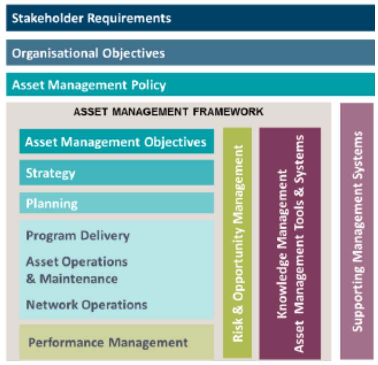
Transmission Line Support Structures – Stuctural Loading and Design

Design Standard



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RESPONSIBILITIES

Western Power's Engineering and Design Function is responsible for this document

CONTACT

Western Power welcomes your comments, questions, and feedback on this document, which can be emailed to standards.excellence@westernpower.com.au

Contents

Revision Details

Version	Date	Summary of change	Section
0	17/06/2015	Initial release	
1	31/3/2017	First revision	
2	12/5/2020	Second revision	
3	20/10/2023	Change to AMS format	

1. Introduction

This standard specifies the loading requirements for all components and the design requirements for support structures on Western Power's high voltage overhead transmission line system in terms of satisfactory compliance with relevant Australian and International Standards.

1.1 Purpose and scope

This standard applies to new transmission line constructions and cases where augmentations of existing transmission line assets are required to meet the latest overhead transmission line design standards. This standard shall be read in conjunction with other Western Power design standards to form a complete design. Table 1.1 gives the classification of a transmission line components and elements. This Standard specifies the limit state loadings requirements for all transmission line components as well as the design requirements for selected structural elements as shown in the shaded areas of Table 1.1.

Table 1.1: Transmission line system, components and elements

Structural System	Components	Elements
Overhead Transmission Line	Supports	Steel, wood, concrete, composite sections and arms
		Plates, bolts, nuts and washers
		Stays and fittings
		Top geometry
		Earthing and Insulations
	Foundations[1]	Anchor bolts, steel piles and cleat angles
		Footings and soil
		Earthing systems
		Underground trenches
	Conductors[2]	Wires
		Joints
		Hardware/shackles
	Insulators[2]	Insulator elements
		Brackets, bolts
		Fittings

[1] The limit state design loadings specified in this standard does not apply to the foundations - *refer to Western Power internal document.*

[2] The limit state design loadings specified in this standard does not apply to the conductors and the insulators - *refer to Western Power internal document.*

Where existing overhead lines or sections are proposed to be altered such that elements of the line are overloaded based on the original design standard; then the line or section shall be designed in accordance with this standard.

Nevertheless, existing lines shall also be upgraded to comply with the latest standard if the cost difference is justifiable or acceptable. Upgrade of strain supports to match the current standard shall be carefully considered for aged asset over 50 years old. This is because failure of an aged strain support structure will likely trigger a cascading event which is costly to restore, and the restoration is a lengthy process (Stayed timber structures designed to the legacy C(b)1 Standard will meet AS/NZS7000 requirements by default).

1.2 Acronyms

Acronym	Definition
ACD	Anti-Climbing Device
C&M	Construction and Maintenance Conditions
DC	Double Circuit
FCC	Failure Containment Conditions
FCL	Failure Containment Load
FPBW	Full Penetration Butt Weld
ILAC	International Laboratory Accreditation Corporation (Mutual Recognition Arrangement)
MC	Multi Circuit - Triple or more
NATA	National Association of Testing Authorities Australia
NOC	Normal Operating Conditions
OHEW or EW	Overhead Earthwire
OPGW	Optical Fibre Ground Wire
RP	Return Period
RSL	Residual Static Load
SC	Single Circuit
SLC	Special Load Conditions
SCL	Short Circuit Load
SLS	Serviceability Limit State
ULS	Ultimate Limit State
UV	Ultraviolet Light
WP	Western Power

1.3 Definitions

For the purpose of this standard, the definitions and notations given in AS/NZS 1170.2:2011 (appendix B), AS/NZS 7000 (clause 1.4), ASCE 10-2015 (clause 1.3), ASCE/SEI 48-11 (clause 3) and AS/NZS 4676:2000 (clause 1.4) shall apply. The definitions below are some of the key terms used in this standard:

Term	Definition
Country	Open space area or zone with low population density where easement width is not normally restricted.
Foundation	The lowest load-bearing part of a structure or stay that is typically below ground level. It includes the structure to foundation interface elements such as the anchor bolts, tower stubs and the buried shaft of a pole or a rod.
Importance level	The importance level of a structure/building is determined by the level of consequence of failure considering both its occupancy and use as described in AS/NZS 1170.0, Table F1.
Line	An overhead transmission line system comprising of supports, foundation, conductor and insulator components.
Longitudinal winds	For a structure without line deviation, this is the wind that blows parallel to the line direction. For an angle structure, this is defined as the wind that blows perpendicular to the bisector of the line.
Metro	Built up area or zone with high population density where easement width is normally limited.
Normal operating conditions	The conductors are intact and operating at normal conditions (e.g. without being subject to breakage, fatigue, construction or maintenance).
Oblique wind	For a structure without line deviation, this is the wind that blows at an angle to the transverse line direction. For an angle structure, this is defined as the wind that blows at an angle to the bisector of the line.
Return period	The return period indicates the average occurrence of a climatic event having a defined intensity (e.g. a wind speed of 39m/s in the Region A of Australia has a return period of 50 years).
Security level	Line security is referred to as the line's ability to withstand a catastrophic loss, particularly a cascade failure. The security level of an overhead line is based on the lines importance to the overall system, and shall be in line with AS/NZS 7000, Section 6.2.2.
Serviceability limit state	The defined damage limit of the component which if exceeded will result in permanent damage to the component (and system).
Stop structure	A designated support structure, typically a strain structure, designed to stop and limit propagation of a cascading event.
Transverse wind	For a structure without line deviation, this is the wind that blows perpendicular to the line direction. For an angle structure, this is defined as the wind that blows parallel to the bisector of the line.
Ultimate limit state	State beyond which the structure, components and elements no longer satisfies the design performance requirements.
Wire	Conductors, overhead and underslung earthwires, stays and cables attached to a structure

1.4 References

References which support implementation of this document

Table 1.2 References

Reference No.	Title
AS/NZS 7000:2016	Overhead line design – Detailed procedures
AS/NZS 1170.0:2002	Structural design actions – General principles
AS/NZS 1170.2:2011 (R2016	Structural design action – Wind actions
AS/NZS 1170.4:2007 (R2018)	Structural design action – Earthquake actions in Australia
ASCE 10-15	Design of Latticed Steel Transmission Structures
ASCE/SEI 48-11	Design of Steel Transmission Pole Structures
AS 1328.1:1998	Glued laminated structural timber – Performance requirements and minimum production requirements
AS 1604.1:2012	Specification for preservative treatment – Sawn and round timber
AS 1720.1:2010	Timber structures – Design methods
AS 1720.2:2006	Timber structures – Timber properties
AS 2082:2007 (R2017)	Timber – Hardwood - Visually stress-graded for structural purposes
AS/NZS 2878:2000 (R2017)	Timber – Classification into strength groups
AS 3818.11:2009	Timber – Heavy structural products – Visually graded –Utility poles
AS 1379:2007 (R2017)	Specification and supply of concrete
AS 3600:2018	Concrete structures
AS/NZS 4065:2010	Concrete utility services poles
AS 1111.1:2015	ISO metric hexagon bolts and screws – Product grade C - Bolts
AS 1112.1:2015	ISO metric hexagon nuts – Style 1 – Product Grade A and B
AS 1112.3:2015	ISO metric hexagon nuts – Product Grade C
AS/NZS 1214:2016	Hot-dip galvanized coatings on threaded fasteners (ISO metric coarse thread series) (ISO 10684:2004, MOD)
AS/NZS 1252.1:2016	High-strength steel fastener assemblies for structural engineering - Bolts, nuts and washers - Technical requirements
AS/NZS 1252.2:2016	High-strength steel fastener assemblies for structural engineering - Bolts, nuts and washers - Verification testing for bolt assemblies
AS 1275:1985 (R2017)	Metric screw threads for fasteners

