OVERHEAD LINE DISTRIBUTION DESIGN MANUAL

THIS DOCUMENT IS TO PROVIDE GUIDELINES ON THE MINIMUM REQUIREMENTS FOR DESIGN OF EVOENERGY OVERHEAD DISTRIBUTION LINES (11KV, 22KV AND 415V).

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CONTENTS

1. SCOPE

The scope of this document is to provide guidelines on the minimum requirements for design of Evoenergy overhead distribution lines (11kV, 22kV and 415V). It is based on AS/NZS 7000.

This document covers the following aspects –

- Design criteria for overhead lines;
- Standard construction practices;
- Application of Australian standards and guidelines.

As design calculations will primarily be performed using software, the manual will provide guidance for setting input parameters on software for line design, rather than detail by-hand calculations. However, this document is a comprehensive design manual providing all necessary design data, requirements, worked examples and engineering notes.

This manual provides the standard approach to overhead line design for the Evoenergy distribution network. If the standard design guidelines are not suitable for any particular situation, the designers may choose to depart from these standard design guidelines and develop a solution based on appropriate engineering analysis. Approval by the Asset Owner is required for departures from this overhead design manual.

For switching requirements and design, the designer should consult with the System Control Manager and Asset Planning section for guidance on network requirement before making a decision.

2. PURPOSE

The guideline is intended to:

- Promote standardisation and a uniform design philosophy
- Be practical and ensure earthing is cost effective to design, install, supervise and maintain
- Provide a convenient reference for design parameters, standards and policy
- Support designers with limited 'first-principles' line engineering expertise
- Support training of new designers (not as complete training material, but as an underpinning reference)
- Support any future auditing of designs submitted by external design consultants.

3. PROCEDURE

3.1 Background

The aim of this standard is to:

- Ensure overhead lines are designed and maintained for acceptable levels of safety
- Ensure lines are designed with appropriate levels of reliability
- Provide a consistent Australia wide approach.
- Assist electricity transmission and distribution service providers in regulatory determinations.

The standard covers a number of related design fields including electrical, structural and mechanical aspects and sets out to:

- Describe Limit State Design methodology
- Identify the main design issues

- Set minimum, or general, requirements for an overhead line
- Establish design principles
- Provide a methodology to produce a first principle overhead line design.

A minimum return period wind load for a line is set by selection of Overhead Line Security Class and Design Working Life. For example, normal distribution lines in Australia are commonly designed for a 50 year life and Level I security, which AS/NZS 7000 specifies as requiring a minimum 50 year return period wind. Based on AS1170.2, the wind pressure on wires in inland regions with common terrain for a 50 year return period is 900Pa.

3.2 Policy

The recommended design standard for design of distribution overhead lines is AS/NZS7000.

3.3 Environmental

Relevant Project / Planning / Asset Engineer or Officer must contact the Environmental Officer to access the site for cultural sensitivity, significant trees, threatened species, asbestos dumping grounds, polluted sites etc. Environmental Protection Management Plan (EPMP) should be in place with DA approval before the start of work. EPMP may not be required for small development and Environmental Officer should be consulted in such case before the start of work.

Some site may require Environmental Impact Statement (EIS) which details the anticipated environmental impacts of a development on the environment as well as proposing avoidance, mitigation and offset measures. An EIS is prepared by a proponent to enable decision makers to understand the environmental consequences of a proposed development.

3.4 Safety in Design

Designs must allow for optimal utilisation of readily available plant materials and equipment as well as standard work practices routinely employed in construction and maintenance activities including the application of live-line working procedures where appropriate. Design also must consider the fire risk of locating asset in the vicinity of building.

Designs must allow for and adhere to the standard safety work practices routinely employed in the construction and maintenance activities within Evoenergy. Designs and must comply with the Utilities Act and its supporting documentation and the Safe Design of Structures Code of Practice under the ACT Work Health Safety Act and Evoenergy’s corporate risk management procedures. For further detail refer to Evoenergy document PO0785 “Capital Works Design Checklist Procedure”.

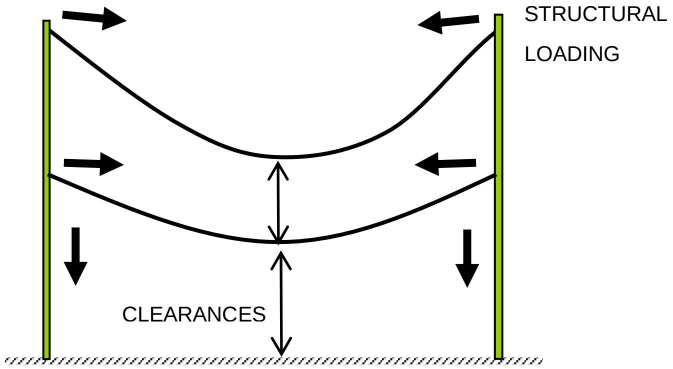
3.5 Design Summary

3.5.1 Design Considerations and Load Cases

At distribution voltages, overhead line design tends to consist more of structural engineering than electrical engineering as shown in figure. The two main technical aspects to the design of overhead distribution lines are:

1. Ensuring that the mechanical load forces do not exceed the strength of the structures or other components, and
2. Ensuring that there are adequate clearances—between the conductors and the ground or from other objects in the vicinity of the line, as well as between the various phase conductors and circuits themselves so that clashing does not occur.

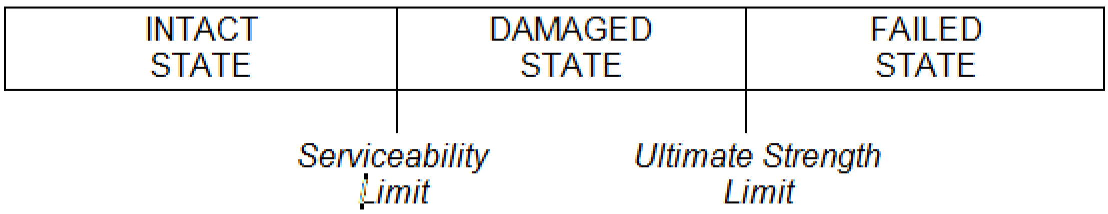
FIGURE 1. DESIGN CONSIDERATIONS AND LOAD CASES



The line must comply with these requirements over the full design range of weather and load conditions that could be reasonably encountered—when the line is cold and taut, when at its maximum design temperature and consequently when conductor sag is at a maximum, and under maximum wind conditions.

3.5.2 Limit States

For structural integrity to be maintained, the structure strength must always exceed the applied mechanical load, otherwise the line passes beyond the limit of its intact state to a damaged state or failed state. Beyond these limits, the line no longer satisfies the design performance requirements.



This may be expressed by the following general limit state equation:

$\varphi R_n >$ effect of loads $(W_n + \Sigma\, \gamma_x X)$ (i.e. strength > applied loading)

where:

φ = the strength factor, which takes into account variability of the material, workmanship etc.

R_n = the nominal strength of the component

γ_x = the load factor, taking into account the variability of the load, importance of structure, dynamics etc.

W_n = wind load on component

X = the applied loads pertinent to each loading condition

Thus, the Ultimate Strength Limit equation, which pertains to loading under short-term wind gusts, with the appropriate load factors applied, may be expressed as follows:

$\varphi R_n > 1.0\, W_n + 1.1\, G_s + 1.25\, G_c + 1.25 Ft_w$

where:

W_n = effect of transverse wind load on structure

G_s = vertical downloads due to the self weight of the structure and fittings

G_c = vertical downloads due to conductors

Ft_w = conductor loads under maximum wind conditions

Note that the limit state equation is not a simple arithmetic equation. The loads include various vector components—vertical, horizontal longitudinal and horizontal transverse. However, for simple distribution lines, vertical downloads are often relatively minor and are not a significant contribution to an overturning moment on the pole, so are often ignored. Note, too, that the structure components have different strengths in different directions and under different actions, e.g. compression, tension, shear or torsion.

The ***Serviceability Limit***, which addresses the effect of sustained (no wind) loading, primarily due to conductor everyday tension must also be checked. This is particularly appropriate with timber and composite fibre components, which may deflect or deform under a sustained load. This limit state is described by the following equation:

$\varphi R_n > 1.1\ G_s + 1.25\ G_c + 1.1Ft_e$

where:

Ft_e = conductor loads under everyday (no wind) conditions

This limit state approach to overhead design has been used widely in Australia since 1999. It is a rationalisation of the earlier working stress method, which applied a general factor of safety, but uses higher, more realistic wind loads (aligned with AS1170 wind code), and material strength factors more closely aligned with reliability of performance. It takes a reliability-based (acceptable risk of failure) approach. Based on this approach, the recommended design for a standard distribution line (i.e. line security level I) with a design life of 50 years is a return period wind of 50 years from Table 6.1, Page 60, of AS/NZS 7000. This means that an Average Recurrence Interval (ARI) of 50 years is used to determine minimum design wind pressures for normal distribution lines. Note that ARI is not probability of failure, as there is a low probability of under-strength material.

AS/NZS 7000 also sets out other limit states that designers may need to check where relevant, such as:

- Failure containment (to prevent a cascading failure after one structure fails) or broken wire condition (where one phase conductor breaks on one side of a strain point, so that the loads applied are then out of balance)
- Maintenance and construction loading
- Snow and ice loading
- Seismic loading
- Torsional loading
- Uplift.

3.5.3 Load Factors and Load Cases

TABLE 1. LOAD FACTORS AND LOAD CASES

LOAD CASE	HORIZONTAL CONDUCTOR FORCES	WIND LOAD ON STRUCTURE	VERTICAL LOADS	
			CONDUCTORS	STRUCTURE
	F_t	W_n	G_c	G_s
No Wind	1.1	_	1.25	1.1
Wind	1.25	1.0	1.25	1.1

Notes:

1. No Wind is a serviceability limit state. For this condition deflection limit is 5% of pole height above ground.
2. Wind is an ultimate strength limit state
3. Refer to AS/NZS 7000:2010, Table 7.4 for additional details.

3.5.4 Design Wind Pressures

Design wind pressures are provided in the Table below. Wind pressures in the column headed “Normal Design Pressure” are to be used for all new lines except for special rural lines. Wind pressures in the last column, “Special Exposed Rural Design Pressure” are only to be used for new rural lines without shielding, either beside lakes and dams, or run over steep ridges.

In general, span reduction factors are not used within Evoenergy distribution design for the sake of simplicity. However, their use may be warranted for very large spans, say in excess of 210m.

TABLE 2. DESIGN WIND PRESSURES

COMPONENT	NORMAL DESIGN PRESSURE	SPECIAL EXPOSED RURAL DESIGN PRESSURE
Conductors	900Pa	1300Pa
Round Poles	1300Pa	1800Pa
Flat Surfaces (Projected Area)	2000Pa	2900Pa

Notes:

1. Wind return period of 50 years has been used based upon AS/NZS 7000:2010, Table 6.1, security level I, 50 year life.
2. Normal Design Wind Pressures are based on region A3, terrain category 2 and 10m pole height which gives 140km/h wind speed.
3. Special Exposed Rural Design Wind Pressures are based on region A3, terrain category 1 (exposed open terrain with few or no obstructions and water surfaces) and 10m height which gives 168km/h wind speed. These wind pressures are also suitable for exposed hills up to topographic multiplier 1.2.
4. The following drag coefficients of the various components have been used:- 1 for conductors, 1.4 for round poles and poles with 8 sides, 2.2 for square sections.

3.5.5 Component Strength Factors

TABLE 3. COMPONENT STRENGTH FACTORS

PART OF OVERHEAD LINE	COMPONENT	LIMIT STATE	STRENGTH FACTOR φ
Wood structures preserved by full length treatment	Pole	Strength	0.60
		Serviceability	0.35
	Crossarm	Strength	0.50
		Serviceability	0.30
Wood structures not preserved by full length treatment	Pole	Strength	0.40
		Serviceability	0.30
	Crossarm	Strength	0.40
		Serviceability	0.30
Concrete structures	Pole	Strength	0.9

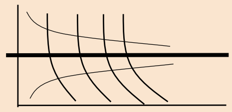
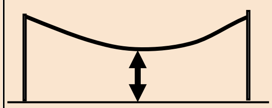
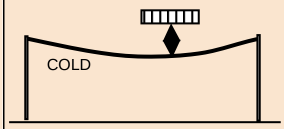
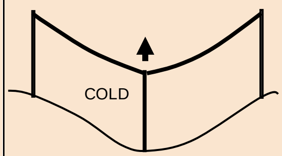
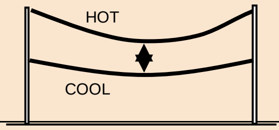
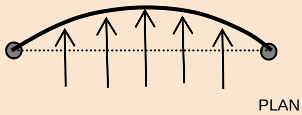
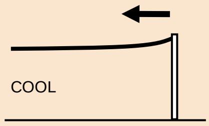
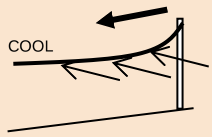
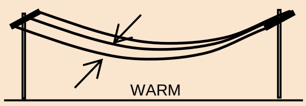
PART OF OVERHEAD LINE	COMPONENT	LIMIT STATE	STRENGTH FACTOR φ
Steel structures	Pole or crossarm	Strength	0.9
Composite Fibre Structures	Pole or Crossarm	Strength	0.75
		Serviceability	0.30
Stays	Cable members	Strength	0.80
	Anchors	Strength	0.40
Conductors		Strength	0.70
		Serviceability	0.50
Fittings and pins—forged or fabricated		Strength	0.80
Fittings--cast		Strength	0.70
Fasteners	Bolts, nuts, washers	Strength	0.90
Porcelain or glass insulators		Strength	0.80
Synthetic composite suspension or strain insulators		Strength	0.5
Synthetic composite line post insulators		Strength	0.9 (max. design cantilever load)
Foundations relying on strength of soil—conventional soil testing		Strength	0.6
Foundations relying on strength of soil—empirical assessment of soil		Strength	0.5

Notes:

1. Refer AS/NZS7000:2010 Table 6.2 for additional details.
2. Serviceability limit – 'No Wind' Condition.
3. Strength limit – 'Wind' Condition.
4. Strength reduction factors for unproven composite fibre structures may be reduced from 0.75 to 0.65 for strength and from 0.3 to 0.25 for serviceability.

3.5.6 Design Temperatures

TABLE 4. DESIGN TEMPERATURES

SITUATION		TEMP	WHEN USED	
Standard (Reference) Temperature		15°C	Reference temperature for conductor stringing tables	
Max. Design Temp. (Hot)	Standard Bare Mains (see Note 1)	75°C	Checking clearance from ground or objects below the line	
Min. Temp. (Cold)		-10°C	Checking clearance from objects above the line	
Uplift		-10°C	Checking for uplift forces, esp. on intermediate structures	
Subcircuit		15°C	Checking intercircuit clearance—hot supercircuit above and cool subcircuit below	
Blowout		30°C	Checking horizontal line displacement (sideways 'sag') under 500Pa wind force	
'No Wind' Load Condition		0°C	Calculating sustained loads	
'Wind' Load Condition		15°C	Calculating loads under maximum wind condition	
Midspan Conductor Clearances		50°C Note 2	Checking interphase conductor spacing to avoid clashing	

Notes:

1. Many older lines were designed to lower temperatures, commonly 50°C or 65°C.
2. Due to cooling effect.

3. Lower temperatures may be required for above 800m altitude where there may be snow and icing.

3.6 Design Process

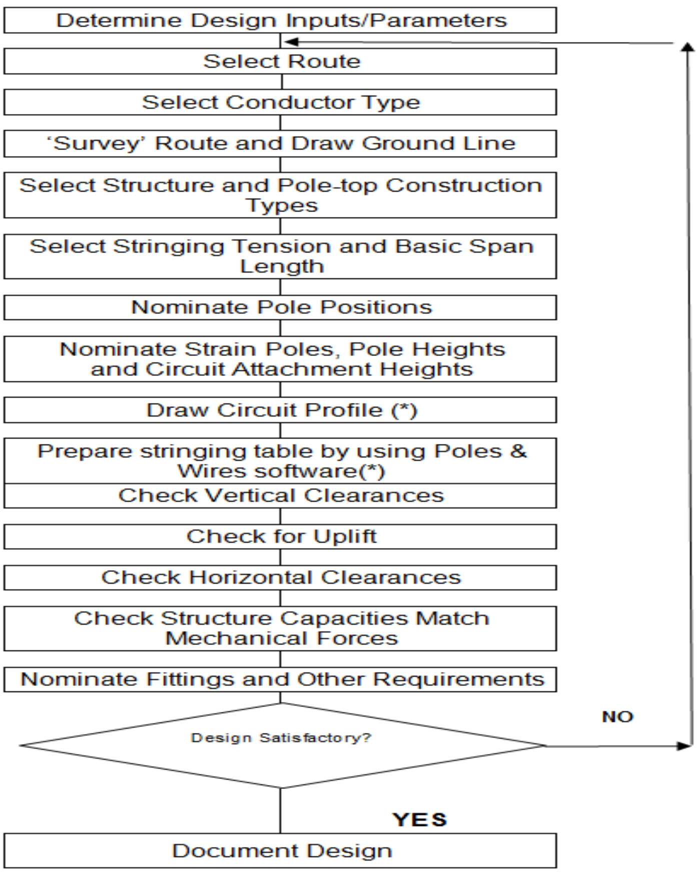
3.6.1 General Design Process

The design process is iterative. The designer initially assumes certain pole positions, pole lengths, pole top constructions and conductor stringing tensions. The design is then analysed and adjusted, sometimes several times over, until an optimum design arrangement is obtained. The final design should be one that:

- Is economical (considering the whole-of-life cost), which usually means keeping structures to a minimum number, and of an economical size
- Meets all applicable technical and regulatory standards (e.g. Voltage drop, current capacity, adequate clearances, not mechanically overloaded)
- Meets all safety and environmental standards
- Is practical to construct, maintain and operate
- Has adequate reliability for the intended purpose.

The design procedure is illustrated below in figure 2. Note that not all steps are required for every design, and the order of the various steps may vary.

FIGURE 2. GENERAL DESIGN PROCESS



Note: Use Poles & Wires software to determine items marked (*)

3.6.2 Design Inputs

The design inputs/parameters must be gathered before commencing design. These may consist of the following:-

- Power transfer.
- Voltage level.
- Line route including beginning and end points, clearances to other structures and vegetation, ground profile.
- Number of circuits.
- Conductor type.
- Aesthetic, heritage and environmental constraints/considerations.
- Planning requirements.
- Coordination with other authorities and services.
- Stakeholder requirements.
- Future developments.
- Land use and property owner requirements.
- Project reports, specifications and requirements.

3.6.3 Route Selection

The aim of the route selection process is to select the lowest cost solution that meets the technical requirements and minimises community impacts.

Appropriate consideration should be given at the route selection stage to the use of the land proposed for the power line corridor. There are zoning maps available from local government authorities which describe the land usage in the region. (i.e. www.actmapi.act.gov.au). Local jurisdiction planning instruments, particularly those regulating the clearing of trees may also influence the selection of the most appropriate route for the power line. Some areas may be of high environmental significance such as aboriginal and cultural heritage or sensitive vegetation (significant trees) and the line route will need to avoid these areas where possible. Generally, overhead lines should be located in road reserves. If there are difficulties with the road reserve option, then an easement across private land may be preferred. Where power lines traverse private property the approval of the property owner is required. This would normally take the form of a negotiated easement detailing any restrictions on land use necessary for safe, reliable operation of the line. On public land the agreement of the management agency should be obtained for the proposed line. Line route should also avoid areas (wherever possible) of native bush land that may be prone to bushfires.

The layout design process should include the identification, assessment and minimisation of risks associated with the construction, maintenance and operation of the proposed line. In particular, access and ease of cut over and minimisation of outages should be taken into account.

The line route should be sensitive to electric and magnetic field exposures.

The total number and angle of deviations should be minimised to control costs and visual impact.

3.6.4 Conductor Selection

The conductor type should be selected based on section 3.7.1 of this manual. The first pass conductor selection is based on current rating as per section 3.7.2 of this manual. In some cases, this selection may be modified by expected future developments, environmental conditions (e.g. vegetation, wildlife and pollution) or the need to be compatible with existing infrastructure.

