9 SOUTH YORKSHIRE SUPERTRAM

9.1 INTRODUCTION

In mid-1976 a Sheffield and Rotherham Land Use Transportation Study was completed which recommended a fixed track system along six corridors in the City of Sheffield. Following the setting up of a Joint Transportation Unit from officers of the South Yorkshire County Council (SYCC) and South Yorkshire Passenger Transport Executive (SYPTE) in 1979 plans were developed for a modern, high quality light rail system. The concept survived changes wrought by the Local Government and Transport Acts that abolished Metropolitan Counties and de-regulated bus services.

Following transportation modelling by MVA Consultants and production of performance specifications by Kennedy Henderson working with the Sheffield City Council (SCC) Department of Design and Building Services (DBS), a project team was formed in 1989 as South Yorkshire Supertram Ltd (the SYSL was a wholly owned subsidiary of the SYPTE). Besides SYPTE and SYSL the project team consisted of Turner & Townsend Project Management Ltd., Kennedy Henderson, DBS and SCC.

The SYPTE deposited an original Bill to Parliament in 1985 to gain powers for Line 1 (Middlewood/Stannington to Halfway). A further Bill was deposited in 1988 for Line 2 (Lower Don Valley to serve the proposed Meadowhall Shopping Centre). Two further Bills were deposited in 1989 and 1990 to gain extra powers. Financial approval was given by the Department of Transport towards the end of 1990.

Expressions of interest from potential contractors had been invited in September 1988, which resulted in Balfour Beatty Power Construction Ltd (BB) being awarded the contract for the design and build of the infrastructure and Siemens/Duewag of Düsseldorf for the supply of vehicles.

Construction of the system was carried out in eight phases:

Phase 1:	Fitzalan Square to Meadowhall (including South Street Bridge)
Phase 2:	South Street Bridge to Spring Lane
Phase 3:	Fitzalan Square to University
Phase 4:	University to Kelvin
Phase 5:	Spring Lane to White Lane and Herdings Park
Phase 6:	White Lane to Donetsk Way
Phase 7:	Donetsk Way to Halfway
Phase 8:	Kelvin to Malin Bridge and Middlewood

9.2 SYSTEM DETAILS

Schematic route map: See Figure 9.1

Route distances:

For convenience the three arms of the system have been detailed separately:
Table 9.1 – Northwest: Middlewood/Malin Bridge to Fitzalan Square (7.113km)
Table 9.2 – Southern: Fitzalan Square to Halfway/Herdings Park (15.149km)
Table 9.3 – Northeast: Fitzalan Square to Meadowhall (7.129km)

Table 9.1 Distance between Middlewood/Malin Bridge and Fitzalan Square SYS tram stops

From	*To*	*Distance (km)*	*Track*
Malin Bridge	Hillsborough	0.620	Double/grooved rail
Middlewood	Leppings Lane	0.740	Double/grooved rail
Leppings Lane	Hillsborough Park	0.710	Double/grooved rail
Hillsborough Park	Hillsborough	0.375	Double/grooved rail
Hillsborough	Bamforth Street	0.603	Double/grooved rail
Bamforth Street	Langsett Primrose View	0.439	Double/grooved rail
Langsett Primrose View	Infirmary Road	0.725	Double/grooved rail
Infirmary Road	Shalesmoor	0.409	Double/grooved rail
Shalesmoor	Netherthorpe Road	0.550	Ballasted
Netherthorpe Road	University	0.480	Ballasted
University	West Street	0.495	Double/grooved rail
West Street	City Hall	0.353	Double/grooved rail
City Hall	Cathedral	0.272	Double/grooved rail
Cathedral	Castle Square	0.210	Double/grooved rail
Castle Square	Fitzalan Square	0.132	Double/grooved rail

Table 9.2 Distance between Fitzalan Square and Halfway/Herdings Park SYS tram stops

From	*To*	*Distance (km)*	*Track*
Fitzalan Square	Sheffield Station	0.865	Double/grooved rail & ballasted
Sheffield Station	Granville College	0.525	Double/ballasted
Granville College	Park Grange Croft	0.470	Double/ballasted[1]
Park Grange Croft	Park Grange Road	0.550	Double/grooved rail
Park Grange Road	Arbourthorne	0.770	Double/grooved rail
Arbourthorne	Spring Lane	0.800	Double/grooved rail
Spring Lane	Manor Top	1.060	Double/grooved rail
Manor Top	Hollingsend Road	0.920	Double/grooved rail
Hollingsend Road	Gleadless Townsend	0.680	Double/grooved rail
Gleadless Townsend	White Lane	0.585	Double/grooved rail
White Lane	Birley Lane	1.615	Double/ballsted[2]
Birley Lane	Birley Moor Road	0.580	Double/grooved rail
Birley Moor Road	Hackenthorpe	0.560	Double/grooved rail
Hackenthorpe	Donetsk Way	0.794	Double/grooved rail
Donetsk Way	Moss Way	0.525	Double/ballasted
Moss Way	Crystal Peaks	0.450	Double/ballasted
Crystal Peaks	Beighton Drake House Lane	0.670	Double/ballasted
Beighton Drake House Lane	Waterthorpe	0.740	Double/ballasted
Waterthorpe	Westfield	0.530	Double/ballasted
Westfield	Halfway	0.360	Double & single/ ballasted
Herdings Park	Herdings Leighton Road	0.460	Single/ballasted
Herdings Leighton Road	Gleadless Townend	0.640	Double/grooved rail

Notes:
[1] Part plinth track
[2] Part grooved rail

Table 9.3 Distance between Fitzalan Square and Meadowhall SYS tram stops

From	*To*	*Distance (km)*	*Track*
Fitzalan Square	Hyde Park	0.865	Double/grooved rail, plinth & ballasted
Hyde Park	Cricket Inn	0.353	Double/ballasted
Cricket Inn	Nunnery Square	0.588	Double/ballasted
Nunnery Square	Woodbourn Road	0.633	Double/ballasted
Woodbourn Road	Attercliffe Road	0.452	Double/ballasted
Attercliffe Road	Arena	0.995	Double/ballasted
Arena	Valley Centertainment	0.720	Double/ballasted
Valley Centertainment	Carbrook	0.370	Double/ballasted
Carbrook	Meadowhall Tinsley South	1.031	Double/ballasted
Meadowhall Tinsley South	Meadowhall	1.122	Double & single/ballasted

The total route distance is 29.4km, of which approximately half is segregated ballasted tracks.

Though there is end-to-end running (driving end changes at termini), vehicles are turned most days using the loop within the Depot.

<u>Power supply:</u>

An overhead conductor system at a nominal 750Vdc supplies the trams with power from twelve 600kW sub-stations .

The 12 sub-stations are detailed in Table 9.4 below:

Table 9.4 Details of South Yorkshire Supertram sub-stations

Distance (km)[1]	*Location*
6.5	Middlewood
4.1	Langsett
1.5	University
0.4	Park Square
6.5	Blackburn Meadows
5.0	Carbrook
1.8	Nunnery
3.2	Arbourthorne
6.0	Gleadless
8.8	Birley
11.3	Crystal Peaks
13.7	Halfway

Notes:
[1] Approximate distances from Fitzalan Square

Tunnels:

There is an underpass just north of the University tram stop, as shown in Figure 9.3. There is a significant stretch of covered track beneath the Sheffield Road over bridge close to Meadowhall Tinsley South tram stop.

Passenger Service Vehicles

Twenty-three out of a total of twenty-five vehicles are required to operate the full service.

Journeys per route:

Services are run over three routes with the following frequencies:

Blue Route (10 minute frequency): Malin Bridge – City Centre – Halfway

Purple Route (30 minute frequency): Herdings Park – City Centre – Meadowhall

Yellow Route (10 minute frequency): Middlewood – City Centre – Meadowhall

The track between Hillsborough and Cathedral shares trams with the Blue and Yellow routes. The track between the Cathedral stop and the delta junction at Park Square, just south of Fitzalan Square, is common to the three routes.

Tram stops:

The trams call at all stops by request to prevent undue delays to services.

The 48 tram stops have platforms serving each direction, except for the termini which have only a side platform face and single track, and the island platforms at Netherthorpe Road and the Meadowhall terminus.

The numbers of tram stops per route are:

Blue Route	(Malin Bridge – City Centre – Halfway)	33 tram stops
Purple Route	(Herdings Park – City Centre – Meadowhall)	26 tram stops
Yellow Route	(Middlewood – City Centre – Meadowhall)	25 tram stops

Start of services:

Supertram opened in stages as follows:

21.03.1994	Fitzalan Square (City Centre) to Meadowhall
22.08.1994	Fitzalan Square to Spring Lane
05.12.1994	Spring Lane to Gleadless Townend
18.02.1995	Fitzalan Square to Cathedral
27.02.1995	Cathedral to Shalesmoor
27.03.1995	Gleadless Townend to Halfway
03.04.1995	Gleadless Townend to Herdings Park
23.10.1995	Shalesmoor to Malin Bridge and Middlewood

9.3 TRACKWORK

9.3.1 Plain track

Grooved track (street running):

Rail types - SEI 35G was used during construction of the system (see Appendix 5 for profile)
- SEI 35GP is used for rail replacement (see Appendix 6 for profile)

British Steel and SOGA, France, manufactured the rail.

A slip form paver was used to produce the concrete base for street running track, the first time this technique had been used for tramway construction. The 2.20m wide concrete bed was cast with two channels of 192mm width by 164.5mm depth into which the continuously welded grooved rail was bonded during construction using Edilon, a solvent free polyurethane adhesive incorporating cork, as illustrated in Figure 9.2(a). This compound was found to be prone to de-bonding and of low skid resistance for motor vehicles. The majority of track has now has the top 25mm replaced using ALH compound mixed with bauxite chippings. An example of embedded rail is shown in Figure 9.2(b).

ALH is used for full depth embedment when grooved rail is replaced.

Astorstag compound has also been used.

Standard Balfour Beatty drain boxes, connected to the street drain system, provide drainage of the rail groove, as shown in Figure 9.4. The capacity of these units has been found to be insufficient. The drainage system incorporates rodding boxes to assist drain cleaning.

Grooved rail expansion switches are provided at bridge structures.

There are no fixed lubrication systems associated with grooved rails.

The nominal grooved track (design) dimensions are: given below in Table 9.5:

Table 9.5 South Yorkshire Supertram nominal grooved track dimensions

Gauge (straight & curved track)	(Main line)1435(+12/-2)mm (Depot) 1435(+12/-3)mm
Rail inclination	Vertical
Minimum track radius	25m
Maximum track cant	150mm
Maximum track gradient	(Park Grange Road) 10%
Rail running surface relative to road	Level
Wear tolerance of keeper flange	Visual inspection only

Ballasted track:

The rail section used for ballasted track throughout the system is BS 80A flat bottom rail, the profile of which is shown in Appendix 10.

Corus, Workington, manufactured the rail.

Stanton Bonna twin block sleepers, type VAX U20, are used for ballasted track together with Sherardised Pandrol rail clips of type E1809, as shown in Figure 9.5 and 9.6. Rail joints are made using fishplates, and are electrically bonded, as can be seen below the rail head and above the fishplate in the foreground of Figure 9.5. To ensure rail ends are held square on curves specially made replacement fishplates have been fitted. Timber sleepers are used for short track sections associated with expansion switches, as shown in Figure 9.7. The track bed construction is of ballast with cess drains. The minimum spacing between track centres is 3.8m.

There are fixed ‘plunger’ lubrication units at three locations:

Meadowhall curve (single track)
Broughton Lane curve (both tracks)
Parkway bridge (single track)

‘Jumbo’ rail lubricators (Partec canisters) at a total of sixteen locations are also in use, generally associated with curved track that has checkrails fitted.

At the level crossing close to Beighton Drake House Lane tram stop twin BS 80A rail is used with flange planing to allow a 50mm head spacing, one of the rails acting as a keeper rail.

The nominal plain track (design) dimensions are given in Table 9.6.

Table 9.6 South Yorkshire Supertram plain ballasted track dimensions

Gauge (straight track)	(Main line)1435(+12/-2)mm (Depot) 1435(+12/-3)mm
Gauge (curved track)	(Over a distance of 10m, Meadowhall curve) 1441mm
Rail inclination	1 in 40 (Vertical through expansion joints)
Minimum track radius	25m
Maximum track cant	(Meadowhall curve) 150mm
Maximum track gradient	(Woodbourne Road) 10%

Effect of wear on the wheel/rail interface:

The permitted track gauge = 1435(+12/-2)mm

Flange back to flange back of the wheelsets = 1379(+2/-0)mm

Wheel flange thickness = 23mm (new)
19mm (min)

Hence, difference between rail and wheel gauges (worst case) is:

Rail maximum gauge (12mm wear) = 1447mm
Wheel minimum gauge (19mm flange) = 1417mm
Difference ('float') = 30mm

For new wheels on minimum gauge, difference = 6mm

For new wheels on nominal gauge, difference = 10mm

9.3.2 Switches & Crossings

Grooved track (street running):

All turnouts are constructed from SEI 35G grooved rail. The majority of turnouts are 25m. Balfour Beatty supplied with spring return units, the remainder being Edgar Allen Ltd flip-flop units. There are also two spring return 100m radius turnouts, one unit being supplied by each of the above companies.

An example of a Balfour Beatty turnout is shown in Figure 9.8. These are equipped with sacrificial check rails, as shown in Figure 9.9, that are adjustable to take account of wear on the checking face.

The method of track bed construction and rail fixing was similar to that for plain track, except that the concrete was hand cast.

The units have under blade drains. The Balfour Beatty units drain at the switch rail heel, and the Edgar Allen units around the switch box.

Turnout mechanisms are inspected and manually lubricated weekly. The turnouts are visually inspected monthly, with an annual detailed inspection.

The nominal grooved turnout (design) dimensions given in Table 9.7.

Table 9.7 South Yorkshire Supertram grooved turnout dimensions

Gauge	1435mm
Radius	25m & 100m
Switch rail type	Flexible (Edgar Allen units have fixed heels) (Balfour Beatty units have wedge fixed heels)
Flange tip running	There is now no flange tip running (The only unit, a diamond crossing at Gleadless Townend, was originally designed as flange tip running but now operates without)

<u>Ballasted track:</u>

All turnouts were supplied by Balfour Beatty and are of vertical design, fabricated from BS 80A flat bottom rail, timber sleepers and Pandrol E1809 fastenings as shown in Figure 9.10. Examples of turnouts and diamond crossings forming part of the Delta Junction at Park Square are shown in Figure 9.11. The ballasted trackbed and drainage is the same as that used for plain track.

Ballasted turnout mechanisms are inspected and manually lubricated weekly. The turnouts are visually inspected monthly, with an annual detailed inspection.

The nominal plain ballasted turnout (design) dimensions are given in Table 9.8.

Table 9.8 South Yorkshire Supertram plain ballasted turnout dimensions

Gauge	1435mm
Radius	25m
Switch rail type	Flexible[1]
Switch rail top planing	Overall length of planing = 1.312m Slope = 8.38mm/m
Crossing flangeway gap	44mm
Flange tip running	Two of the three diamond crossings of the Park Square Delta Junction are flange tip running (constructed with special cast frogs)[2]
Check rail flangeway gap	28 - 31mm
Switch opening	95mm
Additional sleeper bracing to maintain alignment	Bracing fitted outside the gauge on two units (Depot[3] and Alsing Road, Meadowhall)

Notes:
[1] There is no relief of the stock rail.
[2] See Figure 9.11(c)
[3] See Figure 9.10

9.3.3 Switch operation

Grooved track (street running):

All grooved track turnouts are equipped with Hanning & Kahl type HWE 60 electro-hydraulic point setting mechanisms (twin solenoid and hydraulic damping).

Maintenance regime (grooved track):

Cleaning and greasing of the mechanism is carried out twice weekly, and the detection checked weekly.

Ballasted track:

Hanning & Kahl type HWE 150 electro-hydraulic units (twin solenoid and hydraulic damping) are used on the ballasted track turnouts on the mainline.

Unpowered turnouts in the Depot use specially designed Balfour Beatty point machines

Maintenance regime (ballasted track):

Cleaning and greasing of the mechanism and detection checks are carried out every two months.

Switch detection system (all track):

All facing turnouts are fitted with proximity switches.

Permitted open gap (all track):

The switches are set to make at 3mm and break at 4mm.

9.3.4 Track maintenance

Annual ultrasonic rail inspection is carried out.

There are no problems with rail corrosion.

Rail grinding is undertaken. The SPENO HRR12-M1 rail-grinding rig in use during early October 2004 is shown Figure 9.12.

9.4 VEHICLES

All of the 25 identical three section bi-directional vehicles used on the system were supplied by Siemens/Duewag and manufactured in Düsseldorf. A typical vehicle is shown in Figure 9.13.

The vehicles run on four two axle bogies with all axles powered. The floors of the end sections have low floor height in the vicinity of the doors, and account for 40% of the floor area. These vehicles are some of the largest light rail vehicles ever built.

The vehicle passenger capacity (normal load) is 88 seated and 162 standing. The capacity at four standing passengers per m^2 is 155, and 232 at six passengers per m^2. In both end sections low floor areas are available between the doors for wheelchairs and pushchairs.

The air-operated disc brakes are of the spring-applied, air-release type, with each axle having one disc brake. During service braking the regenerative brake is dimensioned such that blending with the air brake is not required. The air brake takes over from the regenerative brake at low speeds, and is also used as the parking brake. It is also used as a second service brake over the range of the regenerative brake should this fail.

Each bogie has two magnetic track brake magnets, each with a contact force of 50kN to provide hazard braking.

Leading dimensions: See Table 9.9.

Table 9.9 South Yorkshire Supertram vehicle dimensions

Length over three section body	34.750m
Body shell width	2.650m
Height of body shell	3.645m
Floor height above head of rail	880mm[1] 450mm[2]
Distance between body articulation centres	9.750m
Distance between end bogie centres and adjacent centres of body articulations	9.000m
Distance between bogie centres on the central body section	5.750m
Bogie axle spacing	1.800m
Wheel diameter	(New) 670mm

Notes:
[1] Above motor bogies at in end sections and the centre section
[2] 40% of total floor in the door area of both end sections

Bogie details: See Table 9.10.

Table 9.10 South Yorkshire Supertram vehicle bogie details

Design	Duewag
Motor bogie	Four motor bogies (see Figure 9.14) One bogie each end and two beneath the centre section) Two powered axles per bogie One motor per bogie (Type 1KB2121) Motors are mounted longitudinally Chevron rubber primary suspension Air spring secondary suspension

Vehicle weights: See Table 9.11.

Table 9.11 South Yorkshire Supertram vehicle weights

Tare weight (design)	46500kg
Tare weight (actual)	About 52000kg
Weight of crush laden	67343kg
Crush laden distribution:	
Car body A	21961kg
Car body B	23486kg
Car body C (centre section)	21896kg

Wheel details: See Table 9.12.

Table 9.12 South Yorkshire Supertram vehicle wheel details

Type	Bochum 84 Resilient (Drawing No. 3RW 7313.422.01) See Figure 9.15
Diameter	670mm (new) 588mm (worn) (1mm difference between wheels of the same bogie) (5mm difference between wheels of different bogies) (15mm difference between bogie groups [A+B] and [C+D])
Tyre width	125mm
Profile	See Appendix 23 and Figure 9.15(c)
Re-profiling criteria	Tyre management procedure has been derived to optimise re-profiling effectiveness A flange width of 21.5mm is used when re-profiling Profiles are measured every four weeks (7000km) Hollowing removed at 21000km (based on smallest diameter) Re-profiling when flange width reduced to 19mm (50000-60000km) A 50 to 60% increase in wear is observed in winter
Wheel discard criteria	Minimum 588mm diameter (Wheel life 250000 to 300000km) (machined tell-tale on outer wheel face)
Tyre material	B5 (Specification UIC 810-1V)
Wheelset back-to-back	1379(+2/-0)mm
Lubrication	REBS oil spray system fitted to end axles Inner and outer flanges treated Only spray units on the leading axle are operable in motion An eight second spray is given every two minutes Spray timing resets every time vehicle stops Stick lubrication has been tried, but found to be costly It has been observed that there is reduced noise with the spray system compared with stick lubrication

The wheel lathe, located in the Depot, is shown in Figure 9.17.

9.5 OPERATIONS INFORMATION

Vehicle operations

The maximum line speed on segregated track is 80km/h. This is achieved in the vicinity of the Arena tram stop. A maximum of 60km/h is achieved in the vicinity of Birley Lane tram stop. The system is signed in mph.

National speed limits are observed during on-street running.

A speed limit of 32km/h applies to through running at tram stops.

The maximum acceleration is limited to $1.3m/s^2$.

The vehicles can achieve maximum service braking of $1.5m/s^2$ and hazard braking of $3.0m/s^2$, though these are limited to 1.16 and $2.46m/s^2$ respectively.

During brake tests vehicles are required to stop with service braking in 210m from a speed of 80km/h and achieve a deceleration of $1.16m/s^2$. For hazard braking this is 100m from 60km/h, achieving $2.46m/s^2$.

Operating environment

In cold dry winter conditions problems with slip and slide can occur due to a film forming on the railhead due to leaves in on-street locations where it is not swept by road traffic. Manual scraping is used to remove the film. These conditions particularly affect short sections of lines adjacent to the Cathedral and Gleadless tram stops.

The vehicles are fitted with air blown sand units that can apply sand at the Axle 1 and 5 positions (in each direction). The sanding is controlled automatically, though the driver can also directly control sand application with a 'sand' pedal. Street sections require the majority of sanding, though all inclines require sand during November and December when rails are wet or are covered with dew or frost. In wet conditions water spray from the wheels can cause clogging of the sand pipes. In winter conditions about two tonnes of sand per day are used on the system.

9.6 OPERATING CHALLENGES

Rail wear

Rail wear surveys are carried out regularly, a typical example of findings is presented in Figure 9.16. There is increased surveillance once the rail head or side wear has exceeded 8mm.

Excessive wear has been found at the Meadowhall curve, which has a check rail, where both head wear and head spread occur. Rail replacement was required after four years.

The need for rail replacement is based on visual inspection and the measurement of gauge, and keeper thickness for grooved rails.

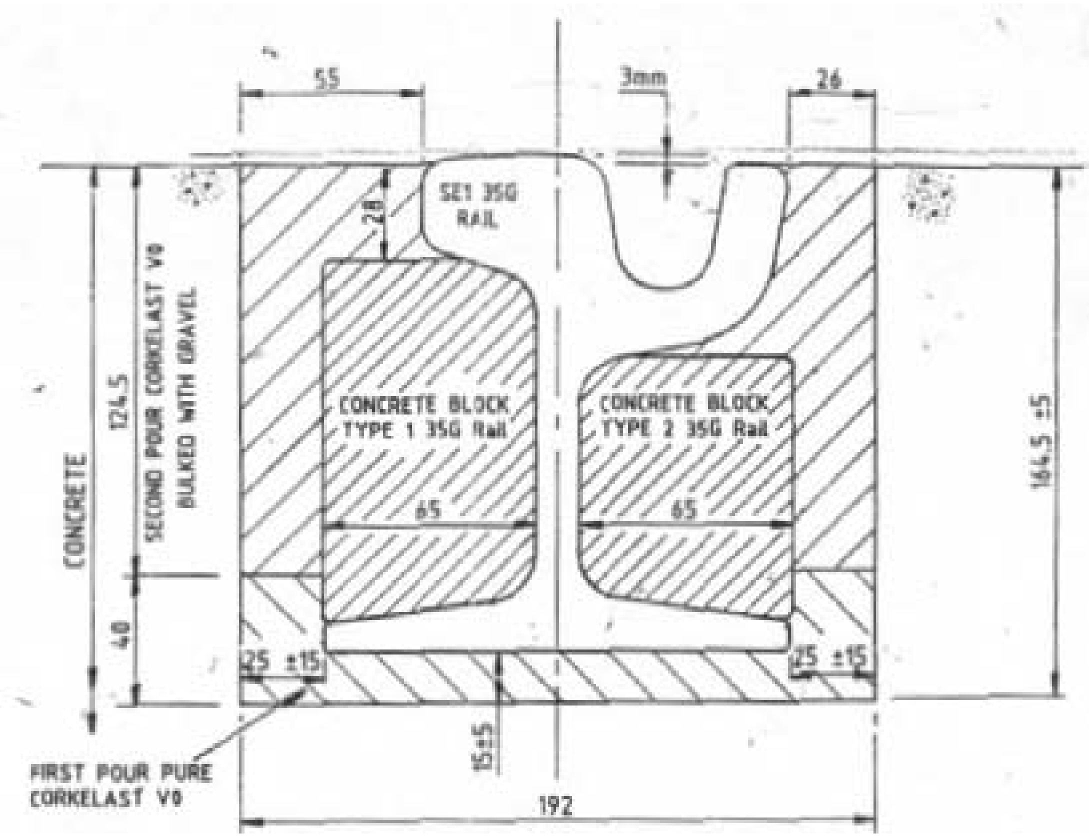
Rail corrugation is found all over the system due to acceleration and braking.

Noise

The use of lubricators has reduced noise at curves, and attention to check rail adjustment reduces noise at turnouts.