AS 1391:2007 (R2017)	Metallic materials – Tensile testing at ambient temperature
AS/NZS 1554.1:2014	Structural steel welding – Welding of steel structures
AS/NZS 1554.5:2014	Structural steel welding – Welding of steel structures subject to high levels of fatigue loading
AS/NZS 1554.7:2014	Structural steel welding – Welding of sheet steel structures
AS 1559:2018	Hot-dip galvanized steel bolts with associated nuts and washers for tower construction
AS 1657:2018	Fixed platforms, walkways, stairways and ladders – Design, construction and installation
AS 1881:1986 (R2018)	Zinc alloys – Casting ingots and castings – Quality requirements
AS/NZS 1891.4:2009	Industrial fall-arrest systems and devices - Selection, use and maintenance
AS 2159:2009	Piling – Design and installation
AS 2312.1:2014	Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings - Paint coatings
AS/NZS 2312.2:2014	Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings-Hot dip galvanizing
AS/NZS 3678:2016	Structural steel – Hot rolled plates, floor plates and slabs
AS/NZS 3679.1:2016	Structural steel – Hot rolled bars and section natural.
AS 3990:1993 (R2016)	Mechanical equipment - Steelwork
AS 4100:1998 (R2016)	Steel Structures
AS/NZS 4671:2019	Steel for the reinforcement of concrete
AS 4291.1:2015	Mechanical properties of fasteners made of carbon steel and alloy steel - Bolts, screws and studs
AS 6947:2009 (R2019)	Crossing of waterways by electricity infrastructure
AS/NZS 4680:2006 (R2017)	Hot-dip galvanized (zinc) coatings on fabricated ferrous articles
AS/NZS 5131:2016	Structural steelwork—Fabrication and erection
AS 5577-2013	Electricity network safety management systems
AS ISO 13822-2005 (R2016)	Basis for design of structures - Assessment of existing structures (ISO 13822:2001, MOD)
ASTM A572/A572M-15	Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
DIN 267-26 (2005-12)	Technical delivery conditions for fasteners - Part 26: Conical spring washers for bolt/nut assemblies
ENA DOC 015-2006	NATIONAL GUIDELINES FOR PREVENTION OF UNAUTHORISED ACCESS TO ELECTRICITY INFRASTRUCTURE

2. Safety In Design

The transmission line loading and support structure design must consider all safety aspects that can arise from the construction, operation, maintenance and decommissioning of the transmission line and other activities within the line corridor.

The Transmission Line Loading and Support Structure Design Hazard Management Register (HMR)[1] captures and document what risks have been controlled by this standard, and what residual risks may remain that should be considered at the project design stages and construction.

Every design is required to have its own project specific Hazard Management Register.

3. Functional Requirements

The design of transmission line system including the support structure shall be fit for purpose by satisfying the following aspects:

1. the electricity supply security and reliability level
2. constructability, durability, serviceability and maintainability
3. structural, electrical, mechanical and environmental performance
4. safety in design
5. value for investment (whole of life cost)

4. Design Philosophy

4.1 Line Reliability

4.1.1 Design Return Period

The reliability requirements for lines or line sections shall be based on their importance (number of connected customers, value of assets), security, ease to restore, and function. Transmission line, its components and elements shall be designed by considering a selected security level (AS/NZS 1170.0), design working life, and exposure to climatic conditions in accordance with Table 4.1. This shall also be the basis for durability requirements and material design standards.

Table 4.1: Minimum design wind return period

Transmission line type and work	Security level	Design/ working life	Design return period	Chance of failure in a given year	Reliability over design life*
Line work over extended period, temporary line and emergency restoration structures.	Level II	Less than 6 months	10 years	10%	94.9%
		Less than 12 months	50 years minimum	2%	98.0%
• Timber pole lines ≤132 kV • Any other type of transmission line < 66 kV[2]	Level II	50 years	100 years	1%	60.5%

[1] See Western Power internal document.

[2] Transmission line structures below 66kV are rare, but in such a case, the structures shall be designed according to Table 4.1

Transmission line type and work	Security level	Design/ working life	Design return period	Chance of failure in a given year	Reliability over design life*
All other transmission lines: • Timber pole lines >132 kV • Any other type of transmission line ≥ 66 kV	Level III	50 years	200 years	0.5%	77.8%

**Refer to Western Power internal document for weather based reliability calculations.*

4.1.2 Line Security Level

All transmission lines shall be designed to a minimum security level II, due to the higher consequences of failure on the network (when compared to a distribution line) in an attempt to better secure the line supply.

Timber pole lines above 132kV[3] and any type of transmission line 66kV or above must be designed to a higher reliability, security level III and a minimum design wind return period of 200, because the collapse of a line in this category can cause elevated risk to life, significant economic loss to the community and business.

A higher security level (i.e. security level III), design working life and design return period for lines or sections of lines shall be considered at the following situations:

1. Lines servicing a building of importance level of 3 or higher in accordance with Table F1 of AS/NZS 1170.0.
2. Zone supply system with limited contingency where affected facilities house life support customer (LSE)
3. Zone supply system with limited contingency where affected facilities lost time cost is significant
4. Sites with difficult or limited access within built up zone, isolated, sensitive, protected or restricted areas where extra time, effort and cost is required to restore or refurbish the line.

Customer funded lines NOT forming part of the Western Power network must be designed based on the design life of the customer's establishment and to level II security as a minimum. For a different design working life and line security level, the minimum design return periods shall be selected from Table 6.1 of AS/NZS 7000.

All temporary lines with design working life greater than 12 months shall be designed as permanent lines to limit the chance of failure[4] as well as to accommodate the possibility of being used as a permanent line in the future.

If costs are justifiable, existing lines shall be upgraded in parts or stages to meet the latest overhead transmission line design standards.

[3] Timber pole lines above 132kV do not exist in the Western Power network currently. However, in the future, if timber lines above 132kV are built, they shall comply with Table 4.1.

[4] For lines of shorter design life, even with lower wind return periods, the reliability is higher. However, the wind return periods must not be reduced, because it will increase the chance of structure failure in any given year (Refer to Western Power internal document).

4.2 Limit State Design

The loading and strength requirements of transmission line supports and foundations shall be based on the limit state concepts. All support structures shall be designed for both ultimate limit states (ULS) and serviceability limit states (SLS) with the following general limit state design equation for overhead lines:

$$\varphi R_n > (W_n + \sum(\gamma_x X))$$

Where

φ	=	the strength reduction factor which takes into account variability of material, workmanship etc.
R_n	=	the nominal strength of the component
X	=	the applied loads pertinent to each loading condition
γ_x	=	are the load factors which take into account variability of loads, importance of structure, stringing, maintenance and safety consideration etc.
W_n	=	wind load based on selected return period wind or a specified design wind pressure.

The limit state equation requires the design loads to be less than the design strengths.

5. Design Load

5.1 Actions on Lines

Structures and components may be subjected to concurrent loadings (actions) during their service life as listed below:

1. Wind loads (W_n): this shall be calculated in accordance with Appendix B of AS/NZS 7000 and AS/NZS 1170.2 as required, and applied to all elements of a structure.
2. Dead loads (G_c & G_s): G_c is the weight of conductors, while G_s is the weight of support structures, cross-arms, insulators and other equipment.
3. Live loads (Q): the weight of line workers and equipment in motion during construction.
4. Everyday tension (F_{te}): the horizontal component of a conductor tension in the direction of the conductor alignment under no wind condition.
5. Wind tension (F_{tw}): the horizontal component of conductor tensile forces in the direction of the conductor alignment under the influence of wind loads.
6. Failure containment tension (F_b): the steady state conductor horizontal tension due to conductor breakage.
7. Maintenance tension (F_{tm}): the unfactored conductor horizontal tension due to the expected wind loads during construction or maintenance.

5.2 Load Conditions

The following load conditions and events and their combined actions on lines shall be considered:

Table 5.1: Transmission line load conditions, events and combined actions

<table>
<tr><th>Limit state</th><th>Load conditions</th><th>Events</th><th>Combined actions</th></tr>
<tr><td rowspan="3">ULS</td><td rowspan="2">Normal Operating Condition (NOC)</td><td>Synoptic wind
Downdraft wind</td><td>Refer to Section 5.3.1</td></tr>
<tr><td>Tornado</td><td>Refer to Section 5.3.2</td></tr>
<tr><td>Failure Containment Condition (FCC)</td><td>Synoptic wind
Downdraft wind</td><td>Refer to Section 5.3.3</td></tr>
<tr><td rowspan="4">SLS</td><td>Construction and Maintenance (C&M)</td><td>General maintenance, dropped conductors, stringing, stringing stations, others</td><td>Refer to Section 5.4.1</td></tr>
<tr><td>Deflection and damage</td><td>Everyday/service wind</td><td>Refer to Section 5.4.2</td></tr>
<tr><td>Fatigue</td><td colspan="2">Refer to Section 5.4.3</td></tr>
<tr><td>Electrical/ Environmental/ Minimum temperature</td><td colspan="2">Refer to Western Power internal document.</td></tr>
<tr><td>ULS</td><td>Special Load Cases (SLC)</td><td>Short circuit force, earthquake, soil instability, liquefaction, avalanches and creeping snow load, vehicle impact, flood, river scour, tidal wave etc.</td><td>Refer to Section 5.5</td></tr>
</table>

Environmental and electrical design inputs are excluded from this standard. Relevant component design standards shall be referred to for this matter. Impacts of undulating terrain, steep slope and uneven span shall be considered.

