TRACK AND CIVIL INFRASTRUCTURE

CODE OF PRACTICE

VOLUME THREE - TRAM SYSTEM [CP3]

TRACK GEOMETRY

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1.0 PURPOSE AND SCOPE

1.1 PURPOSE

The purpose of this part is to set standards to ensure that:

a) the construction and maintenance of tram tracks is carried out within safe geometric limits;

b)` excessive acceleration forces on rolling stock shall be limited and hence ensure passenger comfort is not compromised;

c) tram movements are not subjected to excessive traction requirements beyond current capacity (i.e. they limit grades etc.);

d) track forces which may cause excessive track maintenance are limited.

1.2 PRINCIPLES

This part complies with the principles set out in the “Code of Practice for the Defined Interstate Rail Network”, volume 4, part 2, section 5.

1.3 SCOPE

This part specifies general procedures for:

a) the design/rating of track geometry, including track gauge, tangent track, bends, horizontal curves, gauge widening, cant, maximum vehicle line speed, transition curves, gradients and vertical curves;

b) the determination of allowable track condition and limiting vehicle speeds during construction or re-construction of tracks;

c) the monitoring and maintenance of track geometry;

d) the determination of allowable vehicle track speeds when the track falls below the minimum condition considered safe for operation at full line speed.

1.4 REFERENCES

1.4.1 Industry code of practice

Code of Practice for the Defined Interstate Rail Network, volume 4 (Track, Civil and Electrical Infrastructure), part 2 (Infrastructure Principles), section 5: Track geometry

1.4.2 TransAdelaide documents

a) **CP2**
CP-TS-973: Part 3, Infrastructure management and principles
CP-TS-982: Part 12, Guard/checkrails and buffer stops

b) **Infrastructure Services Management system Procedure Manual**
QP-IS-501: Document and Data Control
CPRD/PRC/046 Records Management

1.4.3 TransAdelaide drawings

304-A3-83-335: Design standard - Roundings

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2.0 DESIGN AND RATING

2.1 GENERAL

a) The aim of the track alignment design shall be to allow trams to maintain the maximum speed for the traffic operating. This is generally best achieved by minimizing the gradients and curvature of the track.

b) Except as provided for elsewhere in this part, the parameters given in table 2.1 shall be adopted:

Table 2.1: Maximum values of track parameters

	PARAMETER	MAXIMUM ALLOWABLE
1	Actual cant: - where rails are continuously welded and curves are properly transitioned .... - where rails are not continuously welded or curves are not properly transitioned .... - at platforms and road crossings	 100mm 70mm 45mm
2	Cant gradient	1:400
3	Cant deficiency [see sub-clause 2.4.3(c)]; - where rails are continuously welded and curves are properly transitioned .... - where rails are not continuously welded or curves are not properly transitioned .... - on the diverging route of conventional turnouts .... - on the diverging routes of tangential turnouts .... - at a horizontal bend	 80mm 50mm 80mm 40mm 40mm
4	Cant excess (negative deficiency)	70mm
5	Rate of change of cant deficiency, excess cant or actual cant [see paragraph 2.4.4(e)(2)]: Plain track .... On diverging route of conventional turnouts .... On diverging routes of tangential turnouts	 35mm/sec 35mm/sec 35mm/sec
6	Horizontal bend angle	1º 50’
7	Horizontal curve radius	See note [1]
8	Vertical curve radius (see clause 2.10.3	
9	Grade (compensated)	1 in 20
10	Nominal spacing of vehicle bogies	9.45m [see note 2]

Note [1]: There is no maximum allowable radius, however for the minimum allowable radius on main lines and sidings see clause 2.4.2.
[2] “H” class trams only.

2.2 TRACK GAUGE

a) The nominal track gauge of TransAdelaide’s tram tracks is 1435mm; all formulae in this part are for this gauge, commonly referred to as standard gauge.

b) Track gauge shall be measured between the running faces of the rails at points 8mm below the running surface and must take into account any rail head flow.

c) Gauge on curves shall be increased as follows:
1) on curves $>$ 100m radius: no widening;
2) on curves from 100m to 50m radius: 3mm widening;
3) on curves $<$ 50m radius: 5mm widening.

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2.3 TANGENT TRACK

Tangent track shall be laid and measured between the tangent points of curves, points and crossings or the ends of the line. In general, tangent track shall be laid and maintained level across the rails. Exceptions to this rule occur at the approach to un-transitioned curves, where half the cant is applied on the tangent track and the other half on the curve.

