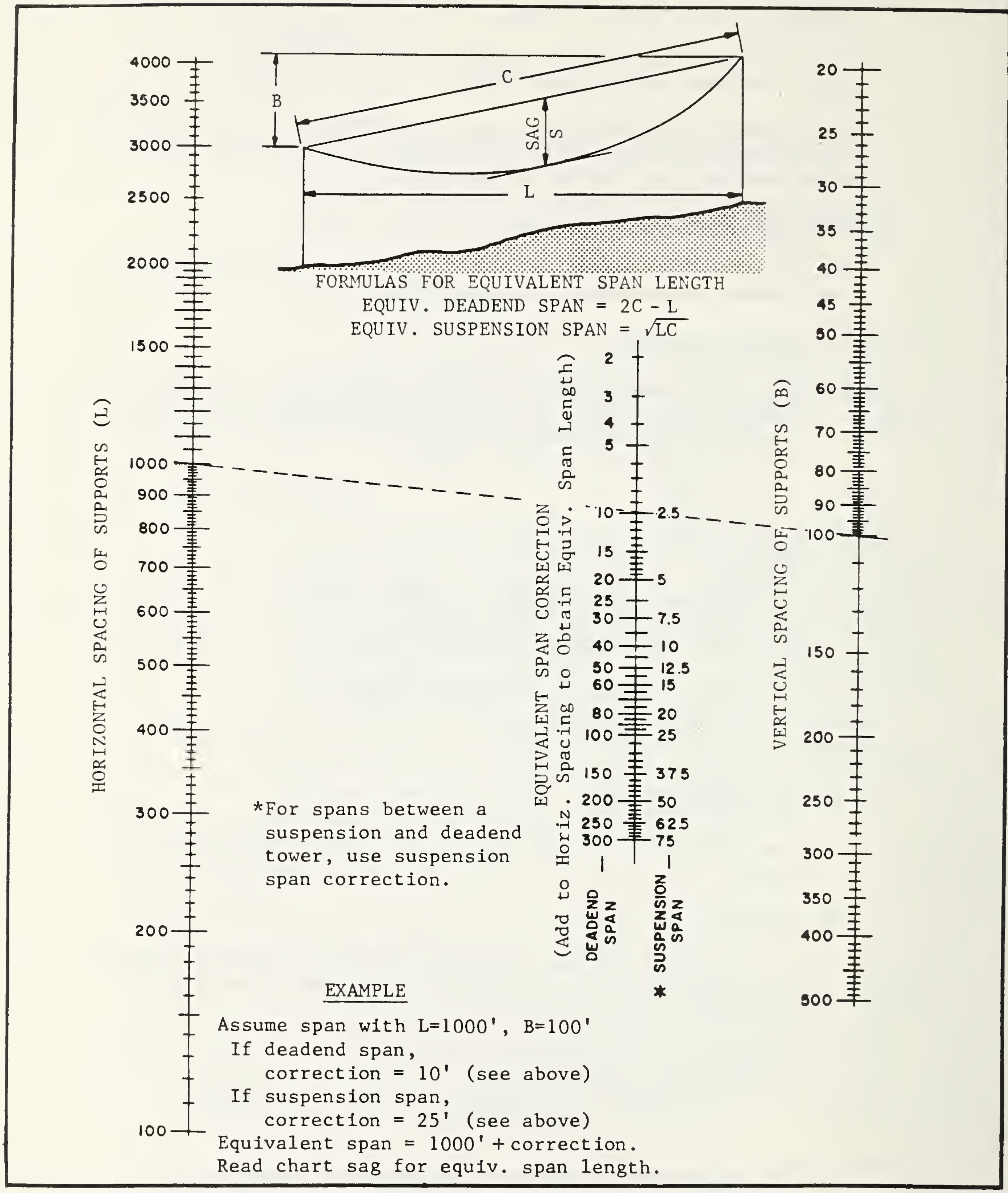


FIGURE IX-6: NOMOGRAPH FOR DETERMINING
LEVEL SPAN EQUIVALENTS OF NON-LEVEL SPANS

average of the tension at the support and the tension at mid-span. Thus:

$$T_{avg} = \frac{T_h + T}{2} = T_h + \frac{w_c S}{2} \qquad \text{Eq. IX-10}$$

where:

T_{avg} = average tension in Newtons (pounds).

M. Stringing and Sagging of Conductors

1. Stringing of Conductors

a. Methods of Stringing Conductors

There are two general methods of stringing conductors; the tension method and the slack method. There are, of course, as many variations on these methods as there are organizations stringing conductor.

(1) Tension Method (Preferred)

Using this method, the conductor is kept under tension during the stringing process. Normally, this method is used to keep the conductor clear of the ground and obstacles which might cause conductor surface damage and clear of energized circuits. It requires the pulling of a light pilot line into the sheaves, which in turn is used to pull in a heavier pulling line. The pulling line is then used to pull in the conductors from the reel stands using specially designed tensioners and pullers. For lighter conductors, a lightweight pulling line may be used in place of the pilot line to directly pull in the conductor. A helicopter or ground vehicle can be used to pull or lay out a pilot line or pulling line. Where a helicopter is used to pull out a line, synthetic rope is normally used to attach the line to the helicopter and prevent the pilot or pulling line from flipping into the rotor blades upon release. The tension method of stringing is applicable where it is desired to keep the conductor off the ground to minimize surface damage, or in areas where frequent crossings are encountered. The amount of right-of-way travel by heavy equipment is also reduced. Usually, this method provides the most economical means of stringing conductor. The use of a helicopter is particularly advantageous in rugged or poorly accessible terrain.

Major equipment required for tension stringing includes reel stands, tensioner, puller, reel winder, pilot line winder, splicing cart and helicopter or pulling vehicle.

(2) Slack or Layout Method

Using this method, the conductor is dragged along the ground by means of a pulling vehicle or the reel carried along the line on a vehicle and the conductor deposited on the ground. The conductor reels are positioned on reel stands or "jacks", either placed on the ground or mounted on a transporting vehicle. These stands are designed to support the reel on an arbor permitting it to turn as the conductor is pulled out. Usually a braking device is provided to prevent overrunning and backlash. When the conductor is dragged past a supporting structure, pulling is stopped and the conductor placed in sheaves attached to the structure before proceeding to the next structure.

This method is chiefly applicable to the construction of new lines in cases where maintenance of conductor surface condition is not critical and where terrain is easily accessible to a pulling vehicle. The method is not usually economically applicable in urban locations where hazards exist from traffic or where there is danger of contact with energized circuits, nor is it practical in mountainous regions inaccessible to pulling vehicles.

Major equipment required to perform slack stringing includes reel stands, pulling vehicle(s) and a splicing cart.

b. Stringing Conductors During Temperature Changes

An examination of conductor sag and tension tables will generally indicate the changes that take place in various span lengths for a change of conditions. For a given set of conditions, spans of various lengths may have a different rate of tension change with a change of loading or temperature. The ruling span tension of an unloaded conductor matches the tension of any other span at only one temperature. Large changes in temperatures during stringing require care in matching average tensions in any section. It is desirable to complete stringing between deadends during minimum changes in temperature and at zero wind load. Where spans are supported by suspension insulators, each span will have an influence on adjacent spans such that no span can be considered independently of the remainder of spans in the same section between anchor structures. Change in temperature has a greater effect on short spans than loading does, while long spans are affected more by loading. However, in short spans a slight movement of supports results in substantial changes in tension while on longer spans relatively greater movement is required. The relation between adjacent span lengths therefore determines the movement required to equalize tension.

2. <u>The Sagging of Conductors</u>

It is important that the conductors be properly sagged in at the right stringing tension for the ruling span used. When installing conductors, a series of several spans is usually sagged in one operation by pulling the conductors to proper tension while they are supported on free rolling sheaves. To obtain the correct sags and to insure that the suspension insulators will hang vertically, the horizontal components of tension must be the same in all spans for a selected condition. In a series of spans of varying length, a greater sag tends to form in the long spans. On steep inclines the sheaves will deflect in the uphill direction and there will be a horizontal component of tension in the sheave itself. The horizontal component of tension in the conductor will therefore increase from one span to the next, as the elevation increases, by an amount equal to the horizontal component in the sheave. As a result, sags will proportionally decrease. In order to avoid this effect, it may be necessary to use a procedure called offset clipping whereby the point along the conductor at which it is attached to the insulator string is moved a specific distance down span from the point at which the conductor sits in the stringing block. See Figure IX-7 for further details on offset clipping.

It is important that the sags of the conductor be properly checked. It is best to do this in a series of level spans as nearly equal to the ruling span as possible.

3. <u>Additional Information</u>

For additional information, see :

<u>A Guide to the Installation of Overhead Transmission Line Conductors</u>, IEEE Standard 524-1980, IEEE, 1980.

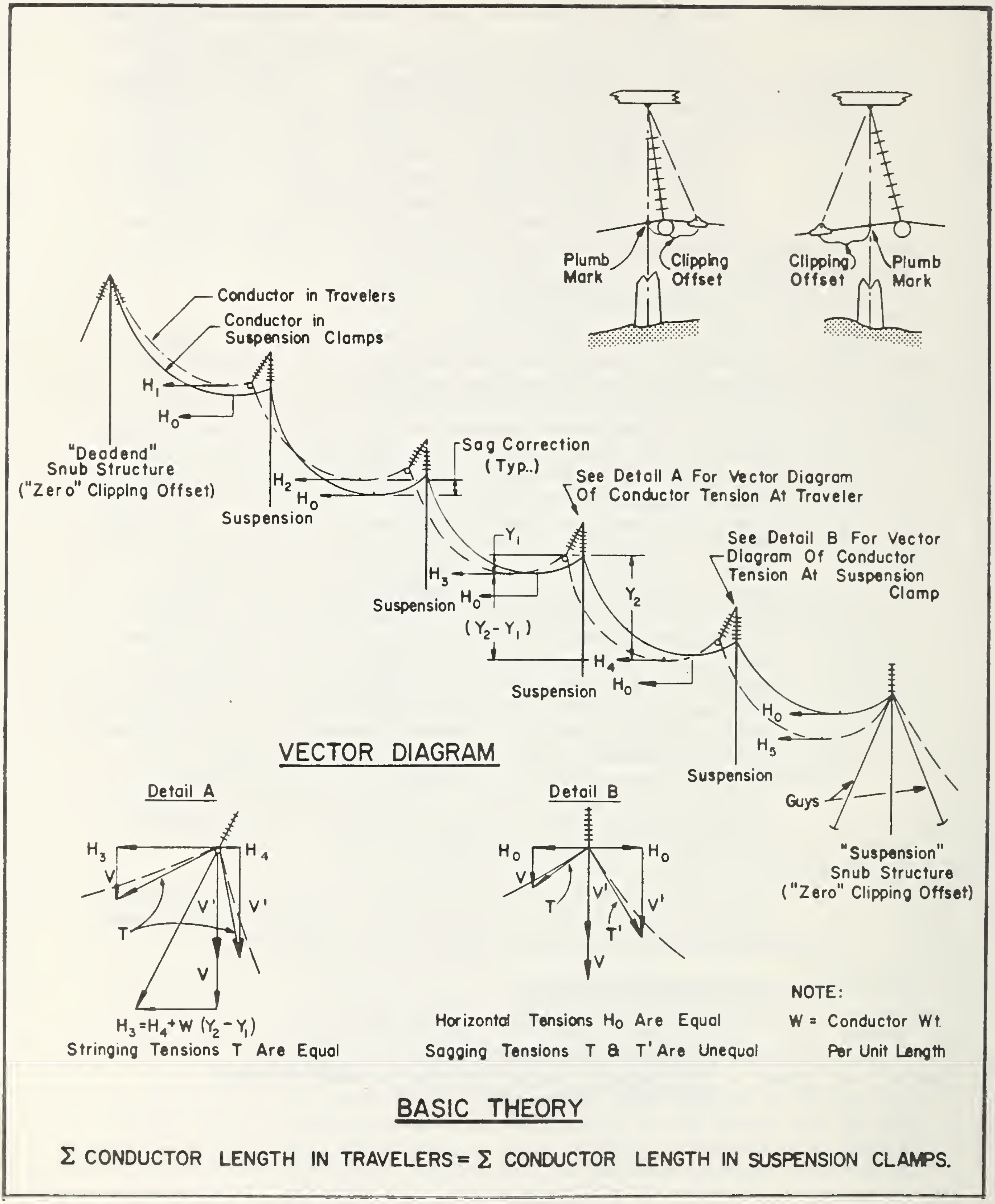


FIGURE IX-7: ANALYSIS FOR APPLICATION OF CLIPPING OFFSETS (From A Guide to the Installation of Overhead Transmission Line Conductors, IEEE Standard 524-1980, IEEE, 1980.

Example IX-1: Determination of Ruling Span

Determine the ruling span for the line segment given below using both the exact and approximate method.

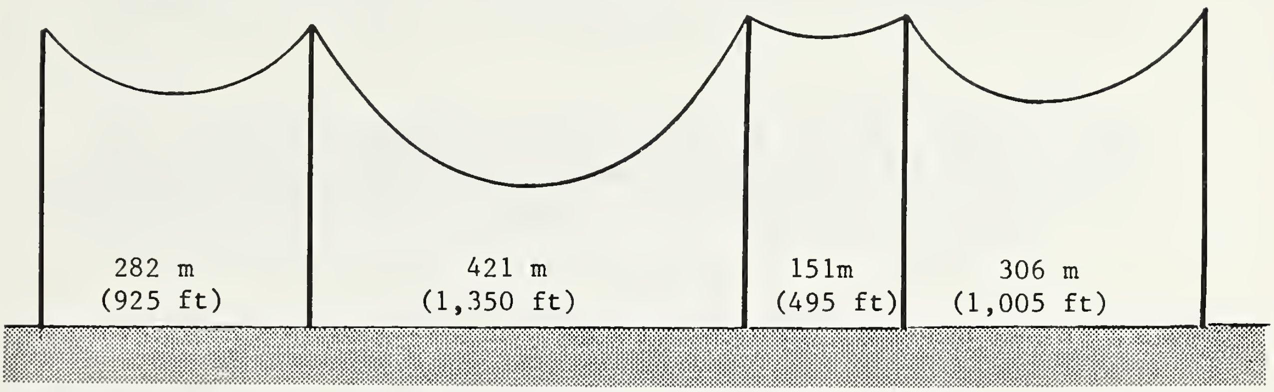


FIGURE IX-8: LINE SECTION FOR EXAMPLE IX-1

Solution

1. Exact Method:

$$RS = \sqrt{\frac{L_1^3 + L_2^3 + L_3^3 + \ldots + L_n^3}{L_1 + L_2 + L_3 + \ldots + L_n}} \qquad \text{Eq. IX-2}$$

$$RS = \sqrt{\frac{282^3 + 421^3 + 151^3 + 306^3}{282 + 421 + 151 + 306}} = 334 \text{ m}$$

$$RS = \sqrt{\frac{925^3 + 1380^3 + 495^3 + 1005^3}{925 + 1380 + 495 + 1005}} = 1094 \text{ ft.}$$

2. Approximate Method:

$$RS = L_{avg} + 2/3(L_{max} - L_{avg}) \qquad \text{Eq. IX-1}$$

$$L_{avg} = \frac{282 + 421 + 151 + 306}{4} = 290 \text{ m}$$

$$L_{max} = 421$$

$$RS = 290 + 2/3(421 - 290)$$

$$RS = 377 \text{ m}$$

$$L_{avg} = \frac{925 + 1380 + 495 + 1005}{4} = 951 \text{ ft.}$$

$$L_{max} = 1005$$

$$RS = 951 + 2/3(1380 - 951)$$

$$RS = 1237 \text{ ft.}$$

As mentioned in the text, the error between the exact and approximate methods of determining ruling span is caused by a rather significant error between the average and maximum span values.

Example IX-2: Maximum Span Determination

Determine the maximum span (for river crossings, etc.) for a 795 kcmil 26/7 ACSR conductor. Assume that under heavy loading district conditions, the conductor can be loaded up to 40 percent of its rated strength.

Solution

From the conductor tables in Appendix B, the rated strength of the conductor is 140,112 N (31,500 lbs.) and the weight of the conductor with 12.7 mm (½ in.) of radial ice is 30.56 N/m (2.0930 lbs/ft.). (Metric values converted from English values in table).

$$T = 140112(.4) = 56045 \text{ N}$$

$$T = 31500(.4) = 12600 \text{ lbs.}$$

$$L_{max} = 1.33 \frac{T}{w_c} \qquad \text{Eq. IX-6}$$

$$L_{max} = 1.33 \frac{56045 \text{ N}}{30.56 \text{ N/m}} = 2439 \text{ m}$$

$$L_{max} = 1.33 \frac{12600 \text{ lbs.}}{2.0930 \text{ lbs/ft.}} = 8007 \text{ ft.}$$

The maximum span is 2439 m (8007 ft.).

Example IX-3: Determination of Tensions at the Mid Span Point and at the Point of Support

A level 244 m (800 ft.) span of 795 kcmil 26/7 ACSR conductor has a sag of 6.70 m (21.95 ft.). The average tension value is 40,860 N (9,182 lbs.) and there is no ice or wind on the conductor. Determine the actual conductor tension values at the mid span point and at the point of conductor support.

Solution

1. Tension at mid span point.

$$T_{avg} = \frac{T_h + T}{2} = T_h + \frac{w_c S}{2} \qquad \text{Eq. IX-10}$$

$$T_h = T_{avg} - \frac{w_c S}{2}$$

From the conductor tables in Appendix B, the weight of the conductor without ice is 15.971 N/m (1.0940 lbs/ft.).

$$T_h = 40860 \text{ N} - \frac{(15.971)(6.70)}{2}$$

$$T_h = 40806 \text{ N}$$

$$T_h = 9182 - \frac{(1.094)(21.95)}{2}$$

$$T_h = 9170 \text{ lbs.}$$

2. Tension at support.

$$T = T_h + w_c S \qquad \text{Eq. IX-9}$$

$$T = 40806 + (15.971)(6.70)$$

$$T = 40913 \text{ N}$$

$$T = 9170 + (1.094)(21.95)$$

$$T = 9194 \text{ lbs.}$$

It can be seen from the values above that the difference between the average tension value and the two actual tension values is relatively small.

X. PLAN-PROFILE DRAWINGS

A. General

The transmission line plan-profile drawings serve an important function in linking together the various stages involved in the design and construction of the line. Initially, the drawings are prepared based on a route survey to show the location and elevation of all natural and man-made features to be traversed by or which are adjacent to the proposed line, including ownership, which affect right-of-way, line design and construction. The drawings are then used to complete line design work such as structure spotting. During material procurement and construction, the drawings are used to control purchase of materials and serve as construction specification drawings. After construction, the final plan-profile drawings become the permanent record of property and right-of-way data, useful in line operation and maintenance or future modifications.

Accuracy, clarity, and completeness of the drawings should be maintained, beginning with initial preparation, to insure economical design and correct construction. All revisions made subsequent to initial preparation and transmittal of drawings should be noted in the revision block by date and brief description of revision. Originals of the plan-profile drawings, revised for as-built conditions, should be filed by the borrower for future reference.

B. Drawing Preparation

Adequate control of field survey, including ground check of aerial survey, and the proper translation of data to the plan-profile drawings are of utmost importance. Errors which occur during this initial stage will affect line design because a graphical method is used to locate the structures and conductor. Normally, plan-profile sheets are prepared using a scale of 61 meters (200 feet) to the inch horizontally and 6 meters (20 feet) to the inch vertically. On this scale, each sheet of plan-profile can conveniently accommodate about 1.6 kilometers (1 mile) of line with overlap to connect the end span on adjacent sheets. For lines with abrupt ground terrain and to minimize breaks in elevation view, a scale of one inch equal to 122 meters (400 feet) horizontally and one inch equal to 12 meters (40 feet) vertically may be used. The comparable metric scales would be: 1cm = 50 m and 1 cm = 5 m.

A sample format for plan-profile drawing is shown by Figure X-1, with units and stationings in U.S. customary units. Increase in stationing and structure numbering usually proceeds from left to right with the profile and corresponding plan view

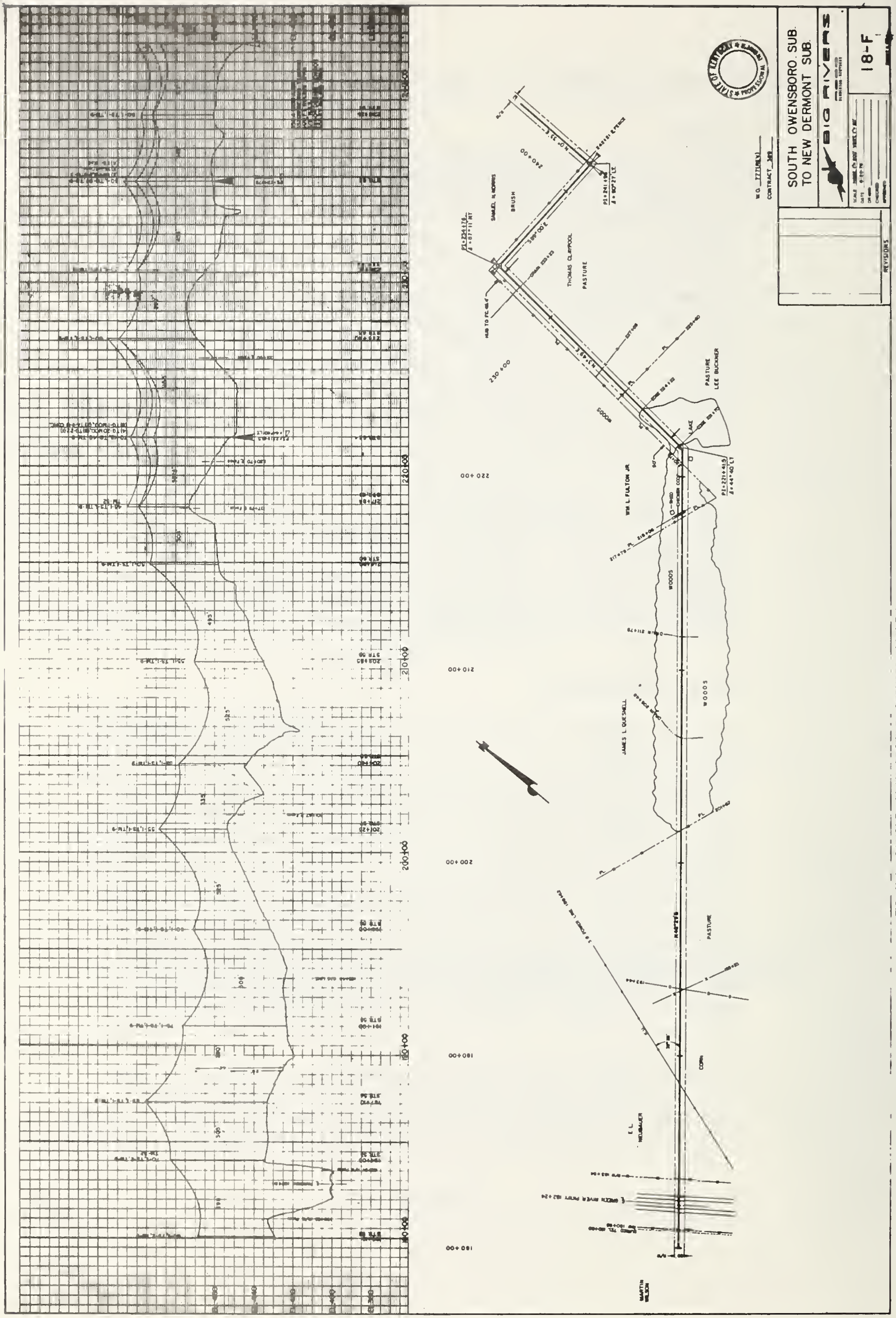


FIG. X-1 SAMPLE PLAN-PROFILE REDUCED SCALE

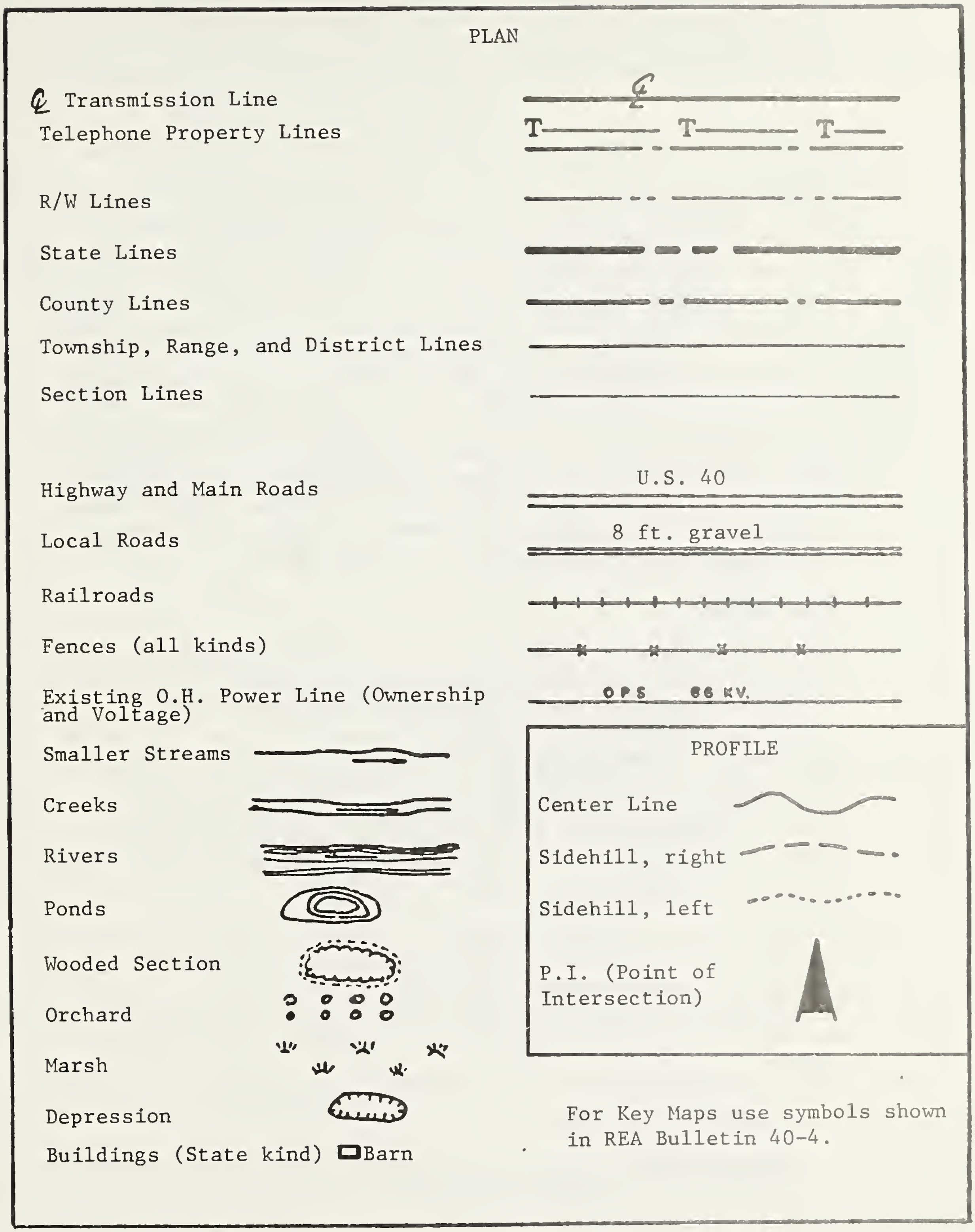


FIGURE X-2: CONVENTIONAL SYMBOLS FOR PLAN-PROFILE on the same sheet. Drawings prepared in ink on mylar or tracing cloth will provide a better permanent record; however, structure spotting initially should be done in pencil on plan-profile drawing paper and transferred to the base tracings after the drawings are approved and the line is released for construction.

Conventional symbols used to denote features on the drawings are shown in Figure X-2. REA Bulletin 40-4, "Guide for Mapping and Location Numbering - Electric Distribution System," gives additional details on symbols for features, lettering sizes, and key map requirements. Existing features to be crossed by the transmission line, including the height and position of power and communication lines, should be shown and noted by station and description in both the plan and profile views. The magnitude and direction of all deflection angles in the line should be given and referenced by P.I. station in plan and elevation. In rough terrain, broken lines representing side-hill profiles should be plotted to assure adequate conductor-ground clearances and pole height. A drawing title block should identify the line, give the stations covered by the sheet, and also include space for recording the personnel and dates involved in various stages of drawing preparation, line design, checking, approval, and revisions.

C. Sag Template

The sag template is a scaling device used for structure spotting and shows the vertical position of conductor (or ground wire) for specified design conditions. A sample of the conductor sag template is shown by Figure X-3. It is used on plan-profile drawings to determine graphically the location and height of supporting structures required to meet line design criteria for vertical clearances, insulator swing, and span limitations. The sag template permits alternate layout for portions of the line to be investigated and thereby aids in optimizing line design for economy.

Generally, the conductor sag curves control the line design. The sag template for the overhead ground wire is used to show its position in relationship to the conductors for special spans or change in conductor configuration. Also, uplift condition at the overhead ground wire may be checked by using its cold curve.

1. Sag Template Curves

The sag template should include the following sag curves based on the design ruling span:

CONDUCTOR: 336.4 kcmil ACSR (26/7)
RULING SPAN: 152.4 m (500 ft)
MAX. DESIGN TENSION: 5786 lb.
DESIGN LOADING: ½ in. ice, 4 psf wind @ 0°F

SCALE: HORIZONTAL 1" = 61 m (200 ft)
VERTICAL 1" = 6.1 m (20 ft)

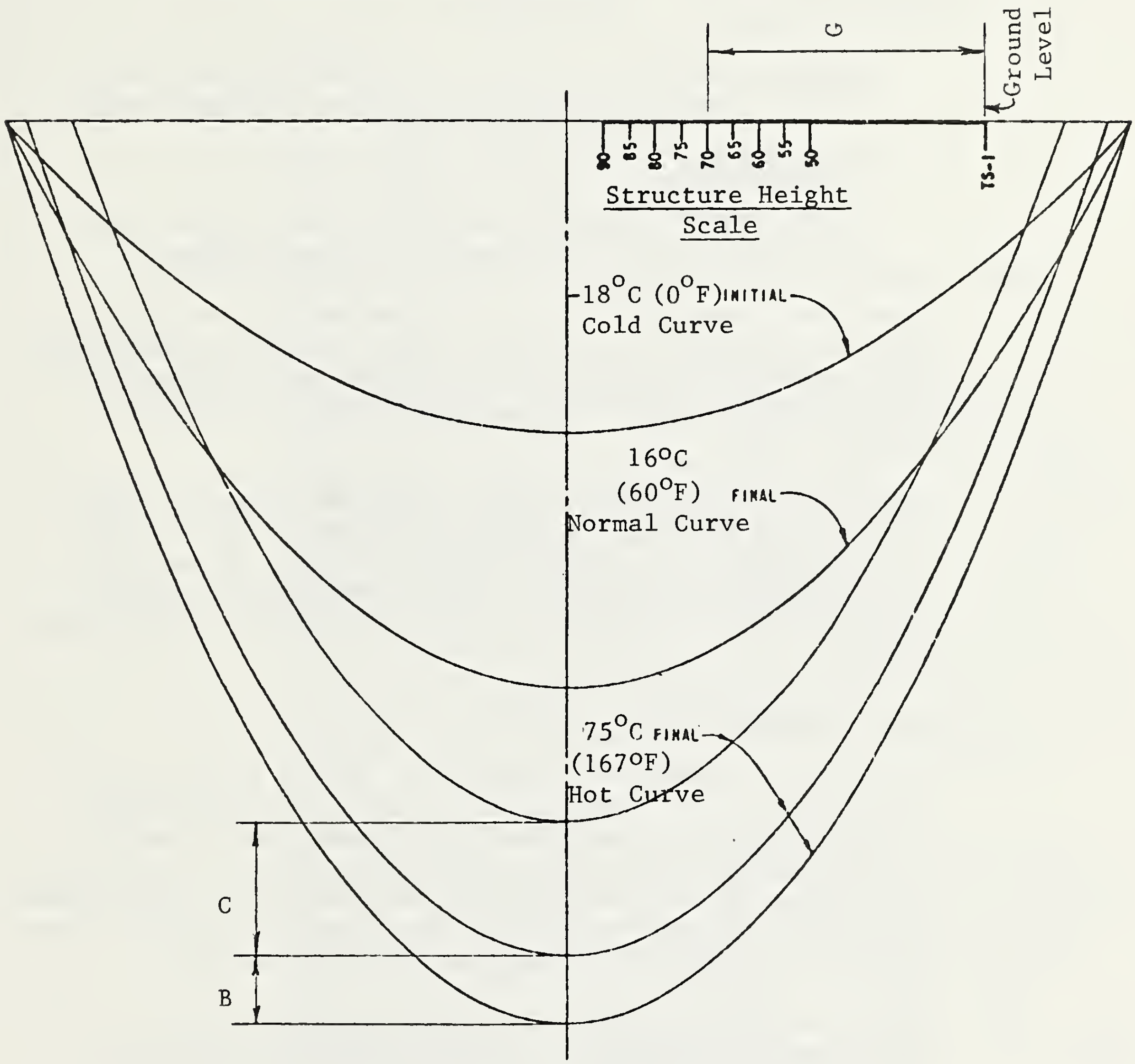


FIGURE X-3: SPECIMEN SAG TEMPLATE FOR CONDUCTOR (REDUCED SIZE - DO NOT SCALE)

a. Hot (Maximum Sag) Curve

Maximum operating temperature, no ice, no wind, final sag curve. Used to check for minimum vertical clearances (or if maximum sag occurs under an icing condition, this value should be used for the sag template).

b. Cold Curve

Minimum temperature, no ice, no wind, initial sag curve. Used to check for uplift and insulator swing.

c. Normal Curve

16°C (60°F), no ice, no wind, final sag curve. Used to check normal clearances and insulator swing.

The above curves are also used to locate the low point of sags and determine the vertical span lengths as illustrated by Figure X-5. The curve intersection with the vertical axis line represents the low point position of sag in Figure X-3.

Conductors of underbuild lines may be of different types or sizes than the transmission conductor. The hot curve of the lowest distribution conductor should be used for checking ground clearance. Cold curves may be required for each size of conductor to check for uplift or insulator swing.

2. Sag Template Design

For a given conductor, ruling span, design condition and temperature, sag values needed to construct the template are available from the conductor manufacturer or may be determined using the graphic method referred to in Section H of Chapter IX. The template should be made to include spans three or four times as long as the normal level ground span to allow for spotting structures on steep terrain.

The form of the template is based on the fact that at the time when the conductors are installed, the horizontal tensions must be equal in all level and inclined spans if the suspension insulators are plumb in profile. This is also approximately true at maximum temperature. To obtain values for plotting the sag curves, sag values for the ruling span are extended for spans shorter and longer than the ruling span. Generally for spans up to 305 meters (1000 feet), it is sufficiently accurate to assume that the sag is proportional to the square of the spans if more accurate computed sag values are unavailable. The sag values used for the template may be determined as follows:

a. For the ruling span and its sag under each appropriate design condition and temperature, calculate other sags by the relationship:

$$S = \left(\frac{L}{RS}\right)^2 (S_{RS}) \qquad \text{Eq. X-1}$$

where:

S = sag of other span in m (ft).
S_{RS} = sag of ruling span in m (ft).
L = length of other span in m (ft).
RS = length of ruling span in m (ft).

b. Apply catenary sag correction for long spans having large sags.

The template should be cut to include a minimum of 0.3 meters (1 foot) additional clearance than given in Table IV-1 in Chapter IV to account for possible minor shifts in structure location and for error in the plotted profile. Where the terrain or the surveying method used in obtaining ground profile are subject to greater unknowns or tolerances, the 0.3 meters (1 foot) additional clearance should be increased accordingly. The vertical offset between the upper two maximum-temperature (hot) curves is equal to the total required clearance, including the specified additional clearance. It is shown as dimension "C" in Figures X-3 and X-4. The minimum temperature and the 16°C (60°F) curves may be placed in any convenient location on the template.

A sag template drawing similar to Figure X-3 made to the same scales as the plan-profile sheets and for the specified conductor, ruling span, and loading condition should be prepared as a guide for cutting the template. A new template should be prepared for each line where there is any variation in voltage, conductor size, loading condition, design tension, or ruling span. A change in any one of these factors may affect the design characteristics of the template.

3. <u>Sag Template Construction</u>

The sag template should be made of dimensionally-stable transparent plastic material. A contrasting colored material, for example red, is very helpful when the template is used to check plan-profile drawings which are blueprints.

The curves are first plotted on paper using the correct scales and then reproduced or copied on the plastic material. To cut a template, the transparent material is fastened securely over the sheet and the centerline and upper curves are etched lightly by a sharp-pointed steel scriber. The outside edges of the template should be etched deeply so that the template can be easily broken out and the edges sanded smooth. Structure height scales may also be drawn or etched on the sag template or a separate template for determining the pole height required for each type of structure used. The etched lines should be filled with ink to make them easier to see when the template is used.

Conductor size, design tension and loading condition, ruling span and descriptive data for each curve should be shown on the template.

D. Structure Spotting

1. General

Structure spotting is the design process which determines the height, location, and type of consecutive structures on the plan-profile sheets. Actual economy and safety of the transmission line depends on how well this final step in the design is performed. The structure spotting should closely conform to the design criteria established for the line. Constraints on structure locations and other physical limitations encountered may prevent structure spotting of structures at optimum locations. Success of the effort to minimize or overcome these special conditions can be judged by how closely the final line layout follows the original design parameters.

Ideally, the desired properties of a well-designed and economical line layout are:

a. Spans approximately uniform in length, equal to or slightly less than the design ruling span. Generally, differential conductor tensions are minimized and may be ignored if adjacent span lengths are kept below a ratio of 1.5 to 1.

b. Maximum use of the basic structure of equal height and type. The basic structure is the pole height and class which has been selected as the most economical structure for the given design condition.

c. The shape of the running conductor profile, also referred to as the grading of the line, should be smooth. If the conductor attachment points at the structures lie in a smooth-flowing curve, the loadings are equalized on successive structures.

For a generally level and straight line with few constraints on structure locations, the above stated objectives do not conflict and can be readily achieved. Greater skill and effort are needed for lines with abrupt or undulating ground profile and where constraints on structure location exist. Examples of these conditions are high or low points in the profile and features such as line angle points, crossings over highway, railroad, water, power and communication lines, and ground with poor soil conditions. Structure locations and heights are often controlled or fixed by these special considerations. Alternate layouts between fixed locations may be required to determine the best arrangement based on factors of cost and effective design.

The following design factors are involved in structure spotting and are covered in the chapters of this manual:

a. Vertical Clearances

    (1) Basic, level ground

    (2) Crossings

    (3) Sidehill

    (4) Underbuild

b. Horizontal Clearances

    (1) For insulator sideswing condition

    (2) To edge of right-of-way, vertical obstructions and steep sidehills

c. Uplift

d. Horizontal or Vertical Span Limitations Due to:

    (1) Vertical sag - clearance requirement

    (2) Conductor separation

    (3) Galloping

    (4) Structure strength

(5) Crossarm strength

e. Angle and Deadend

(1) Guying arrangements

(2) Guy anchors

2. Preparation

The following are required for structure spotting:

a. Plan-profile drawings of the transmission line.

b. Sag template of the same scale as the plan-profile prepared for the design temperatures, loading condition, and ruling span of the specified conductor and overhead ground wire.

c. Table of required minimum conductor clearances over ground features and other overhead lines (Chapter IV).

d. Insulator swing charts (Chapter VII).

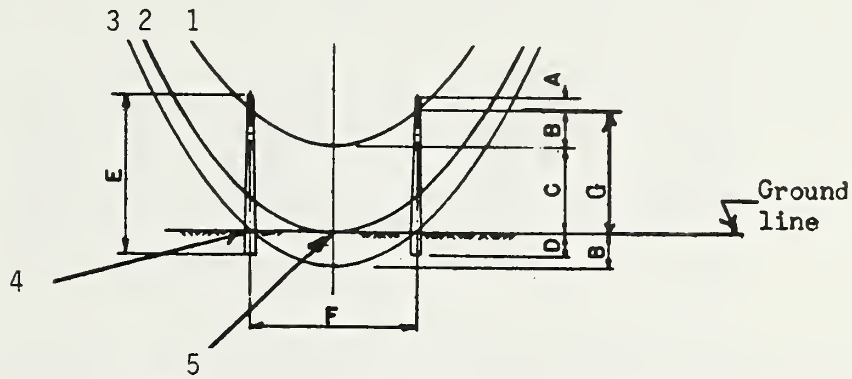
e. Horizontal and vertical span limitations due to clearance or strength requirements (Chapters VIII, IX, and XIII).

f. Guy arrangement and anchor requirements for angle and deadend structures (Chapter XIV).

A height scale prepared for each structure type will aid in height determination. Supporting calculations should be summarized in chart or tabular form to facilitate application during structure spotting. This is especially advisable for the standard suspension structure which has a greater range of pole height and class, as well as bracing variations for H-frame structures. Selection of the proper pole may be affected by different criteria, changing from span controlled by clearance to span limited by pole strength for different pole height and class or bracing.

3. Process of Spotting

The process of spotting begins at a known or established conductor attachment point such as a substation take-off structure. For level terrain, when a sag template is held vertically and the ground clearance curve is held tangent to the profile, the edge of the template will intersect the profile at points where structures of the basic height should be set. This relation is illustrated for a level span in Figure X-4. Curve No. 1 represents the actual position of the lowest conductor, offset by the required total ground clearance, "C".



Hot Curves (Maximum Sag)

Curve 1 -Lowest Conductor Sag Position
2 -Basic Ground Clearance Curve
3 -Edge of Template or Reference Line
Point 4 -Intersection Locates Pole of Basic Height
5 -Tangent to Ground Profile

A = Dimension from top of pole to point of attachment of lowest conductor.
B = Sag in level ground span.
C = Total ground clearance.
D = Setting depth of pole.
E = Length of pole.
F = Level ground span.
G = Dimension from ground to point of attachment of lowest conductor.

FIGURE X-4: APPLICATION OF SAG TEMPLATE - LEVEL GROUND SPAN.

The point where Curve No. 3 intersects the profile determines the location of the next structure and is marked by drawing an arc along the edge of the template where it intersects the profile. The template should then be shifted and adjusted so that with the opposite edge of the template held on the conductor attachment point previously located with the clearance curve again barely touching the profile. The process is repeated to establish the location of each succeeding structure. After all structures are thus located, the structures and lowest conductor should be drawn in.

The above procedure can be followed only on lines that are approximately straight and which cross relatively flat terrain with the basic ground clearances. When line angles, broken terrain, and crossings are encountered, it may be necessary to try several different arrangements of structure locations and heights at increased clearances to determine the arrangement that is most satisfactory. The special considerations often fix or limit the structure locations and it is advisable to examine the profile for several span lengths ahead for these conditions and adjust the structure spotting accordingly. Sometimes, a more balanced arrangement of span lengths is achieved by moving ahead to one of these fixed locations and working back.

The relationship of the ground clearance and conductor curves is also used for spans other than level-ground spans by shifting the sag template until ground profile touches or is below the clearance curve with the previously established conductor attachment point (normally, the left) positioned on the conductor curve. The conductor curve would then indicate the required conductor height for any selected span. Structure height may be determined by scaling or use of the proper structure height template, taking into account the change in the embedded pole length for poles other than the basic pole. Design limitations due to clearance or structure strength should be observed.

4. Crossings

For spans crossing features such as highway and power lines with different clearance requirements than the normal clearance, the ground clearance curve should be adjusted accordingly. In California, adequate ground clearance must be maintained over all crossings over railroads, major highways, major communication and power lines under a broken conductor condition in either of the spans adjacent to the crossing span. Other states are governed by the NESC, which does not require broken conductor condition in the latest edition (1977). The increase in sag due to a broken conductor in adjacent span is usually significant only where suspension-type structures are used at crossing and for voltage at 230 kV or above. Where tension structures are used and for suspension structures at lower voltages the sag increase normally will not seriously affect the clearance.

5. Insulator Sideswing - Vertical Span

Horizontal conductor clearances to supporting structure are reduced by insulator sideswing under transverse wind pressure. This condition occurs where the conductor is supported by suspension-type insulators. Conductors supported by pin-type, post, or tension insulators are not affected and horizontal clearance of the deflected conductor position within the span becomes the controlling factor. Suspension insulators also deflect laterally at line angle locations due to the transverse component of conductor tension.

Chapter VII covers the preparation of insulator swing charts and in Appendix D are insulator swing tables for standard REA structures. At each structure location the charts are used to determine if insulator swing is within the allowed limit for the vertical and horizontal spans and line angle conditions. For suspension insulators supported on horizontal crossarms, a minimum vertical span must be maintained to avoid excessive sideswing. For insulators attached directly to the pole and for some types of angle structures, the vertical span must not exceed a maximum value as indicated by the chart to maintain adequate clearance.

The vertical span is the distance between the conductor low points in spans adjacent to the structure and horizontal span being the average value of the adjacent spans. Where conductor attachments are at different elevations on adjacent structures, the low point is not at mid-span and will shift its position as the temperature changes. This can be readily seen by comparing the low point for the hot curve with its position for the cold curve. The vertical span value used to check the insulator swing should be based on the low point position which yields the most critical condition for the structure type.

Where minimum vertical span or uplift is the concern, the cold curve should be used. The normal temperature is more critical and should be used if the vertical span is limited by a maximum value. Figure X-5 shows some examples of the relationship of conductor low points and vertical spans which may occur in a line profile.

If insulator swing is unacceptable, one of the following corrective steps, in order of preference, is recommended:

a. Relocate structures to adjust horizontal-vertical span ratio

b. Increase structure height or lower adjacent structures

c. Use a different structure, one with greater allowable swing angle or a deadend structure

d. Add weight at insulators to provide the needed vertical force

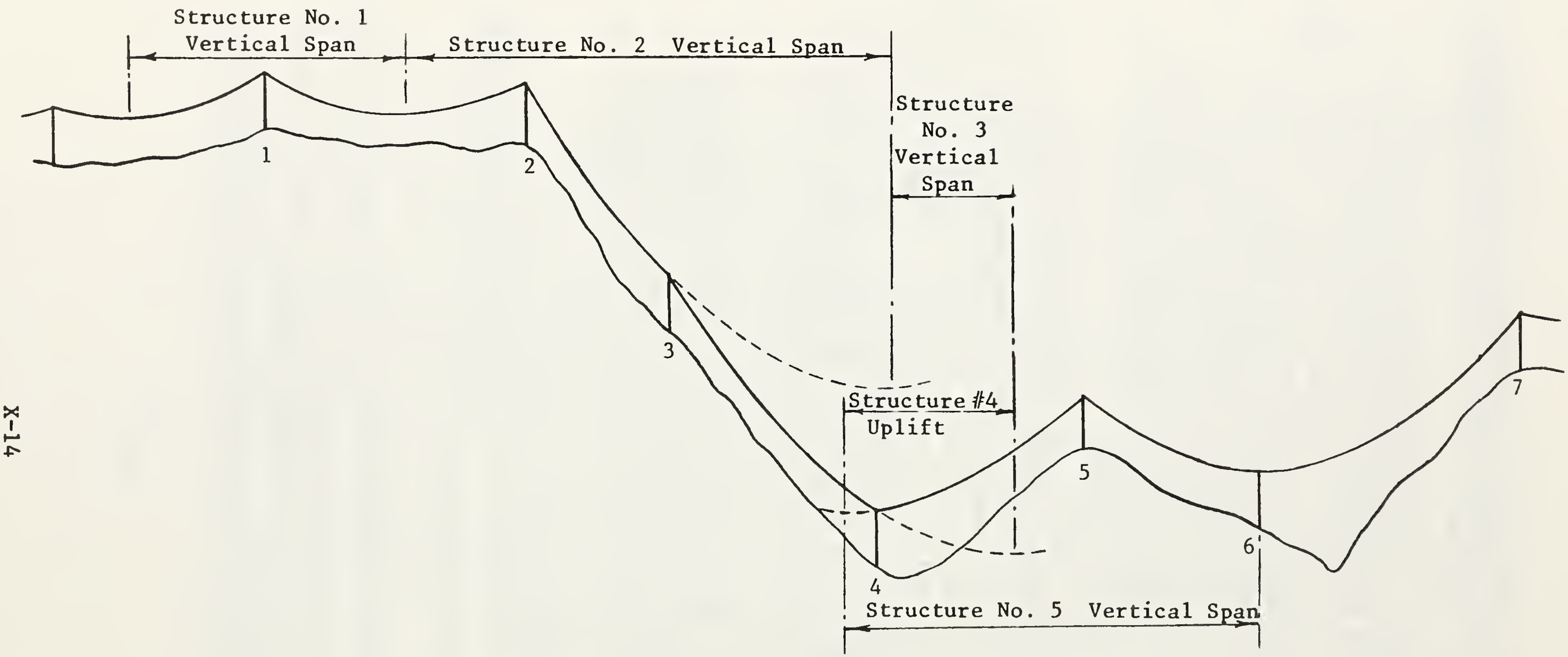


FIGURE X-5: SAG LOW POINT, VERTICAL SPANS, AND UPLIFT.

6. Uplift

Uplift is defined as negative vertical span and is determined by the same procedure as vertical span. On steeply inclined spans when the cold sag curve shows the low point to be beyond the lower support structure, the conductors in the uphill span exert upward forces on the lower structure. The amount of this force at each attachment point is related to the weight of the loaded conductor from the lower support to the low point of sag. Uplift exists at

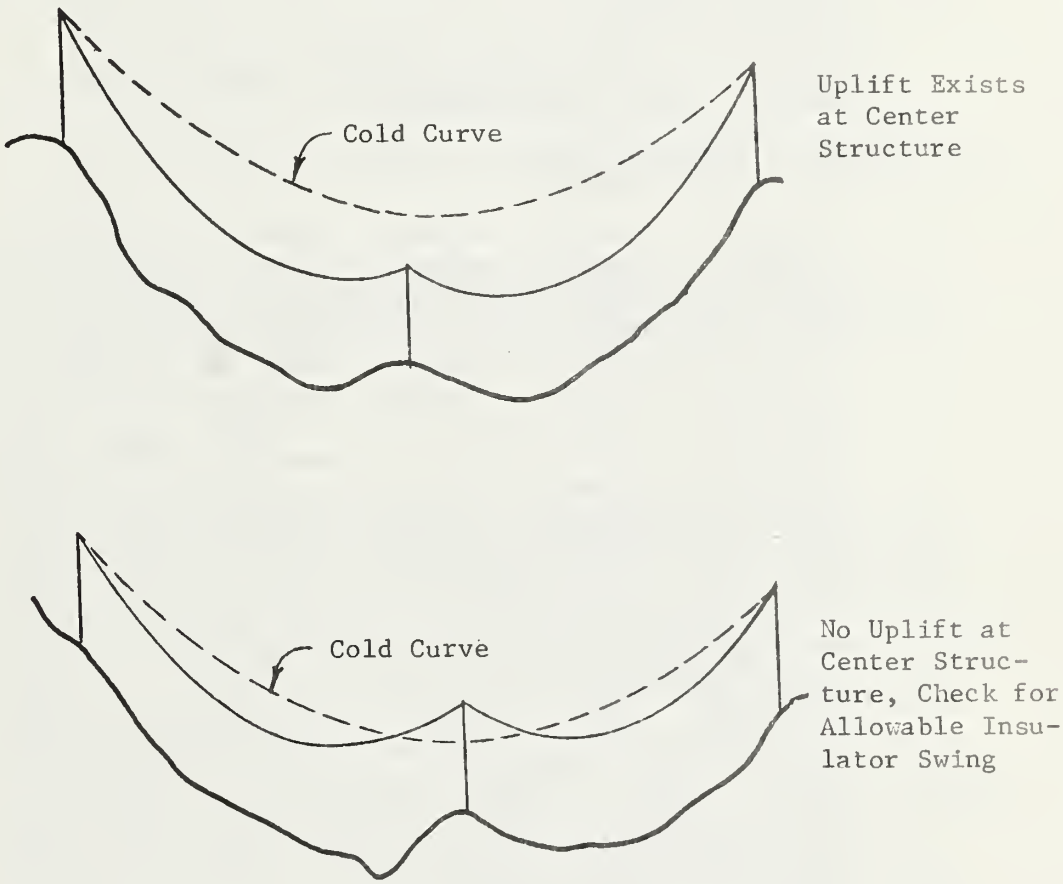


FIGURE X-6: CHECK FOR UPLIFT.

a structure when the total vertical span from the ahead and back spans is negative, as shown by Structure No. 4 in Figure X-5, while no net uplift occurs at Structure No. 3. Uplift must be avoided for suspension, pin-type, and post insulator construction. For structures with suspension insulators, the check for allowable insulator swing is usually the controlling criteria on vertical span. A rapid method to check for uplift is shown by Figure X-6. There is no danger of uplift if the cold curve passes below the point of conductor support on a given structure with the curve on the point of conductor support at the two adjacent structures.

Designing for uplift or minimizing its effects is similar to the corrective measures listed for excessive insulator swing, except that adding of excessive weights should be avoided. Double deadends and certain angle structures can have uplift as long as the total force of uplift does not approach the structure weight. If it does, hold-down guys are necessary.

Care should be exercised to avoid locating structures that result in poor line grading.

7. Other Considerations

If maximum conductor tension or other limits are not exceeded, it may be preferable to use one long span with adequate conductor separation over a depression in the profile rather than use two short spans with a deadend structure at the bottom of the depression which may be subjected to considerable uplift at minimum conductor temperature. Also, poorer soil foundation conditions usually exist in the depression. Care must be exercised at locations where the profile falls sharply away from the structure to see that the maximum allowable vertical span as limited by the strength of the crossarm or insulator is not exceeded. Structure No. 2 in Figure X-5 illustrates this condition. For maximum accuracy in the heavy or medium loading zone, the vertical span for this purpose should be determined with a curve made for the sag under ice load, no wind, at $0^{o}C$ ($32^{o}F$). For most conductors, however, the maximum temperature final sag curve will closely approximate the curve for the ice-loaded conductor, and it may be used when checking for maximum vertical span. For guyed structures, the maximum vertical loads added to the vertical components from guy loads should be checked against the buckling strength of the pole.

The profile in rough country where sidehills are encountered should be prepared so that the actual clearances under the uphill and downhill conductor may be checked. For some long spans it may be necessary to check sidehill clearance with the conductors in their maximum transverse swing position. H-frame type structures installed on sidehills may require different pole heights to keep the crossarm level or one pole may be set at greater than normal setting depth.

Structures with adequate longitudinal strength (normally guyed deadends) are required at locations where longitudinal loading results from unequal line tensions in adjacent spans. For lines subject to heavy ice and high wind conditions and with long, uninterrupted section of standard suspension structures, consideration should be given to include some structures with in-line guys or other means to contain and prevent progressive, cascading-type failure.

This is especially important for H-frame type structures with lower strength in the longitudinal direction when compared with its transverse strength and for lines without overhead ground wire which tends to restrain the structure from collapsing longitudinally. A maximum interval of 8 to 16 km (5-10 miles) is suggested between structures with adequate longitudinal capacity, depending on the importance of the line and the degree of reliability sought.

A combination of long-short-long span in sequence should be avoided if possible. If this combination cannot be avoided due to terrain, offset clipping should be investigated.

E. Other Design Data

The conductor and ground wire sizes, design tensions, ruling span, and the design loading condition should be shown on the first sheet of the plan-profile drawings. For completeness, it is preferable that these design data be shown on all sheets. A copy of the sag template reproduced on the first sheet could serve as a record of design in case the template is misplaced or lost. Design data for underbuild and portions of the line where a change in design parameters occurs should similarly be indicated. The actual ruling spans between deadends should be calculated and noted on the sheets. This serves as a check that the actual ruling span has not deviated greatly from the design ruling span. The significance of this deviation is also covered in the ruling span section of Chapter IX. Where spans are spotted at lengths under one-half or over twice the ruling span, deadending may be required.

As conductor sags and structures are spotted on each profile sheet, the structure locations are marked on the plan view and examined to insure that the locations are satisfactory and do not conflict with existing features or obstructions. To facilitate preparation of a structure list and the tabulation of the number of construction units, the following items, where required, should be indicated at each structure station in the profile view:

1. Structure type designation

2. Pole height and class

3. Pole top, crossarm, or brace assemblies

4. Pole ground unit

5. Miscellaneous hardware units (vibration dampers at span locations)

6. Guying assemblies and anchors

The number of units or items required should be shown in parenthesis if greater than one. Successive plan-profile sheets should overlap, with the end structure on a sheet shown as a broken line on the following sheet for continuity and to avoid duplicate count. The number and type of guying assemblies and guy anchors required at angle or deadend locations, based on guying calculations or application charts, should also be indicated. Design check, line construction, and inspection are facilitated if an enlarged guying arrangement, showing attachments and leads in plan and elevation, is added on the plan-profile sheet adjacent to each guyed structure. Any special notes or large-scale diagrams necessary to guide the construction should be inserted on the plan-profile sheet. This is important at locations where changes in line design or construction occur, such as a slack span adjacent to a substation, line transposition, or change in transmission and underbuild circuits.

F. Drawing Check and Review

The completed plan-profile drawings should be checked to insure that the line meets the design requirements and criteria originally specified, adequate clearances and computed limitations have been maintained, and required strength capacities have been satisfied. The sheets should be checked for accuracy, completeness, and clarity. Figure X-7 is a Specimen Check List for review of plan and profile sheets. An abbreviated list of key items may be prepared and imprinted on each sheet by an inked stamp to aid in recording the check and review process.

Project ______________________________, Date __________

Line ______________________________, Voltage __________ kV

Plan & Profile Drawing Nos. ________, Checked by ____________

Loading Zone ____________, Ruling Span __________, Ft.

Conductor ____________________________, Design Tension ______

OHGW ________________________________, Design Tension ______

Underbuild ___________________________, Design Tension ______

	Sheet Number												
	PLAN:												
	Property Information												
	Swamps, Rivers, Lakes, etc.												
	R/W Data, Boundaries												
	Location, Buildings, Schools, etc.												
	Other Utilities												
	Obstructions, Hazards												
	Roads												
	Angles, P.I., Bearing of Centerline												
	PROFILE:												
	Horizontal Span Length												
	Vertical Span Length												
	Type Structure												
	Pole Strength												
	Pole Height												
	Pole Foundation Stability												
	Crossarm Strength												
	Conductor Clearance:												
	To Ground or Side Hill												
	To Support and Guys												
	To Buildings												
	Crossing												
	Conductor Separation												
	Conductor Tension Limitations												
	Climbing or Working Space												
	Guy Tension												
	Guy Lead & Height												
	Anchors												
	Insulator Swing or Uplift												
	Tap Off, Switches, Substations												
	Underbuild												
	Code Requirements												

Remarks: ____

FIGURE X-7: SPECIMEN CHECK LIST FOR REVIEW OF PLAN AND PROFILE.

XI. LOADINGS AND OVERLOAD FACTORS

A. General

The strength that must be designed into a transmission line depends to a large extent on the wind and ice loads that may be imposed on the conductor, overhead ground wire, and supporting structure. These loadings are related generally to the geographical location of the line.

When selecting appropriate design loads, the engineer must evaluate climatic conditions, previous line operation experience, and the importance of the line to the system. Conservative load assumptions should be made for a transmission line which is the only tie to important load centers.

B. Loads

The NESC divides the country into three weather or loading districts, as shown in Figure XI-1.

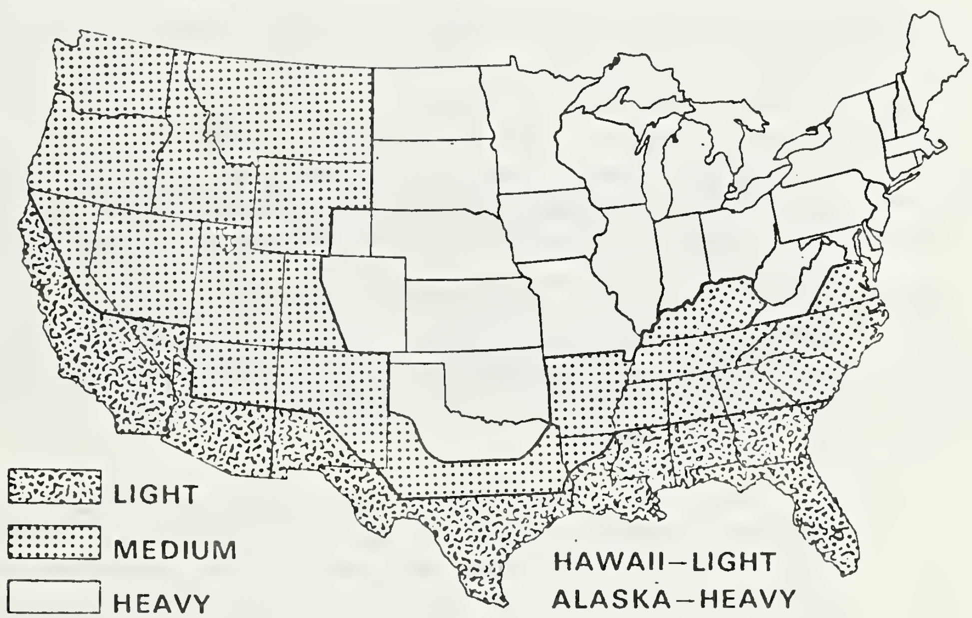


FIGURE XI-1

The minimum design conditions associated with each loading district are given in Table XI-1. Constants found on page IX-12 are to be added to the vector resultant for tension calculations only.

TABLE XI-1
NESC LOADING DISTRICTS

	Design Temperature °C	(°F)	Radial Ice Thickness cm	(in.)	Wind Pressure* pascals	(psf)
Heavy Loading	-17.8	(0°)	1.27	(½")	191.5	4
Medium Loading	- 9.4	(15°)	.63	(¼")	191.5	4
Light Loading	- 1.1	(30°)	0	(0")	430.9	9

*For cylindrical surfaces only.

Designing to these minimum requirements may not be sufficient. Extreme winds and special ice conditions should be investigated. The determination of an appropriate design load to account for extreme winds is easier than determining a heavy ice design load. Whereas meteorological data may be available on high winds, little data is available on extreme ice loads. Heavy ice combined with a relatively high wind should also be considered.

1. Ice

In certain areas of the country heavy ice may be predominant. The engineer should review the experience of utilities or cooperatives in the area of the line concerning ice conditions and determine (1) the number and frequency of outages due to ice storms, and (2) the design assumptions used for existing lines in the area. From this data, the engineer can reasonably determine if a heavy ice condition greater than what is familiar in the NESC needs to be accounted for in the design.

If historical data on icing conditions is lacking, the engineer should consider designing the line for extreme wind conditions without ice, and loading zone conditions, and then calculate the maximum ice load the structure could sustain without wind. The designer would then evaluate whether or not he could "live" with this specific ice condition.

2. Extreme Winds

Although the NESC requires that structures over 60 ft. sustain high winds, REA recommends that all transmission lines meet extreme wind requirements. Figure XI-2 gives minimum horizontal pressures on cylindrical surfaces to be used in calculating loads. For wind pressures at a specific location, use a value not less than that of the nearest pressure line. Local meteorological data should also be evaluated in determining a design high wind speed.

Without a proper engineering study, the extreme wind pressure should not be less than that given in Figure XI-2.

3. Longitudinal Loads

Unbalanced longitudinal loads on a line occur because of a broken conductor, differential ice conditions on equal or unequal spans, stringing loads, etc. Traditionally, the standard tangent wood pole structures have not been designed for broken conductor longitudinal loads and have relied on the restraining capacity of deadends.

C. Strength Factors for Wood Pole Construction

Transmission lines are to be built to Grade B construction. In Table XI-2, the columns under the "REA" headings give the minimum capacity factors to be applied to the light, medium, and heavy loading districts of the NESC in the design of guys, crossarms, and poles.

The recommended overload factors to be applied to extreme wind pressures are in Table XI-3. The factors are intended to take into account approximations made in the design and analysis, variability of wood, gusting on the structure, and increased wind velocity with height. In areas near the coast where transmission lines are subject to hurricane loads, the engineer should consider increasing the appropriate overload factors.

With the exception of the crossarms, underbuild distribution on transmission structures must be built to meet all of the requirements of REA Grade B construction. Distribution crossarms must meet Grade C construction (overload capacity factor of 2). (See Chapter XVI.)

TABLE XI-2

REA GRADE B
MINIMUM OVERLOAD CAPACITY FACTORS
TO BE APPLIED TO LOADING DISTRICTS
(NEW CONSTRUCTION)*

	Overload Capacity Factors		% Rated Breaking Strength of Guy	
	NESC	REA	NESC	REA
DESIGN OF WOOD POLES				
Tangent Structures				
Transverse loads	4.00	4		
Vertical loads	4.00	4		
Longitudinal loads				
General	1.33	2		
Deadends	2.00	2.0		
Angle Structures				
Wind load	4.00	4		
Wire tension load	2.00	2		
DESIGN OF CROSSARMS				
Transverse loads	N.S.	4		
Vertical loads	2	4		
Longitudinal loads				
General	1	2		
Deadends	N.S.	2.0		
DESIGN OF GUYS AND ANCHORS				
Tangent Structures	NESC	REA**		
Transverse loads	2.67	4	90%	100%
Longitudinal loads				
General	1.00	2		
Deadends	1.50	2		
Angle Structures				
Transverse loads due to wind	2.67	4	90%	100%
Wire tension loads	1.50	2	90%	100%

*Refer to REA Bulletin 161-4 for "at replacement" requirements.

**Lower overload factors may be used where justified but should in no case be less than NESC overload factors and percent rated breaking strength of guy.

N.S. - not specified.

FIGURE XI-2: EXTREME WIND PRESSURE IN POUNDS PER SQUARE FOOT AT 30 FT. ABOVE GROUND (50 YEAR MEAN RECURRENCE INTERVAL).

TABLE XI-3

RECOMMENDED OVERLOAD FACTORS TO BE APPLIED TO EXTREME WIND PRESSURES

	New	At Replacement*
DESIGN OF WOOD POLES		
Tangent Structures		
Transverse	1.5	1.0
Longitudinal		
General	1.1	.75
Deadends	1.25	.85
Angle Structures		
Transverse loads due to wind	1.5	1.0
Wire tension loads	1.25	.85

GUYS AND ANCHORS (See Chap. XIV)

*"At replacement" refers to the minimum strength at which deteriorating poles are to be replaced. The replacement poles are to meet "new" construction requirements.

XII. FOUNDATION STABILITY OF WOOD POLES

Every structure standing above ground is subjected to lateral forces. In the case of wood transmission structures, it is desirable to depend on the earth to resist lateral forces. The embedded portion of a wood pole provides this resistance by distributing the lateral load over a sufficient area of soil. For wood poles, a properly selected embedment depth should prevent poles from kicking out. With time, single wood poles may not remain plumb. Leaning of wood pole structures is permitted, provided excessive angular displacements are avoided and adequate clearances are maintained.

The lateral forces which wood transmission structures are subjected to are primarily due to wind and wire tension loads due to line angles. Longitudinal loads due to deadending or uniform ice on unequal spans should be examined to see how they affect embedment depths. Normally, flexible transmission structures are stabilized longitudinally by the overhead ground wire and the phase conductors.

The bearing capacity and lateral earth capacity of soils depend on soil types and these soil characteristics such as internal friction, cohesion, unit weight, moisture content, gradation of fines, consolidation and plasticity. Most soils are a combination of a cohesive soil (clay) and a cohesionless soil (sand).

A. Site Survey

In deciding embedment depths for wood poles, economics dictate that few, if any, soil borings be taken if data and experience from previous lines are available. However, numerous soil conditions will be encountered in the field which, while they may closely resemble each other, may have a wide range of strengths. The engineer, therefore, must identify areas or conditions where pole embedment depths in soil may have to be greater than the minimum depths indicated in REA Form 805 (10 percent, plus .6 meters (2 feet) generally). These areas may include:

1. Low areas near streams, rivers, or other bodies of water where a high water table or a fluctuating water table is probable. Poles in a sandy soil with a high water table may "kick" out. Due to the lubricating action of water, frictional forces along the surface area of embedded poles are reduced. The legs of H-frames may "walk" out of the ground if neither sufficient depth nor bog shoes are provided to resist uplift. Guy anchors may fail if the design capacity does not consider the submerged weight of the soil.

2. Areas where the soil is loose such as soft clay, poorly compacted sand, pliable soil, or soil which is highly organic in nature.

3. Locations where higher safety is desired. This may be at locations of unguyed small angle structures where a portion of the load is relatively permanent in nature, or at river, line, or road crossings.

4. Locations where poles are set adjacent to or on steep grades.

B. Design

1. Pole Stability

In addition to local experience, the following method is useful in determining depth of embedment:

Metric	English	
$P = \dfrac{S_e D_e^{3.75}}{L - .6096 - .662D_e}$	$P = \dfrac{S_e D_e^{3.75}}{L - 2. - .662D_e}$	(Eq. XII-1)

where:

P = horizontal force in Newtons (pounds), .6096 meters (2 feet) from the top that will just overturn the pole.

S_e = soil constant.

- S_e = 1119.7 for good soils (140)
- S_e = 559.8 for average soils (70)
- S_e = 279.9 for poor soils (35)

D_e = embedment depth of pole in meters (feet).

L = total length of pole in meters (feet).

Figures XII-1 to XII-3 are plots of the above equation. For an equivalent horizontal load two feet from the top (total ground line moment divided by the lever arm to .6 meters (2 feet) from the top), the embedment depth can be determined.

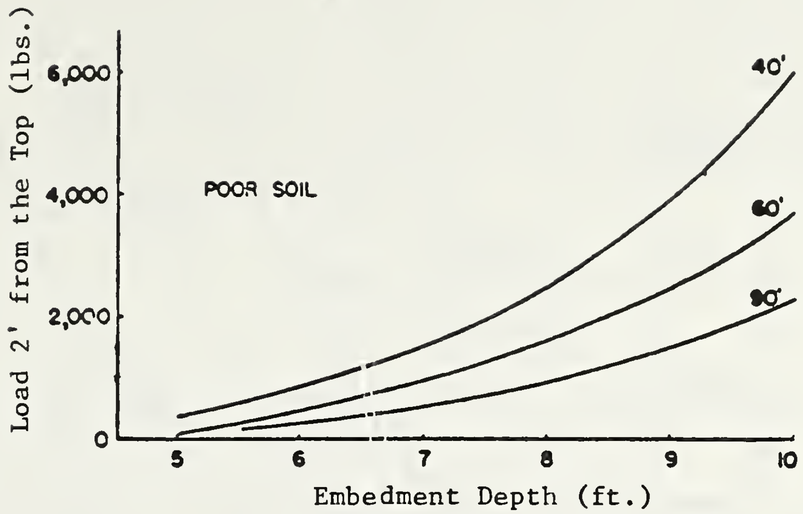


FIGURE XII-1: POOR SOIL

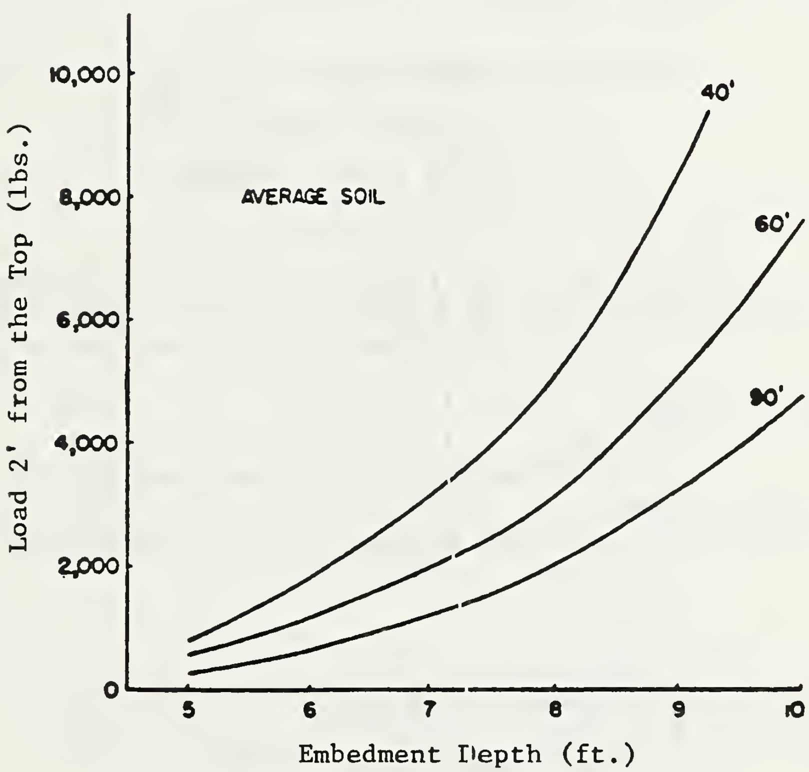


FIGURE XII-2: AVERAGE SOIL

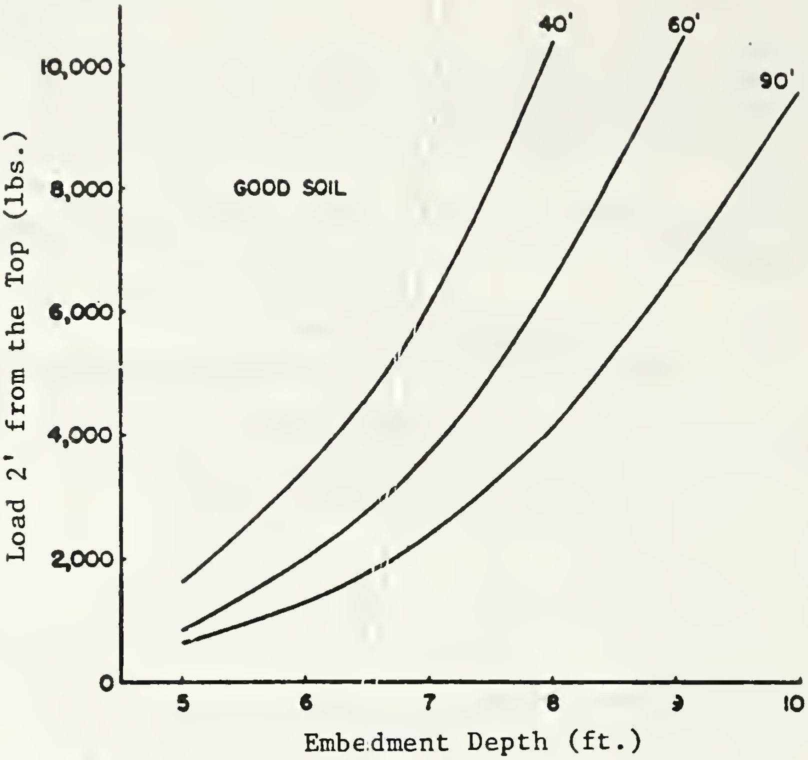


FIGURE XII-3: GOOD SOIL

In order to use the above equation, good, average, and poor soils must be defined. The following is proposed as a description of good, average, and poor soils:

a. Good

- o Very dense, well graded sand and gravel
- o Hard clay
- o Dense, well graded, fine and coarse sand

b. Average

- o Firm clay
- o Firm sand and gravel
- o Claypan
- o Compact sandy loam

c. Poor

- o Soft clay
- o Poorly compacted sands (loose, coarse, or fine sand)
- o Wet clays and soft clayey silt

A field survey is necessary in order to judge whether a soil is "good", "average", or "poor". There are several economical methods of making a field survey for wood transmission lines. The engineer may use a hand auger, light penetrometer, or torque probe. The meaning of firm, soft, dense, loose, etc., may have different connotations. The following table will help in the understanding of these terms:

Cohesive Soils (Clays)

Term	Field Test
Very soft	Squeezes between fingers when fist is closed
Soft	Easily molded by fingers
Firm	Molded by strong pressure of fingers
Stiff	Dented by strong pressure of fingers
Very stiff	Dented only slightly by finger pressure
Hard	Dented only slightly by pencil point

Cohesionless (Sands)

Term	Field Test
Loose	Easily penetrated with a 1.27 cm (½ in.) reinforcing rod pushed by hand
Firm	Easily penetrated with a 1.27 cm (½ in.) reinforcing rod driven with a 2.27 kg (5 lb.) hammer
Dense	Penetrated .3048 meters (1 ft.) with a 1.27 cm (½ in.) reinforcing rod with a 2.27 kg (5 lb.) hammer
Very dense	Penetrated only a few inches with a 1.27 cm (½ in.) reinforcing rod driven with a 2.27 kg (5 lb.) hammer

If experience has indicated that single pole lines have had to be replumbed in an area, there are several methods which should be considered in order to reduce the frequency of replumbing lines. These are as follows:

- Use a lower grade species of wood in order to increase embedment diameters. For instance, embedment diameters for Class 1 Western red cedar poles will be greater than embedment diameters for Douglas fir.