5.3 ULS Load Conditions and Actions ULS

5.3.1 Synoptic and Downdraft Winds

The normal operating conditions shall be designed for synoptic (cyclonic) and downdraft wind actions stated in clause 7.2.2a of AS/NZS 7000 with the following specific requirements in different wind regions A, B, C and D:

1. The wire tension shall be determined after creep at the average steady state wire temperature over the coldest month that coincides with the maximum wind. The wire temperature for a new line shall be 15ºC in absence of reliable weather and ampacity data. Effects of aerial markers and bird deterrents, if any, shall be included. Refer to *Western Power internal document* for in service conductor steady state temperature survey and calculation methods.
2. In lieu of a more accurate analysis (e.g. 3D modelling), the wind pressure on wires shall be based on the average wires attachment elevation.

3. The design wind speed shall be determined from the regional wind map of Australia (Figure 3.1A and Table 3.1 of AS/NZS 1170.2) unless local meteorological data records warrant a higher value.
4. In the tropical cyclone regions C and D, downdraft wind is not applicable. Cyclonic wind amplification factors in Table 3.1 of AS/NZS 1170.2 is set to 1.0 based on line performance (Section B3 of AS/NZS 7000).
5. The transverse and oblique winds shall be applied at an angle of 0º, ±22.5º, ±45º, ±67.5º and ±90º to the transverse axis of the structures within wind region A and B.
6. The transverse, oblique and longitudinal winds shall be applied at an angle of 0º, ±15º, ±30º, ±45º, ±60º, ±75º and ±90º to the transverse axis of structures within wind region C, D and in cases where the design wind speed is in excess of 59 m/s.
7. The directional and shielding multipliers shall be 1.0 unless cardinal winds have been modelled and analysed.
8. The topographic multipliers shall be in accordance with clause 4.4 of AS/NZS 1170.2 and shall allow for effects of wind channelling by applying uneven wind load on adjacent spans. Angle of incidence and applicable wind span shall be specific for channelling and funnelling wind.
9. The span reduction factor and tension span reduction factors for synoptic and downdraft winds shall be in accordance with clause B5.4.1 and B5.4.2 of AS/NZS 7000.
10. Drag coefficient for structural elements shall be in accordance with clause B5 of AS/NZS 7000.
11. Wind laboratory modelling or computer aided 3-dimensional surface flow analysis in conjunction with local meteorological data are acceptable methods for site specific wind studies.
12. Western Power support structures shall be designed with the normal operating load factors and combinations in Table 5.2.

Table 5.2: NOC load factors and combinations

Case	Load combinations	Load factors
1	Vertical maximum[1]	$ØR_n > 1.0*W_n + 1.1*G_s + 1.25*G_c + 1.25*F_{tw}$
2	Vertical minimum[1]	$ØR_n > 1.0*W_n + 0.9*G_s + 0.9*G_c + 1.25*F_{tw}$

[1] Vertical loads can be downward or upward depending on the elevation of adjacent support structures.

13. All terminal structures shall be designed for the maximum wind loads with or without wires on the adjacent spans by assuming:
    (i) fully strung conductors and earthwire(s) on one transverse face of the structure
    (ii) all wires intact
14. The worst case termination scenario shall be considered for non-conventional circuit arrangements e.g. a multi circuit lines or a terminal structure with auxiliary arms.
15. All structures intended for earthwire and/or underslung termination shall be designed for the maximum wind loads by assuming:
    (i) fully strung earthwire(s) and/or underslung on one transverse face of the structure with all other conductors intact
    (ii) all wires intact

5.3.2 Tornadoes

The normal operating conditions shall be designed for Tornado winds. Tornado winds shall be determined in accordance with clause 7.2.2b of AS/NZS 7000 with the following specific requirements:

1. This wind load is applicable only for lattice structures of Level III security level, between -25º to -35º latitude south of Western Australia.
2. The design wind on structures shall be 60m/s (clause B4.3.2 of AS/NZS 7000) without any multipliers.
3. The wire tension shall be derived after creep at the average steady state wire temperature over the coldest month under no wind condition. The temperature shall be 15ºC in absence of reliable weather and ampacity data.
4. The transverse, oblique and longitudinal winds shall be applied at an angle of 0º, ±22.5º, ±45º, ±67.5º and ±90º to the transverse axis of the structure.
5. Torsional wind (a separate load case centred at the structure vertical axis) shall also be applied to lattice structure wider than 15m.

The load combinations and load factors shall be in accordance with Table 5.2

5.3.3 Failure Containment Conditions

The failure containment loads (FCL) under synoptic and downdraft conditions shall be derived in accordance with clause 7.2.2b of AS/NZS 7000 with the following specific requirements:

1. All supports, foundations, crossarms, earthwire peaks and wire attachment members shall be designed for failure containment loads in accordance with Table 5.3.

Table 5.3: FCL application

Line Type	Applicable Structure or Element
≤ 132kV line section and conductor supported on post insulators	Strain structure, Crossarm[1]
All other lines excluding temporary lines	All
Temporary lines	Not applicable

2. Post insulators within a 132kV (or less) line section are not required to be designed for the failure containment loads. However, stop/strain structures shall be put in place in accordance with Section 6.4.3. All strain structures and fixed base crossarms of intermediate supporting structure must be capable of sustaining the failure containment load[5]. Swing-able arm or braced post must be able to relieve the load in a controlled manner.
3. Both suspension and strain structures of all other line sections greater than 132kV (excluding temporary) lines must be designed for failure containment.
4. Temporary lines or structures with design life less than 12 months are not required to be designed for failure containment.

[5] Crossarm may warp or break, especially if its cantilever length is in excess of 3m, and its load rating is below the FCL. This is not a preferred failure mode due to the expected longer structure repair time versus replacing the post insulator

5. The wire tension shall be determined after creep at the average steady state wire temperature over the coldest month that coincides with the maximum wind. The temperature shall be 15ºC in absence of reliable weather and ampacity data.
6. The wind pressure shall be of 0.25 times the ultimate limit state wind pressure.
7. The transverse winds shall be applied normal to the wire and transverse axis of the structures within wind region A and B.
8. The transverse, oblique and longitudinal winds shall be applied at an angle of 0º, ±22.5º, ±45º, ±67.5º and ±90º to the transverse axis of the structures within wind region C, wind region D and where the design wind speed is in excess of 59 m/s.
9. The failure containment load factors for all loading combinations shall be in accordance with Table 5.4 of AS/NZS 7000 as stated below:

Table 5.4: FCC load factors

Load factor
$ØR_n > 0.25*W_n + 1.1*G_s + 1.25*G_c + 1.25*F_{tw} + 1.25*F_b$

10. The conductor weight (G_c) includes weights of the intact and dropped conductors. The dropped conductor weight may be ignored provided the structure was designed for the stringing scenarios in accordance with Table 5.10 and the adjacent spans are on flat terrain.
11. Span reduction factor and tension span reduction factor shall apply to conductor in accordance with clause B5.3 AS/NZS 7000.
12. The residual static load conductor tension (7.2.7.1.5 of AS/NZS 7000) shall be calculated as per Table 5.5 unless otherwise determined using numerical analysis.

Table 5.5: RSL tension

Insulator string	Conductor	RSL tension
Suspension (≥ 1.0m length of free swing insulator, bracket system or arm)	Phase	$F_b = 0.7 \times F_{tw}$
All other insulators	Phase, OHEW or OPGW	$F_b = 1.0 \times F_{tw}$

13. The failure containment loading combinations shall be checked as follows:

Table 5.6: FCC load combinations

Support type	Number of circuits	Broken conductor combinations
Suspension	Single	Any one earthwire/underslung OR any one phase.
Strain	Single	Any one earthwire/underslung and one phase.
Suspension or Strain	Double or more	Either any two phases in the same span, or any one earthwire/underslung and one phase

Support type	Number of circuits	Broken conductor combinations
Legacy suspension or strain designed to C(b)1 for cut in to existing line designed to C(b)1	Double or more	Either one phase from each circuit in the same span (total broken phase to be 2 maximum), or any one earthwire/underslung and one phase in the same span Project specific load combinations may be used to match the design of existing towers
Termination	Any	Refer Section 5.3.1

5.4 SLS Load Conditions and Actions

5.4.1 Construction and Maintenance Conditions

5.4.1.1 General

The construction and maintenance loads shall be derived in accordance with clause 7.2.5 of AS/NZS 7000 with the following specific requirements:

1. Depending on the duration and magnitude of applied load on the conductor or earthwire/underslung, its in-situ tension shall be adjusted for creep and average steady state temperature over the period considered.
2. A maximum soaking (resting on sheaves) period of 12 and 24 hours shall be assumed for a pole and a tower structure respectively when calculating initial stringing tension of a new conductor or earthwire/underslung when specific stringing methodology is unknown. The required minimum soaking period shall be specified in the construction manual.
3. In the absence of reliable weather (and ampacity if relevant) data, an average steady state wire temperature of 15ºC shall be assumed.
4. The transverse winds shall be applied normal to the wire and transverse axis of structures subject to wind pressure of 500 Pa or less.
5. In the event construction exposure period is more than 2 weeks, the transverse, oblique and longitudinal winds shall be applied at an angle of 0º, ±22.5º, ±45º, ±67.5º and ±90º to the transverse axis of the structures subject to the ultimate wind pressure.
6. The construction and maintenance wind load, W_m shall be in accordance with
7.
8. Table 5.7:

Table 5.7: C&M Wind Load

Exposure Period[1]	Wind Region A & B	Wind Region[2] C & D
≤ 5 days	100 Pa (without any reduction factors)	200 Pa (without any reduction factors)
≤ 2 weeks	200 Pa (without any reduction factors)	500 Pa (without any reduction factors)
Other	Design for ultimate wind in accordance with Table 4.1: Minimum design wind return period and Table F1 of AS/NZS 1170.2.	

