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1 GENERAL

This ELASTIC SYSTEM specification is to be read as an addendum to the existing TRAM OVERHEAD CONSTRUCTION SPECIFICATION.

An elastic system, by virtue of its design, provides dynamic flexibility to the pantograph/pole trolley wire interface. Such a system reduces hard spots thereby reducing wear on both the trolley wire and on the carbon collector.

Elasticity is provided by the use of modern resilient support systems including pendulum, steady arm supports and delta systems. Variations in the type of fittings and contact wire clamps exist depending on whether the use is for pantograph only or dual (pole and pantograph) application. For example, single pendulums are used on pantograph only routes and double pendulums on dual routes. Using elastic support systems reduces the unsprung mass of the system, attenuates system oscillation and provides shorter recovery periods to the static situation.

The ELASTIC SYSTEM described herein addresses both Pantograph Only and Dual Pantograph and Pole systems. This addendum does not apply to the catenary and contact system of the Port Melbourne or St Kilda routes.

2 Technical Specification

2.1 Overview

Elastic systems are summarised as follows:

PANTOGRAPH ONLY OPERATION	Elastic system. Pantograph Only is the preferred option as it simplifies trolley system design and offers long term maintenance and operational advantages.		
Principle considerations	129mm ² trolley wire only. Termination constraints regarding positioning of fixed anchor points. Maintain full tension wherever possible (specifically high tensions are maintained around curves). Single pendulum with bow, delta or bridle. Single and dual pull-off arms on tight radius curves.		
Termination	Auto-tensioned	Fixed terminated	Remarks
Application	Open route sections with minimal crossings and right angle curves.	City centres, areas of right angle curves and intersecting junctions.	
Maximum length to a fixed point	800m on long straights without junctions. Reduce length where curve drag reduces tension.	800m on long straights without junctions.	500m has traditionally been used, however, there is an opportunity to minimise visual impact and costs.
Tension	12kN constant	7.6kN @ 20°C. Varies from 12.0kN @ 0°C to 3.9kN @ 50°C based on a 30m span.	On fixed terminated systems, pendulum geometry change accounts for the removal of 50% of the temperature change trolley sag
Pendulum (hanger)	800mm inclined hanger length including bow length.	450mm inclined hanger length including bow length.	Minimum 300mm inclined hanger length including bow. Use pendulums for deviation angles up to 2.5°, or up to 4° with additional design considerations.
Pull-off arm, Single			Use for deviation angles 2° to 9°. Between 2° and 4° will require a nose stay.
Pull-off arm, Double			Use for deviation angles 4° to 25°.
Bullrings	Design for load	Design for load	Due to high radial loads bullrings shall be certified and hardmarked accordingly.
Span length, tangent	40m with pull-off bow	33m with pull-off bow	Span lengths may be extended with use of bridles
Span length, curve	Refer to tables.	Refer to tables.	Varies.
Stagger, tangent	230mm	165mm @ 20°C	Alternate span to span. Midspan offset should be zero.
Stagger, curve	300mm	165mm @ 20°C for	Stagger to outside of curve.

		pendulum. 300mm for pull-off arm	Midspan offset can be critical.
Sweep rate	Not considered important		Refer to notes
Suspension support, boom	Tangent or curved track where poles are close to the track.		Observe position of the insulation and proximity of the live equipment near the pole.
Suspension support, Parafil span wire	Tangent track and large radius curves approximately up to 2° deviation angle. Pendulum fittings.		Damping advantage. Simple fittings. Continuous insulation
Suspension support, steel span wire	Small radius curves and where strength is a requirement.		Existing 6mm steel wire is not satisfactory for fittings or loadings imposed by modern system design.
Intersecting wires	Preference is to take trolley out-of-running in parallel. Cross-contact bars used only if parallel option not available.		This is to avoid trolley side wear at the cross contact overlap point

DUAL OPERATION	Elastic system	
Principle considerations	129mm ² trolley only. Maintain full tension throughout. Double pendulum. Registration on curves, angles of deviation and curve-bars. Crossing pans and frogs. Section insulators with insulated trolley pole running strip	
Termination	Fixed terminated only	
Application	Restricted to areas where Historical, Restaurant and City Circle trams utilising trolley poles are designated to provide a service.	
Aspect	Detail	Remarks
Maximum length to a fixed point	800m on tangent track without junctions	
Tension	7.6kN @ 20°C. Varies from 12.0kN @ 0°C to 3.9kN @ 50°C for a 30m span.	Pendulum geometry change accounts for the removal of 50% of the temperature change trolley sag. Previous tensions of 16.25kN @ 0°C have been found to be difficult to work with in the field.
Pendulum	500mm double pendulum.	For deviation angles not exceeding 1.5°.
Pull-off arm, single	No curve bar	Deviation angles 1.5° - 9°
Curve bars	Single arm, 1.2m curve bar Double arm, 2.4m curve bar Triple arm, 3.6m curve bar	Deviation angles 9° - 12° Deviation angles > 12° Use not recommended due to hanger wire adjustment difficulty
Hanger & ear	Not appropriate for elastic systems.	Hanger & ear may be necessary at trolley intersections to maintain levels when other methods of levelling fail. Note however that the mixed use of insulated and non- insulated span wire fittings is not acceptable
Bullrings	Design for load	Due to high radial loads bullrings shall be certified and hardmarked accordingly.
Span length, tangent	33m	Delta/bridle systems not appropriate for trolley poles

Span length, curve	Refer to tables	Maximise support spans where minor pole operation or future conversion to full pantograph operation imminent.
Stagger, tangent	165mm	Cycle over 2-spans for pendulums. Pendulums must not hang vertically.
Stagger, curve	100mm @ 20°C. Use curvebars	Stagger to outside of curve. Compromise in favour of pantograph operation unless pole operation is predominant.
Sweep rate	Sweep rate not important but pole head horizontal acceleration to be minimised	Adjust stagger to minimise angles of trolley deviation
Suspension support, boom		
Suspension support, Parafil span wire	Tangent track only. 1.5° deviation angle. Pendulum fittings	Damping advantage. Simple fittings. Continuous insulation
Suspension support, steel span wire	Large radius curves up to 1.5° deviation angle. Pendulum fittings. Small radius curves use curvebars	Use 8mm wire throughout.
Intersecting wires	Must use frogs and crossing pans for intersecting wires for pole operation.	