9.7 FIGURES

Figure 9.1 Schematic route map of South Yorkshire Supertram



(a) Cross section showing the grooved rail installation, SYS

FES0409-01/81

(b) Grooved rail near the Cathedral tram stop (07.09.04)

Figure 9.2 Grooved rail embedded in the highway, SYS

FES0409-01/82

Figure 9.3 The underpass adjacent to the University tram stop, SYS (07.09.04)

FES0409-01/96

Figure 9.4 Examples of grooved rail drainage in West Street, SYS (07.09.04)

FES0409-01/59

Figure 9.5 Example of SYS ballasted track with twin block sleepers (07.09.04)

FES0409-01/63

Figure 9.6 Example of twin ballasted tracks close to the SYS Sheffield Station tram stop (07.09.04)

FES0409-01/53

Figure 9.7 Example of a SYS expansion joint on ballasted track close to Sheffield Station tram stop (07.09.04)

FES0409-01/02

Figure 9.8 Example of an SYS grooved rail turnout at the Cathedral tram stop (07.09.04)

FES0409-01/07

Figure 9.9 Sacrificial check rail fitted to grooved rail turnout, close to the SYS Cathedral tram stop (07.09.04)

FES0410-02/42

Figure 9.10 Bracing fitted to a ballasted turnout within the SYS Depot (06.10.04)

FES0409-01/38

(a) General view

FES0409-01/29

(b) Switch rails

FES0409-01/30

(c) Diamond crossing

Figure 9.11 The delta junction at Park Square, SYS (07.09.04)

FES0410-02/33

(a) Power unit

FES0410-02/32

(b) Grinding units

FES0410-02/34

(c) Complete rig

Figure 9.12 Rail grinding rig used on the South Yorkshire Supertram tracks during October 2004 (06.10.04)

HSE0305-033/11

Figure 9.13 South Yorkshire Supertram tram No.111 at Fitzalan Square tram stop (05.10.01)

FES0410-02/23

(a) Bogie frame

(b) Gearbox, flexible drive and brake disc

FES0410-02/10

(c) The motor

FES0410-02/12

Figure 9.14 The Siemens/Duewag bogie, SYS (06.10.04)

(a) Wheel

FES0410-02/14

(b) Tyre

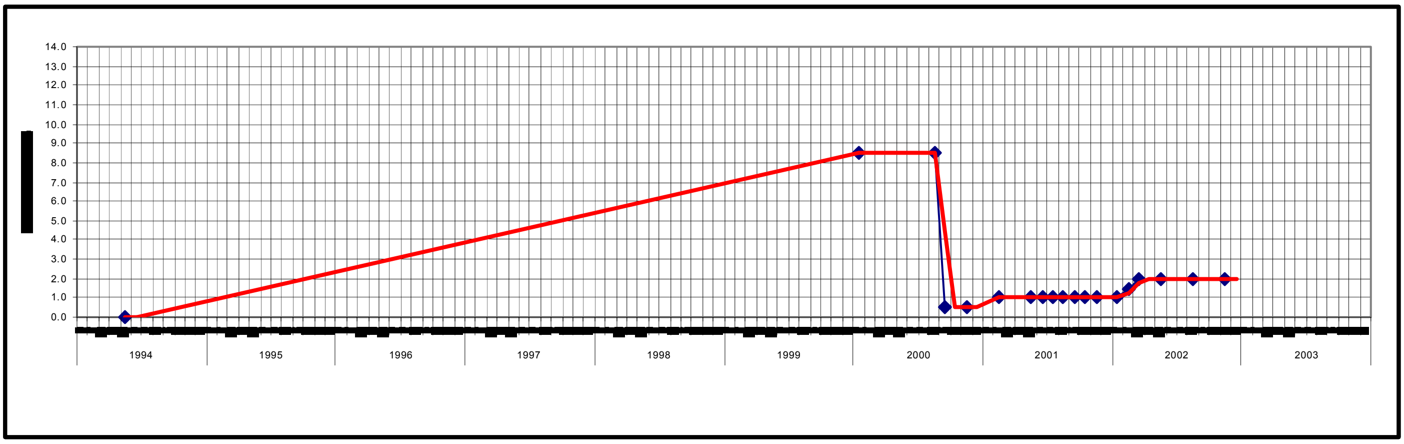
FES0410-02/02

(c) Wheel tread profile

FES0410-02/15

Figure 9.15 Details of SYS wheels (06.10.04)

[Wear in mm against Year]



Stagecoach Supertram

Figure 9.16 Results from an SYS side rail wear survey for the inbound 6ft rail at the Parkway overbridge

FES0410-02/07

Figure 9.17 The SYS wheel lathe at the Depot (06.10.04)

10 TYNE AND WEAR METRO

10.1 INTRODUCTION

The plan for the Metro was developed within various studies prepared in the late sixties and early seventies prior to the formation of the Tyne and Wear County Council. The Tyne Wear Plan, a land use transport study prepared by consultants and local authority staff for national and local government, provided the initial impetus. This study adopted a rapid transit system as the backbone for public transport in the area.

The Tyne Passenger Transport Authority was set up during the preparation of the Tyne Wear Plan, and through its Executive the proposal was developed such that a Parliamentary Bill for construction, together with an infrastructure grant application, were submitted in 1972.

Following a successful outcome to these a review of extension options was undertaken. Tunnelling under the centre of Newcastle began in 1974. Also in that year the new Tyne and Wear County Council assumed the role of the Passenger Transport Authority, and commissioned a further study of possible extensions, which was completed by March 1975. The Metro was a major constituent of a 'Structure Plan' that was submitted to the Secretary of State for the Environment in October 1979, though no decisions concerning extensions were made at that time.

The Metro was designed to run on segregated tracks, mainly over the route of the former London & North Eastern Railway Tyneside electric train service, which were de-electrified and converted to diesel operation in the 1960s. Tunnelling beneath the city centre started on 15.10.74 and was completed by 25.02.77.

The first part of the system, from Tynemouth to Haymarket, was opened on 11.08.80, followed by South Gosforth to Bank Foot on 11.05.81. The track between Benton to Longbenton, and Regent Centre to Bank Foot were joint user sections with BR. The most important section of the system, Haymarket to Heworth, opened for service on 15.11.81. This section includes a 352m long bridge that crosses the River Tyne immediately south of Newcastle Central station, arched upwards to give maximum river clearance. The 14.11.82 saw the opening of the Tynemouth to St. James section.

The final section of the committed system, Heworth to South Shields, was opened on 24.03.1984. This gave a 55.8km long system, 44.5km of which was built on or alongside existing railway together with 4.5km of new surface railway.

An extension from Bank Foot to the Airport was opened on 17.11.92. This was built on the old railway alignment of the North Eastern Railway Ponteland branch, which was closed in 1988. There had been joint operation with BR over a section of this line (Regent Centre to Bank Foot) until BR ceased its operations.

Despite its name the Tyne & Wear Metro did not serve Wearside, and in the mid-1990s there was a strong need to extend the system. Tyne and Wear Passenger Transport Authority and Railtrack joined forces to plan and implement an extension to Sunderland and South Hylton. Construction started in Spring 2000 on a branch starting at Pelaw. Of the 18.5km extension, 14km were used jointly with Railtrack, and a further 4.5km (south of Sunderland to South Hylton) was constructed on a disused railway alignment. This extension opened in 31.03.02.

10.2 SYSTEM DETAILS

Schematic route map: See Figure 10.1.

Route distances: Route distances are given in Table 10.1 and inter station distances in Table 10.2 below:

Table 10.1 Tyne & Wear Metro route details

From	*To*	*Distance (km)*	*Track (all ballasted)*
Tynemouth	Haymarket & Bank Foot	23.4	Double (Originally joint use with BR on Benton to Bank Foot) Jesmond to Haymarket in tunnel
Haymarket	Heworth	6.1	Double Haymarket to Gateshead in tunnel
Tynemouth	St. James	14.0	Double Manors to St. James in tunnel
Heworth	South Shields	12.5	Heworth to Pelaw - Double Pelaw to Bede - mainly Single (with passing loops) Bede to South Shields - Double
Pelaw	Sunderland & South Hylton	18.5	Double
Bank Foot	Airport	6.1	Double

Table 10.2 Distance between Tyne & Wear Metro stations

From	*To*	*Distance (km)*	*Track*
Airport	Callerton Parkway	] 6.1 total	] Double
Callerton Parkway	Bank Foot		
Bank Foot	Kingston Park	0.648	Double
Kingston Park	Fawdon	1.439	Double
Fawdon	Wansbeck Road	0.592	Double
Wansbeck Road	Regent Centre	0.955	Double
Regent Centre	South Gosforth	1.313	Double
St James	Monument	0.442	Double
Monument	Manors	0.643	Double
Manors	Byker	1.650	Double

From	*To*	*Distance (km)*	*Track*
Byker	Chillingham Road	1.103	Double
Chillingham Road	Walkergate	0.836	Double
Walkergate	Wallsend	1.782	Double
Wallsend	Hadrian Road	1.118	Double
Hadrian Road	Howdon	1.380	Double
Howdon	Percy Main	1.371	Double
Percy Main	Smith's Park	0.615	Double
Smith's Park	North Shields	1.331	Double
North Shields	Tynemouth	1.736	Double
Tynemouth	Cullercoats	2.027	Double
Cullercoats	Whitley Bay	0.735	Double
Whitley Bay	Monkseaton	1.049	Double
Monkseaton	West Monkseaton	1.258	Double
West Monkseaton	Shiremoor	1.917	Double
Shiremoor	Palmersville	2.810	Double
Palmersville	Benton	2.052	Double
Benton	Four Lane Ends	0.785	Double
Four Lane Ends	Longbenton	0.869	Double
Longbenton	South Gosforth	1.349	Double
South Gosforth	Ilford Road	0.663	Double
Ilford Road	West Jesmond	0.764	Double
West Jesmond	Jesmond	1.209	Double
Jesmond	Haymarket	0.786	Double
Haymarket	Monument	0.520	Double
Monument	Central	0.517	Double
Central	Gateshead	1.349	Double
Gateshead	Gateshead Stadium	1.158	Double
Gateshead Stadium	Felling	1.154	Double

From	*To*	*Distance (km)*	*Track*
Felling	Heworth	1.035	Double
Heworth	Pelaw	1.898	Double
Pelaw	Hebburn	2.103	Single with passing loops
Hebburn	Jarrow	2.116	Single with passing loops
Jarrow	Bede	1.848	Single with passing loops
Bede	Tyne Dock	2.051	Double
Tyne Dock	Chichester	1.355	Double
Chichester	South Shields	1.319	Double
Pelaw	Fellgate	]	]
Fellgate	Brockley Whins	]	]
Brockley Whins	East Boldon	]	]
East Boldon	Seaburn	]	]
Seaburn	Stadium of Light	]	]
Stadium of Light	St Peter's	] 18.5	] Double
St Peter's	Sunderland	]	]
Sunderland	Park Lane	]	]
Park Lane	University	]	]
University	Millfield	]	]
Millfield	Pallion	]	]
Pallion	South Hylton	]	]

Notes:
[1] Distances (except sub-totals) derived from those given for the "IN" direction by Maxey(2005) [The "IN" direction is from St James via the **in**side of the coastal loop to South Shields] Distances are measured from the top of the platform ramp or the front of a stationary train if this is significantly different.

Power supply:

An overhead conductor system at a nominal 1500Vdc supplies the Metrocars with power.

Tunnels:

There are 7.6km of tracks in tunnels, mainly under central Newcastle.

Tracks run in twin single-line tube tunnels of 4.78m diameter, or double line tubes of 7.0m diameter, both with side walkways at vehicle floor level.

Elevated sections:

The Queen Elizabeth II steel girder bridge between Central and Gateshead stations carries double tracks over the River Tyne. It has a total length of 352.7m, a main span of 164.7m, is 10.2m wide and provides clearance of 25m above high water level.

The Byker Viaduct between Manors and Byker Valley stations is 815m long and about 8.2m wide, and its highest point is 30m above the Ouseburn Valley. It was built as a series of curves on a gradient, and of cantilever construction from counter-cast, pre-cast concrete segments joined with epoxy resin and stressed. Its 18 spans carry double tracks.

The 317m long Howdon Viaduct, which is 25m high, is a wrought iron structure dating from 1869 and originally in BR ownership. Before use the considerable structural repairs were carried out and a new deck constructed. The deck has been strengthened with extra steel supporting members from the arches.

Passenger Service Vehicles

Seventy vehicles out of a total of ninety are required to operate a full service.

Journeys per route:

A 15-minute service is operated over all routes. Each of the 90 vehicles averages 120000km running per year.

Stations:

The service vehicles call at all stations.

Start of services:

11.08.80	Tynemouth to Haymarket
11.05.81	South Gosforth to Bank Foot
15.11.82	Haymarket to Heworth
14.11.83	Tynemouth to St James
24.03.84	Heworth to South Shields
17.11.92	Bank Foot to Airport
31.03.02	Pelaw to Sunderland & South Hylton

10.3 TRACKWORK

10.3.1 Plain track

Ballasted track:

Rail type: - Flat bottom BS 113A (see Appendix 12 for profile)

The rail was been supplied by British Steel, Workington and Voest-Alpine Stahl GmbH (VAE)

The rail is fastened to concrete sleepers by Pandrol clips and rolled steel baseplates laid on a ballast trackbed. Rail joints are made by welding (thermit or flash butt), or fishplates are used.

In tunnels twin block sleepers set in a concrete slab form the trackbed, which incorporate drainage channels.

The double tracks on the Byker Viaduct are laid on concrete slabs constructed by a slip-form paver.

Drainage is provided by pitch fibre pipes in the cess and six-foot.

Thirty-five track mounted Portec rail lubricators are used on curves of less than 1000m radius.

Level crossings are constructed from Strail blocks formed from re-cycled rubber compounds or Dowmac panels. However, the Dowmac units are being replaced with Strail or Holdfast types. The Dowmac crossings were found to cause problems with track circuits due to the metal casing surrounding the concrete panels.

The nominal plain track (design) dimensions are given in Table 10.3.

Table 10.3 Tyne & Wear Metro plain ballasted track dimensions

Gauge (straight track)	(Continuously Welded Rail) 1432mm (Fishplated rail) 1435mm
Gauge (curved track)	Widened by 40mm (Applies to one 50m radius curve)
Rail inclination	1 in 20
Minimum track radius	200m (Except for one 50m radius)
Maximum track cant	110mm
Maximum track gradient	3.0% (Queen Elizabeth II Bridge - Tyne River bridge)

10.3.2 Switches & Crossings

Ballasted track:

Turnouts are fabricated from BS 113A flat bottom rail (profile as Appendix 12) and constructed according to standard heavy rail practice (AV to FV designs) with cast manganese crossings. Diamond crossings also have cast manganese crossings.

The rail is fastened to timber sleepers by Pandrol clips, plates and chair screws. Stretcher bars are used. Roller baseplates are installed beneath switch rails.

Balfour Beatty and Grant Rail supplied the turnouts.

Scissors crossovers within tunnel sections are located at St James and at Steplate Junction Prudhoe Street.

The nominal plain ballasted turnout (design) dimensions are given in Table 10.4.

Table 10.4 Tyne & Wear Metro plain ballasted turnout dimensions

Gauge	1432(+3/-2)mm
Radius	Switch types AV to FV
Switch rail type	Flexible
Crossing flangeway gap	44mm
Check rail flangeway gap	44mm
Switch opening	105 to 110mm

Turnouts are checked using Railtrack S&C maintenance gauges.

10.3.3 Switch operation

Ballasted track:

BR hydraulically operated clamp lock point setting mechanisms are used. The detection system is by micro-switch associated with the setting mechanism.

Planned preventative maintenance is operated. Inspections are carried out every four weeks, with a major inspection every 16 weeks.

10.3.4 Track maintenance

Ultrasonic rail inspection is carried out.

There are problems with rail corrosion in tunnel sections when drainage becomes poor.

De-stressing is carried out with rail replacement.

10.4 VEHICLES

All of the 90 identical two-car articulated bi-directional vehicles used on the system were designed and constructed by Metro-Cammell, Washwood Heath, Birmingham. A typical vehicle is shown in Figure 10.2.

The vehicles run on three two-axle bogies with all axles of the two end bogies powered, as shown in Figure 10.3.

The vehicle passenger capacity (crush laden) is 68 seated and 232 standing. In both end sections level unobstructed floor areas are available between the doors for wheelchairs and pushchairs.

<u>Leading dimensions:</u> See Table 10.5.

Table 10.5 Tyne & Wear Metro vehicle dimensions

Length over two section body	27.800m
Body shell width	2.650m
Height of body shell	3.155m
Floor height above head of rail	959mm
Distance between body articulation centres	9.750m
Distance between motor bogie centres and centre of body articulations	10.400m
Bogie axle spacing	2.100m
Wheel diameter	(New) 740mm (Worn) 660mm

<u>Bogie details:</u> See Table 10.6.

Table 10.6 Tyne & Wear Metro vehicle bogie details

Design	Düwag (Waggonfabrik Uerdingen A.G., Düsseldorf)
Motor bogie	Two motor bogies One fabricated box section bogie each end Two powered axles per bogie One 185kW mono-motor per bogie (Siemens type 1KB2021 4MH02) Motors are mounted longitudinally Thyssen type 2025-01, right angle, spiral bevel with 4.455:1 ratio Axlebox mounted rubber chevron units provide primary suspension Air bags provide secondary suspension (Metro-Cammell Ltd Dwg. No. 231/1005)
Trailer bogie	Similar in basic design to motor bogie Two axles each with twin disc brakes (Metro-Cammell Ltd Dwg. No. 231/1006)

Vehicle weights: See Table 10.7.

Table 10.7 Tyne & Wear Metro vehicle weights

Tare weight	40000kg
Weight of crush laden	59500kg
Crush laden distribution:	
Car body A	29600kg
Car body B[1]	29900kg

Notes:
[1]This end is heavier due to the disposition of equipment, and is taken into account by a small bias to the brake system operation.

Vehicle braking systems: See Table 10.8.

Table 10.8 Tyne & Wear Metro vehicle braking systems

Disc brakes: Poli split disc system Wabco spring applied/air release callipers. Westinghouse Westcode 7 step control.	One disc per axle on motor bogies Two discs per axle on the trailer bogie (Total of eight disc brakes)
Track brakes: Knorr Bremese	Two per bogie (total of six) Track brakes are fed from the battery. A timer releases the track brakes after 30s to avoid running down the battery.
Rheostatic brake: GEC/Alsthom electro-pneumatic camshaft	Motors connected in parallel with cross-field braking. There are five braking rates.
Brake operation:	The first four brake notches (1, 2, 3 & full service) give four stages of rheostatic braking, plus the four disc brakes on the trailer bogie. The other four disc brakes are applied automatically at speeds above 80km/h and below 15km/h, or if the Rheostatic brake fails, The fifth (hazard) notch brings all 8 disc brakes and 6 electromagnetic track brakes into operation. Wheel slide protection during braking is achieved through the detection of excessive deceleration indicative of sliding which brings about release of the air brake on the particular body half until sliding ceases.

Wheel details: See Table 10.9.

Table 10.9 Tyne & Wear Metro vehicle wheel details

Type	Bochumer Verein resilient wheel type 54 (T&WM Tyre Drawing No. 232/0095)
Diameter	740mm (new) 675mm (minimum turned diameter) 670mm (minimum service diameter) 660mm (minimum design diameter)
Tyre width	127(+/-0.5)mm
Profile	P8 profile (as BRB Drawing No. S8-C2-8006239 & T&WM Drawing No. 232/0095). Wheelset dimensions & tolerances are in accordance with Metro Spec. QM3 and Network Rail GM/RT 2020 See Appendix 24
Re-profiling criteria	Worn profile from tracing shown in Figure 10.4. Flange wear is of greater significance than hollow tread wear. The maximum time between wheel re-profiling is 24 months, which equates to approximately 240000km. To avoid the need to remove large amounts of material, re-profiling is usually carried out at 18 to 19 monthly intervals (circa. 180000 to 190000km).
Wheel discard criteria	Wheels rarely wear to the limit of P8 tolerances before inspection. Wheels are discarded when the diameter falls below 675mm diameter when re-machined to the full P8 profile.
Tyre material	BS 5892 Part4 Grade B5E
Wheelset back-to-back	1362(+1.25/-0)mm
Lubrication	10% of the vehicle fleet is fitted with 'Secheron' oil spray flange lubrication equipment (residue is adequate to lubricate the remainder of the vehicle fleet).

10.5 OPERATIONS INFORMATION

Maximum line speed = 80km/h

At level crossings there is a 15km/h speed limit.

Initial service acceleration = 1m/s^2

Maximum service braking rate (all loads) = 1.15m/s^2

Maximum hazard braking rate (tare) = 2.6 m/s^2

Maximum hazard braking (crush load) = 2.1 m/s^2

10.6 OPERATING CHALLENGES

Effects of weather on system:

During hot weather the fixed tension OLE wires can sag. The OLE wires can also be subject to sea spray on the coastal sections (Cullercoats & South Shields), and be affected by high winds in the vicinity of Bank Foot & Callerton Parkway. During cold periods the operation of pneumatic systems can be affected.

Leaf fall:

Significant difficulties with wheel slip/slide due to leaf fall are experienced in a number of locations such as to the east of Benton, Fawdon to Kingston Park, and Millfield to South Hylton. ‘Defensive’ driving by train crew is required.

Vegetation is also cut back regularly. All trees have been removed from a shallow cutting between Jesmond & West Jesmond.

Rail wear by road vehicles:

There is significant lorry traffic at the Fawdon level crossing. This crossing, and others at Kingston Park, Bank Foot and Callerton Parkway can result in road salt contamination of rail-heads leading to wheel slip.

Rail wear:

In the winter of 2003 wheel slide was experienced due to excessive lubrication from rail lubricators. To overcome this problem all track and vehicle lubrication systems were turned off. A consequence was that much greater wheel wear was observed.

Ride quality measurements:

Since 1996 ride quality has been measured throughout the system using the Alrian Rider track recorder. Summaries of the latest measurements recorded on 26.10.04 (courtesy of NEXUS) are given below, according to route, in Table 10.11 to 10.14. Values for acceleration vector sum (**a**), quoted according to vibration bands in the tables, were derived by combining measured anatomical accelerations in the component directions in the following way:

$$\mathbf{a} = [((1.4).a_{XW})^2 + ((1.4).a_{YW})^2 + ((1.4).a_{ZW})^2]^{0.5}$$

where: a_{XW} = vibrations along the length of the train (longitudinal)
a_{YW} = vibrations from side-to-side of the train (transverse)
a_{ZW} = up and down vibrations (vertical)

Table 10.11 Tyne & Wear Metro ride quality (Regent Centre – Airport)

Vibration Band (a)		*Distance*		*Time (s)*	
Assessment	*Range (mg)*	*(m)*	*(% of route)*	*(s)*	*(% of total)*
Good	0-50	6805	97.1	665.9	97.2
Fair	50-100	200	2.9	18.7	2.7

Table 10.12 Tyne & Wear Metro ride quality (Airport – South Shields)

Vibration Band (a)		*Distance*		*Time (s)*	
Assessment	*Range (mg)*	*(m)*	*(% of route)*	*(s)*	*(% of total)*
Good	0-50	27490	90.9	2551.9	94.3
Fair	50-100	2640	8.7	146.1	5.4
Poor	100-150	100	0.3	8.3	0.3

Table 10.13 Tyne & Wear Metro ride quality (South Shields – St James)

Vibration Band (a)		*Distance*		*Time (s)*	
Assessment	*Range (mg)*	*(m)*	*(% of route)*	*(s)*	*(% of total)*
Good	0-50	46470	91.7	4032.7	93.9
Fair	50-100	4135	8.2	248.8	5.8
Poor	100-150	95	0.2	12.1	0.3

Table 10.14 Tyne & Wear Metro ride quality (St James - Longbenton)

Vibration Band (a)		*Distance*		*Time (s)*	
Assessment	*Range (mg)*	*(m)*	*(% of route)*	*(s)*	*(% of total)*
Good	0-50	25410	92.4	2579.0	95.3
Fair	50-100	2025	7.4	119.8	4.4
Poor	100-150	65	0.2	7.5	0.3
Bad	150-200	5	0.0	0.7	0.0

10.7 FIGURES

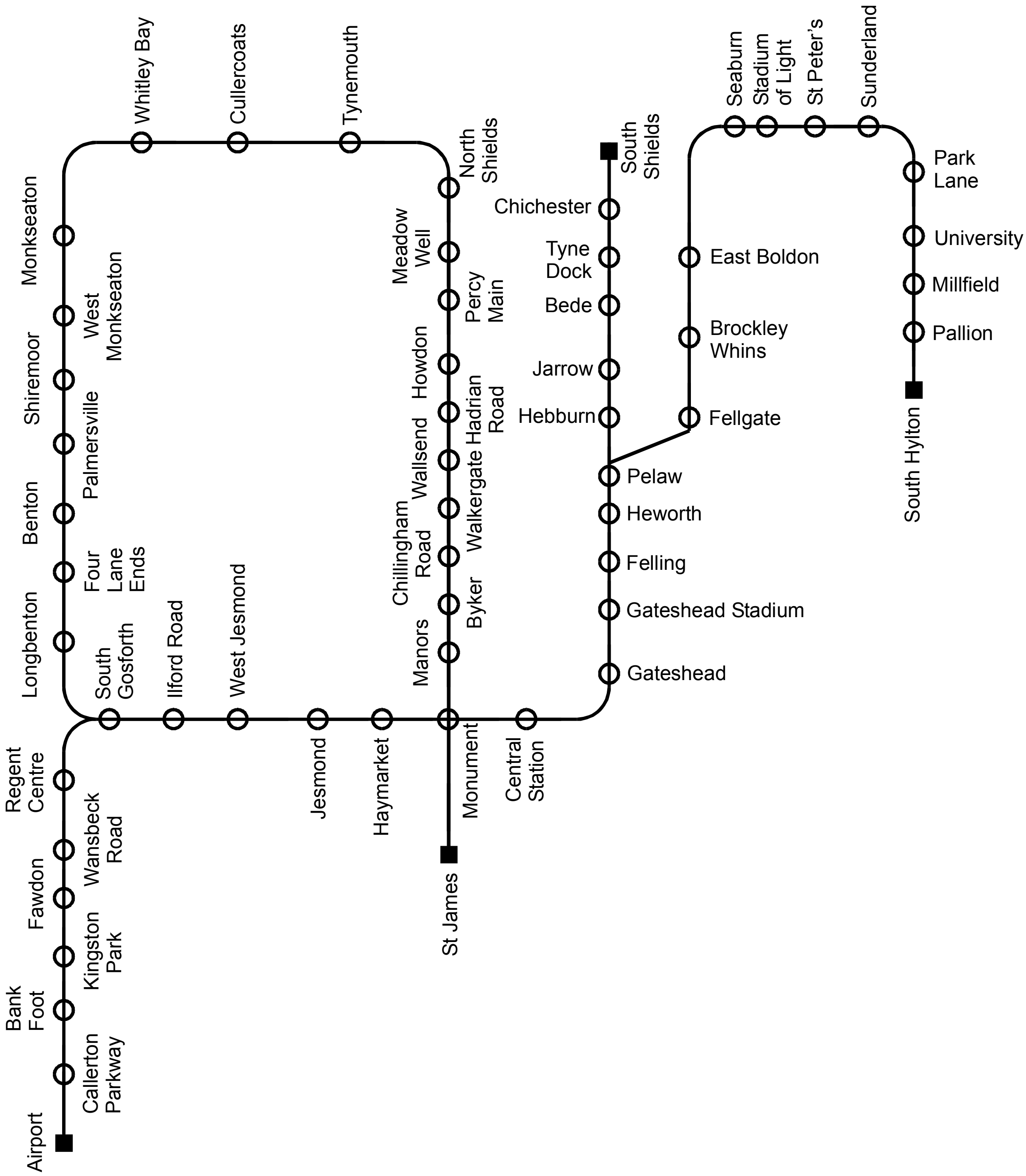


Figure 10.1 Schematic route map of the Tyne & Wear Metro

HSE0305-026/5

Figure 10.2 Tyne & Wear Metro Metrocar No. 4079 approaching Gateshead Stadium (19.09.01)