3.6.5 Route Survey and Ground Profile

Identify constraints and develop a survey plan for the selected route. Ground line profiling is required where poles are to be positioned on undulating terrain. Ground line profiling may not be necessary for areas where the ground level is relatively flat or has a consistent slope.

The route is broken into a number of sections of constant gradient. Slope distance and inclination are then drawn to scale to produce the ground profile. Alternatively, ground profile data may be shown in tabular form, suitable for computer entry. Slope and inclination can be converted to RL (reduced level) and chainage using trigonometry. Relevant features such as trees, roads, gullies, fences and obstacles are also shown on the ground profile. Note vertical scale is selected to exaggerate any slopes.

3.6.6 Structure Selection

Preferred pole sizes should be selected from section 3.9.2 taking into account subcircuits, street light brackets and situations where additional ground clearance may be required.

3.6.7 Tensions

Conductor tensions should be selected as per section 3.8.1 taking into account spanning and conductor type.

3.6.8 Pole Positions and Details

Locate obvious structures such as terminations, transformer poles, tee-off's, service poles (adjacent to entry points), high points, switches and reclosers first. For siting of transformer poles refer to section 3.11.1.

Next nominate strain positions at large deviation angles.

Finally, locate in-line structures based on spanning ability. Ensure adjacent span ratio is within limits of section 3.11.3. Pole positions should be selected based on the ground conditions being suitable for pole foundations (i.e. avoid loose ground such as sand, wet ground, fill and rock). If a pole must be placed in difficult ground conditions (i.e. loose ground such as sand, wet ground, fill or rock) then a special foundation must be designed.

3.6.9 Circuit Profile

Using Poles & Wires software construct a model of the line showing pole positions, ground profile and lowest conductor catenary profile. Conductor catenary is based on mean equivalent span when at maximum operating temperature.

3.6.10 Vertical Clearances

On the circuit profile, draw a ground clearance line above the ground profile line. (Note that extra clearance may be required for crossing highways, rail and rivers.) Check that the conductor profile is above the ground clearance line for all spans. If there is insufficient ground clearance then make adjustments to the layout as follows:-

- Reduce span length
- Change pole positions
- Select taller poles
- Increase stringing tension

Check circuit to circuit clearances when there are super and sub circuits on the poles and also at crossings of other lines. Temperatures for checking circuit to circuit clearances are given in section 3.5.6. Inter-circuit clearances are given in section 3.12.2. If there is inadequate clearance then adjust the design as follows:-

- Reduce span length
- Increase tension on supercircuit
- Reduce tension on subcircuit but must still maintain ground clearance
- Increase separation on pole between super and sub circuits

Clearances to stay wires and poles must also be checked. Conditions are given in section 3.12.9.

3.6.11 Uplift

For structures located in gullies, they may go into uplift under cold conductor tension conditions. If this is possible then the following possible remedial options must be considered:-

- Change the pole to a strain
- Move the pole position

- Reduce conductor tension
- Increase pole height
- Reduce adjacent pole heights if ground clearance allows

Conditions for checking uplift are given in section 3.5.6.

3.6.12 Horizontal Clearances

Check clearances to nearby objects under horizontal blowout due to wind. Worked example and conditions are given in section 3.12.8.

3.6.13 Mechanical Loads

Each pole and crossarm must be checked for the maximum loading (wind, snow and ice) and the everyday condition of sustained load. Note that foundation loading and stay wire tensions also require checking. If structure designs have not previously been assessed, then they must also be checked for maintenance and construction loading.

Note that self windage for poles is included in pole strength given in section 3.9.5. Dimensions and weight for loading determination of large pole transformers is given in section 3.9.7.

Pole loading must be checked against pole capacity summarised in section 3.9.5. If capacity significantly exceeds pole loading, then check next lowest pole strength. Alternatively, if pole capacity is insufficient, then consider:-

- Selecting stronger pole
- Fitting a stay, if space permits
- Reduce conductor tensions for strain poles

In cases where the above options are unsuitable, consider adding a short slack span to an extra pole that can be stayed.

3.6.14 Fittings and Other Requirements

The design is not complete until all the details are complete. Consider the following:-

- Fitting of preform ties in fire prone areas (refer section 3.11.6)
- Fitting of vibration dampers (refer section 3.11.7)
- Fitting of aerial markers (refer section 3.11.8)
- Services and phasing
- Wildlife proofing
- Details of clamps, lugs, connectors, sleeves, bridging
- Details of pole-mounted plant, fusing and settings (refer section 3.11.4)
- Earthing (refer section 3.13)
- Lightning and surge protection
- Vegetation clearing requirements (refer section 3.12.5)
- Special foundations (refer section 3.9.4)

3.6.15 Documentation

3.6.15.1 The following detailed design documentation package is required:-

1. Structure schedule.
2. Conductor schedule (ruling span, sags, tensions).
3. Material and plant list.
4. Single line diagram.

5. Geographical plan.
6. Design calculations.
7. Foundation design.
8. Route plan and longitudinal profile.
9. Crossing details.
10. Construction plans (limitations, archaeological sites, outages).
11. Vegetation clearing.
12. Legal approvals (Property details, wayleaves and Easements).

3.6.15.2 The structure schedule should include the following:-

1. Structure chainage positions and deviation angles.
2. Structure type and height data.
3. Span length, wind span, weight span.
4. Conductor tensions, vibration damper positions.
5. Earthing and foundation requirements.

3.6.15.3 The plan should include the following:-

1. The centerline of the line.
2. All terrain features captured by surveys and mapping scans.
3. All structure locations, structure types and heights.
4. All roads, tracks, water courses, fences, clearance obstructions etc.
5. Conductor stringing chart.

3.6.15.4 The Longitudinal profile should include the following:-

1. All structure locations, structure types and heights.
2. Conductor sag profiles for maximum and minimum temperature conditions.
3. Side slope constraints.
4. Vegetation clearances where preservation measures are applied.

3.6.15.5 The design needs to be traceable to allow verification. Technical review of the following main items is required before construction:-

1. Electrical clearances.
2. Adjacent span ratio.
3. Uplift on structures (cold condition).
4. Structure ultimate and serviceability limit states.
5. Special locations (exposure to EPR and EMF).

3.6.15.6 As-constructed documentation is required as follows:-

1. As-constructed plans.
2. Finalisation of legal requirements including easements.
3. Erection of warning signs (e.g. water crossings).
4. Network data requirements (plant numbers, asset numbers, switching numbers, test results, actual conductor rating).

3.7 Conductors

3.7.1 Selection

In general, the following standard conductors shall be used for new lines:

HV

Urban mains	Neptune 19/3.25mm AAC
Rural mains	Mercury 7/4.50mm AAC
	Banana 6/1/3.75mm ACSR/GZ
Rural take offs	Raisin 3/4/2.50mm ACSR/GZ

LV

Service	LV 25mm2 2 core TW
	LV 25mm2 4 core TW
Commercial	LVABC 150mm2

Only in special situations where standard conductors are not suitable may other conductors may be used. For rural areas, underground or covered conductor is required for bushfire mitigation. The following are possible scenarios requiring non-standard conductors.

For rural where overhead must be used, Grape 30/7/2.50mm ACSR/GZ may be required for long span mains and Imperial (3/12G SC/GZ no longer preferred) for long span, low current.

LVABC is preferred for all LV. For LV where bare overhead must be used, Neptune 19/3.25mm AAC or Mercury 7/4.5mm AAC may be used. Choose Neptune or Mercury based on current rating.

Copper conductors are not to be used for any new works and/or extensions.

No new, bare open wire LV conductors are to be installed in the Bushfire Abatement Zones (BAZ) or rural areas. No bare LV conductors to be used in the first span from the Pole Substation for new designs.

CCT or CC cable systems may be considered for HV lines subject to Asset Strategy and Planning approval:

- In the vicinity of vegetation (present or future)
- Where there is a likelihood of objects falling or blowing onto the mains, e.g. Tree branches, chains
- Where wildlife may otherwise cause outages
- Where mains are likely to be contacted by crane jibs, boat masts or other objects
- For lines located in close proximity to structures

Refer to drawing D204-0005 for details of standard overhead conductors, accessories and interface assemblies.

3.7.2 Electrical Properties and Ratings

3.7.2.1 Bare Mains

TABLE 5. BARE MAINS

CONDUCTOR				SUMMER DAY (A)	WINTER DAY (A)	WINTER NIGHT (A)
MATERIAL	*TYPE*	*STRANDING*	TEMP (°C)			
AAC	**WASP**	**7/0.173”**	**75**	375	477	525
			50	192	363	429
	MERCURY	**7/4.50**	**75**	386	492	541
			50	197	374	442
	HORNET	**19/0.128”**	**75**	478	610	675

CONDUCTOR				SUMMER DAY (A)	WINTER DAY (A)	WINTER NIGHT (A)
MATERIAL	*TYPE*	*STRANDING*	TEMP (°C)			
			50	236	462	552
	NEPTUNE	**19/3.25**	**75**	478	610	675
			50	236	462	552
ACSR	**RAISIN**	**3/4/2.50**	**75**	133	167	182
			50	73	129	149
	FERRET	**6/1/0.118”**	**75**	210	266	289
			50	113	204	237
	APPLE	**6/1/2.50**	**75**	208	262	286
			50	112	201	234
	MINK	**6/1/0.144”**	**75**	265	335	367
			50	139	256	300
	BANANA	**6/1/3.75**	**75**	273	346	379
			50	143	264	310
	GRAPE	**30/7/2.50**	**75**	468	599	664
			50	228	452	543
	WOLF	**30/7/0.102”**	**75**	489	626	695
			50	236	472	568
STEEL	**3/12**	**3/0.104”**	**75**	50	62	67
			50	28	48	55
COPPER	**7/2.00**		**75**	182	229	247
			50	102	177	202
	7/.080"		**75**	186	233	252
			50	104	180	206
	7/.104”		**75**	256	322	350
			50	139	247	285
	19/.064”		**75**	260	328	357
			50	142	252	291
	7/2.75		**75**	268	339	368
			50	146	260	300
	19/.083”		**75**	358	453	495
			50	189	346	404
	7/3.50		**75**	360	456	499
			50	190	349	407
	19/.101”		**75**	455	578	635
			50	234	439	518
	19/2.75		**75**	495	630	694
			50	251	478	566
	37/.083”		**75**	537	684	755
			50	270	518	616
	19/3.00		**75**	550	702	774
			50	275	531	632

Notes:

1. Shaded values (75°C) are for new lines. Ratings at 50°C are for older lines.
2. Ratings are calculated for conditions shown below.

TABLE 6. CONDITION RATINGS

Condition	Ambient Temperature (°C)	Solar Radiation Intensity (W/m^2)
Summer Day	35	1000
Winter Day	15	850
Winter Night	10	0

Notes:

1. Wind speed 1m/s normal to conductor.
2. Emissivity of conductor: 0.5, Solar absorption coefficient: 0.5

3.7.2.2 Insulated Mains Cables

TABLE 7. INSULATED MAINS CABLES

Material	**Conductor Name**	**Nom. CSA** (mm^2)	**DC Resistance** @20°C (Ω/km)	**Current Rating** (A)	
				Summer Day	Winter Night
CCT (AAAC 1120)	CCT40	41.6	0.713	190	253
	CCT80	77.3	0.383	280	375
	CCT180	182.80	0.163	470	648
LVABC	LVABC150 (4C)	4 x 150	0.206	305	418

Notes:

1. Conductor operating temperature 80°C for insulated cables, 40°C ambient.
2. Wind speed 1.0m/s
3. LV Services Cables

TABLE 8. LV SERVICES CABLES

CONDUCTOR	**SUMMER DAY (A)**	**WINTER NIGHT (A)**
ALUMINIUM Metric 25mm^2 2CTW 25mm^2 4CTW	 141 101	 126 106
LVABC 150mm^2	 305	 418

Notes:

1. 150mm2 LVABC is used for commercial/industrial service lines.
2. Maximum conductor temperature 75°C
3. Values are rounded to nearest 1A for values below 100, rounded to nearest 5A for values above 100.
4. Environmental Conditions:

TABLE 9. ENVIRONMENTAL CONDITIONS

Condition	Ambient Temperature (°C)	Solar Radiation Intensity (W/m^2)	Wind Velocity (m/s)
Summer Day Winter Night	35 10	1000 0	1.0 0.0

Note: There are a number of two phase connections in the ACT; in such cases blue phase is normally doubled up with neutral on a 4 core service.

3.7.3 Mechanical Properties

3.7.3.1 Bare Mains

TABLE 10. BARE MAINS

Material	Conductor Name	Strands (No./Dia.)		CSA (mm²)	Nom. Cable Diameter (mm)	Nom. Breaking Load / UTS (kN)	Mass (kg/m)	Modulus of Elasticity (GPa)	Linear Expansion Coefficient (/ºC x 10⁻⁶)
		Metric (mm)	Imperial (inches)						
AAC (1350)	MERCURY	7/4.50		111.30	13.50	16.80	0.305	56	23
	NEPTUNE	19/3.25		157.60	16.25	24.70	0.433	56	23
	WASP		7/0.173	106.19	13.18	16.46	0.290	59	23
ACSR/GZ	APPLE	6/1/3.00		49.50	9.00	14.90	0.171	79	19.3
	BANANA	6/1/3.75		77.31	11.30	22.70	0.268	79	19.3
	CHERRY	6/4.75+7/1.60		120.40	14.30	33.20	0.404	76	19.9
	RAISIN	3/4/2.50		34.36	7.50	24.40	0.195	139	19.3
	FERRET		6/1/.118	49.4	9.0	14.74	0.171	86	19.3
	DOG		6/.186+7/.062	118.5	14.15	32.5	0.396	83	19.9
	WOLF		30/7/.102	194.9	18.13	69.2	0.732	80	18.4
SC/GZ (Steel – Galv.)			3/.104 (3/12)	16.77	5.1	21.85	0.130	193	11.5
		3/2.75		17.82	5.93	22.20	0.139	193	11.5
		7/2.00		21.99	6.00	27.40	0.177	193	11.5
			7/.104 (7/12)	38.70	7.92	50.83	0.304	193	11.5
		7/2.75		41.58	8.25	51.80	0.326	193	11.5
		7/3.25		58.07	9.75	72.30	0.460	193	11.5
HDC (Hard Drawn Copper)		7/1.00		5.5	3	2.31	0.049	118	17
		7/1.25		8.59	3.75	3.61	0.769	118	17
		7/1.75		16.84	5.25	6.89	0.151	118	17
		7/2.00		21.99	6	9.02	0.197	118	17
		7/2.75		41.58	8.25	16.7	0.373	118	17
		19/1.75		45.7	8.75	18.3	0.413	116	17
		19/2.00		59.69	10	23.9	0.538	116	17
		7/3.50		67.35	10.5	26.6	0.603	118	17
		37/1.75		89	12.3	35.6	0.806	115	17
		19/2.75		112.9	13.8	44.5	1.020	116	17
		19/3.00		134.3	15	52.8	1.210	116	17
		37/2.50		181.6	17.5	72.9	1.640	115	17
		37/2.75		219.8	19.3	86.6	1.990	115	17
			7/.064 (7/16)	14.5	4.87	6.1	0.131	124	17
			7/.080 (7/14)	22.7	6.09	9.45	0.206	124	17
			7/.104 (7/12)	38.4	7.92	15.78	0.348	124	17
			19/.064 (19/16)	39.4	8.12	16.2	0.357	124	17
			19/.083 (19/14)	66.3	10.54	26.97	0.603	124	17
			19/.101 (19/12)	98.2	12.8	39.64	0.890	124	17
			19/.116	129.6	14.73	51.72	1.175	124	17
			37/.083 (37/14)	129.1	14.75	51.5	1.170	124	17

Notes:

1. Conductors other than current preferred sizes are included for reference purposes.
2. Conductor data is generally in accordance with Australian Standards. Note that product from various manufacturers may differ slightly from the above data.

3.7.3.2 LV ABC and CCT Cables

TABLE 11. LV ABC AND CCT CABLES

Material	Conductor Name	CSA (mm²)	Nom. Cable Diameter (mm)	Nom. Breaking Load / UTS (kN)	Mass (kg/m)	Modulus of Elasticity (GPa)	Linear Expansion Coefficient (/ºC x 10-6)
CCT (AAAC 1120 / 3.4mm XLPE)	CCT40	41.6	15.6	9.9	0.25	65	23
	CCT80	77.3	18.6	17.6	0.4	65	23
	CCT180	182.80	24.90	41.70	0.78	65	23
LVABC (AAC / XLPE)	LVABC150 (4C)	4 x 150	45.60	84.00	2.02	56	23

3.7.3.3 Broadband Communications Cables

TABLE 12. BROADBAND COMMUNICATIONS CABLES

Network	Conductor Name	CSA Catenary (mm²)	Nom. Cable Diameter (mm)	Nom. Breaking Load / UTS (kN)	Mass (kg/m)	Modulus of Elasticity (GPa)	Linear Expansion Coefficient (/ºC x 10-6)
Telstra	Catenary	23.1	6.15	28.75	0.176	170	11.52
	Catenary + 1 Coax	23.1	18.85	28.75	0.324	170	11.52
Optus	Catenary	30	7.0	37.35	0.18	193	11.52
	Catenary + 1 Coax	30	24.5	37.35	0.361	193	11.52
TransACT 1	7/2.00mm SC/GZ Catenary	21.99	6	27.4	0.177	193	11.52
TransACT 1	7/2.00mm SC/GZ Catenary	21.99	6	27.4	0.177	193	11.52
	Catenary + Green bundle	21.99	35	27.4	0.677	193	11.52
	Catenary + Red bundle	21.99	40	27.4	0.847	193	11.52
	Catenary + Black bundle	21.99	45	27.4	1.062	193	11.52
TransACT 2	6/1/3.75mm ACSR Catenary	77.31	11.3	22.8	0.268	79	19.3
	Catenary + Green bundle	77.31	35	22.8	0.715	79	19.3
	Catenary + Red bundle	77.31	40	22.8	0.885	79	19.3
	Catenary + Black bundle	77.31	45	22.8	1.1	79	19.3

3.7.4 Engineering Notes

3.7.4.1 Conductor Selection

Bare conductor selection consists of consideration of wire size, shape and material, electrical, mechanical, environmental and economic factors. Conductor selection involves the consideration of:-

1. Electrical requirements for load and fault current ratings and joule losses;
2. Mechanical requirements including annealing, drag coefficient, operating temperature, constructability (no birdcaging or unravelling), permanent elongation, fatigue endurance, conductor diameter, sag and strength relationship;
3. Environmental requirements for corrosion and lightning damage; and
4. Economic requirements for cost of losses, capital costs, load profile, interest rate, load growth, inventory costs and construction costs (ratio of tension to suspension structures).

3.7.4.2 Conductor Materials

Whilst copper has the lowest resistivity it is now being replaced by aluminium in most applications due to cost. Bare copper was previously used for distribution lines but is now being replaced by Aluminium. Copper is heavier than Aluminium so it sags more.

There are a number of Aluminium alloys that have been used in Australia. They include 1350, 1120 and 6201. 1350 is virtually pure Aluminium and is manufactured in a range of conductors known as AAC (All Aluminium Conductor). 1350 has the lowest resistance of all the alloys but also has the lowest strength. As strength is not important for distribution with short spans, 1350 is the best conductor for urban distribution. 1120 and 6201 are alloys of Aluminium that have higher resistance but also higher strength. Consequently, these alloys are used for rural distribution, sub-transmission and transmission where strength is important to reduce sag on longer spans. AAC 6201 is no longer manufactured in Australia but was used for some of the early transmission lines e.g. in the Snowy Mountains and Hamersley Iron.

ACSR (Aluminium Conductor Steel Reinforced) has a galvanised steel core with outer layers of Aluminium. The steel core provides strength and the outer Aluminium provides conductivity. This conductor is very strong so it has low sag for long spans and is used for rural distribution, sub-transmission and transmission.

SC/GZ (Steel Conductor Galvanised) is high strength but with high resistance. Consequently, it is used for rural distribution. SC/GZ is also used for stay wires on highly loaded poles.