Note:- All staggers referred to in this document are measured relative to actual reflected canted track centre (and not vertical track centre).

2.2 Operating Temperature Range

The systems described in this specification must be designed for an operating range of 0 to 50 degrees Celsius with the average or "optimum" operating temperature taken as 20 degrees Celsius.

The midpoint positioning of all fittings, booms and wires must be designed at 20 degrees Celsius. At this temperature the system must be designed in its neutral state.

2.3 Isolation of Construction of the Up and Down trolley wires

Wherever practical the up and down trolley wire systems should be constructed to be mechanically independent of each other.

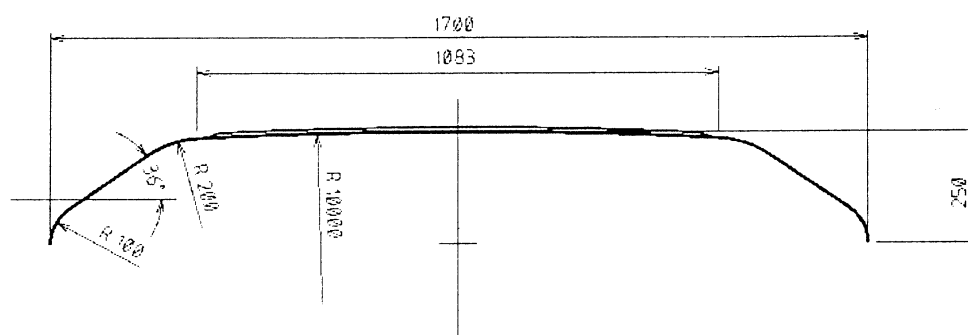
Failures on one trolley wire system should not unduly impact on the other system adjacent.

Whilst this can not be fully achieved at intersections the methods of independently anchoring and other construction methodologies should be designed to minimise interference between the two system.

For this reason square style anchoring systems are not permissible for use as mid point anchors.

2.4 Pantograph

Pantograph profile is the standard VOV European design (Austbreck).



Pantograph working range

Minimum working height	= 3.76m
Maximum working height	= 5.80m
Normal working height	= 5.64m

Span length & stagger design parameters

Roll (Sway) from centreline	= 1.5°
Carbon width	= 1050mm
Blowoff wind speed	= 28m/s
Static tolerances	= 50mm

2.5 Trolley height

Trolley wire shall be designed for a nominal height of 5.64m at 20°C with a maximum deviation above this height of 100mm at 50°C.

The maximum deviation below this height shall be 200mm except where physical obstructions (eg Bridges) prevent installation at nominal height.

The trolley wire at each support point shall be designed for a constant wire height, within practical limits, throughout the operating temperature range. Where the design method is similar for one or more adjacent spans, wire hangers shall be of the same length. Varying the individual pole bracket heights shall be used to attain constant trolley wire height. The design authority shall specify pole bracket heights.

2.6 Poles

The standard range of poles shall be used unless notified otherwise by the Principal.

Where new poles are used every reasonable attempt shall be made to rationalise the number of different poles utilised. Where this does not occur the construction authority must supply at least one spare pole for each non standardised pole type used or two poles for quantities above 10. Complete, as built, pole drawings must be provided for each unique pole type utilised. These drawings must have sufficient information to enable construction of replacement poles.

The overall tension length design should be realised using a minimum number of poles at maximum spacing, however, consideration should be given for some degree

of positional flexibility of poles particularly at road junctions. In open route an allowance of +/- one metre should be allowed in the design as a site tolerance. On curve networks variations in pole positioning should be referred back to the design authority.

The design shall nominate the fixation heights of pole bands on both the inside and outside of curves.

2.6.1 Pole Numbering

Pole numbers must be placed 3 metres above the pavement on the pole in a position so they can be readily viewed from roadway based vehicles and trams.

The pole numbering must be clear and legible and painted in a long lasting paint finish that contrasts with the pole color to enable easy reading

2.6.2 Pole design

Poles shall be designed to accommodate both the deflection limit and the full design moment from the permanently applied loads (at the 0°C temperature condition) and the wind load on the wires, pole and attachments to the pole. The Principal shall nominate if there are to be future additional loads to consider.

Tram poles are classified by the maximum moment applied at the top of the pole together with the overall length of the pole. for example, 6.5kN/11m.

Where tram fittings are attached to power poles. it should noted that these are generally classified by length/load.

2.6.3 Pole Painting

Poles shall be prepared and painted in a long lasting finish consistent with an asset life of 30 years. Galvanised poles shall be suitably prepared. etched and primed to ensure adherence of primer and top coats.

A detailed specification of pole painting requirements can be obtained from Yarra Trams on request.

Single pack paint systems will not be acceptable.

2.6.4 Wind loading

Pole design wind loading shall be based on a wind speed of 41m/s. The wind load on pole and wires, expressed as a Uniformly Distributed Load is:

$$\text{Wind}_{\text{UDL}} (\text{N/m}) = 0.6 * V^2 * D * C_d$$

Where V = Wind velocity in metres per second
 D = Diameter of object in metres
 C_d = Coefficient of drag for the object

2.6.5 Foundation design

Calculated side-bearing foundation depths will depend on the applied moment (permanent + wind loads), the soil bearing capacity and the width of the foundation.

The specified foundation depth shall be not less than that derived from all of the following considerations:

- ☐ the calculated side-bearing depth + any non-effective depth
- ☐ the minimum depth specified for the pole type
- ☐ the full moment capacity of the pole type imposed from any direction

Foundation concrete shall be designed to allow full pole load to be applied at 4 days after construction.

Foundations other than side-bearing types may be installed at the discretion of the Principal. These foundations shall be designed to be stable and within permissible soil bearing capacity when subjected to the full moment capacity of the pole imposed from any direction together with a surcharge from the effect of construction or temporary guys.

Where base mounted poles are utilised the installer must provide full details of how the base system will be installed to enable inspection of construction studs during the pole life.