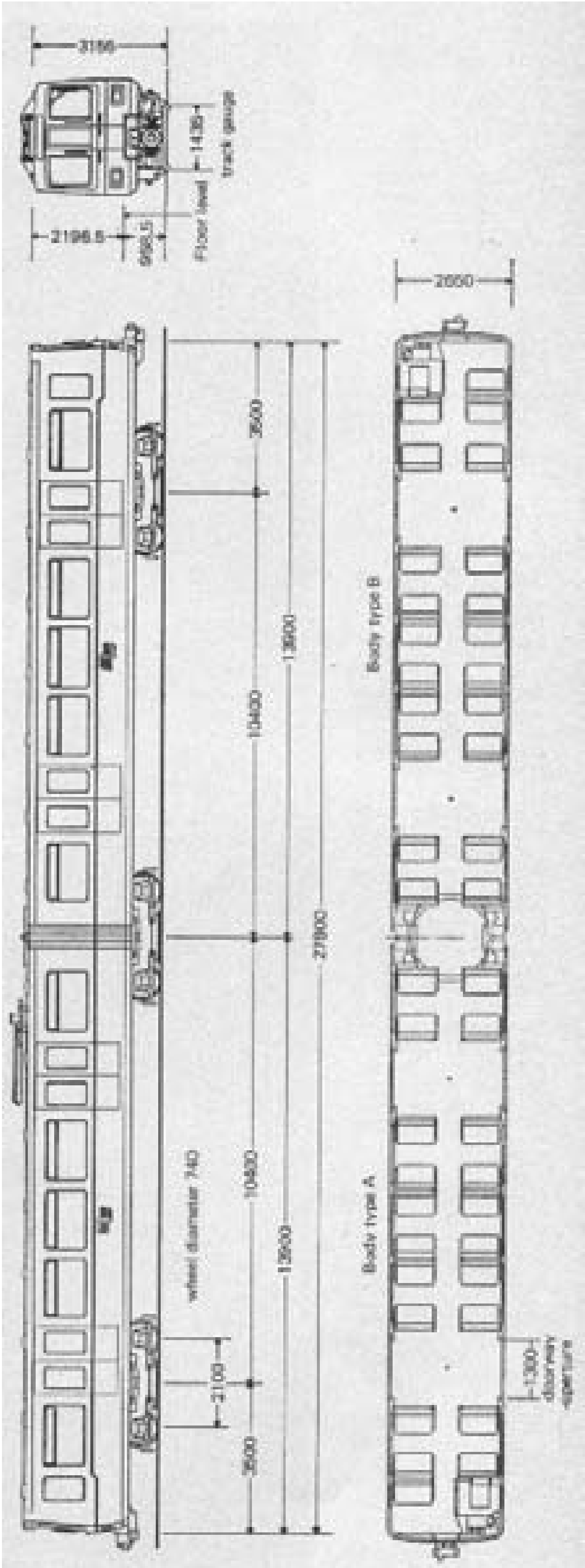
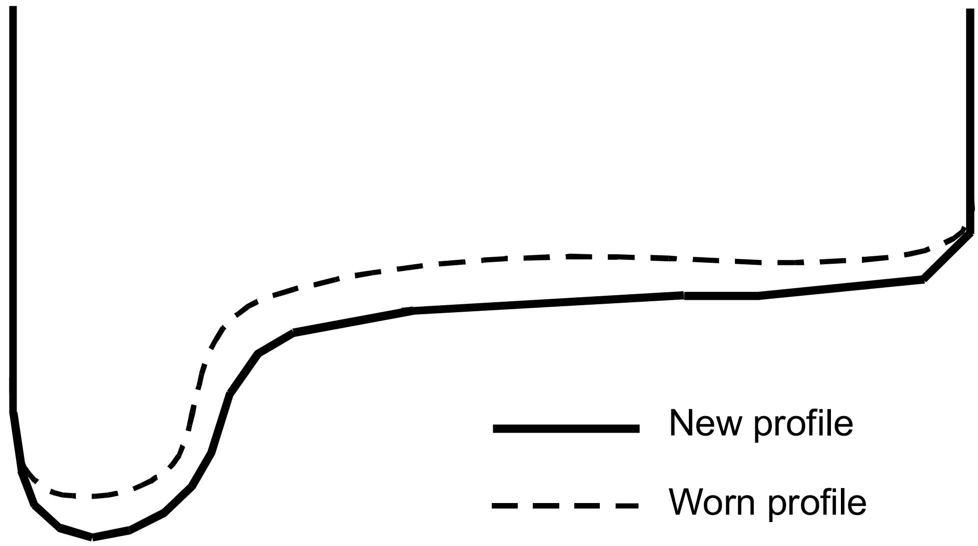


Figure 10.3 Metro-Cammell articulated two-car vehicle for the Tyne & Wear Metro



Worn wheel profile from Car 4071 (centre, unpowered bogie) (Last turned: 21.02.03 / inspected: 16.06.04) compared with the new profile (approximately full size).

Figure 10.4 Example of a worn wheel profile

D Walker NEXUS

(a) Assembly jig

(b) Weighing transducer

D Walker NEXUS

Figure 10.5 Workshop equipment used to ensure correct wheel loadings

11 EUROPEAN STANDARDS AND SYSTEMS

11.1 UIC INTERNATIONAL UNION OF RAILWAYS

There are no standards from this organisation that are applicable to light rail and tram systems.

11.2 GERMAN FEDERAL REGULATIONS

A full review of the German BOStrab standards has not been possible, as full English translations of BOStrab (1987), Kurz (1986), Kurz (1994) and BOStrab (2004) have been found difficult to obtain.

The most recent text, BOStrab (2004), for which only a copy of the English translation without figures has been located, does include a commentary and also some explanations as to why there has been a recent revision of the regulations. According to this the new edition of the regulations (BOStrab (1987)) were preceded by the guidance regulations (BOStrab (1986)). The practical application of these regulations was found to be difficult so the Association of German Transport Undertakings (VDV) attempted to clarify the Guidance Regulations in 1994, as Kurz et al (1994).

Practical problems still however remained and by mutual agreement The Federal Ministry of Transport and the VDV decided to revise the Guidance Regulations completely. A further reason for this initiative was that grooved rail profiles had been developed that matched those of inclined flat bottom rail head sections, therefore ensuring that the same rail head profile can be maintained throughout a complete network. It was also appreciated that tram systems could be constructed with matched wheel/rail profiles for good wear and noise characteristics, thus avoiding any ‘two-point’ contact which would initiate wear. The introduction of low floor vehicles has also brought about a greater range of wheel sizes, and the design of switches and crossings must also accommodate a range of vehicle types.

A further important consideration was that in recent times few completely new tram or light rail transit systems have been built in Germany. The emphasis has been on the expansion of existing systems, which requires that the existing track dimensions be a prime consideration. The last 15 years has also seen tramways develop into light rail transit systems in which higher speeds of up to 80km/h have been achieved with safety.

It has therefore been found impossible to standardise dimension systems for the existing German tramways, light rail transit and metros in accordance with BOStrab and the revised Guidance Regulations acknowledge this. The emphasis is now on standardising how the wheel and rail profiles and dimensional relationships are taken into account so that safe vehicle guidance and maximum ride quality can be achieved on the basis of technical understanding and practical experience.

In summary, it seems that the Guidance Regulations developed in the early 1980s and the 1994 revision, were of little practical use in developing the German LRT systems. The recent complete revision is an attempt to rectify this.

11.3 GRENOBLE

11.3.1 Meeting with M Arras, Service Technique des Remontées Mécaniques et des Transports Guidés (STRMTG) on 01.02.05

This organization is involved with the approval for French guided transport systems. The implications of the new regulations for the authorisation of tramways were outlined. This is summarised in Arras (2005).

11.3.2 Visit to Transports de l'agglomération Grenobloise (TAG) on 01.02.05

Journeys on service trams on Lines 1 and 2 were made, together with visits to the Depot and construction sites associated with Line 3.

Route:

The total route distance of Lines 1 (12.9km) and 2 (7.9km) is 20.8km and that of Line 3, which is under construction, will be 13.5km. All lines, whether street running or segregated, appear to use SEI 35G grooved rail (as Appendix 5) throughout, with a gauge of 1435mm. The first line was opened in 1987 and Line 2 opened in 1990. There are 29 stops on Line 1 and 18 on Line 2. The peak service frequency is 3 minutes on both lines.

Track:

A common method of track construction seems to be used throughout the system, with the finishing surface being varied to suite pedestrian, road or segregated use. Track bed excavation to a depth of about 1m is followed with the laying of a 0.3m deep layer of consolidated hardcore as Figure 11.1(a) onto which is cast a concrete slab of about 0.3m thickness. The track formation is then assembled using SEI 35GP grooved rail fastened to twin block concrete sleepers and levelled using packings where necessary, as shown in Figure 11.1(b) & (c). The fastener type is shown in Figure 11.2(a). A further layer of concrete is then poured to just below sleeper height. Plastic protectors are then applied to all the rail fasteners and segmented insulation is built up to rail head height on both sides of the rails, as shown in Figure 11.2(b). Further concrete is then used to raise the level to mid rail height so that the finishing surface can be laid, which can be tar macadam, brick, stone block or ballast, as illustrated in Figure 11.3 and 11.4. Examples of the turnouts are illustrated in Figure 11.5, with details of switch rails, crossings and diamond crossing given in Figure 11.6.

Vehicles:

Alstom supplied all the 53 identical three-section bi-directional vehicles of type TFS (formerly a French standard) between 1986 and 1997. These vehicles are partly low floor. The external appearance is shown in Figures 11.7 & 11.8. An example of the wheel profile is given in Figure 11.9(a) and the markings on the wheel treads from the resilient wheels in Figure 11.9(b) suggest that the discard diameter is 620mm.

The motor bogie construction is illustrated in Figure 11.10. The mono-motor shown in Figure 11.11 sits longitudinally and centrally in the bogie frame and drives gearboxes associated with each axle through flexible drives. There is a motor bogie at each end of the vehicle. The unpowered centre trailer truck, shown in Figure 11.12, incorporates wheels mounted on stub axles so that the low floor can be accommodated. It is understood that wheels of the trailer truck are linked by auxiliary axles running within the lateral frame members, which are connected by gears to the stub axles. The centre of vehicle articulation is above the centre of this truck.

The wheel lathe located in the Depot is shown in Figure 11.13.

The total annual distance covered by all the trams on Line 1 is 1.55×10^6km and 0.95×10^6km on Line 2.

11.3.3 Figures

(a) Consolidated hardcore trackbed

E Hollis (2010048)

(b) Concrete slab with track being assembled

E Hollis (2010049)

E Hollis (2010050)

(c) Grooved rail track during assembly

Figure 11.1 The initial phases of track construction, TAG Grenoble (01.02.05)

E Hollis (2010053)

(a) Detail of rail fastening

E Hollis (2010063)

(b) Track following concreting of sleeper and with rail cladding in place

Figure 11.2 Track construction, TAG Grenoble (01.02.05)

E Hollis (2020153)

(a) Grand'place (Line A)

(b) Restricted road width,
Rue Voltaire (Line A)

E Hollis (2020172)

E Hollis (2020173)

(c) Street drainage, Sainte-Claire
(Line B)

Figure 11.3 Street running track,
TAG Grenoble (02.02.05)

E Hollis (2010028)

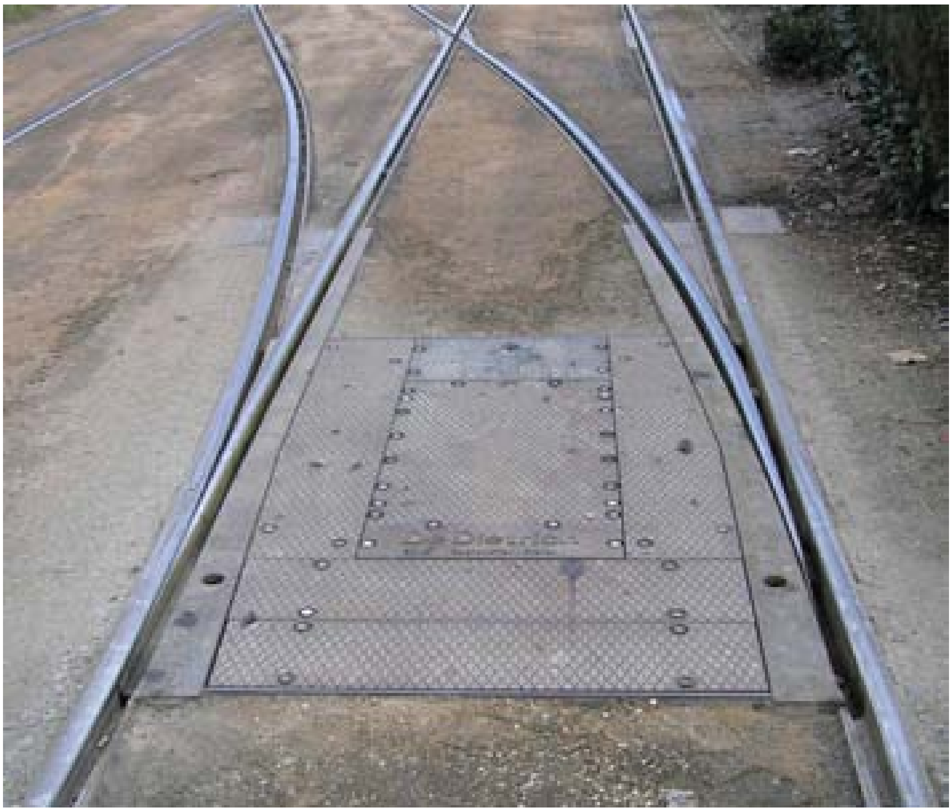
(a) Segregated track

E Hollis (2010031)

(b) Level crossing

Figure 11.4 In the vicinity of Les Taillées (Line B) TAG Grenoble (01.02.05)

E Hollis (2010046)
(a) Cross-over in the vicinity of the Palais de Justice, Line B (01.02.05)



E Hollis (2020135)
(b) Cross-over at the Depot entrance (02.02.05)

Figure 11.5 Turnout examples, TAG Grenoble

E Hollis (2020176)

(a) Switch rails

E Hollis (2020181)

(b) Common crossing

(c) Diamond crossing

E Hollis (2020175)

Figure 11.6 Examples of switches and crossings

E Hollis (201002)
(a) Tram No. 2034 at Saint Martin d’Hères Universitiés (01.02.05)

E Hollis (2020126)
(b) Centre section of tram No. 2013 in the Depot (02.02.05)

Figure 11.7 Side view of TAG Grenoble vehicles

E Hollis (2020085)

(a) Tram No. 2031 in a service road

E Hollis (2020086)

(b) Tram No. 2037 and 2013 lifted for work on bogies

Figure 11.8 Front views of trams in the Depot, TAG Grenoble (02.02.05)

E Hollis (2020099)

(a) Example of a wheel tread profile

E Hollis (2020110)

(b) Wheel rims

Figure 11.9 TAG Grenoble wheel details (02.02.05)

E Hollis (2020101)

(a) Outer bogie end

E Hollis (2020118)

(b) Gearbox and brake detail

Figure 11.10 TAG Grenoble motor bogie with the mono-motor removed

E Hollis (2020105)

(a) Side view

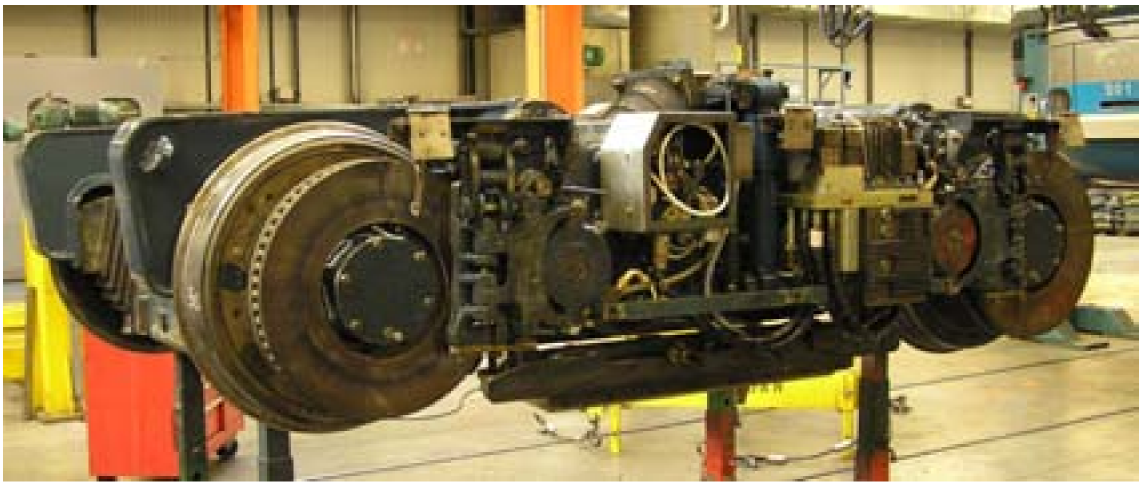
E Hollis (2020104)

(b) End view

Figure 11.11 Longitudinally mounted mono-motor, TAG Grenoble

E Hollis (2020113)

(a) End view



E Hollis (2020103)

(b) Side view

Figure 11.12 The centre (trailing) truck, TAG Grenoble (02.02.05)

E Hollis (2020090)

Figure 11.13 The TAG Grenoble wheel lathe at the Depot (02.02.05)

11.4 MONTPELLIER

11.4.1 Visit to Transports de l'agglomération de Montpellier (TaM) on 03.02.05

During the visit journeys on service trams on Line 1 were made together with visits to the Depot and construction sites associated with Line 2.

Route:

The route distance of Line 1 is 15.2km. It is believed that SEI 35GP grooved rail (as Appendix 6) is used throughout, laid to a gauge of 1435mm. The system opened in 2000 and was so successful that new trams had to be ordered shortly after opening together with new centre sections to extend the existing Alstom Citadis cars. There are 29 stops, and the peak service frequency is 4 minutes.

Line 2, which will connect with line 1 at two points, is due to open in 2006.

Track:

The method of track construction throughout the system appears to be similar to that of the Grenoble system (see section 11.3.2). The track formation assembled using SEI 35GP grooved rail fastened to twin block concrete sleepers, as shown in Figure 11.14(a). A further layer of concrete poured to just below the top of the sleepers locks the track formation in position. After the installation of insulation either sides of the rail, as Figure 11.14, further concrete is added to mid-rail height so that the finishing surface can be laid such as the brick of Figure 11.14(b), stone block as Figure 11.15(a), or tar macadam, ballast or grass as Figures 11.15(b) & (c).

The form of expansion switch is shown in Figure 11.16, and the method of track drainage can be seen in Figure 11.17.

Examples of turnout and diamond crossing construction on Line 2 can be found in Figures 11.18 & 11.19. Concrete sleepers with integral 'T' slots formed in steel appear to be used. These allow the S & C rail formations to be laid out and then readily secured with fasteners that slide within the slots. All exposed slot openings appeared to be fitted with rubber seals as Figure 11.19(a), to prevent concrete from entering the slot when the finishing surface was added. As with the plain track this system allows for relatively straightforward rail replacement or modification. The junction between Lines 1 and 2 at Corum shown in Figure 11.20(b) had been constructed in the manner outlined above and was awaiting the finishing surface. A completed street crossover is shown in Figure 11.20(a).

Whilst the junction at Corum was under construction single line working was in operation. The use of temporary tracks that sat on top of the newly constructed formation permitted tram services to remain in operation, as shown in Figure 11.21.

Vehicles:

Twenty eight identical five-section bi-directional Alstom Citadis 401 vehicles are in use on Line 1 (26 in service and two in reserve). As mentioned above these were originally 30m long type 301 units but have either been modified or supplied new as 40m long, type 401 between 2001 and 2002. They have a body width of 2.65m. These units are partly low floor. The external appearance is shown in Figure 11.22 & 11.23.

The form of wheel construction and tread profile is shown in Figure 11.24.

An example of the two motorised trucks that are used at each end of the vehicle is shown in Figure 11.25. A motor drives each axle. Of the two intermediate trailer trucks, one is motorised, as Figure 11.26, and the other un-motorised as shown in Figure 11.27.

The wheel lathe located at the Depot is shown in Figure 11.28.

The total annual distance covered by all the trams on Line 1 is 1.60×10^6km.

11.4.2 Figures

(a) Track being assembled on a concrete foundation slab

E Hollis (2030242)

(b) View showing installation of brick surfacing

E Hollis (2030213)

E Hollis (2030233)

(c) View illustrating the stages of construction

Figure 11.14 Track construction, TaM Montpellier (03.03.05)

(a) Comédie

E Hollis (2030277)

(b) Segregated track

E Hollis (2030282)

(c) Grassed track

E Hollis (2030284)

Figure 11.15 Examples of street and segregated track, TaM Montpellier (03.03.05)

E Hollis (2030283)

Figure 11.16 Expansion switch example, TaM Montpellier (03.03.05)

E Hollis (2030222)

Figure 11.17 Method of track drainage, TaM Montpellier (03.03.05)

E Hollis (2030227)

(a) Turnout during construction

(b) Crossing detail

E Hollis (2030230)

Figure 11.18 Turnout example, TaM Montpellier (03.03.05)

(a) Concrete sleeper fastener adjustment slots

E Hollis (2030232)

E Hollis (2030260)

(b) Diamond crossing detail

Figure 11.19 Turnout and crossing examples, TaM Montpellier (03.03.05)

E Hollis (2030281)

(a) Example of turnout

E Hollis (2030260)

(b) Junction at Corum between Line 1 and 2, in construction

Figure 11.20 Cross-overs and junctions, TaM Montpellier (03.03.05)

(a) Crossover to single line section

E Hollis (2030214)

(b) Detail of 'ramp' rails

E Hollis (2030220)

(c) Crossover at further end of the single line section

E Hollis (2030246)

Figure 11.21 Temporary crossovers at Corum, TaM Montpellier (03.03.05)

E Hollis (2030005)

(a) Full tram unit

E Hollis (2030011)

(b) Driving end, typical of two

(c) Short truck mounted section, typical of two

E Hollis
(2030008)

(d) Centre section

E Hollis
(2030009)

Figure 11.22 Tram No. 2019, TaM Montpellier (03.03.05)

(a) Tram No. 2019

E Hollis
(2030005)

(b) Depot service road

E Hollis
(2030287)

(c) At Corum

E Hollis
(2030238)

Figure 11.23 Tam Montpellier trams (03.03.05)

E Hollis (2030312)

(a) New wheel

E Hollis (2030309)

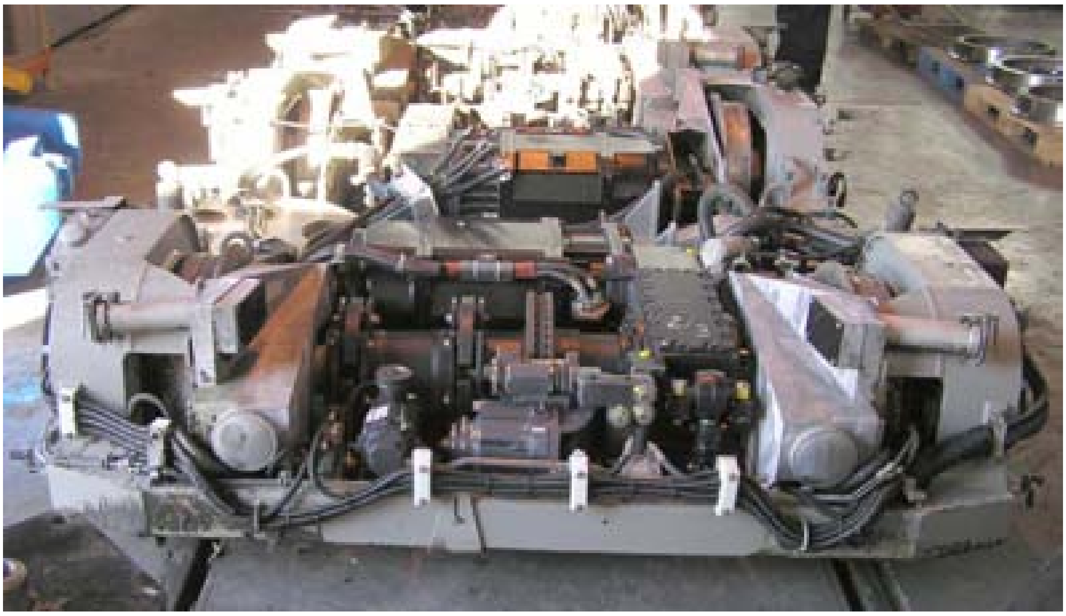
(b) Wheel tread profile

Figure 11.24 TaM Montpellier wheel details (03.03.05)

E Hollis (2030305)
(a) Side view

(b) Motor and gearbox

E Hollis
(2030308)



E Hollis (2030307)
(c) End view

Figure 11.25 Motor bogies from the driving end units, TaM Montpellier (03.03.05)

E Hollis (2030293)