3.7.4.3 Conductor Designations

Conductors can be identified by their material, e.g. AAC and stranding e.g. 7/4.5 which means 7 strands of 4.5mm diameter, or by a unique name e.g. Mercury. Different sizes of conductor made of the same material and often named in a series e.g. Australian AAC series are named after planets and Imperial AAC series are named after insects. Australian ACSR series are named after fruit and the Imperial ACSR series are named after animals.

For conductors made up of the same size strand, each layer has six more strands than the previous layer. All conductors start as one central king wire, the first layer has 6 strands, the second layer has 12 strands, the third layer has 18 strands and so on. Consequently, the overall diameter can be calculated as follows:-

- 7 strands is 3 times the diameter of a single strand
- 19 strands is 5 times the diameter of a single strand
- 37 strands is 7 times the diameter of a single strand

3.7.4.4 Insulated/ Covered Conductor

Insulated/covered conductors are used in the following areas to prevent flashover:

- Occasional contact with nearby vegetation
- High incidence of animal contact
- Bushfire prone requiring prevention of clashing

Insulated conductors have a metallic screen (e.g. LVABC) while covered conductor (e.g. HV CCT) does not. Consequently, covered conductor is not considered touch safe.

3.7.4.5 Conductor Ageing and Thermal Effects

Corrosion can reduce the effective cross section of conductors causing loss of strength and increased sag. Different materials have different corrosion susceptibility and this must be taken into account for industrial and marine pollution. This is not expected to be a problem in the relatively clean environment of the ACT for the standard conductors used.

If conductors are run at elevated temperatures they can be annealed when they cool down, losing strength and increasing sag. Annealing effects are cumulative so the effects of overloads over time may cause excessive sag and loss of Statutory ground clearance. Consequently, conductor maximum temperatures must be limited to prevent excessive annealing over the life of the overhead line. To limit loss of strength to 3% for 1000hours operation, bare Copper and Aluminium alloys should be limited to 100ºC maximum continuous operating temperature.

For transient fault currents, the maximum temperature of common conductor materials should be limited to the following temperatures:-

- 200 ºC for bare Copper, 160 ºC for Aluminium alloys, on the basis of annealing as these materials lose 10% strength at 220 ºC and 210 ºC, respectively.
- 400 ºC of SC/GZ as Zinc melts at 420 ºC.

For LV ABC/covered conductors the maximum continuous operating temperature is limited by the polymeric material to 80ºC. Insulated service lines are limited to 75 ºC due to the insulation.

3.7.4.6 Continuous Current Rating

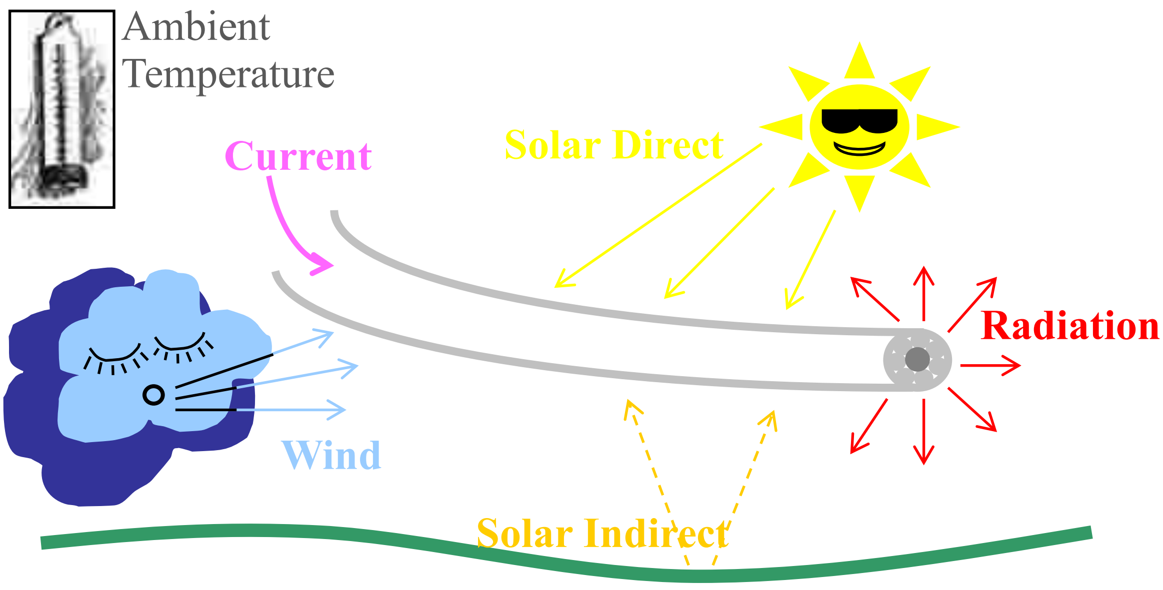
The continuous thermal rating is calculated based on a steady state energy balance. In steady state, the conductor temperature is constant and the heat input is matched by the heat lost. Heating sources are direct and indirect (reflected from the ground), solar radiation and joule heating (i.e. I2R). Heat is lost by convection and radiation from the conductor surface. (Note that heat can also be lost by evaporation of rain water but this is not usually taken into account in the calculation.) Reference 7 gives an explanation of all aspects of conductor thermal rating.

The steady state thermal current rating of a conductor can also be interpreted as the maximum current inducing the maximum steady state temperature for a given ambient condition. The heat balance equation can be represented mathematically as:-

Pj + Ps = Pr+ Pc

Where the heat gain terms are Pj which is the joule heating due to the resistance of the conductor and Ps is the solar heat gain. The heat loss terms are Pc which is natural and forced convection cooling and Pr is the radiation cooling. Note that joule heating is I2 R and the above equation is solved for current.

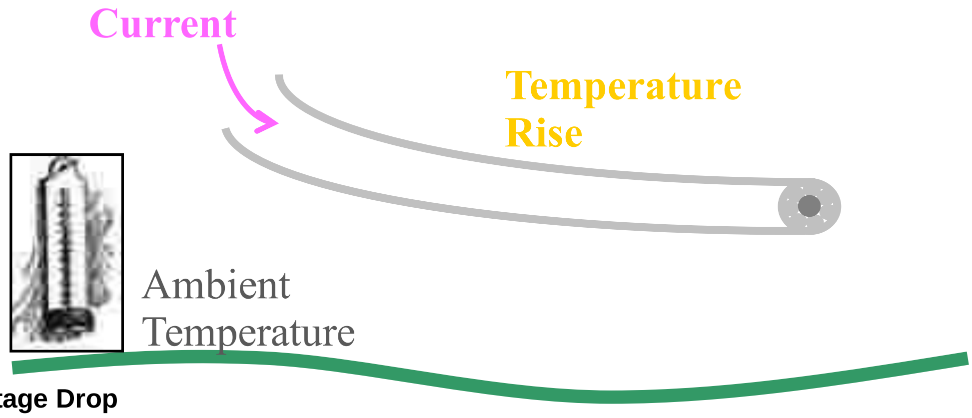
A schematic showing the heating and cooling effects on a conductor is shown below.



Typically, weather data is analysed to determine an ambient temperature/wind speed pair of values that have a low probability of being exceeded. The dominant parameter is wind speed. The traditional wind speed used was 2 ft/second (i.e. 0.6 m/s). Generally, wind speeds in the range 0.5 to 1 m/s are used. In the past, low maximum operating temperatures such as 49ºC have been used resulting in negligible rating in summer. A high maximum operating temperature needs to be used (e.g. greater than 60ºC) otherwise there is insufficient temperature rise to provide adequate current rating in summer.

3.7.4.7 Fault Current Rating

Fault ratings are calculated based on adiabatic heating. It is assumed that no heat is lost or gained during the short period of the fault. All the fault energy (i.e. Joule heating I2R) goes into raising the temperature of the conductor and no heat is lost by convection, nor radiation from the surface. A schematic showing the heating and cooling effects on a conductor is shown below.



3.7.4.8 Voltage Drop

Voltage drop along conductors due to load current must be checked to ensure it is within allowable range. Refer "Supply Voltage Standard". This is typically 230V, +10%, -6%. In certain situations, current flow direction can reverse e.g. due to photovoltaics and other power sources.

Note that voltage drop is due to current flow through not only resistance but also the reactance of conductors.

3.7.5 Worked Example 1 – Continuous Current Rating

OVERHEAD CONDUCTOR THERMAL CURRENT RATING calculation
based on *Current Rating of Bare Overhead Line Conductors*, D (b) 5 - 1988, by ESAA

Constants

$kV \equiv volt \cdot 10^{3}$ $\quad MVA \equiv volt \cdot amp \cdot 10^{6}$ $\quad C \equiv K$ — Define kiloVolt, MegaVolt and Celsius unit

$\sigma \equiv 5.6697 \cdot 10^{-8} \cdot watt \cdot m^{-2} \cdot K^{-4}$ — Stefan-Boltzmann constant for radiant heat transfer

INPUT DATA
Conductor Name :- Neptune, 19/3.25mm
Material :- AAC, All Aluminium, grade 1350

$V \equiv 11 \cdot kV$	Phase to phase rms voltage of three phase line
$\varepsilon \equiv 0.5$	Emissivity of conductor surface. 0.5
$a \equiv 0.5$	Solar absorbtivity of conductor. 0.5
$R_{dc} \equiv 0.183 \cdot ohm \cdot km^{-1}$	Conductor electrical DC resistance at 20 C
$\alpha \equiv 0.00365 \cdot C^{-1}$	Temperature coefficient of resistance for conductor. 0.004 / C for Al
$D \equiv 16.3 \cdot mm$	Diameter of conductor
$I_{dir} \equiv 1000 \cdot watt \cdot m^{-2}$	Direct solar radiation. 1 kW
$I_{diff} \equiv 100 \cdot watt \cdot m^{-2}$	Diffuse solar radiation. 100 W
$\psi \equiv 60 \cdot deg$	Wind angle of attack to conductor longitudinal axis. 60 degrees
$k \equiv 1.003$	Ratio of AC resistance to DC resistance of conductor. 1.005
$F \equiv 0.2$	Albedo or ground reflectance. 0.2
$T_c \equiv 75 \cdot C$	Conductor maximum continuous operating temperature. 90 C for Al, 120 C for ACSR
$T_a \equiv 35 \cdot C$	Ambient temperature. 36 C summer, 15 C winter
$v \equiv 1.1 \cdot m \cdot sec^{-1}$	Wind velocity. 0.7 m/s

CALCULATION

$$P_s := a \cdot D \cdot \left[I_{dir} \cdot \left(1 + \frac{\pi}{2} \cdot F\right) + I_{diff} \cdot \frac{\pi}{2} \cdot (1 + F) \right]$$

Solar power flux

$$P_s = 12.2 \cdot watt \cdot m^{-1}$$

$$T_g := if\left(I_{dir} \le 0, T_a - 5 \cdot C, T_a + 5 \cdot C\right)$$

Ground temperature. (Ambient plus 5 C for sun out, Ambient minus 5 C for night)

$$T_g = 40 \cdot C$$

$$T_d := 0.0552 \cdot \left(T_a + 273 \cdot C\right)^{1.5} \cdot C^{-0.5} - 273 \cdot C$$

Sky temperature

$$T_d = 25.4 \cdot C$$

$$P_r := \pi \cdot D \cdot \sigma \cdot \varepsilon \cdot \left[\left(T_c + 273 \cdot C\right)^4 - \frac{\left(T_g + 273 \cdot C\right)^4 + \left(T_d + 273 \cdot C\right)^4}{2} \right]$$

Radiated power loss flux

$$P_r = 8.6 \cdot watt \cdot m^{-1}$$

$T_f := \dfrac{T_c + T_a}{2}$	Air film temperature
$T_f = 55 \cdot C$	
$\lambda_f := \left(2.42 \cdot 10^{-2} \cdot K + 7.2 \cdot 10^{-5} \cdot T_f\right) \cdot watt \cdot m^{-1} \cdot K^{-2}$	Thermal conductivity of air film
$\lambda_f = 0.028 \cdot watt \cdot m^{-1} \cdot K^{-1}$	
$\nu_f := \left(1.32 \cdot 10^{-5} \cdot C + 9.5 \cdot 10^{-8} \cdot T_f\right) \cdot m^2 \cdot sec^{-1} \cdot K^{-1}$	Kinematic viscosity of air film
$\nu_f = 1.84 \times 10^{-5} \cdot m^2 \cdot sec^{-1}$	
$Re := \dfrac{v \cdot D}{\nu_f}$	Reynolds number
$Re = 973$	
$B := if(Re \le 2650, 0.641, 0.048)$	Constant for forced convection
$B = 0.641$	
$n := if(Re \le 2650, 0.471, 0.8)$	Constant for forced convection
$n = 0.471$	
$c := if(\psi \le 24 \cdot deg, 0.68, 0.58)$	Constant for wind angle
$c = 0.58$	
$P := if(\psi \le 24 \cdot deg, 1.08, 0.9)$	Constant for wind angle
$P = 0.9$	
$P_f := \pi \cdot \lambda_f \cdot \left(T_c - T_a\right) \cdot B \cdot Re^n \cdot \left(0.42 + c \cdot sin(\psi)^P\right)$	Power flux dissipated by forced convection
$P_f = 53.9 \cdot watt \cdot m^{-1}$	
$I := \sqrt{\dfrac{P_r + P_f - P_s}{k \cdot R_{dc} \cdot \left[1 + \alpha \cdot \left(T_c - 20 \cdot C\right)\right]}}$	Continuous current rating
$I = 477 \cdot amp$	
$P_j := I^2 \cdot k \cdot R_{dc} \cdot \left[1 + \alpha \cdot \left(T_c - 20 \cdot C\right)\right]$	Electrical Joule heating power input
$P_j = 50.2 \cdot watt \cdot m^{-1}$	
$P_{elec} := \sqrt{3} \cdot V \cdot I$	Continuous three phase rating for the transmission line
$P_{elec} = 9.1 \cdot MVA$	

3.7.6 Worked Example 2 – Fault Current Rating

Fault current rating based on ENA C b 1- 2006, Appendix D2.4.

Define Units

$C \equiv K$	Define Centigrade units
INPUT DATA	**Neptune 19/3.25mm AAC**
$\rho \equiv 2700 \cdot \frac{kg}{m^3}$	Density, SC/AC 6590kg/m3, SC/GZ 7800kg/m3, 2700 kg/m3
$s_{20} \equiv 900 \cdot \frac{J}{kg \cdot C}$	Specific heat, SC/GZ 500J/kg-C, AAC 900J/kg-C
$A_s \equiv 4.5 \cdot 10^{-4} \cdot C^{-1}$	Temp coefficient of specific heat at 20C
$\alpha \equiv 0.00403 C^{-1}$	Thermal coefficient of resistance
$R_{20} \equiv 28.3 \cdot 10^{-6} \cdot ohm \cdot mm$	Resistivity at 20C
$CSA \equiv 157.6 mm^2$	Cross sectional area
$T_{init} \equiv 35 \cdot C$	Initial temperature
$T_f \equiv 160 \cdot C$	Final temperature
$t \equiv 1 \cdot sec$	Clearing time

CALCULATIONS

$$Rating := \frac{\rho \cdot s_{20} \left[1 + A_s \cdot \left(\frac{T_{init} + T_f}{2} - 20 \cdot C \right) \right]}{\alpha \cdot R_{20}} \cdot \ln \left(\frac{T_f - 20 \cdot C + \frac{1}{\alpha}}{T_{init} - 20 \cdot C + \frac{1}{\alpha}} \right) \cdot CSA^2$$

Equation D1

$Rating = 213 kA^2 \cdot s$

$I := \sqrt{\frac{Rating}{t}}$ Current rating

$I = 14.6 kA$

3.8 Conductor Stringing

3.8.1 Conductor Stringing Tensions

Typical stringing tensions are provided as a percentage of conductor calculated breaking load at design temperature of 15ºC.

3.8.1.1 AAC

TABLE 13. AAC

Span Length (m)	Situation	Design Tension (%CBL)
10-30	Slack	2.5
30-80	Urban	5
50-120	Semi-urban	10
100-170	Rural	20

3.8.1.2 ACSR

TABLE 14. ACST

Span Length (m)	Situation	Design Tension (%CBL)
150-300	Rural	22

3.8.1.3 LV ABC

TABLE 15. LV ABC

Span Length (m)	Situation	Design Tension (%CBL)
10-30	Slack	2.5
30-80	Urban	5
50-120	Semi-urban	10

Note: AAC span and tensions can also be applied to LV service lines.

3.8.2 Stringing Tensions Limits

Conductor tension should be limited to prevent fatigue failures at attachment points. Recommended maximum values are given in AS/NZS7000 Appendix Z, Table Z1, Conductor Everyday Load Horizontal Tension.

Tensions in Table Z1 are based on the average temperature of the coldest month as this is when the tension will be highest. High tension reduces self damping of the conductor and may allow excessive bending stress at attachment points due to Aeolian vibration. Aeolian vibration occurs when low speed laminar wind flows perpendicular to the conductor causing low amplitude (typically one or two diameters) vibration.

The maximum allowable tension is a function of the material in the conductor, the type of clamps and terrain. For example AAC conductor base tension limit is 18% CBL. This increases to 20.5% with helical formed ties with armour rods. If fully damped as well then the tension limit increases to 27%CBL.

3.8.3 Creep Allowance

Conductor creep allowances to be applied:

- No allowance ≤10%CBL stringing tension
- Subtract 15ºC for AAC >10%CBL stringing tension
- Subtract 12ºC ACSR >10%CBL stringing tension.

3.8.4 Engineering Notes

3.8.4.1 Mean Equivalent Span

The mean equivalent span (MES), also known as the equivalent span or the ruling span (RS), is defined as that level dead-end span whose tension behaves identically to the tension in every span of a series of suspension spans under the same loading conditions. Every 1km or less a strain structure should be installed. The ruling span concept can only model a uniformly loaded section, that is, where identical wind and/or ice span exists on all spans in the section.

It is assumed that the attachment point is free to move along the line and there is adequate travel to equalize the tension in adjacent spans without transferring any longitudinal load onto the structure. In general, spans shorter than the ruling span tend to sag more than predicted whilst spans longer than the ruling span sag less than predicted at temperatures above the stringing temperature (assuming that the tensions were equal at the time of stringing conductor).

The MES for a section between strain structures is calculated using:

$$L_r = \sqrt{\frac{\sum_{i=1}^{n} L_i^3}{\sum_{i=1}^{n} L_i}} \quad \text{for level spans} \qquad (1)$$

$$L_r = \sqrt{\frac{\sum_{i=1}^{n} \frac{L_i^4}{I_i}}{\sum_{i=1}^{n} I_i}} \quad \text{for inclined spans} \qquad (2)$$

Where:

$I_i = \sqrt{L_i^2 + h_i^2}$ = the chord length between the supports of span i

L_i = the horizontal span length of span i

h_i = the support height difference of span i

n = the number of spans in the section between strain structures

For a single level, dead-end span the ruling span is $L_r = L$. However, for a single inclined dead-end span, $L_r = L^2/I$.

It is important to ensure the smallest span shall not be less than half the MES, and the largest span shall not be more than double the MES. Otherwise there may be excessive sag and reduced clearance in the longer spans.

Consider an example where the spans are 75, 75, 75 and 100m on flat ground. The MES is then:-

MES = $\sqrt{(75^3 + 75^3 + 75^3 + 100^3)/(75 + 75 + 75 + 100)}$

MES = 83.5m

3.8.4.2 Catenary Curve

A flexible, inelastic conductor with constant load (W per unit of arc length) suspended between supports assumes the shape of a catenary is given by:

$$y = C(\cosh(x/C) - 1) \qquad (3)$$

where:

y is the vertical height of the catenary at the horizontal distance x

H is horizontal tension

the catenary constant, C = H/W 4

An approximation of the catenary is the parabola which uses a constant load (W per horizontal unit length):-

$y = x^2/2C$ 5

For span lengths less than about 0.7 C, or sags less than about 9% of the span length, the difference in sag between the catenary and the parabola is less than 1%.