[1] Exposure period of the line component being worked on.

[2] Or when regional ultimate design wind is in excess of 59m/s.

9. Effects of extreme weather conditions forecast during construction or maintenance periods shall be considered. Appropriate weather monitoring and contingency plan shall be put in place before commencing construction and maintenance work.
10. When a strain (or suspension) structures is required for a short termination period (i.e. for ease of stringing operation), it shall be designed for the expected construction exposure period.

5.4.1.2 Work on conductor

1. The load factors and load combinations for all work relating to conductor or earthwire/underslung shall be in accordance with Table 7.3 of AS/NZS 7000 as stated below:

Table 5.8: C&M Load Factors

Load Factors
$\O R_n > 1.0W_m + 1.1*G_s + 1.50*G_c + 1.5*F_{tm} + 2.0*Q_m$

2. The general construction and maintenance live loads, Qm loading combinations shall be as given in Table 5.9:

Table 5.9: C&M live loads

Load combinations	Live loads, Q_m
Maintenance – General (wire clamped) or Construction – Installing Sheaves (wire clamped)	• Tension of existing intact wire being drawn to release from clamps or attachments. • Weight of phase conductor, earthwire, insulators, sheaves, running boards, aerial markers and bird deterrents. • Unfactored loads related to line maintenance/construction personnel including tools and equipment: Pole crossarm, 3kN Pole EW peak or arm, 3kN Suspension Tower crossarm, 4kN Strain Tower crossarm, 9kN Tower EW peak or arm, 3kN Step bolt, 1.5kN • Factored fall arrest load at attachment point, 15kN. This value shall be 12kN (factored) in case of earthwire/OPGW attachment point.
Maintenance – Dropped conductor (wire clamped)	• Refer Section 5.3.3 • Safety features if any e.g. hurdles and scaffoldings shall be designed for the impacts.
Construction – Stringing (wire on sheaves)	• Tension of wire being drawn. Effects of site specific puller or tensioner position and extreme weather events shall be considered. • Weight of phase conductor, earthwire, insulators, sheaves, running boards. • Factored fall arrest load at attachment point, 15kN. This value shall be 12kN (factored) in case of earthwire/OPGW attachment point.
Construction – Dropped/ Lowered conductor (wire on sheaves)	• Load from this event is not critical on support structure. However, safety features if any, e.g. hurdles and scaffoldings, shall be designed for the impacts. Relevant technical specifications or construction guidelines shall also be referred to for treatment of dropped wire in contact with ground or water bodies etc.

3. As a minimum, the stringing sequences and scenarios given in Table 5.10 shall be allowed for in the design of support structures:

Table 5.10: C&M stringing sequences and scenarios

Structure Type	Stringing sequences and scenarios
Suspension	SC – Top to bottom phase and from left to right. DC – Top to bottom phase on circuit 1 then circuit 2. MC – Project specific. <u>General</u> Assume individual phase conductor or earthwire is in turn strung continuously pass adjacent structure, then transferred from sheave onto clamp. <u>Adjacent to a stringing station</u> Assume individual phase conductor or earthwire is in turn drawn past the support, then dead-ended onto an adjacent strain support. The puller/tensioner shall be stationed along the back/ahead span center line projection and the maximum inclination of the conductor being worked on shall be at 1:6 slopes when connected to the puller/tensioner.
Strain[1]	SC – Top to bottom phase and from left to right. DC – Top to bottom phase on circuit 1 then circuit 2. MC – Project specific. <u>Adjacent to a stringing station</u> Assume individual phase conductor or earthwire is in turn drawn past the support, then dead-ended onto the support with a temporary back stay attached to the phase. The stay shall be inline and anchored to the ground at 1:4 slopes. The puller/tensioner shall be stationed along the back/ahead span centre line projection and the maximum inclination of the conductor being worked on shall be at 1:4 slopes when connected to the puller/tensioner.
Terminal Strain	SC, DC, MC - Top to bottom phase and from left to right. <u>Adjacent to a stringing station</u> Assume individual phase conductor or earthwire on one side/span of the supports is in turn drawn past the support, then terminated onto the support without intact wire on the other side/span. The puller/tensioner shall be stationed along the back/ahead span center line projection and the maximum inclination of the conductor being worked on shall be at 1:4 slopes when connected to the puller/tensioner.

[1] Includes inline strain structures, stop structures and heavy strain structure without full termination capabilities.

4. Support structure shall also be designed for critical site specific and project specific erection methods and construction sequences not covered by the tables above. This shall include any temporary modifications made to support structure to enable stringing work and any suspension structures being converted to strain or used temporarily as a section end structure during stringing. Resultant loads from concurrent stringing of two phases or stringing loads from a helicopter if any shall also be allowed for.

5.4.2.3 Other Construction or maintenance work

1. The load factors and load combinations for all other construction or maintenance work on support structures, which has little or negligible impact on the conductor or earthwire/underslung tension, shall be in accordance with Table 5.11. This may include structural member replacement, foundation refurbishment, partially completed structures and the like while the support is temporarily braced in place.

Table 5.11: C&M Load Combinations - Other

Case	Load combinations	Load factors
1	Vertical maximum[1]	$ØR_n > 1.0*W_m + 1.1*G_s + 1.25*G_c + 1.25*F_{tw}$
2	Vertical minimum[1]	$ØR_n > 1.0*W_m + 0.9*G_s + 0.9*G_c + 1.25*F_{tw}$

[1] Vertical loads can be downward or upward depending on structure position.

2. All temporary modifications made to a support, or any temporary attachments added to a support to enable construction work, shall be designed as an integral element of the support.
3. All detached or standalone temporary structures (excluding plants and machinery) shall be designed for the expected construction period and loadings in accordance with relevant material design standards and safety manuals.
4. Unless otherwise specified by the manufacturer, haulage and lifting of supports or sections shall be designed by assuming a live load equal to 1.5 times the weight.
5. All damages to support elements and substandard materials discovered during construction shall be reported for assessments in accordance with provisions of the relevant construction specifications.
6. Defects in support elements, identified during maintenance, shall be assessed in accordance with defect catalogues, asset serviceability assessment methods and guidelines as relevant.

5.4.2 Deflection and Damage Conditions

The deflection and damage limits loadings shall be derived as per clause 7.4.2 of AS/NZS 7000 with the following specific requirements:

1. The wire tension for structural loading and preset calculations shall be determined after creep at the average wire steady state temperature over the coldest month under service wind conditions. The temperature shall be 15ºC in absence of reliable weather and ampacity data.
2. The wire tension for clearance calculations shall be determined after creep at the average steady state temperature of wire over the coldest and warmest month under service wind conditions. Parabolic equations shall not be used to evaluate sag. The design temperatures and tension model shall be in accordance with *Western Power internal document.*
3. The transverse winds shall be applied normal to the wire and transverse axis of the structures subject to wind pressure of 500 Pa or less.

4. The transverse, oblique and longitudinal winds shall be applied at an angle of 0º, ±22.5º, ±45º, ±67.5º and ±90º to the transverse axis of the structures subject to wind pressure in excess of 500 Pa.
5. The design wind for deflection limit (W_s), also referred to as the everyday wind , and the damage limit (W_d) shall be as follows:

Table 5.12: Serviceability Limit State Design Wind

Wind Region	Deflection Limit Design Wind /Everyday Wind (W_s)	Damage Limit Design Wind (W_d)
A	100 Pa (without any reduction factors)	500 Pa (without any reduction factors)
B		0.5Wn[1] or 500 Pa (without any reduction factors)
C	200 Pa (without any reduction factors)	0.5Wn
D		

[1] Half maximum wind pressure. Required when local wind pressure is amplified significantly in excess of 500 Pa after allowing for span reduction factors.

6. The load factors and load combinations for deflection and damage limits shall be in accordance with Table 7.3 of AS/NZS 7000 as stated below:

Table 5.13: Deflection and Damage Limits Load Combinations

Case	Load combinations	Load factors
1	Deflection	$ØR_n > 1.0W_s + 1.1*G_s + 1.1*G_c + 1.0*F_{tw}$
2	Damage	$ØR_n > 1.0W_d + 1.1*G_s + 1.1*G_c + 1.0*F_{tw}$

5.4.3 Fatigue

Fatigue is assessed for steel structures and components only.

The service loadings shall be used in fatigue assessments. Detailed fatigue assessments are not required for a steel member or connection, if the stress ranges and cycles satisfy Clause 11.4 of AS 4100.