- o Use aggregate backfill.

- o Install a pole key with or without a pole toe of crushed stone, gravel, or concrete.

- o Embed one foot deeper.

The additional cost of the above should be weighed against liability risks and costs of replumbing.

Some general observations can be made when using the equation for pole stability:

- o The rule of thumb of "10 percent + .61 meters (2 ft.)" is adequate for most wood structures in good soil.

- o For Class 2 and higher class poles (poles of heights less than 18.3 meters (60 ft.) pole embedment depths should be increased .61 meters (2 ft.) or more in poor soil (single pole structures).

- o For Class 2 and higher class poles (poles of heights less than 12.2 meters (40 ft.) pole embedment depths should be increased .3 to .6 meters (1-2 ft.) in average soil (single pole structures).

- o For H-frame wood structures, "10 percent + .61 meters (2 ft.)" seems to be adequate for lateral strengths. Embedment depths are often controlled by pullout resistance.

2. Bearing Capacity

In order to prevent a guyed pole from continually sinking into the ground due to induced vertical loads, the pole butt should provide sufficient surface area. If little soil information is available, local building codes might be helpful in determining allowable bearing capacities. These values usually are conservative and reflect the hazards associated with differential deflection in a building. Fortunately, wood transmission lines can sustain deflections on the order to several times that of buildings without detrimentally affecting their performance. As such, the bearing capacity of guyed wood poles is not as critical as that for buildings. Good engineering judgment and local experience should be used in determining if bearing capacities of a certain soil will be exceeded by guyed poles.

TABLE XII-1

PRESUMPTIVE ALLOWABLE BEARING CAPACITIES, kPa (ksf)

Soil Description	Chicago 1966		Atlanta 1950		Uniform Bldg. Code 1964	
Clay, very soft	23.9	(.5)	95.8	(2.0)	71.8	(1.5)
Clay, soft	71.8	(1.5)	95.8	(2.0)	71.8	(1.5)
Clay, ordinary	119.7	(2.5)	191.5	(4.0)		
Clay, medium stiff	167.6	(3.5)			119.7	(2.5)
Clay, stiff	215.5	(4.5)	191.5	(4.0)		
Clay, hard	287.3	(6.0)			383.0	(8.0)
Sand, compact and clean	239.4	(5.0)				
Sand, compact and silty	143.6	(3.0)				
Inorganic silt, compact	119.7	(2.5)				
Sand, loose and fine					71.8	(1.5)
Sand, loose and coarse, or sand-gravel mixture, or compact and fine					119.7	(2.5)
Gravel, loose, and compact coarse sand			383.0	(8.0)	383.0	(8.0)
Sand-gravel, compact			574.6	(12.0)	383.0	(8.0)
Hardpan, cemented sand, cemented gravel	574.6	(12.0)	957.6	(20.0)		
Soft rock						
Sedimentary layered rock (hard shale, sandstone, siltstone)			1,436.4	(30.0)		
Bedrock	9,580.0	(200.0)	9,576.0	(200.0)		

TABLE XII-2

SUGGESTED RANGES OF PRESUMPTIVE ULTIMATE BEARING CAPACITIES, kPa (psf)*

Specific Description (Dry)		
Soft clay	95.8 - 287.3	(2000 - 6000)
Ordinary clay	287.3 - 430.9	(6000 - 9000)
Stiff clay	574.6	(12000)
Hard clay	718.1	(15000)
Loose sand	213.4	(4500)
Compact silty sand	430.9	(9000)
Compact clean sand	718.1	(15000)
Hardpan	1915.2	(40000)
General Description (Dry)		
Poor soil	143.6 - 191.5	(1500 - 4000)
Average soil	239.4 - 430.9	(5000 - 9000)
Good soil	574.6 - 861.7	(12000 - 18000)

*NOTE: Ultimate values are based on three times allowable. The values in the table are considered approximate. For more accurate bearing capacity values, bearing capacity equations should be used.

3. Uplift

When H-frame structures with X-braces are subject to overturning forces, one leg will be in compression and one leg in tension. The skin friction which the engineer assumes in design should be based on his experience, experience of nearby lines, and the results of the field survey. As guidance, the following is suggested for average soil:

a. If the soil is wet or subject to frequent wettings, an ultimate skin friction not greater than 4.79 kPa (100 psf) should probably be assumed.

b. If native soil is used as backfill, an ultimate skin friction between 4.7 and 23.9 kPa (100 and 500 psf) should be assumed, provided the soil is not subject to frequent wettings.

c. If an aggregate backfill is used, an ultimate skin friction between 12.0 and 47.9 kPa (250 and 1000 psf) may be possible.

d. Pole "bearing" shoes increase uplift capacity of a dry hole with natural backfill on the order of 2 to 2.5 times. The use of aggregate backfill with bearing shoes is usually not necessary provided the native backfill material is of relatively good material.

Note: In many cases, double cross-braced H-frame structures may require uplift shoes.

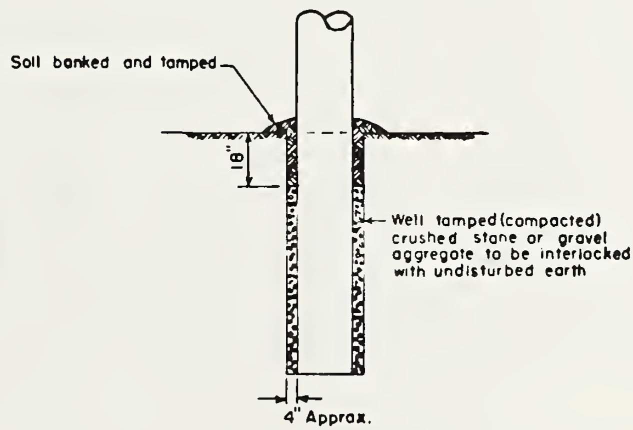
4. Construction - Backfill

Lateral and uplift resistance of wood poles will depend not only on type of soil, moisture content of the soil, depth of setting, but also on how well the backfill has been tamped.

All water should be removed before backfilling. If native backfill material is to be used, it should be free of grass, weeds, and other organic materials. If the dirt removed from the hole is too wet or has frozen, dry, unfrozen material should be obtained for the backfill. Where the earth removed from the hole is unsuitable as backfill, special backfill should be specified by the engineer. Drawing TM-101 of REA Form 805 suggests a gradation of aggregate to be used as backfill material.

When backfilling, the soil should be placed and compacted in shallow layers. Each layer should be compacted until the tamp makes a solid sound as the earth is struck. Power tamping is preferred using two power tampers and one shoveler. The importance of proper compaction of the backfill cannot be overemphasized. Insufficient tamping is a common source of trouble and has been the cause of some failures.

FIGURE XII-4: DRAWING TM-101, FOUNDATION STABILIZER
REA FORM 805



NOTES

1 The TM-101 special backfill shall be specified by Engineer where replacement of earth removed from hole will not provide adequate pole stability.

2 The specification for aggregate given below is minimum. In areas where smaller fines can be procured at reasonable cost it is recommended that Engineer so specify.

3. The aggregate shall be well mixed in stock pile so that materials distributed to individual poles shall essentially conform to specifications.

SIZE OF GRAVEL OR CRUSHED STONE	SIZE OF MESH IN INCHES
100% by weight to pass 1" screen	1.00
60%-90% " " " " 1/2" "	.500
40%-60% " " " " No 4 "	.187
25%-50% " " " " " 8 "	.0937
20%-40% " " " " " 16 "	.0469
15%-30% " " " " " 40 "	.0165

FOUNDATION STABILIZER FOR BRACED H-FRAME STRUCTURE

Scale None | Date 10-26-62 | TM-101

XIII. STRUCTURES

A. Economic Study

During the preliminary planning stages of lines above 161 kV, studies should be made which evaluate the economics of different types of structures as related to conductor size. In most instances, lines of voltages 230 kV and below, wood structures have historically been the economical choice. In some instances, other types of material have been used because of environmental or meteorological constraints. However, for voltages 345 kV and above, it may be difficult to obtain long span construction utilizing wood, due to height or strength reasons.

The preliminary cost estimates are usually based on level ground spans. For EHV lines and many of the higher voltage lines, the economic study should consider material costs, cost of foundations and erection, different structure heights, hardware costs, and right-of-way costs. The estimates are intended to give the borrower an idea as to relative rankings of various structure types and configurations such as steel lattice, steel pole, and wood H-frame or single pole. However, in the decision-making process, the manager may want to consider in his evaluation such intangibles as importance of the line to the power system, appearance, material availability, and susceptibility to environmental attack. In some areas, state or local constraints may ignore economics and specify the type of structure to be used.

In most instances, for lines 230 kV and below where wood has proven to be the structural material choice, the economic study should help to determine structure configuration, base pole class and height.

Factors which limit wood structure spans include:

o <u>Strength</u>-

   a. Horizontal spans limited by crossbrace, poles, etc.

   b. Vertical span limited by crossarms, structure strength.

   c. Spans limited by pullout resistance for H-frame structures.

o <u>Conductor Separation</u> - Conductor separation is intended to provide adequate space for workmen on poles, prevention of contacts and flashovers between conductors.

- o <u>Clearances-to-Ground</u> - Spans are directly related to height of structures.

- o <u>Insulator Swing</u> - The ratio of horizontal to vertical span will be limited by insulator swing and clearance to structure.

For practical purposes, the clearance-to-ground and structure strength is used to determine the level ground span to be used in an economic study. One means of determining the level ground span (points A and B) is by developing a graph as shown in Figure XIII-1.

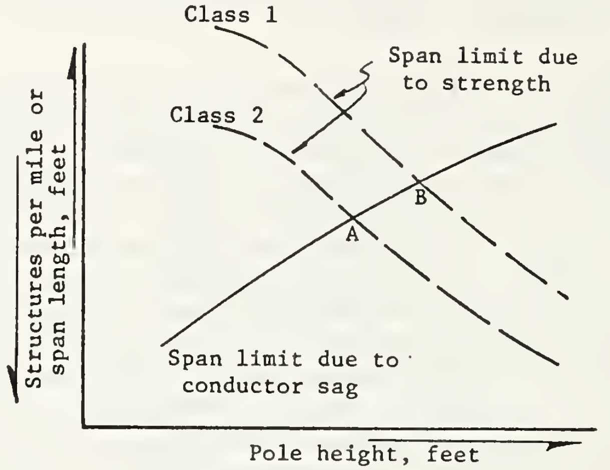


FIGURE XIII-1: SELECTION OF LEVEL GROUND SPAN

Structure cost per mile can then be related to pole height and class of poles as shown in Figure XIII-2.

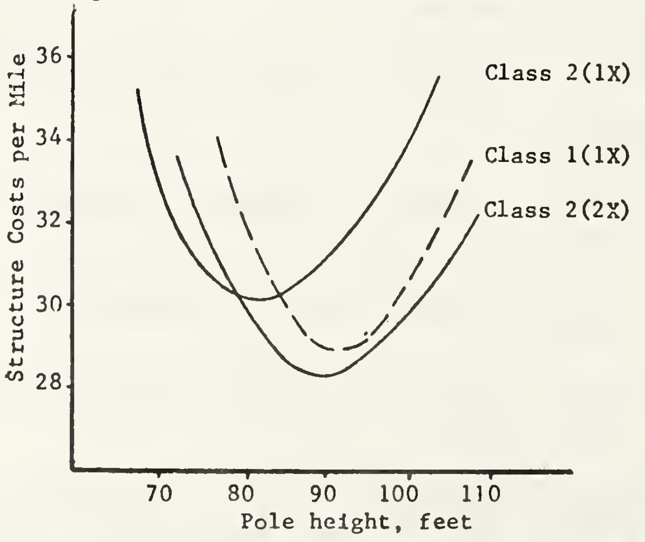


FIGURE XIII-2: STRUCTURE COST PER MILE RELATED TO POLE HEIGHT

In order to keep the cost down for wood transmission lines, the line should be based on one tangent structure type and one class pole for the majority of the line. For H-frame structures, the engineer should consider double crossbraces, as well as single crossbraces.

B. General Design Considerations

1. Stress Limitations

The structural stress limitations set forth in Table XIII-1 are recommended for transmission lines using REA standard wood pole construction. The values in Table XIII-1 are to be used for poles. These values assume that the wood has not deteriorated due to decay occurring in the manufacturing process.

TABLE XIII-1

DESIGNATED STRESSES FOR POLES

Kind of Wood	Modulus of Elasticity x 1000 kPa	(psi)	Designated Ultimate Bending Stress (M.O.R.) kPa	(psi)
Western larch	11,800	(1710)	57,900	(8400)
Southern yellow pine	12,400	(1800)	55,200	(8000)
Douglas fir	13,200	(1920)	55,200	(8000)
Lodgepole pine	9,200	(1340)	45,500	(6600)
Jack pine	8,400	(1220)	45,500	(6600)
Red (Norway) pine	12,400	(1800)	45,500	(6600)
Ponderosa pine	8,700	(1260)	41,400	(6000)
Western red cedar	7,700	(1120)	41,400	(6000)
Northern white cedar	5,500	(800)	27,600	(4000)

Two types of woods may be used for crossarms - Douglas fir and Southern yellow pine. Southern yellow pine has four species which are long leaf (most popular species), loblolly, shortleaf, and slash. The coast type Douglas fir is the only type which should be used when specifying Douglas fir. Table XIII-2 gives strength properties to be used in crossarm design.

TABLE XIII-2

DESIGNATED STRESSES FOR CROSSARMS

Kind of Wood	Modulus of Elasticity x 1000 kPa	(psi)	Designated Ultimate Bending Stress (M.O.R.) kPa	(psi)	End Grain Max. Crushing Strength kPa	(psi)	Across Grain Stress kPa	(psi)	Shear Parallel to Grain kPa	(psi)
Douglas fir	13,200	(1920)	51,000	(7400)	51,200	(7420)	6,300	(910)	7,900	(1140)
Southern yellow pine (all species)	12,400	(1800)	51,000	(7400)	48,700	(7070)	6,900	(1000)	9,000	(1310)

2. Preservative Treatment

The decay of poles results from fungi and other low forms of plant life which attack untreated poles or poles with insufficient preservative. Damage by insect attack (termites, ants, and wood borers) is usually associated with decay. When the preservative treatment of wood is low, the wood cannot resist the attack by fungi and insects. There are two general classes of preservative treatment, oil-borne (creosote oil and penta in petroleum) and water-borne (arsenates of copper).

Creosote oil was the predominent preservative for poles on rural systems until about 1947. Post-war shortages prompted the introduction of pentachlorophenol (penta) and copper naphthenate dissolved in the fuel oils, and other preservatives. Of these new (post 1947) preservatives, only penta has proven its merit. REA is now recommending a retention of 10-12 pounds of creosote or penta per cubic foot of wood for better protection of poles.

The second general class of preservative is the water-borne acid and basic arsenates of copper (CCA and ACA). These poles will be green in appearance. These preservatives were developed before World War II and have proven very effective, if properly used, as wood preservatives around the world. CCA is the standard preservative of the tropics.

C. Single Pole Structures

Single pole wood structures are mainly limited in use to 115 kV and below. The four primary standard single pole structures utilized by REA borrowers are designated as:

TP - pin or post insulators
TS - suspension insulators, crossarm construction
TSZ - suspension insulators, "Z" arm construction
TUS - suspension insulators, upswept arm construction

1. TP and TS Structures

a. General

The following conditions should be taken into account when determining horizontal spans as limited by pole strength for tangent structures:

- Wind on the conductors and OHGW is the primary load. 75 to 90 percent of the horizontal span will be determined by this load.

- o Wind on the structure will affect the horizontal span by 5 to 15 percent.

- o Unbalanced vertical load will increase groundline moments. For single circuit structures, one phase is usually left unbalanced. The vertical load due to the conductor will induce moments at the groundline, and as such will affect horizontal span lengths by 2 to 10 percent. The engineer should determine if this is a significant load to incorporate into the design.

For unguyed structures, vertical loading on the pole does not seem to affect horizontal span capacity when considering the maximum compressive stress approximately equal to the bending stress. Additional moment due to deflection is a secondary effect and usually is not accounted for in wood pole transmission line designs. The high overload factor of four for heavy, medium, and light district loadings is intended to keep the design simple for low height structures and in line with known strength, foundation response, and loading conditions. For tall single pole structures, the designer may want to increase the OCF for NESC district loadings and high wind loadings in order to account for the additional moment due to deflection.

Depending on the taper of the pole, the maximum stress may theoretically occur above the ground level. The general rule of thumb is that if the diameter at ground level is greater than one and a half times the diameter where the net pull is applied, the maximum stress occurs above the ground level. When the point of maximum stress occurs above the groundline, from a practical standpoint for REA Grade B construction, one can assume that spans are based on groundline moments. Spans over river, road, or line crossings should be limited to 75 percent of the calculated spans based on groundline moments.

The strength of the crossarm must be checked to determine its ability to withstand all expected vertical and longitudinal loads. The NESC requires crossarms to be capable of supporting a lineman and his equipment at the outermost extremity, in addition to the weight of bare conductors and insulators. When determining bending stress in crossarms, moments are taken about the through bolt, without considering the strength of the brace. The vertical force is determined by the vertical span under those conditions which yield the maximum vertical weight. The strength of two crossarms will be twice the strength of one crossarm. When considering the strength of the cross-arm to withstand longitudinal loadings, reduction in the moment capacity due to bolt holes should be taken into account.

b. Maximum Horizontal Spans

The general equation for determining the maximum horizontal span of a single pole structure is as follows:

$$HS = \frac{M_g - (OCF)(M_{wp})}{(OCF)(p_t)(h_1) + (OCF)(w_c)(s)} \qquad \text{Eq. XIII-1}$$

where:

M_g = F_bS, the ultimate groundline moment capacity of the pole, N-m (ft-lbs).

where:

F_b = the designated ultimate bending stress (M.O.R.).

S = the section modulus of the pole at the groundline (see Appendix G). For moment capacities of poles at the groundlines, see Appendix F.

$$M_{wp} = \frac{(F)(2d_t + d_g)(h)^2}{6}, \text{ moment due to} \qquad \text{Eq. XIII-2}$$

wind on the pole, N-m, (ft-lbs).

where:

F = wind pressure in Pa (psf).

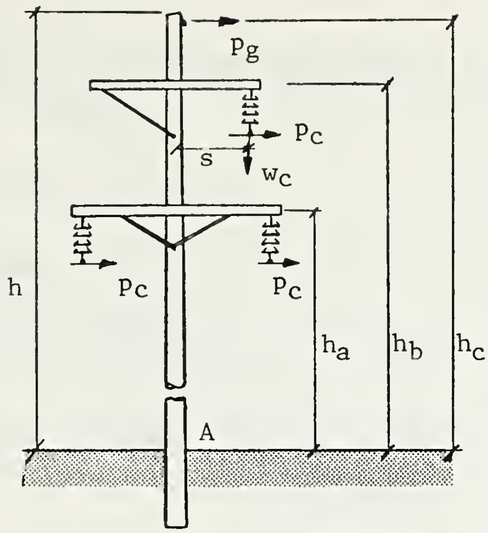
d_t = diameter of pole at top in meters (ft.).

d_g = diameter of pole at groundline in meters (feet).

h = height of pole above groundline meters (feet). For moments at the groundline due to wind on pole, see Appendix F.

h_1 = moment arm of p_t; in the example, Eq. XIII-3

$$h_1 = \frac{(h_a)(p_c) + (h_a)(p_c) + (h_b)(p_c) + (h_c)(p_g)}{p_t}$$



OCF = overload capacity factor.
p_t = sum of transverse unit conductor loads, N/m, (lbs/ft) (in the example, $p_t = 3p_c + p_g$).
w_c = weight of conductor per unit length, N/m, (lbs/ft).
s = moment arm, meters (feet).
HS = horizontal span, meters (feet).

FIGURE XIII-3: TS TYPE STRUCTURE

c. <u>Maximum Vertical Span</u>

To determine the vertical span, the moment capacity of the arm at the pole is calculated. The vertical span follows:

$$VS = \frac{M_a - (OCF)(W_i)(s)}{(OCF)(w_c)(s)} \qquad \text{Eq. XIII-4}$$

where:

M_a = F_bS, moment capacity of the arm, N-m (ft-lbs).

where:

F_b = the designated bending stress.
S = the section modulus of the arm (see Appendix H).

w_c = weight of the conductor per unit length, N/m (lbs/ft).
s = maximum moment arm, meters (feet).
W_i = insulator weight, N (lbs.).
VS = vertical span, meters (feet).

Example XIII-1:

Determine the maximum horizontal and vertical spans for the TSS-1 structure (69 kV). Terrain is predominantly level, flat, and open.

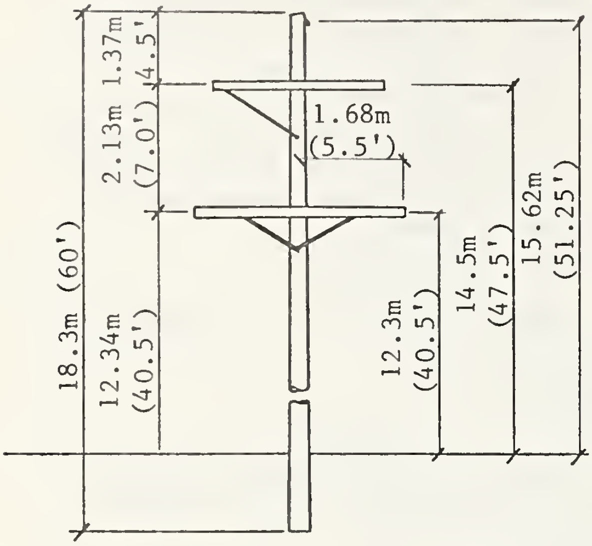


FIGURE XIII-4: TSS-1 STRUCTURE

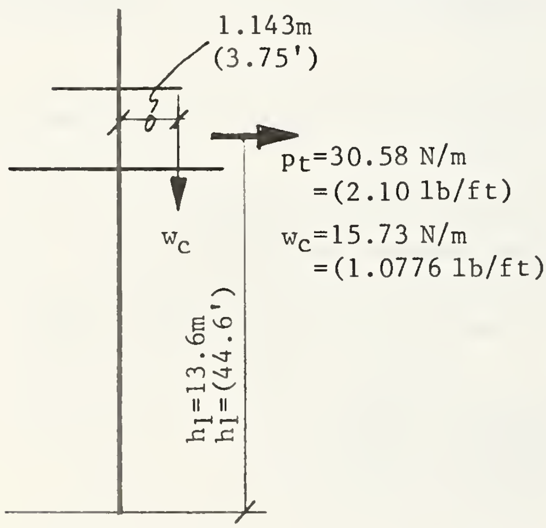


FIGURE XIII-5: APPLICATION OF FORCES (HEAVY LOADING)

Given:

1. NESC heavy loading
   Extreme wind - 766 Pa (16 psf)
2. Pole: Western red cedar, 60'-1
   Cond: 266.8 kcmil, 26/7 ACSR (Partridge)
   Ground wire: 3/8" H.S.S.
3. Conductor loads N/m (lbs/ft):

	Heavy	High Wind
Transverse	7.987(.5473)	12.492(.8560)
Vertical	15.726(1.0776)	5.360(.3673)

   Ground wire loads N/m (lbs/ft):

	Heavy	High Wind
Transverse	6.6250(.4533)	7.005(.4800)
Vertical	11.790 (.8079)	3.984(.2730)

4. F_b(pole) = 41,400 kPa (6000 psi)

   F_b(crossarm) = 51,000 kPa (7400 psi)

   S(groundline) = 7.50×10^{-3} m^3 (458 in^3)

   S(crossarm) = 3.72×10^{-4} m^3 (22.7 in^3)

   Wt. of insulator = 222.4 N (50 lbs.)

   Dia. (top) = .218 m (8.59 in.)

   Dia. (groundline) = .425 m (16.72 in.)

Solution

1. Horizontal Span (Heavy Loading):

Metric

$$HS = \frac{M_g - 4M_{wp}}{4(p_t)(h_l) + 4(w_c)(s)}$$

a. $M_g = F_b(S)$

$M_g = (41,000 \times 10^3)(7.5 \times 10^{-3})$
$= 310,500$ N-m

b. $M_{wp} = (191.5)\left[\frac{2(.218) + .425}{6}\right](15.85)^2$

$= 6900$ N-m

c. $p_t = 3(7.987) + 6.615$
$= 30.58$ N/m

$h_l = 13.6$ m

$w_c = 15.72$ N/m

$s = 1.143$ m

$$HS = \frac{310,400 - 4(6900)}{4(30.58)(13.6) + 4(15.72)(1.143)}$$

$= 163$ m

English

$$HS = \frac{M_g - 4M_{wp}}{4(p_t)(h_l) + 4(w_c)(s)}$$

a. $M_g = F_b(S)$

$M_g = \frac{6000(458)}{12}$

$= 229,000$ ft-lbs.
(or see Appendix G)

b. $M_{wp} = (4)\left[\frac{2(8.59) + 16.72}{72}\right](52)^2$

$= 5100$ ft-lbs.
(or see Appendix G)

c. $p_t = 3(.5473) + .4533$
$= 2.10$ lbs/ft.

$h_l = 44.6$ ft.

$w_c = 1.0776$ lbs/ft.

$s = 3.75$ ft.

$$HS = \frac{229,000 - 4(5100)}{4(2.10)(44.6) + 4(1.0776)(3.75)}$$

$= 534$ ft.

Check High Winds

Metric

$$HS = \frac{M_g - OCF(M_{wp})}{(OCF)(p_t)(h_l) + (OCF)(w_c)(s)}$$

a. $M_g = 310,400$ N-m

b. $M_{wp} = 766\left[\frac{2(.218) + .425}{6}\right](15.85)^2$

$= 27,610$ N-m

c. $p_t = 3(12.49) + (7.005)$
$= 44.48$ N/m

$h_l = 13.4$ m

$w_c = 5.36$ N/m

$s = 1.143$ m

$$HS = \frac{310,400 - 1.5(27,610)}{1.5\,(44.48)(13.4) + 1.0(5.36)(1.143)}$$

$= 299$ m

English

$$HS = \frac{M_g - OCF(M_{wp})}{(OCF)(p_t)(h_l) + (OCF)(w_c)(s)}$$

a. $M_g = 229,000$ ft-lbs.

b. $M_{wp} = 16\left[\frac{2(8.59) + 16.72}{72}\right](52)^2$

$= 20,370$ ft-lbs.

c. $p_t = 3(.8560) + .4800$
$= 3.05$ lbs/ft.

$h_l = 44.1$ ft.

$w_c = .3673$ lbs/ft.

$s = 3.75$ ft.

$$HS = \frac{229,000 - 1.5(20,370)}{1.5\,(3.05)(44.1) + 1.0(.3673)(3.75)}$$

$= 976$ ft.

2. Vertical Span (Heavy Loading):

Metric

$$VS = \frac{M_a - (OCF)(W_i)(s)}{(OCF)(w_c)(s)}$$

a. $M_a = F_b S$

$M_a = (51{,}000 \times 10^3)(3.72 \times 10^{-4})$
$= 18{,}900$ N-m

b. $W_i = 102.3$ N

$$VS = \frac{18{,}900 - (4.0)(222.4)(1.68)}{4(15.726)(1.68)}$$

$= 165$ m

English

$$VS = \frac{M_a - (OCF)(W_i)(s)}{(OCF)(w_c)(s)}$$

a. $M_a = F_b S$

$M_a = 7400(22.7)/12$
$= 14{,}000$ ft-lbs.
(see Appendix H)

b. $W_i = 50$ lbs.

$$VS = \frac{14{,}000 - (4.0)(50)(5.5)}{4(1.0776)(5.5)}$$

$= 544$ ft.

3. Lateral Stability

The Equivalent Load 2 feet from the top is approximately 4400 lbs. from Figure XIII-2 average soil, the embedment depth for a 4400 lb. load 2 feet from the top is between 8 and 8.5 feet. Lines nearby have performed well with the standard embedment depths. Engineering judgment dictates that an 8 foot embedment depth for the 60 foot pole will be sufficient.

2. TSZ Structures

The TSZ structure, a wishbone-type crossarm assembly, is intended for use on 46 kV and 69 kV transmission lines where conductor jumping due to ice unloading and/or conductor galloping are problems. The wishbone provides additional vertical and horizontal offset between phases in order to reduce the possibilities of phase-to-phase faulting due to the above conditions.

Since the crossarms of the wishbone are not horizontal, the vertical span is related to the horizontal span. The maximum vertical load (W_c) the TSZ-1 single crossarm assembly can withstand is 15,100 N (3,400 lbs.) at any conductor position. By calculating moments at point "A" on the assembly, horizontal and vertical spans are related (see example 2). Spans limited by pole strength are calculated in the same manner as the TP and TS structures.

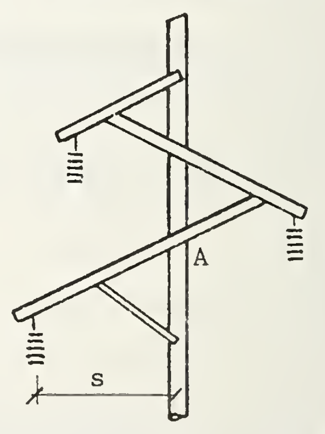


FIGURE XIII-6: TSZ-1

Example XIII-2:

Determine the maximum horizontal and vertical spans for the crossarm assembly for the TSZ-1 structure (69 kV).

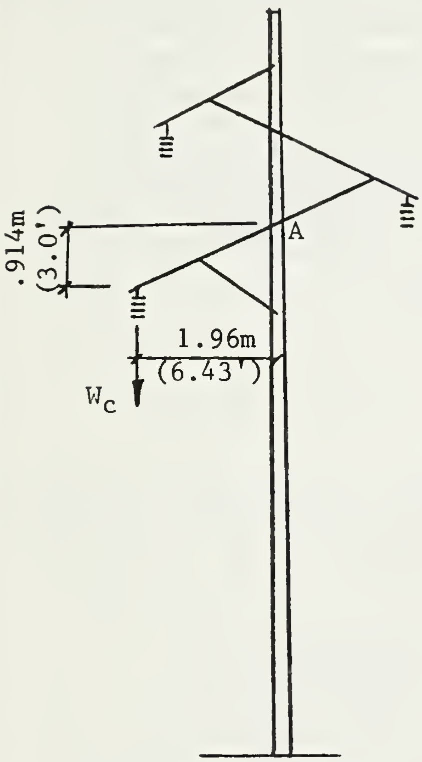


FIGURE XIII-7: TSZ-1

Given:

1. NESC heavy loading district
   Extreme wind - 766 Pa (16 psf)

2. Pole: S.Y.P. (70-1)
   Cond: 266.8 kcmil, 26/7 ACSR (Partridge)
   Ground wire: 3/8" H.S.S.

3. Conductor loads (see example 1)

Solution

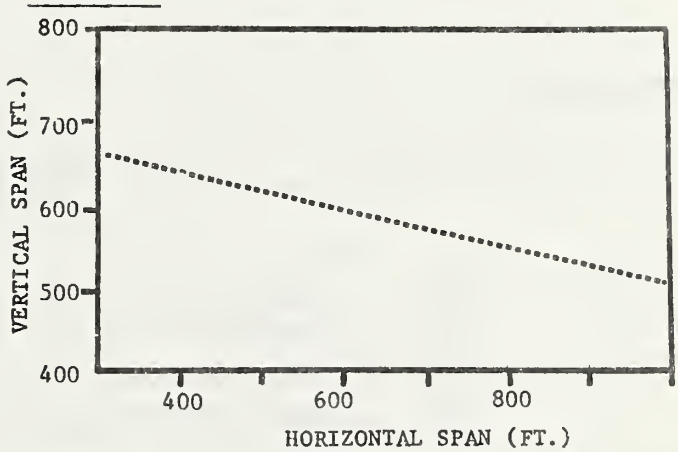


FIGURE XIII-8: HS vs VS FOR TSZ-1

Solution

a. Moment capacity of crossarm at A: $M_a = W_c(s)$

$$M_a = 15{,}100(1.96) = 29{,}600 \text{ N-m}$$

$$M_a = 3{,}400(6.43) = 21{,}860 \text{ ft-lbs.}$$

b. Horizontal and vertical span: (relationship is obtained by summing moments about point A).

(Metric)

$$4(7.987)(.91)HS + 4(15.726)(1.96)VS + 4(222.4)(1.96) = 29{,}600 \text{ N-m}$$
$$29.1HS + 123.3VS = 27{,}856 \text{ N-m}$$

(English)

$$4(.5473)(3.0)HS + 4(1.0776)(6.43)VS + 4(50)(6.43) = 21{,}860 \text{ ft-lbs.}$$
$$6.57HS + 27.7VS = 20{,}574 \text{ ft-lbs.}$$

c. For HS = VS, Span = 183 m (600 ft.). See Figure XIII-8 for application chart.

3. TUS-1 Structures

The three basic types of TUS-1 structures are the single circuit delta conductor arrangement, double circuit conductor arrangement, and the single circuit vertical conductor arrangement, all of which have upswept arms in compliance with REA Specification DT-5B, Specification for Wood Crossarms, Transmission Timbers and Pole Keys. All arms will carry a minimum 700 pounds longitudinal load. Manufacturers' catalog data should be consulted to determine maximum loads which the arms can sustain. Since the arms are upswept, vertical spans are related to horizontal spans and a graph can be made to related horizontal and vertical spans (see figure, example XIII-3). Spans limited by pole strength are calculated in the same manner as the TP and TS structures.

Example XIII-3:

For the 138 kV structure shown, plot the horizontal versus vertical span for the crossarms. Terrain is rolling foothills.

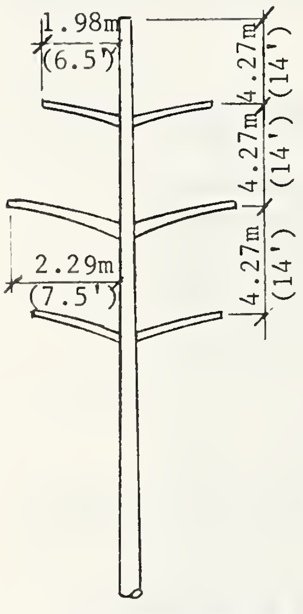


FIGURE XIII-9: DOUBLE CIRCUIT TUS-1 STRUCTURE

Given:

1. NESC light loading district
   Extreme wind - 622 Pa (13 psf)

2. Pole: Southern yellow pine
   Cond: 447 kcmil, 26/7 ACSR (Hawk)
   Ground wire: 3/8" H.S.S.

3. Conductor loads: N/m (lbs/ft.)

	Light	High Wind
Transverse	9.391 (.6435)	13.565 (.9295)
Vertical	9.588 (.6570)	9.588 (.6570)

4. Manufacturers catalog data for crossarms:

S	R	Rated Ult. (W_c) Vertical Load
2.29 m (7.5')	.82 m (2.7')	11,600 N (2600 lbs.)
1.98 m (6.5')	.76 m (2.5')	11,500 N (2580 lbs.)

5. Weight of insulators (W_i) = 454 N (102 lbs.)

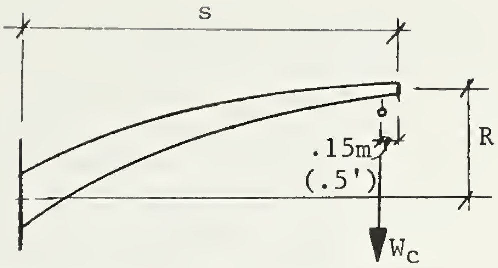


FIGURE XIII-9a: DAVIT ARM

Solution

a. For the 2.29 m (7.5') davit arm:

(1) Moment capacity of arm at pole:

$$M_a = W_c(s) = (11{,}600)(2.29 - .15) = (11{,}600)(2.14) = 24{,}700 \text{ N-m}$$

$$M_a = W_c(s) = (2600)(7.5 - .5) = (2600)(7.0) = 18{,}200 \text{ ft-lbs.}$$

(2) Vertical and horizontal spans: (Metric and English)

$$4(9.391)(.82)HS + 4(9.588)(2.14)VS + 4(454)(2.14) = 24{,}700 \text{ N-m}$$
$$30.9HS + 82.1VS = 20{,}810 \text{ N-m}$$

$$4(.6435)(2.7)HS + 4(.6570)(7.0)VS + 4(102)(7.0) = 18{,}200 \text{ ft-lbs.}$$
$$6.95HS + 18.4VS = 15{,}340 \text{ ft-lbs.}$$

b. For the 1.98 m (6.5') davit arm:

(1) Moment capacity of arm at pole:

$$M_a = W_c(s) = (11{,}500)(1.98 - .15) = (11{,}500)(1.83) = 21{,}000 \text{ N-m}$$

$$M_a = W_c(s) = (2580)(6.5 - .5) = (2580)(6.0) = 15{,}480 \text{ ft-lbs.}$$

(2) Vertical and horizontal spans: (Metric and English)

$$4(9.391)(.762)HS + 4(9.588)(1.83)VS + 4(454)(1.83) = 21{,}000 \text{ N-m}$$
$$28.6HS + 70.2VS = 17{,}680 \text{ N-m}$$

$$4(.6435)(2.5)HS + 4(.6570)(6.0)VS + 4(102)(6.0) = 15{,}480 \text{ ft-lbs.}$$
$$6.44HS + 15.77VS = 13{,}030 \text{ ft-lbs.}$$

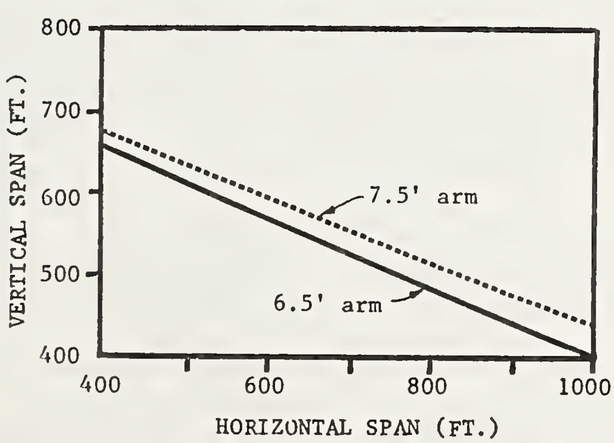


FIGURE XIII-10: VS vs HS FOR TUS-1 STRUCTURE OF EXAMPLE XIII-3

D. H-Frame Structures

1. General

There are various techniques available for analysis of H-frame structures: (1) classical indeterminate structural analysis, (2) matrix methods of structural analysis, and (3) approximate methods.

Conventional indeterminate structural analysis and matrix methods of structural analysis, although more accurate, do not readily lend themselves to design of wood transmission lines. The approximate method of analysis is commonly used for several reasons:

a. Wood is a variable product. More accurate analysis techniques do not always mean assured safety. Approximate analysis techniques should be used as a minimum in design calculations. More sophisticated analysis techniques may be satisfactory provided engineering costs do not become inflated.

b. Classical indeterminate analysis methods are found to be too cumbersome.

c. Matrix methods of analysis require access to a computer, which is not always convenient.

d. Loadings cannot be predicted or determined with a high degree of accuracy. Overload factors are used to account for accuracy and importance of loads, as well as method of analysis, and material or construction variables.

In analyzing a statically indeterminate structure by approximate procedures, one assumption is made for each degree of indeterminacy. These assumptions are based on logical interpretations of how the structure will react to a given loading. For the H-frame with knee and vee braces, we can assume that the structure will behave as shown below:

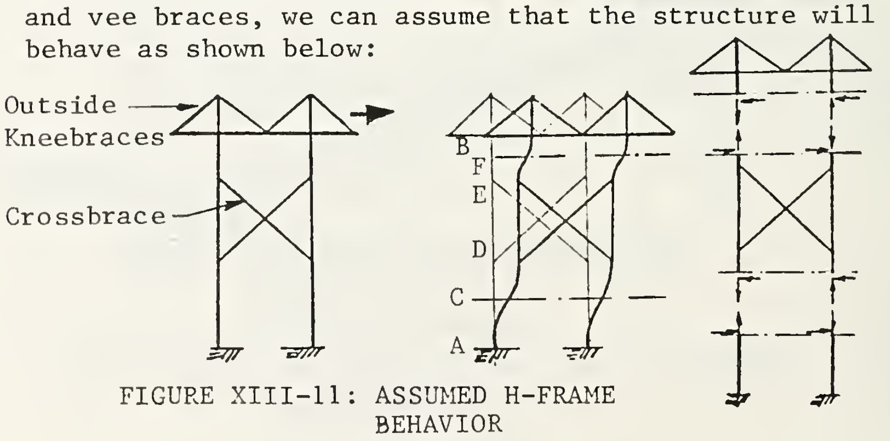


FIGURE XIII-11: ASSUMED H-FRAME BEHAVIOR

At some point in the poles, there will be an inflection point (a point of zero moment). If the pole or column is uniform in cross section, it is common to assume that the inflection point is located midway between points of bracing, shown as a dotted line in Figure XIII-11. However, since the pole is tapered, the following relationship may be used to determine the location of the inflection point (see Appendix H for application chart).

$$\frac{x_o}{x} = \frac{C_A(2C_A + C_D)}{2(C_A^2 + C_A C_D + C_D^2)} \quad \text{Eq. XIII-5}$$

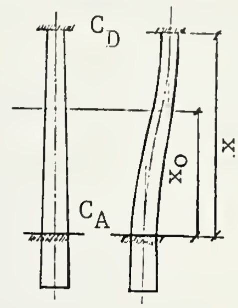


FIGURE XIII-12: LOCATION OF PT. OF CONTRAFLEXURE

where:

C_A = circumference at base
C_D = circumference at top

By applying the same reasoning, the inflection point can be located on the other column. Locating the inflection point on each column, and hence the point of zero moment, entails two assumptions for the frame. Since the frame is statically indeterminate to the third degree, a third assumption must be made. A common third assumption is that the shear in the columns is distributed equally at the inflection points. The shear in the columns is equal to the horizontal force on the structure above the level under consideration.

For a less rigid support, the inflection point moves toward the less rigid support. Two conclusions can be made:

a. For a pole rotating in the ground, the inflection point "C" below the crossbraces, is lowered, thereby increasing the moment induced in the pole at the connection of the lower crossbrace. Since the amount of rotation of a base is difficult to determine, the usual design approach is to always assume a rigid base.

b. For H-frames with outside kneebraces only, the point of inflection "F" above the crossbrace (shown in Figure XIII-11) is higher than the point of inflection for four kneebraces; thereby increasing the moment in the pole at the upper crossbrace-pole connection. For the H-frame with outside kneebraces only, the designer will make one of two assumptions:

(1) The kneebraces are ignored and no point of inflection exists between the crossbrace and the crossarm when determining induced moments in the poles. This is a conservative assumption and assumes that the purpose of outside braces is to increase vertical spans only.

(2) The point of inflection occurs at the crossarm. This assumption will be used in the equations and examples which follow.

2. Crossbraces

The primary purpose of wood X-bracing for H-frame type structures is to increase horizontal spans by increasing structure strength. Additional benefits achieved by wood crossbracing include possible reduction of right-of-way costs by eliminating some guys and reduction of lateral earth pressures. For an efficient design, several calculations should be made in order to correctly locate the crossbrace.

The theoretical maximum tensile or compressive load which the wood crossbrace will be able to sustain will largely be dependent on the capacity of the wood brace to sustain a compressive load. Drawing TM-110, X-brace Assembly, of REA Form 805, is to be used for the 115, 138, and 161 kV tangent structures. The crossbrace dimension is 3-3/8" x 4-3/8" for the 115 kV structure, 3-3/8" x 5-3/8" for 138 and 161 kV structures. The crossbrace indicated in Drawing TM-110A is to be used primarily with TH-230 structures. The dimensions of this X-brace are 3-5/8" x 7-1/2" (minimum).

The maximum compressive load which a wood X-brace is able to sustain is determined by:

$$P_{cr} = \frac{A(\pi^2)E}{\left(\frac{k\ell}{r}\right)^2} \qquad \text{Eq. XIII-6}$$

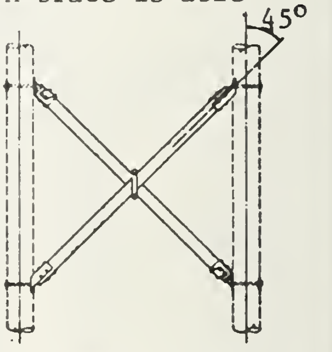


FIGURE XIII-13: CROSSBRACE

where:

P_{cr} = maximum compressive load, N (lbs.).
A = area, m^2 (in^2).
E = modulus of elasticity, Pa (psi).
$k\ell$ = effective unbraced length, m (in.).
r = radius of gyration, m (in.), which will give you the maximum $\frac{k\ell}{r}$ ratio. $k\ell$ and r must be compatible for the same axis.

For an assumed .305 m (1 ft.) diameter pole, the following theoretical values apply:

TABLE XIII-3

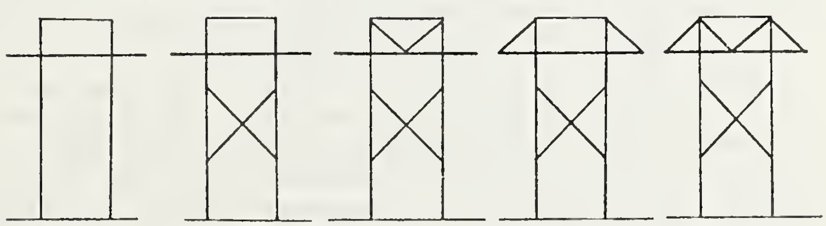
Wood Dimensions	A Area (in^2)	r Least Rad. Gyr.	L Dist. ℄ to ℄ of Poles	.5L/.707 (Less 1' for Pole Dia.)	$\frac{k\ell}{r}$	P_{cr}, N (lbs.) (for E = 1.8×10^6)
TM-110						
3-3/8" x 4-3/8"	14.77	.9743"	12.5'	97.6"	100.2	116,100 (26,100)
3-3/8" x 5-3/8"	18.14	.9743"	15.5'	123.1"	126.3	89,900 (20,200)
TM-110A						
3-5/8" x 7-1/2"	27.19	1.05"	19.5'	157"	149.5	96,100 (21,600)

The above calculations, though, do not reflect the capacity of the hardware. REA Specification T-7, Double Armed and Braced Type Crossarm Assemblies for 138 kV and 161 kV Transmission Lines, and REA Specification T-8, Double Armed and Braced Type Crossarm Assemblies for 230 kV Structures, require X-braces to withstand a tension or compression loading of 89,000 N (20,000 lbs.). This ultimate value correlates with the above theoretical ultimate loads. It is recommended that 89,000 N (20,000 lbs.) (ultimate) be used for design purposes, since this value assures one that the crossbrace will sustain the indicated load.

For the 115 kV structure (TH-1AA) it is recommended that 89,000 N (20,000 lbs.) be used as the ultimate load which the crossbrace is able to sustain. According to the list of materials, the hardware for the crossbrace is the same as that hardware used with 138 and 161 kV structures.

3. Vee Braces

The primary purpose of two-vee braces on the outside of the poles is to increase vertical spans. Two-vee braces on the inside will increase horizontal spans. Four-vee braces increase both horizontal and vertical spans. The various bracing arrangements and their designations for 161 kV structures are shown in Figure XIII-14.



TH-10 TH-10X TH-10VIX TH-10VOX TH-10V4X

FIGURE XIII-14: POLE TOP BRACING ARRANGEMENTS

REA Specification T-7 (138 and 161 kV double crossarm assemblies) has the following minimum strengths:

Maximum vertical load (at any conductor position)

TH-10	35,600 N	(8,000 lbs.)
TH-10V0	62,300 N	(14,000 lbs.)
TH-10V4	62,300 N	(14,000 lbs.)

Maximum transverse conductor load (total)

TH-10V0	66,750 N	(15,000 lbs.)
TH-10V4	66,750 N	(15,000 lbs.)

Maximum tension or compression in V-brace

	89,000 N	(20,000 lbs.)

REA Specification T-8 (230 kV double crossarm assemblies) has the following minimum strengths:

Maximum vertical load (at any conductor position)

TH-230	44,500 N	(10,000 lbs.)

Maximum transverse conductor load (total)

TH-230	66,750 N	(15,000 lbs.)

Maximum tension or compression in V-brace

	89,000 N	(20,000 lbs.)

When determining maximum vertical and horizontal spans as limited by H-frame top assemblies, the above minimum strengths may be used as guidance.

4. Structure Analysis

Pages XIII-22 to XIII-25 indicate equations for calculating forces in the various members of an H-frame structure. Structure 3 with two outside vee braces needs further explanation.

A structure with two outside vee braces has less rigidity above the crossbrace than a structure with four braces. The location of the point of contraflexure is difficult to determine. The equation given which calculates the moment (M_E) at the top of the crossbrace assumes that the point of contraflexure exists at the crossarm. However, when determining span limitations due to strength of the pole top assembly, Equation XIII-7, a point of contraflexure is assumed between the top of the crossbrace and the crossarm.

As part of the structural analysis, span limitations due to strength of the pole top assembly should be considered and suggested methods follow. Appropriate overload capacity factors should be applied in the respective equations.

a. Outside Vee Braces

As mentioned previously, two outside vee braces provide less rigidity than four braces. To determine maximum span limited by the vee braces, a point of contraflexure is assumed between the crossarm and the top of the crossbrace in accordance with Equation XIII-5. The maximum vertical span is determined for the maximum horizontal span.

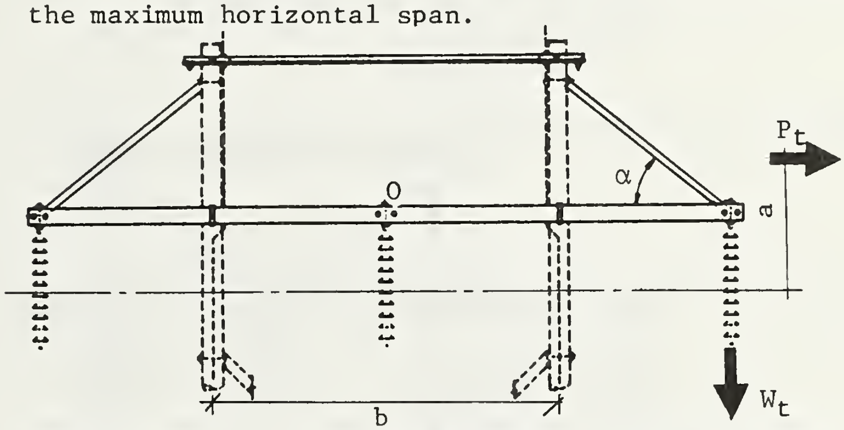


FIGURE XIII-15: POLE TOP ASSEMBLY WITH TWO OUTSIDE BRACES

o Ultimate force in the brace:

$$\frac{W_t}{\sin\alpha} \pm \frac{P_t(a)}{b(\sin\alpha)} \leq 89{,}000\text{ N } (20{,}000\text{ lbs.}) \quad \text{Eq. XIII-7}$$

where:

W_t = total vertical load at the phase wire locations, in N (lbs.), $W_t = VS(w_c) + W_i$

P_t = total transverse load, in N (lbs.), $P_t = (HS)(3p_c + 2p_g)$.

a = distance from the point of contraflexure to equivalent force, m (ft.).

b = distance between poles, m (ft.).

b. <u>Two Inside Vee Braces</u>

Pole bending moment, uplift, and force in the X-brace may be calculated in the same manner as when four braces are used. Crossarm strength controls the maximum vertical span.

(1) Force in the braces:

$$\frac{W_t}{2\sin\alpha} + \frac{P_t(a)}{(b)\sin\alpha} \leq 89{,}000 \text{ N } (20{,}000 \text{ lbs.}) \qquad \text{Eq. XIII-8}$$

(2) Crossarm bending moment:

$$M_o = \frac{W_t(b)}{2} \qquad \text{Eq. XIII-9}$$

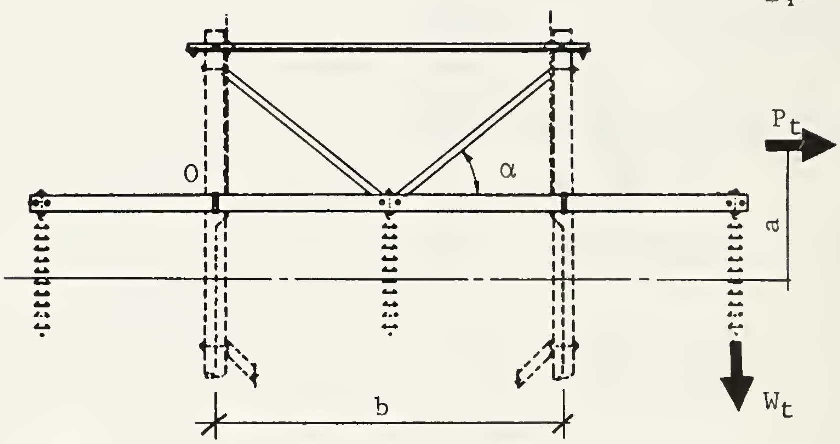


FIGURE XIII-16: POLE TOP ASSEMBLY WITH INSIDE BRACES

c. <u>Four Vee Braces</u>

The following equations can be used to determine the maximum vertical span as limited by the vee braces, given the maximum horizontal span:

(1) Force in the outside braces:

$$\frac{W_t}{\sin\alpha} \leq 88{,}960 \text{ N } (20{,}000 \text{ lbs.}) \qquad \text{Eq. XIII-10}$$

(2) Force in the inside braces:

$$\frac{W_t}{2\sin\alpha} + \frac{P_t(a)}{(b)\sin\alpha} \leq 88{,}960 \text{ N } (20{,}000 \text{ lbs.}) \qquad \text{Eq. XIII-8}$$

The equations for determining spans for different types of wood H-frame structures are given on Pages XIII-22 to XIII-25. All units should be consistent. The following abbreviations apply:

F = wind pressure on a cylindrical surface, Pa (psf).
F_s = presumptive skin friction value, Pa (psf).
HS = horizontal span, m (ft.).
M_a = moment capacity of crossarm.
M_N = moment capacity at the indicated location, N-m (ft-lb.), includes moment reduction due to bolt hole, i.e., $M_N = M_{cap} - M_{bh}$.
OCF = overload capacity factor.
R_N = reaction at the indicated location, N (lbs.).
V_N = induced axial force at the indicated location, N (lbs.).
W_c = weight of conductors (plus ice, if any), N (lbs.).
W_g = weight of OHGW (plus ice, if any), N (lbs.).
W_p = weight of pole, N (lbs.).
W_t = total weight equal to weight of conductors (plus ice, if any)-W_c, plus weight of insulators-W_i.
VS = vertical span, m (ft.).
d_t = diameter of pole at top, m (ft.).
d_{bt} = diameter of pole at butt, m (ft.).
d_{avg} = average diameter of pole between groundline and butt, m (ft.).
d_n = diameter at location "n", m (ft.).
f_s = calculated skin friction value, Pa (psf).
h_n = length as indicated, m (ft.).
p_t = total horizontal force per unit length due to wind on the conductors and overhead ground wire, N/m (lbs/ft.).
s = distance as shown, m (ft.).
U = dummy variable.
V = dummy variable.
w_c = weight per unit length of the conductors (plus ice, if any), N/m (lbs/ft.).
w_g = weight per unit length of overhead ground wire (plus ice, if any), N/m (lbs/ft.).

STRUCTURE 1
(Figure XIII-17)

$$HS_A = \left(M_A - \frac{(OCF)(F)(h)^2(2d_t + d_a)}{6}\right) / \left(\frac{(OCF)(p_t)(h_1)}{2}\right) \quad \text{Eq. XIII-11}$$

$$R_A = W_g + 3/2W_t + W_p \quad \text{Eq. XIII-12}$$

$$VS = \frac{M_a - (OCF)(W_i)(s)}{w_c(s)(OCF)} \quad \text{Eq. XIII-13}$$

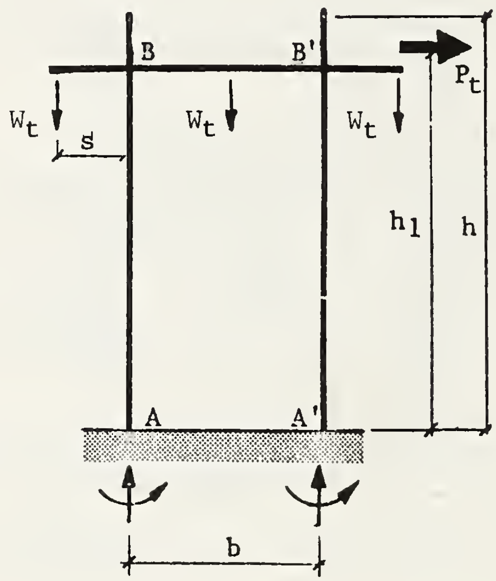


FIGURE XIII-17

STRUCTURE 2
(Figure XIII-18)

$$HS_B = \left[M_B - \frac{(OCF)(F)(y_1)^2(2d_t + d_b)}{6}\right] / (OCF)(p_g)(y_1) \qquad \text{Eq. XIII-14a}$$

$$HS_E = \left[M_E - \frac{(OCF)(F)(y)^2(2d_t + d_e)}{6}\right] \Big/ \frac{(OCF)(p_t)(y_o)}{2} \qquad \text{Eq. XIII-14b}$$

$$HS_D = \left[M_D - \frac{(OCF)(F)(h-x_o)(x_1)(d_t + d_c)}{2}\right] \Big/ \frac{(OCF)(p_t)(x_1)}{2} \qquad \text{Eq. XIII-14c}$$

$$HS_A = \left[M_A - \frac{(OCF)(F)(h-x_o)(x_o)(d_t + d_c)}{2}\right] \Big/ \frac{(OCF)(p_t)(x_o)}{2} \qquad \text{Eq. XIII-14d}$$

For crossbrace:

$$HS_x = \left[125{,}800(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / (OCF)(p_t)(h_2) \qquad \text{(Metric) Eq. XIII-14e}$$

$$HS_x = \left[28{,}300(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / (OCF)(p_t)(h_2) \qquad \text{(English) Eq. XIII-14f}$$

For uplift:

$$HS(p_t)(h_2) - VS(w_g)(b) - 1.5VS(w_c)(b) = W_1(b) + W_p(b) + X - Y \qquad \text{Eq. XIII-14g}$$

For bearing:

$$HS(p_t)(h_2) + VS(w_g)(b) + 1.5VS(w_c)(b) = W_2(b) - W_p(b) + X - Y \qquad \text{Eq. XIII-14h}$$

where:

$W_1 = F_s(D)(d_{avg})\pi/OCF$

$W_2 = (\pi d_{bt}^2/4)(Q_u)/OCF$

$X = (F)(h-x_o)(d_t + d_c)(x_o)$

$Y = 2(F)(h)^2(2d_t + d_a)/6$

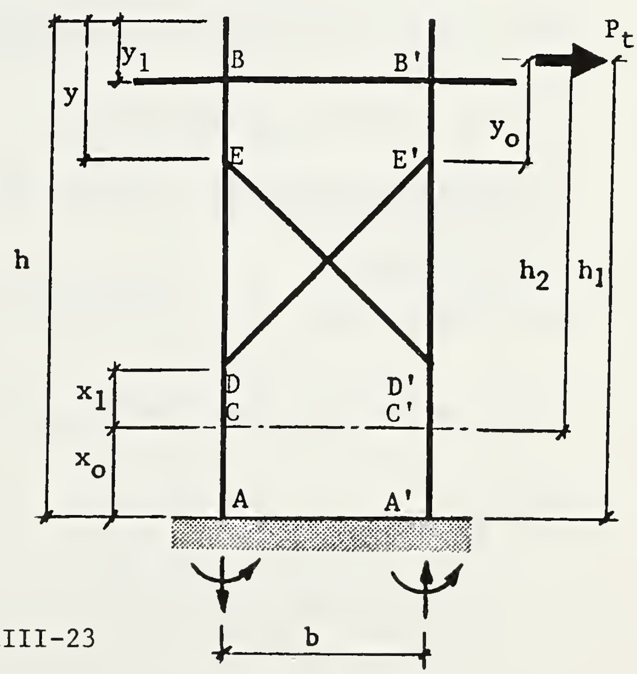


FIGURE XIII-18

STRUCTURE 3
(Figure XIII-19)

$$HS_E = \left[M_E - \frac{(OCF)(F)(y_1)(z)(d_t + d_b)}{2}\right] / \left[\frac{(OCF)(p_t)(z)}{2}\right] \qquad \text{Eq. XIII-15}$$

HS_D, HS_A = same as structure #2.

For crossbrace, uplift, and bearing: same as structure #2.

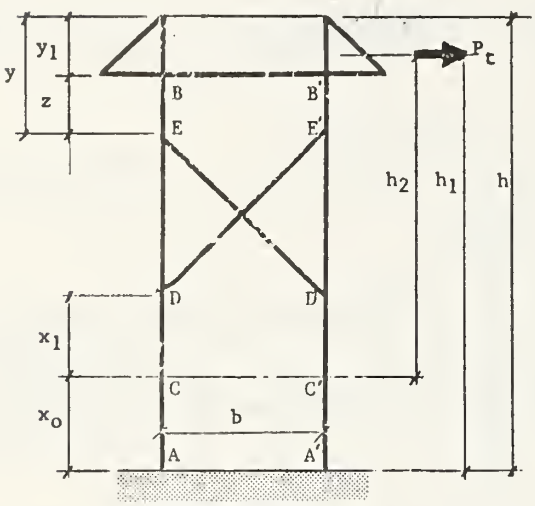


FIGURE XIII-19

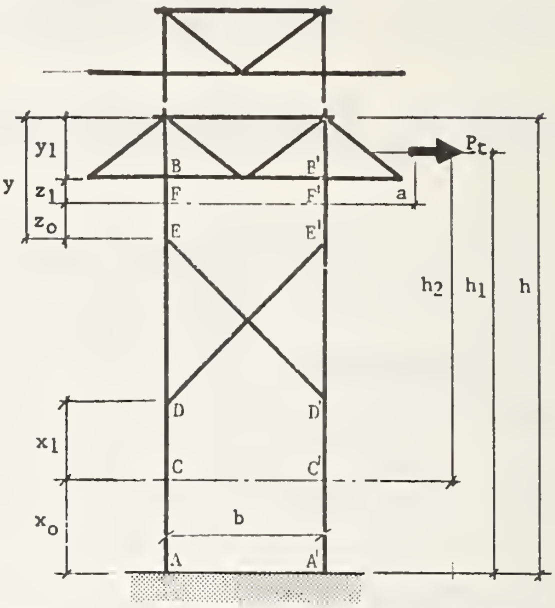


FIGURE XIII-20

STRUCTURE 4
(Figure XIII-20)

$$HS_B = \left[M_B - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_1)}{2}\right] / \left[\frac{(OCF)(p_t)(z_1)}{2}\right] \qquad \text{Eq. XIII-16a}$$

$$HS_E = \left[M_E - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_o)}{2}\right] / \left[\frac{(OCF)(p_t)(z_o)}{2}\right] \qquad \text{Eq. XIII-16b}$$

HS_D, HS_A = same as structure #2.

For uplift and bearing: same as structure #2.

For crossbrace:

$$HS_x = \left[125{,}800(b) - U - V\right] / \left[(OCF)(p_t)(h_2-a)\right] \qquad \text{(Metric) Eq. XIII-16c}$$

$$HS_x = \left[28{,}300(b) - U - V\right] / \left[(OCF)(p_t)(h_2-a)\right] \qquad \text{(English) Eq. XIII-16d}$$

where:

$U = 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6$

$V = 2(OCF)(F)(y-z_o)^2(2d_t + d_f)/6$

STRUCTURE 5
(Figure XIII-21)

For crossbrace:

$$HS_x = \left[252{,}000(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / \left[(OCF)(p_t)(h_2)\right]$$ (Metric) Eq. XIII-18a

$$HS_x = \left[56{,}500(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / \left[(OCF)(p_t)(h_2)\right]$$ (English) Eq. XIII-18b

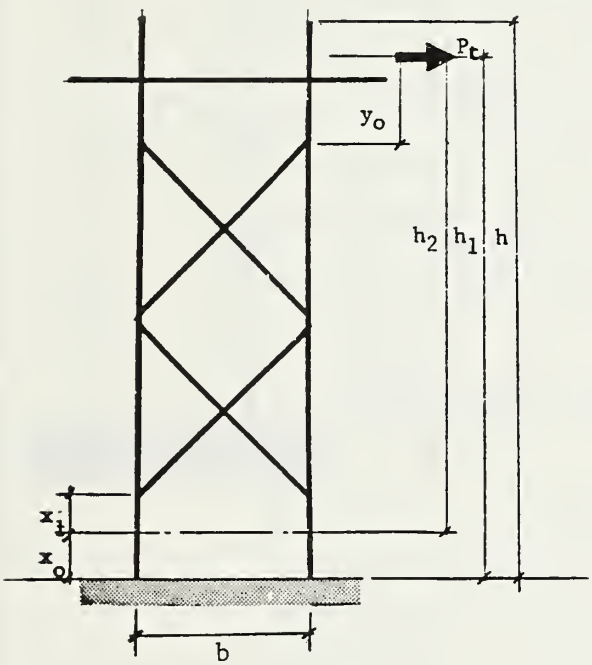


FIGURE XIII-21

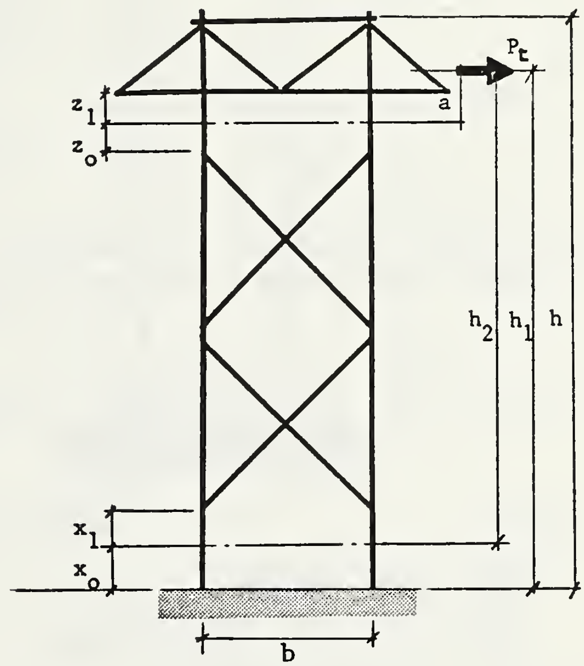


FIGURE XIII-22

STRUCTURE 6
(Figure XIII-22)

For crossbrace:

$$HS_x = \left[252{,}000(b) - U - V\right] / \left[(OCF)(p_t)(h_2-a)\right]$$ (Metric) Eq. XIII-19a

$$HS_x = \left[56{,}500(b) - U - V\right] / \left[(OCF)(p_t)(h_2-a)\right]$$ (English) Eq. XIII-19b

where:

U = same as structure #4.

V = same as structure #4.

Example XIII-4:

For the 161 kV structure shown by Figure XIII-23 below, determine the horizontal span based on structure strength and uplift and plot the horizontal versus vertical span for the pole top assembly.

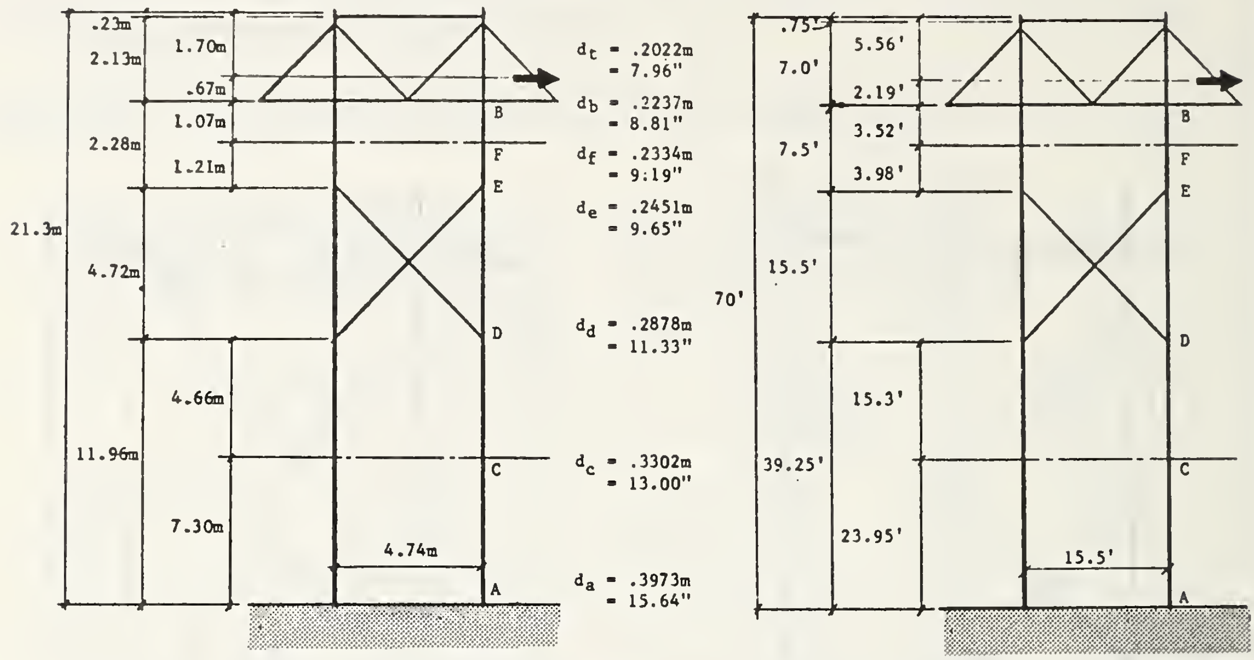


FIGURE XIII-23

Given:

1. NESC heavy loading
   High winds - 766 Pa (16 psf)
   Heavy ice - 25.4 mm (1" radial)

2. Pole: Douglas fir 80-2
   Cond: 795 kcmil 26/7
   OHGW: 7/16 E.H.S.
   R.S.: 244 m (800 ft.)

3. Conductor loads

N/m (lbs/ft):	Heavy Ldg. Dist.	High Wind	Heavy Ice
Transverse	10.255 (.7027)	21.559 (1.4773)	0
Vertical	30.557 (2.0938)	15.965 (1.0940)	54.221 (3.7154)
Tensions N (lbs)	46,300 (10,400)	N.A.	62,300 (14,000)

4. OHGW loads

N/m (lbs/ft):			
Transverse	6.980 (.4783)	8.464 (.5800)	0
Vertical	14.308 (.9804)	5.823 (.3990)	31.865 (2.1835)
Tensions N (lbs)	26,200 (5,900)	N.A.	33,400 (7,500)

5. Soil: Average. Presumptive skin friction (ultimate) of 250 psf for predominantly dry soil areas and using native backfill; 500 psf when aggregate backfill is used.

Solution for Heavy Loading District

1. Maximum horizontal span based on structure strength:

	Metric	English
a. Equivalent force p_t:	$p_t = 2p_g + 3p_c$ $= 2(6.980) + 3(10.255)$ $= 44.725$ N/m	$p_t = 2p_g + 3p_c$ $= 2(.4783) + 3(.7027)$ $= 3.065$ lbs/ft.

b. Determine location of equivalent load p_t:

Metric:

$$\text{Dist. from top} = \frac{2p_g(.23) + 3p_c(2.362)}{p_t} = 1.69 \text{ m}$$

English:

$$\text{Dist. from top} = \frac{2p_g(.75) + 3p_c(7.75)}{p_t} = 5.56 \text{ ft.}$$

c. Determine location of x_o, x_1, z_o, z for the X-brace location shown. All diameters, d_n, determined by Appendix F, Pages F-14 & F-15 and ratio x_o/x_1 or z_o/z determined by Appendix H, Page H-4.