3.8.4.3 Slack

The difference in length between the straight horizontal distance between supports and the distance along the catenary is known as the slack:-

$Slack = L^3/24C^2$ 6

where:

L is span length

C is catenary constant

Consider an example where Neptune conductor is strung at 10% CBL which is 2.47kN on a 75m span. Neptune is 0.433kg/m which is 4.26N/m after multiplying by acceleration due to gravity. The catenary constant is:-

C = 2470/4.26

C = 581m

Slack is then

$Slack = 75^3/24 \times 581^2$

Slack = 52mm

Conductor tension as a function of slack:-

$H = W\sqrt{(L^3/24Slack)}$ 7

Conductor sag as a function of slack:-

$D = L^2/8C$ 8

Where:

D is sag

Continuing the example the sag is then:-

$D = 75^2/8 \times 581$

$D = 1.21\text{m}$ 9

From these equations it can be seen that a small change in slack will result in a large change in tension and also sag.

3.8.4.4 Sag and Tension

Conductor tension and sag are related by the following equation: -

$H = WL^2/8D$ 10

The unstretched conductor length for a given span is S_0 and the stretched length is S. They are related by the following formula:-

$S_0 = S / (1 + H/EA + \alpha t + \varepsilon)$ 11

Where:

E is the modulus of elasticity for the conductor

A is the area of the conductor

α is the thermal coefficient of expansion

ε is conductor permanent stretch or creep

Note that the first term in the denominator is elastic stretch. The second term is thermal elongation and the last term is permanent elongation.

The stretched conductor length for a catenary is:-

$S = 2C \sinh (L/2C)$ 12

For a parabola the stretched conductor length is:-

$S = L + L^3/24C^2$ 13

Note that $L^3/24C^2$ is conductor slack.

The equation for unstretched conductor length is used to determine conductor tension at different conditions. This is also known as tension change or change of state equation.

$$\frac{S_i}{1 + \frac{H_i}{EA} + \alpha t_i + \varepsilon_i} = \frac{S_f}{1 + \frac{H_f}{EA} + \alpha t_f + \varepsilon_f} \qquad 14$$

The subscript “i” denotes initial condition and “f” denotes final condition. Typically the initial condition is the known stringing or everyday condition. The final condition may be maximum temperature, maximum wind condition or some other condition of interest. Using the parabolic equation, the final tension requires solution of the following equation:-

$H_f^3 + aH_f^2 - b = 0$ 15

Where:

$$a = EA\left(\frac{W_i^2 L_r^2}{24H_i^2} + \alpha\left(t_f - t_i\right) + \left(\varepsilon_f - \varepsilon_i\right)\right) - H_i$$

$$b = \frac{EAW_f^2 L_r^2}{24}$$

This equation is usually solved iteratively.

3.9 Poles

3.9.1 General

In suburban areas, overhead lines are installed along the rear property boundaries so that they are out of sight from the front road access. Due to the restricted access of backyards and the 2003 bush fire, timber poles are not used for new designs. Due to its light weight, composite fibre is preferred for hand standing in backyards. Concrete is used for higher loads, where there is good access and also in fire prone areas.

3.9.2 Pole Selection

For LV distribution lines, 9.5m long poles are used. 11m long poles are used for extra clearance, or for tee offs. Refer to drawing 391-743-03 for 9.5m and 11m LV concrete pole general assembly. Both of these poles are type 1 - LV general assemblies.

LV composite fibre service poles are used in backyards. Refer to drawing 391-740-15 for 9.5m 8kN composite LV Utility pole and drawing 391-740-12 for 9.3m 4kN composite Service pole.

12.5m long concrete poles are used for HV (22kV and 11kV). Refer to drawing D201-0038 for 12.5m HV pole types and application. Refer to drawing 391-743-04 for HV 12.5m 8kN types 1, 2 & 3 concrete pole casting details. Note that type 1 is for general application including gas switch installations; type 2 is for Air break switch, Recloser and U/G-O/H termination; and type 3 is for pole substation application.

14m or 15.5m poles are used for HV where more clearance is required. These poles are 8kN type 1 and concrete pole general assembly details are given on drawing 391-743-08.

3.9.3 Pole Data

Previously all poles were given a working stress and ultimate rating. The designation used mostly has been the maximum working rating as maximum working wind was used to determine required strength. The new limit state approach to determine strength is different. Limit state strength is determined by multiplying ultimate strength by the applicable strength reduction factor. Poles are still referred to by their maximum working rating on the drawings. This may be changed to limit state strength in the future.

3.9.4 Foundation

Standard sinking depth of poles is based on 10% length plus 600mm which results in foundation depths between 1.6m and 2.3m.

Foundations for average and poor soils are provided. Soil properties may be assessed using AS1726 – 1993, Geotechnical site investigations. The key geotechnical property of cohesive soils is undrained shear strength which may be assessed in the field using the following table 16 extracted from AS1726 (Table A4).

Term	Undrained shear strength kPa	Field guide to consistency
Very soft	≤12	Exudes between the fingers when squeezed in hand
Soft	>12 ≤25	Can be moulded by light finger pressure
Firm	>25 ≤50	Can be moulded by strong finger pressure
Stiff	>50 ≤100	Cannot be moulded by fingers Can be indented by thumb
Very stiff	>100 ≤200	Can be indented by thumb nail
Hard	>200	Can be indented with difficulty by thumb nail

Foundations for loose ground such as sand, wet ground, fill and rock require special foundation design.

For standard sinking depths on drawing D204-0014 and D204-0017and 600mm diameter auger, in hard ground (i.e. 150kPa, unit weight 18kN/m3) foundation capacity exceeds pole ultimate rating for all poles except the 9.5m long poles. For 9.5m long poles foundation capacity is 15kN.

3.9.5 Pole Tip Loads

TABLE 16. POLE TIP LOADS

Type	Length (m)	Description	Drawing Number	Application	Pole Strength Maximum Working (kN)	Pole Strength Ultimate (kN)	Pole Strength Limit State (kN)	Foundation *Average Soil* Depth (m)	Foundation *Average Soil* Capacity (kN)	Foundation *Poor Soil* Depth (m)	Foundation *Poor Soil* Capacity (kN)
Composite fibre	9.5	TWO PIECE	391-740-15	LV backyard	8	32	Ult. 22.4 Serv. 9.6	1.6	10	2.1	9.9
	9.3	TWO PIECE	391-740-12	LV backyard	4	16	Ult. 11.2 Serv. 4.8	1.6	10	2.1	9.9
Concrete	9.5	TYPE 1, SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-03	LV standard	8	16	12.6	1.6	10	2.1	9.9
	9.5	TYPE 1, SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-03	LV stronger	12	24	18.8	2.0	17.6	2.6	17.4
	11	TYPE 1, SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-03	LV taller	8	16	12.3	1.8	11.5	2.3	10.6
	12.5	TYPE 1, SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-04	HV standard	8	16	11.9	2	13.1	2.5	11.3
	12.5	TYPE 1, SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-04	HV stronger	12	24	18.8	2.3	18.5	3.0	17.7
	12.5	TYPE 2, SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-04	HV Air breaker, U/G-O/H term.	8	16	18.8	2.2	16.6	2.7	13.7
	12.5	TYPE 3, SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-04	HV Transformer	8	16	18.8	2.5	26.9	3.0	21.1
	14	TYPE 1SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-08	HV taller	8	16	11.5	2.15	13.9	2.8	13.2
	15.5	TYPE 1 SPUN REINFORCED CONCRETE, C/W BUTT PLATE EARTH	391-743-08	HV tallest	8	16	11.2	2.3	14.7	3	14.0

Notes:

1. Safety factor on working stress to obtain ultimate is 2 for concrete and 4 for composite fibre.
2. Strength reduction factor for ultimate strength limit state is 0.9 for concrete and 0.75 for composite fibre.
3. Strength reduction factor for serviceability limit state is 0.3 for composite fibre. There is no serviceability limit for concrete poles.
4. Serviceability limit tip load is 9.6kN for 9.5m composite fibre pole.
5. Pole limit state rating already includes allowance for windage of pole (1300Pa) plus 10% for cross arms.
6. Auger diameter is 600mm for all foundations except transformer pole which has 750mm diameter. If smaller augers are used, then foundation strengths will be reduced.
7. Concrete or compacted fine crushed rock backfill.
8. *Average Soil* has shear strength 100kPa, unit weight 18kN/m^3.
9. *Poor soil* has shear strength 50kPa, unit weight 18kN/m^3.
10. Foundation capacity applied to pole tip was calculated using Brinch Hansen method.
11. Strength reduction factor applied for soil is 0.6.
12. The top 200mm of soil is allocated no bearing strength.
13. Foundation depths in *average soil* from drawing D204-0014 and D204-0017.
14. Refer to Section 3.5.2 for details on Serviceability and Ultimate limit states.

3.9.6 Pole Rules

If pole tip load increases by more than 1kN then the pole must be inspected, mechanically tested, or replaced.

Generally, service line loads that are slack strung (i.e. less than 2.5%) can be ignored. In commercial/industrial areas with multiple larger size service lines, the service line loads must be included in the design.

There is no need to include wind on cross arms and small accessories as an allowance has been made in the limit state tip load. However, wind loads on large accessories must be included (i.e. equal to or greater than 100kVA transformers).

3.9.7 Pole–Mounted Pant

For general guidance on selecting an appropriate type of switch for application on the 11 kV and 22 kV overhead distribution network, refer to Appendix 1.

Refer to table 17 below for data on pole mounted plant that can be used to calculate wind loads.

TABLE 17. POLE MOUNTED PLANT

Plant Item	Horizontal Offset from pole axis (mm)	Face Area (m^2)	Side Area (m^2)	Weight (kg)	Attachment Height (m)
100kVA TRFR	495	0.892	0.535	765	7.4
100A REG	330	2.106	1.264	1956	-
200kVA TRFR	412	1.029	0.617	1055	7.4
200A REG	330	2.38	1.428	2836	-
315kVA TRFR	439	1.206	0.724	1425	7.7
500kVA TRFR	480	1.243	0.75	1970	7.4
NGK Gas Switch	650	0.53	0.81	110	8.7
Schneider Recloser	690	0.43	0.4	128	6.7
ABB Air Break Switch	0	0.59	0.41	100	10

Notes:

1. Rural transformer attachment height is 7.55m from drawing D203-0001.

2. TRFR is abbreviation for transformer.
3. REG is abbreviation for regulator.
4. Horizontal offset from pole axis is the horizontal distance from pole axis for the line of action of the transformer weight.
5. Face area is perpendicular to line.
6. Side area is parallel to line.
7. NGK Gas Switch large side area is due to insulators and arresters.
8. Weight for ABB Air Break Switch is approximate.

3.9.8 Worked Examples Pole Tip Loads

The following worked examples show how to calculate the ultimate limit state tip loads for poles. Ultimate limit state stay load calculation is also included. Note that all designs are 22kV but can also be used at 11kV.

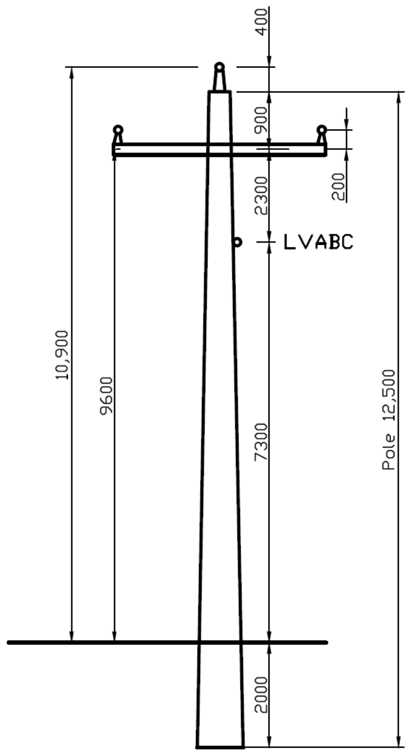
The coordinate system used is:-

- Longitudinal along the line conductors
- Transverse at 90° to the line
- Vertical

3.9.8.1 Worked Example 1 – HV and LVABC in-line 0° deviation

A dimensioned elevation of the pole is shown in Figure 3. The pole has no stay wires and 75m spans on either side. Pole tip load is calculated for the case where wind blows transverse to line.

FIGURE 3. ELEVATION



Example 1 - Calculate tip load for pole based on limit state.

Units

$N \equiv newton$ $kN \equiv 10^3 \cdot newton$ Define Newton and kiloNewton abbreviations

INPUT DATA	22kV ActewAGL single circuit 12.5m/8kN max working concrete pole, composite cross arm, horizontal circuit, 19/3.25mm AAC Neptune, underbuilt 150mm2 LVABC.
Pole	Pole dwg A2-392-41-10 but with LVABC also.
$d_{pt} \equiv 250 \cdot mm$	Pole tip diameter. 250mm
$taper \equiv 15 \cdot mm \cdot m^{-1}$	Taper of pole with height
$h_4 \equiv 9.8 \cdot m$	HV Lowest phase/s attachment height above ground
$n_4 \equiv 2$	Number of conductors at lowest phase height
$h_3 \equiv 0 \cdot m$	HV Middle phase/s attachment height above ground
$n_3 \equiv 0$	Number of conductors at middle phase height
$h_2 \equiv 10.9 \cdot m$	HV Top phase/s attachment height above ground
$n_2 \equiv 1$	Number of conductors at top phase height
$h_1 \equiv 7.3 \cdot m$	LV attachment height above ground
$n_1 \equiv 1$	Number of LV wires
$L \equiv 12.5 \cdot m$	Pole length
$f \equiv 2.0 \cdot m$	Foundation depth
$h_s \equiv 7.1 \cdot m$	Stay attachment height above ground
$R_n \equiv 16 \cdot kN$	Rated ultimate tip load

Wind Pressure, Wind Span & Deviation

$P_w \equiv 900 \cdot Pa$	Wind pressure on conductors
$P_{wp} \equiv 1300 \cdot Pa$	Wind pressure on pole
$windspan \equiv 75 \cdot m$	Wind span of conductors
$wtspan \equiv 75 \cdot m$	Weight span
$\delta \equiv 0 \cdot deg$	Deviation angle
HV Conductor and LVABC	Neptune is at 5% edt. 150mm2 LVABC edt is 8% CBL
$d_e \equiv 45.6 \cdot mm$	LVABC diameter. 150mm2 LVABC is 45.6mm
$d_c \equiv 16.3 \cdot mm$	Conductor diameter, Neptune is 26.3mm
$\tau_e \equiv 14.64 \cdot kN$	LVABC tension at ultimate wind. 14.64kN @900Pa
$\tau_{ee} \equiv 6.72 \cdot kN$	LVABC tension at everyday. 6.72kN
$\tau_c \equiv 4.2 \cdot kN$	Conductor tension at ultimate wind, 4.2kN @ 15C & 900Pa
$\tau_{ce} \equiv 1.24 \cdot kN$	Conductor tension at everyday, 1.24kN @ 15C & no wind

Load Factors & Strength Reduction Factors

$\gamma_{1u} \equiv 1.25$ Load factor on ultimate conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_{1e} \equiv 1.1$ Load factor on everyday conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_{2} \equiv 1.25$ Load factor for conductor vertical loads, 1.25 for ultimate & everyday, 1.5 for maintenance.

$\gamma_{3} \equiv 1.1$ Load factor for structure self weight. 1.1

$\phi \equiv 0.9$ Strength reduction factor for pole. 0.9 for concrete

Weights

$wt_p \equiv 1750 \cdot kg$ Pole weight.

Stay

Stay is 7/3.25mm SC/GZ with 68.7kN CBL.
Limit state strength 55kN, Max working rating 27.5kN.

$\theta \equiv 45 \cdot deg$ Stay angle to horizontal

CALCULATIONS

$h_0 := L - f$ Pole height above ground

$h_0 = 10.5\,m$

$d_p := d_{pt} + taper \cdot \frac{h_0}{2}$ Average diameter of pole above ground

$d_p = 0.329\,m$

Pole Ultimate Tip Load

$F_{wp} := P_{wp} \cdot d_p \cdot h_0$ Force on pole due to wind pressure

$F_{wp} = 4.487 \cdot kN$

$F_{wpt} := \frac{F_{wp} \cdot \frac{h_0}{2}}{h_0}$ Pole windage represented as a tip load

$F_{wpt} = 2.244 \cdot kN$

$F_1 := n_1 \cdot P_w \cdot d_e \cdot windspan$ Force on pole due to LVABC/s

$F_1 = 3.078 \cdot kN$

$F_2 := n_2 \cdot P_w \cdot d_c \cdot windspan$ Force on pole due to top conductor/s

$F_2 = 1.1 \cdot kN$

$F_3 := n_3 \cdot P_w \cdot d_c \cdot windspan$ Force on pole due to middle conductor/s

$F_3 = 0 \cdot kN$

$F_4 := n_4 \cdot P_w \cdot d_c \cdot windspan$ Force on pole due to lowest conductor/s

$F_4 = 2.201 \cdot kN$

$$TL \cdot h_0 = F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + F_{wp} \cdot \frac{h_0}{2}$$

Equation for pole ground line bending moment

$$TL := \frac{F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + \frac{1}{2} \cdot F_{wp} \cdot h_0}{h_0}$$

Tip load for pole

$TL = 7.58 \cdot kN$

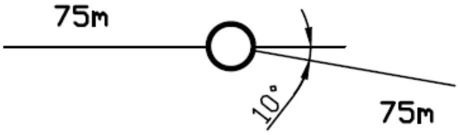
$C_{tip} = \phi \cdot R_n$ Pole tip load limit state strength

$C_{tip} = 14.4 \cdot kN$

3.9.8.2 Worked Example 2 – HV and LVABC 10° deviation

A plan view of the pole is shown in Figure 2 with the spans on either side. Figure 4 is a dimensioned elevation of the pole. Pole tip load and stay load is calculated for case where wind blows transverse to line.

FIGURE 4. PLAN



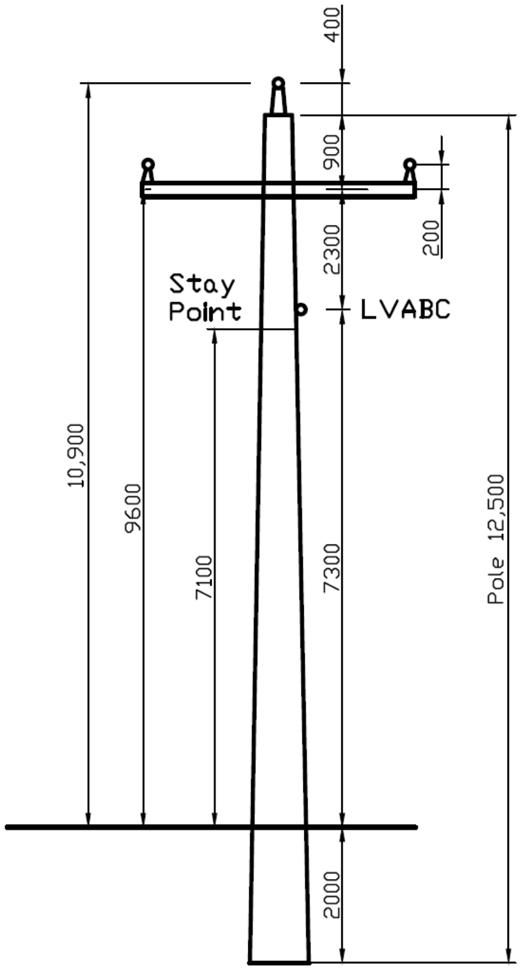


FIGURE 5. ELEVATION

Example 2 - Calculate tip load for pole based on limit state.

Units

$N \equiv newton$ $kN \equiv 10^{3} \cdot newton$ Define Newton and kiloNewton abbreviations

INPUT DATA 22kV ActewAGL single circuit 12.5m/8kN max working concrete pole, composite cross arm, horizontal circuit, 19/3.25mm AAC Neptune, underbuilt 150mm2 LVABC.

Pole Pole dwg A2-392-41-10 but with LVABC also.