2.4 HORIZONTAL CURVES

2.4.1 Radius

The radius of all curves shall be expressed in metres.

2.4.2 Minimum radius

a) The minimum radius of curve for existing running lines and sidings shall be 25m.

b) The minimum radius of curve to be used alongside a passenger platform shall be 800m for all new work.

c) On all curves on main lines where the radius is less than 325m the low leg of the curve shall be fitted with a continuous check rail in accordance with CP-TS-982 (Guard/check rails and buffer stops).

2.4.3 Definitions:

a) The actual cant is that which is applied to the curve in practice.

b) The equilibrium cant is the theoretical cant at which the resultant of the centrifugal force and the vertical force due to the mass of the vehicle is perpendicular to the top plane across the track at the maximum vehicle design speed.

c) The cant deficiency is the amount by which the actual cant would have to be increased to equal the equilibrium cant. Except as provided for in clause 2.6.2, cant deficiency shall not exceed more than 80% of the actual cant.

equilibrium cant = actual cant + cant deficiency

d) Negative cant is where the inside rail on a curve is higher than the outside rail, and is to be avoided where possible, but may occur on a contraflexure turnout where the whole turnout is canted to favour the main running line and thus puts a negative cant on the other leg of the turnout. The maximum negative cant shall be 18mm with a maximum speed of 20km/h (“notch 1”). Above 20km/h, no negative cant is to be used. The cant on the main running line may have to be reduced in order to keep the negative cant within these limits.

2.4.4 Cant and speed - an explanation

a) When a tram enters a curve, centrifugal force acts on the vehicle and any passengers inside. This force is proportional to the square of the speed of the vehicle and inversely proportional to the radius of the curve. At moderate levels of operation centrifugal force has no effect on safety, but may affect the comfort of passengers. To counter the effects of centrifugal force on passengers, cant is applied to the curve by lowering the inside rail and raising the outside rail by equal amounts.

b) For a tram travelling at a different speed than that used to calculate the cant, there shall be an “excess cant” if the tram is travelling too slow or a “cant deficiency” if the tram is travelling too fast.

c) Overseas tests reveal that risk of derailment is increased if the “excess cant” appreciably exceeds one tenth of the gauge, i.e.140mm on TransAdelaide. By

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considering a near stationary tram on a curve (for example, at a “stop” signal), this effectively sets an upper limit for the (total) cant i.e. the original deliberately applied (nominal) cant plus any further cant accidentally applied because of track settlement. As a result, well-maintained track may safely take a higher nominal cant than poorly maintained track.

d) Note: The prime reason for canting curved track is for passenger comfort, not safety. Excessive cant may jeopardize safety; lack of cant will not, (except near the speed at which capsizing may occur, but cant would only have a marginal effect at such an excessive speed).

e) Tests also show that for passenger comfort:

1) cant deficiency should not exceed 80mm;

2) rate of change of cant or cant deficiency should not exceed 35mm/sec. However where space is restricted a rate of up to 55mm/sec may be used in accordance with clause 2.6.2 (a) (Transitions of restricted length);

2.4.5 **Cant / speed relationship**

a) The vehicle design speed shall be the maximum speed that trams shall not normally exceed.

b) The maximum allowable vehicle design speed for any curve shall be determined by the formula in figure 2.1. Where “V” exceeds the maximum allowable line speed, the line speed shall be used and cants recalculated accordingly.

Figure 2.1: Determination of speed

$$V = 0.291\sqrt{E_q . R}$$

where:

V = Maximum allowable vehicle speed for curve in km/h
E_q = Equilibrium cant in mm = $E_a + E_d$
E_a = Actual cant in mm
E_d = Cant deficiency in mm
R = Radius of the curve in metres

c) The cant that may be applied to a curve shall be determined by the formulae in figure 2.2:

Figure 2.2: Determination of cant

1) The equilibrium cant is calculated as follows:

$$E_q = 11.8 \times \frac{V^2}{R}$$

where

E_q = Equilibrium cant in mm
V = Vehicle design speed in km/h
R = Radius of curve in metres

2) The actual cant is calculated as 55% of the equilibrium cant.

3) If this exceeds the value shown in table 2.1 for the location, then determine the maximum allowable equilibrium cant and then calculate the maximum allowable vehicle design speed as in (b).