Without site (dynamic) wind data, the following can be assumed:

1. Design spectrum equivalent to the Gaussian spectrum with 10 million cycles (over 50 years) under a maximum stress of 500 Pa wind (or 0.5Wu in wind region B, C, D) for a strain support.
2. The equivalent cycles can be reduced to 5 million for a suspension support.

5.5 ULS Special Load Conditions

5.5.1 General

Special loads stated in clause 7.2.4 of AS/NZS 7000 and other site specific events shall apply to Western Power transmission line supports and foundations as per the following table:

Table 5.14: Special load event design requirements

Case	Load events	Application
1.	Short circuit force	This force shall only be applied to the structures or elements supporting a slack section (Clamped tension ≤ 5% CBL at 15ºC without wind) up to 0.5 km from a substation. The foundation is not required to be designed for this type of loading.
2.	Earthquake load	This type of load is only relevant to structures supporting heavy equipment in earthquake prone zones or structures within a substation that is designed for earthquake load.
3.	Avalanche and creeping snow load	This type of loading is not required to be considered since such weather is not relevant to the Western Australian climate. Refer *Transmission Lines Electrical and Mechanical Design Standard* for minimum temperature load on conductor.
4.	Soil instability, liquefaction, moving object impact, flood, river scour, tidal wave etc.	These events shall only be considered in design of transmission structures and foundations where relevant. Suitably qualified personnel shall be engaged to conduct a risk analysis and provide a design solution in the relevant fields.

5.5.2 Short Circuit Loads

The short circuit loading shall be applied to transmission support structures as per Appendix C2 of AS/NZS 7000 with the following specific requirements:

1. The wire tension of the phase(s) shall be determined after creep at the average steady state wire temperature over the coldest month that coincides with the maximum wind. The temperature shall be 15ºC in absence of reliable weather and ampacity data.
2. A nominal wind pressure of 0.25 times the ultimate limit state wind pressure shall be considered
3. The transverse winds shall be applied normal to the wire and transverse axis of the cross arm for structures within wind region A and B.
4. The transverse, oblique and longitudinal winds shall be applied at an angle of 0º, ±22.5º, ±45º, ±67.5º and ±90º to the transverse axis of the structures within wind region C, wind region D and where the design wind speed is in excess of 59 m/s.

5. The short circuit load factors for all loading combinations shall be derived from Equation C1 of AS/NZS 7000 as stated in Table 5.15:

Table 5.15: SCL Load Factors

Load Factors
$ØR_n > 0.25*W_n + 1.1*G_s + 1.25*G_c + 1.25*F_t + 1.25*F_{sc}$

5.5.3 Seismic Loads

In rare circumstances (refer Table 5.14, case 2), the earthquake loadings shall be applied to transmission structures and foundations in accordance with Appendix C4 of AS/NZS 7000 and AS 1170.4 with the following specific requirements:

1. The wire tension shall be determined after creep at the average steady state wire temperature over the coldest month under everyday wind condition. The temperature shall be 15ºC in absence of reliable weather and ampacity data.
2. Both the vertical and horizontal ground accelerations (in transverse, longitudinal and diagonal directions) shall be considered.
3. In lieu of a detailed numerical analysis, the seismic load factors for all loading combinations shall be in accordance with Table 5.16 for the primary mode of vibration for structures less than 30m tall. Damping effects from the conductors if any are not required to be considered.

Table 5.16: Seismic load factors

Case	Load combinations	Load factors
1	Vertical maximum	$ØR_n > 1.3*(G_s + G_c) + 1.25*F_{te}$
2	Vertical minimum	$ØR_n > 0.8*(G_s + G_c)$
3	Horizontal acceleration	$ØR_n > 1.0*(G_s + G_c) + 0.34*H_G$[1] $+ 1.25*F_{te}$

[1] Horizontal load equivalent to Gs + Gc

4. Clashing of structures or elements shall be avoided. The required electrical clearances shall be maintained under the most adverse movements.

5.5.4 Land Instability

Land instability includes naturally occurring or induced slips, subsidence and erosion.

Where there is a potential for land instability, the effects on the foundation shall be mitigated to safe guard the line and structure against ground movement. Translational, rotational and differential movements shall be limited such that the prestressing loads from these movements do not jeopardise the ultimate and serviceability load carrying capacity of the structure. In all cases the required electrical clearances shall be maintained.

The design shall be in accordance with established and proven geotechnical design practices. Reference shall be made to Appendix C5 of AS/NZS 7000.

5.5.5 Liquefaction

Liquefaction of loose saturated, cohesion-less soils (sands, silts and loose sandy gravels) shall be considered when designing support structures and foundations for earthquake load. Structure settlement in liquefiable soil shall be limited by extending the foundation into the stable soil layer or reposition the structure.

The design shall be in accordance with established and proven geotechnical design practices. Reference shall be made to Appendix C4.13 of AS/NZS 7000.

5.5.6 River Floodings

Structures positioned within a river bed shall be designed for additional loads due to water pressure, scour and debris build up for a minimum of 1 in 100 years flood event.

The limit state load combinations shall be superimposed with design flood impacts as follows:

Table 5.17: Flood impacts

Case	Load combinations	Flood impacts
1	Maximum Wind	General Scour + Peak Flow + Rolling Debris
2	Everyday Wind	Static Upstream Debris + Normal Flow + Total Scour Downstream

Unless specific studies are undertaken, non-navigable rivers with the following characteristics shall be assumed as a minimum:

1. Normal water depth 2m, flood depth 4m
2. Normal water velocity 3 m/s, flood water velocity 6 m/s
3. Debris raft (≤20mm diameter) on pile upstream 2m deep, 4m wide
4. General scour 2m, local scour 1.5m, total scour 3.5m
5. The pile/pole embedment depth shall be 6m.

Specific flood studies shall be carried out for all detailed designs. Impacts of tidal waves and water chemistry shall be considered.

5.5.7 Overland Floods

Overland floods shall be considered for catchment area below 1 in 20 years flood level. The design flood return period for structured within a substation (plus all adjacent structures within the extent of the flood area) shall be consistent with the substation design. The electrical clearance shall be maintained during a flood. The static water depth shall be considered in the foundation design.

5.5.8 Moving Objects / Mass

Western Power transmission line support structures are not required to be designed to sustain impacts from moving objects, however appropriate measures shall be put in place to reduce the likelihood or effects of such impacts. All auxiliary attachments or features added to the main structure shall be designed accordingly.

5.5.8.1 Watercraft

The impact potential from watercraft shall be considered for structures that are located within navigable waterways. Appropriate warning and/or protection shall be in accordance with AS6947, Section 3.3.

5.5.8.2 land Transport Vehicle

The placement of support structures near roads shall be in accordance with industry guidelines.

5.5.8.3 Hailstorms

Assessments shall be carried out on existing members (including dampers, marker balls, insulators and conductors) sustaining damages from the hail. All unfit members shall be replaced.

5.5.8.4 Other Moving Objects

Appropriate warning signs, deterrents or site management plans shall be put in place for areas prone to falling trees/branches/rocks, at construction sites, hunting or nesting grounds, near aircraft paths or where explosives are used nearby. The local authority shall be consulted and the legislation governing each activity referred to.

5.5.9 Arsons and Sabotages

Transmission line support structure and foundation are not required to be designed to sustain impacts form arsons or sabotages. However, adequate deterrents, such as fences, shall be considered in high risk areas in conjunction with other design aspects e.g. public safety. All auxiliary attachments or features added to the main structure shall be designed accordingly.

5.5.10 Other Hazards

Impacts from environmental and electrical hazards (e.g. lightning strikes, induction, termite attacks, airborne particles and bush fires) are covered in the relevant environmental and electrical standards.

6. Design of Support

6.1 General

The continuity of load paths between various components shall be maintained when exposed to the load events described in Section 5.2. The line and structure shall be stable under the imposed loads. As a minimum, all external loads on a strain or terminal structure shall be evaluated assuming a rigid structure and foundation. All components design model assumptions shall be documented.

Safety in design, constructability, maintainability, quality controls, risks and opportunities management form integral part of the supports design. Their requirements are beyond the scope of this standard.

6.2 Strength Coordination

Western Power does not impose a specific strength coordination model between transmission line components other than the mandated strength reduction factors for each component or element depending on the relevant material design standards in accordance with Table 6.2 of AS/NZS 7000.

In general, the failure sequence based on available resources in a push over analysis shall be a series of line component failures that constitute the least overall repair time and cost.

6.3 Common Supports

When multiple line circuits share a common support, the support and its adjacent sections shall be designed to the highest line security and reliability level. The credible contingency of a line network shall be evaluated when utilising a common support. As such, structures supporting both transmission and distribution circuits should be avoided.

Parallel circuits in vertical configuration are the preferred arrangement for a double circuit support for ease of maintainability, an important aspect of common supports.