$d_{pt} \equiv 250 \cdot mm$	Pole tip diameter. 250mm
$taper \equiv 15 \cdot mm \cdot m^{-1}$	Taper of pole with height
$h_4 \equiv 9.8 \cdot m$	HV Lowest phase/s attachment height above ground
$n_4 \equiv 2$	Number of conductors at lowest phase height
$h_3 \equiv 0 \cdot m$	HV Middle phase/s attachment height above ground
$n_3 \equiv 0$	Number of conductors at middle phase height
$h_2 \equiv 10.9 \cdot m$	HV Top phase/s attachment height above ground
$n_2 \equiv 1$	Number of conductors at top phase height
$h_1 \equiv 7.3 \cdot m$	LV attachment height above ground
$n_1 \equiv 1$	Number of LV wires
$L \equiv 12.5 \cdot m$	Pole length
$f \equiv 2.0 \cdot m$	Foundation depth
$h_s \equiv 7.1 \cdot m$	Stay attachment height above ground
$R_n \equiv 16 \cdot kN$	Rated ultimate tip load

Wind Pressure, Wind Span & Deviation

$P_w \equiv 900 \cdot Pa$	Wind pressure on conductors
$P_{wp} \equiv 1300 \cdot Pa$	Wind pressure on pole
$windspan \equiv 75 \cdot m$	Wind span of conductors
$wtspan \equiv 75 \cdot m$	Weight span
$\delta \equiv 10 \cdot deg$	Deviation angle

HV Conductor and LVABC Neptune is at 5% edt. 150mm2 LVABC edt is 8% CBL

$d_e \equiv 45.6 \cdot mm$	LVABC diameter. 150mm2 LVABC is 45.6mm
$d_c \equiv 16.3 \cdot mm$	Conductor diameter, Neptune is 26.3mm
$\tau_e \equiv 14.64 \cdot kN$	LVABC tension at ultimate wind. 14.64kN @900Pa
$\tau_{ee} \equiv 6.72 \cdot kN$	LVABC tension at everyday. 6.72kN
$\tau_c \equiv 4.2 \cdot kN$	Conductor tension at ultimate wind, 4.2kN @ 15C & 900Pa
$\tau_{ce} \equiv 1.24 \cdot kN$	Conductor tension at everyday, 1.24kN @ 15C & no wind

Load Factors & Strength Reduction Factors

$\gamma_{1u} \equiv 1.25$	Load factor on ultimate conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.
$\gamma_{1e} \equiv 1.1$	Load factor on everyday conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.
$\gamma_{2} \equiv 1.25$	Load factor for conductor vertical loads, 1.25 for ultimate & everyday, 1.5 for maintenance.
$\gamma_{3} \equiv 1.1$	Load factor for structure self weight. 1.1
$\phi \equiv 0.9$	Strength reduction factor for pole. 0.9 for concrete

Weights

$wt_p \equiv 1750 \cdot kg$ — Pole weight.

Stay

Stay is 7/3.25mm SC/GZ with 68.7kN CBL.
Limit state strength 55kN, Max working rating 27.5kN.

$\theta \equiv 45 \cdot deg$ — Stay angle to horizontal

CALCULATIONS

$h_0 := L - f$ — Pole height above ground

$h_0 = 10.5\,m$

$d_p := d_{pt} + taper \cdot \frac{h_0}{2}$ — Average diameter of pole above ground

$d_p = 0.329\,m$

Pole Ultimate Tip Load

$F_{wp} := P_{wp} \cdot d_p \cdot h_0$ — Force on pole due to wind pressure

$F_{wp} = 4.487 \cdot kN$

$F_{wpt} := \frac{F_{wp} \cdot \frac{h_0}{2}}{h_0}$ — Pole windage represented as a tip load

$F_{wpt} = 2.244 \cdot kN$

$F_1 := n_1 \cdot \left(P_w \cdot d_e \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_e \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to LVABC/s

$F_1 = 6.268 \cdot kN$

$F_2 := n_2 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to top conductor/s

$F_2 = 2.015 \cdot kN$

$F_3 := n_3 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to middle conductor/s

$F_3 = 0 \cdot kN$

$$F_4 := n_4 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$$

Force on pole due to lowest conductor/s

$$F_4 = 4.031 \cdot kN$$

$$TL \cdot h_0 = F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + F_{wp} \cdot \frac{h_0}{2}$$

Equation for pole ground line bending moment

$$TL := \frac{F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + \frac{1}{2} \cdot F_{wp} \cdot h_0}{h_0}$$

Tip load for pole

$$TL = 12.456 \cdot kN$$

$$C_{tip} \equiv \phi \cdot R_n$$

Pole tip load limit state strength

$$C_{tip} = 14.4 \cdot kN$$

Stay Tension

$$H_s := \frac{F_4 \cdot h_4 + F_3 \cdot h_3 + F_2 \cdot h_2 + F_1 \cdot h_1 + \frac{1}{2} \cdot F_{wp} \cdot h_0}{h_s}$$

Horizontal force at stay point on pole.

$$H_s = 18.42 \cdot kN$$

$$\tau_s := \frac{H_s}{\cos(\theta)}$$

Stay tension. Stay capacity 55kN.

$$\tau_s = 26.05 \cdot kN$$

3.9.8.3 Worked Example 3 – HV and LVABC 60° deviation

A plan view of the pole is shown in Figure 6 with the spans on either side and the location of the stay wire. Figure 5 is a dimensioned elevation of the pole. Pole tip load and stay load is calculated for the case where wind blows from stay side of pole.

FIGURE 6. PLAN

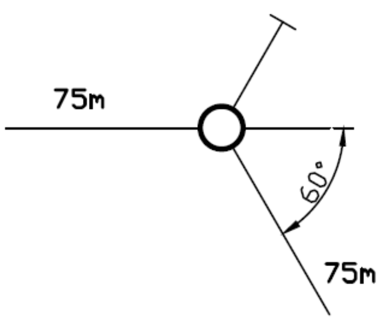
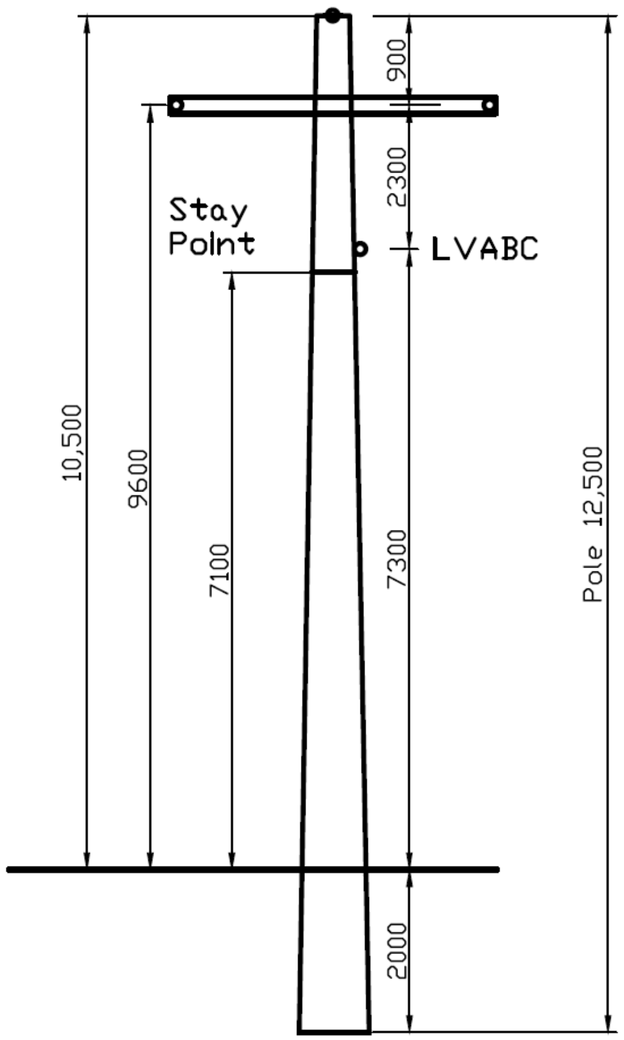


FIGURE 7. ELEVATION



Example 3 - Calculate tip load for pole based on limit state.

Units

$N \equiv newton$	$kN \equiv 10^{3} \cdot newton$	Define Newton and kiloNewton abbreviations

INPUT DATA	22kV ActewAGL single circuit 12.5m/8kN max working concrete pole, composite cross arm, horizontal circuit, 19/3.25mm AAC Neptune, underbuilt 150mm2 LVABC.
Pole	Pole dwg A2-392-41-11 but with LVABC also.
$d_{pt} \equiv 250 \cdot mm$	Pole tip diameter. 250mm
$taper \equiv 15 \cdot mm \cdot m^{-1}$	Taper of pole with height
$h_4 \equiv 9.6 \cdot m$	HV Lowest phase/s attachment height above ground
$n_4 \equiv 2$	Number of conductors at lowest phase height
$h_3 \equiv 0 \cdot m$	HV Middle phase/s attachment height above ground
$n_3 \equiv 0$	Number of conductors at middle phase height
$h_2 \equiv 10.9 \cdot m$	HV Top phase/s attachment height above ground
$n_2 \equiv 1$	Number of conductors at top phase height
$h_1 \equiv 7.3 \cdot m$	LV attachment height above ground
$n_1 \equiv 1$	Number of LV wires
$L \equiv 12.5 \cdot m$	Pole length
$f \equiv 2.0 \cdot m$	Foundation depth
$h_s \equiv 7.1 \cdot m$	Stay attachment height above ground
$R_n \equiv 16 \cdot kN$	Rated ultimate tip load

Wind Pressure, Wind Span & Deviation

$P_w \equiv 900 \cdot Pa$	Wind pressure on conductors
$P_{wp} \equiv 1300 \cdot Pa$	Wind pressure on pole
$windspan \equiv 75 \cdot m$	Wind span of conductors
$wtspan \equiv 75 \cdot m$	Weight span
$\delta \equiv 60 \cdot deg$	Deviation angle
HV Conductor and LVABC	Neptune is at 5% edt. 150mm2 LVABC edt is 8% CBL
$d_e \equiv 45.6 \cdot mm$	LVABC diameter. 150mm2 LVABC is 45.6mm
$d_c \equiv 16.3 \cdot mm$	Conductor diameter, Neptune is 26.3mm
$\tau_e \equiv 14.64 \cdot kN$	LVABC tension at ultimate wind. 14.64kN @900Pa
$\tau_{ee} \equiv 6.72 \cdot kN$	LVABC tension at everyday. 6.72kN
$\tau_c \equiv 4.2 \cdot kN$	Conductor tension at ultimate wind, 4.2kN @ 15C & 900Pa
$\tau_{ce} \equiv 1.24 \cdot kN$	Conductor tension at everyday, 1.24kN @ 15C & no wind

Load Factors & Strength Reduction Factors

$\gamma_{1u} \equiv 1.25$ — Load factor on ultimate conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_{1e} \equiv 1.1$ — Load factor on everyday conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_{2} \equiv 1.25$ — Load factor for conductor vertical loads, 1.25 for ultimate & everyday, 1.5 for maintenance.

$\gamma_{3} \equiv 1.1$ — Load factor for structure self weight. 1.1

$\phi \equiv 0.9$ — Strength reduction factor for pole. 0.9 for concrete

Weights

$wt_p \equiv 1750 \cdot kg$ — Pole weight.

Stay

Stay is 7/3.25mm SC/GZ with 68.7kN CBL.
Limit state strength 55kN, Max working rating 27.5kN.

$\theta \equiv 45 \cdot deg$ — Stay angle to horizontal

CALCULATIONS

$h_0 := L - f$ — Pole height above ground

$h_0 = 10.5\,m$

$d_p := d_{pt} + taper \cdot \frac{h_0}{2}$ — Average diameter of pole above ground

$d_p = 0.329\,m$

Pole Ultimate Tip Load

$F_{wp} := P_{wp} \cdot d_p \cdot h_0$ — Force on pole due to wind pressure

$F_{wp} = 4.487 \cdot kN$

$F_{wpt} := \frac{F_{wp} \cdot \frac{h_0}{2}}{h_0}$ — Pole windage represented as a tip load

$F_{wpt} = 2.244 \cdot kN$

$F_1 := n_1 \cdot \left(P_w \cdot d_e \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_e \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to LVABC/s

$F_1 = 21.378 \cdot kN$

$F_2 := n_2 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to top conductor/s

$F_2 = 6.35 \cdot kN$

$F_3 := n_3 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to middle conductor/s

$F_3 = 0 \cdot kN$

$$F_4 := n_4 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$$

Force on pole due to lowest conductor/s

$$F_4 = 12.7 \cdot kN$$

$$TL \cdot h_0 = F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + F_{wp} \cdot \frac{h_0}{2}$$

Equation for pole ground line bending moment

$$TL := \frac{F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + \frac{1}{2} \cdot F_{wp} \cdot h_0}{h_0}$$

Tip load for pole

$$TL = 35.311 \cdot kN$$

$$C_{tip} \equiv \phi \cdot R_n$$

Pole tip load limit state strength

$$C_{tip} = 14.4 \cdot kN$$

Stay Tension

$$H_s := \frac{F_4 \cdot h_4 + F_3 \cdot h_3 + F_2 \cdot h_2 + F_1 \cdot h_1 + \frac{1}{2} \cdot F_{wp} \cdot h_0}{h_s}$$

Horizontal force at stay point on pole.

$$H_s = 52.22 \cdot kN$$

$$\tau_s := \frac{H_s}{\cos(\theta)}$$

Stay tension. Stay capacity 55kN.

$$\tau_s = 73.85 \cdot kN$$

Note that the tip load on the pole for 60° deviation at ultimate wind is 35.3kN which exceeds the pole limit state capacity of 14.4kN. Consequently, staying is required. The stay load of 73.9kN exceeds the stay limit state strength of 55kN. Consequently, two stays are required.

For a 75m span of Neptune under ultimate wind the maximum deviation angle is 14° for an unstayed 8kN maximum working pole. i.e. the pole must be stayed for deviation angles greater than 14°.

3.9.8.4 Worked Example 4 – Pole Transformer

A plan view of the pole is shown in Figure 6 with the span on one side and the stay on the other. Figure 7 is a dimensioned elevation of the pole. Two cases are considered:-

- Transverse wind
- Longitudinal wind

FIGURE 8. PLAN

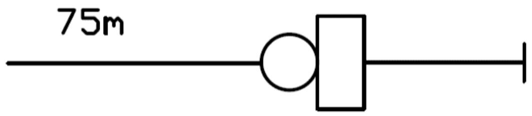
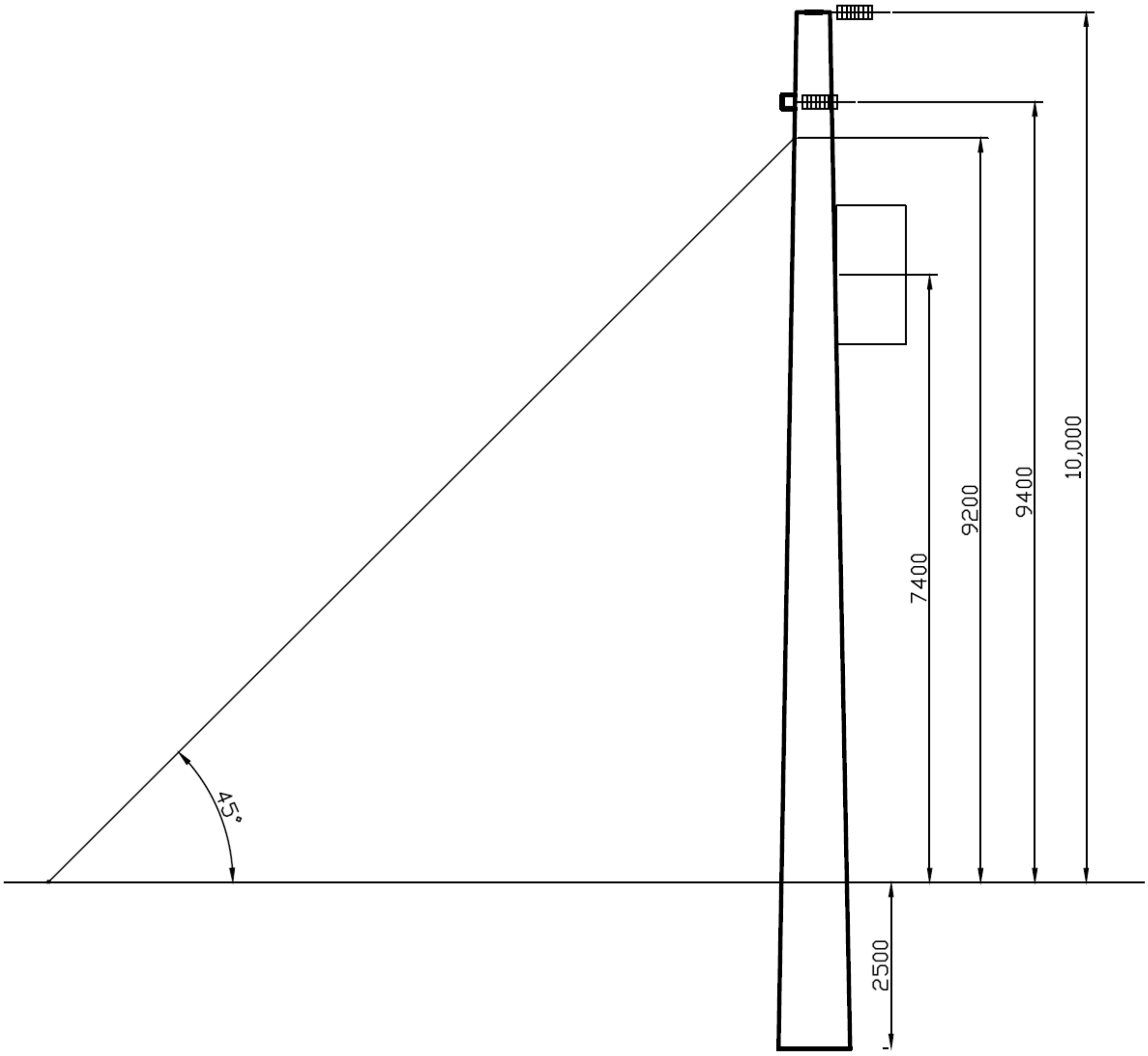


FIGURE 9. ELEVATION



Example 4a - Transverse wind pole tip load calculation based on AS7000 limit state.

Units

$N \equiv newton$ $kN \equiv 10^{3} \cdot newton$	Define Newton and kiloNewton abbreviations

INPUT DATA	22kV ActewAGL 500kVA transformer, 12.5m/12kN maximum working concrete pole. Dwg A3-392-61-04.
Pole	Pole substation drawing A2-392-41-04.
$d_{pt} \equiv 300 \cdot mm$	Pole tip diameter.
$taper \equiv 15 \cdot mm \cdot m^{-1}$	Taper of pole with height
$h_4 \equiv 9.4 \cdot m$	HV Lowest phase/s attachment height above ground
$n_4 \equiv 2$	Number of conductors at lowest phase height
$h_3 \equiv 0 \cdot m$	HV Middle phase/s attachment height above ground
$n_3 \equiv 0$	Number of conductors at middle phase height
$h_2 \equiv 10.0 \cdot m$	HV Top phase/s attachment height above ground
$n_2 \equiv 1$	Number of conductors at top phase height
$h_1 \equiv 0$	LV attachment height above ground
$n_1 \equiv 0$	Number of LV conductors
$L \equiv 12.5 \cdot m$	Pole length
$f \equiv 2.5 \cdot m$	Foundation depth
$R_n \equiv 24 \cdot kN$	Rated ultimate tip load
Wind Pressure, Wind Span & Deviation	
$P_w \equiv 900 \cdot Pa$	Wind pressure on conductors
$P_{wp} \equiv 1300 \cdot Pa$	Wind pressure on pole
$P_{wtx} \equiv 2000 \cdot Pa$	Wind pressure on transformer
$windspan \equiv 75 \cdot m$	Wind span of conductors
$wtspan \equiv 75 \cdot m$	Weight span
$\delta \equiv 0 \cdot deg$	Deviation angle
HV Conductor and LV	Neptune is at 5% CBL edt. 150mm2 LVABC is at 8% CBL edt
$d_e \equiv 45.6 \cdot mm$	LV diameter. 150mm2 LVABC 45.6mm
$d_c \equiv 16.3 \cdot mm$	HV Conductor diameter, Neptune is 16.3mm
$\tau_e \equiv 14.64 \cdot kN$	LV tension at maximum wind. 150mm2 LVABC 14.64kN @ 900Pa
$\tau_c \equiv 4.2 \cdot kN$	HV Conductor tension at maximum wind, 4.2kN @ 15C & 900Pa

Stay Stay is 7/3.25mm SC/GZ with 68.7kN CBL. Limit state strength 55kN, Max working rating 27.5kN.