The base mount foundation and capping system will be designed to ensure that water does not collect over the ground level area surrounding the pole, between the capping system and pole or pole support surfaces or any other area that may be detrimental to the long term integrity of the pole.

2.6.6 Bonding of Base Mount Poles

Bonded base mount poles shall be insulated from their bases to ensure that rail potentials are not transmitted into the ground structure.

2.6.7 Span wire height and imposed permanent loads on poles

Span wire pole band heights shall be determined and shown on the layout drawings.

Design for span wire pole band height shall consider permanent loads only.

Yarra trams is committed to using flatter supporting networks using 1:10 gradients on the span wires. Traditional 1:7 gradients will only be allowed where it can be demonstrated that the 1:10 gradients are not practicably achievable.

2.6.7.1 Tangent and curved track

Span wire pole band height

The span wire pole band height above the rail datum shall be the summation of the following:

- Trolley wire height
- Distance between trolley and the span wire (vertical drop of the pendulum)
- Gradient vertical component of the span wire

2.6.7.2 Inside of curve

There is no radial load to consider. The pole band height depends only on the gradient of the span wire. A gradient not greater than 1 in 7 and less than 1 in 10 shall be applied. The chosen gradient shall be consistent for all span wires on the inside of the curve.

Standard gradients are not applicable on inside curve networks where supplementary pre-loading is applied

Span wire tension

For even span wires, the vertical load at the pole band is half the sum of all the vertical loads acting on the span wire including the span wire weight.

The maximum tension in the span wire for permanent loads only is given by:

Span wire tension = radial load + vertical load at pole $\tan\theta$ where θ is the angle of inclination.

Note that it may be necessary to add 3000N to the span wire tension to control the rotation (kick) of fittings subject to high radial loads. Maximum allowable rotation of fittings from the horizontal is 5°.

2.6.7.3 Outside of curve

Total span wire tension = span wire tension inside of curve + total radial load

Gradient of span wire = (Total span wire tension @ 20°C) / (Half the vertical load on the span wire)

2.6.7.4 Load distribution in Y-pulls

Pole band height and Y-pull leg tensions shall be resolved by apportioning the loads from the geometry of the wires.

2.7 Building attachment

All building attachments shall be designed for an applied loads (permanent + wind) not exceeding 18.0kN.

Building attachments may be a requirement of local streetscapes, councils, heritage organisations and shall be used where directed by the Principal.

Building attachments shall be utilised in any circumstance where the building design is acceptable for an attachment and use of the attachment will result in pole rationalisation. In circumstances where attachment height is required to be variable dual vertical attachments and a vertical vee-pull should be used to enable ready vertical height adjustment.

2.8 Factors of Safety

Factors of safety are given on the load at mechanical failure (ultimate load limit).

When an item is designed or assessed, it shall be under the most onerous loading conditions of wind and temperature.

Minimum FoS Item

3	Inline fittings
3	Conductors (not trolley)
2.0	Trolley, worn
5	Wires on pulleys eg balance weight support wires
4	Parafil ropes

2.9 Drawings and design documentation

2.9.1 Layout drawings

Included on the drawings shall be:

- ☐ Pole data including type, bracket and boom heights, load in each span wire, mounting position of fittings, overall pole reaction and direction.
- ☐ Colour to differentiate between facets of the design, for example, yellow to be used for removal
- ☐ Legend of symbols
- ☐ Known services
- ☐ Eastings and northings of key construction features (eg bull rings)
- ☐ Supplementary Measurement references to known site features where eastings and northings markers may be removed due to construction or road works

2.9.2 Assembly and component drawings

All new drawings produced for a project that reference individual or assembled components shall be produced with a view to future computerised stock control.

Component details for the purpose of manufacture shall not be shown on assembly drawings.

General Arrangements, Technical or Instructional drawings shall not include manufacturing details for components.

2.9.3 Maintenance and Construction instructions

The design authority shall provide fully detailed maintenance and construction instructions and training. Maintenance and construction instructions shall include:

- ☐ design philosophy and scope
- ☐ technical appreciation
- ☐ maintenance procedures for assemblies, for example, weight tensioning systems
- ☐ maintenance procedures for fittings
- ☐ listing of tools
- ☐ listing of recommended spares

2.9.4 Material schedules

Fully detailed material schedules shall be produced in a form that permits easy recompilation of parts following changes to the design.

2.10 Materials, Fittings and Assemblies

All new material and manufactured items shall be subject to approval by the Principal and possible type testing.

With the introduction of the resilient systems, prior use of fittings on the network is not necessarily a justification for reuse of a particular component or fitting.

All fittings proposed for use on a new project must be approved by the Principal. Only fittings with demonstrated quality and life expectancy will be considered.

All material, fittings and assemblies must be consistent with the need to ensure maintenance spares rationalisation.

Yarra Trams reserves the right to reject any component which is not proven in similar service applications or consistent with the need to maintain maintenance spares rationalisation.

Assemblies must consist of integrated fittings that have been proven in service and are efficient and well designed.

The piecemeal application of non-integrated fittings will not be acceptable.

2.11 Trolley tensions and span lengths

To maintain system elasticity, tension shall be maintained throughout the network including at curves and junctions. That is, detensioning devices for curves shall not be introduced into new works.

The maximum tension in 129mm² trolley wire at 0°C, with no wind, shall be 12kN.

2.11.1 Auto tensioned equipment. Pantograph only operation

2.11.1.1 Tension (AT, panto only)

Tension for the 129mm² trolley shall be 12kN and constant across the whole temperature range. Tensioning shall be provided by weights, spring regulation will not be considered.

2.11.1.2 Tension Pulleys

The tension pulley system shall be designed to ensure ready access to all components requiring maintenance.

The tension pulley system shall be designed to align directly with the tension "rope" and there shall be no side thrust transmitted on to the pulley systems.

The pulley wheels and mechanisms shall be painted the same colour as the pole to which the system is installed.

2.11.1.3 Tension Weights and Enclosures

Weight systems must be provided with an indelible and permanent marking system to indicate the correct position of the weights over a temperature range of 0 to 50 degrees Celsius in 5 degree steps

The weight system must be designed for adequate internal clearances to prevent weights binding or rubbing against internal surfaces or fixtures.