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2.5 BENDS

2.5.1 Occurrence of bends

Bends occur where two tangent tracks meet at near 180 degrees without an intermediate curve. Mostly they occur at the toe of straight switches but can occur on the running line due to historical inaccuracies when the line was originally laid out. Except at the toe of conventional points, horizontal bends should be avoided where possible

2.5.2 Allowable maximum speed through a bend

The allowable maximum speed through a bend shall be as shown in figure 2.3:

Figure 2.3: Maximum allowable speed through a bend

$$V = 2.20 \times \sqrt{\frac{Ed \times B}{A}}$$

where: V = Maximum allowable vehicle design speed in km/h

E_d = allowable cant deficiency in mm

B = bogie centres of rolling stock in metres

A = angle between two tangent tracks in degrees

On TransAdelaide tramlines it may be assumed that E_d = 40mm and B = 9.45m, thus: maximum allowable speed = $43 \div \sqrt{A}$

EXAMPLE: For a straight 6.09m switch (angle = 1.28°), max. allowable speed = 35 km/h. Note, however the speed through the turnout may be dependent on its radius.

2.6 TRANSITIONS

2.6.1 Standard transitions

a) All standard curve transitions shall be of cubic parabola form.

b) The centre line of the track on the true curve shall be moved towards the centre of the curve by the "shift" to facilitate the construction of the transition.

c) The rate of change of actual cant or cant deficiency shall be limited to 35mm/sec. and the cant gradient to not steeper than 1 in 400. Thus, the lengths of transitions shall be as shown in figure 2.4:

Figure 2.4: Lengths of transitions

The length of transition on any curve shall be the highest value of the results of the following three calculations:

1) $L = 0.0079.E_a.V$

2) $L = 0.0079.E_d.V$

3) $L = 0.4.\ E_a$

where L = Transition length in metres

E_a = Actual cant in mm

E_d = Cant deficiency in mm

V = Maximum allowable vehicle design speed in km/h

If the theoretical transition length is less than 20m, or the shift is less than 10mm [see clause (b)] no transition shall need to be applied.

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2.6.2 Transitions of restricted length

In certain circumstances it may not be possible to apply the standard transition lengths as calculated from clause 2.6.1(c). If so the alternative solutions, in descending order, may be:

a) Adopt a greater rate of change of cant than that specified in clause 2.6.1(c). Under no circumstances shall this value exceed 55mm / sec. [see paragraph 2.4.4 (e) (2)] and by adopting it, the formulae in figure 2.4 are modified as follows:

   1) $L = 0.005.E_a.V$

   2) $L = 0.005.\ E_d.V$

   3) $L = 0.4.\ E_a$

b) Adopt a higher cant deficiency than that specified in clause 2.4.5 up to, but not exceeding, the actual cant.

c) Adopt a shorter transition than calculated but commence canting the track before the commencement of the transition and increase the cant in accordance with paragraphs 2.6.1(c) or 2.6.2(b) until the full cant is applied. The distance over which the cant is increasing shall be symmetrical with the distance over which the track is transitioned.

2.6.3 Curves without transitions and "virtual" transitions

If it is not possible to apply any transition at all, the following action shall be considered. Between when the first bogie of a bogie vehicle enters a curve and the second bogie enters the curve, the vehicle gradually takes up circular motion. This is the "virtual transition" and is equal in length to the bogie centres. On TransAdelaide, the virtual transition is 9.45m long. By considering the transition as 9.45m long (symmetrical about the tangent point) the alternatives shown in clauses (a) or (b) may be used.

a) If the curve is canted without a transition, the cant shall be applied from zero at the beginning of the virtual transition and increased in accordance with the maximum rate of change of cant or cant deficiency or cant gradient until the maximum cant is reached at the end of the virtual transition. As the maximum vehicle design speed will be attained if the actual cant equals the cant deficiency, the calculation of the cant and speed shall be as in figure 2.5:

Figure 2.5: Curve canted but not transitioned

$V = 0.291\sqrt{E_q.R}$ (see figure 2.2)

But if $E_q = E_a + E_d = 2 \times E_a$; then $V = 0.291\sqrt{2.Ea.R}$

From the transition formula L (= 9.45m) = $0.0079.E_d.V$

Therefore equating V from the two formulae:

$0.291\sqrt{2.Ea.R} = 9.45 \div 0.0079.E_d$

$E_a = E_d = [203.7 \div \sqrt[3]{R}\,]$

EXAMPLE: If $R = 200$m, $E_a = E_d = [203.7 \div \sqrt[3]{200}\,] = 34.8$mm

Then $V = 0.291\sqrt{E_q.R} = 34$ km/h

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b) If the curve is un-canted and without transition, the maximum allowable vehicle design speed shall be determined using the maximum allowable cant deficiency for the curve. The cant deficiency is assumed to build up over the virtual transition and shall need to be checked to ensure that it does not exceed the allowable cant gradient. The calculation of the cant and speed shall be as in figure 2.6:

Figure 2.6: Curve uncanted and not transitioned

$V = 0.291\sqrt{E_q.R}$ (see figure 2.2)

From the transition formula L (= 9.45m) = $0.0079.E_d.V$

Therefore equating V from the two formulae:

$0.291\sqrt{E_q.R} = 9.45 \div 0.0079.E_d$

In this case $E_q = E_d$ therefore $E_d = [256.6 \div \sqrt[3]{R}\,]$

EXAMPLE: If R = 200m; $E_d = [256.6 \div \sqrt[3]{200}\,]$ = 43.9mm

Then $V = 0.291\sqrt{E_q.R}$ = 27km/h]

2.6.4 Compound curves

In compound curves, transitions between different radii of the compound curve shall use the same criteria as for a simple curve with the following variations:

a) Calculations involving cant shall use the difference in cant between the two radii.

b) Calculations involving cant deficiency shall use the difference in cant deficiency for the two radii.

c) The cant and speed shall be determined for each curve individually.

d) The length of transition between the two curves shall be derived from the formulae in figure 2.4, modified as follows:

1) $L = 0.0079.(E_{a1} - E_{a2}).V$

2) $L = 0.0079.(E_{d1} - E_{d2}).V$

3) $L = 0.4.(E_{a1} - E_{a2})$

2.6.5 Reverse curves

In reverse curves, transitions between different radii of the reverse curve shall use the same criteria as for a simple curve with the following variations:

a) Calculations involving cant shall use the sum of the cants for the two radii.

b) Calculations involving cant deficiency shall use the sum of the cant deficiencies for the two radii.

c) The cant and speed shall be determined for each curve individually.

d) The length of transition between the two curves shall be derived from the formulae in figure 2.4, modified as follows:

1) $L = 0.0079.(E_{a1} - E_{a2}).V$

2) $L = 0.0079.(E_{d1} - E_{d2}).V$

3) $L = 0.4.(E_{a1} - E_{a2})$

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2.7 LENGTHS OF STRAIGHTS AND CURVES

For all new work:

a) Between similar flexure curves a transition should be provided.

b) Between contraflexure curves a straight of minimum length should be provided equal to the longest bogie centres of rolling stock in use (9.45m). However, the minimum length of straight may be reduced at crossovers.

c) Circular and transition curves should have a minimum length of 20m.

d) The cant gradient should be not less than 20m long including between curves in a compound curve.

2.8 GEOMETRIC DESIGN DOCUMENTATION *[TO BE DEVELOPED]*

The design details pertaining to the current design should be maintained and should include:

a) Survey co-ordinates and datums if available;

b) Location details;

c) Curvature;

d) Gradient;

e) Cant;

f) Maximum allowable speed;

g) Transition length;

h) Cant gradient.

2.9 POINTS AND CROSSINGS – SPEED THROUGH

The determination of the maximum allowable vehicle design speed through curves in points and crossings shall be made using the standards specified in sub-sections 2.4 and 2.5. In particular, where straight switches are used the standards in sub-section 2.5 (bends) shall be used. For curves in points and crossings without cant or transitions the standards in clause 2.6.3(c) shall be used. Turnouts should be located on tangent track where possible.

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2.10 GRADIENTS

2.10.1 Maximum allowable gradients

a) When most of the existing tracks were built, the gradients were expressed in the form "1 in x" where x is a rational number and cannot be converted to the %age form without the use of an irrational number. It shall be permissible to use both forms.

b) The maximum gradient on existing running lines of TransAdelaide shall be 1 in 20.

c) For new work or track deviations, gradients shall be as near level as possible, but not exceeding the existing running line gradient specified in sub-clause (b).

2.10.2 Curve compensation

a) For new work, in order to achieve a uniform resistance to tram movement, the gradients shall be reduced on curves to compensate for the extra curve resistance. The gradient percentage shall be reduced by:

   1) [100 ÷ R]% for non-lubricated curves; and
   2) [50 ÷ R]% for lubricated curves;

   where R is the radius of the curve in metres.