$\theta \equiv 45 \cdot deg$ Stay angle to horizontal

$h_s \equiv 9.2 \cdot m$ Height of stay attachment point

Transformer - 500kVA

$h_5 \equiv 7.4 \cdot m$ Transformer height above ground

$x_5 \equiv 480 \cdot mm$ Horizontal offset from pole axis

$A_{side} \equiv 0.75 \cdot m^2$ Side area parallel to line

$A_{face} \equiv 1.243 \cdot m^2$ Face area perpendicular to line

Load Factors & Strength Reduction Factors

$\gamma_1 \equiv 1.25$ Load factor on conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_2 \equiv 1.25$ Load factor for conductor vertical loads, 1.25 for ultimate & everyday, 1.5 for maintenance

$\gamma_3 \equiv 1.1$ Load factor for structure self weight. 1.1

$\phi \equiv 0.9$ Strength reduction factor for pole. 0.9 for concrete

Weights

$wt_p \equiv 2170 \cdot kg$ Pole weight.

$wt_{tx} \equiv 1970 \cdot kg$ Transformer weight

CALCULATIONS

$h_0 := L - f$ Pole height above ground

$h_0 = 10\,m$

$d_p := d_{pt} + taper \cdot \frac{h_0}{2}$ Average diameter of pole above ground

$d_p = 0.375\,m$

$F_{wp} := P_{wp} \cdot d_p \cdot h_0$ Force on pole due to wind pressure

$F_{wp} = 4.88 \cdot kN$

$F_{wpt} := \frac{F_{wp} \cdot \frac{h_0}{2}}{h_0}$ Pole windage represented as a tip load

$F_{wpt} = 2.44 \cdot kN$

Transverse Ultimate Wind

$F_{wtx} := P_{wtx} \cdot A_{side}$ Windage on transformer

$F_{wtx} = 1.5 \cdot kN$

$F_1 := n_1 \cdot \left(P_w \cdot d_e \cdot windspan + \gamma_1 \cdot 2 \cdot \tau_e \cdot \sin\left(\frac{\delta}{2}\right)\right)$ Force on pole due to LV

$F_1 = 0 \cdot kN$

$F_2 := n_2 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_1 \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ Force on pole due to top conductor/s

$F_2 = 1.1 \cdot kN$

$F_3 := n_3 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_1 \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ Force on pole due to middle conductor/s

$F_3 = 0 \cdot kN$

$F_4 := n_4 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_1 \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ Force on pole due to lowest conductor/s

$F_4 = 2.2 \cdot kN$

$TL_t \cdot h_0 = F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + F_{wp} \cdot \frac{h_0}{2} + F_{wtx} \cdot h_5$ Equation for pole transverse ground line bending moment

$TL_t := \frac{F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + \frac{1}{2} \cdot F_{wp} \cdot h_0 + F_{wtx} \cdot h_5}{h_0}$ Transverse tip load for pole

$TL_t = 6.72 \cdot kN$

$TL_l := \frac{\gamma_2 \cdot g \cdot wt_{tx} \cdot x_5}{L}$ Longitudinal tip load due to transformer weight

$TL_l = 0.927 \cdot kN$

$TL_r := \sqrt{TL_t^2 + TL_l^2}$ Resultant tip load

$TL_r = 6.78 \cdot kN$

$C_{tip} \equiv \phi \cdot R_n$ Pole tip load limit state strength

$C_{tip} = 21.6 \cdot kN$

Vertical Loads

$V_p := \left(\gamma_3 \cdot wt_p + \gamma_2 \cdot wt_{tx}\right) \cdot g$ Factored vertical downloads at base of pole

$V_p = 47.56 \cdot kN$

Example 4b - Longitudinal wind pole tip load calculation based on AS7000 limit state.

Units

$N \equiv newton$	$kN \equiv 10^{3} \cdot newton$	Define Newton and kiloNewton abbreviations

INPUT DATA	22kV ActewAGL 500kVA transformer, 12.5m/12kN maximum working concrete pole. Dwg A3-392-61-04.
Pole	Pole substation drawing A2-392-41-04.
$d_{pt} \equiv 300 \cdot mm$	Pole tip diameter.
$taper \equiv 15 \cdot mm \cdot m^{-1}$	Taper of pole with height
$h_4 \equiv 9.4 \cdot m$	HV Lowest phase/s attachment height above ground
$n_4 \equiv 2$	Number of conductors at lowest phase height
$h_3 \equiv 0 \cdot m$	HV Middle phase/s attachment height above ground
$n_3 \equiv 0$	Number of conductors at middle phase height
$h_2 \equiv 10.0 \cdot m$	HV Top phase/s attachment height above ground
$n_2 \equiv 1$	Number of conductors at top phase height
$h_1 \equiv 0$	LV attachment height above ground
$n_1 \equiv 0$	Number of LV conductors
$L \equiv 12.5 \cdot m$	Pole length
$f \equiv 2.5 \cdot m$	Foundation depth
$R_n \equiv 24 \cdot kN$	Rated ultimate tip load
Wind Pressure, Wind Span & Deviation	
$P_w \equiv 900 \cdot Pa$	Wind pressure on conductors
$P_{wp} \equiv 1300 \cdot Pa$	Wind pressure on pole
$P_{wtx} \equiv 2000 \cdot Pa$	Wind pressure on transformer
$windspan \equiv 75 \cdot m$	Wind span of conductors
$wtspan \equiv 75 \cdot m$	Weight span
HV Conductor and LV	Neptune is at 5% CBL edt. 150mm2 LVABC is at 8% CBL edt
$d_e \equiv 45.6 \cdot mm$	LV diameter. 150mm2 LVABC 45.6mm
$d_c \equiv 16.3 \cdot mm$	HV Conductor diameter, Neptune is 16.3mm
$\tau_e \equiv 14.64 \cdot kN$	LV tension at maximum wind. 150mm2 LVABC 14.64kN @ 900Pa
$\tau_c \equiv 4.2 \cdot kN$	HV Conductor tension at maximum wind, 4.2kN @ 15C & 900Pa,

Stay — Stay is 7/3.25mm SC/GZ with 68.7kN CBL. Limit state strength 55kN, Max working rating 27.5kN.

$\theta \equiv 45 \cdot deg$ — Stay angle to horizontal

$h_s \equiv 9.2 \cdot m$ — Height of stay attachment point

Transformer - 500kVA

$h_5 \equiv 7.4 \cdot m$ — Transformer height above ground

$x_5 \equiv 480 \cdot mm$ — Horizontal offset from pole axis

$A_{side} \equiv 0.75 \cdot m^2$ — Side area parallel to line

$A_{face} \equiv 1.243 \cdot m^2$ — Face area perpendicular to line

Load Factors & Strength Reduction Factors

$\gamma_1 \equiv 1.25$ — Load factor on conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_2 \equiv 1.25$ — Load factor for conductor vertical loads, 1.25 for ultimate & everyday, 1.5 for maintenance

$\gamma_3 \equiv 1.1$ — Load factor for structure self weight. 1.1

$\phi \equiv 0.9$ — Strength reduction factor for pole. 0.9 for concrete

Weights

$wt_p \equiv 2170 \cdot kg$ — Pole weight.

$wt_{tx} \equiv 1970 \cdot kg$ — Transformer weight

CALCULATIONS

$h_0 := L - f$ — Pole height above ground

$h_0 = 10\,m$

$d_p := d_{pt} + taper \cdot \frac{h_0}{2}$ — Average diameter of pole above ground

$d_p = 0.375\,m$

$F_{wp} := P_{wp} \cdot d_p \cdot h_0$ — Force on pole due to wind pressure

$F_{wp} = 4.88 \cdot kN$

$F_{wpt} := \frac{F_{wp} \cdot \frac{h_0}{2}}{h_0}$ — Pole windage represented as a tip load

$F_{wpt} = 2.44 \cdot kN$

Longitudinal Ultimate Wind

$F_{wtx} := P_{wtx} \cdot A_{face}$ Windage on transformer

$F_{wtx} = 2.49 \cdot kN$

$F_{txwt} := g \cdot wt_{tx}$ Vertical load due to transformer weight

$F_{txwt} = 19.32 \cdot kN$

$F_1 := n_1 \cdot \gamma_1 \cdot \tau_\epsilon$ Force on pole due to LV

$F_1 = 0 \cdot kN$

$F_2 := n_2 \cdot \gamma_1 \cdot \tau_c$ Force on pole due to top conductor/s

$F_2 = 5.25 \cdot kN$

$F_3 := n_3 \cdot \gamma_1 \cdot \tau_c$ Force on pole due to middle conductor/s

$F_3 = 0 \cdot kN$

$F_4 := n_4 \cdot \gamma_1 \cdot \tau_c$ Force on pole due to lowest conductor/s

$F_4 = 10.5 \cdot kN$

$$TL \cdot h_0 = F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + F_{wp} \cdot \frac{h_0}{2} + F_{wtx} \cdot h_5$$

Equation for pole longitudinal ground line bending moment

$$TL := \frac{F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + \frac{1}{2} \cdot F_{wp} \cdot h_0 + F_{wtx} \cdot h_5 + F_{txwt} \cdot x_5}{h_0}$$

Longitudinal tip load for pole

$TL = 20.32 \cdot kN$

$C_{tip} \equiv \phi \cdot R_n$ Pole tip load limit state strength

$C_{tip} = 21.6 \cdot kN$

Stay Tension

$$H_s := \frac{F_4 \cdot h_4 + F_3 \cdot h_3 + F_2 \cdot h_2 + F_1 \cdot h_1 + \frac{1}{2} \cdot F_{wp} \cdot h_0 + F_{wtx} \cdot h_5 + \gamma_2 \cdot F_{txwt} \cdot x_5}{h_s}$$

Horizontal force at stay point on pole.

$H_s = 22.3 \cdot kN$

$$\tau_s := \frac{H_s}{\cos(\theta)}$$

Stay tension. Limit state strength 55kN.

$\tau_s = 31.6 \cdot kN$

3.9.8.5 Worked Example 5 –HV in-line 90° tee off

A plan view of the pole is shown in Figure 8 with 75m spans on either side and the stay opposite the tee off. Figure 10 is a dimensioned elevation of the pole. Pole tip load is calculated for wind blowing from stay side of pole.

FIGURE 10. PLAN

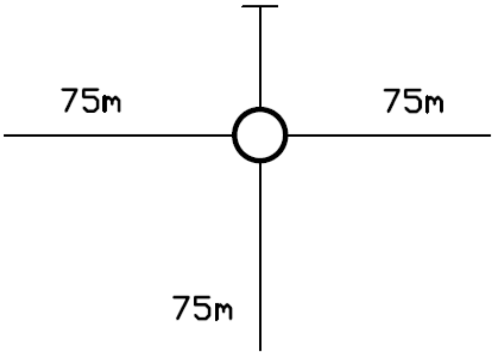
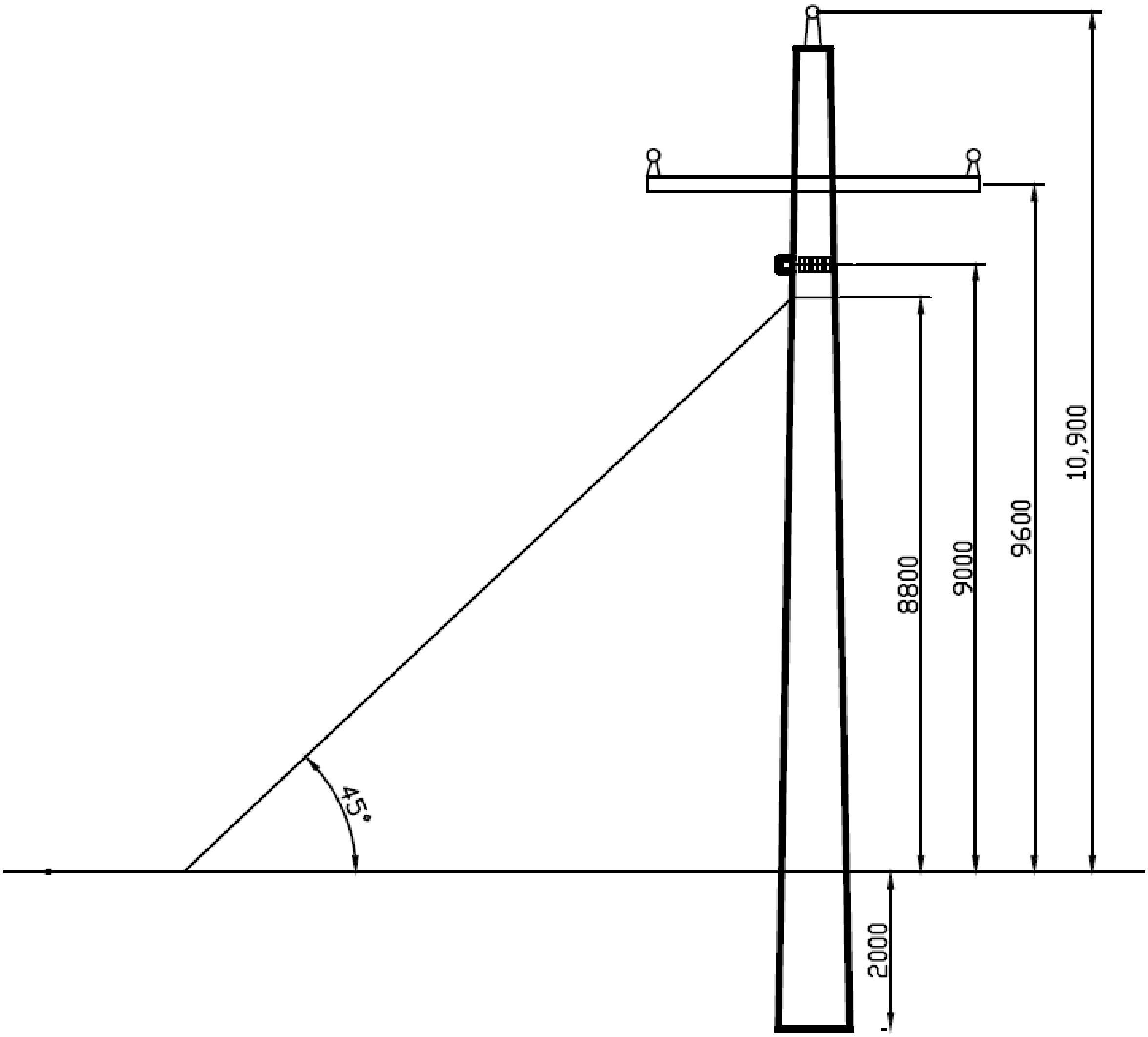


FIGURE 11. ELEVATION



Example 5 - Tip load calculation for pole based on AS7000 limit state.

Units

$N \equiv newton$ $kN \equiv 10^3 \cdot newton$ Define Newton and kiloNewton abbreviations

INPUT DATA	22kV ActewAGL single circuit in-line 90 degree tee off 12.5m/8kN max working concrete pole, composite cross arm, horizontal circuit, 19/3.25mm AAC Neptune.
Pole	Pole dwg A2-392-41-13.
$d_{pt} \equiv 250 \cdot mm$	Pole tip diameter.
$taper \equiv 15 \cdot mm \cdot m^{-1}$	Taper of pole with height
$h_4 \equiv 9.0 \cdot m$	HV Lowest phase/s attachment height above ground
$n_4 \equiv 3$	Number of conductors at lowest phase height
$h_3 \equiv 9.6 \cdot m$	HV Middle phase/s attachment height above ground
$n_3 \equiv 2$	Number of conductors at middle phase height
$h_2 \equiv 10.9 \cdot m$	HV Top phase/s attachment height above ground
$n_2 \equiv 1$	Number of conductors at top phase height
$h_1 \equiv 0 \cdot m$	LV attachment height above ground
$n_1 \equiv 0$	Number of LV wires
$L \equiv 12.5 \cdot m$	Pole length
$f \equiv 2.0 \cdot m$	Foundation depth
$h_s \equiv 8.8 \cdot m$	Stay attachment height above ground
$R_n \equiv 16 \cdot kN$	Rated ultimate tip load

Wind Pressure, Wind Span & Deviation

$P_w \equiv 900 \cdot Pa$	Wind pressure on conductors
$P_{wp} \equiv 1300 \cdot Pa$	Wind pressure on pole
$windspan \equiv 75 \cdot m$	Wind span of conductors
$wtspan \equiv 75 \cdot m$	Weight span
$\delta \equiv 0 \cdot deg$	Deviation angle
HV Conductor and LV	Neptune is at 5% CBL edt. 150mm2 LVABC edt is 8% CBL
$d_e \equiv 45.6 \cdot mm$	LV diameter. 150mm2 LVABC is 45.6mm
$d_c \equiv 16.3 \cdot mm$	HV Conductor diameter, Neptune is 26.3mm
$\tau_e \equiv 14.64 \cdot kN$	LV tension at ultimate wind. 14.64kN @900Pa
$\tau_{ee} \equiv 6.72 \cdot kN$	LV tension at everyday. 6.72kN @ 15C & no wind
$\tau_c \equiv 4.2 \cdot kN$	HV Conductor tension at ultimate wind, 4.2kN @ 15C & 900Pa
$\tau_{ce} \equiv 1.24 \cdot kN$	HV Conductor tension at everyday, 1.24kN @ 15C & no wind

Load Factors & Strength Reduction Factors

$\gamma_{1u} \equiv 1.25$ — Load factor on ultimate conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_{1e} \equiv 1.1$ — Load factor on everyday conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_{2} \equiv 1.25$ — Load factor for conductor vertical loads, 1.25 for ultimate & everyday, 1.5 for maintenance

$\gamma_{3} \equiv 1.1$ — Load factor for structure self weight. 1.1

$\phi \equiv 0.9$ — Strength reduction factor for pole. 0.9 for concrete

Weights

$wt_p \equiv 1750 \cdot kg$ — Pole weight.

Stay — Stay is 7/3.25mm SC/GZ with 68.7kN CBL. Limit state strength 55kN, Max working rating 27.5kN.

$\theta \equiv 45 \cdot deg$ — Stay angle to horizontal

CALCULATIONS

$h_0 := L - f$ — Pole height above ground

$h_0 = 10.5\,m$

$d_p := d_{pt} + taper \cdot \frac{h_0}{2}$ — Average diameter of pole above ground

$d_p = 0.329\,m$

Pole Ultimate Tip Load

$F_{wp} := P_{wp} \cdot d_p \cdot h_0$ — Force on pole due to wind pressure

$F_{wp} = 4.49 \cdot kN$

$F_{wpt} := \frac{F_{wp} \cdot \frac{h_0}{2}}{h_0}$ — Pole windage represented as a tip load

$F_{wpt} = 2.24 \cdot kN$

$F_1 := n_1 \cdot \left(P_w \cdot d_e \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_e \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to LV

$F_1 = 0 \cdot kN$

$F_2 := n_2 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$ — Force on pole due to HV top conductor/s

$F_2 = 1.1 \cdot kN$

$$F_3 := n_3 \cdot \left(P_w \cdot d_c \cdot windspan + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right)\right)$$

Force on pole due to HV middle conductor/s

$$F_3 = 2.201 \cdot kN$$

$$F_4 := n_4 \cdot \gamma_{1u} \cdot \tau_c$$

Force on pole due to HV lowest conductor/s

$$F_4 = 15.75 \cdot kN$$

$$TL := \frac{F_1 \cdot h_1 + F_2 \cdot h_2 + F_3 \cdot h_3 + F_4 \cdot h_4 + \frac{1}{2} \cdot F_{wp} \cdot h_0}{h_0}$$

Tip load for pole

$$TL = 18.94 \cdot kN$$

$$C_{tip} \equiv \phi \cdot R_n$$

Pole tip load limit state strength

$$C_{tip} = 14.4 \cdot kN$$

Stay Tension

$$H_s := \frac{F_4 \cdot h_4 + F_3 \cdot h_3 + F_2 \cdot h_2 + F_1 \cdot h_1 + \frac{1}{2} \cdot F_{wp} \cdot h_0}{h_s}$$

Horizontal force at stay point on pole. Ultimate 39kN horizontal.

$$H_s = 22.6 \cdot kN$$

$$\tau_s := \frac{H_s}{\cos(\theta)}$$

Stay tension. Ultimate tension 55kN

$$\tau_s = 31.96 \cdot kN$$

3.10 Stays

3.10.1 General

Free standing poles of higher strength are preferred over poles with stays. Where stays are required, the following options are available:-

- Conventional ground stay
- Head or aerial stay
- 1.2m long side walk stay
- 2.4m long side walk stay

Ground stays are preferred over aerial and side walk/footpath stays. Standard angle is 45° to the ground. Where space is reduced, maximum angle is 60° to the ground. Note that the tension in the stay increases with angle to the ground. Stays should be attached to the pole close to the conductor load attachment point. It is preferred that there are no stays installed in backyards.