The weight enclosure shall be drained to prevent water build up inside the pole

The weight doors shall be fitted with keyed alike secure locking systems designed to be weatherproof, vandal proof and accessible from ground level for a standing person.

The orientation of the doors shall be arranged to enable maintenance staff to view and be visible to either car or tram traffic whilst maintaining maximum protection.

2.11.1.4 Tension Weight Pole Access

Access to Tension Weight poles shall be arranged for ready access by a normal tram overhead scissor platform. Access shall be aligned to prevent delays to tram operations during normal maintenance access.

2.11.1.5 Tension lengths (AT, panto only)

Tension lengths shall be governed by:

- ☐ The amount of trolley wire that can be carried by one drum
- ☐ The amount of temperature induced movement that can be accommodated by the tension regulation system
- ☐ Tension loss associated with support and registration 'dragging' limited to 10% of the original tension
- ☐ Geographical constraints
- ☐ 'Half' tension lengths shall not exceed 800m (from point of fixity).

Tension length overlaps and midpoints shall be chosen to take advantage of route geographical constraints.

Tension overlaps shall not employ cross contact bars and shall be designed to prevent any interference or contact between the two adjacent section trolley wires.

2.11.1.6 Tension regulation (AT, panto only)

Tension regulation shall be by means of weights supported from a 3:1 ratio pulley with a built in fall arrest mechanism.

The tension regulation shall operate between the temperature of 0°C through to 50°C.

Where the weight system is enclosed within a pole, means of replacing the weights, pulley and rope without removal of the pole shall be provided. The maintenance access must be fully considered and components requiring maintenance shall be readily accessible. Weight heights shall be visible without the need to remove cover plates.

The tension "rope" or anchor must utilise compact inline insulators to maximise aesthetics whilst providing maximum insulation level and minimum vertical sag. "GY2" style insulators will not be acceptable.

2.11.1.7 Provision of spare weight tensioning poles

A spare weight tensioned pole must be supplied for every variation of weight tensioned pole supplied in the construction.

2.11.1.8 Overlaps (AT, panto only)

At the ends of tension lengths, each trolley shall be run in parallel by not less than 20m and pantographs shall contact both trolleys for a minimum distance of two metres. The trolley shall be taken out of running avoiding mechanical touching of the in running wire.

Single point overlaps, employing a cross-contact bar, shall not be used without the written permission of the Principal.

2.11.1.9 Midpoints/Fixed points (AT, panto only)

The term 'Midpoint' is a common colloquialism but is confusing as it only refers to full tension lengths, the term 'Fixed point' accommodates both full and half tension lengths. A tension length is from the anchor at one overlap to the next overlap. The 'Fixed point' of each tension length provides a reaction for the tension regulation device. The midpoint / fixed point can be any distance up to 800m.

2.11.1.10 Span lengths (AT, panto only)

The following assumes new trolley wire and tensioned to 12kN.

For construction purposes a tolerance of one metre shall be allowed for in the design.

Maximum span, tangent track, single pendulum with small delta

Span length 40m equates to a sag of 189mm.

Pendulums shall incorporate bows, deltas or bridles to minimise the trolley wire angle of deviation in the vertical plane.

Maximum span, tangent track, bridle and pulley

Span length 40m plus the length of one bridle.

Span lengths on curves

Because of the restraining effect of small radius curves, the tension length design should place the fixed points at or near the curve wherever practical.

Span lengths on curves will be a consideration of:

- ☐ acceptable wire position on the pantograph
- ☐ allowable radial load on the fittings
- ☐ angle of deviation at registration points

Where the angle of deviation exceeds 10° , pull-off arrangements from bullrings may be alternated with span wires between poles to minimise the number of poles.

The following table is based on the following parameters:

Tension	12kN
Stagger	300mm
Wind	28m/s
Overall span width	1050mm
Vehicle roll	1.5° about centreline

■ *stagger has a significant impact on the table.*

Span m	Curve m	Versine mm	Deviation angle in $^\circ$	Radial load N	Wind N
40	388	515	5.90	1236	260
35	283	541	7.08	1484	227
30	200	563	8.59	1802	195
25	134	583	10.66	2239	162
20	84	595	13.57	2856	130
15	46	611	18.51	3910	97
12.5	32	610	22.09	4685	81
10	20	625	28.07	6000	65

2.11.1.11 Registrations

On the inside of curves a span tension of 3000N shall be maintained to prevent support fittings from kicking up.

Single Pendulums

For weight tension systems, the length of the Pendulum (Hanger) measured on the incline, including the bow, shall be 800mm

Pendulums should be used for trolley wire deviation angles up to 4° (pendulum inclination angles must not exceed 70° at 50 degrees Celsius). Optimally pendulums should be designed for optimum angles of around 40 to 45 degrees at 20 degrees Celsius.

Wind load at 28m/s should be less than the radial load. Where radial load is insufficient, the configuration of the adjacent registration staggers may need to be changed to increase the radial load.

Single pendulums are not suited to trolley shoes because the vertical axis of the trolley wire rotates with the change in pendulum inclination angle. This rotation of the trolley wire is not a problem with pantograph heads.

The clamping of the trolley to the pendulum shall be such that at a temperature of 20 degrees Celsius, the trolley wires axis shall be vertical.

Pull-off arms

Single pull-off arms should be used for deviation angles between 4° and 9° . Single pull-off arms used between 2° and 4° shall be fitted with an inclined nose stay, inclined bridle support or similar device.

Use of chains is not an acceptable method to stay the pull off arm. At critical registration points Yarra Trams requires the use of stay systems which also provide additional registration security (eg deltas attached to the contact wire).

Double pull-off arms should be used for deviation angles between 9° and 25°.

2.11.2 Fixed terminated equipment. Pantograph only operation

Application is primarily Melbourne Central Business District where the number of curves and junctions would nullify any benefits from tension regulation.

2.11.2.1 Tension (FT, panto only)

Full trolley tension will be maintained throughout including curves. It is necessary to account for the full temperature tension variation of the trolley and fittings.