   EXAMPLE: on a 2.22% (1in 45) gradient, on a curve of 200m radius the gradient would be reduced to 1.72% (1 in 58) on a non-lubricated curve or 1.97% (1 in 51) on a lubricated curve.

b) On existing lines, to determine the equivalent gradient on curves, which are not compensated, the gradient percentage shall be increased by:

   1) [100 ÷ R]% for non-lubricated curves; and
   2) [50 ÷ R]% for lubricated curves;

   where R is the radius of the curve in metres.

   EXAMPLE: on a 2.22% (1 in 45) uncompensated gradient, the equivalent gradient on a 200m radius curve would be 2.72% (1 in 36.8) for a non-lubricated curve or 2.47% (1 in 40.5) for a lubricated curve.

2.10.3 Vertical curves in summits and sags

At changes of gradient, a vertical curve shall be used between the two gradients of parabolic form and of length in accordance with Figure 2.7:

Figure 2.7: Vertical curves

$$L = K(a + b)$$

where a and b are the two gradients expressed as a percentage with up grades +ve and down grades -ve.

K = 64.5 at summits and sags on existing lines;
= 200 at summits and sags on new work;
= 10 on sidings where speed is less than 15 km/h.
= 30 on in-street tracks.

Note: The vertical curve is symmetrical about the point where the gradients intersect. Examples of calculations of vertical curves are shown on drawing 304-A3-83-335. A vertical curve is not necessary where a + b is less than 0.2. Otherwise vertical curves should not be less than 20m in length and should be rounded up to the next multiple of 20m.

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3.0 TRACK GEOMETRY REQUIREMENTS FOR CONSTRUCTION

3.1 GENERAL

All track shall be constructed at least within the limits specified in section 4 and nominal final construction tolerances shall generally be significantly better than those specified in section 4. If construction takes place whilst trams are in operation the track geometry shall comply with the requirements of sub-section 3.2.

3.2 ADDITIONAL RESTRICTIONS AT WORKSITES

If track construction takes place while trams are in operation, the track geometry should comply with these requirements. Reference also should be made to the monitoring requirements given under Construction and Monitoring of the Code of Practice for the Defined Interstate Rail Network, volume 4, part 2, section 5. Where track may be at significant variance from designed horizontal or vertical alignment (for example skeleton track following ballast cleaning) the following additional requirements shall apply:

a) the maximum speed allowed shall be 15kph or “notch 1”. (These circumstances may require the operation of trains to be piloted.)

b) the vertical alignment measured using a 20 metre chord and the mid-ordinate offset at any location shall not exceed 75mm;

c) the horizontal alignment measured using a 20 metre chord and the mid-ordinate offset at any location shall not exceed 330mm.

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4.0 MONITORING AND MAINTENANCE OF BALLASTED TRACK

4.1 INSPECTION, ASSESSMENT AND MAINTENANCE ACTIONS

Inspection, assessment and maintenance actions of track geometry shall include the specific conditions shown in table 4.1:

Table 4.1 Track geometry inspections, assessment and maintenance actions

Type of inspection	Specific conditions or actions to observe
Scheduled inspections	
Walking inspections	a) Identify visually, and report, obvious track geometry defects and conditions (i.e. indicators of a defect) that may affect the ability of the track to guide rolling stock or cause unacceptable rolling stock response including the following: 1) track geometry defects including those that may indicate problems with the underlying track and civil infrastructure; 2) locations where the deterioration in track geometry is abnormal since last inspected; 3) indications of track geometry and alignment defects including: i. evidence of recent or current movement; ii. unusual wear patterns on the rails iii. locations where the geometry is inconsistent with the track either side (e.g. a sudden change in curve radius); 4) obvious variations in track alignment that may, for example, affect clearances or track stability; 5) alignment defects and signs of movement that could cause excessive vibration of track-mounted signaling equipment; 6) other obvious defects that may affect track stability and support. b) Intervals between walking inspections shall not exceed 31 days.
On-tram inspections	a) Inspections are to be made from the driver's cab in daylight hours (only) such that identified defects can be located with the highest possible degree of accuracy. Express trams are to be used where possible. Although drivers should at no time be distracted from duty, at an appropriate time their advice with respect to defects should be sought. Problems or defects identified by drivers at any time should be documented as suspected defects and acted upon accordingly. The inspections should: 1) identify suspected geometry defects; 2) determine the relative ride performance on the various lengths of track as a means of setting priorities for maintenance of the track; 3) observe any other obvious non-geometry related defects in the infrastructure. b) suspected defects include those that cause: 1) sharp or high accelerations of the rolling stock; 2) abrupt motion of the rolling stock; 3) rough riding or any feeling of discomfort to drivers or inspectors; 4) resonant type motions of the rolling stock (i.e. cyclical motions of increasing amplitude) resulting from suspected cyclic track geometrical defects. c) Intervals between on-train inspections are not to exceed 31 days.