For new lines, poles that are stayed should be rated for half the applied tip load under wind conditions, if practicable. (This may not be practical on tight strung rural lines.)

Standard stay wires are:-

- 7/3.25mm SC/GZ (Previously 7/10G SC/GZ has been used.) Maximum stay tension is 55kN based on a calculated breaking load of 68.7kN and a strength reduction factor of 0.8.

- 19/2.75mm SC/GZ. Maximum stay tension is 106kN based on a calculated breaking load of 133kN and a strength reduction factor of 0.8.

Preferred installation angle for ground stays is 45º to the horizontal, maximum 60º.

For head, or aerial stays, maximum angle to horizontal is 30º. Refer to drawing D204-0010 for aerial stay assembly drawing.

Refer to Table 18 for maximum pole loads of 7/3.25mm SC/GZ ground and aerial stays. Table 19 provides maximum pole loads for 19/2.75mm SC/GZ.

TABLE 18. GROUND AND AERIAL 7/3.25 SC STAYS

Stay Type	θ	F
Aerial	30	48
Ground	45	21
Ground	60	15

TABLE 19. GROUND AND AERIAL 19/2.75 SC STAYS

Stay Type	θ	F
Aerial	30	58
Ground	45	47
Ground	60	34

Notes:

1. θ is angle in degrees between stay & horizontal.
2. F is horizontal load on pole at stay attachment point in kN.
3. Aerial stay maximum tension 55kN for 7/3.25 SC and 67kN for 19/2.75 SC.
4. Ground stays maximum tension 30kN for 7/3.25 SC and 67kN for 19/2.75 SC.

3.10.2 Stay Foundations

For the 7/3.25mm SC/GZ stay, an in-line "Platypus" anchor is installed with a proof load of 35kN. This proof load sets the maximum load on the stay and connections. (It is approximately half the stay calculated breaking load.) Refer to drawing D204-0009 for assembly details for Platypus anchors and aerial stays for concrete poles.

For the 19/2.75mm SC/GZ stay, a vertical foundation is installed. Consistent with the smaller stay, the maximum stay load is set to 67kN (i.e. half the calculated breaking load.) Therefore, the uplift capacity of the vertical foundation must be 95kN for a 45° stay. Refer to drawing D204-0008 for assembly details for vertical foundation and aerial stays for concrete poles.

3.10.3 Sidewalk/Footpath Stays

Where sidewalk stays are the only option due to space restriction, the 2.4m long sidewalk stay is preferred over the 1.2m sidewalk stay. Refer to Figure 10 for sidewalk stay general arrangement.

FIGURE 12. **SIDEWALK STAYS**

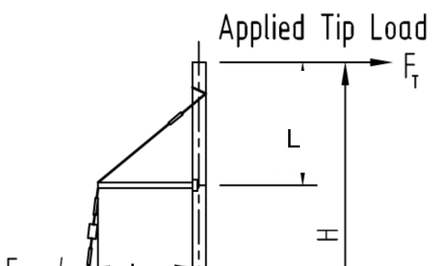


Table 20 provides maximum tip loads for 7/3.25mm SC/GZ sidewalk stays, while Table 21 provides tip loads for 19/2.75mm SC/GZ sidewalk stays. Table 20 tip loads are based on a maximum stay load of 35kN for the 7/3.25mm SC/GZ stay, while Table 21 tip loads are based on a maximum stay load of 67kN for the 19/2.75mm SC/GZ. Tip loads are for a 12.5m long pole with 10.5m above ground level. The sidewalk stay cross arm is held horizontal by a 45º angle stay to the top of the pole. Tip load is applied at 10.5m height above ground.

TABLE 20. 7/3.25MM SC/GZ SIDEWALK STAYS

2.4m	**θ**	0	5	10	15	20
	D	2.7	3.41	4.13	4.87	5.65
	F_t	9.0	11.3	13.6	15.7	17.7
1.2m	**θ**	0	5	10	15	20
	D	1.5	2.31	3.14	3.99	4.88
	F_t	5.0	7.7	10.3	12.9	15.3

TABLE 21. 19/2.75MM SC/GZ SIDEWALK STAYS

2.4m	**θ**	0	5	10	15	20
	D	2.7	3.41	4.13	4.87	5.65
	F_t	17.2	21.7	25.9	30.0	33.9
1.2m	**θ**	0	5	10	15	20
	D	1.5	2.31	3.14	3.99	4.88
	F_t	9.6	14.7	19.7	24.6	29.2

Notes:

1. L is length of sidewalk crossarm in metres.
2. θ is angle in degrees between stay & vertical at ground level.
3. D is horizontal distance in metres between stay and pole axis at ground level.

4. F_t is Tip load in kN.
5. H is height of pole above ground, 10.5m.

Refer to drawing D204-0011 (7/3.25mm SC/GZ) and D204-0013 (19/2.75mm SC/GZ) for assembly details for side walk stays.

3.10.4 TransACT Stays

Refer to drawing 392-2-02 for pole stay for TransACT cables.

3.10.5 Worked Examples – Ground Stays

Refer to the tip load calculations in sections 3.9.8.2, 3.9.8.3, 3.9.8.4, and 3.9.8.5 for how to calculate loads in ground stays.

3.10.6 Worked Examples – Sidewalk Stay

Consider a 7/3.25mm SC/GZ side walk stay as in Figure A with 2.4m long crossarm and stay 15° to the vertical. Distance from pole to ground anchor, D, is,

$$D = (10.5 – 2.4)\text{m} \times \tan 15° + 2.4\text{m} + 0.3\text{m pole radius}$$

$$D = 4.87\text{m}$$

Taking moments about the base of the pole,

$$F_{stay} \cos 15° \times D = F_t \times 10.5\text{m}$$

Solving for pole tip load, given maximum stay tension of 35kN,

$$F_t = F_{stay} \cos 15° \times D/10.5\text{m}$$

$$F_t = 35\text{kN} \times \cos 15° \times 4.87\text{m} /10.5\text{m}$$

$$F_t = 15.7\text{kN}$$

3.10.7 Engineering Notes

Stays should be positioned to achieve the most effective use of the stay's strength. In particular, position stay on outside of deviation angle so that it bisects the deviation angle. Keep angle between stay and ground in the range 45° to 60°.

Stay insulators should be positioned such that the stay wire on the structure side of the stay insulator cannot be accessed from the ground by workers or the general public when intact (minimum 2.4 metres above ground) or when in a broken stay wire state and also positioned such to maximise the ability to insulate the stay to ground in the event of a fallen conductor directly onto the stay. Ensure that stay wire insulators have a withstand rating that exceeds line voltage are installed in stay wires. The stay insulator also prevents leakage currents from corroding stay anchors.

3.11 Pole Top Constructions

3.11.1 Introduction

Refer to drawing D204-0025 for pole top construction selection giving allowed construction types and reference to sub-assembly drawings.

Refer to the following drawings for assembly details:-

- For 25kVA single phase transformers, drawing D203-0001
- For 25kVA 3 phase transformers, drawing D203-0020
- For 100kVA to 500kVA transformers, drawing D203-0002
- For 11kV recloser, drawings D201-0036 and D201-0037
- For 11kV U/G-O/H with gas switch, drawing D301-0005
- For 11kV gas switch on double strain, drawing D201-0021
- For 11kV air break switch, drawing D201-0035

3.11.2 Pole Layout Rules

The following strain section rules should be applied:-

- If strung tight (i.e. greater than or equal to 10%CBL) then limit ratio of smallest to largest span in the tension section to 2:1.
- If strung slack (i.e. less than 10%CBL) then limit ratio of smallest to largest span in the tension section to the range 0.5xMES to 2xMES.
- If differences in smallest to largest span in the tension section exceed these limits then install a shackle pole.

Where the route traverses a rail corridor, approval for the crossing must be obtained from the appropriate Rail authority, RailCorp (ex State Rail). Designers are responsible for obtaining approval for the design of the crossing from RailCorp in accordance with the requirements of the relevant Master Access Deed (MAD). All proposed rail crossings should allow for all line supports to be located OFF rail property wherever possible. Poles should be located in the road either side of a rail crossing, provided the RailCorp's technical requirements on maximum span lengths and angle of crossing permit this.

Waterway crossings should be designed to comply with AS6947.

3.11.3 Maximum Span/Deviation Limitations

Maximum span limitation is determined by:-

- Strength of poles, cross arms, insulators and fittings (e.g. conductor ties)
- Mid span clashing
- Deviation angle clearances (e.g. conductor to earth/pole/stay, phase to phase)
- Clearance for suspension insulators

Maximum deviation angles for LV Bare Open Wire hand ties:-

- Inline 3° Max
- Side tie 3° - 15° Max
- Strain 15° - 30° Max
- Double termination >30°

Note: LV phase to earth clearances should not be less than 85mm.

LVABC maximum deviation angles:-

- Inline 25°

- Double Yoke 25° - 50°
- Double Termination > 50°

Maximum deviation angles for 11kV HV Bare Open Wire with preformed tie:-

- Inline 10°
- Side tie 10° - 15°. (Not permitted on subsidiary arms on conductive poles)
- Strain 15°- 30°
- Double termination > 30°

Note: 11kV phase to earth clearances should not be less than 450mm.

Refer to drawing 392-36-04 for LV hand ties and HV bridging tie requirements. Refer to drawing 392-36-01 for HV intermediate (top) and angle (side) hand tie requirements.

The probability of mid-span conductor clashing increases as conductor sag increases, which in turn increases with span length. Increasing separation between phase conductors at supports reduces the probability of clashing. In general, to avoid clashing between conductors, the following condition (equation from AS/NZS7000) must be met:

$$\sqrt{(X^2 + 1.2Y^2)} \geq U/150 + K\sqrt{(D + l_i)}$$

where:

X	is the horizontal distance between the conductors at mid-span (m)
Y	is the vertical distance between the conductors at mid-span (m)
U	is the rms difference in potential between the two conductors (kV)
D	is the greater of the two conductor sags (m) – No Wind, 50°C
l_i	is the length of any freely swinging suspension insulator with either conductor (m)

For the mid-span clearance equation the following applies:-

- K=0.4 standard
- K=0.6 in fire prone areas

For 11kV delta configuration with 600mm middle phase vertical offset and 0.85m horizontal offset between middle and outside phases for strain construction the allowable 50ºC sag is 6.7m from AS7000 formula using k=0.4. (For 11kV delta configuration with 600mm middle phase vertical offset and 0.95m horizontal offset between middle and outside phases for intermediate construction the allowable 50ºC sag is 7.8m.) These sags are much more than generally occur for distribution spans and tensions.

Under "wind" condition cantilever load on insulators should be limited to the following:-

- 2.5kN for LV pins
- 6kN for LV shackles
- 4kN for 11kV pins

4kN is the maximum allowable tension on an 11kV pin insulator. Consequently, the maximum allowable deviation angle for a 75m span of Neptune at ultimate wind is 32°. At greater deviation angles the vectored tension is higher and loading will exceed the 11kV pin limit state capacity.

LV spreader rules are provided on drawing 3812-001.

3.11.4 Plant Position on Poles

Refer to drawing 392-43-06 for rules for positioning LV and HV plant on poles. This drawing specifies:-

- King bolt separations (i.e. vertical clearances between crossarms at same and different voltages). E.g. 600mm between different LV cross arms, 1500mm between LV and HV cross arms.
- Clearances to LV and HV plant on poles.

3.11.5 Cross Arms

Standard cross arm material is composite fibre. Application of cross arms:-

- 100mm x 100mm x 1.7m for LV intermediate poles. Drawing D104-0003.
- 100mm x 100mm x 2m for HV intermediate poles. Drawing D104-0054.
- 125mm x 125mm x 2m for HV strain/termination poles. Drawing D104-0031.
- 125mm x 125mm x 2.7m for HV recloser links. Drawing D104-0119.

Cross arm strength limits are as follows:-

TABLE 22. CROSS ARM STRENGTH LIMITS

Cross Arm Size (mm^3)	Length (m)	Cantilever Serviceability (kN)	Load Wind (kN)
100x100x5	1.7	6.3	15.7
100x100x5	2	5.9	14.7
125x125x6.5	2	11.7	29.3
125x125x6.5	2.7	8.2	20.5

Notes:

1. Based on Wagner ultimate moment rating of 16.7kN.m for 100x100x5.
2. Based on Wagner ultimate moment rating of 33.16kN.m for 125x125x6.5.
3. Lever arm for 1.7m cross arm of 0.8m.
4. Lever arm for 2m cross arm of 0.85m.
5. Lever arm for 2.7m cross arm of 1.212m.
6. Strength reduction factor of 0.75 for strength and 0.3 for serviceability.

3.11.6 Perform Ties

Armour rods and perform ties are to be installed in fire prone areas and areas with conductor tension greater than 10%CBL.

3.11.7 Vibration Dampers

Vibration dampers are to be installed on conductors:-

- In rural areas where spans exceed 100m.
- Strung tighter than 15% cbl

Refer to drawing D204-0001 and 3810-001 for spiral vibration damper selection and installation details.

3.11.8 Aerial Markers

There are two situations where aerial markers are required:-

1. Two poles back on a distribution line either side prior to the line traversing a transmission line.
2. Helicopter pads, airstrips and when the ground clearance or conductor length exceeds AS3891 requirements e.g deep valleys.

Where there is potential for aircraft strike to longer spans in deep valleys, markers are required. E.g. rural lines subject to helicopter patrols.

For air navigation overcrossing marker installation rules refer to drawing A2-392-41-20.

Permanent design marking of overhead conductors and their supporting structures should be undertaken in accordance with AS 3891.1-2008: Air navigation - Cables and their supporting structures - Marking and safety requirements - Permanent marking of overhead cables and their supporting structures for other than planned low-level flying. This is generally a design requirement around airports and helicopter landing strip or where conductors traverse a valley and heights above the tree canopy. Where low-level flying is undertaken e.g. line patrols, then AS3891.2 should also be used.

3.11.9 Worked Example - Force from conductor at a deviation angle

This worked example calculates the transverse force applied to the attachment point by a conductor under ultimate wind. The transverse force is due to the sum of vectored conductor tension and transverse 900Pa wind.

Calculation of transverse force applied by conductor at a deviation angle based on AS7000 limit state.

Units

$N \equiv \text{newton}$ $\quad kN \equiv 10^3 \cdot \text{newton}$ — Define Newton and kiloNewton abbreviations

INPUT DATA — 19/3.25mm AAC Neptune

$n_1 \equiv 1$ — Number of conductors connected to insulators

Wind Pressure, Wind Span & Deviation

$P_w \equiv 900 \cdot Pa$ — Wind pressure on conductors

$\text{windspan} \equiv 75 \cdot m$ — Wind span of conductors

$\delta \equiv 32 \cdot \text{deg}$ — Deviation angle

HV Conductor — Neptune is at 5% CBL everyday tension.

$d_c \equiv 16.3 \cdot mm$ — HV Conductor diameter, Neptune is 26.3mm

$\tau_c \equiv 4.2 \cdot kN$ — HV Conductor tension at ultimate wind, 4.2kN @ 15C & 900Pa, 2.6kN @ 15C & 900Pa

$\tau_{ce} \equiv 1.24 \cdot kN$ — HV Conductor tension at everyday, 1.24kN @ 15C & no wind

Load Factors & Strength Reduction Factors

$\gamma_{1u} \equiv 1.25$ — Load factor on ultimate conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_{1e} \equiv 1.1$ — Load factor on everyday conductor tension. 1.25 for ultimate, 1.1 everyday, 1.1 for cold, 1.5 for maintenance.

$\gamma_2 \equiv 1.25$ — Load factor for conductor vertical loads, 1.25 for ultimate & everyday, 1.5 for maintenance

CALCULATIONS

$$F_1 := n_1 \cdot \left(P_w \cdot d_c \cdot \text{windspan} + \gamma_{1u} \cdot 2 \cdot \tau_c \cdot \sin\left(\frac{\delta}{2}\right) \right)$$

Transverse Force on insulators due to HV conductor/s

$F_1 = 3.99 \cdot kN$

4kN is the maximum allowable tension on an 11kV pin insulator. Consequently, the maximum allowable deviation angle for a 75m span of Neptune at ultimate wind is 32°. At greater deviation angles the vectored tension is higher and loading will exceed the 11kV pin ultimate capacity.

3.12 Clearances

3.12.1 Ground and Structure

Refer to drawing 392-43-07 for minimum phase to earth, phase to phase and bridging separations on poles. Note that extra clearances are required for wildlife (e.g. birds and possums).

Refer to drawing 3811-004 for minimum clearances, insulated and bare conductors. This drawing provides ground clearances and clearances to nearby structures.

Notes for table 23:

1. The above clearances may need to be increased due to local factors.
2. The clearances in this table may need to be increased to account for safe approach distances required for construction, operation and maintenances and for blow out on large spans.
3. The above clearances are based on the upper circuit being at maximum conductor temperature and the lower circuit at ambient temperature.
4. These clearances apply to altitudes up to 1000 m. Correction factors at higher altitudes are contained in AS2650.
5. The “Wind” condition corresponds to serviceable load conditions

3.12.2 Inter-Circuit

TABLE 23. MINIMUM VERTICAL SEPARATION FOR UNATTACHED CROSSINGS (IN METRES)

			UPPER CIRCUIT									
			U ≤ 500 kV U > 330 kV Bare	U ≤ 330 kV U > 275 kV Bare	U ≤ 275 kV U >132 kV Bare	U ≤ 132 kV U > 66 kV Bare	U ≤ 66 kV U > 33 kV Bare	U ≤ 33 kV U > 1000 V Bare or covered	U ≤ 33 kV U > 1000 V Insulated	U < 1000 V Bare, covered and insulated	Other cables (Conductive)	Other cables (Non-conductive)
LOWER CIRCUIT	330 kV <U ≤ 500 kV Bare	No wind	5.2									
		Wind	3.6									
	275 kV < U ≤ 330 kV Bare	No wind	5.2	3.8								
		Wind	3.6	2.6								
	132 kV < U ≤ 275 kV Bare	No wind	5.2	3.8	2.8							
		Wind	3.6	2.6	2.2							
	66 kV < U ≤ 132 kV Bare	No wind	5.2	3.8	2.8	2.4						
		Wind	3.6	2.6	2.2	1.5						
	33 kV < U ≤ 66 kV Bare	No wind	5.2	3.8	2.8	2.4	1.8					
		Wind	3.6	2.6	2.2	1.5	0.8					
	1000 V < U ≤ 33 kV Bare or covered	No wind	5.2	3.8	2.8	2.4	1.8	1.2				
		Wind	3.6	2.6	2.2	1.5	0.8	0.5				
	1000 V < U ≤33 kV Insulated	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6			
		Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4			
	U ≤ 1000 V Bare, covered and insulated	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6	0.6		
		Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4	0.4		
	Other cables (Conductive)	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6	0.6	0.6	0.4
		Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4	0.4	0.4	0.2
	Other cables (Non conductive)	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6	0.6	0.4	0.4
		Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4	0.4	0.2	0.2

TABLE 24. VERTICAL SEPARATION AT SUPPORTS FOR ATTACHED CROSSINGS (IN METRES)

		UPPER CIRCUIT							
		U ≤ 132 kV U > 66 kV Bare	**U ≤ 66 kV U > 33 kV Bare**	**U ≤ 33 kV U > 1000 V Bare or covered**	**U ≤ 33 kV U > 1000 V Insulated**	**U < 1000 V Bare and covered**	**U < 1000 V Insulated**	**Other cables (Conductive)**	**Other cables (Non-conductive)**
LOWER CIRCUIT	66 kV <U ≤ 132 kV Bare	2.4							
	33 kV < U ≤ 66 kV Bare (Note 1)	2.4	1.5						
	1000 V < U ≤ 33 kV Bare or covered	2.4	1.5	0.9	0.9				
	1000 V < U ≤ 33 kV Insulated	2.4	1.5	0.9	0.2				
	U < 1000 V Bare and covered	2.4	1.8	1.2	0.6	0.3	0.3		
	U < 1000 V Insulated	2.4	1.8	1.2	0.6	0.3	0.2	0.3	
	Other cables (Conductive)	2.4	1.8	1.2	0.6	0.3	0.3	0.2	0.2
	Other cables	2.4	1.8	1.2	0.6	0.3	0.2	0.2	0.2

Notes:

1. The clearances in the table are based on the lower circuit conductors being attached to pin or post insulators. Additional clearance is required to allow for conductor movement, if the lower circuit is attached by suspension or strain insulators.
2. The clearances in this table may need to be increased to account for safe approach distances required for construction, operation and maintenances.