Tensions and pendulum geometry for 33m spans is as follows:

Wire temp.	0°C	10°C	20°C	30°C	40°C	50°C
Tension, N	12000	9650	7570	5910	4720	3910
Stagger, mm	99	132	165	195	218	234

2.11.2.2 Tension lengths (FT, panto only)

Tension lengths in Melbourne's CBD generally extend from junction to junction or curve to curve.

Tension lengths on open route shall be defined as the distance from anchor point to anchor point and not more than 800m in length.

2.11.2.3 Tension regulation (FT, panto only)

Tension varies with temperature. However, approximately 50% of the temperature-induced sag should be attenuated by the change in pendulum geometry.

Trolley tension is maintained usually from junctions and curves where legs and spines anchor on poles.

2.11.2.4 Overlaps (FT, panto only)

Overlaps need not be provided on fixed terminated trolley equipment.

2.11.2.5 Midpoints/fixed points (FT, panto only)

On long straight lengths, trolley fixity shall be provided by anchors (similar to MPA's) with a spacing not exceeding 800m. The fixity is to limit damage extent following wire breakage.

2.11.2.6 Span lengths (FT, panto only)

A design should be based on providing a minimum number of spans each of maximum length. Maximising the span length will be compromised by:

- ☐ Road crossings and tram junctions
- ☐ Availability of pole positions

- ☐ Underground utilities and services

2.11.2.7 Maximum span tangent track (FT, panto only)

Span length shall not exceed 33m for supports with pendulums (with or without small deltas).

Span lengths shall not exceed 33m plus length of bridle for supports including a bridle arrangement.

2.11.2.8 Span lengths on curves (FT, panto only)

The Span/Curve table is based on the following parameters:

Temperature	°C	0	20	50
Tension	N	12000	7570	3910
Stagger	mm	300	300	300

Wind 28m/s
Overall pantograph width 1050mm
Vehicle roll 1.5° about centreline
Static pantograph tolerances 50mm

Stagger is to the outside of the curve and assumes that pull-off arms are used throughout.

Based on 50°C condition				@ 50°C		@ 0°C	
Span m	Curve m	Versine mm	Deviation angle in °	Radial Load, N	Wind Load, N	Radial Load, N	Wind Load, N
33	339	402	5.58	381	214	1169	214
30	255	441	6.73	460	195	1411	195
25	157	498	9.11	623	162	1912	162
20	92	543	12.40	849	130	2606	130
15	48	586	17.76	1222	97	3750	97
12.5	33	592	21.45	1481	81	4547	81
10	21	595	26.77	1861	65	5712	65

2.11.2.9 Registrations

On the inside of curves a span tension of 3000N shall be maintained to prevent support fittings from kicking up.

Pendulums

For fixed terminated pantograph only operation, the length of the pendulum (hanger) measured on the incline, including the bow, shall be 450mm

Pendulums should be used for trolley wire deviation angles up to 4° (but not more than pendulum inclination angles of 70°).

Wind load at 28m/s should be less than the radial load. Where radial load is insufficient, the configuration of the adjacent registration staggers may need to be changed to increase the radial load.

Pull-off arms

Single pull-off arms should be used for deviation angles between 4° and 9°. Single pull-off arms used between 2° and 4° shall be fitted with an inclined nose stay, inclined bridle support or similar device.

Double pull-off arms should be used for deviation angles between 9° and 25°.

2.11.3 Fixed terminated equipment. Dual Pantograph and Pole shoe operation

Application is primarily for existing routes where there is a requirement to support the Restaurant, City Circle and fleet of other historical trams.

2.11.3.1 Tension (FT, Dual)

Full trolley tension will be maintained throughout including curves. It is necessary to account for the full temperature tension variation of the trolley and fittings.

Tensions and double pendulum geometry for 33m spans is as follows:

Wire temp.	0°C	10°C	20°C	30°C	40°C	50°C
Tension, N	12000	9650	7570	5910	4720	3910
Stagger, mm	99	132	165	195	218	234

2.11.3.2 Tension lengths (FT, Dual)

Tension lengths in Melbourne's CBD generally extend from junction to junction or curve to curve.

Tension lengths on open route shall be defined as the distance from anchor point to anchor point and not more than 800m in length.

2.11.3.3 Tension regulation (FT, Dual)

Tension varies with temperature. However, approximately 50% of the temperature-induced sag should be attenuated by the change in double pendulum geometry.

Trolley tension is maintained usually from junctions and curves where legs and spines anchor on poles.

2.11.3.4 Overlaps (FT, Dual)

Overlaps are not suitable or for pole shoes.

2.11.3.5 Midpoints/fixed points (FT, Dual)

On long straight lengths, trolley fixity shall be provided by anchors (similar to MPA's) with a spacing not exceeding 800m. The fixity is to limit damage extent following wire breakage.

2.11.3.6 Span lengths (FT, Dual)

A design should be based on providing a minimum number of spans each of maximum length. Maximising the span length will be compromised by:

- ☐ Road crossings and tram junctions
- ☐ Availability of pole positions
- ☐ Underground utilities and services

2.11.3.7 Maximum span tangent track (FT, dual)

Span length shall not exceed 33m for supports with pendulums. Deltas or bridles are not appropriate for dual operation.

2.11.3.8 Span lengths on curves (FT, dual)

The Span/Curve table is based on the following parameters:

Temperature	°C	0	20	50
Tension	N	12000	7570	3910
Stagger	mm	100	100	100

Wind 28m/s
Overall pantograph width 1050mm
Vehicle roll 1.5° about centreline
Static pantograph tolerances 50mm

Stagger is to the outside of the curve where there is predominantly pantograph operation and assumes that pull-off arms and/or curve bars are used throughout.

Based on 50°C condition				@ 50°C		@ 0°C	
Span m	Curve m	Versine mm	Deviation angle in °	Radial Load, N	Wind Load, N	Radial Load, N	Wind Load, N
33	676	201	2.79	191	214	585	214
30	468	240	3.67	250	195	768	195
25	262	298	5.46	373	162	1144	162
20	145	345	7.89	540	130	1656	130
15	74	380	11.57	792	97	2432	97
12.5	49	399	14.55	998	81	3064	81
10	31	403	18.31	1261	65	3869	65
7.5	17	414	24.9	1727	49	5299	49

2.11.3.9 Registrations

On the inside of curves a span tension of 3000N shall be maintained to prevent support fittings from kicking up.