(a) Underside view of truck beneath vehicle

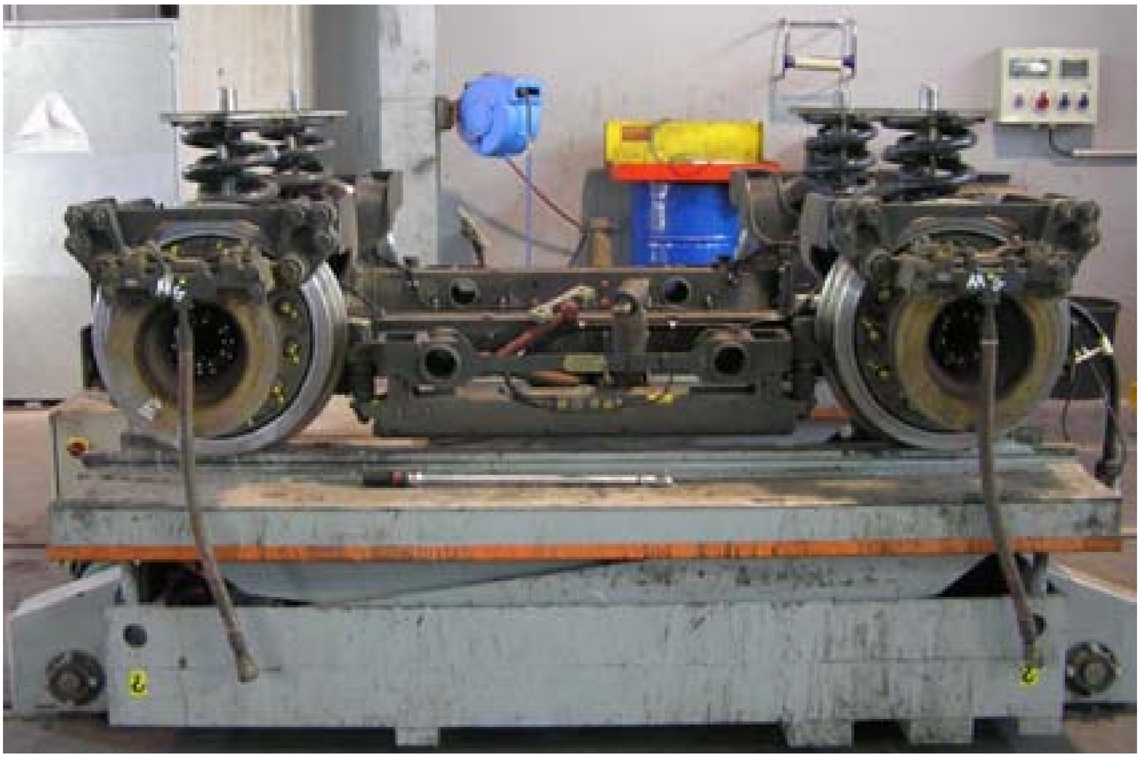
E Hollis (2030316)

(b) End view of truck

Figure 11.26 Motorised truck from beneath one of the short body sections, TaM Montpellier (03.03.05)

E Hollis (2030310)

(a) End view



E Hollis (2030311)

(b) Side view

Figure 11.27 Un-motorised truck from beneath one of the short body sections, TaM Montpellier (03.03.05)

E Hollis (2030300)

Figure 11.28 The TaM Montpellier wheel lathe at the Depot (03.03.05)

12 SUMMARY

12.1 TABLE 12.1 SYSTEM SURVEY INFORMATION

System	*Year of Opening*	*Length (km)*	*Grooved Track Length (km)*	*Number of Stops*	*Vehicle Fleet for Service*	*Total Vehicle Fleet Size*
Blackpool & Fleetwood Tramway	1885	18.0	9.4	60	12	80
Croydon Tramlink	2000	28.0	6.9	38	21	24
Docklands Light Railway	1987	27.9	0	34	70	94
Manchester Metrolink	1992	38.4	10.3	25	29	32
Midland Metro	1999	20.1	2.0	23	10	16
National Tramway Museum	1959	1.6	1.6	4	3	18
Nottingham Express Transit	2004	14.0	4.0	23	13	15
South Yorkshire Supertram	1994	29.4	~14	48	23	25
Tyne & Wear Metro	1980	80.6	0	58	70	90

12.2 TABLE 12.2 GROOVE RAIL SURVEY INFORMATION

Groove Rail	Rail Profile (vertical - unless otherwise specified)	*Gauge (mm)*	*Min Radius (m)*	*Max Cant (mm)*	*Max Gradient (%)*	*Tie Bars Used*
Blackpool & Fleetwood Tramway	Ri 60	1435/45[1]	19.3	0	2.5	Yes
Croydon Tramlink	Ri 59 Ri 60	1435	25	15	9	No
Docklands Light Railway	No grooved rail used					
Manchester Metrolink	Ri 59 SEI 35G [1 : 40]	1432	25.0	35	5.56	No
Midland Metro	SEI 35G	1435+3/-0	40.0	150	4.264	No
National Tramway Museum	BS7, BS 8 SEI 35G	1435	-	-	-	Yes
Nottingham Express Transit	SEI 41GP	1435	18.0	-	8.5	No
South Yorkshire Supertram	SEI 35G SEI 35GP	1435	18.0	-	8.5	No
Tyne & Wear Metro	No grooved rail used					

Notes:
[1] Gauge widening on curves

12.3 TABLE 12.3 BALLASTED TRACK SURVEY INFORMATION

Ballasted Track	*Rail Profile [inclination 1:20 unless otherwise specified]*	*Gauge (mm)*	*Min Radius (m)*	*Max Cant (mm)*	*Max Gradient (%)*
Blackpool & Fleetwood Tramway	BS 95RBH BS 113A	1435/45[1]	18.3	-	-
Croydon Tramlink	BR 109lb BS 110A BS 113A S 49	1435	25	150	8
Docklands Light Railway	BS 80A BS 110A BS 113A	1435	40	150	6
Manchester Metrolink	BS 95RBH BR 109 BS 80A BS 110A BS 113A	1435	121.3	150	5.18
Midland Metro	BS 80A BS 113A[2] [1:40]	1435+3/-0	25	-	3.364
National Tramway Museum	No Bull Head or Flat Bottom track				
Nottingham Express Transit	BS 80A [1:40]	1435	25	-	-
South Yorkshire Supertram	BS 80A [1:40]	1435+12/-2	25	150	10
Tyne & Wear Metro	BS 113A	1432&1435	50	110	3

Notes:
[1] Gauge widening on curves
[2] Short section

12.4 TABLE 12.4 GROOVE RAIL SWITCH AND CROSSING SURVEY INFORMATION

Groove rail switch & crossings	*Rail Profile [vertical]*	*Switch rail type*	*Flange tip running*	*Radius (m)*	*Check rail gap (mm)*	*Tie Bars Used*
Blackpool & Fleetwood Tramway	Ri 60	Pivot	All + ◊[1]	45.7	Rail groove	Yes
Croydon Tramlink	Ri 59(?)	Flexible	None	50 & 100	Rail groove	No
Docklands Light Railway	No groove rail switch and crossings					
Manchester Metrolink	Ri 59	Flexible	None	30	-	No
Midland Metro	SEI 35G	Semi-pivot & flexible	◊ (one)	25	26	No
National Tramway Museum	BS 8	Pivot	All	-	Rail groove	Yes
Nottingham Express Transit	SEI 41GP	-	None	25	-	No
South Yorkshire Supertram	SEI 35G	Flexible	None	25	-	No
Tyne & Wear Metro	No groove rail switch and crossings					

Notes:
[1] ◊ denotes a diamond crossing

12.5 TABLE 12.5 BALLASTED TRACK SWITCH AND CROSSING SURVEY INFORMATION

Ballasted track switch & crossings	*Rail Profile [vertical]*	*Switch rail type*	*Radius (m)*	*Switch opening (m)*	*Check rail gap (mm)*
Blackpool & Fleetwood Tramway	No Bull Head or Flat Bottom track				
Croydon Tramlink	S 49	Flexible	50 100	60	22.5
Docklands Light Railway	80A?	Flexible	40 100 200 245	114	44
Manchester Metrolink	113A	Flexible	246	102	44
Midland Metro	80A	Flexible	100	-	26 [Adjustable to 44 for maintenance]
National Tramway Museum	No Bull Head or Flat Bottom track				
Nottingham Express Transit	80A	Flexible	184	-	-
South Yorkshire Supertram	80A [2 flange tip running crossings]	Flexible	25	95	41
Tyne & Wear Metro	113A	Flexible	145 to 1166	105 to 10?	44

12.6 TABLE 12.6 VEHICLE TYPE SURVEY INFORMATION

Vehicles	*Type*	*Source*	*Date Introduced*	*Tare weight (tonne)*	*Max passenger capacity (sitting + standing)*
Blackpool & Fleetwood Tramway	SD[1] & DD[2]	East Lancs[1]/EE[2]	1984[1]/34[2]	-/-	75[1]/94 seated[2]
Croydon Tramlink	CR-4000	Bombardier	2000	-	208
Docklands Light Railway	B92	Bombardier	1991/92	36	292
Manchester Metrolink	T68 & T68A	Firema	1992/97	49.0/49.6	210
Midland Metro	T69	Firema	1999	35.9	160
National Tramway Museum	Large mixed collection of 80 four wheel and bogie stock				
Nottingham Express Transit	Incentro	Bombardier	2003	39.3	261
South Yorkshire Supertram	SYS	Duewag	1994	46.5	250
Tyne & Wear Metro	T&WM	Metro-Camm	1980	40	300

Notes:
[1] SD denotes Single Deck
[2] DD denotes Double Deck

12.7 TABLE 12.7 VEHICLE DIMENSION SURVEY INFORMATION

Vehicle Dimensions	*Total unit length (m)*	*Body width (m)*	*Body height (m)*	*Floor height (mm)*	*Bogie or (articulation) centres (m)*
Blackpool & Fleetwood Tramway	SD[1] = 15.24 DD[2] = 12.88	SD = 2.44 DD = 2.27	SD = - DD = -	SD = 925 DD = -	SD = 8.13 DD = 5.94
Croydon Tramlink	31.00	2.65	3.36	400	11.55 (Articulation)
Docklands Light Railway	28.00	2.65	3.47	1025	10.00
Manchester Metrolink	29.00	2.57	3.36	940	3.36
Midland Metro	24.24	2.65	3.55	350 & 850	7.75 (Articulation)
National Tramway Museum	Large mixed collection of 80 four wheel and bogie stock				
Nottingham Express Transit	33.00	2.40	3.35	-	6.7+5.0+ 6.7 (Articulation)
South Yorkshire Supertram	34.75	2.65	3.65	450 & 850	9.75 (Articulation)
Tyne & Wear Metro	27.80	2.65	3.16	959	10.40

Notes:
[1] SD denotes Single Deck
[2] DD denotes Double Deck

12.8 TABLE 12.8 VEHICLE BOGIE SURVEY INFORMATION

Vehicle bogie	*Bogie/truck type (motor/trailer)*	*Number of motor+trailer bogies/trucks[1] per unit*	*Motors per bogie*	*Number of powered axles per bogie/truck[1]*	*Wheel base (m)*
Blackpool & Fleetwood Tramway	-	2+0	1	1	1.66
Croydon Tramlink	-	2+1T	2	2	1.80
Docklands Light Railway	-	2+1	1	2	1.90
Manchester Metrolink	M048E/P048E	2+1	2	2	2.07
Midland Metro	M046 (motor)	2+1T	1	2	1.80
National Tramway Museum	Large mixed collection of 80 four wheel and bogie stock				
Nottingham Express Transit	-	2T+1T	4T	2T[2]	1.80
South Yorkshire Supertram	-	4+0	1	2	1.80
Tyne & Wear Metro	-	2+1	1	1	2.10

Notes:
[1] T indicates that a truck (4 wheeled chassis unit) is used instead of a bogie
[2] The NET vehicles do not have conventional axles. Each wheel of the motor trucks have their own motor.

12.9 TABLE 12.9 VEHICLE WHEEL SURVEY INFORMATION

Wheels	*Type*	*New diameter (mm)*	*Worn diameter (mm)*	*Tread width (mm)*	*Wheelset back-to-back distance (mm)*
Blackpool & Fleetwood Tramway	Tyre with solid centre	686	623	85.7	1389
Croydon Tramlink	BO54[1] Resilient	630	550	115.0	1380(+4/-0)
Docklands Light Railway	BO34 Resilient	740	660	127.0	1362 (+0.5/-1.5)
Manchester Metrolink	BO54[1] Resilient	740	680	127.0	1362(+0/-2)
Midland Metro	Resilient	680	620	125.0	1379
National Tramway Museum	Various			75.2	1392
Nottingham Express Transit	SAB Resilient	660(+/-0.5)	580	110(+1/-0)	1380(+1/-3)
South Yorkshire Supertram	BO84[2] Resilient	670	588	125.0	1379(+2/-0)
Tyne & Wear Metro	BO54[1] Resilient	740	675	127(+/-0.5)	1362

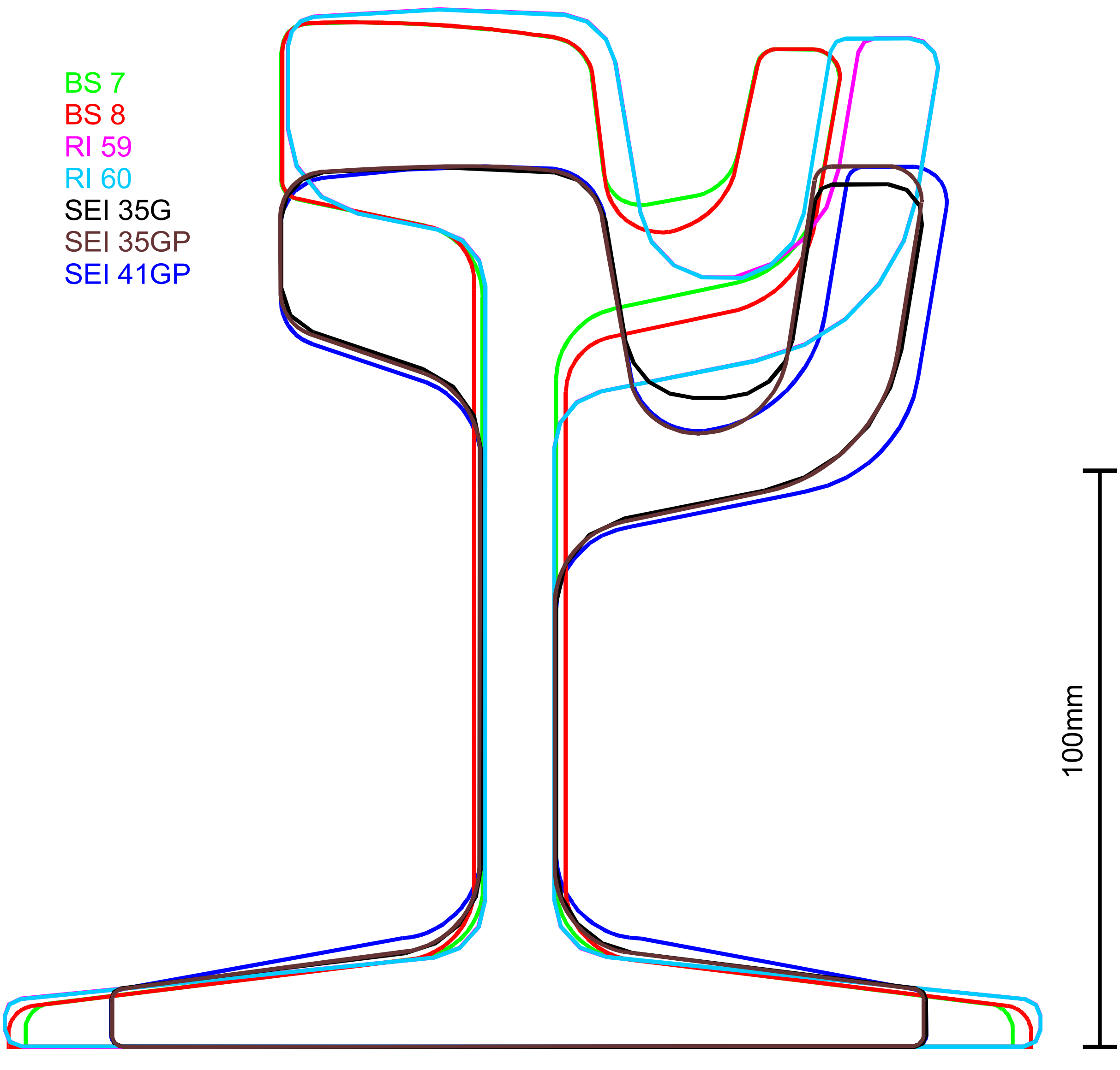
Notes:
[1] BO54 tyres cannot be replaced without removing the wheel from the vehicle.
[2] BO84 tyres can be replaced without removing the wheel from the vehicle.

12.10 TABLE 12.10 SUMMARY OF WHEEL TREAD AND RAIL PROFILES

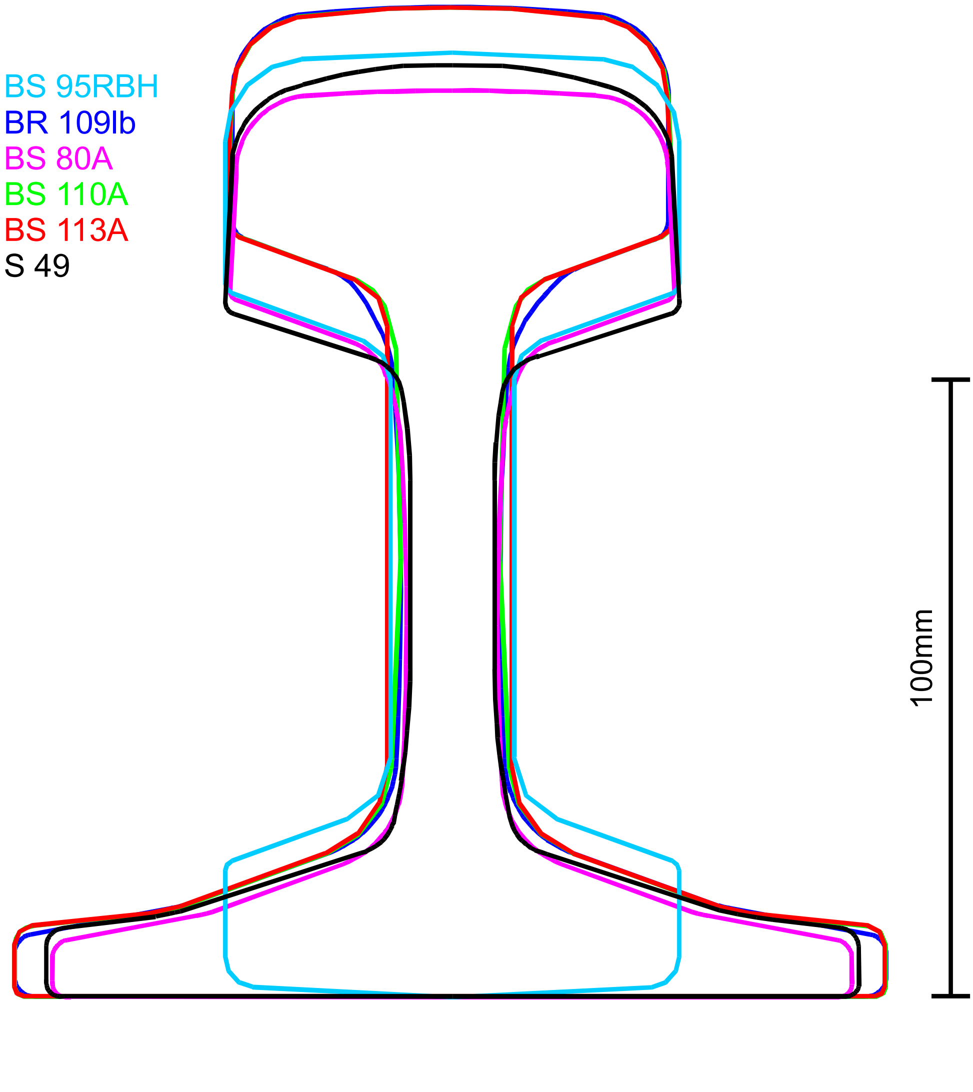
System	***Wheel tread profile***	***Rail profile***		***Flange Running Wheel Profile***	***Flange Tip Profile***	***Flange Running S & C***
		Grooved	***Ballasted track***			
	[Appendix]	***[Appendix]***	***[Appendix]***			
Blackpool & Fleetwood Tramway	Blackpool Corp. Transport Dept. 27inch tyre section (Dwg No. 44-10/1)	Ri 60	BS 95RBH BS 113A	Yes	Round	Yes
	[14]	[4]	[8 & 12]			
Croydon Tramlink	Croydon	Ri 59 Ri 60	BS 110A BS 113A S 49	Yes	Square	No
	[15]	[3 & 4]	[11, 12 & 13]			
Docklands Light Railway	DLR5	None	BS 80A BS 110A BS 113A	No	Round	No
	[17]	-	[10, 11 & 12]			
Manchester Metrolink	GEC Alsthom MML-2 (Dwg No. 1917)	Ri 59 SEI 35G	BS 95RBH BR 109lb BS 80A BS 110A BS 113A	No	Round	No
	[18]	[3 & 5]	[8, 9, 10, 11 & 12]			
Midland Metro	T69 (Revision 'A')	SEI 35G	BS 80A BS 113A[1]	Yes	Square	Yes
	[20]	[5]	[10 & 12]			
National Tramway Museum	BS 101 (1929)	BS 7 BS 8 SE1 35G	None	Yes	Round	Yes
	[21]	[1, 2 & 5]	-			
Nottingham Express Transit	Gutehoffnungshütte Radsatz GmbH (Dwg No. P-3-102639)	SEI 41GP	BS 80A	Yes	Square	No
	[22]	[7]	[10]			
South Yorkshire Supertram	SYS	SEI 35G SEI 35GP	BS 80A	Yes	Square	No
	[23]	[5 & 6]	[10]			
Tyne & Wear Metro	BRB P8 (Dwg No. S8-C2-8006239)	None	BS 113A	No	Round	No
	[24]	-	[12]			

Notes:
[1] Used for very short lengths of track only

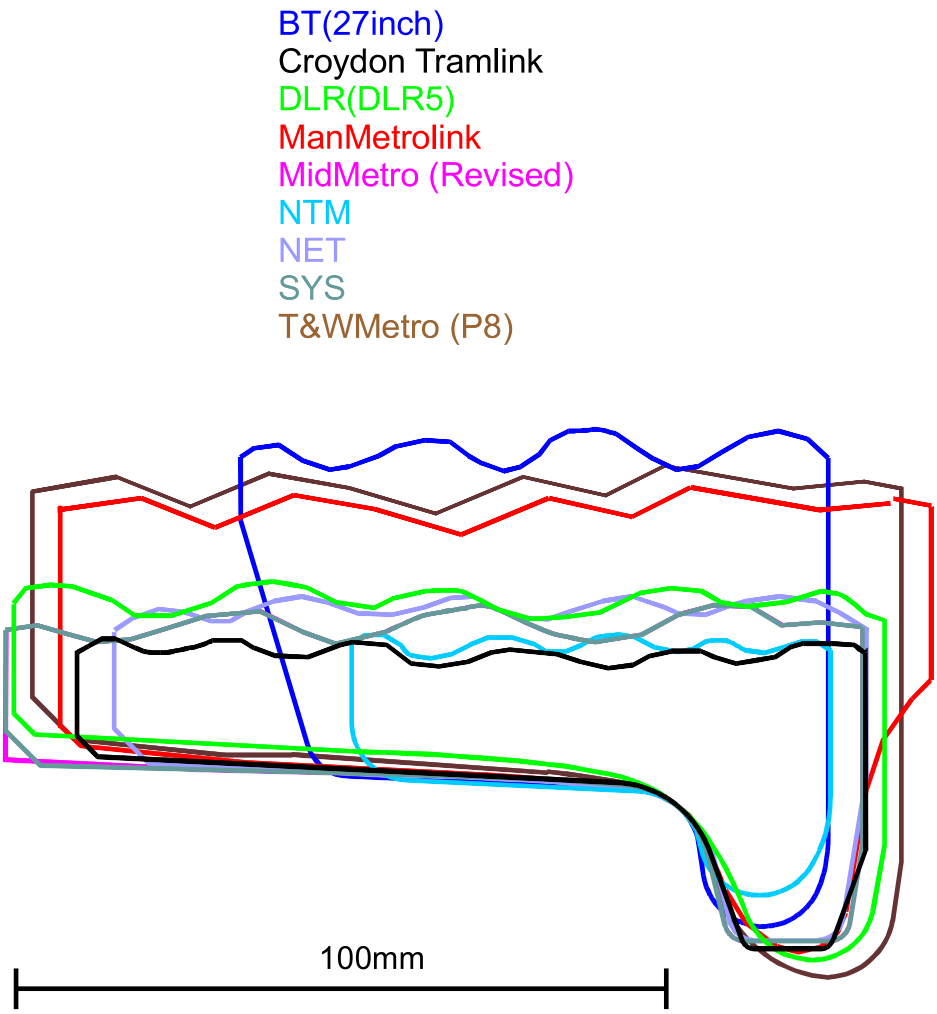
12.11 SUMMARY OF GROOVED RAIL PROFILES



12.12 SUMMARY OF NON GROOVED RAIL PROFILES



12.13 SUMMARY OF WHEEL PROFILES



13 OBSERVATIONS

13.1 SPECIFIC OBSERVATIONS

The following list of observations relevant to the wheel/rail interface has been gathered during the project:

13.1.1 Track

1. Care is needed at the transition from slab to ballast track to avoid the need for continuous maintenance to prevent dips forming in the track level. Cross drains installed at the end of slab track may assist in preventing rainwater carrying debris into the ballast and creating drainage problems in this critical transition area.
2. The provision of grooved rail track drainage generally appears to be inadequate.
3. Sand used for traction/braking control can contribute considerably to the blockage of drains on street running grooved rail track, so the provision of suitable sand traps seems appropriate.
4. During the construction of concrete slab plain track with grooved rail it has been observed that the track can be over gauge. This arises when the rail is set to gauge and clamped to baseplates bolted to the foundation slab prior to a second pour of concrete. On occasion the rail has been forced apart during the curing of the second pour of concrete by as much as 10mm. To rectify this the concrete had to be broken out around one of the rails, and jacks used to hold the rails to gauge whilst a new pour of concrete cured. The voids formed by the jacks had then to be filled. The use of tie bars with this and the alternative forms of grooved rail concrete slab construction would ensure that the gauge was maintained at all times.
5. With grooved rails held by polymer within cast concrete channels the wheel/rail forces have a tendency to tip the rails over on curves, thereby spreading the gauge, at such locations shown in Figure 13.1. This is also a situation where tie bars would be beneficial.
6. The purpose of the keeper flange of grooved rail is to maintain a free passage for the tram wheels in the road or other paved surface. It is not designed or intended to be a check rail except where specially strengthened and arranged at specific areas, usually at switch and crossing work in the track layout. Forces normally associated with guiding vehicles around curves or through switches and crossings should properly be taken by the rail running edge and the front face of the wheel flange, which are designed for this purpose. Should the keeper flange show signs of wear, some other deficiency should be suspected. This may be significant wear at the running edge of the opposite rail or vehicle flange face wear. Alternatively, it is possible that the rails are not be being properly held within the required gauge tolerances.