The above tables for circuit to circuit clearances are from AS7000.

3.12.3 Telecommunications

Refer to drawing 390-018 for clearance requirements for TransACT cable.

3.12.4 Streetlights

The following clearances apply to street lights:-

- 100mm from bare LV to street light bracket on same pole.
- 1200mm from bare HV (11kV or 22kV) to street light bracket on same pole.

3.12.5 Vegetation

Refer to draft Evoenergy overhead asset vegetation clearances document (reference 5).

3.12.6 Worked Example 1 – HV in-line Mid Span Clearance

Consider an 11kV in-line concrete pole construction as per drawing D201-0026 with a 2m fibreglass crossarm and 75m span of Neptune conductor at 5% CBL (calculated breaking load) everyday tension. Neptune conductor sag at 50°C is 2.74m using a sag tension program. The horizontal offset between adjacent phase conductors is 0.95m and the vertical offset is 1.1m because the centre phase is on the top of the pole. Using the AS/NZS7000 Section 3.9.3.1 midspan formula as follows,

$$\sqrt{(X^2 + 1.2Y^2)} \geq U/150 + K\sqrt{(D + l_i)}$$

Where:

$X=0.95m$ the horizontal distance between the conductors at mid-span (m).

$Y=1.1m$ the vertical distance between the conductors at mid-span (m).

$U=11kV$ the rms difference in potential between the two conductors (kV).

$D=2.74m$ No Wind, 50°C sag (m) for 75m span of Neptune strung at 5%CBL everyday tension (m).

$l_i=0m$ the length of any freely swinging suspension insulator with either conductor (m).

K=0.4 standard factor.

Geometric distance is then,

$S = \sqrt{(0.95^2 + 1.2 \times 1.1^2)}$

S = 1.63m which has to be greater than the following clearance,

$C = 11/150 + 0.4\sqrt{2.74}$

C = 0.74m

As the geometric distance of 1.63m exceeds this clearance of 0.74m, midspan clashing is unlikely. The maximum allowable sag for this conductor geometry is 15.1m. Note that even a 200m span strung at 20%CBL everyday tension has only 6.1m of sag at 75°C. Note that this delta conductor configuration is much better than conventional flat distribution construction as far as midspan clashing is concerned.

3.12.7 Worked Example 2 – HV Strain Mid Span Clearance

Consider an 11kV concrete strain pole construction as per drawing D201-0021 with a 2m fibreglass crossarm and 75m span of Neptune conductor at 5% CBL (calculated breaking load) everyday tension. Neptune conductor sag at 50°C is 2.74m using a sag tension program. The horizontal offset between adjacent phase conductors is 0.85m and the vertical offset is 0.9m because the centre phase is on the top of the pole. Using the AS/NZS7000 Section 3.9.3.1 midspan formula as follows,

$\sqrt{(X^2 + 1.2Y^2)} \geq U/150 + K\sqrt{(D + l_i)}$

where:

X=0.85m the horizontal distance between the conductors at mid-span (m)

Y=0.9m the vertical distance between the conductors at mid-span (m)

U=11kV the rms difference in potential between the two conductors (kV)

D=2.74m No Wind, 50°C sag (m) for 75m span of Neptune strung at 5%CBL everyday tension (m)

l_i*=0m* the length of any freely swinging suspension insulator with either conductor (m)

K=0.4 standard factor

Geometric distance is then,

$S = \sqrt{(0.85^2 + 1.2 \times 0.9^2)}$

S = 1.37m which has to be greater than the following clearance,

$C = 11/150 + 0.4\sqrt{2.74}$

C = 0.74m

As the geometric distance of 1.37m exceeds this clearance of 0.74m, midspan clashing is unlikely. The maximum allowable sag for this conductor geometry is 10.6m.

3.12.8 Worked Example 3 – Conductor Blowout

Consider an 11kV pole construction with a 75m span of Neptune conductor at 5% CBL (calculated breaking load) everyday tension. Conductor clearances to nearby structures must be checked under a 500Pa blowout.

Neptune conductor sag at 500Pa wind and 15°C is 2.48m using a sag tension program. Neptune diameter is 16.3mm and it has a weight of 0.433kg/m. Conductor blowout angle to the vertical is,

$\tan\theta = P \times d / (w \times g)$

Where

θ = blow out angle to the vertical

P = wind pressure in Pascal

D = conductor diameter (m)

w = conductor weight per unit length (kg/m)

g = acceleration due to gravity 9.81m/s²

Substituting,

$\tan\theta = 500\text{Pa} \times 0.0163\text{m} / (0.433\ \text{kg/m} \times 9.81\text{m/s}^2)$

$\theta = 62.5°$

Horizontal blow out distance is,

$H = Sag \times \sin \theta$

$H = 2.48 \sin 62.5°$

$H = 2.2m$

Sag in Vertical direction due to blowout is,

$V = Sag \times \cos \theta$

$V = 2.48 \cos 62.5°$

$V = 1.15m$

Ensure that at the blown out position of the conductor the clearances to nearby structures on drawing 3811-004 are met.

3.12.9 Stay Clearances

Clearance is required between energised conductors and stay wires to prevent flashover and clashing. The minimum separation under 500Pa wind is the phase to earth clearance from drawing 392-43-07:

- 85mm for LV
- 280mm for 11kV and 22kV

3.13 Earthing

Refer to the Evoenergy Earthing Standard for earthing requirements of overhead lines.

3.14 Software

Poles & Wires software is used for distribution line design.

3.15 Policy and Practice

In bush fire abatement zones the following is required:-

- Install perform ties rather than ties
- Install vibration dampers

4. REFERENCES AND STANDARDS

Evoenergy documents	
Document number	**Document title**

PO07201	Chamber type substation design and construction standard
PO07395	Technical Specification – Cables and Conductors
PO07127	Earthing Design Manual
PO07173	Service and Installation rules
PO07454	Electrical Data Manual
PO07110	Standard Design & Constructions Manual
PR1115	Supply Voltage Standard for Low Voltage Systems
PO07106	Technical Specification – Composite Power Pole
PO07451	Technical Specification – Pole Mounted Substations
Australian Standards	
Document number	**Document title**
AS 2067	Substations And High Voltage Installations Exceeding 1 KV A.C.
AS/NZS 3000	Electrical Installations
AS 1726 – 1993	Geotechnical site investigations
AS/NZS 7000	Overhead line design
AS 3891.1-2008	Air navigation - Cables and their supporting structures - Marking and safety requirements - Permanent marking of overhead cables and their supporting structures for other than planned low-level flying
AS 3891.2-2008	Air navigation - Cables and their supporting structures - Marking and safety requirements - Marking of overhead cables for planned low-level flying operations.
AS 2947-2009	Crossing of waterways by electricity infrastructure.
Other Documents	
Document owner	**Document title**
Safe Work Australia	Model Code of Practice: Safe design of structures
National Construction Code	National Construction Code Volume One
National Construction Code	National Construction Code Volume two
Transport Canberra and City Services	Standard Specification for Urban Infrastructure Works
ESAA	NENS 04 – 2003National guidelines for safe approach distances to electrical and mechanical apparatus
ACT Government	Design Standards for Urban Infrastructure Series

5. ABBREVIATIONS

5.1 Acronyms

Term	Definition
2CTW	2 Wire Twisted (1 phase) service
4CTW	4 Wire Twisted (3 phase) service
4WL	4 Wire Lateral (open wire 3 phase) service

ACT	Australian Capital Territory
AAC	All Aluminium Conductor
AAAC	All Aluminium Alloy Conductor
ACSR	Aluminium Conductor Steel Reinforced
ADSS	All Dielectric Self-supporting (Communications cable—optical fibre)
AHD	Australian Height Datum
Al	Aluminium
BAZ	Bushfire Abatement Zone
CBL	Calculated Breaking Load. In relation to a conductor, means the calculated minimum breaking load determined in accordance with the relevant Australian/New Zealand Standard.
CSA	Cross-sectional Area
Cu	Copper
CLAH	Current-limiting Arcing Horn, or gapped surge arrester
EMF	Electromagnetic Field
GL	Ground Level
HDC	Hard Drawn Copper
OPGW	Optical Ground Wire—an overhead earth wire with internal optical fibre/s.
SF	Safety Factor, also Strength Factor
SC/GZ	Steel Conductor / Galvanized
UTS	Ultimate Tensile Strength – the maximum mechanical load which may be applied to a conductor, beyond which failure occurs.

6. DEFINITIONS

Term	Definition
Action	Force (load) applied to a mechanical system, as well as imposed or constrained deformation or acceleration, e.g. due to earthquakes, temperature or moisture changes.
Aerial Bundled Cable (ABC)	Two or more XLPE insulated aluminium overhead conductors twisted together to form a single bundled assembly.
Alignment	A distance relative to the edge of the footpath (usually the property boundary side) used to describe the position of a pole, cable or other service.
Average Recurrence Interval (ARI)	Or "Return Period", is the inverse of the annual probability of exceeding wind speed, as applied in AS/NZS 1170.2
Blowout	The horizontal 'sag' or deviation of powerline conductors from the centre as a result of wind forces.
Bridging	Relatively short, flexible or rigid, bare, covered or insulated leads which electrically connect lines at termination or tee-off points or connect electrical lines to electrical apparatus. Also known as 'droppers' or 'jumpers'.
Cadastral Map	A map or plan showing details of land tenure (e.g., property boundaries or natural features).
Chainage	The distance from a datum along the centreline of a roadway. This term and offset are used to reference points on roadworks plans.
Common MEN System	An earthing system in which the LV MEN system is connected to the HV system earthing. This is used commonly in urban areas where there are numerous interconnected earth rods all meshed together over a wide areas and a low resistance to earth can be obtained. See 'Multiple Earth Neutral'.
Conductor	A wire or other form of conducting material used for carrying current.

Term	Definition
Covered Conductor Thick (CCT)	An unscreened overhead conductor around which is applied a specified thickness of insulating material dependant on the working voltage.
Creep (or Inelastic Stretch)	The process where a conductor increases in length over time when under tension in service. This causes an increase in sag in a span.
Customer	A person or organisation that has applied for or receives electrical supply from the electricity network.
Easement	A strip of land registered on the title deed in the office of the Registrar of Titles allowing access or other rights to a public body or party other than the owner of the parcel of land on which the easement exists.
Earthing	The process of connecting components of electricity supply networks to ground to prevent dangerous voltages occurring which may damage equipment or injure individuals coming into contact with them.
Everyday Tension	The sustained load (continuous force) exerted by conductors under no wind conditions.
Feeder	A circuit (normally HV) emanating from a substation for distributing electric power.
FoS	Factor of Safety
Ground Clearance	The vertical distance between the conductor at its lowest point of sag and ground.
High Voltage (HV)	Electrical potential that is in the range of 1kV to 33kV.
King Bolt Spacing	The vertical distance between king bolt attachment points on a support structure e.g. a pole.
Load Case	A compatible set of load arrangements or conditions to be considered in evaluating a structure, e.g. sustained load, maximum wind load, ice load.
Load Factor	A factor in a limit state equation which takes into account the variability and dynamics of a load, as well as the importance of a structure.
Low Voltage (LV)	Electrical potential that is in the range of 32V to 1kV.
Mains	Main lines or cables of a network connecting various sites — does not include services to individual consumers.
Maximum Wind Tension	The force applied by conductors to a support structure in an intense wind, generally a 3s gust corresponding to the overhead line design period.
Mean Equivalent Span (MES)	A theoretical span used to represent the behaviour of a number of spans of varying lengths in a strain section of an overhead powerline, also known as Ruling Span.
Multiple Earth Neutral (MEN)	An earthing system connecting the network neutral conductors to the earth electrodes in customers' electrical installations, the electricity authority transformers and earths at multiple locations on the electricity distribution network.
Overhead Mains	Aerial conductors or cables together with associated supports, insulators and apparatus used for the transmission or distribution of electrical energy.
Phasing	The relative positions of phases (A,B, C) in a polyphase power system.
Pole	A structure (wood, concrete, steel, composite fibre) supporting conductors and other equipment forming part of the overhead mains.
Profile	A longitudinal cross section of ground and an existing or proposed powerline used to check clearances and select optimum pole positions.
RL (Reduced Level)	The elevation of a point above an adopted datum.
Ruling Span	Ruling Span – see Mean Equivalent Span
Sag	The vertical distance between a conductor and a line joining the two attachment points. Usually the term refers to the maximum distance within a span at or near the midpoint.
Service	The electricity authority's conductors connecting individual customer's installation to the electricity network.

Term	Definition
Serviceability Limit State	State beyond which specified service criteria for a structure or structural element are no longer met.
Sinking Depth	The depth of a pole below ground—also known as embedment or planting depth.
Span	A section of overhead conductor between two supporting poles or structures. The term may also refer to the horizontal distance between the two pole attachment points.
Span Reduction Factor (SRF)	A reduction applied to design wind pressure on conductors on long spans taking into account that wind gusts tend to be localised in their intensity.
Stay	A steel wire that is used to support a pole when the tip load exceeds the pole capacity. The stay may be anchored in the ground or to another pole. Also known as a 'guy'.
Strain Point	The structure on a pole that supports the tension of a line in both directions, where conductors are terminated, as opposed to an intermediate support. Used to sectionalise a line for electrical isolation or to provide convenient stringing sections. Also known as a 'Shackle Point'.
Strain Section	A section of overhead powerline between fixed strain points or terminations.
Strength Factor, or Strength Reduction Factor	A factor in a limit state equation used to derate the nominal strength of a component to a practical design value, taking into account variability of the material, workmanship, maintenance and other factors.
Subcircuit	A circuit below another circuit, e.g. LV mains below 11kV.
Supercircuit	A circuit above another circuit, e.g. 11kV mains above LV.
Tip Load	The equivalent mechanical load applied to a pole tip by attached conductors or stays, as well as wind on the pole/structure.
Uplift	A vertical upward force applied to a structure by attached conductors—generally not desirable for intermediate (non-strain) structure types.
Ultimate Limit State	State associated with collapse or structural failure. Generally corresponds with the maximum load-carrying resistance of a structure or component thereof.
Ultimate Strength	The maximum load (nominal or actual) which may be applied to a structural component without inducing failure.
Wayleave	A written authority that the owner/occupier of a property uses to authorise an electricity authority to construct, maintain and clear vegetation for electrical line installations.
Weight Span	The equivalent span that gives the vertical conductor load applied to a support and equals the span between the lowest points on the catenary on either side of that support.
Wind Span	The equivalent span that gives the horizontal lateral component of the conductor load applied to a support and equals one half of the sum of the spans on either side of that support.
Working Strength	A nominal maximum working load obtained by dividing the ultimate strength by a safety factor. This value is not relevant to limit state design but existing poles may be labelled with a working strength.

VERSION CONTROL

VERSION	DETAILS	APPROVED
1.0	Initial Document	Santanu Chaudhuri, Wayne Cleland 23/03/2015

VERSION	DETAILS	APPROVED
2.0		Wayne Cleland 09/04/2015
3.0	Version 3 Formatting Document	Wahid Ibrahim, Jasmina Atanasievska 8/09/2015
4.0	Rebranding to EVO Energy	Wahid Ibrahim 16/01/2018
4.1	Minor Update	N. Azizi; W. Cleland; 15 Oct 2020

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APPENDIX A – APPLICATION OF SWITCHES ON DISTRUBUTION OVERHEAD NETWORK

This section provides general guidance to the designers and other relevant personnel on the application of switches on the overhead 11 kV and 22 kV network.

The following principles should be applied when selecting an appropriate type of switch for application on a distribution overhead feeder.

Generally, the switching devices to be used on the overhead distribution network will have switching functionality as stated below. However, each design and application needs to be consistent with switch capability and therefore needs to be confirmed by reference to the detailed switch specification.

Three phase air-break switch - Typical operational functionality: load break, load make.
Note: Load break and load make capacity of the switch is limited to switch specification. Generally, these switches **DO NOT** have fault make or fault break functionality.

Three phase gas switch - Typical operational functionality: load break, load make, fault make. Note: Any make/break capacity is limited by the switch specification. Generally, these switches **DO NOT** have fault break capacity. Most gas switches have provisions for remote operation or monitoring.

Three phase reclosers - Typical operational functionality: load break, load make, fault make, fault break. Reclosers, if necessary, can be set for multiple fault break/fault make operation. (i.e. typically two or three attempts to clear the fault. Most recloser switches have provisions for remote operation or monitoring.

Warning *- Application of switches which is not consistent with their intended use or specification creates a safety hazard.*

The following principles should be applied when installing a new switch, or replacing an existing switching device, on the overhead distribution network.

- Each switching device needs to be applied consistently with the intended use and manufacturer's specifications;
- Mandatory consultation with system control personnel (Control Room Manager) and system planning personnel (Primary Assets Manager) for all design projects is required to determine:
- Whether the switch is required in the specific location.
- If the switch is essential, what functionality of the switch is required (i.e. what type of switch);

In case of existing switch replacements, if there is no need for the switching device in the specific location, remove the device from the network rather than replace. Generally, the switch selection is based on economic, operational and safety factors. From a cost perspective, the preference for the switching devices is as follows:

1. First preference : Air break switch
2. Second preference : Gas switch
3. Third preference : Recloser

From an operational perspective, installation of a device other than an air-break switch can be applied in the following circumstances:

- Locations which require frequent operations of a switching device;
- Frequented and special locations (e.g. next to schools etc);
- Feeder open points, on long feeders, located far away from a zone substation.

From an operational perspective, air break switches should NOT be used in the following situations:

- Locations which are prone to ferroresonance may require a gas switch;
- In rural areas, BAZ and other fire prone areas
- On 11 kV feeders at points which interface 132 kV and 66 kV bulk supply networks.
- 11 kV or 22 kV links which have to be replaced should only be replaced with a suitably selected three phase switching device where there is a technical need, such as ferroresonance.
- Reclosers should be installed in locations where they can be justified by an improvement in reliability (e.g. through Service Target Performance Incentive Scheme or sectionalise poorly performing sections of a feeder etc);
- For gas switches and reclosers, remote operation/monitoring should be installed only if the additional cost can be justified (e.g. through Service Target Incentive Scheme, savings in cost and switching time etc)
- The above principles provide general guidance. However, in specific circumstances a departure from the above principles may be justified. Additional information and guidance should be sought from the Standards Section.