6.4 Selection and Placement

Support selection and placement for normal line operation shall be optimised by considering physical, electrical, environmental and regulatory constraints by referring to relevant structural, electrical and environmental design standards or work practise manuals with the following additional requirements:

6.4.1 Support Type Selection

The general selection of various support types shall be in the following order starting with the least expected installed structure cost:

1. Light Suspension (intermediate structure)
2. Heavy or Angle Suspension
3. Light or Inline Strain
4. Heavy or Angle Strain
5. Terminal Strain

6.4.2 Restricted Zones

Supports at or within the following locations or zones shall be avoided whenever possible:

1. Area where design wind speed is in excess of 59 m/s
2. Marshland and basins or water catchment areas below 1 in 20 years flood level
3. Within 1 in 100 years flood zone of major waterways (e.g. rapids, streams, rivers, lakes, bays)
4. Highly corrosive environment – airborne and soil
5. Slip face, fault line and exposed terrain steeper than 1 in 2 slopes without any stabilisation work
6. Over underground services, tunnels or mines

7. Support footing less than 10 m from the banks of minor open drains, seasonal streams, spillways and other man-made water features
8. Support footing less than twice the vertical drop distance from the edge of a cliff, retaining wall or open mine
9. Support footing less than twice the liquefiable soil layer depth from the edge of an area with medium to high liquefaction risk
10. Support footing less than 5m from a commercial railway track[6] to minimise effect of soil disturbance near railway track during installation and maintenance.
11. Within isolated geological features accessible only by helicopter
12. Within the clear zone of primary highways (freeway) or motorways

Lines crossing the following areas shall be avoided:

1. Sections containing buildings of importance level of 3 or higher in accordance with Table F1 of AS/NZS 1170.0.
2. High security, protected or high commercial value zone where access is not normally granted
3. Built up (or proposed if known) zone without adequate access.

6.4.3 Anti-Cascading

Stop or anti cascading structure shall be positioned at 10–15 km intervals for a country line and between 3–6 km for a metro line to suit conductor drum length, stringing station locations, geological features and design solutions mentioned in Section 6.4.4.

Stop structures are not mandatory for temporary lines with design working life of 12 months or less. Supports designed as strain in accordance with this standard are deemed appropriate stop structure. Stop structure foundation shall be designed to exceed the support capacity to minimise repair costs.

6.4.4 Line Sections

All line sections shall start and end with a strain structure.

A shorter line section shall be positioned over areas prone to accelerated structural degradation and also where an extended construction or maintenance period will incur significant social economic costs or in some cases grievances.

[6] Transmission structure distance to railway track does not consider fall of structure onto track because of limited easement widths and construction corridors. This is acceptable considering that transmission structures are designed to a much higher reliability in comparison to distribution structures (Section 4.1).

Table 6.1: Reduced line section conditions and considerations

Crossing type	Conditions	No. of spans in a section	Section length
River crossing	Corrosive environment or navigable metropolitan waterway.	To suit	Length across the river plus up to 500 m each side of the riverbank.
Valley crossing and narrow channel	Subjected to funnelling wind or intensified aeolian vibration.	Between 1 to 3 spans	-
Carriageway/Freeway	Average daily traffic volume between 20,000 to 40,000	To suit	Up to 3 km
Carriageway/Freeway	Average daily traffic volume > 40,000	Up to 3 spans	-
Commercial Railway Line	Exclude miniature train and recreational tracks less than 5km long.	1	-

A design solution requiring conductor type or configuration change or its tension to be stepped up or down shall be joined to the adjacent section on a strain or termination structure. Undergrounding of a short line section shall be considered as part of the design solutions.

The minimum reliability, security and safety levels shall be maintained within each line section. Unless transposition or location specific support configuration is required, the suspension support structures configuration (top geometry) within a line section shall be consistent. The visual impacts of out of character configurations shall be minimised.

The total numbers of strain structures on a line shall be minimised by adjusting various sections start and end position. Stringing stations of parallel lines (including temporary lines) shall be synchronised as much as possible.

6.4.5 Terminal Supports

Terminal support structures shall be positioned at:

1. the entries into substations and where undergrounding of conductors is required.

Site conditions permitting, terminal support shall be installed at:

1. each end of a span crossing a commercial railway route
2. tee off (cut in cut out) junctions.
3. one or both sides of primary (national, interstate, or interregional) highways or motorway crossings to minimise disruptions to traffic during stringing operations.
4. locations where frequent and/or expedited construction works are required.
5. locations where stringing work has to be carried out on a free standing structure.
6. locations where design solution requires a step change in conductor tension ≥ 4% of conductor breaking load on a free standing structure (i.e.unstayed)

6.4.6 Emergency and Temporary Support

Selection and placement of emergency and temporary supports shall minimise the line construction and/or restoration period and disruptions to local activities. Conductor swing oscillation post wind actions towards parallel line shall be considered (Refer *Western Power internal document*).

6.5 Lattice Steel Towers

6.5.1 General

All supports shall be designed in accordance with ASCE 10-15 and Appendix G of AS/NZS 7000.

The support analysis and design shall be carried out by using conventional three dimensional linear elastic analyses (clause G1.1 of AS/NZS 7000).

Guyed structures shall require a second-order analysis.

The tower design shall comply with the ultimate limit state performance requirements without permanent deformation of any member or connection. No deflection limits are imposed on tower design, however clearance to external objects shall be checked based on the deflected shape as required.

6.5.2 Tower Geometry

A basic suspension support up to 70m tall should be capable of body height extensions of -6m, -3m, +3m and +6m from and in addition to the standard height (±0m) support. Other height extensions may be added or removed in step of 3m as required. All other support types shall have extension capabilities in 3m, 6m or 9m steps.

The top geometry shall conform to all electrical and maintenance clearance requirements. Line deviation shall be considered when designing insulator attachment points spacing for bundled conductors.

On sloping ground without benching, support bases shall be designed to accommodate individual leg extensions in 1m segment to enable optimum setting with minimal earthwork.

All self-supported lattice towers shall be designed with the same base width in the transverse and longitudinal direction. A tower body and leg slope (and external stay inclination for a guyed tower) shall be optimised to suit available or attainable easement width. The extent of foundation earthwork (e.g. pads adjacent to boundary line) shall be checked.

The heights of conductors, earthwires, crossarms, lowest main horizontal member and the `K’ point (outer most bolt hole on the stub jointed to the diagonal outline member) shall be measured to the datum natural ground level at the support centre peg.

Standard concrete leg encasement columns shall extend at least 150 mm above ground level and with at least a 30 mm or 1.5° watershed.

The `K’ point shall be 50-200mm from the top of concrete encasement or chimney to avoid conflict between the concrete and flange of K-bracing, and to limit the unbraced length of leg member.

6.5.3 Tower Bracing Patterns

A fully triangulated system of bracing shall preferably be adopted. If full triangulation is not adopted, the overall stability and secondary bending stresses shall be considered in the design.

Paired tension only cross braces (i.e. supports where the use of compression bracing members is avoided by provision of two sets of tension bracing members) are not acceptable.

For heavily loaded towers, the preferred brace method is to stagger redundant bracing members and connect the main bracing members on the adjacent faces at a common panel point.

Internal and external stays shall not be used on a terminal or strain tower (excluding temporary structure) to avoid structure deformation due to creep in stay.

6.5.4 Minimum Size of Steel Tower Members

The minimum thickness of material used for legs and all members below ground or within exposure class C region in accordance with Table D1 AS/NZS 7000 shall be 6 mm before galvanising.

The minimum thickness of steel above ground within exposure class B region shall be 5 mm.

All other members shall have a minimum thickness of 4 mm.

6.5.5 Tower Materials

All structural members shall be fabricated from hot rolled steel sections.

All members comprising the framework of the support shall be fabricated from hot rolled steel sections to AS/NZS 3679.1.

Plates shall be fabricated from hot rolled plate to AS/NZS 3678.

All material properties shall satisfy the Charpy V-notch test (impact) requirements as per Section 10 of AS 4100 to avoid brittle fracture. The basic design temperature shall not exceed the permissible service temperature.

All international steel shall comply with the requirements of AS/NZS 5131 construction category 3 (CC3).

The international fabrication standards shall be equivalent to the Australia Standards. Current international standards accepted by Western Power include the American, European and Chinese standards.

6.5.6 Surface Finish of Tower Materials

All materials shall be hot dipped galvanised as per AS/NZS 4680 and Clause 8.3 of AS/NZS 7000. Reference shall be made to AS 2159, AS 2312 for members below ground or within exposure class C region and for design durability in excess of 50 years. All reusable temporary supports shall be durable for at least 25 years within exposure class C region.

6.5.7 Plan Bracings

Plan bracings shall be designed to ensure the supports stability under torsional load.

A tower structure shall have plan bracing at locations specified in clause G8 of AS/NZS 7000.

6.5.8 Design of Tower Members and Connections

Members and connections shall be designed in accordance with ASCE 10 unless otherwise modified by this standard.

Wind pressure on lattice steel towers shall be as per clause B5.1 of AS/NZS 7000.

A strength factor, Ø of 0.9 shall be used for all members excluding cables and connections to account for the variability of materials and workmanship (Clause G9 of AS/NZS 7000).