13.1.2 Switches & crossings

1. Arrange for the switch opening of ballasted track turnouts to have the same switch opening dimension as for the grooved rail turnouts to minimise the amount of work required from the switch mechanisms.
2. The use of adjustable check rails allows wear to be readily compensated for.
3. To avoid excessive wear and maintenance of street running turnouts locations should be used where road traffic will not directly cross S&C units. To achieve this it may be necessary to locate the turnout earlier and use interlaced tracks (parallel running) through the traffic zone.

4. If there is a lack of wheel profile maintenance excessive hollow wear of the tread can lead to the formation of a shallow flange on the outside of the wheel tread. In extreme cases significant damage, rough riding and noise can be generated when the shallow flanges of such wheels meet the wing rails and incoming running rails at the ‘vee’ of a common crossing as Figure 6.8(a).

13.1.3 Wheel/rail interface

1. It has been observed that there is reduced noise with wheel flange spray lubrication systems compared with stick lubrication.
2. On systems with many sharp curves wheel tyre profiles start with the correct cone angle but are soon found to wear flat as Figure 13.2, thereby compromising the self-centering ability of wheelsets.
3. Wheels with a square flange tip are not tolerant of errors and will often ride up on open switch rail tips and derail.
4. For the majority of UK LRT systems a rounded flange tip is probably more appropriate then the square tip, as flange tip running is not common.
5. The use of a rounded flange tip wheels would allow the use of more realistic maintenance tolerances for switch tip gaps.
6. German wheel re-profiling practice is to re-dress the flange angle and not the whole flange, which accepts that the flange gets thinner.
7. A cone angle of about 10deg towards the edge of wheels reduces damage to the road surface adjacent to the rail for in-street running.
8. Hollow worn wheels may give rise to running on the adjacent roadway with resultant damage and shorting out of the rail insulation, as shown in Figure 13.3. In extreme cases the current path through the rails can be compromised.

13.2 FACTORS ASSOCIATED WITH TURNOUTS THAT CAN CONTRIBUTE TO DERAILMENTS

13.2.1 Wheel flange overlap with switch rails at first contact

As constructed, a number of systems initially had flat bottom rail switch rails with blunt ends such that first contact (point of diversion) with a modern wheel form was very close to the corner between the flange side and the square tip. Flange overlaps as little as 5mm have been found, a situation in which there was potential for the flange striking the end of the switch rail and subsequent risk of derailment. Prior to service running on some systems, such turnouts have had the switch rails re-profiled to provide a flange overlap of 12mm at the point of diversion

13.2.2 Partially open switches at turnouts

If a closed switch is open by more than the permitted tolerance the flat tip flange of a modern tram wheel may strike and climb up the end of the switch rail. It can then run along the top of the rail until, lacking guidance, it falls off into the gap between the switch and stock rails and derail. There are two ways in which this can arise, as outlined below.

13.2.2.1 Switches which have not thrown fully

The common factor is the relative stiffness of the flexible (‘spring’) switch rails, which for ballasted (off-street) tracks are of heavy rail section and which have large throws in relation to switch rail length. The power switch mechanism used on the running lines of LTR systems is often of the Hanning & Kahl type, one of whose characteristics is that the operating force diminishes towards the end of the stroke. If this is combined with switches that are already stiff, both as a consequence of friction and bending effort, the result can be switches that cannot be relied upon to close fully every time, as Figure 13.4. If such incorrectly set switches are mechanically detected, indicated and confirmed by a Point End Indicator then trams should stop before crossing the turnout, unless the tram driver fails to notice the change of indicator aspect, in which cases derailment can result.

It has been found that the fitting of roller units beneath the switch rails, which lifts them clear of the baseplates when not part of the running line, can significantly reduce the frictional effects and result in reliable operation using the same type of switch mechanism.

The greatest number of derailments from this cause occurs in Depots where generally the points are hand operated and the switches are not provided with detection. The hand lever mechanisms are usually of the ‘over-centre spring’ type that suffers from the same operating characteristics as the power mechanisms, which is exacerbated by the extreme shortness of the switch rails. Typically these turnouts are of 25m radius, yet have the same tip openings as heavy rail turnouts, so that that the ratio of tip opening to switch rail length is greater than on the running lines. It is not practical to fit roller units to such turnouts so the only feasible solution appears to be that of allowing the switches to articulate by the use of a fishplated joint. Such ‘loose heel’ switches are used on heavy rail industrial lines and are directly analogous to the pivoted switches found on older tramway track, such as on Blackpool & Fleetwood Tramway system.

13.2.2.2 Stuck switches

Derailment due to a set of spring switches moving underneath a passing tram has been observed. The cause was found to be a combination of high friction forces between switch rails and baseplates, and the inherent characteristics of the switch mechanism in which the spring can be balanced in mid-position (a characteristic of all spring toggle mechanisms). An example of a switch mechanism is shown in Figure 13.5. After the tram had trailed through such a turnout the switches were left stuck in the ‘reverse’ position, as illustrated in Figure 13.6(a), due to friction, whilst the mechanism was left balanced to the ‘normal’ side of dead centre. Upon the trams return the vibration from the leading bogie passing through the turnout was sufficient to jar the switch mechanism causing the switches to change from ‘reverse’ to ‘normal’ in front of the middle section of the tram, as simulated in Figure 13.6(b).

The fitting of low friction roller units, as described in 13.2.2.1 above, can prevent switch rails from sticking in the wrong position.

13.2.2.3 Switches which spring open under the passage of trams

With the very small radius turnouts found on tramways there is an increased tendency for gaps in the fit between the switch rail and the distance blocks which hold it clear of the stock rail in the flexible section, and for a poor fit along the length of the planing of the switch rail tip, as can be seen in Figure 13.7. If, with the switch closed, there are gaps between the rail and the distance blocks, the switch rail will deflect outwards, opening the gauge, due to the lateral forces exerted by the wheelsets, particularly through the curved route. With the point of contact at the tip end of the planing the switch rail bends about the tip and so remains closed. If, however, the point of contact is as at the heel end the switch rail will pivot about this point with the result that the switch tip will open. It is sometimes the case that the switch mechanism has insufficient force to push it closed so the gap remains until the next wheel arrives, which then climbs the switch tip and derails.

13.2.3 Wheel/rail interface failures

Derailment can occur as a consequence of wheel/rail friction and lateral wheelset forces due to rail curvature, which enables wheels to climb the sides of switch tips. Turnouts in Depot areas have been found to be particularly prone to this. The relatively sharp corner between the flat tip and flange side of the modern form of tram wheel is suspected as having been instrumental in these derailments as there is a higher propensity of the wheel to dig into the side of the rail than the standard 'rounded' railway wheel profile, as shown in Figure 13.8. Weekly standing maintenance action to grease the sides of switch tips has been found to be effective in preventing such derailments.

Derailment following tyre re-profiling on the wheel lathe has also occurred. In this instance the poor surface finish of the wheel tread and flange was suspected of enhancing the wheel/rail friction, resulted in derailment in the manner described above. This highlights the importance of controlling wheel tyre surface finish during machining to avoid the condition shown in Figure 13.9.

13.3 GENERAL OBSERVATIONS

1. A depot located wheel lathe is vital to promoting minimum wear to wheels and rails, and preventing damage to the road surface.
2. There is a need for standardisation in UK LRT systems to reduce the diversity of standards, reduce innovative features that may require corrective action, and promote cost effective operation.
3. There is a need for greater knowledge sharing within the LRT industry.
4. There is a much greater emphasis on stray current protection in the UK than in Europe.
5. The information concerning maintenance passed to the operator by the supplier is often inadequate.
6. Experience has been lost following the closure of earlier tramway systems in the UK and is therefore not available to guide the creation of new ones.
7. Managing the wheel/rail interface should be in the hands of a single engineering authority. Experience has shown that such management can be frustrated by commercially driven contract arrangements between the owner, operator and maintainer which prevent clear lines of responsibility for design, maintenance and operational decisions.
8. All switches should be detected and indicated and not rely on driver observation and judgement.
9. The management of engineering systems design and their investigation should not permit compromise by commercial loyalties or considerations. All significant design proposals should be determined and demonstrated before equipment is ordered and construction commenced (e.g. the compatibility of wheelsets/switch geometry and switch machine/switch rail).
10. Check rails should always be used with expansion switches on curves (see Figure 5.8(a) and Figure 6.4(b))

13.4 MODERN FRENCH SYSTEMS (GRENOBLE & MONTPELLIER)

1. The method of track construction appeared to be the same throughout the systems irrespective of location (in-street or reserved).
2. The basic form of track construction consists of a concrete foundation slab supporting conventionally sleepered track that is concreted in place following packing to achieve the desired alignment.

3. Ballast, grass, macadam, brick or stone is used to form the finishing track surface, applied to the railhead level, depending upon location.
4. Grooved rail of the same profile is used throughout the systems.
5. Grooved rail turnouts have the switch rail stiffness matched to the power of switch machines.
6. Turnouts and diamond crossings incorporate sleepers that have 'T' slots let into their top surface with rubber seals so that rail fastenings can be readily adjusted during construction or rail replacement.

13.5 SUMMARY

In general terms there are two types of wheel used for tram and light rail systems:

- A profile similar to standard railway wheels with typical heavy rail wheel spacing of about 1362mm.
- A wheel that incorporates a square flange tip that makes it more suitable for flange running typically with a wheel spacing of about 1380mm.

Though there appears to be no consensus as to which form of profile is most advantageous it can be argued that higher speeds and greater distance require railway wheels and lower speeds and shorter distance in-street running requires flange running wheels. Flange running wheels allow a narrower groove width to be used and also reduce noise due to the continuous wheel support through crossings with flange running. It is also maintained that the square flange tip was adopted by many continental operators on the grounds that a flange running round tip was found to quickly wear to a flat profile. Also, during this wear process the flange angle changed towards the vertical reducing the flange corner radius and therefore making it more susceptible to derailment through flange climbing.

UK experience has shown that square flange tips can have disadvantages when running through small radius turnouts constructed from flat bottom rail to 'heavy rail' norms. For such units it seems convention to use switch mechanisms designed for the lighter switch rail design of grooved rail turnouts. On occasion such machines, and their manual counterpart, have been found to be underpowered to fully switch such turnouts due to the greater stiffness of the short stiff flat bottom rail switch rails used. This can result in switch rails not being fully seated and held against the stock rail. In such situations, the wheel with a square tip flange has been found to be intolerant of these errors and may tend to readily ride up onto the switch rail and bring about derailment. The poor finish of some new switch rail tips, or the 'ramp' offered by worn blades, appears to aid this process. The corner between the square flange tip and the angled flange running face has also been found to rapidly wear switch rails if regular lubrication is not provided. This also applies to sharp curves, typical of street running and elsewhere.

In general terms it therefore seems that a rounded flange tip profile may be the most appropriate for UK conditions, as seems to be the case for North American systems (Parsons Brinckerhoff (2000)), where the amount of flange tip running also appears to be minimal. Generally, round tip profiles offer a greater flange depth and as a consequence of this, the shallower flange angle and the rounded tip profile make it less susceptible to flange climb. It should be noted that a round tip wheel flange is used for flange running through all the crossings on the Blackpool & Fleetwood Tramway system, which are exclusively constructed from grooved rail.

13.6 FIGURES

J Snowdon

Figure 13.1 Example of curved track where rail tipping has been found

J Snowdon

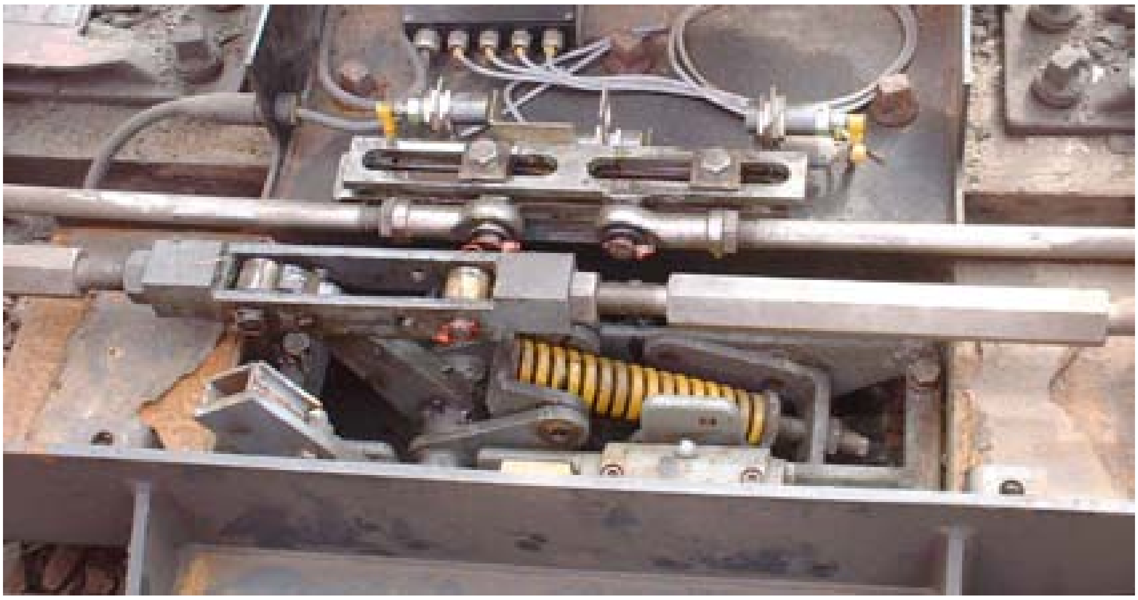
Figure 13.2 Example of an ‘in service’ wheel profile

A Steel

Figure 13.3 Road surface damage due to hollow wheel wear.

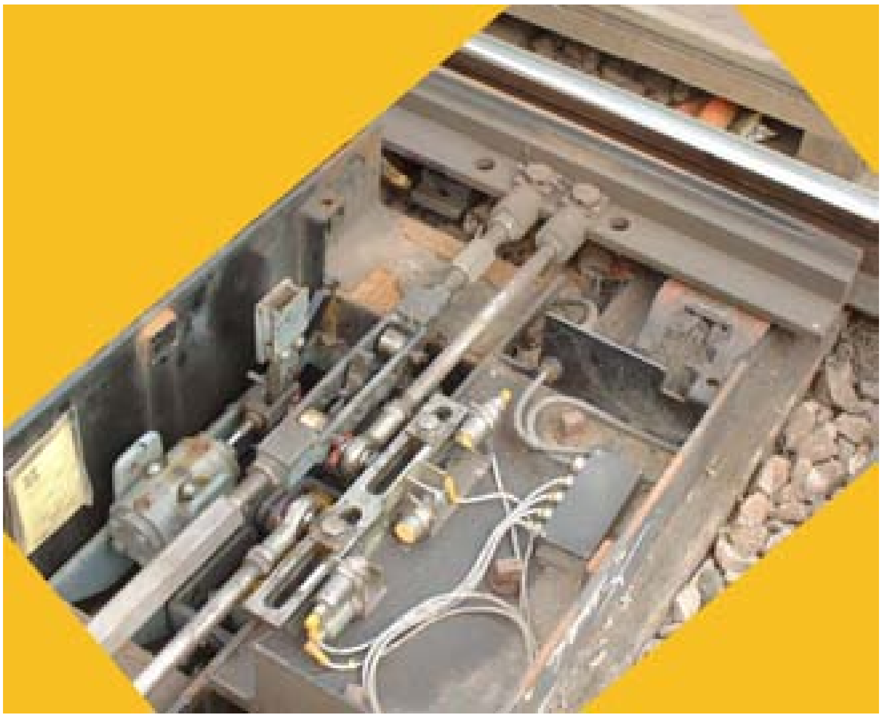
J Snowdon

Figure 13.4 Example of a switch rail that has not been fully closed by the switch mechanism

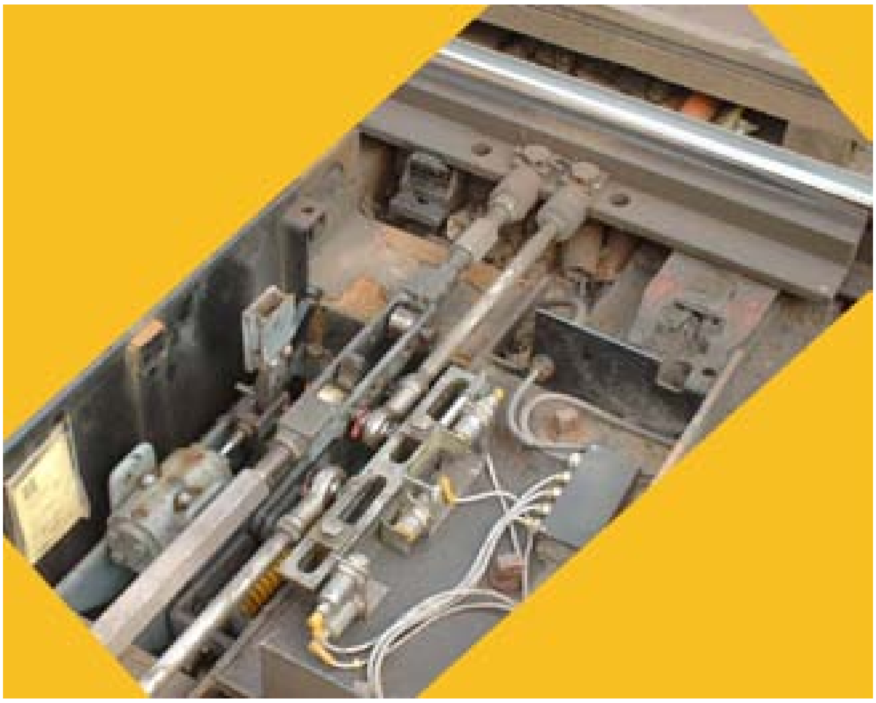


I Raxton

Figure 13.5 Example of a switch mechanism showing the spring toggle



I Raxton
(a) Blades fully thrown to set the ‘reverse’ position that is maintained through friction



I Raxton
(b) Simulation of blades returned to the ‘normal’ by tram vibration

Figure 13.6 Example of a ‘stuck switch’, bar used to move switch rails to demonstrate bi-stable positions, with the lever in the centre position

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Figure 13.7 An example of switch rail fit against the stock rail

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Figure 13.8 Example of a switch rail wear mark made by wheels with square flange tips

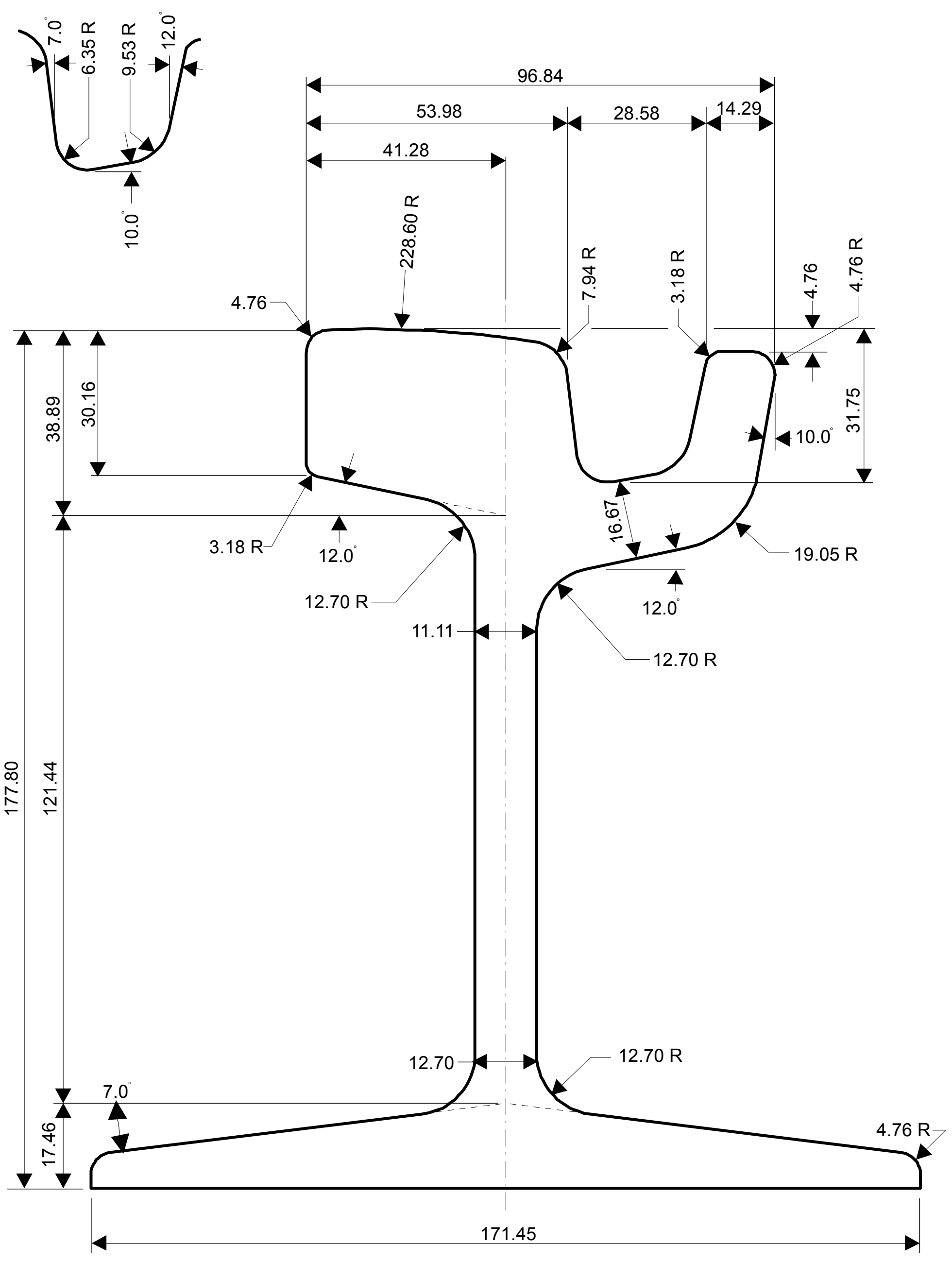
J Brown

Figure 13.9 Wheel marks following a derailment

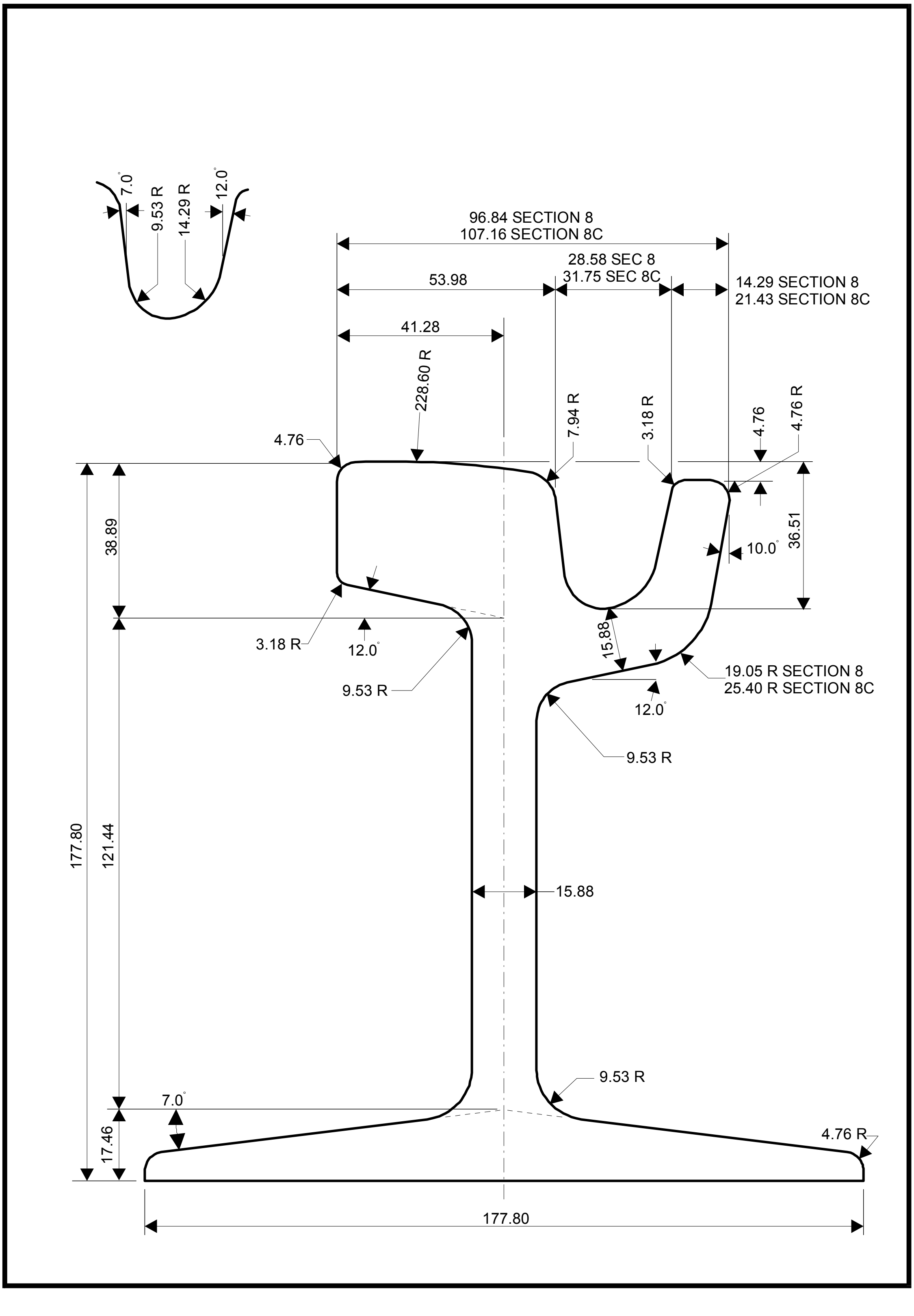
14 APPENDICES

All dimensions given in the rail and wheel profiles of these appendices are in millimetres.