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Table 4.1*(continued)*: Track geometry inspections, assessment and maintenance actions

Type of inspection	Specific conditions or actions to observe
Scheduled inspections *(continued)*	
Detailed inspections	a) Inspection measuring gauge, cross level and short twist (2m). Record type, size and location of exceedences; or inspections should be carried out by measuring gauge, top, horizontal alignment, cant, short twist, and long twist. Record type, size and location of exceedences. b) The following should be achieved: 1) identification of track geometry defects in a way which will allow priorities for remedial action to be assessed; and 2) provision of statistical measurements of the quality of track geometry which can be used as a predictive or planning tool. c) Interval between inspections not to exceed twelve (12) months.
Unscheduled inspections	
General inspections	A general inspection should be carried out at specific locations when suspected defects are identified from conditions determined during other inspections and as defined by the responses to Table 4.5. The geometry at the location should be measured and compared with specific limits. The cause, restrictions and repair work should be determined taking into account the local conditions at the site that may affect deterioration rates. General inspections should also identify the need for further specialist inspection.
Assessment and method of assessment	
Assess-ment and actions	a) For track designed and constructed in accordance with the requirements of Section 2 and 3 the assessment for track geometry defects shall be in accordance with tables 4.2 and 4.3. These tables group defects into defect bands for each measured parameter and method of measurement. The track is also grouped into speed bands. The response for a specific defect is determined from the intersection of the defect band (row) and speed band (column). c) Table 4.5 gives the response codes (i.e. E1, E2, P1, P2 and N) which define the maximum period which can be allowed to elapse before inspection and response action of identified geometric defects should be undertaken. d) Imposing a lower speed restriction may moderate the response, i.e. by using the restricted speed to determine the response as though it were the original track speed. Speed restrictions can therefore be used to manage and prioritise the inspection and response action of defects. e) The responses defined in tables 4.2 and 4.3 are based on isolated geometric defects. A more stringent response than that mandated by the geometry alone may be necessary if deterioration of the infrastructure both at the defect and on adjoining tracks is in evidence, see CP-TS-973, (Infrastructure management and principles). f) Defects may be reassessed. This reassessment may result in a response action that is more stringent or less stringent.

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Table 4.1*(continued)*: Track geometry inspections, assessment and maintenance actions

Type of inspection	Specific conditions or actions to observe
Assessment and method of assessment *(continued)*	
Geometry defect categories	Limits have been specified in tables 4.2 and 4.3 for the following geometry defect categories a) **Gauge** is measured between points on the gauge (or inside) face of the rails 8mm below the top. The wide gauge values in the table apply to well tied timber sleepered track only. For tracks with concrete sleepers, where a higher than expected deterioration in gauge has been detected between inspections the track should be subjected to an unscheduled detailed inspection and appropriate actions taken. Measurement of tight gauge includes the effect of any head flow present. b) **Horizontal alignment** is measured using the mid-ordinate offset (versine) of a 10m chord. Limits in table 4.2 have been set based on the variation from the actual design versine. A fitted versine [see note 1] can be used in lieu of the design versine where the fitted versine still complies with the minimum design standards. At low speeds, in table 4.2, the minimum radius negotiable by rolling stock is used as the limiting criterion. c) **Top (vertical alignment)** is assessed using two criteria. Short top is measured using the offset 1.5m from one end of a 5m chord. d) **Cant variation.** Cant is the difference in level of the two rails at a single point along the track. The variation in cant is measured as a variation from the design cant, in mm. The absolute value of cant shall not be allowed to exceed 140mm (anywhere). e) **Twist** is the variation in actual track cant (i.e. the difference in level of the two rails) over a defined length. Twist shall be assessed using two criteria: short twist, in mm, shall be measured over 2m; and long twist, in mm, shall be measured over 14m. Different long twist parameter limits may apply in transition curves than in other track (ie. tangent and circular curves), where the long twist may be primarily the result of a designed cant variation.
Document-ation	Scheduled track geometry car inspection and assessment documentation and records should be kept for a minimum of two years.