For x_o, x_1:

Metric	English
$\frac{d_d}{d_a} = \frac{.2878}{.3973} = .72$	$\frac{d_d}{d_a} = \frac{11.33}{15.64} = .72$
$\therefore \frac{x_o}{x} = .61$	$\therefore \frac{x_o}{x} = .61$
$x_o = .61(11.96)$	$x_o = .61(39.25)$
$x_o = 7.29$ m	$x_o = 23.9$ ft.
$x_1 = 4.66$ m	$x_1 = 15.3$ ft.
and $d_c = .3302$ m	and $d_c = 13.0$ in.

For z_o, z:

Metric	English
$\frac{d_b}{d_e} = \frac{.2238}{.2451} = .91$	$\frac{d_b}{d_e} = \frac{8.81}{9.65} = .91$
$\therefore \frac{z_o}{z} = .53$	$\therefore \frac{z_o}{z} = .53$
$z_o = .53(2.29)$	$z_o = .53(7.5)$
$z_o = 1.21$ m	$z_o = 3.98$ ft.
$z_1 = 1.07$ m	$z_1 = 3.52$ ft.
and $d_f = .2334$ m	and $d_f = 9.19$ in.

d. Horizontal span limited by pole strength at B:

$$HS_B = \left[M_B - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_1)}{2}\right] / \frac{(OCF)(p_t)(z_1)}{2}$$

a. M_B = 60,600 N-m $\qquad$ M_B = 44,700 ft-lbs.

(Metric)

b. $$HS_B = \left[60,600 - \frac{4(191.5)(4.65 - 1.21)(.2022 + .2334)(1.07)}{2}\right] / \frac{(4)(44.725)(1.07)}{2}$$

= 625 m

(English)

$$HS_B = \left[44,700 - \frac{4(4)(15.25 - 3.98)(.663 + .766)(3.52)}{2}\right] / \frac{4(3.065)(3.52)}{2}$$

= 2,050 ft.

e. Horizontal span limited by pole strength at E:

$$HS_E = \left[M_E - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_o)}{2}\right] / \frac{(OCF)(p_t)(z_o)}{2}$$

a. $M_E = M_{cap} - M_{bh}$

M_E = 79,700 - 11,400 N-m $\qquad$ M_E = 58,800 - 8,400 ft-lbs.
M_E = 68,300 N-m $\qquad$ M_E = 50,400 ft-lbs.

(M_{bh} from Appendix F, page 25)

(Metric)

b. $$HS_E = \left[68,300 - \frac{4(191.5)(4.65 - 1.21)(.2022 + .2334)(1.21)}{2}\right] / \frac{(4)(44.725)(1.21)}{2}$$

= 624 m

(English)

$$HS_E = \left[50,400 - \frac{4(4)(15.25 - 3.98)(.663 + .766)(3.98)}{2}\right] / \frac{4(3.065)(3.98)}{2}$$

= 2,044 ft.

f. For horizontal span limited by pole strength at locations D and A, similar calculations can be made. The results are as follows:

HS_D = 238 m $\qquad$ HS_D = 780 ft.
HS_A = 488 m $\qquad$ HS_A = 1600 ft.

g. For horizontal span limited by strength of the crossbrace:

$$HS_X = \left[125{,}800(b) - U - V\right] / \left[(OCF)(p_t)(h_2 - a)\right] \quad \text{(Metric)}$$

$$HS_X = \left[28{,}300(b) - U - V\right] / \left[(OCF)(p_t)(h_2 - a)\right] \quad \text{(English)}$$

where:

$U = 2(OCF)(F)(h - x_o)^2(2d_t + d_c)/6$

$V = 2(OCF)(F)(y - z_o)^2(2d_t + d_f)/6$

$$U = 2(4)(191.5)(21.34 - 7.29)^2(2(.2022) + .3302)/6 \quad \text{(Metric)}$$
$$= 37{,}026 \text{ N-m}$$

$$U = 2(4)(4)(70 - 23.9)^2(2(.663) + 1.083)/6 \quad \text{(English)}$$
$$= 27{,}305 \text{ ft-lbs.}$$

$$V = 2(4)(191.5)(4.65 - 1.21)^2(2(.2022) + .2334)/6 \quad \text{(Metric)}$$
$$= 1927 \text{ N-m}$$

$$V = 2(4)(4)(15.25 - 3.98)^2(2(.663) + .766)/6 \quad \text{(English)}$$
$$= 1417 \text{ ft-lbs.}$$

$$HS_X = \left[125{,}800(4.72) - 37{,}026 - 1927\right] / \left[(4)(44.725)(10.60)\right] \quad \text{(Metric)}$$
$$= 287 \text{ m}$$

$$HS_X = \left[28{,}300(15.5) - 27{,}305 - 1417\right] / \left[(4)(3.065)(34.78)\right] \quad \text{(English)}$$
$$= 960 \text{ ft.}$$

2. Maximum spans limited by pole top assembly:

a. From Equation XIII-10.

$$\frac{W_t(VS)}{\sin\alpha} \leq 88{,}960 \text{ N} \quad (20{,}000 \text{ lbs.})$$

$$VS = \frac{88{,}960 \sin 39^\circ - 4(600)}{30.557(4)} \qquad VS = \frac{20{,}000 \sin 39^\circ - 4(135)}{2.0938(4)}$$

$$= 438 \text{ m} \qquad = 1440 \text{ ft.}$$

b. From Equation XIII-8:

$$\frac{w_c(VS)}{2\sin\alpha} + \frac{P_t(a)(HS)}{b\sin\alpha} \leq 88,900 \text{ N } (20,000 \text{ lbs.})$$

$$\frac{4(30.557)(VS)}{2\sin 39^o} + \frac{4(44.725)(.67+1.07)(HS)}{4.72\sin 39^o} \leq 88,960 \text{ N} \qquad \text{(Metric)}$$

$$97.11VS + 104.80HS \leq 88,960 \text{ N}$$

$$\frac{4(2.0938)(VS)}{2\sin 39^o} + \frac{4(3.065)(2.19+3.52)(HS)}{15.5\sin 39^o} \leq 20,000 \text{ lbs.} \qquad \text{(English)}$$

$$6.65VS + 7.18HS \leq 20,000 \text{ lbs.}$$

(By inspection, Equation XIII-8 does not control design).

3. Maximum span limited by uplift: Dry native backfill, safety factor of 4 assumed.

$$HS(p_t)(h_2) - VS(w_g)(b) - 1.5VS(w_c)(b) = W_1(b) + W_p(b) + X - Y \qquad \text{(Eq. XIII-14g)}$$

where:

$W_1 = F_s(D)(d_{avg})\pi/OCF$
$= 11,780$ N

$W_1 = F_s(D)(d_{avg})\pi/OCF$
$= 2649$ lbs.

W_p = Wt. of one pole and half the weight of pole top assembly and crossbrace.
$= 20,500$ N

$= 4200 + 800/2 = 4600$ lbs.

$X = F(h-x_o)(d_t + d_c)(x_o)$
$= 10,440$ N-m

$X = F(h-x_o)(d_t + d_c)(x_o)$
$= 7705$ ft-lbs.

$Y = 2(F)(h^2)(2d_t + d_a)/6$
$= 23,290$ N-m

$Y = 2(F)(h^2)(2d_t + d_a)6$
$= 17,182$ ft-lbs.

The equations are as follows:

$551HS - 283VS = 139,500$

$124.13HS - 63.88VS = 102,900$

(For VS=0, maximum HS=830 ft.)

Check for Extreme Wind Conditions:

1. Span limitations based on pole strength controlled by NESC conditions.

2. By inspection, maximum vertical span limited by extreme ice conditions does not control.

3. Span limitations based on uplift (controls).

   a. For dry native backfill, safety factor of 1.5 assumed, the following equations result:

   $$989.1HS - 140.5VS = 193{,}662 \qquad 222.2HS - 25.4VS = 142{,}862$$

   (For VS=0, maximum HS=640 ft.)

   b. For aggregate backfill, safety factor of 1.5 assumed:

   $$989.1HS - 140.5VS = 342{,}000 \qquad 222.2HS - 25.4VS = 252{,}400$$

   (For VS=0, maximum HS=1,135 ft.)

When considering uplift, it is sometimes prudent to base calculations on the minimum vertical span as limited by insulator swing.

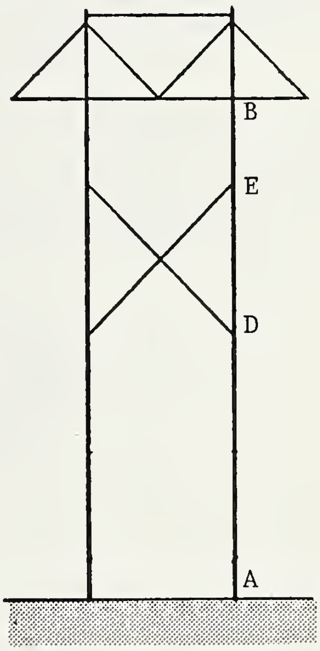
Summary

HS_A = 488 m (1600 ft.)
HS_D = 238 m (780 ft.)
HS_E = 624 m (2044 ft.)
HS_B = 625 m (2050 ft.)
HS_x = 287 m (960 ft.)

Dry native backfill:
HS_{uplift} = 196 m (643 ft.), max.
VS = 0 m (0 ft.)

Aggregate backfill:
HS_{uplift} = 346 m (1,135 ft.), max.
VS = 0 m (0 ft.)

$VS_{poletop}$ = 438 m (1,440 ft.), max.



A more efficient design could be achieved by moving the crossbrace.

XIV. GUYED STRUCTURES

A. Introduction

When a wood structure is guyed, loading on the poles is due to the combined action of vertical and horizontal forces. Vertical forces on the pole are due to the vertical component of the tension in the guy and the weight of the conductors and insulators. Horizontal loads result from transverse loads due to wire tensions at angle structures and from unbalanced vertical and longitudinal forces from deadending.

Bisector guys are usually used on small angle structures, whereas head and back guys are used on large angle structures and double deadends. Angles between 10 and 45 degrees may be turned on what is called a "running" vertical angle, utilizing bisector guys. Above 45 degrees unequal stresses will be set up in the conductor where it attaches to the suspension insulator clamp. The sharper the angle or bend in the conductor at the clamp, the more unequal the stresses will be. Any unbalanced longitudinal wire tension loads on double deadend and large angle structures can be more effectively carried by head and back guys. For large angle structures, the transverse load due to wire tension loads will be a heavy permanent load, therefore, head and back guys will be more effective in carrying this load.

An example of a deadend structure is shown below, in which the conductors are connected to the structure by strain insulators. There are two different types of deadend structures - a deadend and a "full" deadend structure.

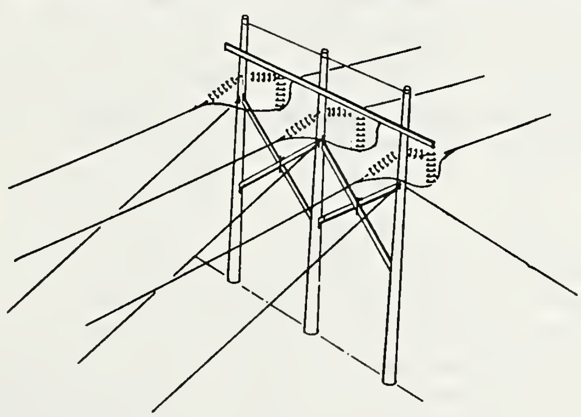


FIGURE XIV-1: DEADEND STRUCTURE

A deadend structure need only be designed to withstand the load resulting from the difference in tensions of the conductor for the forward and back spans. This condition occurs where there is a change in ruling spans. For a full deadend structure, the guys and anchors are designed to withstand the resultant load when the conductors are assumed to be broken or slack on one side of the structure. As mentioned in Chapter X, it is suggested that full structure deadends be located every five to ten miles to prevent progressive cascading-type failures.

In general, guys and anchors should be installed at deadends, angles, long spans where pole strength is exceeded, and at points of excessive unbalanced conductor tension. The holding power and condition of the soil (whether wet or dry, packed or loose, disturbed or undisturbed, etc.) and the ability of the pole to resist buckling and deflection should be considered.

B. Strength Factors

In Chapter XI, Table XI-2 gives the minimum overload capacity factors associated with the design of guyed tangent and angle structures. Based on Tables XI-2 and XI-3, the following table summarizes design requirements for guys and anchors:

TABLE XIV-1

APPLICATION OF OCF FOR GUYED STRUCTURES
(GUYS AND ANCHORS)

		NESC	REA*
Loading Districts	or	$(2.67)(a+b) + 1.5c = .90\,G\cos\phi$ $(2.97)(a+b) + 1.67c = G\cos\phi$	$4(a+b) + 2c = G\cos\phi$
Extreme Winds	or	$(a+b) + c = .90\,G\cos\phi$ $1.1(a+b) + 1.1c = G\cos\phi$	$(OCF)(a+b) + 1.25c = G\cos\phi$

*Lower overload factors may be used where justified but should in no case be less than NESC overload factors.

In the above table:

a = transverse wind load on the conductor.
b = transverse wind load on pole surface.
c = transverse component of wire tension load.
G = the calculated force in the guy, considering guy lead. The rated breaking strength of the guy wire (G_u) and anchor capacity (A_u) must equal or exceed this value.
OCF = overload capacity factor associated with "a" and "b" for extreme winds. See Chapter XI.
$\cos\phi$ = true guy slope with horizontal.

Longitudinal strength ("in general" category) is applicable to crossings and locations where unequal spans and unequal vertical loadings may occur. At crossings, the NESC states that wood tangent structures which meet transverse strength requirements without guys, shall be considered as having the required longitudinal strength, provided that the longitudinal strength of the structure is comparable to the transverse strength of the structure. If there is an angle in the line, the wood structure will have the required longitudinal strength provided:

1. The angle is not over 20 degrees.

2. The angle structure is guyed in the plane of the resultant conductor tensions.

3. The angle structure has sufficient strength to withstand, without guys, the transverse loading which would exist if there were no angle at that structure with an overload factor of 4.0.

Guying and anchors for distribution underbuild must meet the strength requirements in Table XIV-1. Refer to Chapter XVI for additional information concerning underbuild.

C. Clearances

The clearances to be maintained between any phase conductor and guy wires are indicated in Table XIV-2. Refer to Chapter VII for further details.

TABLE XIV-2

	NESC	REA Requirements (mm, in)		
Voltage	mm (in)	No Wind	6 psf wind	Ext. wind
34.5	318 (12.5")	483 (19")	330 (13")	76 (3")
46	389 (15.3")	483 (19")	406 (16")	76 (3")
69	556 (21.9")	635 (25")	559 (22")	127 (5")
115	864 (34.0")	1067 (42")	889 (35")	254 (10")
138	1016 (40.0")	1219 (48")	1041 (41")	305 (12")
161	1168 (46.0")	1524 (60")	1194 (47")	356 (14")
230	1631 (64.2")	(1803-2108) (71"-83")	1651 (65")	508 (20")

D. Design

1. Bisector Guys

For structures utilizing bisector guys, the guys must sustain the resultant transverse load due to longitudinal wire tension loads, given below:

$c = 2(T)\sin \theta/2$, where T is the maximum design tension and θ is the line angle.

The transverse load due to wind on the conductors for an angle structure is given as:

a = (p)(HS)(cos $\theta/2$), where "p" is the wind load in N/m (lb/ft), HS is the horizontal span, and θ is the line angle. Cos $\theta/2$ could be set equal to one.

Wind on the structure should be converted to a horizontal force "b" at the point of guy attachment.

2. Head and Back Guys

Deadends, double deadends, and large angle structures will normally require head and back guys. For tangent deadends and double deadends, the transverse strength of the structure must be sufficiently strong to carry the appropriate wind load. In some cases, bisector guys or crossbraces may have to be used to meet transverse strength requirements. The tension in the guy should take into account the slope of the guy.

E. Pole Strength

Once the tension in the guy wire has been calculated, the compressive strength of the pole should be checked.

1. Stability Concept

The selection of structural members is based on three characteristics: strength, stiffness, and stability. When considering a guyed wood pole, the possible instability of the structure should be considered.

An example of stability is to consider the axial load carrying capabilities of the two rods shown below.

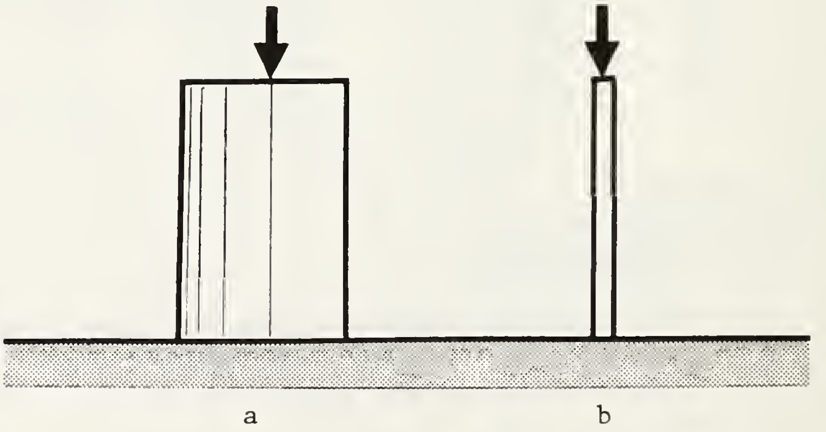


FIGURE XIV-2: COMPARISON OF RODS TO SHOW STABILITY CONCEPT

The rod on the left is unquestionably "more stable" to axial loads than the rod on the right. When the rod on the right is subjected to a smaller axial force than that which the rod on the right would carry, "b" rod would become laterally unstable through sidewise buckling and could collapse. The consideration of material strength alone is not sufficient to predict the behavior of a long slender member. As an example, the rod on the right might be able to sustain 4450 N (1000 lbs.) axial load when considering strength (ultimate compressive stress times area), but could only sustain 3336 N (750 lbs.) when considering stability of the system.

2. Critical Column Loads

In transmission structures, the guyed pole acts as a column, sustaining axial loads induced in the pole from vertical guy components. The taller the pole, the less load the guyed pole can sustain in compression before the structure becomes "unstable".

Stability of a column can be thought of in one of two ways:

a. The column is unstable when the axial force would cause large lateral deflections even when the lateral load was very small.

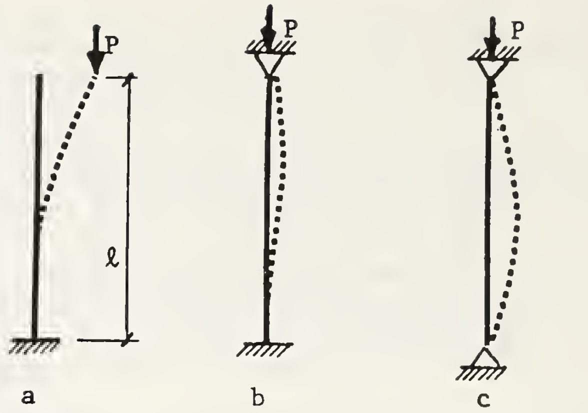
b. A column subjected to an axial force is stable if a lateral force is applied and a small deflection is produced, but disappears when the lateral force is removed, and the bar returns to its straight form. If P (axial) is gradually increased, a condition is reached in which the straight form of equilibrium becomes unstable and a small lateral force will produce a deflection which does not disappear when the lateral force is removed. The "critical" load is then the axial force which is sufficient to keep the bar in such a slightly bent form.

3. Calculation of Buckling Loads

In general, for long slender columns, the critical buckling load is determined from:

$$P_{cr} = \frac{\pi^2 EI}{(k\ell)^2}$$ (P_{cr} is independent of the yield stress of the material).

where for the various end conditions, P_{cr} is idealized below:



$$P_{cr} = \frac{\pi^2 EI}{4\ell^2} \quad (k = 2.0) \qquad P_{cr} = \frac{2\pi^2 EI}{\ell^2} \quad (k = .7) \qquad P_{cr} = \frac{\pi^2 EI}{\ell^2} \quad (k = 1.0)$$

k = theoretical coefficient of unbraced length of column for various end conditions, already in P_{cr}.

FIGURE XIV-3: EFFECTIVE UNBRACED LENGTH FOR VARIOUS END CONDITIONS

There are several assumptions made in the above calculations.

a. The column is perfectly straight initially.

b. The axial load is concentrically applied at the end of the column.

c. The column is assumed to be perfectly elastic and stresses do not exceed the proportional limit.

d. The column is uniform in section properties.

For a guyed wood pole, all the assumptions are violated. As such, the engineer must apply appropriate safety factors to account for realistic cases and the variability of wood.

With regards to assumption d, the critical buckling load can be estimated by one of two methods:

a. Assume that the moment of inertia in the above equation is at the section of the pole 2/9 the distance from the top (or point of guy attachment) to the bottom.

b. Assume that the moment of inertia is at the section of the pole 1/3 the distance from the top (or point of guy attachment) to the bottom. (American Institute of Timber Construction).

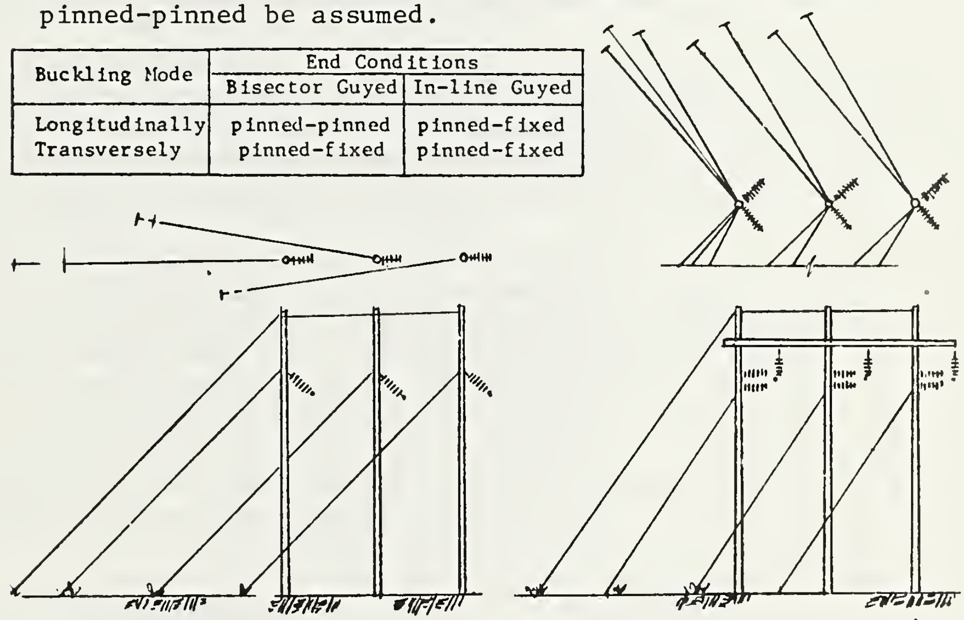
4. Safety Factor

For working loads, REA recommends that for tangent structures and small angle structures, a minimum factor of safety of 2 must be attained. For deadends and large angles the engineer should strive for a factor of safety of 3.0.

5. General Application Notes

a. For unbraced guyed single poles using bisector guys, certain assumptions are made as to the end constraints. In the direction of the bisector guy, the structure appears to be pinned at the point of the guy attachment and fixed at the base. However, 90^{o} to the bisector guy, the structure appears to be a cantilevered column. Since the conductors and phase wires offer some constraint, the actual end conditions may be between fix-free and fixed-pinned. When checking buckling, it is suggested that the end conditions of pinned-pinned be assumed.

Buckling Mode	End Conditions	
	Bisector Guyed	In-line Guyed
Longitudinally	pinned-pinned	pinned-fixed
Transversely	pinned-fixed	pinned-fixed



Bisector Guyed Structure In-line Guyed Structure

FIGURE XIV-4: END CONDITIONS FOR BISECTOR AND IN-LINE GUYED STRUCTURES

For in-line guyed poles, the structure appears to be pinned at the point of guy attachment and fixed at the base in both directions (Figure XIV-4).

b. In many instances, axial loads are applied intermittently along the pole. In Figure XIV-5a below, the static wire and phase wire are guyed at their respective locations. The axial loads acting on the pole on the left are applied as shown in Figure XIV-5b.

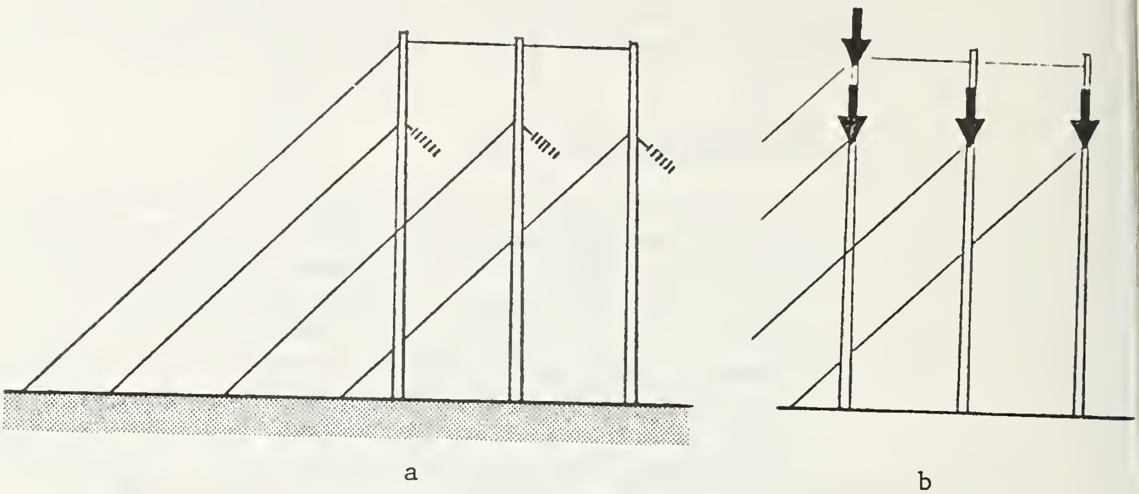


FIGURE XIV-5: REPRESENTATION OF AXIAL LOADS

In such instances, the usual engineering practice is to assume an unbraced length from the groundline to the lowest guy attachment and the induced axial load in the pole equal to the sum of all axial loads incurred by the vertical component of the guys.

c. When the structure is considered as a double deadend or large angle, the pole, guys, and anchors must sustain the full deadend load with an appropriate overload factor. For the tangent double deadend shown in Figure XIV-6, the poles must sustain the maximum axial load which might occur if all phase conductors on one side of the structure were removed. (See Figure XIV-7a and XIV-7b). However, to "double account" the loads, as shown in Figure XIV-7c would be too conservative.

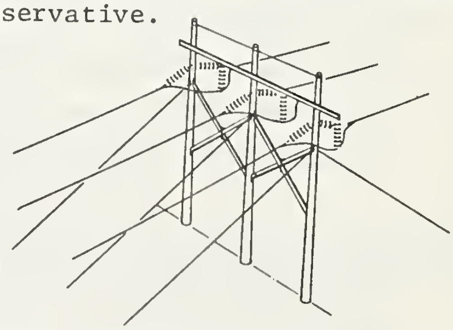


FIGURE XIV-6: TANGENT DOUBLE DEADEND

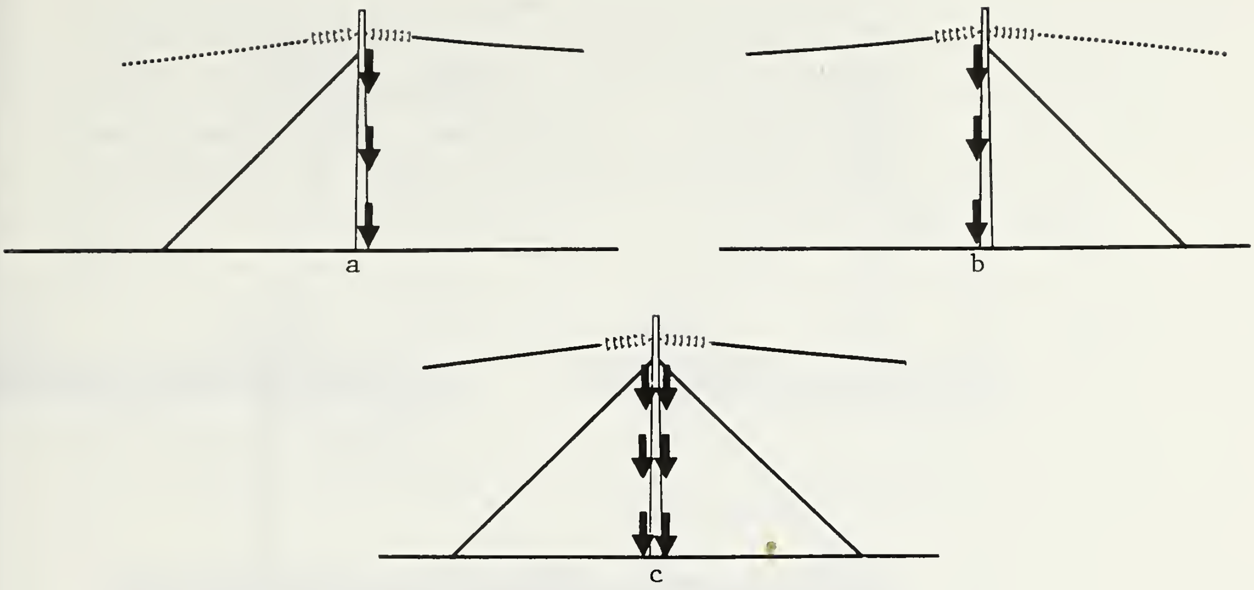


FIGURE XIV-7: REPRESENTATION OF AXIAL LOADS (a&b) AND DOUBLE ACCOUNTING OF LOADS (c)

In many instances, deadends and large angle structures will have to have a class higher pole than what is used as the base class pole for the line. There are ways to control or reduce the pole class needed at deadends and large angles.

- o Relocate and/or increase height of tangent structures adjacent to guyed angle and deadends. This would allow the use of shorter poles at guyed structures, and as a result, a lower class pole, but with no sacrifice in safety.

- o Decreasing the guy slope will decrease the vertical load component on the pole.

As a note, angle and deadend structures usually comprise about five percent of the total structures of a line. Therefore, the use of conservative safety factors for these critical structures results in a greater overload margin without significantly affecting the total cost of the transmission line.

d. The engineer should consider guying single pole structures which are used for small angles, even if the pole has adequate strength to carry the load. Wood poles have a tendency to "creep" with time when subjected to a sustained load. For the case shown below, engineering judgment should be used to determine whether or not two guys should be used.

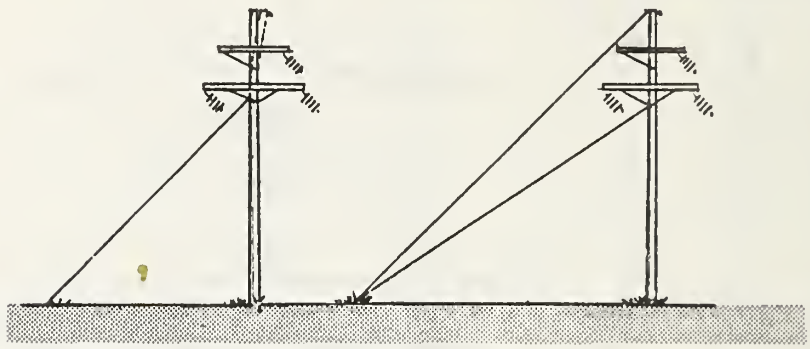
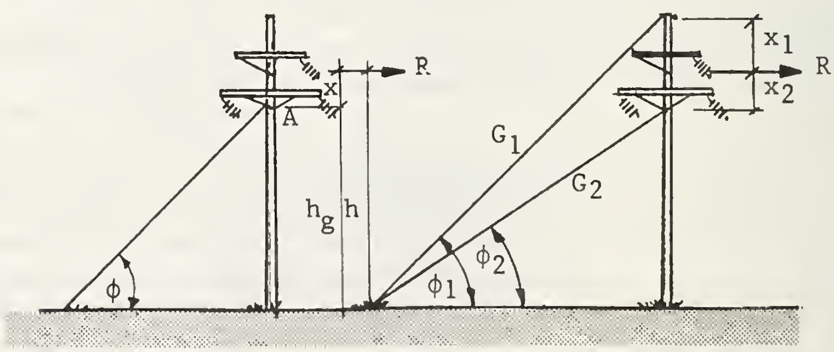


FIGURE XIV-8: GUYED SINGLE POLE STRUCTURES

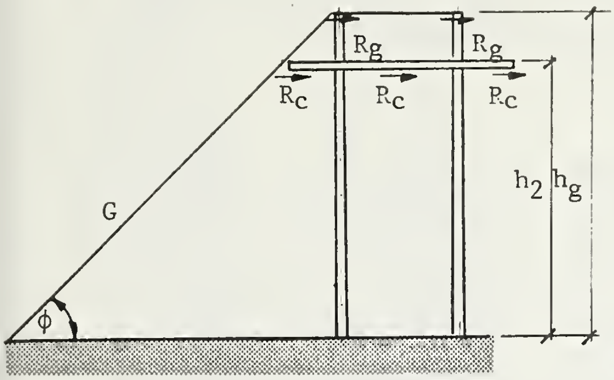
When structures utilize several guys and possibly various bracing to sustain loads, the engineer must determine appropriate methods of analysis and distribution of forces in the guys. Examples of suggested methods for calculating forces in guys (G) and in the structures follow. The total transverse load (R) which the structure and guy must sustain is due to the wind on the conductors and structure and due to longitudinal wire tension load with appropriate overload factors. The poles should be checked for buckling.



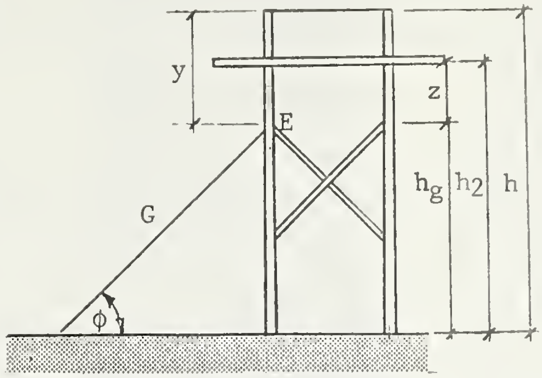
$G = Rh/(h_g \cos\phi)$ $\qquad$ $G_1 = Rx_2/(x_1 + x_2)\cos\phi_1$

$M_A = Rx$ $\qquad$ $G_2 = Rx_1/(x_1 + x_2)\cos\phi_2$

FIGURE XIV-9: SUGGESTED METHODS FOR CALCULATING FORCE IN GUYS

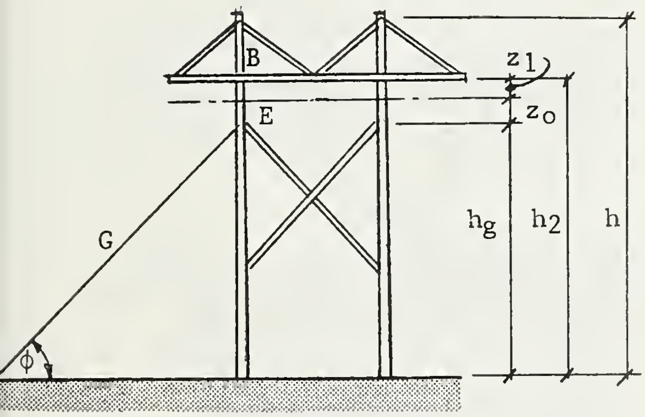


$$G = \left[3R_c(h_2)/h_g + 2R_g\right]/\cos\phi$$



$$G = \left[(2R_c h_2/h_g) + R_g(h/h_g)\right]/\cos\phi$$

$$M_E = (2R_c)z + (R_g)y$$



$$G = \left[(2R_c + 1.34R_g)(h_g + z_o)/h_g\right]/\cos\phi$$

$$M_E = (2R_c + 1.34R_g)(z_o)$$

$$M_B = (2R_c + 1.34R_g)(z_1)$$

FIGURE XIV-9 CONTINUED

F. Anchors

The holding power of the anchor will largely depend on the condition of the soil, whether it is wet or dry, packed or loose, disturbed or undisturbed. Since soils vary considerably between locations, the holding power of an anchor should generally be based on tests.

In areas where there may be a fluctuating water table, the capacity of the anchors should take into account the submerged unit weight of the soil. If at any time the holding power of an anchor is questionable due to variable soil conditions, the anchor should be tested. The primary types of anchors include log anchors, plate anchors, power screw anchors, and rock anchors. The selection of the appropriate anchor will largely depend on the type of soil condition.

1. Log Anchor Assemblies

The two log anchors are shown in Drawings TA-1-5 and TA-1-8. They are respectively 8" x 5'-0" and 8" x 8'-0", and have an ultimate holding power of 71,000 N (16,000 lbs.) and 142,000 N (32,000 lbs.). These logs, using one or two anchor rods, may be used in combination to provide sufficient holding power for guys. "Average" soil may be considered as any soil having an allowable bearing capacity of 3000 psf. As such, log anchors should be derated or should not be used in soils of soft clay, or organic material, saturated material or loose sand or silt.

2. Plate Anchors

The plate anchor assembly as shown in Drawing TA-3, REA Form 805, is rated at an ultimate holding power of 71,000 N (16,000 lbs.). In firm soils, where the engineer would like to minimize digging, plate anchors may prove economical.

3. Power Screw Anchors

Screw anchors are being used more often because of their easy installation. They are most appropriate for locations where firm soils exist at large depths (refer to REA Specification T-10).

G. Drawings

For each line, a summary drawing should be prepared showing the arrangement of guys for each type of structure to be used. The drawing will greatly facilitate the review of the plan and profile, and simplify the construction of the line. See page XIV-13 for an example of such a drawing. Several items should be noted in the drawing.

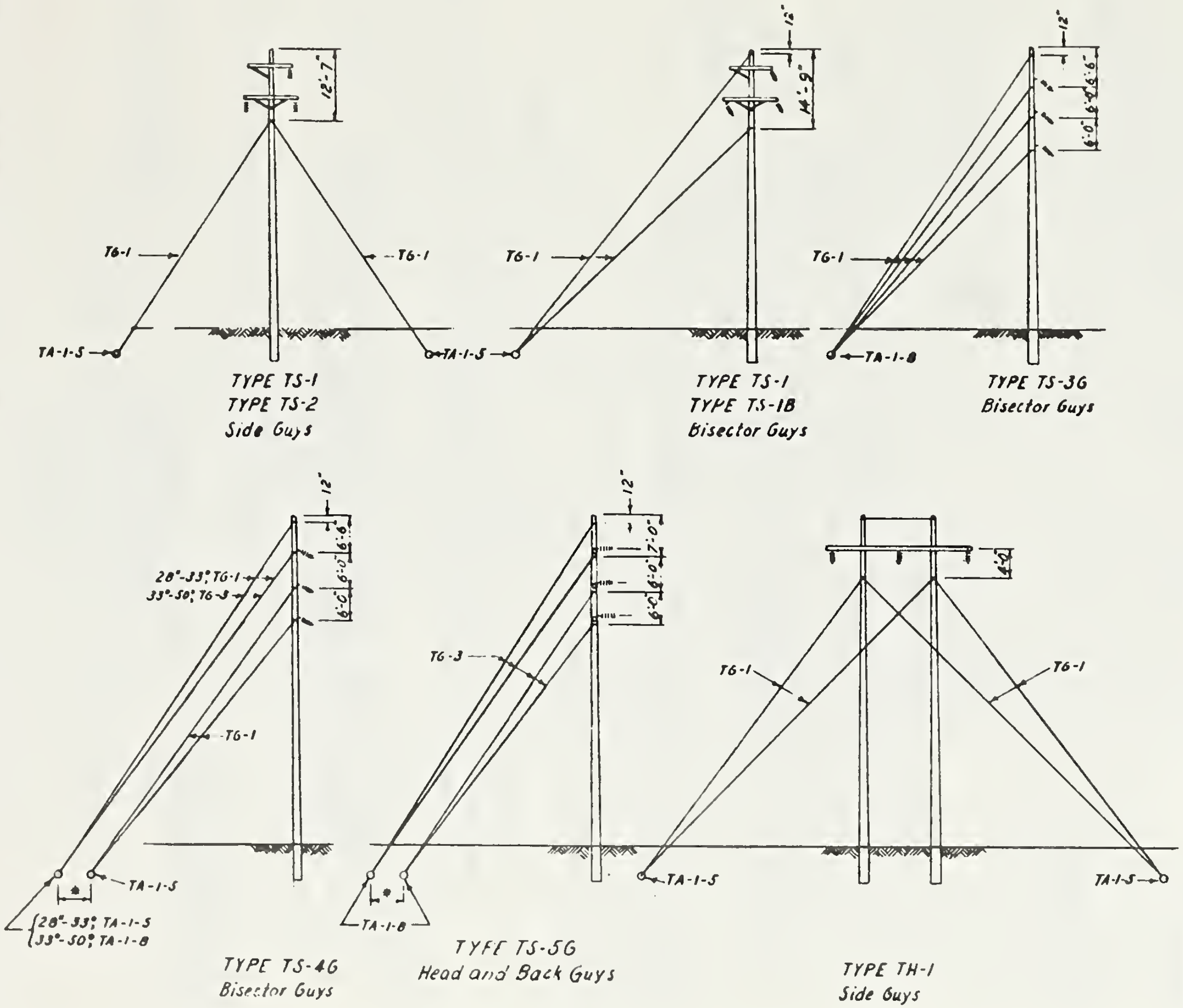
1. The guys required for various line angles are based on assumed spans. Since actual spans will vary, the guying requirements shown will not be exact for all conditions. Sometimes, it is desirable to make a guying guide for each angle structure, which relates horizontal span to the angle of the line.

2. The drawing shows (1) points of attachment of the guy to the pole, (2) slope of the guys, (3) type of structure, and (4) guys and anchors required.

CONDUCTOR: Design Tension - 3337 Lbs., Size - 3/0
Material - ACSR, Stranding - 6/1
GROUND WIRE: Design Tension - 3700 Lbs., Size - 3/8"
Material - H. S. Steel, Stranding - 7
LOADING: 1/2" Ice, + 4 Lb. Wind + Constant (.31) at 0°F.
RULING SPAN: 600' STANDARD POLE: 50' Class 2
MINIMUM GROUND CLEARANCE: 21'
VOLTAGE: 69 KV.

NOTES:

1. Slope guys 45°. If other slopes are occasionally used, this should be shown on the plan and profile drawing.
2. * Minimum spacing between anchors shall be sufficient to provide maximum holding power for each anchor.



GUYS BASED ON 500' LEVEL GROUND SPAN				
TYPE STRUCTURE	LINE ANGLE	GUYS REQUIRED	ANCHORS REQUIRED	GUY LOCATION
TS-1	0°	1 - TG-1	1 - TA-1-5	Each Side
TH-1	0°	2 - TG-1	1 - TA-1-5	Each Side
TS-1	0° - 4°	1 - TG-1	1 - TA-1-5	Bisector
TS-2	0° - 4°	1 - TG-1	1 - TA-1-5	Bisector
TS-1B	4° - 12°	2 - TG-1	1 - TA-1-5	Bisector
TS-3G	12° - 28°	4 - TG-1	1 - TA-1-8	Bisector
TS-4G	28° - 33°	4 - TG-1	2 - TA-1-5	Bisector
TS-4G	33° - 50°	2 - TG-1, 2 - TG-3	1 - TA-1-5, 1 - TA-1-8	Bisector
TS-5G	50° - Up	4 - TG-3	2 - TA-1-8	Head and Back

SPECIMEN DRAWING ONLY
(Not For Use As A Construction Drawing)
ARRANGEMENT OF GUYS AND DESIGN SUMMARY SHEET
FOR SUSPENSION TYPE STRUCTURES

Scale: None
Date:
TM-6

Example XIV-1:

Develop guying guides for TH-12 161 kV structure.

Given:

1. NESC heavy loading
   High winds - 766 Pa (16 psf)
   Heavy ice - 25.4 mm (1" radial)

2. Pole: Douglas fir 80-2
   Cond: 795 kcmil 26/7
   OHGW: 7/16 E.H.S.
   R.S.: 244 m (800 ft.)

3. Conductor loads

N/m (lbs/ft):	Heavy Ldg. Dist.	High Wind	Heavy Ice
Transverse	10.255 (.7027)	21.559 (1.4773)	0
Vertical	30.557 (2.0938)	15.965 (1.0940)	54.221 (3.7154)
Tensions N (lbs)	46,300 (10,400)	N.A.	62,300 (14,000)

4. OHGW loads

N/m (lbs/ft):			
Transverse	6.980 (.4783)	8.464 (.5800)	0
Vertical	14,308 (.9804)	5.823 (.3990)	31.865 (2.1835)
Tensions N (lbs)	26,200 (5,900)	N.A.	33,400 (7,500)

5. Guy wire: 7/16 E.H.S. Ultimate tension = 92,500 N (20,800 lbs.). Horizontal strength with 1/1 lead = 65,500 N (14,700 lbs).

   Anchors: 8,000 lb. and 16,000 lb. Ultimate capacity = 71,000 N (16,000 lbs) and 142,000 N (32,000 lbs). Horizontal strength with 1/1 lead = 50,000 N (11,300 lbs) and 100,000 N (22,600 lbs) respectively.

6. Soil: Average. Presumptive ultimate bearing capacity of 200 kPa (approximately 4,000 psf).

Solution for Heavy Loading District

	Metric	English
1. Wind on the wires		
Conductor:	$a = 10.255(HS)(\cos \theta/2)$	$a = .7027(HS)(\cos \theta/2)$
OHGW:	$a = 6.980(HS)(\cos \theta/2)$	$a = .4783(HS)(\cos \theta/2)$
2. Wind on the pole:	$b \doteq 875$ n	$b \doteq 196$ lbs.

"b" is based on an 80' pole, with the guy located 23 m (ft.) from the ground. The equivalent horizontal load, "b", at this location is determined by M_{wp}/lever arm.

Metric	English
b = 20,000 N-m/23 m	b = 14,760 ft-lbs/75.5 ft.

3. Wire tension loads	Metric	English
Conductor:	$c = 2(46{,}300)\sin \theta/2$	$c = 2(10{,}400)\sin \theta/2$
OHGW:	$c = 2(26{,}200)\sin \theta/2$	$c = 2(5{,}900)\sin \theta/2$

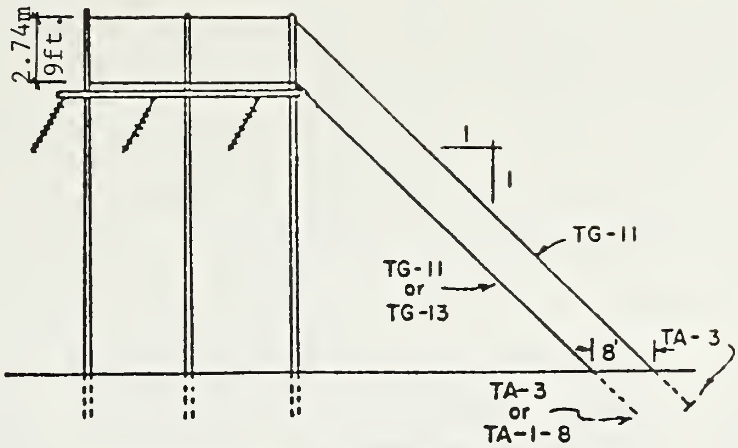


FIGURE XIV-10: STRUCTURE TH-12

METRIC

4(a). General equation: $4(a+b)+2c = G\cos\phi$

For the conductor:

$$4\left[(10.255)(HS)(\cos\theta/2) + (875)\right] + 2\left[2(46,300)(\sin\theta/2)\right] = G\cos\phi$$

$$3,500 + (41.020)(HS)(\cos\theta/2) + (185,200)(\sin\theta/2) = G\cos\phi$$

For the OHGW:

$$4\left[(6.980)(HS)(\cos\theta/2) + (neg.)\right] + 2\left[2(26,200)(\sin\theta/2)\right] = G\cos\phi$$

$$(27.920)(HS)(\cos\theta/2) + (104,800)(\sin\theta/2) = G\cos\phi$$

Case 1: Using 1 guy wire and 1 anchor for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:

$$3(3,500) + 3(41.020)(HS)(\cos\theta/2) + 3(185,200)(\sin\theta/2) \le G\cos\phi$$

$$10,500 + (123.060)(HS)(\cos\theta/2) + (555,600)(\sin\theta/2) \le 65,500\ N$$ (for guy)

$$10,500 + (123.060)(HS)(\cos\theta/2) + (555,600)(\sin\theta/2) \le 50,000\ N$$ (for anchor)

For the 2 OHGW:

$$2(27.920)(HS)(\cos\theta/2) + 2(104,800)(\sin\theta/2) \le G\cos\phi$$

$$55.840(HS)(\cos\theta/2) + (209,600)(\sin\theta/2) \le 65,500\ N$$ (for guy)

$$55.840(HS)(\cos\theta/2) + (209,600)(\sin\theta/2) \le 50,000\ N$$ (for anchor)

Case 2: Using 2 guy wires and 2 anchors for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:

$$10,500 + (123.060)(HS)(\cos\theta/2) + (555,600)(\sin\theta/2) \le 2(65,500)N$$ (for guy)

$$10,500 + (123.060)(HS)(\cos\theta/2) + (555,600)(\sin\theta/2) \le 2(50,000)N$$ (for anchor)

For the OHGW: (same as above)
(See Guying Guide for plot of controlling equation).

4(b). General equation: $4(a+b)+2c = G\cos\phi$

For the conductor:

$$4\left[.7027(HS)(\cos\theta/2)+196\right]+2\left[2(10{,}400)(\sin\theta/2)\right] = G\cos\phi$$

$$785+(2.811)(HS)(\cos\theta/2)+(41{,}600)(\sin\theta/2) = G\cos\phi$$

For the OHGW:

$$4\left[.4783(HS)(\cos\theta/2)+(\text{neg.})\right]+2\left[2(5{,}900)(\sin\theta/2)\right] = G\cos\phi$$

$$(1.913)(HS)(\cos\theta/2)+(23{,}600)(\sin\theta/2) = G\cos\phi$$

Case 1: Using 1 guy wire and 1 anchor for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:

$$3(785)+3(2.811)(HS)(\cos\theta/2)+3(41{,}600)(\sin\theta/2) \le G\cos\phi$$

$$2355+8.433(HS)(\cos\theta/2)+(124{,}800)(\sin\theta/2) \le 14{,}700 \text{ lbs. (for guy)}$$

$$2355+8.433(HS)(\cos\theta/2)+(124{,}800)(\sin\theta/2) \le 11{,}300 \text{ lbs. (for anchor)}$$

For the 2 OHGW:

$$2(1.913)(HS)(\cos\theta/2)+2(23{,}600)(\sin\theta/2) \le G\cos\phi$$

$$3.826(HS)(\cos\theta/2)+(47{,}200)(\sin\theta/2) \le 14{,}700 \text{ lbs. (for guy)}$$

$$3.826(HS)(\cos\theta/2)+(47{,}200)(\sin\theta/2) \le 11{,}300 \text{ lbs. (for anchor)}$$

Case 2: Using 2 guy wires and 2 anchors for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:

$$2355+(8.433)(HS)(\cos\theta/2)+(124{,}800)(\sin\theta/2) \le 2(14{,}700) \text{ lbs. (for guy)}$$

$$2355+(8.433)(HS)(\cos\theta/2)+(124{,}800)(\sin\theta/2) \le 2(11{,}300) \text{ lbs. (for anchor)}$$

For the OHGW: (same as above)

See Guying Guide on page XIV-18 for plot of controlling equation.

5. Check for buckling of the poles. Since the outside poles carry the maximum axial load, it is necessary only to examine this pole. Longitudinal buckling is considered since this condition is the critical case. Weight of the conductor and OHGW is included in the calculations.

Case 1:

(a) For the various heights of structures, the maximum axial load which various poles can sustain can be calculated. Method "b", page XIV-5 is used to calculate P_{cr} below:

Pole Height	Unbraced length, l Groundline to lowest guy attachment m (ft)	kl (k = 1.0) pinned-pinned	dia. @ 1/3 l mm (in)	$P_{cr} = \frac{\pi^2 EI}{(kl)^2}$ N (lbs)
60-1	13.1 (43)	13.1 (43)	292 (11.5)	269,000 (60,500)
60-2			272 (10.7)	202,000 (45,300)
60-3			264 (10.4)	180,000 (40,500)
80-1	18.6 (61)	18.6 (61)	305 (12.0)	158,000 (35,600)
80-2			290 (11.4)	129,000 (29,000)
80-3			269 (10.6)	96,500 (21,700)
100-1	24.4 (80)	24.4 (80)	330 (13.0)	127,000 (28,500)
100-2			302 (11.9)	89,000 (20,000)

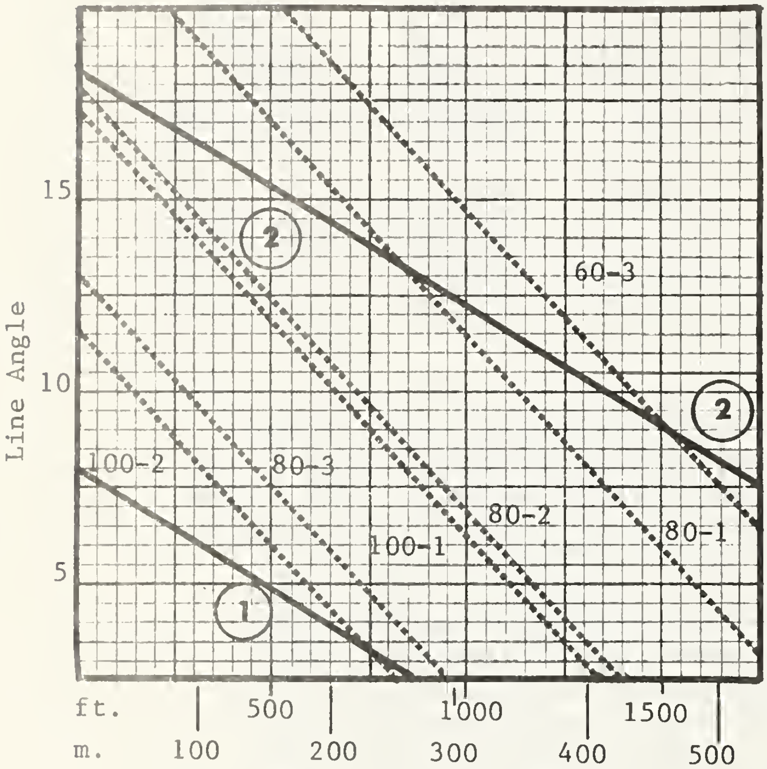
(b) Assuming the horizontal spans are equal to the vertical span, the previous equations in 4(a) can be revised to include the weight of the conductor and OHGW on the outside pole. The total axial load in the pole is the sum of the axial loads induced in the pole from guying the three conductors and two OHGW and the vertical weight of the OHGW and the conductor. Half of the vertical load from the outside phase is carried by the middle pole and other half is carried by the outside pole. The vertical load is multiplied by an OCF of 2 in order to insure a safety factor of 2 against buckling. For this example, since the guy leads are 1 to 1, the vertical axial load from the guy wire will be equal to the horizontal component of the guy wire.

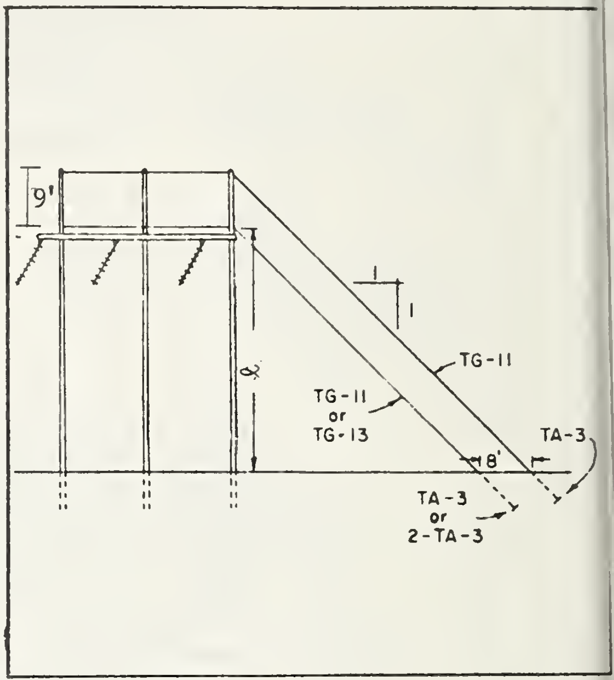
METRIC	2 x weight	+	4a	+	4b	+	2c	
Cond.	2(.5)(30.557)HS	+	123.060(HS)(cos θ/2)	+	10,500	+	555,600(sin θ/2)	
OHGW	2(14.308)HS	+	55.840(HS)(cos θ/2)	+		+	209,600(sin θ/2)	
	(59.174)HS	+	178.90(HS)(cos θ/2)	+	10,500	+	765,200(sin θ/2)	$\leq P_{cr}$

ENGLISH								
Cond.	2(.5)(2.0938)HS	+	8.433(HS)(cos θ/2)	+	2,355	+	124,800(sin θ/2)	
OHGW	2(.9804)HS	+	3.826(HS)(cos θ/2)	+		+	47,200(sin θ/2)	
	(4.055)HS	+	12.259(HS)(cos θ/2)	+	2,355	+	172,000(sin θ/2)	$\leq P_{cr}$

GUYING GUIDE

Structure TH-12 Ruling Span 244m (800 ft)
Conductor
Type 795 26/7 Max. Tension (L,M,H) 46,300(10,400) p_c 10.255(.7027)
OHGW w_c 30.557(2.0938)
Type 7/16E.H.S. Max. Tension (L,M,H) 26,200 (5,900) p_g 6.980(.4783)
Guy Wire w_g 14.308(.9804)
Type 7/16E.H.S. Ult. Strength 92,500(20,800)





Case 1

For OHGW: TG-11, TA-3
For cond: TG-11, TA-3

Total guys and anchors:
2-TG-11
2-TA-3

Limitation: TA-3 to cond.

Case 2

For OHGW: TG-11, TA-3
For cond: TG-13, 2-TA-3

Total guys and anchors:
1-TG-11
1-TG-13
3-TA-3

Limitation: TA-3 to cond.

XV. HARDWARE

A. General

Hardware for transmission lines can be separated into conductor related hardware and structure related hardware.

For many transmission lines, the conductor may constitute the most expensive single component of investment. Yet, this is the one component which is most exposed to danger and most easily damaged. In the design of any line, appropriate emphasis should be given to the mechanical and electrical demands on the design of conductor related hardware which will support, join, separate, reinforce, and mechanically damp overhead conductors.

Structure related hardware includes any hardware necessary to frame structures, to provide guying and pole attachments to the structure, and to provide necessary line to structure clearances. As connecting pieces for structural members, proper selection of hardware is necessary to assure structure strength. At the same time, proper selection of hardware to be static proof aids in reducing possible radio and television interference.

B. Conductor Related Hardware

The selection and proper installation of conductor accessories will have considerable influence on the operation and maintenance of a transmission line. The electrical, mechanical, and material design considerations are generally involved in the design of conductor support hardware and conductor motion hardware.

1. Conductor Support Hardware

a. Suspension Clamps

Contoured suspension clamps are designed to match the conductor diameter in order to guard against conductor ovalling and excessively high compressive stresses. Suspension clamps may be made from galvanized malleable iron or forged steel with appropriate aluminum liners (not recommended for copper conductors) or copper liners. The connector fitting will usually be either a socket or clevis (see Figure XV-1). When armor rods and liners are used, proper selection of the seating diameter of the clamps should be made. Liners can be expected to add 2.54 mm (.1 in.) to the conductor diameter. There are a few clamps made for large angles (up to 120°). However, these clamps are available only for small conductor sizes. When angles are encountered on a transmission line using large conductors, strain clamps should be used, or in the case of medium angles, double suspension clamps connected to a yoke plate may be needed to make a gradual turn.

Cushioned suspension clamps are sometimes used to support the conductor and to reduce the static and bending stresses in the conductor. Cushioned suspension units are further explained in the conductor motion hardware section (page XV-8).

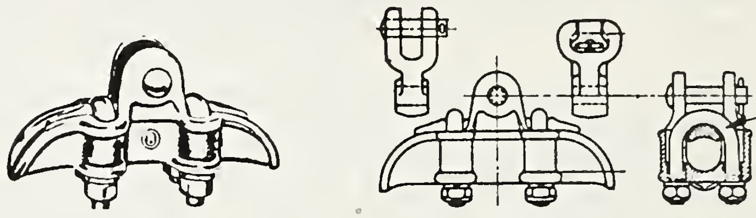


FIGURE XV-1: SUSPENSION CLAMP WITH CLEVIS OR BALL AND SOCKET TYPE OF CONNECTION. ("U" bolts insure permanent conductor to clamp contact and prevents burning of the conductor).

b. <u>Clamp Top Clamps</u>

Clamp top clamps for vertical and horizontal post insulators are popular because of their simplicity of installation. The clamps, either made of malleable iron or aluminum alloy, are mounted on a metal cap. The clamp itself is composed of a removable trunion capscrew (keeper piece) and a trunion saddle piece. Straight line clamps are designed to hold conductors without damage on tangent and line angles of up to approximately 15°. The maximum acceptable vertical angle (each side of clamp) is usually taken to be approximately 15° with the horizontal. Since the keeper piece of the clamp is not designed to provide the support for upward loading, uplift conditions should be avoided. There are angle clamps available which are designed to take up to a 60° line angle. However, when line angles are greater than 15° to 20°, suspension insulators are usually recommended.

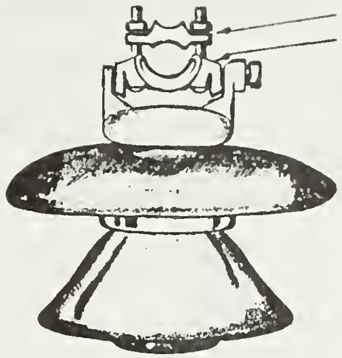


FIGURE XV-2: PIN TYPE INSULATOR WITH CLAMP TOP CLAMP.

c. Tied Supports

A large portion of lower voltage construction involves tying of conductors to pin and post insulator supports. Hand ties are occasionally vulnerable to loosening from various forces and motion from differential ice buildup, ice dropping, galloping, and vibration. Factory formed ties with the characteristics of a secure fit, low stress concentration, and uniformity of installation, supposedly eliminate mechanical difficulties and radio interference problems associated with loose tie wires.

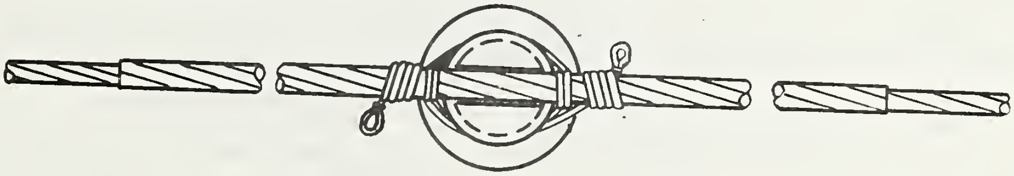


FIGURE XV-3: TOP GROOVE TIE, ACSR CONDUCTOR WITH STRAIGHT OR PREFORMED ARMOR RODS.

d. Deadend Clamps

Deadending a conductor may be accomplished using formed type deadends, automatic deadends, bolted or compression type deadends. Because of the strength limitations of the formed and automatic deadends, these types are limited to primarily small conductor sizes and distribution use. The two basic methods of deadending a transmission conductor are by the use of bolted or compression type deadend clamp.

(1) Bolted Clamp

Deadend clamps or strain clamps as they are sometimes called, are made from three basic types of material as follows:

(a) Aluminum Alloy Type (most prevalent)

General notes: Corrosion resistant, minimizes power losses, minimizes hysteresis and eddy currents, minimizes excessive conductor heating in the conductor clamping area, lightweight.
Application: No armor rods or tape required. Use with ACSR or all aluminum conductors. Clamps are not to be used with copper or copperweld conductors.

(b) Malleable Iron

General notes: Somewhat lightweight, range of conductor sizes limited.
Application: Must use aluminum or copper liners. May be used with copperweld, ACSR, and other composite conductors.

(c) Forged Steel

General notes: Heavy in weight.
Application: Use liners of the same material as the conductor. May be used for all aluminum, copper or ACSR conductors.

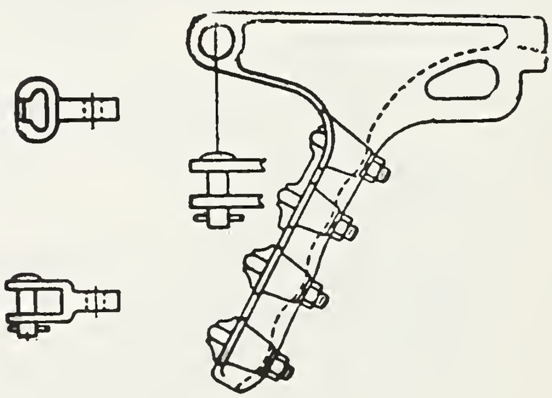


FIGURE XV-4a: TYPICAL BOLTED DEADEND CLAMP

(2) Compression Type

The drawing below depicts the typical compression clamp:

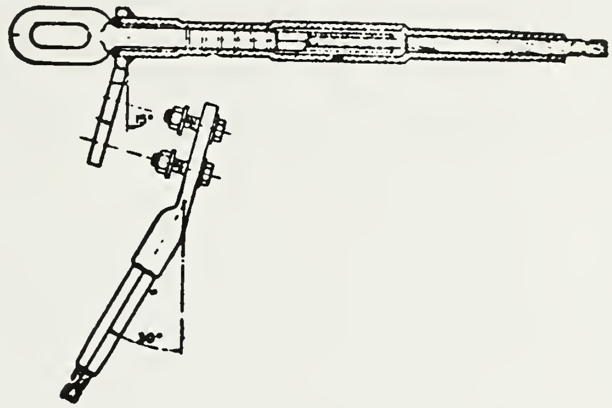


FIGURE XV-4b: TYPICAL COMPRESSION DEADEND CLAMP

(3) Strength

The ultimate strength of the body of the bolted clamps should meet or exceed the ultimate strength of the conductor. The holding power of the bolted type of compression type clamp must meet the following criteria:*

(a) Clamps shall hold 90 percent of the strength of the largest conductor in a short-time load.

(b) Clamps must hold a sustained load of 75 percent of the strength of the conductor for three days.

(4) General

For high voltage, suspension and deadend clamps are designed to control corona by smoothing and rounding all edges and by placing within the electrical shielding of the clamp body all nuts and studs that present sharp edges.

*For bolted type clamps, bolts should be tightened to 400 in./lbs. of torque. Clamps and splices should also meet certain corrosion resistance tests and heat cycling tests.

e. <u>Splices</u>

Conductor splices may be formed utilizing automatic compression type splices, formed type, or crimp compression type splices. For most transmission conductors, the crimped compression type splice is used because of its high strength capabilities. Splices should meet the same strength, corrosion resistance, and heat cycling requirements as the deadend clamps.

f. <u>Strain Yokes</u>

Two or more insulator strings may be connected in parallel by using yokes in order to: (1) sustain heavy loads; (2) increase the safety factor for long-span river crossings; (3) make a gradual turn at large angles; (4) deadend. Usually, it is more economical to supply higher strength rating insulators than using yokes.

g. <u>Insulators</u>

The mechanical and electrical requirements of insulators are discussed in Chapter VIII. Where suspension insulators are exposed to salt sprays or corrosive industrial emissions, insulators using enlarged pin shafts or corrosion intercepting sleeves prolong the life of the insulator pin. The "CIS" leaves an air space between the pin and the cement. The corrosion will attack the long-lived but expendable sleeve and any volumetric increase at the rust line will distort the sleeve without imposing bursting stresses on the adjacent porcelain. Other types of insulators have an enlarged shaft near the cement line which provides additional sacrificial metal for corrosion.

FIGURE XV-5: SUSPENSION INSULATORS - BALL AND SOCKET TYPE (LEFT) AND CLEVIS-EYE TYPE (RIGHT).

For lower voltages, pin and post type insulators are mounted on structure crossarms. The side and top wire groove generally limits the size of the conductor with armor rod to a maximum of 4/0 and 336.4 kcmil ACSR.

h. Fittings

There are a variety of fittings used to attach the insulator to the structure. These may include hooks, "Y" ball/clevis, ball eyes, ball clevises and chain, anchor or vee shackles. The "C" hooks suggested on REA construction are the self locking hooks. With the insulator cap in place, the opening of the hook is sufficiently restricted so that accidental disconnection cannot occur. The various fitting types are shown below.

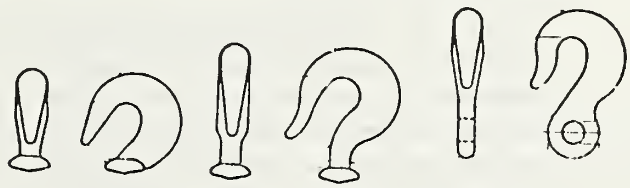


FIGURE XV-6: DIFFERENT TYPES OF HOOKS. SELF LOCKING "C" HOOK (LEFT); BALL HOOK (MIDDLE); CLEVIS TYPE HOOK (RIGHT).

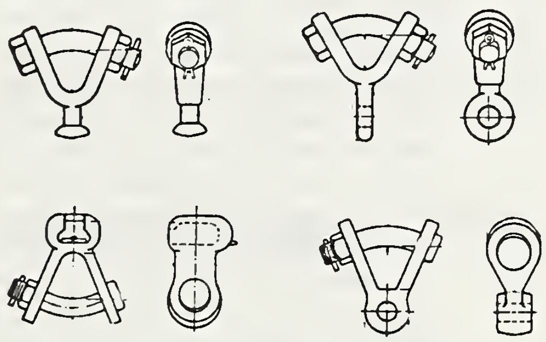


FIGURE XV-7: VARIOUS TYPES OF BALL AND CLEVIS "Y" CONNECTIONS.

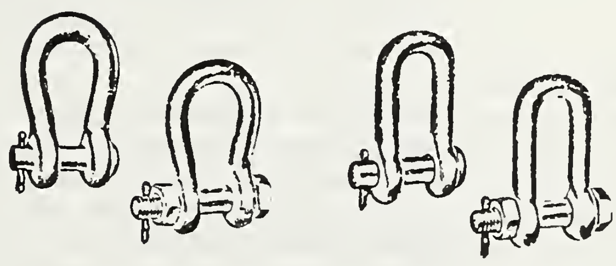


FIGURE XV-8: ANCHOR SHACKLE (LEFT); CHAIN SHACKLE (RIGHT).

The load on all fittings should not exceed 50 percent of their ultimate strength under NESC light, medium, or heavy loading conditions. For extreme ice and wind conditions, the fittings should not be stressed beyond 70 percent of the rated ultimate capacity. For highly corrosive environments, these values should be reduced.

2. Conductor Motion Hardware

a. Aeolian Vibration

There are several methods to reduce the effects that aeolian vibration has on lines. The selection of the proper hardware to improve conductor life will depend on the degree of vibration. All conductors are in some state of vibration, varying from extremely slight to temporarily severe. Suspension clamps do not restrict vibration, but the design of suspension clamps should keep to an absolute minimum the effect of such vibration on the conductor.

(1) Armor Rods

Armor rods should be used on lines in areas where mild vibrations may occur. Armor rods, wrenched or preformed, are helical layers of round rods which are installed over the conductor at the points of attachment to the supporting structures. The primary purpose of armor rods is to provide additional rigidity to the conductor at its point of support. The use of armor rods accomplishes several things: (1) the armor rods provide a gentler slope of curvature for the incoming conductor and hence alleviates the changes of mechanical stress buildup at the point of support; (2) by increasing the flexural rigidity of the conductor, bending stresses are reduced in the conductor, thereby increasing its fatigue life; (3) the conductor is protected from flashover damage and mechanical wear at the points of support.

In laboratory tests, the placement of armor rods on the conductor has shown that the conductor is able to withstand considerably more vibration cycles without fatigue failure. Tests such as these show that there is a significant reduction in stress afforded through the use of armor rods.

FIGURE XV-9: ARMOR RODS USED WITH SUSPENSION INSULATORS.

(2) Cushioned Suspension

Cushioned suspension units use the concept of a resilient cushioning in conjunction with armor rods to further reduce the static and dynamic bending stresses in the conductor. The compressive clamping force is decreased, thereby reducing stress concentration notches and the degree of fitting. For line angles greater than 30°, single support units should be replaced with double units. When considering longitudinal loads for a line using cushioned suspension units, the designer should consider that the units have a slip load of approximately 20 percent of the rated breaking strength of the conductor.

FIGURE XV-10: CUSHIONED SUSPENSION UNIT.

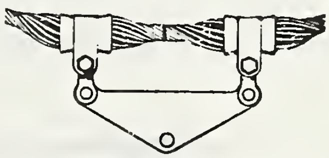


FIGURE XV-11: DOUBLE CUSHIONED SUSPENSION FOR LINE ANGLES GREATER THAN 30°

(3) Dampers

Dampers are used in areas of severe vibration in order to attenuate aeolian vibration amplitudes, thereby reducing the dynamic bending stress at hardware locations and extending conductor life. Most of the present suspension dampers make use of the connecting cables between weights to dissipate the energy supplied to the damper. The other type of vibration damper is the spiral damper which is limited to small conductor sizes (Figure IV-13).

When a vibration wave passes the damper location, the clamp of the suspension type damper oscillates up and down, causing flexure of the damper cable and creating a relative motion between the damper clamp and damper weights. The stored energy from the vibration wave is dissipated to the damper in the form of heat. For a damper to be effective, its response characteristics should be consistent with the frequencies of the conductor on which it is installed. Dampers of various designs are available from a number of manufacturers. The number of dampers required, as well as their location in the span should be determined by the damper manufacturer.