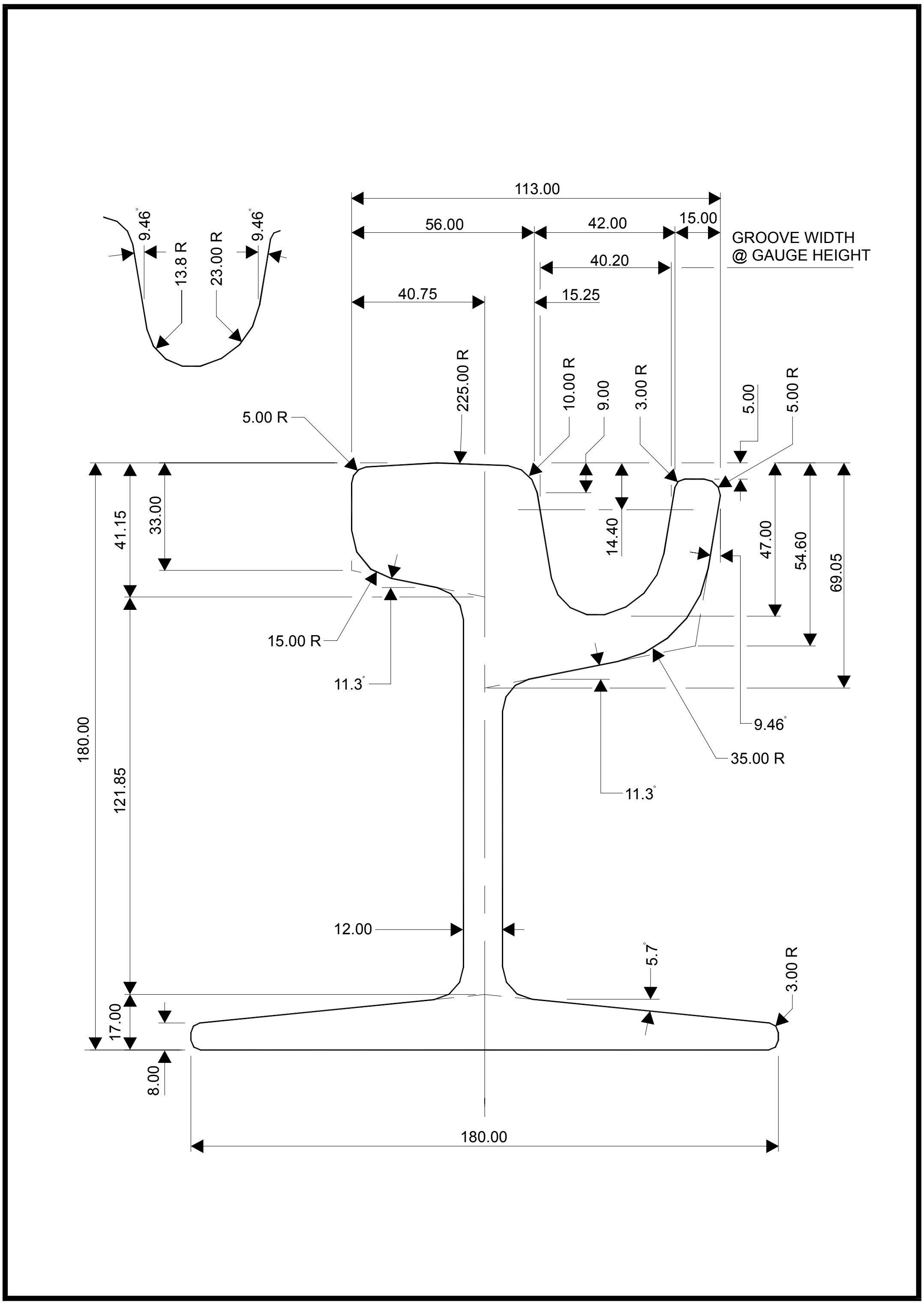
14.1 APPENDIX 1 BS SECTION NO. 7 GROOVED RAIL



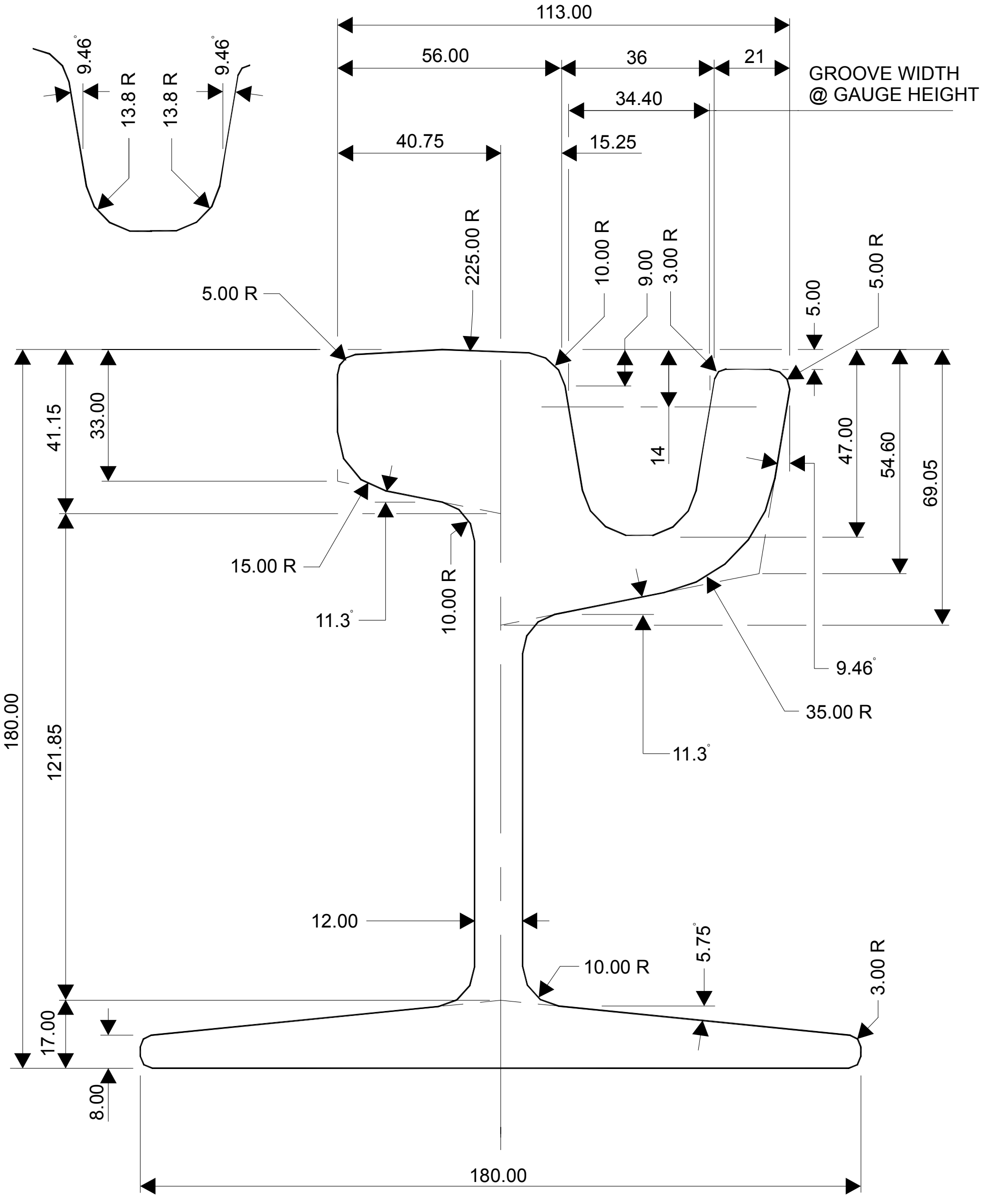
14.2 APPENDIX 2 BS SECTION NO. 8 & 8C GROOVED RAIL