A strength factor, Ø of 0.7 shall be used for stay or guy design.

A maximum strength factor Ø of 0.9 shall be used for connection design of bolts in accordance with AS 1559. A maximum strength factor, Ø of 0.8 shall be used for connection design of bolts not in accordance with AS 1559.

Welded connections are not acceptable due to brittle failure mode.

Bending of plates manufactured in accordance with AS/NZS 3678 shall be in accordance with Appendix C of the Standard. Bends shall not be located more than 1.5 times the flange width from the closest bolt hole of a compression member. If required, bends on only one flange of an angle member and plate with a single bend line are the preferred options.

Insulator attachment points shall be designed to allow wire swing in the transverse direction. Bending load on bolts or pins due to various take off angles shall be minimised by providing additional pivotal points and/or by adjusting the attachment point orientations.

Design inaccuracy revealed by load testings shall be corrected in the design of all other supports (refer *Western Power internal document*).

6.5.9 Tension Only Members

No member (including cross arm top chord) shall be designed as a tension only member unless it satisfies the following:

1. Stress distribution can be achieved with a high slenderness ratio (≥ 300)
2. Fabrication arrangement allows tension only members to flex under compression without plastic deformation while maintaining structural stability.

6.5.10 Fasteners and Splices for Lattice Supports

All connections shall be bolted in accordance with AS/NZS 1559 (and referenced standard AS 1112.1 for nuts). High strength bolts in accordance with AS 1252.1 and AS 1252.2 (for nuts AS 1112.3) may be used instead of the tower bolts (AS/NZS 1559) at locations other than the conductor or earthwire attachment points.

Spring washers shall be in accordance with DIN 267-26.

Only metric size fasteners shall be used. Imperial size fasteners will not be acceptable. Only one structural bolt grade shall be used in a tower design. No more than 3 bolt sizes are allowed in a tower design for ease of maintenance and construction.

Bolts of property class 4.8, 5.8, 6.8 and any other bolts using free cutting steel according to AS/NZS 4291.1 or ISO 898.1 are not acceptable due its limited ductility and unfavourable surface for galvanisation.

All bolts, nuts and washers shall be hot dipped galvanised in accordance with AS/NZS 1214 to protect against corrosion.

Leg splices shall be located as close as possible above panel joints and be of a form that minimises eccentricity. Where butt joints are used, they shall be plated on both sides.

6.5.11 Design of Ancillaries

6.5.11.1 Anti-climbing device (ACD)

The ACD design shall ensure that the structure cannot be climbed without additional efforts from the climber having to pass over or through the device, e.g. by cutting, damaging or partially dismantling the device or by using a climbing aid or other means requiring greater than normal agility.

The following minimum shall be followed in the ACD design:

1. All supports shall be fitted with anti-climbing devices constructed from 2 ply, 2.5 mm, 4 point barbed wire.
2. The anti-climbing device shall comprise nine wires, spaced at less than or equal to 230mm, constructed around the support body, five of which shall be outside the frame and four within. The wires shall be separated by rigid spacer bars spaced at less than or equal to 690mm and fitted more than 3m above ground level in accordance with ENA DOC 015-2006.
3. Anti-climbing devices shall be symmetrical about the supports on which they are installed. All gates if any, and frame members shall have close wrapped barbed wire at 50-75 mm spacing.
4. The ACD shall be extended beyond the diagonal member of the plan brace if the forward inclined inner face of the leg frame is scalable. Additional grind infill to be installed as required.
5. The main ACD frame and their connections to the tower shall match the durability requirements of the tower.

6.5.11.2 Climbing Facilities

Step bolts shall be provided on one leg of all single circuit supports and on two diagonally opposite legs of all double circuit supports. The positioning of step bolts shall be on the forward inclination face without the need to sidestep or leaning sideways.

The step bolts shall be provided at uniform centres of not more than 325 mm on alternative flanges of the chosen legs starting immediately above the anti-climbing device leading to the earthwire peak(s).

Step bolts shall not be less than 16 mm diameter, fitted with two nuts and a spring washer with the backing of a flat washer. The bolt head shall project not less than 130 mm from the support when fitted. For a straight bar, the protruding ends shall either be capped with a nut, or similar blunt edge or bend upward not higher than 10 mm from the shaft. A 20 mm diameter step bolt with crisscross grip tread pattern shall be provided for all towers above 220kV. All protruding ends shall be chamfered and free from sharp edges. Out of plane bending stresses on the attached main angle flanges or members shall be checked. The flanges shall not deform beyond its elastic range under live loads.

All secondary angle member flanges which protruded more than 60 mm from the main members along the climbing route shall be chamfered full depth of the flange as such the pointed edge is at an angle of 135° or more. The climbing routes shall include the full extent of crossarms and earthwire peaks.

Short guard rails or rung type ladders in accordance with AS 1657 shall be considered for awkward climbing angles of stayed towers and frequently accessed towers. Live line maintenance ladder if any shall be designed for the anticipated live loads and required electrical clearances.

6.5.11.3 Maintenance holes

A standard 32 mm diameter maintenance hole shall be provided adjacent to insulator attachment point and at the crossarm bottom chords to the superstructure connections.

6.5.11.4 Fall arrest

Regular fall arrest attachment points shall be provided along the climbing routes to limit the free fall drop distance. The free fall limit shall be in accordance with Table 2.1 of AS/NZS 1891.4. The first fall arrest point shall be 2.0m above the ACD. Tower body members may be used as fall arrest points. U-Shaped ring type brackets within arm reach of each other's shall be provided along the crossarm top chords.

6.6 Pole Support

6.6.1 General

The pole design shall comply with the limit state performance requirements stipulated in clause 6.3 of AS/NZS 7000 without permanent deformation of any member or connection.

All poles shall have minimum down-line strength of at least 50% of their transverse strength. Components subjected to accelerated degradation shall be protected to minimise refurbishment frequency throughout their design life.

6.6.2 Pole Geometry

The top geometry shall conform to all electrical and maintenance clearance requirements.

6.6.3 Pole System

Both monopole and multi pole systems are acceptable solutions to suit design span, footprint area and easement. Pole structures shall be designed as either self-supporting or stayed structures.

6.6.4 Deflection Limits

The pole deflection limits under serviceability loads shall conform to the requirements stated in Table 6.2.

Table 6.2: Pole shaft deflection limit

Pole Element	Loading mode	Damage limit (500 Pa)	Deflection limit (Everyday wind 100 Pa)
Pole shafts with rigid foundation	Bending	Structure elastic plus plastic deformation ≤ 3% of pole height above ground + depth to foundation pivot or fixity point (refer to *Western Power internal document*) AND Structure and foundation elastic plus permanent deformation that impairs clearances and easement.	Suspension, strain pole: Structure elastic plus plastic deformation ≤ 2% of pole height above ground + depth to foundation pivot or fixity point. Self-supporting full termination or deadend pole: Structure elastic plus plastic deformation ≤ 2%[7] of pole height above ground + depth to foundation pivot or fixity point.
	Compression	-	Non elastic deformation from L/500 to L/100
Timber pole and other pole shaft with non-rigid footing	Bending	Structure elastic deflection ≤ 5% of pole height above ground + depth to foundation pivot or fixity point AND Foundation rotation + creep ≤ 3% above ground height AND Structure and foundation elastic plus permanent deformation that impairs clearances and easement.	N/A
	Compression	-	Non elastic deformation from L/500 to L/100
Crossarm	Bending + Compression		20mm/m

Preset of the pole shaft, if any, shall be between 0.5 to 1.0 time the pole deflection (measured from the foundation pivot point) under everyday wind condition.

[7] For poles subject to large differential loads, the impact on the pole's deflection needs to be considered.

The combined impact of crossarm (or line post) deflection, earthwire arm (or peak) deflection, foundation movements (e.g. rotation and settlement) and pole deflection at point of interest shall be calculated when assessing clearances.

6.6.5 Fasteners for Pole Supports

All fasteners shall be in accordance with AS/NZS 1111 (for Grade 4.6 only), AS/NZS 1252.1 and AS/NZS 1252.2 (for al Grade 8.8) or AS 4291.1 (for M20 and Grade 8.8 only).

In addition, Western Power allows the use of threaded reinforcement bars complying with AS/NZS 4671 threaded to AS 1275.

The requirement of AS 4100 shall apply in regards to bolted connections. The anchor bolt shall be designed as per ASCE/SEI 48-11 combined shear and tension/ compression requirement. Bolted flange joints shall be designed with high-strength bolts of strength grade 8.8 or 10.9 as per AS/NZS 4291.1.

All bolts, nuts and washers shall be hot dipped galvanised in accordance with AS/NZS 1214. Single eye or hex nut without locking device shall not be used on components susceptible to vibration. Single cantilever bolt supporting post insulator shall be checked for fatigue failure.