2.11.3.10 Double Pendulums

For fixed terminated pantograph and pole operation, the length of the double pendulum (hanger) measured on the incline, shall be 500mm

Double Pendulums should be used for trolley wire deviation angles up to 1.5° (but not more than double pendulum inclination angles of 40°).

Double pendulums maintain the same trolley wire vertical axis regardless of change of their inclination angle. Single pendulums are not suited to trolley shoes because the vertical axis of the trolley wire rotates with the change in pendulum inclination angle.

Wind load at 28m/s should be less than the radial load. Where radial load is insufficient, the configuration of the adjacent registration staggers may need to be changed to increase the radial load.

2.11.3.11 Pull-off arms

Single pull-off arms should be used for deviation angles between 1.5° and 9°. Single pull-off arms used between 1.5° and 4° shall be fitted with an inclined nose stay, inclined bridle support or similar device.

2.11.3.12 Curve bars

Single pull-off arms with 1.2m curve bars should be used for deviation angles between 9° and 12°.

Double pull-off arms with 2.4m curve bars should be used for deviation angles greater than 12°.

Curve bars with more than two pull-off arms shall not be used.

2.11.3.13 Curve Offsets

For pole operation it is normal practice to offset the curve wire to the inside of the track centreline to prevent the trolley pole collector shoe from rubbing on the side of the trolley wire. Where curve bars are installed they shall be suitably positioned to prevent the collector shoe from rubbing on the curve bar clamp or trolley wire.

2.12 Statutory regulations

- ☐ Electricity Safety (Network Assets) Regulations 1999
- ☐ Tram Electrical Safety and Operating Rules
- ☐ Code of practice for powerline clearance [vegetation] 1996

2.13 Other requirements

The Office of the Chief Electrical Inspector has ruled that the 600V dc feeders shall be below the Low Voltage ac distribution conductors.

2.14 Clearances

Minimum acceptable clearances between earthed structures and live fittings shall be 1200mm.

Where 1200mm is unobtainable then insulated fittings shall be used. For example, polymeric registration arms on centre poles.

3 Component and Assembly Details

3.1 Installation Methodology

All Components and assemblies shall be installed in accordance with the manufacturers instructions and good overhead construction practice.

Where a dispute exists over the method of installation of a fitting or component Yarra Trams reserves the right to seek independent advice confirming the method in which the item is installed.

The installation must be performed in accordance with correct practices but must also be installed to ensure symmetry and correct look. Fittings which sit off vertical excessively, cause uneven pull in span wires or abnormal drops in centres will not be acceptable

The positioning of fittings shall be designed for maintenance and aesthetic rationalisation. For example, the midpoint anchor brackets on a boom can be installed independently with "U" bolts or can be bolted back to back. The latter improves both the look of the fittings and aligns the anchor wires in both directions above the top of the wire. The constructor must perform obvious rationalisation of this type.

3.2 Trolley wire

Material	Resistivity (microhm-metre)	Conductivity 100% IACS
Hard drawn (only Port Melb. & St Kilda)	0.01777	97%
Silver copper (Siemens catalogue)	0.017857	96%
Cadmium copper (BS23)	0.020525	84%
Magnesium copper (0.2%) European	0.02312	75%
Tin bearing copper (0.12%) Australian	0.0236	73%
Tin bearing copper (0.2%) European	0.02472	70%

Tin bearing copper shall not be used for new projects due to inherent fatigue problems.

129mm² and 81mm² trolley wire profiles shall be in accordance with drawing O6887 Rev C.

Trolley wire shall be in accordance with PTC specifications:

- a) TS:94 007 Trolley wire, 81mm², cadmium copper
- b) 17/OH 4 96 Trolley wire, 129mm², cadmium copper

Maximum length of trolley wire on drum shall be determined from the capacity of the supporting cradle and the drum lifting capabilities at the stores.

3.3 Bullrings

Shall be in accordance with drawing D3885.

3.4 Pole bands

Extra strong pole bands and fastenings are required for tensioned curves.

Pole bands should be provided for each span leg for ease of adjustment of trolley heights.

3.5 Building attachment

A minimum two-metre length of Parafil shall be used adjacent to the building attachment to attenuate vibration.

Building fastenings shall be designed for a Working Load Limit of 18.0kN.

The attached Parafil or fittings shall be designed to fail before failure of the building attachment to prevent structural damage to buildings.

3.6 Wire

3.6.1 Span

3.6.1.1 Steel

Shall be in accordance with reference D3218 24 (7/2.50, 8.25mm diameter, Grade G820, galvanised). Working Load Limit shall be taken as 10kN.

Multiple stage hand crimping techniques are preferred.

6mm diameter wire shall not be used.

3.6.1.2 Parafil (Terylene)

2-tonne and 5-tonne Terylene Parafil are to be used as standard on the Tram Network. Refer to drawing D4464 and D4465 for technical details, references and procedures.

1-tonne Parafil shall not be used.

3.6.1.3 Parafil (Kevlar)

Kevlar is not acceptable for normal span work for the following reasons:

- ☐ Cost of replacement
- ☐ Introduction of an orphan component
- ☐ Risk of replacement with a weaker material (Terylene) under maintenance
- ☐ Risk of sudden failure

5-tonne Kevlar may be used for anchoring if it can be shown that anchor stretch may create tension maintenance difficulties.

3.6.1.4 Clamps

Metal clamps shall not be used for suspended fittings on Parafil.

3.6.2 Legs

The loading in each leg shall be calculated to ensure that the load in the wire is within allowable limits.

3.6.3 Spines

Spines will be used to effectively replace the function of poles in junction areas where poles cannot be positioned.

3.6.4 Head Spans

Where head spans are installed they shall be arranged to lay in parallel to the main support span. The positioning and length of headspan droppers shall be calculated by design and then tailored in the field to meet the application.

Headspans shall generally be constructed of Parafil although steel is acceptable provided suitable insulators are cut in.