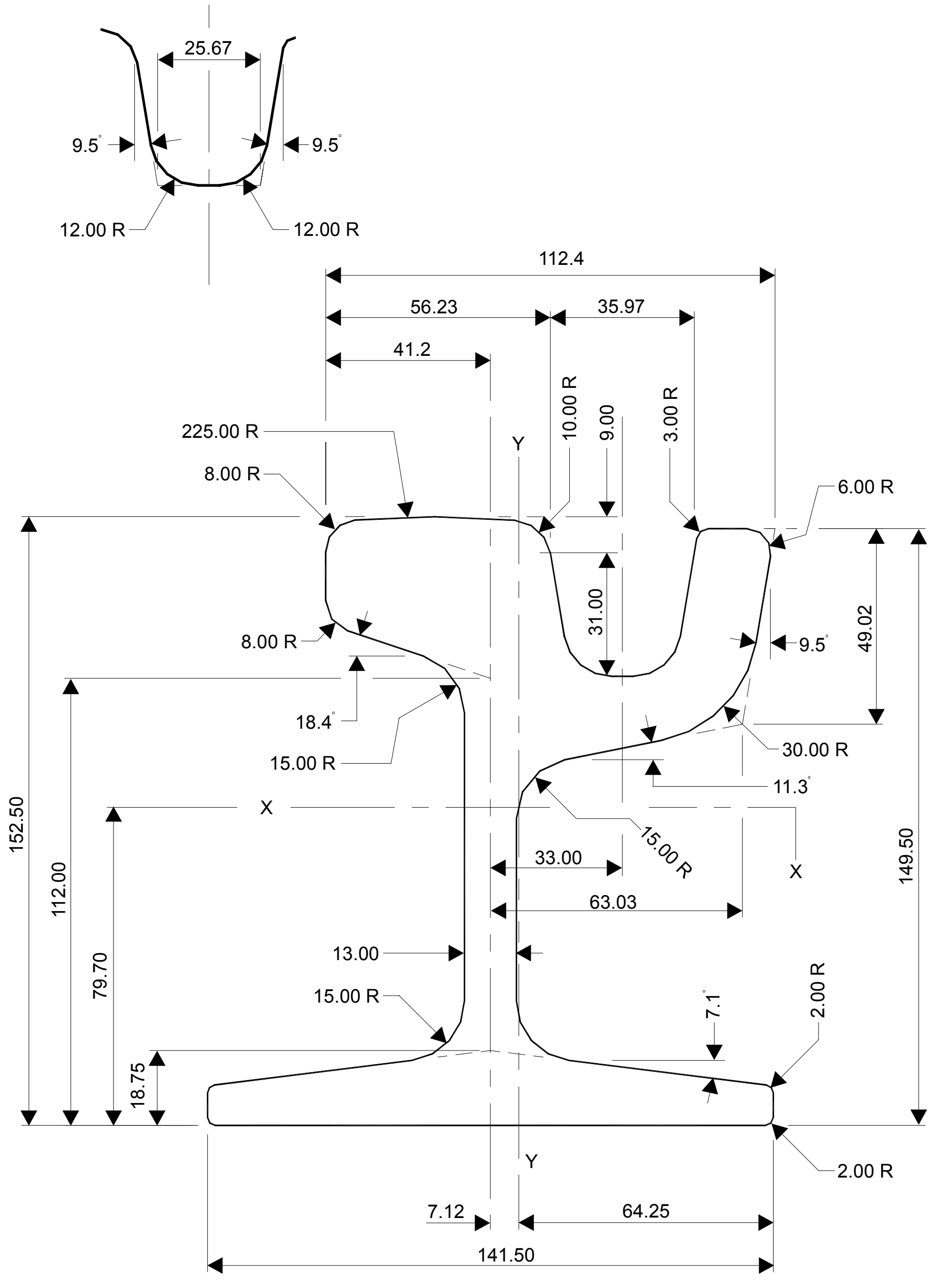
14.3 APPENDIX 3 RI 59 GROOVED RAIL



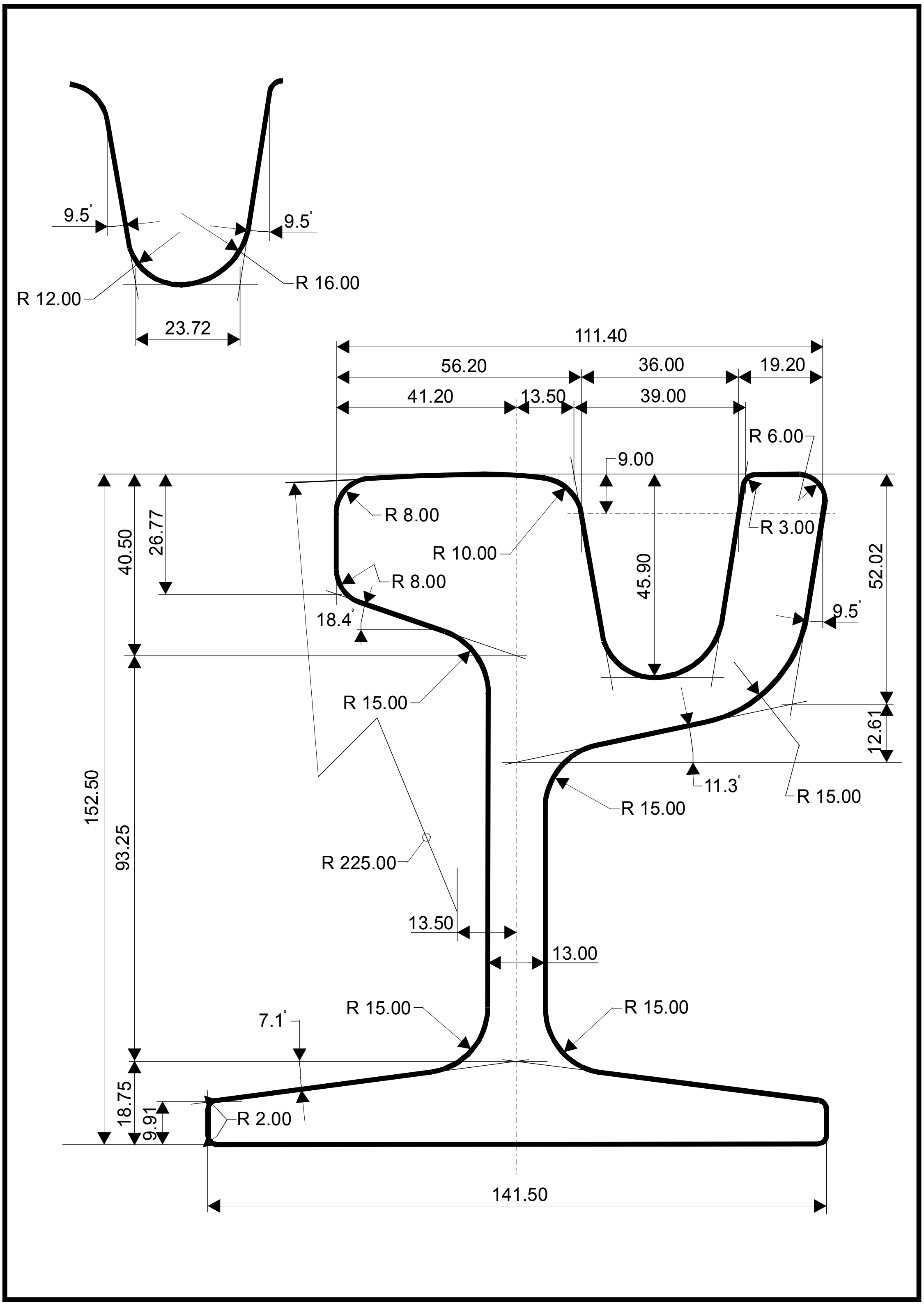
14.4 APPENDIX 4 RI 60 GROOVED RAIL



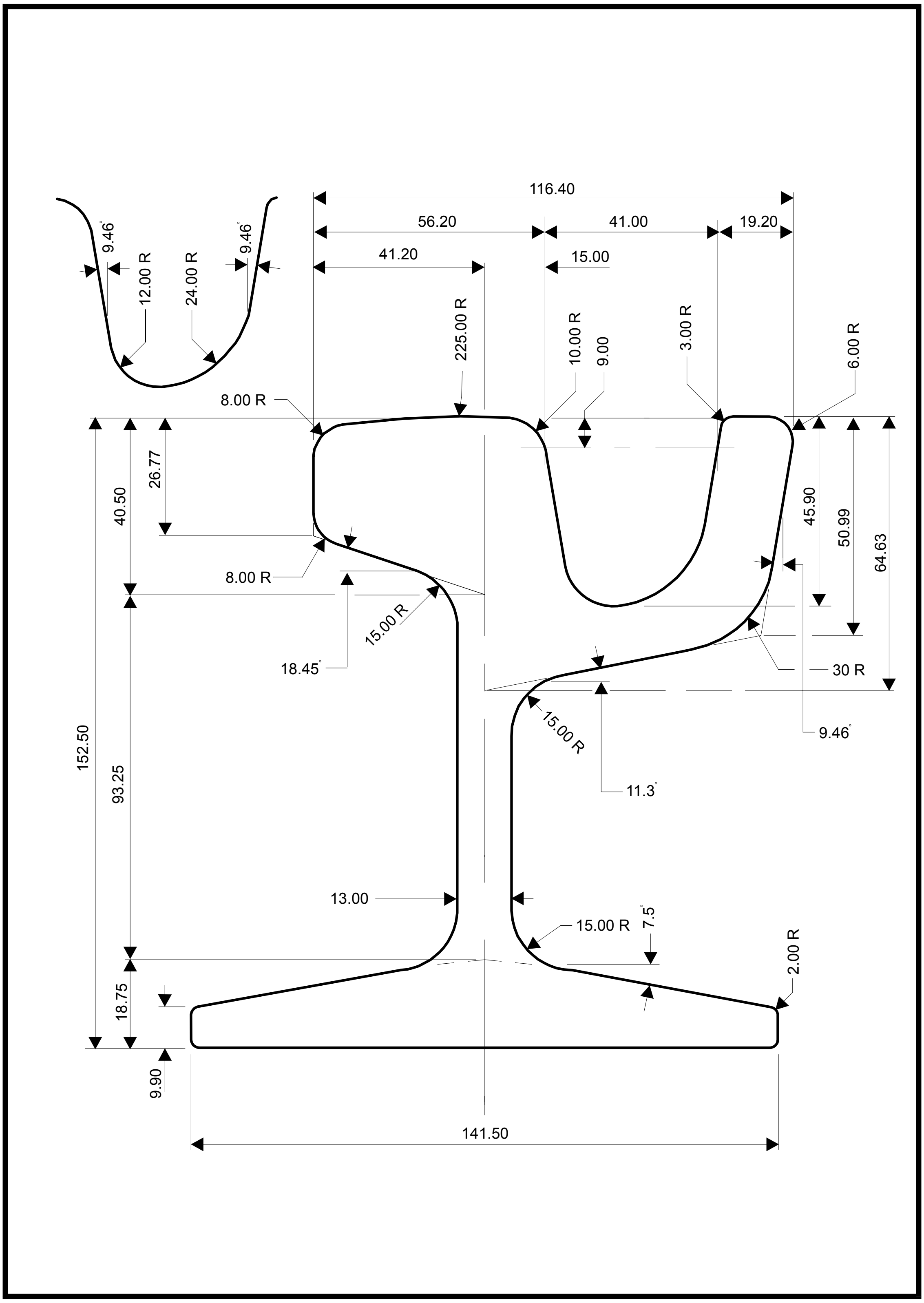
14.5 APPENDIX 5 SEI 35G GROOVED RAIL



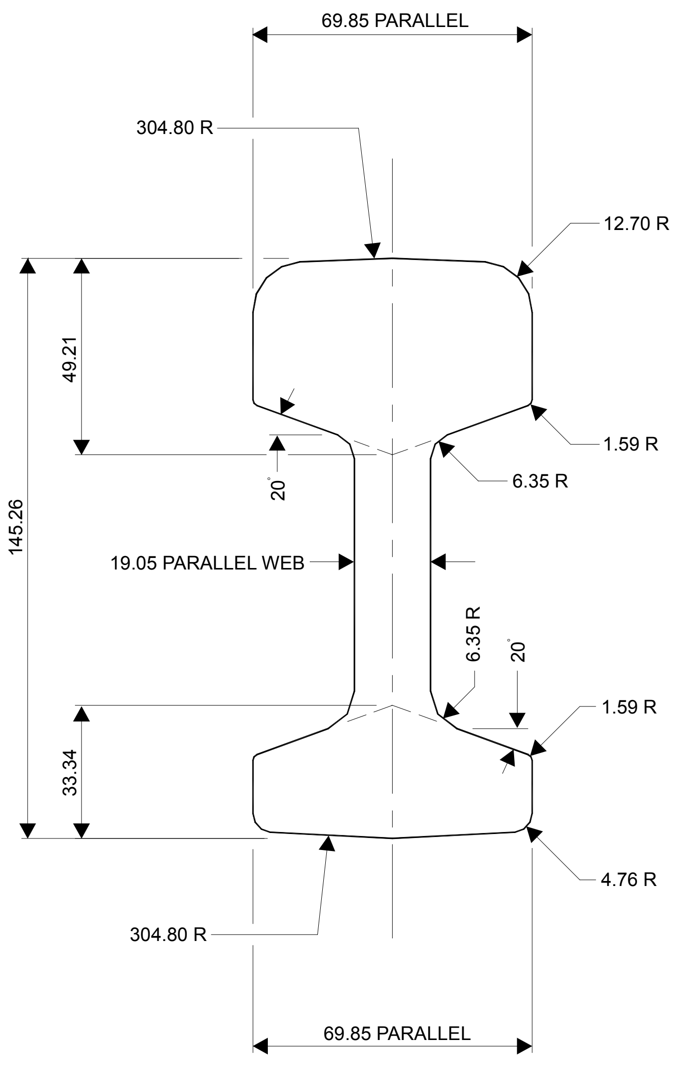
14.6 APPENDIX 6 SEI 35GP GROOVED RAIL



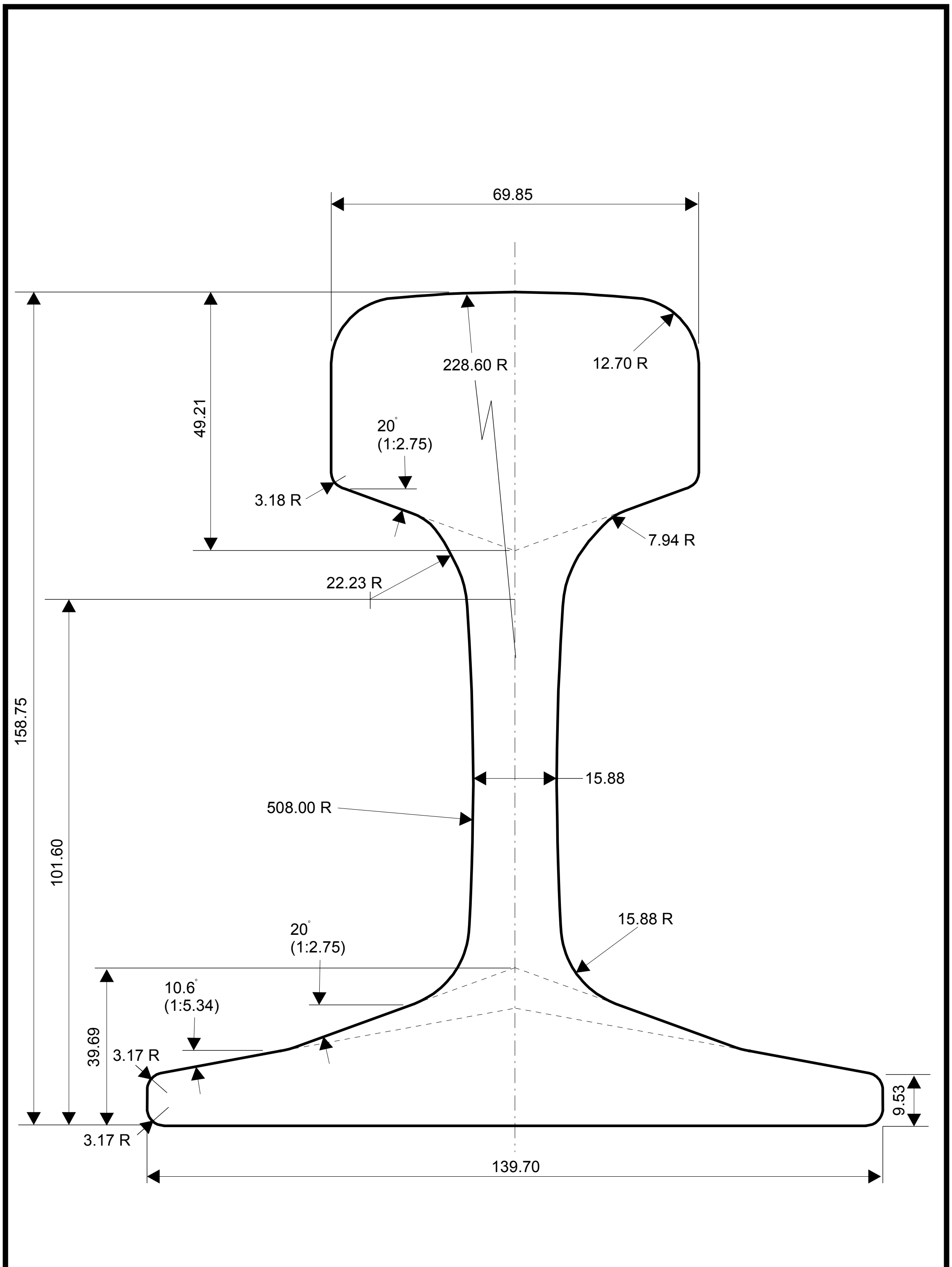
14.7 APPENDIX 7 SEI 41GP GROOVED RAIL



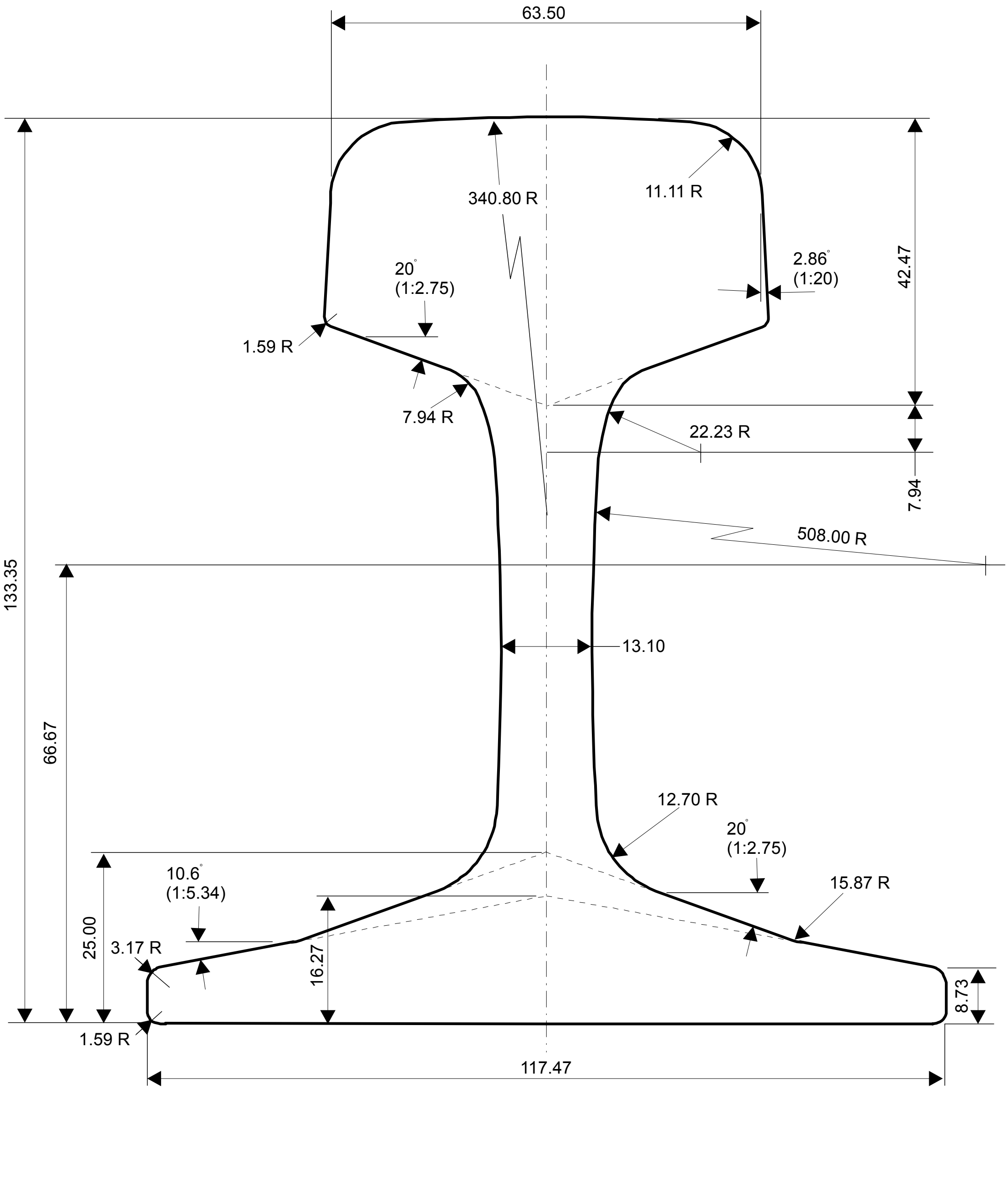
14.8 APPENDIX 8 BS 95RBH BULL HEAD RAIL



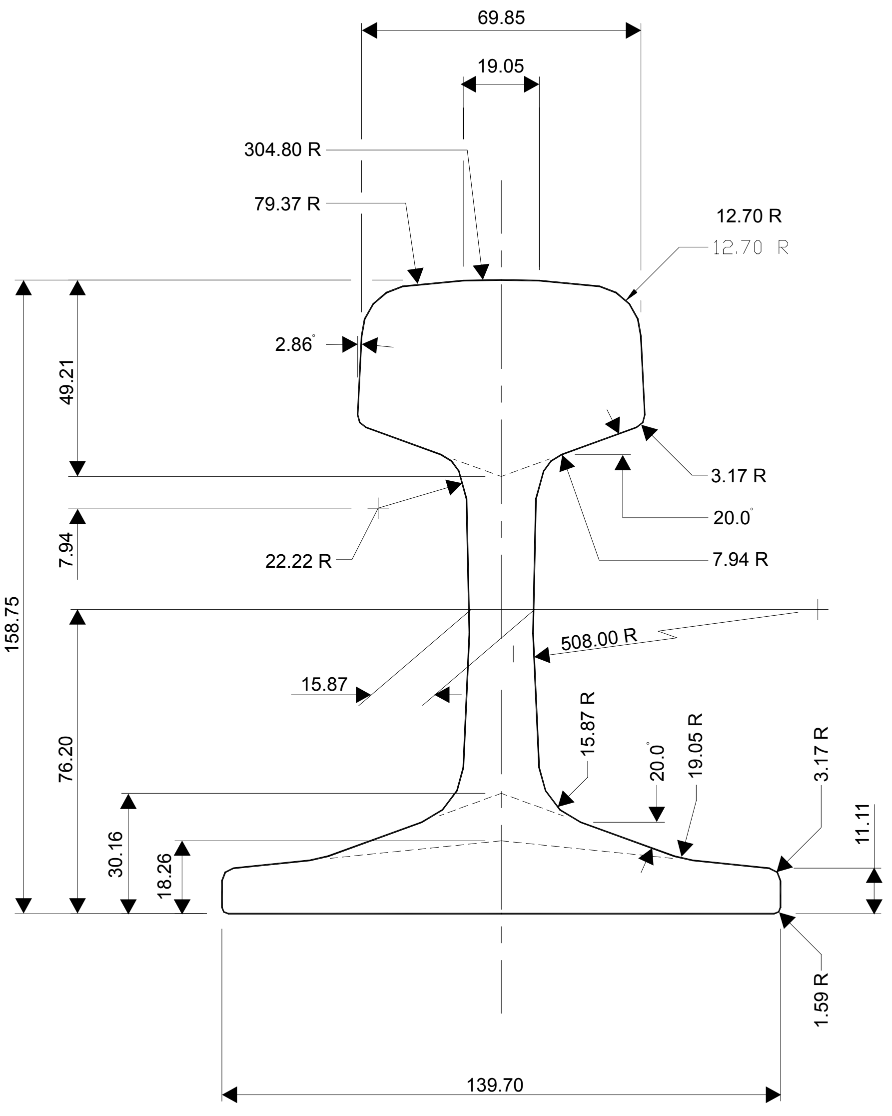
14.9 APPENDIX 9 BR STANDARD 109LB FLAT BOTTOM RAIL



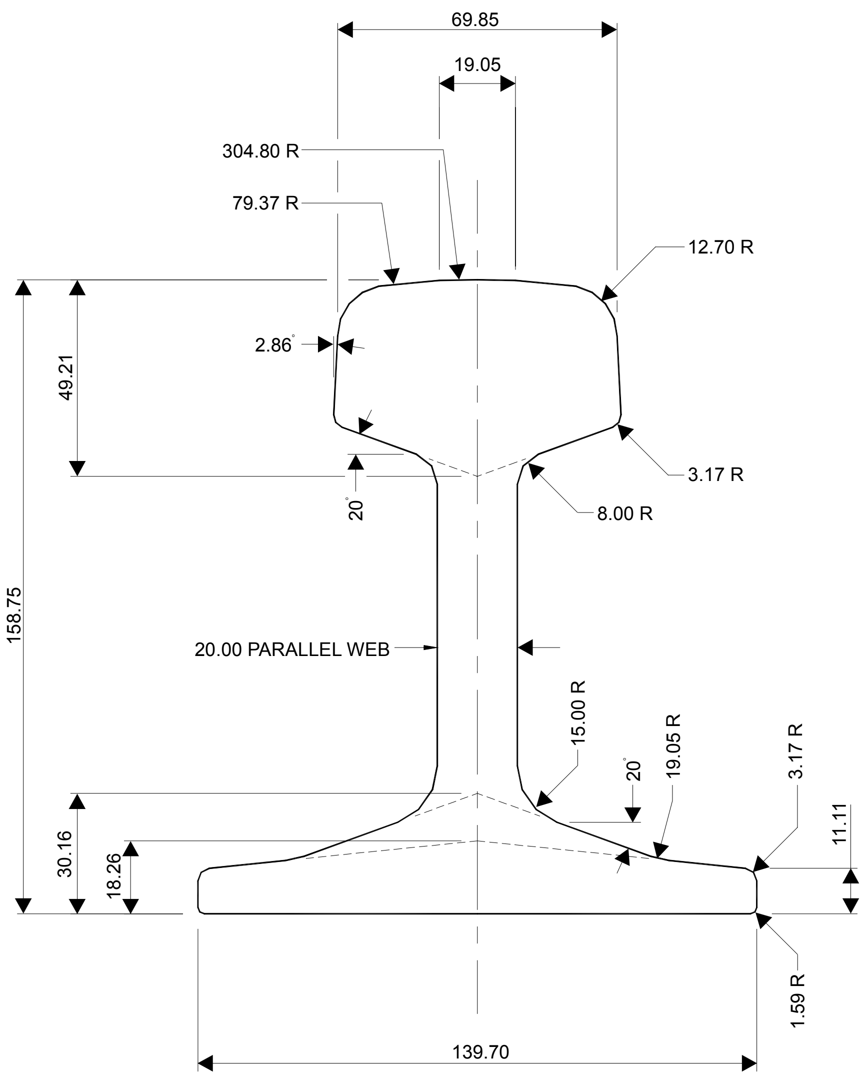
14.10 APPENDIX 10 BS 80A FLAT BOTTOM RAIL



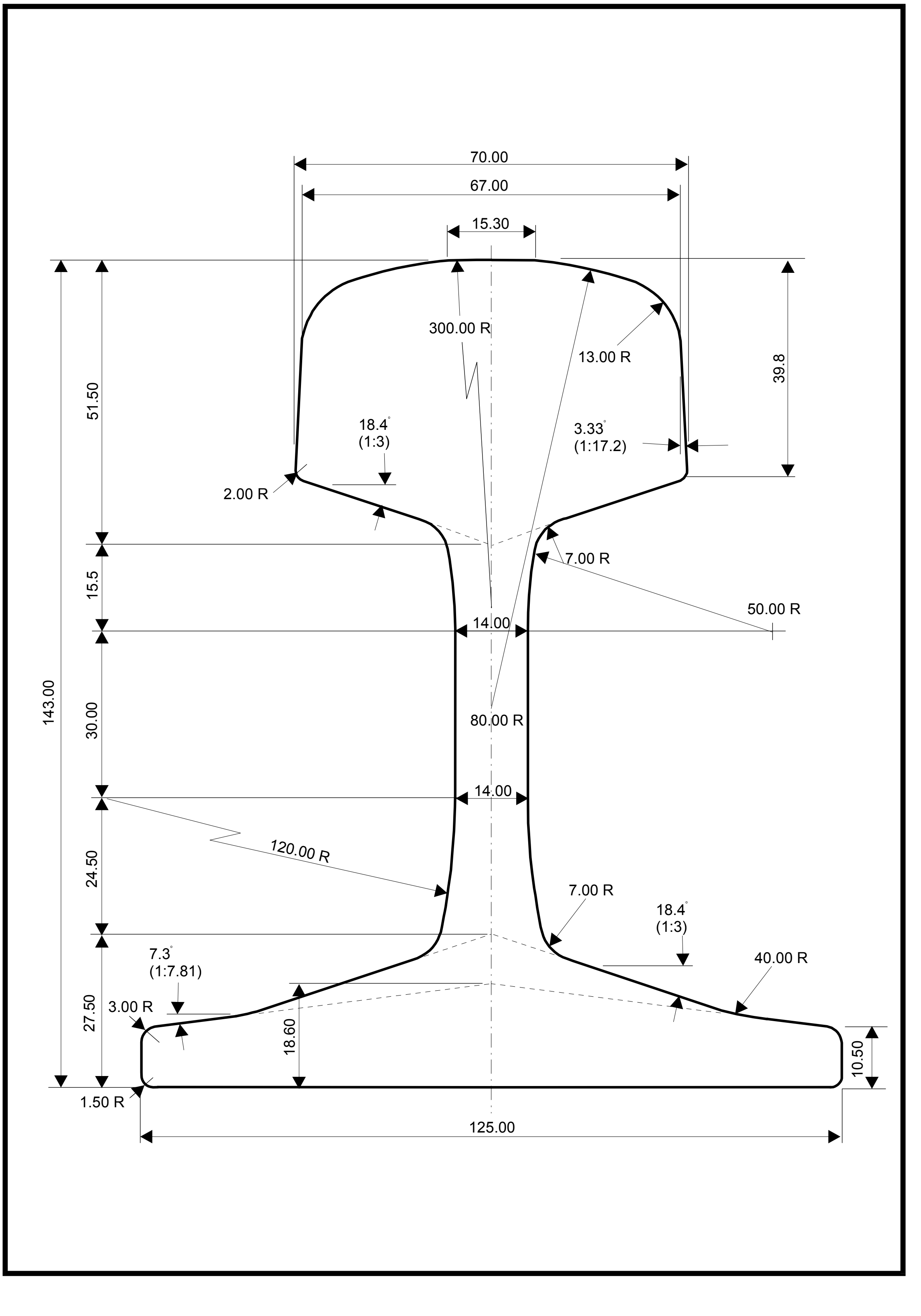
14.11 APPENDIX 11 BS 110A FLAT BOTTOM RAIL



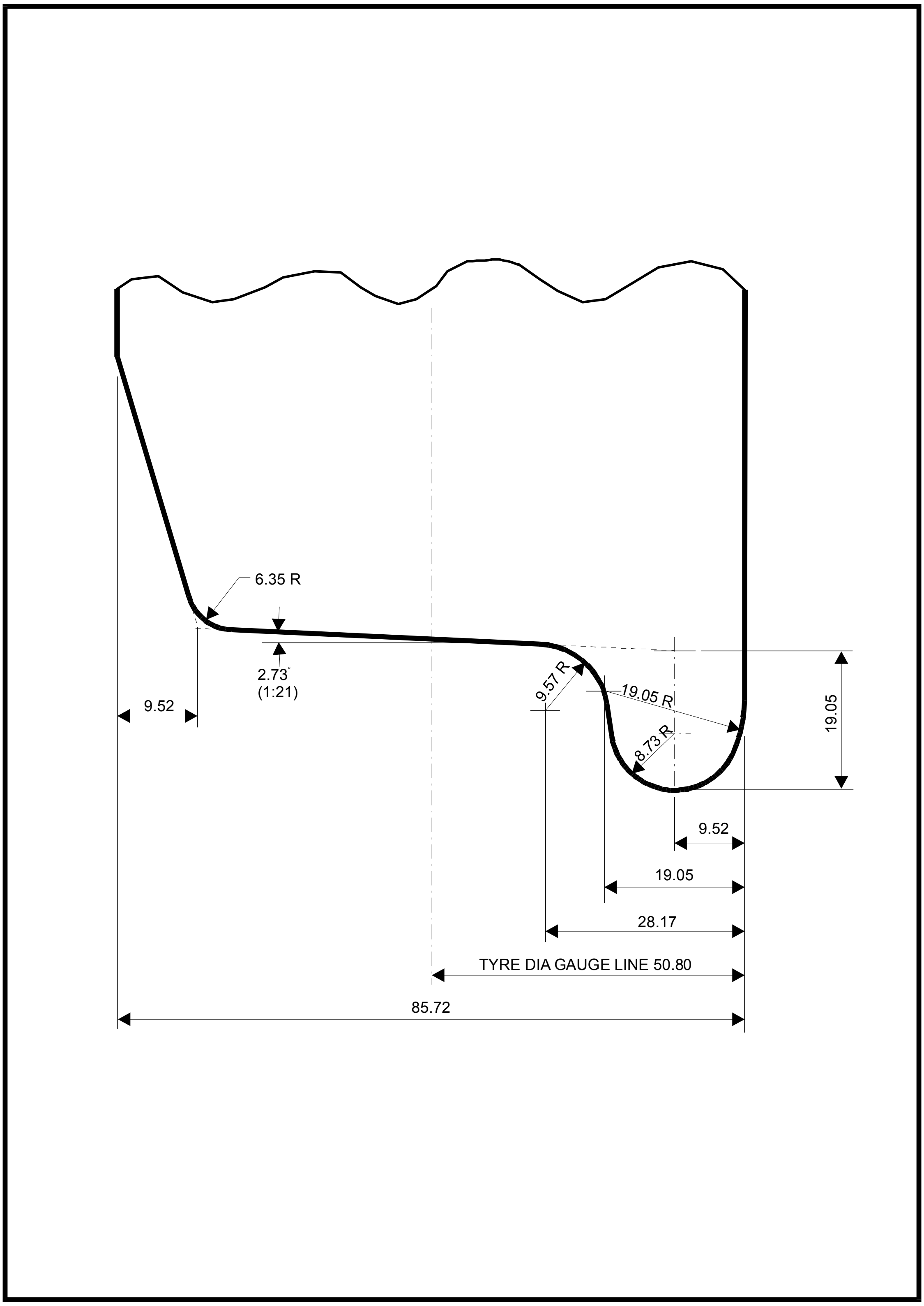
14.12 APPENDIX 12 BS 113A FLAT BOTTOM RAIL



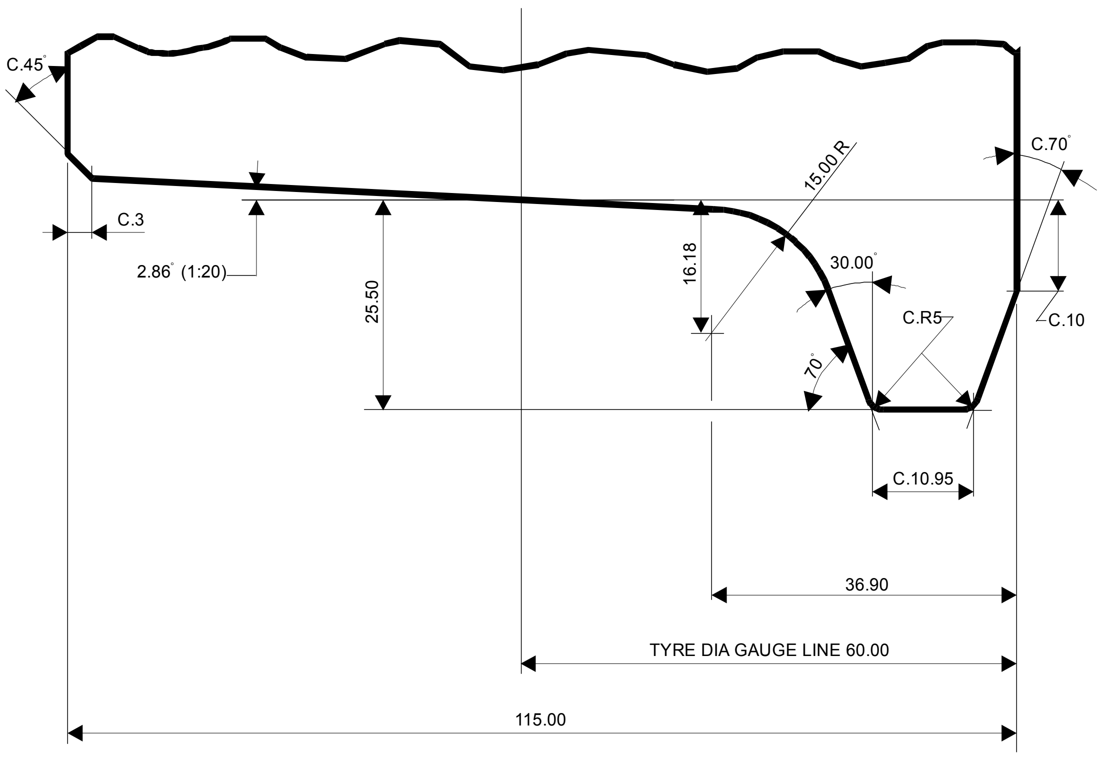
14.13 APPENDIX 13 S 49 FLAT BOTTOM RAIL



14.14 APPENDIX 14 BLACKPOOL TRANSPORT WHEEL TREAD PROFILE

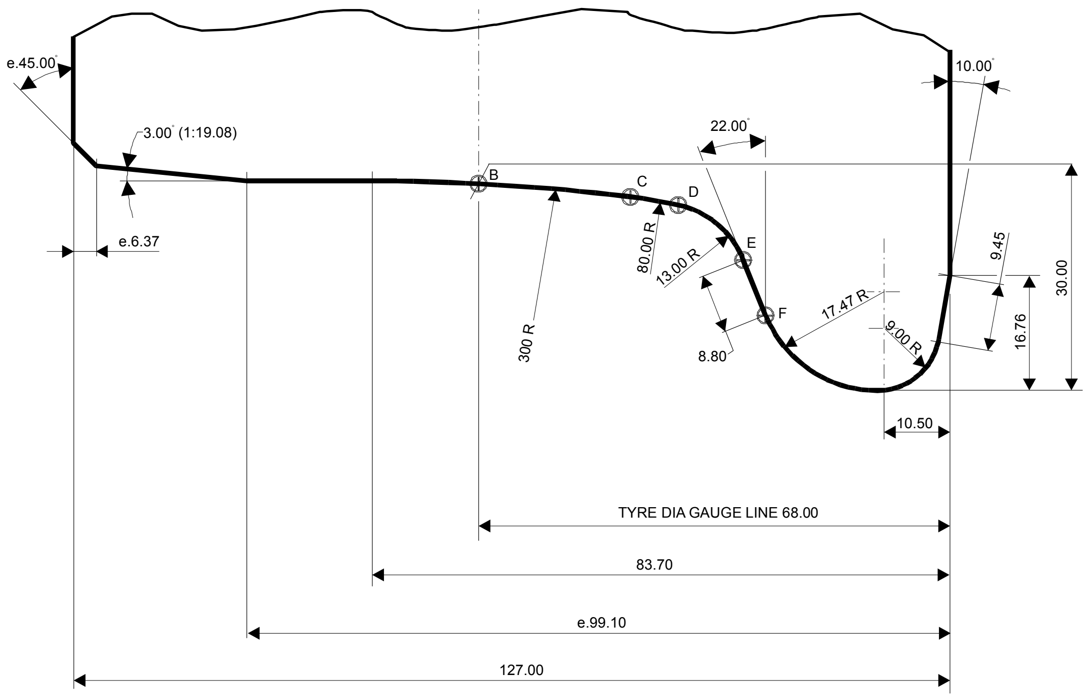


14.15 APPENDIX 15 CROYDON TRAMLINK WHEEL TREAD PROFILE



Note: 'C.' denotes dimensions taken from
Figure 2.6.3 of Parsons Brinckerhoff
(2000) for the Cologne wheel profile

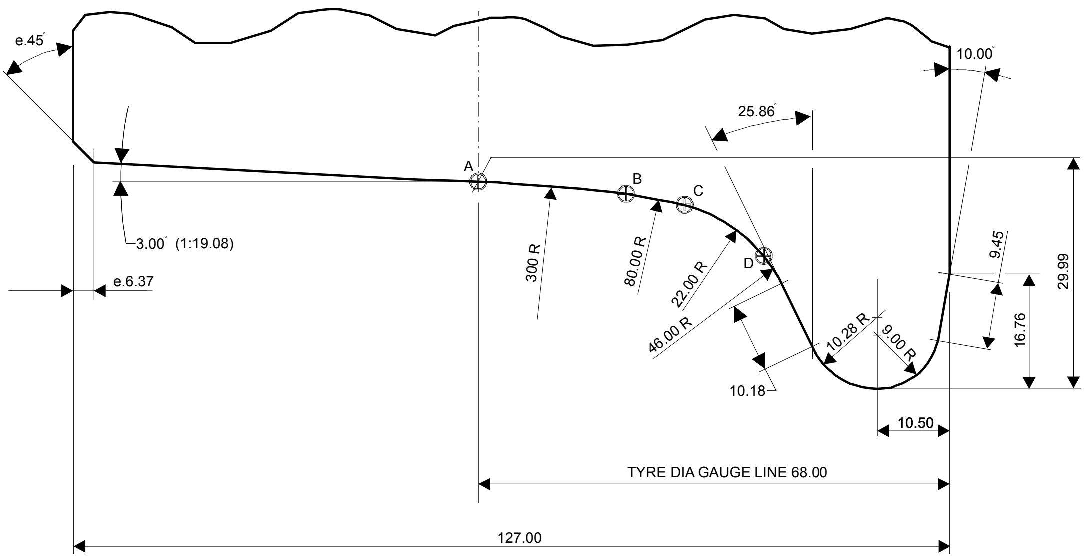
14.16 APPENDIX 16 DOCKLANDS LR WHEEL TREAD PROFILE DLR2



Note: 'e.' denotes an estimated dimension

Co-ordinates		
Point	X	Y
B	0.00	0.00
C	21.70	-1.89
D	28.70	-3.08
E	38.00	-10.92
F	41.30	-19.08