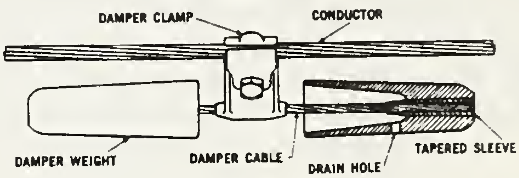


FIGURE XV-12: TYPICAL DAMPER

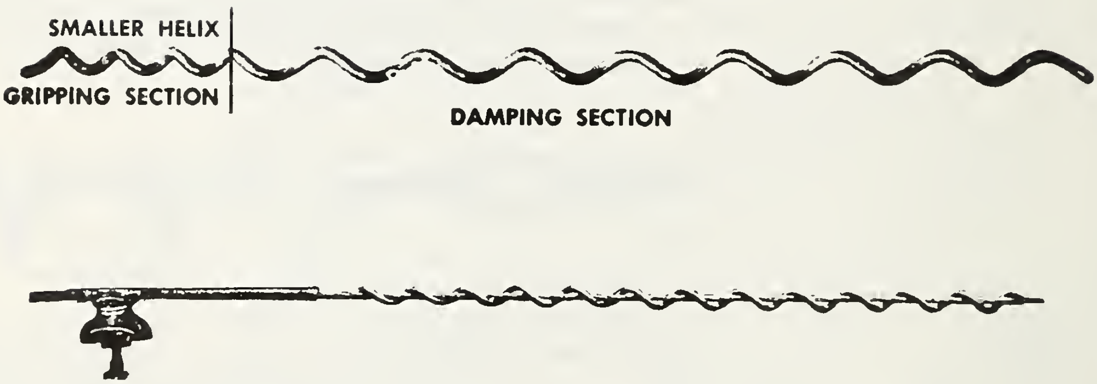


FIGURE XV-13: SPIRAL VIBRATION DAMPER FOR SMALL CONDUCTORS.

(4) Application

The application of armor rods, armor grip suspension and dampers or a combination thereof should be on a case-by-case basis. A certain item should not be used merely because it has given satisfactory performance in another location.

If the prevailing wind conditions and the terrain are such that the vibration will occur most of the time, then some form of vibration protection should be investigated. Dampers should be selected on the basis of the frequencies one expects to encounter in the terrain that must be traversed. The engineer should not specify a certain type of damper or armor rod simply because everyone else is using them. An improperly located damper can accentuate vibration and cause as much damage as if no damper existed.

Armor rods are meant to be reinforcement items and not dampers. Because of this, vibrations are passed on through the conductor clamp basically without any attenuation, and then are dissipated in the supporting structure. If the structure is made of steel and if fatigue should become a problem, then the use of dampers along with armor rods should be investigated. However, care should be exercised in selecting the distance between the ends of the armor rods and the dampers, if both are to be used.

b. Galloping

The hazards associated with galloping conductors are contact between phases or between phase conductors and ground wires, racking of the structure, and possible mechanical damage at supports. Aerodynamic drag dampers and interphase spacers are two types of hardware used to limit the amplitude of the conductor during galloping. The historical effectiveness of antigalloping devices has been sporadic.

c. Bundled Conductors

Bundled conductors are not used very often on transmission lines under 230 kV but are often economically justified above 230 kV. Bundled conductors can experience aeolian vibration, galloping, corona vibration, and subconductor oscillation. For a bundled conductor with spacers, aeolian vibration may be reduced by a factor of 10. However, galloping of ice coated conductors will occur more readily and more severely on bundled lines than on single conductors in the same environment. Subconductor oscillation, though, has caused the major share of the problems to date. It is caused by one conductor lying in the wake of an upstream conductor and thereby being excited in nearly a horizontal ellipse. Damage has consisted of conductor wear and spacer deterioration and breakage. In order to reduce subconductor oscillation, subspan length or the distance between spacers should be kept below 250 feet.

There are a number of different types of spacers and spacer dampers. The primary purpose of spacers is to reduce the probability of conductor contact and magnitude of vibration. Spacers may be rigid, articulated or flexible, open-coil and closed-coil springs, and wire rope and steel strand connecting members. Spacers should grip the conductor securely to avoid abrasion of the subconductors and to prevent conductor entanglement during strong winds.

d. Insulator Swing

Occasionally, tie down weights are used to control conductor position by preventing excessive uplift and swinging. A line should not be designed to use tie down weights as a means of preventing the conductor from swinging into the structure, but sometimes due to a low V/H span ratio, weights may have to be used on an occasional structure. Two types are shown below in Figure XV-14.

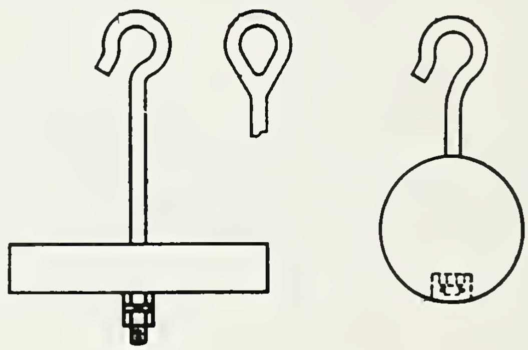


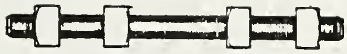
FIGURE XV-14: DISC WEIGHTS (LEFT);
BALL WEIGHTS (RIGHT)

C. Structure Related Hardware

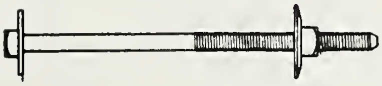
1. Fasteners

The threaded rod and machine bolt are frequently used with wood transmission structures. Static proof bolts have a washer securely fixed to the head of the bolt and are furnished with washer nuts. Modifications to these bolts include shoulder eye bolts with round or curved washers welded to the eye, forged shoulder eye bolts and forged eye bolts. M-F type locknuts, used in conjunction with a regular nut or washer nut, form a solid unit which does not loosen from vibration and helps to maintain a static proof installation.

Machine Bolt

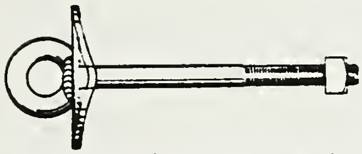


Threaded Rod



Static Proof Bolt
with Forged Washer Nut

Double End Bolts



Shoulder Eye Bolt
with Curved Washer

Double Arming Bolt

MF type Locknut

FIGURE XV-15: FASTENERS

TABLE XV-1
Strengths for Machine Bolts, Double Arming Bolts, Double End Bolts, Conforming to ANSI C135.1

Machine Bolt Diameter		Stress Area		Min. Tensile Strength	
mm	(in.)	mm^2	(in^2)	N	(lbs.)
12.7	(1/2")	50.0	(.0775)	34,700	(7,800)
15.8	(5/8")	91.5	(.1419)	55,200	(12,400)
19.0	(3/4")	145.8	(.226)	81,600	(18,350)
22.2	(7/8")	215.5	(.334)	112,900	(25,400)
25.4	(1")	391.0	(.606)	149,000	(33,500)

Lag screws (Figure XV-16) are sometimes used in lieu of bolts when shear loads are small. A lag screw with fettered edges is driven into the wood and maintains its holding power by the cone shaped threads. When used, the moment capacity of the pole is reduced in the same manner as a bolt hole reduces moment capacity.

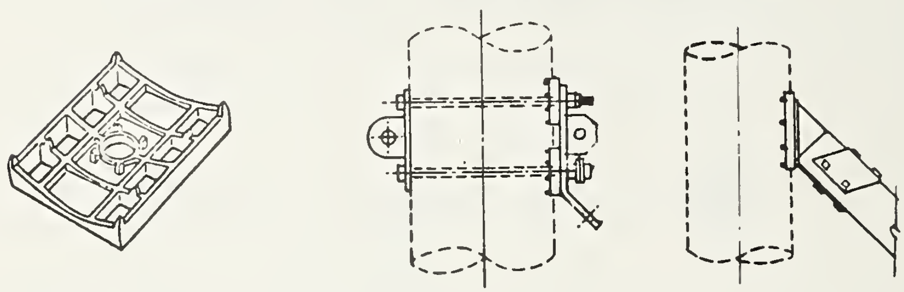
FIGURE XV-16: LAG SCREW

Anti-split bolts (machine bolts with washer and nut) help prevent the propagation of checking and splitting beginning at the end of crossarms. A three inch edge distance should be provided between the anti-split bolt and the edge of the arm.

2. Framing Fittings

a. Grid Gains

The primary purpose for using grid gains is to reduce bolt hole slotting by distributing the shear load of the bolt over a large wood area. The special shaped teeth of the grid gain press into the wood surface and offer maximum resistance to movement both with and across the grain of the wood. The use of grid gains will strengthen bolt connections and are recommended anytime the bolt must carry a substantial shear load.



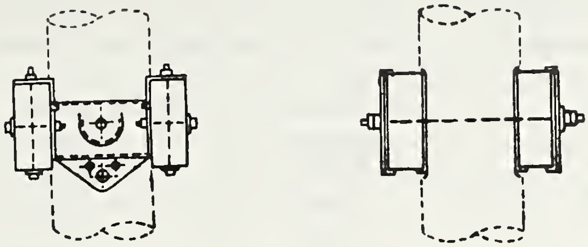
Grid Gain Application of Grid Gains

FIGURE XV-17: GRID GAINS

b. Crossarm Fittings

The gain plate between the pole and the crossarm and the reinforcing plate on the outside of the arm provide additional metal bearing surface in order to transfer the vertical load from the crossarm to the bolt. The gain plate eliminates the decay area between two wood contact areas. The reinforcing plate, also called a ribbed tie plate, will prevent the crossarm from splitting or checking when the nut is tightened.

When double crossarms are used to increase vertical spans or longitudinal strength capabilities, spacer fittings are needed to separate the crossarms and to provide a point of attachment for suspension insulators. If fixed spacers are used, poles are gained in accordance with Drawing TM-204, REA Form 805. Since the standard fixed spacing sizes are 7-1/2", 9", 10-1/2", and 12", the crossarm may be bowed $\pm 1/2$". The brand on the butt and face of the pole should include proper designation of the fixed spacer size. Adjustable spacers will fit a range of pole diameters and as such the pole need not be gained.



Spacer Fitting

Reinforcing Plate and Gain Plate

FIGURE XV-18

3. <u>Swing Angle Brackets</u>

In order to increase clearance between phase conductors and the structure, swing brackets are mounted horizontally or vertically. The two primary types of angle brackets are the rod type for light loads, and the angle iron type for heavier loads.

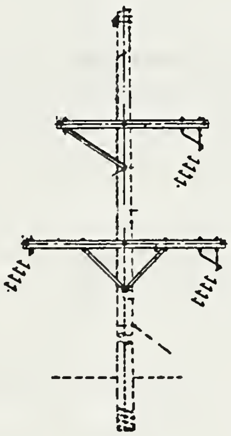


FIGURE XV-19: SMALL ANGLE STRUCTURE WITH SWING ANGLE BRACKETS.

D. <u>Corrosion of Hardware</u>

Corrosion may be defined as the destruction of a metal by a chemical or electro-chemical reaction with its environment. Certain industrial and sea coast environments accelerate the rate of corrosion. Parameters which stimulate corrosion include air (oxygen) dissolved in water, air borne acids, sulphur compounds (from cinders, coke, coal dust), salt dissolved in water, corona, etc.

Any two dissimilar metals when placed together in the presence of an electrolyte form a simple battery, one metal becoming an anode and sacrificing itself to the other metal (cathode). One method to reduce the rate of corrosion is to select metals which are compatible with one another. For the table below, the greater the algebraic difference between metals, the more rapid the rate of corrosion of the electronegative element.

Silver	+ .79
Copper	+ .34
Lead	- .13
Tin	- .15
Iron	- .35
Chromium	- .47
Zinc	- .77
Aluminum	-1.337

As an example, when malleable iron suspension clamps are used, aluminum liners should be furnished in order to reduce the rate of corrosion of the aluminum conductor. As in another example, the selection of staples to be used on the pole ground wire must be a compatible material to the ground wire (see Drawing TM-9, REA Form 805).

Other methods of reducing the rate of corrosion are to increase metal thickness, galvanize, tin plate, paint or cover with corrosion inhibitors.

REA Bulletin 161-23, "Manual on Underground Corrosion Control in Rural Electric Systems," contains additional basic information concerning the galvanic corrosion process.

XVI. UNDERBUILD

A. General

The placing of underbuild distribution or communication circuits on transmission lines is a practice that should be avoided where possible. Underbuild can add a significant amount of cost to the line and may decrease reliability as well as make it more difficult for maintenance crews to work. If a separate distribution pole line is not feasible, consideration should be given to placing the distribution circuit underground as well as on the transmission structure.

Underbuild distribution must meet all of the requirements for standard REA distribution lines but must also meet the special, more stringent requirements as set forth in this chapter.

B. Addition of Distribution Underbuild to an Existing Transmission Line

Distribution circuits should not be added to existing transmission structures unless the structures were originally designed for underbuild.

C. Strength Requirements

Standard distribution construction is normally required to meet NESC Grade C construction. However, underbuild distribution on transmission circuits, with the exception of the crossarms, must be built to meet all requirements of REA Grade B construction (see Chapter XI, Table XI-2). The two most important consequences of this are that: (1) the loading on the pole due to the distribution circuits must be calculated using an overload capacity factor of four, and (2) all guying for the underbuild must meet the guying requirements for transmission. Distribution crossarms on transmission structures must meet Grade C construction (overload capacity factor of 2).

D. Line-to-Ground Clearances

Line-to-ground clearances for underbuild transmission should meet the requirements given specifically for underbuild in REA Bulletin 160-2, "Distribution Line Design, Mechanical".

Since the closest conductor to ground will usually be that of the distribution circuits, the clearances to ground and clearances in crossing situations will most probably be controlled by the limits set up for the distribution circuits.

The problem of providing satisfactory clearance becomes more involved when crossing other utility circuits. In these instances, very careful attention must be given to the allowable clearance as specified in Section 23 of the NESC.

Particular attention should be given to the use of reduced size distribution neutrals since the clearance to ground for the neutral, by virtue of its increased sag and position on the pole or crossarm, may be the controlling factor for pole height. In some cases, it may be more economical to increase the size of the neutral so as to reduce its sag.

E. Separation Between Transmission and Underbuild Distribution Circuits

The clearances given in this section are intended to provide not only operating clearances but also sufficient working clearances. A lineman must be able to work on the underbuild without getting into the space occupied by the transmission conductors.

1. Horizontal Separation

The horizontal separation at the support between the lowest transmission conductor(s) and the highest distribution conductor(s) or neutral should be at least .3 meter (1 foot) if possible as illustrated in Figure XVI-1.

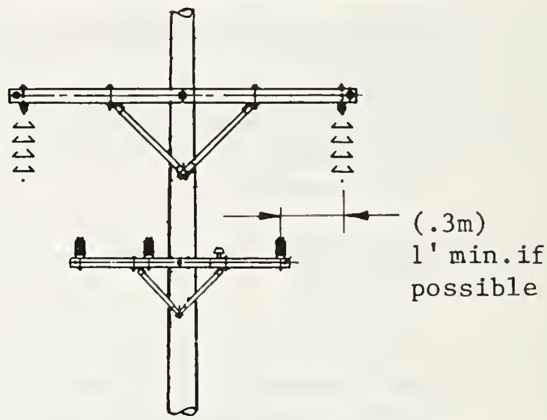


FIGURE XVI-1: HORIZONTAL SEPARATION REQUIREMENTS BETWEEN TRANSMISSION AND UNDERBUILD

2. Vertical Clearances to Underbuild

a. Vertical Clearance to Underbuild at Supports

The required minimum vertical clearances between the transmission conductors and the underbuild conductors at the support are given in Table XVI-1. The minimum vertical clearances apply regardless of the amount of horizontal separation between transmission and underbuild conductors (see Figure XVI-2).

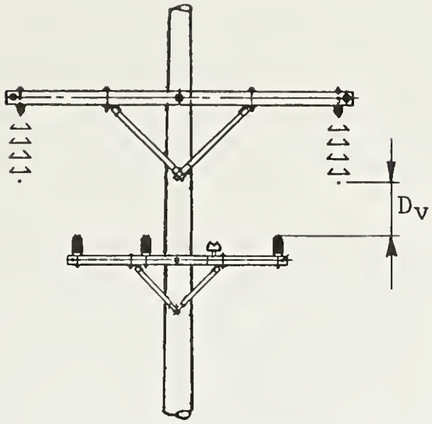


FIGURE XVI-2: VERTICAL CLEARANCE REQUIREMENTS AT STRUCTURE, FOR UNDERBUILD

b. Vertical Clearance to Underbuild at any Point in the Span

The required minimum vertical clearances at any point along the span are given in Table XVI-1.

(1) Conditions Under Which Clearances Apply

The clearances apply for an upper conductor at final sag for the condition below yielding the greatest sag for the line.

(a) A conductor temperature of 0°C (32°F), no wind, with the radial thickness of ice for the applicable loading district;

(b) A conductor temperature of 75°C (167°F)*;

(c) Maximum design conductor temperature, no wind, under emergency loading conditions**. For high voltage bulk transmission lines of major importance to the system, consideration should be given to the use of 100°C (212°F) as the maximum design conductor temperature.

The sag of the underbuild conductor to be used is the final sag, at 16°C (60°F), no wind.

(2) Altitude Greater than 1000 Meters (3300 Feet)

If the altitude of the transmission line or portion thereof is greater than 1000 meters (3300 feet), an additional clearance as indicated

*See first footnote, page IV-2.

**See second footnote, page IV-2.

TABLE XVI-1

MINIMUM VERTICAL CLEARANCES TO DISTRIBUTION OR COMMUNICATION UNDERBUILD ON TRANSMISSION LINES IN METERS (FEET) (CIRCUITS MAY BE OF THE SAME OR DIFFERENT UTILITIES)

CLEARANCES BETWEEN TRANSMISSION AND DISTRIBUTION CONDUCTORS:	Nominal Line-to-Line Voltage in kV					
	34.5-46	69	115	138	161	230
1. Clearance from point of suspension of transmission conductor to point of suspension of underbuild distribution or communication conductor.						
Nominal underbuild voltage in kV line-to-line:						
a. 25 kV and below (including communication conductors)	1.6 (5)	1.6 (5.3)	1.9 (6.2)	2.1 (6.7)	2.2 (7.1)	2.6 (8.5)
b. 34.5 kV	1.6 (5)	1.7 (5.5)	2.0 (6.4)	2.1 (6.9)	2.3 (7.3)	2.7 (8.7)
2. Clearance at any point in span from transmission conductor to underbuild conductor.						
Nominal underbuild voltage in kV line-to-line:						
a. 25 kV and below (including communication conductors	1.2 (3.8)	1.3 (4.0)	1.5 (5.0)	1.7 (5.4)	1.8 (5.9)	2.3 (7.3)
b. 34.5 kV	1.2 (3.8)	1.3 (4.2)	1.6 (5.2)	1.7 (5.6)	1.9 (6.1)	2.3 (7.5)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:						
Additional meters of clearance per 1000 meters of altitude above 1000 meters (same value also represents additional feet of clearance per 1000 feet of altitude above 3300 feet).	0	.02	.05	.06	.07	.12

in Table XVI-1 must be added to both category 1 and 2 clearances (clearance at the structure and at the midspan point) given.

c. Additional Clearance Requirements for Communication Underbuild

For communication underbuild the low point of the transmission conductors at final sag, 16°C (60°F), no wind, shall not be lower than a straight line joining the points of support of the highest communication underbuild.

d. Span Length and Clearance to Underbuild

The requirements of either a. or b. above will dictate what the minimum clearance to underbuild at the structure must be. If the clearance to underbuild at the support as dictated by a. above results in a clearance at midspan inadequate to meet the requirements of b., the clearance at the structure would have to be increased. Since the vertical separation at the structure may depend upon the relative sags of transmission and underbuild conductors and since the span length has an effect on relative sags, the resulting minimum necessary vertical separation at the support may change with span length. It is recommended that a maximum span as limited by vertical clearance to underbuild be calculated to insure that for each span the vertical separation at the support is correct.

The formula for maximum span as limited by clearance to underbuild is:

$$L_{max} = (RS)\sqrt{\frac{A - B}{S_{\ell} - S_u}} \qquad \text{Eq. XVI-1}$$

where:

L_{max} = maximum span in meters (feet).
RS = the ruling span in meters (feet).
A = the allowable separation at midspan in meters (feet).
B = the vertical separation at supports in meters (feet).
S_{ℓ} = the underbuild sag at 16°C (60°F), final, in meters (feet).
S_u = the transmission conductor sag at worst case condition, final sag, in meters (feet).

F. Climbing Space

Climbing space through lower circuits shall be preserved on one side of the pole or in one quadrant from the ground to the top of the pole as required by the NESC. Working space should be provided in the vicinity of crossarms. Jumpers should be kept short enough to prevent their being displaced into the climbing space.

G. Overhead Ground Wires and Distribution Neutrals

Distribution underbuild must have its own separate neutral. The transmission overhead groundwire should not be used as a distribution neutral. In addition, the pole groundwire for the distribution neutral should be separate from the pole ground wire connected to the overhead ground wire.

H. Additional Poles for Underbuild

There may be structures where it is either desirable or necessary to transfer distribution circuits to separate poles, even though two separate rights-of-way cannot be obtained. The situations are:

- Large Line Angles
- Deadends
- Tap-offs
- Sectionalizing Structures
- Substation Approaches
- Transformers or Regulators
- Capacitors

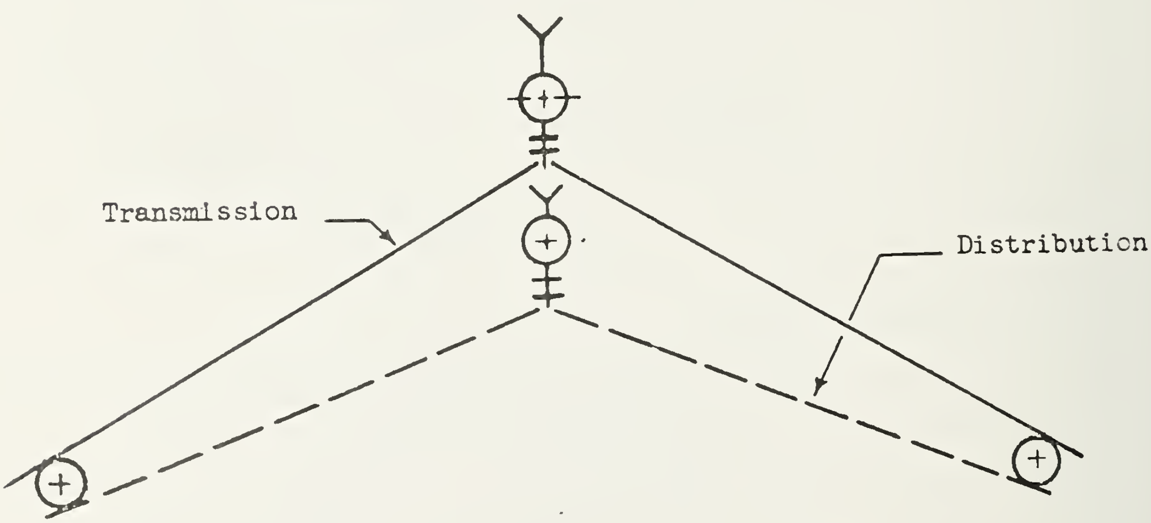


FIGURE XVI-3: THE TRANSFERENCE OF THE DISTRIBUTION CIRCUIT TO A SEPARATE POLE AT A LARGE ANGLE.

The location of transformers on structures carrying both transmission and distribution lines should be avoided. Not only does the transformer create an unbalanced load on the structure, but the additional circuits necessary for service drops may become extremely hazardous to operating personnel.

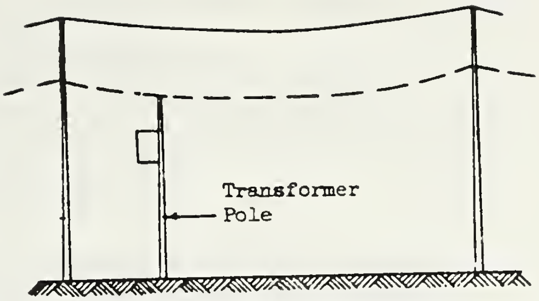


FIGURE XVI-4: THE USE OF A SEPARATE POLE TO MOUNT A DISTRIBUTION TRANSFORMER.

Example XVI-1: Maximum Span as Limited by Clearance to Underbuild

A 69 kV single pole transmission is to be built with a 25 kV under-build distribution circuit. Determine maximum span as limited by clearance between transmission conductors and underbuild.

Given:

1. Vertical separation between transmission and distribution conductors at structure: 2.13 m (7.0 ft.).

2. RS: 91 m (300 ft.).

3. Conductor sags in m (ft.).

Transmission Conductor
477 kcmil 26/7 ACSR

	initial	final
16°C (60°F)	.98 (3.22)	1.20 (3.91)
0°C (32°F) 12.7mm(½") ice	1.27 (4.17)	1.34 (4.40)
75°C (167°F)	1.77 (5.81)	1.98 (6.49)

Distribution Conductor
4/0 26/7 ACSR

	initial	final
16°C (60°F)	.63 (2.06)	.93 (3.03)

Solution

From Table XVI-1 the required vertical clearance at midspan between the transmission and distribution conductors is 1.3 m (4.0 ft.).

The worst case sag for the transmission conductor is at 75°C (167°F) at final sag condition which is 1.98 m (6.49 ft.), and the sag value to be used for the distribution conductor is .93 m (3.03 ft.).

$$L_{max} = (RS)\sqrt{\frac{A - B}{S_\ell - S_u}} \qquad \text{Eq. XVI-1}$$

Substituting:
$RS = 91\ (300)$
$A = 1.3\ (4)$
$B = 2.13\ (7)$
$S_\ell = .92\ (3.03)$
$S_u = 1.98\ (6.49)$

$$L_{max} = (91)\sqrt{\frac{1.3 - 2.13}{.92 - 1.98}}$$

$$L_{max} = 81 \text{ m}$$

$$L_{max} = (300)\sqrt{\frac{4 - 7}{3.03 - 6.49}}$$

$$L_{max} = 279 \text{ ft.}$$

The maximum span is limited by separation between transmission and underbuild distribution is 81 m (279 ft.). The slight difference between the absolute distances represented by the metric and English values is due to the rounding of the metric clearance requirements.

APPENDIX A

REA FORM 265 - TRANSMISSION LINE DESIGN DATA SUMMARY SHEET AND SUPPORTING INFORMATION

NOTES

USDA—REA

TRANSMISSION LINE DESIGN DATA SUMMARY

I. GENERAL INFORMATION

BORROWER			DATE
LINE IDENTIFICATION			
VOLTAGE		LENGTH *(Miles)*	
TRANSMISSION ______ kV	UNDERBUILD ______ kV	TRANSMISSION ______ Mi	UNDERBUILD ______ 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 *(LB/FT.)*				
RATED STRENGTH *(LBS)*				

III. DESIGN LOADS

		TRANSMISSION *(LBS/FT)*	OHGW *(LBS/FT)*	UNDERBUILD *(LBS/FT)*	COMM. NEUTRAL *(LBS/FT)*
NESC: ______ LDG. DISTRICT					
a. ICE: ______ IN	Vertical				
b. WIND ON ICED CONDUCTOR ______ 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		COMMON 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 ½" ICE, NO WIND 32°F								

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT:

CLEARANCES IN FEET	RAILROADS	HIGHWAY	CULTIVATED FIELDS			ADD. ALLOW. FOR TEMPLATE
TRANSMISSION						
UNDERBUILD						

VI. RIGHT OF WAY

WIDTH: ______ FT. *(MIN.)* ______ FT. *(MAX.)*

REA FORM 265 REV 9-79

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING:

HISTORY OF AEOLIAN VIBRATION:

a. TYPE OF VIBRATION DAMPERS USED *(IF ANY)*:

b. TYPE OF ARMOR RODS USED *(IF ANY)*:

VIII. INSULATION

NO. OF THUNDERSTORM DAYS/YR ______ ELEV. ABOVE SEA LEVEL *(MIN, MAX, FT)* ______

CONTAMINATION EXPECTED? ______ MAX. EST. FOOTING RESISTANCE ______ Ω SHIELD ANGLE ______ °

STRUCTURE TYPE	STRUCTURE DESIGNATION	NO. OF BELLS PIN OR POST	60 HZ DRY FLASHOVER	INSULATOR SIZE	M & E RATING OR CANTILEVER STR.	OTHER
TANGENT						
ANGLE						
STRAIN STRUCTURE						

IX. INSULATOR SWING

CRITERIA: (1) ______ PSF ON BARE CONDUCTOR AT ______ °F (6 psf MIN) FOR ______ IN. CLEARANCE

(2) ______ PSF HIGH WIND ON BARE CONDUCTOR AT ______ °F FOR ______ IN. CLEARANCE

ALLOWABLE ANGLE OF SWING:

STRUCTURE TYPE	NO. INSULATORS	ANGLE IN DEGREES: 6 PSF MIN. WIND (1)	HIGH WIND (2)	NO WIND	OTHER

X. ENVIRONMENTAL AND METEORLOGICAL DATA

TEMPERATURE: MIN ______ °F MAX ______ °F

AVERAGE YEARLY LOW ______ °F

EXTREME WIND VELOCITIES *(MPH)*:

10 YR ______ 50 YR ______ 100 YR ______

MAXIMUM HEIGHT OF SNOW ON THE GROUND UNDER THE CONDUCTOR *(FT)*

DESCRIBE TERRAIN AND CHARACTERISTICS OF SOIL

CORROSIVENESS OF ATMOSPHERE:

XI. STRUCTURE DATA

SPECIES WOOD: POLE: ______

ARM: ______

DESIGNATED BENDING FIBER STRESS *(PSI)*: POLE: ______ ARM: ______

SPANS *(FT)* FOR TANGENT TYPE ______	BASE POLE ______ FT ______ CL	OTHER HEIGHTS/CLASSES AND BRACING		
LEVEL GROUND SPAN				
MAX. HORIZON. SPAN LIMITED BY STRUCTURE STRENGTH				
MAX. VERTICAL SPAN LIMITED BY STRUCTURE STRENGTH				
MAX. HORIZONTAL SPAN LIMITED BY COND. SEPARATION				
MAX. SPAN LIMITED BY UNDERBUILD				
MAX. SPAN LIMITED BY GALLOPING				

ENBEDMENT DEPTH :

PRESERVATIVE: *(Type & Retention)* POLE ______ ARM ______

GUYING: TYPE OF ANCHORS: ______ GUY SIZE AND R. B. S: ______

XII. LINE DESCRIPTION *(IF INFORMATION CAN BE ESTIMATED)*

TANGENTS ______ % LIGHT ANGLES ______ %

AVERAGE NUMBER OF LINE ANGLES PER MILE . . . . ______

MEDIUM ANGLES ______ % DEADEND AND HEAVY ANGLES ______ %

MAXIMUM DISTANCE BETWEEN FULL DEADENDS *(IN MILES)* . . . . . . ______

REA FORM 265 REV 9-79

INSTRUCTIONS FOR FILLING OUT REA FORM 265

I. GENERAL INFORMATION

BORROWER - REA borrower designation.

DATE - Date when design data was completed.

LINE IDENTIFICATION - The name of the line usually expressed in terms of the line's endpoints. If the line design is a "project design data" that is to be used for several line designs, the term "project design data" should be entered.

VOLTAGE - Nominal line-to-line voltage of both transmission and underbuild distribution circuit in kV. If there is no underbuild, fill in N.A. (not appropriate).

LENGTH - Self-explanatory.

TYPE OF TANGENT STRUCTURE - Give REA designation for tangent structure type used. For example, "TH-10". If the structure is not a standard REA structure, the word "special" should be filled in.

BASE POLE - The height and class of pole used most widely in line.

DESIGNED BY - Individual and/or firm doing the designing.

II. CONDUCTOR DATA

SIZE - For conductors, size in AWG numbers or kcmil. For steel wire, diameter in inches.

STRANDING - Number of strands. For ACSR conductor, give aluminum first, steel second. For example: 26/7.

MATERIAL - Indicate conductor or wire type. For example, ACSR, 6201; or EHS (extra high strength steel).

DIAMETER - Diameter of conductor in inches.

WEIGHT - Weight per foot of bare conductor.

RATED STRENGTH - Standard rated strength of conductor.

III. DESIGN LOADS

NESC LOADING DISTRICT - Indicate the National Electrical Safety Code loading district on which design is based. Use "H" for heavy, "M" for medium, and "L" for light loading district.

a. ICE - radial inches of ice on conductor for loading district specified.
b. WIND - wind force in pounds assumed to be blowing on ice covered conductor for loading district specified.
c. CONSTANT "K" - constant from NESC to be added to resultant of horizontal and vertical load (at standard loading district condition) for determining conductor sags and tensions.

HEAVY ICE - (no wind - in.) - Radial thickness of ice in inches on conductor of heavy icing condition for which line is designed (if any).

HIGH WIND - (no ice - psf) - The high wind value in pounds per square foot for which the line is designed.

OTHER - Other special load conditions, if any.

LOADING TABLE - Conductor or wire loads in pounds per linear foot for conditions indicated at left.

IV. SAG & TENSION DATA

SPANS - AVG., MAX., and RULING - Self-explanatory.

SOURCE OF SAG-TENSION DATA - Self-explanatory.

TENSION TABLE - Initial and final tension values in percent of rated strength at loading conditions indicated on the left should be given. In those boxes where there is a dotted line in the center, the specified tension limiting values* (in percent) should be given above the line and the actual resulting tension value (in percent) given below. For all other boxes the tension value should be the actual resulting value (in percent). The details of loading condition should be filled in on the left as follows:

a. UNLOADED (0^o, 15^o, 30^o) - Indicate appropriate temperature. Heavy loading district will be 0^oF, medium, 15^oF, and light, 30^oF.
b. NESC LOADED (0^o, 15^o, 30^o) - Specify appropriate temperature. Use same value as UNLOADED.
c. MAXIMUM ICE - Use the same maximum radial ice as indicated in the DESIGN LOAD section.
d. HIGH WIND - Use same value as in DESIGN LOAD section above.
e. UNLOADED LOW TEMPERATURE - Specify lowest temperature that can be expected to occur every winter.

SAG TABLE - Specify initial and/or final sags in feet for conditions indicated. Specify maximum conductor operation temperature (167^oF recommended minimum) in appropriate box on the left. Sags for the overhead ground wire and underbuild conductors are for a temperature of 120^oF.

*When sag and tension calculations are done, tension limits are usually specified at several conditions. However, usually only one of the conditions will control resulting in tensions at the other conditions to be lower than the limit.

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT - Specify maximum sag condition at which minimum clearances are to be maintained. Generally, it will be at the high temperature condition (167°F recommended minimum) but it may be possible for the sag at NESC loading (H, M, L) to be the controlling case.

CLEARANCE TABLE - Indicate clearance which will be used for plan and profile and design. Extra boxes are for special situations.

VI. RIGHT-OF-WAY WIDTH

Indicate width value used. If more than one value is used, give largest and smallest value.

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING - Indicate if conductor galloping has ever occurred in the area and how often it can be expected.

HISTORY OF AEOLIAN VIBRATION - Indicate whether or not the line is in an area prone to aeolian vibration.

a. TYPE OF VIBRATION DAMPERS USED (if any) - Self-explanatory.
b. TYPE OF ARMOR RODS USED (if any) - Indicate whether standard armor rods, cushioned suspension units or nothing is used.

VIII. INSULATION

NUMBER OF THUNDERSTORM DAYS/YEAR - Self-explanatory.

ELEVATION ABOVE SEA LEVEL (min., max., ft.) - Give the altitude in feet above sea level of the minimum and maximum elevation points of the line.

CONTAMINATION EXPECTED? - Indicate contamination problems which may effect the performance of the insulation. The following are recommended terms: None, Light, Medium, Heavy, Sea Coast Area.

MAXIMUM ESTIMATED FOOTING RESISTANCE - The estimated maximum electrical footing resistance (in ohms) expected to be encountered along the length of the line. Where the footing resistance is high, the value to which the footing resistance will be reduced by using special measures should be indicated by putting this second value in parentheses. For example, 70(20)Ω.

SHIELD ANGLE - If the basic tangent structure being used is not a standard REA structure, its shield angle should be given.

INSULATION TABLE - For the structure type indicated the structure numerical designation, and the number of suspension bells should be given. If post insulators are used instead of suspension, the word "post" or "pin" should be put in the second column. The

60 Hz dry flashover value for the entire string of insulators (or post) should be given. The column "insulator size" should contain the diameter and length of the insulator. For suspension bells, the M&E strength should be given. For post insulator, the ultimate cantilever strength should be entered.

IX. INSULATOR SWING

CRITERIA - Self-explanatory.

INSULATOR SWING TABLE - For the primary structures used in the line and the number of insulators used, the insulator swing angles under the 6 pound minimum condition, the high wind condition and under the no wind condition should be given. Angles measured from a vertical through the point of insulator string suspension away from structure should be indicated by following them with an asterisk (*).

X. ENVIRONMENTAL & METEOROLOGICAL DATA

TEMPERATURE - The minimum, maximum, and average yearly low temperatures recorded in the area of the line should be given.

MAXIMUM HEIGHT OF SNOW ON GROUND UNDER CONDUCTOR (ft.) - Self-explanatory.

CORROSIVENESS OF ATMOSPHERE - Indicate corrosiveness of the atmosphere by severe, moderate, or light.

EXTREME WIND VELOCITIES - The annual extreme wind with mean recurrence intervals of 10, 50, and 100 years.

DESCRIBE TERRAIN & CHARACTER OF SOIL - A brief description should be given as to whether the terrain is flat, hilly, rolling piedmont, or mountainous. Indicate whether the soil firmness is good, average, or poor. Give approximate depth of ground water table. Describe corrosiveness of soil.

XI. STRUCTURE DATA

SPECIES WOOD - Self-explanatory.

DESIGNATED BENDING FIBER STRESS (psi) - Self-explanatory.

STRUCTURE TABLE - The various maximum span values should be given for the base pole and structure configuration. Values should also be given for other pole heights, classes or bracing and configurations that are expected to be commonly used.

a. LEVEL GROUND SPAN - Maximum span for height of pole, limited by clearance to ground only.
b. MAXIMUM HORIZONTAL SPAN LIMITED BY STRUCTURE STRENGTH - For single pole structures, this is the maximum span as limited

by pole strength. For H-frame structures, the effect of the bracing must be included. If vertical post insulators are used, their maximum horizontal span value should be included if it is less than that of the rest of the structure, and should be indicated as such by placing the term "ins" after the value. If underbuild is to be used on the line, its effect should be included.

c. MAXIMUM VERTICAL SPAN LIMITED BY STRUCTURE STRENGTH - The maximum vertical span limited by either crossarm strength, crossarm brace strength, or horizontal post insulator strength. If horizontal post insulators are the limiting factor, the term "ins" should be placed after the span value. If the structure is such that the maximum horizontal span effects the maximum vertical span, the assumed maximum horizontal span should be the value shown in the "maximum horizontal span" box.

d. MAXIMUM HORIZONTAL SPAN LIMITED BY CONDUCTOR SEPARATION - Maximum span value using Equation VI-1 (VI-2) in text.

e. MAXIMUM SPAN LIMITED BY UNDERBUILD - Give the maximum span limited by separation between underbuild conductors or between underbuild and transmission conductors, whichever is more limited.

f. MAXIMUM SPAN LIMITED BY GALLOPING - Give the maximum span that can be allowed before galloping ellipses touch.

EMBEDMENT DEPTH - Indicate the pole embedment depth used. If the standard values are used, indicate "standard"; if the other values are used, indicate by how much they differ from the standard value. For example, std + 2'.

PRESERVATIVE - Type and retention level of preservative.

GUYING - Indicate whether log, screw or other anchors are used and the predominant anchor capacity. For example, Log, 8,000/16,000 lbs. The diameter, type and rated breaking strength (rbs) of the guy strand should be given.

XII. LINE DESCRIPTION

For the respective structure types, indicate the percentage of the total number of structures used. Calculate the average number of line angles per mile and give the maximum distance in miles between full deadends*.

*Note: "Full" deadends refer to strain type structures that are designed to remain standing if all conductors and overhead ground wires are cut on either side of the structure.

NOTES

USDA—REA

TRANSMISSION LINE DESIGN DATA SUMMARY

SAMPLE

I. GENERAL INFORMATION

BORROWER: XYZ Cooperative			DATE: 8/14/80
LINE IDENTIFICATION: Springfield - Center City			
VOLTAGE		LENGTH *(Miles)*	
TRANSMISSION: 115 kV	UNDERBUILD: NA kV	TRANSMISSION: 29.7 Mi	UNDERBUILD: NA Mi
TYPE OF TANGENT STRUCTURE: TH1-AAX		BASE POLE: 70 Ht 3 Cl	
DESIGNED BY: GH&B Consultants			

II. CONDUCTOR DATA

	TRANSMISSION	OHGW	UNDERBUILD	COMMON NEUTRAL
SIZE *(kcmil or IN.)*	477	3/8		
STRANDING	26/7	7		
MATERIAL	ACSR	HSS		
DIAMETER *(IN.)*	.858	.360		
WEIGHT *(LB/FT.)*	.6570	.2730		
RATED STRENGTH *(LBS)*	19,500	10,800		

III. DESIGN LOADS

		TRANSMISSION *(LBS/FT)*	OHGW *(LBS/FT)*	UNDERBUILD *(LBS/FT)*	COMM. NEUTRAL *(LBS/FT)*
NESC: H LDG. DISTRICT					
a. ICE: ½ IN	Vertical	1.5014	.8077		
b. WIND ON ICED CONDUCTOR 4 PSF	Transverse	.6193	.4533		
c. CONSTANT K: .30	Resultant + K	1.9241	1.2262	NONE	
HEAVY ICE *(NO WIND)* 1 IN	Vertical	2.967	1.9642		
HIGH WIND *(NO ICE)* 16 PSF	Transverse	1.1440	.4800		
OTHER					

IV. SAG & TENSION DATA

SPANS AVERAGE *(EST.)* 763 FT. MAXIMUM *(EST.)* 1000 FT. RULING *(EST.)* 800 FT.

SOURCE OF SAG–TENSION DATA:

TENSIONS *(% RATED STRENGTH)*		TRANSMISSION Initial	TRANSMISSION Final	OHGW Initial	OHGW Final	UNDERBUILD Initial	UNDERBUILD Final	COMMON NEUTRAL Initial	COMMON NEUTRAL Final
NESC:									
a. UNLOADED (0° 15° 30°)		20	18	25	25				
	0 °F	20	17.7	25	20				
b. LOADED (0° 15° 30°)		40		50					
	0 °F	38.2		45.2					
MAXIMUM ICE 1"	32 °F	61.3		53.6					
HIGH WIND *(NO ICE)*	30 °F	36.3		19					
UNLOADED LOW TEMPERATURE	-30 °F	22.4		26.1					
SAGS *(FT)*									
NESC DISTRICT LOADED	0 °F		15.3		10.0				
UNLOADED HIGH TEMP. *(120° FOR OHGW & U.B.)*	167 °F		21.51		13.1				
MAXIMUM ICE	32 °F		23.4		16.6				
LOADED ½" ICE, NO WIND	32 °F		15.4		10.1				

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT: 167°F

CLEARANCES IN FEET	RAILROADS	HIGHWAY	CULTIVATED FIELDS			ADD. ALLOW. FOR TEMPLATE
TRANSMISSION	31.7	23.7	23.7			+1
UNDERBUILD						

VI. RIGHT OF WAY

WIDTH: 100 FT. *(MIN.)* 100 FT. *(MAX.)*

REA FORM 265 REV 9-79

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING: Has occurred in area; can be severe.

HISTORY OF AEOLIAN VIBRATION: Little problem.

a. TYPE OF VIBRATION DAMPERS USED (IF ANY): None.

b. TYPE OF ARMOR RODS USED (IF ANY): Standard Armor Rods.

VIII. INSULATION

NO. OF THUNDERSTORM DAYS/YR 50 ELEV. ABOVE SEA LEVEL (MIN, MAX, FT) 2000;3200

CONTAMINATION EXPECTED? no MAX. EST. FOOTING RESISTANCE 20 Ω SHIELD ANGLE ____ °

STRUCTURE TYPE	STRUCTURE DESIGNATION	NO. OF BELLS PIN OR POST	60 HZ DRY FLASHOVER	INSULATOR SIZE	M & E RATING OR CANTILEVER STR.	OTHER
TANGENT	TH-1AAX	7	435	5-3/4"x10"	20,000	
ANGLE	TH-4A	8	485	5-3/4"x10"	20,000	
STRAIN STRUCTURE	TH-5A	9	540	5-3/4"x10"	20,000	

IX. INSULATOR SWING

CRITERIA: (1) 6 PSF ON BARE CONDUCTOR AT 0 °F (6 psf MIN) FOR 26 IN. CLEARANCE

(2) 12 PSF HIGH WIND ON BARE CONDUCTOR AT 30 °F FOR 10 IN. CLEARANCE

ALLOWABLE ANGLE OF SWING:

		ANGLE IN DEGREES			
STRUCTURE TYPE	NO. INSULATORS	6 PSF MIN. WIND (1)	HIGH WIND (2)	NO WIND	OTHER
TH-1AAX	7	55.5	78.1	22.1	
TH-4A	8	27.4*	8.1*	51.2*	

X. ENVIRONMENTAL AND METEORLOGICAL DATA

TEMPERATURE: MIN -30 °F MAX 121 °F

AVERAGE YEARLY LOW -5 °F

EXTREME WIND VELOCITIES (MPH): 10 YR 68 50 YR 79 100 YR 83

MAXIMUM HEIGHT OF SNOW ON THE GROUND UNDER THE CONDUCTOR (FT) 1.5

CORROSIVENESS OF ATMOSPHERE: light

DESCRIBE TERRAIN AND CHARACTERISTICS OF SOIL

Rolling hills and cultivated land. Soil is a sand-gravel mixture.

XI. STRUCTURE DATA

SPECIES WOOD: POLE: D. fir ARM: D. fir

DESIGNATED BENDING FIBER STRESS (PSI): POLE: 8000 ARM: 7400

SPANS (FT) FOR TANGENT TYPE TH-1	BASE POLE 70 FT 3 CL	OTHER HEIGHTS/CLASSES AND BRACING 70/3Xbrace	75/2Xbrace	
LEVEL GROUND SPAN	763	763	810	
MAX. HORIZON. SPAN LIMITED BY STRUCTURE STRENGTH	510	753	884	
MAX. VERTICAL SPAN LIMITED BY STRUCTURE STRENGTH	1720	1720	1720	
MAX. HORIZONTAL SPAN LIMITED BY COND. SEPARATION	1013	1013	1013	
MAX. SPAN LIMITED BY UNDERBUILD	NA			
MAX. SPAN LIMITED BY GALLOPING	625	625	625	

ENBEDMENT DEPTH: Standard

PRESERVATIVE: (Type & Retention) POLE Penta (Heavy) ARM Penta (Heavy)

GUYING: TYPE OF ANCHORS: Log 8000 GUY SIZE AND R. B. S: 3/8 HSS 10,800

XII. LINE DESCRIPTION (IF INFORMATION CAN BE ESTIMATED)

TANGENTS 86 % LIGHT ANGLES 8 %

MEDIUM ANGLES 1 % DEADEND AND HEAVY ANGLES 4 %

AVERAGE NUMBER OF LINE ANGLES PER MILE .... .63

MAXIMUM DISTANCE BETWEEN FULL DEADENDS (IN MILES) 10

SUGGESTED OUTLINE FOR DESIGN DATA SUMMARY BOOK

Given below is a suggested outline for a Design Data Summary Book. The outline is primarily intended for lines of 230 kV and below that follow REA design standards. Generally, a well prepared design data book should include all the material indicated below. However, some judgment should be used in submitting more or less information as deemed appropriate.

The starred (*) items indicate that a sample calculation and a table or results should be provided. If computer programs are utilized for calculations, the formulas and procedures used in the program should be included.

I. Transmission Line Design Data Summary (REA Form 265)

II. General Information

   A. Line identification, description and role in system

   B. Description of terrain and weather

   C. Design Criteria and Applicable Codes and Standards

   D. Selection of Conductor and OHGW

      1. Selection of Conductor and OHGW type

      2. Selection of Conductor and OHGW size-
         Economic Conductor Analysis

   E. Determination of Maximum Conductor Temperature (this section is only needed if a temperature other than 75°C (167°F) is selected).

   F. Selection of Structure Type and average height

      1. Economic evaluation of alternate structures

      2. Selection of optimum structure height

   G. Construction Cost Estimate

III. Supporting Calculations to Part I

A. Conductor sag and tension tables (Computer Printout)

B. OHGW sag and tension values (Computer Printout)

C. Vertical and Horizontal Clearances and ROW Width

D. Insulation Considerations

E. Level Ground Span*

F. Maximum span limited by conductor separation

1. Horizontal Separation*

2. Vertical and Diagonal Separation*

G. Maximum span limited by Underbuild (if applicable)

H. Galloping Analysis

I. Unguyed Structure Strength Calculations

1. Maximum horizontal span limited by pole strength, 'X' bracing, pole* (including post insulators; if applicable)

2. Maximum vertical span calculations* (including post insulators; if applicable)

3. Hardware limitations

4. Insulator strength requirements

J. Guyed Structure Calculations

1. Minimum spacing of anchors*

2. Guys and Anchor Calculations and Application Charts*

3. Maximum Axial Loads for guyed poles*

4. Arrangement of Guys and Anchors and Application Guides*

K. Sample insulator swing calculations and application charts for all structures*

L. Diagrams for all non-standard structures or assemblies anticipated for use on the line

M. Sag-Clearance Template (printed on transparent material)

APPENDIX B

CONDUCTOR TABLES

CONDUCTOR MECHANICAL LOADING TABLES

The tables that follow give horizontal, vertical, and resultant vector loads on conductors and overhead ground wires under standard NESC loading district conditions, high wind conditions, and heavy ice conditions. Also given are conductor strengths and conductor swing angles under an assumed six pound wind.

ACSR Conductors
NESC District Loadings

NAME	SIZE	STRAND	LIGHT .00"ICE 9 LB WIND K=.05 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	MEDIUM .25"ICE 4 LB WIND K=.20 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	HEAVY .50"ICE 4 LB WIND K=.30 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.
RAVEN	1/0	6/1	.1452	.2985	.3819	.3467	.2993	.6580	.7036	.4660	1.1439	4380	.398
QUAIL	2/0	6/1	.1831	.3353	.4320	.3998	.3157	.7094	.7719	.4823	1.2102	5310	.447
PIGEON	3/0	6/1	.2309	.3765	.4917	.4647	.3340	.7723	.8539	.5007	1.2899	6620	.502
PENGUIN	4/0	6/1	.2911	.4223	.5629	.5439	.3543	.8491	.9520	.5210	1.3853	8350	.563
WAXWING	266.8	18/1	.2894	.4568	.5907	.5565	.3697	.8681	.9789	.5363	1.4162	6880	.609
PARTRIDGE	266.8	26/7	.3673	.4815	.6556	.6446	.3807	.9486	1.0774	.5473	1.5084	11300	.642
MERLIN	336.4	18/1	.3653	.5130	.6798	.6557	.3947	.9653	1.1015	.5613	1.5363	8680	.684
LINNET	336.4	26/7	.4630	.5408	.7619	.7649	.4070	1.0664	1.2222	.5737	1.6501	14100	.721
ORIOLE	336.4	30/7	.5271	.5558	.8160	.8352	.4137	1.1320	1.2987	.5803	1.7225	17300	.741
CHICKADEE	397.5	18/1	.4316	.5573	.7548	.7403	.4143	1.0484	1.2045	.5810	1.6373	9940	.743
IBIS	397.5	26/7	.5469	.5873	.8525	.8680	.4277	1.1677	1.3446	.5943	1.7701	16300	.783
LARK	397.5	30/7	.6228	.6045	.9179	.9511	.4353	1.2460	1.4348	.6020	1.8560	20300	.806
PELICAN	477.	18/1	.5180	.6105	.8506	.8488	.4380	1.1551	1.3350	.6047	1.7656	11800	.814
FLICKER	477.	24/7	.6145	.6345	.9333	.9552	.4487	1.2554	1.4514	.6153	1.8765	17200	.846
HAWK	477.	26/7	.6570	.6435	.9696	1.0015	.4527	1.2990	1.5014	.6193	1.9241	19500	.858
HEN	477.	30/7	.7470	.6623	1.0483	1.0992	.4610	1.3920	1.6069	.6277	2.0251	23800	.883
OSPREY	556.5	18/1	.6040	.6593	.9441	.9550	.4597	1.2599	1.4614	.6263	1.8900	13700	.879
PARAKEET	556.5	24/7	.7170	.6855	1.0420	1.0789	.4713	1.3773	1.5962	.6380	2.0190	19800	.914
DOVE	556.5	26/7	.7660	.6953	1.0845	1.1319	.4757	1.4278	1.6533	.6423	2.0737	22600	.927
EAGLE	556.5	30/7	.8720	.7148	1.1775	1.2460	.4843	1.5368	1.7754	.6510	2.1910	27800	.953
KINGBIRD	636.	18/1	.6910	.7050	1.0372	1.0610	.4800	1.3645	1.5064	.6467	2.0131	15700	.940
ROOK	636.	24/7	.8190	.7328	1.1489	1.2005	.4923	1.4975	1.7374	.6590	2.1581	22000	.977
GROSBEAK	636.	26/7	.8750	.7425	1.1976	1.2605	.4967	1.5548	1.8014	.6633	2.2197	25200	.990
EGRET	636.	30/19	.9880	.7643	1.2991	1.3825	.5063	1.6723	1.9325	.6730	2.3463	31500	1.019
CUCKOO	795.	24/7	1.0240	.8190	1.3612	1.4412	.5307	1.7358	2.0139	.6973	2.4312	27900	1.092
DRAKE	795.	26/7	1.0940	.8310	1.4238	1.5162	.5360	1.8081	2.0938	.7027	2.5086	31500	1.108
MALLARD	795.	30/19	1.2350	.8550	1.5521	1.6671	.5467	1.9545	2.2547	.7133	2.6649	38400	1.140
TERN	795.	45/7	.8960	.7773	1.2493	1.3042	.5210	1.6044	1.8678	.6877	2.2904	22100	1.063
CONDOR	795.	54/7	1.0240	.8198	1.3617	1.4415	.5310	1.7362	2.0145	.6977	2.4319	28200	1.093
RAIL	954.	45/7	1.0750	.8737	1.4353	1.5149	.5550	1.8134	2.1103	.7217	2.5302	25900	1.165
CARDINAL	954.	54/7	1.2290	.8970	1.5715	1.6785	.5653	1.9712	2.2835	.7320	2.6980	33800	1.196
BUNTING	1192.5	45/7	1.3440	.9765	1.7113	1.8265	.6007	2.1227	2.4644	.7673	2.8811	32000	1.302
GRACKLE	1192.5	54/19	1.5330	1.0035	1.8822	2.0267	.6127	2.3173	2.6758	.7793	3.0870	41900	1.338
BITTERN	1272.	45/7	1.4340	1.0088	1.8033	1.9299	.6150	2.2255	2.5812	.7817	2.9969	34100	1.345
PHEASANT	1272.	54/19	1.6350	1.0365	1.9859	2.1424	.6273	2.4323	2.8052	.7940	3.2154	43600	1.382
LAPWING	1590.	45/7	1.7920	1.1265	2.1667	2.3367	.6673	2.6301	3.0368	.8340	3.4492	42200	1.502
FALCON	1590.	54/19	2.0440	1.1588	2.3996	2.6020	.6817	2.8898	3.3155	.8483	3.7223	54500	1.545
CHUKAR	1780.	84/19	2.0740	1.2015	2.4469	2.6498	.7007	2.9408	3.3810	.8673	3.7904	51000	1.602
BLUEBIRD	2156.	84/19	2.5110	1.3215	2.8875	3.1365	.7540	3.4259	3.9175	.9207	4.3242	60300	1.762

ACSR
High Wind Ldg.

ACSR Conductors
High Wind Loading

NAME	SIZE	STRAND	VERT. LB/FT	13 LBS TRANS. LB/FT	13 LBS TOTAL LB/FT	16 LBS TRANS. LB/FT	16 LBS TOTAL LB/FT	21 LBS TRANS. LB/FT	21 LBS TOTAL LB/FT	26 LBS TRANS. LB/FT	26 LBS TOTAL LB/FT	31 LBS TRANS. LB/FT	31 LBS TOTAL LB/FT	6 LBS TRANS. LB/FT	6 LBS SWING ANGLE
RAVEN	1/0	6/1	.1452	.4312	.4550	.5307	.5502	.6965	.7115	.8623	.8745	1.0282	1.0384	.1990	53.88
QUAIL	2/0	6/1	.1831	.4843	.5177	.5960	.6235	.7823	.8034	.9685	.9857	1.1548	1.1692	.2235	50.67
PIGEON	3/0	6/1	.2309	.5438	.5908	.6693	.7080	.8785	.9083	1.0877	1.1119	1.2968	1.3172	.2510	47.39
PENGUIN	4/0	6/1	.2911	.6099	.6758	.7507	.8051	.9853	1.0274	1.2198	1.2541	1.4544	1.4833	.2815	44.04
WAXWING	266.8	18/1	.2894	.6598	.7204	.8120	.8620	1.0658	1.1043	1.3195	1.3509	1.5733	1.5996	.3045	46.46
PARTRIDGE	266.8	26/7	.3673	.6955	.7865	.8560	.9315	1.1235	1.1820	1.3910	1.4387	1.6585	1.6987	.3210	41.15
MERLIN	336.4	18/1	.3653	.7410	.8262	.9120	.9824	1.1970	1.2515	1.4820	1.5264	1.7670	1.8044	.3420	43.11
LINNET	336.4	26/7	.4630	.7811	.9080	.9613	1.0670	1.2618	1.3440	1.5622	1.6293	1.8626	1.9193	.3605	37.90
ORIOLE	336.4	30/7	.5271	.8028	.9603	.9880	1.1198	1.2968	1.3998	1.6055	1.6898	1.9143	1.9655	.3705	35.10
CHICKADEE	397.5	18/1	.4316	.8049	.9133	.9907	1.0806	1.3003	1.3700	1.6098	1.6667	1.9194	1.9673	.3715	40.72
IBIS	397.5	26/7	.5469	.8483	1.0093	1.0440	1.1786	1.3703	1.4754	1.6965	1.7825	2.0228	2.0954	.3915	35.60
LARK	397.5	30/7	.6228	.8732	1.0725	1.0747	1.2421	1.4105	1.5419	1.7463	1.8541	2.0822	2.1733	.4030	32.91
PELICAN	477.	18/1	.5180	.8818	1.0227	1.0853	1.2026	1.4245	1.5158	1.7637	1.8382	2.1028	2.1657	.4070	38.16
FLICKER	477.	24/7	.6145	.9165	1.1034	1.1280	1.2845	1.4805	1.6030	1.8330	1.9333	2.1855	2.2702	.4230	34.54
HAWK	477.	26/7	.6570	.9295	1.1383	1.1440	1.3192	1.5015	1.6389	1.8590	1.9717	2.2165	2.3118	.4290	33.14
HEN	477.	30/7	.7470	.9566	1.2137	1.1773	1.3943	1.5453	1.7163	1.9132	2.0538	2.2811	2.4003	.4415	30.58
OSPREY	556.5	18/1	.6040	.9523	1.1277	1.1720	1.3185	1.5383	1.6526	1.9045	1.9980	2.2708	2.3497	.4395	36.04
PARAKEET	556.5	24/7	.7170	.9902	1.2225	1.2187	1.4139	1.5995	1.7529	1.9803	2.1061	2.3612	2.4676	.4570	32.51
DOVE	556.5	26/7	.7660	1.0043	1.2630	1.2360	1.4541	1.6223	1.7940	2.0085	2.1496	2.3948	2.5143	.4635	31.18
EAGLE	556.5	30/7	.8720	1.0324	1.3514	1.2707	1.5411	1.6678	1.8820	2.0648	2.2414	2.4619	2.6118	.4765	28.65
KINGBIRD	636.	18/1	.6910	1.0183	1.2306	1.2533	1.4312	1.6450	1.7842	2.0367	2.1507	2.4283	2.5247	.4700	34.22
ROOK	636.	24/7	.8190	1.0584	1.3383	1.3027	1.5387	1.7098	1.8958	2.1168	2.2697	2.5239	2.6535	.4885	30.81
GROSBEAK	636.	26/7	.8750	1.0725	1.3842	1.3200	1.5837	1.7325	1.9409	2.1450	2.3166	2.5575	2.7030	.4950	29.50
EGRET	636.	30/19	.9880	1.1039	1.4815	1.3587	1.6799	1.7833	2.0387	2.2078	2.4188	2.6324	2.8117	.5095	27.28
CUCKOO	795.	24/7	1.0240	1.1830	1.5646	1.4560	1.7800	1.9110	2.1681	2.3660	2.5781	2.8210	3.0011	.5460	28.07
DRAKE	795.	26/7	1.0940	1.2003	1.6241	1.4773	1.8383	1.9390	2.2263	2.4007	2.6382	2.8623	3.0643	.5540	26.86
MALLARD	795.	30/19	1.2350	1.2350	1.7466	1.5200	1.9585	1.9950	2.3463	2.4700	2.7615	2.9450	3.1935	.5700	24.78
TERN	795.	45/7	.8960	1.1516	1.4591	1.4173	1.6768	1.8603	2.0648	2.3032	2.4713	2.7461	2.8886	.5315	30.68
CONDOR	795.	54/7	1.0240	1.1841	1.5654	1.4573	1.7811	1.9128	2.1696	2.3682	2.5801	2.8236	3.0035	.5465	28.09
RAIL	954.	45/7	1.0750	1.2621	1.6579	1.5533	1.8890	2.0388	2.3048	2.5242	2.7435	3.0096	3.1958	.5825	28.45
CARDINAL	954.	54/7	1.2290	1.2957	1.7858	1.5947	2.0133	2.0930	2.4272	2.5913	2.8680	3.0897	3.3251	.5980	25.95
BUNTING	1192.5	45/7	1.3440	1.4105	1.9483	1.7360	2.1955	2.2785	2.6454	2.8210	3.1248	3.3635	3.6221	.6510	25.84
GRACKLE	1192.5	54/19	1.5330	1.4495	2.1098	1.7840	2.3522	2.3415	2.7987	2.8990	3.2794	3.4565	3.7812	.6690	23.58
BITTERN	1272.	45/7	1.4340	1.4571	2.0444	1.7933	2.2962	2.3538	2.7562	2.9142	3.2479	3.4746	3.7589	.6725	25.13
PHEASANT	1272.	54/19	1.6350	1.4972	2.2169	1.8427	2.4635	2.4185	2.9193	2.9943	3.4116	3.5702	3.9267	.6910	22.91
LAPWING	1590.	45/7	1.7920	1.6272	2.4205	2.0027	2.6874	2.6285	3.1812	3.2543	3.7151	3.8802	4.2740	.7510	22.74
FALCON	1590.	54/19	2.0440	1.6738	2.6419	2.0600	2.9020	2.7038	3.3894	3.3475	3.9222	3.9913	4.4842	.7725	20.70
CHUKAR	1780.	84/19	2.0740	1.7355	2.7043	2.1360	2.9772	2.8035	3.4873	3.4710	4.0434	4.1385	4.6291	.8010	21.12
BLUEBIRD	2156.	84/19	2.5110	1.9088	3.1542	2.3493	3.4387	3.0835	3.9766	3.8177	4.5694	4.5518	5.1985	.8810	19.33

ACSR Conductors
Miscellaneous Loadings

NAME	SIZE	STRAND	1.0" ICE VERT. LB/FT	1.0" ICE TRANS. LB/FT	1.5" ICE VERT. LB/FT	1.5" ICE TRANS. LB/FT
RAVEN	1/0	6/1	1.8837	.1998	3.6856	.2832
QUAIL	2/0	6/1	1.9825	.2039	3.8149	.2873
PIGEON	3/0	6/1	2.0987	.2085	3.9653	.2918
PENGUIN	4/0	6/1	2.2348	.2136	4.1393	.2969
WAXWING	266.8	18/1	2.2903	.2174	4.2234	.3008
PARTRIDGE	266.8	26/7	2.4092	.2202	4.3628	.3035
MERLIN	336.4	18/1	2.4594	.2237	4.4392	.3070
LINNET	336.4	26/7	2.6031	.2268	4.6059	.3101
ORIOLE	336.4	30/7	2.6921	.2284	4.7073	.3118
CHICKADEE	397.5	18/1	2.5991	.2286	4.6155	.3119
IRIS	397.5	26/7	2.7641	.2319	4.8054	.3153
LARK	397.5	30/7	2.8686	.2338	4.9242	.3172
PELICAN	477.	18/1	2.7738	.2345	4.8343	.3178
FLICKER	477.	24/7	2.9101	.2372	4.9905	.3205
HAWK	477.	26/7	2.9675	.2382	5.0554	.3215
HEN	477.	30/7	3.0886	.2403	5.1921	.3236
OSPREY	556.5	18/1	2.9406	.2399	5.0416	.3233
PARAKEET	556.5	24/7	3.0971	.2428	5.2199	.3262
DOVE	556.5	26/7	3.1623	.2439	5.2931	.3273
EAGLE	556.5	30/7	3.3006	.2461	5.4476	.3294
KINGBIRD	636.	18/1	3.1035	.2450	5.2424	.3283
ROOK	636.	24/7	3.2775	.2481	5.4394	.3314
GROSBEAK	636.	26/7	3.3497	.2492	5.5196	.3325
EGRET	636.	30/19	3.4987	.2516	5.6867	.3349
CUCKOO	795.	24/7	3.6255	.2577	5.8589	.3410
DRAKE	795.	26/7	3.7154	.2590	5.9588	.3423
MALLARD	795.	30/19	3.8962	.2617	6.1594	.3450
TERN	795.	45/7	3.4614	.2553	5.6768	.3386
CONDOR	795.	54/7	3.6267	.2578	5.8608	.3411
RAIL	954.	45/7	3.7673	.2638	6.0461	.3471
CARDINAL	954.	54/7	3.9598	.2663	6.2579	.3497
BUNTING	1192.5	45/7	4.2066	.2752	6.5706	.3585
GRACKLE	0192.5	54/19	4.4404	.2782	6.8268	.3615
BITTERN	1272.	45/7	4.3501	.2788	6.7408	.3621
PHEASANT	1272.	54/19	4.5971	.2818	7.0108	.3652
LAPWING	1590.	45/7	4.9034	.2918	7.3917	.3752
FALCON	1590.	54/19	5.2088	.2954	7.7239	.3788
CHUKAR	1780.	84/19	5.3097	.3002	7.8602	.3835
BLUEBIRD	2156.	84/19	5.9457	.3135	8.5957	.3968

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 477 kcmil 26/7 conductor covered by 1 inch of radial ice is:

$$.2382(6) = 1.4292 \text{ lb/ft.}$$

6201
NESC Dist. Ldgs.

6201 Aluminum Alloy Conductors
NESC District Loadings

NAME	SIZE	STRAND	LIGHT .00"ICE 9 LB WIND K=.05 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	MEDIUM .25"ICE 4 LB WIND K=.20 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	HEAVY .50"ICE 4 LB WIND K=.30 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.
AZUSA	123.3	7	.1157	.2985	.3701	.3172	.2993	.6361	.6741	.4660	1.1195	4460	.398
ANAHEIM	155.4	7	.1459	.3353	.4156	.3626	.3157	.6807	.7347	.4823	1.1789	5390	.447
AMHERST	195.7	7	.1837	.3765	.4689	.4175	.3340	.7347	.8067	.5007	1.2495	6790	.502
ALLIANCE	246.9	7	.2318	.4223	.5317	.4846	.3543	.8003	.8927	.5210	1.3337	8560	.563
BUTTE	312.8	19	.2936	.4815	.6140	.5709	.3807	.8862	1.0037	.5473	1.4432	11000	.642
CANTON	394.5	19	.3703	.5408	.7054	.6722	.4070	.9858	1.1295	.5737	1.5668	13300	.721
CAIRO	465.4	19	.4369	.5873	.7819	.7580	.4277	1.0704	1.2346	.5943	1.6702	15600	.783
DARIEN	559.5	19	.5252	.6435	.8806	.8697	.4527	1.1804	1.3696	.6193	1.8031	18800	.858
ELOIN	652.4	19	.6124	.6953	.9765	.9783	.4757	1.2878	1.4997	.6423	1.9314	21900	.927
FLINT	740.8	37	.6754	.7433	1.0543	1.0612	.4970	1.3718	1.6025	.6637	2.0345	24400	.991
GREELEY	927.2	37	.8704	.8310	1.2534	1.2926	.5360	1.5993	1.8702	.7027	2.2979	30500	1.108

6201 Aluminum Alloy Conductors
High Wind Loadings

NAME	SIZE	STRAND	VERT. LB/FT	13 LBS TRANS. LB/FT	13 LBS TOTAL LB/FT	16 LBS TRANS. LB/FT	16 LBS TOTAL LB/FT	21 LBS TRANS. LB/FT	21 LBS TOTAL LB/FT	26 LBS TRANS. LB/FT	26 LBS TOTAL LB/FT	31 LBS TRANS. LB/FT	31 LBS TOTAL LB/FT	6 LBS TRANS. LB/FT	6 LBS SWING ANGLE
AZUSA	123.3	7	.1157	.4312	.4464	.5307	.5431	.6965	.7060	.8623	.8701	1.0282	1.0347	.1990	59.83
ANAHEIM	155.4	7	.1459	.4843	.5058	.5960	.6136	.7823	.7957	.9685	.9794	1.1548	1.1639	.2235	56.86
AMHERST	195.7	7	.1837	.5438	.5740	.6693	.6941	.8785	.8975	1.0877	1.1031	1.2968	1.3098	.2510	53.80
ALLIANCE	246.9	7	.2318	.6099	.6525	.7507	.7856	.9853	1.0122	1.2198	1.2417	1.4544	1.4728	.2815	50.53
BUTTE	312.8	19	.2936	.6955	.7549	.8560	.9050	1.1235	1.1612	1.3910	1.4216	1.6585	1.6843	.3210	47.55
CANTON	394.5	19	.3703	.7811	.8644	.9613	1.0302	1.2618	1.3150	1.5622	1.6055	1.8626	1.8990	.3605	44.23
CAIRO	465.4	19	.4369	.8483	.9542	1.0440	1.1317	1.3703	1.4382	1.6965	1.7519	2.0228	2.0694	.3915	41.86
DARIEN	559.5	19	.5252	.9295	1.0676	1.1440	1.2588	1.5015	1.5907	1.8590	1.9318	2.2165	2.2779	.4290	39.24
ELGIN	652.4	19	.6124	1.0043	1.1762	1.2360	1.3794	1.6223	1.7340	2.0085	2.0998	2.3948	2.4718	.4635	37.12
FLINT	740.8	37	.6754	1.0736	1.2684	1.3213	1.4839	1.7343	1.8611	2.1472	2.2509	2.5601	2.6477	.4955	36.27
GREELEY	927.2	37	.8704	1.2003	1.4827	1.4773	1.7147	1.9390	2.1254	2.4007	2.5536	2.8623	2.9917	.5540	32.48

Miscellaneous Loadings

NAME	SIZE	STRAND	1.0" ICE VERT. LB/FT	1.0" ICE TRANS. LB/FT	1.5" ICE VERT. LB/FT	1.5" ICE TRANS. LB/FT
AZUSA	123.3	7	1.8542	.1998	3.6561	.2832
ANAHEIM	155.4	7	1.9453	.2039	3.7777	.2873
AMHERST	195.7	7	2.0515	.2085	3.9181	.2918
ALLIANCE	246.9	7	2.1755	.2136	4.0800	.2969
BUTTE	312.8	19	2.3355	.2202	4.2891	.3035
CANTON	394.5	19	2.5104	.2268	4.5132	.3101
CAIRO	465.4	19	2.6541	.2319	4.6954	.3153
DARIEN	559.5	19	2.8357	.2382	4.9236	.3215
ELGIN	652.4	19	3.0087	.2439	5.1395	.3273
FLINT	740.8	37	3.1513	.2493	5.3219	.3326
GREELEY	927.2	37	3.4918	.2590	5.7352	.3423

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 559.5 kcmil conductor covered by 1 inch of radial ice is:

$$.2382(6) = 1.4292 \text{ lb/ft}.$$

1350 (EC)
NESC Dist. Ldgs.