Note [1]: A fitted versine is derived automatically by the track geometry car. The car measures the versine on a 10 metre chord every one (1) metre. If the value of the versine at point A is ‘a’ then this value is stored and also recorded as the actual versine at point A. After traveling a further 39m, the car mathematically examines the stored versines over the previous 40m and decides whether point A was on straight track or on curve. If it decides that it was on straight, the value ‘a’ is also recorded as a variation from design versine (i.e. 0). If it decides it was on curve or transition at point A it will calculate what the versine should have been at point A and will derive the difference between the calculated (or fitted) versine and ‘a’ and record it as a versine variation (i.e. a misalignment) at the point where it was taken (i.e point A). This process gives a good approximation of what the versine should be and is termed a “fitted versine” to distinguish it from the design versine which would be exact. The process is similar to the automatic lining of a tamping machine that uses a laser beam from a trolley at a fixed distance ahead of the machine as it travels along.

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Table 4.2: Minimum response requirements and allowable tram speeds.

Measured parameters in mm under loaded track						Speed band		
Gauge [10]		Horiz. align. 10m. chord [7]	Short top 10m [8]	Cant [9]	Short twist 2m [10]	"notch 3" or 75/80 km/h speed	"notch 2" or 40km/h speed	"notch 1" or 20km/h speed
Wide	Tight							
>17	>11	>40	>22	>140	>14	E1	E1	E1
16-17	10-11	35-40	20-21	110-140	12-14	E2	E2	E2
13-15	8-9	30-34	18-19	80-109	10-11	P1	P2	N
9-12	6-7	20-29	15-17	55-79	8-9	P2	N	Nil
7-8	4-5	10-19	13-14	44-54	6-7	N	Nil	Nil
0-6	0-3	0-9	0-12	0-43	0-5	Nil	Nil	Nil

Table 4.3: Minimum response requirements for cant variation.

Cant variation	Tangent track (incl radii ≥ 2000m	Curved track including transitions, radii < 2000m	
		Insufficient cant based on maximum design speed	Excess cant based on maximum design speed
Absolute cant > 140mm requires E1 response [note 11]			
>60	E2	E2 [note 12]	E2 [note 14]
50-60	P1	P1 [note 13]	P1 [note 14]

Notes on tables 4.2 and 4.3:

[1] All geometry parameters used are based on the unloaded condition. Due allowance shall be made for the additional impact of loading and dynamics.

[2] The measured parameter limits set in the above table are derived from commonly occurring defects in actual conditions. Normally occurring multiple defects are provided for in the limits set, for example top and twist defects would commonly be expected to occur together. In such cases the most stringent response criterion of the two shall be selected. Unusual combinations of defects which are considered to act together, for example: horizontal alignment with twist, shall require special attention. A more stringent response than that specified for rectifying the defects individually shall be considered.

[3] Defect parameters selected represent only one range of defects historically specified by tramline systems. Defect types including cyclic, excess cant deficiency and other types giving rise to rough track shall not be ignored. Assessments shall be made by observation and experience, including on-tram riding. Each defect located in this manner is to be classified using the same response categories specified in table 4.3. Acceleration based measuring devices may also be used to identify defects of this type.

[4] Actual defects shall be rounded to the nearest mm. when using this table.

[5] The limits specified in table 4.2 are for the geometry defects defined in notes [6] to [10]:

[6] Gauge shall be measured, in mm, between the inside face of the rails, 8mm below the top surface. Tight gauge shall be measured including any head flow present. Wide gauge on curves where curve wear is part of the wide gauge may be permitted up to a maximum of 10mm without action, provided the track shall be secured against further widening (due to lateral movement of the rail) and the rail side wear limits are not exceeded. The table applies to track well-tied with timber or concrete sleepers only. For

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tracks with concrete sleepers, where a higher than expected deterioration in gauge has been detected between inspections the track shall be subjected to an unscheduled detailed inspection and appropriate actions taken.