3.6.5 Legs over the top of bare service wires

Legs over the top of bare service wires shall be constructed in Parafil or Kevlar to eliminate possible electrical shorting.

3.7 Trolley (contact) clamp angle

For fittings such as pull-off arms and single-delta clamps the trolley wire should not rotate through an angle of more than 10 degrees from the vertical position throughout the entire temperature range.

3.8 Cross-contact bar

Cross-contact bars should be designed out of the system where possible. Significant trolley wear can occur in the area of the strike-point.

The method adopted at intersection points must take into account all possible failure modes to prevent catastrophic failure, particularly the potential for the pantograph to become entangled.

Where cross contacts are used, care must be taken to ensure that there is no undue uplift or downward force exerted from one intersecting contact wire. Preferably the intersecting wire should float inside the cross contact bar region.

The position and length of the cross contact bar assembly must be designed to prevent fouling with other fittings installed on the overhead and to prevent damage to the intersection point in the event of normal operation and normal maintenance deviations.

Cross contact assemblies can not be used in any area of pole operation even if the pole will always operate on the lowest wire only. This is because the collector shoe will hit the upper intersecting contact wire.

Centre spacing. Pantograph only. Curve-bar????

More work
required

3.9 Bridle wires and other vertical restraint systems

Where bridle wires are installed the bridle support insulator shall be installed vertically above a straight line drawn between the two trolley wire bridle clamps.

Where installed, bridle wires must take only vertical load, not radial load. Any indication of wire hogging in the radial direction by bridles (or any other vertical registration component) used in conjunction with a radial pull off arm or support will not be acceptable.

3.10 Turnbuckles on Spans and Legs

Spans and legs that require constant re-tensioning shall be fitted with turnbuckles to allow for ready adjustment. On initial installation the turnbuckle shall be extended out to maximum travel to maximise future tightening. Examples of spans requiring turnbuckles would be spans on critical sections of overlaps and spans or legs used on curves where levelling or span pre-load may be required.

3.11 Section insulators with bypass (bridging) runners

Where modern section insulators are used with side runners (bypass or bridging runners) the section insulator shall be supported on four corners by means of an insulated turnbuckle system supported from dual support spans or a support square.

3.12 Insulator positioning

3.12.1 Philosophy of insulation

Insulators are to be positioned to prevent public and maintenance staff coming into contact with live span wires. Insulator positioning shall consider all nominal failure modes of Overhead support networks and fittings.

Mixed systems of insulation shall not be installed. For example, insulated and non-insulated line clamps shall not be used on the same network curve network.

It is permissible to omit the between tracks span wire insulator where continuous Parafile span wire or insulated line clamps are used and the route is designated for pantograph only operation.

Insulators may require staggering at the convergence of legs to avoid clashing.

Reel insulators shall not be used at intersections or areas where legs incur high radial loads.

The adoption of any insulator systems must be logical and consistent and not introduce potential maintenance hazards. For example, selective use of marginal strength insulators in some construction legs of a network will not be acceptable. The construction must be consistent to ensure that a maintenance linesman does not accidentally substitute and inadequate fitting into the overhead system during future maintenance.

Positioning of insulators for revised design using pull off arms Refer to drawing O15-024 revision C8 for standard insulator positioning.

3.13 Types of insulator – insulator strengths

Type	Reel (Poles)	GY1 (Inspan)	GY2 (Termination s)	Loop (Assembly type fittings)
WLL - kN				14
Restrictions	Not suitable for full tension curves			Not suitable for salt environment

More work
required

Working Load Limit (WLL) is taken as the Ultimate or failure load with a factor of safety of 3.

3.14 Power connections

Power connections for taps to trolley, equalisers and intersecting wire jumpers shall be made utilising dedicated power-clamps. Traditional 10-inch feeder ear power connections shall not be acceptable.

Intersecting wire jumpers must be provided at every contact wire intersection point except when intersecting fittings designed for power transfer are installed (eg for conventional frogs and crossing pans)

The cross section of power feeder taps must be consistent with the power feeder circuit feeding the overhead. For example, where the power feeder cable is 400mm² cross section, the taps to trolley connected to that feeder shall be equivalent to 400mm² cross section. Generally in power connections, 400mm² cross section can be split between the up and down tracks provided equalisers have been used consistently along the overhead section. For example, an "up" tap and a "down" tap to trolley of 200mm² cross section can be connected in series to 400mm² power feeder.

3.15 Power Clearances

3.15.1 Clearances from live components to earthed (or rail short circuited) components

Notwithstanding the electrical safety clearances identified in the next clause the physical electrical clearances for 600 volt dc components to earthed or rail shorted components shall be in accordance with British Standard 2618. (what is current VDE which covers this?)

More work
required

Whilst nominally 600 volts the insulation design of the traction system should be based on 750 volts dc.

Refer to the Electricity Safety (Network Assets) Regulations 1999.

3.15.2 Maintenance Safety clearances

For the safety of Maintenance linesman it is important that minimum clearances are maintained from live 600 volt systems to earthed structures such as poles and bridges.

For centre-mount poles the clearance from live traction apparatus to the pole or other adjacent earthed structures shall not be less than 1 metre. This applies to the location of all metallic components (for example steel steady arms) that are directly attached to contact wire.

This should have a diagram or something???

More work
required

4 Construction

4.1 Pole back rake

Poles shall be installed with a back rake of 1:100 in the direction of the resultant moment as shown on the layout drawing.

Poles in visual distance must be raked consistently to ensure maximum aesthetics.

Poles with negative rake (pointing in towards the track) will not be acceptable and must be corrected or replaced.

In areas of high architectural profile additional consideration may be required to ensure that the rake is consistent with the environment in which the poles are installed.

4.2 Tensioning trolley wire

All trolley wire runs shall be tensioned with a dynamometer installed in the line. Measuring sags against temperature shall not be used for new works.

4.2.1 Strain creep & cut backs

New trolley wire tension lengths shall be over tensioned by 10% for a minimum period of 2 hours. This is to compensate for the initial stretch of new conductor.

Further strain creep will be removed by trolley cutbacks under maintenance procedures.