1350 (EC) Conductors
NESC District Loadings

			LIGHT			MEDIUM			HEAVY				
			.00"ICE 9 LB WIND K=.05			.25"ICE 4 LB WIND K=.20			.50"ICE 4 LB WIND K=.30				
NAME	SIZE	STRAND	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.
POPPY	1/0	7	.0991	.2760	.3433	.2912	.2893	.6105	.6388	.4560	1.0849	1990	.368
ASTRE	2/0	7	.1249	.3105	.3847	.3313	.3047	.6501	.6932	.4713	1.1383	2510	.414
PHLOX	3/0	7	.1575	.3480	.4320	.3795	.3213	.6972	.7569	.4880	1.2006	3040	.464
OXLIP	4/0	7	.1986	.3915	.4890	.4386	.3407	.7554	.8341	.5073	1.2762	3830	.522
VALERIAN	250.	19	.2347	.4305	.5403	.4909	.3580	.8076	.9025	.5247	1.3439	4660	.574
DAISY	266.8	7	.2505	.4395	.5559	.5104	.3620	.8257	.9257	.5287	1.3661	4830	.586
LAUREL	266.8	19	.2505	.4448	.5604	.5126	.3643	.8289	.9301	.5310	1.3710	4970	.593
TULIP	336.4	19	.3158	.4995	.6410	.6006	.3887	.9154	1.0408	.5553	1.4797	6150	.666
CANNA	397.5	19	.3731	.5430	.7088	.6759	.4080	.9895	1.1342	.5747	1.5714	7110	.724
GOLDENTUFT	450.	19	.4224	.5775	.7655	.7395	.4233	1.0521	1.2121	.5900	1.6480	7890	.770
COSMOS	477.	19	.4478	.5948	.7945	.7721	.4310	1.0042	1.2518	.5977	1.6871	8360	.793
SYRINGA	477.	37	.4478	.5963	.7957	.7727	.4317	1.0051	1.2530	.5983	1.6885	8690	.795
DAHLIA	556.5	19	.5220	.6420	.8774	.8658	.4520	1.1767	1.3651	.6187	1.7988	9750	.856
MISTLETOE	556.5	37	.5220	.6435	.8786	.8665	.4527	1.1776	1.3664	.6193	1.8002	9940	.858
ORCHID	636.	37	.5970	.6885	.9613	.9601	.4727	1.2702	1.4787	.6393	1.9110	11400	.918
ARBUTUS	795.	37	.7460	.7695	1.1217	1.1427	.5087	1.4508	1.6948	.6753	2.1244	13900	1.026
LILAC	795.	61	.7460	.7710	1.1228	1.1433	.5093	1.4516	1.6961	.6760	2.1258	14300	1.028
ANEMONE	874.5	37	.8210	.8078	1.2017	1.2335	.5257	1.5409	1.8015	.6923	2.2300	15000	1.077
CROCUS	874.5	61	.8210	.8085	1.2023	1.2339	.5260	1.5413	1.8022	.6927	2.2307	15800	1.078
MAGNOLIA	954.	37	.8960	.8430	1.2802	1.3232	.5413	1.6296	1.9058	.7080	2.3330	16400	1.124
GOLDENROD	954.	61	.8960	.8445	1.2813	1.3238	.5420	1.6304	1.9070	.7087	2.3344	16900	1.126
HAWTHORN	1192.5	61	1.1190	.9435	1.5137	1.5878	.5860	1.8925	2.2121	.7527	2.6366	21100	1.258
NARCISSUS	1272.	61	1.1940	.9750	1.5915	1.6759	.6000	1.9800	2.3132	.7667	2.7369	22000	1.300

1350 (EC) Conductors
High Wind Loadings

NAME	SIZE	STRAND	VERT. LB/FT	13 LBS TRANS. LB/FT	13 LBS TOTAL LB/FT	16 LBS TRANS. LB/FT	16 LBS TOTAL LB/FT	21 LBS TRANS. LB/FT	21 LBS TOTAL LB/FT	26 LBS TRANS. LB/FT	26 LBS TOTAL LB/FT	31 LBS TRANS. LB/FT	31 LBS TOTAL LB/FT	6 LBS TRANS. LB/FT	6 LBS SWING ANGLE
POPPY	1/0	7	.0991	.3987	.4108	.4907	.5006	.6440	.6516	.7973	.8035	.9507	.9558	.1840	61.69
ASTRE	2/0	7	.1249	.4485	.4656	.5520	.5660	.7245	.7352	.8970	.9057	1.0695	1.0768	.2070	58.89
PHLOX	3/0	7	.1575	.5027	.5268	.6187	.6384	.8120	.8271	1.0053	1.0176	1.1987	1.2090	.2320	55.83
OXLIP	4/0	7	.1986	.5655	.5994	.6960	.7238	.9135	.9340	1.1310	1.1483	1.3485	1.3630	.2610	52.73
VALERIAN	250.	19	.2347	.6218	.6647	.7653	.8005	1.0045	1.0316	1.2437	1.2656	1.4828	1.5013	.2870	50.72
DAISY	266.8	7	.2505	.6348	.6825	.7813	.8205	1.0255	1.0557	1.2697	1.2941	1.5138	1.5344	.2930	49.47
LAUREL	266.8	19	.2505	.6424	.6895	.7907	.8294	1.0370	1.0676	1.2848	1.3090	1.5319	1.5523	.2965	49.81
TULIP	336.4	19	.3158	.7215	.7876	.8080	.9425	1.1655	1.2075	1.4430	1.4772	1.7205	1.7492	.3330	46.52
CANNA	397.5	19	.3731	.7843	.8686	.9653	1.0349	1.2670	1.3208	1.5687	1.6124	1.8703	1.9072	.3620	44.13
GOLDENTUFT	450.	19	.4224	.8342	.9350	1.0267	1.1102	1.3475	1.4122	1.6683	1.7210	1.9892	2.0335	.3850	42.35
COSMOS	477.	19	.4478	.8591	.9688	1.0573	1.1483	1.3878	1.4582	1.7182	1.7756	2.0486	2.0970	.3965	41.52
SYRINGA	477.	37	.4478	.8613	.9707	1.0600	1.1507	1.3913	1.4615	1.7225	1.7798	2.0530	2.1020	.3975	41.59
DAHLIA	556.5	19	.5220	.9273	1.0642	1.1413	1.2550	1.4980	1.5863	1.8547	1.9267	2.2113	2.2721	.4280	39.35
MISTLETOE	556.5	37	.5220	.9295	1.0660	1.1440	1.2575	1.5015	1.5896	1.8590	1.9309	2.2165	2.2771	.4290	39.41
ORCHID	636.	37	.5970	.9945	1.1599	1.2240	1.3618	1.6065	1.7138	1.9890	2.0767	2.3715	2.4455	.4590	37.55
ARBUTUS	795.	37	.7460	1.1115	1.3386	1.3680	1.5582	1.7955	1.9443	2.2230	2.3448	2.6505	2.7535	.5130	34.52
LILAC	795.	61	.7460	1.1137	1.3404	1.3707	1.5605	1.7990	1.9475	2.2273	2.3489	2.6557	2.7585	.5140	34.57
ANEMONE	874.5	37	.8210	1.1668	1.4267	1.4360	1.6541	1.8848	2.0558	2.3335	2.4737	2.7823	2.9009	.5385	33.26
CROCUS	874.5	61	.8210	1.1678	1.4275	1.4373	1.6553	1.8865	2.0574	2.3357	2.4758	2.7848	2.9033	.5390	33.29
MAGNOLIA	954.	37	.8960	1.2177	1.5118	1.4987	1.7461	1.9670	2.1615	2.4353	2.5949	2.9037	3.0388	.5620	32.10
GOLDENROD	954.	61	.8960	1.2198	1.5135	1.5013	1.7484	1.9705	2.1646	2.4397	2.5990	2.9088	3.0437	.5630	32.14
HAWTHORN	1192.5	61	1.1190	1.3628	1.7634	1.6773	2.0163	2.2015	2.4696	2.7257	2.9464	3.2498	3.4371	.6290	29.34
NARCISSUS	1272.	61	1.1940	1.4083	1.8464	1.7333	2.1048	2.2750	2.5693	2.8167	3.0593	3.3583	3.5643	.6500	28.56

1350 (EC)
Misc. Loadings

1350 (EC) Conductors
Miscellaneous Loadings

NAME	SIZE	STRAND	1.0" ICE VERT. LB/FT	1.0" ICE TRANS. LB/FT	1.5" ICE VERT. LB/FT	1.5" ICE TRANS. LB/FT
POPPY	1/0	7	1.8003	.1973	3.5835	.2807
ASTRE	2/0	7	1.8833	.2012	3.6951	.2845
PHLOX	3/0	7	1.9781	.2053	3.8210	.2887
OXLIP	4/0	7	2.0913	.2102	3.9703	.2935
VALERIAN	250.	19	2.1920	.2145	4.1034	.2978
DAISY	266.8	7	2.2228	.2155	4.1416	.2988
LAUREL	266.8	19	2.2315	.2161	4.1546	.2994
TULIP	336.4	19	2.3875	.2222	4.3561	.3055
CANNA	397.5	19	2.5170	.2270	4.5216	.3103
GOLDENTUFT	450.	19	2.6235	.2308	4.6567	.3142
COSMOS	477.	19	2.6775	.2328	4.7250	.3161
SYRINGA	477.	37	2.6800	.2329	4.7287	.3163
DAHLIA	556.5	19	2.8300	.2380	4.9167	.3213
MISTLETOE	556.5	37	2.8325	.2382	4.9204	.3215
ORCHID	636.	37	2.9821	.2432	5.1073	.3265
ARBUTUS	795.	37	3.2654	.2522	5.4578	.3355
LILAC	795.	61	3.2679	.2523	5.4615	.3357
ANEMONE	874.5	37	3.4038	.2564	5.6279	.3398
CROCUS	874.5	61	3.4051	.2565	5.6298	.3398
MAGNOLIA	954.	37	3.5373	.2603	5.7906	.3437
GOLDENROD	954.	61	3.5398	.2605	5.7943	.3438
HAWTHORN	1192.5	61	3.9269	.2715	6.2635	.3548
NARCISSUS	1272.	61	4.0542	.2750	6.4169	.3583

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 336.4 kcmil conductor covered by 1 inch of radial ice is:

$$.2222(6) = 1.3332 \text{ lb/ft.}$$

Overhead Ground Wires

NESC District Loadings

NAME	SIZE	STRAND	LIGHT .00"ICE 9 LB WIND K=.05 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	MEDIUM .25"ICE 4 LB WIND K=.20 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	HEAVY .50"ICE 4 LB WIND K=.30 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.	X-AREA SQ.IN.
HS STL	3/8	7	.2730	.2700	.4340	.4626	.2867	.7443	.8077	.4533	1.2262	10800	.360	.0792
HS STL	7/16	7	.3990	.3263	.5654	.6120	.3117	.8868	.9804	.4783	1.3908	14500	.435	.1156
EHS STL	3/8	7	.2700	.2700	.4318	.4596	.2867	.7417	.8047	.4533	1.2236	15400	.360	.0792
EHS STL	7/16	7	.3990	.3263	.5654	.6120	.3117	.8868	.9804	.4783	1.3908	20800	.435	.1156
AL CLAD	7 NO.9		.2076	.2573	.3806	.3920	.2810	.6823	.7318	.4477	1.1578	12630	.343	.0720
AL CLAD	7 NO.8		.2618	.2888	.4398	.4592	.2950	.7458	.8121	.4617	1.2341	15930	.385	.0908
AL CLAD	7 NO.7		.3300	.3248	.5130	.5423	.3110	.8252	.9101	.4777	1.3278	19060	.433	.1145

High Wind Loadings

NAME	SIZE	STRAND	VERT. LB/FT	13 LBS TRANS. LB/FT	TOTAL LB/FT	16 LBS TRANS. LB/FT	TOTAL LB/FT	21 LBS TRANS. LB/FT	TOTAL LB/FT	26 LBS TRANS. LB/FT	TOTAL LB/FT	31 LBS TRANS. LB/FT	TOTAL LB/FT	6 LBS TRANS. LB/FT	SWING ANGLE
HS STL	3/8	7	.2730	.3900	.4761	.4800	.5522	.6300	.6866	.7800	.8264	.9300	.9692	.1800	33.40
HS STL	7/16	7	.3990	.4713	.6175	.5800	.7040	.7613	.8595	.9425	1.0235	1.1238	1.1925	.2175	28.60
EHS STL	3/8	7	.2700	.3900	.4743	.4800	.5507	.6300	.6854	.7800	.8254	.9300	.9684	.1800	33.69
EHS STL	7/16	7	.3990	.4713	.6175	.5800	.7040	.7613	.8595	.9425	1.0235	1.1238	1.1925	.2175	28.60
AL CLAD	7 NO.9		.2076	.3716	.4256	.4573	.5022	.6003	.6351	.7432	.7716	.8861	.9101	.1715	39.56
AL CLAD	7 NO.8		.2618	.4171	.4924	.5133	.5762	.6738	.7228	.8342	.8743	.9946	1.0285	.1925	36.33
AL CLAD	7 NO.7		.3300	.4691	.5735	.5773	.6650	.7578	.8265	.9382	.9945	1.1186	1.1662	.2165	33.27

Miscellaneous Loadings

TYPE		1.0"ICE VERT. LB/FT	TRANS. LB/FT	1.5"ICE VERT. LB/FT	TRANS. LB/FT
3/8	HS STL	1.9642	.0300	3.7425	.0300
7/16	HS STL	2.1835	.0363	4.0084	.0363
3/8	EHS STL	1.9612	.0300	3.7395	.0300
7/16	EHS STL	2.1835	.0363	4.0084	.0363
7 NO.9	AL CLAD	1.8777	.0286	3.6454	.0286
7 NO.8	AL CLAD	1.9841	.0321	3.7779	.0321
7 NO.7	AL CLAD	2.1120	.0361	3.9357	.0361

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 3/8" high strength steel OHGW covered by 1" of radial ice:

.0300(6) = .1800 lb/ft.

CONDUCTOR AMPACITY
TABLES

The basic conditions on which all the ampacity tables have been calculated are:

1. Conductivity, 1350(EC)-61%, 6201-52.5%, IACS; ACSR: Al-61%, Steel 8% IACS.
2. Conductor temperature, 75°C.
3. Ambient temperature, 25°C.
4. Wind Velocity 2 ft/s.
5. Solar absorption, 0.5.
6. Sun altitude at 12:00 noon, 83°.
7. Azimuth of line, 270°.
8. East-west line at latitude 30°N.
9. Elevation, sea level.
10. Azimuth of sun, 180°.
11. Emissivity, bare 0.5

The values shown in the tables were based on the following reference works:

a. "Current Carrying Capacity of ACSR" by House and Tuttle A.I.E.E. Transactions paper 58-41, Feb. 1958.
b. "The Resistance and Reactness of ACSR" by Lewis and Tuttle A.I.E.E. Transactions, Vol. 77, Part III 1958

AMPACITIES FOR ACSR CONDUCTORS

Code Word	Size kcmil or AWG	Strand	AMPACITY (Amperes) Sun No Wind	No Wind No Sun	Sun Wind	Wind No Sun
Raven	1/0	6/1	150	175	240	255
Quail	2/0	6/1	175	205	275	295
Pigeon	3/0	6/1	205	240	315	340
Penguin	4/0	6/1	240	275	365	390
Waxwing	266.8	18/1	300	345	445	480
Partridge	266.8	26/7	305	355	455	490
Merlin	336.4	18/1	350	405	515	560
Linnet	336.4	26/7	360	420	530	570
Oriole	336.4	30/7	365	425	530	575
Chickadee	397.5	18/1	390	460	575	620
Ibis	397.5	26/7	405	470	590	640
Lark	397.5	30/7	410	475	590	640
Pelican	477.0	18/1	440	520	640	700
Flicker	477.0	24/7	450	530	670	710
Hawk	477.0	26/7	460	540	660	720
Hen	477.0	30/7	460	540	660	720
Osprey	556.5	18/1	490	580	710	770
Parakeet	556.5	24/7	500	590	720	790
Dove	556.5	26/7	510	600	730	790
Eagle	556.5	30/7	510	600	730	800
Rook	636.0	24/7	550	650	780	860
Grosbeak	636.0	26/7	560	660	790	860
Egret	636.0	30/19	560	660	790	870
Flamingo	666.6	24/7	570	670	810	880
Tern	795.0	45/7	630	750	890	970
Condor	795.0	54/7	640	760	900	990
Drake	795.0	26/7	650	770	910	990
Mallard	795.0	30/19	660	780	910	1000
Rail	954.0	45/7	720	850	970	1070
Cardinal	954.0	54/7	730	870	990	1090
Bunting	1,192.5	45/7	830	990	1120	1240
Grackle	1,192.5	54/19	850	1010	1130	1260
Bittern	1,272.0	45/7	870	1030	1160	1290
Pheasant	1,272.0	54/19	890	1050	1180	1320
Bobolink	1,431.0	45/7	940	1120	1250	1390
Plover	1,431.0	54/19	950	1140	1270	1420
Lapwing	1,590.0	45/7	1010	1200	1340	1490
Falcon	1,590.0	54/19	1030	1230	1360	1520
Chukar	1,780.0	84/19	1090	1300	1440	1600
Bluebird	2,156.0	84/19	1230	1480	1610	1810

AMPACITIES FOR 6201 ALUMINUM ALLOY CONDUCTORS

Code Word	Size kcmil or AWG	Strand	AMPACITY (Amperes) Sun No Wind	No Wind No Sun	Sun Wind	Wind No Sun
Azusa	123.3	7	160	185	255	270
Anaheim	155.4	7	190	220	295	315
Amherst	195.7	7	220	255	340	365
Alliance	246.9	7	260	300	395	420
Butte	312.8	19	310	360	455	490
Canton	394.5	19	360	420	530	570
Cairo	465.4	19	410	470	590	640
Darien	559.5	19	460	540	660	720
Elgin	652.4	19	510	600	730	790
Flint	740.8	37	560	660	790	860
Greeley	927.2	37	650	770	900	990

AMPACITIES FOR ALUMINUM 1350 CONDUCTOR

Code Word	Size kcmil or AWG	Strand	AMPACITY (Amperes) Sun No Wind	No Wind No Sun	Sun Wind	Wind No Sun
Poppy	1/0	7	155	175	245	260
Aster	2/0	7	180	205	285	305
Phlox	3/0	7	210	245	330	350
Oxlip	4/0	7	250	290	380	410
Daisy	266.8	7	290	340	440	475
Laurel	266.8	19	295	340	445	475
Tulip	336.4	19	345	400	510	550
Canna	397.5	19	390	450	570	615
Cosmos	477.0	19	440	510	640	690
Syringa	477.0	37	440	510	640	690
Dahlia	556.5	19	490	570	700	760
Mistletoe	556.5	37	490	570	700	760
Orchid	636.0	37	530	630	760	830
Heuchera	650.0	37	540	640	770	840
Arbutus	795.0	37	620	730	880	960
Lilac	795.0	61	620	730	880	960
Magnolia	954.0	37	700	830	980	1080
Goldenrod	954.0	61	700	830	980	1080
Hawthorn	1,192.5	61	820	970	1120	1240
Narcissus	1,272.0	61	850	1010	1170	1290

APPENDIX C

INSULATION TABLES

NOTES

STRING FLASHOVER DATA
FOR 5-3/4" X 10" STANDARD SUSPENSION
INSULATORS

Units in String	60-Hz Flashover-KV Dry	60-Hz Flashover-KV Wet	Impulse Flashover-KV 1.5 X 50 Positive	Impulse Flashover-KV 1.5 X 50 Negative
2	155	90	250	250
3	215	130	355	340
4	270	170	440	415
5	325	215	525	495
6	380	255	610	585
7	435	295	695	670
8	485	335	780	760
9	540	375	860	845
10	590	415	945	930
11	640	455	1025	1015
12	690	490	1105	1105
13	735	525	1185	1190
14	785	565	1265	1275
15	830	600	1345	1360
16	875	630	1425	1440
17	920	660	1505	1530
18	965	690	1585	1615
19	1010	720	1665	1700
20	1055	750	1745	1785
21	1095	775	1820	1865
22	1135	800	1895	1945
23	1175	825	1970	2025
24	1215	850	2045	2105
25	1255	875	2120	2185

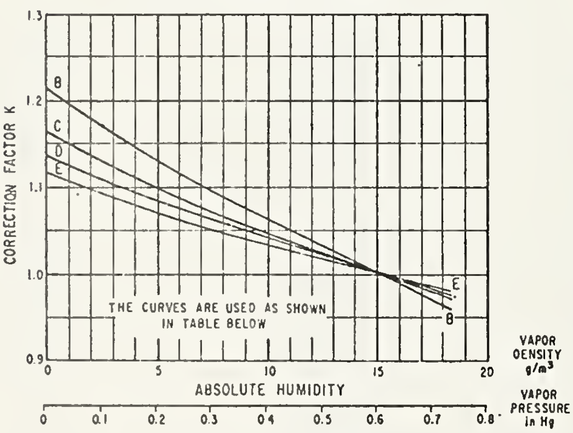
7.5 The Rod Gap. The rod gap consists ordinarily of two one-half-inch-square rod electrodes, each cut off squarely and mounted horizontally on supports so that a length of rod equal to or greater than one-half the gap spacing overhangs the inner edge of the support. The height of the rods above the ground plane should be at least 1.3 times the gap spacing plus 4 inches. Sparkover values for rod gaps are given in Table 3. Rod-gap sparkover voltage varies with air density and humidity. For power-frequency voltages, air density may be corrected by applying the relative air-density factor from paragraph 2.5.3.3. Humidity corrections are given in Figure 14.

A gap arrangement consisting of one-half-inch-square rods as described above may be used for measuring surge voltages. The relation of gap spacings to critical sparkover voltage for the 1.2 × 50 microsecond wave is given in Table 3. The sparkover of the rod gap is dependent on air density (paragraph 2.5.3.3) and humidity (Figure 14).

The accuracy of rod-gap measurements has been established within ±8 percent.

Rod-gap sparkover voltages for overvoltage conditions on the gap have not been standardized and are greatly dependent on the applied voltage waveshape.

Humidity Correction factor k, USA and Canadian practice, Figure 14.



	Power Frequency	Positive Standard Impulse	Negative Standard Impulse
Rod gaps	B	C	D
Suspension insulators	B	C	D
Apparatus insulators	B	D	E
Bushings (gapped)	B	D	E

Table-3 Rod Gap Sparkover Crest Voltages

Gap Spacing		Critical Sparkover in Kilovolts Crest				
		60 Hz	Nonstandard (1.2 × 5) Wave		(1.2 × 50) Wave	
cm	inches		Positive	Negative	Positive	Negative
2	0.8	26	32	32	32	32
3	1.2	37	42	42	42	42
4	1.6	47	51	51	51	51
5	2.0	55	60	62	60	62
6	2.4	62	65	70	65	70
8	3.1	72	80	86	77–78*	86
10	3.9	81	94	102	89–93*	101
12	4.7	89	113	119	102–109*	118
14	5.5	98	132	136	117–128*	135
16	6.3	107	150	152	132–145*	150
18	7.1	115	167	168	142–156*	164
20	7.9	124	185	185	157–164*	180
25	9.8	147	230	228	188	222
30	11.8	172	272	269	222	255–266*
35	13.8	198	315	311	255	290–313*
40	15.7	225	356	352	287	320–355*
45	17.7	251	396	396	316	355–383*
50	19.7	278	436	440	346	390–400*
60	23.6	332	515	525	400	465
70	27.6	382	595	610	460	535
80	31.5	435	675	695	520	600
90	35.4	488	750	775	580	665
100	39.4	537	830	865	640	730
120	47.2	642	975	1025	750	855
140	55.1	744	1125	1195	870	985
160	63.0	847	1285	1365	985	1115
180	70.9	950	1460	1555	1124	1265
200	78.7	1054	1585	1695	1220	1370
220	86.6	1160	1740	1865	1340	1500
240	94.5	——	1900	2045	1460	1640

*Dual values are due to unstable conditions, the cause being unknown.

Note: At standard atmospheric conditions, USA and Canadian practice, paragraph 1.3.4.1. For nonstandard atmospheric conditions, use correction factors in paragraphs 1.3.4.2, 1.3.4.3, and 1.3.4.4, and also Figure 14.

Figure-14 Continued

Use correction factor k for test voltages of 141-kilovolt crest and above. For test voltage below 141-kilovolt crest use correction factor k_1. For impulse testing at time to sparkover less than 10 microseconds use correction factor k_2.

$$k_1 = 1 + (k - 1)\, V/V_0$$

where

V = crest voltage
V_0 = 141 kilovolts.

$$k_2 = 1 + (k_x - 1)\, t_c/t_0$$

where

t_c = time to sparkover
t_0 = 10 microseconds
k_x = k or k_1.

For use of atmospheric correction factors see paragraphs 1.3.4.2, 1.3.4.3, and 1.3.4.4.

Reproduced from ANCI C68.1, 1978, IEEE No. 4 standard "Techniques for Dielectric Tests".

APPROXIMATE WEIGHTS AND LENGTH OF
INSULATOR STRINGS USING STANDARD
5-3/4" x 10" SUSPENSION BELLS*

Number of Insulators	Length of String in m (ft.) (Includes suspension hardware)		Weight of String in N (lbs.) (Includes suspension hardware)		Max. Voltage for the No. of Insulators (tangent)
3	.60	(1.94)	201	(45)	34.5 kV, 46 kV
4	.74	(2.42)	258	(58)	69 kV
5	.88	(2.90)	315	(71)	
6	1.03	(3.38)	371	(84)	
7	1.18	(3.85)	428	(96)	115 kV
8	1.32	(4.33)	485	(109)	
9	1.47	(4.81)	542	(122)	
10	1.61	(5.29)	598	(135)	161 kV
11	1.76	(5.77)	654	(147)	
12	1.91	(6.25)	712	(160)	230 kV
13	2.05	(6.73)	768	(173)	
14	2.20	(7.21)	825	(186)	
15	2.34	(7.69)	882	(198)	
16	2.49	(8.17)	939	(211)	

*Exact length and weight will vary slightly depending upon conductor suspension hardware used.

APPENDIX D

INSULATOR SWING TABLES

NOTES

The tables that follow give the allowable insulator swing values for standard REA structures. The values given 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 requirement 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 (TS-1 for instance) 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. Those swing angle values that have an asterisk (*) next to them represent a situation where 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.

The swing values given in parentheses are maximum backswing angles (see Chapter VII-Part C).

The tables are based on:

- o Standard REA structure types and dimension as given in REA Form 805.
- o The clearance values given in Table VII-1.
- o The assumption that standard suspension units used (cushioned suspension units will result in somewhat different allowable swing angles).
- o An assumed pole diameter of .305 m (12 in.).

Further information concerning the derivation of the values in the tables may be obtained from REA.

TANGENT STRUCTURES

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	6 lb/ft² Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
34.5 kV				
TS-1, TS-1X	3	40.8	62.1	83.9
TS-1L, TS-1LX	3	40.8	62.1	83.9
TS-2, TS-2X	3	41.3	62.3	84.1
TS-6	3	25.3	45.8	68.7
TS-7	3	68.5	85.8	113.9
TSS-1, TSS-2	3	40.8	64.5	89.5
TSS-1L	3	40.8	64.5	89.5
TSS-7	3	77.0	95.1	117.2
TSZ-1, TSZ-2	3	52.6	70.4	92.7
TH-1, TH-1G	3	41.3	64.9	89.8
TH-1B, TH-1BG	3	77.0	95.1	117.1
46 kV				
TS-1, TS-1X	3	40.8	62.1	83.9
TS-1L, TS-1LX	3	40.8	62.1	83.9
TS-2, TS-2X	3	41.3	62.3	84.1
TS-6	3	25.3	45.8	68.7
TS-7	3	68.5	85.8	113.9
TSS-1, TSS-2	3	40.8	64.5	89.5
TSS-1L	3	40.8	64.5	89.5
TSS-7	3	77.0	95.1	117.2
TSZ-1, TSZ-2	3	52.6	70.4	92.7
TH-1, TH-1G	3	41.3	64.9	89.8
TH-1B, TH-1BG	3	77.0	95.1	117.1
69 kV				
TS-1, TS-1X	4	21.3	41.4	74.9
TS-1L, TS-1LX	4	33.5	53.3	74.9
TS-2, TS-2X	4	21.3	41.4	75.1
TS-6	4	17.8	39.9	63.1
TS-7	4	49.5	72.5	95.6
TSS-1, TSS-2	4	27.6	49.5	85.4
TSS-1L	4	35.1	60.9	85.4
TSS-7	4	49.5	81.5	107.7
TSZ-1, TSZ-2	4	41.7	61.2	82.6
TH-1, TH-1G	4	35.6	61.2	85.6
TH-1B, TH-1BG	4	66.5	86.2	107.7

TANGENT STRUCTURES

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	6lb/ft^2 Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
69 kV (Continued)				
TH-1A, TH-1AA,	4	35.6	61.2	85.6
TH-1AA, TH-1AAX	4	27.2	56.1	81.3
TUS-1, Type 1,2,3	4	25.6	46.9	68.8
TUS-2, Type 1,2,3	4	34.2	59.2	86.2
TUS-2, Type 1,2,3	5	17.8	46.2	85.4
TS-115	4	33.7	60.0	84.6
115 kV				
TS-115	7	26.9	57.3	80.2
TH-1A	7	28.3	58.7	80.8
TH-1AA, TH-1AAX	7	22.1	55.5	78.1
TH-10 Series	7	22.1	55.5	78.1
TUS-1, Type 1,2,3	7	19.2	46.9	67.0
TUS-2, Type 1,2,3	7	30.2	56.3	77.1
TUS-2, Type 1,2,3	8	19.8	48.7	76.6
138 kV				
TH-10 Series	8	19.9	54.5	77.1
TUS-1, Type 1,2,3	8	17.4	45.8	66.2
TUS-2, Type 1,2,3	8	26.8	52.0	74.4
TUS-2, Type 1,2,3	9	17.8	45.4	73.9
161 kV				
TH-10 Series	10	16.4	53.2	77.7
TUS-1, Type 1,2,3	10	15.0	47.9	68.0
TUS-2, Type 1,2,3	10	23.1	52.0	71.3
TUS-2, Type 1,2,3	11	18.0	46.9	70.5
230 kV				
TH-230	12	16.5	47.8	74.8
TH-230	13	15.2	45.5	76.0
TUS-1, Type 1,2,3	12	15.3	41.1	66.2
TUS-1, Type 1,2,3	13	13.9	42.0	66.5

TANGENT STRUCTURES

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	6lb/ft^2 Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
230 kV(Continued)				
TUS-1, Type 1,2,3	14	12.7	40.9	66.7
TUS-2, Type 1,2,3	12	21.0	41.7	65.1
TUS-2 Type 1,2,3	13	19.3	41.8	64.4
TUS-2 Type 1,2,3	14	17.7	38.4	63.6

ANGLE STRUCTURES

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	6 lb/ft^2 Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
34.5 kV				
TS-1B, TS-1BX	3	68.5	85.8	113.9
TS-1C	3	68.5	85.8	113.9
TS-3,3X,3G,3GX	3	13.0*	5.9	31.6
TS-4,4X,4G,4GX	3	50.8*	26.6*	1.5*
TSS-1B	3	77.0	95.1	117.2
TSS-1C	3	43.9	78.3	117.2
TH-3	3	12.8*	6.0	31.9
TH-4	3	48.7*	25.1*	0.2*
TH-6	3	77.2	95.3	117.3
46 kV				
TS-1B, TS-1BX	3	68.5	85.8	113.9
TS-1C	3	68.5	85.8	113.9
TS-3,3X,3G,3GX	4	10.2*	4.6	24.4
TS-4,4X,4G,4GX	4	37.6*	20.6*	1.2*
TSS-1B	3	77.0	95.1	117.2
TSS-1C	3	43.9	78.3	117.2
TH-3	4	10.1*	4.8	24.5
TH-4	4	36.3*	19.5*	0.1*
TH-6	3	77.2	95.3	117.3

*Angle measured from a vertical through the point of insulator string suspension away from structure.

ANGLE STRUCTURES

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	6lb/ft^2 Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
69 kV				
TS-1B, TS-1BX	4	49.5	72.5	95.6
TS-1C	4	49.5	72.5	95.6
TS-3, 3X,3G,3GX	5	19.2*	3.2*	16.2
TS-4,4X,4G,4GX	5	43.3*	24.4*	4.5*
TSS-1B	4	62.3	81.5	107.7
TSS-1C	4	21.3	41.4	107.7
TH-3	5	19.1*	3.1*	16.3
TH-4	5	42.2*	23.4*	3.6*
TH-6	4	66.7	86.3	107.8
TH-3A	5	19.1*	3.1*	16.3
TH-4A	5	42.2*	23.4*	3.6*
TUS-2, Type 4	5	37.5*	19.5*	0.0*
TUS-2, Type 4	6	42.3*	16.5*	0.0*
115 kV				
TH-3A	8	33.6*	13.6*	4.9
TH-4A	8	51.2*	27.4*	8.1*
TH-11B Series	7	53.5	76.5	97.3
TH-12	7	53.5	76.5	96.8
TH-13	8	22.3*	3.4*	15.0
TH-14	8	51.8	27.8*	8.5*
TUS-2, Type 4	8	47.6*	24.8*	5.7*
TUS-2, Type 4	9	50.3*	22.1*	5.1*
138 kV				
TH-11B Series	8	49.8	73.3	94.1
TH-12	8	49.8	73.3	93.9
TH-13	9	26.6*	7.2*	11.4
TH-14	9	54.3*	29.3*	9.7*
TUS-2, Type 4	9	50.3*	26.6*	7.2*
TUS-2, Type 4	10	52.7*	23.9*	6.5*

* Angle measured from a vertical through the point of insulator string suspension away from structure.

ANGLE STRUCTURES

Structure and Voltage	Number of Insulators	No Wind Clearance Insulator Swing Angle In Degrees	6lb/ft^2 Clearance Insulator Swing Angle In Degrees	High Wind Clearance Insulator Swing Angle In Degrees
161 kV				
TH-11B Series	10	36.9	59.4	91.5
TH-12	10	43.9	71.7	91.4
TH-13	11	33.3*	10.3*	7.7
TH-14	11	58.4*	28.7*	9.7*
TUS-2, Type 4	11	54.7*	26.4*	7.7*
TUS-2, Type 4	12	55.1*	24.2*	7.1*
230 kV				
TH-231B	12	48.9	67.2	91.3
TH-231B	13	38.9	67.3	91.2
TH-232	12	47.5	67.2	91.2
TH-232	13	44.5	67.3	91.2
TH-232A	12	47.5	67.2	91.3
TH-232A	13	45.4	67.3	91.2
TH-233	13	34.8*	17.7*	4.4
TH-233	14	37.1*	17.9*	4.1
TH-233X,233XA	13	45.9*	29.8*	10.5*
TH-233X,233XA	14	47.4*	29.3*	9.9*
TH-234, 234A	13	60.1*	36.9*	12.7*
TH-234, 234A	14	61.5*	35.7*	11.8*
TUS-2, Type 4	13	56.8*	34.8*	11.0*
TUS-2, Type 4	14	58.3*	33.7*	10.2*
TUS-2, Type 4	15	59.7*	34.4*	9.6*

* Angle measured from a vertical through the point of insulator string suspension away from structure.

APPENDIX E

WEATHER DATA

NOTES

WIND VELOCITIES AND PRESSURES*

Actual Wind Velocity in kM/hr (mph)		Kilopascals (lbs./sq. ft.) on Cylindrical Surface		Kilopascals (lbs./sq. ft.) on Flat Surface	
56.3	(35)	.149	(3.1)	.230	(4.8)
64.4	(40)	.192	(4.0)	.302	(6.3)
72.4	(45)	.249	(5.2)	.388	(8.1)
78.8	(49)	.288	(6.0)	.460	(9.6)
80.5	(50)	.307	(6.4)	.479	(10.0)
88.5	(55)	.369	(7.7)	.575	(12.0)
91.2	(56.6)	.383	(8.0)	.599	(12.5)
96.7	(60)	.431	(9.0)	.676	(14.1)
104.6	(65)	.518	(10.8)	.810	(16.9)
112.7	(70)	.599	(12.5)	.934	(19.5)
120.7	(75)	.690	(14.4)	1.078	(22.5)
128.7	(80)	.786	(16.4)	1.226	(25.6)
136.8	(85)	.886	(18.5)	1.384	(28.9)
144.8	(90)	.992	(20.7)	1.547	(32.3)
152.9	(95)	1.106	(23.1)	1.729	(36.1)
160.9	(100)	1.226	(25.6)	1.916	(40.0)
169.0	(105)	1.351	(28.2)	2.112	(44.1)
177.0	(110)	1.485	(31.0)	2.318	(48.4)
185.1	(115)	1.624	(33.9)	2.538	(53.0)
193.1	(120)	1.767	(36.9)	2.763	(57.7)

*Based on:

$F = .0025V^2$ (for cylindrical surfaces)

where:

F = wind force in pounds per square foot.
V = wind velocity in miles per hour.

2 Year Mean Wind

Annual Extreme Wind in mph 30 feet Above Ground
2 Year Mean Recurrence Interval

FIG. 1. - ISOTACH 0.50 QUANTILES, IN MILES PER HOUR. ANNUAL EXTREME-MILE 30 FT ABOVE GROUND, 2-YR MEAN RECURRENCE INTERVAL.

Reprinted from page 5 of Conference Preprint 431 - "New Distribution of Extreme Winds in the United States" by H.C.S. Thom ASCE -- February 6-9, 1967

Annual Extreme Wind in mph 30 feet Above Ground
10 Year Mean Recurrence Interval

FIG. 2. - ISOTACH 0.10 QUANTILES, IN MILES PER HOUR. ANNUAL EXTREME-MILE 30 FT ABOVE GROUND, 10-YR MEAN RECURRENCE INTERVAL.

Reprinted from page 6 of Conference Preprint 431 - "New Distribution of Extreme Winds in the United States" by H.C.S. Thom ASCE -- February 6-9, 1967

50 Year Mean Wind

Annual Extreme Wind in mph 30 feet Above Ground
50 Year Mean Recurrence Interval

FIG. 4. - ISOTACH 0.02 QUANTILES, IN MILES PER HOUR. ANNUAL EXTREME-MILE 30 FT ABOVE GROUND, 50-YR MEAN RECURRENCE INTERVAL
Reprinted from page 8 of Conference Preprint 431 - "New Distribution of Extreme Winds in the United States" by H.C.S. Thom ASCE -- February 6-9, 1967

Annual Extreme Wind in mph 30 feet Above Ground
100 Year Mean Recurrence Interval

FIG. 5. - ISOTACH 0.01 QUANTILES, IN MILES PER HOUR. ANNUAL EXTREME-MILE 30 FT ABOVE GROUND, 100-YR MEAN RECURRENCE INTERVAL.
Reprinted from page 9 of Conference Preprint 431 - "New Distribution of Extreme Winds in the United States" by H.C.S. Thom ASCE -- February 6-9, 1967


MEAN ANNUAL NUMBER OF DAYS WITH THUNDERSTORMS
LEGEND
UNDER 20
20-40
40-60
60-80
80-100
OVER 100
BASED ON RECORDS THROUGH 1960
LESS THAN 1 IN 2 YEARS
GULF OF MEXICO
HAWAII
ALASKA
PUERTO RICO AND VIRGIN ISLANDS

NORMALS, MEANS AND EXTREMES

Temperature (°C) and Normal Heating Degree Days

State and Station		Elevation Ground (Meters)	Normal (1941-1970) January Daily Maximum	January Daily Minimum	July Daily Maximum	July Daily Minimum	Annual	Extremes Length (Yrs)	Record Highest	Record Lowest	Normal Heating Degree Days (1941-1970) January	Seasonal
ALABAMA								94	44.4	-32.8		
BIRMINGHAM		189	12.4	1.2	32.4	20.8	16.9	34	41.1	-20.0	363	1580
HUNTSVILLE		190	10.3	-0.4	32.3	20.4	16.0	10	38.3	-18.3	415	1834
MOBILE		64	16.2	5.2	32.5	22.6	19.7	36	40.0	-13.3	251	935
MONTGOMERY		59	14.4	2.8	32.5	21.9	18.2	33	40.6	-15.0	309	1260
ALASKA								94	37.8	-62.2		
ANCHORAGE		35	-6.7	-15.8	18.7	10.1	1.7	24	29.4	-36.7	916	6061
ANNETTE		34	3.3	-1.7	17.8	10.9	7.6	30	32.2	-17.2	543	3918
BARROW X		9	-22.2	-29.6	6.8	0.6	-12.6	57	25.6	-48.9	1373	11257
BARTER ISLAND V		12	-22.5	-29.9	7.5	1.4	-12.2	28	25.6	-50.6	1381	11107
BETHEL		38	-10.9	-19.0	16.6	8.6	-1.8	19	30.0	-43.3	1032	7334
BETTLES		196	-20.7	-29.5	20.1	8.6	-5.9	27	33.3	-56.7	1347	8846
BIG DELTA		386	-16.4	-24.6	20.4	10.0	-2.5	36	33.3	-52.8	1204	7609
COLD BAY		29	0.3	-4.6	12.4	7.6	3.3	33	25.6	-25.0	634	5480
FAIRBANKS		133	-19.0	-29.8	22.1	9.8	-3.5	26	35.6	-52.2	1324	7969
GULKANA		479	-16.7	-26.9	20.1	7.6	-2.9	32	32.8	-53.9	1245	7743
HOMER		19	-2.2	-9.6	15.6	6.9	2.5	34	26.7	-29.4	751	5757
ILIAMNA	1969	57						27	32.8	-43.9		
JUNEAU		4	-1.6	-7.9	17.6	8.7	4.6	34	32.2	-30.0	715	5003
KING SALMON		15	-6.1	-14.6	16.9	8.0	0.7	35	31.1	-43.3	889	6434
KODIAK		4	1.4	-3.2	15.1	9.5	4.8	29	30.0	-24.4	596	4922
KOTZEBUE		3	-16.0	-23.7	14.8	8.4	-6.2	35	29.4	-46.7	1183	8910
MC GRATH		103	-17.5	-27.9	19.8	9.3	-3.8	35	32.2	-55.0	1273	8048
NOME		4	-10.3	-18.7	13.2	6.9	-3.6	31	30.0	-43.3	1016	7958
ST. PAUL ISLAND		7	-1.1	-5.6	9.7	5.6	1.4	60	17.8	-32.2	670	6177
SHEMYA	1972	37	1.3	-1.7	9.3	6.3	3.5	27	17.2	-13.9	575	5408
SUMMIT	1976	731	-13.4	-20.4	15.7	6.6	-3.6	35	31.7	-42.8	1092	7981
TALKEETNA		105	-7.2	-18.0	19.7	9.0	0.4	38	32.8	-44.4	958	6504
UNALAKLEET		5	-12.1	-19.7	15.8	8.6	-3.1	28	30.6	-45.6	1061	7792
VALDEZ		11	-3.9	-11.9	16.2	7.5	1.2	6	27.2	-28.9	813	5858
YAKUTAT		9	-0.4	-8.3	15.2	8.6	3.8	31	30.0	-31.1	703	5296
ARIZONA								83	52.8	-40.0		
FLAGSTAFF		2135	5.2	-9.8	27.1	10.2	7.4	28	36.1	-30.0	639	4067
PHOENIX		339	18.2	3.1	40.4	25.3	21.3	40	47.8	-8.3	238	862
TUCSON		788	17.5	3.4	36.8	23.4	19.9	37	43.9	-8.9	246	973
WINSLOW		1492	7.6	-6.9	34.2	17.2	12.9	46	42.8	-27.8	558	2629
YUMA		59	19.7	6.3	41.1	27.4	23.2	27	48.3	-4.4	171	558
ARKANSAS								87	48.9	-33.9		
FORT SMITH		136	9.9	-2.2	34.3	21.4	16.3	32	43.9	-23.3	448	1853
LITTLE ROCK		78	10.1	-1.7	33.7	21.2	16.1	36	42.2	-20.6	439	1863
TEXARKANA	1968	119	12.7	1.8	34.1	22.2	17.9	3	38.3	-12.8	348	1407
CALIFORNIA								93	56.7	-42.8		
BAKERSFIELD		145	14.2	3.0	37.3	20.4	18.3	40	46.1	-6.7	302	1214
BISHOP		1252	12.0	-6.4	36.4	13.2	13.3	30	42.8	-21.7	481	2396
BLUE CANYON M		1609	6.1	-1.2	25.3	14.8	10.1	34	35.0	-16.1	493	3169
EUREKA U		13	11.9	5.1	15.8	11.2	11.2	67	29.4	-6.1	305	2599
FRESNO		100	12.7	2.1	36.8	17.2	16.8	28	43.9	-7.2	339	1472
LONG BEACH		8	18.4	6.2	28.2	16.4	17.4	25	43.9	-3.9	188	892
LOS ANGELES		30	17.5	7.4	23.8	16.7	16.5	42	43.3	-5.0	184	1010
LOS ANGELES U		82	19.2	8.2	28.3	17.5	18.2	37	43.3	-2.2	149	692
MT SHASTA R		1077	5.4	-3.7	29.4	10.3	9.8	35	39.4	-20.6	541	3272
OAKLAND		2	12.5	5.9	20.9	13.6	14.1	49	41.7	-5.0	282	1616
RED BLUFF		104	12.0	2.6	36.7	19.2	17.1	33	48.3	-6.7	341	1493
SACRAMENTO		5	11.7	2.8	33.8	14.2	15.7	27	46.1	-6.7	343	1579
SANDBERG R		1377	8.0	1.1	29.5	17.2	12.8	43	38.9	-16.1	427	2459

Precipitation (Millimeters)

State and Station	Normal (1941-1970) Wettest Month	Driest Month	Annual	Extremes Wettest Month	Driest Month	Maximum In 24 Hours	Snow @ Mean Total January	Seasonal	Extreme Maximum In 24 Hours
ALABAMA					0	516			
BIRMINGHAM	157	66	1352	449	T	179	13	30	213
HUNTSVILLE	147	65	1325	375	20	196	33	64	91
MOBILE	229	65	1701	490	1	339	5	13	91
MONTGOMERY	155	57	1266	542	1	224	8	10	79
ALASKA					0	359			
ANCHORAGE	60	14	374	138	T	52	274	1783	450
ANNETTE	453	128	2903	886	14	193	396	1501	361
BARROW X	26	4	124	71	0	25	56	726	381
BARTER ISLAND V	33	6	179	125	T	57	132	1110	432
BETHEL	101	11	402	148	1	51	135	1255	208
BETTLES	76	16	360	150	0	49	297	1946	551
BIG DELTA	65	7	291	157	T	54	150	1029	254
COLD BAY	109	39	844	253	1	124	224	1430	290
FAIRBANKS	56	8	285	157	T	87	262	1748	511
GULKANA	47	6	282	110	0	52	178	1184	305
HOMER	86	23	586	218	0	77	264	1527	622
ILIAMNA				280	T	67	277	1636	399
JUNEAU	199	74	1389	387	T	118	650	2748	787
KING SALMON	88	23	502	185	0	51	183	1171	241
KODIAK	169	90	1440	401	5	113	480	2344	452
KOTZEBUE	57	7	223	132	T	45	152	1199	254
MC GRATH	89	17	425	159	T	65	353	2273	386
NOME	91	19	418	199	T	76	234	1384	229
ST. PAUL ISLAND	87	28	623	237	2	49	318	1494	351
SHEMYA	84	38	716	221	4	134	290	1448	389
SUMMIT	84	17	510	171	T	71	361	3053	711
TALKEETNA	124	28	727	303	T	79	457	2703	914
UNALAKLEET	99	10	360	205	T	39	130	1013	356
VALDEZ	197	69	1506	523	T		1481	7577	
YAKUTAT	496	144	3364	1115	13	198	1072	5834	823
ARIZONA					0	290			
FLAGSTAFF	67	14	490	250	0	87	396	2250	693
PHOENIX	31	3	179	141	0	78	T	T	15
TUCSON	67	4	281	201	0	100	5	36	173
WINSLOW	38	7	186	142	0	56	64	282	432
YUMA	11	0	68	75	0	69	0	T	T
ARKANSAS					0	305			
FORT SMITH	139	60	1074	356	T	181	51	145	188
LITTLE ROCK	135	76	1232	367	T	202	56	130	287
TEXARKANA	135	69	1249	423	T	166	38	69	191
CALIFORNIA					0	663			
BAKERSFIELD	26	T	145	117	0	43	T	T	38
BISHOP	36	2	145	227	0	92	97	218	457
BLUE CANYON M	347	3	1717	1146	0	237	1176	6015	978
EUREKA U	188	4	1010	421	0	148	5	5	76
FRESNO	47	0	260	217	0	66	T	T	38
LONG BEACH	57	0	260	285	0	174	T	T	T
LOS ANGELES	64	T	294	281	0	157	T	T	T
LOS ANGELES U	76	0	357	379	0	155	T	T	8
MT SHASTA R	169	8	952	447	0	177	836	2797	950
OAKLAND	102	T	475	287	0	138	T	T	25
RED BLUFF	114	1	560	289	0	102	33	61	251
SACRAMENTO	99	T	437	321	0	142	T	T	51
SANDBERG R	67	1	304	289	0	174	229	724	978

Relative Humidity, Wind Speed and Sunshine

State and Station	Relative Humidity (Percent) January 7:00 a.m. EST	January 1:00 p.m. EST	January 7:00 p.m. EST	July 7:00 a.m. EST	July 1:00 p.m. EST	July 7:00 p.m. EST	Wind Speed (m.p.s.) Mean Speed January	Mean Speed July	Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	July
BIRMINGHAM	81	63	66	89	62	66	3.8	2.5	29.1	42	59
HUNTSVILLE	83	68	71	88	60	65	4.2	2.7	20.6		
MOBILE	82	63	70	89	60	71	4.8	3.1	28.2		
MONTGOMERY	82	62	65	90	61	67	3.5	2.6	32.2	48	63
ANCHORAGE	71	72	71	80	74	61	2.6	3.2	27.3	42	45
ANNETTE	78	78	74	87	77	69	5.4	3.6	26.8		
BARROW X	66	67	67	94	91	87	5.1	5.2	25.9		
BARTER ISLAND V	69	69	69	93	89	86	6.6	4.7	36.2		
BETHEL	76	76	75	92	85	86	6.3	5.0	27.7		
BETTLES	72	66	67	83	67	51	2.6	3.0	17.9		
BIG DELTA	70	71	71	79	73	58	4.8	2.7	33.1		
COLD BAY	85	85	82	91	89	80	8.0	7.0	32.6		
FAIRBANKS	68	68	68	78	68	50	1.3	2.9	17.9		
GULKANA	67	68	64	84	70	48	2.3	3.7	23.2		
HOMER	77	77	72	92	78	69	3.5	30.2	17.9		
ILIAMNA	73	74	72	87	79	64	6.6	3.7			
JUNEAU	80	79	76	90	81	70	3.8	3.4	25.9	32	31
KING SALMON	72	73	71	86	80	63	4.7	4.5	31.7		
KODIAK	80	79	76	88	82	78	5.5	3.1	24.6		
KOTZEBUE	71	71	71	87	84	77	6.5	5.8	41.6		
MC GRATH	70	69	69	85	74	55	1.3	2.6	33.5		
NOME	72	71	71	81	76	71	5.2	4.5	24.6	40	35
ST. PAUL ISLAND	86	86	85	96	96	90	9.3	5.8	36.7		
SHEMYA	82	82	82	95	96	92	9.6	6.1	40.2		
SUMMIT	68	68	69	89	78	62	6.8	3.5	21.5		
TALKEETNA	68	71	62	89	75	60	2.8	1.7	17.0		
UNALAKLEET	60	68	66	87	79	72	8.0	4.8	25.0		
VALDEZ	92	83	83	91	80	69			19.7		
YAKUTAT	80	80	77	97	85	79	3.4	3.1	33.5		
FLAGSTAFF	73	51	48	70	34	40	3.4	2.8	20.6	75	75
PHOENIX	66	43	30	46	28	20	2.3	3.2	38.4	78	85
TUCSON	62	39	32	58	33	29	3.5	3.7	31.7	81	78
WINSLOW	78	62	50	58	30	27	3.2	4.0	28.2		
YUMA	55	38	27	50	32	22	3.3	4.2	26.8	84	89
FORT SMITH	80	59	61	88	54	62	3.6	2.8	25.9	49	71
LITTLE ROCK	81	61	65	87	58	61	3.9	3.1	29.1	46	71
TEXARKANA	79	62	62	90	60	62	3.7	2.8			
BAKERSFIELD	83	75	60	48	32	20	2.3	3.2	20.6		
BISHOP		48	34		19	14			33.5		
BLUE CANYON M	46	58	48	38	32	27	4.4	3.1	34.0		
EUREKA U							3.1	3.0	25.0	42	52
FRESNO	91	85	67	64	39	23	2.4	3.2	19.2	51	96
LONG BEACH	73	57	50	81	61	53	2.5	3.0	19.7		
LOS ANGELES	69	54	59	86	68	68	3.0	3.4	27.7		
LOS ANGELES U	63	51	50	84	54	53	3.0	2.4	21.9	69	82
MT SHASTA R	79	74	68	67	39	29	2.2	2.1			
OAKLAND	83	77	71	87	76	67	3.0	4.2	21.9		
RED BLUFF	81	72	59	50	30	18	4.0	3.6	30.4	54	96
SACRAMENTO	89	85	69	76	47	28	3.4	4.1	31.3	47	97
SANDBERG R	51	56	52	42	26	28	7.6	5.7	34.4		

Annual Mean Number of Days

State and Station	Sunrise to Sunset Clear	Partly Cloudy	Cloudy	Precipitation .25mm or More	Snow, Sleet, Hail 25.4mm or More	Thunderstorms	Heavy Fog	Temperature Max ≥ 32.2°C	Min ≤ 0°C	Min ≤ -17.8°C
BIRMINGHAM	99	111	155	118	*	59	9	42	61	*
HUNTSVILLE	108	99	158	121	1	59	22	41	65	*
MOBILE	100	118	147	124	*	80	39	81	20	0
MONTGOMERY	107	110	148	109	*	62	23	69	41	0
ALASKA								B		
ANCHORAGE	64	66	235	113	21	1	27	13	191	40
ANNETTE	41	59	265	224	17	1	15	23	82	0
BARROW X	59	52	188	76	7	*	65	*	323	170
BARTER ISLAND V	52	69	192	90	13	*	76	*	313	168
BETHEL	65	59	241	137	17	2	57	12	228	81
BETTLES	86	93	186	105	26	5	8	36	246	139
BIG DELTA	60	91	214	91	15	3	10	36	224	98
COLD BAY	12	47	306	213	19	*	25	*	163	2
FAIRBANKS	69	84	212	102	22	5	21	53	223	122
GULKANA	68	88	209	87	17	5	18	30	235	107
HOMER	68	68	229	143	24	*	9	2	195	13
ILIAMNA	81	68	216	137	22	0	12	10	195	45
JUNEAU	44	39	282	221	30	*	22	19	149	10
KING SALMON	55	65	245	151	16	1	35	10	206	58
KODIAK	63	73	229	189	26	*	14	9	146	2
KOTZEBUE	93	72	200	107	16	1	19	3	252	171
MC GRATH	67	70	228	133	28	7	14	31	231	115
NOME	90	65	210	125	17	*	24	7	245	91
ST. PAUL ISLAND	21	62	282	204	19	*	57	0	193	6
SHEMYA	5	52	298	212	19	*	82	0	129	0
SUMMIT	68	70	227	138	41	5	12	9	251	86
TALKEETNA	78	76	211	131	35	4	4	32	228	68
UNALAKLEET	86	62	217	107	12	2	15	7	236	83
VALDEZ				177	55			1	178	5
YAKUTAT	40	47	278	231	57	2	31	4	181	18
FLAGSTAFF	169	97	99	76	21	51	11	3	213	9
PHOENIX	213	83	69	34	0	23	2	165	12	0
TUCSON	198	90	77	50	1	40	1	139	20	0
WINSLOW	179	96	90	53	4	35	5	73	142	5
YUMA	247	68	50	15	0	7	1	166	2	0
FORT SMITH	125	93	147	96	3	57	15	67	80	*
LITTLE ROCK	119	101	145	104	2	57	16	70	63	*
TEXARKANA	126	95	144	98	1	62	18	64	44	0
BAKERSFIELD	201	81	83	36	*	3	22	110	11	0
BISHOP	202	89	74	29	2	13	*	95	143	*
BLUE CANYON M	175	64	126	89	40	12	68	1	101	0
EUREKA U	78	99	188	117	*	5	49	0	5	0
FRESNO	200	71	94	43	*	5	40	10[illegible]	28	0
LONG BEACH	155	123	87	30	0	4	53	24	1	0
LOS ANGELES	144	113	108	35	0	4	44	5	*	0
LOS ANGELES U	183	108	74	34	0	6	17	20	*	0
MT SHASTA R	163	85	117	90	21	13	7	21	136	*
OAKLAND	147	113	105	63	*	2	14	2	1	0
RED BLUFF	175	71	119	69	1	10	18	98	22	0
SACRAMENTO	192	72	101	57	*	5	35	70	17	0
SANDBERG R	208	79	78	40	7	4	79	20	59	0

NORMALS, MEANS AND EXTREMES

YEAR 1977

State and Station	Elevation Ground (Meters)	Temp. Normal (1941-1970) January Daily Maximum	January Daily Minimum	July Daily Maximum	July Daily Minimum	Annual	Extremes Length (Yrs)	Record Highest	Record Lowest	Normal Heating Degree Days (1941-1970) January	Seasonal	Precip. Normal (1941-1970) Wettest Month	Driest Month	Annual	Precip. Extremes Wettest Month	Driest Month	Maximum In 24 Hours	Snow @ Mean Total January	Seasonal	Snow Extreme Maximum In 24 Hours
CALIFORNIA																				
SAN DIEGO	4	18.1	7.7	24.1	17.7	17.2	37	43.9	-1.7	174	837	48	T	240	193	0	78	7	T	7
SAN FRANCISCO	2	12.9	5.1	21.6	12.2	13.8	50	41.1	-6.7	288	1690	111	T	496	312	0	116	T	T	38
SAN FRANCISCO U C	16	13.3	7.6	17.7	11.8	13.7	41	38.3	-1.1	243	1711	119	T	525	291	0	93	T	T	T
SANTA CATALINA 1968	478	15.4	8.6	25.5	15.2	16.1	5	39.4	1.1	196	1140	80	1	365	190	0	107	0	T	T
SANTA MARIA	72	17.1	3.5	22.1	11.3	13.8	35	40.0	-6.7	250	1696	61	1	311	246	0	80	7	T	7
STOCKTON	7	11.6	2.4	34.8	14.8	15.9	18	45.6	-7.2	351	1559	74	7	360	204	0	76	0	7	8
COLORADO							90	47.8	-51.1							0	281			
ALAMOSA	2297	1.7	-18.2	27.8	8.8	5.3	32	33.9	-45.6	823	4782	30	6	176	89	T	46	112	899	401
COLORADO SPRINGS	1873	5.0	-8.8	29.1	13.9	9.1	29	37.8	-32.8	627	3596	79	7	400	203	7	95	112	998	457
DENVER	1610	6.4	-8.8	30.8	14.8	10.1	43	40.0	-34.4	604	3342	67	11	394	186	7	90	203	1499	493
GRAND JUNCTION	1476	2.6	-8.6	33.9	17.9	11.5	31	40.6	-30.6	661	3114	27	12	214	88	0	40	191	668	231
PUEBLO	1428	7.5	-9.6	32.8	16.4	11.6	37	40.6	-35.0	601	2996	50	7	303	157	7	96	135	785	427
CONNECTICUT							90	40.6	-35.6							0	308			
BRIDGEPORT	2	2.7	-4.4	27.5	18.9	11.1	29	39.4	-20.6	599	3034	97	65	981	450	2	175	185	681	424
HARTFORD	52	0.8	-8.8	28.9	16.2	9.5	28	38.9	-32.2	692	3527	110	77	1102	555	9	308	302	1346	381
NEW HAVEN 1969	2	2.8	-5.6	26.9	17.3	10.1	25	37.8	-22.2	609	3276	117	81	1169	278	3	141	236	942	437
DELAWARE							85	43.3	-27.2							0	216			
WILMINGTON	23	4.6	-4.6	29.7	18.9	12.2	30	38.9	-20.0	568	2744	109	66	1022	307	4	158	145	505	396
DIST. OF COLUMBIA																				
WASHINGTON DULLES	88	5.1	-5.0	30.2	17.8	12.1	15	39.4	-22.2	567	2783	108	66	1019	462	T	302	140	554	391
WASHINGTON NATIONAL	3	6.4	-2.4	31.2	20.6	14.1	36	39.4	-17.2	506	2339	119	62	988	363	T	183	119	414	366
FLORIDA							88	42.8	-18.9							0	983			
APPALACHICOLA U	6	16.2	7.9	30.8	24.0	20.3	48	38.9	-10.6	204	756	229	68	1453	573	T	297	T	T	30
DAYTONA BEACH	9	20.6	8.7	32.0	22.4	21.4	34	38.9	-6.1	134	498	180	50	1276	505	7	236	T	T	T
FORT MYERS	5	23.7	11.3	32.8	23.2	23.3	38	38.3	-3.3	71	254	226	33	1370	511	0	276	0	0	0
JACKSONVILLE	8	18.1	6.9	32.2	22.2	20.2	36	40.6	-11.1	193	737	200	45	1384	492	T	258	T	T	38
KEY WEST INTL AP	1	24.2	18.8	31.8	26.7	25.7	25	35.0	7.8	9	36	186	39	1016	548	0	226	0	0	0
LAKELAND U	65	21.4	10.6	32.4	22.6	22.3	37	38.3	-6.7	104	377	205	41	1256	398	0	257	T	T	25
MIAMI INTL AP	2	24.2	14.8	31.7	24.2	24.2	33	36.7	-0.6	29	114	229	42	1519	620	7	294	0	0	0
ORLANDO	29	21.4	10.0	32.1	22.7	22.1	35	38.9	-6.7	109	407	211	40	1301	497	7	246	T	T	T
PENSACOLA 1/	34	16.2	6.1	32.1	23.3	20.0	14	37.8	-12.2	237	877	207	80	1631	407	0	255	5	8	48
TALLAHASSEE	17	17.9	5.0	32.6	22.0	19.8	17	37.8	-12.2	227	868	227	71	1564	511	T	241	T	T	10
TAMPA	6	21.4	10.1	32.3	23.2	22.3	31	36.7	-7.8	113	399	214	45	1254	523	T	308	T	T	5
WEST PALM BEACH	5	23.9	13.3	32.0	23.4	23.6	41	38.3	-2.8	46	166	250	56	1576	631	1	387	T	T	T
GEORGIA							86	44.4	-27.2							0	457			
ATHENS	244	11.8	0.8	31.9	20.4	16.4	34	40.6	-18.3	372	1653	145	69	1285	380	7	252	18	43	127
ATLANTA	308	10.8	0.8	30.3	20.8	16.0	29	39.4	-19.4	389	1719	148	64	1228	399	T	144	18	38	211
AUGUSTA	41	14.2	1.1	32.7	21.1	17.4	27	41.1	-15.0	334	1415	129	55	1083	290	7	152	5	22	348
COLUMBUS	117	14.3	2.2	32.7	21.3	17.9	32	40.0	-16.1	317	1321	153	50	1294	336	0	173	T	10	356
MACON	108	14.8	2.7	33.4	21.5	18.4	29	41.1	-16.1	302	1244	131	59	1129	299	0	136	8	25	419
ROME	194	11.2	-1.1	32.4	19.5	15.7	30	41.1	-20.6	412	1856	157	74	1336	441	T	191	18	51	208
SAVANNAH	14	16.2	3.7	32.7	21.8	18.8	27	40.0	-12.8	268	1084	200	49	1299	511	1	179	T	10	91
HAWAII							73	37.8	-7.8							0	965			
HILO	8	26.4	17.1	28.3	19.7	23.0	31	34.4	11.7	0	0	400	168	3393	1291	9	399	0	0	0
HONOLULU	2	26.3	18.5	30.4	23.0	24.8	8	33.3	11.7	0	0	112	8	582	528	T	434	0	0	0
KAHULUI	15	26.4	17.7	30.2	21.1	24.0	13	35.6	8.9	0	0	91	5	468	347	0	148	0	0	0
LIHUE	31	25.5	18.0	28.9	22.6	23.9	27	32.2	10.0	0	0	161	40	1122	582	8	293	0	0	0
IDAHO							85	47.8	-51.1							0	182			
BOISE	865	2.5	-5.9	32.5	14.7	10.5	38	43.9	-30.6	620	3240	37	4	292	102	0	57	191	546	330
LEWISTON	431	3.3	-4.2	31.8	14.2	10.9	31	46.1	-30.0	582	3035	46	13	336	122	T	44	180	455	325
POCATELLO	1358	0.2	-10.0	31.6	12.3	8.2	28	40.0	-34.4	720	3923	33	9	274	101	0	46	251	1016	257

State and Station	Relative Humidity (Percent) January 7:00 a.m. EST	January 1:00 p.m. EST	January 7:00 p.m. EST	July 7:00 a.m. EST	July 1:00 p.m. EST	July 7:00 p.m. EST	Wind Speed (m.p.s.) Mean Speed January	Mean Speed July	Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	July	Annual Mean Number of Days: Sunrise to Sunset Clear	Partly Cloudy	Cloudy	Precipitation .25mm or More	Snow, Sleet, Hail 25.4mm or More	Thunderstorms	Heavy Fog	Temperature Max ≥ 32.2°C	Min ≤ 0°C	Min ≤ -17.8°C
CALIFORNIA																					
SAN DIEGO	68	63	54	81	69	66	2.5	3.2	22.8	72	67	151	115	99	41	0	3	27	3	*	0
SAN FRANCISCO	86	78	66	87	66	60	3.2	6.0	25.9			162	103	100	62	*	2	17	4	3	0
SAN FRANCISCO U C	81	72	63	92	73	74	3.0	5.0	21.0	56	66				67	0	2		1	*	0
SANTA CATALINA 1968												173	94	98	42	0	4	158	15	0	0
SANTA MARIA	81	62	59	86	63	61	3.0	2.9				176	110	79	45	0	2	87	[illegible]	24	0
STOCKTON	90	87	69	65	41	26	3.0	3.7	20.6			186	75	104	52	0	3	43	86	24	0
COLORADO																					
ALAMOSA	77	60	59	84	39	37	2.4	3.8				148	137	80	67	12	44	15	1	227	49
COLORADO SPRINGS	57	41	46	70	38	62	4.4	4.3	26.8			129	120	116	87	11	60	20	15	161	7
DENVER	63	44	47	70	36	56	4.1	3.8	25.0	72	71	115	132	118	88	18	41	10	32	162	9
GRAND JUNCTION	77	66	62	47	28	21	2.5	4.2	29.5	80	77	140	108	117	70	9	34	8	60	139	7
PUEBLO	66	48	45	72	38	44	3.6	3.9	35.8	75	78	138	123	104	69	9	40	8	63	153	8
CONNECTICUT																					
BRIDGEPORT	72	61	65	77	60	69	5.8	4.4	30.0			100	107	158	118	8	22	29	6	102	*
HARTFORD	71	57	62	79	51	62	4.2	3.5	23.7	58	62	76	115	174	129	14	22	32	21	136	6
NEW HAVEN 1969	76	63		81	66		3.7	2.8	25.5	55	58	100	109	156	128	11	27	28	3	113	1
DELAWARE																					
WILMINGTON	75	60	69	80	54	66	4.4	3.4	25.9			96	106	163	116	6	31	38	19	102	*
DIST. OF COLUMBIA																					
WASHINGTON DULLES	79	59	68	87	55	68	3.7	2.8	20.6			96	105	164	114	6	27	35	25	118	2
WASHINGTON NATIONAL	68	54	59	75	52	60	4.5	3.6	34.9	49	63	104	102	159	111	5	29	12	37	75	0
FLORIDA																					
APPALACHICOLA U	86	68	79	85	71	76	3.8	3.0	30.0	59	64	132	121	112	106	*	70	28	20	5	0
DAYTONA BEACH	88	60	78	88	65	78	4.1	3.4	25.9			92	137	136	115	0	80	31	54	5	0
FORT MYERS	89	58	73	88	60	75	3.8	3.0	41.1			104	159	102	113	0	95	22	101	1	0
JACKSONVILLE	87	57	74	87	58	75	3.8	3.4	36.7	57	60	99	128	138	116	*	64	36	82	13	0
KEY WEST INTL AP	82	69	77	76	66	71	5.4	4.4	37.6	72	77	100	163	102	111	0	63	1	42	0	0
LAKELAND U							3.3	2.5		62	61	100	159	106	120	*	100	19	83	2	0
MIAMI INTL AP	84	60	69	86	65	72	4.2	3.5	33.1	60	79	75	171	119	129	0	74	7	31	*	0
ORLANDO	88	57	69	89	59	74	4.0	3.4	28.6			92	149	124	116	0	81	29	104	3	0
PENSACOLA 1/	81	64	73	88	63	71	4.0	3.0	16.5	48	57	101	119	145	115	*	74	36	53	16	0
TALLAHASSEE	87	60	73	93	61	74	3.4	2.5	25.9			96	136	133	119	0	86	53	88	37	0
TAMPA	86	59	73	86	62	71	4.0	3.4	30.0	65	61	98	139	128	107	0	88	24	82	4	0
WEST PALM BEACH	82	59	73	84	64	75	4.4	3.4	38.4			73	155	137	131	0	79	8	54	1	0
GEORGIA																					
ATHENS	81	59	65	91	60	70	3.8	2.8	23.2			112	106	147	111	1	52	39	48	53	*
ATLANTA	79	60	64	90	63	70	4.7	3.3	31.3	48	62	108	111	146	116	1	50	30	20	60	*
AUGUSTA	83	55	68	89	57	70	3.1	2.6	27.7			108	106	151	107	*	56	28	60	59	0
COLUMBUS	85	60	71	89	59	70	3.4	2.5	24.6			115	98	152	112	*	59	20	73	46	0
MACON	83	59	65	90	58	68	3.7	3.1	31.3	54	64	112	105	148	112	*	57	26	71	50	0
ROME	81	58	73	88	54	67						105	117	143	123	1	61	26	59	81	*
SAVANNAH	84	55	68	90	60	74	3.8	3.3	29.5	54	63	105	111	149	112	*	64	40	57	36	0
HAWAII																					
HILO	84	79	67	88	[illegible]	67	3.3	3.1	13.4	45	42	31	126	208	282	0	9	0	1	0	0
HONOLULU	81	61	63	69	65	51	4.4	6.1	30.0	63	73	90	173	102	102	0	7	0	10	0	0
KAHULUI	85	85	64	80	71	54	5.0	7.1	19.2	66	75	124	148	93	95	0	5	0	20	0	0
LIHUE	83	83	68	80	75	65	4.6	5.8	32.6	51	62	51	177	137	202	0	9	0	*	0	0
IDAHO																					
BOISE	80	74	71	53	33	22	3.8	3.8	27.3	41	88	124	90	151	91	8	15	19	43	124	2
LEWISTON	81	76	72	60	37	23			32.2			93	76	196	103	6	16	21	39	94	2
POCATELLO	75	71	67	61	33	23	5.0	4.1	32.2	37	83	109	99	157	93	13	23	16	33	172	10

NORMALS, MEANS AND EXTREMES

YEAR 1977

State and Station	Elevation Ground (Meters)	Normal (1941-1970) January Daily Maximum	January Daily Minimum	July Daily Maximum	July Daily Minimum	Annual	Extremes Length (Yrs)	Record Highest	Record Lowest	Normal Heating Degree Days (1941-1970) January	Seasonal	Precipitation Normal (1941-1970) Wettest Month	Driest Month	Annual	Extremes Wettest Month	Driest Month	Maximum In 24 Hours	Snow @ Mean Total January	Seasonal	Extreme Maximum In 24 Hours
ILLINOIS							88	47.2	-37.2							0	420			
CAIRO U	96	6.5	-1.8	32.1	22.0	15.2	35	40.0	-20.6	494	2129	132	68	1197	380	T	192	76	239	267
CHICAGO O HARE	201	-0.5	-9.6	28.4	15.9	9.4	19	37.2	-28.9	725	3609	105	33	806	291	3	117	241	950	460
CHICAGO MIDWAY	185	-0.3	-8.3	29.1	18.3	10.3	35	40.0	-28.3	701	3404	104	40	875	360	5	158	251	1044	503
MOLINE	177	-1.1	-10.6	29.6	17.7	9.9	45	41.1	-32.2	749	3552	114	33	909	360	T	160	196	770	417
PEORIA	199	-0.1	-9.1	29.7	18.1	10.4	36	39.4	-31.7	709	3387	111	39	891	332	1	129	152	617	259
ROCKFORD	221	-1.7	-11.4	29.0	16.3	8.9	27	39.4	-30.0	772	3802	117	33	933	300	T	141	201	866	277
SPRINGFIELD	179	1.6	-7.4	30.3	18.7	11.5	30	44.4	-30.0	659	3087	106	44	890	252	4	130	140	587	277
INDIANA							91	46.7	-37.2							0	309			
EVANSVILLE	116	5.3	-4.6	31.6	19.3	13.3	37	40.6	-30.6	558	2569	119	64	1064	343	T	154	94	340	269
FORT WAYNE	241	0.3	-7.8	28.7	16.9	9.9	31	39.4	-28.3	684	3449	99	52	909	247	4	117	173	800	345
INDIANAPOLIS	241	2.2	-6.8	29.7	18.1	11.3	36	40.0	-28.9	639	3098	104	60	984	322	4	120	132	549	318
SOUTH BEND	236	-0.3	-8.6	28.2	16.5	9.5	38	38.3	-30.0	706	3590	102	49	919	248	1	119	419	1740	445
IOWA							105	47.8	-43.9							0	424			
BURLINGTON	211	-0.2	-9.9	30.1	18.1	10.4	80	43.9	-32.8	725	3416	120	32	880	384	2	160	183	653	330
DES MOINES	286	-2.5	-11.5	29.4	18.5	9.4	38	40.6	-31.1	785	3727	124	27	784	360	1	157	216	841	503
DUBUQUE	322	-3.3	-12.6	27.8	16.3	8.1	27	37.2	-33.3	814	4042	134	32	1023	393	T	225	211	1082	394
SIOUX CITY	334	-2.1	-13.5	30.4	17.7	9.1	37	41.7	-32.2	809	3862	117	17	654	262	T	140	160	777	290
WATERLOO	265	-3.5	-13.9	28.7	16.4	8.0	29	39.4	-36.7	839	4119	127	23	857	320	T	236	163	792	376
KANSAS							91	49.4	-40.0							0	320			
CONCORDIA	448	2.7	-9.0	32.1	18.9	11.7	16	42.2	-27.2	665	3124	127	17	701	359	T	139	127	551	335
DODGE CITY	787	5.9	-7.2	33.0	19.4	12.7	35	41.7	-26.1	599	2803	85	13	523	232	T	116	102	462	325
GOODLAND	1114	5.3	-10.2	32.5	16.1	10.3	57	43.9	-32.2	644	3399	74	9	423	205	0	98	137	853	386
TOPEKA	267	3.5	-7.9	31.8	19.6	12.4	31	42.8	-28.9	637	2912	147	25	880	386	T	140	145	528	386
WICHITA	403	5.2	-6.0	33.2	20.9	13.7	25	45.0	-24.4	580	2604	114	22	777	266	T	126	107	384	343
KENTUCKY							89	45.6	-36.7							0	264			
COVINGTON	265	4.3	-5.3	30.3	18.1	12.2	16	38.9	-31.7	584	2816	105	55	992	309	5	132	173	607	249
LEXINGTON	294	5.2	-4.2	30.2	18.8	12.9	33	39.4	-29.4	553	2627	129	54	1130	423	6	149	142	404	241
LOUISVILLE	145	5.6	-4.2	30.7	19.1	13.1	30	40.6	-28.9	546	2578	128	60	1095	379	6	177	137	447	330
LOUISIANA							87	45.6	-26.7							0	559			
ALEXANDRIA 1977	28	14.8	2.6	33.0	21.3	18.3	17	40.0	-15.0	304	1222	142	83	1373	332	2	157	10	18	185
BATON ROUGE	20	16.4	4.7	32.9	22.6	19.7	27	39.4	-12.2	251	928	165	67	1373	369	2	307	T	5	46
LAKE CHARLES	3	16.4	6.1	32.9	23.1	20.2	13	37.2	-7.8	231	832	164	89	1409	507	T	358	8	8	102
NEW ORLEANS INTL AP	1	16.8	6.4	32.4	22.9	20.2	31	37.8	-10.0	224	814	171	57	1442	485	0	250	T	5	69
SHREVEPORT	77	13.7	3.2	34.2	22.7	18.8	25	41.7	-16.1	307	1204	132	68	1136	315	0	182	18	36	137
MAINE							90	40.6	-44.4							0	204			
CARIBOU	190	-6.8	-16.9	24.2	12.3	3.8	38	35.6	-40.6	935	5351	101	52	910	215	3	158	584	2868	462
PORTLAND	13	-0.4	-11.3	26.2	13.8	7.2	37	39.4	-39.4	749	4165	129	66	1036	312	T	196	460	1892	579
MARYLAND							82	42.8	-40.0							0	375			
BALTIMORE INTL AP	45	5.5	-3.9	30.4	19.2	12.8	27	38.9	-21.7	544	2627	107	71	1028	466	T	199	130	538	394
MASSACHUSETTS							90	41.7	-36.7							0	461			
BLUE HILL OBS R	192	0.9	-7.4	26.9	16.5	9.3	92	38.3	-29.4	668	3519	129	75	1189	477	2	252	391	1532	716
BOSTON	5	2.2	-5.3	27.4	18.4	10.7	26	38.9	-24.4	617	3122	119	70	1080	434	9	213	310	1069	493
NANTUCKET 1969	13	3.5	-3.7	23.7	16.2	9.7	4	32.2	-16.7	572	3294	110	59	1101	328	T	166	221	884	511
PITTSFIELD 1968	357	-0.8	-10.5	26.2	13.6	7.2	29	35.0	-31.7	744	4210	124	64	1128	262	11	108	483	1981	432
WORCESTER	301	-0.6	-8.8	26.3	16.0	8.4	22	35.6	-28.3	713	3804	119	81	1149	334	17	122	417	1885	610
MICHIGAN							91	44.4	-46.1							0	248			
ALPENA	210	-2.8	-12.9	26.1	11.1	5.6	19	36.7	-33.3	813	4732	89	34	701	213	4	81	528	2156	409
DETROIT CITY AP	189	-0.2	-7.1	28.4	17.4	9.9	43	40.6	-26.7	680	3460	87	46	786	204	3	94	201	805	254
DETROIT METRO. AP	193	-0.1	-8.2	28.6	16.2	9.5	19	38.9	-27.8	695	3566	87	44	805	199	4	94	219	1013	488
DETROIT W R 1968	217	0.8	-6.8	30.0	16.9	10.0	7	37.2	-25.0	661	3476	89	49	779	221	6	121	183	831	221
FLINT	235	-1.2	-9.7	27.3	14.6	8.2	21	37.2	-31.7	735	3911	87	40	756	280	2	153	282	1151	503