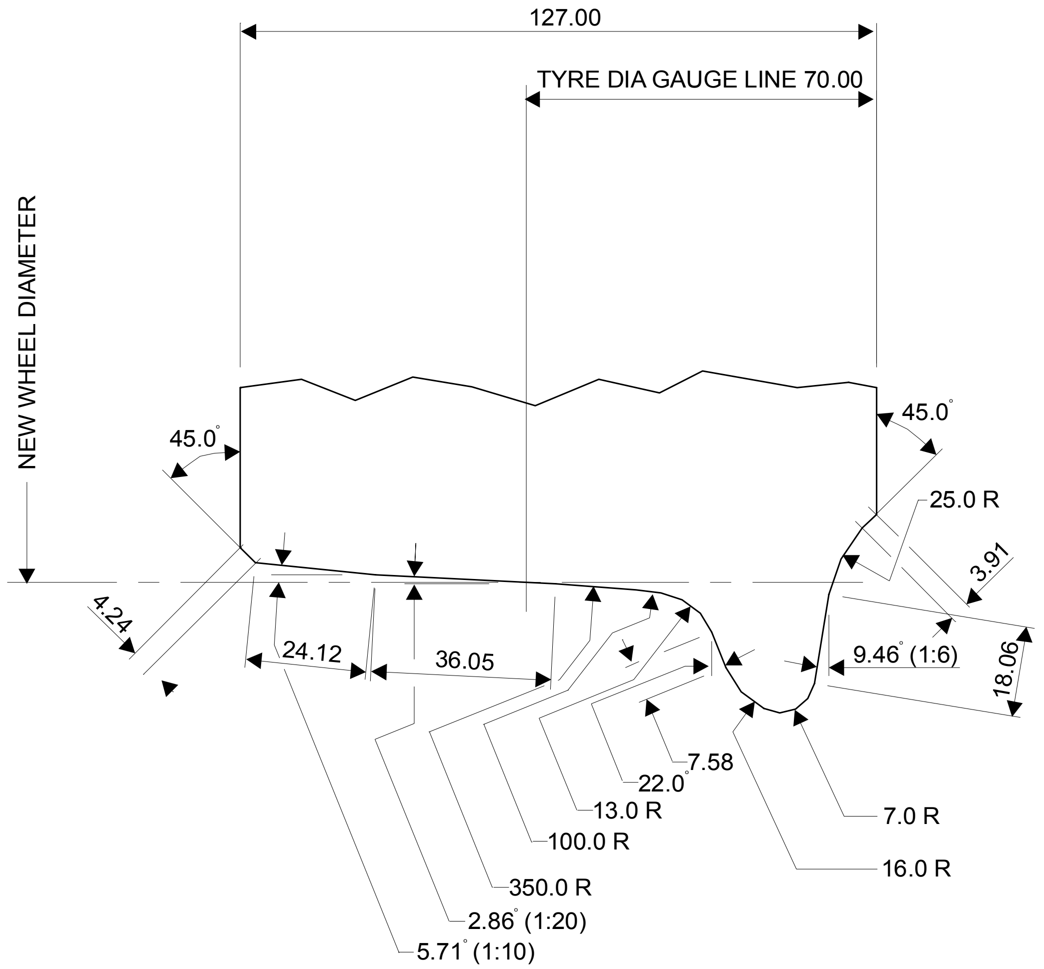
14.17 APPENDIX 17 DOCKLANDS LR WHEEL TREAD PROFILE DLR5



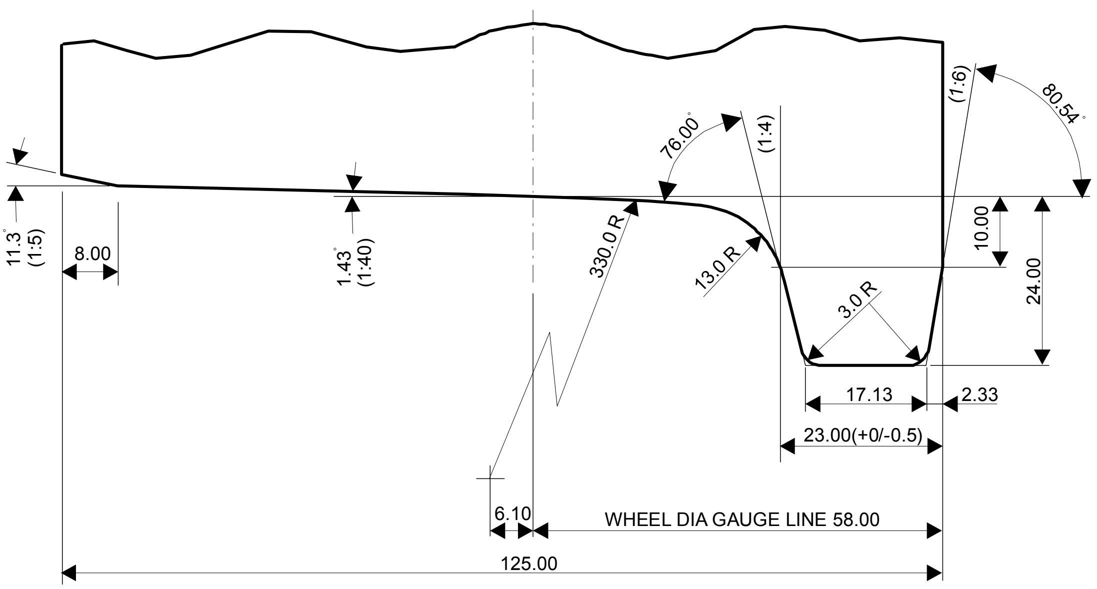
Note: 'e.' denotes an estimated dimension

Co-ordinates		
Point	X	Y
A	0.00	0.00
B	21.96	-1.96
C	28.92	-3.18
D	42.14	-12.12

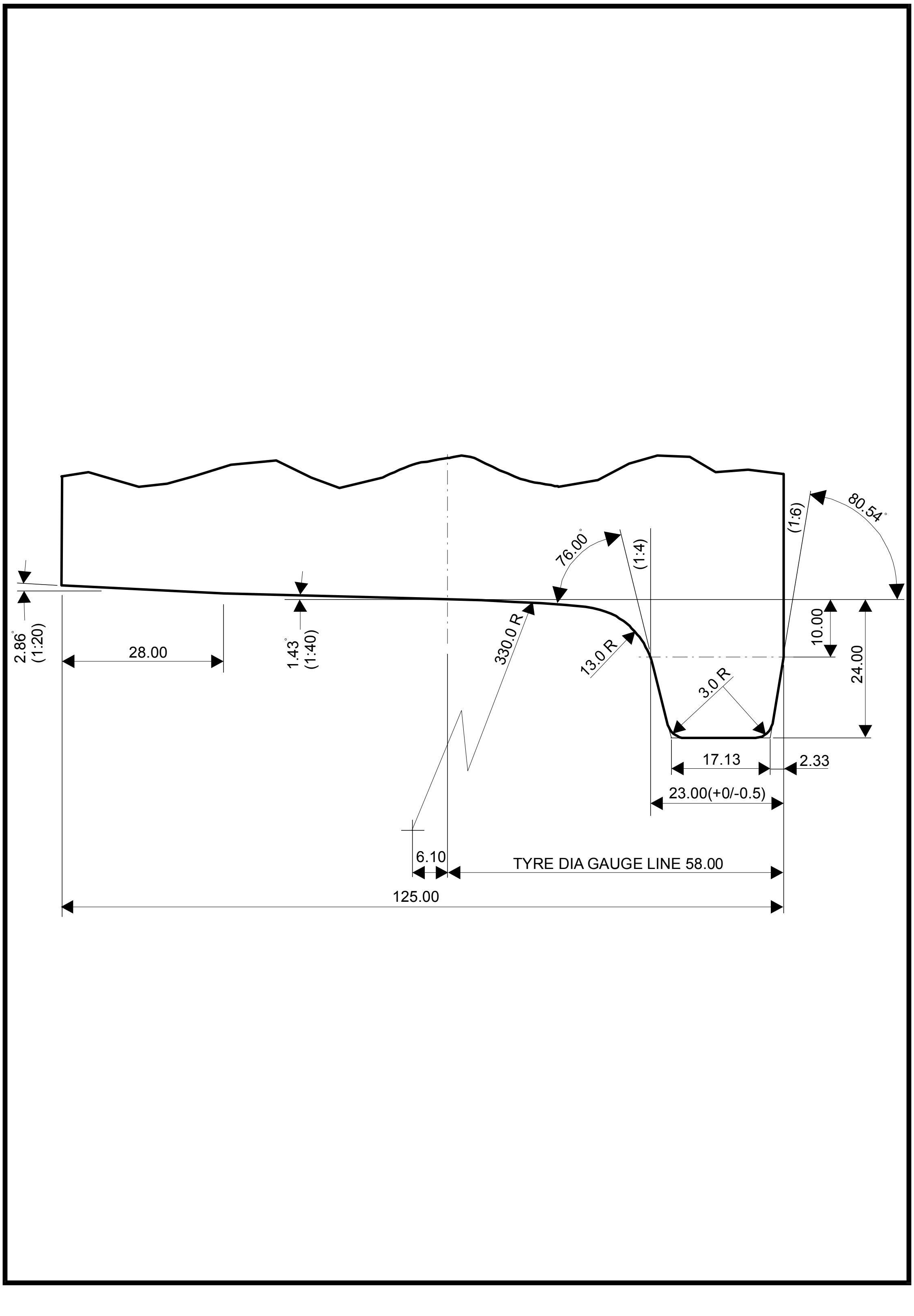
14.18 APPENDIX 18 MANCHESTER METROLINK WHEEL TREAD PROFILE



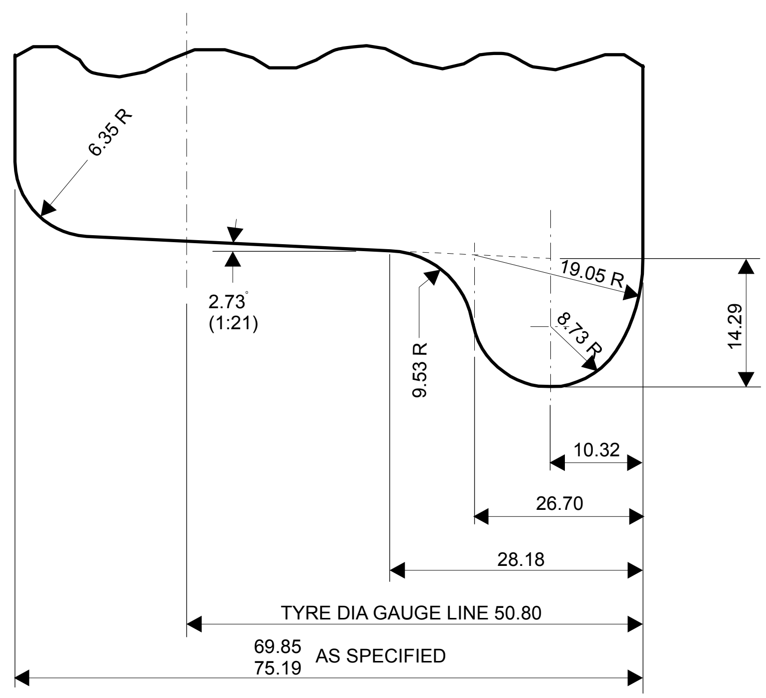
14.19 APPENDIX 19 MIDLAND METRO ORIGINAL WHEEL TREAD PROFILE



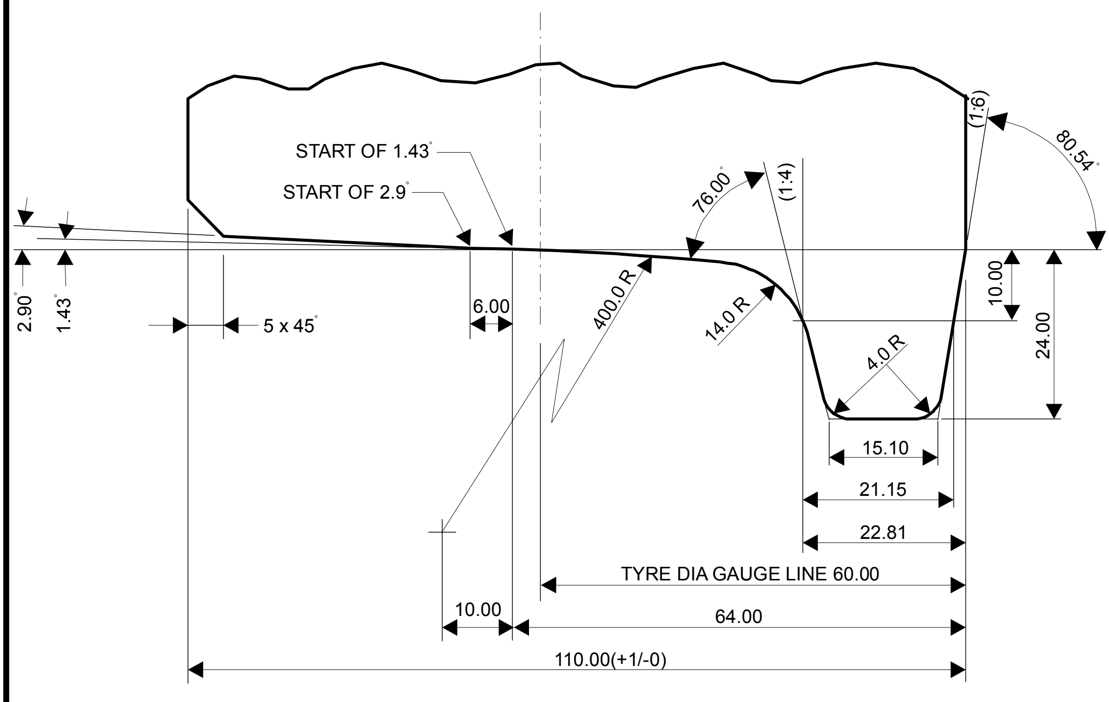
14.20 APPENDIX 20 MIDLAND METRO REVISED WHEEL TREAD PROFILE



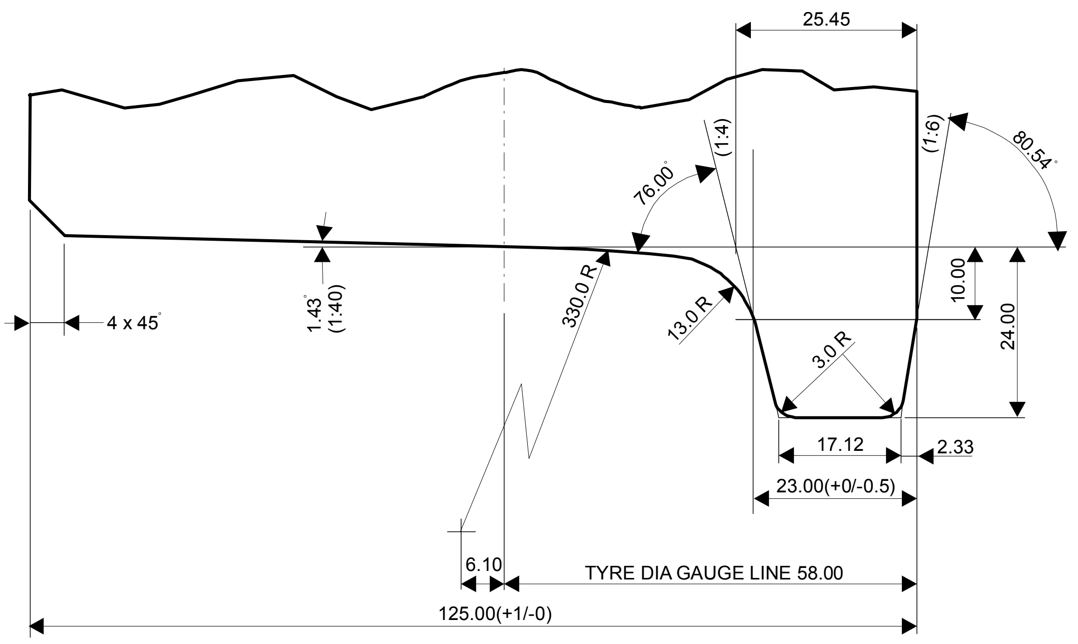
14.21 APPENDIX 21 NATIONAL TRAMWAY MUSEUM WHEEL TREAD PROFILE



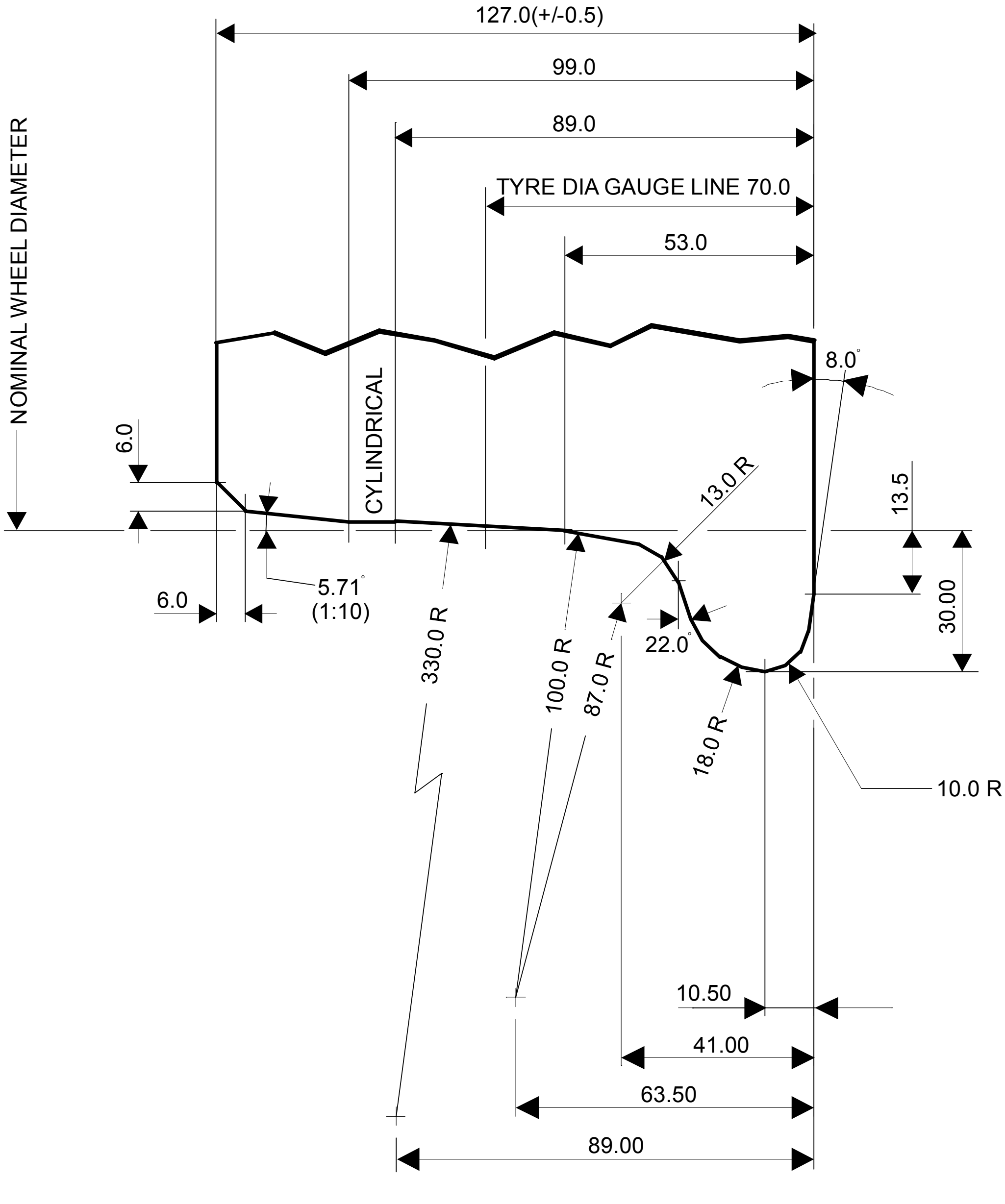
14.22 APPENDIX 22 NOTTINGHAM EXPRESS TRANSIT WHEEL TREAD PROFILE



14.23 APPENDIX 23 SOUTH YORKSHIRE SUPERTRAM WHEEL TREAD PROFILE



14.24 APPENDIX 24 TYNE & WEAR METRO P8 WHEEL TREAD PROFILE



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Hanning & Kahl	www.hanning-kahl.de/
HoldFast Level Crossings Ltd	www.railcrossings.co.uk
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17 GLOSSARY

(See Figure 17.1 for a summary of turnout terminology)

adjustment switch	Device between continuously welded rail and jointed rail and/or unstrengthened S&C units to permit longitudinal movement.
baseplate	Metal plate that supports flat bottom rail.
bogie	A sub-chassis with two wheelsets that is used under long-bodied trams and which is attached by a pivot that allows it to turn as the track curves and thus guide the vehicle.
bay platform	Elevated structure for entraining and detraining passengers on one or both sides of a track with a buffer stop.
cant	Prescribed height by which high rail is raised above low rail in order to counter centrifugal and other forces.
check rail	Rail provided alongside *running rail* to restrict lateral wheel movement.
Cologne Eggs	Resilient track fastenings used to reduce track noise and vibration, named after the German city where they were first installed
common crossing	Part of a *crossing* that comprises a *crossing vee* and two *wing rails*.
cross level	Difference in level between gauge rails measured across track.
crossing	Assembly to permit the passage of wheel flanges across other rails where tracks intersect.
crossing gap	Distance between points of wheel contact in a *crossing* to permit passage of wheel flanges.
crossing nose	Chamfered end of *crossing vee*, obtuse crossing point rail or common crossing point rail.
crossing vee	Two rails joined at an acute angle.
diamond crossing	Junction that consists of two *common crossings* and two obtuse crossings.
equilibrium cant	Cant that provides equal loading on each rail for a given traffic speed.
fishplate	Plate used to connect rail ends.
flangeway	Gap between *running face* of rail and *check rail* or *guard rail* for passage of a wheel flange.

flip-flop	A *turnout* which may be reversed by the passage of a tram in a trailing direction and which will retain the latest route setting on completion of the passage of the tram.
guard rail	A rail provided alongside *running rail* at specific locations, such as viaducts and level crossings, for added security.
gauge widening	Specified increase of gauge in track with sharp curvature.
island platform	Elevated structure for entraining and detraining passengers with tracks on both sides which continue beyond the ends of the platform.
interlaced track	Track in which adjacent tracks overlap, usually temporarily, to allow two-way traffic working within restricted width.
keeper flange (keeper rail)	The part of a grooved rail that forms the groove adjacent to the *running face*. Its purpose is to hold back any surfacing within the four-foot so that a *flangeway* is maintained.
overhead line equipment	Equipment erected above track to provide electric traction current.
rail clip	Metal fastening for fixing flat bottom rail to a *baseplate* or sleeper.
rail lubricator	Apparatus for lubricating running face on curved track to reduce *sidewear*.
running face	Inside face of head of rail contacted by wheel flange.
running rail	Rail that supports the flanged steel wheels of a vehicle.
running surface	Part of head of rail in contact with wheel tread.
side platform	Elevated structure for entraining and detraining passengers with tracks on one side which continue beyond the ends of the platform.
sidewear	Wear of metal from *running face*.
slab track	Rails and fittings fixed to sleepers or precast concrete panels embedded in an in situ reinforced concrete slab, or rails and fittings fixed to an in situ reinforced concrete slab.
spring return	A *turnout* which is always set for the diverging route but which is trailable from the normal direction.
stock rail	Fixed rail of a *switch*.
stretcher bar	Flexible bar that provides lateral connection between *switch rails*.
swing nose crossing	A *common crossing* in which the crossing vee is moved to close the *flangeway* to give continuous support to a wheel.

switch	Assembly of rails and other components for diverting vehicles from one track to another.
switch heel	Rear portion of a *switch* within which all rails are fixed.
switch opening	Prescribed gap between *switch rail* and *stock rail* at *switch toe*.
switch planing	Reduced cross section of a *switch rail*.
switch rail	Rail component of *switch*, part of which moves relative to *stock rails*
switch tip	Top of *switch toe*.
switch toe	Front end of *switch rail*.
tie bar	Adjustable metal bar, fixed between gauge rails, to maintain or restore gauge.
trailable turnout	A *turnout* which may be reversed by the passage of a tram from the trailing direction (*switch heel* to *switch toe*) and which resets itself after a trailing movement.
trailing switch	*Switch* installed where traffic predominantly travels from *switch heel* towards *switch toe*.
truck	A sub-chassis with two wheelsets that is fixed to the tram body without the use of a pivot.
turnout (point)	Junction that comprises a *switch*, a *crossing* and closure rails, as Figure 17.1.
twist	Difference in cross levels measured over a stated distance, such as wheel base of vehicle.
versine	The offset to the circumference at the centre of a chord of a circle measured at right angles to the chord.
vertical curve	Curve on longitudinal profile of a way.
wing rail	Short length of angled rail fastened to *switch rail* or obtuse crossing point rail.

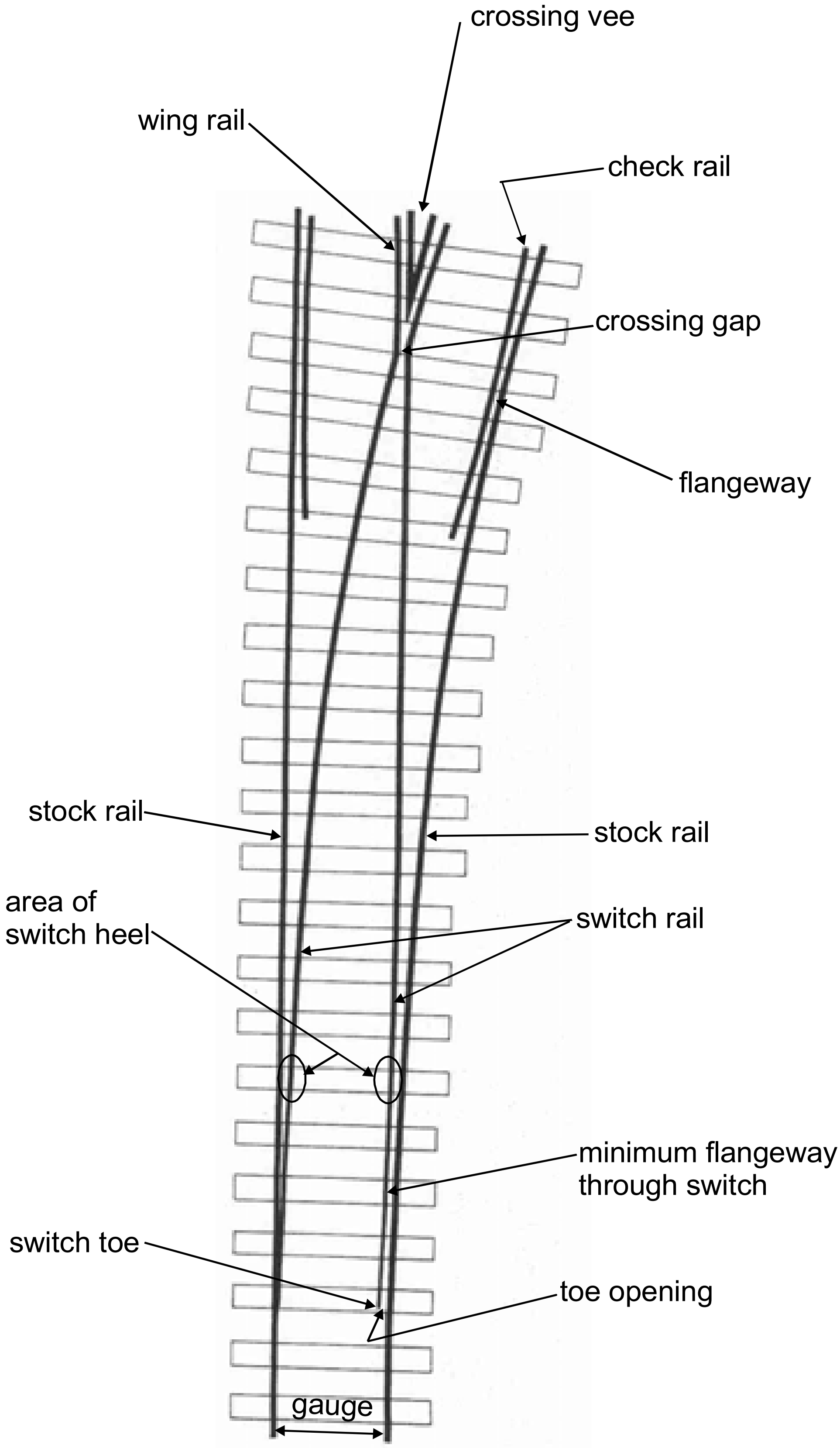

Figure 17.1 Turnout terminology