4.3 Verification of angle of deviation (approximate method for site work)

Measure 60cm along a projected line from where the trolley deviation occurs. The offset, measured in centimetres, is roughly the angle of deviation in degrees. Theoretical error is less than 10%.

4.4 Insufficient radial load

Construction shall not retrofit chain supports to lift the ends of steady-arms. The Contractor shall notify the Principal where there is insufficient radial load to maintain the correct heel setting.

If it is not possible to design higher radial loads, for example, by changing adjacent support staggers, then it may be acceptable to include a small bridle installed at an angle or a pendulum fitting if suitable.

5 Acceptance, Inspection and Testing

5.1 Documentation

Complete as-built documentation shall be provided to the Principal on completion of the works. Drawing records are necessary for both Overhead maintenance and 'Dial before you dig' operations.

Appendix A Nomenclature

Common Acronyms:

BWA	Balance Weight Anchor
FXA	Fixed Anchor
SPA	Spring Anchor
MPA	Mid Point Anchor
SI	Section Insulator
IR	In-Running
OOD	Out-Of-Running
TO	Turnout
XO	Crossover
STC	Single Track Cantilever
TTC	Two Track Cantilever
SPS	Small-Part Steelwork
SSA	Self Supporting Anchor
RSJ	Rolled Steel Joist
UC	Universal Column
OHE	Overhead Equipment
OCS	Overhead Contact System
TBR	To Be Removed

5.2 Definitions:

General	
Overhead	General term referring to traction infrastructure including foundations, structures, fittings, conductors, and pantographs.
Blow-off	Horizontal displacement of wires due to wind pressure.
Encumbrance	Separation between catenary and contact
Registration	Horizontal fixity of trolley wire at a structure location.
Span	Distance between catenary or trolley supports
Bay	Distance between droppers on a catenary system. Same as span on trolley systems.
Stagger	Trolley wire offset from the canted track centre-line at a registration location.
Strike-point	Positions on a converging trolley wire that first strike the horn radius of a pantograph.
Support	Vertical fixity of Overhead type at a support location.
Sweep	Trace imposed by a staggered trolley wire on a pantograph between registration points.
Uplift	Vertical displacement of trolley wire due to pantograph pressure.
Vee-dropper	Hanger supporting the boom tube from the catenary.
Curve	Where trolley wire deviation wires exceed 4°.
Versine	The maximum dimension from a chord between two adjacent registration points to the rail on curved track. Also known as "String line" or "Mid-

	Ordinate Offset".
Climatic considerations	
Maximum Temperature	Temperature of the catenary conductor including ambient, solar radiation and current heating effects. Used for calculating conductor "fall", ie minimum clearances to track. If not known use 50°C for the metropolitan area.
Minimum Temperature	Used for calculating the "rise" of conductors. Generally taken as 0°C in the metropolitan area.
Normal Temperature	Temperature at which cantilevers are set normal to track. This is 20°C throughout the system.
Wind Speed Operating	Maximum design wind speed for which the Overhead remains usable by LRV's. Velocity 28 m/s.
Wind Speed Non-operating	Maximum design wind speed for Overhead structural integrity. Velocity 41 m/s.
Wires and Conductors	
Catenary	Conductor that supports the contact wire. Also known as a Messenger wire.
Contact	Conductor on which the pantograph runs. Also known as a Trolley wire.
Trolley	See 'Contact' wire. Term generally used where there is no supporting catenary wire.
Traction Return	Is usually provided by the trackwork rails bonded to ensure good electrical continuity to the substation, but can be a cable or wire conductor used where the rail cross-section is inadequate for the load or between the rail and the substation negative busbar.
Electrolysis	Conductor for low voltage high current leakage. Runs between utility services and the Substation negative bus.
Along Track Feeder	Either for supplementary copper area to an electrical section or as a feeder from the substation to an electrical section remote from the substation.
Bond wire	Connects the electrically negative infrastructure together.
Earth-wire	Connects an apparatus directly to the general body of the earth.
Full Current Jumper	Provides sufficient copper area to transfer the full power demand from a train.
Potential Equalising Jumper	Provides a connection between conductors or fittings to eliminate sparking due to voltage differences.
Fittings	
Bridle or Delta	Vee stranded wire support for trolley wire. Extends span lengths.
Pull-off bow	Solid wire support for trolley wire. Removes vertical support kink.
Hanger	Support wire.
Dropper	Hanger supporting the contact wire from a catenary.
Double pendulum	Parallelogram hangers to maintain vertical trolley to suit pole shoes.
Single pendulum	Inclined hanger (dropper). Pantograph only operation.
Section Insulator	Device inserted into the contact wire which separates electrical sections whilst providing a path for pantographs.
Steady-arm	Lightweight arm holding contact wire in position.
Curve bar	Long curved trolley wire clamp for guiding pole shoes on curves.
Equipment Types	
Simple	Catenary / contact system with droppers and level contact.
Simple Sag	Catenary / contact system with droppers and a pre-sagged contact wire.
Tramway or Trolley	Contact wire only, span lengths sometimes increased by employing a stitch (bridle).
Contentary	Stranded catenary wire is replaced with solid copper contact wire in areas of restricted encumbrance to avoid mechanical attrition on strands.

Termination Types	
Fixed	Catenary and contact wire terminates directly to a structure without any tensioning devices.
Auto	Catenary wire is Fixed terminated, contact wire only is terminated via a balance weight or spring device to maintain constant tension over a temperature range.
Full Auto	Both catenary and contact wires are weight regulated.
Suspension	
Span, steel	Supports weight of trolley wires. Transfers radial and wind loads to supporting structure. Used for high radial loads and in areas where there is danger of pole strike.
Span, Parafil	Supports weight of trolley wires. Transfers radial and wind loads to supporting structure. Used for low radial loads.
Trapeze	Placed above and supports section insulators. Also provides support to feeders.
Registration	
Hanger & ear	Not used on elastic systems.
Networks & anchoring	
Lacing	Provides for short equal spans to trolley wire registration on curves.
Spines	Provides a longitudinal wire anchoring point for several legs.
Legs	Ties network to either a pole or spine.
Snowshoes	Used for detensioning the trolley wires leading into a curve.