State and Station	Relative Humidity (Percent) January 7:00 a.m. EST	January 1:00 p.m. EST	January 7:00 p.m. EST	July 7:00 a.m. EST	July 1:00 p.m. EST	July 7:00 p.m. EST	Wind Speed (m.p.s.) Mean Speed January	Mean Speed July	Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	Sunshine July	Annual Mean Number of Days Sunrise to Sunset Clear	Partly Cloudy	Cloudy	Precipitation .25mm or More	Snow, Sleet, Hail 25.4mm or More	Thunderstorms	Heavy Fog	Temperature Max ≥ 32.2°C	Min ≤ 0°C	Min ≤ -17.8°C
ILLINOIS																					
CAIRO U	80	67		84	59		4.4	2.9	28.2	45	75	114	104	147	115	3	53	7	47	65	*
CHICAGO O HARE	76	68	71	81	57	57	5.2	3.6	25.9			85	108	172	125	11	38	16	16	130	13
CHICAGO MIDWAY	72	65	68	77	54	55	5.1	3.8	26.8	44	70	94	102	169	123	13	41	12	22	119	8
MOLINE	72	65	68	84	56	58	4.8	3.4	34.4	49	71	101	102	162	112	10	47	19	22	135	17
PEORIA	78	68	72	86	58	59	5.0	3.6	33.5	46	69	98	99	168	112	8	49	21	17	131	12
ROCKFORD	77	69	73	85	55	56	4.6	3.6	24.1			96	100	169	115	11	42	23	13	142	18
SPRINGFIELD	78	69	72	83	55	57	5.8	3.8	33.5	47	73	107	94	164	113	8	50	18	28	118	9
INDIANA																					
EVANSVILLE	77	66	68	84	57	58	4.2	2.8	26.4	43	76	103	100	162	115	4	46	14	39	102	4
FORT WAYNE	79	71	75	83	54	57	5.2	3.7	29.1	43	73	79	102	184	131	10	41	19	14	133	11
INDIANAPOLIS	81	69	72	87	60	62	5.0	3.4	40.2	42	70	92	99	174	123	8	45	20	19	121	8
SOUTH BEND	80	73	75	84	57	59	5.4	3.7	28.2			73	104	188	142	23	43	24	11	124	7
IOWA																					
BURLINGTON	79	69	73	85	58	60	5.1	3.5	23.2	53	77	101	105	159	104	9	51	18	31	128	11
DES MOINES	76	69	70	81	56	55	5.3	4.0	34.0	51	72	104	96	165	106	10	50	17	24	136	17
DUBUQUE	73	66	73	83	59	64						91	99	175	114	14	45	28	[illegible]	149	23
SIOUX CITY	77	69	71	85	58	55	5.0	4.1	40.7	58	76	107	103	155	98	10	45	19	24	149	23
WATERLOO	75	68	72	86	58	59	5.1	3.9	24.1			91	105	169	98	9	42	22	14	160	29
KANSAS																					
CONCORDIA	82	67	70	81	51	47	5.4	5.2	30.4	64	80	134	94	137	89	7	59	17	47	129	8
DODGE CITY	76	57	58	75	44	39	6.1	5.8	34.9	68	79	137	105	123	77	6	53	23	64	125	4
GOODLAND	77	56	60	82	45	40	5.5	5.4	29.5			142	122	101	76	11	49	28	45	158	8
TOPEKA	77	65	67	85	58	56	4.6	4.0	36.2	55	69	112	97	156	95	7	58	14	38	122	6
WICHITA	79	63	65	78	49	45	5.5	5.0	29.5	60	74	128	96	141	84	4	55	17	64	113	2
KENTUCKY																					
COVINGTON	78	67	69	85	57	61	4.8	3.2	20.6			79	100	186	129	7	44	26	21	109	6
LEXINGTON	78	67	69	85	59	64	5.1	3.3	20.6			94	103	168	131	5	47	19	16	96	3
LOUISVILLE	77	64	64	86	58	60	4.3	3.0	27.3	42	66	93	104	168	125	5	45	9	25	92	2
LOUISIANA																					
ALEXANDRIA 1977	88	67	73	96	60	68	3.3	2.2	20.6			110	109	146	106	*	69	39	75	43	0
BATON ROUGE	85	65	67	91	62	70	4.2	2.7	25.9			100	118	147	108	*	70	37	82	24	0
LAKE CHARLES	88	70	77	93	64	72	4.6	2.9	25.9			96	121	148	97	*	77	48	69	13	0
NEW ORLEANS INTL AP	86	67	73	91	66	73	4.2	2.8	30.8	47	58	109	120	136	114	*	69	30	66	13	0
SHREVEPORT	83	63	65	90	57	57	4.4	3.3	23.2	50	73	117	102	146	97	*	54	27	88	35	0
MAINE																					
CARIBOU	73	67	72	82	58	70	5.5	4.4				57	101	207	160	31	20	27	2	189	44
PORTLAND	77	62	70	80	60	75	4.1	3.4	34.0	56	64	107	97	161	127	18	18	52	5	160	15
MARYLAND																					
BALTIMORE INTL AP	72	58	62	81	53	64	4.4	3.6	35.8	52	65	107	108	150	112	7	28	29	31	99	*
MASSACHUSETTS																					
BLUE HILL OBS R	76	62	68	81	58	74	7.8	5.8	41.1	46	57				135	16			3	132	4
BOSTON	66	57	61	73	56	66	6.3	4.8	27.3	54	66	99	105	161	128	11	19	23	14	99	1
NANTUCKET 1969	79	67	75	87	76	91	6.6	4.9	32.6	42	60	86	93	186	125	8	20	98	1	108	0
PITTSFIELD 1968												57	127	181	152	24	28		3	163	14
WORCESTER	74	59	66	74	57	67	5.5	3.8	34.0			91	106	168	129	18	21	64	3	147	7
MICHIGAN																					
ALPENA	78	69	73	83	53	60	3.7	3.0	19.7	39	68	72	106	187	146	26	33	26	9	183	25
DETROIT CITY AP	78	68	73	74	51	54	5.2	3.8	20.6	32	70	80	108	177	131	11	32	11	13	124	2
DETROIT METRO. AP	79	70	74	82	52	57	5.3	3.9	38.9	30	69	76	108	181	134	13	33	23	14	138	7
DETROIT W R 1968	78	70	72	82	49	52	5.4	3.9	26.8			78	107	180	125	12	33	29	13	143	7
FLINT	77	69	72	82	55	58	5.3	3.4	36.2			67	107	191	132	14	33	19	9	138	9

NORMALS, MEANS AND EXTREMES

State and Station	Elevation Ground (Meters)	Temp. Normal (1941-1970) January Daily Maximum	January Daily Minimum	July Daily Maximum	July Daily Minimum	Annual	Extremes Length (Yrs)	Record Highest	Record Lowest	Normal Heating Degree Days (1941-1970) January	Seasonal	Precip. Normal (1941-1970) Wettest Month	Driest Month	Annual	Precip. Extremes Wettest Month	Driest Month	Maximum In 24 Hours	Snow @ Mean Total January	Seasonal	Ex-treme Maximum In 24 Hours
MICHIGAN																				
GRAND RAPIDS	239	-0.9	-8.9	28.5	15.3	8.8	14	37.8	-28.3	720	3778	87	38	823	205	4	83	531	1946	384
HOUGHTON LAKE	350	-3.4	-12.8	26.0	12.0	5.9	13	35.6	-37.8	820	4637	85	30	721	182	8	66	480	2113	297
LANSING	256	-1.2	-9.3	28.1	15.1	8.6	19	37.8	-31.7	730	3835	88	41	772	249	4	110	295	1237	518
MARQUETTE U	206	-4.0	-11.1	24.1	14.1	5.9	41	40.0	-29.4	803	4639	89	39	783	259	5	118	544	2725	409
MUSKEGON	191	-1.1	-7.9	26.9	15.3	8.5	38	37.2	-26.1	706	3827	85	45	801	251	3	94	767	2436	511
SAULT STE MARIE	220	-5.6	-14.2	23.9	11.4	4.4	37	36.7	-34.4	875	5107	98	38	805	241	4	150	678	2814	363
MINNESOTA							91	45.6	-50.6							0	275			
DULUTH	435	-8.0	-18.1	24.7	12.6	3.7	36	36.1	-39.4	973	5419	113	22	767	262	3	103	434	1976	645
INTERNATIONAL FALLS	359	-10.7	-22.8	25.7	11.9	2.5	36	36.7	-43.3	1087	5859	101	18	652	286	3	124	292	1527	450
MINNEAPOLIS	254	-6.0	-16.0	28.0	16.3	6.7	39	40.0	-36.7	909	4532	100	19	659	236	T	187	234	1171	411
ROCHESTER	395	-5.6	-15.6	27.1	15.3	6.4	18	38.9	-35.6	897	4570	115	17	698	212	1	83	224	1128	287
ST CLOUD	313	-7.1	-18.6	27.7	14.8	5.4	38	39.4	-41.7	966	4926	118	19	682	237	T	117	218	1095	368
MISSISSIPPI							89	46.1	-28.3							0	398			
JACKSON	94	14.7	2.1	33.7	21.4	18.3	14	39.4	-14.4	318	1278	143	56	1249	384	0	178	13	30	135
MERIDIAN	88	14.7	1.9	33.6	21.1	18.1	32	40.0	-17.8	319	1327	158	55	1310	427	0	207	13	36	381
MISSOURI							90	47.8	-40.0							0	462			
COLUMBIA MUNI 1969	237	4.1	-5.9	32.1	19.8	12.8	30	45.0	-27.8	598	2803	119	43	939	338	2	111	112	493	262
COLUMBIA REGIONAL	270	3.3	-6.3	30.8	19.5	12.4	8	39.4	-27.8	615	2821	119	40	950	256	5	101	127	549	300
KANSAS CITY	309	2.1	-7.6	31.1	19.4	12.1	5	41.7	-25.0	653	2976	141	32	940	288	3	224	150	495	155
KANSAS CITY 1971	226	4.4	-4.8	33.3	21.7	13.8	12	41.1	-22.8	573	2617	114	31	865	303	1	189			
ST JOSEPH	247	2.2	-8.7	31.7	19.7	12.1	28	41.7	-31.7	668	3022	165	26	906	349	T	181	147	488	287
ST LOUIS	163	4.4	-5.2	31.3	20.4	13.3	20	41.1	-25.6	580	2639	112	47	912	231	2	84	117	470	305
SPRINGFIELD	386	6.2	-5.2	31.7	19.2	13.4	32	45.0	-23.9	553	2539	129	42	1008	476	2	174	79	394	399
MONTANA							111	47.2	-56.7							0	292			
BILLINGS	1087	-0.4	-10.9	29.8	14.4	7.9	43	41.1	-38.9	742	4036	66	16	359	194	T	72	239	1422	602
GLASGOW	696	-7.3	-18.1	29.1	13.7	5.3	22	41.1	-43.9	961	4982	69	8	276	136	T	101	178	683	224
GREAT FALLS	1116	-1.5	-11.3	28.7	12.7	7.2	40	41.1	-41.7	767	4251	79	17	381	207	T	81	254	1468	427
HAVRE	788	-5.5	-17.5	29.4	12.7	5.7	17	43.9	-46.7	925	4826	69	10	293	127	T	59	241	1107	683
HELENA	1167	-2.1	-13.4	28.7	11.2	6.2	37	40.6	-41.1	808	4550	60	10	289	120	1	52	231	1222	546
KALISPELL	904	-2.7	-11.7	27.1	8.8	5.4	28	40.6	-38.9	790	4752	65	22	412	120	T	60	485	1702	391
MILES CITY	801	-3.3	-15.2	31.6	15.4	7.4	40	43.3	-38.3	854	4382	84	12	354	248	T	69	163	820	267
MISSOULA	972	-1.9	-10.6	29.1	9.4	6.5	33	40.6	-36.1	761	4406	54	18	339	106	T	46	335	1250	366
NEBRASKA							107	47.8	-43.9							0	334			
GRAND ISLAND	561	0.7	-11.6	31.5	17.7	10.1	32	42.8	-33.3	735	3566	112	13	595	355	0	149	145	737	307
LINCOLN	359	0.4	-11.3	31.6	18.7	10.6	6	41.1	-36.1	737	3434	131	19	727	191	T	89	173	721	264
LINCOLN U 1971	351	1.1	-8.8	33.5	19.9	11.6	7	40.6	-27.8	687	3237	114	23	697	328	1	137	160	734	483
NORFOLK	471	-1.3	-13.3	30.6	17.7	9.1	32	45.0	-32.8	794	3878	124	16	618	310	T	140	145	732	267
NORTH PLATTE	846	2.6	-12.2	30.9	16.1	9.2	26	44.4	-31.7	717	3746	96	10	505	203	T	97	137	759	302
OMAHA	298	0.4	-10.9	31.4	18.8	10.8	42	45.6	-30.0	730	3360	129	19	767	349	T	164	216	813	465
OMAHA (NORTH)	399	-1.6	-11.6	29.7	18.2	9.7	23	41.7	-30.0	772	3667	125	18	748	358	1	94	36	622	112
SCOTTSBLUFF	1206	3.6	-11.5	31.6	14.8	9.0	35	42.8	-35.6	690	3763	85	8	370	212	T	95	155	965	381
VALENTINE	789	0.7	-13.4	31.3	15.4	8.3	23	42.8	-33.9	768	4055	91	8	452	228	T	86	114	721	610
NEVADA							89	50.0	-45.6							0	188			
ELKO	1539	2.2	-12.0	32.4	9.2	7.4	47	40.0	-41.7	720	4157	29	9	248	117	0	105	254	988	424
ELY	1906	3.3	-12.7	30.2	8.9	6.7	39	37.2	-33.3	713	4341	25	14	221	90	0	39	216	1209	333
LAS VEGAS	659	13.2	0.3	39.9	24.1	18.8	29	46.7	-13.3	358	1445	17	2	96	66	0	66	28	36	229
RENO	1342	7.4	-7.6	32.8	8.6	9.7	36	40.0	-26.7	570	3345	31	6	183	132	0	60	160	673	429
WINNEMUCCA	1311	4.8	-9.1	32.8	10.5	8.8	24	41.1	-36.7	634	3682	24	6	215	73	0	45	145	645	251
NEW HAMPSHIRE							101	41.1	-43.3							0	264			
CONCORD	104	-0.4	-12.3	28.1	13.7	7.6	36	38.9	-37.3	764	4088	101	62	919	257	10	114	437	1646	483
MT WASHINGTON OBS	1909	-9.9	-19.3	12.6	6.1	-2.8	45	22.2	-43.9	1021	7709	195	130	1935	649	19	264	930	6259	1252
NEW JERSEY							93	43.3	-36.7							0	376			
ATLANTIC CITY	20	5.2	-4.4	29.3	18.6	12.1	34	41.1	-23.3	556	2748	124	76	1155	332	3	164	124	401	366
NEWARK	7	3.6	-4.3	29.8	19.6	12.2	36	40.6	-21.7	579	2796	108	72	1053	301	2	199	175	693	660

State and Station	Relative Humidity (Percent) January 7:00 a.m. EST	January 1:00 p.m. EST	January 7:00 p.m. EST	July 7:00 a.m. EST	July 1:00 p.m. EST	July 7:00 p.m. EST	Wind Speed (m.p.s.) Mean Speed January	Mean Speed July	Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	July	Annual Mean Number of Days Sunrise to Sunset Clear	Partly Cloudy	Cloudy	Precipitation 25mm or More	Snow, Sleet, Hail 25.4mm or More	Thunderstorms	Heavy Fog	Temperature Max ≥ 32.2°C	Min ≤ 0°C	Min ≤ 17.8°C
MICHIGAN																					
GRAND RAPIDS	81	72	77	82	54	56	5.2	3.8	29.5	33	66	65	97	203	145	25	37	27	14	149	9
HOUGHTON LAKE	83	73	78	85	55	58	4.6	3.4	17.9			69	100	196	147	28	35	30	12	175	24
LANSING	82	74	78	84	55	59	5.5	3.7	28.2	36	71	75	105	185	140	16	34	23	14	150	12
MARQUETTE U	75	68	72	76	63	66	4.0	3.2	26.4	35	67	61	101	203	158	32	28	17	5	160	11
MUSKEGON	80	75	77	83	58	59	5.7	3.9	20.6			78	90	197	144	31	38	23	3	140	5
SAULT STE MARIE	82	76	81	86	62	67	4.5	3.7	26.8	35	63	66	90	209	165	36	29	46	1	179	29
MINNESOTA																					
DULUTH	75	69	69	84	58	58	5.4	4.4	33.5	49	67	77	102	186	135	22	35	54	2	185	51
INTERNATIONAL FALLS	73	68	69	87	56	57	4.1	3.6	23.2			82	101	182	133	18	31	15	4	198	49
MINNEAPOLIS	73	67	68	81	54	53	4.6	4.2	41.1	50	71	98	103	164	114	14	37	11	15	158	35
ROCHESTER	77	73	75	84	59	60	6.4	4.7	23.7			88	100	177	116	13	41	34	7	163	36
ST CLOUD	76	68	71	87	54	55	3.7	3.1				96	101	168	108	14	36	20	11	177	46
MISSISSIPPI																					
JACKSON	87	65	71	93	59	66	4.0	2.7	20.1	49	62	111	106	148	112	*	66	25	79	48	0
MERIDIAN	86	61	70	91	58	66	3.1	2.1	17.9			111	112	142	104	*	59	26	75	54	0
MISSOURI																					
COLUMBIA MUNI 1969	79	65	68	85	55	56	5.0	3.6	28.2	52	74	116	96	153	107	6	55	14	40	109	4
COLUMBIA REGIONAL	78	67	68	83	52	52	4.8	3.8	25.9	54	75	97	92	176	110	8	52	24	34	106	7
KANSAS CITY	74	64	58	80	52	50	4.9	3.8	31.3	62	82	125	90	150	102	7	51	25	37	105	7
KANSAS CITY 1971																					
ST JOSEPH	74	63	68	82	56	52	4.7	3.5	26.8			124	98	143	93	6	56	19	44	120	7
ST LOUIS	82	65	69	86	57	56	4.6	3.4	26.8	54	72	103	103	159	109	6	45	11	37	106	4
SPRINGFIELD	77	60	64	86	56	57	5.4	3.9	29.5	51	72	117	98	150	107	5	58	20	40	105	3
MONTANA																					
BILLINGS	64	60	57	63	39	40	5.9	4.4	35.3	47	78	89	117	159	95	19	29	18	28	151	18
GLASGOW	71	68	69	74	44	45	4.6	4.8	20.6			84	111	170	90	9	27	12	21	181	42
GREAT FALLS	66	62	61	64	37	28	7.1	4.6	36.7	48	80	81	105	179	100	20	26	13	24	156	28
HAVRE	73	68	68	71	36	27	4.8	4.2	31.7	48	84	84	104	177	86	14	22	9	28	181	43
HELENA	68	64	62	66	39	28	3.2	3.5	32.6	46	79	81	103	181	96	14	34	8	17	189	21
KALISPELL	79	79	73	81	43	33	3.0	3.0	23.2			73	80	212	131	23	24	31	16	192	16
MILES CITY	74	70	70	68	38	31	4.3	4.4				101	98	156	94	13	28	11	38	171	31
MISSOULA	85	81	77	76	42	40	2.3	3.0	32.2	29	79	74	81	210	123	16	24	27	23	189	10
NEBRASKA																					
GRAND ISLAND	76	64	67	81	51	47	5.3	4.8	25.5			122	102	141	87	9	49	18	40	149	16
LINCOLN	78	67	71	77	46	43	4.4	4.7	26.4	59	74	113	99	153	89	8	48	12	42	145	17
LINCOLN U 1971							4.4	4.2	28.6	58	75	115	104	146	96	8	49	8	33	129	8
NORFOLK	76	64	68	83	52	49	6.2	5.6	0.0			118	99	148	87	9	50	11	34	155	20
NORTH PLATTE	78	63	65	84	52	49	4.1	4.3	32.2	60	74	117	113	135	84	9	48	18	31	180	18
OMAHA	76	65	68	83	56	54	5.0	4.1	48.7			114	106	145	99	9	49	15	37	137	13
OMAHA (NORTH)									0.0	55	75	121	96	148	93	10	41	3	23	140	16
SCOTTSBLUFF	74	58	58	80	42	37	4.8	4.2	35.8			121	108	136	83	12	44	10	38	170	15
VALENTINE	80	66	67	83	50	42	4.5	4.5	32.6	65	77	123	105	137	79	9	45	5	34	175	26
NEVADA																					
ELKO	74	69	75	55	25	19	2.4	2.8	25.9			132	98	135	77	14	21	6	43	193	12
ELY	71	60	64	51	24	22	4.7	4.6	33.1	66	80	133	110	122	72	15	32	2	16	218	19
LAS VEGAS	52	38	28	29	19	14	3.2	4.5	28.6	78	87	215	83	67	24	*	15	1	134	39	0
RENO	75	67	50	66	28	19	2.6	3.0	35.8	66	92	165	90	110	49	9	14	9	52	189	3
WINNEMUCCA	77	66	74	52	22	15	3.4	3.8	29.5	48	86	137	89	139	67	9	14	4	56	192	7
NEW HAMPSHIRE																					
CONCORD	74	59	66	85	53	67	3.3	2.5	32.2	52	62	93	111	161	125	18	20	51	14	176	27
MT WASHINGTON OBS	83	83	83	91	87	90	20.7	11.2	3.3	33	30	49	73	243	208	68	16	317	0	243	66
NEW JERSEY																					
ATLANTIC CITY	75	57	69	84	58	72	5.2	4.0	26.8	50	60	97	107	161	112	4	25	47	19	110	1
NEWARK	73	58	64	71	51	58	5.0	3.4	36.7			96	112	157	122	7	25	19	24	87	*

NORMALS, MEANS AND EXTREMES

State and Station	Elevation Ground (Meters)	Temp. Normal (1941-1970) January Daily Maximum	Temp. Normal January Daily Minimum	Temp. Normal July Daily Maximum	Temp. Normal July Daily Minimum	Temp. Normal Annual	Temp. Extremes Length (Yrs)	Temp. Extremes Record Highest	Temp. Extremes Record Lowest	Normal Heating Degree Days (1941-1970) January	Normal Heating Degree Days Seasonal	Precip. Normal (1941-1970) Wettest Month	Precip. Normal Driest Month	Precip. Normal Annual	Precip. Extremes Wettest Month	Precip. Extremes Driest Month	Precip. Extremes Maximum In 24 Hours	Snow @ Mean Total January	Snow @ Mean Total Seasonal	Snow @ Extreme Maximum In 24 Hours	RH January 7:00 a.m. EST	RH January 1:00 p.m. EST	RH January 7:00 p.m. EST	RH July 7:00 a.m. EST	RH July 1:00 p.m. EST	RH July 7:00 p.m. EST	Wind Mean Speed January	Wind Mean Speed July	Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	Sunshine July	Sunrise to Sunset Clear	Partly Cloudy	Cloudy	Precipitation .25mm or More	Snow, Sleet, Hail 25.4mm or More	Thunderstorms	Heavy Fog	Temperature Max ≥ 32.2°C	Temperature ≤ 0°C	Temperature Min ≤ -17.8°C
NEW JERSEY																																											
TRENTON U	17	3.8	-3.7	29.4	19.3	12.2	45	41.1	-25.6	567	2748	120	64	1020	358	1	192	145	577	422							4.4	3.5	28.6	51	55	100	116	149	121	7	33		17	88	*
NEW MEXICO							86	46.7	-45.6							0	287																								
ALBUQUERQUE	1619	8.3	-4.7	33.4	18.4	13.8	38	40.6	-27.2	513	2384	35	7	197	85	0	49	58	267	361	59	69	38	62	36	28	3.6	4.1	40.2	73	76	174	108	83	59	4	42	5	61	123	1
CLAYTON	1515	8.6	-7.4	30.7	15.5	11.5	33	40.0	-29.4	549	2892	70	7	404	197	0	119	81	483	323	64	42	47	78	42	42						164	97	104	67	7	54	11	35	143	3
RATON 1968	1944	7.4	-10.8	30.3	11.6	9.4	23	36.7	-35.0	620	3460	67	7	375	303	0	142	122	615	257		45			38							134	132	99	78	9	75	8	16	182	9
ROSWELL 1972	1101	12.8	-6.3	35.2	16.5	14.7	12	43.3	-22.2	467	2107	46	9	295	142	0	108	69	282	389	70	46	37	73	40	35	3.8	4.2	33.5	78	76	178	102	85	50	4	40	9	107	109	1
ROSWELL	1112	13.0	-6.2	34.8	17.6	15.1	5	41.7	-16.1	463	2054	41	7	269	165	0	100	66	269	119	68	48	38	73	45	36	3.5	4.1	32.6	69	76	173	118	74	46	3	33	14	83	90	0
SILVER CITY 1968	1638	11.4	-3.1	32.4	17.7	14.6	7	38.9	-22.8	439	2058	61	7	273	114	0	53	66	213	178		43	39		36	36						187	110	68	60	3	54	1	43	105	
NEW YORK							88	42.2	-46.7							0	284																								
ALBANY	84	-0.9	-10.8	28.8	15.6	8.7	31	37.8	-33.3	749	3826	83	54	847	228	5	115	381	1669	556	79	63	73	80	55	64	4.4	3.3	31.7	46	63	71	110	184	136	16	28	23	8	154	16
BINGHAMTON	485	-1.8	-9.3	25.8	15.3	7.8	26	35.6	-28.9	740	4047	97	57	949	245	7	99	483	2207	584	80	72	75	85	58	66	5.2	3.8	32.2	38	55	46	106	213	164	25	31	53	2	149	8
BINGHAMTON U 1968	262	1.2	-7.3	28.4	15.8	9.3	77	39.4	-33.3	661	3584	97	60	932	244	4	116	325	1326	533															151	15				133	7
BUFFALO	215	-1.2	-8.0	26.4	15.9	8.4	34	37.2	-28.9	711	3848	99	57	917	271	8	99	584	2360	617	78	73	76	79	55	61	6.5	4.7	40.7	33	69	55	102	208	169	27	31	19	2	136	5
NEW YORK CENTRAL PK.	40	3.6	-3.4	29.6	20.0	12.5	109	41.1	-26.1	565	2693	102	69	1021	428	1	284	193	737	671	68	60	61	75	55	63	4.8	3.4	31.3	50	65	107	125	133	121	8	19		1	81	*
NEW YORK KENNEDY	4	3.3	-4.0	28.4	19.4	11.7	17	40.0	-18.9	579	2880	109	68	1055	442	T	167	170	597	505	71	59	64	74	58	71	6.0	4.8	23.2			96	122	147	118	7	22	32	10	85	*
NEW YORK LA GUARDIA	3	3.2	-3.1	28.9	20.7	12.4	16	41.7	-18.9	567	2727	114	73	1057	408	1	181	163	665	579	65	56	58	71	52	60	6.2	4.6	31.3			93	117	155	120	7	24	13	13	75	*
ROCHESTER	167	-0.4	-8.5	27.9	15.7	8.8	37	37.8	-26.7	706	3732	79	57	796	246	6	98	546	2207	475	75	68	73	81	53	59	5.3	3.6	32.6	37	69	61	109	195	155	27	29	13	10	135	6
SYRACUSE	125	-0.3	-9.0	27.8	16.1	8.9	28	36.7	-32.2	713	3710	89	68	925	312	5	108	668	2812	622	76	68	74	81	56	64	4.9	3.8	28.2	35	65	63	100	202	169	33	29	9	7	137	9
NORTH CAROLINA							91	42.8	-33.9							0	564																								
ASHEVILLE	652	9.1	-2.6	29.1	17.0	13.2	19	35.6	-21.7	467	2354	124	75	1148	287	4	130	112	442	414	86	60	69	96	64	75	4.3	2.6	26.8	56	60	101	113	151	127	5	49	84	6	105	1
CAPE HATTERAS R	2	11.3	3.4	28.8	22.3	16.5	20	35.0	-11.1	339	1517	171	79	1413	372	11	206	10	41	178	80	68	78	85	70	82	5.6	4.6	19.7	49	63	106	100	159	122	1	45	17	3	32	0
CHARLOTTE	224	11.2	0.1	31.3	20.4	15.8	38	40.0	-19.4	394	1788	114	68	1085	317	T	136	53	135	305	78	57	62	88	58	67	3.6	3.0	26.4	55	59	111	104	150	111	2	42	26	33	72	0
GREENSBORO	273	9.3	-1.9	30.8	19.4	14.5	49	38.9	-21.7	453	2125	112	67	1051	337	3	190	84	221	363	81	58	65	90	60	70	3.7	3.0	28.2	52	62	112	105	148	118	2	47	32	29	85	*
RALEIGH	132	10.6	-1.1	30.9	19.6	15.1	33	40.6	-18.3	422	1952	129	71	1081	329	6	132	66	173	236	78	55	63	90	59	72	3.8	3.0	32.6	55	61	114	106	145	112	2	46	36	27	82	*
WILMINGTON	9	13.7	2.3	31.6	22.2	17.6	20	40.0	-12.2	326	1352	212	75	1361	394	4	209	10	48	297	81	58	72	87	64	78	4.2	3.6	39.3	57	63	114	105	146	118	1	46	24	41	42	0
NORTH DAKOTA							86	49.4	-51.1							0	206																								
BISMARCK	502	-7.2	-19.3	29.1	14.1	5.2	38	42.8	-42.2	978	5024	91	11	410	211	T	83	178	983	394	73	67	69	82	46	42	4.5	4.2	32.2	54	76	94	107	164	96	12	34	12	21	186	50
FARGO	273	-9.2	-19.8	28.2	14.8	4.9	25	41.1	-37.2	1018	5150	81	11	498	239	1	120	185	902	320	73	71	72	85	54	52	5.8	4.9	31.4	50	71	87	112	166	102	12	33	13	14	180	54
WILLISTON	579	-7.1	-19.3	28.9	13.4	4.9	16	41.7	-40.6	977	5089	83	12	364	187	T	128	178	945	236	78	72	74	81	46	38	4.5	4.2	31.3	48	75	88	108	169	95	12	27	10	20	190	53
OHIO							104	45.0	-39.4							0	267																								
AKRON	368	1.1	-7.4	28.1	16.0	9.8	29	37.8	-29.4	667	3457	98	55	892	290	5	106	264	1214	455	78	69	71	84	56	62	5.2	3.4	22.8			70	100	195	153	15	40	28	7	127	6
CINCINNATI ABBE OBS.	232	4.3	-4.3	30.3	18.8	12.7	62	42.8	-27.2	567	2691	105	56	1017	347	3	121	130	480	279							3.7	2.3	21.9	41	68				131	6	50		28	98	2
CLEVELAND	237	0.8	-6.5	27.6	16.2	9.8	36	39.4	-28.3	656	3419	89	55	889	241	9	102	274	1326	381	76	69	71	82	58	62	5.6	3.9	33.1	32	68	69	100	196	157	18	36	13	8	124	6
COLUMBUS	247	2.4	-6.4	29.3	16.9	10.8	38	38.9	-28.3	630	3167	107	48	940	248	3	122	191	704	226	76	67	69	84	56	60	4.6	3.0	28.2	37	63	74	106	185	136	9	42	18	15	122	5
DAYTON	303	2.1	-6.4	29.3	18.0	11.1	34	38.9	-29.4	635	3134	99	49	873	277	3	109	178	706	287	75	67	70	81	54	58	5.3	3.6	34.9	42	68	80	103	182	130	9	40	23	17	117	6
MANSFIELD	395	1.8	-6.3	28.7	17.4	10.7	18	36.1	-28.9	637	3232	96	50	855	205	11	129	246	1046	312	81	72	76	83	56	65	6.0	3.8	20.6			71	100	194	139	14	40	31	7	126	7
TOLEDO	204	0.2	-8.2	28.8	16.0	9.6	22	38.3	-27.2	692	3545	86	44	800	215	T	112	229	988	353	78	68	73	85	54	60	4.9	3.4	32.2	43	68	73	109	183	136	12	40	18	14	144	9
YOUNGSTOWN	359	0.6	-7.6	27.7	15.3	9.3	34	37.8	-27.8	677	3570	99	61	965	251	T	109	323	1463	526	81	73	76	85	55	64	5.3	3.5	25.9			66	98	201	162	19	36	29	7	136	6
OKLAHOMA							86	48.9	-32.8							0	398																								
OKLAHOMA CITY	392	8.7	-3.3	33.7	21.3	15.5	24	42.2	-20.0	486	2053	137	28	797	274	T	195	71	224	213	79	60	61	81	50	67	5.9	5.0	38.9	59	75	141	96	128	81	3	51	19	66	80	*
TULSA	198	8.3	-3.3	33.8	21.9	15.7	39	44.4	-22.2	489	2044	130	36	937	478	T	192	79	231	249	78	59	59	83	54	60	4.8	4.2	33.5	53	72	125	103	137	90	4	52	10	70	84	1
OREGON							88	48.3	-47.8							0	258																								
ASTORIA	2	8.1	1.4	19.8	11.2	10.3	24	37.8	-14.4	420	2941	268	24	1685	556	T	110	79	157	274	86	84	79	89	75	69	4.2	3.7	24.6			50	75	240	198	2	8	43	1	38	0
BURNS U	1265	1.9	-9.4	29.8	10.6	7.8	27	39.4	-32.2	685	4006	49	8	300	146	0	55	361	1201	279	82	76	80	53	36	21	2.8	3.4	33.1			124	92	149	90	16	14	12	21	187	5
EUGENE	109	7.6	0.6	28.1	10.6	11.4	35	41.1	-24.4	441	2633	194	7	1081	532	0	124	127	193	582	91	87	80	87	56	37	3.7	3.6	28.2			74	83	208	137	2	5	58	15	54	*
MEACHAM 1975	1234	0.1	-6.6	25.1	9.9	6.5	31	40.6	-30.6	668	4368	117	14	830	262	0	76	833	3858	582	87	81	79	62	39	26			19.7			94	67	204	146	44	16	31	3	166	4
MEDFORD	396	6.8	-1.7	31.9	12.1	11.7	48	46.1	-21.1	489	2739	94	6	524	323	0	95	102	221	236	89	88	73	73	44	26	1.8	2.6	24.6			118	79	168	101	3	9	48	55	93	*
PENDLETON	452	3.7	-3.7	31.2	14.9	11.3	42	45.0	-30.0	568	2911	41	7	313	119	0	39	196	450	338	80	76	74	53	33	22	3.8	4.2	34.4			106	89	170	99	6	10	29	35	82	3
PORTLAND	6	6.4	0.9	26.1	12.9	11.4	37	41.7	-19.4	463	2662	153	12	955	326	0	67	107	188	269	85	82	76	82	61	45	4.5	3.4	39.3	25	69	70	69	226	152	2	7	33	10	44	*
SALEM	60	7.4	0.1	28.0	10.4	11.3	40	42.2	-24.4	451	2695	179	9	1043	391	0	80	94	178	274	85	83	75	85	57	40	3.9	2.9	25.9			79	80	206	150	2	6	38	17	69	*
SEXTON SUMMIT R	1169	4.3	-1.6	24.3	10.8	8.7	33	37.8	-18.9	526	3572	166	8	934	612	0	152	632	2703	866	80	79	75	65	40	40	5.7	5.3	28.2			128	67	170	129	29	6	160	3	114	*

NORMALS, MEANS AND EXTREMES

State and Station	Elevation Ground (Meters)	Temp. Normal January Daily Maximum	Temp. Normal January Daily Minimum	Temp. Normal July Daily Maximum	Temp. Normal July Daily Minimum	Temp. Normal Annual	Temp. Extremes Length (Yrs)	Record Highest	Record Lowest	Normal Heating Degree Days (1941–1970) January	Heating Degree Days Seasonal	Precip. Normal (1941–1970) Wettest Month	Normal Driest Month	Normal Annual	Precip. Extremes Wettest Month	Extremes Driest Month	Extremes Maximum In 24 Hours	Snow Mean Total January	Snow Mean Total Seasonal	Snow Extreme Maximum In 24 Hours	RH January 7:00 a.m. EST	RH January 1:00 p.m. EST	RH January 7:00 p.m. EST	RH July 7:00 a.m. EST	RH July 1:00 p.m. EST	RH July 7:00 p.m. EST	Wind Mean Speed January	Wind Mean Speed July	Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	Sunshine July	Clear	Partly Cloudy	Cloudy	Precipitation .25mm or More	Snow, Sleet, Hail 25.4mm or More	Thunderstorms	Heavy Fog	Max ≥ 32.2 °C	Max ≤ 0 °C	Min ≤ -17.8 °C
PACIFIC AREA																																									
MARCUS ISLAND 1968	6	24.4	20.1	30.7	25.6	25.7	4	33.9	12.8	0	0	189	41	1081	343	3	144	0	0	0	72	75	68	79	83	71	6.3	5.2	51.0	58	73	85	147	133	146	0	5	1	23	0	0
GUAM TAGUAC R	110	28.4	21.9	30.1	22.6	25.9	21	35.0	12.2	0	0	366	75	2303	1019	13	686	0	0	0	87	88	78	93	94	80	3.7	2.3	35.8	56	51	7	136	222	269	0	27	*	4	0	0
JOHNSTON	2	27.1	22.7	29.2	25.0	26.1	22	31.7	16.7			88	26	713	401	2	242	0	0	0	75	76	67	78	77	69	6.3	7.1	46.9	68	78	85	165	115	161	0	4	0		0	0
KOROR R	29	30.2	23.8	30.6	24.0	27.5	28	35.0	20.6	0	0	411	189	3650	884	31	355	0	0	0	88	90	81	89	91	81	3.8	3.0	32.6	56	51	0	49	316	267	0	37	1	54	0	0
KWAJALEIN	7	29.4	25.2	30.4	25.3	27.7	25	36.1	20.6	0	0	304	60	2573	772	1	436	0	0	0	79	80	71	84	85	78	7.5	4.8	24.6			17	82	266	240	0	10	0	15	0	0
MAJURO	3	29.3	25.0	29.7	24.8	27.3	22	32.8	20.6	0	0	404	177	3629	790	10	454	0	0	0	80	81	75	83	84	77	5.7	3.8	17.0	59	53	11	81	273	259	0	17	0	1	0	0
PAGO PAGO	4	30.6	23.3	28.7	22.8	26.4	18	33.3	16.7	0	0	377	154	3265	830	18	274	0	0	0	88	88	75	84	84	75	3.8	5.3	25.5	49	53	21	149	195	248	0	26	0	13	0	0
PONAPE R	37	29.9	24.2	30.7	22.7	26.9	27	35.6	18.9	0	0	497	291	4920	982	27	571	0	0	0	83	84	76	93	95	79	3.8	2.2	16.1	49	48	2	66	297	298	0	28	0	40	0	0
TRUK MOEN ISLAND	2	29.6	24.9	30.3	23.9	27.3	27	34.4	20.0	0	0	400	163	3701	886	21	379	0	0	0	81	82	76	88	91	79	4.7	3.4	34.9	60	55	0	50	315	268	0	19	0	6	0	0
WAKE	3	27.6	22.5	30.6	25.0	26.6	30	33.3	17.8	0	0	161	27	950	449	2	381	0	0	0	76	77	65	81	82	70	6.0	5.7	46.5	70	75	113	154	98	181	0	7	0	17	0	0
YAP R	13	29.6	24.2	30.7	24.0	27.3	29	36.1	18.3	0	0	389	137	3087	882	23	265	0	0	0	85	87	78	89	92	80	4.6	2.7	32.2	61	52	7	69	289	261	0	16	0	32	0	0
PENNSYLVANIA							90	43.9	-41.1							0	876																								
ALLENTOWN	118	2.1	-6.6	29.7	17.1	10.6	34	40.6	-24.4	640	3237	111	69	1079	307	2	122	198	800	445	76	62	69	82	52	61	4.8	3.2	36.2			94	113	158	124	9	33	28	19	125	2
ERIE	223	-0.2	-7.5	25.2	15.6	8.4	24	34.4	-26.1	687	3806	94	54	970	281	15	123	511	2116	584	76	73	74	83	65	66	6.0	4.1	24.6			66	94	205	162	27	38	14	1	133	5
HARRISBURG	103	3.2	-5.3	30.4	18.6	11.9	39	41.7	-22.2	601	2902	96	61	926	471	1	319	229	876	533	71	58	63	78	52	60	3.8	2.8	30.4	48	68	85	107	173	125	9	33	20	24	107	1
PHILADELPHIA	2	4.5	-4.2	30.4	19.3	12.6	36	40.0	-20.6	563	2703	104	64	1014	246	2	144	145	513	371	73	59	66	79	54	63	4.6	3.6	32.0	51	63	93	112	160	116	6	27	25	19	101	*
PITTSBURGH GRT. AP	347	1.8	-6.2	28.1	16.3	10.2	25	37.2	-27.8	635	3294	98	60	920	208	4	90	284	1151	373	76	66	67	83	53	59	4.8	3.4	25.9	35	60	58	103	204	153	14	36	18	7	124	5
PITTSBURGH U	228	3.0	-4.6	28.9	18.4	11.7	43	39.4	-25.6	592	2932	94	58	920	225	4	91	193	762	511										26	53				147	9			16	98	1
READING U 1960	81	3.9	-3.2	30.2	19.6	12.4	28	39.4	-18.9	556	2747	10?	67	1052	377	4	154	213	777	475	71			75			5.1	3.8	35.8	46	63	98	110	157	122	8	32	8	24	92	
W B SCRANTON AVOCA	283	0.8	-7.6	28.3	16.3	9.7	22	38.3	-23.9	672	3487	104	56	884	206	1	92	279	1285	521	76	65	67	84	55	62	4.0	3.3	26.8	45	61	69	107	189	141	13	31	24	*	132	4
WILLIAMSPORT	160	1.7	-7.0	29.1	16.3	10.2	33	38.9	-27.2	651	3322	104	64	1016	427	5	220	249	1113	587	77	62	68	87	55	64	4.0	3.0	34.9			67	115	183	144	12	34	39	13	129	4
RHODE ISLAND							90	40.0	-30.6							0	308																								
BLOCK ISLAND	34	3.0	-3.7	24.2	17.4	10.1	26	33.3	-20.0	579	3206	110	56	1029	292	T	216	130	526	429	73	65		87	72							97	114	154	112	6	17	82	*	89	*
PROVIDENCE	14	2.3	-6.3	27.3	17.2	10.0	24	40.0	-25.0	630	3317	115	67	1086	302	10	168	244	965	465	71	56	63	78	57	67	5.1	4.2	40.2	57	60	102	103	160	125	10	20	26	9	123	3
SOUTH CAROLINA							93	43.9	-28.9							0	337																								
CHARLESTON	12	15.4	2.9	31.7	21.8	18.2	35	39.4	-13.3	289	1192	209	54	1324	692	T	257	T	15	150	84	56	72	88	63	78	4.1	3.6	31.7	57	67	103	110	152	115	*	56	29	48	36	0
COLUMBIA	65	13.8	1.1	33.3	21.3	17.5	30	41.7	-15.6	338	1443	144	59	1178	425	T	195	10	43	399	83	56	66	90	56	69	3.1	2.9	26.8	57	64	119	104	142	110	1	54	27	66	61	0
GRNVLLE SPRTNBRG	292	10.9	0.6	30.9	20.6	15.9	15	38.3	-21.1	391	1757	139	75	1208	296	6	158	53	145	290	78	56	63	86	58	67	3.2	2.6	23.2	53	59	119	105	141	119	2	44	36	31	68	*
SOUTH DAKOTA							88	48.9	-50.0							0	203																								
ABERDEEN	395	-6.4	-18.6	29.5	14.7	6.0	18	44.4	-39.4	956	4787	92	11	485	226	0	102	183	925	381	73	70	72	83	50	46	5.1	4.3	25.9			104	99	162	87	12	36	15	26	180	44
HURON	390	-4.8	-16.9	30.4	15.9	7.1	36	44.4	-39.4	904	4475	96	11	494	211	T	139	173	1003	447	73	67	71	85	50	46	5.2	4.8	34.4	57	77	105	107	153	93	12	41	14	31	173	38
RAPID CITY	964	1.2	-12.4	30.2	14.9	8.1	35	43.3	-37.8	742	4068	93	10	435	187	T	102	137	998	414	68	59	64	72	45	40	4.8	4.5	29.5	55	72	110	113	142	96	17	42	15	31	169	20
SIOUX FALLS	432	-4.1	-15.7	29.5	16.4	7.4	32	42.2	-37.8	875	4354	110	14	628	231	T	117	155	993	660	75	67	72	81	51	48	4.9	4.4	31.3			105	106	154	93	11	44	22	26	169	34
TENNESSEE							95	45.0	-35.6							0	279																								
BRISTOL	459	7.8	-2.9	29.9	18.0	13.4	32	38.9	-26.1	493	2392	126	57	1053	247	2	93	122	396	411	80	62	66	92	61	68	2.9	1.8	22.4			90	112	163	134	5	46	44	13	96	2
CHATTANOOGA	203	9.9	-0.8	31.9	20.1	15.4	38	41.1	-23.3	427	1947	149	75	1319	360	5	168	43	102	226	82	63	67	89	57	64	3.2	2.3	36.7	42	61	107	107	151	121	2	56	36	49	75	*
KNOXVILLE	299	9.4	0.1	31.1	20.2	15.4	36	39.4	-22.8	490	1932	129	68	1173	298	T	129	97	310	462	80	64	65	90	61	65	3.6	2.8	32.6	39	61	95	108	162	128	4	46	32	21	71	1
MEMPHIS	79	9.7	-0.2	33.1	21.9	16.4	36	41.1	-25.0	422	1793	138	66	1247	312	T	151	53	140	409	79	64	68	85	57	59	4.7	3.4	17.9	49	73	119	99	147	106	2	53	11	65	58	*
NASHVILLE	180	8.7	-1.7	32.3	20.6	15.2	38	41.7	-26.1	460	2053	127	55	1168	354	T	136	102	277	259	80	65	69	91	59	63	4.1	2.8	32.6	41	65	104	106	155	119	4	55	17	39	75	1
OAK RIDGE R	276	8.4	-1.6	30.8	19.1	14.3	30	40.6	-22.8	463	2191	144	69	1336	489	T	190	81	246	305							2.1	1.7	26.4			108	90	167	128	3	53	34	24	83	*
TEXAS							97	48.9	-30.6							0	970																								
ABILENE	544	13.2	-0.2	35.2	22.4	18.1	38	42.8	-22.8	367	1450	95	25	599	335	0	170	46	114	191	71	53	48	71	46	40	5.4	4.9	48.7	63	78	149	97	119	65	2	42	7	90	56	*
AMARILLO	1098	9.7	-5.3	33.0	18.8	14.1	37	42.2	-25.6	499	2324	88	13	515	279	0	171	86	363	343	69	48	44	73	43	39	5.9	5.6	37.6	69	77	161	103	101	67	4	49	25	64	108	2
AUSTIN	182	15.6	4.1	35.2	23.2	20.1	36	42.8	-18.9	268	965	101	48	825	313	0	183	13	25	178	79	60	57	87	50	46	4.4	3.8	25.5	49	76	116	115	134	82	*	41	24	104	23	0
BROWNSVILLE	6	20.8	10.6	33.8	24.4	23.2	39	40.0	-7.2	125	361	133	18	637	489	T	310	T	T	T	87	68	74	90	57	64	5.2	5.2	30.8	44	81	96	137	132	73	0	24	27	105	2	0
CORPUS CHRISTI	12	19.2	7.8	34.7	24.0	22.2	39	40.0	-10.0	169	517	124	28	725	516	0	223	T	T	28	89	71	73	93	58	64	5.4	5.2	53.6	47	72	104	120	141	77	*	31	29	98	7	0
DALLAS FT WORTH	168	13.2	1.1	35.3	23.3	18.6	24	42.8	-15.6	348	1323	114	46	820	321	T	150	38	74	307	80	60	58	81	50	46	5.1	4.2	32.6			140	94	131	78	1	45	11	91	39	0
DALLAS 1973	147	13.2	2.2	34.7	24.1	18.8	15	41.7	-13.3	334	1313	129	49	878	391	T	233	30	51	188	77	59	56	77	51	44	4.7	4.5	29.1	51	77	139	93	133	80	1	40	8	95	35	0
DEL RIO	313	17.4	3.4	37.3	23.4	21.1	15	42.8	-8.3	249	846	77	13	429	401	0	193	T	15	76	75	55	46	79	53	39	3.9	4.9	26.8			121	104	140	60	*	35	15	121	15	0
EL PASO	1194	13.9	-1.0	34.8	21.1	17.4	36	42.8	-22.2	368	1488	39	6	197	170	0	67	36	119	198	61	42	33	62	39	30	4.0	4.0	31.3	78	79	193	101	71	45	2	36	2	104	64	*
GALVESTON U	2	15.2	9.1	30.8	26.1	21.0	107	38.3	-13.3	203	680	142	64	1072	661	0	364	T	8	391	85	77	80	81	70	73	5.2	4.4	44.7	48	72				96	*			11	4	0

NORMALS, MEANS AND EXTREMES

State and Station	Elevation Ground (Meters)	Temp. Normal (1941–1970) January Daily Maximum	January Daily Minimum	July Daily Maximum	July Daily Minimum	Annual	Extremes Length (Yrs)	Record Highest	Record Lowest	Normal Heating Degree Days (1941–1970) January	Seasonal	Precip. Normal (1941–1970) Wettest Month	Driest Month	Annual	Precip. Extremes Wettest Month	Driest Month	Maximum In 24 Hours
TEXAS																	
HOUSTON INTERCON	29	17.0	5.3	34.3	22.7	20.5	8	38.3	-7.8	231	797	130	68	1224	366	T	207
HOUSTON HOBBY 1969	15	17.6	6.4	33.4	23.2	20.7	9	41.1	-8.3	213	775	111	68	1167	567	T	398
LUBBOCK	992	11.9	-4.0	33.6	19.4	15.4	31	41.7	-26.7	446	1969	81	12	468	225	0	145
MIDLAND	869	14.3	-1.4	35.0	20.8	17.7	30	42.8	-22.2	368	1456	59	12	343	196	0	152
PORT ARTHUR	5	16.4	5.6	33.3	23.3	20.3	24	41.7	-10.0	233	843	150	77	1399	475	0	335
SAN ANGELO	580	15.1	0.9	36.1	22.4	19.0	30	43.9	-17.2	321	1244	70	18	445	234	0	153
SAN ANTONIO	242	16.4	4.3	35.3	23.2	20.4	36	41.1	-17.8	251	872	94	37	700	401	0	185
VICTORIA	32	17.4	6.4	34.1	24.1	21.2	17	41.7	-8.9	207	682	117	45	871	369	T	236
WACO	153	14.1	2.6	35.7	23.9	19.5	35	44.4	-20.6	310	1143	117	37	794	381	0	182
WICHITA FALLS	303	11.9	-1.4	37.3	22.4	17.8	31	45.0	-20.6	405	1613	114	27	691	306	0	146
UTAH							87	46.7	-45.6							0	152
MILFORD	1533	3.6	-10.6	33.8	13.2	9.6	29	40.6	-35.6	677	3562	26	13	213	66	0	34
SALT LAKE CITY	1288	3.0	-7.5	33.8	15.8	10.6	49	41.7	-34.4	637	3324	54	17	385	124	0	61
WENDOVER 1976	1291	2.2	-7.3	33.3	19.2	11.2	36	44.4	-28.3	648	3200	19	6	124	76	0	34
VERMONT							90	40.6	-45.6							0	223
BURLINGTON	101	-3.4	-13.6	27.2	14.7	6.9	34	38.3	-34.4	830	4375	94	43	827	293	7	91
VIRGINIA							87	43.3	-33.9							0	686
LYNCHBURG	279	7.7	-2.6	30.1	18.6	13.5	33	39.4	-22.2	489	2351	105	64	972	290	7	159
NORFOLK	7	9.3	0.1	30.3	21.1	15.2	29	39.4	-15.0	422	1938	150	69	1135	349	9	290
RICHMOND	50	8.6	-2.4	31.2	19.7	14.3	48	40.6	-24.4	474	2188	143	70	1082	479	8	223
ROANOKE	350	7.6	-2.7	29.9	18.0	13.3	30	40.0	-20.0	493	2393	105	63	991	247	5	163
WASHINGTON							111	47.8	-44.4							0	777
OLYMPIA	59	6.7	-0.9	25.8	9.3	10.1	36	39.4	-21.7	479	3072	208	18	1289	504	0	125
QUILLAYUTE	55	6.7	0.7	19.8	10.2	9.3	11	35.6	-13.9	453	3306	394	60	2667	690	9	211
SEATTLE EMSU U	6	7.1	1.5	24.3	13.1	11.4	44	37.8	-12.2	436	2626	134	22	906	278	T	84
SEATTLE TACOMA	122	6.3	0.6	23.9	12.1	10.6	33	37.2	-17.8	462	2880	151	19	985	328	T	87
SPOKANE	718	-0.5	-6.9	29.1	12.8	8.5	30	42.2	-31.7	682	3797	63	10	442	145	T	53
STAMPEDE PASS R	1206	-2.6	-7.3	18.6	8.3	4.0	34	32.2	-29.4	722	5222	361	39	2313	773	5	202
WALLA WALLA U	289	4.1	-2.5	31.6	16.8	12.3	63	45.0	-26.7	550	2686	53	8	407	149	0	51
YAKIMA	321	2.4	-7.4	31.2	11.8	9.9	31	43.3	-31.7	646	3338	34	4	203	106	0	40
WEST INDIES																	
SAN JUAN P.R.	4	27.7	20.4	30.6	23.8	25.9	23	35.6	15.6	0	0	177	52	1502	383	11	162
SWAN ISLAND 1970	9	28.1	23.3	30.7	25.3	27.2	27	33.3	17.8	0	0	188	16	1311	801	T	274
WEST VIRGINIA							87	44.4	-38.3							0	483
BECKLEY	763	4.4	-5.1	26.7	15.5	10.5	14	32.2	-27.8	579	3119	111	63	1083	233	4	136
CHARLESTON	286	6.4	-3.7	29.8	17.9	12.9	30	38.9	-24.4	526	2550	125	62	1035	344	2	142
ELKINS	594	4.6	-7.1	26.8	13.9	9.8	33	36.1	-30.0	603	3319	125	69	1098	236	8	82
HUNTINGTON	252	6.1	-3.6	29.8	18.2	12.9	17	37.8	-26.1	529	2569	106	53	988	235	T	108
PARKERSBURG U	187	5.2	-4.2	29.8	18.2	12.6	89	41.1	-32.8	553	2676	109	54	976	306	2	122
WISCONSIN							87	45.6	-47.8							0	298
GREEN BAY	208	-4.5	-13.9	27.1	14.3	6.5	28	37.2	-35.0	854	4498	87	26	686	230	T	117
LA CROSSE	198	-3.9	-13.8	28.3	16.9	8.0	27	39.4	-38.3	842	4120	113	22	739	267	T	100
MADISON	262	-3.7	-13.2	27.4	14.9	7.2	36	40.0	-38.3	830	4294	110	24	768	278	2	133
MILWAUKEE	205	-2.6	-11.4	26.9	15.2	7.6	37	38.3	-31.1	785	4135	91	29	738	251	1	134
WYOMING							118	45.6	-52.8							0	148
CASPER	1627	0.9	-10.7	30.6	12.7	7.4	27	40.0	-40.0	720	4197	49	12	285	142	T	76
CHEYENNE	1867	3.4	-9.5	28.7	12.5	7.7	42	37.8	-36.7	661	4030	64	9	372	136	T	87
LANDER	1696	-0.5	-13.3	30.0	12.8	6.9	31	38.3	-38.3	782	4371	66	11	352	175	T	90
SHERIDAN	1209	0.8	-13.1	30.1	12.6	7.2	37	41.1	-37.2	758	4282	74	18	410	242	T	98

State and Station	Snow Mean Total January	Snow Mean Total Seasonal	Snow Ex-treme Maximum In 24 Hours	Relative Humidity (Percent) January 7:00 a.m. EST	January 1:00 p.m. EST	January 7:00 p.m. EST	July 7:00 a.m. EST	July 1:00 p.m. EST	July 7:00 p.m. EST	Wind Speed (m.p.s.) Mean Speed January	Mean Speed July	Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	Sunshine July	Sunrise to Sunset Clear	Partly Cloudy	Cloudy	Precipitation 25mm or More	Snow, Sleet, Hail 25.4mm or More	Thunderstorms	Heavy Fog	Temp. Max ≥ 32.2°C	Min ≤ 0°C	Min ≤ -17.8°C
TEXAS																								
HOUSTON INTERCON	5	10	51	88	64	70	93	58	63	3.6	2.9	20.6	45	67	95	112	158	106	*	68	39	85	25	0
HOUSTON HOBBY 1969	5	10	112	84	64	67	91	59	64	5.3	3.9	24.1	47	74	87	126	152	103	0	59	42	95	13	0
LUBBOCK	46	236	307	72	48	46	76	48	40	5.5	5.1	31.3	70	74	163	104	98	60	3	45	16	78	98	1
MIDLAND	36	86	172	69	45	49	71	41	34	4.5	4.7	30.0			166	99	100	51	2	36	15	92	64	0
PORT ARTHUR	T	13	112	89	70	78	94	64	72	5.0	3.5	33.1	43	66	93	124	148	105	*	64	41	82	15	0
SAN ANGELO	28	76	147	73	51	46	76	43	37	4.6	4.3	33.5			157	96	112	56	1	37	7	110	52	0
SAN ANTONIO	5	13	119	80	60	57	87	51	45	4.1	4.1	33.1	49	75	109	118	138	81	*	36	23	111	22	*
VICTORIA	T	5	30	86	65	68	92	56	60	4.7	4.0	44.3			84	121	160	88	*	48	41	101	12	0
WACO	23	38	178	82	63	61	79	48	43	5.4	4.9	30.8			131	101	133	77	1	45	13	104	33	0
WICHITA FALLS	43	140	150	81	56	56	78	44	40	5.1	4.9	26.8			154	94	117	69	2	49	12	105	65	*
UTAH																								
MILFORD	213	1113	414		66	60		24	20			25.5	65	75	153	104	108	63	14	32	7	58	182	13
SALT LAKE CITY	335	1481	460	77	69	67	52	26	20	3.4	4.2	31.7	48	84	128	103	134	88	18	35	11	58	133	3
WENDOVER 1976	56	191	216	70	62	59	33	22	15						152	92	121	48	3	29	5	50	128	1
VERMONT																								
BURLINGTON	455	2014	419	69	63	65	81	55	63	4.3	3.5	32.2	42	65	57	103	205	153	23	25	16	6	161	28
VIRGINIA																								
LYNCHBURG	132	460	340	72	53	60	86	57	71	3.9	3.0	25.0	51	62	113	105	147	120	5	41	40	19	94	1
NORFOLK	79	178	290	75	59	68	82	60	71	5.2	3.9	34.9	57	65	110	104	151	115	2	37	22	31	54	0
RICHMOND	132	353	549	81	57	69	85	56	72	3.5	3.0	30.4	51	65	102	108	155	113	4	37	29	42	86	1
ROANOKE	163	612	442	68	52	56	83	55	63	4.4	3.0	25.9			103	114	148	121	7	38	25	23	92	*
WASHINGTON																								
OLYMPIA	231	488	521	91	88	81	91	64	49	3.4	2.7	26.8			50	89	226	163	6	5	90	6	89	*
QUILLAYUTE	229	523	213	90	89	85	94	73	64	3.4	2.7	20.6	20	46	47	69	249	214	7	7	50	1	67	0
SEATTLE EMSU U	99	211	292									29.1	28	53	71	93	201	151	3	6		4	15	0
SEATTLE TACOMA	173	371	544	80	79	75	83	65	49	4.6	3.8	20.1	21	67	55	83	227	160	5	7	47	3	31	0
SPOKANE	465	1354	330	83	82	77	60	38	25	4.0	3.7	26.4	26	80	88	87	190	114	18	11	47	21	141	4
STAMPEDE PASS R	2096	1344	958	93	92	91	86	66	69						68	56	241	206	87	7	252	*	188	3
WALLA WALLA U	198	508	356		76			34		2.3	2.4	30.0	23	85	114	87	164	106	7	11	14	37	64	2
YAKIMA	251	622	356	83	77	70	68	35	24	2.6	3.4	21.5			110	93	162	67	8	7	18	34	150	4
WEST INDIES																								
SAN JUAN P.R.	0	0	0	80	64	74	78	66	77	4.1	4.5	35.8	65	65	59	210	96	199	0	40	0	36	0	0
SWAN ISLAND 1970	0	0	0												79	159	127	153	0			13	0	0
WEST VIRGINIA																								
BECKLEY	358	1417	351	80	68	72	90	61	73	4.9	3.1	25.9			66	94	205	163	18	46	45	*	115	4
CHARLESTON	226	752	384	77	63	65	90	60	66	3.4	2.2	24.6			59	115	191	149	9	43	117	21	101	1
ELKINS	376	1709	475	80	64	71	95	61	72	3.3	1.9	24.6			50	108	207	167	22	44	81	2	143	6
HUNTINGTON	208	612	267	79	66	65	91	60	66	3.3	2.1	21.0			62	104	199	139	7	44	64	17	99	3
PARKERSBURG U	175	607	465	82	66	74	80	52	67	3.2	2.3	29.5	32	62	109	103	153	142	8	44	12	22	98	2
WISCONSIN																								
GREEN BAY	254	1133	259	76	70	72	85	56	59	5.0	3.8	48.7	46	65	89	104	172	121	14	35	27	6	162	30
LA CROSSE	241	1090	399	76	66	70	87	57	77	3.8	3.4	28.2			95	97	173	110	12	40	21	10	152	26
MADISON	224	1021	406	78	68	73	86	56	67	4.7	3.7	34.4	49	69	93	96	176	117	12	41	22	13	163	26
MILWAUKEE	310	1166	424	75	68	71	82	60	63	5.8	4.3	32.6	45	71	96	99	170	123	13	36	27	9	145	16
WYOMING																								
CASPER	231	1877	419	68	59	61	70	33	26	7.5	4.5	36.2			110	110	145	92	23	34	9	24	185	18
CHEYENNE	147	1300	419	54	44	48	68	34	37	7.0	4.7	33.5	61	68	106	128	131	96	16	50	23	10	172	12
LANDER	221	2644	587	66	59	59	56	34	28	2.8	3.4	35.8	67	77	115	126	124	71	25	32	3	14	187	20
SHERIDAN	274	1781	678	68	60	63	73	38	34	3.5	3.2	37.6	55	75	99	111	155	108	23	36	6	24	192	24

NORMALS, MEANS AND EXTREMES

State and Station	Elevation Ground (Meters)	Temperature (°C) Normal (1941-1970) January Daily Maximum	Temperature (°C) Normal (1941-1970) January Daily Minimum	Temperature (°C) Normal (1941-1970) July Daily Maximum	Temperature (°C) Normal (1941-1970) July Daily Minimum	Temperature (°C) Normal (1941-1970) Annual	Temperature (°C) Extremes Length (Yrs)	Temperature (°C) Extremes Record Highest	Temperature (°C) Extremes Record Lowest	Normal Heating Degree Days (1941-1970) January	Normal Heating Degree Days (1941-1970) Seasonal	Precipitation (Millimeters) Normal (1941-1970) Wettest Month	Precipitation (Millimeters) Normal (1941-1970) Driest Month	Precipitation (Millimeters) Normal (1941-1970) Annual	Precipitation (Millimeters) Extremes Wettest Month	Precipitation (Millimeters) Extremes Driest Month	Precipitation (Millimeters) Extremes Maximum In 24 Hours	Snow @ Mean Total January	Snow @ Mean Total Seasonal	Snow @ Extreme Maximum In 24 Hours	Relative Humidity (Percent) January 7:00 a.m. EST	Relative Humidity (Percent) January 1:00 p.m. EST	Relative Humidity (Percent) January 7:00 p.m. EST	Relative Humidity (Percent) July 7:00 a.m. EST	Relative Humidity (Percent) July 1:00 p.m. EST	Relative Humidity (Percent) July 7:00 p.m. EST	Wind Speed (m.p.s.) Mean Speed January	Wind Speed (m.p.s.) Mean Speed July	Wind Speed (m.p.s.) Fastest Mile (1.6 Kilometers)	Sunshine (% of Possible) January	Sunshine (% of Possible) July	Annual Mean Number of Days Sunrise to Sunset Clear	Annual Mean Number of Days Sunrise to Sunset Partly Cloudy	Annual Mean Number of Days Sunrise to Sunset Cloudy	Annual Mean Number of Days Precipitation .25mm or More	Annual Mean Number of Days Snow, Sleet, Hail 25.4mm or More	Annual Mean Number of Days Thunderstorms	Annual Mean Number of Days Heavy Fog	Annual Mean Number of Days Temperature Max ≥ 32.2°C	Annual Mean Number of Days Temperature Min ≤ 0°C	Annual Mean Number of Days Temperature Min ≤ -17.8°C

Data from airport or from airport and Urban site records combined.
U indicates Urban, R indicates Rural Sites.
Data for this table are based on records through 1976 except as indicated in notes.
Date after station name indicates last year included in summarization of data.
Normal values are based on the period 1941-1970, and are means adjusted to represent observations taken at the present standard location, except that stations closed before 1971 are based on the 1931-1960 period.
Degree days are based on a daily average of 18.3°C.
For detailed periods of record see ANNUAL LOCAL CLIMATOLOGICAL DATA, 1976.
Clear Day averages 0-3 tenths sky cover, Partly Cloudy 4-7 tenths and Cloudy 8-10 tenths.
Heavy Fog includes data formerly referred to as "Dense" or "Thick". The upper visibility limit for heavy fog is 402.3 meters.
* Less than one-half.
B Number of days Maximum 21.1° or above (Alaskan stations).

1/ Means and extremes are from post office location through 1962.
c Relative Humidity readings 8:00 a.m. and NOON Local Time.

x Sun below horizon continuously Nov. 19 - Jan. 23.
v Sun below horizon continuously Nov. 24 - Jan. 17.
(x and v)-Yearly totals for period sun above horizon.
m Mean wind speed record for 1949-1951, 1958-1962.
@ Includes all forms of frozen precipitation, except hail occurring alone.

APPENDIX F

POLE DATA

NOTES

Moment Capacities (ft-k) at Groundline for
Western Red Cedar (6000 psi), Lodgepole Pine (6600 psi),
Douglas Fir and Southern Yellow Pine (8000 psi),
and Western Larch (8400 psi)

		6000 PSI				6600 PSI			
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	222.2	186.1	154.2	126.2		186.9	153.9	125.1	50
55	245.4	206.9	172.7	137.9		202.5	167.8	137.2	55
60	270.4	229.3	192.7	150.4		225.5	182.5	150.2	60
65	297.1	246.7	202.4	163.7		243.4	198.2	159.0	65
70	317.7	265.1	218.6	177.9		262.4	214.8	173.4	70
75	339.4	284.4	235.7	192.9		282.4	232.4	188.8	75
80	362.2	304.8	253.8	203.1		303.4	251.0	205.1	80
85	386.1	326.2	266.0	219.6		317.5	263.6	216.1	85
90	411.1	348.6	285.6	230.7		340.4	283.8	227.5	90
95	441.6	367.3	301.9			368.0	300.5		95
100	473.4	395.5	326.6			387.8	317.7		100
105	487.2	408.0	337.8			400.9	337.7		105
110	521.2	438.1	356.0			431.5	356.3		110

		8000 PSI				8400 PSI			
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	220.3	187.2	152.1	121.7	224.2	183.9	148.7	123.0	50
55	246.4	204.2	167.1	134.7	243.6	201.1	163.8	136.4	55
60	266.8	222.3	183.0	148.7	264.3	219.4	179.9	145.4	60
65	288.4	241.5	200.0	163.5	294.4	238.9	203.5	160.4	65
70	311.2	261.9	218.1	179.4	318.0	259.5	215.3	176.4	70
75	335.3	283.4	230.3	190.2	333.8	281.3	227.7	187.3	75
80	360.6	306.2	250.2	201.5	359.6	296.1	247.8	198.7	80
85	387.2	321.5	263.7	213.3	386.7	320.0	261.5	210.6	85
90	405.2	337.5	285.5	225.5	405.0	336.2	275.8	229.9	90
95	438.0	357.3	303.2		438.3	365.6	301.5		95
100	461.5	387.3	321.5		462.1	386.7	319.9		100
105	477.7	401.9	334.6		478.7	401.7	333.4		105
110	514.2	424.1	354.1		504.0	424.1	353.1		110

Moments (ft-k) at Groundline
Due to a 4 psf Wind on a Pole

	6000 PSI				6600 PSI				
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	3.6	3.4	3.1	2.9		3.3	3.1	2.9	50
55	4.5	4.2	3.9	3.6		4.1	3.8	3.5	55
60	5.4	5.1	4.8	4.4		5.0	4.6	4.3	60
65	6.5	6.1	5.7	5.2		6.0	5.6	5.1	65
70	7.7	7.2	6.7	6.2		7.1	6.6	6.1	70
75	8.9	8.4	7.8	7.3		8.2	7.7	7.1	75
80	10.3	9.7	9.0	8.4		9.5	8.9	8.2	80
85	11.8	11.1	10.3	9.6		10.9	10.1	9.4	85
90	13.4	12.6	11.8	10.9		12.4	11.5	10.7	90
95	15.4	14.4	13.4			14.2	13.2		95
100	17.5	16.4	15.3			16.1	14.9		100
105	19.2	18.0	16.8			17.6	16.5		105
110	21.6	20.2	18.8			19.8	18.5		110

	8000 PSI				8400 PSI				
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	3.4	3.2	3.0	2.8	3.4	3.2	3.0	2.8	50
55	4.3	4.0	3.7	3.4	4.2	3.9	3.7	3.4	55
60	5.2	4.8	4.5	4.2	5.1	4.8	4.5	4.1	60
65	6.2	5.8	5.4	5.0	6.2	5.7	5.4	4.9	65
70	7.3	6.8	6.4	5.9	7.3	6.8	6.3	5.9	70
75	8.5	8.0	7.4	6.9	8.4	7.9	7.3	6.8	75
80	9.8	9.2	8.6	7.9	9.8	9.1	8.5	7.9	80
85	11.3	10.5	9.8	9.1	11.2	10.4	9.7	9.0	85
90	12.8	11.9	11.2	10.3	12.7	11.8	11.0	10.3	90
95	14.6	13.6	12.8		14.5	13.6	12.7		95
100	16.6	15.5	14.5		16.4	15.4	14.4		100
105	18.2	17.1	15.9		18.0	16.9	15.8		105
110	20.5	19.1	17.9		20.2	19.0	17.7		110

Moments (ft-k) at Groundline
Due to a 9 psf Wind on a Pole

	6000 PSI				6600 PSI				
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	8.1	7.6	7.1	6.6	0.0	7.5	7.0	6.4	50
55	10.0	9.4	8.8	8.1	0.0	9.2	8.6	8.0	55
60	12.2	11.5	10.7	9.9	0.0	11.3	10.5	9.7	60
65	14.6	13.7	12.7	11.8	0.0	13.5	12.5	11.6	65
70	17.3	16.2	15.1	14.0	0.0	15.9	14.8	13.7	70
75	20.1	18.9	17.6	16.3	0.0	18.5	17.3	16.0	75
80	23.2	21.8	20.3	18.8	0.0	21.4	20.0	18.5	80
85	26.6	25.0	23.2	21.6	0.0	24.4	22.8	21.2	85
90	30.2	28.4	26.4	24.5	0.0	27.8	26.0	24.0	90
95	34.6	32.4	30.2	0.0	0.0	31.9	29.7		95
100	39.4	36.9	34.4	0.0	0.0	36.1	33.6		100
105	43.2	40.5	37.8	0.0	0.0	39.7	37.1		105
110	48.5	45.5	42.3	0.0	0.0	44.6	41.6		110

	8000 PSI				8400 PSI				
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	7.7	7.3	6.7	6.2	7.7	7.2	6.7	6.2	50
55	9.6	9.0	8.3	7.7	9.5	8.9	8.3	7.7	55
60	11.6	10.9	10.1	9.4	11.5	10.8	10.0	9.3	60
65	13.9	13.0	12.1	11.3	13.8	12.9	12.1	11.1	65
70	16.4	15.4	14.3	13.3	16.3	15.2	14.2	13.2	70
75	19.1	18.0	16.7	15.5	19.0	17.8	16.5	15.3	75
80	22.1	20.8	19.3	17.9	21.9	20.5	19.1	17.7	80
85	25.4	23.7	22.1	20.4	25.1	23.5	21.9	20.2	85
90	28.7	26.9	25.2	23.2	28.5	26.7	24.8	23.1	90
95	32.9	30.7	28.7		32.6	30.6	28.5		95
100	37.3	34.9	32.6		37.0	34.6	32.3		100
105	40.9	38.4	35.8		40.6	38.1	35.5		105
110	46.0	43.0	40.2		45.5	42.7	39.8		110

Moment Capacities (ft-k) for Douglas Fir and Southern Yellow Pine Poles

The following tables give ultimate moment capacities (ft-k) of Douglas Fir and Southern Yellow Pine poles at one foot increments. The moment capacities are based on a constant 8000 psi modulus of rupture. Also included in the tables are other section properties which may be useful for design, such as diameter (inches) and area (square inches). The three columns in each table labeled 'DIST/FT' give the distance from the top of the pole in feet.