6.6.6 External Stays/Guys

1. Stays shall be designed in accordance with the AS/NZS 7000 (Clause 10.7 for electrical interface and L5 for foundation) and ASCE 10-15 (Clause 3.10.5) unless otherwise modified by this specification.
2. The strength factor shall be 0.7. A reduced capacity of the pole structure in the direction perpendicular to the stay orientation shall be considered.

The positioning and number of stays shall cater for the intended pole duty, orientations, clearance and electrical requirements. The maximum number of stays per pole shall be 6. The slope of the stay wire shall be within the range of 45 to 60 degrees from the horizontal plan. The maximum horizontal extent of stays shall be 30m from the pole centreline. All stays shall be external of the pole shaft and connected to ground anchors.

3. All external stays shall be insulated, designed with turnbuckles and connection mechanisms to facilitate above ground maintenance and replacement. For a conductive shaft, the stay insulation shall utilise an insulator rated to match the support insulator. The insulator on stay shall be positioned 2.4m above ground and below the lowest conductor attachment point. The turnbuckle shall be placed between 2.4m and 3.4m above ground. The proposed turnbuckle adjustment length shall match the anticipated combined long term creep of the stay and anchor movement.
4. The stay attachment point and supporting members shall cater for all possible load directions i.e. cases when the stay axial load projection does not pass through the pole centreline. The maximum allowable pivot angle (in the horizontal plan, relative to the line axis formed by the attachment point and pole centreline of the stay) shall be specified.
5. The attachment plate thickness and specified minimum edge distance/radius shall suit commercially available shackle sizes and ratings. The minimum edge distance in the direction of component of force shall also satisfy the requirement of AS 3990:1993, Clause 9.6.2.2. The stay

attachment points on the strain poles shall cater for the required range of line deviation and out of balance longitudinal loads.

6.6.7 Climbing Facilities

Climbing facilities are not required for poles less than 50m above ground and accessible by mechanical platforms. Basic climbing facilities shall be added to section of poles beyond the reach of attainable mechanical platforms, mobile booms or lifts (generally available between 6m to 60m reach with various footprint requirements) and at sites with limited vehicle access.

6.6.8 Steel Poles

Design of steel poles in the transmission lines shall be in accordance with ASCE/SEI 48-11 and Appendix K of AS/NZS 7000 unless otherwise modified by this Standard.

6.6.8.1 Pole Section length

The pole section lengths shall be limited to suit the size and weight requirements for transportation and the size of the galvanising bath.

6.6.8.2 Minimum size of steel members

The minimum thickness of material near or below ground or within exposure class C region in accordance with Table D1 AS/NZS 7000 shall be 6 mm before galvanising.

The minimum thickness of steel within exposure class B region shall be 5 mm. All other members shall have a minimum thickness of 4 mm.

6.6.8.3 Steel pole materials

Steel pole material shall comply with AS/NZS 3678 and Clause 2.2.2 of AS 4100 or equivalent ASTM standards (e.g. ASTM A572/A572M-12).

The Charpy V-notch property shall comply with the requirement of ASCE/SEI 48-11, clause 5.2.1.3. All steel components shall meet the durability requirements in AS/NZS 2312.

For consistency, only one steel grade should be specified for the shaft.

The following are specific requirements of material conforming to AS 4100:1998.

Overseas Steel procurement

All international material supply shall comply with the AS/NZS 5131 for requirements relating to the construction category 3 (CC3).

Unidentified Steels

All unidentified steel without a full test in accordance with AS 1391 shall be de-rated as per AS 4100, clause 2.2.3.

Test Certificates

All test certificates shall be issued by an ILAC/NATA Accredited Laboratory.

Product Conformity

The supplier shall be certified by ACRS (Australasian Standards Certification & Verification of Reinforcing, Prestressing & Structural Steels) for the supply of reinforcement and structural steel in accordance with Australian Standards.

6.6.8.4 Surface Finish

The surface finish shall comply with Clause 8.3 of AS/NZS 7000 unless otherwise specified.

All materials shall be either hot dipped galvanised, coated, thermal metal sprayed, or a combination of finishes as per AS/NZS 4680 to meet, or exceed the durability requirements especially at locations with limited access or high replacement cost.

The inside surface of hollow sections shall also be protected against corrosion by coating, galvanising or concealment. Reference shall be made to AS 2159, AS 2312 for members below ground or within exposure class C region and for design durability in excess of 50 years. All reusable temporary supports shall be durable for at least 25 years within exposure class C region.

6.6.8.5 Strength Factors

For materials supplied, tested and fabricated in accordance with AS 4100, a strength factor of 0.9 shall be used for the design of the pole members to account for the variability in material and workmanship (Clause K2 of AS/NZS 7000). The strength factor for the design of connections shall be in accordance with Table 3.4 AS 4100.

Equivalent reduction factors shall be selected for supply, test and fabrication of materials not in accordance with AS 4100.

6.6.8.6 Pole Joints

The impact of joint movement on pole coating and insulation shall be considered. The number of joints shall be kept to a minimum and preferably above ground.

Bolted flange joints:

The flange joints shall be arranged along the outside perimeter of the pole shaft.

Slip / internal sleeved joints:

Minimum slip length shall be 1.5 times the average joint diameter. Taper above and below the slip joint shall be the same. Slip joint shall not be placed within the pole top geometry between the earthwire and/or the conductor attachment points.

Unless otherwise specified, the following pole shaft length tolerances shall be followed:

Table 6.3: Shaft length tolerances

Pole system	Overall shaft length tolerances
Slip jointed monopole	± 150 mm (up to 2 joints) ± 200 mm (3 or more joints)
Slip jointed PI pole with pin jointed crossarm	± 50 mm
All other poles	± 10 mm

Slip jointed poles should be avoided in the following scenario:

1. where clearances are critical or potentially an issue
2. when a pole is loaded close to its full utilisation (≥ 95%) under the most adverse loading condition while sustaining permanent heavy equipment weight or high torsional loads.

6.6.8.7 Welding

Welding category SP as per AS/NZS 1554.1 shall be used for welded connections. If the parent steel cannot be identified as weldable and/or not "pre-qualified" to the structural welding Standard AS/NZS 1554, it shall be treated as unidentified steel. Components subjected to high levels of fatigue loading shall be welded in accordance with AS/NZS 1554.5. Welding of sheet steel structures shall be in accordance with AS/NZS 1554.7 Equivalent international standards may be specified as the alternative.

Full penetration butt weld (FPBW) shall be used to joint two load bearing members unless the alternative weld types will not reduce the fatigue strength of the structural element. 80% penetration longitudinal weld is acceptable one diameter from pole joints and along the neutral axis of shaft under EDT wind condition.

6.6.8.8 Joint Fatigue

Joints, notches, bends and welds subjected to dynamic loadings shall be checked for fatigue failure. Unbraced gusset plates supporting the main structure components shall be checked for lateral stability. Joints shall be detailed to control the impacts of high stress concentration.

In lieu of a detailed analysis in accordance with Section 11 of AS 4100, the residual fatigue strength may be assumed to be 30% of the yield strength under static design wind with a unity strength factor.

6.6.8.9 Plates

Connection relying on plate bending and shear capacity shall be checked for localised tear out, buckling and distortion using established plate theories or numerical analysis.

6.6.9 Concrete Poles

Design of concrete poles shall comply with Appendix I of AS/NZS 7000 and AS/NZS 4065.

6.6.9.1 Concrete Material

Reinforced concrete properties and durability requirements shall be as per AS 3600, AS 2159 and AS 2312. Detailing of concrete poles shall consider thermal expansion and corrosion of reinforcing bars at sea spray zones and near geothermal fields. Supply of concrete shall be in accordance with AS 1379.

6.6.9.2 Specific Design Requirements

Concrete poles shall be prestressed. The concrete shaft extreme fibre shall be in compression under service loads. Cover concrete shall not crack or spall under bearing stress from attached bolts, crossarms or coupling loads from insulators and back stays. Minimum concrete compressive strength shall be 40 MPa.

Localised tension cracks (e.g. due to thermal expansion) shall be checked.

6.6.10 Wood Poles

Wood poles shall be designed in accordance with Appendix F of AS/NZS 7000 and AS 1720.1. All wood pole within medium to high-risk bush fire zone shall have groundline protection against fire to maintain its structural adequacy for the expected fire load and duration.

6.6.10.1 Wood Pole Material

Selection of materials shall consider consistency of properties, supply and durability.

Reference shall be made to *Western Power internal document* for types of timber and material properties. Reference shall be made to AS 1720.2, AS 2082, AS 2878 and AS 3818.11 for requirements of visual and strength graded round timber utility poles. Glued laminated structural timber shall be in accordance with AS/NZS 1328.1. Timber treatment shall be in accordance with AS 1604.1.

6.6.10.2 Specific Design Requirements

Galvanised steel in contact with treated timber shall be coated to reduce the rate of components degradation, otherwise a reduced section shall be assumed.

Cantilevering king bolts and pin joints shall be checked for fatigue and timber crushing.

Timber crossarms and peak extensions shall not be used.

Splitting and fire risk on the pole top shall be evaluated and mitigated.