[7] Horizontal alignment shall be measured in mm using the mid-ordinate offset (versine) of a 10m chord. Limits shown in table 4.2 have been set based on the variation from the actual design versine. Absolute versines shall not exceed 40mm on track without continuous check rails or 125mm on track with continuous check rails. If the actual versine exceeds 125 the restrictions in table 4.4 shall apply:

Table 4.4: Restrictions where versine exceeds 125mm

Actual versine	**Maximum speed**		
	“notch 3” or 75/80 km/h speed	**“notch 2” or 40km/h speed**	**“notch 1” or 20km/h speed**
> 156	E1	E1	E1
125 – 156	E1	E2	E2

[8] Short top shall be measured manually, in mm, using the offset at the mid-ordinate of a 10m chord. Long top, measured manually, in mm, using the offset at the mid-ordinate of a 20m chord is only used in the construction of new track and is not relevant to on-going maintenance inspection, assessment and action.

[9] Cross level (cant) defects shall be measured as the variation from the design difference in rail level, in mm. The absolute value of cross level shall not be allowed to exceed 140mm (anywhere). The maximum design negative cant is defined in paragraph 2.4.3 (d) and for operational track the values shown in this sub-clause are not to be exceeded.

[10] Short twist is the variation in cross-level along the track measured over 2m in mm.

[11] This is the actual cant measurement (the actual difference in rail levels, not variation from design.)

[12] The response can be reduced to P1 by a speed reduction of 40km/h from the design speed.

[13] The response can be reduced to P2 by a speed reduction of 30km/h from the design speed.

[14] A speed reduction should not be applied for excess cant geometry defects.

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Table 4.5: Response requirement definitions

Response category	Inspect [note 1]	Repair [note 2]	Other requirements
Emergency class 1, E1	Prior to the passage of the next tram	Prior to the passage of the next tram	Where the response category can-not be reduced below E1 by a reduction in speed, trams may only pass the site under the control of a pilot. Assessment of the defect by a competent worker must be made to determine if trams can be piloted
Emergency class 1, E2	Either before the next tram or within 2 hours (whichever is the longer)	within 24 hours	If the defect cannot be inspected or repaired within the nominated time and the response category can not be reduced below E2 by a reduction in speed, trams may only pass the site at speeds up to 15km/h (“notch 1”) following assessment by a competent worker.
Priority class 1, P1	Within 24 hrs	within 7 days	
Priority class 2, P2	Within 7 days	within 28 days	
Routine inspection, N			A deviation from design geometry up to the lowest level of P2 defect does not require any action above the normal inspection regime.

Notes on Table 4.5

[1] In the event of failure to inspect reported faults by the specified time the allowable vehicle speed must be reduced by at least one speed band. A revised inspection period in line with the lower speed band may then be used. If the defect is subsequently inspected the speed may be raised to the higher band subject to repair being achievable within the nominated period for the higher band.

[2] In the event of inability to repair the track as the specified time approaches, the fault must be reassessed on site prior to the expiry of the action response time and the allowable vehicle speed shall be reduced by at least one speed band. When the last speed band is exceeded trams may continue to run at the maximum speed for “notch 1” subject to re-inspection each 24 hrs.

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5.0 MONITORING AND MAINTENANCE OF IN-STREET TRACK

5.1 INSPECTION, ASSESSMENT AND MAINTENANCE ACTIONS

Inspection, assessment and maintenance actions of in-street track for track geometry shall include the specific conditions shown in table 5.1:

Table 5.1: In-street track geometry inspections, assessment and maintenance actions

Type of inspection or action	Specific conditions to look for or other actions
Scheduled inspections	
Walking inspections	a) Identify visually, and report, obvious track geometry defects. b) Intervals between walking inspections shall not exceed 93 days.
General Inspections	a) Visual inspection to be carried out as an on-tram inspection reporting any visually apparent defects or bad riding of the vehicle. b) Intervals between on-tram inspections shall not exceed 93 days.
Unscheduled inspections	Measurements of gauge, cross-level, short twist, horizontal alignment and short top to be undertaken manually as necessary, following a report of a defect or of bad riding of a tram as the result of a walking or general inspection.
Assessment, method of assessment and maintenance action	As for ballasted track (see section 4).

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6.0 DOCUMENTATION

6.1 SCHEDULES OF CURVES AND GRADIENTS

Schedules shall be maintained, in accordance with QP-IS-501 (Document and Data Control), of:

a) all curves on the tramline system showing for each curve the line, km of each tangent point, radius, design actual cant, cant deficiency and equilibrium speed;

b) all gradients on the tramline system showing for each line the km of each change of grade and the grade between each change of grade.

SCHEDULES TO BE PREPARED

6.2 INSPECTION REPORTS

All inspection reports shall be maintained in accordance with CPRD/PRC/046 Records Management.

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