NOTES

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.80	53.8	8.72	59.78	43.5	1	8.08	51.29	34.5	7.44	43.44	26.9	1
2	9.50	70.86	56.1	8.85	61.58	45.4	2	8.20	52.86	36.1	7.55	44.80	28.2	2
3	9.63	72.87	58.5	8.99	63.41	47.5	3	8.33	54.45	37.8	7.67	46.18	29.5	3
4	9.77	74.91	61.0	9.12	65.26	49.6	4	8.45	56.08	39.5	7.78	47.59	30.9	4
5	9.90	76.98	63.5	9.25	67.13	51.7	5	8.57	57.72	41.2	7.90	49.02	32.3	5
6	10.03	79.07	66.1	9.38	69.04	53.9	6	8.70	59.39	43.0	8.02	50.46	33.7	6
7	10.17	81.20	68.8	9.51	70.97	56.2	7	8.82	61.08	44.9	8.13	51.93	35.2	7
8	10.30	83.35	71.6	9.64	72.93	58.6	8	8.94	62.79	46.8	8.25	53.42	36.7	8
9	10.44	85.53	74.4	9.77	74.91	61.0	9	9.06	64.53	48.7	8.36	54.93	38.3	9
10	10.57	87.74	77.3	9.90	76.92	63.4	10	9.19	66.30	50.8	8.48	56.46	39.9	10
11	10.70	89.97	80.2	10.03	78.96	66.0	11	9.31	68.08	52.8	8.59	58.01	41.5	11
12	10.84	92.24	83.3	10.16	81.03	68.6	12	9.43	69.89	54.9	8.71	59.59	43.2	12
13	10.97	94.53	86.4	10.29	83.12	71.2	13	9.56	71.73	57.1	8.83	61.18	45.0	13
14	11.10	96.85	89.6	10.42	85.23	74.0	14	9.68	73.59	59.4	8.94	62.79	46.8	14
15	11.24	99.20	92.9	10.55	87.38	76.8	15	9.80	75.47	61.6	9.06	64.43	48.6	15
16	11.37	101.58	96.3	10.68	89.55	79.7	16	9.93	77.37	64.0	9.17	66.09	50.5	16
17	11.51	103.98	99.7	10.81	91.75	82.6	17	10.05	79.30	66.4	9.29	67.77	52.5	17
18	11.64	106.41	103.2	10.94	93.97	85.7	18	10.17	81.26	68.9	9.40	69.47	54.4	18
19	11.77	108.87	106.8	11.07	96.22	88.7	19	10.29	83.23	71.4	9.52	71.19	56.5	19
20	11.91	111.36	110.5	11.20	98.50	91.9	20	10.42	85.23	74.0	9.64	72.93	58.6	20
21	12.04	113.88	114.3	11.33	100.80	95.2	21	10.54	87.26	76.6	9.75	74.69	60.7	21
22	12.18	116.44	118.1	11.46	103.13	98.5	22	10.66	89.31	79.4	9.87	76.47	62.9	22
23	12.31	119.00	122.1	11.59	105.49	101.9	23	10.79	91.38	82.1	9.98	78.28	65.1	23
24	12.44	121.60	126.1	11.72	107.87	105.3	24	10.91	93.47	85.0	10.10	80.10	67.4	24
25	12.58	124.23	130.2	11.85	110.28	108.9	25	11.03	95.59	87.9	10.21	81.95	69.8	25
26	12.71	126.89	134.4	11.98	112.72	112.5	26	11.16	97.74	90.9	10.33	83.82	72.2	26
27	12.84	129.53	138.7	12.11	115.19	116.2	27	11.28	99.90	93.9	10.45	85.71	74.6	27
28	12.98	132.29	143.1	12.24	117.68	120.0	28	11.40	102.09	97.0	10.56	87.62	77.1	28
29	13.11	135.03	147.5	12.37	120.19	123.9	29	11.52	104.31	100.2	10.68	89.55	79.7	29
30	13.25	137.80	152.1	12.50	122.74	127.9	30	11.65	106.55	103.4	10.79	91.50	82.3	30
31	13.38	140.60	156.8	12.63	125.31	131.9	31	11.77	108.81	106.7	10.91	93.47	85.0	31
32	13.51	143.43	161.5	12.76	127.90	136.0	32	11.89	111.09	110.1	11.03	95.47	87.7	32
33	13.65	146.28	166.4	12.89	130.53	140.2	33	12.02	113.40	113.6	11.14	97.48	90.5	33
34	13.78	149.17	171.3	13.02	133.18	144.5	34	12.14	115.74	117.1	11.26	99.52	93.3	34
35	13.92	152.08	176.3	13.15	135.85	148.9	35	12.26	118.09	120.7	11.37	101.58	96.3	35
36	14.05	155.02	181.5	13.28	138.56	153.4	36	12.39	120.47	124.3	11.49	103.65	99.2	36
37	14.18	157.99	186.7	13.41	141.29	157.9	37	12.51	122.88	128.1	11.60	105.75	102.3	37
38	14.32	160.78	192.1	13.54	144.04	162.6	38	12.63	125.31	131.9	11.72	107.87	105.3	38
39	14.45	164.01	197.5	13.67	146.83	167.3	39	12.75	127.76	135.8	11.84	110.01	108.5	39
40	14.58	167.06	203.0	13.80	149.64	172.1	40	12.88	130.23	139.7	11.95	112.18	111.7	40
41	14.72	170.14	208.7	13.93	152.47	177.0	41	13.00	132.73	143.8	12.07	114.36	115.0	41
42	14.85	173.25	214.4	14.06	155.34	182.0	42	13.12	135.26	147.9	12.18	116.57	118.3	42
43	14.99	176.38	220.3	14.19	158.23	187.1	43	13.25	137.80	152.1	12.30	118.79	121.7	43
44	15.12	179.55	226.2	14.32	161.14	192.3	44	13.37	140.37	156.4	12.41	121.04	125.2	44
45	15.25	182.74	232.3	14.45	164.09	197.6	45	13.49	142.97	160.7	12.53	123.31	128.7	45
46	15.39	185.96	238.4	14.58	167.06	203.0	46	13.61	145.59	165.2	12.65	125.59	132.3	46
47	15.52	189.21	244.7	14.71	170.05	208.5	47	13.74	148.23	169.7	12.76	127.90	136.0	47
48	15.66	192.49	251.1	14.84	173.08	214.1	48	13.86	150.90	174.3	12.88	130.23	139.7	48
49	15.79	195.79	257.6	14.98	176.13	219.8	49	13.98	153.59	179.0	12.99	132.59	143.5	49
50	15.92	199.12	264.2	15.11	179.20	225.6	50	14.11	156.30	183.7	13.11	134.96	147.4	50

55'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MBM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.87	53.7	8.72	59.73	43.4	1	8.08	51.25	34.5	7.43	43.41	26.9	1
2	9.50	70.84	56.1	8.85	61.48	45.3	2	8.20	52.79	36.1	7.55	44.75	28.1	2
3	9.63	72.84	58.5	8.97	63.26	47.3	3	8.32	54.34	37.7	7.66	46.11	29.4	3
4	9.76	74.87	60.9	9.10	65.05	49.3	4	8.44	55.93	39.3	7.78	47.49	30.8	4
5	9.90	76.93	63.4	9.23	66.88	51.4	5	8.56	57.53	41.0	7.89	48.89	32.1	5
6	10.03	79.01	66.0	9.35	68.73	53.6	6	8.68	59.16	42.8	8.00	50.31	33.5	6
7	10.16	81.12	68.7	9.48	70.60	55.8	7	8.80	60.81	44.6	8.12	51.75	35.0	7
8	10.30	83.26	71.4	9.61	72.50	58.0	8	8.92	62.48	46.4	8.23	53.20	36.5	8
9	10.43	85.43	74.2	9.73	74.42	60.4	9	9.04	64.17	48.3	8.34	54.68	38.0	9
10	10.56	87.63	77.1	9.86	76.37	62.8	10	9.16	65.89	50.3	8.46	56.18	39.6	10
11	10.70	89.85	80.1	9.99	78.35	65.2	11	9.28	67.63	52.3	8.57	57.71	41.2	11
12	10.83	92.10	83.1	10.11	80.35	67.7	12	9.40	69.40	54.4	8.69	59.25	42.9	12
13	10.96	94.38	86.2	10.24	82.37	70.3	13	9.52	71.18	56.5	8.80	60.81	44.6	13
14	11.10	96.69	89.4	10.37	84.42	72.9	14	9.64	72.99	58.6	8.91	62.39	46.3	14
15	11.23	99.02	92.7	10.49	86.50	75.6	15	9.76	74.82	60.9	9.03	63.99	48.1	15
16	11.36	101.39	96.0	10.62	88.60	78.4	16	9.88	76.68	63.1	9.14	65.61	50.0	16
17	11.49	103.78	99.4	10.75	90.73	81.3	17	10.00	78.55	65.5	9.25	67.25	51.9	17
18	11.63	106.20	102.9	10.87	92.88	84.2	18	10.12	80.45	67.9	9.37	68.92	53.8	18
19	11.76	108.64	106.5	11.00	95.05	87.1	19	10.24	82.37	70.3	9.48	70.60	55.8	19
20	11.89	111.12	110.1	11.13	97.26	90.2	20	10.36	84.32	72.8	9.59	72.30	57.8	20
21	12.03	113.62	113.9	11.25	99.48	93.3	21	10.48	86.29	75.4	9.71	74.03	59.9	21
22	12.16	116.15	117.7	11.38	101.73	96.5	22	10.60	88.28	78.0	9.82	75.77	62.0	22
23	12.29	118.71	121.6	11.51	104.01	99.7	23	10.72	90.29	80.7	9.94	77.53	64.2	23
24	12.43	121.29	125.6	11.63	106.31	103.1	24	10.84	92.32	83.4	10.05	79.32	66.4	24
25	12.56	123.90	129.7	11.76	108.64	106.5	25	10.96	94.38	86.2	10.16	81.12	68.7	25
26	12.69	126.55	133.9	11.89	110.99	110.0	26	11.08	96.46	89.1	10.28	82.95	71.0	26
27	12.83	129.21	138.1	12.01	113.37	113.5	27	11.20	98.57	92.0	10.39	84.79	73.4	27
28	12.96	131.91	142.5	12.14	115.78	117.1	28	11.32	100.69	95.0	10.50	86.66	75.9	28
29	13.09	134.64	146.9	12.27	118.20	120.8	29	11.44	102.84	98.1	10.62	88.55	78.3	29
30	13.23	137.39	151.4	12.39	120.66	124.6	30	11.56	105.01	101.2	10.73	90.45	80.9	30
31	13.36	140.17	156.0	12.52	123.14	128.5	31	11.68	107.21	104.4	10.85	92.38	83.5	31
32	13.49	142.98	160.8	12.65	125.64	132.4	32	11.80	109.42	107.6	10.96	94.33	86.1	32
33	13.63	145.82	165.6	12.77	128.17	136.4	33	11.92	111.66	110.9	11.07	96.29	88.8	33
34	13.76	148.68	170.5	12.90	130.72	140.5	34	12.04	113.92	114.3	11.19	98.28	91.6	34
35	13.89	151.57	175.5	13.03	133.30	144.7	35	12.16	116.21	117.8	11.30	100.29	94.4	35
36	14.03	154.49	180.6	13.15	135.91	149.0	36	12.28	118.52	121.3	11.41	102.32	97.3	36
37	14.16	157.44	185.7	13.28	138.54	153.3	37	12.40	120.85	124.9	11.53	104.36	100.2	37
38	14.29	160.41	191.0	13.41	141.19	157.8	38	12.52	123.20	128.6	11.64	106.43	103.2	38
39	14.42	163.42	196.4	13.53	143.88	162.3	39	12.64	125.58	132.3	11.75	108.52	106.3	39
40	14.56	166.45	201.9	13.66	146.58	166.9	40	12.76	127.97	136.1	11.87	110.63	109.4	40
41	14.69	169.51	207.5	13.79	149.31	171.6	41	12.89	130.40	140.0	11.98	112.76	112.6	41
42	14.82	172.60	213.2	13.91	152.07	176.3	42	13.01	132.84	144.0	12.10	114.91	115.8	42
43	14.96	175.71	219.0	14.04	154.85	181.2	43	13.13	135.31	148.0	12.21	117.08	119.1	43
44	15.09	178.85	224.9	14.17	157.66	186.1	44	13.25	137.79	152.1	12.32	119.27	122.5	44
45	15.22	182.02	230.9	14.29	160.49	191.2	45	13.37	140.31	156.3	12.44	121.48	125.9	45
46	15.36	185.22	237.0	14.42	163.34	196.3	46	13.49	142.84	160.5	12.55	123.71	129.4	46
47	15.49	188.45	243.2	14.55	166.23	201.5	47	13.61	145.40	164.9	12.66	125.96	132.9	47
48	15.62	191.70	249.6	14.67	169.13	206.8	48	13.73	147.98	169.3	12.78	128.24	136.5	48
49	15.76	194.98	256.0	14.80	172.07	212.2	49	13.85	150.58	173.7	12.89	130.53	140.2	49
50	15.89	198.29	262.6	14.93	175.02	217.7	50	13.97	153.21	178.3	13.01	132.84	144.0	50
51	16.02	201.63	269.2	15.05	178.01	223.3	51	14.09	155.85	182.9	13.12	135.17	147.8	51
52	16.16	205.00	276.0	15.18	181.02	229.0	52	14.21	158.52	187.7	13.23	137.52	151.6	52
53	16.29	208.39	282.9	15.31	184.05	234.8	53	14.33	161.22	192.5	13.35	139.90	155.6	53
54	16.42	211.81	289.9	15.43	187.11	240.7	54	14.45	163.93	197.4	13.46	142.29	159.6	54
55	16.56	215.26	297.0	15.56	190.19	246.6	55	14.57	166.67	202.3	13.57	144.70	163.7	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.82	53.7	8.72	59.70	43.4	1	8.08	51.22	34.5	7.43	43.39	26.9	1
2	9.49	70.74	55.9	8.84	61.40	45.2	2	8.19	52.73	36.0	7.55	44.71	28.1	2
3	9.62	72.68	58.3	8.97	63.13	47.2	3	8.31	54.26	37.6	7.66	46.05	29.4	3
4	9.75	74.66	60.7	9.09	64.89	49.1	4	8.43	55.81	39.2	7.77	47.41	30.7	4
5	9.88	76.66	63.1	9.21	66.67	51.2	5	8.55	57.38	40.9	7.88	48.78	32.0	5
6	10.01	78.68	65.6	9.34	68.47	53.3	6	8.67	58.97	42.6	7.99	50.18	33.4	6
7	10.14	80.73	68.2	9.46	70.30	55.4	7	8.78	60.59	44.3	8.11	51.60	34.8	7
8	10.27	82.81	70.9	9.58	72.15	57.6	8	8.90	62.22	46.2	8.22	53.03	36.3	8
9	10.40	84.92	73.6	9.71	74.03	59.9	9	9.02	63.88	48.0	8.33	54.49	37.8	9
10	10.53	87.05	76.4	9.83	75.93	62.2	10	9.14	65.56	49.9	8.44	55.96	39.4	10
11	10.66	89.21	79.2	9.96	77.85	64.6	11	9.25	67.27	51.9	8.55	57.46	41.0	11
12	10.79	91.39	82.2	10.08	79.80	67.0	12	9.37	68.99	53.9	8.67	58.97	42.6	12
13	10.92	93.60	85.1	10.20	81.77	69.5	13	9.49	70.74	55.9	8.78	60.51	44.3	13
14	11.05	95.84	88.2	10.33	83.77	72.1	14	9.61	72.51	58.1	8.89	62.06	46.0	14
15	11.18	98.10	91.4	10.45	85.79	74.7	15	9.73	74.30	60.2	9.00	63.63	47.7	15
16	11.31	100.39	94.6	10.57	87.83	77.4	16	9.84	76.11	62.4	9.11	65.23	49.5	16
17	11.44	102.71	97.9	10.70	89.90	80.1	17	9.96	77.94	64.7	9.23	66.84	51.4	17
18	11.57	105.05	101.2	10.82	91.99	83.0	18	10.08	79.80	67.0	9.34	68.47	53.3	18
19	11.69	107.42	104.7	10.95	94.11	85.8	19	10.20	81.68	69.4	9.45	70.12	55.2	19
20	11.82	109.82	108.2	11.07	96.25	88.8	20	10.32	83.58	71.8	9.56	71.80	57.2	20
21	11.95	112.24	111.8	11.19	98.41	91.8	21	10.43	85.50	74.3	9.67	73.49	59.2	21
22	12.08	114.69	115.5	11.32	100.60	94.9	22	10.55	87.44	76.9	9.79	75.20	61.3	22
23	12.21	117.16	119.2	11.44	102.81	98.0	23	10.67	89.40	79.5	9.90	76.93	63.4	23
24	12.34	119.66	123.1	11.57	105.05	101.2	24	10.79	91.39	82.2	10.01	78.68	65.6	24
25	12.47	122.19	127.0	11.69	107.31	104.5	25	10.91	93.40	84.9	10.12	80.45	67.9	25
26	12.60	124.74	131.0	11.81	109.60	107.9	26	11.02	95.43	87.7	10.23	82.24	70.1	26
27	12.73	127.32	135.1	11.94	111.91	111.3	27	11.14	97.48	90.5	10.35	84.05	72.5	27
28	12.86	129.93	139.3	12.06	114.24	114.8	28	11.26	99.56	93.4	10.46	85.88	74.8	28
29	12.99	132.56	143.5	12.18	116.60	118.4	29	11.38	101.65	96.4	10.57	87.73	77.3	29
30	13.12	135.22	147.9	12.31	118.98	122.0	30	11.49	103.77	99.4	10.68	89.60	79.8	30
31	13.25	137.91	152.3	12.43	121.38	125.7	31	11.61	105.91	102.5	10.79	91.49	82.3	31
32	13.38	140.62	156.8	12.56	123.81	129.5	32	11.73	108.07	105.6	10.91	93.40	84.9	32
33	13.51	143.36	161.4	12.68	126.27	133.4	33	11.85	110.25	108.9	11.02	95.33	87.5	33
34	13.64	146.13	166.1	12.80	128.74	137.4	34	11.97	112.46	112.1	11.13	97.28	90.2	34
35	13.77	148.92	170.9	12.93	131.24	141.4	35	12.08	114.69	115.5	11.24	99.24	93.0	35
36	13.90	151.74	175.7	13.05	133.77	145.5	36	12.20	116.93	118.9	11.35	101.23	95.8	36
37	14.03	154.58	180.7	13.17	136.32	149.7	37	12.32	119.21	122.4	11.47	103.24	98.6	37
38	14.16	157.45	185.8	13.30	138.89	153.9	38	12.44	121.50	125.9	11.58	105.27	101.6	38
39	14.29	160.35	190.9	13.42	141.49	158.3	39	12.56	123.81	129.5	11.69	107.31	104.5	39
40	14.42	163.27	196.2	13.55	144.11	162.7	40	12.67	126.15	133.2	11.80	109.38	107.6	40
41	14.55	166.22	201.5	13.67	146.76	167.2	41	12.79	128.51	137.0	11.91	111.46	110.7	41
42	14.68	169.20	206.9	13.79	149.43	171.8	42	12.91	130.89	140.8	12.03	113.57	113.8	42
43	14.81	172.20	212.5	13.92	152.12	176.4	43	13.03	133.29	144.7	12.14	115.70	117.0	43
44	14.94	175.23	218.1	14.04	154.84	181.2	44	13.15	135.71	148.7	12.25	117.84	120.3	44
45	15.07	178.29	223.8	14.16	157.58	186.0	45	13.26	138.16	152.7	12.36	120.01	123.6	45
46	15.20	181.37	229.7	14.29	160.35	190.9	46	13.38	140.62	156.8	12.47	122.19	127.0	46
47	15.33	184.48	235.6	14.41	163.14	195.9	47	13.50	143.11	161.0	12.59	124.39	130.5	47
48	15.46	187.62	241.6	14.54	165.95	201.0	48	13.62	145.62	165.2	12.70	126.62	134.0	48
49	15.59	190.78	247.8	14.66	168.79	206.2	49	13.73	148.15	169.6	12.81	128.86	137.5	49
50	15.72	193.96	254.0	14.78	171.66	211.5	50	13.85	150.71	174.0	12.92	131.12	141.2	50
51	15.84	197.18	260.3	14.91	174.54	216.8	51	13.97	153.29	178.4	13.03	133.41	144.9	51
52	15.97	200.42	266.8	15.03	177.45	222.3	52	14.09	155.88	183.0	13.15	135.71	148.7	52
53	16.10	203.69	273.3	15.16	180.39	227.8	53	14.21	158.50	187.6	13.26	138.03	152.5	53
54	16.23	206.98	280.0	15.28	183.35	233.4	54	14.32	161.14	192.3	13.37	140.37	156.4	54
55	16.36	210.30	286.8	15.40	186.33	239.2	55	14.44	163.81	197.1	13.48	142.74	160.3	55
56	16.49	213.65	293.6	15.53	189.34	245.0	56	14.56	166.49	202.0	13.59	145.12	164.4	56
57	16.62	217.02	300.6	15.65	192.37	250.9	57	14.68	169.20	206.9	13.71	147.52	168.5	57
58	16.75	220.42	307.7	15.77	195.42	256.9	58	14.80	171.93	212.0	13.82	149.94	172.6	58
59	16.88	223.85	314.9	15.90	198.50	263.0	59	14.91	174.68	217.1	13.93	152.38	176.9	59
60	17.01	227.30	322.2	16.02	201.61	269.2	60	15.03	177.45	222.3	14.04	154.84	181.2	60

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.78	53.6	8.72	59.66	43.3	1	8.07	51.20	34.4	7.43	43.38	26.9	1
2	9.48	70.65	55.8	8.84	61.34	45.2	2	8.19	52.68	35.9	7.54	44.68	28.1	2
3	9.61	72.55	58.1	8.96	63.03	47.1	3	8.31	54.18	37.5	7.65	46.00	29.3	3
4	9.74	74.48	60.4	9.08	64.75	49.0	4	8.42	55.70	39.1	7.76	47.34	30.6	4
5	9.86	76.43	62.8	9.20	66.50	51.0	5	8.54	57.25	40.7	7.87	48.70	32.0	5
6	9.99	78.41	65.3	9.32	68.26	53.0	6	8.65	58.82	42.4	7.98	50.07	33.3	6
7	10.12	80.41	67.8	9.44	70.05	55.1	7	8.77	60.40	44.1	8.10	51.47	34.7	7
8	10.25	82.44	70.4	9.57	71.86	57.3	8	8.89	62.01	45.9	8.21	52.89	36.2	8
9	10.37	84.49	73.0	9.69	73.70	59.5	9	9.00	63.64	47.7	8.32	54.32	37.6	9
10	10.50	86.57	75.7	9.81	75.56	61.8	10	9.12	65.29	49.6	8.43	55.78	39.2	10
11	10.63	88.67	78.5	9.93	77.44	64.1	11	9.23	66.96	51.5	8.54	57.25	40.7	11
12	10.75	90.80	81.4	10.05	79.34	66.5	12	9.35	68.66	53.5	8.65	58.74	42.3	12
13	10.88	92.96	84.3	10.17	81.27	68.9	13	9.47	70.37	55.5	8.76	60.25	44.0	13
14	11.01	95.14	87.3	10.29	83.22	71.4	14	9.58	72.11	57.6	8.87	61.79	45.7	14
15	11.13	97.34	90.3	10.42	85.20	73.9	15	9.70	73.86	59.7	8.98	63.34	47.4	15
16	11.26	99.57	93.4	10.54	87.19	76.6	16	9.81	75.64	61.9	9.09	64.91	49.2	16
17	11.39	101.83	96.6	10.66	89.22	79.2	17	9.93	77.44	64.1	9.20	66.50	51.0	17
18	11.51	104.11	99.9	10.78	91.26	82.0	18	10.05	79.26	66.3	9.31	68.10	52.8	18
19	11.64	106.41	103.2	10.90	93.33	84.8	19	10.16	81.10	68.7	9.42	69.73	54.8	19
20	11.77	108.74	106.6	11.02	95.42	87.6	20	10.28	82.96	71.1	9.53	71.38	56.7	20
21	11.89	111.10	110.1	11.14	97.53	90.6	21	10.39	84.84	73.5	9.64	73.04	58.7	21
22	12.02	113.48	113.7	11.26	99.67	93.6	22	10.51	86.75	76.0	9.75	74.73	60.7	22
23	12.15	115.89	117.3	11.39	101.83	96.6	23	10.63	88.67	78.5	9.86	76.43	62.8	23
24	12.27	118.32	121.0	11.51	104.01	99.7	24	10.74	90.62	81.1	9.98	78.16	65.0	24
25	12.40	120.77	124.8	11.63	106.21	102.9	25	10.86	92.59	83.8	10.09	79.90	67.2	25
26	12.53	123.26	128.7	11.75	108.44	106.2	26	10.97	94.58	86.5	10.20	81.66	69.4	26
27	12.65	125.76	132.6	11.87	110.70	109.5	27	11.09	96.59	89.3	10.31	83.44	71.7	27
28	12.78	128.30	136.6	11.99	112.97	112.9	28	11.21	98.62	92.1	10.42	85.24	74.0	28
29	12.91	130.86	140.7	12.11	115.27	116.4	29	11.32	100.67	95.0	10.53	87.06	76.4	29
30	13.03	133.44	144.9	12.24	117.59	119.9	30	11.44	102.74	97.9	10.64	88.90	78.8	30
31	13.16	136.05	149.2	12.36	119.94	123.5	31	11.55	104.84	100.9	10.75	90.76	81.3	31
32	13.29	138.68	153.6	12.48	122.30	127.2	32	11.67	106.95	104.0	10.86	92.63	83.8	32
33	13.41	141.34	158.0	12.60	124.69	130.9	33	11.79	109.09	107.1	10.97	94.53	86.4	33
34	13.54	144.02	162.5	12.72	127.11	134.7	34	11.90	111.25	110.3	11.08	96.45	89.1	34
35	13.67	146.73	167.1	12.84	129.55	138.6	35	12.02	113.43	113.6	11.19	98.38	91.8	35
36	13.80	149.47	171.8	12.96	132.01	142.6	36	12.13	115.63	116.9	11.30	100.34	94.5	36
37	13.92	152.23	176.6	13.09	134.49	146.7	37	12.25	117.85	120.3	11.41	102.31	97.3	37
38	14.05	155.01	181.5	13.21	137.00	150.8	38	12.37	120.09	123.7	11.52	104.30	100.2	38
39	14.18	157.82	186.4	13.33	139.53	155.0	39	12.48	122.36	127.3	11.63	106.31	103.1	39
40	14.30	160.66	191.5	13.45	142.08	159.2	40	12.60	124.64	130.8	11.75	108.34	106.0	40
41	14.43	163.52	196.6	13.57	144.66	163.6	41	12.71	126.95	134.5	11.86	110.39	109.1	41
42	14.56	166.41	201.8	13.69	147.25	168.0	42	12.83	129.27	138.2	11.97	112.46	112.1	42
43	14.68	169.32	207.2	13.81	149.88	172.5	43	12.95	131.62	142.0	12.08	114.55	115.3	43
44	14.81	172.25	212.6	13.94	152.52	177.1	44	13.06	133.99	145.8	12.19	116.66	118.5	44
45	14.94	175.22	218.1	14.06	155.19	181.8	45	13.18	136.38	149.8	12.30	118.79	121.7	45
46	15.06	178.20	223.7	14.18	157.88	186.5	46	13.29	138.79	153.7	12.41	120.93	125.0	46
47	15.19	181.22	229.4	14.30	160.60	191.4	47	13.41	141.23	157.8	12.52	123.10	128.4	47
48	15.32	184.25	235.2	14.42	163.34	196.3	48	13.53	143.68	161.9	12.63	125.28	131.9	48
49	15.44	187.32	241.1	14.54	166.10	201.3	49	13.64	146.15	166.1	12.74	127.49	135.3	49
50	15.57	190.41	247.0	14.66	168.88	206.4	50	13.76	148.65	170.4	12.85	129.71	138.9	50
51	15.70	193.52	253.1	14.79	171.69	211.5	51	13.87	151.17	174.8	12.96	131.95	142.5	51
52	15.82	196.66	259.3	14.91	174.52	216.8	52	13.99	153.71	179.2	13.07	134.21	146.2	52
53	15.95	199.82	265.6	15.03	177.38	222.1	53	14.11	156.27	183.7	13.18	136.49	149.9	53
54	16.08	203.01	272.0	15.15	180.25	227.5	54	14.22	158.85	188.2	13.29	138.79	153.7	54
55	16.20	206.23	278.5	15.27	183.15	233.1	55	14.34	161.45	192.9	13.40	141.11	157.6	55
56	16.33	209.46	285.0	15.39	186.08	238.7	56	14.45	164.07	197.6	13.51	143.45	161.5	56
57	16.46	212.73	291.7	15.51	189.02	244.4	57	14.57	166.72	202.4	13.63	145.81	165.5	57
58	16.58	216.02	298.5	15.63	191.99	250.1	58	14.69	169.38	207.3	13.74	148.18	169.6	58
59	16.71	219.34	305.4	15.76	194.98	256.0	59	14.80	172.07	212.2	13.85	150.58	173.7	59
60	16.84	222.68	312.4	15.88	198.00	262.0	60	14.92	174.77	217.3	13.96	153.00	177.9	60
61	16.96	226.04	319.5	16.00	201.04	268.0	61	15.03	177.50	222.4	14.07	155.43	182.2	61
62	17.09	229.43	326.8	16.12	204.10	274.2	62	15.15	180.25	227.5	14.18	157.88	186.5	62
63	17.22	232.85	334.1	16.24	207.19	280.4	63	15.27	183.02	232.8	14.29	160.36	190.9	63
64	17.35	236.29	341.5	16.36	210.30	286.7	64	15.38	185.82	238.2	14.40	162.85	195.4	64
65	17.47	239.76	349.1	16.48	213.43	293.2	65	15.50	188.63	243.6	14.51	165.36	199.9	65

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.74	53.6	8.71	59.63	43.3	1	8.07	51.18	34.4	7.43	43.36	26.9	1
2	9.48	70.58	55.8	8.83	61.28	45.1	2	8.19	52.64	35.9	7.54	44.65	28.1	2
3	9.60	72.44	58.0	8.95	62.95	47.0	3	8.30	54.12	37.4	7.65	45.96	29.3	3
4	9.73	74.33	60.3	9.07	64.64	48.9	4	8.42	55.62	39.0	7.76	47.28	30.6	4
5	9.85	76.24	62.6	9.19	66.35	50.8	5	8.53	57.14	40.6	7.87	48.62	31.9	5
6	9.98	78.18	65.0	9.31	68.08	52.8	6	8.64	58.69	42.3	7.98	49.98	33.2	6
7	10.10	80.14	67.5	9.43	69.84	54.9	7	8.76	60.25	44.0	8.09	51.37	34.6	7
8	10.23	82.13	70.0	9.55	71.62	57.0	8	8.87	61.83	45.7	8.20	52.76	36.0	8
9	10.35	84.13	72.6	9.67	73.42	59.2	9	8.99	63.44	47.5	8.31	54.18	37.5	9
10	10.47	86.17	75.2	9.79	75.25	61.4	10	9.10	65.06	49.3	8.42	55.62	39.0	10
11	10.60	88.23	77.9	9.91	77.09	63.6	11	9.22	66.71	51.2	8.52	57.08	40.5	11
12	10.72	90.31	80.7	10.03	78.96	66.0	12	9.33	68.37	53.2	8.63	58.55	42.1	12
13	10.85	92.41	83.5	10.15	80.85	68.4	13	9.44	70.06	55.1	8.74	60.04	43.7	13
14	10.97	94.55	86.4	10.27	82.77	70.8	14	9.56	71.77	57.2	8.85	61.56	45.4	14
15	11.10	96.70	89.4	10.38	84.70	73.3	15	9.67	73.50	59.2	8.96	63.09	47.1	15
16	11.22	98.88	92.5	10.50	86.66	75.9	16	9.79	75.25	61.4	9.07	64.64	48.9	16
17	11.34	101.08	95.6	10.62	88.64	78.5	17	9.90	77.01	63.5	9.18	66.21	50.7	17
18	11.47	103.31	98.7	10.74	90.64	81.1	18	10.02	78.80	65.8	9.29	67.79	52.5	18
19	11.59	105.56	102.0	10.86	92.67	83.9	19	10.13	80.61	68.1	9.40	69.40	54.4	19
20	11.72	107.84	105.3	10.98	94.72	86.7	20	10.25	82.45	70.4	9.51	71.02	56.3	20
21	11.84	110.14	108.7	11.10	96.79	89.5	21	10.36	84.30	72.8	9.62	72.67	58.2	21
22	11.97	112.47	112.1	11.22	98.88	92.5	22	10.47	86.17	75.2	9.73	74.33	60.3	22
23	12.09	114.82	115.7	11.34	101.00	95.4	23	10.59	88.06	77.7	9.84	76.01	62.3	23
24	12.22	117.19	119.3	11.46	103.13	98.5	24	10.70	89.97	80.2	9.95	77.71	64.4	24
25	12.34	119.59	123.0	11.58	105.29	101.6	25	10.82	91.91	82.8	10.06	79.43	66.6	25
26	12.46	122.01	126.7	11.70	107.47	104.8	26	10.93	93.86	85.5	10.17	81.17	68.8	26
27	12.59	124.46	130.5	11.82	109.68	108.0	27	11.05	95.84	88.2	10.28	82.93	71.0	27
28	12.71	126.93	134.5	11.94	111.91	111.3	28	11.16	97.83	91.0	10.38	84.70	73.3	28
29	12.84	129.42	138.4	12.06	114.16	114.7	29	11.28	99.85	93.8	10.49	86.50	75.6	29
30	12.96	131.94	142.5	12.18	116.43	118.1	30	11.39	101.88	96.7	10.60	88.31	78.0	30
31	13.09	134.48	146.6	12.29	118.72	121.6	31	11.50	103.94	99.6	10.71	90.14	80.5	31
32	13.21	137.05	150.9	12.41	121.04	125.2	32	11.62	106.02	102.6	10.82	91.99	83.0	32
33	13.33	139.64	155.2	12.53	123.38	128.9	33	11.73	108.12	105.7	10.93	93.86	85.5	33
34	13.46	142.26	159.5	12.65	125.74	132.6	34	11.85	110.23	108.8	11.04	95.75	88.1	34
35	13.58	144.90	164.0	12.77	128.12	136.4	35	11.96	112.37	112.0	11.15	97.66	90.7	35
36	13.71	147.57	168.6	12.89	130.53	140.2	36	12.08	114.53	115.3	11.26	99.58	93.4	36
37	13.83	150.26	173.2	13.01	132.96	144.1	37	12.19	116.71	118.6	11.37	101.53	96.2	37
38	13.96	152.97	177.9	13.13	135.41	148.2	38	12.30	118.91	121.9	11.48	103.49	99.0	38
39	14.08	155.71	182.7	13.25	137.88	152.2	39	12.42	121.13	125.4	11.59	105.47	101.9	39
40	14.20	158.47	187.6	13.37	140.37	156.4	40	12.53	123.38	128.9	11.70	107.47	104.8	40
41	14.33	161.26	192.5	13.49	142.89	160.6	41	12.65	125.64	132.4	11.81	109.49	107.7	41
42	14.45	164.07	197.6	13.61	145.43	164.9	42	12.76	127.92	136.0	11.92	111.53	110.8	42
43	14.58	166.90	202.7	13.73	148.00	169.3	43	12.88	130.23	139.7	12.03	113.59	113.8	43
44	14.70	169.76	208.0	13.85	150.58	173.7	44	12.99	132.55	143.5	12.14	115.67	117.0	44
45	14.83	172.65	213.3	13.97	153.19	178.3	45	13.11	134.89	147.3	12.24	117.76	120.2	45
46	14.95	175.55	218.7	14.09	155.82	182.9	46	13.22	137.26	151.2	12.35	119.88	123.4	46
47	15.07	178.49	224.2	14.20	158.47	187.6	47	13.33	139.64	155.2	12.46	122.01	126.7	47
48	15.20	181.44	229.8	14.32	161.14	192.3	48	13.45	142.05	159.2	12.57	124.16	130.1	48
49	15.32	184.42	235.5	14.44	163.84	197.2	49	13.56	144.48	163.3	12.68	126.33	133.5	49
50	15.45	187.43	241.3	14.56	166.56	202.1	50	13.68	146.93	167.5	12.79	128.52	137.0	50
51	15.57	190.46	247.1	14.68	169.30	207.1	51	13.79	149.39	171.7	12.90	130.73	140.5	51
52	15.70	193.51	253.1	14.80	172.07	212.2	52	13.91	151.88	176.0	13.01	132.96	144.1	52
53	15.82	196.59	259.2	14.92	174.85	217.4	53	14.02	154.39	180.4	13.12	135.20	147.8	53
54	15.95	199.69	265.3	15.04	177.66	222.7	54	14.13	156.92	184.8	13.23	137.47	151.5	54
55	16.07	202.82	271.6	15.16	180.49	228.0	55	14.25	159.47	189.4	13.34	139.75	155.3	55
56	16.19	205.97	277.9	15.28	183.35	233.4	56	14.36	162.04	194.0	13.45	142.05	159.2	56
57	16.32	209.14	284.1	15.40	186.22	238.9	57	14.48	164.63	198.6	13.56	144.37	163.1	57
58	16.44	212.34	290.9	15.52	189.12	244.5	58	14.59	167.24	203.4	13.67	146.71	167.1	58
59	16.57	215.57	297.6	15.64	192.04	250.2	59	14.71	169.88	208.2	13.78	149.07	171.1	59
60	16.69	218.81	304.3	15.76	194.98	256.0	60	14.82	172.53	213.1	13.89	151.45	175.2	60
61	16.82	222.09	311.2	15.88	197.95	261.9	61	14.94	175.20	218.1	14.00	153.84	179.4	61
62	16.94	225.38	318.2	16.00	200.94	267.8	62	15.05	177.90	223.1	14.11	156.26	183.7	62
63	17.06	228.70	325.2	16.11	203.95	273.9	63	15.16	180.61	228.2	14.21	158.69	188.0	63
64	17.19	232.05	332.4	16.23	206.98	280.0	64	15.28	183.35	233.4	14.32	161.14	192.3	64
65	17.31	235.42	339.6	16.35	210.04	286.2	65	15.39	186.10	238.7	14.43	163.62	196.8	65
66	17.44	238.81	347.0	16.47	213.11	292.5	66	15.51	188.88	244.1	14.54	166.11	201.3	66
67	17.56	242.23	354.5	16.59	216.21	298.9	67	15.62	191.68	249.5	14.65	168.61	205.9	67
68	17.69	245.67	362.1	16.71	219.34	305.4	68	15.74	194.49	255.0	14.76	171.14	210.5	68
69	17.81	249.14	369.8	16.83	222.48	312.0	69	15.85	197.33	260.6	14.87	173.69	215.2	69
70	17.93	252.63	377.6	16.95	225.65	318.7	70	15.97	200.19	266.3	14.98	176.25	220.0	70

75'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.71	53.6	8.71	59.61	43.3	1	8.07	51.13	34.4	7.43	43.33	26.8	1
2	9.48	70.52	55.7	8.83	61.23	45.1	2	8.18	52.54	35.8	7.53	44.57	28.0	2
3	9.60	72.35	57.9	8.95	62.87	46.9	3	8.29	53.97	37.3	7.64	45.84	29.2	3
4	9.72	74.20	60.1	9.06	64.54	48.8	4	8.40	55.43	38.8	7.75	47.12	30.4	4
5	9.84	76.08	62.4	9.18	66.22	50.7	5	8.51	56.90	40.4	7.85	48.42	31.7	5
6	9.96	77.98	64.8	9.30	67.93	52.6	6	8.62	58.39	41.9	7.96	49.74	33.0	6
7	10.09	79.91	67.2	9.42	69.66	54.7	7	8.73	59.90	43.6	8.06	51.07	34.3	7
8	10.21	81.86	69.6	9.54	71.41	56.7	8	8.84	61.42	45.3	8.17	52.42	35.7	8
9	10.33	83.83	72.2	9.65	73.19	58.9	9	8.95	62.97	47.0	8.28	53.79	37.1	9
10	10.45	85.82	74.8	9.77	74.98	61.0	10	9.06	64.54	48.8	8.38	55.18	38.5	10
11	10.58	87.84	77.4	9.89	76.80	63.3	11	9.18	66.12	50.6	8.49	56.59	40.0	11
12	10.70	89.89	80.1	10.01	78.63	65.6	12	9.29	67.73	52.4	8.59	58.01	41.5	12
13	10.82	91.95	82.9	10.12	80.49	67.9	13	9.40	69.35	54.3	8.70	59.45	43.1	13
14	10.94	94.04	85.8	10.24	82.38	70.3	14	9.51	71.00	56.3	8.81	60.91	44.7	14
15	11.06	96.15	88.7	10.36	84.28	72.7	15	9.62	72.66	58.2	8.91	62.39	46.3	15
16	11.19	98.29	91.6	10.48	86.20	75.3	16	9.73	74.34	60.3	9.02	63.88	48.0	16
17	11.31	100.45	94.7	10.59	88.15	77.8	17	9.84	76.05	62.4	9.12	65.40	49.7	17
18	11.43	102.63	97.8	10.71	90.12	80.4	18	9.95	77.77	64.5	9.23	66.92	51.5	18
19	11.55	104.84	100.9	10.83	92.11	83.1	19	10.06	79.51	66.7	9.34	68.47	53.3	19
20	11.68	107.07	104.2	10.95	94.12	85.9	20	10.17	81.27	68.9	9.44	70.04	55.1	20
21	11.80	109.33	107.5	11.06	96.15	88.7	21	10.28	83.04	71.2	9.55	71.62	57.0	21
22	11.92	111.60	110.9	11.18	98.21	91.5	22	10.39	84.84	73.5	9.66	73.22	58.9	22
23	12.04	113.90	114.3	11.30	100.29	94.4	23	10.50	86.66	75.9	9.76	74.84	60.9	23
24	12.16	116.23	117.8	11.42	102.39	97.4	24	10.61	88.50	78.3	9.87	76.47	62.9	24
25	12.29	118.58	121.4	11.54	104.51	100.5	25	10.73	90.35	80.8	9.97	78.13	64.9	25
26	12.41	120.95	125.1	11.65	106.65	103.6	26	10.84	92.23	83.3	10.08	79.80	67.0	26
27	12.53	123.34	128.8	11.77	108.81	106.7	27	10.95	94.12	85.9	10.19	81.49	69.2	27
28	12.65	125.76	132.6	11.89	111.00	110.0	28	11.06	96.03	88.5	10.29	83.19	71.3	28
29	12.78	128.20	136.5	12.01	113.21	113.3	29	11.17	97.97	91.2	10.40	84.92	73.6	29
30	12.90	130.67	140.4	12.12	115.44	116.6	30	11.28	99.92	93.9	10.50	86.66	75.9	30
31	13.02	133.16	144.5	12.24	117.69	120.0	31	11.39	101.89	96.7	10.61	88.42	78.2	31
32	13.14	135.67	148.6	12.36	119.96	123.5	32	11.50	103.88	99.6	10.72	90.20	80.5	32
33	13.27	138.20	152.8	12.48	122.25	127.1	33	11.61	105.89	102.5	10.82	91.99	83.0	33
34	13.39	140.76	157.0	12.59	124.57	130.7	34	11.72	107.92	105.4	10.93	93.80	85.4	34
35	13.51	143.35	161.4	12.71	126.91	134.4	35	11.83	109.97	108.4	11.03	95.63	87.9	35
36	13.63	145.95	165.8	12.83	129.27	138.2	36	11.94	112.04	111.5	11.14	97.48	90.5	36
37	13.75	148.58	170.3	12.95	131.65	142.0	37	12.05	114.12	114.6	11.25	99.35	93.1	37
38	13.88	151.23	174.9	13.06	134.05	145.9	38	12.16	116.23	117.8	11.35	101.23	95.8	38
39	14.00	153.91	179.5	13.18	136.48	149.9	39	12.28	118.35	121.1	11.46	103.13	98.5	39
40	14.12	156.61	184.3	13.30	138.93	154.0	40	12.39	120.50	124.4	11.57	105.05	101.2	40
41	14.24	159.33	189.1	13.42	141.39	158.1	41	12.50	122.66	127.7	11.67	106.99	104.1	41
42	14.37	162.08	194.0	13.54	143.88	162.3	42	12.61	124.85	131.2	11.78	108.94	106.9	42
43	14.49	164.85	199.0	13.65	146.40	166.6	43	12.72	127.05	134.6	11.88	110.91	109.8	43
44	14.61	167.64	204.1	13.77	148.93	170.9	44	12.83	129.27	138.2	11.99	112.90	112.8	44
45	14.73	170.46	209.3	13.89	151.48	175.3	45	12.94	131.51	141.8	12.10	114.91	115.8	45
46	14.85	173.30	214.5	14.01	154.06	179.8	46	13.05	133.77	145.5	12.20	116.93	118.9	46
47	14.98	176.17	219.9	14.12	156.66	184.4	47	13.16	136.05	149.2	12.31	118.98	122.0	47
48	15.10	179.05	225.3	14.24	159.28	189.0	48	13.27	138.35	153.0	12.41	121.04	125.2	48
49	15.22	181.97	230.8	14.36	161.92	193.7	49	13.38	140.67	156.9	12.52	123.12	128.4	49
50	15.34	184.90	236.4	14.48	164.59	198.5	50	13.49	143.00	160.8	12.63	125.21	131.7	50

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.47	187.06	242.1	14.59	167.27	203.4	51	13.60	145.36	164.8	12.73	127.32	135.1	51
52	15.59	190.84	247.9	14.71	169.98	208.4	52	13.72	147.73	168.8	12.84	129.45	138.5	52
53	15.71	193.84	253.8	14.83	172.71	213.4	53	13.83	150.13	173.0	12.94	131.60	142.0	53
54	15.83	196.87	259.7	14.95	175.46	218.5	54	13.94	152.54	177.2	13.05	133.77	145.5	54
55	15.95	199.93	265.8	15.06	178.23	223.7	55	14.05	154.98	181.4	13.16	135.95	149.1	55
56	16.08	203.00	272.0	15.18	181.03	229.0	56	14.16	157.43	185.7	13.26	138.16	152.7	56
57	16.29	206.10	278.2	15.30	183.85	234.4	57	14.27	159.90	190.1	13.37	140.37	156.4	57
58	16.32	209.22	284.6	15.42	186.68	239.8	58	14.38	162.39	194.6	13.48	142.61	160.1	58
59	16.44	212.37	291.0	15.53	189.54	245.4	59	14.49	164.90	199.1	13.58	144.87	163.9	59
60	16.57	215.54	297.5	15.65	192.42	251.0	60	14.60	167.43	203.7	13.69	147.14	167.8	60
61	16.69	218.73	304.2	15.77	195.33	256.7	61	14.71	169.98	208.4	13.79	149.43	171.8	61
62	16.81	221.95	310.9	15.89	198.25	262.5	62	14.82	172.55	213.1	13.90	151.74	175.7	62
63	16.93	225.19	317.7	16.01	201.20	268.3	63	14.93	175.14	217.9	14.01	154.06	179.8	63
64	17.05	228.45	324.7	16.12	204.17	274.3	64	15.04	177.74	222.8	14.11	156.41	183.9	64
65	17.18	231.74	331.7	16.24	207.16	280.4	65	15.15	180.37	227.8	14.22	158.77	188.1	65
66	17.30	235.05	338.8	16.36	210.17	286.5	66	15.27	183.01	232.8	14.32	161.14	192.3	66
67	17.42	238.38	346.1	16.48	213.20	292.7	67	15.38	185.68	237.9	14.43	163.54	196.6	67
68	17.54	241.74	353.4	16.59	216.26	299.0	68	15.49	188.36	243.1	14.54	165.95	201.0	68
69	17.67	245.12	360.8	16.71	219.34	305.4	69	15.60	191.07	248.3	14.64	168.39	205.5	69
70	17.79	248.52	368.4	16.83	222.43	311.9	70	15.71	193.79	253.7	14.75	170.84	210.0	70
71	17.91	251.95	376.0	16.95	225.55	318.5	71	15.82	196.53	259.1	14.85	173.30	214.5	71
72	18.03	255.40	383.8	17.06	228.70	325.2	72	15.93	199.29	264.5	14.96	175.79	219.1	72
73	18.16	258.88	391.6	17.18	231.86	332.0	73	16.04	202.07	270.1	15.07	178.29	223.8	73
74	18.28	262.37	399.6	17.30	235.05	338.8	74	16.15	204.87	275.7	15.17	180.81	228.6	74
75	18.40	265.90	407.7	17.42	238.25	345.8	75	16.26	207.69	281.4	15.28	183.35	233.4	75

80'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.68	53.5	8.71	59.59	43.3	1	8.07	51.12	34.4	7.42	43.29	26.8	1
2	9.47	70.46	55.6	8.83	61.19	45.0	2	8.18	52.52	35.8	7.53	44.50	27.9	2
3	9.59	72.27	57.8	8.94	62.81	46.8	3	8.29	53.93	37.2	7.63	45.73	29.1	3
4	9.71	74.09	60.0	9.06	64.45	48.7	4	8.40	55.37	38.7	7.73	46.98	30.3	4
5	9.83	75.94	62.2	9.18	66.12	50.5	5	8.51	56.83	40.3	7.84	48.24	31.5	5
6	9.95	77.81	64.5	9.29	67.80	52.5	6	8.62	58.30	41.9	7.94	49.52	32.8	6
7	10.07	79.71	66.9	9.41	69.51	54.5	7	8.73	59.80	43.5	8.04	50.82	34.1	7
8	10.19	81.63	69.3	9.52	71.23	56.5	8	8.84	61.31	45.1	8.15	52.13	35.4	8
9	10.31	83.57	71.8	9.64	72.98	58.6	9	8.94	62.84	46.8	8.25	53.46	36.8	9
10	10.44	85.53	74.4	9.76	74.75	60.8	10	9.05	64.39	48.6	8.35	54.81	38.1	10
11	10.56	87.51	77.0	9.87	76.54	63.0	11	9.16	65.96	50.4	8.46	56.17	39.6	11
12	10.68	89.52	79.6	9.99	78.35	65.2	12	9.27	67.55	52.2	8.56	57.55	41.0	12
13	10.80	91.55	82.4	10.10	80.18	67.5	13	9.38	69.16	54.1	8.66	58.94	42.6	13
14	10.92	93.61	85.2	10.22	82.04	69.9	14	9.49	70.78	56.0	8.77	60.36	44.1	14
15	11.04	95.68	88.0	10.34	83.91	72.3	15	9.60	72.43	58.0	8.87	61.79	45.7	15
16	11.16	97.78	90.9	10.45	85.81	74.7	16	9.71	74.09	60.0	8.97	63.23	47.3	16
17	11.28	99.91	93.9	10.57	87.73	77.3	17	9.82	75.78	62.0	9.08	64.70	48.9	17
18	11.40	102.05	96.9	10.68	89.67	79.8	18	9.93	77.48	64.1	9.18	66.18	50.6	18
19	11.52	104.22	100.0	10.80	91.63	82.5	19	10.04	79.20	66.3	9.28	67.68	52.3	19
20	11.64	106.41	103.2	10.92	93.61	85.2	20	10.15	80.94	68.5	9.39	69.19	54.1	20
21	11.76	108.62	106.4	11.03	95.61	87.9	21	10.26	82.70	70.7	9.49	70.72	55.9	21
22	11.88	110.86	109.8	11.15	97.63	90.7	22	10.37	84.47	73.0	9.59	72.27	57.8	22
23	12.00	113.12	113.1	11.27	99.68	93.6	23	10.48	86.27	75.3	9.70	73.83	59.6	23
24	12.12	115.40	116.6	11.38	101.74	96.5	24	10.59	88.09	77.7	9.80	75.41	61.6	24
25	12.24	117.71	120.1	11.50	103.83	99.5	25	10.70	89.92	80.2	9.90	77.01	63.5	25
26	12.36	120.03	123.7	11.61	105.94	102.5	26	10.81	91.77	82.7	10.01	78.62	65.6	26
27	12.48	122.38	127.3	11.73	108.07	105.6	27	10.92	93.64	85.2	10.11	80.25	67.6	27
28	12.60	124.76	131.0	11.85	110.22	108.8	28	11.03	95.54	87.8	10.21	81.90	69.7	28
29	12.72	127.15	134.8	11.96	112.39	112.0	29	11.14	97.44	90.4	10.31	83.57	71.8	29
30	12.84	129.57	138.7	12.08	114.58	115.3	30	11.25	99.37	93.1	10.42	85.25	74.0	30
31	12.96	132.01	142.6	12.19	116.80	118.7	31	11.36	101.32	95.9	10.52	86.94	76.2	31
32	13.09	134.48	146.6	12.31	119.03	122.1	32	11.47	103.29	98.7	10.62	88.66	78.5	32
33	13.21	136.96	150.7	12.43	121.29	125.6	33	11.58	105.27	101.6	10.73	90.39	80.8	33
34	13.33	139.47	154.9	12.54	123.57	129.2	34	11.69	107.28	104.5	10.83	92.14	83.2	34
35	13.45	142.01	159.1	12.66	125.87	132.8	35	11.80	109.30	107.4	10.93	93.90	85.6	35
36	13.57	144.56	163.4	12.78	128.19	136.5	36	11.91	111.34	110.5	11.04	95.68	88.0	36
37	13.69	147.14	167.8	12.89	130.53	140.2	37	12.02	113.40	113.6	11.14	97.48	90.5	37
38	13.81	149.74	172.3	13.01	132.89	144.0	38	12.13	115.48	116.7	11.24	99.30	93.0	38
39	13.93	152.36	176.8	13.12	135.27	147.9	39	12.24	117.58	119.9	11.35	101.13	95.6	39
40	14.05	155.01	181.5	13.24	137.68	151.9	40	12.35	119.70	123.1	11.45	102.98	98.3	40
41	14.17	157.68	186.2	13.36	140.10	155.9	41	12.45	121.84	126.4	11.55	104.84	100.9	41
42	14.29	160.37	191.0	13.47	142.55	160.0	42	12.56	123.99	129.8	11.66	106.72	103.7	42
43	14.41	163.09	195.8	13.59	145.02	164.2	43	12.67	126.17	133.2	11.76	108.62	106.4	43
44	14.53	165.82	200.8	13.70	147.51	168.5	44	12.78	128.36	136.7	11.86	110.54	109.3	44
45	14.65	168.58	205.8	13.82	150.02	172.8	45	12.89	130.57	140.3	11.97	112.47	112.2	45
46	14.77	171.37	210.9	13.94	152.55	177.2	46	13.00	132.80	143.9	12.07	114.42	115.1	46
47	14.89	174.17	216.1	14.05	155.10	181.6	47	13.11	135.05	147.6	12.17	116.39	118.1	47
48	15.01	177.00	221.4	14.17	157.68	186.2	48	13.22	137.32	151.3	12.28	118.37	121.1	48
49	15.13	179.85	226.8	14.29	160.27	190.8	49	13.33	139.61	155.1	12.38	120.37	124.2	49
50	15.25	182.73	232.3	14.40	162.89	195.5	50	13.44	141.91	159.0	12.48	122.36	127.3	50

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.37	185.62	237.8	14.52	165.53	200.2	51	13.55	144.24	162.9	12.59	124.42	130.5	51
52	15.49	188.54	243.4	14.63	168.19	205.1	52	13.66	146.58	166.9	12.69	126.47	133.7	52
53	15.61	191.49	249.2	14.75	170.87	210.0	53	13.77	148.95	170.9	12.79	128.53	137.0	53
54	15.73	194.45	255.0	14.87	173.57	215.0	54	13.88	151.33	175.0	12.90	130.61	140.4	54
55	15.86	197.44	260.9	14.98	176.29	220.1	55	13.99	153.73	179.2	13.00	132.71	143.8	55
56	15.98	200.45	266.9	15.10	179.04	225.3	56	14.10	156.15	183.5	13.10	134.83	147.2	56
57	16.10	203.49	272.9	15.21	181.80	230.5	57	14.21	158.59	187.8	13.21	136.96	150.7	57
58	16.22	206.54	279.1	15.33	194.59	235.8	58	14.32	161.05	192.2	13.31	139.11	154.3	58
59	16.34	209.62	285.4	15.45	167.39	241.2	59	14.43	163.52	196.6	13.41	141.28	157.9	59
60	16.46	212.72	291.7	15.56	190.22	246.7	60	14.54	166.02	201.1	13.52	143.46	161.6	60
61	16.58	215.85	298.2	15.68	193.07	252.3	61	14.65	168.53	205.7	13.62	145.66	165.3	61
62	16.70	219.00	304.7	15.80	195.94	257.9	62	14.76	171.07	210.4	13.72	147.88	169.1	62
63	16.82	222.17	311.4	15.91	198.84	263.6	63	14.87	173.62	215.1	13.82	150.11	172.9	63
64	16.94	225.36	318.1	16.03	201.75	269.4	64	14.98	176.19	219.9	13.93	152.36	176.8	64
65	17.06	228.58	324.9	16.14	204.68	275.3	65	15.09	178.78	224.8	14.03	154.63	180.3	65
66	17.18	231.82	331.9	16.26	207.64	281.3	66	15.20	181.39	229.7	14.13	156.91	184.8	66
67	17.30	235.08	338.9	16.38	210.62	287.4	67	15.31	184.02	234.7	14.24	159.21	188.9	67
68	17.42	238.36	346.0	16.49	213.61	293.6	68	15.42	186.67	239.8	14.34	161.53	193.0	68
69	17.54	241.67	353.3	16.61	216.63	299.8	69	15.53	189.33	245.0	14.44	163.87	197.2	69
70	17.66	245.00	360.6	16.72	219.67	306.1	70	15.64	192.02	250.2	14.55	166.22	201.5	70
71	17.78	248.35	368.0	16.84	222.74	312.6	71	15.75	194.72	255.5	14.65	168.58	205.8	71
72	17.90	251.73	375.5	16.96	225.82	319.1	72	15.86	197.44	260.9	14.75	170.97	210.2	72
73	18.02	255.13	383.2	17.07	228.92	325.7	73	15.96	200.18	266.3	14.86	173.37	214.6	73
74	18.14	258.55	390.9	17.19	232.05	332.4	74	16.07	202.94	271.8	14.96	175.79	219.1	74
75	18.26	261.99	398.7	17.30	235.19	339.2	75	16.18	205.72	277.4	15.06	178.22	223.7	75
76	18.38	265.46	406.7	17.42	238.36	346.0	76	16.29	208.52	283.1	15.17	180.67	228.3	76
77	18.51	268.95	414.7	17.54	241.55	353.0	77	16.40	211.34	288.9	15.27	183.14	233.0	77
78	18.63	272.46	422.9	17.65	244.76	360.1	78	16.51	214.17	294.7	15.37	185.62	237.8	78
79	18.75	276.00	431.1	17.77	247.99	367.2	79	16.62	217.03	300.6	15.48	188.13	242.6	79
80	18.87	279.55	439.5	17.89	251.24	374.5	80	16.73	219.90	306.6	15.58	190.64	247.5	80

85'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.66	53.5	8.71	59.55	43.2	1	8.06	51.08	34.3	7.42	43.26	26.8	1
2	9.47	70.42	55.6	8.82	61.10	44.9	2	8.17	52.44	35.7	7.52	44.45	27.9	2
3	9.59	72.20	57.7	8.93	62.67	46.7	3	8.28	53.82	37.1	7.62	45.64	29.0	3
4	9.71	74.00	59.9	9.05	64.26	48.4	4	8.38	55.22	38.6	7.72	46.86	30.2	4
5	9.83	75.82	62.1	9.16	65.88	50.3	5	8.49	56.63	40.1	7.82	48.09	31.4	5
6	9.94	77.67	64.4	9.27	67.51	52.2	6	8.60	58.07	41.6	7.93	49.33	32.6	6
7	10.06	79.53	66.7	9.38	69.16	54.1	7	8.71	59.52	43.2	8.03	50.60	33.8	7
8	10.18	81.42	69.1	9.50	70.84	56.1	8	8.81	60.99	44.8	8.13	51.87	35.1	8
9	10.30	83.34	71.5	9.61	72.53	58.1	9	8.92	62.47	46.4	8.23	53.17	36.5	9
10	10.42	85.27	74.0	9.72	74.24	60.1	10	9.03	63.98	48.1	8.33	54.48	37.8	10
11	10.54	87.23	76.6	9.84	75.98	62.3	11	9.13	65.50	49.8	8.43	55.80	39.2	11
12	10.66	89.20	79.2	9.95	77.73	64.4	12	9.24	67.04	51.6	8.53	57.14	40.6	12
13	10.78	91.21	81.9	10.06	79.50	66.7	13	9.35	68.60	53.4	8.63	58.50	42.1	13
14	10.90	93.23	84.6	10.17	81.29	68.9	14	9.45	70.18	55.3	8.73	59.88	43.6	14
15	11.01	95.27	87.4	10.29	83.11	71.2	15	9.56	71.77	57.2	8.83	61.27	45.1	15
16	11.13	97.34	90.3	10.40	84.94	73.6	16	9.67	73.38	59.1	8.93	62.67	46.7	16
17	11.25	99.43	93.2	10.51	86.79	76.0	17	9.77	75.01	61.1	9.03	64.09	48.2	17
18	11.37	101.54	96.2	10.63	88.67	78.5	18	9.88	76.66	63.1	9.13	65.53	49.9	18
19	11.49	103.68	99.3	10.74	90.56	81.0	19	9.99	78.33	65.2	9.24	66.98	51.5	19
20	11.61	105.83	102.4	10.85	92.47	83.6	20	10.09	80.01	67.3	9.34	68.45	53.3	20
21	11.73	108.01	105.6	10.96	94.40	86.2	21	10.20	81.71	69.5	9.44	69.94	55.0	21
22	11.85	110.21	108.8	11.08	96.36	88.9	22	10.31	83.43	71.7	9.54	71.44	56.8	22
23	11.96	112.44	112.1	11.19	98.33	91.7	23	10.41	85.17	73.9	9.64	72.96	58.6	23
24	12.08	114.68	115.5	11.30	100.32	94.5	24	10.52	86.93	76.2	9.74	74.49	60.4	24
25	12.20	116.95	118.9	11.41	102.34	97.3	25	10.63	88.70	78.5	9.84	76.04	62.3	25
26	12.32	119.24	122.4	11.53	104.37	100.3	26	10.73	90.49	80.9	9.94	77.60	64.3	26
27	12.44	121.55	126.0	11.64	106.42	103.2	27	10.84	92.30	83.4	10.04	79.18	66.3	27
28	12.56	123.88	129.6	11.75	108.49	106.3	28	10.95	94.13	85.9	10.14	80.78	68.3	28
29	12.68	126.24	133.4	11.87	110.59	109.3	29	11.05	95.97	88.4	10.24	82.39	70.3	29
30	12.80	128.62	137.2	11.98	112.70	112.5	30	11.16	97.84	91.0	10.34	84.02	72.4	30
31	12.92	131.02	141.0	12.09	114.83	115.7	31	11.27	99.72	93.6	10.44	85.67	74.6	31
32	13.03	133.44	144.9	12.20	116.99	119.0	32	11.37	101.62	96.3	10.54	87.33	76.7	32
33	13.15	135.88	148.9	12.32	119.16	122.3	33	11.48	103.53	99.1	10.65	89.00	79.0	33
34	13.27	138.35	153.0	12.43	121.35	125.7	34	11.59	105.47	101.8	10.75	90.69	81.2	34
35	13.39	140.84	157.2	12.54	123.56	129.2	35	11.69	107.42	104.7	10.85	92.40	83.5	35
36	13.51	143.35	161.4	12.66	125.80	132.7	36	11.80	109.39	107.6	10.95	94.13	85.9	36
37	13.63	145.89	165.7	12.77	128.05	136.2	37	11.91	111.38	110.5	11.05	95.87	88.3	37
38	13.75	148.44	170.1	12.88	130.32	139.9	38	12.02	113.38	113.5	11.15	97.62	90.7	38
39	13.87	151.02	174.5	12.99	132.62	143.6	39	12.12	115.41	116.6	11.25	99.40	93.2	39
40	13.99	153.62	179.0	13.11	134.93	147.4	40	12.23	117.45	119.7	11.35	101.18	95.7	40
41	14.10	156.24	183.6	13.22	137.26	151.2	41	12.34	119.51	122.8	11.45	102.99	98.3	41
42	14.22	158.89	188.3	13.33	139.61	155.1	42	12.44	121.59	126.1	11.55	104.81	100.9	42
43	14.34	161.55	193.1	13.45	141.99	159.1	43	12.55	123.68	129.3	11.65	106.64	103.6	43
44	14.46	164.24	197.9	13.56	144.38	163.1	44	12.66	125.80	132.7	11.75	108.49	106.3	44
45	14.58	166.95	202.8	13.67	146.79	167.2	45	12.76	127.93	136.1	11.85	110.36	107.0	45
46	14.70	169.69	207.8	13.78	149.23	171.4	46	12.87	130.08	139.5	11.95	112.25	111.8	46
47	14.82	172.44	212.9	13.90	151.68	175.6	47	12.98	132.25	143.0	12.06	114.15	114.7	47
48	14.94	175.22	218.1	14.01	154.15	180.0	48	13.08	134.43	146.6	12.16	116.06	117.6	48
49	15.06	178.02	223.3	14.12	156.64	184.3	49	13.19	136.63	150.2	12.26	117.99	120.5	49
50	15.17	180.84	228.7	14.24	159.16	188.8	50	13.30	138.86	153.9	12.36	119.94	123.5	50

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.29	183.69	234.1	14.35	161.69	193.3	51	13.40	141.09	157.6	12.46	121.90	126.6	51
52	15.41	186.55	239.6	14.46	164.24	197.9	52	13.51	143.35	161.4	12.56	123.88	129.6	52
53	15.53	189.44	245.2	14.57	166.81	202.6	53	13.62	145.63	165.2	12.66	125.88	132.8	53
54	15.65	192.35	250.8	14.69	169.41	207.3	54	13.72	147.92	169.2	12.76	127.89	136.0	54
55	15.77	195.28	256.6	14.80	172.02	212.1	55	13.83	150.23	173.1	12.86	129.92	139.2	55
56	15.89	198.24	262.4	14.91	174.65	217.0	56	13.94	152.56	177.2	12.96	131.96	142.5	56
57	16.01	201.22	268.4	15.03	177.31	222.0	57	14.04	154.91	181.3	13.06	134.02	145.9	57
58	16.13	204.22	274.4	15.14	179.98	227.0	58	14.15	157.27	185.4	13.16	136.09	149.3	58
59	16.24	207.24	280.5	15.25	182.67	232.1	59	14.26	159.65	189.7	13.26	138.18	152.7	59
60	16.36	210.28	286.7	15.36	185.38	237.3	60	14.36	162.05	194.0	13.36	140.29	156.2	60
61	16.48	213.35	293.0	15.48	188.12	242.6	61	14.47	164.47	198.3	13.47	142.41	159.8	61
62	16.60	216.44	299.4	15.59	190.87	247.9	62	14.58	166.91	202.8	13.57	144.55	163.4	62
63	16.72	219.55	305.9	15.70	193.64	253.4	63	14.68	169.36	207.2	13.67	146.71	167.1	63
64	16.84	222.68	312.4	15.81	196.43	258.9	64	14.79	171.83	211.8	13.77	148.88	170.8	64
65	16.96	225.83	319.1	15.93	199.25	264.4	65	14.90	174.32	216.4	13.87	151.06	174.6	65
66	17.08	229.01	325.9	16.04	202.08	270.1	66	15.00	176.83	221.1	13.97	153.27	178.4	66
67	17.19	232.21	332.7	16.15	204.93	275.8	67	15.11	179.36	225.9	14.07	155.48	182.3	67
68	17.31	235.43	339.7	16.27	207.80	281.7	68	15.22	181.90	230.7	14.17	157.72	186.2	68
69	17.43	238.68	346.7	16.38	210.70	287.6	69	15.33	184.46	235.6	14.27	159.97	190.2	69
70	17.55	241.94	353.9	16.49	213.61	293.6	70	15.43	187.04	240.5	14.37	162.23	194.3	70
71	17.67	245.23	361.1	16.60	216.54	299.6	71	15.54	189.64	245.5	14.47	164.52	198.4	71
72	17.79	248.54	368.4	16.72	219.49	305.8	72	15.65	192.25	250.6	14.57	166.81	202.6	72
73	17.91	251.87	375.9	16.83	222.47	312.0	73	15.75	194.89	255.8	14.67	169.13	206.8	73
74	18.03	255.23	383.4	16.94	225.46	318.3	74	15.86	197.54	261.0	14.78	171.46	211.1	74
75	18.15	258.60	391.0	17.06	228.47	324.7	75	15.97	200.20	266.4	14.88	173.80	215.4	75
76	18.26	262.00	398.8	17.17	231.50	331.2	76	16.07	202.89	271.7	14.98	176.17	219.9	76
77	18.38	265.43	406.6	17.28	234.56	337.8	77	16.18	205.60	277.2	15.08	178.54	224.3	77
78	18.50	268.87	414.5	17.39	237.63	344.4	78	16.29	208.32	282.7	15.18	180.94	228.8	78
79	18.62	272.33	422.6	17.51	240.72	351.2	79	16.39	211.06	288.3	15.28	183.35	233.4	79
80	18.74	275.82	430.7	17.62	243.83	358.0	80	16.50	213.82	294.0	15.38	185.77	238.1	80
81	18.86	279.33	439.0	17.73	246.97	364.9	81	16.61	216.59	299.7	15.48	188.21	242.8	81
82	18.98	282.86	447.3	17.85	250.12	371.9	82	16.71	219.39	305.5	15.58	190.67	247.6	82
83	19.10	286.42	455.8	17.96	253.29	379.0	83	16.82	222.20	311.4	15.68	193.14	252.4	83
84	19.22	290.00	464.3	18.07	256.48	386.2	84	16.93	225.03	317.4	15.78	195.63	257.3	84
85	19.33	293.59	473.0	18.18	259.70	393.5	85	17.03	227.88	323.5	15.88	198.14	262.2	85

90'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.61	53.4	8.70	59.51	43.2	1	8.06	51.07	34.3	7.42	43.24	26.7	1
2	9.46	70.32	55.4	8.81	61.02	44.8	2	8.17	52.42	35.7	7.52	44.39	27.8	2
3	9.58	72.05	57.5	8.92	62.55	46.5	3	8.28	53.79	37.1	7.62	45.56	28.9	3
4	9.69	73.80	59.6	9.03	64.10	48.3	4	8.38	55.18	38.5	7.72	46.75	30.1	4
5	9.81	75.57	61.8	9.14	65.67	50.0	5	8.49	56.59	40.0	7.81	47.95	31.2	5
6	9.92	77.36	64.0	9.25	67.25	51.9	6	8.59	58.01	41.5	7.91	49.17	32.4	6
7	10.04	79.17	66.2	9.36	68.86	53.7	7	8.70	59.45	43.1	8.01	50.40	33.6	7
8	10.16	81.00	68.5	9.47	70.49	55.6	8	8.81	60.91	44.7	8.11	51.65	34.9	8
9	10.27	82.86	70.9	9.58	72.13	57.6	9	8.91	62.39	46.3	8.21	52.91	36.2	9
10	10.39	84.73	73.3	9.69	73.80	59.6	10	9.02	63.88	48.0	8.31	54.19	37.5	10
11	10.50	86.63	75.8	9.80	75.48	61.7	11	9.12	65.40	49.7	8.40	55.48	38.9	11
12	10.62	88.57	78.3	9.91	77.18	63.8	12	9.23	66.92	51.5	8.50	56.79	40.2	12
13	10.73	90.48	80.9	10.02	78.90	65.9	13	9.34	68.47	53.3	8.60	58.11	41.7	13
14	10.85	92.41	83.6	10.13	80.64	68.1	14	9.44	70.04	55.1	8.70	59.45	43.1	14
15	10.96	94.42	86.3	10.24	82.40	70.3	15	9.55	71.62	57.0	8.80	60.81	44.6	15
16	11.08	96.42	89.0	10.35	84.18	72.6	16	9.66	73.22	58.9	8.90	62.18	46.1	16
17	11.20	98.45	91.8	10.46	85.97	75.0	17	9.76	74.84	60.9	9.00	63.56	47.6	17
18	11.31	100.49	94.7	10.57	87.79	77.3	18	9.87	76.47	62.9	9.09	64.96	49.2	18
19	11.43	102.55	97.7	10.68	89.62	79.8	19	9.97	78.13	64.9	9.19	66.38	50.8	19
20	11.54	104.64	100.6	10.79	91.48	82.3	20	10.08	79.80	67.0	9.29	67.81	52.5	20
21	11.66	106.74	103.7	10.90	93.35	84.8	21	10.19	81.49	69.2	9.39	69.25	54.2	21
22	11.77	108.87	106.8	11.01	95.24	87.4	22	10.29	83.19	71.3	9.49	70.71	55.9	22
23	11.89	111.02	110.0	11.12	97.15	90.0	23	10.40	84.92	73.6	9.59	72.19	57.7	23
24	12.00	113.19	113.2	11.23	99.08	92.7	24	10.50	86.66	75.9	9.69	73.68	59.5	24
25	12.12	115.38	116.5	11.34	101.03	95.5	25	10.61	88.42	78.2	9.78	75.19	61.3	25
26	12.24	117.59	119.9	11.45	103.00	98.3	26	10.72	90.20	80.5	9.88	76.71	63.2	26
27	12.35	119.82	123.3	11.56	104.98	101.1	27	10.82	91.99	83.0	9.98	78.25	65.1	27
28	12.47	122.07	126.8	11.67	106.99	104.1	28	10.93	93.80	85.4	10.08	79.80	67.0	28
29	12.58	124.35	130.4	11.78	109.01	107.0	29	11.03	95.63	87.9	10.18	81.37	69.0	29
30	12.70	126.64	134.0	11.89	111.05	110.0	30	11.14	97.48	90.5	10.28	82.95	71.0	30
31	12.81	128.96	137.7	12.00	113.12	113.1	31	11.25	99.35	93.1	10.38	84.55	73.1	31
32	12.93	131.30	141.5	12.11	115.20	116.3	32	11.35	101.23	95.8	10.47	86.16	75.2	32
33	13.05	133.65	145.3	12.22	117.30	119.5	33	11.46	103.13	98.5	10.57	87.79	77.3	33
34	13.16	136.03	149.2	12.33	119.42	122.7	34	11.57	105.05	101.2	10.67	89.43	79.5	34
35	13.28	138.43	153.1	12.44	121.56	126.0	35	11.67	106.99	104.1	10.77	91.09	81.7	35
36	13.39	140.85	157.2	12.55	123.71	129.4	36	11.78	108.94	106.9	10.87	92.77	84.0	36
37	13.51	143.29	161.3	12.66	125.89	132.8	37	11.88	110.91	109.8	10.97	94.46	86.3	37
38	13.62	145.76	165.5	12.77	128.08	136.3	38	11.99	112.90	112.8	11.07	96.16	88.7	38
39	13.74	148.24	169.7	12.88	130.30	139.8	39	12.10	114.91	115.8	11.16	97.88	91.1	39
40	13.85	150.75	174.0	12.99	132.53	143.5	40	12.20	116.93	118.9	11.26	99.62	93.5	40
41	13.97	153.27	178.4	13.10	134.78	147.1	41	12.31	118.98	122.0	11.36	101.37	96.0	41
42	14.09	155.82	182.9	13.21	137.05	150.9	42	12.41	121.04	125.2	11.46	103.13	98.5	42
43	14.20	158.39	187.4	13.32	139.34	154.7	43	12.52	123.12	128.4	11.56	104.91	101.0	43
44	14.32	160.97	192.0	13.43	141.65	158.5	44	12.63	125.21	131.7	11.66	106.71	103.6	44
45	14.43	163.58	196.7	13.54	143.98	162.4	45	12.73	127.32	135.1	11.75	108.52	106.3	45
46	14.55	166.21	201.5	13.65	146.33	166.4	46	12.84	129.45	138.5	11.85	110.35	109.0	46
47	14.66	168.87	206.3	13.76	148.69	170.5	47	12.94	131.60	142.0	11.95	112.19	111.7	47
48	14.78	171.54	211.2	13.87	151.08	174.6	48	13.05	133.77	145.5	12.05	114.05	114.5	48
49	14.89	174.23	216.2	13.98	153.48	178.8	49	13.16	135.95	149.1	12.15	115.92	117.4	49
50	15.01	176.95	221.3	14.09	155.90	183.0	50	13.26	138.16	152.7	12.25	117.81	120.2	50

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.13	179.68	226.5	14.20	158.34	187.3	51	13.37	140.37	156.4	12.35	119.71	123.2	51
52	15.24	182.44	231.7	14.31	160.80	191.7	52	13.48	142.61	160.1	12.44	121.63	126.1	52
53	15.36	185.22	237.0	14.42	163.28	196.2	53	13.58	144.87	163.9	12.54	123.56	129.1	53
54	15.47	188.01	242.4	14.53	165.78	200.7	54	13.69	147.14	167.8	12.64	125.51	132.2	54
55	15.59	190.83	247.9	14.64	168.30	205.3	55	13.79	149.43	171.8	12.74	127.48	135.3	55
56	15.70	193.67	253.4	14.75	170.84	210.0	56	13.90	151.74	175.7	12.84	129.45	138.5	56
57	15.82	176.54	259.1	14.86	173.39	214.7	57	14.01	154.06	179.8	12.94	131.45	141.7	57
58	15.93	199.42	264.8	14.97	175.96	219.5	58	14.11	156.41	183.9	13.04	133.46	145.0	58
59	16.05	202.32	270.6	15.08	178.56	224.3	59	14.22	158.77	188.1	13.13	135.48	148.3	59
60	16.17	205.25	276.5	15.19	181.17	229.3	60	14.32	161.14	192.3	13.23	137.52	151.6	60
61	16.28	208.19	282.5	15.30	183.80	234.3	61	14.43	163.54	196.6	13.33	139.58	155.1	61
62	16.40	211.16	288.5	15.41	186.45	239.4	62	14.54	165.95	201.0	13.43	141.65	158.5	62
63	16.51	214.14	294.7	15.52	187.12	244.5	63	14.64	168.37	205.5	13.53	143.74	162.0	63
64	16.63	217.15	300.9	15.63	191.81	249.8	64	14.75	170.84	210.0	13.63	145.84	165.6	64
65	16.74	220.18	307.2	15.74	194.52	255.1	65	14.85	173.30	214.5	13.73	147.95	169.2	65
66	16.86	223.23	313.6	15.85	197.24	260.5	66	14.96	175.79	219.1	13.82	150.09	172.9	66
67	16.97	226.30	320.1	15.96	199.99	265.9	67	15.07	178.29	223.8	13.92	152.23	176.6	67
68	17.09	229.40	326.7	16.07	202.75	271.5	68	15.17	180.81	228.6	14.02	154.40	180.4	68
69	17.21	232.51	333.4	16.18	205.53	277.1	69	15.28	183.35	233.4	14.12	156.57	184.2	69
70	17.32	235.64	340.1	16.29	208.34	282.7	70	15.38	185.90	238.3	14.22	158.77	188.1	70
71	17.44	238.80	347.0	16.40	211.16	288.5	71	15.49	188.47	243.3	14.32	160.97	192.0	71
72	17.55	241.97	353.9	16.51	214.00	294.4	72	15.60	191.07	248.3	14.41	163.20	196.0	72
73	17.67	245.17	361.0	16.62	216.86	300.3	73	15.70	193.67	253.4	14.51	165.44	200.1	73
74	17.78	248.39	368.1	16.73	219.73	306.3	74	15.81	196.30	258.6	14.61	167.69	204.2	74
75	17.90	251.63	375.3	16.84	222.63	312.3	75	15.92	198.94	263.8	14.71	169.96	208.3	75
76	18.01	254.87	382.6	16.95	225.55	318.5	76	16.02	201.61	269.2	14.81	172.24	212.6	76
77	18.13	258.17	390.0	17.06	228.48	324.7	77	16.13	204.28	274.5	14.91	174.54	216.8	77
78	18.25	261.47	377.5	17.17	231.43	331.1	78	16.23	206.98	280.0	15.01	176.86	221.1	78
79	18.36	264.79	405.2	17.28	234.41	337.5	79	16.34	209.70	285.5	15.10	179.19	225.5	79
80	18.48	268.14	412.8	17.39	237.40	343.9	80	16.45	212.43	291.1	15.20	181.53	230.0	80
81	18.59	271.50	420.6	17.50	240.41	350.5	81	16.55	215.18	296.8	15.30	183.89	234.5	81
82	18.71	274.89	428.5	17.61	243.44	357.1	82	16.66	217.95	302.5	15.40	186.27	239.0	82
83	18.82	278.30	436.5	17.72	246.49	363.9	83	16.76	220.73	308.4	15.50	188.66	243.7	83
84	18.94	281.72	444.6	17.83	249.56	370.7	84	16.87	223.53	314.2	15.60	191.07	248.3	84
95	19.06	285.17	452.8	17.94	252.64	377.6	85	16.98	226.35	320.2	15.70	193.49	253.1	85
86	19.17	288.64	461.1	18.05	255.75	384.6	86	17.08	229.19	326.3	15.79	195.92	257.9	86
87	17.29	272.13	467.5	18.16	258.87	391.6	87	17.19	232.05	332.4	15.89	178.38	262.7	87
88	19.40	295.65	478.0	18.26	262.01	398.8	88	17.29	234.92	338.6	15.99	200.84	267.6	88
89	19.52	299.18	486.6	18.37	265.18	406.0	89	17.40	237.81	344.8	16.09	203.33	272.6	89
90	19.63	302.73	495.3	18.48	268.36	413.4	90	17.51	240.72	351.2	16.19	205.82	277.6	90

95'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.59	53.4	8.70	59.47	43.1	1	8.06	51.04	34.3	7.42	43.21	26.7	1
2	9.46	70.28	55.4	8.81	60.95	44.7	2	8.17	52.36	35.6	7.51	44.35	27.8	2
3	9.57	72.00	57.4	8.92	62.44	46.4	3	8.27	53.70	37.0	7.61	45.49	28.9	3
4	9.69	73.73	59.5	9.02	63.95	48.1	4	8.37	55.06	38.4	7.71	46.66	30.0	4
5	9.80	75.48	61.7	9.13	65.48	49.8	5	8.48	56.43	39.9	7.80	47.83	31.1	5
6	9.92	77.25	63.8	9.24	67.03	51.6	6	8.58	57.82	41.3	7.90	49.02	32.3	6
7	10.03	79.05	66.1	9.35	68.59	53.4	7	8.68	59.23	42.9	8.00	50.23	33.5	7
8	10.15	80.86	68.4	9.45	70.18	55.3	8	8.79	60.65	44.4	8.09	51.45	34.7	8
9	10.26	82.69	70.7	9.56	71.78	57.2	9	8.89	62.09	46.0	8.19	52.68	36.0	9
10	10.38	84.55	73.1	9.67	73.40	59.1	10	8.99	63.55	47.6	8.29	53.93	37.2	10
11	10.49	86.42	75.5	9.77	75.04	61.1	11	9.10	65.02	49.3	8.38	55.20	38.6	11
12	10.60	88.32	78.0	9.88	76.70	63.2	12	9.20	66.51	51.0	8.48	56.48	39.9	12
13	10.72	90.24	80.6	9.99	78.37	65.2	13	9.31	68.02	52.7	8.58	57.77	41.3	13
14	10.83	92.17	83.2	10.10	80.06	67.4	14	9.41	69.54	54.5	8.67	59.08	42.7	14
15	10.95	94.13	85.9	10.20	81.77	69.5	15	9.51	71.08	56.4	8.77	60.40	44.1	15
16	11.06	96.11	88.6	10.31	83.50	71.7	16	9.62	72.64	58.2	8.87	61.74	45.6	16
17	11.18	98.11	91.4	10.42	85.25	74.0	17	9.72	74.22	60.1	8.96	63.09	47.1	17
18	11.29	100.13	94.2	10.53	87.01	76.3	18	9.82	75.81	62.1	9.06	64.46	48.7	18
19	11.41	102.17	97.1	10.63	88.80	78.7	19	9.93	77.42	64.1	9.16	65.84	50.2	19
20	11.52	104.23	100.1	10.74	90.60	81.1	20	10.03	79.05	66.1	9.25	67.24	51.8	20
21	11.63	106.31	103.1	10.85	92.42	83.5	21	10.14	80.69	68.2	9.35	68.65	53.5	21
22	11.75	108.41	106.1	10.95	94.26	86.0	22	10.24	82.35	70.3	9.45	70.07	55.2	22
23	11.86	110.54	109.3	11.06	96.11	88.6	23	10.34	84.02	72.4	9.54	71.51	56.9	23
24	11.98	112.68	112.5	11.17	97.98	91.2	24	10.45	85.72	74.6	9.64	72.97	58.6	24
25	12.09	114.84	115.7	11.28	99.88	93.9	25	10.55	87.43	76.9	9.74	74.44	60.4	25
26	12.21	117.03	119.0	11.38	101.78	96.6	26	10.65	89.16	79.2	9.83	75.92	62.2	26
27	12.32	119.23	122.4	11.49	103.71	99.3	27	10.76	90.90	81.5	9.93	77.42	64.1	27
28	12.44	121.46	125.9	11.60	105.66	102.1	28	10.86	92.66	83.9	10.02	78.93	65.9	28
29	12.55	123.70	129.4	11.71	107.62	105.0	29	10.97	94.44	86.3	10.12	80.46	67.9	29
30	12.66	125.97	132.9	11.81	109.60	107.9	30	11.07	96.23	88.8	10.22	82.00	69.8	30
31	12.78	128.26	136.6	11.92	111.60	110.9	31	11.17	98.05	91.3	10.31	83.56	71.8	31
32	12.89	130.56	140.3	12.03	113.62	113.9	32	11.28	99.88	93.9	10.41	85.13	73.9	32
33	13.01	132.89	144.0	12.14	115.66	117.0	33	11.38	101.72	96.5	10.51	86.72	75.9	33
34	13.12	135.24	147.9	12.24	117.71	120.1	34	11.48	103.58	99.1	10.60	88.32	78.0	34
35	13.24	137.61	151.8	12.35	119.79	123.3	35	11.59	105.46	101.8	10.70	89.94	80.2	35
36	13.35	140.00	155.8	12.46	121.88	126.5	36	11.69	107.36	104.6	10.80	91.57	82.4	36
37	13.47	142.41	159.8	12.56	123.98	129.8	37	11.80	109.27	107.4	10.89	93.21	84.6	37
38	13.58	144.84	163.9	12.67	126.11	133.2	38	11.90	111.20	110.3	10.99	94.87	86.9	38
39	13.69	147.29	168.1	12.78	128.26	136.6	39	12.00	113.15	113.2	11.09	96.55	89.2	39
40	13.81	149.76	172.3	12.89	130.42	140.0	40	12.11	115.11	116.1	11.18	98.24	91.5	40
41	13.92	152.26	176.7	12.99	132.60	143.6	41	12.21	117.09	119.1	11.28	99.94	93.9	41
42	14.04	154.77	181.0	13.10	134.80	147.2	42	12.31	119.09	122.2	11.38	101.66	96.4	42
43	14.15	157.31	185.5	13.21	137.02	150.8	43	12.42	121.11	125.3	11.47	103.39	98.8	43
44	14.27	159.86	190.0	13.32	139.25	154.5	44	12.52	123.14	128.5	11.57	105.14	101.4	44
45	14.38	162.43	194.7	13.42	141.50	158.3	45	12.63	125.19	131.7	11.67	106.90	103.9	45
46	14.50	165.03	199.3	13.53	143.77	162.1	46	12.73	127.25	135.0	11.76	108.68	106.5	46
47	14.61	167.65	204.1	13.64	146.06	166.0	47	12.83	129.33	138.3	11.86	110.47	109.2	47
48	14.72	170.28	208.9	13.74	148.37	169.9	48	12.94	131.43	141.7	11.96	112.28	111.9	48
49	14.84	172.94	213.8	13.85	150.70	173.9	49	13.04	133.55	145.1	12.05	114.10	114.6	49
50	14.95	175.62	218.8	13.96	153.04	178.0	50	13.14	135.68	148.6	12.15	115.93	117.4	50

95'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.07	178.32	223.9	14.07	155.40	182.2	51	13.25	137.83	152.2	12.25	117.78	120.2	51
52	15.18	181.04	229.0	14.17	157.78	186.4	52	13.35	140.00	155.8	12.34	119.65	123.1	52
53	15.30	183.78	234.3	14.28	160.18	190.6	53	13.45	142.18	159.4	12.44	121.53	126.0	53
54	15.41	186.54	239.6	14.39	162.60	194.9	54	13.56	144.38	163.1	12.54	123.42	128.9	54
55	15.53	189.32	244.9	14.50	165.03	199.3	55	13.66	146.60	166.9	12.63	125.33	131.9	55
56	15.64	192.12	250.4	14.60	167.48	203.8	56	13.77	148.84	170.7	12.73	127.25	135.0	56
57	15.75	194.94	255.9	14.71	169.95	208.3	57	13.87	151.09	174.6	12.83	129.19	138.1	57
58	15.87	197.78	261.5	14.82	172.44	212.9	58	13.97	153.35	178.6	12.92	131.14	141.2	58
59	15.98	200.65	267.2	14.92	174.95	217.6	59	14.08	155.64	182.6	13.02	133.11	144.4	59
60	16.10	203.53	273.0	15.03	177.47	222.3	60	14.18	157.94	186.6	13.12	135.09	147.6	60
61	16.21	206.43	278.9	15.14	180.01	227.1	61	14.28	160.26	190.8	13.21	137.09	150.9	61
62	16.33	209.36	284.8	15.25	182.57	232.0	62	14.39	162.60	194.9	13.31	139.10	154.3	62
63	16.44	212.30	290.9	15.35	185.15	236.9	63	14.49	164.95	199.2	13.40	141.13	157.6	63
64	16.56	215.27	297.0	15.46	187.75	241.9	64	14.60	167.32	203.5	13.50	143.17	161.1	64
65	16.67	218.26	303.2	15.57	190.37	247.0	65	14.70	169.70	207.9	13.60	145.22	164.6	65
66	16.78	221.26	309.5	15.68	193.00	252.1	66	14.80	172.11	212.3	13.69	147.29	168.1	66
67	16.90	224.29	315.8	15.78	195.65	257.3	67	14.91	174.53	216.8	13.79	149.38	171.7	67
68	17.01	227.34	322.3	15.89	198.32	262.6	68	15.01	176.97	221.4	13.89	151.48	175.3	68
69	17.13	230.41	328.9	16.00	201.01	268.0	69	15.11	179.42	226.0	13.98	153.59	179.0	69
70	17.24	233.50	335.5	16.11	203.71	273.4	70	15.22	181.89	230.7	14.08	155.72	182.7	70
71	17.36	236.61	342.2	16.21	206.43	278.9	71	15.32	184.38	235.4	14.18	157.86	186.5	71
72	17.47	239.74	349.0	16.32	209.18	284.5	72	15.43	186.88	240.2	14.27	160.02	190.3	72
73	17.59	242.87	355.9	16.43	211.94	290.1	73	15.53	189.40	245.1	14.37	162.19	194.2	73
74	17.70	246.06	362.9	16.53	214.71	295.8	74	15.63	191.94	250.0	14.47	164.38	198.2	74
75	17.81	249.25	370.0	16.64	217.51	301.6	75	15.74	194.50	255.1	14.56	166.58	202.2	75
76	17.93	252.47	377.2	16.75	220.32	307.5	76	15.84	197.07	260.1	14.66	168.80	206.2	76
77	18.04	255.70	384.5	16.86	223.15	313.4	77	15.94	199.66	265.3	14.76	171.03	210.3	77
78	18.16	258.96	391.8	16.96	226.00	319.5	78	16.05	202.27	270.5	14.85	173.27	214.5	78
79	18.27	262.23	397.3	17.07	228.87	325.6	79	16.15	204.89	275.8	14.95	175.53	218.7	79
80	18.39	265.53	406.8	17.18	231.76	331.7	80	16.26	207.53	281.1	15.05	177.81	222.9	80
81	18.50	268.84	414.5	17.29	234.66	338.0	81	16.36	210.19	286.5	15.14	180.10	227.3	81
82	18.62	272.18	422.2	17.39	237.59	344.3	82	16.46	212.86	292.0	15.24	182.40	231.6	82
83	18.73	275.53	430.0	17.50	240.53	350.7	83	16.57	215.55	297.6	15.34	184.72	236.1	83
84	18.84	278.91	438.0	17.61	243.48	357.2	84	16.67	218.26	303.2	15.43	187.06	240.6	84
85	18.96	282.31	446.0	17.71	246.46	363.8	85	16.77	220.98	308.9	15.53	189.40	245.1	85
86	19.07	285.73	454.1	17.82	249.46	370.5	86	16.88	223.72	314.6	15.63	191.77	249.7	86
87	19.19	289.17	462.4	17.93	252.47	377.2	87	16.98	226.48	320.5	15.72	194.14	254.4	87
88	19.30	292.63	470.7	18.04	255.50	384.0	88	17.09	229.26	326.4	15.82	196.54	259.1	88
89	19.42	296.11	479.1	18.14	258.55	390.9	89	17.19	232.05	332.4	15.92	198.94	263.8	89
90	19.53	299.61	487.6	18.25	261.61	397.9	90	17.29	234.86	338.4	16.01	201.37	268.7	90
91	19.65	303.13	496.2	18.36	264.70	404.9	91	17.40	237.68	344.5	16.11	203.80	273.6	91
92	19.76	306.67	505.0	18.47	267.80	412.1	92	17.50	240.53	350.7	16.21	206.25	278.5	92
93	19.87	310.24	513.8	18.57	270.92	419.3	93	17.60	243.38	357.0	16.30	208.72	283.5	93
94	19.99	313.82	522.7	18.68	274.06	426.6	94	17.71	246.26	363.4	16.40	211.20	288.6	94
95	20.10	317.42	531.8	18.79	277.22	434.0	95	17.81	249.15	369.8	16.49	213.69	293.7	95

100'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3		
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.34	68.55	53.4	8.70	59.46	43.1	1	8.06	51.01	34.3	7.41	43.15	26.7	1
2	9.45	70.20	55.3	8.81	60.93	44.7	2	8.16	52.31	35.6	7.50	44.23	27.7	2
3	9.57	71.87	57.3	8.91	62.41	46.4	3	8.26	53.62	36.9	7.60	45.31	28.7	3
4	9.68	73.56	59.3	9.02	63.92	48.0	4	8.36	54.95	38.3	7.69	46.41	29.7	4
5	9.79	75.27	61.4	9.13	65.44	49.8	5	8.47	56.29	39.7	7.78	47.52	30.8	5
6	9.90	77.00	63.5	9.23	66.97	51.5	6	8.57	57.65	41.2	7.87	48.64	31.9	6
7	10.01	78.75	65.7	9.34	68.53	53.3	7	8.67	59.02	42.6	7.96	49.78	33.0	7
8	10.12	80.52	67.9	9.45	70.10	55.2	8	8.77	60.41	44.2	8.05	50.93	34.2	8
9	10.24	82.30	70.2	9.55	71.70	57.1	9	8.87	61.82	45.7	8.14	52.09	35.4	9
10	10.35	84.11	72.5	9.66	73.31	59.0	10	8.97	63.25	47.3	8.24	53.27	36.6	10
11	10.46	85.94	74.9	9.77	74.93	61.0	11	9.08	64.69	48.9	8.33	54.46	37.8	11
12	10.57	87.78	77.3	9.87	76.58	63.0	12	9.18	66.14	50.6	8.42	55.66	39.0	12
13	10.68	89.65	79.8	9.98	78.24	65.1	13	9.28	67.61	52.3	8.51	56.87	40.3	13
14	10.80	91.53	82.3	10.09	79.92	67.2	14	9.38	69.10	54.0	8.60	58.10	41.6	14
15	10.91	93.44	84.9	10.19	81.62	69.3	15	9.48	70.61	55.8	8.69	59.35	43.0	15
16	11.02	95.36	87.6	10.30	83.34	71.5	16	9.58	72.13	57.6	8.78	60.60	44.4	16
17	11.13	97.30	90.3	10.41	85.07	73.8	17	9.68	73.67	59.5	8.88	61.87	45.8	17
18	11.24	99.27	93.0	10.51	86.83	76.1	18	9.79	75.22	61.3	8.97	63.15	47.2	18
19	11.35	101.25	95.8	10.62	88.60	78.4	19	9.89	76.79	63.3	9.06	64.44	48.6	19
20	11.47	103.25	98.7	10.73	90.39	80.8	20	9.99	78.38	65.2	9.15	65.75	50.1	20
21	11.58	105.28	101.6	10.83	92.19	83.2	21	10.09	79.98	67.3	9.24	67.07	51.6	21
22	11.69	107.32	104.5	10.94	94.02	85.7	22	10.19	81.60	69.3	9.33	68.41	53.2	22
23	11.80	109.38	107.6	11.05	95.86	88.2	23	10.29	83.23	71.4	9.42	69.75	54.8	23
24	11.91	111.46	110.6	11.15	97.72	90.8	24	10.40	84.88	73.5	9.52	71.11	56.4	24
25	12.02	113.56	113.8	11.26	99.60	93.5	25	10.50	86.55	75.7	9.61	72.49	58.0	25
26	12.14	115.68	117.0	11.37	101.49	96.1	26	10.60	88.23	77.9	9.70	73.87	59.7	26
27	12.25	117.82	120.3	11.47	103.41	98.9	27	10.70	89.93	80.2	9.79	75.27	61.4	27
28	12.36	119.98	123.6	11.58	105.34	101.7	28	10.80	91.65	82.5	9.88	76.68	63.1	28
29	12.47	122.16	127.0	11.69	107.29	104.5	29	10.90	93.38	84.8	9.97	78.11	64.9	29
30	12.58	124.36	130.4	11.79	109.26	107.4	30	11.01	95.13	87.2	10.06	79.55	66.7	30
31	12.70	126.58	133.9	11.90	111.24	110.3	31	11.11	96.89	89.7	10.16	81.00	68.5	31
32	12.81	128.82	137.5	12.01	113.24	113.3	32	11.21	98.67	92.2	10.25	82.47	70.4	32
33	12.92	131.08	141.1	12.11	115.26	116.4	33	11.31	100.47	94.7	10.34	83.94	72.3	33
34	13.03	133.35	144.8	12.22	117.30	119.5	34	11.41	102.28	97.3	10.43	85.44	74.3	34
35	13.14	135.65	148.6	12.33	119.36	122.6	35	11.51	104.11	99.9	10.52	86.94	76.2	35
36	13.25	137.97	152.4	12.43	121.43	125.8	36	11.61	105.96	102.6	10.61	88.46	78.2	36
37	13.37	140.30	156.3	12.54	123.53	129.1	37	11.72	107.82	105.3	10.70	89.99	80.3	37
38	13.48	142.66	160.2	12.65	125.64	132.4	38	11.82	109.69	108.0	10.80	91.53	82.3	38
39	13.59	145.04	164.2	12.75	127.76	135.8	39	11.92	111.59	110.8	10.89	93.09	84.4	39
40	13.70	147.43	168.3	12.86	129.91	139.2	40	12.02	113.50	113.7	10.98	94.66	86.6	40
41	13.81	149.84	172.5	12.97	132.07	142.7	41	12.12	115.43	116.6	11.07	96.24	88.8	41
42	13.92	152.28	176.7	13.07	134.26	146.3	42	12.22	117.37	119.6	11.16	97.84	91.0	42
43	14.04	154.73	181.0	13.18	136.46	149.9	43	12.33	119.33	122.6	11.25	99.45	93.2	43
44	14.15	157.21	185.3	13.29	138.67	153.5	44	12.43	121.30	125.6	11.34	101.07	95.5	44
45	14.26	159.70	189.8	13.39	140.91	157.3	45	12.53	123.29	128.7	11.44	102.71	97.9	45
46	14.37	162.21	194.3	13.50	143.16	161.1	46	12.63	125.30	131.9	11.53	104.36	100.2	46
47	14.48	164.75	198.8	13.61	145.43	164.9	47	12.73	127.32	135.1	11.62	106.02	102.6	47
48	14.59	167.30	203.5	13.71	147.72	168.8	48	12.83	129.36	138.3	11.71	107.69	105.1	48
49	14.71	169.87	208.2	13.82	150.03	172.8	49	12.94	131.42	141.7	11.80	109.38	107.6	49
50	14.82	172.46	213.0	13.93	152.35	176.8	50	13.04	133.49	145.0	11.89	111.08	110.1	50

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	14.93	175.07	217.8	14.03	154.70	180.9	51	13.14	135.58	148.4	11.98	112.80	112.6	51
52	15.04	177.70	222.7	14.14	157.06	185.1	52	13.24	137.69	151.9	12.08	114.52	115.2	52
53	15.15	180.35	227.7	14.25	159.43	189.3	53	13.34	139.81	155.4	12.17	116.27	117.9	53
54	15.27	183.02	232.8	14.35	161.83	193.6	54	13.44	141.94	159.0	12.26	118.02	120.6	54
55	15.38	185.71	238.0	14.46	164.25	197.9	55	13.55	144.10	162.6	12.35	119.79	123.3	55
56	15.49	188.42	243.2	14.57	166.68	202.3	56	13.65	146.27	166.3	12.44	121.57	126.0	56
57	15.60	191.15	248.5	14.67	169.13	206.8	57	13.75	148.45	170.1	12.53	123.36	128.8	57
58	15.71	193.90	253.9	14.78	171.59	211.4	58	13.85	150.65	173.9	12.62	125.17	131.7	58
59	15.82	196.66	259.3	14.89	174.08	216.0	59	13.95	152.87	177.7	12.72	126.99	134.6	59
60	15.94	199.45	264.9	14.99	176.58	220.6	60	14.05	155.11	181.6	12.81	128.82	137.5	60
61	16.05	202.26	270.5	15.10	179.10	225.4	61	14.15	157.36	185.6	12.90	130.66	140.4	61
62	16.16	205.09	276.2	15.21	181.64	230.2	62	14.26	159.62	189.6	12.99	132.52	143.4	62
63	16.27	207.93	281.9	15.31	184.20	235.1	63	14.36	161.91	193.7	13.08	134.40	146.5	63
64	16.38	210.80	287.8	15.42	186.78	240.0	64	14.46	164.21	197.9	13.17	136.28	149.6	64
65	16.49	213.68	293.7	15.53	189.37	245.0	65	14.56	166.52	202.1	13.26	138.18	152.7	65
66	16.61	216.59	299.7	15.63	191.98	250.1	66	14.66	168.85	206.3	13.36	140.09	155.9	66
67	16.72	219.51	305.8	15.74	194.61	255.3	67	14.76	171.20	210.6	13.45	142.02	159.1	67
68	16.83	222.46	312.0	15.85	197.25	260.5	68	14.87	173.57	215.0	13.54	143.95	162.4	68
69	16.94	225.42	318.2	15.95	199.92	265.8	69	14.97	175.95	219.4	13.63	145.90	165.7	69
70	17.05	228.41	324.6	16.06	202.60	271.2	70	15.07	178.34	223.9	13.72	147.87	169.1	70
71	17.17	231.41	331.0	16.17	205.30	276.6	71	15.17	180.76	228.5	13.81	149.84	172.5	71
72	17.28	234.43	337.5	16.27	208.02	282.1	72	15.27	183.18	233.1	13.90	151.84	175.9	72
73	17.39	237.47	344.1	16.38	210.75	287.7	73	15.37	185.63	237.8	14.00	153.84	179.4	73
74	17.50	240.54	350.8	16.49	213.51	293.3	74	15.48	188.09	242.6	14.09	155.86	183.0	74
75	17.61	243.62	357.5	16.59	216.28	299.1	75	15.58	190.57	247.4	14.18	157.88	186.5	75
76	17.72	246.72	364.4	16.70	219.07	304.9	76	15.68	193.06	252.2	14.27	159.93	190.2	76
77	17.84	249.84	371.3	16.81	221.88	310.8	77	15.78	195.57	257.2	14.36	161.98	193.8	77
78	17.95	252.98	378.3	16.91	224.70	316.7	78	15.88	198.10	262.2	14.45	164.05	197.6	78
79	18.06	256.14	385.5	17.02	227.54	322.7	79	15.98	200.64	267.2	14.54	166.13	201.3	79
80	18.17	259.32	392.7	17.13	230.41	328.8	80	16.08	203.20	272.4	14.64	168.23	205.2	80
81	18.28	262.52	399.9	17.23	233.28	335.0	81	16.19	205.77	277.5	14.73	170.34	209.0	81
82	18.39	265.74	407.3	17.34	236.18	341.3	82	16.29	208.37	282.8	14.82	172.46	213.0	82
83	18.51	268.98	414.8	17.45	239.10	347.6	83	16.39	210.97	288.1	14.91	174.60	216.9	83
84	18.62	272.24	422.3	17.55	242.03	354.0	84	16.49	213.60	293.5	15.00	176.74	220.9	84
85	18.73	275.51	430.0	17.66	244.98	360.5	85	16.59	216.24	299.0	15.09	178.90	225.0	85
86	18.84	278.81	437.7	17.77	247.95	367.1	86	16.69	218.89	304.5	15.18	181.08	229.1	86
87	18.95	282.13	445.6	17.87	250.93	373.8	87	16.80	221.56	310.1	15.28	183.27	233.3	87
88	19.06	285.46	453.5	17.98	253.94	380.5	88	16.90	224.25	315.8	15.37	185.47	237.5	88
89	19.18	288.82	461.5	18.07	256.76	387.3	89	17.00	226.96	321.5	15.46	187.68	241.8	89
90	19.29	292.20	469.6	18.17	260.00	394.2	90	17.10	229.68	327.3	15.55	189.91	246.1	90
91	19.40	295.59	477.9	18.30	263.05	401.2	91	17.20	232.41	333.2	15.64	192.15	250.4	91
92	19.51	299.01	486.2	18.41	266.13	408.2	92	17.30	235.17	339.1	15.73	194.40	254.9	92
93	19.62	302.44	494.6	18.51	269.22	415.4	93	17.41	237.94	345.1	15.82	196.66	259.3	93
94	19.74	305.90	503.1	18.62	272.33	422.6	94	17.51	240.72	351.2	15.92	198.94	263.8	94
95	19.85	309.37	511.6	18.73	275.46	429.9	95	17.61	243.52	357.3	16.01	201.24	268.4	95
96	19.96	312.86	520.3	18.83	278.61	437.3	96	17.71	246.34	363.5	16.10	203.54	273.0	96
97	20.07	316.38	529.1	18.94	281.77	444.7	97	17.81	249.18	369.8	16.19	205.86	277.7	97
98	20.18	319.91	538.0	19.05	284.96	452.3	98	17.91	252.03	376.2	16.28	208.19	282.5	98
99	20.29	323.46	547.0	19.15	288.16	459.9	99	18.02	254.89	382.6	16.37	210.54	287.2	99
100	20.41	327.03	556.1	19.26	291.38	467.7	100	18.12	257.78	389.1	16.46	212.89	292.1	100

Moment Reduction Due to a Bolt Hole in a Pole

The reduction in moment capacity of a pole caused by a bolt hole is calculated by the equation:

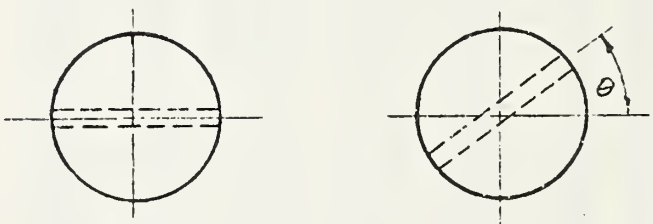
$$M_{bh} = \frac{(F_b)(b)(b^2 \sin^2\theta + d_n^{\,2} \cos^2\theta)}{72(1000)}$$

where:

F_b = ultimate fiber stress of the wood (psi)
d_n = pole diameter at location 'n' (inches)
b = width of hole, taken as bolt diameter plus 1/16 inch (inches)
M_{bh} = reduction in strength (ft-kips)

The drawings below explain the table which follows:

$\theta = 0^{\circ}$ $\qquad\qquad$ $\theta = \sin^{-1}(3.5/d_n)$



POLE MOMENT (FT-K) REDUCTION
DUE TO BOLT HOLES* (8000 psi wood)

POLE DIAM	3/4" 0 DEGREES	THETA	7/8" 0 DEGREES	THETA	1" 0 DEGREES	THETA
9.0	7.3	6.2	8.4	7.2	9.6	8.1
9.1	7.5	6.4	8.6	7.4	9.8	8.3
9.2	7.6	6.5	8.8	7.6	10.0	8.6
9.3	7.8	6.7	9.0	7.7	10.2	8.8
9.4	8.0	6.9	9.2	7.9	10.4	9.0
9.5	8.1	7.0	9.4	8.1	10.7	9.2
9.6	8.3	7.2	9.6	8.3	10.9	9.4
9.7	8.5	7.4	9.8	8.5	11.1	9.7
9.8	8.7	7.6	10.0	8.7	11.3	9.9
9.9	8.8	7.7	10.2	8.9	11.6	10.1
10.0	9.0	7.9	10.4	9.1	11.8	10.4
10.1	9.2	8.1	10.6	9.4	12.0	10.6
10.2	9.4	8.3	10.8	9.6	12.3	10.8
10.3	9.6	8.5	11.1	9.8	12.5	11.1
10.4	9.8	8.7	11.3	10.0	12.8	11.3
10.5	10.0	8.9	11.5	10.2	13.0	11.6
10.6	10.1	9.0	11.7	10.4	13.3	11.8
10.7	10.3	9.2	11.9	10.7	13.5	12.1
10.8	10.5	9.4	12.2	10.9	13.8	12.3
10.9	10.7	9.6	12.4	11.1	14.0	12.6
11.0	10.9	9.8	12.6	11.3	14.3	12.8
11.1	11.1	10.0	12.8	11.6	14.5	13.1
11.2	11.3	10.2	13.1	11.8	14.8	13.4
11.3	11.5	10.4	13.3	12.0	15.1	13.6
11.4	11.7	10.6	13.5	12.3	15.3	13.9
11.5	11.9	10.8	13.8	12.5	15.6	14.2
11.6	12.1	11.0	14.0	12.7	15.9	14.4
11.7	12.4	11.3	14.3	13.0	16.2	14.7
11.8	12.6	11.5	14.5	13.2	16.4	15.0
11.9	12.8	11.7	14.8	13.5	16.7	15.3
12.0	13.0	11.9	15.0	13.7	17.0	15.6
12.1	13.2	12.1	15.3	14.0	17.3	15.8
12.2	13.4	12.3	15.5	14.2	17.6	16.1
12.3	13.7	12.6	15.8	14.5	17.9	16.4
12.4	13.9	12.8	16.0	14.7	18.2	16.7
12.5	14.1	13.0	16.3	15.0	18.4	17.0
12.6	14.3	13.2	16.5	15.3	18.7	17.3
12.7	14.6	13.5	16.8	15.5	19.0	17.6
12.8	14.8	13.7	17.1	15.8	19.3	17.9
12.9	15.0	13.9	17.3	16.1	19.6	18.2
13.0	15.3	14.2	17.6	16.3	20.0	18.5
13.1	15.5	14.4	17.9	16.6	20.3	18.8
13.2	15.7	14.6	18.2	16.9	20.6	19.1
13.3	16.0	14.9	18.4	17.2	20.9	19.4
13.4	16.2	15.1	18.7	17.4	21.2	19.8
13.5	16.5	15.4	19.0	17.7	21.5	20.1
13.6	16.7	15.6	19.3	18.0	21.8	20.4
13.7	16.9	15.8	19.6	18.3	22.2	20.7
13.8	17.2	16.1	19.8	18.6	22.5	21.0
13.9	17.4	16.3	20.1	18.9	22.8	21.4
14.0	17.7	16.6	20.4	19.1	23.1	21.7
14.1	17.9	16.8	20.7	19.4	23.5	22.0
14.2	18.2	17.1	21.0	19.7	23.8	22.4
14.3	18.5	17.4	21.3	20.0	24.1	22.7
14.4	18.7	17.6	21.6	20.3	24.5	23.0
14.5	19.0	17.9	21.9	20.6	24.8	23.4
14.6	19.2	18.1	22.2	20.9	25.2	23.7
14.7	19.5	18.4	22.5	21.2	25.5	24.1
14.8	19.8	18.7	22.8	21.5	25.9	24.4
14.9	20.0	18.9	23.1	21.9	26.2	24.8

*Bolt Hole = Bolt diameter +1/16".

Pole Classes

Wood poles are separated into 15 classes based on the minimum circumference of the pole 6 feet from the butt. The minimum circumferences have been calculated in order for each species in a given class to develop at the groundline stresses approximately equal to those shown in the table when a horizontal load is applied 2 feet from the top of the pole. The horizontal loads used in these calculations are as follows:

Class	Horizontal Load (Pounds)	Class	Horizontal Load (Pounds)
H6	11,400	4	2400
H5	10,000	5	1900
H4	8,700	6	1500
H3	7,500	7	1200
H2	6,400	9	740
H1	5,400	10	370
1	4,500		
2	3,700		
3	3,000		

Weight and Volume of Douglas Fir and Southern Yellow Pine Poles

Pole Volumes (cubic feet)

Height	Pole Class H1	1	2	3
50	44.1	39.3	34.1	24.4
55	51.2	45.0	39.2	33.7
60	58.0	51.1	44.6	38.6
65	65.2	57.2	50.5	43.8
70	72.8	64.5	56.7	49.3
75	80.9	71.8	62.3	54.4
80	89.5	79.6	69.3	59.7
85	98.5	86.6	75.6	65.2
90	106.6	93.9	83.3	71.1
95	116.5	101.6	90.2	77.1
100	125.5	111.6	97.4	80.1

Pole Weights for Douglas Fir (treated)
(50 pcf assumed)

Height	Pole Class H1	1	2	3
50	2200	1970	1700	1220
55	2560	2250	1960	1690
60	2900	2560	2230	1930
65	3260	2860	2530	2190
70	3640	3225	2840	2470
75	4050	3590	3120	2720
80	4480	3980	3470	2990
85	4930	4330	3780	3260
90	5330	4700	4170	3560
95	5830	5080	4510	3860
100	6280	5580	4870	4000

Pole Weights of Southern Yellow Pine (treated)
(60 pcf assumed)

Height	Pole Class H1	1	2	3
50	2650	2360	2050	1470
55	3070	2700	2350	2020
60	3480	3070	2680	2320
65	3900	3430	3030	2630
70	4370	3870	3400	2960
75	4850	4300	3740	3260
80	5380	4780	4160	3580
85	5910	5200	4540	3910
90	6400	5630	5000	4270
95	6990	6100	5410	4630
100	7530	6700	5840	4800

APPENDIX G

CROSSARM DATA

NOTES

Moment Capacities of
Standard Crossarm Sizes

The following table gives moment capacities (M_{xx},M_{yy}) of standard size crossarms for transmission structures in REA Form 805. The moment capacities are based on the dressed size of the arms and a modulus of rupture of 7400 psi. M_{xx} is the moment resistance for vertical and M_{yy} is the moment resistance for longitudinal loads. Section moduli are also given for the respective axis.

Crossarm Size	S_{xx} cm^3 (in^3)	M_{xx} N-m (ft-k)	S_{yy} cm^3 (in^3)	M_{yy} N-m (ft-k)
3-5/8 x 9-3/8	818 (49.9)	41.7 (30.8)	310 (18.9)	15.8 (11.7)
(2)3-5/8 x 9-3/8	1640 (99.8)	83.5 (61.6)	619 (37.8)	31.6 (23.3)
3-5/8 x 5-5/8	289 (17.7)	14.8 (10.9)	184 (11.2)	9.4 (6.9)
(2)3-5/8 x 5-5/8	578 (35.3)	29.5 (21.8)	368 (22.5)	18.8 (13.9)
4-1/8 x 5-1/8	273 (16.7)	14.0 (10.3)	219 (13.3)	11.1 (8.2)
(2)4-1/8 x 5-1/8	546 (33.3)	27.9 (20.6)	437 (26.7)	22.3 (16.5)
4-5/8 x 5-5/8	372 (22.7)	19.0 (14.0)	304 (18.6)	15.5 (11.5)
(2)4-5/8 x 5-5/8	744 (45.4)	37.9 (28.0)	608 (37.1)	31.0 (22.9)
5-3/8 x 7-5/8	807 (49.2)	41.2 (30.4)	565 (34.5)	28.8 (21.2)
5-5/8 x 7-3/8	789 (48.2)	40.3 (29.7)	599 (36.6)	30.6 (22.5)

Example: Determine the maximum vertical span for a TSS-1L (69 kV)
Given : Conductor: 266.8 26/7 ACSR
Ldg. Dist: Heavy
Cond. Wt. (w_c): 1.0776 lbs/ft.
Insulator wt. (W_i): 51 lbs.
Moment arm(s): 5.5 ft.

Procedure: Moment capacity of TSS-1L arm (4-5/8" x 5-5/8") is 13.99 ft-k.

$$V.S. = \frac{M_a - (OLF)(W_i)(s)}{(OLF)(w_c)(s)}$$

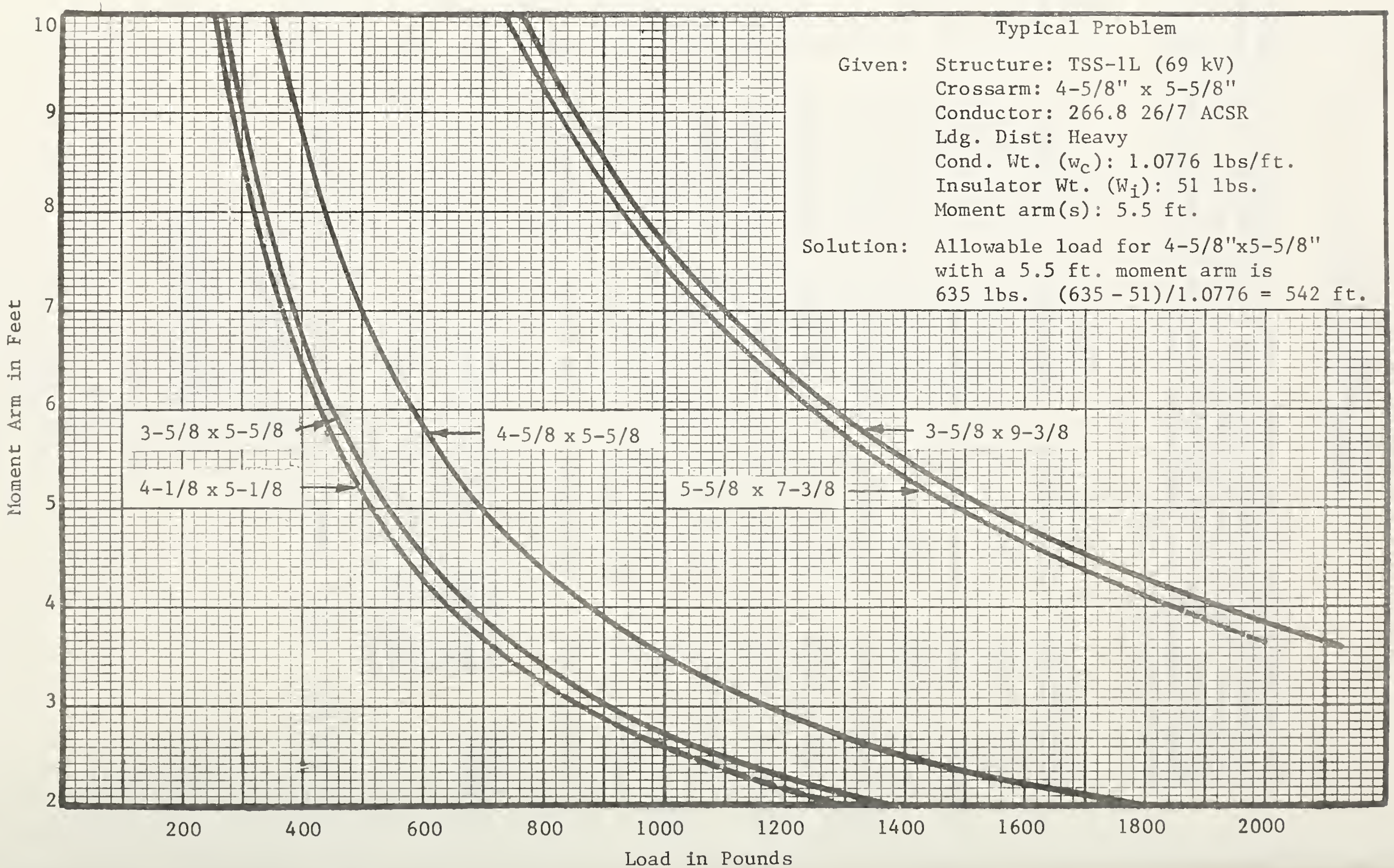
$$= \frac{13{,}990 - 4(51)(5.5)}{(4)(1.0776)(5.5)}$$

$$= 543 \text{ ft.}$$

CROSSARM LOADING CHART

Maximum Allowable Vertical Loads on Various Sizes of Douglas Fir Crossarms. A Fiber Stress of 7400/4 or 1850 is Assumed.

(For maximum ultimate vertical loads, multiply allowable loads by 4).



APPENDIX H

MISCELLANEOUS STRUCTURAL DATA

NOTES

PROPERTIES OF COMMON SECTIONS

A = area (in^2, cm^2)

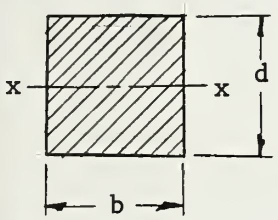
I_{y-y} = moment of inertia about the y-y axis

S_{y-y} = section modulus about the y-y axis

I_{x-x} = moment of inertia about the x-x axis (in^4, cm^4)

S_{x-x} = section modulus about the x-x axis (in^3, cm^3)

r_{x-x} = radius of gyration of x-x axis (in., cm)

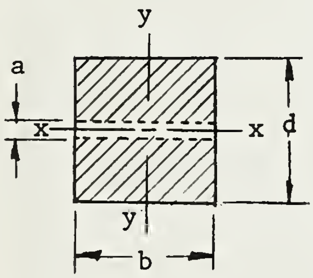


$$A = bd$$

$$S_{x-x} = \frac{bd^2}{6}$$

$$I_{x-x} = \frac{bd^3}{12}$$

$$r_{x-x} = \frac{d}{\sqrt{12}}$$



$$A = b(d - a)$$

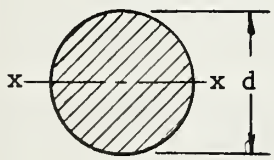
$$r_{x-x} = \sqrt{\frac{d^2 + ad + a^2}{12}}$$

$$I_{x-x} = \frac{b(d^3 - a^3)}{12}$$

$$I_{y-y} = \frac{(d - a)(b)^3}{12}$$

$$S_{x-x} = \frac{b(d^3 - a^3)}{6d}$$

$$S_{y-y} = \frac{(d - a)(b)^2}{6}$$

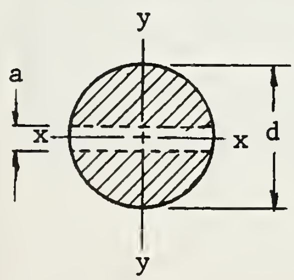


$$A = \frac{\pi d^2}{4} = \pi R^2$$

$$S_{x-x} = \frac{\pi d^3}{32} = \frac{\pi R^3}{4}$$

$$I_{x-x} = \frac{\pi d^4}{64} = \frac{\pi R^4}{4}$$

$$r = \frac{d}{4} = \frac{R}{2}$$



$$A = \frac{\pi d^2}{4} - da$$

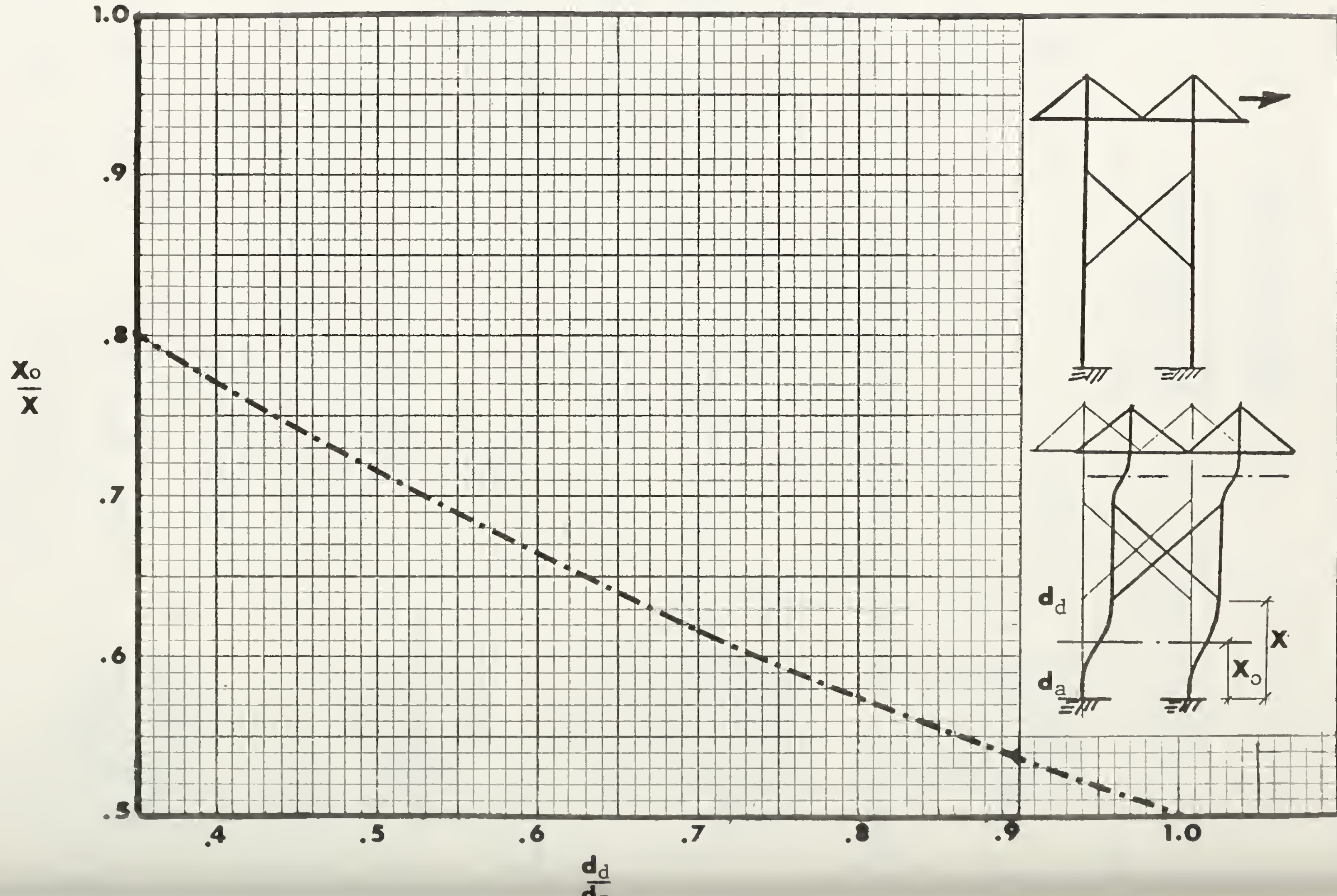
$$I_{x-x} = \frac{\pi d^4}{64} - \frac{da^3}{12}$$

$$I_{y-y} = \frac{\pi d^4}{64} - \frac{ad^3}{12}$$

$$S_{x-x} = \frac{\pi d^3}{32} - \frac{da^2}{6}$$

$$S_{y-y} = \frac{\pi d^3}{32} - \frac{ad^2}{6}$$

Curve for Locating Plane of Contraflexure
in X-braced H-frame Structures



Strengths for Machine Bolts
Double Arming Bolts, Double End Bolts,
Conforming to ANSI C135.1

Machine Bolt Diameter mm	(in.)	Stress Area mm^2	$in.^2$	Min. Tensile Strength N	(lbs)
12.7	(1/2")	50.0	(.0775)	34,700	(7,800)
15.8	(5/8")	91.5	(.1419)	55,200	(12,400)
19.0	(3/4")	145.8	(. 226)	81,600	(18,350)
22.2	(7/8")	215.5	(. 334)	112,900	(25,400)
25.4	(1")	390.9	(. 606)	149,000	(33,500)

Strength of Guy Strands

Strand Size mm	in.	Description	Minimum Breaking Strength N	(lbs)
6.35	(1/4")	H.S	21,100	(4,750)
7 No. 12 AWG		A.C.S	28,000	(6,300)
6.35	(1/4")	E.H.S	29,600	(6,650)
7 No. 11 AWG		A.C.S	35,300	(7,940)
7 No. 10 AWG		A.C.S	44,570	(10,020)
9.53	(3/8")	H.S	48,000	(10,800)
7 No. 9 AWG		A.C.S	56,000	(12,600)
9.53	(3/8")	E.H.S	64,000	(14,400)
11.11	(7/16")	H.S	64,500	(14,500)
7 No. 8 AWG		A.C.S	70,800	(15,930)
7 No. 7 AWG		A.C.S	84,800	(19,060)
11.11	(7/16")	E.H.S	89,300	(20,080)

APPENDIX I

RI AND TVI

NOTES

INSULATOR AND HARDWARE RIV PERFORMANCE VALUES

The values below give recommended maximum RIV levels for insulators plus hardware assemblies for various voltages. The RIV values are measured using the procedure outlined in NEMA Publication 107, "Method of Measuring Radio Noise" - 1964.

kV_{LL}	RIV Level in Microvolts at 1000 kH_Z*
34.5	100
46	200
69	200
115	200
138	200
161	500
230	500

*The values are from Figure 3 of "Transmission System Radio Influence" - IEEE Committee Report - Power Apparatus and Systems, August 1965. (This publication is the major work on the subject.

SOME POSSIBLE SOURCES OF RI OR TVI ON TRANSMISSION LINES

(1) Poor contact between metal parts of suspension insulators - an insufficient vertical span or an uplift condition can cause this.

(2) Poor contact between clamp and clamp support bracket on clamp-top insulators.

(3) Loose conductor clamp.

(4) Loose hardware - can result from wood shrinkage or wind movement:

Crossarm braces or bolts;

Insulator mounting brackets.

(5) Loose staples, bonding wire or ground wire.

(6) Staples, bonding wire or ground wire too near ungrounded hardware.

(7) Bond or ground wire clamped against wood under washer.

(8) Unbonded guy wires too close to each other or to pole hardware.

(9) Slack guy wire causing poor contact at pole attachments or at anchor eye.

(10) Metal-to-metal clearance insufficient on pole hardware.

(11) "Trash" on conductors (bits of wire, metal kite strings, tree limb, etc.).

FORMULAE FOR CALCULATING SURFACE GRADIENTS OF CONDUCTORS

Excessively high conductor surface gradients can result in radio noise, television interference, and corona. The equations below can be used to check the surface gradient. They are approximate but yield reasonably accurate results. They assume phase conductors that are far apart compared to their diameter.

A. Equation for Single Conductor per Phase

$$g = \frac{kV_{LL}}{\sqrt{3}\, r \ln \frac{D}{r}} \qquad \text{(Eq. I-1)}$$

where:

kV_{LL} is the line-to-line voltage, in kV

r is the conductor radius, in cm.

D is the geometric mean distance (GMD) of the phase conductors, in cm.

g is the conductor surface gradient, in kV/cm.

B. Equation for Two Conductor Bundle per Phase

$$g = \frac{kV_{LL}(1+2\, r/s)}{2\sqrt{3}\, r \ln \frac{D}{\sqrt{rs}}} \qquad \text{(Eq. I-2)}$$

where all the sumbols are the same as those above with the addition that:

s is the separation between subconductors, in cm.

C. Application of Formulae

It is recommended that transmission line designs that have unusually close phase spacing have the conductor surface gradient checked. A maximum conductor gradient of 16 kV/cm should be used.

D. Example

Determine the conductor gradient for a 230 kV line with (1) a 556.5 kcmil (dove) ACSR conductor and (2) a 1272 kcmil (pheasant) conductor. GMD for TH-230 is 24.57 feet or 748.90 cm.

1. 556.5 kcmil conductor

$$r = \frac{.927}{2}(2.54) = 1.18$$

$$g = \frac{230(1.05)}{\sqrt{3}(1.18)\ \ln \frac{748.90}{1.18}}$$

$$g = 18.3 \text{ kV/cm.}$$

2. 1272 kcmil conductor (1 conductor)

$$r = \frac{1.382}{2}(2.54) = 1.755$$

$$g = \frac{230(1.05)}{\sqrt{3}(1.755)\ \ln \frac{748.90}{1.755}}$$

$$g = 13.12 \text{ kV/cm.}$$

APPENDIX J

FORMAT GUIDES

NOTES

GUYING GUIDE

Structure ________ Ruling Span ______

Conductor

Type ________ Max. Tension (L,M,H) __________ P_c __________

OHGW

Type ________ Max. Tension (L,M,H) __________ w_c __________

Guy Wire

Type ________ Ult. Strength __________ P_g __________

w_g __________

INSULATOR SWING CALCULATIONS

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

	θ				
	$\sin\theta/2$				
	a) $(2)(T)(\sin\theta/2)$				
	b) $(HS)(p_c)$				
	$(a + b)$				
	c) $(w_c)(\tan\phi)$				
	d) $(a+b)/c$				
	e) $W_i/(2)(w_c)$				
	$d - e = VS$				

	θ				
	$\sin\theta/2$				
	a) $(2)(T)(\sin\theta/2)$				
	b) $(HS)(p_c)$				
	$(a + b)$				
	c) $(w_c)(\tan\phi)$				
	d) $(a+b)/c$				
	e) $W_i/(2)(w_c)$				
	$d - e = VS$				

	θ				
	$\sin\theta/2$				
	a) $(2)(T)(\sin\theta/2)$				
	b) $(HS)(p_c)$				
	$(a + b)$				
	c) $(w_c)(\tan\phi)$				
	d) $(a+b)/c$				
	e) $W_i/(2)(w_c)$				
	$d - e = VS$				

ϕ = 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 conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.

SKETCH

Structure________ Ruling Span________ft.

Conductor________ Loading Dist.(L,M,H)________

Voltage________kV No. of Insulators________

Type of Insulator Swing________

________(F)lbs. Wind________°F

ϕ = ________ °
p_c = ________ lbs/ft.
w_c = ________ lbs/ft.
T = ________ lbs.
W_i = ________ lbs.

Cond. Dia.(d)________

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

APPENDIX K

SYMBOLS AND ABBREVIATIONS

NOTES

SYMBOLS AND ABBREVIATIONS

A =	Cross sectional area.	m^2, mm^2 or ft^2, in^2
A =	Separation between points of suspension of insulator string for two phases.	m, ft. m, ft.
A =	Allowable separation at midspan.	m, ft.
A_u =	Designated ultimate anchor capacity.	N, lbs.
B =	Vertical separation at supports.	m, ft.
C =	Clearance between a supply conductor and an object or ground. May be specified as C_1, C_2, C_3, etc.	m, mm or ft., in.
C =	Circumference of a pole. Depending on the location, the circumference may be indicated as C_A, C_B, C_C, etc.	cm, in.
D_e =	Embedment depth.	m, ft.
D_v =	Vertical separation between conductors.	m, ft.
E_c =	Experience factor for horizontal separation requirements. It is generally recommended that E be greater than 1.25.	
E =	Modulus of elasticity of wood.	Pa, psi
F =	Wind pressure on a cylindrical surface.	Pa, psi
F_b =	Designated ultimate bending stress for either the pole or the crossarm.	Pa, psi
F_c =	Experience factor to be used in horizontal separation requirements (F_c = 1.15 for light loading district, 1.2 for medium loading district, and 1.25 for heavy loading district).	
F_s =	Designated ultimate skin friction of soil.	Pa, psf
G, G_N =	Calculated force in the guy, considering guy lead.	N, lbs.
G_u =	Rated breaking strength of guy.	N, lbs.
H =	Horizontal separation between the phase conductors at the structure.	m, ft.

HS =	Horizontal span. For any structure, the $HS = (L_1 + L_2)/2$ and is the horizontal distance between the midspan points of adjacent spans. The horizontal span times the wind force per foot on the conductor (p_c) will yield the total horizontal force per conductor on the structure.	m, ft.
HS_N =	For an H-frame structure, HS_A, HS_B, etc., are the horizontal spans limited by pole strength at the various locations on the pole.	m, ft.
HS_R =	Horizontal span limited by uplift or bearing.	m, ft.
HS_X =	Horizontal span as limited by crossbrace strength of an H-frame structure.	m, ft.
I =	Moment of inertia of a structural member.	cm^4, in^4
L =	Total length of a pole.	
L =	Span length or the horizontal distance from one structure to an adjacent structure. L_1, L_2, L_3, etc. are designations for different spans.	m, ft.
L_{avg} =	Average span length.	m, ft.
L_{max} =	Maximum span.	m, ft.
LL =	Loop length of conductor when vibrating.	m, ft.
M =	Major axis of Lissagous ellipses.	m, ft.
M_a =	Moment capacity of crossarm.	N-m, ft-lbs.
M_g =	Moment capacity of a pole at groundline.	N-m, ft-lbs.
M_N =	Moment capacity at the indicated location.	N-m, ft-lbs.
M_{bh} =	Moment capacity reduction due to a bolt hole.	N-m, ft-lbs.
M_{wp} =	Moment due to wind on the pole.	N-m, ft-lbs.
OCF =	Overload capacity factor.	N-m, ft-lbs.
P =	Horizontal force.	N, lbs.
P_c =	Force due to wind on conductors (plus ice, if any).	N, lbs.
P_g =	Force due to wind on OHGW (plus ice, if any).	N, lbs.
P_t =	Force due to wind on conductors and OHGW (plus ice, if any).	N, lbs.

P_{cr} = Critical buckling load for a member in compression. N, lbs.

R = Rise of a davit arm.

R = Total transverse load due to wind on the conductors and OHGW and wire tension load for conductors and OHGW. N, lbs.

R_c = Total transverse load due to wind on the conductors (P_c) and wire tension load for conductors (T_c). N, lbs.

R_g = Total transverse load due to wind on the OHGW (P_g) and wire tension load for OHGW (T_g). N, lbs.

RS = Ruling span. m, ft.

S = Section modulus of a structural member equal to I/c. cm^3, in^3

S = Sag of conductor.

S_e = Soil constant.

S_f = Final sag of a bare conductor at condition specified. m, ft.

S_i = Sag of an iced conductor. m, ft.

S_ℓ = Sag of the lower bare conductor. m, ft.

$S_{i\ell}$ = Sag of an iced lower conductor. m, ft.

S_{RS} = Sag at midspan for a span equal to the ruling span. m, ft.

S_u = Sag of an upper conductor. m, ft.

S_{iu} = Sag of an iced upper conductor. m, ft.

SP = Diagonal distance between phase conductors at structure. m, ft.

T = Resultant tension at support. N. lbs.

T_c = Average conductor tension N, lbs.

T_g = Average OHGW tension. N, lbs.

T_h = Horizontal component of tension. N, lbs.

T_{avg} = Average conductor tension in a span ($T_{avg} = \frac{T_h + T}{2}$). N, lbs.

V =	Wind velocity.	km/hr, miles/hr
V =	Vertical separation between phase conductors at a structure.	m, ft.
VS =	Vertical span, the horizontal distance between the maximum sag points of two adjacent spans. The vertical span times the weight of the loaded conductor per foot (w_c) will yield the vertical force per conductor bearing down on the structure.	
W =	Weight.	N, lbs.
W =	Right-of-way width.	m, ft.
W_c =	Weight of conductors (plus ice, if any).	N, lbs.
W_g =	Weight of OHGW (plus ice, if any).	N, lbs.
W_p =	Weight of pole.	
W_i =	Weight of insulators.	N, lbs.

a =	Length as indicated.	m, ft.
a =	Insulator swing clearance for normal condition.	mm, in.
b =	Distance between two poles for an H-frame structure.	m, ft.
b =	Bolt hole diameter; width of a section.	mm, in.
b =	Insulator swing clearance for 6 psf wind condition.	mm, in.
c =	Insulator swing clearance for high wind condition.	mm, in.
c =	Distance from the neutral axis to the extreme fiber.	cm, in.
d_c =	Diameter of conductor.	mm, cm, in.
d_g =	Diameter of overhead ground wire.	cm, in.
d_g =	Diameter at the groundline of a pole.	cm, in.
d_n =	Diameter of a pole. Depending on the location the diameter may be indicated as d_a, d_b, d_c, d_d, etc.	cm, in.
d_t =	Diameter at the top of a pole.	cm, in.
f =	Frequency of conductor vibration.	Hz
f_b =	Computed bending stress.	Pa, psi
f_s =	Computed skin friction of soil.	Pa, psf
g =	Acceleration due to gravity 9.81 (32.2).	m/sec^2, ft/sec^2
g =	Conductor surface gradient.	
h_n =	Length, May be indicated as h_1, h_2, h_3, or h_a, h_b, h_c, etc.	m, ft.
kV_{LG} =	Line to ground voltage.	kV
kV_{LL} =	Line to line voltage.	kV
ℓ =	Unbraced length used in buckling calculations.	m, ft.
ℓ_i =	Insulator string length.	mm, m or in, ft.

m_c =	Mass per unit length of the conductor.	kg/m, lb_m/ft.
m_g =	Mass for unit length of the overhead ground wire.	kg/m, lb_m/ft.
p_c =	Horizontal force per unit length due to wind on the conductors (plus ice, if any).	N/m, lbs/ft.
p_g =	Horizontal force per unit length due to wind on the overhead ground wire (plus ice, if any).	N/m, lbs/ft.
p_t =	Total horizontal force per unit length due to wind on the conductors and overhead ground wire.	N/m, lbs/ft.
q_a =	Calculated allowable soil bearing capacity.	Pa, psf
q_u =	Calculated ultimate soil bearing capacity.	Pa, psf
r =	Radius of gyration. A property of a cross section equal to $\sqrt{I/A}$.	mm, in.
r =	Radius of conductor.	mm, in.
r_c =	Resultant load per unit length on conductor including ice and wind and K factor.	N/m, lbs/ft.
s =	Maximum moment arm for a crossarm.	m, ft.
w_c =	Weight per unit length of the conductors (plus ice, if any).	N/m, lbs/ft.
w_g =	Weight per unit length of the overhead ground wire (plus ice, if any).	N/m, lbs/ft.
x_n, y_n, z_n =	Length. May be indicated as x_0, x_1, z_0, z_1, etc.	m, ft.

α	= Linear coefficient of expansion per degree C (degree F).	m/deg, ft/deg
β	= Angle which the guy makes with the groundline.	deg.
δ	= Structure deflection.	mm, m or in., ft.
ϕ	= Guy angle with ground.	deg.
ϕ	= Insulator swing angle.	deg.
ϕ_{max}	= Maximum insulator swing angle.	deg.
θ	= Line angle.	deg.

APPENDIX L

SELECTED SI-METRIC CONVERSIONS

NOTES

Selected SI-Metric Conversions

AREA

To Convert From	To	Multiply by	
circular mil (cmil)	square meter (m^2)	5.067075	E-10
square centimeter (cm^2)	square meter (m^2)	*1.000	E-04
square foot (ft^2)	square meter (m^2)	*9.290304	E-02
square inch (in^2)	square meter (m^2)	*6.451600	E-04
square kilometer (km^2)	square meter (m^2)	*1.000	E+06
square mile (mi^2)	square meter (m^2)	2.589988	E+06

FORCE

To Convert From	To	Multiply by	
kilogram force (kgf)	newton (N)	*9.806650	
kip	newton (N)	4.448222	E+03
pound force (lbf)	newton (N)	4.448222	

FORCE PER LENGTH

To Convert From	To	Multiply by	
kilogram force per meter (kgf/m)	newton per meter (N/m)	*9.806650	
pound per foot (lb/ft)	newton per meter (N/m)	1.459390	E+01

DENSITY

To Convert From	To	Multiply by	
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767990	E+04
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	1.601846	E+01

LENGTH

To Convert From	To	Multiply by	
foot (ft)	meter (m)	3.048	E-01
inch (in)	meter (m)	*2.540	E-02
kilometer (km)	meter (m)	*1.000	E+03
mile (mi)	meter (m)	*1.609344	E+03

*Exact Conversion.

Selected SI-Metric Conversions, cont.

LINEAR DENSITY

To Convert From	To	Multiply by	
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488164	
pound per inch (lb/in)	kilogram per meter (kg/m)	1.785797	E+01

LOAD CONCENTRATION

To Convert From	To	Multiply by	
pound per square inch (lb/in^2)	kilogram per square meter (kg/m^2)	7.030696	E+02
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882428	
ton per square foot (ton/ft^2)	kilogram per square meter (kg/m^2)	9.071847	E+02

MASS

To Convert From	To	Multiply by	
pound (avoirdupois)(lb)	kilogram (kg)	4.535924	E-01

PRESSURE

To Convert From	To	Multiply by	
kip per square inch (kip/in^2)	pascal (Pa)	6.894757	E+06
kip per square foot (kip/ft^2)	pascal (Pa)	4.788026	E+04
newton per square meter (N/m^2)	pascal (Pa)	*1.000	
pound per square foot (lb/ft^2)	pascal (Pa)	4.788026	E+01
pound per square inch (lb/in^2)	pascal (Pa)	6.894757	E+03

BENDING MOMENT

To Convert From	To	Multiply by	
kilogram force meter (kgf-m)	newton meter (N-m)	*9.806650	
kip-foot (kip-ft)	newton meter (N-m)	1.355818	E+02
pound-foot (lb-ft)	newton meter (N-m)	1.355818	

*Exact Conversion.

Selected SI-Metric Conversions, cont.

VELOCITY

To Convert From	To	Multiply by	
foot per second (ft/s)	meter per second (m/s)	*3.048	E-01
kilometer per hour (km/h)	meter per second (m/s)	2.777778	E-01
mile per hour (mi/h)	meter per second (m/s)	4.470400	E-01
meter per hour (m/h)	meter per second (m/s)	2.777778	E-04

VOLUME

To Convert From	To	Multiply by	
cubic foot (ft^3)	cubic meter (m^3)	2.831685	E-02
cubic inch (in^3)	cubic meter (m^3)	1.638706	E-05
cubic kilometer (km^3)	cubic meter (m^3)	*1.000	E+09
cubic millimeter (mm^3)	cubic meter (m^3)	*1.000	E-09

TEMPERATURE

	Degrees Celcius ^oC	Degrees Fahrenheit ^oF
X^oC =	----	$\frac{9}{5}X + 32$
X^oF =	$\frac{5}{9}(X - 32)$	----

*Exact Conversion.

INDEX

A

B

C

H

I

S

V

W

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International System of Units

In December 1975, Congress passed the "Metric Conversion Act of 1975." This Act declares it to be the policy of the United States to plan and coordinate the use of the metric system.

The metric system, designated as the International System of Units (SI), is presently used by most countries of the world. The system is a modern version of the meter, kilogram, second, ampere (MKSA) system which has been in use for years in various parts of the world.

To promote greater familiarization of the metric system in anticipation of the U.S. converting to the system, REA is including metric units in its publications. This bulletin has, therefore, been prepared with the International System of Units (SI) obtained from ANSI Z 210-1976 - Metric Practice. Approximately equivalent Customary Units are included to permit ease in reading and usage, and to provide a comparison between the two systems.